Proceedings of Seminar on Small Earth Terminals

October 31, 1975

Executive Office of the President
Office of Telecommunications Policy

PROCEEDINGS OF

SEMINAR ON

SMALL EARTH TERMINALS

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I. INTRODUCTION

As part of the continuing effort to prepare for the 1979 World Administrative Radio Conference (WARC), the Office of Telecommunications Policy (OTP) sponsored a joint session of Ad Hoc 144-III of the IRAC and of the CCIR U.S. Study Groups 2, 4, 8, 9. Ad Hoc 144-III is a special subcommittee of the IRAC, instituted by OTP, to prepare draft position papers for the Federal government for consideration at the WARC.

The purpose of this special session, which was held on October 31, 1975, was to discuss the technical problems associated with the introduction of "small earth terminals" (SET) in those space services employing geostationary satellites. SET's imply the use of antennas which have considerably less equivalent aperture than is normally employed in the Fixed-Satellite service. Current regulations do not adequately consider the technical and operational factors unique to SET usage. For example, the coordination procedures embodied in Appendices 28 and 29 of the ITU Radio Regulations are not designed to use D/λ ratios smaller than 100.

Essentially all present day satellite communications services, both government and non-government, utilize large fixed earth station with large antenna apertures. These antennas are usually parabolic in form yielding symmetrical beam shapes and relatively good sidelobe suppression. The cost of such stations normally limit their use in readily transportable or mobile configurations for low traffic volume users.

With substantial reductions in the cost of launching satellites and substantial increases in the size and weight of satellite payloads, it has become economically practical to realize increased on-orbit satellite effective radiated power levels. The increased power levels in turn make it practical to reduce the size of the earth station antenna, and as such to reduce the overall system cost and to permit greater direct use of the system by a large number of small users.

Such departures from existing applications of the technology create major problems for the earth stations. For example:

(1) Increase in on-orbit and terrestrial interference due to the substantially wider antenna beam widths;

(2) Reduced antenna main beam gains of small antennas requiring more antenna input power to achieve the same e.i.r.p., thus increasing the radiated power in the antenna side lobes;

(3) Degradation of the satellite systems orbit/spectrum utilization due to the inter-mixing of wider antenna beamwidths with the presently existing narrow antenna beamwidths;

(4) Use of such SET's for "thin route" applications causing increase in required orbital spacing of associated satellite networks;

(5) Minimum satellite orbit separations, currently practical when using large earth station antennas, may not be feasible when using small station antennas.

Limiting is also imposed by the criteria for sharing of frequencies between terrestrial and space services.

Such technical departures from past and current practice may require regulatory changes. In this regard, the objective of this seminar was to determine answers to the folhowing questions:

° How can the foreseen requirements for SET's in the various satellite services be accommodated?

° Can SET's conform to international technical criteria?

° Do special allocation provisions need to be provided for SET's?

° What are the conditions for minimizing that separation?

Section II of these proceedings presents an overview of a cross section of government and non-government systems that are now using or will utilize SET's. Section

III addresses the question of sharing between SET's and other large terminal systems. The results of several analyses dealing with the impact of small earth terminals are highlighted.

Finally, Section IV will indicate those areas where the most beneficial action may result in improved spectrum use and provide a basis for accommodating small terminals for a variety of functional applications.

II. SYSTEM REQUIREMENTS AND CHARACTERISTICS

A. National Environmental Satellite Service (NESS) National Oceanographic and Atmospheric Administration - (NOAA)

Presentation:

The presentation provided an overview discussion of the various capabilities of the Geostationary Operational Environmental Satellite (GOES) system and other NESS systems.

In particular, it indicated that the NESS provides five specific satellite capabilities, four of which are for the direct use of the public. Of those four, three are accessible without the advance knowledge or permission of the government. The five capabilities are:

Automatic Picture Taking (APT)
Weather Facsimile (WEFAX)
Turn Around Ranging System (TARS)
Satellite Field Service Station (SFSS)
Data Collection System (DCS)

Selected parameters and summary statements of mission objectives are given in Appendix I. Satellites used to support these capabilities include the ATS series and the SMS/GOES series. The frequency bands currently in use are at VHF, UHF, L-Band and S-Band.

Discussion:

NOAA officials indicated that their biggest potential problem from a spectrum use point of view is the high power flux density levels presently in use by their systems. These levels are about 8 dB higher than that permitted by the Radio Regulations. At present, NOAA systems do not radiate into Region 1 countries necessitating coordination. However, moving one of the NOAA GOES satellites further west over the Pacific Ocean could cause radiation into the U.S.S.R. and subsequently cause coordination problems. The NOAA officials indicated that their organization was not, at this time, recommending an increase in the PFD limit.

It was also noted that the public use nature of the satellite services provided by NOAA together with the need to collect data from many remote points for water usage and flood control measures has led to an extensive deployment of small earth terminals. Many of these terminals are built and operated by Amateur and other non-professional weather forecasters. The quality of their instrumentation and size of their antennas require power flux densities at least as high as those now being provided by NOAA.

B. RCA Global Communications

Presentation:

The RCA Globcom presentation was based on a formal RCA study titled "Small Station Performance and Interference Analysis" (Appendix II). The study was prepared to support and justify the use of small earth terminals in the State of Alaska communications system. The document provides the detailed data and assumptions used in the RCA analysis of Small Station Performance and Interference impact. Both 10 foot and 15 foot diameter antennas are considered. A basic five satellite interference model was assumed including Canadian and COMSAT/ATT satellites located on the geostationary orbit between 114°W and 131°W longitude. The RCA satellite is analyzed at a proposed position of 119°W.

The presentation noted that the study referred to a real and specific system for which present traffic requirements could be stated and growth requirements could be reliably predicted. RCA, in conjunction with the State of Alaska, is planning to have in operation a voice communication system based on 15 foot diameter terminals at the beginning of the 1976 construction season. RCA believes that the analysis as presented in their study demonstrates that small terminals can operate in the same environment as large terminals and they further believe that the analysis justifies proceeding with the SET concept in Alaska.

Discussion:

Discussion brought out the fact that the RCA analysis was predicated on a 32-25 logθ description of side lobe performance for small earth stations. Using this characterization for the antenna, RCA did not find a need to increase the spacing between satellites as presently proposed for the first generation of DOMSATS using large antennas. This spacing, according to RCA computations should not have to be greater than 5° and is probably somewhere between 4° and 5°.

Acknowledging that the 32-25 logθ criterion was not intended to characterize small antennas, the RCA representative noted nevertheless that their 15 foot antennas did comply with the criterion. Their 10 foot antennas needed some "adjustment" in order to comply.

Coordination of the present system now being installed was reported to have been accomplished with COMSAT/ATT without difficulty. Coordination is in process for the proposed system based on 15 foot antennas, higher G/T and a greater number of channels than was originally coordinated.

C. National Aeronautics and Space Administration Presentation:

A joint Canadian-US experimental satellite program, the Communications Technology Satellite (CTS), was described by NASA. Canada is supplying the satellite and the US (NASA) is providing the launch and the high power final amplifier.

The satellite is intended to support a variety of experiments of a mainly societal nature. Several figures from the NASA presentation are included as Appendix III.

Several classes of small terminals were postulated in the early stages of the program but there finally evolved a need for just three. The largest class is Video/Telephony transmit and receive capability. One version uses a single 15 foot antenna with a diplexer while a second version uses a 10 foot transmit and 15 foot receive antenna. The Class II and Class III terminals will use 6 to 10 foot antennas; the Class II being a capability for the transmission of telephony and reception of both telephony and video and the Class III being a receive video only capability.

The CTS system will operate in the 12/14 GHz bands. Small terminal capability is possible because of the high efficiency 200 watt final amplifier tube used on the satellite together with extendable solar panels that generate about 1 kW of prime power for the satellite.

Discussion:

A question on control of antenna sidelobes elicited the information that NASA had specified 17-18dB suppression of the first side lobe; this was the only spec on sidelobe performance for the earth terminals. Measured data from the various manufacturers indicate that this specification has been met. The measured data is not yet generally available.

With regard to potential interference from CTS earth stations, studies have shown that such interference could occur between CTS terminals and commercial small boat radars. As a result, a coordination procedure has been proposed for application in situations where a CTS terminal is within 5 miles of a navigable waterway. Other studies have shown that their is no potential interference to AT&T mobile operations from CTS terminals.

D. Satellite Communications Agency (SATCOMA) United States Army

Presentation:

SATCOMA is the primary development agency for all ground based small earth terminals for military use. The Army presentation was oriented toward their program in support of the Ground Mobile Forces Satellite Communications Systems. This program involves the design and development of a variety of small terminals. The characteristics of these terminals were presented and discussed. Copies of the briefing data are included in Appendix IV.

Discussion:

Military satellite communications services are provided in two regions of the spectrum: UHF between 225-400 MHz and SHF between 7250-8400 MHz. A variety of terminals have been developed for both bands. In the SHF band a Small Terminal Family has been designed and implemented based on an 8 foot diameter antenna. Typical deployment scenarios show terminal usage down to the Brigade level.

The Army has sponsored a program to measure the antenna pattern of the 8 foot dish employed in their SHF systems. This program is being conducted at the Institute of Telecommunications Sciences, Boulder, Colorado. The Army representative noted that the detailed data from the measurements had just been assembled by ITS and is now being analyzed. The next presentation at the seminar dealt with the results of that program.

E. Department of Commerce - Office of Telecommunications (OT) Institute of Telecommunications Sciences (ITS)

Presentation:

This presentation dealt with a program, being conducted by ITS for the Army Satellite Communications Agency, in which ITS is addressing the question of spectrum accommodation of small military earth stations. The program has been underway for only a few months; the first task, recently completed, involved measurements of the radiation pattern of the 8 foot antenna used by the Army in their SHF family of earth terminals. Some examples of the measured data were shown; they are included here as Appendix V.

Discussion:

The data presented by ITS has not been fully processed. About 40,000 data points in the upper hemisphere of the antenna were collected. The data will be processed by computer to develop statistical representations of the off axis behavior of the pattern.

Some composite plots of the preliminary data were used to illustrate the fall off rate of the sidelobe pattern. It was not possible to determine how closely the antenna pattern approached the 32-25 logθ CCIR reference pattern for large antennas. Establishment of this comparison over a range of statistical levels will be an objective of the data processing effort.

F. Corps of Engineers

Presentation:

Several Corps of Engineer experimental programs employing ERTS and GOES satellites and specialized data collection platforms (DCP) were described. The DCP's are intended to measure and relay various data on Hydrologic conditions to central offices for the purpose of Water Resources Management.

The Corps of Engineers operational system presently relies on ground based point to point relay of these data from many remote locations in the nation's various watershed areas and river basins. The move toward satellite relay of the data is still in an experimental phase. Decision on operational implementation has not yet been made.

A copy of the Corps of Engineers presentation is included as Appendix VI.

G. Navy

Presentation:

The Navy shore terminals are developed and procured by the Army SATCOMA as was noted earlier. However, Navy shipboard terminals, which utilize 4 foot and 8 foot cassegrain fed antennas, are developed and procured by the Navy. The nature of the operational requirement dictates a more elaborate capability than is seen in non-military systems. High powered transmitters and broadband (spread spectrum) modulations are employed. The terminals operate into the DSCS system. A copy of the Navy briefing material is included as Appendix VII.

Discussion:

During the open discussion the Navy official stated that he computed a required spacing of 10°-15° for satellite systems sharing the SHF band and using 4 foot diameter dishes. A comment from the audience provided the information that a proposed spacing of 6° between a DSCS satellite and a NATO satellite in the SHF band led to a computed increase in equivalent noise temperature in excess of the 2% threshold of Appendix 29 of the Radio Regulations. The comment was not further qualified as to the size of antennas involved in the calculation.

The Navy program has maintained a coordination effort with the Fixed Service users in the SHF band at and near the development sites for the Navy system. The Navy does not anticipate a requirement for coordination with terrestrial services under at-sea operational conditions.

III. SHARING CRITERIA AND REGULATORY ALTERNATIVES

A. Defense Communications Agency (DCA)

The DCA presentation dealt with an approach to the quantitative assessment of the effect of various system parameters on orbit utilization. The approach is an extrapolation of the Appendix 29 procedure for determining the impact of one satellite system on another. It developes an equation which can be used to evaluate changes in orbit angular separation due to changes in such system design parameters as:

Receiver Temperatures
Antenna Side Lobe Levels
Energy Dispersal Levels
Carrier to Noise Ratios
Change in Link Noise Temperature
Downlink to Uplink Noise Allocation Ratios

The application of the equation to a variety of scenarios was illustrated including small terminal to small terminal, small terminal to large terminal, and small and large terminals sharing the same transponder.

Based on the application of the equation to several sets of typical satellite system parameters, it was concluded that the controlling scenario on spacing between large and small terminal systems is the one in which the critical interference path is from the small terminal system to the large terminal system. Moreover, the dominant factor tends to be antenna gain suggesting that one parameter that might be considered a possible regulatory factor is the product of a system's earth station and space station antenna gains. Quantitative limits for such a factor were not suggested.

The concept of "grouping" was highlighted as a means of improving orbit utilization. Techniques listed included orbital arcs, reverse band usage, polarization control, and frequency band separation.

The equation has not been programmed for a computer but it would be a fairly simple matter. There are many variables involved and an automated approach to the application would permit rapid evaluation of the sensitivity of the equation to various parameter adjustment strategies.

The DCA presentation is given in detail in Appendix VIII.

B. Communications Satellite Corporation

The Communications Satellite Corporation representatives presented material describing sharing criteria developed by COMSAT principally for use with the INTELSAT series of satellites and associated ground stations. It was noted that small terminals have long been an element of the INTELSAT system. Early applications were primarily on a temporary basis as most INTELSAT operations were and are conducted with large (high G/T) terminals. The advent of INTELSAT IV and the plans for INTELSAT V and VI recognize possible large expansion in the use of small terminals in the INTELSAT system because of the increase in available power in the satellite and the principle of individual transponder operation.

As a result COMSAT established two criteria for assessing intersatellite system interference. They are: (1) that the acceptable level of interference from one system into another will conform with CCIR Rec. 466-1, namely 400 PWP in a baseband channel, and (2) that the maximum allowable off-beam emission power density will be 20dBw/4kHz. These values were predicated on 3° spacing between adjacent INTELSAT satellites.

An illustration of the impact of these criteria on INTELSAT IV and IV A system operation led to the conclusion that, in general they can be achieved irrespective of actual antenna diameter, albeit with some degree of frequency control to minimize co-frequency operation. In all computations it was assumed that the off-axis behavior of the antenna pattern conformed with the 32-25 logθ CCIR criterion.

Measured patterns of several types of small horn antennas for use on satellite earth terminals were shown. These data illustrate that there are many types of small horn antennas of 8, 10 and 14 foot sizes that comply with the CCIR criterion.

It was noted that the use of smaller antennas (G/T of about 31.7) are coming into service for domestic services through leased transponders. They are generally equipped to provide telephony (usually SCPC or FDM/FM) and TV.

SCPC operations increase the space segement capacity per unit bandwidth. Their lower power requirements, however, increase their susceptibility to interference.

The COMSAT presentation material is included here as Appendix IX.

C. INTELSAT - International Telecommunications Satellite Organization

The INTELSAT representative presented a market oriented discussion of INTELSAT analyses of the need for small earth terminals for use internationally to provide Interconnected Global Services. It was noted that what most agencies consider a large terminal (i.e., antennas with diameters of 30 meters) INTELSAT considered to be a standard size whereas the medium size terminal of ten meter or twelve meter diameter is considered to be a "secondary standard" in INTELSAT. The INTELSAT presentation dealt with the question of secondary standard terminals, their use and integration into the INTELSAT network.

A chart showing INTELSAT market penetration in countries as a function of the size of their telephone system was presented. The chart illustrated that even in countries whose systems have as few as 100,000 telephones, there is a 50% penetration. The data goes on to show likely traffic demand in the three principal service areas of INTELSAT and the tradeoff in cost between standard and secondary standard terminals.

Anticipating that countries, not yet served by INTELSAT with standard terminals, may wish to join the network using secondary standard terminals, INTELSAT has defined some possible control methods for achieving compatible operations between the two classes of terminals. These are listed in the briefing charts which are Appendix X to these proceedings.

It was concluded by INTELSAT that the "INTELSAT System is likely to cause less interference to systems utilizing higher satellite EIRP and small terminals than vice-versa."

Small systems operating in the INTELSAT system are subject to controls within INTELSAT. In contrast small terminals in other systems are viewed as likely sources of large interference to INTELSAT and are not subject to direct control of INTELSAT operations. Therefore, it is an INTELSAT suggestion that limits on small terminal operation, in general, need to evolve from CCIR and WARC final acts.

In this context, INTELSAT believes that likely directions for decisions at the 1979 WARC would be:

° Limitations on off axis EIRP density

° Segregation of high density carriers to preferred regions of the spectrum and low density carriers to other regions of the spectrum

° Development of reference antenna patterns for D/λ smaller than 100.

° Protection ratios or criteria for interference into modulation techniques other than FDM/FM.

D. Stanford University

Some economic factors affecting technical sharing decisions were presented by the Stanford University representative. The comments were based on work performed at Stanford and reported in a doctoral dissertation by Steven P. Russell (Appendix XI).

It is the thesis of the Stanford work that efficient use of the geostationary orbit and the radio spectrum is not solely a matter of control of interference and antenna size. In fact such efficient use is not an exclusive question of spectrum conservation. Rather it is a function of the least total cost of providing the desired services and the determination of which steps should be taken and when should they be taken to minimize that cost.

The basic resource in question is the product of the 360° of orbit space and the finite amount of spectrum available to the various space services. This basic resource is measured in units of gigahertz-degrees.

The work from which the Stanford presentation was extracted was based on a survey of all of the various techniques for improving efficiency of use of the spectrum orbit resource. This survey was used to establish a maximum capacity for the resource. The computed capacity was compared to the requirements for the foreseeable future and predicted to be far in excess of those requirements. This prediction was based on the application of the various spectrum orbit conservation techniques such as multiple beams, frequency reuse, polarization discrimination, efficient modulation schemes and larger antenna diameters.

In this context, the question of orbit spectrum use became not one of who should or shouldn't use the resource, but rather who should adopt the most costly techniques to assure availability of capacity.

The conclusions of the Stanford study are given with detailed backup in Appendix XI. A summary of those conclusions is quoted below:

o "When spectrum saving measures are needed, it is the communication satellite systems with few ground stations, each carrying a lot of traffic, that ought to take these measures.

o "Candidates for spectrum conservation measures can be selected by identifying those systems with a low intensity of investment in spectrum use. This intensity is given by the ratio:

$$\frac{\text{Present Value of Satellite System Cost Stream}}{\text{Total Orbit - Spectrum Used}}$$

o "Prohibiting small aperture ground stations is an extraordinarily expensive way of conserving orbit-spectrum.

o "The capacity available at 4 and 6 GHz, without incuring significant spectrum conservation costs, is very large. Consequently, expenditures for conservation measures [in these bands] ought to be delayed.

o "If it is desired to relieve spectrum congestion by "offloading" services to terrestrial facilities, it is best to offload the trunk services.

o "Use of the 12 and 14 or 20 and 30 GHz bands should be regarded as just another technique for relieving spectrum congestion. In this role, these bands will probably be most useful for trunk telephony applications."

IV SUMMARY

The thrust of the seminar presentations centered on accommodation and conformance: accommodation of small earth terminals in an environment already populated and oriented toward large earth terminals and conformance (or lack thereof) of those small earth terminals with criteria intended for application to large terminals.

Systems utilizing "small" antennas ranging from 4 foot to 30 foot diameters were described. Parabolic dishes as small as fifteen foot diameter and horn antennas of even smaller dimensions were described as complying with the CCIR reference radiation pattern of $32 - 25 \log\theta$.

The requirements for SET's in support of a wide variety of functional applications were highlighted. Applications in the scientific and resources management areas were of special interest because of the extremely widespread use and large numbers of terminals involved. Literally thousands of data collection locations are potential candidates for terminals using such systems as GOES and ERTS. Perhaps hundreds more may be expected to go into operation to use the public services provided by the NESS.

Communications terminals, while not so numerous as the scientific and data relay terminals, are nevertheless ubiquitous. Moreover, the problem of sharing between "large" and "small" is more intense in the communications area, because the development history has led to early establishment of systems oriented toward large terminals and thus the small terminal technology must try to "fit in."

In fact the question of sharing between "large" and "small" in communications satellite applications has matured to the point wherein many studies have been conducted and much has already been added to the literature. But the criteria for sharing and the necessary regulatory controls have not been established.

During the seminar, the need to initiate action in appropriate CCIR Study Groups was repeatedly emphasized. Sharing criteria based on various grouping strategies were proposed; papers expounding on these strategies should be developed and funneled into the CCIR process. Only in this way can the various ideas and opinions discussed at the seminar receive broadbased technical scrutiny. Such scrutiny and review is necessary to the establishment of rational recommendations on an unquestionably international issue.

Questions raised but not answered during the seminar included such factors as:

o Should presently allocated bands be broken up and suballocated for separate use by small and large terminal systems?

o Should grouping strategies on the geostationary orbit be employed and if so what are the best strategies?

o What are the quantitative advantages of cross polarization, sidelobe control, more efficient modulation techniques, etc.?

o What limits should be established for sidelobe levels of small earth terminal antennas and for received power flux densities?

o How should the economics of each proposed action be best considered? Who shall pay and on what basis is that decision made?

o What changes need to be made to present coordination procedures in order to better accommodate large numbers of small terminals?

o Where should the line be drawn to differentiate large antennas from small antennas with regard to special regulatory provisions?

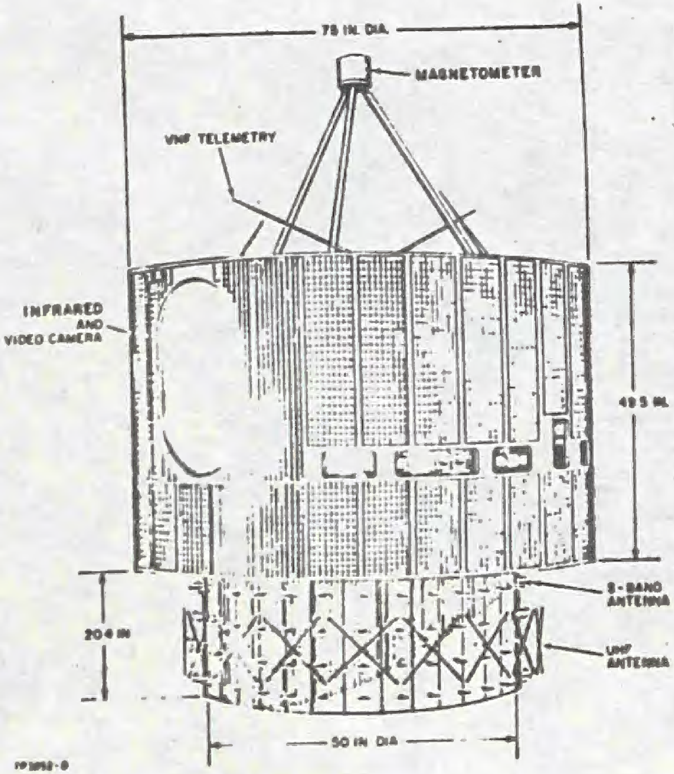
o Should reverse frequency paterns be used to separate small and large terminal systems?

Answers to these questions are not likely to come easily. There are competing philosophies as well as diverse objectives within the community of small terminal users. Care must be taken less too much regulatory action inhibit the development of these philosophies and objectives. Regulations that are enabling rather than restrictive, that provide a "loose harness" allowing some freedom of movement but always forward, are to be preferred.

APPENDIX A

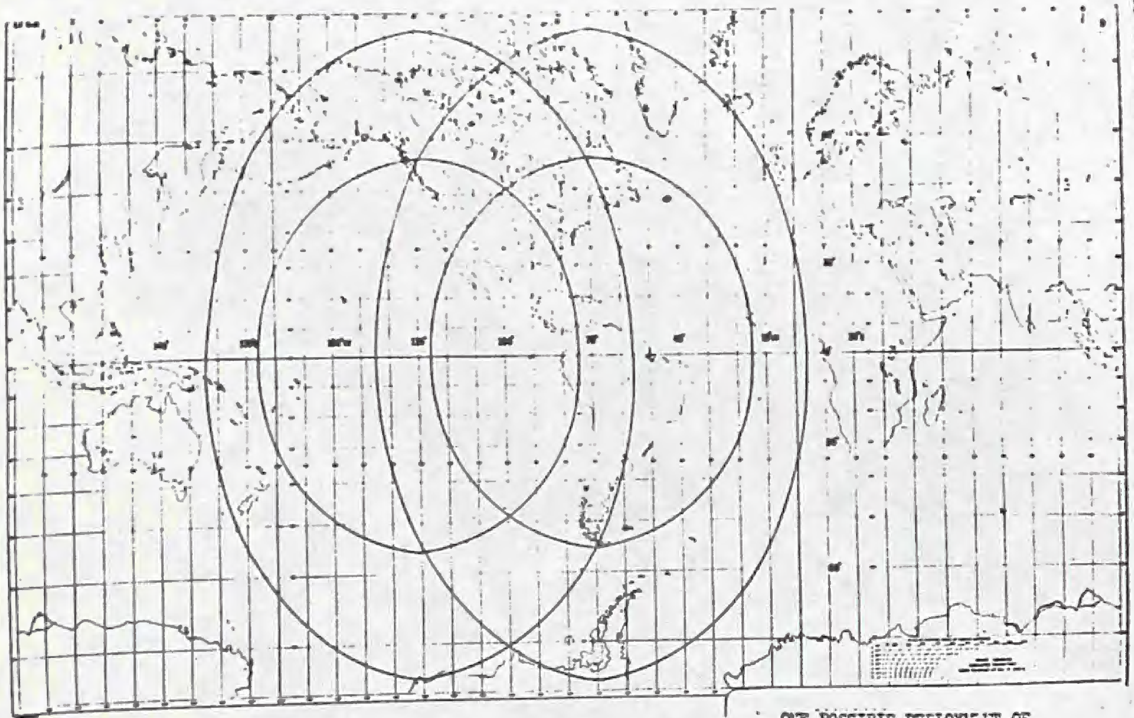
GOES SATELLITE SYSTEM CAPABILITIES; SMALL EARTH TERMINALS USED BY NESS

SMS/GOES SATELLITE



GOES SATELLITE SYSTEM CAPABILITIES

- Visible and Infrared Spin-Scan Radiometer - VISSR
- Retransmission of Weather Facsimile, WEFAX
- Retransmission of Stretched VISSR
- Space Environment Monitoring, SEM
- Data Collection System, DCS



ONE POSSIBLE DEPLOYMENT OF
A TWO GOES SYSTEM 130, 70 °W

Objectives of the GOES DCS Communication Program

- TO COLLECT AND DISTRIBUTE ENVIRONMENTAL DATA MEASURED ON REMOTELY LOCATED, ATTENDED AND UNATTENDED DATA COLLECTION PLATFORMS (DCP'S) LOCATED ON LAND, AT SEA, OR IN THE ATMOSPHERE
- COLLECT DATA IN A SIX-HOUR SYNOPTIC PERIOD
- COLLECT DATA FROM A MINIMUM OF 10,000 DCP'S
- PROVIDE CAPABILITY FOR COLLECTING DATA IN A ROUTINE OR EMERGENCY MANNER

VG6934

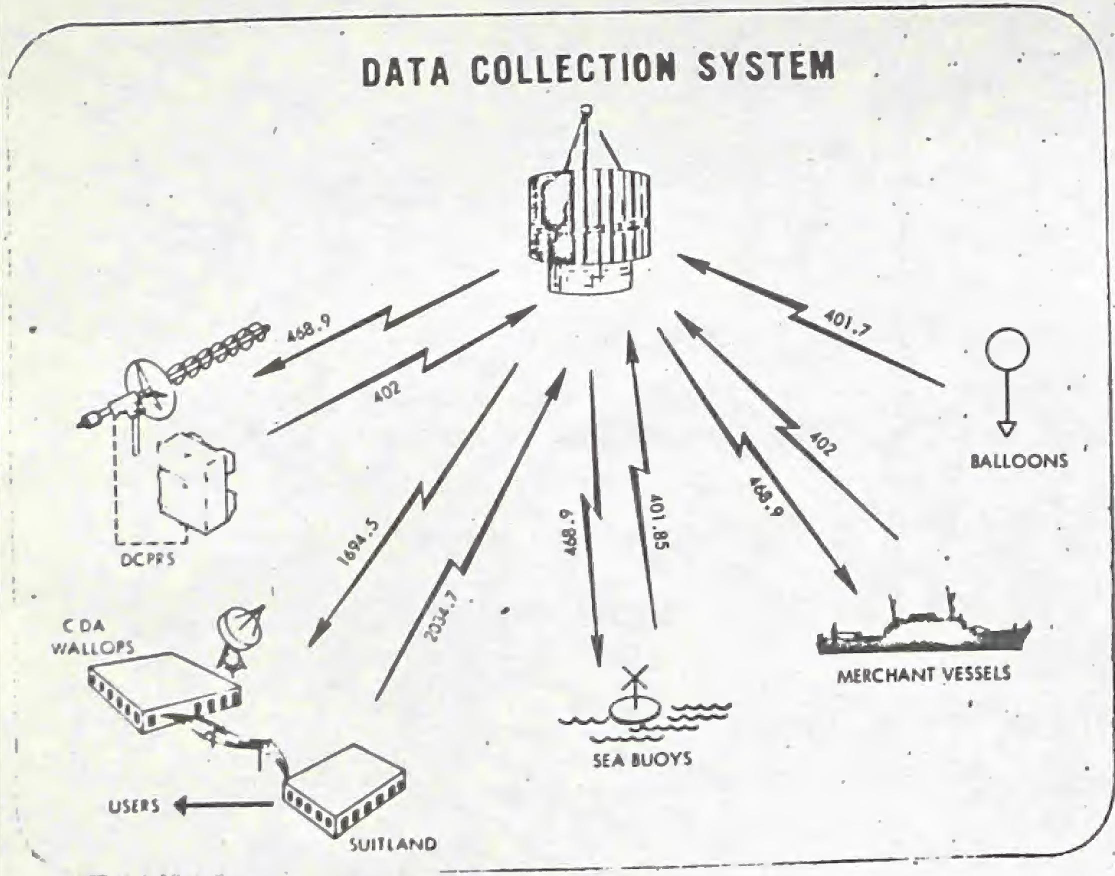
To Meet These Objectives, the Command and Data Acquisition Station at Wallops Station, Virginia, Will Have the Following Capability:

- CENTRAL MASTER TERMINAL
- CONTINUOUS DEDICATED OPERATION
- OPERATION KEYED TO A SIX-HOUR SYNOPTIC PERIOD
- USER ACCESS FOR INTERROGATION AND DATA DISSEMINATION VIA LAND LINES
- ON-SITE SURVEILLANCE OF LINK INTEGRITY

VG6936

To Meet These Objectives, the DCP Will Be Provided with the Following Capabilities:

- EACH DCP IS CAPABLE OF MULTIPLE UNIQUE ADDRESSES
- DATA RESPONSES BOTH TIME AND FREQUENCY ORDERED
- TWO BASIC CLASSES OF PLATFORMS
  - INTERROGABLE OR COMMANDABLE
  - SELF-TIMED OR PROGRAMMABLE
- EMERGENCY REPORTING CAPABILITY
  - PARAMETERS EXCEEDING A THRESHOLD
  - UPON COMMAND FROM COMMAND AND DATA ACQUISITION STATION



System Specification for the Downlink from Spacecraft to DCP (Interrogated Platforms Only)

FREQUENCY	468.825 MHZ 468.8375 MHZ
CHANNELS	1
UNIQUE ADDRESSES	>100,000
MODULATION FORMAT	$\pm 60^0$ PSK, MANCHESTER CODED
DATA RATE	100 BPS, BINARY
METHOD OF ADDRESSING	TDMA WITH BASELINE REQUIREMENT FOR SIX-HOUR SYNOPTIC PERIOD
ERROR RATE	1 PART IN 10^6
EMERGENCY REQUIREMENT	TIME SLOTS RESERVED FOR PRIORITY INTERRUPT
MAXIMUM NO. OF SYNOPTIC INTERROGATIONS	45,000/SIX HOURS
MESSAGE RELIABILITY	PROBABILITY OF CORRECT RESPONSE >0.999966 PROBABILITY OF FALSE RESPONSE $<1.36 \times 10^{-10}$

VG6939

System Specification for the Uplink from DCP to Spacecraft (Interrogated Platforms Only)

FREQUENCY	401.850 MHZ TO 402 MHZ
NO. OF CHANNELS	100
CHANNEL SPACING	1.5 KHZ
METHOD OF RESPONDING	TDMA/FDMA
CODE FORMAT	ANSCII
BIT RATE	100 BAUD
ERROR RATE	1 PART IN 10^6
MODULATION FORMAT	$\pm 60^0$ PSK, MANCHESTER CODED
EMERGENCY REQUIREMENT	FREQUENCY CHANNELS RESERVED FOR RESPONSES TO: • EMERGENCY COMMANDS • PARAMETER MEASURES EXCEEDING PREDETERMINED THRESHOLD

VG6940

System Specification for the Uplink from DCP to Spacecraft (Self-Timed Only)

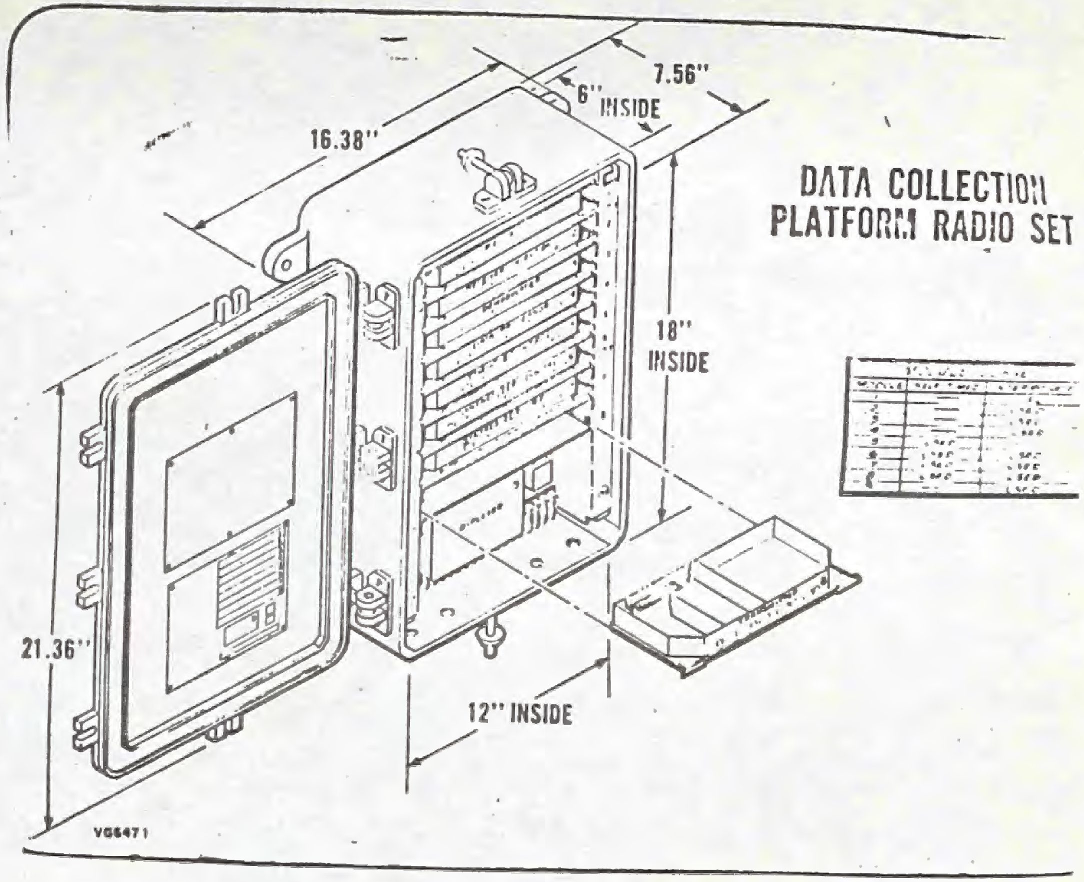
FREQUENCY	401.7 MHZ TO 401.85 MHZ
NO. OF CHANNELS	50
CHANNEL SPACING	3 KHZ
METHOD OF RESPONDING	TDMA/FDMA
CODE FORMAT	ANSCII
BIT RATE	100 BAUD
ERROR RATE	1 PART IN 10^6
MODULATION FORMAT	$\pm 60^0$ PSK, MANCHESTER CODED
SYNOPTIC INTERVAL	1 TO 12 HOURS IN ONE HOUR INCREMENTS.
MINIMUM NO. OF RESPONSES FOR ONE YEAR UNATTENDED OPERATION	17,000/SIX HOUR PERIOD
EMERGENCY REQUIREMENT	FREQUENCY CHANNELS RESERVED FOR RESPONSE AS A RESULT OF A PARAMETER EXCEEDING A PREDETERMINED THRESHOLD

941

DCP Radio Set Specification Fixed Locations

PARAMETER	SELF-TIMED	INTERROGATED
• FREQUENCY		
RECEIVE	N/A	468.825 MHZ
TRANSMIT	401.7 MHZ TO 401.85 MHZ	401.85 MHZ TO 402 MHz
• NO. OF CHANNEL		
RECEIVE	N/A	1
TRANSMIT	50	100
• MODULATION TECHNIQUE	± 60° PSK MANCHESTER	± 60° PSK MANCHESTER
• TRANSMITTED POWER	5 WATTS	5 WATTS
• STANDBY POWER DISSIPATION	< 100 MW	< 200 MW
• RECEIVER SENSITIVITY	N/A	-130 DBM
• ANTENNA	HELIX, RH CIRCULAR POLARIZATION 13 DB, 60° BW @ 3 DB POINTS	
• SUPPLY VOLTAGE	5V, 12.5V	5V, 12.5V
• TEMPERATURE RANGE	-20°C TO 50°C	
• SIZE	15.63" X 21.63" X 12.88"	
• WEIGHT	12.07 POUNDS LESS CHASSIS	

VG6942



UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite Service
Washington, D.C. 20233

S23

Nov. 4, 1975

SMALL EARTH TERMINALS USED BY NESS

by

John J. Nagle
Office of System Engineering
NOAA/NESS

NESS has five types of systems using small earth terminals. These are:

1. APT from orbiting satellites
2. WEFAX from stationary satellites
3. DCS platforms
4. TARS (housekeeping service)
5. SFSS (Satellite Field Service Station)

The DCS platforms have been described by Mr. Puerner; I will describe the other four. Of these five, three are intended for direct use by the public, and two of these three do not require the permission, or even knowledge of the Satellite Service. Because of this, new small earth terminals can come and go with little, if any, advanced knowledge of the Government. The fifth is intended for professional meteorologists.

1. APT (Automatic Picture Taking)

Historically, the first direct readout type of service was APT. With APT, orbiting satellites transmit facsimile pictures of the cloud cover within view of the satellite. Thus, a suitable equipped ground station can record in real-time the weather conditions within a radius of a few hundred miles of the ground station. This service has proven to be very popular with the public. It is estimated that there are about 800 APT ground stations around the world. Equipment requirements are very modest; a 10dB Yagi antenna and a 6dB noise figure receiver with a facsimile recorder capable of tuning 136-138 MHz are all that is required. Figure 1 is a view of typical APT equipment, while the second slide is an APT image taken over Italy.

2. WEFAX (Weather Facsimile)

WEFAX is a service that uses geostationary satellites to rebroadcast cloud cover imagery that has been computer processed on the ground. At the present time, ATS-1 and 3 broadcast WEFAX in the 136-138 MHz region. The SMS/GOES family of geostationary metsats, as well as metsats planned by ESA, the USSR and the Japanese will all broadcast WEFAX on 1691 MHz. The signal characteristics and format for WEFAX are the same as for APT so that the same equipment can be used for APT, and VHF WEFAX. A simple frequency translator can be used to convert the 1691 WEFAX to VHF frequencies for VHF equipped stations. A 2 to 3 meter paraboloidal antenna is adequate for the 1691 MHz frequencies, depending on the input noise figure of the translator.

When the GOES satellites became operational, it was expected that the VHF WEFAX would be discontinued; however, due to "popular demand" it is now expected that the VHF broadcasts will be continued as long as the ATS satellites are viable. When these satellites fail, all WEFAX will be on 1691 MHz. It is estimated there are approximately 175 WEFAX users at the present time. Typical APT and WEFAX users are educational institutions, TV stations, ships at sea, amateur meteorologists as well as small, isolated met stations.

Figure 3 shows a photo of an image photographed by an orbiting satellite which was transmitted to a CDA station. Latitude and longitude markings as well as geographical outlines were computer added on the ground and the image rebroadcast on WEFAX. Baja California is in the upper right-hand corner. Figure 4 shows an image taken by an SMS satellite at about 75° West Longitude. This photograph was received by a teenager, using the home-made equipment of Figure 5. Figures 6, 7, and 8 show a WEFAX installation at the airport in Trinidad.

3. TARS (Turn-Around Ranging System)

The TARS is strictly a housekeeping system used to determine the position of the satellite. A tone is transmitted from the CDA station to the satellite. This tone is both returned to the CDA station directly, and also retransmitted to a TARS station and then returned to the CDA station through the satellite. By using two TARS stations and measuring various phase shifts, the position of the satellite can be determined to within a few hundred meters. The tone may vary from 35 Hz for coarse ranging to 200 KHz for fine ranging.

TARS stations are presently located in Seattle, Washington; Honolulu, Hawaii; Santiago, Chile and Ascension Island. The TARS station in Honolulu is seen in Figure 9, and the Seattle TARS in Figure 10. The characteristics of these stations are summarized in Figure 11; antenna patterns, as provided by the manufacturers, are shown in Figure 12 and 13.

4. SFSS (Satellite Field Service Station)

The fifth and last type of small earth terminal in use is the SFSS. This terminal provides high resolution imagery and is intended for professional meteorologists.

The GOES satellite is spin stablized with its axis parallel to the earth's axis; it spins at about 100 rpm from East to West across the earth's surface, and each line of high resolution imagery is transmitted to the CDA ground station in real-time. This requires a data rate of 28m bits/sec. In order to receive this high a data rate with an acceptable error rate, the CDA station requires a 20 meter antenna with a cooled parametric amplifier. This is a fairly elaborate and expensive installation. To enable smaller and less expensive ground stations to receive high resolution images, the burst of data as received is "stretched" at the CDA station from about 30m sec., to 540m sec. This results in a much lower bit rate. The stretched data is then retransmitted back to the satellite during the next 540m sec., for relay to the ground where it can be received, typically, by an 8 meter antenna and an ambient temperature parametric amplifier, which is a considerably less expensive installation than the equipment required to receive the high data rate imagery. In this manner the GOES satellite is used to relay its own data at a much lower data rate. This type of data is intended for use by regional weather stations in this country, or the principal weather facility in smaller countries. The SFSS receives in the 1680 MHz region. A brief outline of the "in place", measured antenna characteristics for these systems is given in Figures 14 and 15. (Note: We can supply detailed pattern measurements to anyone interested.)

So much for the different types of small earth terminals used by the Satellite Service; how do these effect our frequency coordination problems? As metsats operate on frequencies exclusively reserved for meteorological purposes, we do not have the hassle of the 4/6 and 7/8 GHz bands. Our biggest coordination type problem is a power-flux-density problem with WEFAX and TARS in the 1690 MHz region. With WEFAX, the higher our PFD, the cheaper the SET can be made. With the GOES satellites in their present position, one country has objected and this is being negotiated.

The TARS presents a slightly different problem since this signal consists of single tones instead of a continuous spectrum so that the transmitted signal consists of a series of impulse functions in the frequency domain; this may be more or less objectionable depending on the terrestrial system.

Also, since the TARS signals are of little direct benefit to users, the political situation here is somewhat different. We are, however, hopeful of being able to clear these problems in the future.

From the above material, it can be seen that the National Environmental Satellite Services uses a wide variety of small earth terminals, including receive only terminals, transmit only terminals, and terminals that both transmit and receive.

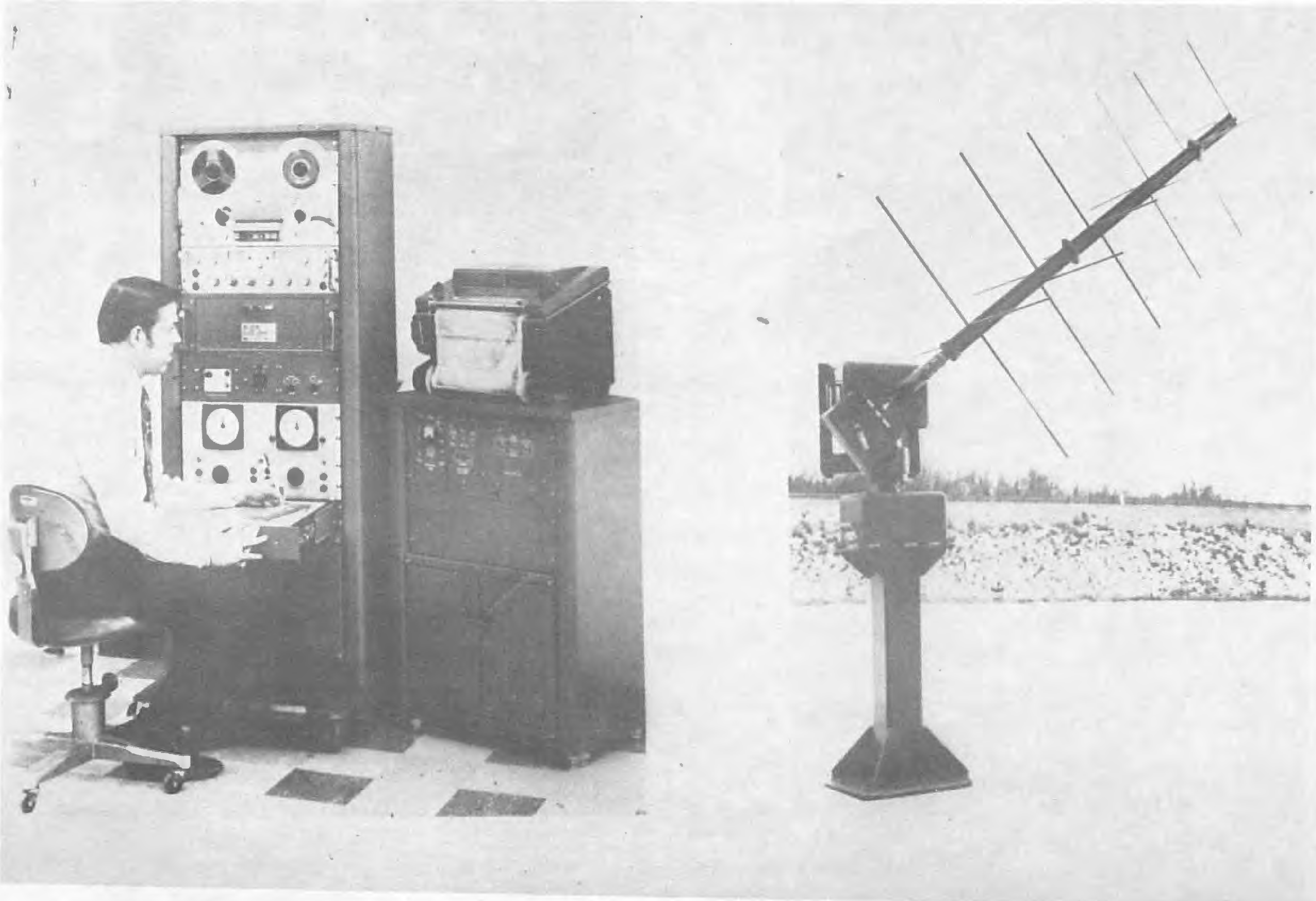


FIGURE 1. Equipment required for a typical APT Station

FIGURE 2. This is an APT image taken over Italy. The reference mark in the center is approximately over Rome; Corsica and Sardinia are to the left of Italy and the Swiss Alps are under cloud cover at the top of the image.

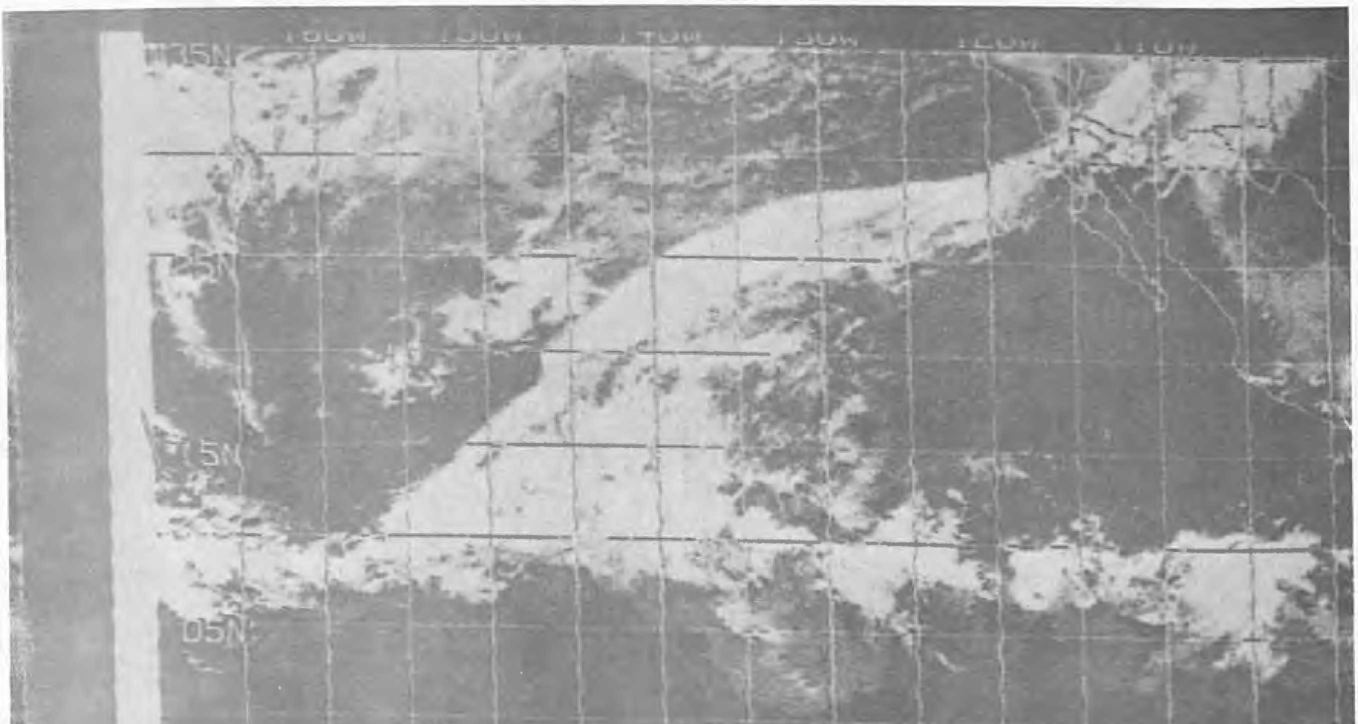


FIGURE 3. A WEFAX picture taken over the Pacific. Baja California is seen outlined in the upper right-hand corner.

2

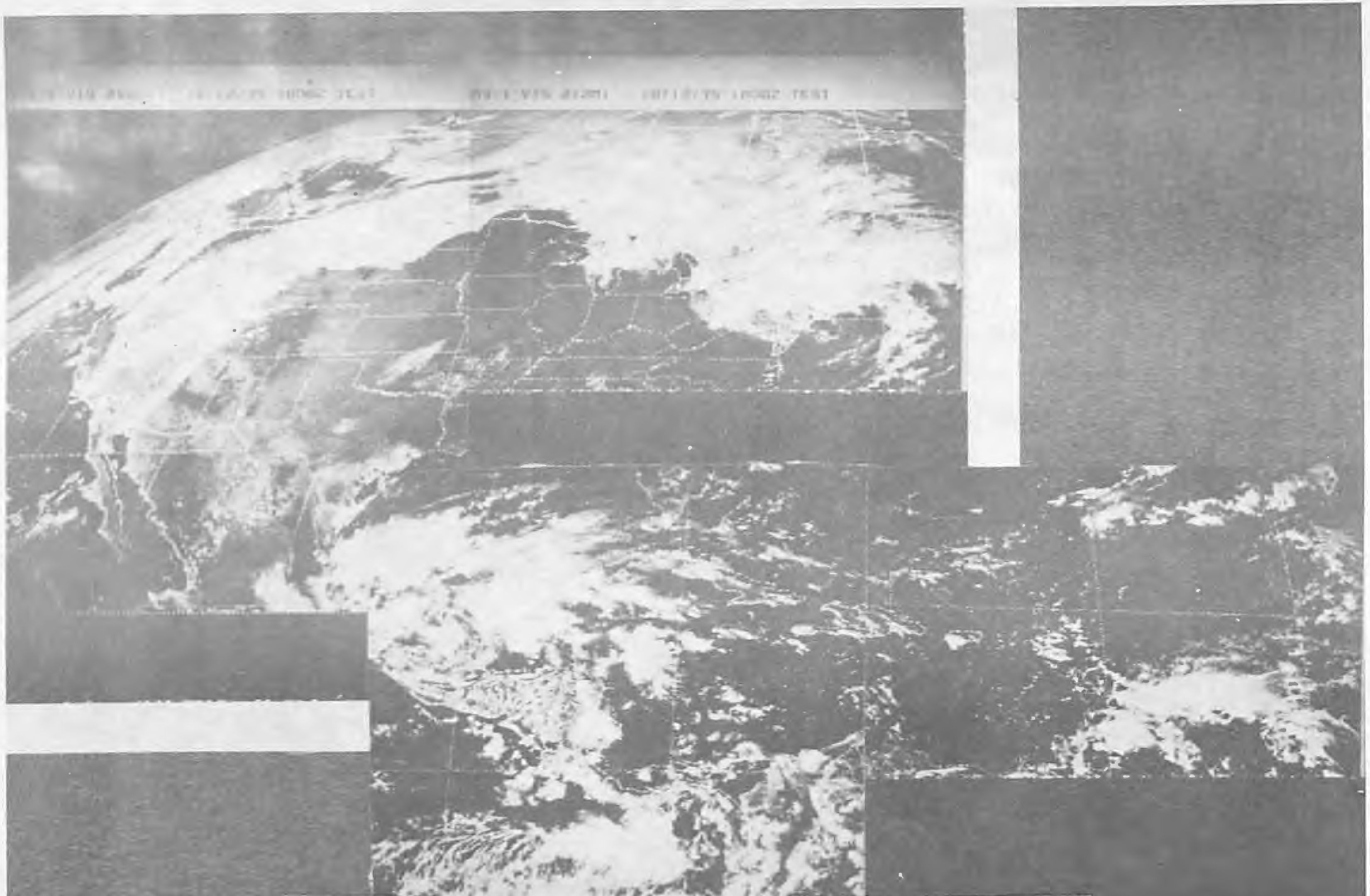


FIGURE 4. A portion of a full earth disc as taken by an SMS/GOES satellite. The image was computer processed on the ground to add the geographical outlines and retransmitted as WEFAX. This image was received by a teenager shown in FIGURE 5.

FIGURE 5. This teenager, using the home made equipment shown received the image in FIGURE 4.

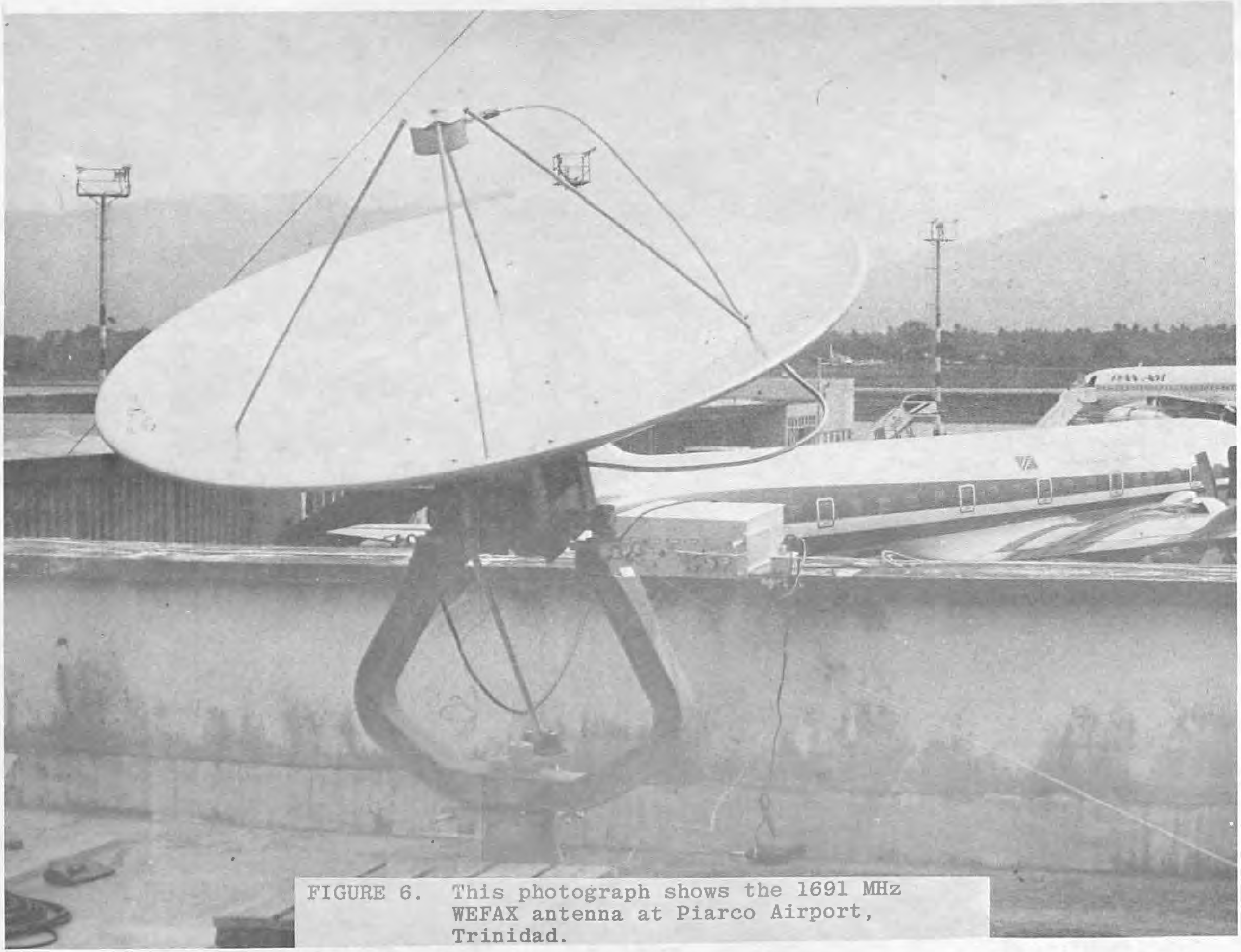


FIGURE 6. This photograph shows the 1691 MHz WEFAX antenna at Piarco Airport, Trinidad.

FIGURE 7. The VHF WEFAX antenna at Piarco Airport, Trinidad, is shown here.

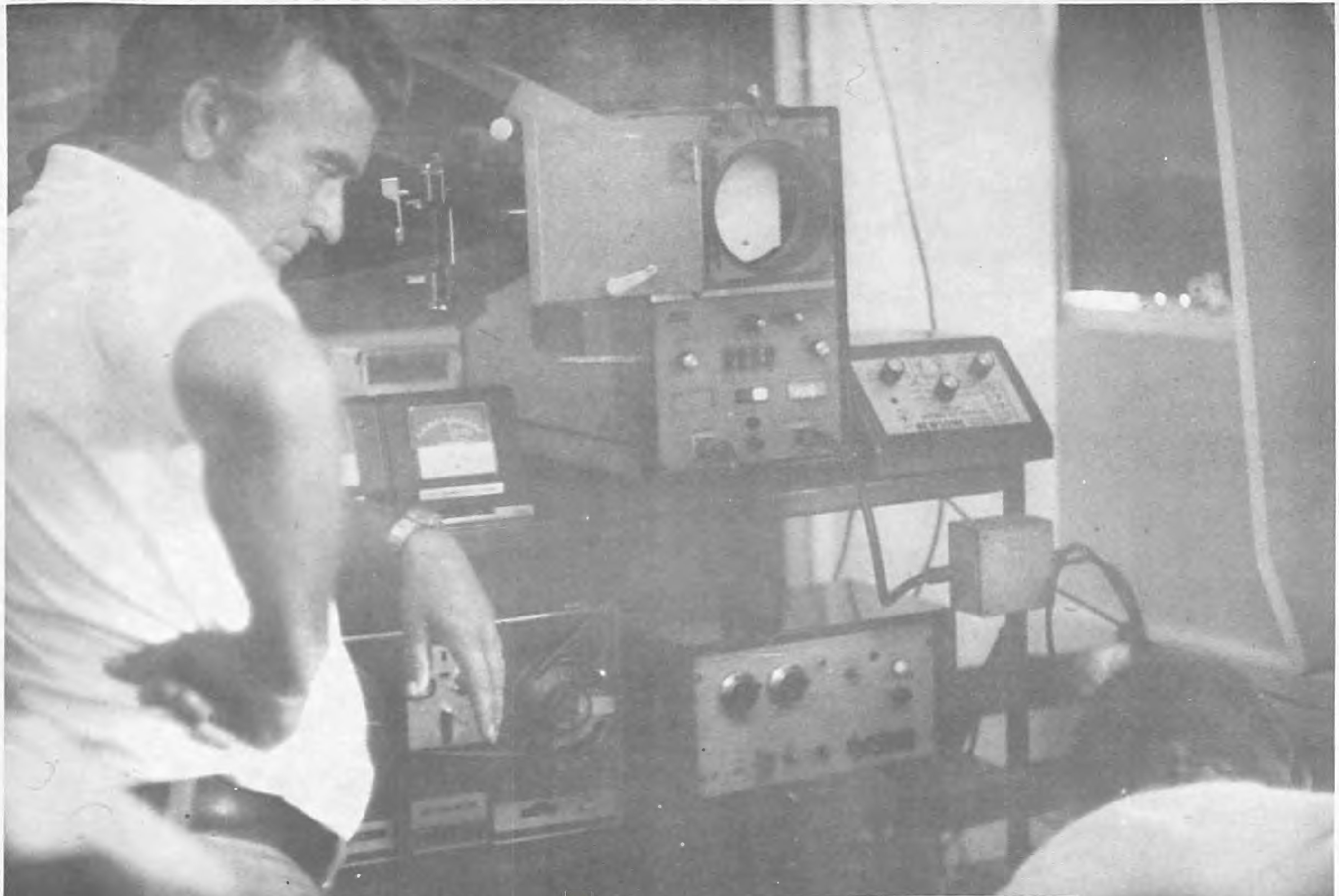


FIGURE 8. The "inside" receiving, recording and monitoring equipment at Piarco Airport is seen in this figure.

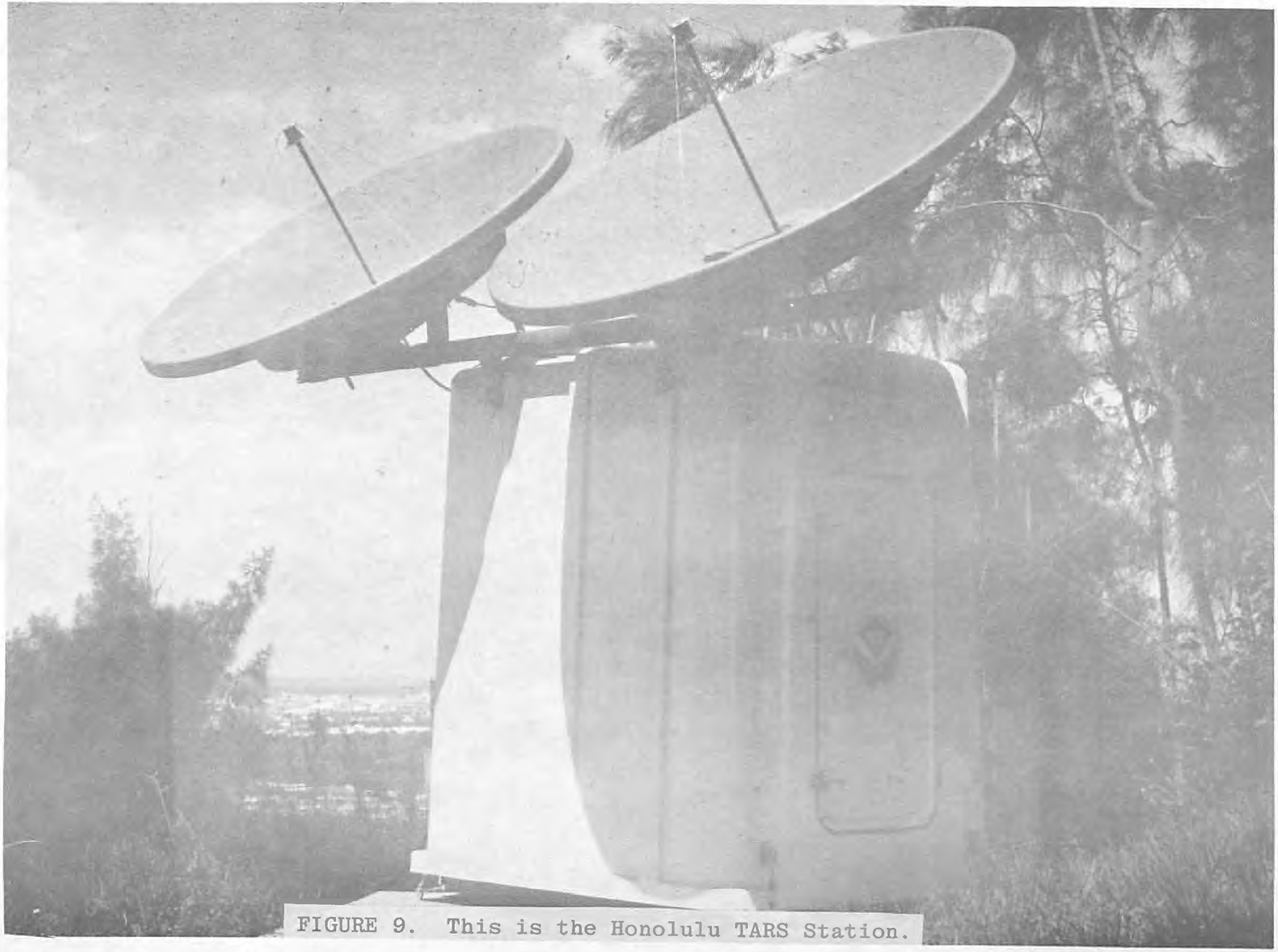


FIGURE 9. This is the Honolulu TARS Station.

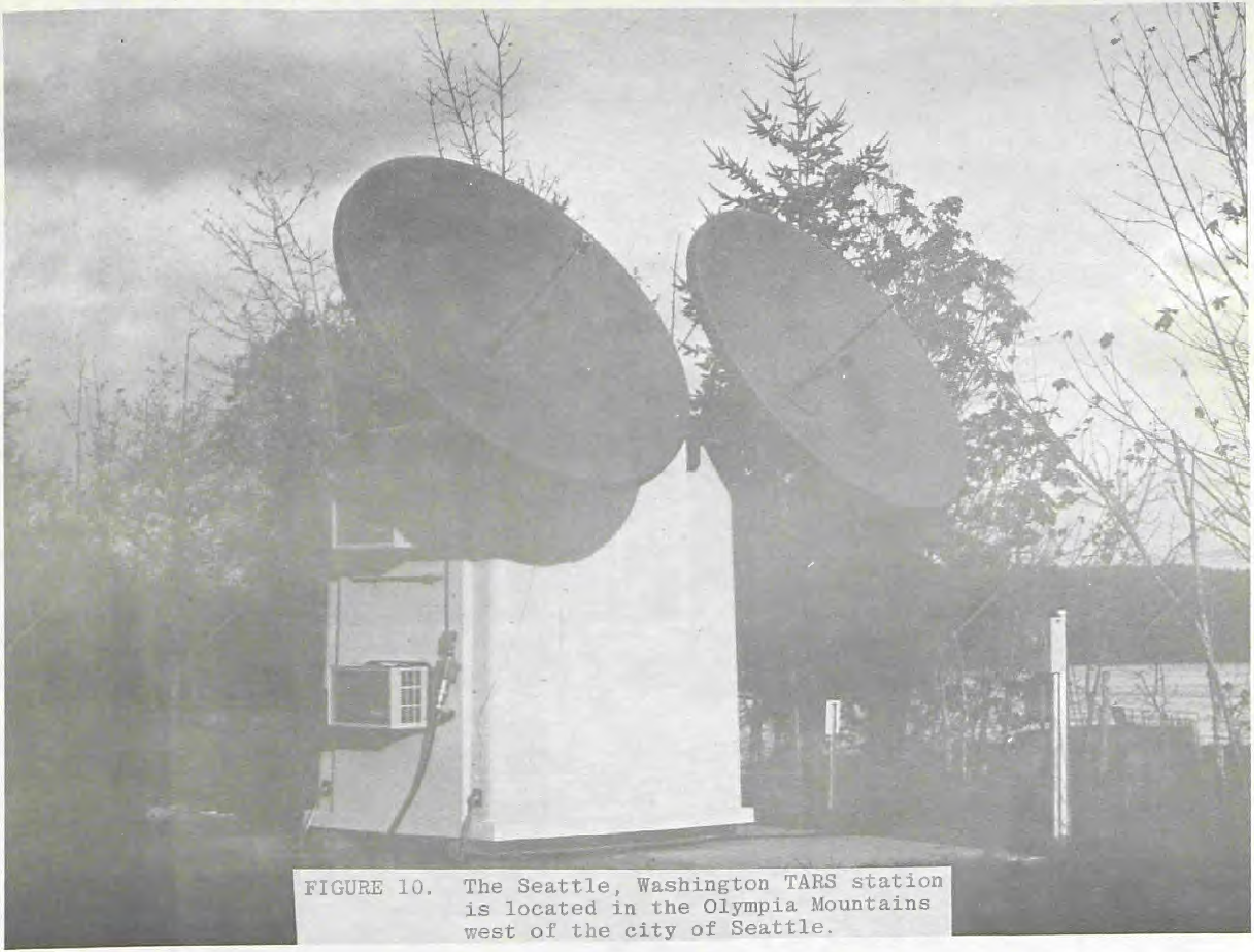


FIGURE 10. The Seattle, Washington TARS station is located in the Olympia Mountains west of the city of Seattle.

TARS I AND II LINK ANALYSIS

3 dB BANDWIDTH = 1.00000E'06 Hz

HIGHEST RANGE TONE FREQ = 200000.00

CDA TRANSMITTER POWER = 48.0 dBm

		LINK 1 CDA TO S/C	LINK 2 S/C TO TARS	LINK 3 TARS TO S/C	LINK4 S/C TO CDA
TRANSMITTER POWER	(dBm)	48.00	43.00	46.00	43.00
X-PONDER POWER SHARING LOSS	(dB)	.00	-0.57	-1.13	-28.03
TX LINE LOSS	(dB)	-1.60	-3.40	-1.70	-3.40
TX ANTENNA GAIN	(dB)	48.00	19.10	31.80	19.10
EIRP	(dBm)	94.40	58.13	74.97	30.67
TX OFF BEAM CENTER LOSS	(dB)	-1.00	-2.50	-3.00	-1.60
(ANGLE IN DEGREES)		0.25	9.00	2.20	7.00
FREE SPACE LOSS	(dB)	-190.20	-189.50	-191.10	-188.60
POLARIZATION LOSS	(dB)	-0.20	-0.20	-0.20	-0.20
RX ANTENNA GAIN	(dB)	13.40	30.40	13.40	48.00
RX OFF BEAM CENTER LOSS	(dB)	-1.40	-2.40	-2.80	-0.70
(ANGLE IN DEGREES)		7.00	2.20	9.00	0.25
RX LINE LOSS	(dB)	-4.50	-0.70	4.5	-0.40
RX INPUT POWER LEVEL	(dBm)	-89.50	-106.77	-112.73	-112.83
SYSTEM NOISE TEMPERATURE	(dB-K)	32.12	28.00	32.12	20.00
BOLTZMAN'S CONSTANT	(dBm/Hz-K)	-198.60	-198.60	-198.60	-198.60
RX INPUT NZ	(dBm/Hz)	-166.48	-170.60	-166.48	-178.60
RX INPUT C/NZ	(dB-Hz)	76.98	63.83	53.75	65.77
OVERALL C/NZ	(dB-Hz)	76.98	63.62	53.32	53.08
RECEIVER BANDWIDTH	(MHz)	12.00	1.00	12.00	
RECEIVER BANDWIDTH	(dB)	70.79	60.00	70.79	
RX OUTPUT C/N OR C/SIGNAL	(dB)	6.19	3.62	-17.47	
LIMITER IMPROVEMENT	(dB)	2.31	1.65	-2.02	
TX OUTPUT C/N	(dB)	8.50	65.27	19.8	
C/NZ OUTPUT	(dB)	79.29	65.27	50.8	50.67
MODULATION LOSS	(dB)				-2.20
S/N OUTPUT					48.97
TWO-WAY RANGE TIMING ERROR	(SEC)	2.22	NANOSECONDS		

FIGURE 11. TARS LINK ANALYSIS

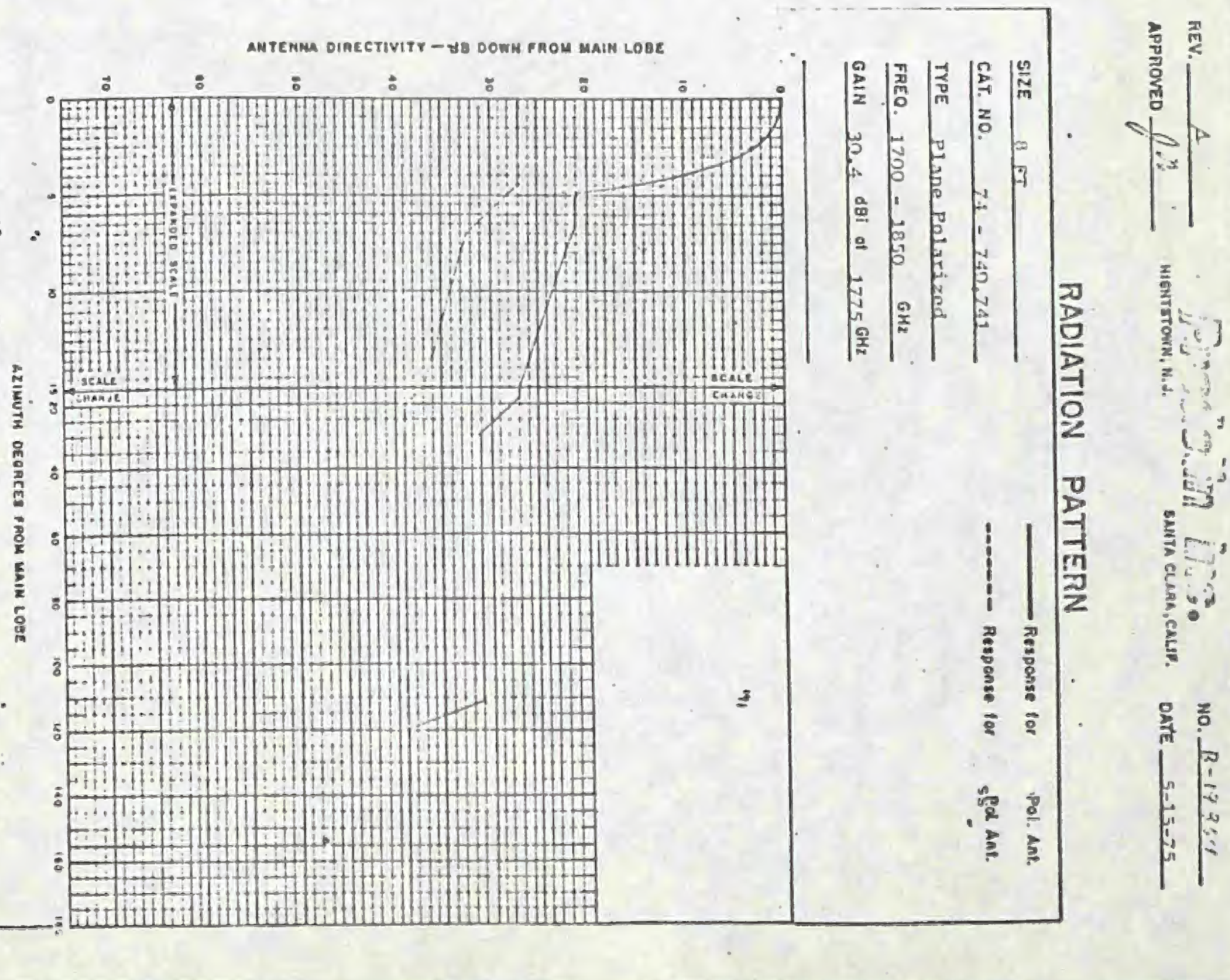


FIGURE 12. The TARS receiving antenna pattern.

Table 1. NOAA 24-foot Dish Antenna Pattern Evaluation, Antenna No. 1

ass No.	Element Orientation	Plane	East Side Lobe (dB)	East Null (dB)	West Null (dB)	West Side Lobe (dB)	Beamwidth (degrees)	Gain (dB)	Offset (degrees)
25	H	Aircraft RHC	22	28	29	21	3.2	39.5	+0.5
32	H	RHC	22	25	25	21	2.5	40.0	-1.2
34	H	RHC	21	26	28	21	2.3	40.0	-1.3
37	H	RHC	20	22	*	*	2.5	38.0	-1.2
24	V	RHC	*	*	*	*	*	39.0	*
22	V	RHC	19	23	*	*	3.2	40.5	*
21	V	RHC	*	*	23	20	3.1	35.5	+1.8
28	H	RHC	*	*	26	21	*	40.0	*

Data not available from pattern.

FIGURE 14. A summary of an SFSS, 8 meter antenna as measured in-place.

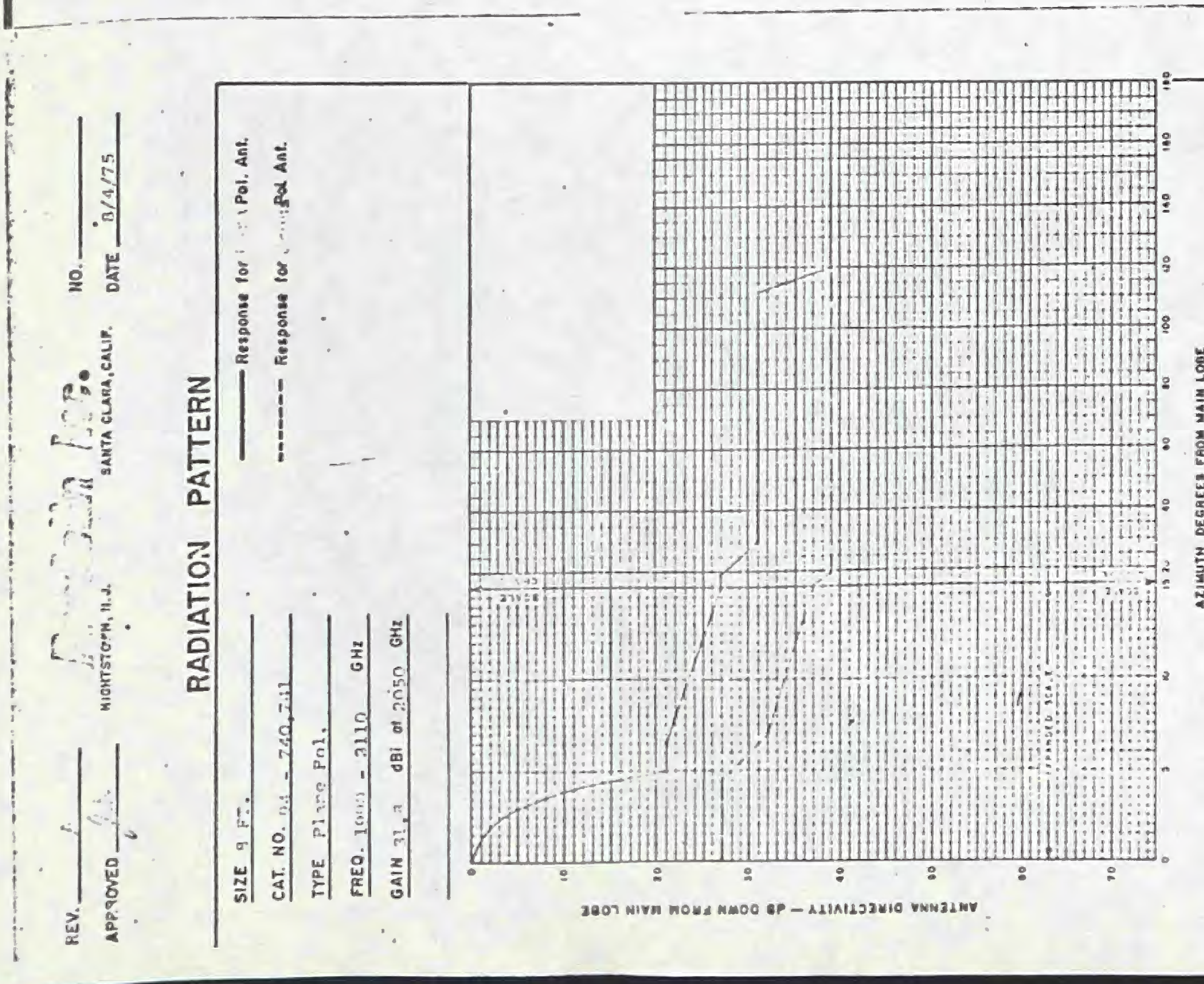


FIGURE 13. The TARS transmit antenna pattern.

Table 2. NOAA 24-foot Dish Antenna Pattern Evaluation, Antenna No. 2

Pass No.	Element Orientation	Plane	West Side Lobe (dB)	West Null (dB)	East Null (dB)	East Side Lobe (dB)	Beamwidth (degrees)	Gain (dB)	Offset (degree
1	V	Aircraft RHC	*	*	*	*	2.7	38.5	-1.2
3	V	RHC	*	*	*	*	2.4	39.5	-0.6
4	V	RHC	20	*	*	*	*	34.5	-2.1
5	V	RHC	24	39	40	25	2.7	39.5	-0.6
7	V	RHC	21.5	*	*	*	2.7	38.5	+0.5
8	V	RHC	26	*	*	*	2.4	38.5	-1.0
9	V	RHC	*	*	35	23	3.0	40.0	+0.1
10	V	RHC	27.5	35	35	26.5	2.7	40.5	+0.4
13	H	RHC	*	*	*	*	*	35.5	-2.1
14	H	RHC	*	*	*	*	*	39.5	-0.1
15	H	RHC	*	*	*	*	*	40.0	-0.8

*Data not available from pattern.

FIGURE 15. A summary of a second SFSS, 8 meter antenna. Antennas referred to in this and the preceeding figure are installed on FOB-4, Suitland, Md.

APPENDIX B

THE ALASKA COMMUNICATION PLAN; SMALL STATION PERFORMANCE AND INTERFERENCE ANALYSIS

Attachment F

to

The Alaska Communication Plan

Small Station Performance and Interference Analysis

SMALL STATION PERFORMANCE AND INTERFERENCE ANALYSIS

CONTENTS

A.1 Telephone Services

Telephone Service Analysis: The maximum number of events to provide P 10 service to the bush communities via satellite has been calculated. Only one phone per village is planned initially. This will result in slightly less than P 10 service.

Assumptions:

A. Assumes that the addition of phones does not increase the total amount of traffic.

B. Use of Demand Assignment Multiple Access to route traffic.

C.

Number of Telephones	56	148
Erlangs*	7.63	7.63
P 10 Channels (one way)*	32	32

* If calls are Poisson distributed and call duration times are exponentially distributed.

Voice Quality: This performance is intended for use with Delta Modulation voice modems. However, the criteria used for this digital technique are not the same as for an analog technique. For example, the analog systems criteria for a

voice channel are related to the interference noise received in that voice channel. This noise is directly related to the carrier-to-noise ratio, C/N, of the channels. In the case of digital signals, the relationships are somewhat different. With infinite C/N and associated zero bit-error rate (BER), a digital system will have noise present during speech utterances only. This noise is due to the sampling or quantizing process which results in a signal to quantizing noise ratio (SQR). A voice signal SQR of 30 dB results in excellent speech quality and will not be significantly degraded at a lower C/N and associated higher BER. BER's of about 10^{-3} will not significantly affect an SQR of 30 dB.

A.2 References

Ref. 1. Analysis of Intermodulation Distortion In An FDMA Satellite Communication System with a Bandwidth Constraint: Richard B. McClure.

Ref. 2. Attachment I, Technical Definition of R.F. Channel Service (Telesat Document which specifies the characteristics of the satellite channels to which Telesat agrees to provide access).

Ref. 3. RFP for RCA Alaska Communications, Inc. for 10 foot and 15 foot diameter earth stations.

Ref. 4. Domestic Communication Satellite Spacecraft Specification Revision B; January 18, 1974.

Ref. 5. Notebook of L. Ottenberg. Systems Performance of G.E. Delta Mod Equipment obtained from F. Klippel and B. Milton of G.E. Also, System Aspects of the Initial Telesat Thin Route Satellite Communication System, P. Rossiter, Telesat Canada.

System C/N vs Bit Error Rate:

System C/N in a 40 kHz NBW (dB)	BER
6.6	1×10^{-2}
8.0	3.5×10^{-3}
9.0	1.2×10^{-3}
10.0	3.3×10^{-4}
11.0	7.0×10^{-5}
12.0	1.2×10^{-5}
13.0	1.6×10^{-6}

A.3 Link Analysis

Derivation of Equations

Carrier to Noise Ratio (C/N_T): The C/N_T derived in this expression is the ratio of the received modulated signal relative to the thermal noise in the system. This expression can be used for the uplink and downlink upon substitution of the appropriate path loss and other parameters in the equation.

Carrier to Noise Ratio (C/N_T): The C/N_T is obtained as follows:

Let:
P_R = Received Power
P_T = Transmitted Power
G_T = Transmit Antenna Gain
G_R = Receive Antenna Gain
L = Path Loss
T_S = System Noise Temperature

Then:
$$P_R = P_T G_T G_R L$$
$$P_R/T_S = P_T G_T \times G_R/T_S \times L$$
$$P_R/T_S = EIRP \times G/T \times L \quad (1)$$

From ITT Reference Data for Satellite Communication Earth Stations (Page 24):

$$C/N = C/KTB$$
$$C/T = CKB/N$$
$$C/T = C/N + 10 \log B - 228.6 \text{ dBw/Hz/}^\circ K \quad (2)$$

However:

$C/T = P_R/T_S$. Therefore, equating 1 and and expressing the terms in log form:

$$C/N + 10 \log B - 228.6 = EIRP + G/T + L$$
$$C/N = EIRP + G/T + L + 228.6 - 10 \log B \quad (3)$$

Path Loss, (L): This path loss is due to the R.F. signal being attenuated as a result of the transmission path between two antennas.

The expression for the path loss (L) is obtained from Reference Data for Radio Engineers, Fifth Edition, Pgs. 26-20.

$L = 36.6 + 20 \log f(\text{MHz}) + 20 \log d$ (miles)

For Alaska the slant range is 25,500 miles and therefore

$L = -196.8$ dB @ 4GHz

$L = -200.3$ dB @ 6GHz

Flux to EIRP Conversion: The received power to satellite is expressed in dBw/M^2 and the radiated power from earth stations (EIRP) in dBw. Accordingly, an equation must be found that relates the power expressed in dBw to the power expressed in dBw/M^2.

Derivation: Consider a point source of P watts radiating to the surface of a sphere of radius R. The area of this sphere is $4\pi R^2$. The flux density at the surface of a sphere is $P/4\pi R^2$. Now if R is in meters, then the flux is in watts/M^2. Converting watts/M^2 to log form:

$\text{dbw}/M^2 = 10 \log \text{watts} - 10 \log 4\pi R^2$

$\text{Flux density} = \text{dBw} - 10 \log 4\pi R^2$

Now, substitute EIRP for dBw and an R of 25,500 miles (after converting to meters) and

$\text{Flux density} = \text{EIRP} - 163.3$ (dBw/M^2)

Transponder Channel Capacity: The number of equal amplitude carriers in one transponder channel for the single channel per carrier (SCPC) mode is found as follows. If p is the power required for one channel, np is the power required for n channels. Accordingly, the total power required is

expressed as:

$P_t = np$

Converting to log form

$10 \log P_t = 10 \log n + 10 \log p$ (dBw)

However, the total power available is the satellite EIRP subtracted by the output back-off (OPBO) required to meet intermodulation distortion (IM) requirements. Accordingly,

$10 \log P_t = \text{EIRP} - \text{OPBO} = 10 \log n + 10 \log p$

$10 \log p = \text{EIRP} - \text{OPBO} - 10 \log n$

Where

$10 \log p = \text{EIRP/carrier}$

Frequency Staggering Improvement: The C/N for the SCPC mode will be further degraded by distortion products due to intermodulation products (IM). These products will add to the thermal noise of the system on a power basis for a large number of carriers as the IM products can be considered random. However, for a "small" number of carriers the IM products are not quite so random. As a result, the carriers can be spaced such that some IM products do not fall into their modulated bandwidths. This will result in an improvement in the ratio of the modulated carrier to unwanted IM product (C/IM) due to frequency staggering. The frequency staggering improvement (FSI) has been determined by Telesat to be as follows:

$\text{FSI} = 10 \log \text{AFA}/n$

where,

AFA = Available frequency assignments

and,

n = number of carriers

AFA = Transponder BW/carrier separation

Transponder BW = 34 MHz (Reference 4)

Carrier Separation = 60 KHz (Reference 5)

AFA = $34 \times 10^6 / 60 \times 10^3$

= 566

Therefore FSI = 10 log 566/n

Sample Calculation for Uplink (C/N_U) and Downlink (C/N_D) Carrier to Noise Ratio

Downlink C/N_{TD}: The C/N_{TD} is due to thermal noise.

C/N_{TD}	= EIRP/CXR + G/T + L + 228.6 - 10 log B	(1)
G/T	= 13.8 dB/°K (Reference 2)	(2)
L	= -196.8 dB	(3)
10 log B	= 10 log 40,000 (Reference 5)	
	= 46 dB	(4)

Substituting 2, 3, 4 into 1:

C/N_{TD}	= EIRP/CXR + 13.8 - 196.8 + 228.6 - 46	
C/N_{TD}	= EIRP/CXR - 0.4	(5)
EIRP/CXR	= EIRP - OPBO - 10 log n	(6)
EIRP	= 32 dBw (at the beam edge-Reference 4)	(7)
Assume OPBO = 2.6 dB		(8)

Substituting 7 and 8 into 6,

EIRP/CXR	= 32 - 2.6 - 10 log n	(9)

Substituting 9 into 5:

C/N_{TD}	= 32 - 2.6 - 10 log n - 0.4
C/N_{TD}	= 29.0 - 10 log n
For n	= 70
C/N_{TD}	= 29.0 - 10 log 70
	= 29.0 - 18.5
C/N_{TD}	= 10.5 dB

Carrier-to-Intermodulation Distortion Ratio (C/IM)

For n	= 70
FSI	= 10 log 566/70
FSI	= 9 dB

An OPBO of 2.6 dB results in an input backoff (IPBO) of 4 dB. From data in Reference 1, it is estimated that a C/IM of 7 dB at this IPBO. As a result, the

C/IM	= 7 + FSI
C/IM	= 7 + 9
C/IM	= 16 dB

Uplink C/N_{TU}: The C/N_{TU} is due to thermal noise

C/N_{TU}	= EIRP/CXR + G/T + L + 228.6 - 10 log B	(1)
G/T	= -5.5 dB/°K (Reference 4)	(2)
L	= -200.3 dB	(3)
10 log B	= 10 log 40,000 Hz	(4)
	= 46 dB	

Substitute 2, 3, 4 into 1:

C/N_{TU} = EIRP/CXR - 5.5 - 200.3 + 228.6 - 46

C/N_{TU} = EIRP/CXR - 23.2 (5)

Equation 5 will be substituted in the following developed equations for finding the EIRP/CXR:

Flux Density = EIRP - 163.3

EIRP = 163.3 + Flux Density (6)

The EIRP of (6) is reduced by the amount the input must be backed off from the saturated value of -84 dBw/M^2. The IPBO as previously determined is 4.0 dB. Substituting these values in (6) results in

EIRP = 163.3 - 84 - 4

= 75.3 dBw

However, to obtain the value on a per carrier basis, this value must be reduced by 10 log n where n is the number of carriers.

EIRP/CXR = 75.3 - 10 log n

For 70 carriers,

EIRP/CXR = 75.3 - 10 log 70

= 75.3 - 18.5

= 56.8 dBw (7)

Substituting 7 into 5,

C/N_{TU} = 56.8 - 23.2

= 33.6 dB

Uplink Power from the Earth Station: The gain of a 10 foot

antenna with 55% efficiency is 43.0 db. Accordingly, the power per carrier up including 0.5 db line loss is:

Power/CXR = 56.8 - 43.0 + 0.5

= 14.3 dBw (26.9 watts)

Summary of System Carrier to Noise Ratio (C/N_S):

Contribution Due to	How Obtained	Symbol	Value (dB)
Downlink Thermal	A3	C/N_{TD}	10.5
Uplink Thermal	A3	C/N_{TU}	33.6
Intermodulation	A3	C/IM	16.0
Satellite Internal Interference	A4	C/I_{SI}	27.9
Satellite External Interference	A5	C/I_{SE}	20.6
TOTAL	Power Combination	C/N_S	9.0

A.4 Satellite Internal Interference Model

The interference model of Section F of this attachment was used to obtain the carrier-to-internal interference ratio, C/I_{SI}.

The following table summarizes the parameters and their associated values used in determining system depolarization isolation:

Spacecraft Cross-polarization Isolation	33 dB
Earth Station Cross-polarization Isolation (including pointing error)	33 dB
Rain Depolarization (99.5% of the time)	34 dB
Depolarization due to Faraday Rotation (if feed is set to the middle of the daily variation at sunspot maximum)	35 dB
Voltage Summation	21.7 dB
Power Summation	27.7 dB
Average of Voltage and Power Summation (one way link cross-polarization isolation)	24.7 dB

The cross-polarization isolation of the uplink and down-downlink are almost identical. Accordingly, they are assumed equal for purposes of this analysis. Using the Equations of Section F, the system carrier-to-internal interference ratio equals 27.86 dB.

A5 - Satellite External Interference Model

Introduction:

General: Interference analysis plays an important role in the formulation of a satellite communications system. Various mutual interference possibilities exist between the ground and space segments of the proposed Alaskan Bush Satellite Communications System, and adjacent outer-system satellite earth stations and terrestrial stations sharing the same frequency bands.

Interference Model: A basic 5-satellite interference model is used in the analysis of interference into the Alaskan Bush System from adjacent satellite systems. This interference model is centered about a reference RCA 24-channel (Frequency Reuse) satellite nominally located at a geostationary orbital position of 119°W. The adjacent orbital slots to the east of this reference position are presently occupied by the 12-transponder Telesat ANIK I (located at 114°W longitude). Orbital positions west of the reference satellite placement are considered occupied by a 24-transponder Comsat/ATT spacecraft nominally placed at 123°W longitude, and a 24-channel RCA Satcom satellite nominally placed at 127°W longitude, and a 24-transponder Comsat/ATT Spacecraft nominally placed at 131°W longitude, as outlined in Figures 1 and 2.

The total interference affecting the desired signal is found by considering:

a) the interference in the uplink (I_U) contributed by all interfering earth stations illuminating the RCA satellite and

b) the interference in the downlink (I_D) contributed by all interfering satellites whose radiation affects the RCA 10 foot earth station.

The carrier-to-total external interference ratio $(C/I)_{S.E.}$ is expressed mathematically as

$$(C/I)_{S.E.} = (C/I)_U \boxed{+} (C/I)_D \qquad (1)$$

where

$(C/I)_U$ = (Carrier/Interference) in the uplink

$(C/I)_D$ = (Carrier/Interference) in the downlink

$\boxed{+}$ = Denotes power addition

Uplink Interference: The RCA satellite, assumed at 119°W longitude is illuminated with power in the same frequency band occupied by voice signals radiated from interfering earth stations. The interfering earth stations are those whose antenna gain main-lobe axes are pointing to satellites at 114°W, 123°W, 127°W and 131°W respectively. The RCA satellite at 119°W will be illuminated by power from these stations due to off-axis main lobe radiation at angles of 5°, 4°, 8°, and 12° respectively. The above

situation is shown pictorially in Figures 1 and 2. The off axis gain G (θ) for these angles is given by CCIR* as

$$G(\theta) = 32 - 25 \log \theta$$

Downlink Interference: The satellites adjacent to the RCA satellite are shown in Figure 1. Signals radiated from these satellites are received by the RCA 10 foot earth station with an off-axis gain, G(θ), that meets the CCIR* requirement as follows:

$$G(\theta) = 32 - 25 \log \theta$$

*CCIR XII Plenary Assembly New Delhi, 1970;Report 391

Expression for $(C/I)_U$:

$(C/I)_U$ = [Wanted power illuminating the satell in frequency band of interest (40 KH

minus [Unwanted power illuminating th satellite in 40 KHz bandwidth]

Wanted Power Illuminating the Satellite, $(C)_U$:

$(C)_U$ = (EIRP/carrier) $- L_U + G_{sat}$ (dBw) (2)

where:

(EIRP/carrier) = Transmitted Power/Carrier from 10' earth station

L_U = uplink path loss = 200.3 dB

G_{sat} = RCA satellite receiving antenna gain in the direction of 10' earth station in Alaska = 27 dB

from A3, for 70 carriers, the transmitter power/carrier is 14.3 dBw and the 10' earth station transmit antenna gain is 43.0 dB and the waveguide loss is 0.5 dB therefore:

EIRP/carrier = 14.3 + 43.0 − 0.5

= 58.6 dBw

Uplink Unwanted Power Illuminating the Satellite $(I)_U$

$$(I)_U = \boxed{\sum_{i=1}^{4}} [(EIRP)_i - G_i + G(\theta_i) - L_{ui} + (G_{sat})_i + R_i + P_i] \quad (3)$$

where

Σ denotes power summation

$(EIRP)_i$ = Unwanted i^{th} interfering earth station EIRP in main axis direction

$G(\theta_i)$ = Transmit antenna gain of unwanted interfering i^{th} earth station at angle θ, off main axis

L_{ui} = i^{th} up-path loss which will be taken as 200.3 dB for all i.

R_i = i^{th} power spreading factor

P_i = i^{th} polarization discrimination factor

G_i = i^{th} unwanted interfering earth station antenna gain (on axis).

$(G_{Sat})_i$ = RCA Satellite Antenna Gain in the direction of i^{th} earth station. Because the antenna pattern is broad and not precisely specified, the gain in the direction of i^{th} station will be taken to be the beam edge gain for all i directions.

Power Spreading Factor (R)

The interfering channel power is distributed within the considered channel bandwidth according to the type of modulation of the interfering signal.

From the interference point of view, the 40 KHz slot in the interfering signal bandwidth carrying the highest amount of power is considered because this is the band containing the largest amount of power.

The power spreading within the channel bandwidth is considered as follows:

a) For the FDM/FM channels: The power is assumed to have gaussian distribution and results in a level of -24 dB below the unmodulated carrier in a 40 KHz band, therefore R = -24 dB (See A7)

b) For the TV channels: a 2 MHz bandwidth containing all the R.F. power will be considered, therefore:

$$R = 10 \text{ Log } \frac{40 \text{ KHz}}{2 \text{ MHz}} = -17 \text{ dB}$$

Polarization Discrimination

Since the study model includes a combination of RCA/Telesat/Comsat-ATT satellites, the adjacent satellite interference will be co-polarized or cross-polarized, as appropriate. The approved ground rules for polarization discrimination calling for 7 dB cross polarization discrimination factor for systems cross polarized with an RCA system will be adopted in the analysis.

Expression for $(C/I)_D$:

$(C/I)_D$ = (Wanted satellite radiated power in the direction of wanted earth station) – (Unwanted satellites' radiated power the direction of wanted earth station).

Wanted Power In The Direction of Wanted Earth Station, $(C)_D$:

$$(C)_D = (\text{EIRP/carrier})_{Sat.} - L_d + G_{E.St.} \quad (\text{dB}) \qquad (4)$$

where:

$(\text{EIRP/carrier})_{Sat.}$ = Wanted (RCA) satellite radiated EIRP/Carrier = 10.9 dBw

L_d = Downlink path loss = 196.8 dB

$G_{E.St.}$ = Wanted 10 foot earth station receive antenna gain (on-axis) = 39.6 dB.

Unwanted Power in the Direction of Wanted Earth Station, $(I)_D$:

$$(I)_D = \boxed{\sum_{i=5}^{8}} \left[(\text{EIRP}_{sat.})_i - L_{di} + G_{E.St.}(\theta_i) + R_i + P_i\right] \quad (\text{dBw})$$

where:

$(\text{EIRP}_{sat})_i$ = i^{th} unwanted satellite EIRP in the direction of wanted 10 foot earth station. (dB)

L_{di} = i^{th} down-path loss and will be taken as 196.8 for all i.

$G_{E.St.}(\theta_i)$ = 10 foot earth station antenna gain at θ_i angle with the main axis.

R_i, P_i, Σ = previously defined.

System Parameters

Interfering Systems Parameters

Telesat Canada (Anik I) Parameters

a)	Heavy route earth station EIRP	= 83 dBw
	Earth station 98' transmit antenna gain (on-axis)	= 63 dB
b)	Satellite Antenna Gain (on-axis)	= 29.5 dB
	Satellite EIRP in direction of Alaska	= 33 dBw

ATT Parameters

a)	Earth station EIRP	= 90.6 dBw
	Earth Station 100 foot antenna gain (on-axis)	= 62.3 dB
b)	Satellite Antenna Gain (on-axis)	= 26 dB
	Satellite EIRP in direction of Alaska	= 33 dBw
	Satellite saturation flux density	= -72.7 dBw/M^2

RCA Parameters

a)	Earth Station EIRP	= 85 dBw
	15/33' earth station receive antenna gain (on axis)	= 43/51 dB
	15/33' earth station transmit antenna gain (on axis)	= 46.5/54 dB
b)	Satellite antenna gain (on axis) transmit or receive	= 30 dB
	Satellite EIRP in the direction of Alaska	= 32 dBw

Summary of RCA 10 Foot Earth Station Parameters (See A3)

For 70 Carriers

10' Earth Station EIRP/carrier	= 56.8 dBW
10' Earth Station transmit antenna gain	= 43.0 dB
10' Earth Station receive antenna gain	= 39.6 dB
Satellite EIRP/carrier	= 10.9 dBW

Values For $(C/I)_U$, $(C/I)_D$ For The System Considered

1) The reference channel at the reference earth station is considered to be cross polarized with the same channel in the Te sat Canada System. Therefore according to the frequency plans used by Telesat Canada, ATT and RCA Systems, the reference RCA channel in the uplink is:

a) Cross-polarized with respect to Telesat Canada and ATT channels occupying the same frequency band.

b) Co-polarized with respect to another RCA satellite system.

Therefore in the uplink the polarization discrimination factors (P) are:

$$P_1 = -7 \text{ dB} \quad P_2 = -7 \text{ dB} \quad P_3 = 0 \text{ dB} \quad P_4 = -7 \text{ dB}$$

where P_1 is the polarization discrimination at the RCA satellite between transmissions from Telesat ground stations and RCA ground stations. P_2 is between RCA & AT&T, P_3 is between RCA & RCA and P_4 is between RCA and AT&T.

The reference channel on the downlink is:

a) Cross-polarized with same channel of Telesat Canada.

b) Co-polarized with same channels in AT&T and RCA Systems.

Therefore in the downlink:

$$P_5 = -7 \text{ dB} \quad P_6 = 0 \text{ dB} \quad P_7 = 0 \text{ dB} \quad P_8 = 0 \text{ dB}$$

where P_5 is the polarization discrimination at the RCA ground station between transmissions from the RCA satellite and the Telesat Canada satellite, P_6 is between transmissions from RCA and AT&T, P_7 is for RCA and RCA, and P_8 is for RCA and AT&T.

2) The interfering channels carry the following types of signals: TV, FDM/FM, TV, FDM/FM associated with satellites at 114°W, 123°W, 127°W, 131°W, respectively,

therefore:

R_1 & R_5 = -17 dB for TV

R_2 & R_6 = -24 dB for FDM/FM

R_3 & R_7 = -17 dB for TV

R_4 & R_8 = -24 dB for FDM/FM

where R denotes spreading factor.

3) The satellites at 114°W, 123°W, 127°W, and 131°W are Anik I,A RCA, and ATT respectively.

a) $(C/I)_U$

Equations 2 and 3 are used to find $(C/I)_U$. Because up-path loss L_{ui} and RCA satellite antenna gain (G_{sat}) assume the same values for wanted-signal and all interfering signals, these two terms can be dropped from Equations 1 and 2 without affecting the final result.

Therefore:

$$(C/I)_U = (\text{EIRP/carrier}) - \boxed{\sum_{i=1}^{4}} \Big[(\text{EIRP})_i - G_i + G(\theta_i) + R_i +$$

Using system parameter values in Equation 6 results in

$$(C/I)_U = 56.8 - \Big[(83-63 + 32-23 \log 5 - 17 - 7) \boxed{+}$$
$$(90.6 - 62.3 + 32 - 25 \log 4 - 24 - 7) \boxed{+}$$
$$(85 - 54 + 32 - 25 \log 8 - 17 - 0) \boxed{+}$$
$$(90.6 - 62.3 + 32 - 25 \log 12 - 24 - 7)\Big]$$

$$(C/I)_U = 56.8 - (10.53 \boxed{+} 14.25 \boxed{+} 23.42 \boxed{+} 2.32)$$

$$(C/I)_U = 56.8 - 24.1 = 32.7 \text{ dB}$$

b) $(C/I)_D$

Since down-path loss L_{di} assumes the same values for wanted signal and all interfering signals, this term can be dropped from Equations 4 and 5 without affecting the final result.

Therefore:

$$(C/I)_D = (EIRP/carrier)sat + G_{E.St.} - \boxed{\sum_{i=5}^{8}} \left[(EIRPsat)i + G_{E.St.}(\theta_i) + R_i + P_i\right] \qquad (7)$$

Using system parameter in Equation 7 results in

$$(C/I)_D = 10.9 + 39.6 - [\,(33 + 32 - 25 \log 5 - 17 - 7) \boxplus (33 + 32 - 25 \log 4 - 24) \boxplus (32 + 32 - 25 \log 8 - 17) \boxplus (33 + 32 - 25 \log 12 - 24)\,]$$

$$(C/I)_D = 50.5 - (23.53 \boxplus 25.95 \boxplus 24.42 \boxplus 14.02)$$

$$(C/I)_D = 50.5 - 29.6$$

$$(C/I)_D = 20.9 \text{ dB}$$

Therefore $(C/I)'_{S.E.} = (C/I)_U \boxplus (C/I)_D$

$$= 32.7 \boxplus 20.9$$

$$(C/I)_{S.E.} = 20.6 \text{ dB}$$

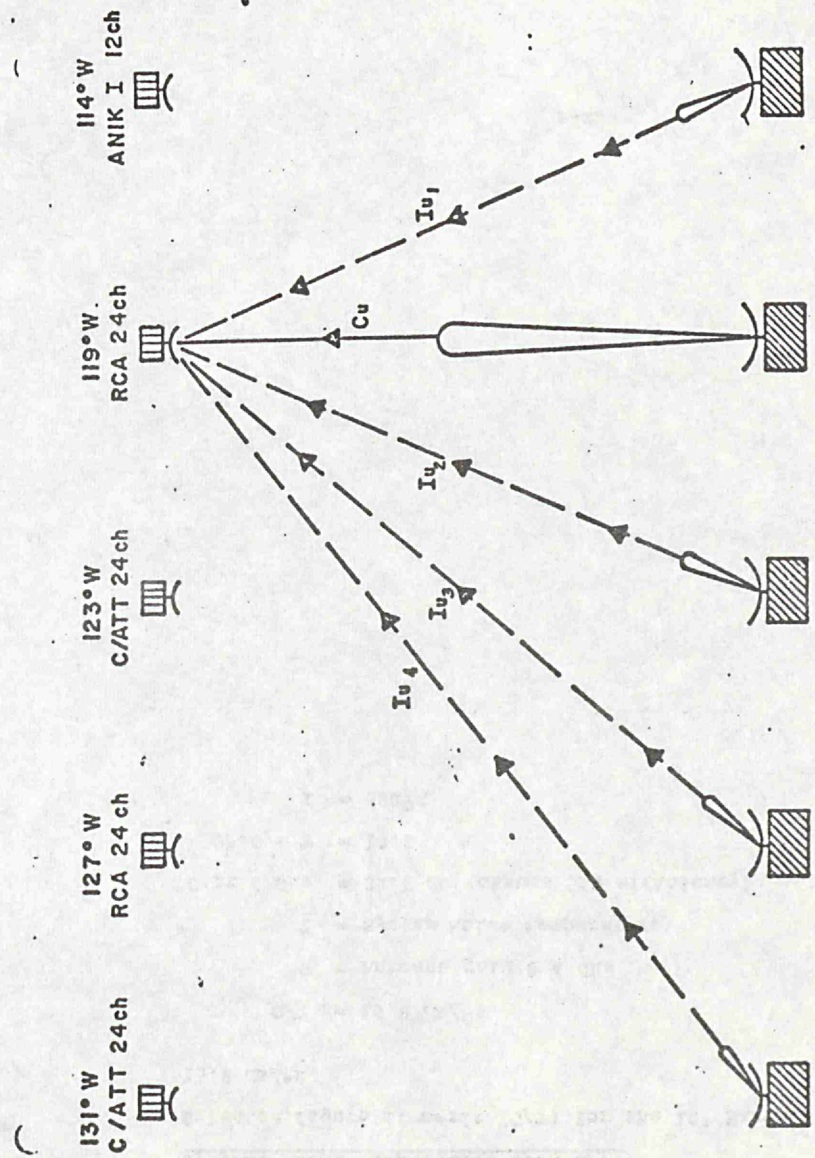


FIG. 4 UP-LINK INTERFERENCE

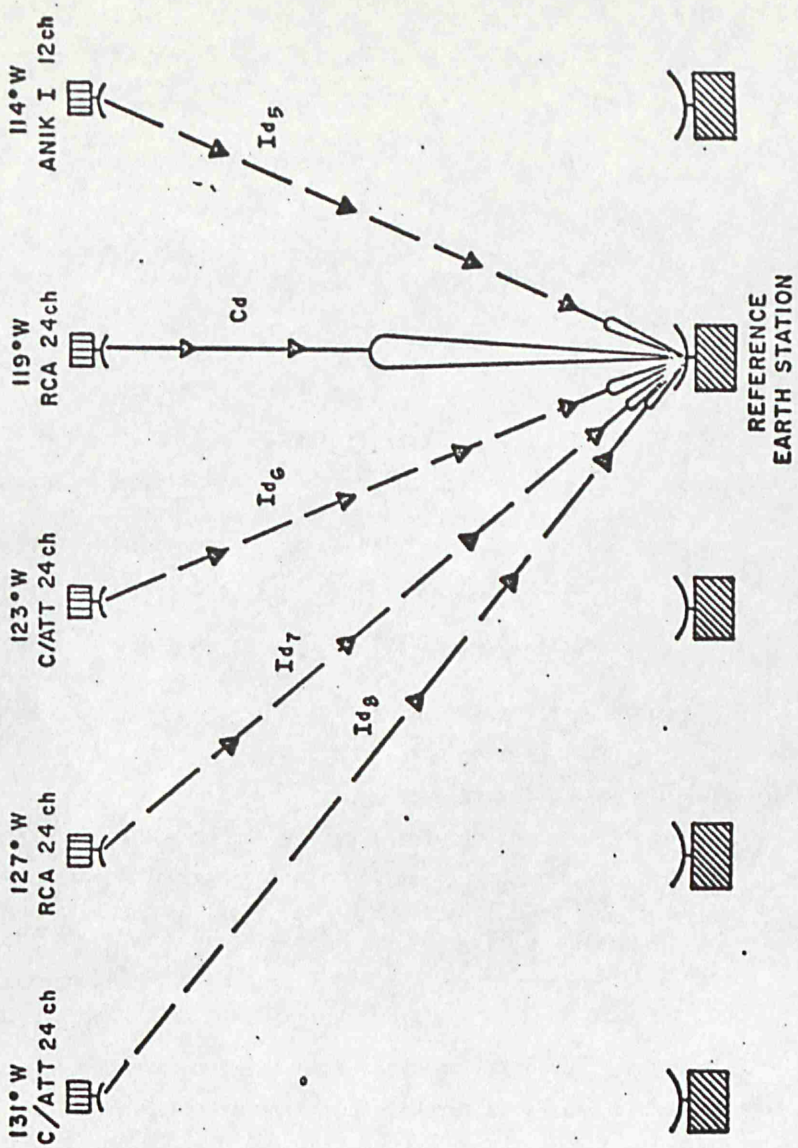


FIG. 2 DOWN-LINK INTERFERENCE

A.6 <u>Systems Noise Temperature</u>

<u>Systems Noise Temperature from G/T:</u>

Selected figure of merit (G/T) for the 10' Earth Station is 13.8 dB/°K.

$G/T = 13.8$ dB/^{O}K

G = Antenna gain @ 4 GHz

T = System Noise temperature

G at 4 GHz = 39.6 dB (assume 55% efficiency)

$39.6 - T = 13.8$

$T = 380^{O}$K

A.7 Power Spectrum of a FDM-FM Carrier

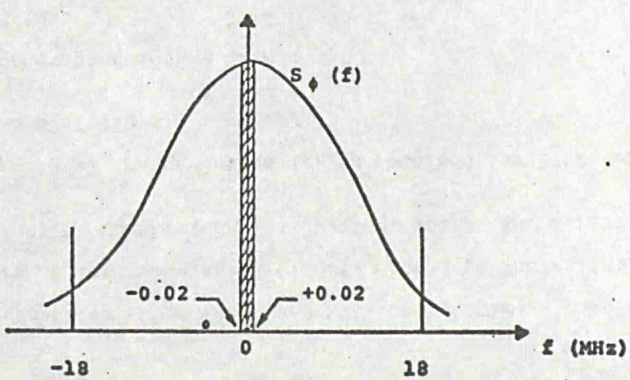
The spectrum of a carrier that is frequency modulated by a multiplexed telephony baseband is, in general, a complicated function which depends on many parameters. With increasing modulation index, the spectrum approximates a Gaussian shape near the carrier frequency.[1] Thus the power spectral density $S_\phi(f)$ can be expressed as follows:

$$S_\phi(f) = \frac{K}{\sqrt{2\pi}\,\sigma} e^{\frac{-f^2}{2\sigma^2}}$$

where, K = constant depending on carrier level

σ = multichannel rms deviation

f = frequency relative to carrier frequency in MHz



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Accordingly, the power in a 40 KHz band around the carrier frequency relative to the total power can be found as follows:

$$\frac{P_{(40\ \text{KHz})}}{P_{(\text{Total})}} = \frac{\int_0^{0.02} e^{\frac{-f^2}{2\sigma^2}}\,df}{\int_0^{18} e^{\frac{-f^2}{2\sigma^2}}\,df}$$

$$= \frac{\text{erf}\left(\frac{0.02}{2\sigma}\right)}{\text{erf}\left(\frac{18}{2\sigma}\right)} \quad \text{where erf} \triangleq \text{error function}$$

$$= 0.004 \quad \text{for } \sigma = 4 \text{ MHz} \quad [2]$$

$$= -24.0 \text{ dB}$$

[1] J.C. Fuenzalida, O. Shimbo, and W.L. Cook, "Time - Domain Analysis of Intermodulation Effects Caused by Non - linear Amplifiers." COMSAT Technical Review, Vol 3, No. 1, 1973.

[2] A multichannel rms deviation (σ) is obtained for 1280 voice channels as follows:

Transponder bandwidth = 36 MHz

Peak factor = 3.16

Maximum Baseband freq. = 4.2 X n in kHz

$\therefore$ BW = 36 MHz

36 = $2(3.16\sigma + 4.2 \times 10^{-3}\ (1280))$

σ = 4MHz

B. TV Transmission Performance Objective for Reception via a 15 Foot Diameter Earth Station

B1. TV Services

This analysis establishes the performance for TV to a 15 foot diameter earth station from a 33 foot diameter earth station. The baseline is established by combining the effects of intermodulation, thermal noise and satellite interference. Rain attenuation is considered as an independent variable since TASO performance requirements are subjective. The margin shown for TASO 2 performance is considerable as shown in the calculations.

Performance Objective: The performance objective to be achieved with 15 foot earth stations is TASO Grade 2 television as calculated in B3.

B2. References

Ref 1. Measurements of the Subjective Effects of Interference in Television Reception.
Charles E. Dean. Proceedings of the IRE

Ref 2. Modulation, Noise, and Spectral Analysis
Philip F. Panter (p. 441)

Ref 3. C.C.I.R Xllth PLENARY Assembly, New Delhi, 1970
Volume V, Part 2, Rec. 421-2

Ref 4. Domestic Communication Satellite Spacecraft Specification.
Revision B; January 18, 1974

Ref 5. RFP for RCA Alaska Communications, Inc. for 10 foot and 15 foot Diameter Earth Stations.

Ref 6. Evans, H.W. "Technical Background (page 11), AT&T Domestic Satellite Proposal". AIAA Paper No. 68-411 presented at AIAA 2nd Communication Satellite Systems Conference, San Francisco, Calif. (April 8-10, 1968).

3 Link Analysis

Introduction: The received signal will not be a function of the satellite saturated power and G/T, since the link is limited by earth station performance.

Derivation of the Peak-to-Peak Picture Signal to RMS Noise Ratio, (S_{pp}/N_{RMS}):

Carrier-to-Noise Ratio, (C/N_T): The C/N_T derived in this expression is the ratio of the received modulated signal relative to the thermal noise in the system.

Carrier-to-Noise Ratio, (C/N_T): The C/N_T is obtained as follows:

Let: P_R = Received Power

P_T = Transmitted Power

G_T = Transmit Antenna Gain

G_R = Receive Antenna Gain

L = Path Loss

T_S = System Noise Temperature

Then: $P_R = P_T G_T G_R L$

$$P_R/T_S = P_T G_T \times G_R/T_S \times L$$

$$P_R/T_S = EIRP \times G/T \times L \quad (1)$$

From ITT Reference Data for Satellite Communication Earth Stations (Page 24):

$$C/N = C/KTB$$

$$C/T = CKB/N$$

$$C/T = C/N + 10 \log B - 228.6 \text{ dBW/Hz/°K} \quad (2)$$

However $C/T = P_R/T_S$. Therefore, equating (1) and (2) and expressing the terms in log form:

$$C/N + 10 \log B - 228.6 = EIRP + G/T + L$$

$$C/N = EIRP + G/T + L + 228.6 - 10 \log B \quad (3)$$

Output Signal-to-Noise Ratio, (S/N_O): The standard FM improvement equation is obtained from Reference 2 as follows:

$$S/N_O = (3/2)(C/N)\,\beta^2 \frac{B}{fm} \quad (1)$$

C/N = the predetection carrier to noise ratio

$\pm\Delta f$ = peak FM deviation

β = FM modulation index and is $\pm\Delta f/fm$

fm = highest modulating frequency

B = the predetection noise bandwidth

Equation (1) must be modified by a noise weighting and improvement factor (W). Thus:

$$S/N_O = (3/2)(C/N)\,\beta^2 \frac{B}{fm} W \quad (2)$$

Equation 2 represents the S/No for sine wave signals. However, this signal must be modified to represent a peak-to-peak (pp) signal in order to conform to standard TV performance objectives which are presented as peak-to-peak signal to rms noise (S_{pp}/N_{rms}).

Path Loss , (L):

This path loss is due to the R.F. signal being attenuated as a result of the transmission path in between two antennas.

The expression for the path loss (L) is obtained from Reference Data for Radio Engineers, Fifth Edition, Pg.26-20.

$$L = 36.6 + 20 \log f(\text{MHz}) - 20 \log d \ (\text{miles})$$

For Alaska the slant range is 25,500 miles and therefore

$$L = -196.8 \text{ dB @ 4 GHz}$$

$$L = -200.3 \text{ dB @ 6 GHz}$$

Flux To EIRP Conversion

The received power to satellites is expressed in dBw/M^2 and the radiated power from earth stations (EIRP) in dBw. Accordingly, an equation must be found that relates the power expressed in dbw to the power expressed in dBw/M^2.

Derivation

Consider a point source radiating to the surface of a sphere of radius R. The area of this sphere is $4\pi R^2$. The power at the surface of a sphere is $P/4\pi R^2$. Now if R is in meters, then the flux is in $watts/M^2$. Converting $watts/M^2$ to log form:

$$dBw/M^2 = 10 \log \text{watts} - 10 \log 4\pi R^2$$

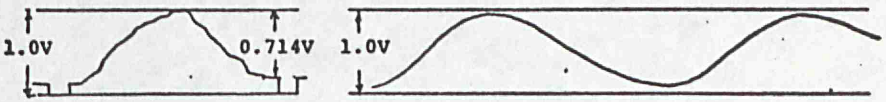
$$\text{Flux} = dBw - 10 \log 4\pi R^2$$

Now substitute EIRP for dBw and a R of 25,000 miles (after converting to meters) and

$$(dBw/M^2) = EIRP - 163.3$$

Sine Wave RMS to TV Peak-to-Peak Conversion

The CCIR Standard TV Signal (Reference 3) is shown below along with a one volt peak-to-peak sine wave signal.



The ratio between the video (pp) picture signal and the sine wave RMS signal will now be calculated.

(Spp) = CCIR picture peak-to-peak voltage = 0.714
(Srms) = Equivalent sine wave rms voltage = $1/(2\sqrt{2})$

$$\frac{(S_{pp})}{(S_{rms})} = \frac{0.714}{1/2\sqrt{2}}$$

$$(S_{pp}) = 0.714\ (2\sqrt{2})\ (S_{rms})$$

$$(S_{pp}) = 2.0\ (S_{rms})\ (\text{Voltage})$$

Now; power is proportional to the square of the boltage, therefore the power conversion is

$$(S_{pp}) = (2.0)^2\ (S_{rms})$$

$$(S_{pp}) = 4 (S_{rms})\ (\text{Power})$$

As a result, Equation 2 is modified as follows:

$$\frac{S_{pp}}{N_{rms}}{}_o = (4)\ \left(\frac{3}{2}\right)\ (C/N)\ \beta^2\ \frac{B}{fm}\ W \qquad (3)$$

But $B = 2\ (\Delta f + fm)$ (4)

Substituting 4 into:

$$\frac{S_{pp}}{N_{rms}}{}_o = (4)\ \left(\frac{3}{2}\right)\ (C/N)\ \beta^2\ \frac{2(\Delta f + fm)}{fm}\ W$$

$$= 12\ (C/N)\ \beta^2\ (\beta+1)\ W$$

In log form:

$$\frac{S_{pp}}{N_{rms}}{}_o = 10.8 + C/N + 10 \log \beta^2\ (\beta+1) + W \qquad (5)$$

Calculation of $(S_{pp}/N_{rms})_o$:

Calculation of Downlink Carrier-to-Noise Ratio (C/N_{TD})

C/N_{TD} = EIRP + G/T + L + 228.6 - 10 log B

where: EIRP = 32 dBw (Reference 4)

G/T = 22 dB/°K (Reference 5)

Therefore: C/N_{TD} = 32 + 22 - 196.8 + 228.6 - 10 log B

C/N_{TD} = 85.8 - 10 log B

B (MHz)	10 log B	C/N_{TD} (dB)
25	74.0	11.8
22	73.4	12.4
18	72.6	13.2

Calculation of Uplink Carrier-to-Noise Ratio (C/N_{TU})

C/N_{TU} = EIRP + G/T + L + 228.6 - 10 log B (1)

EIRP = Flux + 163.3 (2)

G/T = - 5.5 dB/°K (3)

Flux = - 81.5 dBW/M^2 (conus) (4)

Substituting 2, 3, 4 and the loss (L) into 1 results in:

C/N_{TU} = - 81.5 + 163.3 - 5.5 - 200.3 + 228.6 - 10 log B

= 104.6 - 10 log B

B (MHz)	10 log B	C/N_{TU} (dB)
25	74.0	30.6
22	73.4	31.2
18	72.6	32.0

System Carrier-to-Noise Ratio, (C/N_S):

Bandwidth (MHz)	C/N_{TD}	C/N_{TU}	C/I_{SI} (1)	C/I_{SE} (2)	C/N_S (dB)
25	11.8	30.6	25.5	23.8	11.3
22	12.4	31.2	25.5	23.8	11.9
18	13.2	32.0	25.5	23.8	12.6

(1) Obtained in Section B4
(2) Obtained in Section B5

Calculation of $(S_{pp}/N_{rms})_o$:

$$(S_{pp}/N_{rms})_o = 10.8 + C/N + 10 \log \beta^2 (\beta + 1) + W$$

where W = 14 dB (Reference 6)

Therefore,

$$(S_{pp}/N_{rms})_o = 24.8 + C/N_S + 10 \log \beta^2 (\beta + 1)$$

In order to obtain the SNR, the modulation index (β) is calculated as follows:

$B = 2 (\pm \Delta f + f_m)$ (Carson Bandwidth)

$\pm\Delta f_m = B/2 - f_m$

$\beta = \pm\Delta f/f_m$

C/N_S (1) (dB)	B (MHz)	f_m (MHz)	$\pm \Delta f$ (MHz)	β	$10 \log \beta^2 (\beta + 1)$	$(S_{pp}/N_{rms})_o$ (dB)
11.3	25	5.225	7.3	1.39	6.7	42.8
11.9	22	5.225	5.8	1.10	4.1	40.8
12.6	18	5.225	3.8	0.72	-0.5	36.9

(1) An improvement of up to 2.0 dB may be realized by using an overdeviation technique.

B.4 Satellite Internal Interference Model

The interference model of Section F of this Attachment was used to obtain the carrier-to-internal interference ratio, C/I_{SI}.

The following table summarizes the parameters and their associated values used in determining system depolarization isolation:

Spacecraft Cross-polarization Isolation	33 dB
Earth Station Cross-polarization Isolation (including pointing error)	33 dB
Rain Depolarization (99.5% of the time)	34 dB
Depolarization due to Faraday Rotation (if feed is set to the middle of the daily variation at sunspot maximum)	35 dB
Voltage Summation	21.7 dB
Power Summation	27.7 dB
Average of Voltage and Power Summation (one way link cross-polarization isolation)	24.7 dB

The cross-polarization isolation of the uplink and downlink are almost identical. Accordingly, they are assumed equal for purposes of this analysis.

Using the Equations of Section F, the system carrier-to-internal interference ratio equals 25.47 dB.

B.5 Satellite External Interference Model

Introduction: The TV signal is transmitted from a 33' RCA earth station and received via RCA satellite by a 15' earth station in Alaska. Referring to A.5, the same interference model will be used.

Wanted Power Illuminating the Satellite, $(C)_U$:

$$(C)_U = (EIRP) - L_u + G_{sat} \quad (dBw) \qquad (1)$$

where

(EIRP) = Total Power Transmitted by a 33' E.S.
= 85 dBW

L_u = uplink path loss
= 200.3 dB

G_{sat} = RCA Satellite receiving antenna gain in the direction of 15' E.S. in Alaska
= beam edge gain
= 27 dB.

Uplink Unwanted Power Illuminating the Satellite, $(I)_U$

$$(I)_U = \boxed{\sum_{i=1}^{4}} \left[(EIRP)_i - G_i + G(\theta_i) - L_{ui} + (G_{sat})_i + P_i\right]$$

where

$\boxed{\Sigma}$ denotes power summation

$(EIRP)_i$ = Unwanted i^{th} interfering earth station EIRP in main axis direction.

$G(\theta_i)$ = Transmit antenna gain of unwanted interfering i^{th} earth station at angle θ_i off main axis.

L_{ui} = i^{th} up-path loss which will be taken as 200.3 dB for all i.

P_i = i^{th} polarization discrimination factor

G_i = i^{th} unwanted interfering earth station antenna gain (on-axis).

$(G_{sat})_i$ = RCA Satellite antenna gain in the direction of earth station. Because the antenna pattern is broa and not precisely specified, the gain in the direction of i^{th} station will be taken to be the beam edge gain for all i directions.

Since up-path loss, L_{ui}, and RCA Satellite antenna gain, $(G_{sat})_i$, have the same values for wanted signal and all interfering signals, they can be dropped from Equations 1 and 2 without affecting the final result.

Therefore:

$$(C/I)_U = C - \boxed{\sum_{i=1}^{4}} [(EIRP)_i - G_i + G(\theta_i) + P_i] \qquad (3)$$

The values for the parameters of the interfering system in Equation (3) are summarized in section A.5 The frequency plan used is same as in A.5 Using the values of the parameters and appropriate polarization discrimination factor results in

$$\begin{aligned}(C/I)_U = 85 - [&(83 - 63 + 32 - 25 \log 5 - 7) \boxed{+} \\ &(90.6 - 62.3 + 32 - 25 \log 4 - 7) \boxed{+} \\ &(85 - 54 + 32 - 25 \log 8) \boxed{+} \\ &(90.6 - 62.3 + 32 - 25 \log 12 - 7)]\end{aligned}$$

$$(C/I)_U = 85 - (27.53 \boxed{+} 38.25 \boxed{+} 40.42 \boxed{+} 26.32)$$

$$(C/I)_U = 85 - 42.72 = 42.28 \text{ dB.}$$

Expression for $(C/I)_D$:

$(C/I)_D$ = (Wanted satellite radiated power in the direction of wanted earth station) - (Unwanted satellites radiated power in the direction of wanted earth station).

Wanted Power in the Direction of Wanted Earth Station, $(C)_D$:

$$(C)_D = (EIRP)_{sat} - L_d + G_{E.St.} \quad \text{(dBw)}$$

where

$(EIRP)_{sat}$ = Wanted (RCA) satellite radiated EIRP

= 32 dBW

L_D = Downlink path loss

= 196.8 dB

$G_{e.st.}$ = Wanted 15 foot earth station receive antenna gain (on axis)

= 43.0 dB

Unwanted Power in the Direction of Wanted Earth Station, (I_D):

$$(I_D) = \boxed{\sum_{i=5}^{8}} [(EIRP_{sat})_i - L_{di} + G_{E.St.}(\theta_i) + P_i] \text{(dBw)}$$

where:

$(EIRP_{sat})_i$ = i^{th} unwanted satellite EIRP in the direction of wanted 15 foot earth station. (dBw).

L_{di} = i^{th} down-path loss and will be taken as 196.8 for all i.

$G_{E.St.}(\theta_i)$ = 15 foot earth station antenna gain at θ_i angles with the main axis.

P_i, Σ = as previously defined

Since down path losses, L_{di}, have the same value for wanted signal and all interfering signals they can be dropped from Equations 4 and 5 without affecting the final results.

therefore:

$$(C/I)_D = \left[(EIRP)_{sat} + G_{E.St}\right] - \boxed{\sum_{i=5}^{8}} \left[(EIRP_{sat})_i + G_{E.St.}(\theta_i) + P_i\right] \qquad (6)$$

The values for the parameters of the interfering and referenced systems in Equation 6 are summarized. in section A.5. The frequency plans used are the same as in Section A.5. Using the values for the parameters and appropriate polarization discrimination factors results in

$$\begin{aligned}(C/I)_D = \Big[32 + 43 - [&(33 + 32 - 25 \log 5 - 7) \boxed{+} \\ &(33 + 32 - 25 \log 4 - 0) \boxed{+} \\ &(32 + 32 - 25 \log 8 - 0) \boxed{+} \\ &(33 + 32 - 25 \log 12 - 0)\Big]\end{aligned}$$

$$(C/I)_D = 75 - (40.53 \boxed{+} 49.95 \boxed{+} 41.42 \boxed{+} 38.02)$$

$$(C/I)_D = 75.0 - 51.15$$

$$(C/I)_D = 23.85 \text{ dB.}$$

Therefore the carrier to interference ratio due to external satellite interference, $(C/I)_{SE}$, is

$$\begin{aligned}(C/I)_{S.E.} &= (C/I)_U \boxed{+} (C/I)_D \\ &= 42.28 \boxed{+} 23.85 \\ &= 23.79 \text{ dB.}\end{aligned}$$

B-6. Systems Noise Temperature (T_s):

Systems Noise Temperature From G/T.

G/T_s = 22 dB/°K (Reference 5)

G = Antenna Gain at 4 GHz

T_s = System Noise Temperature

G at 4 GHz = 43.0 dB (assume 55% efficiency)

22 = 43.0 - T

T_S = 125.9°K

C. Interference to Other Systems from a 10 Foot Earth Station Transmitting SCPC

Introduction

This analysis will consider the interference caused by RCA SCPC system utilizing either Delta modulation (ΔM) or frequency modulation (FM) into

(a) An ATT FDM/FM System

(b) A Telesat FDM/FM System

The interference to other systems is based upon 70 carriers in one transponder channel. When the carriers utilize SCPC/FM, the power radiated from an earth station may be less than that required for SCPC/ΔM transmission due to the lower i.f. noise bandwidth (N.B.W.). The NBW for ΔM system is 40 KHz and the NBW for an FM system is 25.7 KHz. As a result, the interference from the RCA SCPC/FM system to the adjacent C/ATT or Telesat Canada may be less than the interference from an RCA SCPC/ΔM system. Accordingly, the following analysis will be for a ΔM System since this is the worst case.

The interference level from the RCA System was estimated to be below the level of thermal noise introduced into the ATT or Telesat detectors, which are assumed to be linear. Therefore, the detector operating point will not be determined by the interference. Accordingly, the interference is treated as noise added to the thermal noise and hence the noise output in pWp0 will be determined by using the follwoing equations.

$$[S/N]^* = [C/N]\ B/b\ [f_r/f_m]^2\ P \cdot W$$

Converting to dB notation,

$$[S/N] = [C/N] + 10 \log [B/b] + 20 \log [f_r/f_m] + P + W$$

$$B = 2[3.16\ gf_r + f_m]$$
$$= \text{Carson Bandwidth} = 36 \text{ MHz}$$

where $[S/N]$ = weighted signal-to-noise ratio at the 1-mW test-tone level

$[C/N]$ = carrier-to-noise ratio over the Carson's Rule bandwidth, B

b = channel bandwidth = 3.1 kHz

f_r = rms test-tone deviation

f_m = maximum baseband frequency ≈ 4.2 x n, in kHz

n = number of telephone channels

P = psophometric weighting factor = 2.5 dB

W = pre-emphasis weighting factor = 4 dB

g = antilog [L/20]

L = $-15 + 10 \log n$, $n \geq 240$ channels

= $-1 + 4 \log n$, $n < 240$ channels

* Comsat Tech. Rev., Volume 2, Number 2, Pg. 460

Values for Parameters

Values for the parameters listed for use in the S/N equation are determined as follows:

$\boxed{C/N}$:

Based on the assumption in the introduction, the inital calculation of C/N is performed on the basis that the power in the 70 RCA interfering carriers is uniformly spread over 36 MHz and subsequently will be appropriately adjusted to account for the actual power distribution. The initial C/N is determined by the power addition of the uplink interference (C/I_U) and the downlink interference $(C/I)_D$.

A) C/N for an RCA-70-Carriers Channel Interfering with an FDM/FM ATT Channel

$$(C/I)_U = EIRP_{AT\&T\ E.S.} - [EIRP/CXR_{RCA\ E.S.} + 10 \log 70 - G_{10'\ Ant.} + G_{Sidelobe}] + \text{Polarization Discrimination Factor} \quad (1)$$

$$(C/I)_U = 90.6 - [56.8 + 10 \log 70 - 43.0 + 32 - 25 \log 4] + 7$$

$$(C/I)_U = 48.4 \text{ dB}$$

$$(C/I)_D = [EIRP_{AT\&T\ Sat.} + G_{AT\&T\ E.S.}] - [EIRP/CXR_{RCA\ Sat.} + 10 \log 70 + G_{Sidelobe}]$$

$$(C/I)_D = (33 + 60.5) - (10.9 + 10 \log 70 + 32 - 25 \log 4)$$

$$(C/I)_D = 47.2 \text{ dB}$$

C/N = power addition of $(C/I)_U$ and $(C/I)_D$

C/N = 44.7 dB

b) C/N for an RCA 70 Carriers (SCPC) Channel Interfering with an FDM/FM Telesat Channel

$$(C/I)_U = EIRP_{Telesat\ E.S.} - [EIRP/CXR_{RCA\ E.S.} + 10 \log 70 - G_{10'Ant.} + G_{Sidelobe}] + \text{Polarization Discrimination Factor}$$

$$(C/I)_U = 83 - [56.8 + 10 \log 70 - 43.0 + 32 - 25 \log 5] + 7$$

$$= 43.2 \text{ dB}$$

$$(C/I)_D = [EIRP_{Telesat\ Sat.} + G_{Telesat\ E.S.}] - [EIRP/CXR_{RCA\ Sat.} + 10 \log 70 + G_{Sidelobe}] + \text{Polarization Discrimination Factor}$$

$$= (33 + 63) - (10.9 + 10 \log 70 + 32 - 25 \log 5) + 7$$

$$= 59.1 \text{ dB}$$

C/N = power addition of $(C/I)_U$ and $(C/I)_D$

C/N = 43.1 dB

Carson Bandwidth (B)

B = 36 MHz

Voice Channel Bandwidth (b)

b = 3.1 kHz

Maximum Baseband Frequency $[f_m]$

$$f_m = 4.2 \times 10^3 \times 1200 = 5.04 \text{ MHz}$$

Loading Factor [L]

$$L = -15 + 10 \log 1200 = 15.79 \text{ dB}$$

RMS Test Tone Deviation $[f_r]$

$$f_r = 0.66 \text{ MHz}$$

Substituting these values for the parameters in Equation 1 results in the following:

a) S/N in the output of a C/ATT Channel

$$[S/N] = 44.7 + 10 \log \frac{36 \times 10^6}{3.1 \times 10^3} + 20 \log \frac{0.66 \times 10^6}{5.04 \times 10^6} + 2.5 + 4$$

$$= 74.2 \text{ dB}$$

b) S/N in the output of a Telesat-Canada Channel

$[S/N]$ = 72.6 dB

Calculation of Output Noise in pWp0

a) Output Noise in a C/ATT Channel.

S/N = 74.2 dB

Therefore the noise at the output of the ATT detector is:

(N) = S - 74.2 dBm where S = 0 dBm reference level

= 0 - 74.2 = -74.2 dBm

N = 38 pWpO

b) Output Noise in a Telesat, Canada Channel

N = -72.6 dBm = 55 pWp0

It was initially assumed that the power from the 70 RCA Carriers was spread over 36 MHz. However, this carrier power is spread in 40 kHz slots around 70 carriers. Accordingly, the noise power (38 pWp0) must be increased to account for this difference.

The increase in power relative to the 36 MHz assumed spread is found as follows:

Number of 40 kHz bands in 36 MHz = 900

Actual number of 40 kHz bands = 70

Power increase = 10 log 900/70 = 11.1 dB

However this increased power is spread over a 40 kHz band and not a 4 kHz band.

Accordingly, the increase of 11.1 dB must be reduced by 10 log 40/4 or 10 dB to arrive at the increased power in a 4 kHz band. This results in a net increase in interference power in the voice band of 1.1 dB more.

That is, rather than 38 pWp0, we will have 49 pWp0 noise interference in a voice channel at the zero toll level position in an AT&T channel and will have 70.8 pWp0 noise interference in a voice channel of Telesat, Canada.

D. Voice Transmission Performance Objectives Between 15-Foot Earth Stations using Delta Modulation

Scope: This analysis establishes the performance objectives for voice communications between 15-foot earth stations using delta modulation Modems. The baseline is established by combining the degradations of intermodulation, thermal noise, and satellite interference.

Performance Objectives: The performance objectives contained below are based upon current Alaskan village experience relative to telephone service. (See D1 through D7 for details). Further, the number of carriers in a transponder channel required to support P 10 telephone service is based upon a signal quality that is considered to be excellent. That is, a BER of 10^{-3} will provide service to $>$ 50db SNR while a BER of 10^{-2} will degrade this slightly. It should be noted that a transmitter of less than 15 watts per carrier is required for a BER of 1×10^{-3}.

Telephone Service to be provided: One transponder channel is capable of supporting P 10 telephone service as described in the following table:

Telephones	Maximum Carriers in a Transponder	Earth Station Power per carrier required	Received C/N_S	BER
120	70	14.1 watts	9.2 dB	1.0×10^{-3}

D.1 Telephone Services

Telephone Service Analysis: The maximum number of events to provide P 10 service to the bush communities via satellite has been calculated. Only one phone per village is planned initially. This will result in slightly less than P 10 service.

Assumptions:

A. Assumes that the addition of phones does not increase the total amount of traffic.

B. Use of Demand Assignment Multiple Access to route traffic.

C.

Number of Telephones	56	148
Erlangs*	7.63	7.63
P 10 Channels (one way)*	32	32

*If calls are Poisson distributed and call duration times are exponentially distributed.

Voice Quality: This performance is intended for use with Delta Modulation voice modems. However, the criteria used for this digital technique is not the same as for an

analog technique. For example, the analog systems criteria for a voice channel is related to the interference noise received in that voice channel. This noise is directly related to the carrier-to-noise ratio (CNR) of the channels. In the case of digital signals, the relationships are somewhat different. With infinite CNR and associated zero bit error rate (BER), a digital system will have noise present during speech utterances only. This noise is due to the sampling or quantizing process which results in a signal to quantizing noise ratio (SQR). A voice signal SQR of 30 dB results in excellent speech quality and will not be significantly degraded at a lower CNR and associated higher BER. BER's of about 10^{-3} will not significantly affect an SQR of 30 dB.

D.2 References

Ref. 1. Analysis of Intermodulation Distortion In An FDMA Satellite Communication System With A Bandwidth Constraint: Richard B. McClure.

Ref. 2. Attachment I, Technical Definition of R.F. Channel Service (Telesat Document which specifies the characteristics of the satellite channels to which Telesat agrees to provide access).

Ref. 3. RFP for RCA Alaska Communications, Inc. for 10-foot and 15-foot diameter earth stations.

Ref. 4. Domestic Communication Satellite Spacecraft Specification Revision B; January 18, 1974.

Ref. 5. Notebook of L. Ottenberg. Systems Performance of G.E. Delta Mod Equipment obtained from F. Klippel and B. Milton of G.E. Also, system aspects of the initial Telesat thin Route Satellite Communication System. P. Rossiter, Telesat Canada.

System C/N vs Bit Error Rate:

System C/N in a 40 KHz NBW (dB)	BER
6.6	1×10^{-2}
8.0	3.5×10^{-3}
9.0	1.2×10^{-3}
10.0	3.3×10^{-4}
11.0	7.0×10^{-5}
12.0	1.2×10^{-5}
13.0	1.6×10^{-6}

D.3 Link Analysis

Derivation of Equations

Carrier-to-Noise Ratio, (C/N_T): The C/N_T derived in this expression is the ratio of the received modulated signal relative to the thermal noise in the system. This expression can be used for the uplink and the downlink upon substitution of the appropriate path loss and other parameters in the equation.

Carrier-to-Noise Ratio, (C/N_T): The C/N_T is obtained as follows:

Let: P_R = Received Power

P_T = Transmitted Power

G_T = Transmit Antenna Gain

G_R = Receive Antenna Gain

L = Path Loss

T_S = System Noise Temperature

Then:

$$P_R = P_T G_T G_R L$$

$$P_R/T_S = P_T G_T \times G_R/T_S \times L$$

$$P_R/T_S = EIRP \times G/T \times L \quad (1$$

From ITT Reference Data for Satellite Communication Earth Stations (Page 24):

$$C/N = C/KTB$$

$$C/T = CKB/N$$

$$C/T = C/N + 10 \log B - 228.6 \text{ d w/Hz/°K} \quad ($$

However $C/T = P_R/T_S$. Therefore, equating 1 and 2 and expressing the terms in log form:

$$C/N + 10 \log B - 228.6 = EIRP + G/T + L$$

$$C/N = EIRP + G/T + L + 228.6 - 10 \log B \quad (3)$$

Path Loss, (L): This path loss is due to the R.F. signal being attenuated as a result of the transmission path between two antennas.

The expression for the path loss (L) is obtained from Reference Data for Radio Engineers, Fifth Edition, Pgs.26-20

$$L = 36.6 + 20 \log f(\text{MHz}) + 20 \log d \text{ (miles)}$$

For Alaska the slant range is 25,500 miles and therefore

$$L = -196.8 \text{ dB @ 4 GHz}$$

$$L = -200.3 \text{ dB @ 6 GHz}$$

Flux to EIRP Conversion: The received power to satellite is expressed in dBw/M^2 and the radiated power from earth stations (EIRP) in dBw. Accordingly, an equation must be found that relates the power expressed in dBw to the power expressed in dBw/M^2.

Derivation: Consider a point source of P watts radiating to the surface of a sphere of radius R. The area of this sphere is $4\pi R^2$. The flux density at the surface of a sphere is $P/4\pi R^2$. Now if R is in meters, then the flux is in $watts/M^2$. Converting $watts/M^2$ to log form:

$$dbw/M^2 = 10 \log watts - 10 \log 4\pi R^2$$

$$\text{Flux density} = dBw - 10 \log 4\pi R^2$$

Now, substitute EIRP for dBw and a R of 25,500 miles (after converting to meters) and

$$\text{Flux density} = EIRP - 163.3 \ (dBw/M^2)$$

Transponder Channel Capacity: The number of equal amplitude carriers in one transponder channel for the single channel per carrier (SCPC) mode is found as follows If p is the power required for one channel, np is the power required for n channels. Accordingly, the total power required is expressed as:

$$p_t = np$$

Converting to log form:

$$10 \log p_t = 10 \log n + 10 \log p \ (dBw)$$

However, the total power available is the satellite EIRP subtracted by the output back-off (OPBO) required to meet intermodulation distortion (IM) requirements. Accordingly

$$10 \log p_t = EIRP - OPBO = 10 \log n + 10 \log p$$

$$10 \log p = EIRP - OPBO - 10 \log n$$

Where

$$10 \log p = EIRP/carrier$$

Frequency Staggering Improvement: The C/N for the SCPC mode will be further degraded by distortion products due to intermodulation products (IM). These products will add to the thermal noise of the system on a power basis for a large number of carriers as the IM products can be conside:

random. However, for a "small" number of carriers the IM products are not quite so random. As a result, the carriers can be spaced such that some IM products do not fall into their modulated bandwidth . This will result in an improvement in the ratio of the modulated carrier to unwanted IM product (C/IM) due to frequency staggering. The frequency staggering improvement (FSI) has been determined by Telesat to be as follows:

FSI = 10 log AFA/n

where,

AFA = Available frequency assignments

and,

n = number of carriers

AFA = Transponder BW/carrier separation

Transponder BW = 34 MHz (Reference 4)

Carrier Separation = 60 KHz (Reference 5)

$$AFA = 34 \times 10^6/60 \times 10^3$$

$$= 566$$

Therefore FSI = 10 log 566/n

Sample Calculation for Uplink (C/N_U) and Downlink (C/N_D)

Carrier to Noise Ratio

Downlink C/N_{TD}: The C/N_{TD} is due to thermal noise.

$$C/N_{TD} = EIRP/CXR + G/T + L + 228.6 - 10 \log B \quad (1)$$

$$G/T = 13.8 \text{ dB/°K (Reference 2)} \quad (2)$$

$$L = -196.8 \text{ dB} \quad (3)$$

$$10 \log B = 10 \log 40{,}000 \text{ (Reference 5)}$$

$$= 46 \text{ dB} \quad (4)$$

Substituting 2, 3, 4 into 1:

$$C/N_{TD} = EIRP/CXR + 13.8 - 196.8 + 228.6 - 46$$

$$C/N_{TD} = EIRP/CXR - 0.4 \quad (5)$$

$$EIRP/CXR = EIRP - OPBO - 10 \log n \quad (6)$$

$$EIRP = 32 \text{ dBw (at the beam edge-Reference 4)} \quad (7)$$

$$\text{Assume } OPBO = 2.6 \text{ dB} \quad (8)$$

Substituting 7, 8 into 6,

$$EIRP/CXR = 32 - 2.6 - 10 \log n \quad (9)$$

Substituting 9 into 5,

$$C/N_{TD} = 32 - 2.6 - 10 \log n - 0.4$$

$$C/N_{TD} = 29.0 - 10 \log n$$

For n = 70

$$C/N_{TD} = 29.0 - 10 \log 70$$

$$= 29.0 - 18.5$$

$$C/N_{TD} = 10.5 \text{ dB}$$

Carrier to Intermodulation Distortion Ratio, (C/IM)

For n = 70

FSI = 10 log 566/70

FSI = 9 dB

An OPBO of 2.6 dB results in an input back-off (IPBO) of 4 dB. From data in Reference 1, it is estimated that a C/IM of 7 dB occurs for a 4 db IPBO. As a result, the

$C/IM = 7 + FSI$

$C/IM = 7 + 9$

$C/IM = 16$ dB

Uplink C/N_{TU}: The C/N_{TU} is due to thermal noise.

$$C/N_{TU} = EIRP/CXR + G/T + L + 228.6 - 10 \log B \quad (1)$$

$$G/T = -5.5 \text{ dB/°K} \quad (2)$$

$$L = -200.3 \text{ dB} \quad (3)$$

$$10 \log B = 10 \log 40{,}000 \text{ Hz} = 46 \text{ dB} \quad (4)$$

Substitute 2, 3, 4 into 1:

$$C/N_{TU} = EIRP/CXR - 5.5 - 200.3 + 228.6 - 46$$

$$C/N_{TU} = EIRP/CXR - 23.2 \quad (5)$$

Equation 5 will be substituted in the following developed equations for finding the EIRP/CXR:

$$\text{Flux Density} = EIRP - 163.3$$

$$EIRP = 163.3 + \text{Flux Density} \quad (6)$$

The EIRP of (6) is reduced by the amount the input must be backed off from the saturated value of -84 dBw/M^2. The IPBO as previously determined is 4.0 dB. Substituting these values in (6) results in

$$EIRP = 163.3 - 84 - 4 = 75.3 \text{ dBw}$$

However, to obtain the value on a per carrier basis, this value must be reduced by 10 log n where n is the number of carriers.

$$EIRP/CXR = 75.3 - 10 \log n$$

For 70 carriers,

$$EIRP/CXR = 75.3 - 10 \log 70 = 75.3 - 18.5 = 56.8 \text{ dBw} \quad (7)$$

Substituting 7 into 5,

$$C/N_{TU} = 56.8 - 23.2 = 33.6 \text{ dB}$$

Uplink Power Required at the Earth Station: Transmit gain of a 15-foot antenna is 45.8 db. Accordingly, the power per carrie including 0.5 dB line loss is:

$$\text{Power/CXR} = 56.8 - 45.8 + 0.5 = 11.5 \text{ dBw (14.1 watts)}$$

Summary of System Carrier To Noise Ratio (C/N_S):

Contribution Due to	How Obtained	Symbol	Value (db)
Downlink Thermal	D3	C/N_{TD}	10.5
Uplink Thermal	D3	C/N_{TU}	33.6
Intermodulation	D3	C/IM	16.0
Satellite Internal Interference	D4	C/I_{SI}	27.9
Satellite External Interference	D5	C/I_{SE}	23.6
TOTAL	Power Combination	C/N_S	9.2

D.4 Satellite Internal Interference Model

The interference model of Section F of this Attachment was used to obtain the carrier-to-internal interference ratio, C/I_{SI}.

The following table summarizes the parameters and their associated values used in determining system depolarization isolation:

Spacecraft Cross-polarization Isolation	33 dB
Earth Station Cross-polarization Isolation (including pointing error)	33 dB
Rain Depolarization (99.5% of the time)	34 dB
Depolarization due to Faraday Rotation (if feed is set to the middle of the daily variation at sunspot maximum)	35 dB
Voltage Summation	21.7 dB
Power Summation	27.7 dB
Average of Voltage and Power Summation (one way link cross-polarization isolation)	24.7 dB

The cross-polarization isolation of the uplink and downlink are almost identical. Accordingly, they are assumed equal for purposes of this analysis.

Using the Equations of Section F, the system carrier-to-internal interference ratio equals 27.86 dB.

D.5 - Satellite External Interference Model

Introduction:

General: Interference analysis plays an important role in the formulation of a satellite communications system. Various mutual interference possibilities exist between the ground and space segments of the proposed Alaskan Bush Satellite Communications System, and adjacent outer-system satellite earth stations and terrestrial stations sharing the same frequency bands.

Interference Model: A basic 5-satellite interference model is used in the analysis of interference into the Alaskan Bush System from adjacent satellite systems. This interference model is centered about a reference RCA 24-channel (Frequency Reuse) satellite nominally located at a geostationary orbital position of 119°W. The adjacent orbital slots to the east of this reference position are presently occupied by the 12-transponder Telesat ANIK-I (located at 114°W longitude). Orbital positions west of the reference satellite placement are considered occupied by a 24-transponder Comsat/ATT spacecraft nominally placed at 123°W longitude, and a 24-channel RCA Satcom satellite nominally placed at 127°W longitude, and a 24 transponder Comsat/ATT Spacecraft nominally placed at 131°W longitude, as outlined in Figures 1 and 2.

The total interference affecting the desired signal is found by considering:

a) the interference in the uplink (I_U) contributed by all interfering earth stations illuminating the RCA satellite and

b) the interference in the downlink (I_D) contributed by all interfering satellites whose radiation affects the RCA 15 foot earth station.

The carrier-to-total external interference ratio $(C/I)_{S.E.}$, is expressed mathematically as

$$(C/I)_{S.E.} = (C/I)_U \boxed{+} (C/I)_D \qquad (1)$$

where

$(C/I)_U$ = (Carrier/Interference) in the uplink

$(C/I)_D$ = (Carrier/Interference) in the downlink

$\boxed{+}$ = Denotes power addition

Uplink Interference: The RCA satellite, assumed at 119°W longitude is illuminated with power in the same frequency band occupied by voice signals radiated from interfering earth stations. The interfering earth stations are those whose antenna gain main-lobe axes are pointing to satellites at 114°W, 123°W, 127°W and 131°W respectively. The RCA satellite at 119°W will be illuminated by power from these stations due to off-axis main lobe radiation at angles of 5°, 4°, 8°, and 12° respectively. The above

situation is shown pictorially in Figures 1 and 2. The off axis gain G (θ) for these angles is given by CCIR* as

$$G(\theta) = 32 - 25 \text{ Log } \theta$$

Downlink Interference: The satellites adjacent to the RCA satellite are shown in Figure 1. Signals radiated from these satellites are received by the RCA 15 foot earth station with an off-axis gain G(θ) that meets the CCIR* requirement as follows:

$$G(\theta) = 32 - 25 \text{ Log } \theta$$

*CCIR XII Plenary Assembly New Delhi, 1970; Report 391-1

Expression for $(C/I)_U$:

$(C/I)_U$ = [Wanted power illuminating the satellite in frequency band of interest (40 KHz)] minus [Unwanted power illuminating the satellite in 40 KHz bandwidth]

Wanted Power Illuminating the Satellite, $(C)_U$:

$$(C)_U = (EIRP/carrier) - L_U + G_{sat}$$

where:

(EIRP/carrier) = Transmitted Power/ Carrier from 15' earth station

L_U = uplink path loss = 200.3 dB

G_{sat} = RCA satellite receiving antenna gain in the direction of 15' earth station in Alaska = 27 db

From D3 for 70 carriers, the transmitted power/carrier is 11.5 dBw and the 15' earth station transmit antenna gain is 45.8 dB and the waveguide loss is 0.5 dB. Therefore:

$$\begin{aligned} EIRP/Carrier &= 11.5 + 45.8 - 0.5 \\ &= 56.8 \text{ dBw} \end{aligned}$$

Uplink Unwanted Power Illuminating the Satellite $(I)_U$

$$(I)_U = \boxed{\sum_{i=1}^{4}} \left[(EIRP)_i - G_i + G(\theta_i) - L_{ui} + (G_{sat})_i + R_i + P_i\right]$$

where

$\boxed{\Sigma}$ denotes power summation

$(EIRP)_i$ = Unwanted $_i$th interfering earth station EIRP in main axis direction

$G(\theta_i)$ = Transmit antenna gain of unwanted interfering i^{th} earth station at angle θ, off main axis

L_{ui} = $_i$th uplink path loss which will be taken as 200.3 dB for all i.

R_i = $_i$th power spreading factor

P_i = $_i$th polarization discrimination factor

G_i = $_i$th unwanted intefering earth station antenna gain (on-axis).

$(G_{Sat})_i$ = RCA Satellite Antenna Gain in the direction of i^{th} earth station. Because the antenna pattern is broad and not precisely specified, the gain in the direction of i^{th} station will be taken to be the beam edge gain for all i directions.

Power Spreading Factor (R)

The interfering channel power is distributed within the considered channel bandwidth according to the type of modulation of the interfering signal.

From the interference point of view, the 40 KHz slot in the interfering signal bandwidth carrying the highest amount of power is considered because this is the band containing the largest amount of power.

The power spreading within the channel bandwidth is considered as follows:

a) For the FDM/FM channels: The power is assumed to have gaussian distribution and results in a level of -24 dB below the unmodulated carrier in a 40 KHz band, therefore R = -24 dB (See D7).

b) For the TV channels: a 2 MHz bandwidth containing all the R.F. power will be considered, therefore:

$$R = 10 \text{ Log } \frac{40 \text{ KHz}}{2 \text{ MHz}} = -17 \text{ dB}$$

Polarization Discrimination

Since the study model includes a combination of RCA/Telesat/Comsat-ATT satellites, the adjacent satellite interference will be co-polarized or cross-polarized, as appropriate. The approved ground rules for polarization discrimination calling for 7 dB cross-pol-

arization discrimination factor for systems cross-polarized with an RCA system will be adopted in the analysis.

Expression for $(C/I)_D$:

$(C/I)_D$ = (Wanted satellite radiated power in the direction of wanted earth station) - (Unwanted satellites' radiated power in the direction of wanted earth station).

Wanted Power In The Direction of Wanted Earth Station, $(C)_D$:

$$(C)_D = (\text{EIRP/carrier})_{Sat.} - L_d + G_{E.St.} \quad (\text{dBw}) \qquad (4)$$

where:

$(\text{EIRP/carrier})_{Sat.}$ = Wanted (RCA) satellite radiated EIRP/carrier = 10.9 dBw

L_d = Downlink path loss = 196.8 dB

$G_E.St.$ = Wanted 15 foot earth station receive antenna gain (on-axis) = 42.9 dB.

Unwanted Power in the Direction of Wanted Earth Station $(I)_D$:

$$(I)_D = \boxed{\sum_{i=5}^{8}} [(\text{EIRP}_{sat.})i - L_{di} + G_{E.St.} \cdot (\theta_1) + R_i + P_i] (\text{dBw}) \quad (5)$$

where:

$(\text{EIRP}_{sat\ i})$ = i^{th} unwanted satellite EIRP in the direction of wanted 15 foot earth station. (dBw)

L_{di} = i^{th} down path loss and will be taken as 196.8 dB for all i.

$G_{E.St.}$ (θ_i) = 15 foot earth station antenna gain at θ_i angle with the main axis.

R_i, P_i, Σ = previously defined.

Systems Parameters

Interfering Systems Parameters

Telesat Canada (Anik I) Parameters

a) Heavy route earth station EIRP = 83 dBw

Earth station 98' transmit antenna gain (on axis) = 63 dB

b) Satellite Antenna Gain (on axis) = 29.5 dB

Satellite EIRP in direction of Alaska = 33 dBw

Satellite (G/T) = -7.0 dB/°K

ATT Parameters

a) Earth Station EIRP = 90.6 dBw

Earth Station 100 foot antenna(on-axis) = 62.3 dB

b) Satellite Antenna Gain (on axis) = 26 dB

Satellite EIRP in direction of Alaska = 33 dBw

Satellite saturation flux density = -72.7 dBw/M^2

RCA Parameters

a) Earth Station EIRP = 85 dBw

33' earth station receive antenna gain (on axis) = 51 dB

33' earth station transmit antenna gain (on axis) = 54 dB

b) Satellite antenna gain (on-axis) transmit or receive = 30 dBw

Satellite EIRP in the direction of Alaska = 32 dB

Summary of RCA 15 Foot Earth Station Parameters (See D3)

For 70 Carriers

15' Earth Station EIRP/carrier = 56.8 dB

15' Earth Station transmit antenna gain = 45.8 dB

15' Earth Station receive antenna gain = 42.9 dB

Satellite EIRP/carrier = 10.9 dBW

Values For $(C/I)_U$, $(C/I)_D$ For The System Considered

1) The reference channel at the reference earth station is considered to be cross polarized with the same channel in the Telesat Canada System. Therefore according to the frequency plans used by Telesat Canada, ATT and RCA Systems, the reference RCA channel in the uplink is:

a) Cross-polarized with respect to Telesat Canada and ATT channels occupying the same frequency band.

b) Co-polarized with respect to another RCA satellite system.

Therefore in the uplink the polarization discrimination factors (P) are:

$$P_1 = -7 \text{ dB} \quad P_2 = -7 \text{ dB} \quad P_3 = 0 \text{ dB} \quad P_4 = -7 \text{ dB}$$

where P_1 is the polarization discrimination at the RCA satellite between transmissions from Telesat ground stations and RCA ground stations, P_2 is between RCA & AT&T, P_3 is between RCA & RCA and P_4 is between RCA and AT&T.

The reference channel on the downlink is:

a) Cross-polarized with same channel of Telesat Canada.

b) Co-polarized with same channels in AT&T and RCA Systems.

Therefore in the downlink:

$$P_5 = -7 \text{ dB} \quad P_6 = 0 \text{ dB} \quad P_7 = 0 \text{ dB} \quad P_8 = 0 \text{ dB}$$

where P_5 is the polarization discrimination at the RCA ground station between transmissions from the RCA satellite and the Telesat Canada satellite, P_6 is between transmissions from RCA and AT&T, P_7 is for RCA and RCA, and P_8 is for RCA and AT&T.

2) The interfering channels carry the following types of signals: TV, FDM/FM, TV, FDM/FM associated with satellites at 114°W, 123°W, 127°W, 131°W, respectively,

therefore:

R_1 & R_5 = -17 dB for TV

R_2 & R_6 = -24 dB for FDM/FM

R_3 & R_7 = -17 dB for TV

R_4 & R_8 = -24 dB for TDM/FM

where R denotes spreading factor.

3) The satellites (and corresponding earth stations) at 114°W, 123°W, 127°W, and 131°W are Anik I, ATT, RCA and ATT respectively.

a) $(C/I)_U$

Equations 2 and 3 are used to find $(C/U)_I$. Because up path loss L_{ui} and RCA satellite antenna gain (G_{sa} have the same values for wanted signal and all interfering signals, these two terms can be dropped from Equations 1 and 2, therefore:

$$(C/I)_U = (\text{EIRP/carrier}) - \boxed{\sum_{i=1}^{4}} \left[(\text{EIRP})_i - G_i + G(\theta_i) + Ri + Pi\right]$$

Using system paramter values in Equation 6 results in

$$\begin{aligned}(C/I)_U = 56.8 - \big[&(83-63 + 32-25 \log 5 -17 - 7) \boxed{+} \\ &(90.6 - 62.3 + 32 - 25 \log 4 - 24 - 7) \boxed{+} \\ &(85 - 54 + 32 - 25 \log 8 - 17 - 0) \boxed{+} \\ &(90.6- 62.3 + 32 - 25 \log 12 -24 - 7)\big]\end{aligned}$$

$$(C/I)_U = 56.8 - (10.53 \boxed{+} 14.25 \boxed{+} 23.42 \boxed{+} 2.32)$$

$$(C/I)_U = 56.8 - 24.1 = 32.7 \text{ dB}$$

b) $\underline{(C/I)_D}$

Since down-path losses Ldi have the same values for wanted signal and all interfering signals, this term can be dropped from Equations 4 and 5 without affecting the final result.

therefore:

$$(C/I)_D = (EIRP/carrier)_{Sat.} + G_{E.St.} - \boxed{\sum_{i=5}^{8}} \left[(EIRPsat)i + G_{E.St.}(0_i) + R_i + P_i\right] \qquad (7)$$

Using system parameters in Equation 7 results in

$$(C/I)_D = 10.9 + 42.9 - \{(33 + 32 - 25 \log 5 - 17 - 7) \boxed{+} (33 + 32 - 25 \log 4 - 24) \boxed{+} (32 + 32 - 25 \log 8 - 17) \boxed{+} (33 + 32 - 25 \log 12 - 24)\}$$

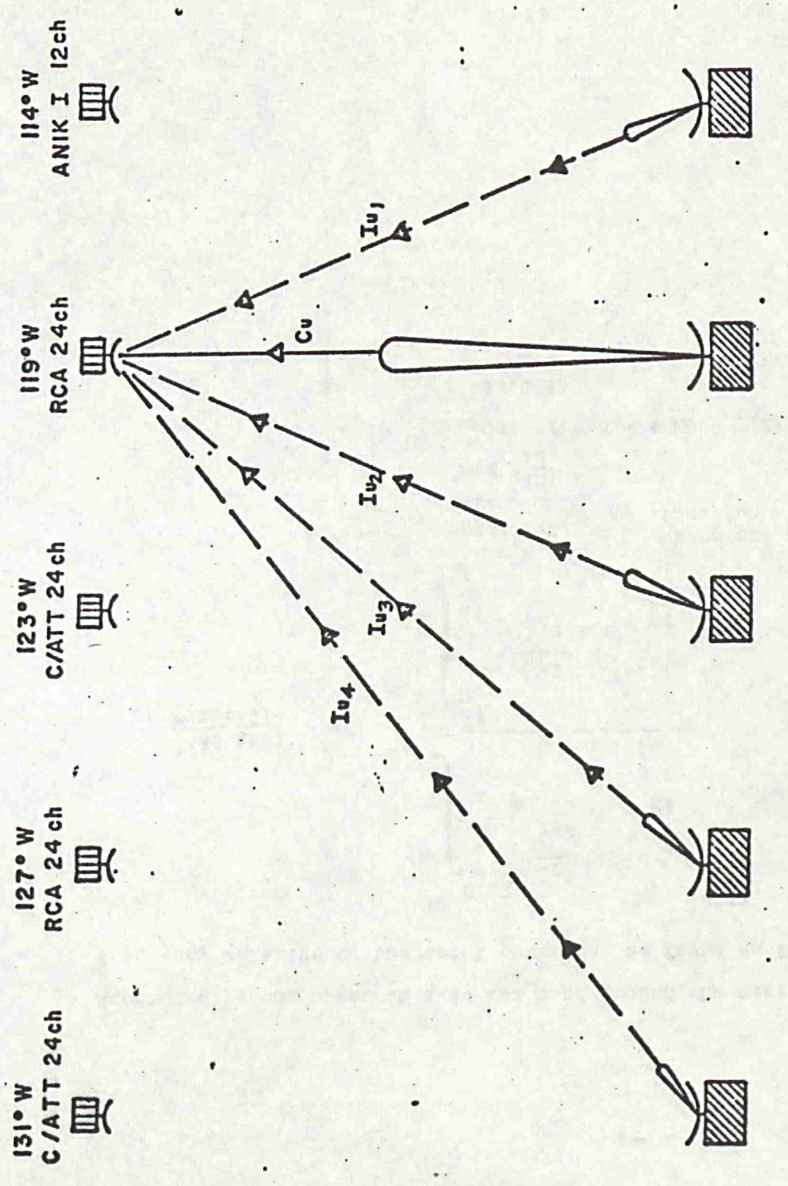
$$(C/I)_D = 53.8 - (23.53 \boxed{+} 25.95 \boxed{+} 24.42 \boxed{+} 14.02)$$

$$(C/I)_D = 53.8 - 29.6$$

$$(C/I)_D = 24.2 \text{ dB}$$

$$\text{Therefore } (C/I)_{S.E.} = (C/I)_U \boxed{+} (C/I)_D = 32.7 \boxed{+} 24.2$$

$$(C/I)_{S.E.} = 23.6 \text{ dB}$$



D.7 Power Spectrum of a FDM-FM Carrier

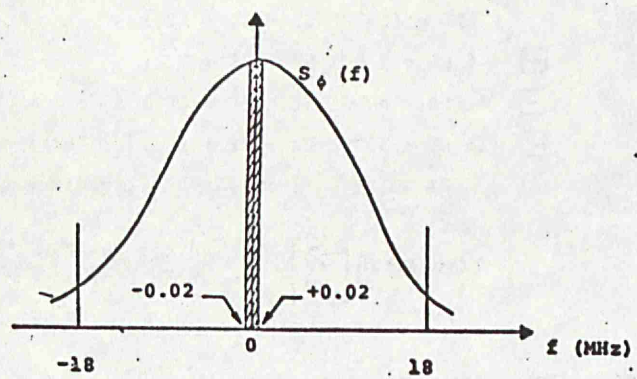
The spectrum of a carrier that is frequency modulated by a multiplexed telephony baseband is, in general, a complicated function which depends on many parameters. With increasing modulation index, the spectrum approximates a Gaussian shape near the carrier frequency. [1] Thus the power spectral density $S_\phi(f)$ can be expressed as follows:

$$S_\phi(f) = \frac{K}{\sqrt{2\pi}\,\sigma}\, e^{\frac{-f^2}{2\sigma^2}}$$

where, K = constant depending on carrier level

σ = multichannel rms deviation

f = frequency relative to carrier frequency in MHz



Accordingly, the power in a 40 kHz band around the carrier frequency relative to the total power can be found as follows:

$$\frac{P(40\ \text{kHz})}{P(\text{Total})} = \frac{\int_0^{0.02} e^{\frac{-f^2}{2\sigma^2}}\, df}{\int_0^{18} e^{\frac{-f^2}{2\sigma^2}}\, df}$$

$$= \frac{\operatorname{erf}\left(\frac{0.02}{2\sigma}\right)}{\operatorname{erf}\left(\frac{18}{2\sigma}\right)} \qquad \text{where erf} \triangleq \text{error function}$$

$$= .004 \quad \text{for } \sigma = 4 \text{ MHz} \qquad (2)$$

$$= -24.0 \text{ dB}$$

[1] J.C. Fuenzalida, O. Shimbo, and W.L. Cook/ "Time - Domain Analysis of Intermodulation Effects Caused by Non-Linear Amplifiers." COMSAT Technical Review, Vol. 3, No. 1, 1973.

[2] A multichannel rms deviation (σ) is obtained for 1280 voice channels as follows:

Transponder bandwith = 36 MHz

Peak factor = 3.16

Maximum Baseband Frequency= 4.2 x n in kHz

$$\text{Then, BW} = 36 \text{ MHz}$$

$$36 = 2(3.16\sigma + 4.2 \times 10^{-3}\ (1280)\ )$$

$$\sigma = 4 \text{ MHz}$$

E. Interference to Other Systems from a 15 Foot Earth Station Transmitting SCPC

Introduction

This analysis will consider the interference caused by RCA SCPC system utilizing either Delta modulation (ΔM) or frequency modulation (FM) into

(a) An ATT FDM/FM System

(b) A Telesat FDM/FM System

The interference to other systems is based upon 70 carriers in one transponder channel. When the carriers utilize SCPC/FM, the power radiated from an earth station may be less than that required for SCPC/ΔM transmission due to the lower i.f. noise bandwidth (N.B.W.). The NBW for ΔM system is 40 KHz and the NBW for an FM system is 25.7 KHz. As a result, the interference from the RCA SCPC/FM system to the adjacent C/ATT or Telesat Canada may be less than the interference from an RCA SCPC/ΔM system. Accordingly, the following analysis will be for a ΔM System since this is the worst case.

The interference level from the RCA System was estimated to be below the level of thermal nosie introduced into the ATT or Telesat detectors, which are assumed to be linear. Therefore, the detector operating point will not be determined by the interference. Accordingly, the interference is treated as noise added to the thermal noise and hence the noise output in pWp0 will be determined by using the follwoing equations.

[1] J.C. Fuenzalida, O. Shimbo, and W.L. Cook/ "Time - Domain Analysis of Intermodulation Effects Caused by Non-Linear Amplifiers." COMSAT Technical Review, Vol. 3, No. 1, 1973.

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$$36 = 2(3.16\sigma + 4.2 \times 10^{-3} (1280))$$

$$\sigma = 4 \text{ MHz}$$

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Introduction

This analysis will consider the interference caused by RCA SCPC system utilizing either Delta modulation (ΔM) or frequency modulation (FM) into

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$$[S/N]^* = [C/N]\ B/b\ [f_r/f_m]^2\ P \cdot W$$

Converting to dB notation,

$$[S/N] = [C/N] + 10 \log [B/b] + 20 \log [f_r/f_m] + P + W$$

$$B = 2[3.16\ gf_r + f_m] = \text{Carson Bandwidth} = 36\ \text{MHz}$$

where $[S/N]$ = weighted signal-to-noise ratio at the 1-mW test-tone level

$[C/N]$ = carrier-to-noise ratio over the Carson's Rule bandwidth, B

b = channel bandwidth = 3.1 kHz

f_r = rms test-tone deviation

f_m = maximum baseband frequency = 4.2 X n, in kHz

n = number of telephone channels

P = psophometric weighting factor = 2.5 dB

W = pre-emphasis weighting factor = 4 dB

g = antilog [L/20]

L = $-15 + 10 \log n$, $n \geq 240$ channels

= $-1 + 4 \log n$, $n < 240$ channels

*Comsat Tech. Rev., Volume 2, Number 2, Pg. 460.

Values for Parameters

Values for the parameters listed for use in the S/N equation are determined as follows:

C/N

Based on the assumption in the introduction, the initial calculation of C/N is performed on the basis that the power in the 70 RCA interfering carriers is uniformly spread over 36 MHz and subsequently will be appropriately adjusted to account for the actual power distribution. The initial C/N is determined by the power addition of the uplink interference $(C/I)_U$ and the downlink interference $(C/I)_D$.

a) C/N for an RCA-70-Carriers Channel Interfering with an FDM/FM ATT Channel

$$(C/I)_U = EIRP_{AT\&T\ E.S.} - [EIRP/CXR_{RCA\ E.S.} + 10 \log 70 - G_{15'\ Ant.} + G_{Sidelobe}] + \text{Polarization Discrimination Factor} \quad (1)$$

$$(C/I)_U = 90.6 - [56.8 + 10 \log 70 - 45.8 + 32 - 25 \log 4] + 7$$

$$(C/I)_U = 51.2\ \text{dB}$$

$$(C/I)_D = [EIRP_{AT\&T\ Sat.} + G_{AT\&T\ E.S.}] - EIRP/CXR_{RCA\ Sat.} + 10 \log 70 + G_{Sidelobe} \quad (2)$$

$$(C/I)_D = (33 + 60.5) - (10.9 + 10 \log 70 + 32 - 25 \log 4)$$

$$(C/I)_D = 47.2\ \text{dB}$$

C/N = power addition of $(C/I)_U$ and $(C/I)_D$

$C/N = 45.7$ dB

b) <u>C/N for an RCA 70 Carriers (SCPC) Channel Interfering with an FDM/FM Telesat Channel</u>

$(C/I)_U = EIRP_{\text{Telesat E.S.}} - \left[EIRP/CXR_{\text{RCA E.S.}} + 10 \log 70 - G_{15' \text{ Ant.}} + G_{\text{Sidelobe}}\right]$ + Polarization Discrimination Factor

$(C/I)_U = 83 - [56.8 + 10 \log 70 - 45.8 + 32 - 25 \log 5] + 7$

$= 46.0$ dB

$(C/I)_D = \left[EIRP_{\text{Telesat Sat.}} + G_{\text{Telesat E.S.}}\right] - \left[EIRP/CXR_{\text{RCA Sat.}} + 10 \log 70 + G_{\text{Sidelobe}}\right]$ + Polarization Discrimination Factor

$= (33 + 63) - (10.9 + 10 \log 70 + 32 - 25 \log 5) + 7$

$= 59.1$ dB

C/N = power addition of $(C/I)_U$ and $(C/I)_D$

$C/N = 45.8$ dB

<u>Carson Bandwidth (B)</u>

$B = 36$ MHz

<u>Voice Channel Bandwidth (b)</u>

$b = 3.1$ kHz

<u>Maximum Baseband Frequency (f_m)</u>

$f_m = 4.2 \times 10^3 \times 1200 = 5.04$ MHz

<u>Loading Factor</u>

$L = -15 + 10 \log 1200 = 15.79$ dB

<u>RMS Test Tone Deviation (f_r)</u>

$f_r = 0.66$ MHz

Substituting these values for the parameters in Equation 1 results in the following:

a) <u>S/N in the output of a C/ATT Channel</u>

$$S/N = 45.7 + 10 \log \frac{36 \times 10^6}{3.1 \times 10^3} + 20 \log \frac{0.66 \times 10^6}{5.04 \times 10^6} + 2.5 + 4$$

$= 75.2$ dB

b) <u>S/N in the output of a Telesat-Canada Channel</u>

$[S/N] = 75.3$ dB

<u>Calculation of Output Noise in pWp0</u>

A) Output Noise in a C/ATT Channel.

$S/N = 75.2$ dB

Therefore the noise at the output of the ATT detector is:

$(N) = S - 75.2$ dBm where $S = 0$ dBm reference level

$= 0 - 75.2 = -75.2$ dBm

$N = 30.2$ pWp0

b) Output Noise in a Telesat, Canada Channel

N = -75.3 dBm = 29.5 pWpO

It was initially assumed that the power from the 70 RCA Carriers was spread over 36 MHz. However, this carrier power is spread in 40 KHz slots around 70 carriers. Accordingly, the noise power (30.2 pWp0) must be increased to account for this difference.

The increase in power relative to the 36 MHz assumed spread is found as follows:

Number of 40 kHz bands in 36 MHz = 900

Actual number of 40 kHz bands = 70

Power increase = 10 log 900/70 = 11.1 dB

However, this increased power is spread over a 40 kHz band and not a 4 kHz band.

Accordingly, the increase of 11.1 dB must be reduced by 10 log 40/4 or 10 dB to arrive at the increased power in a 4 kHz band. This results in a net increase in interference power in the voice band of 1.1 dB more.

That is, rather than 30.2 pWp0, we will have 38.9 pWp0 noise interference in a voice channel at the zero toll level position in an AT&T channel and will have 38.0 pWp0 noise interference in a voice channel of Telesat, Canada.

F. Voice Transmission Performance Objectives Between 15 Foot Earth Stations Using FM Modulation

Scope: This analysis establishes the performance objectives for voice communications between 15-foot earth stations using FM modulation Modems. The baseline is established by combining the degradations of intermodulation, thermal noise, and satellite interference.

Performance Objectives: The performance objectives contained below are based upon current Alaskan village experience relative to telephone service. Further, the number of carriers in a transponder channel required to support P 10 telephone service is based upon a signal quality that is considered to be excellent. That is, a carrier-to-noise ratio (CNR) of 11.0 dB will provide service equal to 51.2 dB SNR while the threshold CNR of the demodulator is of the order of 7.6 dB (Reference 1). It should be noted that a transmitter of less than 15 watts per carrier is required for a CNR of 11.0 dB.

Telephone Service to be Provided: One transponder channel is capable of supporting P 10 telephone service as described in the following table:

Telephones	Maximum Carriers in a Transponder	Earth Station Power per Carrier Required	Received C/N$_S$	SNR
120	70	14.1 watts	11.0dB	51.2dB

F.1 Telephone Services

Telephone Service Analysis: The maximum number of events to provide P 10 service to the bush communities via satellite has been calculated. Only one phone per village is planned initially. This will result in slightly less than P 10 service.

Assumptions:

A. Assumes that the addition of phones does not increase the total amount of traffic.

B. Use of Demand Assignment Multiple access to route traffic.

C.

Number of Telephones	56	148
Erlangs*	7.63	7.63
P 10 Channels (One Way)*	32	32

*If calls are Poisson distributed and call duration times are exponentially distributed.

Voice Quality: This performance is intended for use with FM Modulation voice modems. However, the criteria used for this analog technique is not the same as for digital technique as was discussed in Section D.7. For example, the analog systems criteria for a voice channel is related to the interference noise received in that voice channel. This noise is directly related to the carrier-to-noise ratio (CNR) of the channel. Once the CNR is above the threshold value, the signal-

to-noise ratio (SNR) is almost directly proportional to the CNR dB by dB. A voice signal of >50 dB SNR results in excellent speech quality and will be slightly degraded at lower CNR's.

F.2 References

Ref. 1. Letter, entitled "Request for Information on FM SCPC", from James H. Smith, California Microwave, Inc. August 13, 1975.

F.3 FM System Performance (Reference 1)

System C/N vs SNR

System C/N in a 25.7 KHz NBW (dB)	SNR (dB) (Without Companding)
7.0	27.5
7.7	30.0
8.0	30.8
9.0	32.3
10.0	33.2
11.0	34.2
12.0	35.1
13.0	36.3
20.0	42.9

With companding, the above SNR can be improved by 17 dB

Noise Bandwidth: 25.7 ± 1 KHz

Threshold CNR of Demodulator: 7.6 dB

F.4 Link Analysis and Satellite Internal and External Interferences

The number of carriers and the power radiated from the earth station are assumed to be the same as those discussed for the SCPC Delta mod transmission. Therefore, exactly the same link analysis that was described in Section D.3 can be carried out. The only exception is that the noise bandwidth (NBW) of the carrier has to be changed to 25.7 KHz due to the smaller NBW of the FM carrier (25.7 KHz). Therefore, the carrier-to-thermal noise ratio, C/N_T, (C/N_{TU} for the uplink and C/N_{TD} for the downlink) has to be increased by 1.9 dB (the power ratio of 40 KHz NBW to 25.7 KHz NBW), respectively. The carrier-to-intermod noise ratio can also be increased by the same amount due to the reduction of the noise bandwidth.

Adding 1.9 dB to the values of C/N_{TD}, C/N_{TU}, C/IM shown in Section D.3, respectively, C/N_{TD}, C/N_{TU}, and C/IM in the case of SCPC/FM transmission will be as follows:

Downlink Thermal	C/N_{TD}	= 12.4 dB	(1)
Uplink Thermal	C/N_{TU}	= 35.5 dB	(2)
Intermodulation	C/IM	= 17.9 dB	(3)

Due to the reduction of the noise bandwidth, the internal interference from the adjacent co- and cross- polarized channels will also be reduced from the case for the Delta mod transmission for the same internal interference model that was described in Section F. However, the value that was shown in Section D.4 will be used for the carrier-to-satellite internal interference ratio in the calculation of the system CNR. This results in a conservative model. Therefore,

$$C/I_{SI} = 27.9 \text{ dB} \qquad (4)$$

The satellite external interference is also reduced from the case for the Delta mod transmission. The wanted power illuminating the satellite or the earth station in a frequency band of 25.7 KHz for the FM transmission is the same as the wanted power illuminating a frequency band of 40 KHz for the Delta mod transmission since the EIRP per carrier is the same for both cases. However, the unwanted power coming from a 25.7 KHz interfering band will be less than that coming from a 40 KHz interfering band if this interfering band is located at the center of the power spectrum of the unwanted carrier (the band containing the largest amount of power) as was assumed in the external interference model of Section D.5. Therefore, the carrier-to-external interference ratio for the FM case will be higher than that for the Delta mod case. In the calculation of the system CNR, the value shown in Section D.5 will be used since this results in a conservative model for the FM case. Therefore,

C/I_{SE} = 23.6 dB (5)

Summary of System Carrier-to-Noise Ratio (C/N_S):

Contribution Due to	Symbol	Value (dB)
Downlink Thermal	C/N_{TD}	12.4
Uplink Thermal	C/N_{TU}	35.5
Intermodulation	C/IM	17.9
Satellite Internal Interference	C/I_{SI}	27.9
Satellite External Interference	C/I_{SE}	23.6
Total	C/N_S	11.0

A system carrier-to-noise ratio C/N_S of 11.0 dB results in SNR of 51.2 dB (Reference 1).

G

Transmission Engineering Report TER-003-75, RCA Satcom

Internal Interference Model, March 14, 1975

RCA GLOBAL COMMUNICATIONS INC.
P. O. Box 2244
PRINCETON, N. J. 08540

TRANSMISSION ENGINEERING REPORT

RCA SATCOM INTERNAL INTERFERENCE MODEL

REPORT NUMBER: TER-003-75

RELEASE DATE: March 14, 1975

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TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Adjacent Channel Interference - Interference analysis plays an important role in the formation of a satellite communications system. For the system under consideration, there are 24 channels. If every channel carries traffic, for any one channel, the remaining 23 channels act as interfering channels. From this large number of interfering channels, however, only four occupy the identical portion of the spectrum thus causing interference as follows:

(a) Interference from adjacent co-polarized channels - Two channels whose center frequencies are 40 MHz above and below the center frequency of the desired channel, reduced in amplitude only by the suppression of the input and output Mux filters.

(b) Interference from adjacent cross-polarized channels - Two channels whose center frequencies are 20 MHz above and below the center frequency of the desired channel (20 MHz offset from the desired channel), reduced in amplitude mostly by the cross-polarization isolation and to some extent by the suppression and shaping of the input and output Mux filters.

All these interferences are assumed to be incoherent. Furthermore, each cross-polarized interfering channel

contributes interference to two cross-polarized channels. It will be shown that cross-polarized channels provide most of the interference to the desired channel and therefore a certain amount of cross-polarization isolation has to be achieved for a desired system performance. The amount of this type of interference can be computed by convolving the spectra of the wanted and unwanted signals.

1.2 Objective - The performance objectives for voice and TV that were calculated in Attachment F (Small Station Performance and Interference Analysis) of Alaska Communication Plan[1] are based in part on the information in a report supplied to Astro Electronics Division by RCA Ltd. entitled "Performance Analysis of RCA Satcom Communication System"[2]. This report is deficient in many areas. As a result, many parameters had to be approximated, resulting in a conservative model. This conservative model in turn resulted in a performance which is not optimistic. For example, the carrier to interference ratio of 17.5 dB was reported for the interference to a SCPC channel, and 17.58 dB for the interference to a TV channel

The objective of this report is to obtain a more accurate model and the associated magnitude of carrier to interference ratio for the same traffic modes analyzed in Attachment F.

2.0 ANALYSIS

2.1 Power Spectra of Interfering Carriers

(a) Power Spectrum of a FDM/FM Carrier - The spectrum of a carrier that is frequency modulated by a multiplexed telephony baseband is, in gereral, a complicated function which depends on many parameters. When the baseband signal consists of many single-sideband, frequency-multiplexed telephone channels, it is often convenient to simulate the baseband signal by an equivalent band of random noise. The determination of the power spectrum when the modulating signal consists of random noise involves considerable analysis. A particular case of interest, often assumed in the analysis of a radio system, is that of frequency modulation by a random noise signal of uniform power density[3]. The shape of the power spectrum in this case largely depends on the modulation index (r.m.s. modulation index is useful since the modulating signal is a random-noise voltage).

When the r.m.s. modulation index is very small and the lowest modulation frequency is not zero as arises in practice, a bounded continuous spectrum results, together with a residual carrier at the mean carrier frequency as shown in Figure 1 (the case for $m = 0.1$, $m^2/x_1 = 0.1$, x_1 being f_1/f_n). The residual carrier corresponds to the carrier component of the spectrum when a single modulating tone is used and the ratio of f_1/f_n is that of the lowest to the highest modulating frequency.

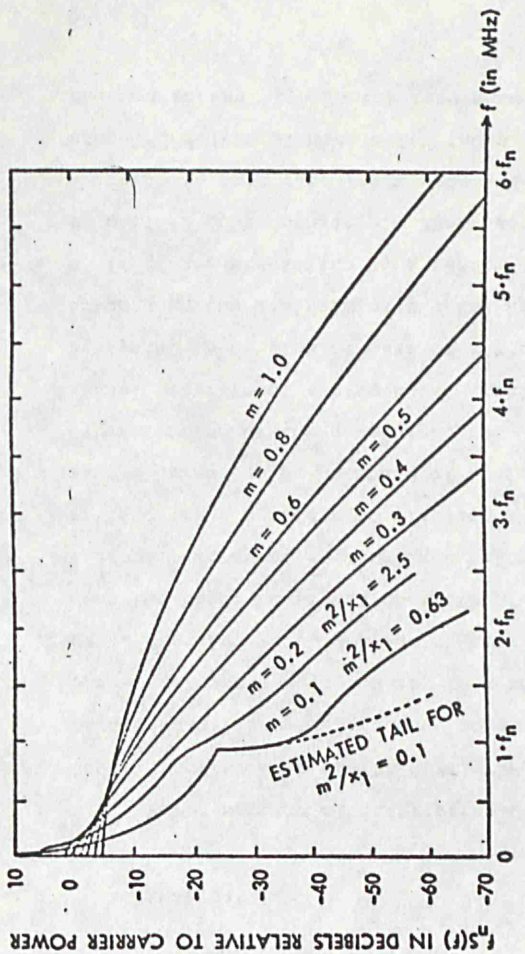
For intermediate values of r.m.s. modulation index, power spectra based on measurement are believed to be the most reliable. Normalized spectrum curves obtained form the measurements[4] are also shown in Figure 1 for eight values of m between 0.1 and 1.0.

When the r.m.s. modulation index is large (greater than about 1.5) the mean power spectrum normalized for unit carrier power is of Gaussian form:[4,5]

$$S_\phi(f) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{f^2}{2\sigma^2}}$$

Where

σ = multichannel r.m.s. deviation in Hz



f_n: HIGHEST MODULATING FREQUENCY IN MHz
S(f): POWER SPECTRUM IN dB/MHz
m: MULTICHANNEL RMS DEVIATION
x: f/f_n

FIGURE 1. POWER SPECTRUM OF A FDM-FM CARRIER FOR RMS MODULATION INDEX m = 0.1 ~ 1.0, $S(f)f_n$ EXPRESSED IN dB RELATIVE TO UNMODULATED CARRIER POWER (NORMALIZED FOR UNIT CARRIER POWER).

f = frequency relative to carrier frequency in MHz

$\phi(t)$ = multiplexed telephone baseband signal, simulated by a random-noise signal of unifor power spectrum.

Figure 2 shows the power spectrum when r.m.s. deviation is 4 MHz. In order for r.m.s. modulation index, m to be great than 1.5, highest modulation frequency has to be less than 2.96 MHz resulting in Carson's bandwidth of 34 MHz. In this case 705 voice channels can be multiplexed.

(b) Power Spectrum of a TV/FM Carrier - According to the calculation made by Bell Labs[6], the power in any 4 KHz band is at least 30 dB below (i.e., 66 dB/Hz below) the power of the unmodulated carrier when the peak frequency deviation ratio is 3, using Bell system standard preemphasis. These calculations assumed that the frequency-modulation spectrum of a band of white noise is similar to the spectra of preemphasized FM television signals near the carrier where the density is highest. Their measured spectra agreed quite well with those

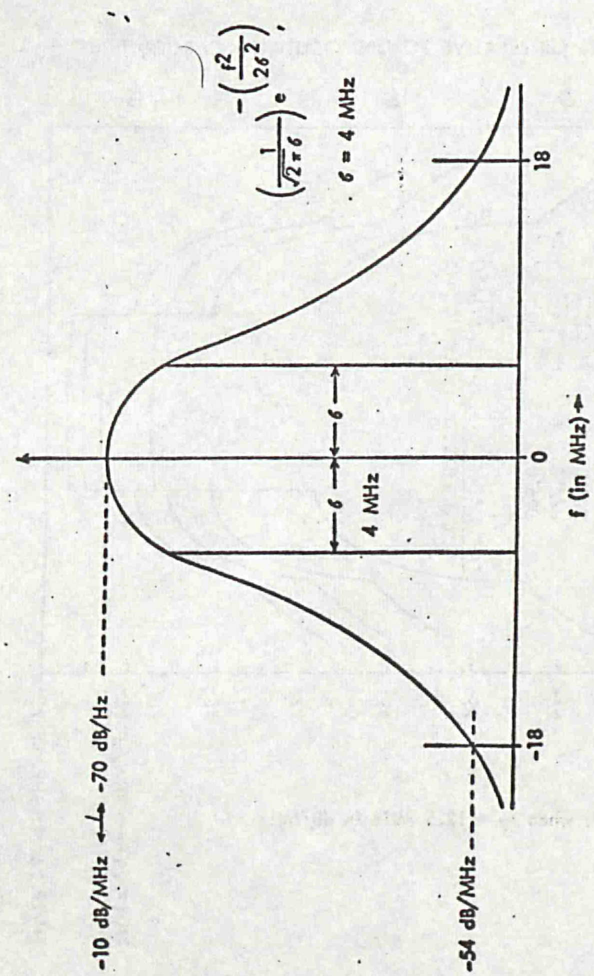


FIGURE 2. POWER SPECTRUM OF A FDM-FM CARRIER WHEN RMS MODULATION INDEX IS LARGE.

calculated by this method even at the low deviation ratios.

According to the power spectrum as shown in Figure 3[7], the power spectra is almost flat over the bandwidth of 2 f_T. (centered at carrier frequency) and drops faster outside of this range as the r.m.s. phase deviation decreases. This power spectral shape is similar to the power spectrum reported by COMSAT as shown in Figure 4[8]. The power spectrum in this case is flat over 25 MHz, ± 12.5 MHz from the carrier and

B_{IF} = 2 ($\Delta f + f_m$)

= 2 (12.5 + 5.5) = 36 MHz. If we assume most of the power is contained in this 25 MHz band at this frequency deviation, the power in any 1 MHz band is 14 dB below the power of the unmodulated carrier [10 log ($\frac{1}{25}$) = - 14 dB]. This can easily be seen from Figure 4. Beyond this 25 MHz band, the power in unit bandwidth drops by about 20 dB from the power level in any 1 MHz band over 25 MHz band. As the r.m.s. frequency deviation increases,

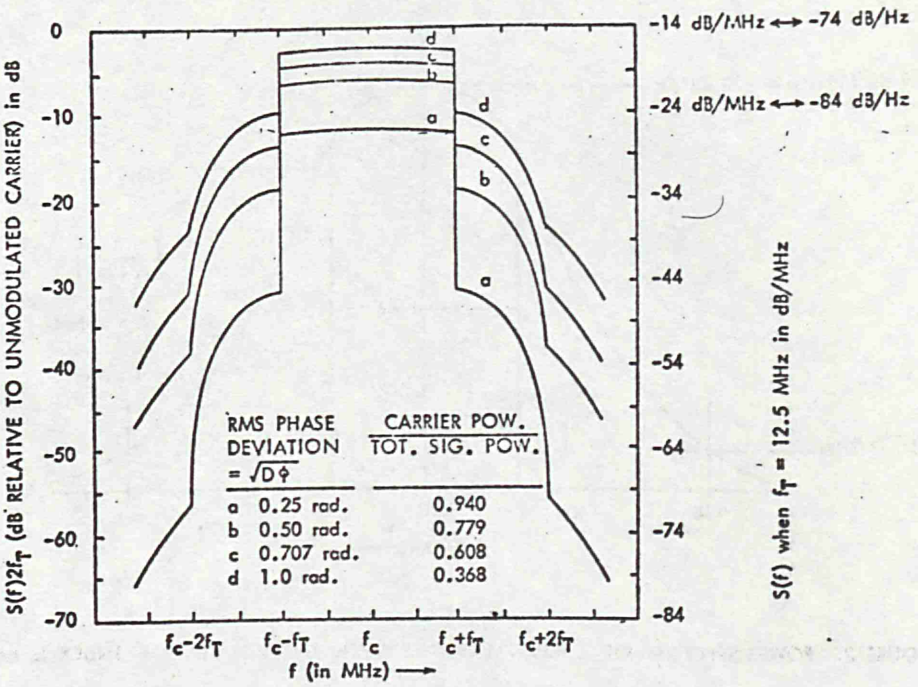
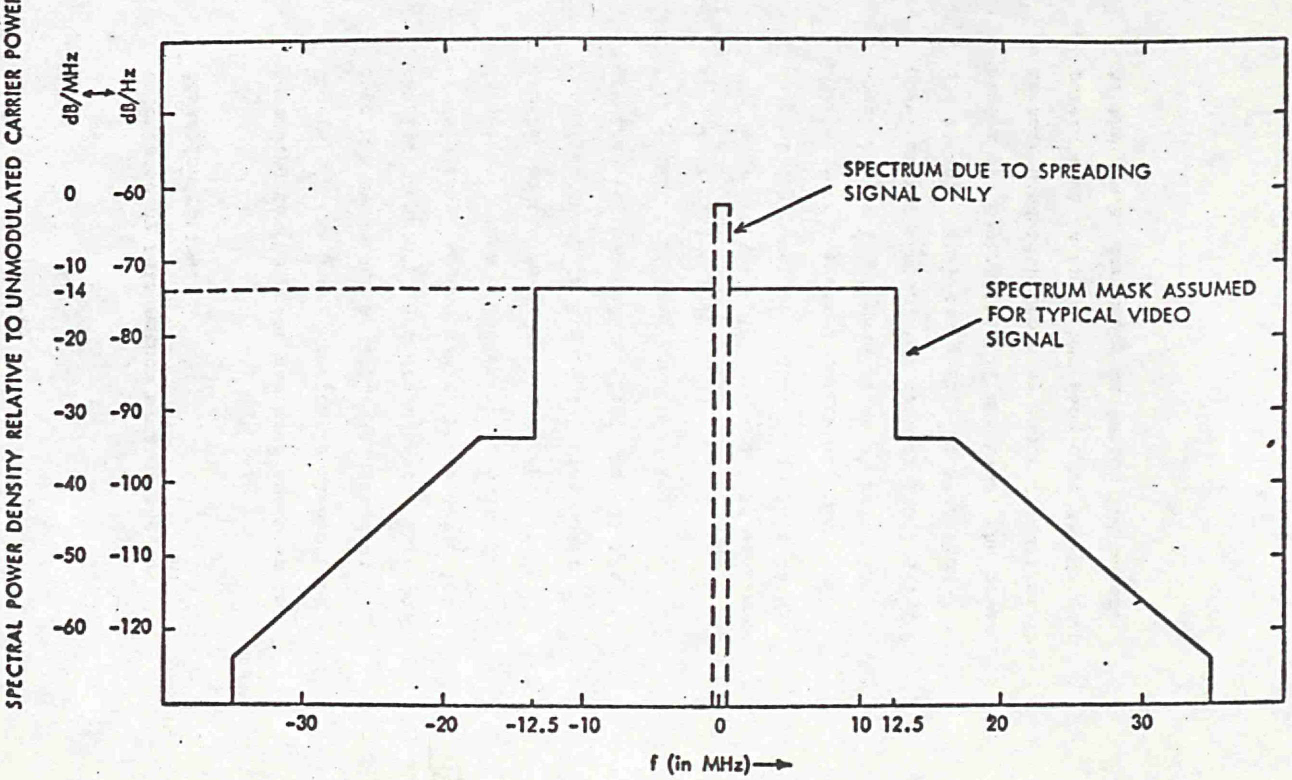


FIGURE 3. SIDEBAND SPECTRA OF A CARRIER PHASE-MODULATED BY A BASEBAND SIGNAL CONSISTING OF A FLAT BAND OF RANDOM NOISE WHICH EXTENDS FROM 0 TO f_T Hz.



the power level outside the 25 MHz band will be expected to drop less from the constant level over 25 MHz. In this case the assumption that most of the power is contained in 25 MHz band may not be valid depending on the r.m.s. frequency deviation. Therefore, at low r.m.s. frequency deviation the crude power spectrum as shown in Figure 5 will be used.

(c) Power Spectrum of a 4ϕ-PSK Carrier Which is Carrying High Bit Rate Data - The primary cause of adjacent channel interference from PSK carriers is the power spectrum spreading due to TWT non-linearities. Power spectrum spreading was discussed extensively by Shimbo et.al.[9] and Lyons[10], with good agreement between their results.

Shimbo simulated power spectrum spreading in the following manner. By computing the in-phase and quadrature components of the pulse response of the cascaded filters between the PSK modem and the TWT, the input $e_i(t)$ to the TWT is determined and the complex non-linear transfer function takes care of the TWT output, $e_o(t)$. To obtain the

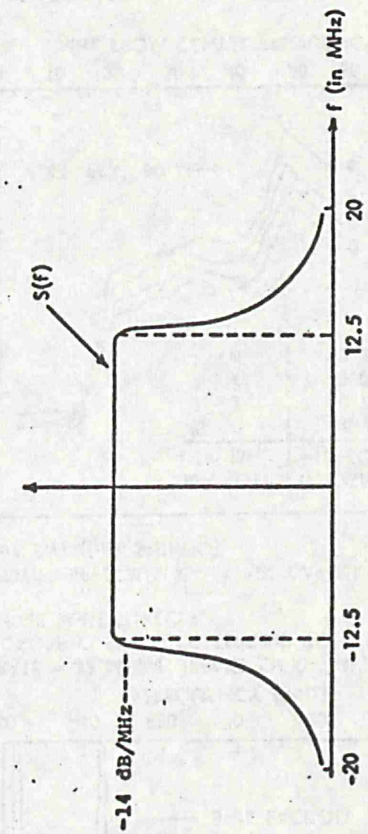
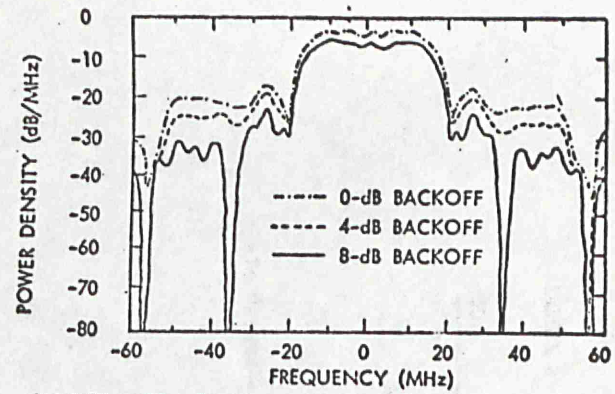


FIGURE 5. APPROXIMATE POWER SPECTRUM OF A FM/TV CARRIER USED FOR THE ANALYSIS.

power spectrum of $e_o(t)$, the product $e_o(t) \cdot e_o(t+\tau)$ is formed; the ensemble average of this product is taken on the in-phase and quadrature random variables of the PSK signal, and the time average is taken over t; and finally the Fourier transform of the averaged version is taken with respect to τ. One of the results is shown in Figure 6. Using TWT output filter and modem receive filter, the adjacent channel interference from both sides (two adjacent PSK channels) was evaluated[11] as shown in Figure 8.

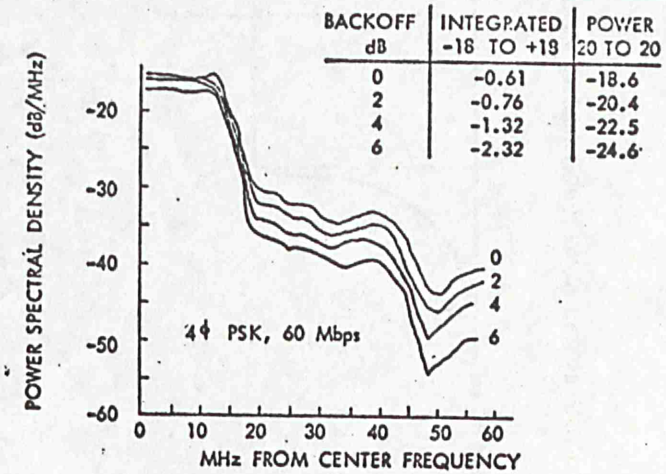
Lyons also showed a similar analysis by employing 36 MHz square root raised cosine transmit filter responses to get the TWT output power spectra and evaluate several types of interference from PSK channel to wideband and narrow band FM, TV/FM, and PSK channels. One of the power spectrum at the TWT output is shown in Figure 7 for 60 Mbits/s data stream.

It was found in both studies that the power spectrum spreading caused by TWT non-linearities is not



SYMBOL RATE = 32 Mbaud. (PEAKS OF 0-, 4-, AND 8-dB INPUT BACKOFF CURVES CORRESPOND TO -15.5, -16, AND -17.5 dB REPSECTIVELY).

FIGURE 6. POWER SPECTRUM OF A PSK CARRIER AT THE OUTPUT OF TWT (from SHIMBO).



BACKOFF dB	INTEGRATED -18 TO +18	POWER 20 TO 20
0	-0.61	-18.6
2	-0.76	-20.4
4	-1.32	-22.5
6	-2.32	-24.6

FIGURE 7. POWER SPECTRUM OF A PSK CARRIER AT THE OUTPUT OF TWT (from LYONS).

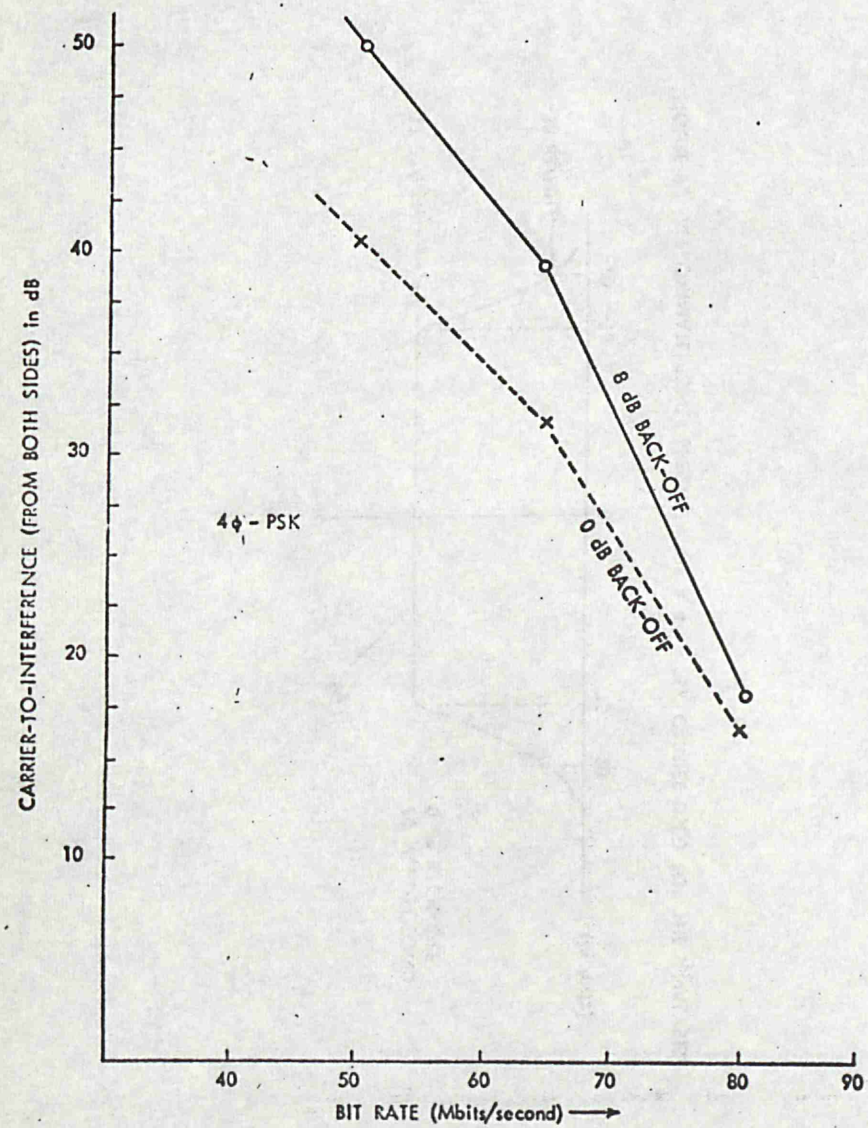


FIGURE 8. INTERFERENCE FROM ADJACENT CO-POLARIZED PSK CHANNELS TO A PSK CHANNEL.

greatly affected by the data or bit rates of the PSK signal, but that the power level of the spread power in adjacent channels is highly dependent on TWT backoff. Lyons also found that power spreading causes severe interference to narrowband FM systems, but the interference to wideband FM and PSK systems is less severe. Also, SCPC systems are vulnerable to interference from strong line components in the PSK spectrum.

For our purpose of analysis, the approximate power spectrum shown in Figure 9 will be used in this report.

(d) Power Spectrum of SCPC Carriers and the Associated Intermod Power Spectrum - Because the bandwidth of each single channel carrier is much less than that of any of the other types of signals being considered, no interference to the adjacent co-polarized channels will result directly from the single channel carriers. However, a large number of intermodulation products produced by the single channel carriers will fall in adjacent channels. Therefore, the intermodulation power spectrum is

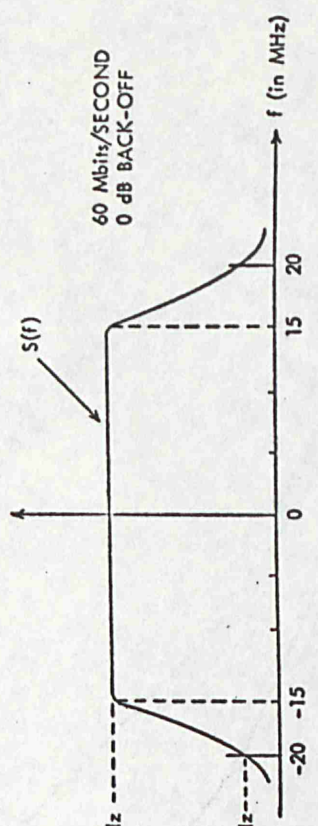


FIGURE 9. APPROXIMATE POWER SPECTRUM OF A 4Φ - PSK CARRIER USED FOR THE ANALYSIS.

important in this case. The transmitted waveform associated with a SCPC carrier has a power spectral density of the form[12].

$$G(W) = \left[\frac{\sin\frac{WT}{2}}{\frac{WT}{2}}\right]^2 \left[\frac{1}{1 + W^{14}}\right]$$

Where the first term is due to the modulated carrier and the second is due to the 7-pole Butterworth filter which follows the modulator. Figure 10 shows the power spectral shape associated with SCPC carriers with the intermod power spectrum. If number of SCPC carriers is very large and if these carriers are equally spaced, the intermod power spectrum is almost uniform over the channel bandwidth and decreases slowly outside of the band. A computer program was written which plots the distribution of intermodulation products from a group of single channel carriers versus frequency[13]. A sample output of this program is shown in Figure 11, for 51 equally spaced carriers and a C/IM in the worst channel of 16 dB was assumed. The level of intermod power at any frequency is also assumed to be proportional to the number of intermod products

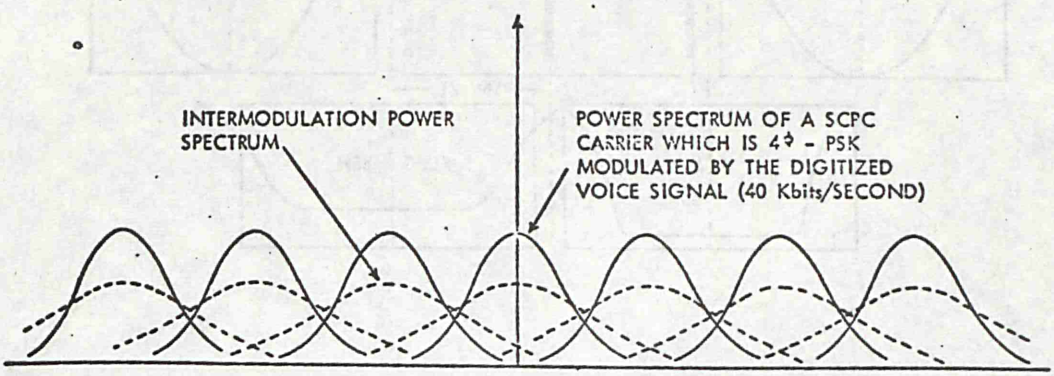
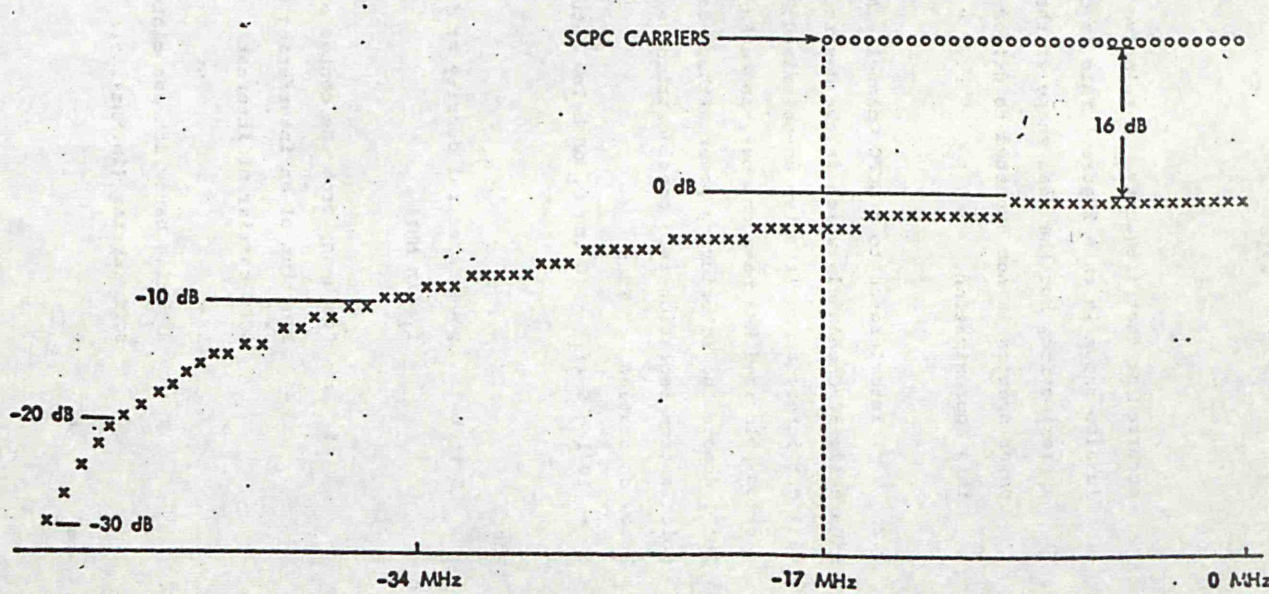


FIGURE 10. POWER SPECTRUM OF SCPC CARRIERS AND THE ASSOCIATED INTERMOD POWER SPECTRUM.



occurred at that frequency. A relative level is also shown in this figure. This is only an approximation, but the real shape of the intermod power spectra is not expected to differ much from this approximation.

2.2 Interference to a SCPC Channel - As shown in Figure 12, SCPC channel, which is the desired channel, will get interference from two co-polarized FDM/FM channels, a cross-polarized HBR Data channel, and a FM/TV channel. Let I denote the interfering power without taking the cross-polarization isolation into consideration, expressed in dB below saturation. Then

$I = 10 \log S(f_1) + 10 \log B$, dB below saturation

Where

$S(f_1)$: power spectral density at frequency f_1 (in MHz)

f_1 : frequency from the center of the power spectrum of an interfering signal to the SCPC carrier of interest

B : RF noise bandwidth associated with a SCPC carrier (in MHz)

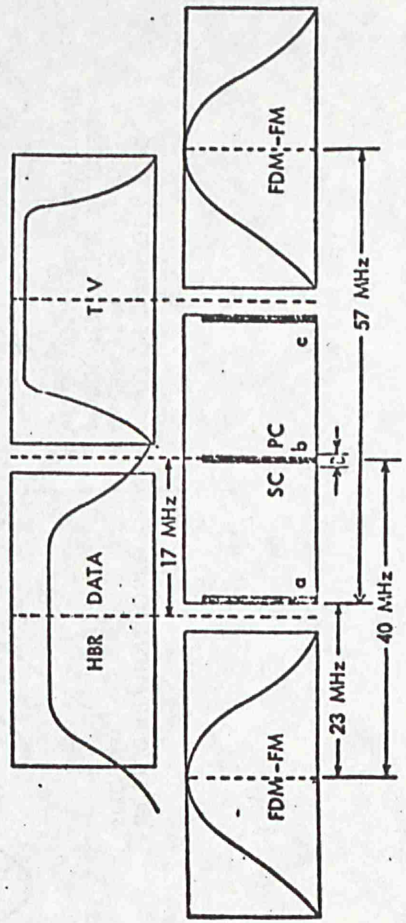


FIGURE 12. INTERFERENCE MODEL TO SCPC CHANNEL.

(i) For a SCPC carrier located at the left edge of the desired channel.

(a) FDM/FM carrier (right-hand side co-polarized channel)

$$I = 10 \log \left(\frac{1}{\sqrt{2\pi}\cdot 4} e^{-\frac{57^2}{2 \times 4^2}} \right)$$

$$+ 10 \log (40 \times 10^{-3}) \text{ dB}$$

and is negligible.

RF noise bandwidth of a SCPC is assumed to be 40 KHz.

(b) FDM/FM carrier (left-hand side co-polarized channel)

$$I = 10 \log \left(\frac{1}{\sqrt{2\pi}\cdot 4} e^{-\frac{23^2}{2 \times 4^2}} \right)$$

$$+ 10 \log (40 \times 10^{-3})$$

$$= -81.8 + (-13.98)$$

$$= -95.8 \text{ dB below saturation}$$

$$= \text{negligible}$$

(c) TV

Interfering power from cross-polarized TV channel is negligible as seen obviously from Figure 12. A FM/TV carrier in this case is located far away from the SCPC of our interest.

(d) HBR Data

$$I = -17 \text{ dB/MHz} + 10 \log (40 \times 10^{-}$$

$$= -17 + (-13.98)$$

$$= -30.98 \text{ dB below saturation}$$

Therefore it was shown that the interference from cross-polarized HBR Data channel is only important. For this offset cross-polarized HBR Data channel, I is -30.98 dB below saturation. This means that the interfering power into the SCPC channel on the uplink is

$$-81.5 \text{ dBW/m}^2 + (-37 \text{ dB}\cdot\text{m}^2) + G_{sat} - 30.98 - (XPI)_U$$

Where

$-81.5\ dBW/m^2$	:	saturation flux density
$-37\ dB\cdot m^2$	:	the effective area of an isotropic antenna at 6 GHz
G_{sat}	:	RCA satellite receiving antenna gain in the direction of small earth station in Alaska
$(XPI)_U$	:	cross-polarization isolation on the uplink

The power of a SCPC on the uplink will be

$$(-81.5\ dBW/m^2 - 4.0) + (-37\ dB\cdot m^2) - 10 \log 70 + G_{sat}$$

Where

-4.0 dB	:	input back-off
70	:	number of SCPC carriers

Therefore, carrier-to-interference ratio on the uplink is:

$$\left(\frac{C}{I}\right)_U = 8.53 + (XPI)_U$$

For the downlink, the interfering power is

$$\text{Sat. EIRP} - \text{Path loss} + G_{E.S.} - 30.98 - (XPI)_D$$

Where

Sat. EIRP	:	satellite EIRP for single carrier saturation
$G_{E.S.}$	:	gain of the small earth station antenna
$(XPI)_D$	:	cross-polarization isolation on the down link

The power of a SCPC carrier on the downlink will be

$$(\text{Sat. EIRP} - 2.6) - 10 \log 70 - \text{Path loss} + G_{E.S.}$$

Where

-2.6 dB : output back-off

Therefore, carrier to interference ratio on the downlink is

$$\left(\frac{C}{I}\right)_D = 9.93 + (XPI)_D$$

The total carrier to interference ratio is expressed as follows:

$$\left(\frac{C}{I}\right)_{Total} = \left(\frac{C}{I}\right)_U \boxplus \left(\frac{C}{I}\right)_D$$

Where $\boxplus$ denotes the power summation. The results are tabulated in Table 1 for various values of cross-polarization isolation

(ii) For a SCPC carrier located at the right edge of the desired channel - Interfering power from a FM/TV channel is only important in this case. The interfering power is

$$I = -14 \text{ dB/MHz} + 10 \log (40 \times 10^{-3})$$

TABLE 1 -- CARRIER TO INTERFERENCE RATIO FOR A SCPC CARRIER LOCATED AT THE LEFT EDGE OF THE DESIRED CHANNEL (in dB)

$(XPI)_U$	$(XPI)_D$	$(XPI)_{SYSTEM}$	$(\frac{C}{I})_U$	$(\frac{C}{I})_D$	$(\frac{C}{I})_{TOTAL}$
16	16	13	24.53	25.93	22.16
19	19	16	27.53	28.93	25.16
22	22	19	30.53	31.93	28.16
25	25	22	33.53	34.93	31.16
28	28	25	36.53	37.93	34.16
31	31	28	39.53	40.93	37.16

TABLE 2 -- CARRIER TO INTERFERENCE RATIO FOR A SCPC CARRIER LOCATED AT THE RIGHT EDGE OF THE DESIRED CHANNEL (in dB)

$(XPI)_U$	$(XPI)_D$	$(XPI)_{SYSTEM}$	$(\frac{C}{I})_U$	$(\frac{C}{I})_D$	$(\frac{C}{I})_{TOTAL}$
16	16	13	21.53	22.93	19.16
19	19	16	24.53	25.93	22.16
22	22	19	27.53	28.93	25.16
25	25	22	30.53	31.93	28.16
28	28	25	33.53	34.93	31.16
31	31	28	36.53	37.93	34.16

Where

$-81.5\ dBW/m^2$: saturation flux density

$-37\ dB \cdot m^2$: the effective area of an isotropic antenna at 6 GHz

G_{sat} : RCA satellite receiving antenna gain in the direction of small earth station in Alaska

$(XPI)_U$: cross-polarization isolation on the uplink

The power of a SCPC on the uplink will be

$$(-81.5\ dBW/m^2 - 4.0) + (-37\ dB \cdot m^2) - 10 \log 70 + G_{sat}$$

Where

-4.0 dB : input back-off

70 : number of SCPC carriers

Therefore, carrier-to-interference ratio on the uplink is:

$$\left(\frac{C}{I}\right)_U = 8.53 + (XPI)_U$$

For the downlink, the interfering power is

$$\text{Sat. EIRP} - \text{Path loss} + G_{E.S.} - 30.98 - (XPI)_D$$

Where

Sat. EIRP : satellite EIRP for single carrier saturation

$G_{E.S.}$: gain of the small earth station antenna

$(XPI)_D$: cross-polarization isolation on the down link

The power of a SCPC carrier on the downlink will be

$$(\text{Sat. EIRP} - 2.6) - 10 \log 70 - \text{Path loss} + G_{E.S.}$$

Where

-2.6 dB : output back-off

Therefore, carrier to interference ratio on the downlink is

$$\left(\frac{C}{I}\right)_D = 9.93 + (XPI)_D$$

The total carrier to interference ratio is expressed as follows:

$$\left(\frac{C}{I}\right)_{Total} = \left(\frac{C}{I}\right)_U \boxed{+} \left(\frac{C}{I}\right)_D$$

Where $\boxed{+}$ denotes the power summation. The results are tabulated in Table 1 for various values of cross-polarization isolation

(ii) For a SCPC carrier located at the right edge of the desired channel - Interfering power from a FM/TV channel is only important in this case. The interfering power is

$$I = -14 \text{ dB/MHz} + 10 \log (40 \times 10^{-3})$$

TABLE 1 -- CARRIER TO INTERFERENCE RATIO FOR A SCPC CARRIER LOCATED AT THE LEFT EDGE OF THE DESIRED CHANNEL (in dB)

$(XPI)_U$	$(XPI)_D$	$(XPI)_{SYSTEM}$	$(\frac{C}{I})_U$	$(\frac{C}{I})_D$	$(\frac{C}{I})_{TOTAL}$
16	16	13	24.53	25.93	22.16
19	19	16	27.53	28.93	25.16
22	22	19	30.53	31.93	28.16
25	25	22	33.53	34.93	31.16
28	28	25	36.53	37.93	34.16
31	31	28	39.53	40.93	37.16

TABLE 2 -- CARRIER TO INTERFERENCE RATIO FOR A SCPC CARRIER LOCATED AT THE RIGHT EDGE OF THE DESIRED CHANNEL (in dB)

$(XPI)_U$	$(XPI)_D$	$(XPI)_{SYSTEM}$	$(\frac{C}{I})_U$	$(\frac{C}{I})_D$	$(\frac{C}{I})_{TOTAL}$
16	16	13	21.53	22.93	19.16
19	19	16	24.53	25.93	22.16
22	22	19	27.53	28.93	25.16
25	25	22	30.53	31.93	28.16
28	28	25	33.53	34.93	31.16
31	31	28	36.53	37.93	34.16

$$= \quad -27.98 \text{ dB below saturation}$$

Proceeding as in the previous section,

$$\left(\frac{C}{I}\right)_U = 5.53 + (XPI)_U$$

$$\left(\frac{C}{I}\right)_U = 6.93 + (XPI)_D$$

The results are shown in Table 2.

2.3 Interference to a FM/TV channel - As shown in Figure 13, FM/TV channel, which is the desired channel, will get the interference from a co-polarized HBR Data channel, a co-polarized FDM/FM channel, a cross-polarized SCPC channel, and a cross-polarized FDM/FM channel. The interfering power, I will be as follows:

a. interfering power from cross-polarized FDM/FM channel

$$I = 10 \log \left[\int_{-\infty}^{-3} \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{f^2}{2\sigma^2}} df \right]$$

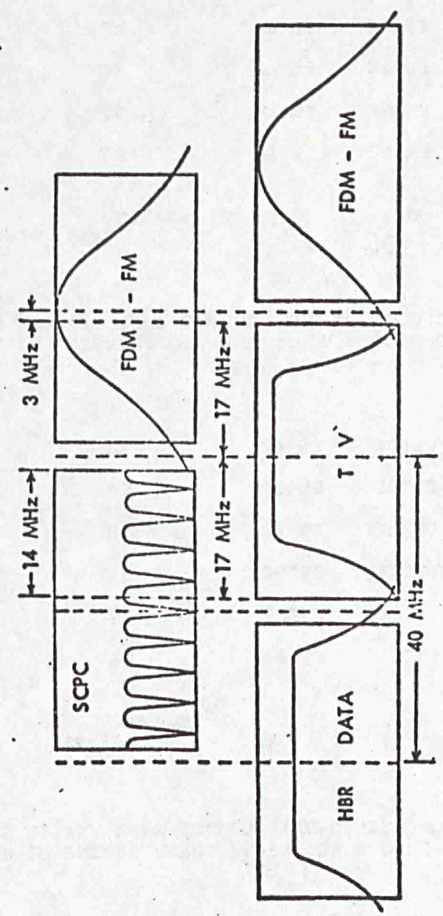


FIGURE 13. INTERFERENCE MODEL TO A TV CHANNEL

$$\sigma = 4 \text{ MHz}$$

$$= 10 \log (0.2266)$$

$$= -6.45 \text{ dB below saturation}$$

b. Interfering power from cross-polarized SCPC channel - By assuming that SCPC carriers in 14 MHz band (as shown in Figure 13) are directly interfering with FM/TV channel, interfering power will be

$$I = 10 \log \left(\frac{14 \text{ MHz}}{34 \text{ MHz}}\right)$$

$$= -3.9 \text{ dB below saturation}$$

Equally spaced SCPC carriers are assumed and the effect of intermod is neglected, since the level of the intermod power spectrum is so many dB below the power spectrum associated with SCPC carriers.

c. Interfering power from co-polarized FDM/FM channel is neglected as shown previously.

d. Interfering power from co-polarized HBR Data channel

is also assumed to be neglected as shown in Figure 8 for the bit stream the rate of which is below 60 mbits/s.

(i) $(\frac{C}{I})$ due to cross-polarized FDM/FM Channel - For this offset cross-polarized FDM/FM channel, the interfering power, I is -6.45 dB below saturation. This means that the interfering power into the FM/TV channel on the uplink is

$$-81.5 \text{ dBW/m}^2 + (-37 \text{ dB}\cdot\text{m}^2) + G_{sat} - 6.45 - (XPI)_U$$

The power of a FM/TV carrier on the up-link is

$$-81.5 \text{ dBW/m}^2 + (37 \text{ dB}\cdot\text{m}^2) + G_{sat}$$

Therefore, carrier to interference ratio on the uplink is

$$(\frac{C}{I})_U = 6.45 + (XPI)_U$$

For the downlink, the interfering power is

$$32 \text{ dBW} - \text{Path loss} + G_{E.S.} - 6.45 - (XPI)_D$$

The power of a FM/TV carrier on the downlink is

32 dBW - Path loss + $G_{E.S.}$

Therefore,

$$\left(\frac{C}{I}\right)_D = 6.45 + (XPI)_D$$

Then, total carrier to interference ratio will be

$$\left(\frac{C}{I}\right) = \left(\frac{C}{I}\right)_U \; |\pm| \; \left(\frac{C}{I}\right)_D$$

$$= [6.45 + (XPI)_U] \; |\pm|$$

$$[6.45 + (XPI)_D]$$

The results are tabulated in Table 3.

(ii) $\left(\frac{C}{I}\right)$ due to cross-polarized SCPC channel - For this offset cross-polarized SCPC channel, the interfering power, I is -3.9 dB below saturation. The means that the interfering power into the FM/TV channel on the uplink is

TABLE 3 -- CARRIER TO INTERFERENCE RATIO DUE TO CROSS-POLARIZED FDM/FM CHANNEL (in dB)

$(XPI)_U$	$(XPI)_D$	$(XPI)_{SYSTEM}$	$\left(\frac{C}{I}\right)_U$	$\left(\frac{C}{I}\right)_D$	$\left(\frac{C}{I}\right)$
16	16	13	22.45	22.45	19.45
19	19	16	25.45	25.45	22.45
22	22	19	28.45	28.45	25.45
25	25	22	31.45	31.45	28.45
28	28	25	34.45	34.45	31.45
31	31	28	37.45	37.45	34.45

TABLE 4 -- CARRIER TO INTERFERENCE RATIO DUE TO CROSS-POLARIZED SCPC CHANNEL (in dB)

$(XPI)_U$	$(XPI)_D$	$(XPI)_{SYSTEM}$	$\left(\frac{C}{I}\right)_U$	$\left(\frac{C}{I}\right)_D$	$\left(\frac{C}{I}\right)$
16	16	13	23.9	22.5	20.13
19	19	16	26.9	25.5	23.13
22	22	19	29.9	28.5	26.13
25	25	22	32.9	31.5	29.13
28	28	25	35.9	34.5	32.13
31	31	28	38.9	37.5	35.13

$$(-81.5\ \text{dBW/m}^2 - 4.0) + (-37\ \text{dB}\cdot\text{m}^2) + G_{sat}$$

$$-3.9 - (XPI)_U$$

Where

-4.0 dB : input back-off

The power of a FM/TV carrier on the uplink is

$$-81.5\ \text{dBW/m}^2 + (-37\ \text{dB}\cdot\text{m}^2) + G_{sat}$$

Therefore,

$$(\frac{C}{I}) = 7.9 + (XPI)_U$$

On the downlink, the interfering power is

$(32\ \text{dBW} - 2.6) - \text{Path loss} + G_{E.S.} - 3.9 - (XPI)_D$

The power of a FM/TV carrier on the downlink is then,

$$32\ \text{dBW} - \text{Path loss} + G_{E.S.}$$

Therefore, carrier to interference ratio on the downlink is

TABLE 5 -- TOTAL CARRIER TO INTERFERENCE RATIO (INTERFERENCE INTO FM/TV CHANNEL)

SYSTEM CROSS-POLARIZATION ISOLATION, $(XPI)_{SYSTEM}$	TOTAL CARRIER TO INTERFERENCE RATIO, $(\frac{C}{I})_{TOTAL}$
13 dB	16.78 dB
16 dB	19.78 dB
19 dB	22.78 dB
22 dB	25.78 dB
25 dB	28.78 dB
28 dB	31.78 dB

$$\left(\frac{C}{I}\right)_D \quad = \quad 6.5 + (XPI)_D$$

Then, total carrier to interference ratio will be

$$\left(\frac{C}{I}\right) \quad = \quad \left(\frac{C}{I}\right)_U \; |\mp| \; \left(\frac{C}{I}\right)_D$$

$$= \quad [7.9 + (XPI)_U] + [6.5 + (XPI)_D]$$

The results are also tabulated in Table 4.

(iii) Total Carrier to Interference Ratio - By adding up the carrier to interference ratios obtained (i) and (ii) powerwise, the total carrier to interference ratio is calculated and the results are tabulated in Table 5.

2.4 Cross-Polarization Isolation - Since the polarization isolation between the orthogonally polarized beams is not perfect in practice, the desired channel will get interferences from adjacent cross-polarized channels as explained in the previous sections. This interference causes a degradation of performance to the desired channel. Therefore, a certain amount of beam isolation (polarization) must be realized between two orthogonally polarized beams.

The planned approach to determining the amount of this isolation for various SATCOM services is described in Communication Systems Engineering Memorandum, CSEM-003-74, entitled "The Approach to Determining the Specification for System Cross-Polarization Isolation". The polarization isolation is degraded due to various depolarization mechanisms such as

- .Depolarization due to angular misalignment (pointing error)
- .Depolarization due to the misalignment of the antenna polarization vectors
- .Depolarization due to rain
- .Depolarization due to Faraday rotation

The discussion of these depolarization mechanism is quite involved and is beyond the scope of this report. However, detailed analysis on some of these depolarization mechanism was made available.[14,15] According to the preliminary analysis made, the cross-polarization isolation, which can be achieved without employing various compensation techniqu for the depolarization mechanisms mentioned above, is of the order of 22 dB or more. This will be summarized as follows:

S/C X-polarization Isolation	: 33 dB
E/S X-polarization Isolation (including pointing error of ± 0.15°)	: 36.5 dB
Rain Depolarization (99% of the time)	: 34 dB
Depolarization due to Faraday rotation (if feed is set to the middle of the daily variation at sunspot maximum, and adding 3 dB for the average condition)	: 35 dB
Voltage summation	22.7 dB
Power Summation	28.5 dB
Average of voltage and power summation (one way link X - polarization isolation)	: 25.6 dB

∴ System cross-polarization Isolation : 22.6 dB

For this magnitude of cross-polarization isolation, the interference to a SCPC is such that (C/I) is about 28 dB. This is 10 dB better than the value reported in Attachment F of Alaska Communication Plan. For the carrier-to-interference ratio for a FM/TV channel, (C/I) is about 26 dB which is about 7.2 dB better than that reported in Attachment F.

If various compensation techniques for the depolarization mechanisms are utilized, then the cross-polarization isolation can be further improved, resulting in higher carrier-to-interference ratio.

3.0 CONCLUSION - The main objective of this report is to obtain a more accurate interference model and the associated magnitude of carrier to interference ratio for the same traffic modes analyzed in Attachment F in Alaska Communication Plan. The results are summarized in Fig. 14.

(a) The interference from adjacent co-polarized channels is negligible and the cross-polarized channels provide most of the interference to the desired channel for the traffic modes assumed in this report. This is why carrier-to-interference ratio increases linearly with the system cross-polarization isolation as shown in Fig. 14.

(b) Carrier-to-interference ratio for SCPC channel is approximately 2.4 dB higher than that for TV channel for the traffic modes assumed in this report.

(c) For the cross-polarization achievable without utilizing any compensation techniques for the various depolarization mechanisms (about 22 dB), carrier-to-interference ratio, C/I for SCPC channel is about 28 dB. This is 10 dB better than the value reported

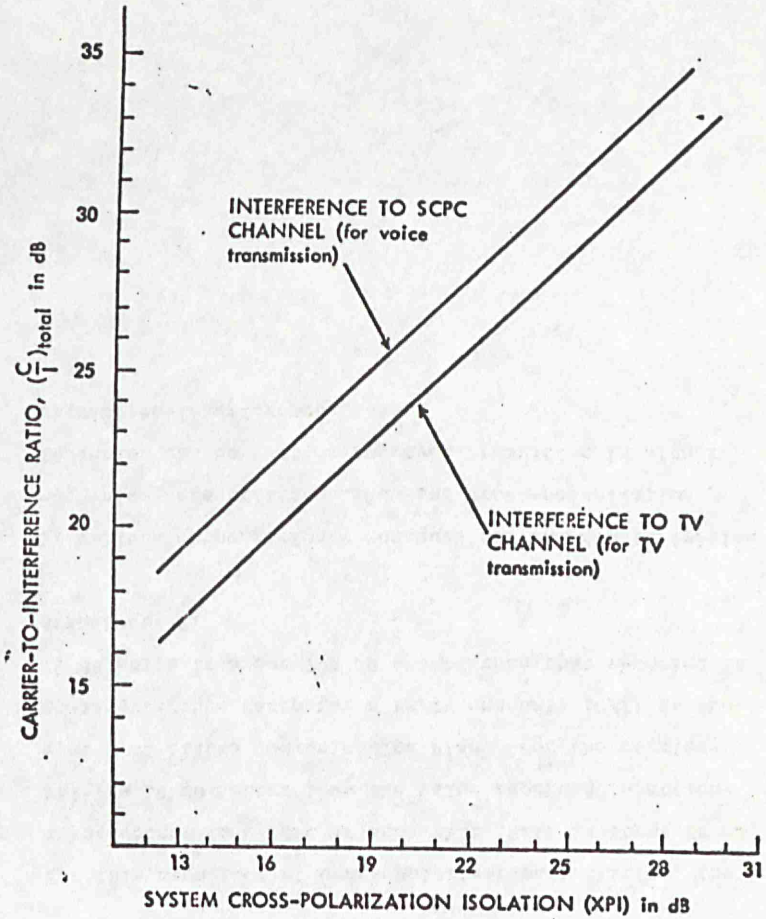


FIGURE 14. CARRIER-TO-INTERFERENCE RATIO FOR THE ASSUMED INTERFERENC MODEL.

in Attachment F. Carrier-to-interference ratio for TV channel is about 26 dB which is 7.2 dB better than that reported in Attachment F. Even if 19 dB is assumed for the cross-polarization isolation instead of 22 dB, the carrier-to-interference ratios for both SCPC channel and TV channel are still greater than those reported in Attachment F by 7 dB and 4.2 dB respectively. In this case the computed carrier-to-interference ratio for SCPC channel is 25 dB, and about 23 dB for TV channel.

As discussed above, the analysis of small earth station performance in Attachment F of Alaska Communication Plan resulted in a conservative model in terms of carrier-to-interference ratio for the RCA SATCOM internal interference model. The higher carrier-to-interference ratio is expected than the value reported in Attachment F. The results will be modified when more accurate spectrum analysis associated with various types of interfacing signal is made.

References

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(5) J. C. Fuenzalida, O. Shimbo, and W. L. Cook, Time-Domain Analysis of Intermodulation Effects Caused by Non-linear Amplifiers, COMSAT Technical Review, Vol. 3, No. 1, 1973.

(6) H. W. Evans, AIAA 2nd Communication Satellite Systems Conference, AIAA Paper No. 68-411, April 8-10, 1968.

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(10) R. G. Lyons, Effects of PSK Spectral Spreading in a Satellite Transponder, IEEE International Communications Conference, pp. 36B-1, June 1974.

(11) M. K. Lee, American Satellite Corporation Support Status Report on Digital Transmission, Fairchild Space and Electronics Company, April 5, 1974.

(12) R. B. McClure, Analysis of Intermodulation Distortion in an FDMA Satellite Communications System with a Bandwidth Constraint, International Communications Conference, Paper 70-CP-239-COM, 1970.

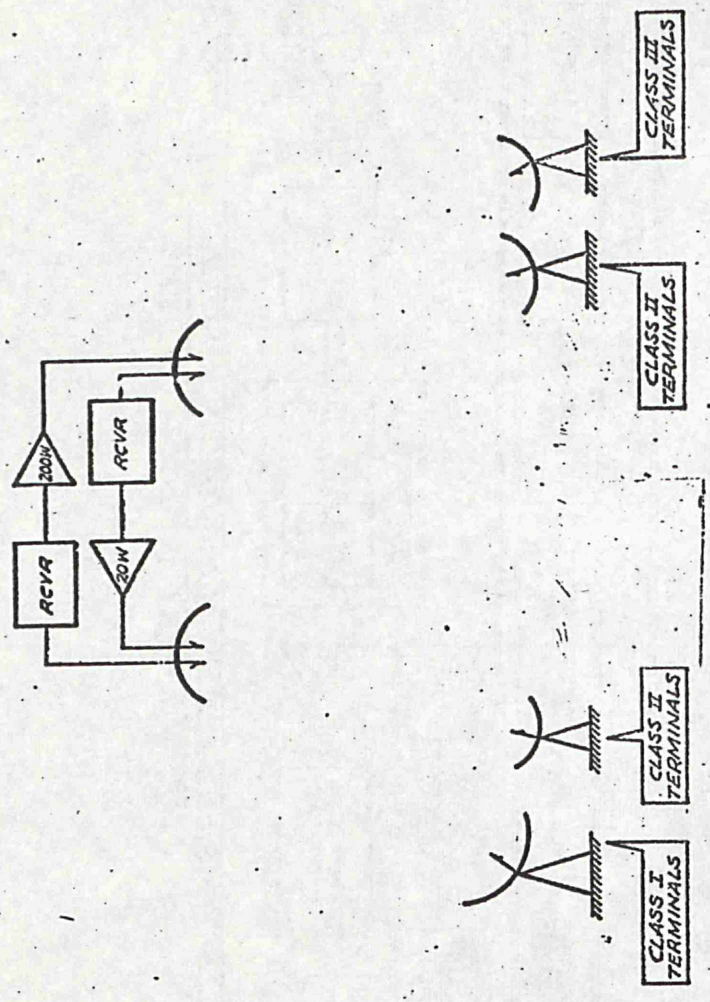
(13) A. Schoen, RCA Global Communications Inc., Transmission Engineering, P. O. Box 2244, Princeton, New Jersey, February 1975.

(14) M. K. Lee, Depolarization Effect Due to Rain in the Spectrum Reuse System, Transmission Engineering Report TER-001-75, RCA Global Communications Inc., P. O. Box 2244, Princeton, New Jersey.

(15) M. K. Lee, Depolarization Effect Due to Faraday Rotation in the Spectrum Reuse System, To Be Published.

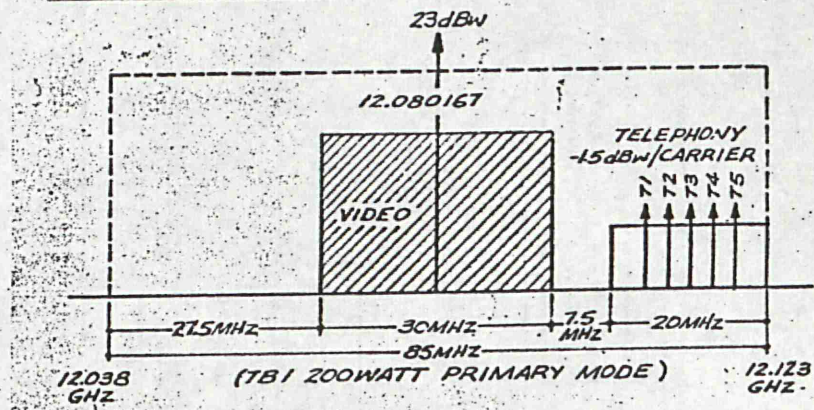
CTS TERMINAL CHARACTERISTICS

NETWORK CONFIGURATION



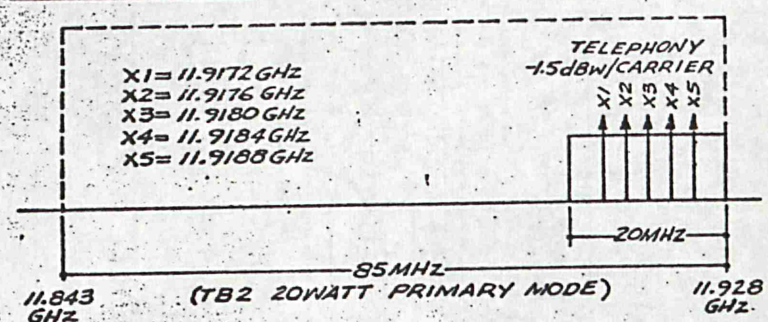
FREQUENCY PLAN

• TRANSMIT ANTENNA 2 200 WATT MODE

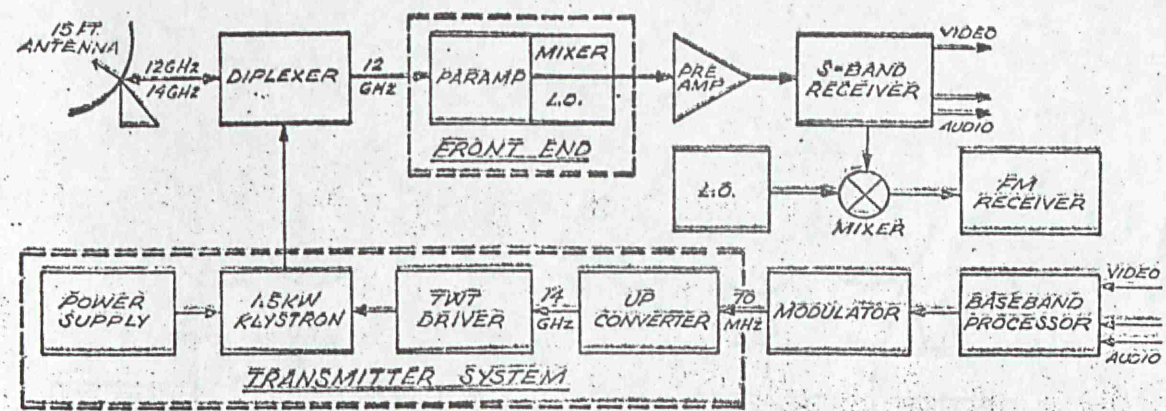


T1 = 12.1122 GHz
T2 = 12.1126 GHz
T3 = 12.1130 GHz
T4 = 12.1134 GHz
T5 = 12.1138 GHz

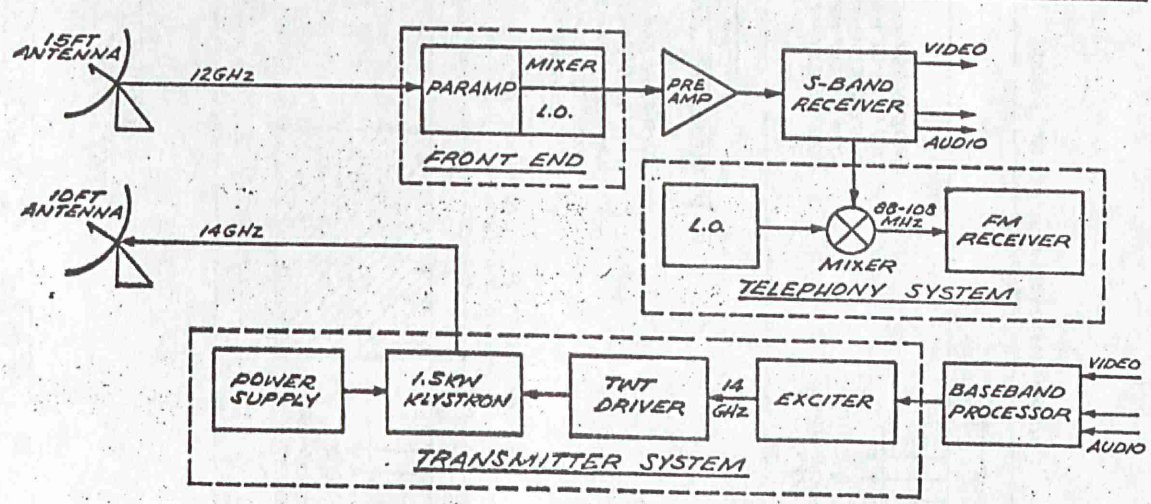
• TRANSMIT ANTENNA 1 20 WATT MODE



CLASS I LARGE TERMINAL
TRANSMIT & RECEIVE VIDEO/AUDIO SUBCARRIERS AND TELEPHONY

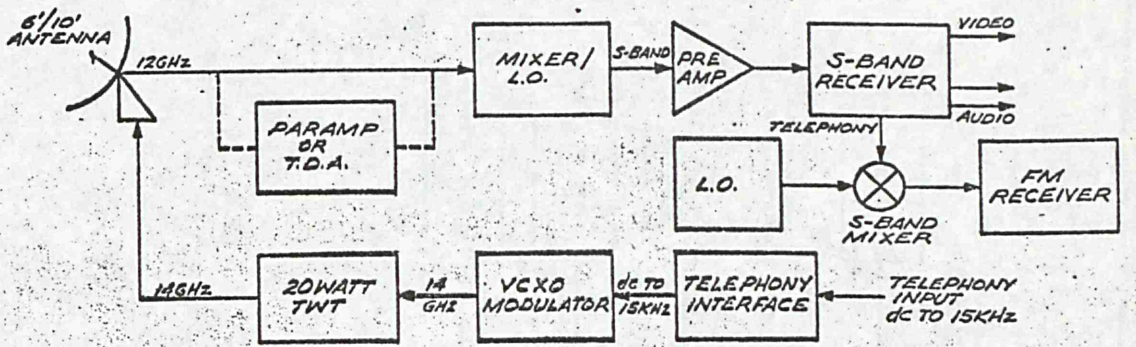


CLASS I-A LARGE TERMINAL
TRANSMIT & RECEIVE VIDEO/AUDIO SUBCARRIERS AND TELEPHONY



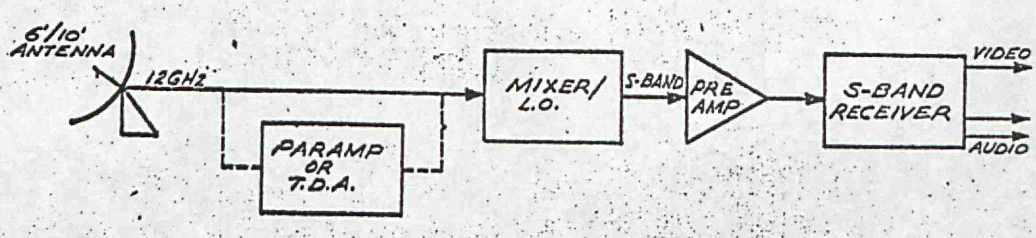
CLASS II SMALL TERMINAL

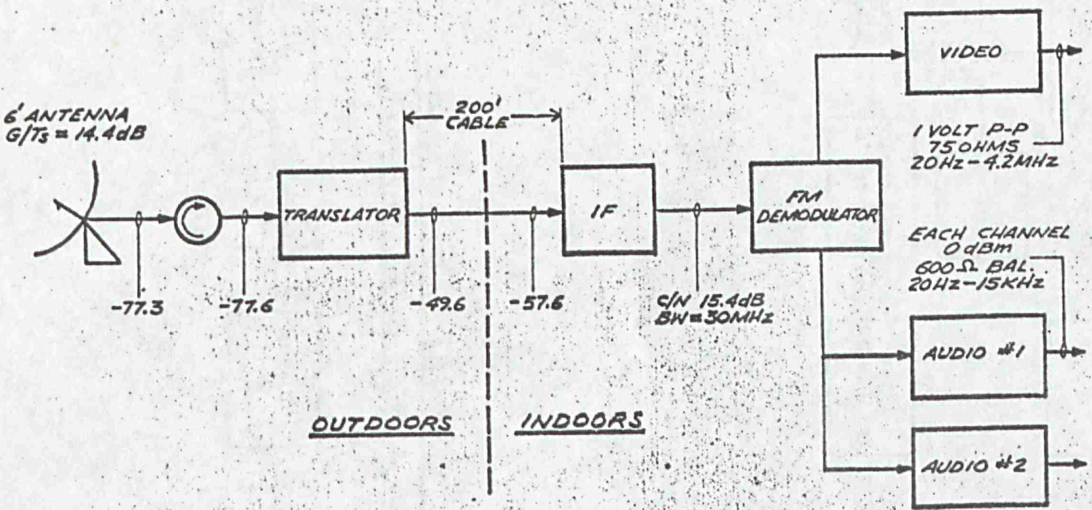
TRANSMIT TELEPHONY; RECEIVE VIDEO/AUDIO SUBCARRIERS & TELEPHONY



CLASS III SMALL TERMINAL

RECEIVE VIDEO/AUDIO SUBCARRIERS





SYSTEM LEVELS

APPENDIX D

GROUND MOBILE FORCES
EARTH SATELLITE COMMUNICATIONS SYSTEM

GROUND MOBILE FORCES EARTH SATELLITE COMMUNICATIONS SYSTEM
US ARMY SATELLITE COMMUNICATIONS AGENCY
FORT MONMOUTH, NEW JERSEY

DOMENIC L. LABANCA
CHIEF, SYSTEMS DEVELOPMENT OFFICE

31 OCTOBER 1975

Ground Mobile Forces Earth Satellite Communications System
US Army Satellite Communications Agency

Vugraph 1 - ON

The Ground Mobile Forces Satellite Communications System provides an answer to the problem of maintaining reliable communications when conventional means are limited by range, terrain, and frequency considerations.

A region as demanding as high mountains and large distances; surface features as varied as tropical rain forest , most often have an almost insiginficant effect on the systems performance. The flexibility of system configuration, by comparison to the line-of-sight radio relay or tropospheric scatter radio offers an advantage which in the Army environment becomes highly significant and very desirable.

The Ground Mobile Forces Satellite Communications System, commonly referred to as GMF satellite communications system, developed by the United States Army

Satellite Communications Agency (USASATCOMA) can be grouped into two broad categories. The first is characterized by a low data rate, usually half duplex netting communications operating in the UHF region of the frequency spectrum (225 to 400 MHz), and the second, a high data rate, full duplex multichannel trunking communications, operating in the SHF region

Vugraph 1 - OFF of the frequency spectrum (7250 to 8400 MHz).

Vugraph 2 - ON The first of the UHF family, a Manpack Terminal, is currently in development by Cincinnati Electronics Corporation. It is a highly advanced concept, expanding the state-of-the-art in satellite radio design. Its small size, 3.5x10x10 inches and light weight, 23 pounds with

Vugraph 2 - OFF batteries, make it ideally suited for one-man operation.

Vugraph 3 - ON The Manpack is capable of spanning the full UHF band in 5 KHz increments. It features a quick erect 6 dB antenna for its communication modes of push-to-talk

voice---clear or secure---and pre-structured burst transmissions. Paging can be received by whip antenna. The power output in the line-of-sight mode is limited to two watts; however, in the satellite mode it is raised to 35 watts. Conventional radio systems can be connected to the manpack by means of a wire interface, thereby increasing their range and scope of operations. A single satellite with earth coverage antenna can extend the

Vugraph 3 - OFF effective communications range out to 9,000 miles.

Vugraph 4 - ON The planned UHF Vehicular Radio will be available in two configurations-jeep mounted and installed in a S-250 shelter. The UHF Vehicular Radio will provide communications both in motion and at rest. Its major characteristics

Vugraph 4 - OFF are as follows:

Vugraph 5 - ON The set will communicate directly with the UHF Manpack in all the manpack modes. It can serve as a base station for netting many manpacks, or act as a net member in conjunction with other UHF Vehicular transceivers. It can also be used in the non-satellite line-of-sight mode.

In addition to the push-to-talk voice and pre-structured burst transmission communication modes, two other important modes of operation will be available. One; a spread-band anti-jam mode, and the other; a Time Division Multiple Access (TDMA) mode. These two modes will provide the UHF Vehicular Radio with the future satellite operational capabilities.

The data rates available in the UHF Vehicular Radio will be from 75 bits per second for teletype, through the intermediate rates of TOS, TACFIRE, and ARTADS up to 16K bits per second for secure voice, using PSK modulation.

During operation in-motion, an omnidirectional circularly polarized antenna will be used, while at rest a specially designed compact 9 dB gain atenna is planned. The set will incorporate the standard radio wire interface

and will be able to operate from either 28 volt DC vehicular battery or 115 volt, 60 cycle AC. Power output to the antenna in the satellite mode will be 100 watts and in the line-of-sight mode--20 watts.

Vugraph 5 - OFF

The UHF Manpack and the UHF Vehicular Radio Set are designed to operate with the interim GAPSAT Satellite System and later with future satellites such as FLEETSAT and AFSAT.

The second category of the GMF Satellite Communications Systems are the tactical multichannel satellite terminals, the AN/MSC-59 and AN/TSC-85. Both type terminals are full duplex, multichannel, secure, high data rate systems, produced by RCA. A high degree of subsystem commonality has been achieved in the terminal designs which should result in lowered logistic support costs and simplified training. All terminals operate with existing Army type multiplex equipment operating at 48 kilobits per second per voice channel.

Vugraph 6 - ON

The AN/MSC-59 is a 100 watt, trailer-mounted SHF Multichannel terminal. It incorporates a complete non-redundant communications facility with both baseband and radio equipment. While it has the capability of operating over a wide range of data rates, it is intended for transmission of 6 or 12 full fuplex voice channels with a TD-660 multiplexer. Power is furnished by redundant 3 kw generators. An 8 foot diameter parabolic antenna is mounted on top of the terminal trailer, and a trained crew of three men can install the terminal in about 20 minutes under good conditions.

Vugraph 6 - OFF

Vugraph 7 - ON

The AN/TSC-85 SHF Multichannel Terminal is mounted on a 1-1/4 ton truck. It can handle medium and high capacity voice, data and teletype traffic. The terminal is fully redundant, except for the 8 foot diameter parabolic antenna. Power is furnished by a 10 kw turbo-alternator mounted on a trailer.

The AN/TSC-85 SHF Terminal comes in two versions, called (V)1 and (V)2. The (V)1 version is a point-to-point, also called non-nodal terminal. The (V)2 version is a multipoint or nodal terminal, capable of simultaneously communicating with up to four other (V)1 terminals. Both versions have a capacity for accommodating up to 96 voice channels when operated at higher data rates in conjunction with the Tactical Signal Speech Processor (TSSP).

A separate secure single voice channel at 16 kilobits per second is available for use with Saville applique. The AN/TSC-85 is a 500 watt satellite terminal which can be deployed by a trained four-man crew in about 20 minutes under good conditions.

Vugraph 7 - OFF

Both the AN/MSC-59 and the AN/TSC-85 terminals are currently undergoing operational testing in accordance with the Army's coordinated Test Program.

It is planned to operate both versions of the AN/TSC-85 and the AN/MSC-59 SHF Terminals with the narrowbeam antennas on the Defense Satellite Communication System spacecraft and other SHF satellites. The present Phase II satellites are located in Geostationary orbits above the Atlantic and Pacific Oceans, respectively. The steerable narrowbeam antennas illuminate an area of approximately 1,000 miles diameter on the earth's surface, within the 9,000 mile diameter viewing area of each satellite.

Vugraph 8 - ON

In addition to the communication terminals, a SHF control terminal is planned. This control facility will monitor the technical performance of the GMF Satellite Communications network on a real time basis using manual and processor controlled automatic spectrum analyzers. It provides initial planning and allocation for the GMF network, insures proper set-up and calibration of each remote terminal and provides a constant monitoring function during system operation.

Vugraph 8 - OFF

The GMF satellite communication terminals briefly

described here will be dispersed throughout a tactical area in an integrated communications network. The SHF group will share a common satellite transponder. It is estimated that a traffic load of as many as 100 to 150 terminals may access the satellite at any given time. For efficient operation, this will require use of a well regulated multiple access method. The usual approaches are: frequency division, time division, and code division.

Vugraph 9 - ON

Looking at Frequency Division Multiple Access (FDMA), the satellite repeater bandwidth is divided into a number of frequency bands and these frequencies are then assigned to the operating terminals. In this way each terminal is assigned a unique frequency for transmission to and from the satellite. The system drawbacks are the need for careful power control and the relatively inefficient use of satellite radiated power. Because of system simplicity, however, this is the method of multiple access to be used initially with the SHF, GMF system.

Vugraph 9 - OFF

Vugraph 10 - ON

The second method is Time Division Multiple Access (TDMA). This method allows one terminal at a time to access the satellite. The result is a system efficiency improvement over the FDMA method, but where the problem of uplink power control is traded in favor of a time coordinated system.

Vugraph 10 - OFF

Vugraph 11 - ON

The third multiple access method is Code Division using pseudonoise or other spread band techniques. It does not lend itself well to high data rate systems; its most common application is in anti-jamming.

Vugraph 11 - OFF

The US Army SATCOM Agency was assigned the task of developing a more efficient method of multiple access for the GMF Satellite Communication System operating in the SHF band. The method being considered is a Demand Assigned Multiple Access system.

Vugraph 12 - ON

The system is intended to provide a satellite access to a terminal on demand rather than on a fixed assigned basis.

It can be used in conjunction with the three previously mentioned methods, however, the most efficient combination is when used with the Time Division Multiple Access method, as illustrated here.

The Demand Assigned Multiple Access scheme takes advantage of the light loading requirements for some users serviced by the system.

In a preassigned system, a user is given a full time transmission channel regardless of his duty factor. In demand assigned systems, the channel is provided only when requested, therefore, that one channel can be shared in time by many users.

The specifics of the system being evolved include single channel per burst operation at both 16 and 32 kilobits/sec channel rates, up to 40 megabits/sec burst rate, bulk encryption and decentralized system control.

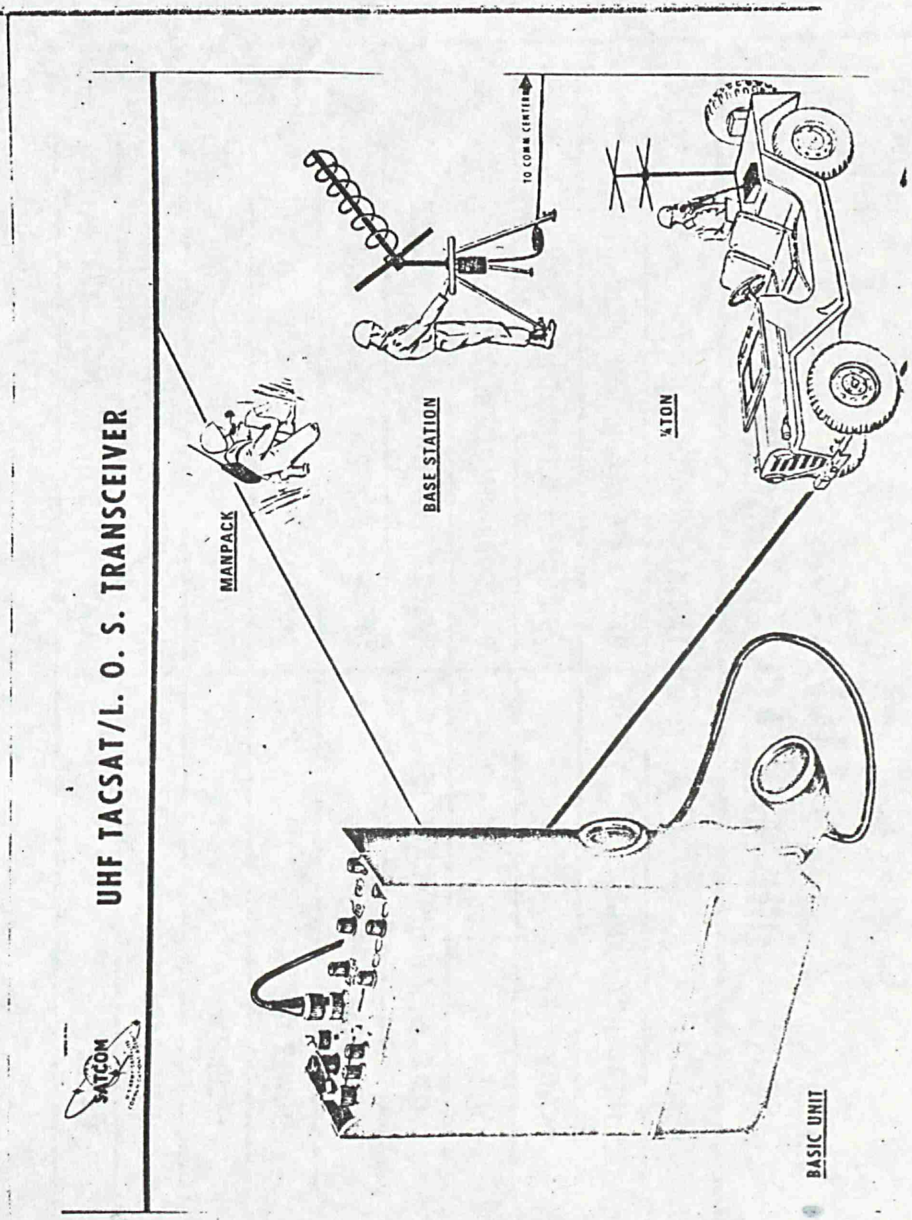
Vugraph 12 - OFF

Vugraph 1 - ON

The design of the Demand Assigned/TDMA system is based on compatibility of operation within both the TRI-TAC land based and naval switch systems in terms of expected traffic models and communication parameters.

These then are the essential elements of the Ground Mobile Forces Earth Satellite Communications Systems. They are expected to provide reliable worldwide or local communications capability in the diverse environmental conditions encountered by the tactical communicator.

Vugraph 1 - OFF



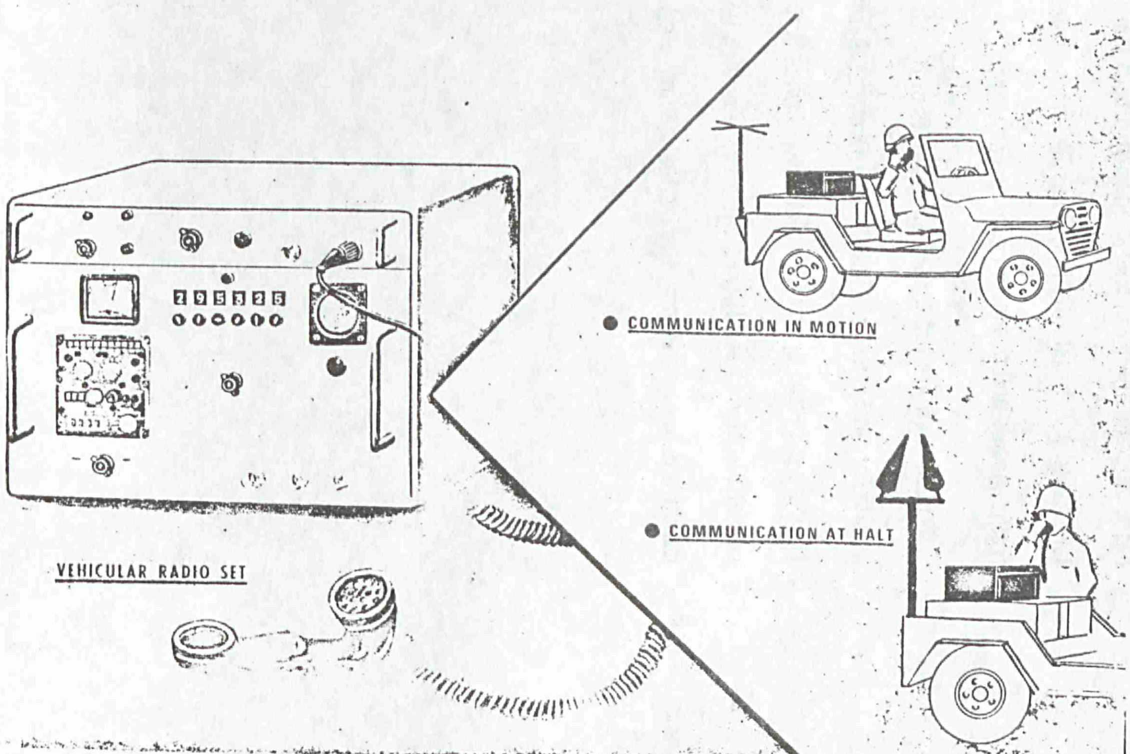
SATCOM
U.S. ARMY SATELLITE COMMUNICATIONS AGENCY

TACSATCOM
UHF MANPACK TRANSCEIVER

MODES	TACSAT AND LOS
FREQUENCY RANGE	225 TO 400MHz (5 KHz INCREMENTS)
WEIGHT	25 POUNDS MAX WITH BATTERY
SIZE	300 CUBIC INCHES MAX
COMMUNICATIONS FUNCTIONS	HALF DUPLEX VOICE, BURST, PAGING
ANTENNAS	12" ROD AND DEPLOYABLE YAGI
POWER OUTPUT	35 WATTS
SECURITY	SAVILLE
INTERFACE	RADIO WIRE
RANGE	CONTINUOUS UP TO 9000 MILES

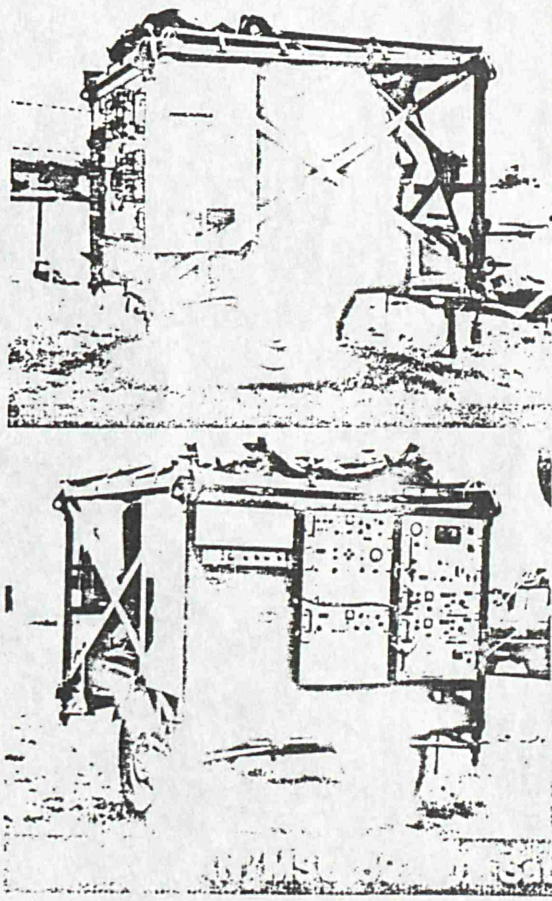
SATCOM
U.S. ARMY SATELLITE COMMUNICATIONS AGENCY

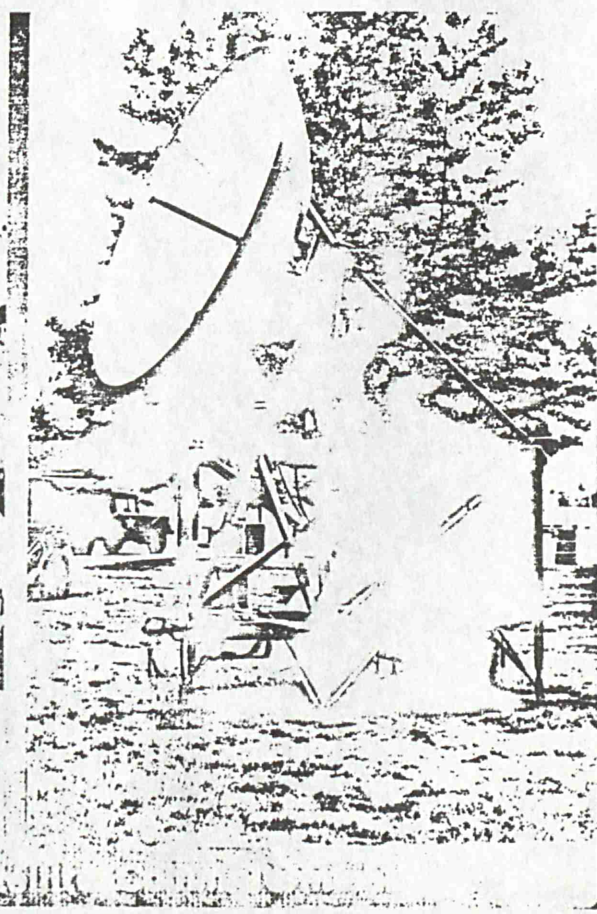
UHF TACSAT VEHICULAR RADIO SET

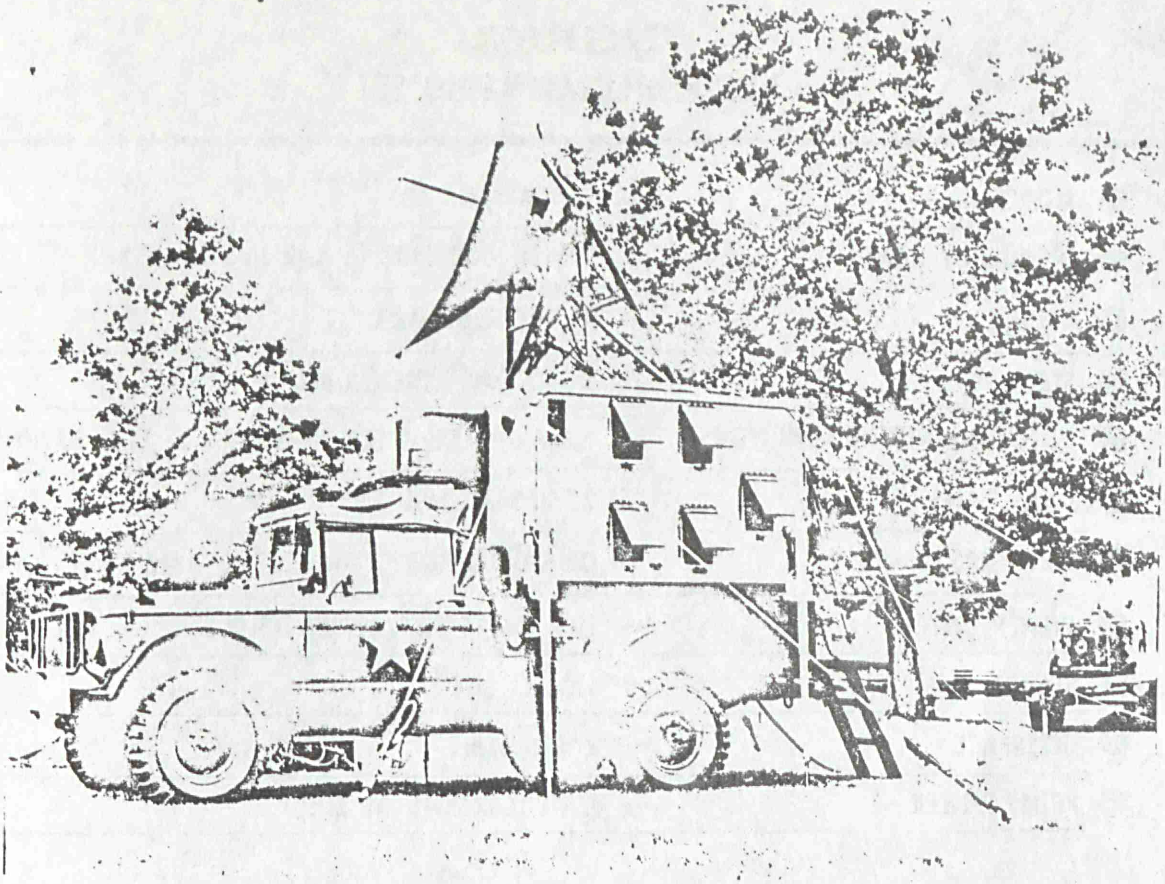


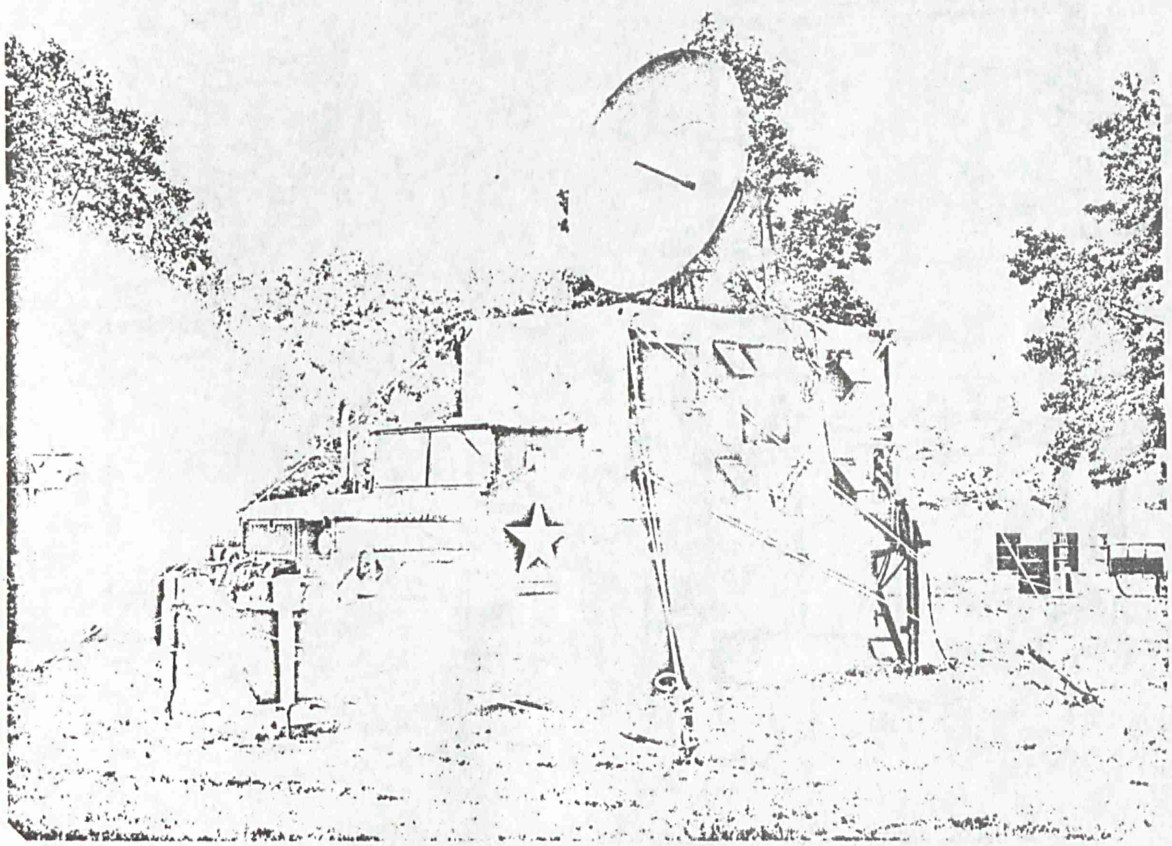
TACSATCOM
UHF VEHICULAR RADIO SET

MODES	— TACSAT AND LOS
FREQUENCY RANGE	— 225 TO 400 MHZ (5 KHZ INCREMENTS)
WEIGHT	— 115 POUNDS MAX
SIZE	— 6600 CUBIC INCHES MAX
COMMUNICATIONS FUNCTIONS	— HALF DUPLEX VOICE BURST, DATA, TTY, PAGING
DATA RATES	— 75 BPS TO 16.0 KBPS
ANTENNAS	— OMNIDIRECTIONAL AND DEPLOYABLE YAGI
POWER OUTPUT	— 100 WATTS SAT/20 WATTS LOS
SECURITY	— SAVILLE
INTERFACE	— RADIO WIRE
PRIME POWER	— VEHICULAR AND AC LINE



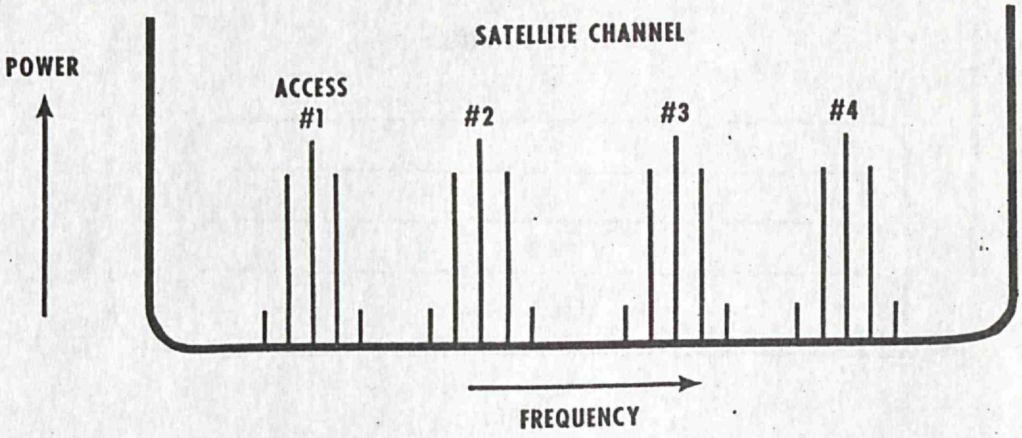






MULTIPLE ACCESS METHODS

FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)



ADVANTAGES

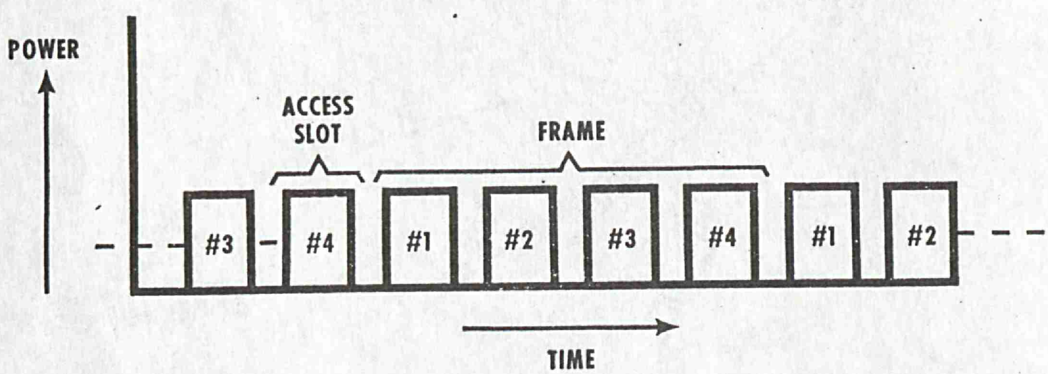
- SIMPLE TUNING OF RECEIVERS
- NETWORK TIMING NOT REQUIRED
- COMPATIBLE WITH EXISTING HARDWARE

DISADVANTAGES

- INTERMODULATION PRODUCTS CAUSE DISTORTION AND POWER LOSS
- POWER CONTROL IS NECESSARY
- VULNERABLE TO RFI

MULTIPLE ACCESS METHODS

TIME DIVISION MULTIPLE ACCESS (TDMA)



ADVANTAGES

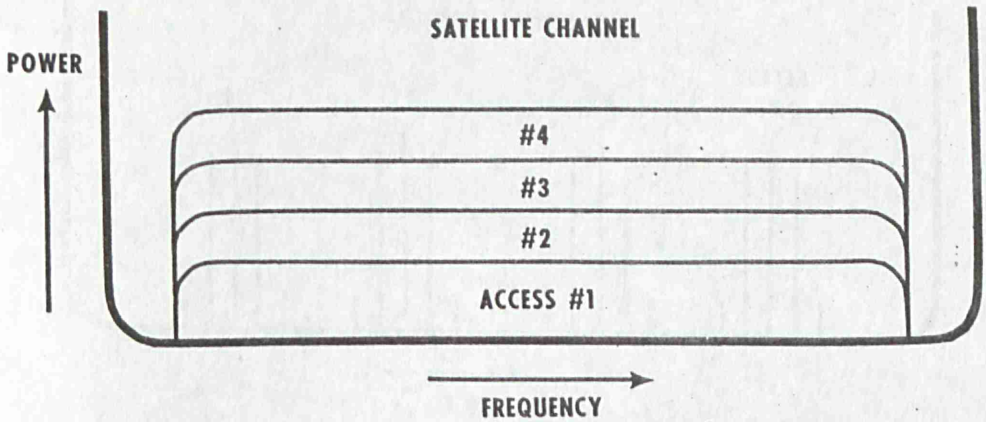
- NO MUTUAL INTERFERENCE BETWEEN ACCESSES
- NO POWER CONTROL REQUIRED
- POTENTIALLY MOST EFFICIENT SYSTEM

DISADVANTAGES

- REQUIRES NETWORK TIMING
- REQUIRES SYSTEM DISCIPLINE
- VULNERABLE TO SELECTIVE RFI (UNLESS TIME SLOTS ARE SCRAMBLED)

MULTIPLE ACCESS METHODS

CODE DIVISION MULTIPLE ACCESS (CDMA)



ADVANTAGES

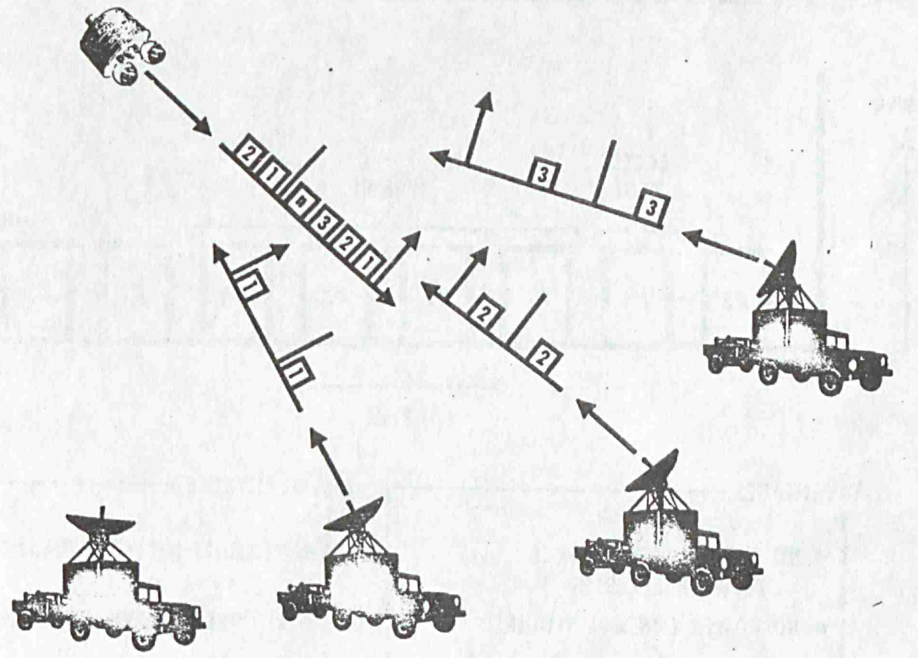
- RFI CAPABILITY
- NETWORK TIMING NOT REQUIRED
- TRAFFIC ANALYSIS NOT POSSIBLE

DISADVANTAGES

- WIDE BANDWIDTH OCCUPANCY PER USER
- REQUIRES LINK ACQUISITION AND SYNCHRONIZATION
- POWER CONTROL NECESSARY FOR EFFICIENT MULTIPLE ACCESS

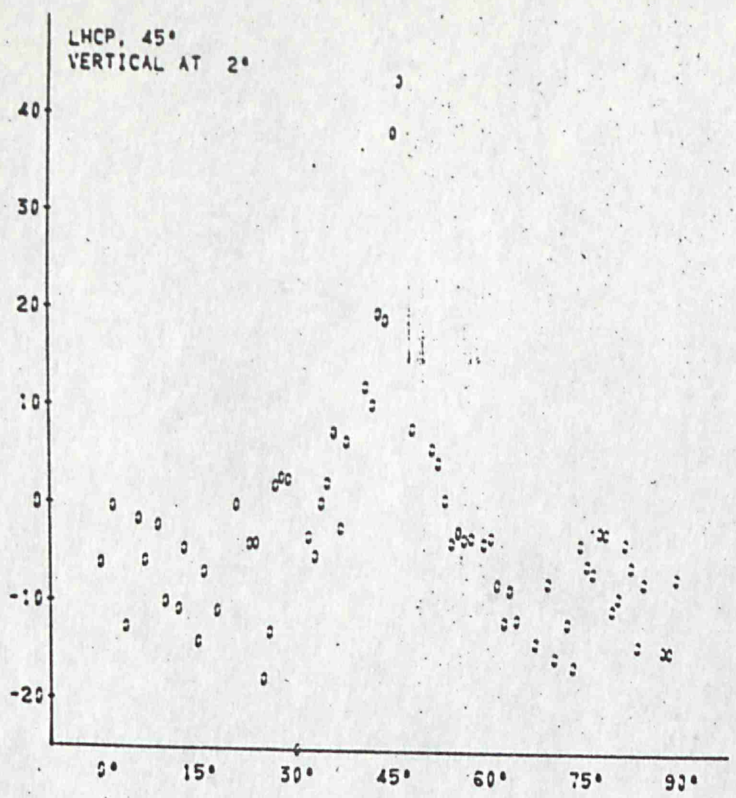
DEMAND ASSIGNED MULTIPLE ACCESS (DAMA)

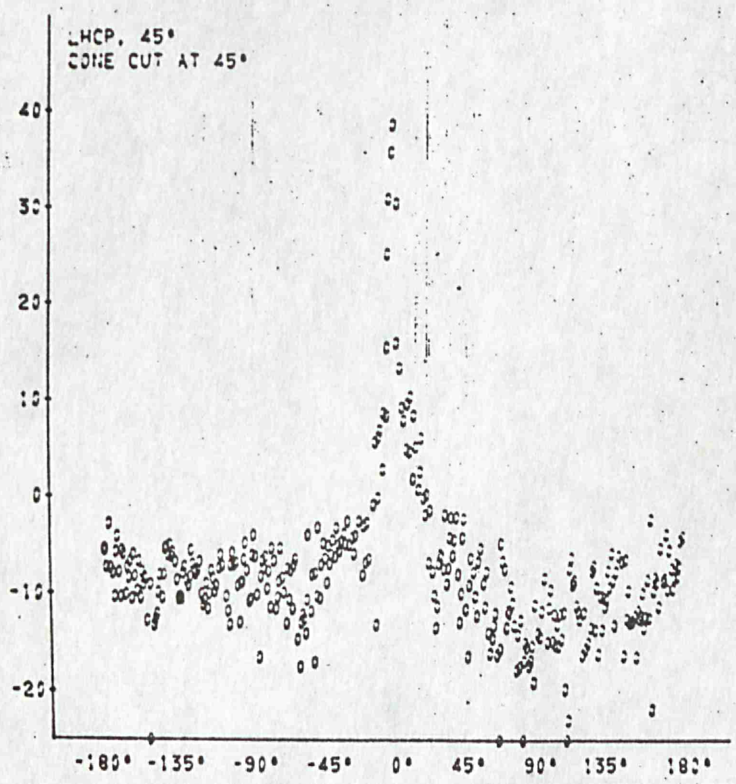
TIME DIVISION MULTIPLE ACCESS (TDMA)

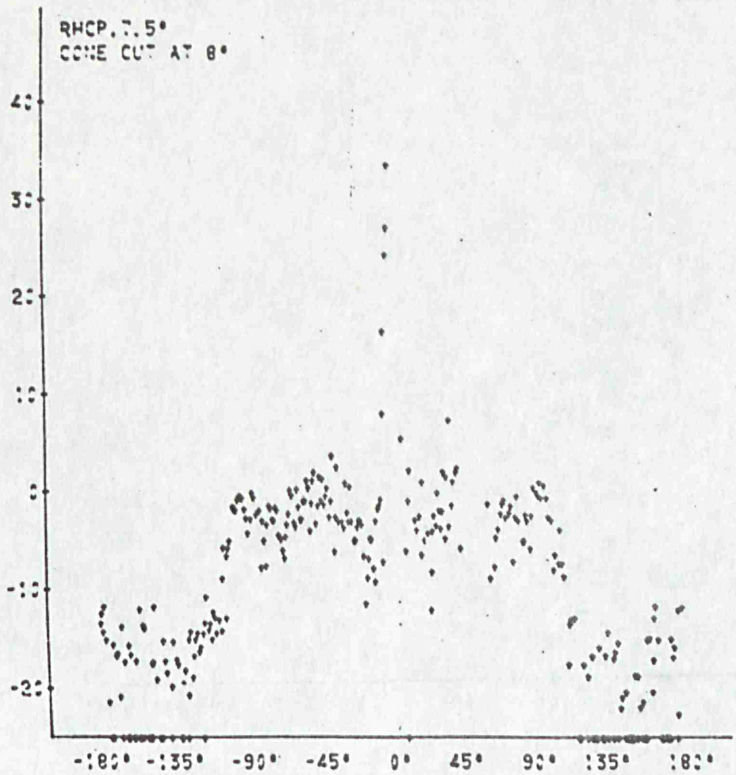


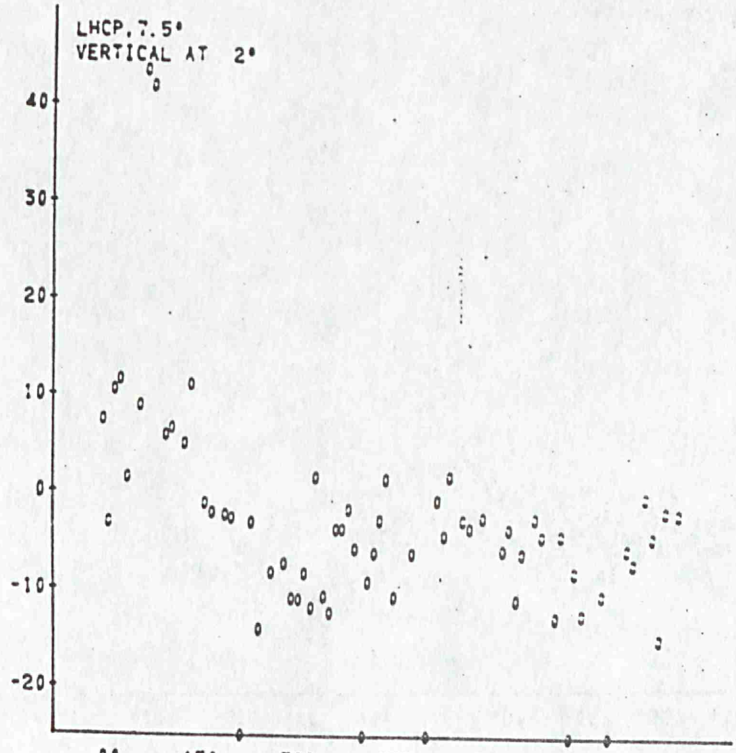
APPENDIX E

ANTENNA PATTERN MEASUREMENTS OF ARMY SMALL TERMINALS


LHCP, 45°
VERTICAL AT 2°
40
30
20
10
0
-10
-20
0°
15°
30°
45°
60°
75°
90°


LHCP, 45°
CONE CUT AT 45°
40
30
20
10
0
-10
-20
-180°
-135°
-90°
-45°
0°
45°
90°
135°
180°


RHCP,7.5°
CONE CUT AT 8°
40
30
20
10
0
-10
-20
-180° -135° -90° -45° 0° 45° 90° 135° 180°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VERTICAL AT 2°
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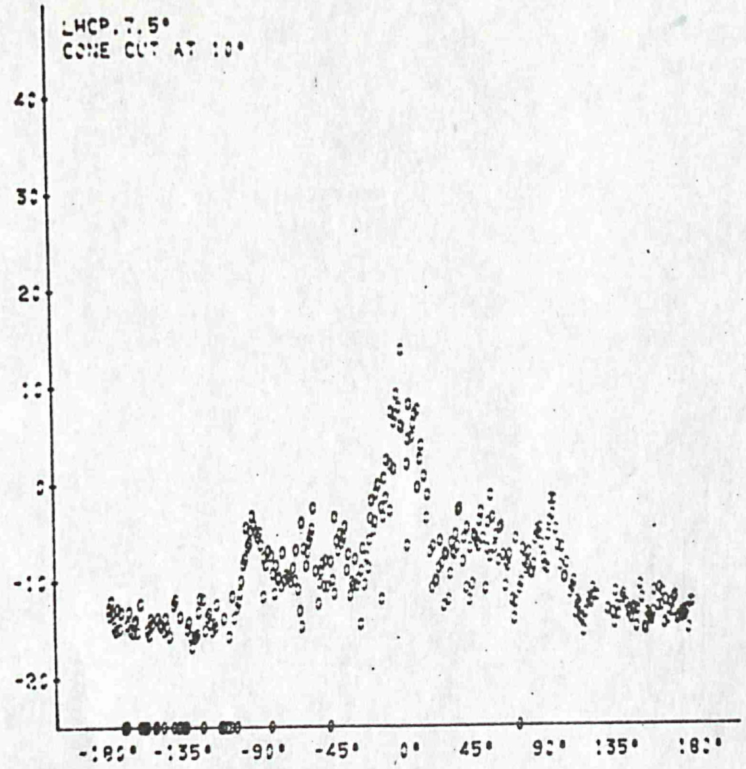
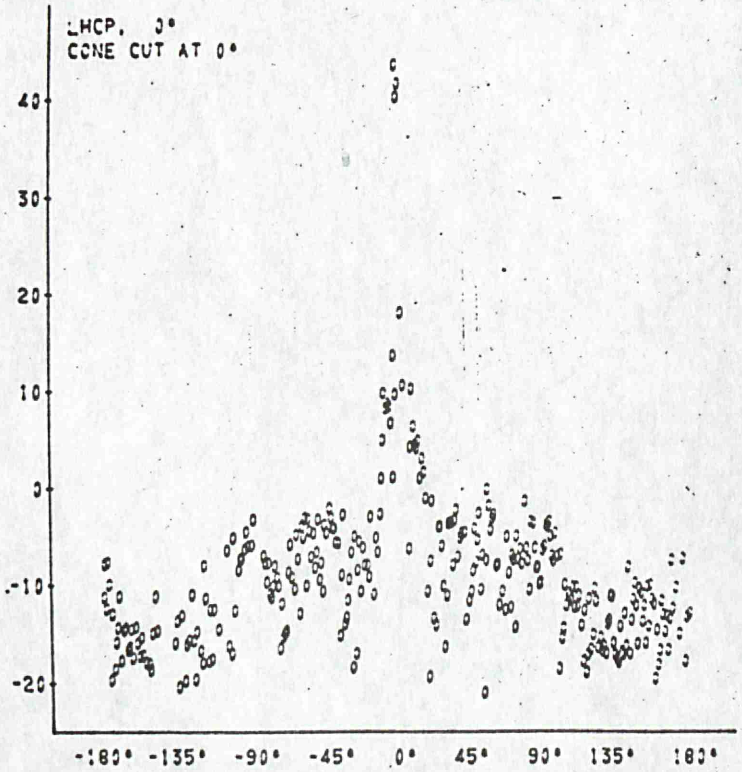
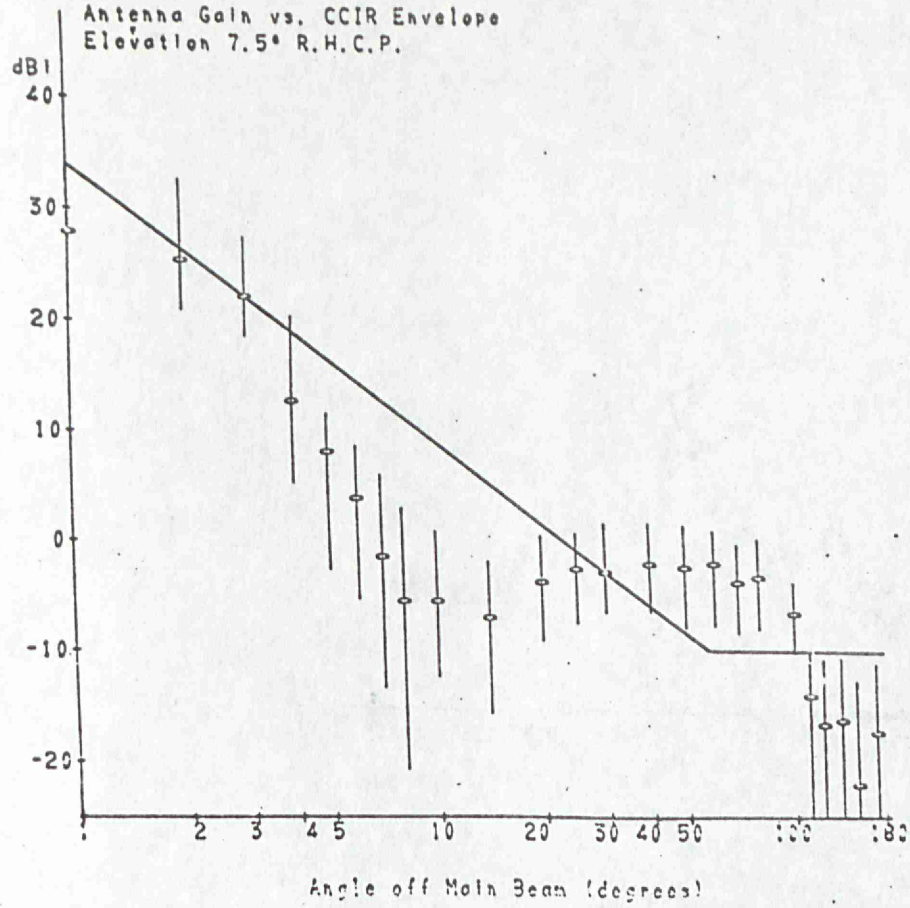
30
20
10
0
-10
-20
0° 15° 30° 45° 60° 75° 90°

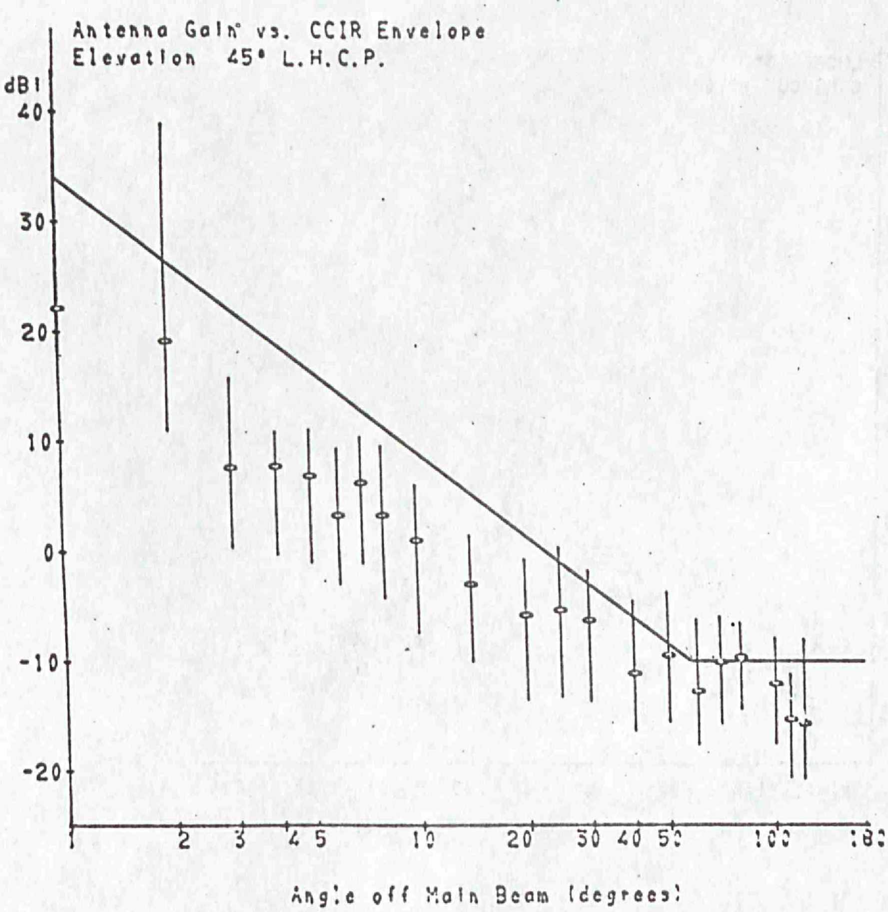


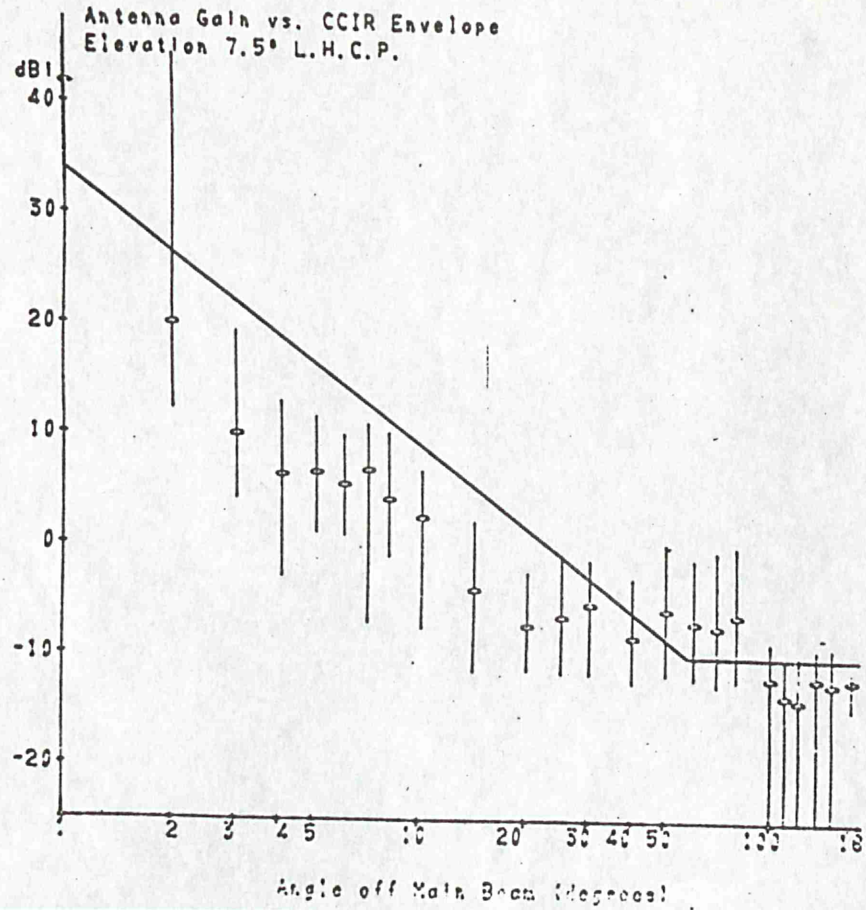
LHCP, 7.5°
CONE CUT AT 10°
40
30
20
10
0
-10
-20
-180° -135° -90° -45° 0° 45° 90° 135° 180°

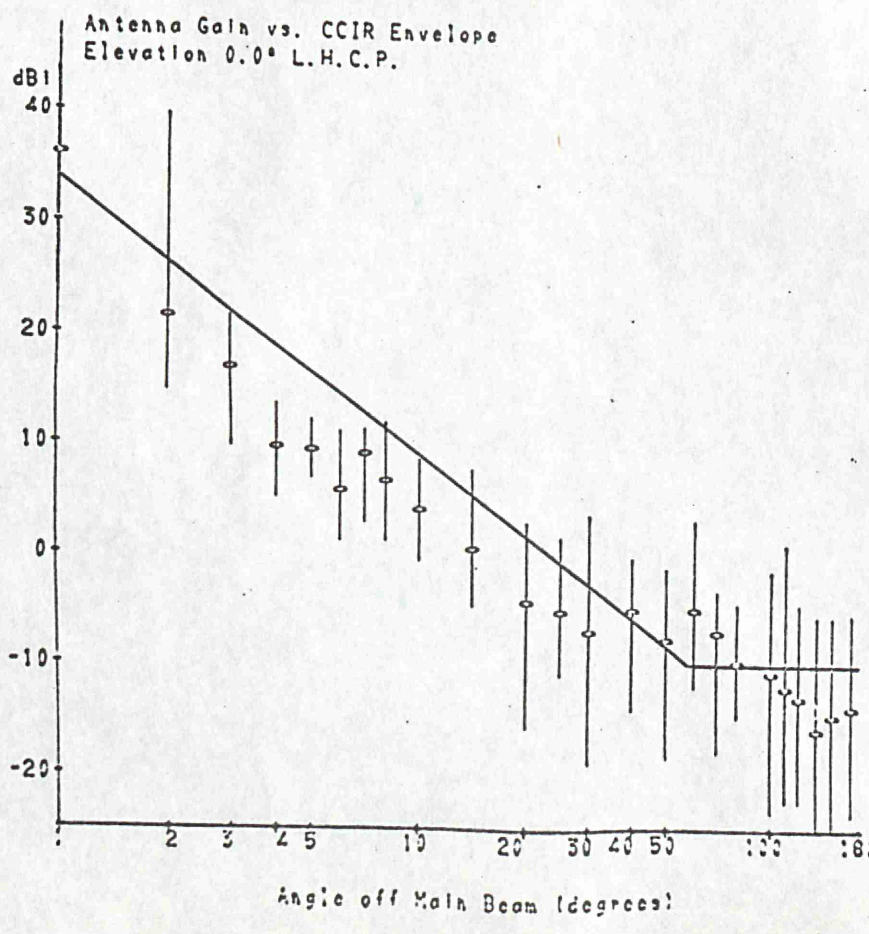


LHCP, 0°
CONE CUT AT 0°
40
30
20
10
0
-10
-20
-180° -135° -90° -45° 0° 45° 90° 135° 180°


Antenna Gain vs. CCIR Envelope
Elevation 7.5° R.H.C.P.
dBi
40
30
20
10
0
-10
-20
1
2
3
4 5
10
20
30 40 50
100
180
Angle off Main Beam (degrees)


Antenna Gain vs. CCIR Envelope
Elevation 45° L.H.C.P.
dBi
40
30
20
10
0
-10
-20
1
2
3
4 5
10
20
30 40 50
100
180
Angle off Main Beam (degrees)


Antenna Gain vs. CCIR Envelope
Elevation 7.5° L.H.C.P.
dBi
40
30
20
10
0
-10
-20
1
2
3
4 5
10
20
30 40 50
100
180
Angle off Main Beam (degrees)


Antenna Gain vs. CCIR Envelope
Elevation 0.0° L.H.C.P.
dBi
40
30
20
10
0
-10
-20
1
2
3
4 5
10
20
30 40 50
100
180
Angle off Main Beam (degrees)

APPENDIX F

U.S. ARMY CORPS OF ENGINEERS
DATA COLLECTION

U. S. ARMY CORPS OF ENGINEERS SATELLITE DATA COLLECTION [1]

As most of you may know, the Corps Civil Works Directorate is primarily involved in water resources development and management. Typical projects include reservoir operations for flood control, hydropower generation, navigation, water supply, water quality, recreation, etc.

To effectively manage these projects we need reliable and timely information on hydrologic data within the watersheds in which our projects are located. Many hydrologic data that we are most concerned with are precipitation, reservoir level, river stage, snow cover and water quality. A good number of these data are collected at remote sites where access is generally difficult.

Conventionally, these hydrologic data are collected and transmitted by either telephone lines and/or ground-based radio relay from gaging stations to a regional control center. Data received almost instantaneously provides the basis for implementing management decisions during periods of critical flooding.

Unfortunately such communication is either subject to interruption by natural disasters or disadvantages related to distance and type of terrain. Installation and maintenance of equipment servicing remote reaches of rivers in hilly terrain are costly because of the large number of relays and repeaters necessary to transmit the radio signals to central control facility.

During the past 2 years the Corps has been experimenting in the use of satellite data communication systems. The New England Division of the Corps has been evaluating the utility of the ERTS (LANDSATS) data communication system. Twenty-seven platforms have been operating in parallel with the 41 station ground-based Automatic Hydrologic Radio Reporting Network which is the present backbone for flood control reservoir regulation activities in the Division.

The ERTS data originates from gages at key river locations. Each gage senses the stage of the river it is measuring and relays the readings to a NASA-operated ground receiving station at Greenbelt, Maryland which teletypes the data into the New England Division.

An ERTS data collection platform transmits a signal every 3 minutes. At mid-latitude locations the orbital path provides 4 to 6 daily opportunities for data transmission.

[1] Material presented to the Joint Session IRAC/CCIR, 31 Oct 75, Wash DC by M. Tseng

To transmit the data from Greenbelt, Maryland to Waltham, Massachusetts it generally takes about 45 minutes. Considering 4 daily passages of the satellite over the gaging stations, we will have the situation of getting data once in about every 6-7 hours. For flood fighting such a data frequency is often inadequate. We generally need to have real time data at more frequent intervals.

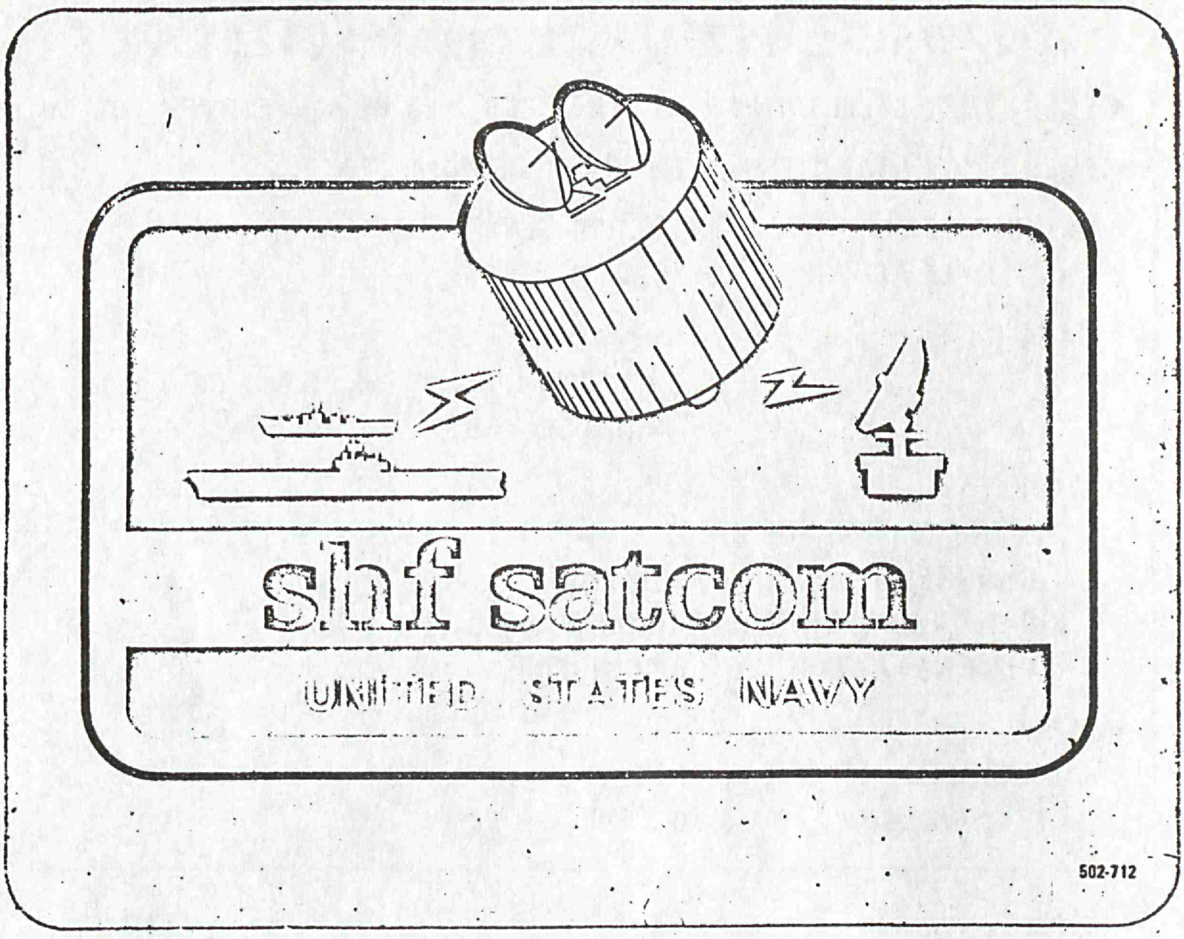
Recently our NED has constructed a ground receiving station at Waltham, Massachusetts for direct data acquisition from the satellite. This is an experiment and is in cooperation with NASA. This will remove all ground transmission problems that can occur with teletype relay between NASA and Waltham. This is a 15-foot dish antenna equipped with mini computer for tracking satellites and data processing. The system is in pseudo-operation condition.

Elsewhere our Lower Mississippi Valley Division in cooperation with NASA's National Space Technology Lab. at Bay St. Louis, Mississippi is involved in a program for development of satellite ground receiving stations at Vicksburg, Mississippi. A 30-foot dish antenna will be installed to receive data from 55 DCP's within the Mississippi River Basin. Both LANDSATS and GOES systems will be used in the experimental program. Data frequency of once in every 4 hours is anticipated.

Over the next 5 years we anticipate nearly 4,500 data collection locations will be needed Corps-wide for relay of hydrologic information for water management activities.

APPENDIX G

SHF SATCOM, UNITED STATES NAVY



AN/WSC-2(V)

SHIPBOARD SATCOM SET

X32-94 20 FEB 75

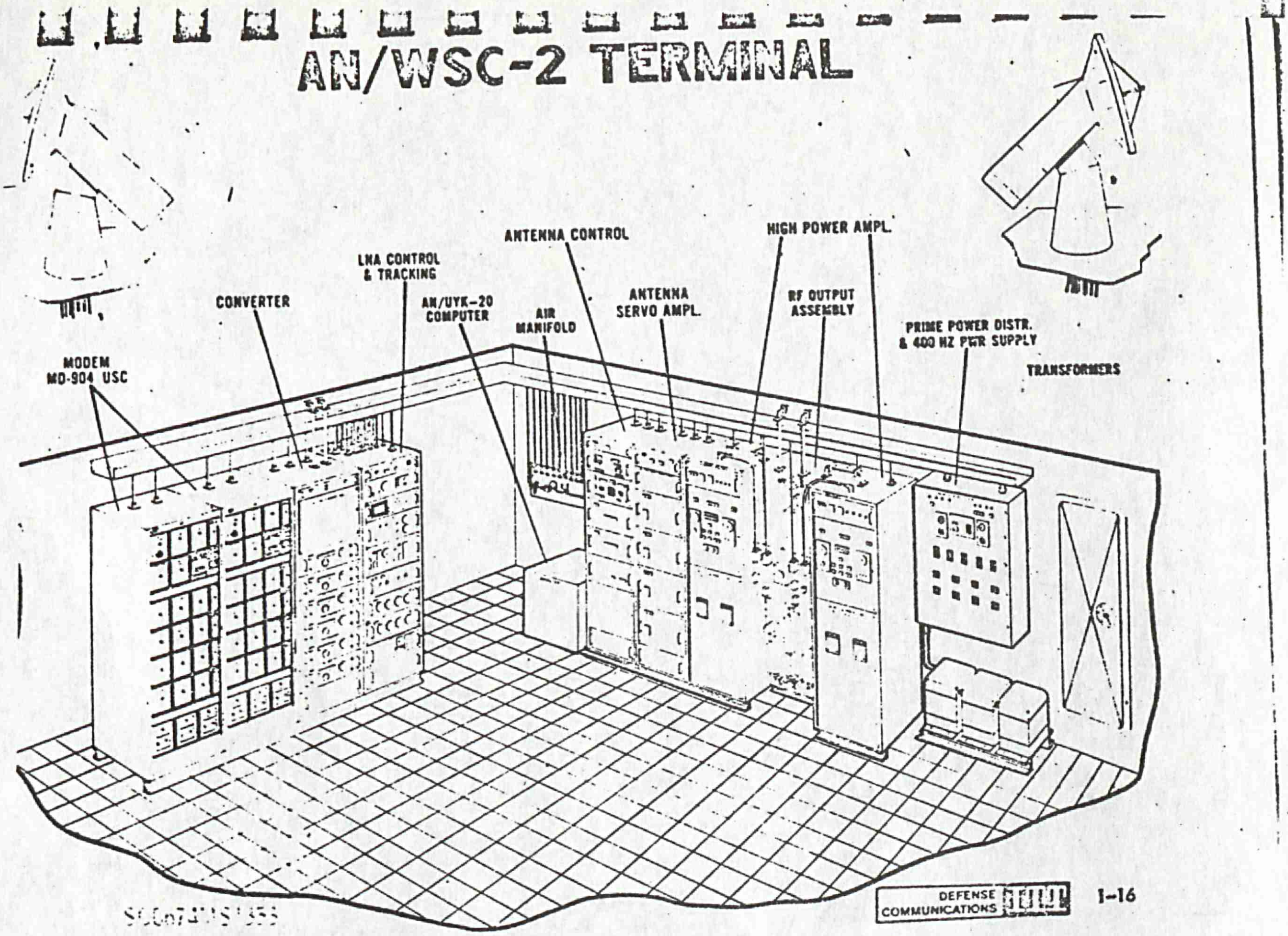
AN/WSC-2 TERMINAL CHARACTERISTICS

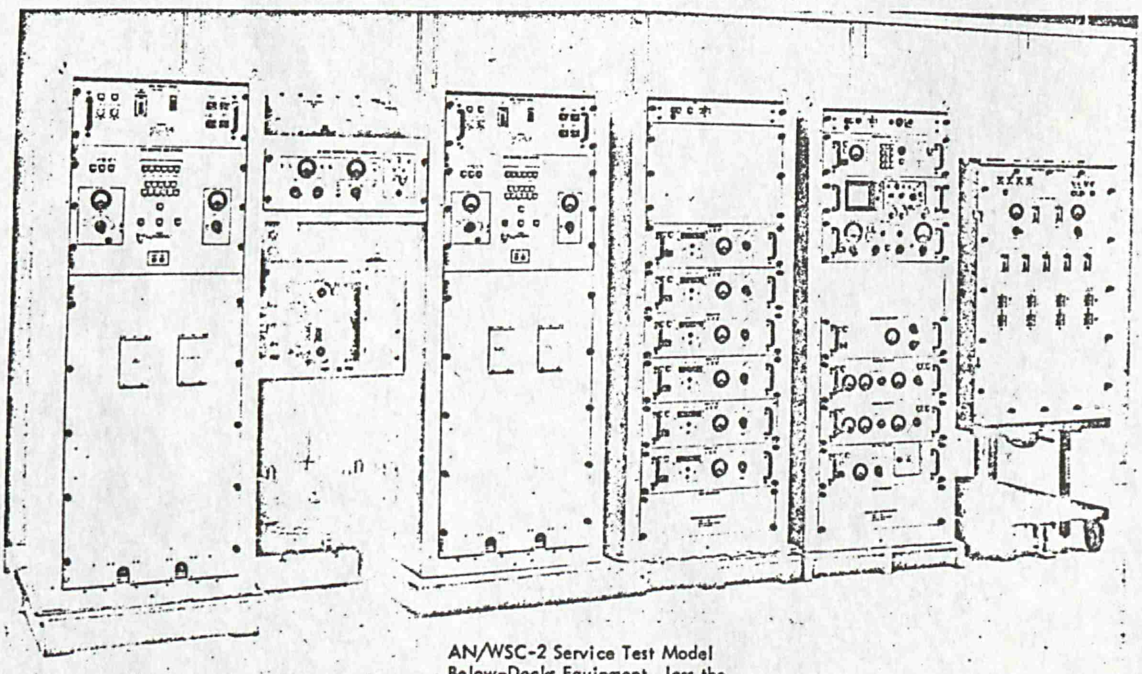
• FREQUENCY SELECTIVITY	SYNTHESIZER – 10 Hz STEPS OVER 500 MHz
• FREQUENCY STABILITY	1×10^{-11} CESIUM STD
• MODULATION	SPREAD SPECTRUM PSK
MULTIPLE ACCESS	TDMA & CDMA
• DATA RATES	75 bps
	1.2, 2.4, 4.0, 4.8, 9.6, 16.0 & 32.0 kbps
	ANALOG VOICE
• MTBF	
AN/WSC-2 (FOR 1 OF 2 CHANNELS)	1000 HRS
MD-904/USC (FOR MAIN FRAME WITH 6 CHANNEL UNITS)	1000 HRS
• MTTR	
AN/WSC-2	1 HR
MD-904/USC	0.5 HR

X32-94 20 FEB 75

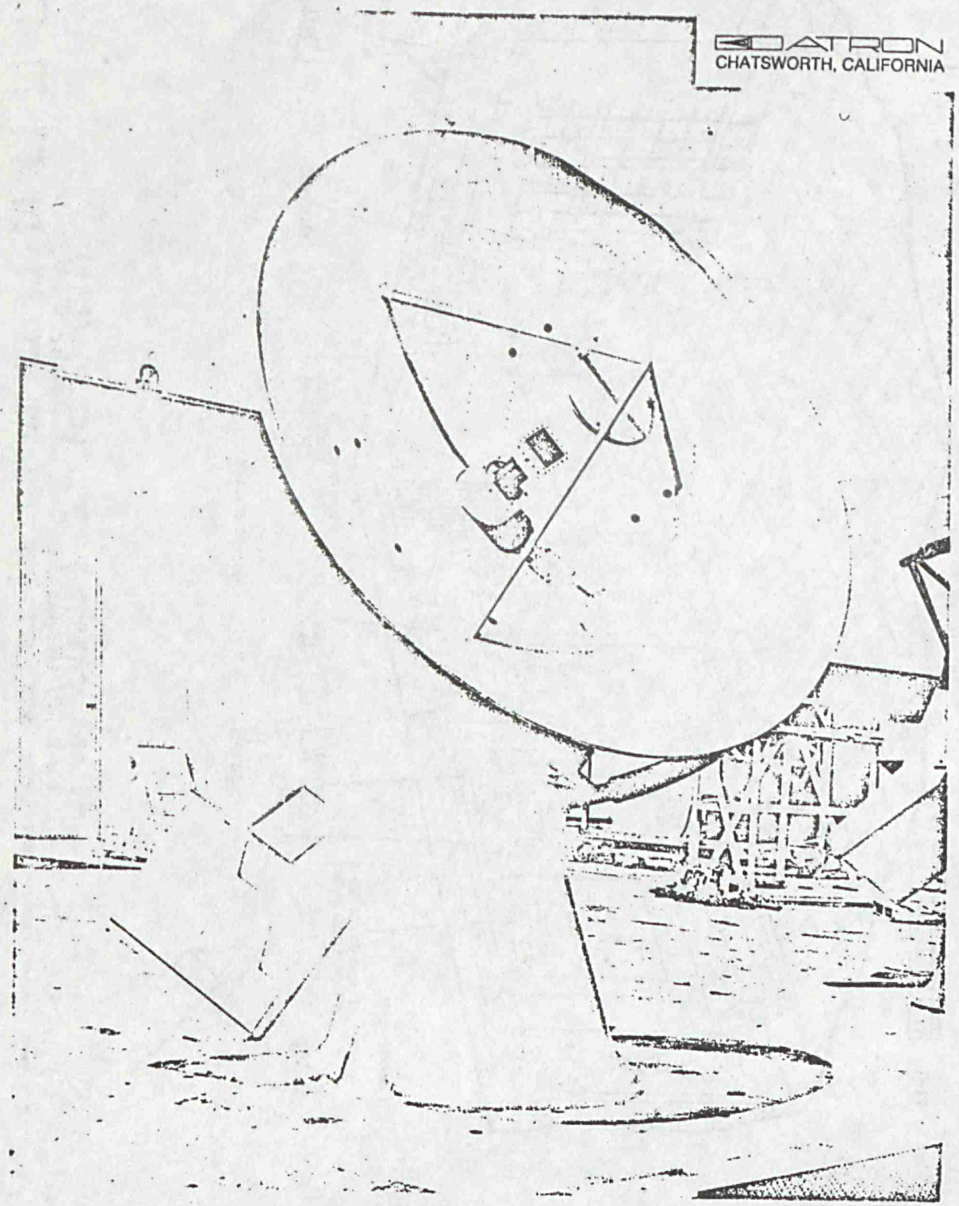
AN/WSC-2 TERMINAL CHARACTERISTICS

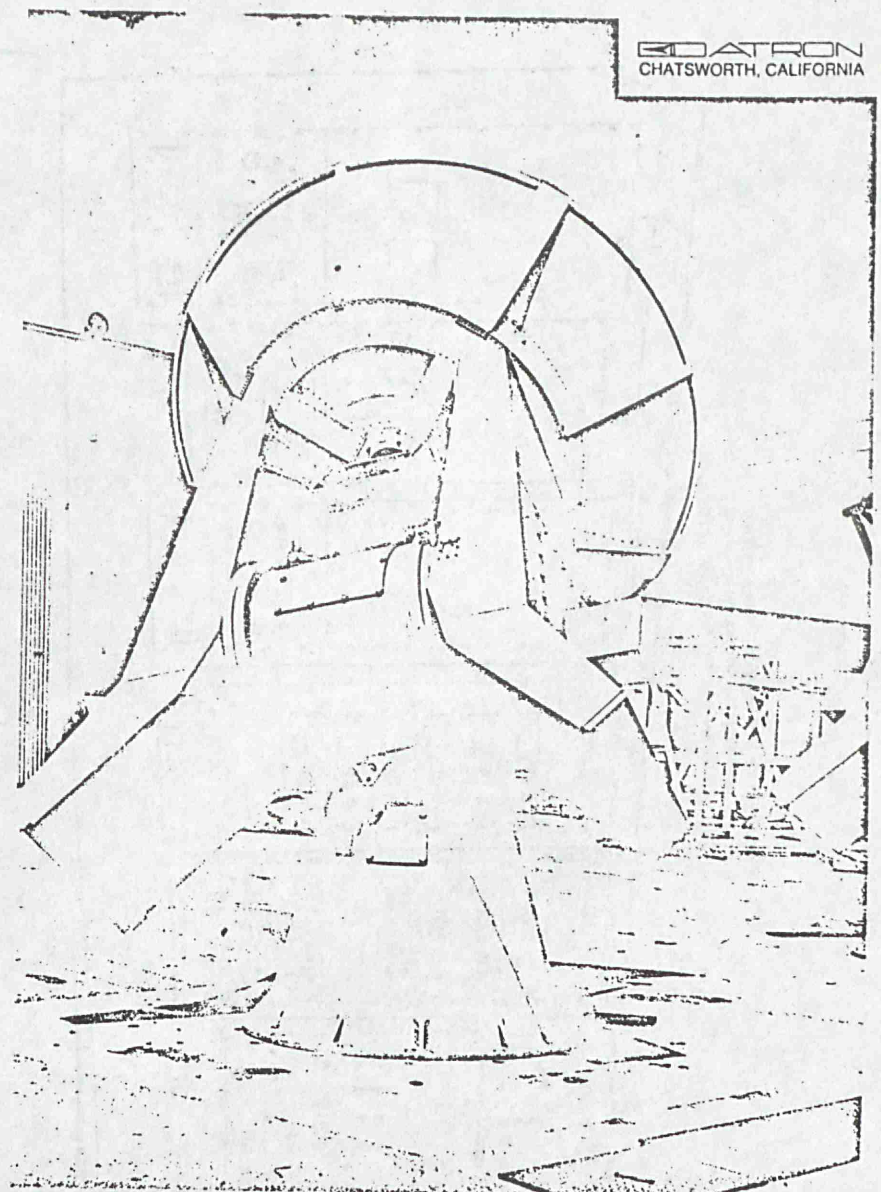
• ANTENNAS	DUAL 2-AXIS 8 FT CASSEGRAIN OR DUAL 2-AXIS 4 FT CASSEGRAIN
• OPERATION WITH SHIP MOTION	
FULL HEMISPHERIC COVERAGE	SEA STATE 5
DEGRADED COVERAGE	SEA STATE 7
• TRACKING	BEACON TRACK WITH PHASE LOCK LOOP RECEIVERS - DOPPLER DERIVATION INCLUDED
• RECEIVER BANDWITH (PARAMETRIC AMPLIFIER)	500 MHz
• IF INTERFACE	70 MHz – 700 MHz
BANDWIDTH	2 MHz – 60 MHz
• TRANSMITTERS	DUAL
POWER OUTPUT	3 KW EACH
BANDWIDTH	50 MHz TUNABLE OVER 500 MHz

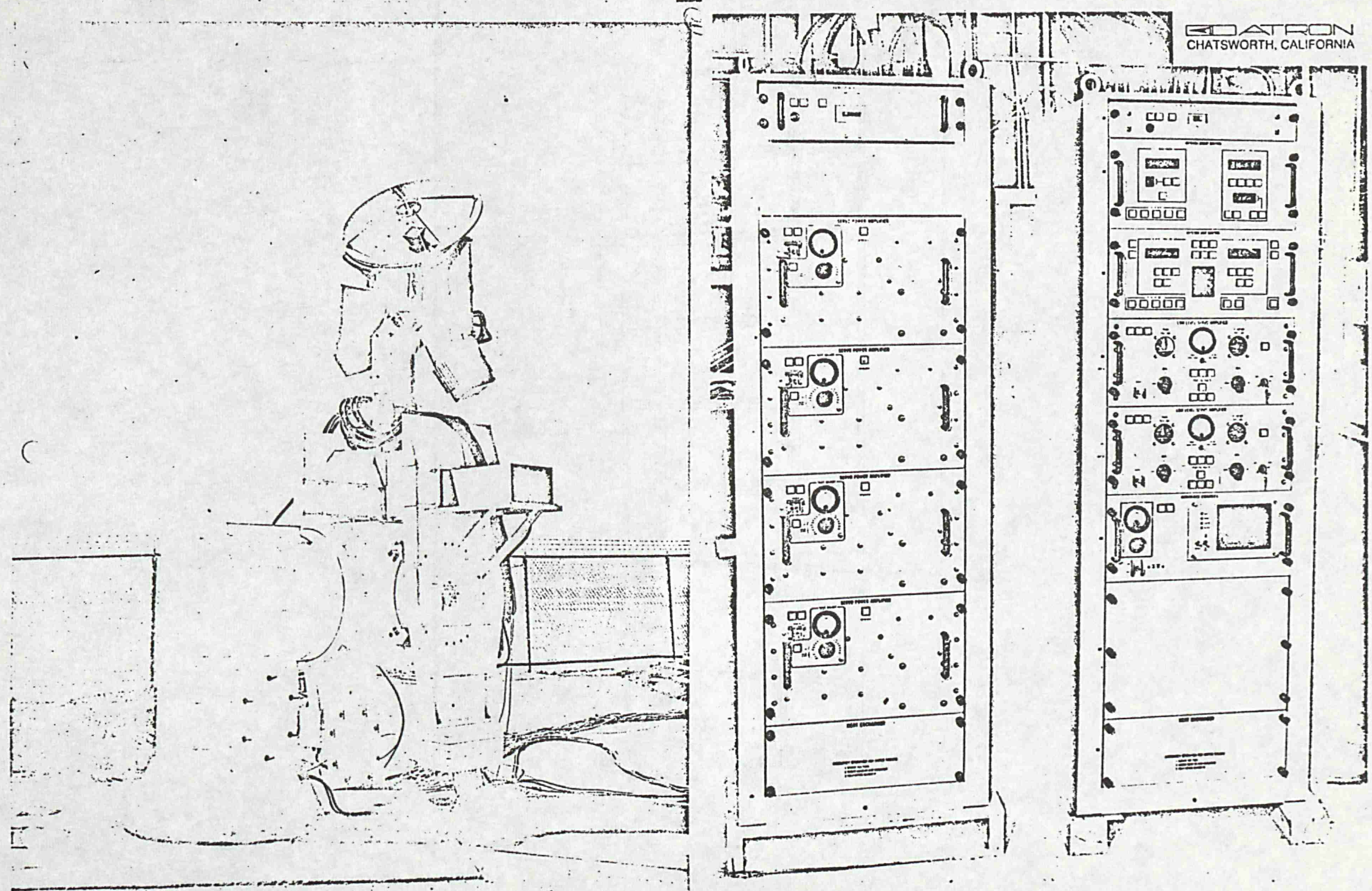




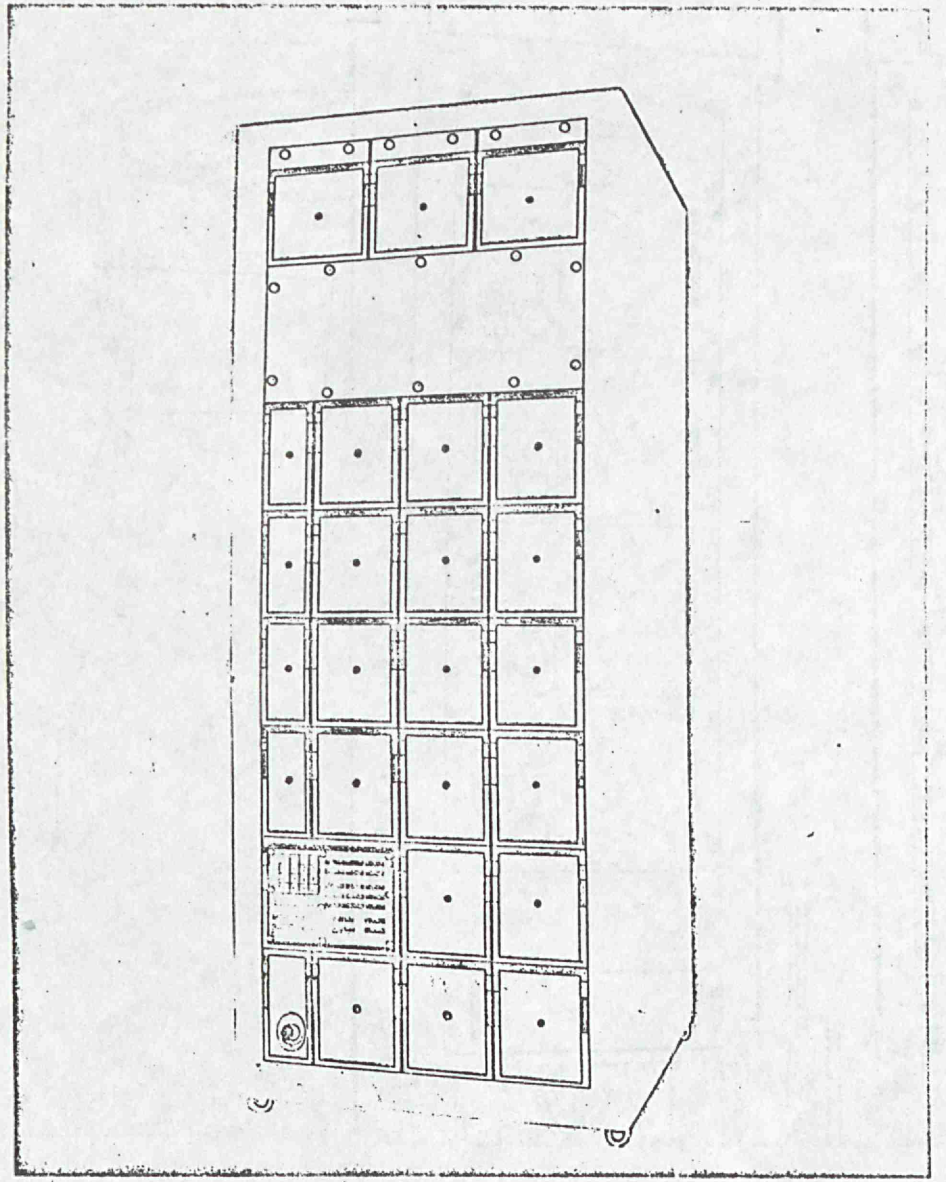
AN/WSC-2 Service Test Model
Below-Decks Equipment, less the
Antenna Control Cabinet and Antenna Servo
Cabinet


DATRON
CHATSWORTH, CALIFORNIA


DATRON
CHATSWORTH, CALIFORNIA



EDATRON
CHATSWORTH, CALIFORNIA



APPENDIX H

ORBIT UTILIZATION OF SATELLITE COMMUNICATIONS SYSTEMS EMPLOYING BOTH LARGE AND SMALL EARTH STATION ANTENNAS

ORBIT AND SPECTRUM UTILIZATION
OF SATELLITE COMMUNICATIONS SYSTEMS
EMPLOYING BOTH LARGE AND SMALL
EARTH STATION ANTENNAS

WILLIAM G. LONG, JR.
DEFENSE COMMUNICATIONS AGENCY
WASHINGTON, D.C., U.S.A.

ORBIT AND SPECTRUM UTILIZATION
OF SATELLITE COMMUNICATIONS SYSTEMS
EMPLOYING BOTH LARGE AND SMALL
EARTH STATION ANTENNAS

1. Introduction

The use of small earth stations (small antennas) have been envisioned since the advent of satellite communications for a variety of reasons and applications. These include: low cost stations for communications service expansion in developing nations; economic communications services to remote areas; educational and other public service functions to large user communities; on-site communications for disaster relief; communications to small platforms such as ships, aircraft, and ocean oil rigs, and last but not lease, highly mobile and flexible communications for military applications.

Developments in satellite technology have resulted in Effective Isotropically Radiated Powers (EIRPs) which are now adequate to support communications among small earth stations and thus their use is expected to increase dramatically in the future.

However, the characteristics of small earth stations (particularly antenna discrimination) tend to result in less utilization of the orbit and spectrum than achieved with only large earth stations. This paper addresses some aspects of orbit and spectrum utilization when large disparities exist in the antenna characteristics of earth stations associated with satellite communications systems.

2. Analyses

Basic Functions

The basic intersatellite system interference modes are shown in Figure 1. By combining the basic system design functions with the interference functions, the $\Delta T/T$ ratio as employed in Appendix 29, of the ITU Radio Regulations, may be expressed as follows:

$$\frac{\Delta T}{T_1} = \left(\frac{C}{N}\right)_{T_2} \left(\frac{B}{S}\right)_2 \left(\frac{1+\mu_2}{1+\mu_1}\right) \frac{1}{G_{ed2}} \left[\frac{T_{s2}\, G_{su1}(\delta_1) G_{e2}(\theta)}{T_{s1}\, r^2\, G_{su2}} + \frac{\mu_1 T_{e2}\, G_{sd2}(\mathcal{E}_2) G_{e1}(\theta)}{\mu_2 T_{e1}\, G_{sd2}}\right] \quad (1$$

Where:

ΔT	-	Interference expressed as Noise Temperature
T	-	Noise Temperature
(C/N)	-	Carrier/Noise in B, including uplink and downlink noise
B	-	RF Signal Bandwidth
S	-	Energy Dispersal Factor
μ	-	Downlink/Uplink Noise Ratio
G	-	Antenna Gain
r	-	Uplink/Downlink Frequency Ratio
$\theta, \delta, \mathcal{E}$	-	As in Figure 1

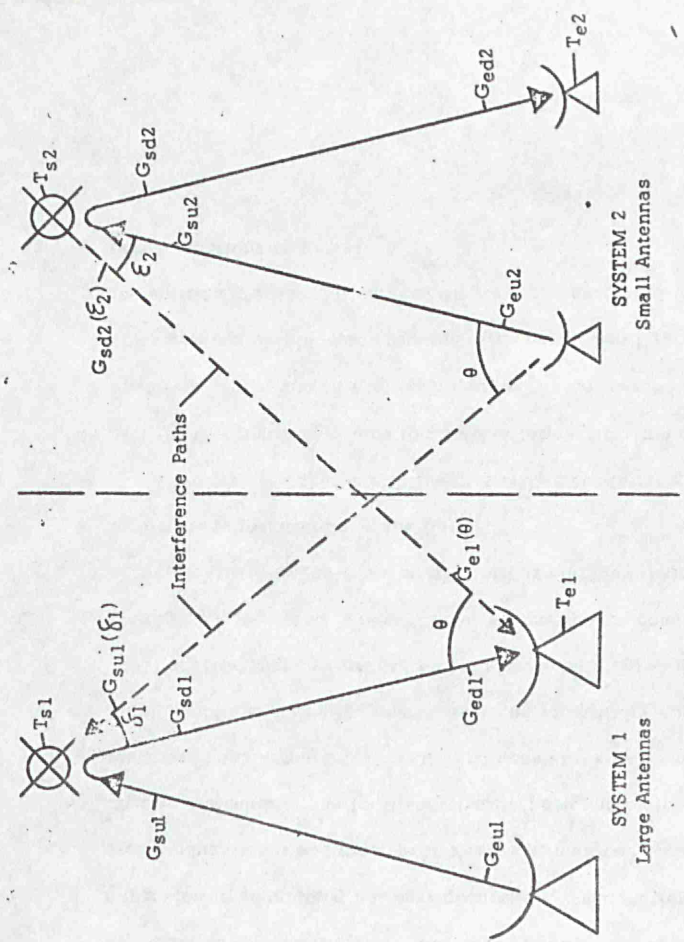


FIGURE 1

INTERSATELLITE SYSTEM INTERFERENCE

and subscripts:

- e - Earth Station
- s - Satellite
- u - Uplink
- d - Downlink
- 1 - System 1
- 2 - System 2

As indicated by Figure 1, the intersatellite interference is an additive, two path, phenomenon and the terms in the bracket of equation (1) represent the uplink and downlink interference paths. For purposes herein, System 1 has large earth station antennas and System 2 has small earth station antennas thus equation (1) represents the interference to System 1 from System 2. The effect of variations in each parameter of equation (1) can be assessed.

Noise Temperatures

In practice T_{e2} may be greater than T_{e1}, i.e.; the small earth stations will generally have higher noise temperatures than large earth stations, thus the second term in the brackets is increased. However, the effect on $\Delta T/T_1$ may be small if the first term dominates. The value of T_{e2}/T_{e1} would probably not exceed about 5. It would be reasonable to assume that T_{s2} is equal to T_{s1}.

Side Lobe Envelope Gains

Again in practice, $G_{e2}(\theta)$ will probably be greater than $G_{e1}(\theta)$. The CCIR Recommendation of (38-25 log θ) is usually used for large antenna $(\frac{D}{\lambda} \geq 100)$. Values, four times higher, have been assumed for small antennas. The value of $G_{e2}(\theta)$ effects the first term in the brackets of equation (1).

Spacecraft Antenna Discrimination

The terms $G_{su1}(\delta_1)$ and $G_{sd2}(\varepsilon_2)$ are related to the commonality of the satellite antenna coverage areas of the two systems. If the coverage areas of the satellite antennas are sufficiently separated so that only the side lobe areas are common, then the value of the brackets in equation (1) could be 20 db or more below the value obtained when the coverage areas are common. Under this condition the value of G_{ed2} could be proportionally smaller for the same value of $\Delta T/T_1$. However, if spacecraft antenna discrimination is achieved only in one of the terms of the brackets, the value of $\Delta T/T_1$ may not be significantly reduced. This condition may occur when widebeam spacecraft antennas are cross connected to narrowbeam spacecraft antennas.

Uplink/Downlink Noise Allocations

Another parameter which may be varied in equation (2) is the value of μ_2. Equating the derivative of μ_2 with respect to $\Delta T/T_1$ to zero results in an optimum value of μ_2.

$$\mu_{2\,OPT} = \left[\mu_1 \frac{T_{e2}}{T_{e1}} \frac{T_{s1}}{T_{s2}} \frac{G_{sd2}(\varepsilon_2)\,G_{e1}(\theta)\,r^4}{G_{su1}(\delta_1)\,G_{e2}(\theta)}\right]^{\frac{1}{2}} \quad (2)$$

With this value of μ_2, the optimum value of μ_1 is:

$$\mu_1 = \mu_2 = \frac{T_{e2}}{T_{e1}} \frac{T_{s1}}{T_{s2}} \frac{G_{sd2}(\varepsilon_2)\,G_{e1}(\theta)\,r^4}{G_{su1}(\delta_1)\,G_{e2}(\theta)} \quad (3)$$

If all parameters of the two Systems were equal, then, $\mu_1 = \mu_2 = r^4$. If $r = 1.5$, then $\mu_1 = \mu_2 \approx 5$, a typical value for the downlink to uplink noise allocation.

The values of μ_1 & μ_2 may be adjusted to compensate for differences in satellite antenna discrimination or satellite antenna gain so as to minimize the value of $\Delta T/T_1$. The sensitivity of $\Delta T/T_1$ as a function of μ_1 & μ_2 is of interest. Equation (1) may be expressed as:

$$\frac{\Delta T}{T_1} \propto A\left(\frac{1+\mu_2}{1+\mu_1}\right) + B\left(\frac{1+{}^{1}/\mu_2}{1+{}^{1}/\mu_1}\right) \quad (4)$$

The first term in equation (5) represents uplink interference and the second term downlink interference. If downlink interference dominates, then $\Delta T/T_1$ is relatively insensitive to val ues of μ_1 and μ_2 when μ_2 are considerably greater than one. Conversely, $\Delta T/T_1$ is proportional to μ_2/μ_1 when uplink interference dominates.

If A = B and μ_1 and μ_2 are considerably greater than one, then:

$$\frac{\Delta T}{T_1} \propto 1 + \frac{\mu_2}{\mu_1}$$

In this case, $\Delta T/T_1$ is not highly sensitive to the values of μ_1 and μ_2 when μ_1 and μ_2 are comparable in magnitude. Thus, the degree of reduction of $\Delta T/T_1$ by adjusting the values of μ is limited when considering practical values of μ which are usually in the range of 5 to 10.

Energy Dispersal

The term (B/S) in equation (1) relates to the amount of energy dispersal employed. The term can have high values if energy dispersal is not employed, resulting in high values for $\Delta T/T_1$. With maximal energy dispersal techniques, (B/S) will have values in the range of 2 to 4. For a multichannel FDM/FM signal the value of B/S is approximately:

$$B/S \approx 3.2\left(\frac{1+M}{M}\right) \quad (5)$$

for a full traffic load. If the modulation index, $M >> 1$, then $B/S \approx 3.2$.

Carrier-to-Noise Ratio

The term (C/N) in equation (1) relates to the nominal operating carrier-to-noise ratio at the receiver. In power limited satellite systems, which would generally be the case with small earth station antennas, the design value of C/N tends to be minimized thus minimizing $\Delta T/T_1$. For bandwidth-limited systems, the nominal value of C/N may be case in systems with large earth station antennas.

Earth Station Antenna Gain

The remaining dominant term in equation (1) is the earth station antenna gain. $\Delta T/T_1$ is inversely proportional to G_{ed2}.

3. Orbit Utilization

Angular Spacing Requirements

The angular separations required for a given interference level ($\Delta T/T_1$) may be developed from the preceding equations. For purposes of further development a number of assumptions are made.

a. The earth stations associated with the two systems are in the common coverage area of the satellite antennas.

b. The satellite noise temperatures of the two systems are the same.

c. The downlink/uplink noise allocations are equal in the two systems.

d. Maximum energy dispersal is utilized so that the values of (B/S) are equal.

e. The CCIR sidelobe envelope slope is used, but the small antenna sidelobe envelope gain is related to the large antenna sidelobe envelope gain by a factor (K).

The satellite angular separation (θ) between two identical System 1 configurations is used as a reference. The angular separation required between the System 1 and System 2 satellite for the same value of ($\Delta T/T_1$) as the reference is defined as (θ_1). With these assumptions:

$$\frac{\theta_1}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}} \; \frac{G_{ed1}}{G_{ed2}} \; \frac{r^2}{(1+r^2)} \left[\frac{KG_{su1}}{r^2 G_{su2}} + \frac{T_{e2}}{T_{e1}}\right]\right]^{0.4} \qquad (6)$$

where as defined above, (θ_1) is the angular separation required by System 1 due to interference from System and (θ) is the angular separation required by System 1 due to interference from an identical System 1. This ratio represents a measure of orbit utilization.

The range of values in equation (6) may be assessed. The value of (T_{e2}/T_{e1}) is in the range of 1 to 5. K may range from about 1 to 4. G_{su2} would generally be equal to or greater than G_{su1}, although there may be exceptions where broad beam satellite antennas are used with small earth stations and narrow beam antennas are used with large earth stations. The value of $(C/N)_{T2}$ would generally be equal to $(C/N)_{T1}$ for power limited system and could be less the $(C/N)_{T1}$ if System 1 were bandwidth limited. The ratio of G_{ed1}/G_{ed2} could have very large values (up to 1000) so that this can be the dominant factor in equation (6).

The satellite angular spacing required by System 2 due to interference from System 1 may be defined as (θ_2). For this case:

$$\frac{\theta_2}{\theta} = \left[\frac{r^2}{(1+r^2)}\left[\frac{G_{su2}}{r^2 G_{su1}} + \frac{K\,T_{e1}}{T_{e2}}\right]\right]^{0.4} \tag{7}$$

If $G_{su2} = G_{su1}$ and $KT_{e1} = T_{e2}$ then $\theta_2/\theta = 1$. θ_2/θ will increase as G_{su2}/G_{su1} increases. If $G_{su2} \gg G_{su1}$, then from equations (6) and (7) $\theta_1 = \theta_2$ when:

$$\frac{G_{ed1}}{G_{ed2}}\frac{G_{su1}}{G_{su2}} = \frac{T_{e1}\,(C/N)_{T1}}{r^2\,T_{e2}\,(C/N)_{T2}} \tag{8}$$

This indicates that when the product of the earth station and satellite antenna gains of System (1) with large earth station antennas is greater than that of System (2) with small earth station antennas, interference to System (1) will determine the required satellite spacing. Even if the optimum indicated by equation (8) were achieved, assuming that $G_{su2} \gg G_{su1}$ and $G_{ed1} \gg G_{ed2}$:

$$\frac{\theta_1}{\theta} = \frac{\theta_2}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}}\,\frac{G_{ed1}}{G_{ed2}}\,\frac{r^2}{(1+r^2)}\,\frac{T_{e2}}{T_{e1}}\right]^{0.4} \tag{9}$$

Thus, under this condition the angular separation is determined by downlink interference to the system with the large earth station antennas, and this separation is not significantly less than the case where $G_{su1} = G_{su2}$.

In the preceding analysis System 2 utilizes only earth stations with small antennas. A System 2 can also be defined consisting of earth stations with both large and small antennas in which links are established only between earth stations with small antenna and earth stations with large antennas as shown in Figure 2. For the case of transmission from a large earth station to a small earth station:

$$\frac{\theta_1}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}}\,\frac{G_{ed1}}{G_{ed2}}\,\frac{r^2}{(1+r^2)}\left[\frac{G_{ed2}\,G_{su1}}{r^2\,G_{ed1}\,G_{su2}} + \frac{T_{e2}}{T_e}\right]\right]^{0.4} \tag{10}$$

and for transmission from a small earth station to a large earth station:

$$\frac{\theta_1}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}}\,\frac{G_{ed1}}{G_{ed2}}\,\frac{r^2}{(1+r^2)}\left[\frac{KG_{su1}}{r^2 G_{su2}} + \frac{G_{ed2}}{G_{ed1}}\right]\right]^{0.4} \tag{11}$$

For the first case, equation (10), downlink interference would normally dominate, while in the second case, equation (11), uplink interference would normally dominate. However, the values of (θ_1/θ) from equations (10) and (11) may not be significantly less than value of (θ_1/θ) from equation (6).

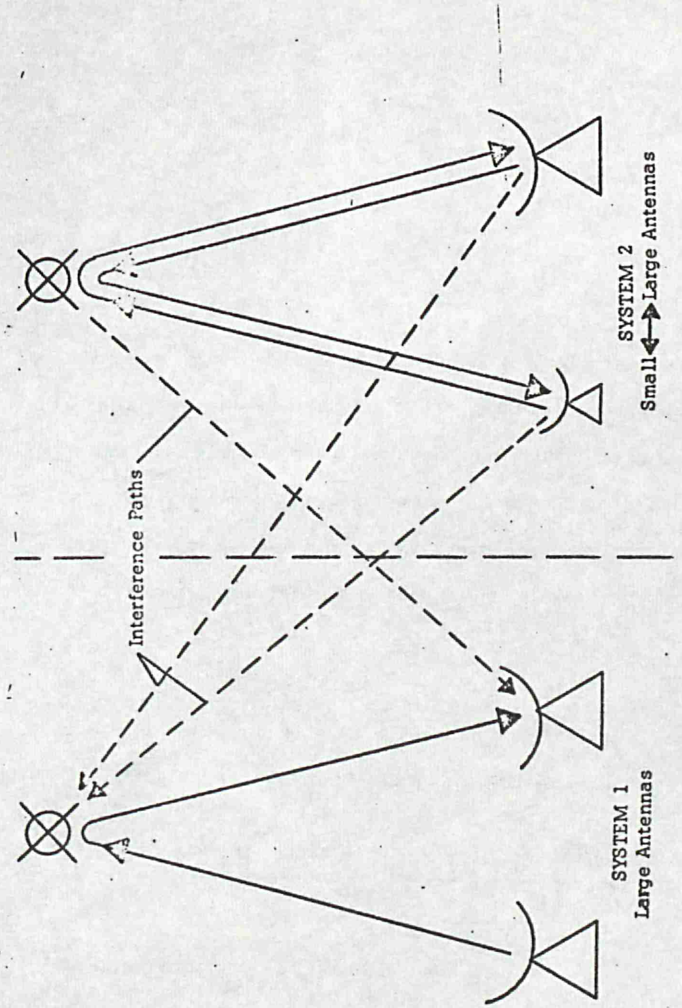


FIGURE 2

INTERSATELLITE SYSTEM INTERFERENCE

Thus, the presence of an earth station with a small antenna in a system basically determines the angular spacing requirement and is primarily a function of the antenna gain; i.e.:

$$\frac{\theta_1}{\theta} \propto \left[\frac{G_{ed1}}{G_{ed2}}\right]^{0.4} \qquad (12)$$

For a numerical example, assume System 1 characteristics of:

$G_{ed1} = 10^6 = 60$ db

$B/S = 4$

$C/N = 10$

$r' = 1.5$

$\Delta T/T = 0.02$

The angular separation required from another system is then about 1.85 degrees. If System 2 has identical characteristics except an earth station antenna gain of 50 db, the spacing requirement is about 4.6 degrees using equation (12). For System 2 earth station antenna gains of 40 db and 30 db the spacing requirements are about 11.6 and 29 degrees respectively. Thus the orbit utilization can be significantly less with systems employing small earth station antennas as compared to system employing large earth station antennas.

A third configuration for System 2 may be postulated in which earth stations with large antennas are linked together, earth stations with small antennas are linked together and all earth stations access the same transponder as shown in Figure 3. Under this condition the downlink/uplink noise allocation associated with the small earth stations will be greater than that associated with the large earth stations by a factor approximately equal to the ratio of the (G/T)'s. Thus the angle ratio is:

$$\frac{\theta_1}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}} \frac{r^2}{(1+r^2)} \frac{G_{ed1}}{G_{ed2}} \left[\left(\frac{1}{1+\mu_1}\right) + \left(\frac{\mu_1}{1+\mu_1}\right)\frac{(G/T)_1}{(G/T)_2}\right] \cdot \left[\frac{KG_{su1}}{r^2 G_{su2}} + \frac{(G/T)_2}{(G/T)_1}\frac{T_{e2}}{T_{e1}}\right]\right]^{0.} \quad (13$$

Uplink interference to System 1 will normally dominate. And again, the dominate factors are the antenna gains such that to a first order approximation:

$$\frac{\theta_1}{\theta} \propto \left[\frac{G_{ed1}}{G_{ed2}}\right]^{0.8} \quad (14)$$

Comparing this result with equation (14) shows that this configuration leads to an angle ratio which is the square of the previous two configurations.

Using the values of the numerical examples given in the preceding paragraphs, System 2 earth station antenna gains of 50 db, 40 db and 30 db results in spacing requirements of 11.6 degrees for the 50 db case, while a $\Delta T/T = 0.02$ cannot be achieved with the 40 db and 30 db antenna gains.

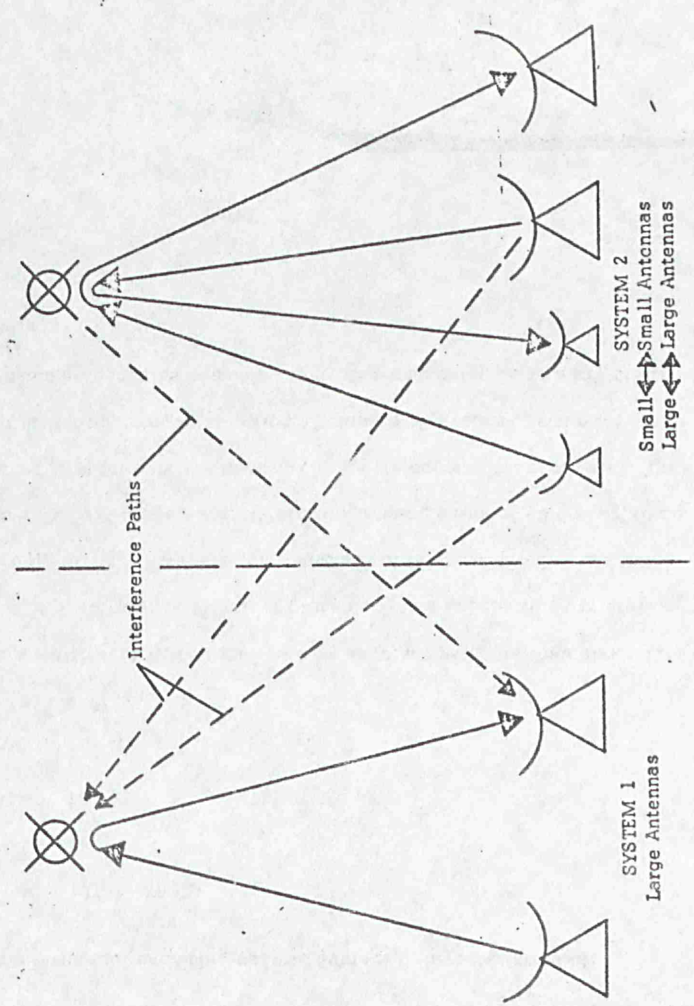


FIGURE 3

INTERSATELLITE SYSTEM INTERFERENCE

Thus, large differences in (G/T)'s should be avoided in accessing a single transponder.

Grouping Strategies

The above values of spacing would apply for the case of alternating satellite systems with large earth station antennas and small earth station antennas. If, however, the satellites were grouped so that all satellites associated with large earth station antennas were in one orbit segment and all satellites associated with small earth station antennas were in another orbit segment, then the approximate relative angular separations, would be

$$\frac{\theta_S}{\theta_L} \propto \left[\frac{G_{edL}}{\beta G_{edS}}\right]^{0.4} \qquad (15)$$

where the subscripts (S) and (L) refer to large and small earth station antennas. The term β is included in this expression based on the postulate that systems employing small earth station antennas should be designed for larger external interference allowances. Increasing the external interference allowance tends to improve the orbit utilization, i.e., decreases the satellite spacing requirement between similar satellite systems.

If $\beta = 10$, which would correspond to a $\Delta T/T$ of 20% as compared to the 2% used in the preceding examples, then the corresponding values of angular separation would be reduced by a factor of 2.5. Thus a system with

earth station antenna gains of 40 db or 30 db would require 4.6 or 11.6 degree spacings which can be compared to the 11.6 and 29 degree spacings based on a 2% external interference allowance.

It should be emphasized that increasing the external noise allocation must be coupled with some grouping strategy in order to minimize losses in orbit utilization when small earth station antennas are employed.

The orbital space grouping arrangement suggested above may not be compatible with system coverage requirements. Segregation by normal up/down band pair use and reversed band pair use is another alternative but direct intersatellite and/or inter-earth station interference may limit use of this strategy. Segregation by polarization is another possibility. Perhaps the most practical and feasible method would be by frequency band, noting that EIRP limitations may limit the bandwidth requirements for systems with small earth station antennas to a relatively small value.

4. Conclusions

Based on the preceding analyses and comments, the following general conclusions may be postulated.

a. Earth station antenna gains are the dominant factor in determining orbit spacing requirements.

b. Orbit utilization with systems employing small earth station antennas can be quite low as compared to systems using large earth station antennas.

c. Satellite spacing requirements are generally determined by interference from the system employing small earth station antennas to the system employing large earth station antennas. Interference in the opposite direction is generally much smaller.

d. Adjustment of the uplink to downlink noise allocation ratio in adjacent satellite systems may allow closer satellite spacing.

e. Placing satellite systems, which do not have overlapping satellite antenna coverage areas adjacent to each other, may improve orbit utilization.

f. Large differences in (G/T)'s should be avoided in accessing a single transponder.

g. Isolating satellite systems employing small earth station antennas from those employing large earth station antennas coupled with a higher external noise allocation for the small earth station antenna systems can improve the overall orbit utilization. A number of isolation techniques may be considered, including frequency division.

h. Generally, maximum energy dispersal should be employed.

i. Satellite antenna patterns should conform to the coverage area as closely as possible.

j. Side lobe envelopes should be as low as practical on both the satellite and earth station antennas.

Considering the potential demand for systems employing small earth station antennas, it appears that appropriate strategies, techniques, and criteria are necessary to insure reasonable utilization of the orbit and spectrum resource.

ORBIT UTILIZATION OF

SATELLITE COMMUNICATIONS SYSTEMS

EMPLOYING BOTH LARGE AND SMALL

EARTH STATION ANTENNAS

INTRODUCTION

REASONS FOR SMALL EARTH STATIONS

- LOW COST - LARGE NUMBERS
- PHYSICAL CONSTRIANTS - SMALL PLATFORMS
- LOW CAPACITY

APPLICATIONS

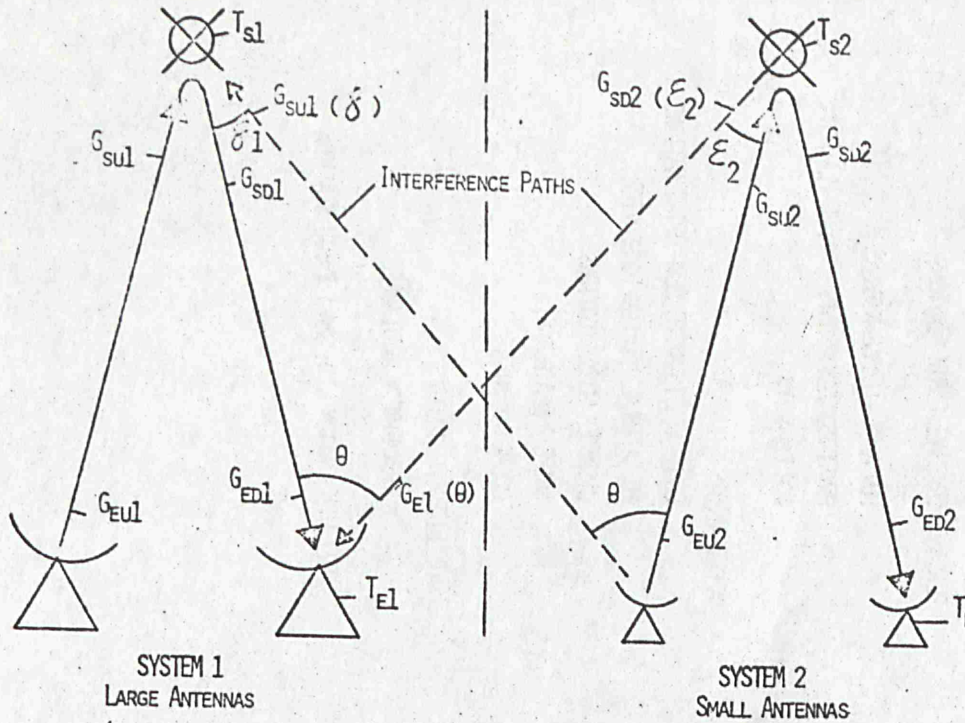
- COMMUNICATIONS FOR DEVELOPING NATIONS
- EDUCATIONAL AND PUBLIC SERVICE
- DISASTER COMMUNICATIONS
- SHIPS AND AIRCRAFT
- OCEAN OIL RIGS

SATELLITE TECHNOLOGY

- HIGH EIRP's AVAILABLE

ORBIT UTILIZATION WITH SMALL EARTH STATIONS

INTERSATELLITE SYSTEM INTERFERENCE



ANALYSIS (1)

$$\frac{\Delta T}{T_1} = \left(\frac{C}{N}\right)_{T_2} \left(\frac{B}{S}\right)_2 \left(\frac{1+\mu_2}{1+\mu_1}\right) \frac{1}{G_{ED2}} \left[\frac{T_{s2}\, G_{su1}(\delta_1)\, G_{E2}(\theta)}{T_{s1}\; R^2\; G_{su2}} + \frac{\mu_1\, T_{E2}\, G_{sD2}(\mathcal{E}_2)\, G_{E1}(\theta)}{\mu_2\, T_{E1}\, G_{sD2}}\right]$$

ΔT	-	INTERFERENCE EXPRESSED AS NOISE TEMPERATURE
T	-	NOISE TEMPERATURE
(C/N)	-	CARRIER NOISE IN B, UPLINK AND DOWNLINK NOISE
B	-	RF SIGNAL BANDWIDTH
S	-	ENERGY DISPERSAL FACTOR
μ	-	DOWNLINK/UPLINK NOISE RATIO
G	-	ANTENNA GAIN
R	-	UPLINK/DOWNLINK FREQUENCY RATIO

SUBSCRIPTS:

E	-	EARTH STATION
s	-	SATELLITE
U	-	UPLINK
D	-	DOWNLINK
1	-	SYSTEM 1
2	-	SYSTEM 2

ANALYSIS (2)

$$\frac{\Delta T}{T_1} = \left(\frac{C}{N}\right)_{T_2} \left(\frac{B}{S}\right)_2 \left(\frac{1+\mu_2}{1+\mu_1}\right) \frac{1}{G_{ED2}} \left[\frac{T_{s2}\, G_{su1}(\delta_1)\, G_{E2}(\theta)}{T_{s1}\; R^2\; G_{su2}} + \frac{\mu_1\, T_{E2}\, G_{sD2}(\varepsilon_2)\, G_{E1}(\theta)}{\mu_2\, T_{E1}\, G_{sD2}}\right]$$

- NOISE TEMPERATURES - T_{s2}/T_{s1} AND T_{E2}/T_{E1}
- SIDELOBE ENVELOPE GAINS - $G_{E2}(\theta)$ AND $G_{E1}(\theta)$
- SATELLITE ANTENNA GAINS - $G_{su1}(\delta_1)/G_{su2}$ AND $G_{sD2}(\varepsilon_2)/G_{sD2}$
- ENERGY DISPERSAL - B/S
- CARRIER/NOISE - C/N

ANALYSIS (3)

$$\frac{\Delta T}{T_1} = \left(\frac{C}{N}\right)_{T_2} \left(\frac{B}{S}\right)_2 \left(\frac{1+\mu_2}{1+\mu_1}\right) \frac{1}{G_{ED2}} \left[\frac{T_{s2}\, G_{su1}(\delta_1)\, G_{E2}(\theta)}{T_{s1}\; R^2\; G_{su2}} + \frac{\mu_1\, T_{E2}\, G_{sD2}(\varepsilon_2)\, G_{E1}(\theta)}{\mu_2\, T_{E1}\, G_{sD2}}\right]$$

- DOWNLINK/UPLINK NOISE ALLOCATIONS - μ

$$\mu_{2_{OPT}} = \left[\mu_1 \frac{T_{E2}}{T_{E1}} \frac{T_{s1}}{T_{s2}} \frac{G_{sD2}(\varepsilon_2)\, G_{E1}(\theta)\, R^4}{G_{su1}(\delta_1)\, G_{E2}(\theta)}\right]^{\frac{1}{2}}$$

$$\mu_1 = \mu_2 = \frac{T_{E2}}{T_{E1}} \frac{T_{s1}}{T_{s2}} \frac{G_{sD2}(\varepsilon_2)\, G_{E1}(\theta)\, R^4}{G_{su1}(\delta_1)\, G_{E2}(\theta)}$$

- SENSITIVITY - μ TO $\Delta T/T$
- EARTH STATION ANTENNA GAIN

ORBIT UTILIZATION (1)

- ASSUMPTIONS
  - COMMON COVERAGE OF S/C ANTENNAS
  - SAME S/C NOISE TEMPERATURES
  - SAME DOWNLINK/UPLINK NOISE ALLOCATION
  - CCIR SIDELOBE ENVELOPE SLOPE

- SPACING — SYSTEM 2 TO SYSTEM 1

$$\frac{\theta_1}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}} \; \frac{G_{ED1}}{G_{ED2}} \; \frac{R^2}{(1+R^2)} \left[\frac{KG_{su1}}{R^2 G_{su2}} + \frac{T_{E2}}{T_{E1}}\right]\right]^{0.4}$$

- SPACING — SYSTEM 1 TO SYSTEM 2

$$\frac{\theta_2}{\theta} = \left[\frac{R^2}{1+R^2} \left[\frac{G_{su2}}{R^2 G_{su1}} + \frac{K T_{E1}}{T_{E2}}\right]\right]^{0.4}$$

ORBIT UTILIZATION (2)

- EQUAL SPACING - $\theta_1 = \theta_2$

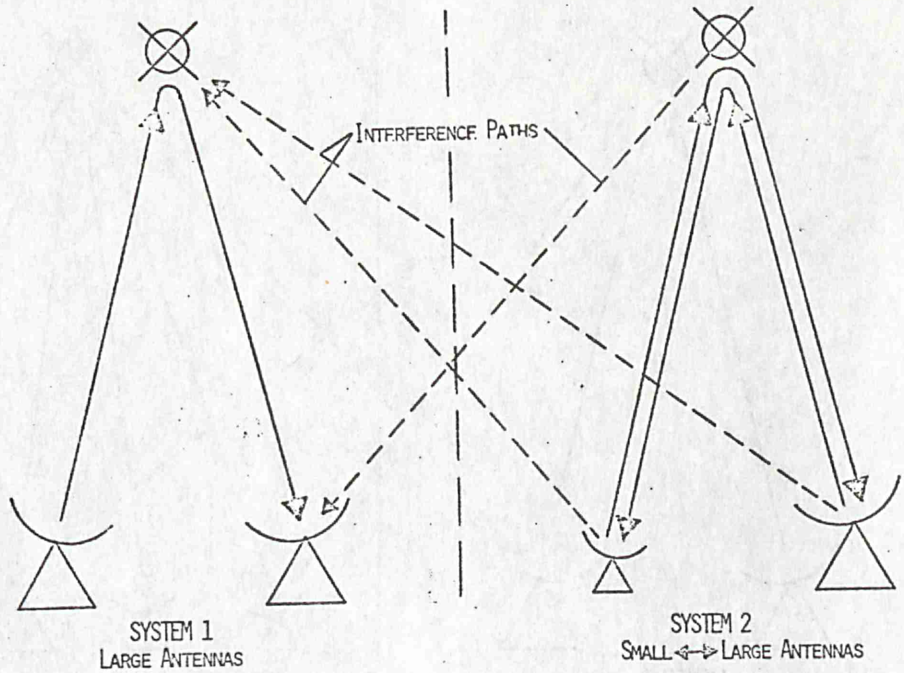
  — IF $G_{su2} >> G_{su1}$

$$\frac{G_{ED1}\, G_{su1}}{G_{ED2}\, G_{su2}} = \frac{T_{E1}\,(C/N)_{T1}}{R^2\, T_{E2}\,(C/N)_{T2}}$$

  — IF ALSO $G_{ED1} >> G_{ED2}$

$$\frac{\theta_1}{\theta} = \frac{\theta_2}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}} \; \frac{G_{ED1}}{G_{ED2}} \; \frac{R^2}{(1+R^2)} \; \frac{T}{T_{E1}}\right]^{0.4}$$

INTERSATELLITE SYSTEM INTERFERENCE



ORBIT UTILIZATION (3)

- SPACING - SYSTEM 2 TO SYSTEM 1

TX - LARGE EARTH STATION TO SMALL EARTH STATION

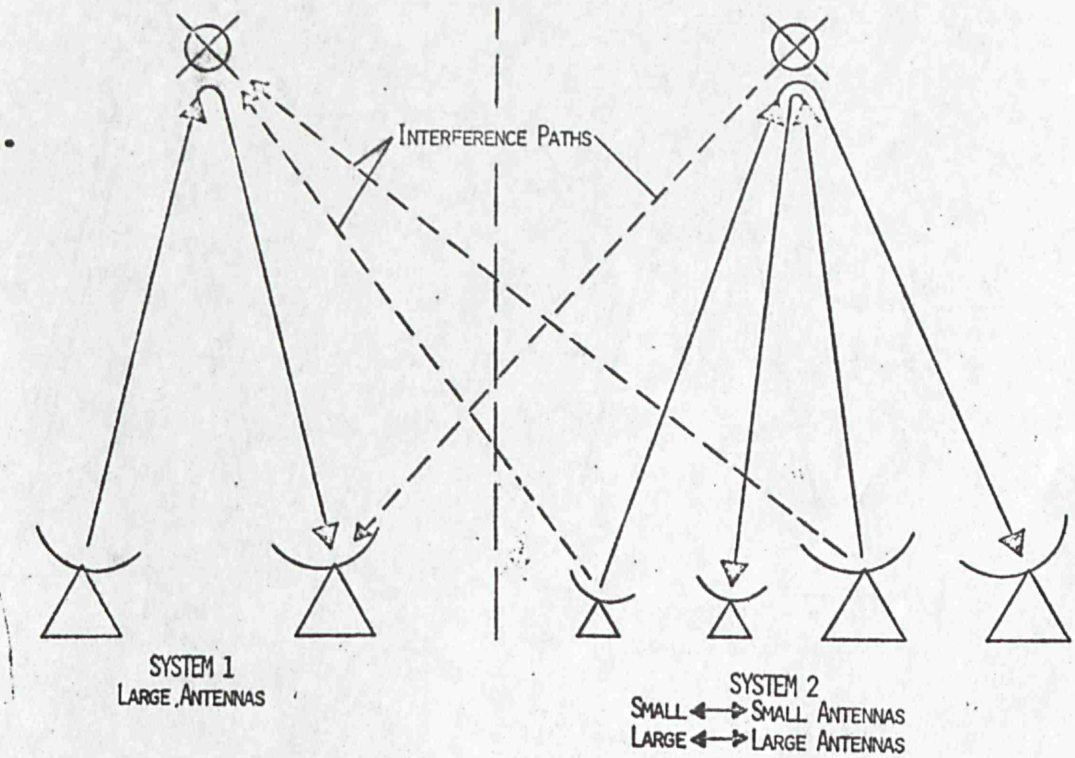
$$\frac{\theta_1}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}} \; \frac{G_{ED1}}{G_{ED2}} \; \frac{R^2}{(1 + R^2)} \left[\frac{G_{ED2}\, G_{SU1}}{R^2\, G_{ED1}\, G_{SU2}} + \frac{T_{E2}}{T_{E1}} \right] \right]^{0.4}$$

TX - SMALL EARTH STATION TO LARGE EARTH STATION

$$\frac{\theta_1}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}} \; \frac{G_{ED1}}{G_{ED2}} \; \frac{R^2}{(1 + R^2)} \left[\frac{K G_{SU1}}{R^2\, G_{SU2}} + \frac{G_{ED2}}{G_{ED1}} \right] \right]^{0.4}$$

- FIRST ORDER APPROXIMATION $\quad \frac{\theta_1}{\theta} \propto \left[\frac{G_{ED1}}{G_{ED2}} \right]^{0.4}$

INTERSATELLITE SYSTEM INTERFERENCE



ORBIT UTILIZATION (4)

- SPACING - SYSTEM 2 TO SYSTEM 1

$$\frac{\theta_1}{\theta} = \left[\frac{(C/N)_{T2}}{(C/N)_{T1}} \; \frac{R^2}{(1 + R^2)} \; \frac{G_{ED1}}{G_{ED2}} \left[\left(\frac{1}{1+\mu_1} \right) + \left(\frac{\mu_1}{1+\mu_1} \right) \frac{(G/T)_1}{(G/T)_2} \right] \left[\frac{KG_{su1}}{R^2 \; G_{su2}} + \frac{(G/T)_2}{(G/T)_1} \; \frac{T_{E2}}{T_{E1}} \right] \right]^{0.4}$$

- FIRST ORDER APPROXIMATION $\frac{\theta_1}{\theta} \propto \left[\frac{G_{ED1}}{G_{ED2}} \right]^{0.8}$

GROUPING TECHNIQUES

- SPACING REQUIREMENTS - GROUPED

$$\frac{\theta_S}{\theta_L} \propto \left[\frac{G_{EDL}}{\beta G_{EDS}}\right]^{0.4}$$

L - LARGE EARTH STATIONS

S - SMALL EARTH STATIONS

β - INCREASE IN EXTERNAL INTERFERENCE ALLOWANCE

- GROUPING TECHNIQUES

  ORBITAL ARCS

  REVERSED BAND USE

  POLARIZATION

  FREQUENCY

EXAMPLES

ASSUME: $G_{ED1} = 10^6 = 60$ DB   R = 1.5

B/S = 4 $\Delta T/T = 0.02$

C/N = 10

ANGULAR SPACING - DEGREES

G_{ED2} - DB	60	50	40	30	$\Delta T/T$
SAME G/T's/TRANSPONDER	1.85	4.6	11.6	29	0.02
MIXED G/T's/TRANSPONDER	-	11.6	-	-	0.02
SAME G/T's/TRANSPONDER (GROUPED)	-	1.85	4.6	11.6	0.20

APPENDIX I

FUTURE DEVELOPMENT OF SMALL EARTH STATIONS IN THE INTELSAT SYSTEM

FUTURE DEVELOPMENT OF SMALL EARTH STATIONS IN THE INTELSAT SYSTEM

J. DICKS
COMSAT
OCTOBER 31, 1975.

1. BACKGROUND

(A) SMALL OR 'NON-STANDARD' EARTH STATIONS I.E. THOSE WITH G/T < 40.7 HAVE BEEN USED IN THE INTELSAT SYSTEM FROM THE DAYS OF 'EARLY BIRD' OR 'INTELSAT 1'.

(B) THEY HAVE CONTINUED TO BE USED THROUGH INTELSAT II AND III FOR VARIOUS SERVICES, USUALLY FOR TEMPORARY PURPOSES. THE ONLY EXCEPTION GENERALLY IS THE NASA SERVICE WHICH HAS USED THEM CONTINUOUSLY.

(C) THE POSSIBLE USES OF SMALL EARTH STATIONS WAS GREATLY EXPANDED WITH THE INTRODUCTION OF THE 'INTELSAT IV' SATELLITE BECAUSE OF:

(I) THE LARGE INCREASE IN POWER AVAILABLE

(II) THE PRINCIPLE OF INDIVIDUAL TRANSPONDER OPERATION.

(D) THE CONCEPT OF LEASING TRANSPONDERS WHICH COULD BE USED TO PROVIDE A WIDE RANGE OF DOMESTIC SERVICES EMPLOYING A LARGE NUMBER OF SMALL OR 'NON-STANDARD' ANTENNAS FOCUSED OUR ATTENTION ON THE IMPACT THEY COULD HAVE ON THE REGULAR INTERNATIONAL SERVICE.

2. DETERMINATION OF INTERFERENCE CRITERIA

(A) INTERFERENCE CRITERIA WERE REQUIRED TO BE SPECIFIED FOR INTRA-SYSTEM COORDINATION, SINCE IT WAS FORESEEN THAT INTELSAT SATELLITES WOULD BE REQUIRED TO BE OPERATED WITH AS LITTLE AS 3° OF ORBITAL SEPARATION.

(B) THESE CRITERIA WERE TO BE CONSIDERED AS MANDATORY FOR EARTH STATIONS OPERATING WITH LEASED TRANSPONDERS. AND COULD BE EXPECTED TO PROVIDE A USEFUL GUIDELINE FOR SMALL EARTH STATIONS INTER-CONNECTED INTO THE GLOBAL NETWORK.

THEY ARE AS FOLLOWS:

(I) ACCEPTABLE INTERFERENCE LEVEL INTO ADJACENT SATELLITE

THE LEVEL OF INTERFERENCE CONSIDERED ACCEPTABLE TO THE BASEBAND OF A REGULAR INTELSAT CARRIER IN AN ADJACENT SATELLITE WAS SPECIFIED AS 400 PWP. THIS LEVEL WAS SELECTED SINCE IT CONFORMS WITH CCIR REC. 466 (REV 74) AND IS CONSISTENT WITH NOMINAL INTELSAT OPERATING PARAMETERS.

(II) DETERMINATION OF THE INTERFERENCE CRITERIA

THE LEVEL OF INTERFERENCE WOULD BE EXPRESSED IN DBW/4KHZ SINCE IT IS CONSISTENT WITH PRESENT INTELSAT EMISSION STANDARDS AND CONFORMS WITH CCIR POWER DENSITY UNITS. THE MAX OFF-BEAM EMISSION POWER DENSITY SELECTED WAS 20 DBW/4KHZ.

THE OFF-BEAM ANGLE WAS NOT SPECIFIED SINCE THIS UNIT WAS SELECTED WITH A 3^{o} SEPARATION IN MIND.

(C) IT IS EXPECTED THAT WITH AN EMISSION LIMIT OF 20 DBW/4KHZ, AN AVERAGE INTERFERENCE LEVEL OF 400 PWP CAN BE MAINTAINED.

3. IMPACT ON SYSTEM OPERATION

(A) THE INTELSAT SYSTEM PROVIDES FOR A WIDE RANGE OF TRANSMISSION PARAMETERS. THERE ARE LARGE SIZE (36 MHZ/972 CHANS) CARRIERS AND SMALL SIZE (2.5 MHZ/24 CHANNELS) FDM/FM CARRIERS AS WELL AS 64 KBPS PCM/PSK SINGLE CHANNEL PER CARRIER CARRIERS, AND 17.5 MHZ TELEVISION CARRIERS.

EXAMPLES OF OTHER CARRIER SIZES:

25 MHZ/792 CHS
20 MHZ/612 CHS
15 MHZ/312 CHS OR 432 CHS
10 MHZ/252 CHS OR 132 CHS
7.5 MHZ/192 CHS OR 132 CHS
5 MHZ/96 CHS, 72 CHS, 60 CHS.

MODULATION INDICES RANGE FROM ABOUT 0.7 TO 2.4

(B) SATELLITE TRANSPONDERS HAVE A WIDE RANGE OF OPERATING PARAMETERS.

INTELSAT IV	GLOBAL BEAM EIRP	= 22 DBW AT BEAM EDGE
	SPOT BEAM EIRP	= 34 DBW AT BEAM EDGE
INTELSAT IV-A	GLOBAL BEAM EIRP	= 22 DBW AT BEAM EDGE
	HEMISPHERIC BEAM EIRP	= 26 DBW AT BEAM EDGE
	SPOT BEAM EIRP	= 29 DBW AT BEAM EDGE

TRANSPONDERS OPERATE IN BOTH SINGLE CARRIER PER TRANSPONDER (I.E. AT SATURATION) OR IN A MULTI-CARRIER MODE (I.E. BACK-OFF FROM SATURATION).

(C) TABLE 1 SHOWS TYPICAL LINK PARAMETERS FOR INTELSAT IV-A TRANSPONDERS.

NOTE: AVERAGE C/N VARIES BETWEEN 13 DB AND 23 DB.

(D) TABLE 2 SHOWS TYPICAL VALUES OF INTERFERENCE IF THE INTERFERRING CARRIER IS CO-FREQUENCY WITH THE DESIRED CARRIER. THIS DEMONSTRATES THAT SOME DEGREE OF CONTROL OF FREQUENCY PLANNING IS REQUIRED IN ORDER TO MINIMIZE CO-FREQUENCY OPERATION SO THAT A 400 PWP AVERAGE INTERFERENCE LEVEL IS MAINTAINED WITH AN OFF BEAM EMISSION LEVEL OF 20 DBW/4KHZ.

(E) TABLE 3 SHOWS A DETAILED LIST OF EARTH STATION E.I.R.P VALUES FOR THE VARIOUS CARRIERS IN USE IN THE INTELSAT SYSTEM. THE NOMINAL MAXIMUM POWER DENSITY PER 4 KHZ.

(F) TABLE 4 SHOWS THE INTERFERENCE EXPECTED FROM SMALL EARTH STATIONS INTO MULTI-CARRIER INTELSAT IV & IV-A TRANSPONDERS FOR SATELLITE SEPARATIONS OF 3^{o}.

4. RESULTS

(A) FOR TRANSMIT PURPOSES AN OFF BEAM POWER LIMIT OF 20 DBW/4KHZ IS EXPECTED TO ENABLE ADJACENT SATELLITE INTERFERENCE TO BE MAINTAINED AT OR BELOW 400 PWP. THIS EMISSION LEVEL IS APPLIED IRRESPECTIVE OF THE ACTUAL ANTENNA DIAMETER.

TABLE 1

TYPICAL INTELSAT IV-A TRANSMISSION LINK PARAMETERS

ITEM	SPOT BEAM			HEMISPHERIC BEAM			GLOBAL BEAM
	Single Carrier	3 & 4 Carriers	Multi-Carrier	Single Carrier	3 & 4 Carriers	Multi-Carrier	Multi-Carrier
e.i.r.p. (beam edge) (dBW)	29.0	29.0	29.0	26.0	26.0	26.0	22.0
Back Off$_{in}$ (dB)	--	-9.0	-12.5	--	-8.0	-11.5	-10.0
Back Off$_{out}$ (dB)	--	-3.5	-6.0	--	-3.1	-5.2	-4.2
Usable Bandwidth (MHz)	36 MHz	32.4	32.4	36.0	32.4	32.4	32.4
(36 MHz - 10% guard-band for multiple carriers)	(75.6 dBHz)	(75.1dBHz)	(75.1dBHz)	(75.6 dBHz)	(75.1dBHz)	(75.1dBHz)	(75.1dBHz)
Saturation Flux Density (dBW/m^2)	-75.0	-67.5	-67.5	-75.0	-67.5	-67.5	-67.5
Satellite G/T (dB/°K)	-11.6	-11.6	-11.6	-11.6	-11.6	-11.6	-17.6
C/N$_{up\text{-}path}$	29.0	28.4	24.9	29.0	29.4	25.9	21.4
C/N$_{inter\text{-}mod}$	--	23.4	21.7	--	22.0	20.3	18.9
C/N$_{down\text{-}path}$ (inc 0.6dB geo adv)	26.7	23.6	21.1	23.7	21.0	18.9	15.9
C/N$_{Total}$	24.7	19.8	17.5	22.6	18.1	16.1	13.4
Due to Co-Channel Interference	≈1.5	≈1.2	≈0.8	≈1.5	≈1.2	≈0.8	--
C/N$_{available}$ (dB)	23.2	18.6	16.7	21.1	16.9	15.3	13.4
Typical Number of Channels per Transponder	≈1,300	≈850	≈700	≈1,100	≈760	≈600	≈450

TABLE 2

Off-Angle Emission Limit Calculations

Parameter	Global	Frequency Re-Use	
		Hemi	Spot
Up-Path C/N (dB)	21.4	25.9	24.9
Up-Path Noise (pWOp)	1190	650	1140
Total Space Segment C/N (dB)	13.4	15.3	16.7
Total Space Segment Noise (pWOp)	7500	7500	7500
Satellite G/T (dB/K)	-17.6	-11.6	-11.6
BO_i	-10.0	-11.5	-12.5
Off-Beam Power Density Emission Limit for 400 pWOp of Interference (dBW/4 kHz)	20.5	17.5	15.1

TABLE 3

REQUIRED EIRP

Reuse Carriers (for 10° elevation including 1 dB margin)

Bandwidth Unit (MHz)	REGULAR CARRIERS: Carrier Size (channels)	e.i.r.p. (dBW)	Spreading Factor[1]	e.i.r.p. (dBW/4 kHz)	HIGH DENSITY CARRIERS: Carrier Size (channels)	e.i.r.p. (dBW)	Spreading Factor[1]	e.i.r.p. (dBW/4 kHz)
2.5	24	74.7	22.3	52.4	72	83.7	20.2	63.5
	36	77.7	22.8	54.9				
	60	81.4	22.4	59.0				
5.0	60	77.8	25.3	52.5	192	89.0	20.6	68.4
	72	78.6	25.8	52.8				
	96	82.2	25.6	56.6	252	88.2	23.7	64.5
	132	83.9	24.2	59.7				
7.5	96	79.5	27.0	52.5	312	88.2	26.0	62.2
	132	81.8	27.5	54.3				
	192	84.7	25.8	58.9	—	—		
10.0	132	80.6	28.0	52.6	792	92.4	26.4	66.0
	192	83.3	28.6	54.7				
	252	87.8	27.0	60.8	972	92.9	27.6	65.3
15.0	252	82.8	30.0	52.8	1332	88.6	29.8	58.8
	312	85.2	30.2	55.0				
	432	86.4	27.6	58.8	—	—		
20.0	432	84.6	31.5	53.1	—	—		
	612	88.1	28.9	59.2				
25.0	792	89.5	30.0	59.5				
36.0	972	86.6	34.5	52.1				
17.5	432	88.0						
17.5	TV	88.0						
30.0	TV	88.0						

Required e.i.r.p.[2] for Regular Global Beam Carriers
(for 10° elevation angle including 1 dB margin)

Bandwidth Unit (MHz)	REGULAR CARRIERS: Carrier Size (channels)	e.i.r.p. (dBW)	Spreading Factor[1]	e.i.r.p. dBW/4 kHz
2.5	24	74.7	22.3	52.4
	36	77.7	22.8	54.9
	60	83.7	22.4	61.3
5.0	60	77.8	25.3	52.5
	72	78.6	25.8	52.8
	96	82.2	25.6	56.6
	132	86.3	24.2	62.1
7.5	96	79.5	27.0	52.5
	132	81.8	27.5	54.3
	192	87.1	25.8	61.3
10.0	132	90.6	28.0	52.6
	192	83.3	28.6	54.7
	252	87.8	27.0	60.8
15.0	252	82.8	30.0	52.8
	312	85.2	30.2	55.0
20.0	432	86.6	31.5	55.1
25.0	432	85.1	32.2	52.9
36.0	972	90.1	34.5	55.6
	1092	93.6	32.2	61.2
17.5	432	88.0	30.8	57.2
17.5	TV	88.0		
30.0	TV	88.0		

NOTES:

[1] This spreading factor is calculated as shown in the notes of Tables 3.7(a) and 3.7(b) of DC-11-40. It is the ratio of unmodulated carrier power to maximum carrier power density under full load conditions (dB/4 kHz).

[2] These tables are extracts from above referenced document.

INTERFERENCE FROM SMALL EARTH STATION INTO MULTI-CARRIER INTELSAT TRANSPONDERS FOR SATELLITE SEPARATIONS OF 3°

INTELSAT IV and IV-A

Mode of Operation	97' (30 Meter) Telephony (pWOp)	97' TV (pWOp) Typical	97' TV Max.	32' (10 Meter) Telephony (pWOp)	32' TV (pWOp) Typical	32' TV Max.	25' (8 Meter) Telephony (pWOp)	25' TV (pWOp) Typical	25' TV Max.	16' (5 Meter) Telephony (pWOp)	16' TV (pWOp) Typical	16' TV Max.	10' (3 Meter) Telephony (pWOp)	10' TV (pWOp) Typical	10' TV Max.
A. INTER-Connected SERVICE															
• Global	0	50	200	150	650	*	300	850	*	550	*	*	1000	*	*
• Spot	0	100	350	300	850	*	400	1050	*	750	*	*	1200	*	*
• Freq. re-use	0	200	500	400	~1300	*	500	~2000	*	1100	*	*	*	*	*
B. LEASED SERVICE															
• Global	0	100		50	700		175	900		350	*		600	*	
• Spot	0	150		150	900		325	1100		450	*		800	*	
• Freq. re-use	0	300		200	~1500		450	~2200		850	*		1300	*	

*Interference too high to be considered (i.e., above 1500 pWOp).

NOTES:

The following small earth station e.i.r.p. levels apply to above table.

A. For inter-connected service:

1. global, spot, and frequency re-use -- (range of 24-60 channels per carrier) ≈ 52 dBW/4 kHz
2. typical TV -- ~ 80 dBW/MHz (full-transponder) ≈ 56 dBW/4 kHz
3. maximum TV -- ~ 85 dBW/MHz (½-transponder) ≈ 61 dBW/4 kHz

B. Leased service:

1. global, spot, frequency re-use -- ≈ 48 dBW/4 kHz
2. TV -- ~ 80.9 dBW/MHz ≈ 56.9 dBW/4 kHz

C. In the case of telephony, 2 dB has been added to the dBW/4 kHz conversion to represent the equivalent ratio of unmodulated carrier power to maximum carrier power density under full load conditions.

(B) WITHIN THE INTELSAT SYSTEM, CONSIDERING THE TYPE OF TRANSMISSION PARAMETERS, IT IS CONSIDERED A ROUGH RULE OF THUMB THAT IF THE REFERENCE SIDELOBE PATTERN PERTAINS (I.E $G = 32-25 \log \theta$) THAT THIS MAY LIMIT TV TRANSMISSION TO ANTENNAS OF NO SMALLER THAN 10M. TELEPHONY SERVICE ON THE OTHER HAND CAN BE TRANSMITTED FROM MUCH SMALLER STATIONS E.G. 3M OR 5M ANTENNAS.

(C) IT MAY BE POSSIBLE IN CERTAIN PARTICULAR CASES TO INTERPRET THE SPECTRAL E.I.R.P DENSITIES AS AVERAGE LEVELS OVER BANDWIDTHS WIDER THAN 4 KHz WHERE THE INTELSAT SERVICES LIABLE TO SUFFER INTERFERENCE THEMSELVES HAVE RELATIVELY WIDE BANDWIDTHS. THIS FACTOR PRIMARILY ENTERS INTO ACCOUNT WHEN SCPC CARRIERS ARE INVOLVED.

(D) ON THE DOWNLINK SIDE IT IS NOT EXPECTED THAT THE SMALLER EARTH STATIONS WILL SUFFER ANY SIGNIFICANT INTERFERENCE SINCE THEY WILL NORMALLY HAVE A HIGHER SYSTEM NOISE TEMPERATURE TO BEGIN WITH. FOR CALCULATION PURPOSES THE REFERENCE SIDELOBE PATTERN $32-25 \log \theta$ IS USED.

5. FUTURE DEVELOPMENT

(A) EARTH STATIONS WITH G/T VALUES OF 31.7 dB/^{o}K ARE COMING INTO SERVICE FOR DOMESTIC SERVICES THROUGH LEASED TRANSPONDERS. THEY ARE GENERALLY EQUIPPED TO PROVIDE BOTH TELEPHONY (USUALLY SCPC OR FDM/FM) AND TV.

(B) IN THE AREA OF SCPC, COMPANDED FM AND DELTA MODULATION ARE CANDIDATES FOR APPLICATION TO THE SPACE SEGMENTS. USE OF SUCH CARRIERS SUBSTANTIALLY INCREASES THE SPACE SEGMENT CAPACITY PER UNIT BANDWIDTH, COMPARED TO THE USE OF THE PRESENT STANDARD FDM/FM OR 64 KBps PCM/PSK CARRIERS. THEIR LOW POWER REQUIREMENTS, HOWEVER, INCREASE THEIR SUSCEPTIBILITY TO INCREASE, PARTICULARLY FROM A TV CARRIER WITH SPREADING ONLY FROM AN ADJACENT SATELLITE, AND THIS WILL REQUIRE CAREFUL FREQUENCY PLAN COORDINATION.

TABLE 5 SHOWS TYPICAL CAPACITIES THAT ARE ATTAINABLE WHEN USING THESE HIGHER EFFICIENCY SYSTEMS.

(C) INVESTIGATIONS ARE BEING CARRIED OUT TO DETERMINE THE TYPES OF SERVICES THAT CAN BE PROVIDED THROUGH SMALLER ANTENNAS, E.G. 3M OR 5M. THESE CAN PROVIDE SMALL SCALE TELEPHONY AND DATA SERVICES TO WIDELY DISPERSED AREAS. IN GENERAL IT WILL BE EXPECTED THAT THE OFF-BEAM POWER DENSITY LIMIT SHOULD BE ADHERED TO, AND THAT THIS CAN BE ACCOMPLISHED BY SPECTRUM SPREADING TECHNIQUES.

INTELSAT IV or IV-A global beam transponder	Earth Station G/T = 40.7 dB/^{o}K			Earth Station G/T = 31.7 dB/^{o}K	
		Single Channel per Carrier [2]		Single Channel per Carrier [2]	
	Regular FDM/FM/FDMA [1]	64 KBps 4-Phase PCM/PSK	Companded FM or Delta Mod.	64 KBps 4-Phase PCM/PSK	Companded FM or Delta Mod.
5 MHz BANDWIDTH UNIT					
No. of channels:					
(i) without voice activation	~65	70	-	14	55
(ii) activity factor	-	1.6	-	1.2	1.7
(iii) with voice activation	-	110	-	17	94
10 MHz BANDWITH UNIT					
No. of channels:					
(i) without voice activation	~130	140	-	28	110
(ii) activity factor	-	1.6	-	1.5	1.8
(iii) with voice activation	-	220	-	42	198

[1] FDM/FM/FDMA capacity is based on a nominal 450 channels per transponder.

[2] SCPC carriers are assumed to be voice activated. The activity factor is a function of the number of carriers. The capacity shown is based on all carriers being received at a small earth station.

TABLE 5: Comparison of Channel Capacities for Bandwidths of 5 and 10 MHz

Characteristics on Network Isolation

C H Sc[illegible]

It can be shown that the "basic isolation" of a satellite network N from another satellite network N' is approximated by the expression:

$$c_o/i_o = \left[\frac{T_s'(c_o/n_o)_u'}{T_s(c_o/n_o)_u} \cdot \frac{g_2(\eta')}{g_2'(0)} \cdot \frac{g_1'(\theta)}{g_1'(0)} + \frac{T_e'(c_o/n_o)_d'}{T_e(c_o/n_o)_d} \cdot \frac{g_3'(\delta)}{g_3'(o)} \cdot \frac{g_4(\theta)}{g_4'(o)} \right]^{-1} \quad (1)$$

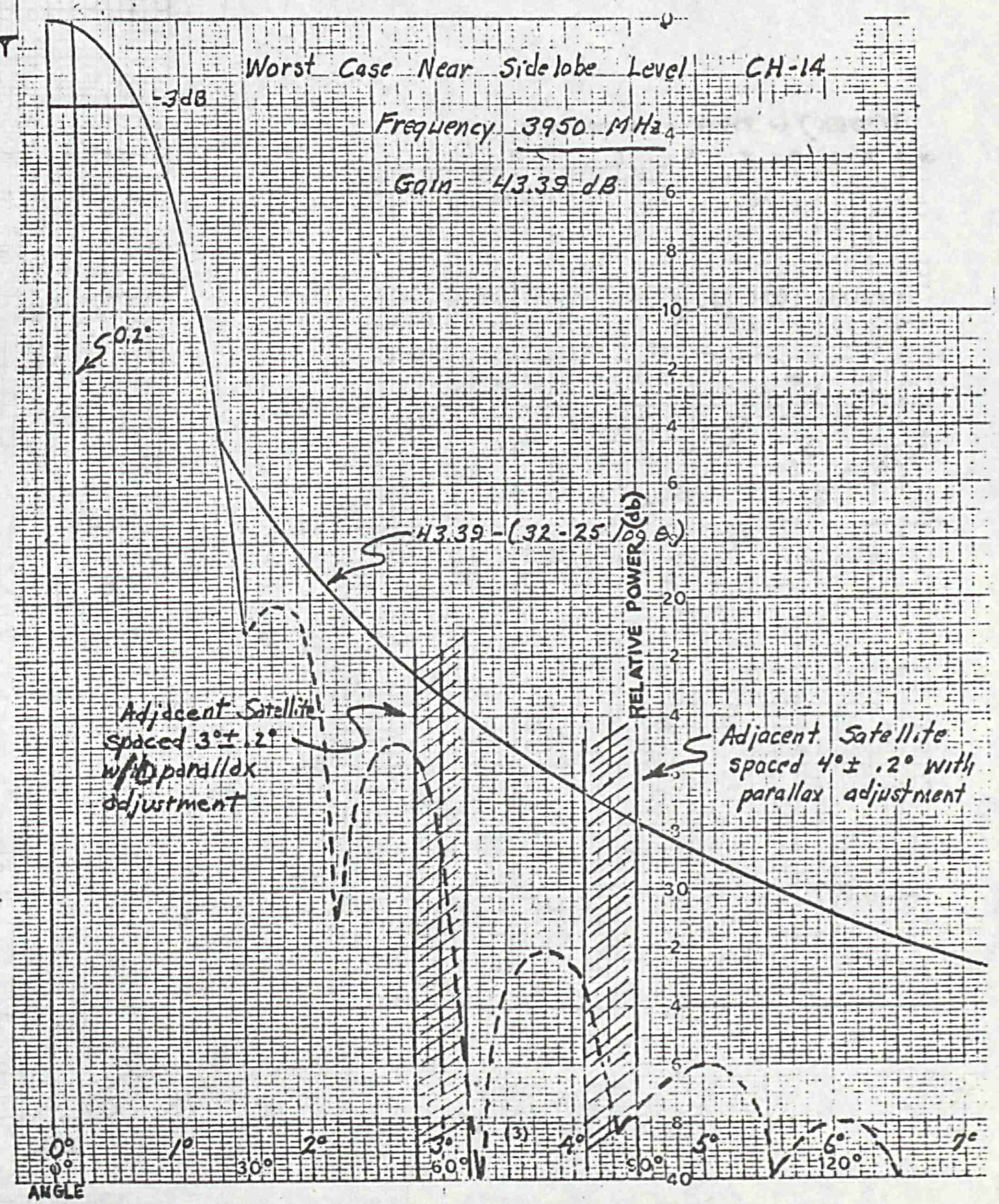
where parameters with primes refer to the network N'; all other parameters to the network N, and

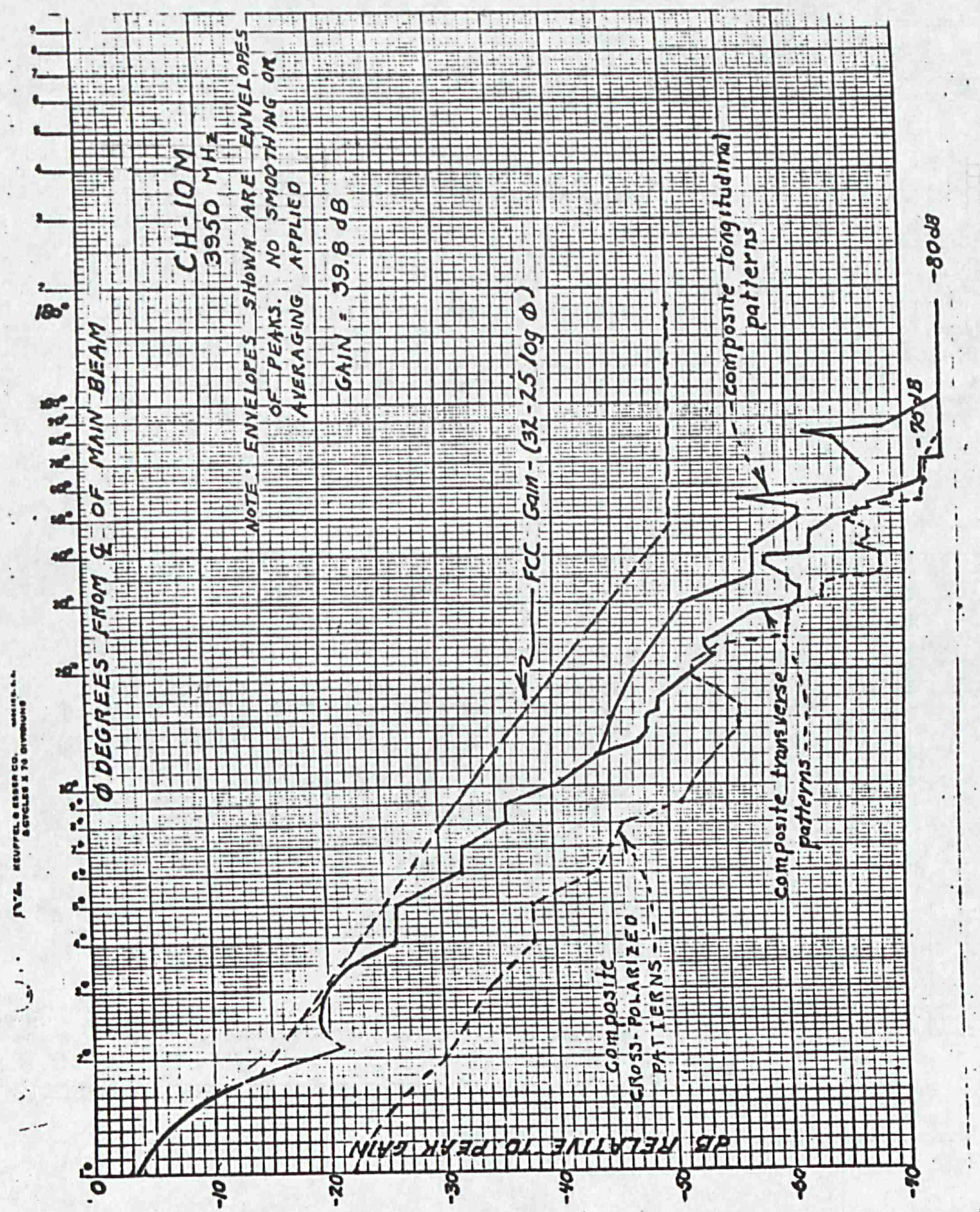
T_s, T_e	=	satellite (s) and earth station (e) receiving system noise temperatures (K);
$(c_o/n_o)_{u,d}$	=	mean carrier/thermal noise density ratios in the up-(u) and down-(d) paths at the nominal mean earth station and satellite transmitter operating levels;
$g_2(x)$	=	net satellite transmitting antenna gain in the direction x;
(0)	=	nominal operating direction;
(η')	=	direction to an earth station of network N';
$g_1(y)$	=	transmitting antenna gain of an earth station in the direction y;
θ	=	geocentric angular separation between satellites of the networks N and N';
$g_3'(z)$	=	transmitting antenna net gain of the satellite of the network N' in the direction z;
(δ)	=	direction to an earth station in the network N;
$g_4(u)$	=	receiving antenna gain of an earth station in the direction u.

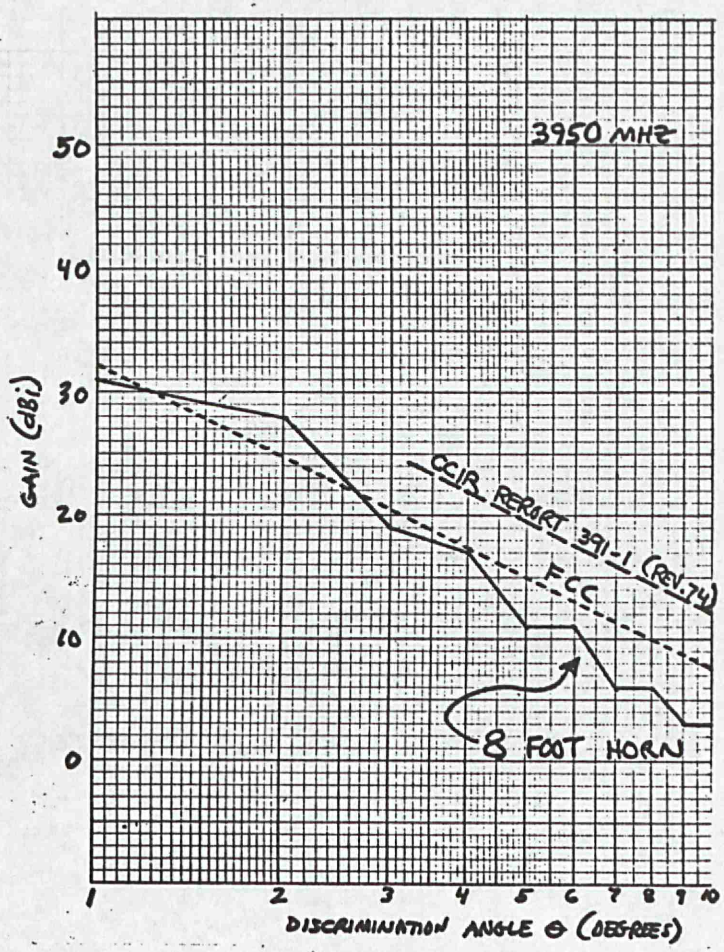
The net "basic isolation" of network N from network N' is that for which the term in square brackets of equation (1) is a minimum when considering all possible consistent combinations of values for the parameters.

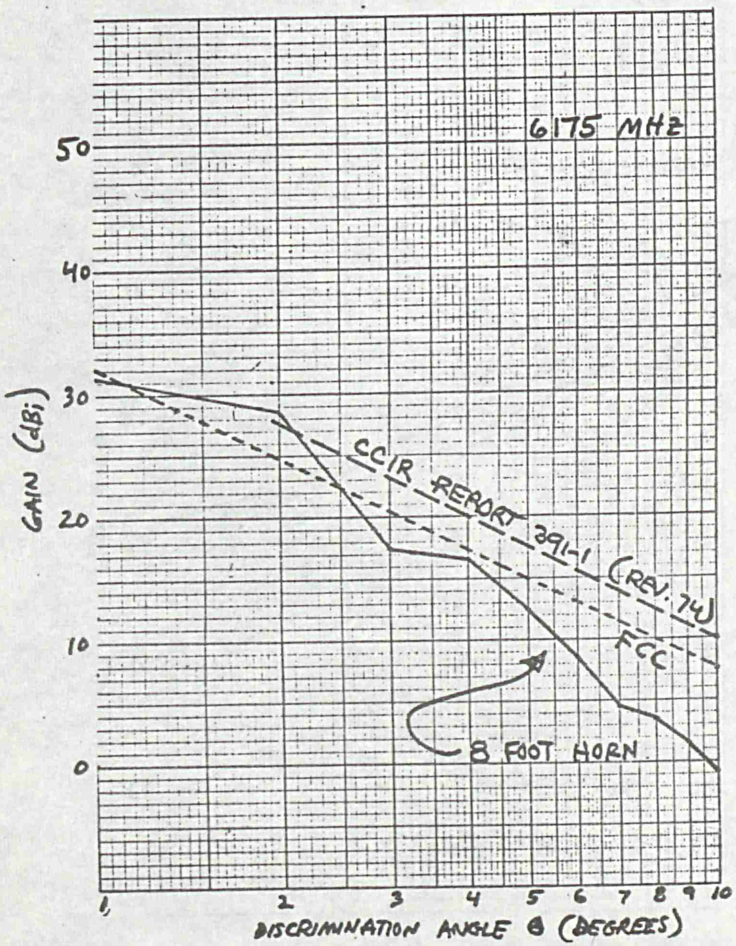
For identical networks with essentially overlapping coverages and identical mean transmission characteristics, equation (1) is reduced to the mean earth station antenna discrimination:

$$(c_o/i_o)_{id} = \left[\frac{g_1(\theta)}{g_1(o)} + \frac{g_4(\theta)}{g_4(o)} \right]^{-1} \quad (2)$$

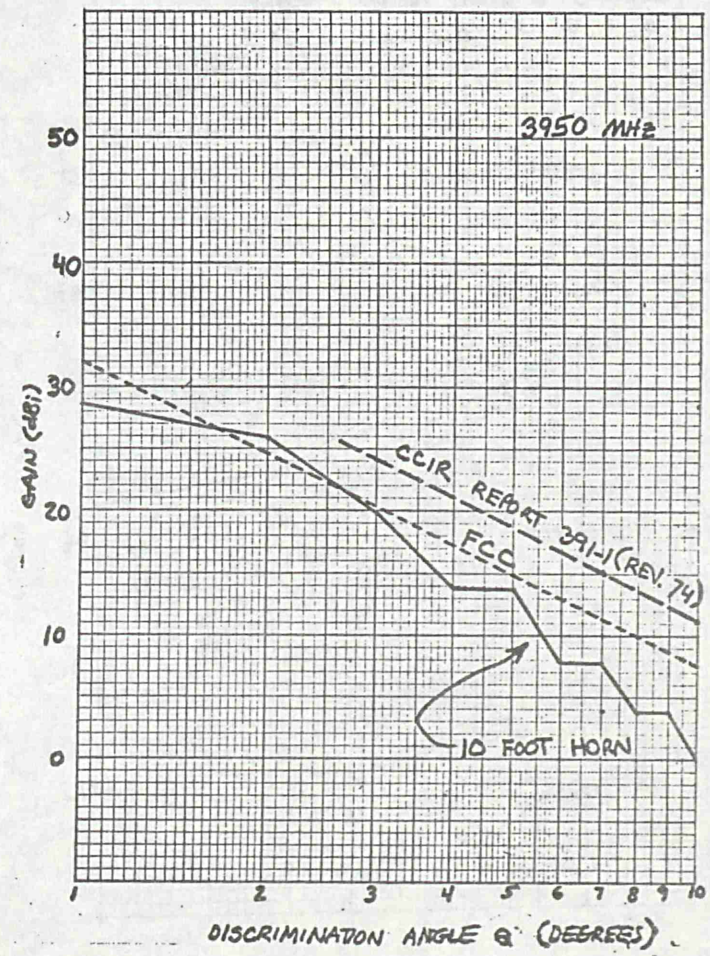



CH-10M
3950 MHz
NOTE: ENVELOPES SHOWN ARE ENVELOPES OF PEAKS. NO SMOOTHING OR AVERAGING APPLIED
GAIN = 39.8 dB
φ DEGREES FROM ℄ OF MAIN BEAM
FCC Gain - (32-25 log φ)
composite longitudinal patterns
composite transverse patterns
composite cross-polarized patterns
-70dB
-80dB
dB RELATIVE TO PEAK GAIN
0
-10
-20
-30
-40
-50
-60
-70
-80
-90

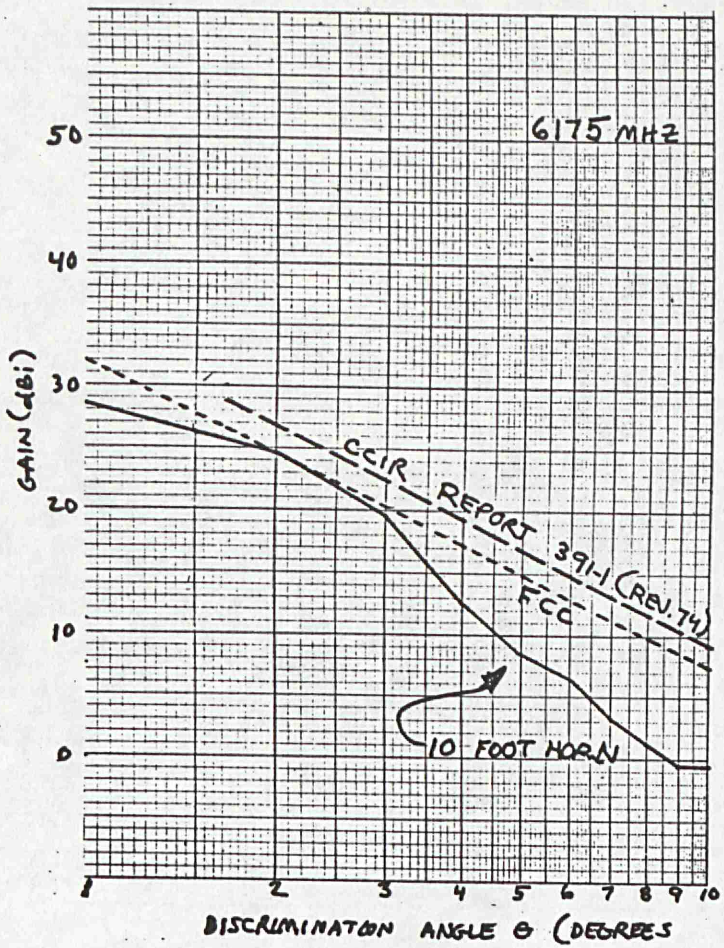

3950 MHZ
GAIN (dBi)
50
40
30
20
10
0
CCIR REPORT 391-1 (REV.74)
FCC
8 FOOT HORN
1
2
3
4
5
6
7
8
9
10
DISCRIMINATION ANGLE θ (DEGREES)

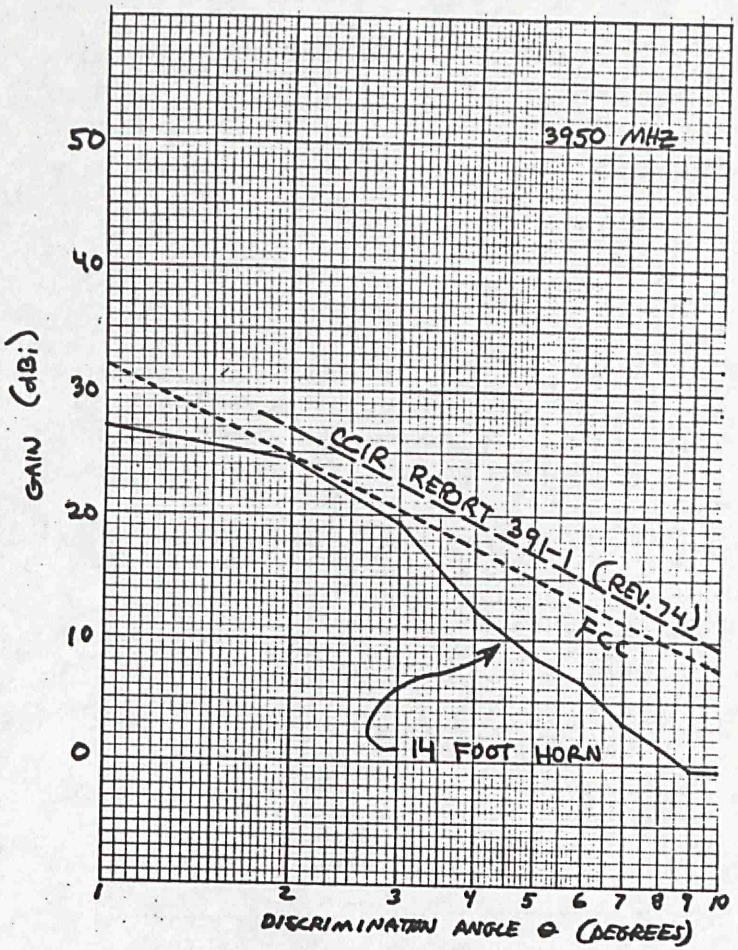


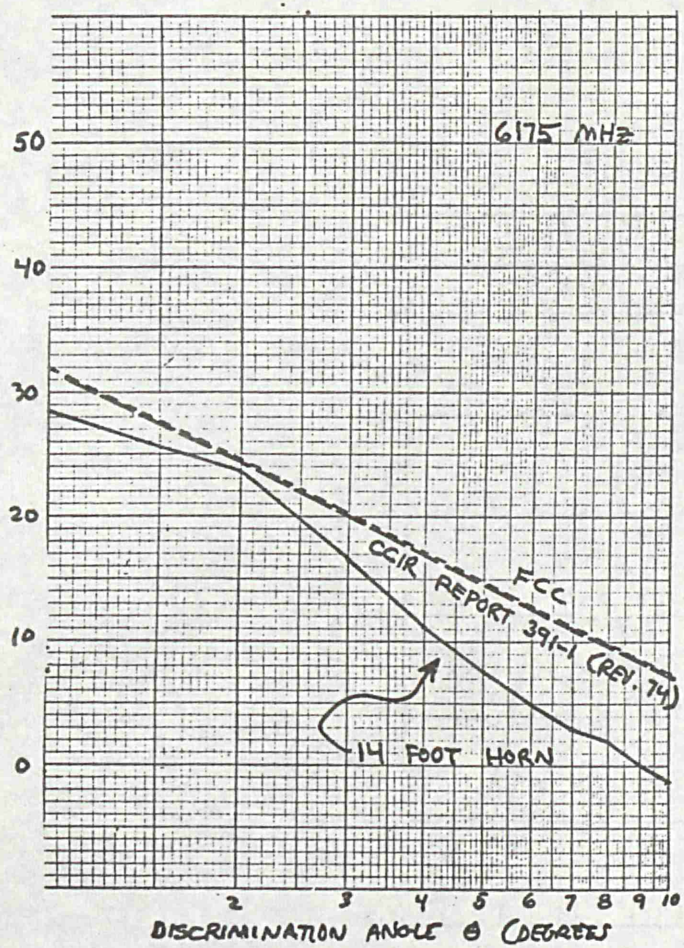
6175 MHz
GAIN (dBi)
50
40
30
20
10
0
CCIR REPORT 391-1 (REV. 74)
FCC
8 FOOT HORN
1
2
3
4
5
6
7
8
9
10
DISCRIMINATION ANGLE θ (DEGREES)



3950 MHz
GAIN (dBi)
50
40
30
20
10
0
CCIR REPORT 391-1 (REV. 74)
FCC
10 FOOT HORN
1
2
3
4
5
6
7
8
9
10
DISCRIMINATION ANGLE θ (DEGREES)


6175 MHZ
GAIN (dBi)
50
40
30
20
10
0
CCIR REPORT 391-1 (REV. 74)
FCC
10 FOOT HORN
1
2
3
4
5
6
7
8
9
10
DISCRIMINATION ANGLE Θ (DEGREES


3950 MHZ
GAIN (dBi)
50
40
30
20
10
0
CCIR REPORT 391-1 (REV. 74)
FCC
14 FOOT HORN
1
2
3
4
5
6
7
8
9
10
DISCRIMINATION ANGLE Θ (DEGREES)



UPLINK AND DOWNLINK ANTENNA DISCRIMINATION FOR VARIOUS COMBINATIONS OF ANTENNA SIZES (all in dB)

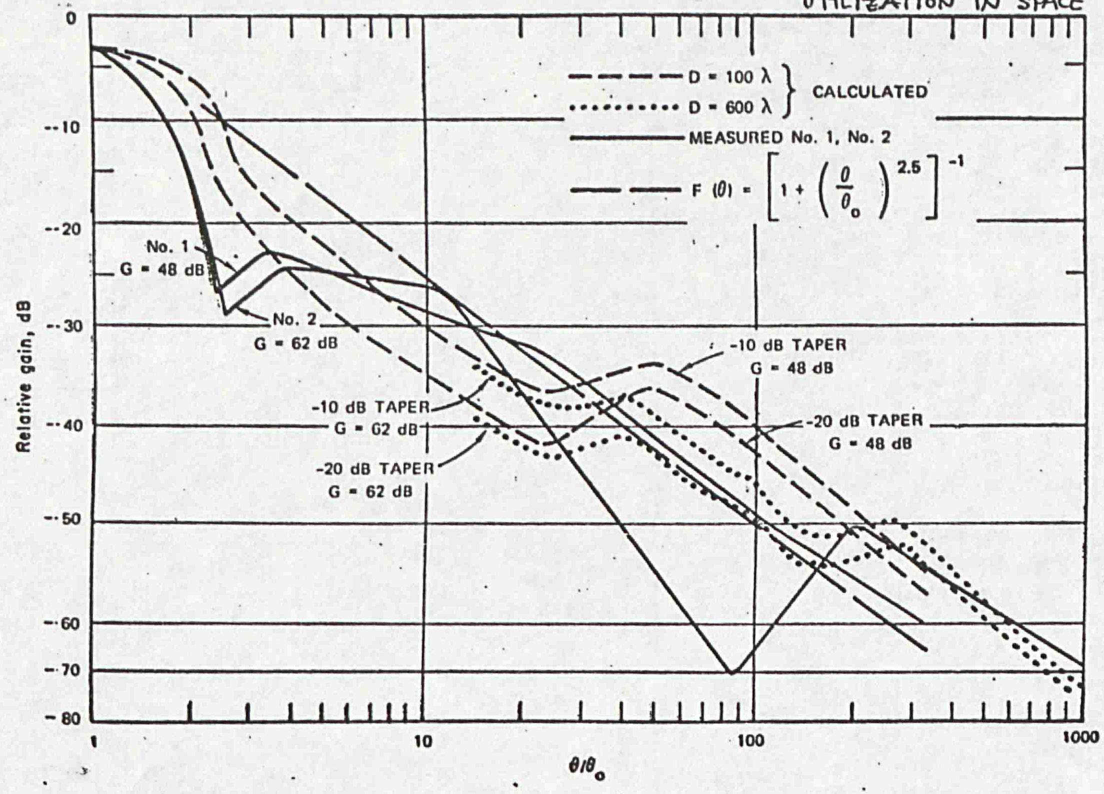
Transmitting antenna diameter (M)	(FT)			Receiving antenna diameter (M) 2.4 / (FT) 7.7 CCIR	2.4 / 7.7 HORN	2.9 / 9.5 CCIR	2.9 / 9.5 HORN	4.3 / 14 CCIR	4.3 / 14 HORN
2.4	7.7	CCIR	UP	17.8	17.8	17.8	17.8	17.8	17.8
			DN	11.5	18.9	15.1	20.0	20.3	24.0
			T	29.3	36.7	32.9	37.8	38.1	41.8
		HORN	UP	24.0	24.0	24.0	24.0	24.0	24.0
			DN	11.5	18.9	15.1	20.0	20.3	24.0
			T	35.5	42.9	39.1	44.0	44.3	48.0
2.9	9.5	CCIR	UP	20.9	20.9	20.9	20.9	20.9	20.9
			DN	11.5	18.9	15.1	20.0	20.3	24.0
			T	32.4	39.8	36.0	40.9	41.2	44.9
		HORN	UP	23.6	23.6	23.6	23.6	23.6	23.6
			DN	11.5	18.9	15.1	20.0	20.3	24.0
			T	35.1	42.5	38.7	43.6	43.9	47.6
4.3	14	CCIR	UP	25.6	25.6	25.6	25.6	25.6	25.6
			DN	11.5	18.9	15.1	20.0	20.3	24.0
			T	37.1	44.5	40.7	45.6	45.9	49.6
		HORN	UP	29.5	29.5	29.5	29.5	29.5	29.5
			DN	11.5	18.9	15.1	20.0	20.3	24.0
			T	41.0	48.4	44.6	49.5	49.8	53.5

UP = DIFFERENCE BETWEEN MAIN BEAM GAIN AT 6 GHz AND THE GAIN AT 3° OFF MAIN BEAM.

DN = DIFFERENCE BETWEEN MAIN BEAM GAIN AT 4 GHz AND THE GAIN AT 3° OFF MAIN BEAM.

T = SUM OF UP AND DN.

CASSEGRAN ANTENNA PATTERN CHARACTERISTICS FROM RADIO SPECTRUM UTILIZATION IN SPACE



APPENDIX J

SMALL EARTH TERMINALS
IN THE INTELSAT SYSTEM

SMALL EARTH TERMINALS IN THE INTELSAT SYSTEM

N.K.M. CHITRE
INTELSAT

OCTOBER 1975

POTENTIAL DEMAND

- NUMBER OF SMALL TERMINALS
- SERVICES THROUGH SMALL TERMINALS
  - CONVENTIONAL
    - TELEPHONY
    - TV
    - RECORD/DATA
  - EMERGING
    - CORPORATE DATA NETWORKS
    - DATA COLLECTION
    - MOBILE AND OTHERS

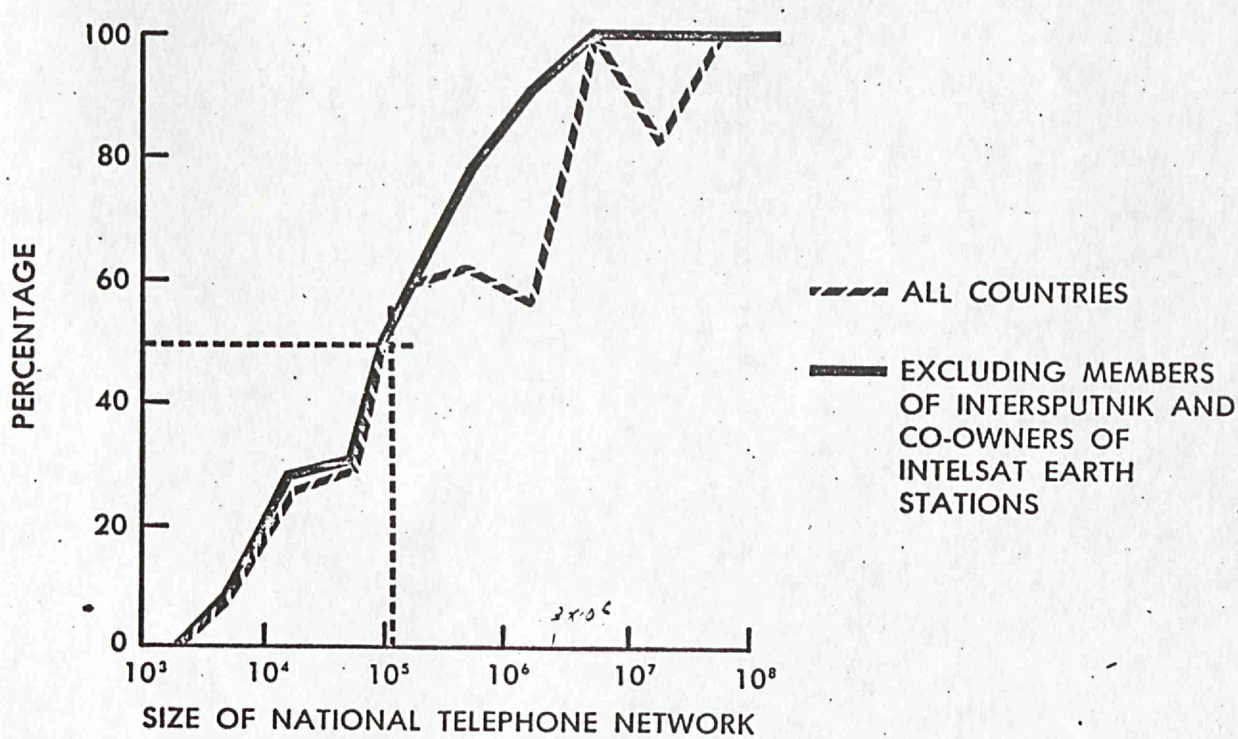
CONVENTIONAL SERVICES

HOW WELL HAS INTELSAT PENETRATED THE MARKET FOR INTERNATIONAL PUBLIC TELECOMMUNICATIONS SERVICES?

POSSIBLE CRITERIA:

SIZE OF THE NATIONAL TELEPHONE NETWORK

PERCENTAGE OF COUNTRIES HAVING STANDARD INTELSAT EARTH STATIONS VS. SIZE OF THE NATIONAL TELEPHONE NETWORK



# of Telephones in the country

INTELSAT

- NEED FOR A SECONDARY STANDARD EARTH TERMINAL IS LIKELY TO EXIST FOR NATIONS WITH LESS THAN 100,000 TELEPHONES
    - SMALL TRAFFIC STREAMS
    - SMALL TOTAL PROJECTED TRAFFIC
- POSSIBLE NEED FOR LOCATIONS WHERE PHYSICAL CONDITIONS PROHIBIT LARGE STATIONS
- COULD STIMULATE DEMAND FOR UNUSED CAPACITY
- COMMITMENT TO EXTEND SERVICE TO ALL POSSIBLE USERS

COUNTRIES WITH LESS THAN 100,000 TELEPHONES (1974)

TOTAL	136
INTELSAT USERS	48
OWNERS OF STANDARD EARTH STATIONS	22
PLANNING STANDARD EARTH STATIONS	25

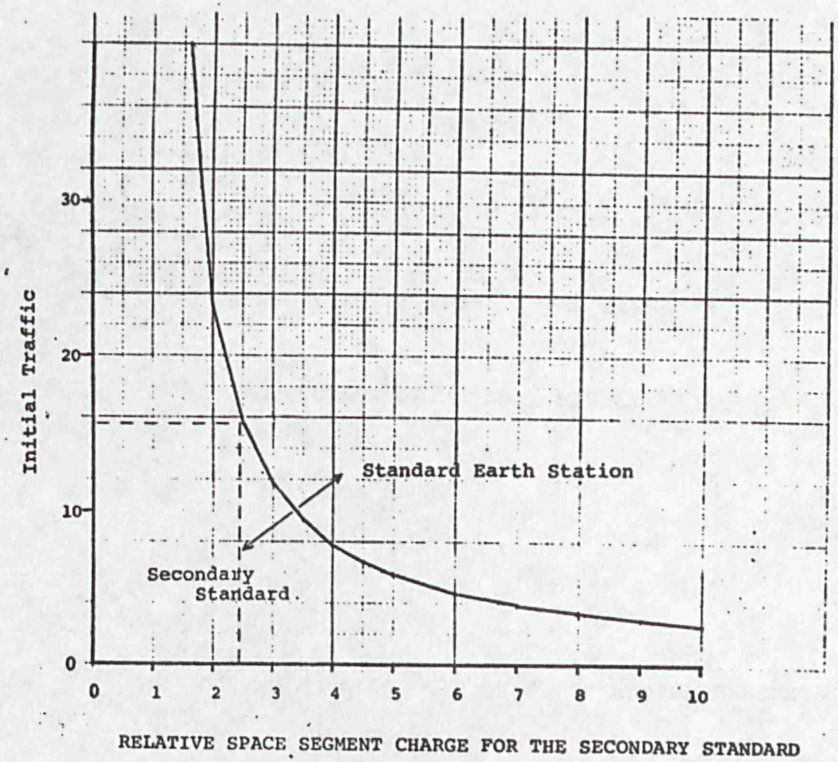
POTENTIAL USERS AND TRAFFIC DEMAND

Ocean Region	Number of Potential Areas	Telephone Population Distribution <2,000 (6)	2,000-10,000 (12)	11,000-100,000 (24)	
Atlantic	32	3	18	11	(500)
Indian	17	5	11	1	(250)
Pacific	8	5	2	1	(75)

Note: Figures in parentheses are approximate potential traffic demand in next 5 years

INITIAL TRAFFIC FOR ECONOMIC OPERATION

(This figure trades off the reduced cost of a secondary standard earth station against the increased relative charge of the space segment.)



- Cost Difference Between Standard and Non-Standard Earth Stations = \$1.5M
- Traffic Growth Rate = 20%/Year
- Reference Date: Year-End 1979
- Space Segment Charge for Standard Earth Stations \$6,330 Per Annum/Half Circuit in 1980, Reducing to \$4,100 Per Annum/Half Circuit in 1986
- Discount Rate: 10%

PROBABLE SECONDARY STANDARD EARTH STATION: G/T = 31.7 dB/k

POSSIBLE CONTROLS

- UPPER LIMIT ON NUMBER OF CIRCUITS
- LIMIT ON PERIOD OF OPERATION
- SPECIFIC AVAILABLE BANDWIDTH AND SATELLITE
- LIMIT ON NUMBER OF DESTINATIONS (FDM/FM/FDMA)
- RELATIVE CHARGE
- MORE EFFICIENT MODULATION/ACCESS TECHNIQUES

EXISTING

TOTAL	42
DOMESTIC SERVICE	28
INTERNATIONAL SERVICE	5
TTC&M	3

ANNOUNCED PLANS

TOTAL	24

MODULATION/ACCESS TECHNIQUES

INCREASING EFFICIENT USE OF POWER/ BANDWIDTH RESOURCE

STANDARD C.C.I.T.T. CHANNEL QUALITY

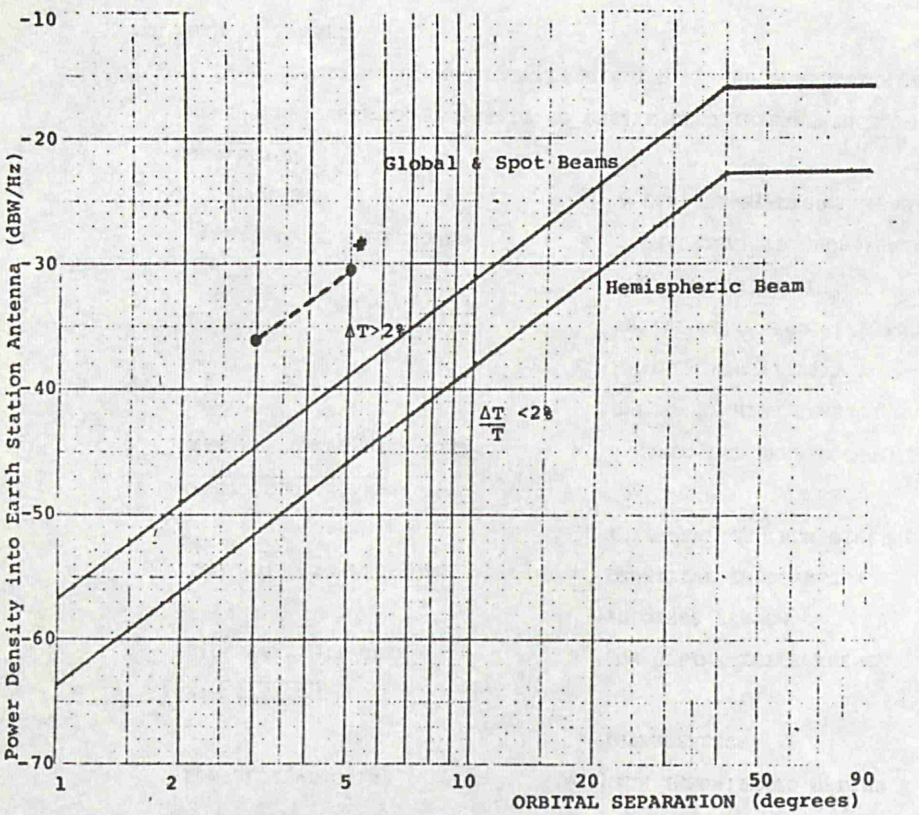
- FDM/FM/FDMA
- SCPC/FDMA
  - PCM/Q·PSK
    64 Kb/s
  - UNCOMPANDED FM

NON-STANDARD CHANNEL QUALITY

- SCPC/FDMA
  - COMPANDED FM
  - VARIABLE SLOPE DELTA MOD
    32 Kb/s

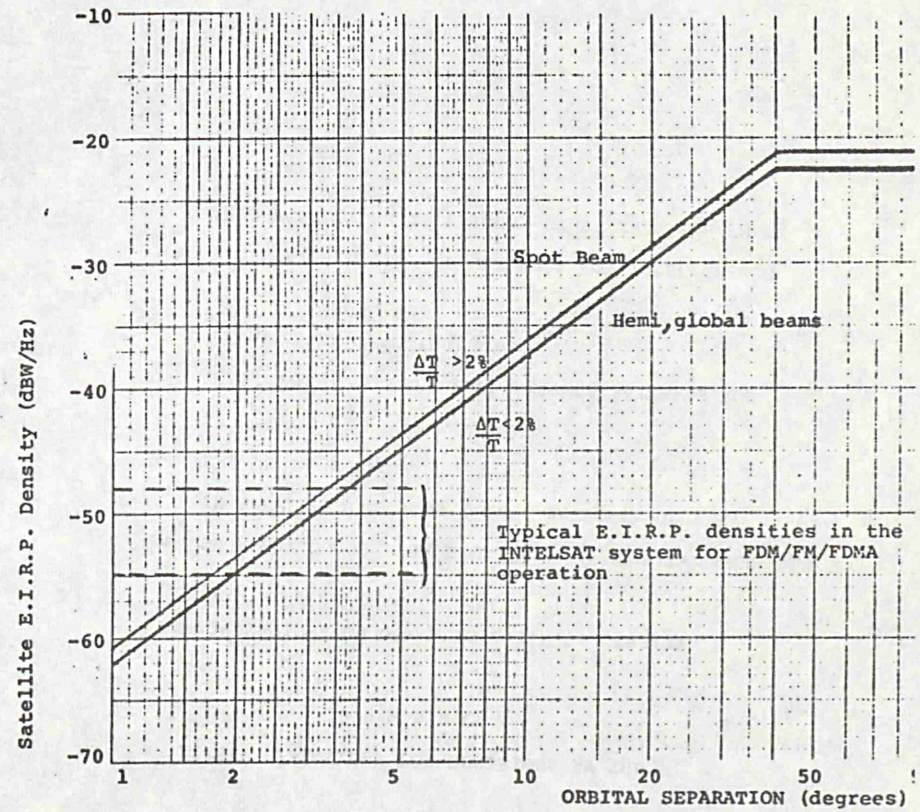
ORBIT/SPECTRUM UTILIZATION

- SMALL TERMINALS OPERATING WITH THE INTELSAT SYSTEM
  - IMPACT ON OTHER INTELSAT SERVICES:
    LIKELY TO PRODUCE MORE UPLINK INTERFERENCE
  - CONTROLS:
    APPROVAL OF TRANSMISSION PLANS
    OFF-AXIS E.I.R.P. DENSITY LIMIT
    (FOR OPERATION WITH LEASED TRANSPONDERS:
    20 dBW/4KHz IN THE DIRECTION OF NEIGHBORING
    SATELLITE AT 3° OR 5°)
- SMALL TERMINALS OPERATING WITH OTHER SYSTEMS
  - IMPACT ON INTELSAT SERVICES:
    LIKELY TO PRODUCE LARGE INTERFERENCE
  - CONTROLS:
    ?
  - LIMITS:
    C.C.I.R. RECOMMENDATIONS AND FINAL ACTS OF
    THE W.A.R.C.



UPLINK INTERFERENCE INTO MULTICARRIER FDM/FM

* Power density limitation on small terminals in leased transponder services.



DOWNLINK INTERFERENCE INTO MULTICARRIER FDM/FM

INTELSAT SYSTEM CHARACTERISTICS	ORBIT/SPECTRUM IMPLICATIONS
<u>SATELLITE</u>	
LOW E.I.R.P. DENSITY	• LOW DOWNLINK INTERFERENCE TO OTHER SYSTEM
LOW RECEIVE GAIN	• HIGH IMMUNITY TO UPLINK INTERFERENCE
<u>EARTH STATION</u>	
HIGH TRANSMIT GAIN	• LOW UPLINK INTERFERENCE TO OTHER SYSTEM
LOW NOISE TEMPERATURE	• SENSITIVE TO DOWNLINK INTERFERENCE FROM OTHER SYSTEM
<u>TRANSMISSION PLANS</u>	
VARIETY OF CARRIER SIZES	• MAXIMUM INTERFERENCE TO OTHER SYSTEM BY HIGH DENSITY CARRIERS • MAXIMUM SENSITIVITY TO INTERFERENCE FOR SCPC AND SMALL CARRIERS
FLEXIBILITY IN FREQUENCY PLANNING	• IMPRACTICAL TO COORDINATE ON A CARRIER-BY-CARRIER BASIS

<u>CONCLUSION</u>

THE INTELSAT SYSTEM IS LIKELY TO CREATE LESS INTERFERENCE TO SYSTEMS UTILIZING HIGHER SATELLITE E.I.R.P. AND SMALL TERMINALS THAN VICE-VERSA.

LIKELY DIRECTIONS FOR DECISIONS AT THE 1979 W.A.R.C.

- LIMITATIONS ON OFF-AXIS E.I.R.P. DENSITY
- SEGREGATION OF HIGH DENSITY (LOW DENSITY) CARRIERS IN PREFERRED REGIONS (OTHER REGIONS) OF THE FREQUENCY BANDS
- DEVELOPMENT OF REFERENCE ANTENNA PATTERNS FOR D/λ SMALLER THAN 100
- PROTECTION RATIOS OR CRITERIA FOR INTERFERENCE INTO MODULATION TECHNIQUES OTHER THAN FDM/FM

APPENDIX K

TECHNO-ECONOMICS OF U.S. DOMESTIC SATELLITE ORBIT-SPECTRUM UTILIZATION

TECHNO-ECONOMICS OF U.S. DOMESTIC SATELLITE

ORBIT-SPECTRUM UTILIZATION

by

Steven P. Russell

DRAFT
of
Technical Report No. 3
COMMUNICATION SATELLITE PLANNING CENTER

Radioscience Laboratory
Stanford University
Stanford, California 94305

October 1975

DRAFT

INTRODUCTION

The rapid growth of the U.S. domestic satellite industry has led to some concern about the adequacy of the available orbit-spectrum to meet the demands that may be placed on it. In particular, considerable concern has been expressed about the wisdom of permitting the use of 4.57-meter ground stations given the fact that these are less directional than ground stations of greater aperture and thus might require greater satellite spacings than ground stations of greater aperture. Herein, we present a summary of an analysis done at Stanford University of the problems posed by the fact that the available orbit-spectrum is limited.[1] Particular attention is paid to the problem of regulating antenna aperture.[2]

---

[1]The study is being submitted as a doctoral dissertation in Electrical Engineering at Stanford University.

[2]It must be pointed out that many issues beside orbit-spectrum conservation are involved in the question of allowing small ground stations. Such issues include:

a) Whether or not "private" satellites and user-owned ground stations ought to be allowed.
b) Whether or not competition in the provision of various kinds of satellite service ought to be allowed.
c) Whether or not the present rate base of established carriers ought to be supported in the face of such radical technological changes as end-to-end satellite service.

We believe that it is absolutely essential that these related issues be addressed on their merits alone in proceedings separate from proceedings on orbit-spectrum *per se*. Discussion of orbit-spectrum regulation ought to stick to traditional spectrum management issues. Of course, final policy on small ground stations, or any other specific problem, must take account of all the relevant issues, but mixing issues while analyzing them can only lead to confusion. Only questions of orbit-spectrum utilization were examined in this study.

DRAFT

The basic objective of the analysis was to obtain a sound and logical method for regulating the U.S. domestic satellite orbit-spectrum. We believe that such regulation should be based on the following facts:

- Even though the amount of spectrum available to the communication satellite services is limited, the amount of communication that can be provided within the allocated spectrum given foreseeable technology is much greater than conceivable needs.

- Consequently, the only unavoidable impact of the spectrum limitation is that costs are imposed on society that would not be imposed if spectrum were unlimited.

We believe that the objective of regulation ought to be to minimize those extra costs. This objective is best attained by taking the spectrum saving measures that minimize dollars spent per unit spectrum saved, and by delaying investment in spectrum saving measures until they are needed. The analysis summarized here conforms to these principles. Key results include:

- Major investment in spectrum saving measures are not needed now and should not be made.

- When spectrum saving measures are needed, it is the communication satellite systems with few ground stations carrying a lot of traffic that ought to take these measures. It is these systems that need spend the fewest additional dollars per unit spectrum saved.

- Conversely, prohibiting small aperture ground stations is an inefficient way of conserving spectrum because it is enormously more expensive per unit spectrum saved than other methods.

- The latter two statements are reflections of the fact that the ratio between investment in communication satellite system hardware and spectrum used is far higher for small aperture systems than it is for systems with large ground stations carrying heavy traffic.

The development of these results is fully discussed in the complete analysis. This summary presents the viewpoint adopted to attack the problems posed by the orbit-spectrum limitation, the major conclusions reached as outlined in the above statement, and quantitative illustration of the major conclusions. The reader who desires a full discussion of the techniques employed in the analysis for the purposes of a detailed critical assessment of the analysis may consult the full text of the analysis itself.

ORBIT-SPECTRUM REGULATION: A VIEWPOINT

Through use of advanced spectrum conservation and re-use technologies, a very large amount of communication (as measured in erlangs of traffic or number of channels) may be provided in the bands allocated to communication satellite service. This quantity of satellite communication, which is possible by virtue of the use of all available technological advances, is far in excess of projected needs.[3] Further, many other alternatives to microwave satellite communications exist.[4] Consequently, the limited availability of orbit-spectrum does not require that all available spectrum conservation and re-use techniques be used. Only a subset that meets the forecast requirements need be used. We believe that the subset chosen should be the least expensive combination of techniques, and that the objective of orbit-spectrum regulation ought to be to minimize the additional costs for communication imposed on society that would not be imposed if the orbit-spectrum were not limited.

As this point is important and is somewhat novel, it bears amplification. Reinhart [1] stated the goals of orbit-spectrum regulation thus:

> Most fundamentally, the objectives are to permit the systems of all nations and services that are authorized to share a given allocation to satisfy the total communication need for which the allocation was established without causing excessive intersystem interference.
>
> Ideally, the objectives of an intersystem orbit-spectrum sharing strategy would also include the following points:
>
> 1. Ensure reasonably efficient utilization of the orbit-spectrum resource by the systems of each service.
> 2. Ensure that systems of each service and nation will have access to a share of this resource proportional to its foreseeable needs.
> 3. Permit each service to grow at its own pace and with as much design independence as is consistent with objectives 1 and 2.
> 4. Equalize and, to the extent possible, minimize the economic impact of sharing on each service.

Except for a change in emphasis, we substantially agree with this excellent statement of the objectives of orbit-spectrum management. We would emphasize, however, economic measures of the effectiveness of policy rather than technical measures of effectiveness. We believe that, for a given mix of communication services, "reasonably efficient utilization of the orbit-spectrum resource" ought to mean utilization that minimizes the cost of providing that mix of services. We believe that "excessive intersystem interference" ought to mean interference that imposes more costs on all systems in the aggregate than is necessary. Since the coordination that would be required by some policies can in itself impose significant costs, we agree with Reinhart's statement that policy should "permit each service to grow at its own pace and with as much design independence as is consistent" with the fundamental goal of economic efficiency in a dynamic, growing industry.[5]

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[3] Satellites could be spaced 1° apart in the 20 and 30 GHz band, and frequencies could be re-used tens of times through employment of spot beams. Through these means, a few tens of millions of simultaneous telephone conversations could be carried. This would be expensive, and it would require solution of significant technical problems. Nevertheless, such large orbit capacities are no doubt technically feasible.

[4] The terrestrial technologies of millimeter waveguide and optical waveguide have been advancing rapidly. The debate over the relative economics of satellites and coaxial cable continues. Finally, optical or millimeter wave ground-satellite links are a possibility.

[5] We also agree with the sentiment behind Reinhart's point 4; we agree that it is important to be fair and to avoid arbitrary decisions. We would, however, rephrase the point to read, "Minimize and, to the extent possible, equalize the economic impact of sharing on each service."

Debates over spectrum policy occasionally include discussion of the social worth of the various contending services. It may be argued that one service may be more valuable than another in a social sense, and hence that it should be given preferential access to spectrum so that some essential form of communication will not be denied the public. Such discussions need not enter the deliberation over orbit-spectrum policy since all demands can be met within the available orbit-spectrum.[6]

Reinhart [1] points out many ways in which the capacity of the orbit, as calculated by him, can be doubled and redoubled; by considering technologies that he did not include in his study, we have found additional ones. It seems to us that the major factor limiting the capacity of the available orbit-spectrum is the cost of increasingly sophisticated technologies for dealing with orbit-spectrum shortage and the attendant inter-system interference. The orbit-spectrum shortage does not make itself felt by challenging our technical ability to meet growing communication needs; it makes itself felt by forcing the expenditure of funds both to limit interference and spectrum use and to deal with interference.

[6]Since there is no need to divide a limited amount of communications capacity among competing claimants, there is no need to consider the social worth of what each of the claimants has to communicate. Worth of service should not be part of the scales that are used to weigh the claims of the various parties because the technical ability to provide service is not in question. The essential question should be, "How do various forms of orbit-spectrum management increase the costs of the parties involved?" If the answer to this question is ever completely understood, then study of the technical problems of the orbit-spectrum limitation has nothing more to offer.

The objection might be raised that these expenditures could raise the cost of some socially desirable services to "unreasonable" levels, even though the aggregate level of these expenditures is minimized. In essence, this is arguing that some service should be subsidized for social reasons. We believe that such subsidy should be considered outside the realm of orbit-spectrum regulation. Subsidy and orbit-spectrum management are separate issues. The former seeks development of a socially beneficial mix of services; the latter seeks minimization of the total cost of dealing with the orbit-spectrum limitation.

Consequently, an economic measure of policy effectiveness can avoid the "social benefits" quagmire. Policies and strategies for orbit-spectrum management in meeting increasing communication demands can be judged on an objective basis: their effect on communications costs. To reiterate, we believe that the goal of orbit-spectrum policy should be to minimize these costs for society as a whole. Equivalently, the goal of policy ought to be to <u>minimize the total cost of dealing with the orbit-spectrum limitation while meeting the communication demands of the society</u>.

Since the available quantity of orbit-spectrum is limited, policy clearly must limit the amount that each user occupies. The main technical question is deciding the form that these limits should take.

In answering this question, we believe that it is vital to avoid confusing the need for conserving depletable resources, such as oil, with the need for managing non-depletable resources, such as spectrum. Inhibiting the use of spectrum today in no sense increases the amount available for use tomorrow. Indeed, a realistic view is that since time is one dimension of spectrum, spectrum is instantaneously lost and recreated at a constant rate. Spectrum is a flow resource; spectrum not used today is forever wasted. Resource not used at any instant is gone and cannot be reclaimed.

Reinhart [1] has suggested a strategy to take advantage of the non-depletable property of orbit-spectrum:

> ...it should be noted that a sharing strategy might include a sequence of design constraints to be applied progressively as the total number and diversity of active systems grows in time. The guideline here would be to constrain each new system only to the extent required for the maximum degree of sharing anticipated during its lifetime.

Such a strategy of imposing successively tighter limits on spectrum use would have several advantages over a "static" strategy:

- Sharing tactics can more readily take advantage of technical advances, thus lowering the cost of achieving a given level of sharing.
- Use can be made of spectrum that would lie vacant under a "static" strategy.
- The investment required to achieve a given level of sharing could be delayed, thus lowering the costs of such investment as discounted to present value.
- The sharing tactics adopted could be adapted to the actual mix of services rather than being ased on a forecast of this mix.

However, as Reinhart states, "An obvious problem in the practical application of such a phased strategy is its requirement for accurate long-range predictions of future systems growth" (to determine the

maximum degree of sharing required during the lifetime of each system).[7] In short, a strategy of progressive sharing has many advantages, but some means must be used to deal with risks and future uncertainty. The alternative to a strategy of progressive sharing is to reserve, at the outset, orbit-spectrum for future growth.[8] In a sense, this alternative begs the question as one must still predict long-range growth to determine how much orbit-spectrum to reserve.

In any case, we believe that the nature of the sharing tactics that should be adopted are independent of which of the above alternatives is chosen. We have argued that the goal of orbit-spectrum policy ought to be minimization of the total cost of dealing with the orbit-spectrum limitation, while meeting the communication demands of society. It follows that when orbit-spectrum is either vacated or reserved, this

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[7] Another objection may be as follows: since in fact it is very difficult to reduce a user's spectrum assignment once spectrum has been assigned to that user, we must reserve spectrum for future needs so as to avoid so-called "grandfathering." The channel splitting that has been used to multiply the number of aeronautical and land mobile radio channels shows that re-assignment of spectrum is possible, but the difficulties must not be underestimated. We will not address the administrative problems posed by grandfathering; here we wish merely to provide an unbiased assessment of the technical and economic factors. The actual formulation of policy must necessarily be a compromise between the ideal and the possible given administrative and political constraints.

[8] As Reinhart has shown [1], the satellites that will occupy the reserved arc should be as homogeneous as possible. Thus, if arc is reserved for future use, the reservations should be made on the basis of the technical characteristics of the satellites for which the arc is being reserved. The reservation should not be made on the basis of the type of service to be provided or the type of user obtaining the service.

"conservation" ought to be done in the cheapest way possible. Orbit-spectrum use ought to be restricted in a way that minimizes the dollars spent per unit of orbit-spectrum vacated or reserved. If the various sharing tactics involve different expenditures at different times, then the costs of these tactics can be compared by discounting them to present value.[9]

In sum, the point of view is as follows: ORBIT-SPECTRUM POLICY OUGHT TO FOCUS ON MINIMIZING THE ECONOMIC IMPACT OF THE ORBIT-SPECTRUM LIMITATION THROUGH EMPLOYMENT OF EFFECTIVE TECHNICAL MEANS. THE BEST MEASURE OF EFFECTIVENESS IS THE COST OF SPECTRUM SAVINGS DISCOUNTED TO PRESENT VALUE DIVIDED BY THE ORBIT-SPECTRUM SAVED. We have called this ratio the "normalized cost of spectrum savings."

[9] The difference between depreciation accounting and capital budgeting must be kept clearly in mind. The latter is used in planning expenditures; the former is used in allocating sunk costs. The interest rate for the latter reflects risk, availability of alternative investments, and the cost of capital; the depreciation rate for the former reflects asset lifetimes, taxes, and tariff setting. It could make perfect sense to analyze a proposed investment using 50% discount rate, but depreciate the investment after it is made at a 4% annual rate.

IMMEDIATE CONSEQUENCES

The above viewpoint leads to two immediate consequences. These are given below. The first has to do with the timing of measures to conserve spectrum.

INVESTMENT IN SPECTRUM SAVING TECHNOLOGY SHOULD BE DELAYED UNTIL IT COSTS MORE TO DELAY THAN IT DOES TO INSTALL, WHERE ALL COSTS ARE DISCOUNTED TO PRESENT VALUE.

Because of the discount rate that should be used in the capital budgeting decisions, it is generally economic to conserve capital by installing spectrum conserving hardware only when it is necessary, even if a substantial penalty must be paid in the retrofit: it is better policy to invest in a cheap system when orbit-spectrum is plentiful and to retrofit later when orbit-spectrum is in greater demand than it is to invest in an expensive system initially.[10] Investment should not be

[10] For example, large users should be allowed to install multi-channel per carrier FM/FDM equipment now, even though other modulations would use spectrum more efficiently. (Both Single Channel per Carrier FM and Digital Speech Interpolation are more efficient; they are discussed later.) When spectrum becomes more valuable in the future, the large users may retrofit. Such a strategy is considerably cheaper than having large users install these newer technologies now.

The retrofit itself would leave most of the installed equipment intact. Further, it may be possible to install the more efficient modulations as the older equipment nears the end of its life. Thus, a retrofit could involve merely replacing equipment that would have to be replaced in any case.

Finally, this example illustrates the essential role of technical change in orbit-spectrum management. With the passage of time, more effective satellite technologies should become available at less cost. It may pay to maintain flexibility in order to exploit these developments. Thus, although we used an interest rate of 10% in our calculations of present worth, a higher interest rate may well be appropriate. An interest rate of 10% is appropriate for stabilized technologies; a higher rate would reflect the uncertainties of technological change.

made now in anticipation of later scarcity. Rather, the scarcity should be dealt with as it arises.[11]

The second immediate conclusion specifies a method for selecting the system to take spectrum conservation measures when such measures are required.

THE SYSTEM THAT OUGHT TO BE REQUIRED TO TAKE ORBIT-SPECTRUM CONSERVATION MEASURES IS THE SYSTEM THAT CAN SAVE THE MOST SPECTRUM PER DOLLAR SPENT. THE MEASURE THAT OUGHT TO BE TAKEN BY THAT SYSTEM IS THE ONE THAT SAVES THE MOST SPECTRUM PER DOLLAR.[12]

This consequence follows immediately because the normalized cost of orbit-spectrum savings is least for this system and this measure.[13]

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[11]Users should be warned that spectral rights are not granted in perpetuity. New restrictions and orders will be issued as conditions warrant. However, the general nature of probable new restrictions and orders should be specified well in advance so that realistic planning can be done by the users, and so that the necessary investment capital may be attracted.

[12]For example, suppose that a candidate satellite system must reduce its consumption of orbit spectrum. Imagine that the system now uses one satellite, requires 4° spacing, and does not employ cross-polarized frequency re-use. 500 MHz of bandwidth are occupied. A new modulation technology would require an incremental investment of 10 million dollars and would reduce bandwidth occupancy to 450 MHz: 200 MHz-degree of orbit-spectrum are saved at a cost of five million dollars per GHz-degree. A sidelobe suppression technology would cost two million dollars and would cut required satellite spacing to 2°. One GHz-degree is saved at a cost of two million dollars per GHz-degree. Therefore, the latter alternative should be chosen, even though the increment of expenditure is larger. The spectral saving that a dollar can buy is greater in the latter case than in the former: the <u>normalized incremental cost</u> is less in the latter case than in the former.

[13]It might seem that it is not "fair" to thus single out one system and require it to bear the brunt of spectrum conservation. Fairness in the strict legal sense of due process ought to be accorded all parties

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immediately affected by regulation, but fairness in the sense of watching out for everybody's best interest can only apply to U.S. society as a whole. If investment capital is to be attracted, a reasonably stable and predictable regulatory climate must be assured. But stability has nothing to do with equalizing the economic impact of the orbit-spectrum limitation on all services solely for the sake of equalization. We believe that it is the economic impact on the public that ought to be of concern. The particular parties being regulated must be regarded as concessionaires, and all decisions must be made with only the public's best interests at heart.

The approach that we adopted, if followed in detail, would yield the same technical outcome as the ideal theoretical shadow pricing scheme. The same conservation measures and timing would be adopted in each case, and the total cost of dealing with the spectrum limitation would be the same in each case. Thus, from the standpoint of aggregate costs, our approach is optimum. However, an advantage of the ideal theoretical shadow pricing scheme is that the costs of dealing with the spectrum limitation are equitably distributed amongst the various services. Each pays for the spectrum he uses. Our approach does not yield this result. However, most of the services that will use satellites will serve the public at large. Thus, no single group will be significantly hurt by the uneven distribution of the costs of dealing with the orbit-spectrum limitation. The aggregate cost to the public is minimized, and those providing each service will compete under equal terms.

RANKING THE ALTERNATIVES

The foregoing discussions laid out the principles upon which orbit-spectrum policy ought to be based. Using these principles, we evaluated various strategies for dealing with the orbit-spectrum limitation. This section briefly describes the process of evaluation; much detail is relegated to tables. Following this section, we discuss the conclusions we reached, referring to examples drawn from this section. Finally, a recapitulation of the essential aspects of the study is given.

Strategies for dealing with the orbit-spectrum limitation were evaluated by examining the spectrum saving technical alternatives open to the different kinds of satellite services, and ranking these alternatives according to the principles that have been given above.

We hypothesized a variety of satellite system configurations; each configuration represented a satellite service carrying a certain amount of erlangs or channels of traffic and having a certain number of ground stations. For each configuration, we estimated the cost and spectrum used as a function of the various technical alternatives that might be employed to reduce cost or to reduce spectrum use. (Thus, we were able to calculate the normalized cost of orbit-spectrum saving for each configuration assumed.) Next, we found the important parameters that control the major aspects of the relationships among cost, spectrum use, system configuration, and technical alternative adopted. This data was distilled to find general characteristics of those configurations and alternatives that can (cost-) effectively reduce spectrum use and those that cannot. This list of general characteristics was one of the major objectives of the study.

The full analysis used many configurations and variations in assumptions. Here, the process used in the analysis is illuminated with but four examples. This preserves the essential character of the analysis without drowning it in detail. Two examples are from the television distribution satellite service; two are from the telephone satellite service. Their characteristics are listed in the chart below.

CHARACTERISTICS OF
FIXED SATELLITE AND BROADCAST SATELLITE SERVICES

	Fixed Satellite		Broadcast Satellite		
Example	No.Stations	Erlangs/Station	Receive Only	Transmit	TV Channels
No. 1	4	1000			
No. 2	1000	1			
No. 3			1000	2	4
No. 4			100	2	4

For each of the configurations, we evaluated numerous technical alternatives for reducing spectral use, including various combinations of modulations, cross-polarized frequency re-use, reduction in satellite spacings, use of 4 and 6 GHz, use of 12 and 14 GHz, use of 20 and 30 GHz with spot beams, and use of terrestrial communication links. A listing and discussion of these various means is given in Tables 1 through 5. Two points from these tables must be given prominent mention since they are at variance with commonly held opinions. First, as in Table 1, small aperture antennas can easily meet the FCC sidelobe pattern specification (Sidelobes $<$ 32 - 25 log θ dBi). Second, as in Table 3, single-channel-

TABLE 1

SATELLITE SPACING AND SIDELOBE LEVEL REDUCTION

Main Ideas: The FCC standards on sidelobe levels are achievable with small aperture ground stations; two degree satellite spacings are possible with small ground stations. There is no fixed relationship between a satellite spacing and the antenna diameter optimum for that spacing.

Point 1: The following sidelobe performances can be achieved. The figures are taken from a report done by Stanford University for NASA Ames.

FCC Standard: Sidelobe level relative to isotropic

Level $\leq 32 - 25 \log_{10} \theta$, θ in degrees from center (dBi)

Achievable: with prime focus feed dish, 9 dB illumination taper center to edge

Level $\leq 29 - 25 \log_{10} \theta$ (dBi)

Point 2: Carrier to Interference levels are shown below for the above patterns as a function of satellite spacing. 3.2-meter and 4.6-meter antennas are examined. Equally spaced homogeneous satellites are assumed. These levels are calculated at 6 GHz, the transmit frequency.

		5°	4°	3°	2°
3.2-meter}	FCC	24.2	21.5	17.9	—
	Achievable	29.0	26.3	22.6	17.4
4.6-meter}	FCC	27.8	25.1	21.4	15.9
	Achievable	32.5	29.8	26.0	20.6

C/I levels (dB)

Note: Recent data we are now incorporating in this study shows that even better C/I ratios are achievable.

TABLE 2

SPECTRAL RE-USE; 12 and 14 GHz; 20 and 30 GHz

Main Ideas: There are many ways in which spectrum may be re-used, or in which higher frequency bands may be used, but the impact on total system costs can be significant.

Point 1: Our data on cross-polarized frequency re-use indicates that the following isolations can be achieved between beams:

METHOD	COST/STATION	C/I at 6 GHz
Tracking feed	~ $100,000	30 dB
Fixed feed	~ $3,000	20 dB

Point 2: A system designed for use at frequencies higher than 4 to 6 GHz will be more expensive than the same system designed for 4 and 6 GHz. Reasons are: Increased rain margins are needed, finer machining tolerances are required because of the shorter wavelengths, and preamplifier noise temperatures are higher. In the continental U.S., additional margins of up to 10 dB and perhaps more might be required.

Point 3: Space diversity can be employed to reduce the size of the extra margin required at the high frequencies. Space diversity can be expensive because the earth station expense is nearly doubled, and terrestrial communication links must be provided. Our data indicates that the margins listed above can be reduced by the following amounts when space diversity of greater than 20 miles is employed [3].

Frequency	Fade Depth with no Diversity	Diversity Gain
13 GHz	4 dB	3 dB
	8 dB	6 dB
	12 dB	9 dB
	16 dB	12 dB
	20 dB	15 dB

Point 4: Frequency re-use through employment of spot beams is more difficult for domestic systems than for international systems because of the smaller areas involved. Nevertheless, at the higher frequencies spot beams may be attractive. Frequency may be re-used two to three times at 12 and 14 GHz, and up to 10 times at 20 and 30 GHz with reasonably sized launch vehicles. The primary penalty paid for spot beams is increased satellite cost. It is important to note that spot beams may be very attractive to telephony systems carrying a great deal of traffic. Through use of spot beams, the utilization at the satellite and ground stations may be greatly increased, resulting in significant economics. For example, one 20 and 30 GHz satellite operaing with 6 spot beams could provide roughly 2.5 GHz of bandwidth to each of six ground stations; presently six ground stations must share one GHz of bandwidth. (500 MHz with polarization re-use yields about one GHz of useful bandwidth.)

TABLE 3

TELEPHONY MODULATIONS AND CODING

Main Idea: Practical modulations that use bandwidth much more efficiently than conventional Multi-Channel Per Carrier FM are available.

Discussion: Until recently, Multi-Channel Per Carrier FM/FDM modulation was used on almost all satellite communication systems, the SPADE system of COMSAT being a notable exception. However, other modulations are making rapid progress.

Single-Channel-Per-Carrier compandered FM with voice activated carriers was recently specified for the Alaskan bush system. This modulation uses both power and bandwidth much more efficiently than does MCPC FM/FDM when only a few voice channels are to be transmitted. For very large numbers of voice channels, the performance gap narrows. A detailed comparison of the two was conducted by Carl Mitchell [4]; data from that comparison are included in the table below.

COMSAT Laboratories has developed a digital coding technique for large numbers of voice channels that looks very attractive. Called Digital Speech Interpolation (DSI), it is a technique similar to the TASI system used in undersea cable but is based on DPCM rather than AM. Essentially, DSI achieves a doubling in channel utilization by transmitting data for a voice channel only when a speaker is active. DSI can work with any digital modulation; in the table below it is shown with bandlimited QPSK.

RF Bandwidth and C/kT (dB) Required Per Channel

	12 channels	1000 channels
FM/FDM	100 kHz, 70.0 dB	36 kHz, 63.0 dB
SCPC FM	32 kHz, 54.5 dB	32 kHz, 54.5 dB
DSI-QPSK	———	24 kHz, 55.0 dB

TABLE 4

TELEVISION MODULATIONS AND CODING

Main Points: Major savings in the bandwidths required for television transmission are possible but are not certain. Costs especially are uncertain. This is typical of technological advance; both uncertainties and possible benefits are high.

Discussion: Encouraging work is proceeding at NASA Ames and other places on television data compression through transform coding techniques. NASA Ames has built a real time Hadamard data compressor, and reports that data rates as low as 10 Mbps can be achieved for black and white television with no perceptible degradation. This is a compression of over five to one. Color television should require data rates that are somewhat higher.

The estimated cost of the present coder is roughly $30,000; in the future, this could drop considerably.

TABLE 5

TERRESTRIAL ALTERNATIVES

Main Ideas:

1. Terrestrial communication pathways exhibit very great economies of scale: As the initial costs of a terrestrial pathway are high, but the incremental cost of additional circuits is very low, the cost per circuit drops almost inversely with the number of circuits.

2. For a given number of circuits, there is some distance below which the terrestrial paths are cheaper and above which the satellite paths tend to be cheaper. This threshold distance increases as the number of circuits increases.

3. Finally, technical advance has in the past dramatically lowered the cost of terrestrial long-haul facilities, and we can expect this trend to continue.

per-carrier FM for telephony uses less bandwidth per channel than does multi-channel-per-carrier FM/FDM, and also usually uses considerably less satellite power per channel. (Large stations use MCPC FM/FDM now because the equipment is cheaper and the SCPC gear has become available only recently.)

A computer program was used to aid in the evaluation of each of the many technical alternatives. For the interested reader, the program and its assumptions are outlined in Table 6. (A full discussion of the computer models is contained in the complete analysis.) Basically, however, the computer program does the following: A set of technical alternatives, including satellite spacing, is assumed. Adjacent system interference is calculated by assuming that all the adjacent satellites are associated with systems having characteristics identical to the system being modeled.[14] The lowest cost combination of hardware to satisfy the performance objectives is then found by exhaustive search. The spectrum used is calculated from the bandwidth occupied and the satellite spacing assumed. The functional relationships among cost, spectrum used, and the technical alternative assumed are thus built up and are printed for study.

When the various technical alternatives are evaluated as above, it becomes obvious that some of the alternatives are inferior to others from the twin standpoints of cost and spectral utilization. In most

[14] This is Reinhart's "homogeneous" case. In the complete analysis, the problems of nonhomogeneities are analyzed and are found not to affect the conclusions presented in this paper. In fact, the conclusions presented here were found to be very robust and to depend only on the most gross features of the input data. Even fairly major variations in the input data and assumptions had no impact on the conclusions.

TABLE 6

COMPUTER PROGRAM TO AID IN RANKING TECHNICAL ALTERNATIVES

Main Ideas: The computer program was used to establish the relationships:

SATELLITE SYSTEM CONFIGURATION	TECHNICAL ALTERNATIVE	COST OF SYSTEM	SPECTRAL USE
Configuration 1	Alternative A	Cost A	Use A
	Alternative B	Cost B	Use B
	...	...	...
	...	...	...
...			

These relationships were used to find the cost of spectral saving and how this cost depends on both the technical means used to save spectrum and the configuration of the satellite system that is doing the saving. The input to the program were the satellite system configuration and a list of alternatives; output were the corresponding costs and quantities of spectrum used.

Discussion: The satellite system configuration was defined by the number of ground station sites required, the type and intensity of system traffic, and the required link reliability. The technical alternatives were defined by specifying a combination of coding, modulation, multiple-access, satellite spacing, frequency band, and frequency re-use plan; frequency re-use options include no re-use, reuse through orthogonally polarized carriers, and re-use through spot beams. A configuration and technical alternatives were input to the program; from them, the spectrum requirement and the minimum cost system are found by the program as described below.

The spectrum requirement is found directly from the technical alternative assumed. The combination of coding, modulation, and multiple-access determines the total bandwidth requirement; the frequency band selected and the frequency re-use options selected determine how this bandwidth requirement will be met; and the satellite spacing determines the orbital arc required.

The minimum cost system is found by first calculating the link requirements as dictated by the technical alternative assumed. The lowest cost means of meeting this link requirement is then found by a process of exhaustive search over the available hardware alternatives. The search demands calculation of both a noise budget and a total cost figure for each collection of hardware considered. (The noise budget is used to determine if the link requirements are met.) Hardware elements considered are: coding, modulation, and multiple-access devices at both the transmitting and receiving ends, transmitting and receiving antennas of various diameters, cross-polarized capability, and sidelobe performances (these are briefly discussed in Table 1), high-powered amplifiers at the transmitting end of various saturated outputs, low-noise amplifiers at the receiving end of various system noise temperatures, and satellites possessing various levels of EIRP, transponder bandwidth, cross-polarized capability and other re-use options. A 92% learning curve is applied to the capital cost of the various items, and O&M costs are discounted to present value.

Noises taken into account in finding the noise budgets are: intermodulation noise in the uplink amplifier, adjacent system noise in the uplink, satellite receiver thermal noise (assumed to be a 1200 degree system temperature), satellite intermodulation noise, adjacent satellite noise in the downlink, and thermal noise in the downlink receiving amplifier, and noise from cross-polarized carriers in both the uplinks and downlinks. Satellite back-off and transponder bandwidth are both variable. Adjacent system interference is calculated by assuming that the orbital arc is filled with uniformly spaced satellites that are associated with systems having characteristics identical to the system being modeled. A link margin is applied to the noises of thermal origin, and a separate margin is applied to the interference noises. The latter margin serves two purposes: it functions both as a real margin and as a factor to allow for the non-thermal characteristic of the interference.

TABLE 7

TRUNK TELEPHONY ALTERNATIVES

Telephony

4 Ground Stations

1,000 Erlangs generated at each station

ALTERNATIVE	SPECTRUM USED	SPECTRUM/ERLANG	COST
4 degree satellite spacing; XPOL re-use; MCPC FM/FDM at threshold	1 GHz-degree	240 kHz-degree	$53.4 million
5 degree spacing; XPOL re-use; DSI QPSK	400 MHz-degree	100 kHz-degree	$21.0 million
4 degree spacing; XPOL re-use; DSI QPSK	320 MHz-degree	80 kHz-degree	$21.48 million
3 degree spacing; XPOL re-use; DSI QPSK	240 MHz-degree	60 kHz-degree	$21.5 million
2 degree spacing; XPOL re-use; DSI QPSK	160 MHz-degree	40 kHz-degree	$23.6 million

NOTE: These costs are preliminary, but serve to illustrate the principles of our approach. More accurate cost data is now being incorporated in the analysis. We do not expect that the basic conclusions of this study will be changed by the new data.

TABLE 8

THIN ROUTE TELEPHONY ALTERNATIVES

Telephony

1,000 Ground Stations

One Erlang/Ground Station

ALTERNATIVE	SPECTRUM USED	SPECTRUM/ERLANG	COST
5° satellite spacing; SCPC FM	300 MHz/degree	300 kHz-degree	$48.4 million
4° satellite spacing; SCPC FM	240 MHz-degree	240 kHz-degree	$51.7 million
3° satellite spacing; SCPC FM	180 MHz-degree	180 kHz-degree	$54.0 million
2° satellite spacing; SCPC FM	120 MHz-degree	120 kHz-degree	$59.1 million

NOTE: These costs are preliminary, but serve to illustrate the principles of our approach. More accurate cost data is now being incorporated in the analysis. We do not expect that the basic conclusions of the study will be changed by the new data.

TABLE 9

TELEVISION DISTRIBUTION WITH 100 GROUND STATIONS; ALTERNATIVES

2 Transmit Stations

100 Receive Only Stations

4 Channels Transmitted by the Satellite

ALTERNATIVE	SPECTRUM USED	SPECTRUM/CHANNEL	COST
40 MHz FM 5° satellite spacing	800 MHz-degree	200 MHz-degree	$25.8 million
40 MHz FM 4° satellite spacing	640 MHz-degree	160 MHz-degree	$26.0 million
40 MHz FM 3° satellite spacing	480 MHz-degree	120 MHz-degree	$26.6 million
40 MHz FM 2° satellite spacing	320 MHz-degree	80 MHz-degree	$28.0 million
Hadamard data compression Rate: 3/4 coded QPSK 3° satellite spacing	192 MHz-degree	48 MHz-degree	$29.8 million
Hadamard data compression Rate: 3/4 coded QPSK 2° satellite spacing	128 MHz-degree	32 MHz-degree	$30.0 million

NOTE: These costs are preliminary but serve to illustrate the principles of our approach. More accurate cost data is now being incorporated in the analysis. We do not expect that the basic conlcusions of the study will be changed by the new data.

TABLE 10

TELEVISION DISTRIBUTION WITH 1,000 GROUND STATIONS: ALTERNATIVES

2 Transmit Stations

1,000 Receive Only Stations

4 Channels Transmitted by the Satellite

ALTERNATIVE	SPECTRUM USED	SPECTRUM/CHANNEL	COST
40 MHz FM 5° satellite spacing	800 MHz-degree	200 MHz-degree	$49.4 million
40 MHz FM 4° satellite spacing	640 MHz-degree	160 MHz-degree	$49.6 million
40 MHz FM 3° satellite spacing	480 MHz-degree	120 MHz-degree	$54.6 million
40 MHz FM 2° satellite spacing	320 MHz-degree	80 MHz-degree	$63.8 million
Hadamard data compression Rate: 3/4 coded QPSK 3° satellite spacing	128 MHz-degree	48 MHz-degree	$79.8 million

NOTE: These costs are preliminary, but serve to illustrate the principles of our approach. More accurate cost data is now being incorporated in the analysis. We do not expect that the basic conclusions of this study will be changed by the new data.

cases, these alternatives would never be adopted, and can be ignored in further analysis. Tables 7 through 10 list the alternatives that remain for each of the examples, showing also the cost and the spectrum used. Link calculations and the cost breakdowns for each of the more important alternatives are given in the appendix.

The data on cost and spectrum utilization can be graphed as in Figures 1 through 4. From these graphs, finally, the costs of spectrum saving can be calculated. These normalized costs, upon which spectrum saving decisions ought to be based, are given in Figures 5 through 8. For purposes of comparison and for later reference, the ratio between investment and spectrum used is also plotted in Figures 5 through 8. The tables and figures are the sort of data from which the conclusions of this study were drawn.

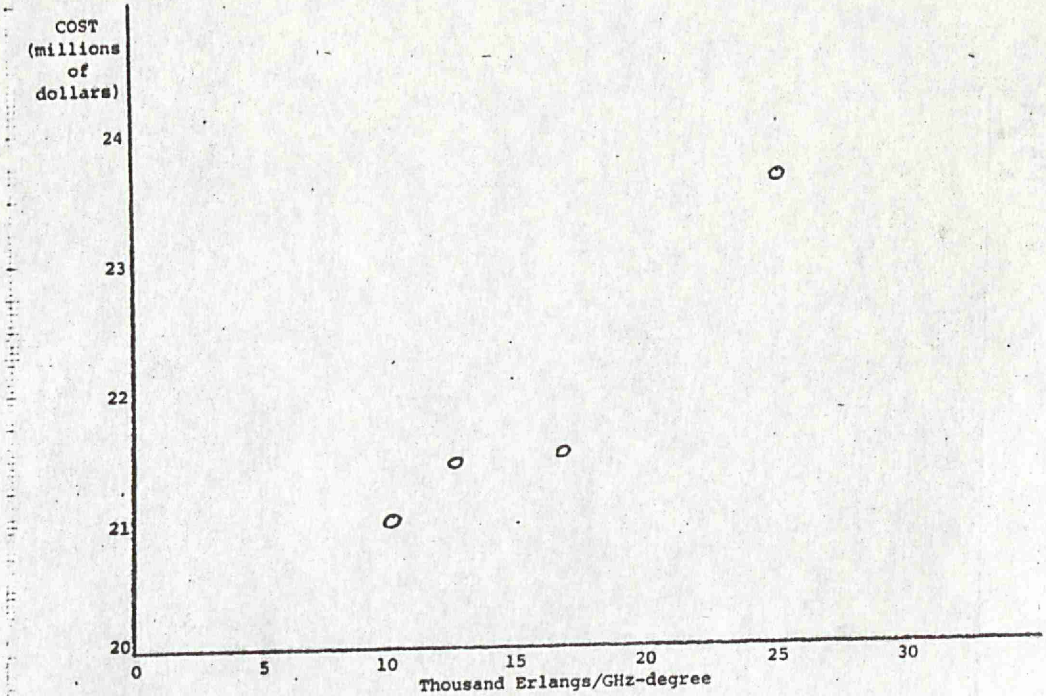

Fig. 1. TELEPHONY, FOUR GROUND STATIONS, 1,000 ERLANGS/GROUND STATION.

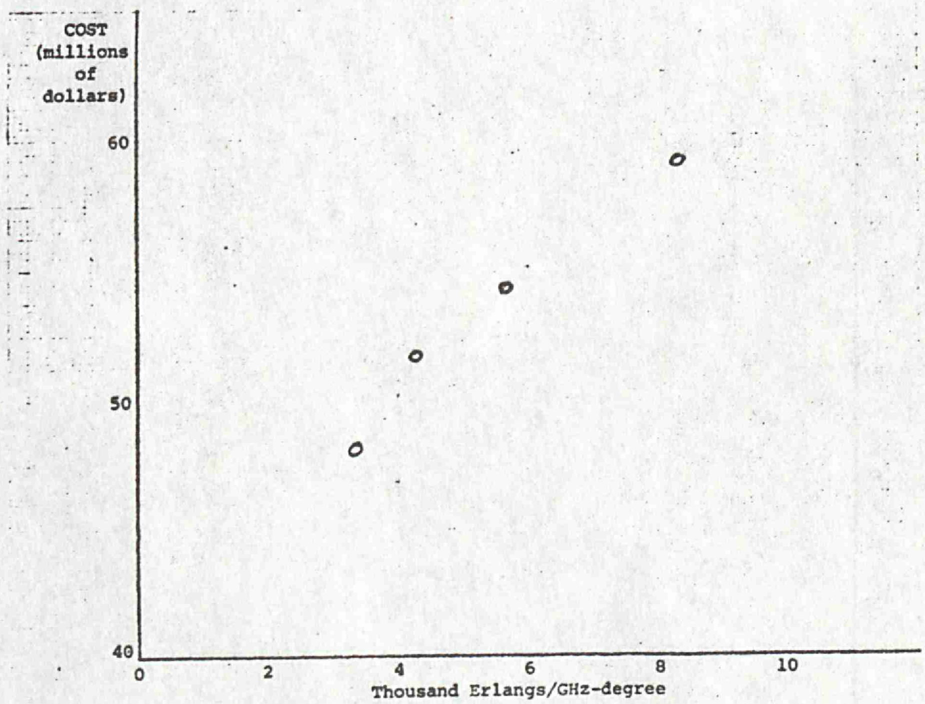

Fig. 2. TELEPHONY, 1,000 GROUND STATIONS, ONE ERLANG/GROUND STATION.

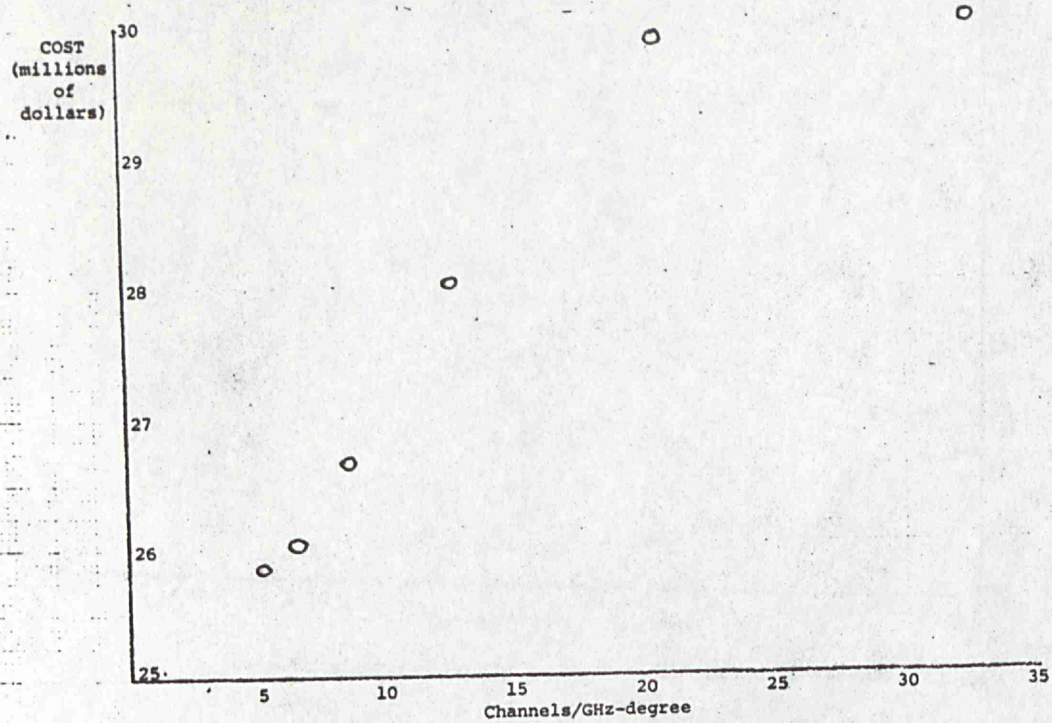

Fig. 3. TELEVISION DISTRIBUTION, 100 RECIEVE STATIONS, FOUR CHANNELS

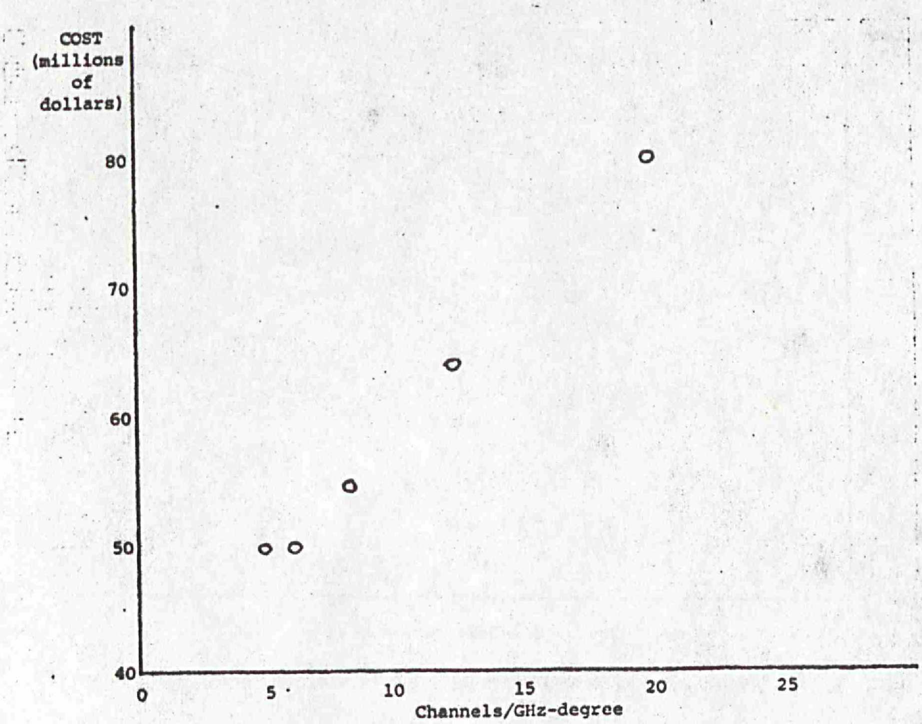

Fig. 4. TELEVISION DISTRIBUTION, 1,000 RECEIVE STATIONS, FOUR CHANNELS.

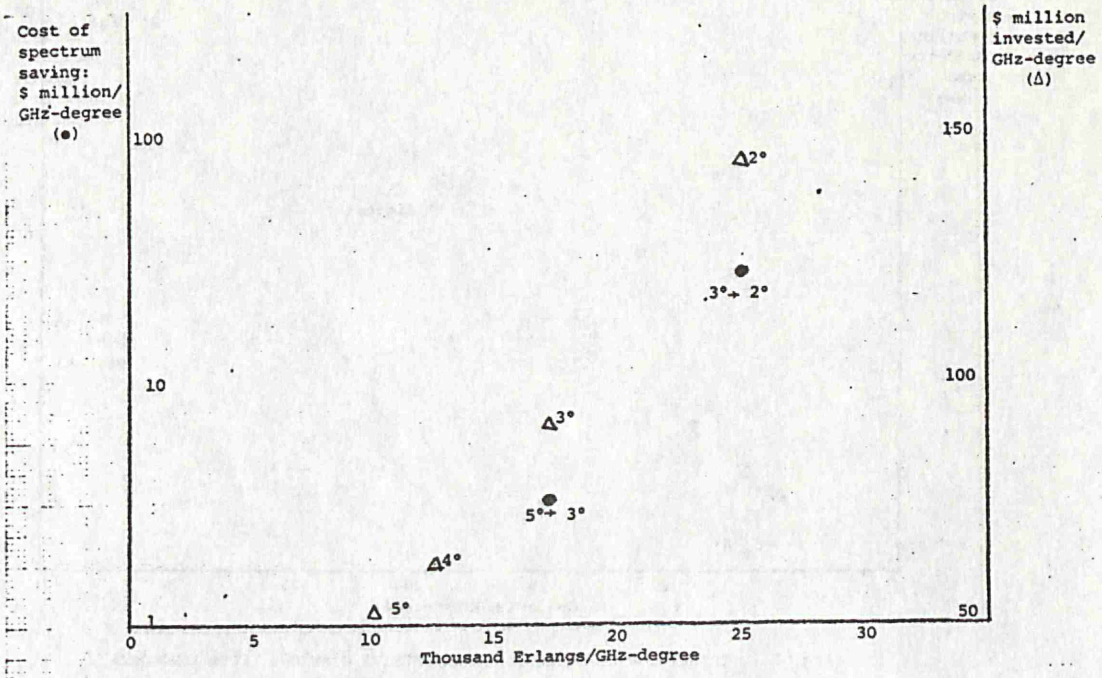

Fig. 5. TELEPHONY, 4 GROUND STATIONS, 1,000 ERLANGS/GROUND STATION

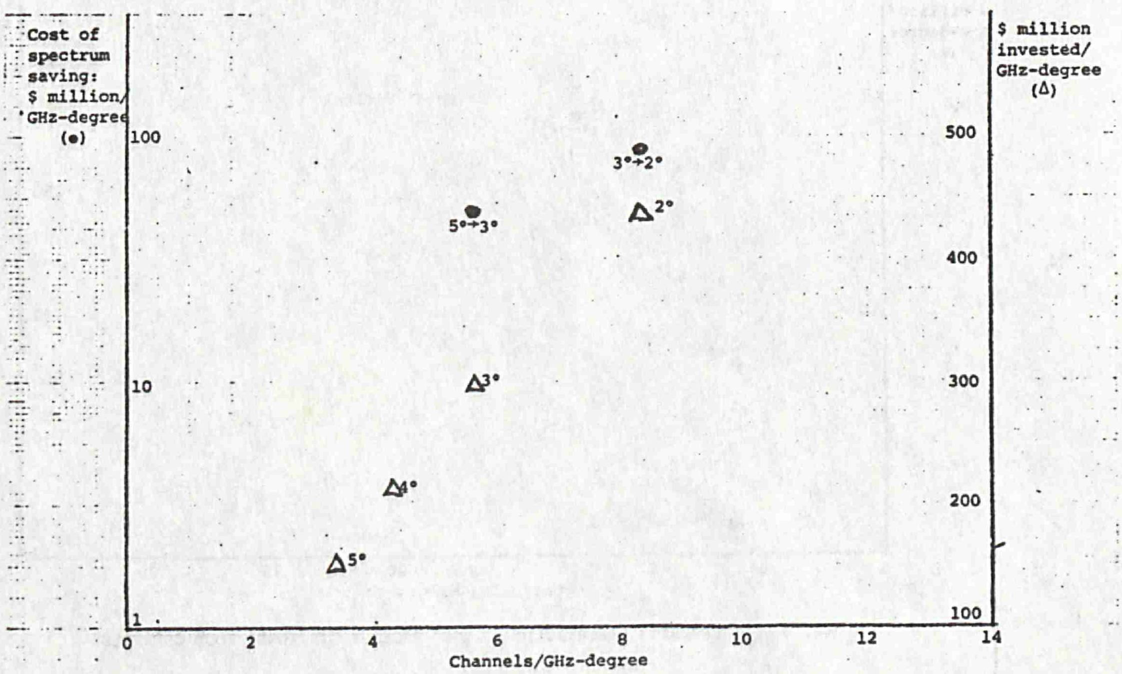

Fig. 6. TELEPHONY, 1,000 GROUND STATIONS, ONE ERLANG/GROUND STATION

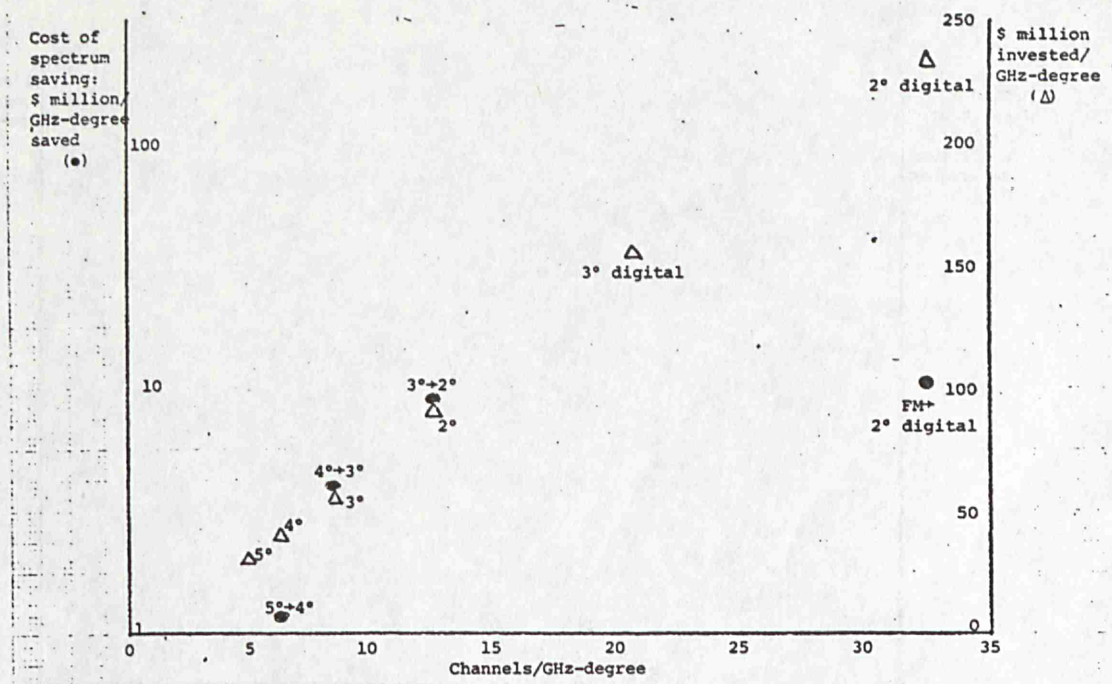

Fig. 7. TELEVISION DISTRIBUTION, 100 RECEIVE STATIONS, FOUR CHANNELS

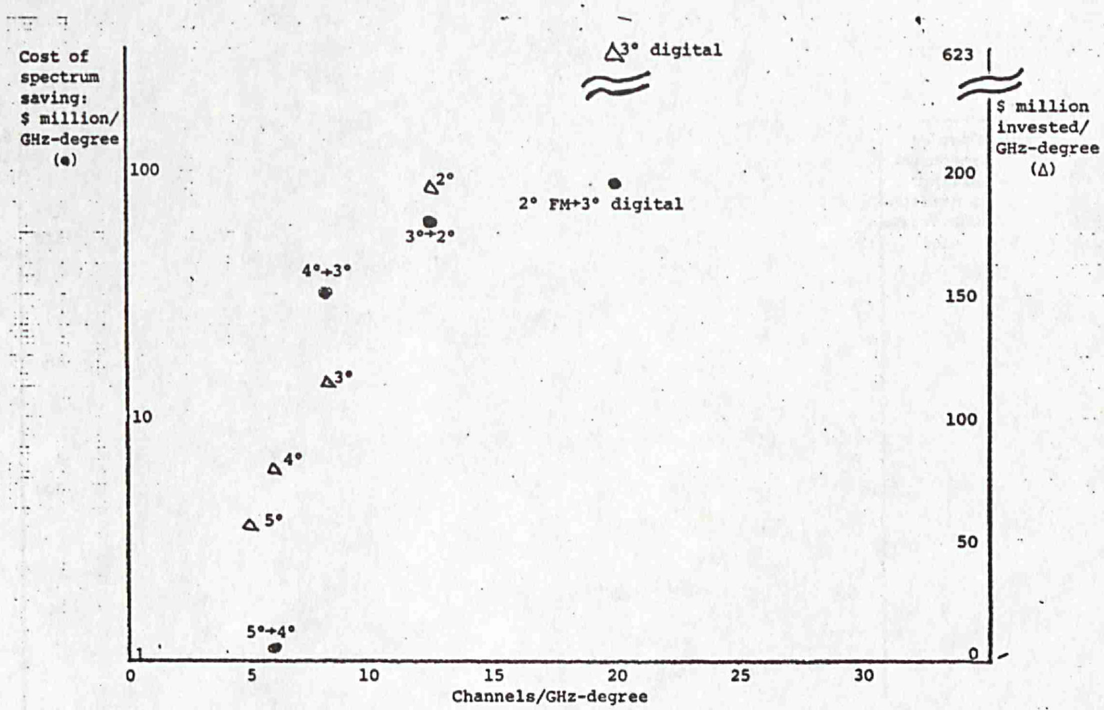

Fig. 8. TELEVISION DISTRIBUTION, 1,000 RECEIVE STATIONS, FOUR CHANNELS

CONCLUSIONS FROM THE RANKING

The first actions that should be taken are those that have the lowest normalized cost: those that cost the fewest dollars per GHz-degree saved. The normalized costs of various technical alternatives were ranked in Figs. 5 through 8; in Fig. 9 the most attractive alternatives are displayed in the order in which they should be taken. The conclusions from the study are illuminated with the aid of these figures.

<u>First Conclusion</u>: *WHEN SPECTRUM SAVING MEASURES ARE NEEDED, IT IS THE COMMUNICATION SATELLITE SYSTEMS WITH FEW GROUND STATIONS, EACH CARRYING A LOT OF TRAFFIC, THAT OUGHT TO TAKE THESE MEASURES.*

This is most easily seen by comparing the two telephony examples in Figs.5&6. The system with four ground stations ought to take spectrum saving measures before the system with 1000 ground stations. The cost of saving spectrum is 3.1* million dollars per GHz-degree for the former and 47* million dollars per GHz-degree for the latter. Briefly, the reason is that it is better to spend a moderate amount of money at a few places to save a lot of spectrum than it is to spend a little money at each of very many places to save a little spectrum. A dollar spent at a ground station of the "trunk" system affects 1000 erlangs of traffic; a dollar spent at the thin route system affects only one erlang. This feature of the analysis came out very strongly and was not affected by any variation in the technical assumptions made in the study.

A second interesting feature of the table is that the trunk system adopts many spectrum saving measures in the lowest cost system. The

	UNCROWDED SITUATION	FIRST ACTION	SECOND ACTION	THIRD ACTION
Trunk Telephony	Digital Speech Interpolation; QPSK; Frequency re-use through orthogonal polarization; 5° satellite spacing			Digital Speech Interpolation; QPSK; Frequency re-use through orthogonal polarization; 3° satellite spacing
Erlangs/GHz-degree	10,000			16,700
System Cost	$21 million			$21.5 million
Spectrum Used	400 MHz-degree			240 MHz-degree
Investment/GHz-degree used	$52.5 million/GHz-degree			$90 million/GHz-degree
Thin Route Telephony	Single-Channel-Per-Carrier FM with compandering and voice activation: 5° satellite spacing		*NOTE: These costs are preliminary, but serve to illustrate the principles of our approach.*	
Erlangs/GHz-degree	3,300 erlangs			
System Cost	$48.4 million			
Spectrum Uses	300 MHz-degree			
Investment/GHz-degree used	$161 million/GHz-degree			
Television Distribution 100 Ground Stations	40 MHz FM television 5° satellite spacing	40 MHz FM television 4° satellite spacing		
Channels/GHz-degree	5 channels	6 channels		
System Cost	$25.8 million	$26 million		
Spectrum Used	800 MHz-degree	640 GHz-degree		
Investment/GHz-degree used	$32.3 million/GHz-degree	$40.6 million/GHz-degree		
Television Distribution 1,000 Ground Stations	40 MHz FM television 5° satellite spacing	40 MHz FM television 4° satellite spacing		
Channels/GHz-degree	5 channels	6 channels		
System Cost	$49.4 million	$49.6 million		
Spectrum Used	800 MHz-degree	640 MHz-degree		
Investment/GHz-degree used	$61.8 million/GHz-degree	$77.5 million/GHz-degree		
COST OF SAVING:	———	$1.2 million/GHz-degree		$3.1 million/GHz-degree

Fig. 9. SPECTRUM CONSERVATION ACTIONS

reason is that the cost of these measures is offset by cost savings obtained through improved satellite utilization. These measures thus ought to be taken for reasons quite apart from any spectral shortage. By improving equipment utilization, the measures lower the per circuit cost and would make sense even if spectrum were completely unlimited. The thin route system does not ever take these measures because the economies of utilization that would be gained would be completely outweighed by the cost of the measures.

A third interesting feature of the comparison is that the per erlang costs of spectrum saving are enormously greater for the thin route system than for the trunk route system. The per erlang cost of spectrum saving is $3300* for the thin route system; the cost is only $125* for the trunk system. The disparity in the normalized cost of spectrum saving is not as great because the trunk route system uses much less spectrum per erlang than does the thin route system.

Finally, we note that in a purely technical sense, the trunk route system uses spectrum more "efficiently." Nevertheless, it should be the first to conserve spectrum. This might surprise the reader.

The conventional view is that satellite systems using a lot of orbit-spectrum per voice circuit — satellite systems making inefficient use of the orbit-spectrum — ought to be the first ones to conserve spectrum. "Inefficient use of the orbit-spectrum": this phrase is at the root of the seeming contradiction. The apparent contradiction is cleared by defining what is meant by the words "efficient" or "inefficient" when applied to spectral use. Efficient use of the orbit-spectrum is use that minimizes the impact of spectral limitation on costs. Efficient use of

the orbit-spectrum is not use that maximizes the capacity of the available resource. Since, with foreseeable technology, the capacity of the available resource is practically unlimited, maximization of capacity has no purpose and is efficent only a purely technical sense. Striving after spectral efficiency in the technical sense as a goal in itself misses the entire rationale for orbit-spectrum regulation.

Striving after spectral efficiency in the economic sense of minimizing the cost imposed by spectral limitation should be the goal. The means for attaining the goal when spectrum becomes scarce is to find the satellite system that can save the most spectrum at the least added cost and require that system to take spectral saving measures. As a general rule, the systems that can most efficiently save spectrum are the ones with a lot of traffic and few ground stations. Consequently, these ought to be the first ones required to take spectral saving measures when spectrum is scarce.

* The cost data used was preliminary. More accurate cost data is now being incorporated, but is not expected to change the conclusions in any respect.

Second Conclusion: *CANDIDATES FOR SPECTRUM CONSERVATION MEASURES CAN BE SELECTED BY IDENTIFYING THOSE SYSTEMS WITH A LOW INTENSITY OF INVESTMENT IN SPECTRUM USE. THIS INTENSITY IS GIVEN BY THE RATIO:*

$$\frac{\textit{Present Value of Satellite System Cost Stream}}{\textit{Total Orbit-Spectrum Used}}$$

In the debate on orbit-spectrum policy, there has been a tendency to focus discussion on parameters that are easily and unambiguously measured; spectrum used per voice channel, antenna diameter and satellite spacing to meet a given noise requirement with an assumed sidelobe pattern have all been used. For the purpose of making policy, they may often lead to incorrect actions. We have proposed a more complicated measure of the desirability of spectrum saving that we believe is the proper approach to policy: incremental cost normalized by incremental spectrum saved. Unfortunately, in the real world of regulation, this measure is difficult to calculate objectively.

Fortunately, we have found an indicator variable that is both calculable and reasonably well correlated with the more complicated and correct measure. This indicator variable is:

$$\text{Intensity of Investment} = \frac{\text{Present Value of Satellite System Cost Stream}}{\text{Total Spectrum Used}}$$

If the indicator variable is relatively small for a given satellite system, then it is likely that the satellite system can save a relatively large amount of orbit-spectrum for a relatively low cost. Conversely, if the indicator variable is relatively large, it is likely that spectrum

saving with the system under consideration is not cost-effective. Decisions made on the basis of the indicator variable are usually identical to decisions made on the basis of the more correct normalized incremental cost. The indicator variable is graphed in Figs. 5 through 8.

Third Conclusion: *PROHIBITING SMALL APERTURE GROUND STATIONS IS AN EXTRAORDINARILY EXPENSIVE WAY OF CONSERVING ORBIT-SPECTRUM.*

We have shown that initially thin-route systems should not be required to conserve spectrum. Here we show that when thin-route systems must conserve spectrum, increased antenna apertures should not play a role.

In Table 8, the costs of various levels of spectrum use for the thin-route telephony example are shown, and the resulting costs of spectrum saving are shown in Fig. 6. The minimum cost system for spacings of 5, 4, and 3 degrees used 4.57 meter antennas; a larger aperture of 6.1 meters was not chosen until the satellite spacing was reduced to 2 degrees. Figure 6 shows that the first spectrum conservation step for the thin-route system is to reduce satellite spacing to 3 degrees while retaining 4.57 meter antennas. At 47 million dollars per GHz degree saved, this step is expensive (compare Fig. 9), but it is much cheaper than going to 6.1 meter antennas and 2 degree spacings ($86 million/GHz degree saved). Further, mandating 6.1 meter antennas, or larger, for spacings greater than 2 degrees would be even more expensive per GHz degree saved. Mandating 6.1 meter antennas as a minimum aperture does not open new spectrum saving alternatives; it merely inflates the costs.

The foregoing was for the case of thin-route systems interfering with other thin-route systems. The same conclusion — regulating antenna diameter is a bad idea — also holds for interference between thin-route systems and trunk systems.

Finally, it could be argued that thin-route service should not be allowed with stations of any size. It could be argued that since small ground stations use a lot of spectrum per channel, spectrum could be saved if the small station traffic were transmitted through the big stations. For example, private users might be required to lease circuits from an established large carrier rather than be allowed to erect a small private ground station. The nation would reap the additional economies of scale from larger trunks and more intensive use of available facilities, and spectrum would be saved.

However, the objective of domestic satellite orbit-spectrum policy ought to be to minimize the costs imposed on society by the orbit-spectrum limitation. In many cases, it is clear that a thin route satellite system is by far the cheapest means of providing communication. For example, it is enormously cheaper to provide telephone service to the Alaskan bush via thin route satellite than it is to provide the service by stringing wire from many villages to a distant large ground station. The cost saved per GHz-degree used is very large. In other cases, the benefits are not so clear-cut. For example, the end-to-end business service that has been suggested would compete directly with established terrestrial and satellite trunk route carriers. One might assert that any cost advantage of end-to-end service over leased service from a conventional

carrier is only apparent, that the difference is merely one of price, that the actual costs to U.S. society favor the leased system even though the prices do not reflect this, and that consequently, end-to-end service ought to be discouraged as false economy. Such an assertion is really a statement that the rate base of the present carriers ought to be protected. This may be so, the the issue ought to be examined on its merits outside of any orbit-spectrum proceeding.

Fourth Conclusion: *THE CAPACITY AVAILABLE AT 4 and 6 GHz WITHOUT INCURRING SIGNIFICANT SPECTRUM CONSERVATION COSTS IS VERY LARGE. CONSEQUENTLY, EXPENDITURES FOR CONSERVATION MEASURES OUGHT TO BE DELAYED.*

Roughly 70° of arc are available to veiw the entire continental U.S. Purely for illustrative purposes, this can be allocated as shown below, and will result in the capacites shown without necessitating any spectrum conservation measures.

Service	Arc	Capacity, with no Conservation Measures
Trunk tele.	40°	200,000 erlangs
Thin tele.	5°	6,000 ground stations
Trunk TV	10°	30 channels
Thin TV	15°	45 channels

These are much larger than present requirements.

Fifth Conclusion: *IF IT IS DESIRED TO RELIEVE SPECTRUM CONGESTION BY "OFFLOADING" SERVICES TO TERRESTRIAL FACILITIES, IT IS BEST TO OFFLOAD THE TRUNK SERVICES.*

When satellites are used in preference to terrestrial facilities, the reason is that the satellite communications cost less than the equivalent communications on terrestrial facilities. Under some future circumstances, the situation might be reversed, and it may be economically attractive to offload service from the satellite back to terrestrial communication means. Such circumstances would arise either if the per-circuit cost of the terrestrial means falls significantly or if orbit-spectrum becomes sufficiently scarce and valuable that offloading is attractive because of the spectrum freed. In the former case, offloading would directly decrease the costs of the offloaded service; in the latter, the cost of offloading would be more than offset by the savings that some other service could realize with the freed spectrum.

If either of these circumstances comes to pass, we believe that it will be the trunk services that will offload. The reasons are discussed below. These reasons are qualitative; detailed quantitative work is proceeding at Stanford.

It is well known that satellite communication becomes increasingly attractive relative to terrestrial communication as the distance over which the communication is to be accomplished increases. Generally speaking, at some distance the two communication means are equally attractive. For links shorter than this critical distance, the terrestrial means are cheaper; for longer links, the satellite means are cheaper.

The value of this critical distance depends on the costs of both satellite communications and terrestrial communications. Swenson [2] has analyzed the annualized per-circuit costs of terrestrial trunk facilities, and finds that

> ... the full capacity cost per voice circuit decreases as the system's cross section; i.e., capacity in terms of voice circuits, increases. Indeed, this must be true or there is no real economic incentive to develop newer systems with larger cross sections.

The per-circuit costs of satellite communications also falls as the link cross section increases, but the fall is not nearly as steep. Thus, the distance within which the terrestrial means are superior will increase as the number of circuits increases. Further, for a given distance, the attractiveness of the terrestrial alternative is substantially greater for the trunk system than it is for the thin-route system. We conclude that offloading will be attractive to the trunk systems earlier than it will for the thin-route systems.[15,16]

Satellites have a natural role to play in the development of terrestrial trunk facilities quite aside from any considerations of orbit-spectrum limitation. Long-haul terrestrial communication pathways are characterized by a very large first cost and a very small incremental cost. For example, the cost of the "first circuit" on an

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[15] Some of the problems of offloading thin-route services to terrestrial means were discussed in Conclusion 3, on page 42.

[16] Continuing rapid developments in optical fiber technology add emphasis to the above discussion. It is too early to tell, but optical fibers may lead, within a few years, to very high capacity communication trunks with a ver low per-circuit cost.

L4 cable system is nearly 80% of the cost of the entire complement of 32,000 duplex circuits.[17] If only a fraction of the capacity of a terrestrial path can be used, the per-circuit cost of the path may thus be very high. Conversely, if the path can be fully utilized, the per-circuit cost may be fairly low.

Because of these economies of scale, the major problem in building low-cost terrestrial paths is getting a large enough initial traffic load factor to make the facilities economic. (Swenson has shown that the initial traffic load is the most important factor in average circuit costs over the lifetime of the facilities.) Here the satellite plays an ideal complementary role. The satellite can absorb traffic growth until a large enough volume has built up on a link that the terrestrial means are economic. This link is then off-loaded, enabling the terrestrial system to start at nearly full capacity, and freeing the satellite to resume its role of accumulating traffic growth. For very long distances, this process is not applicable because the satellite is then the cheapest trunk facility. For short to medium distances, such as New York-Chicago, the process makes sense. The distance over which it makes sense will increase as traffic volumes grow, terrestrial technology advances, and spectrum becomes crowded.

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[17] This property of terrestrial trunk facilities is the major reason for the very rapid fall-off of per-circuit cost as the system cross-section increases.

<u>Sixth Conclusion:</u> *USE OF THE 12 and 14 OR 20 and 30 GHz BANDS SHOULD BE REGARDED AS JUST ANOTHER TECHNIQUE FOR RELIEVING SPECTRUM CONGESTION. IN THIS ROLE, THESE BANDS WILL PROBABLY BE MOST USEFUL FOR TRUNK TELEPHONY APPLICATIONS.*

It is widely believed that the 12 and 14 GHz bands are naturally better suited to applications such as thin-route telephony and television distribution than the 4 and 6 GHz bands. It appears that this may not in fact be the case. The drawbacks of the 12 and 14 GHz band are as follows:

- o Much greater rain margins must be provided at 12 and 14 GHz than at 4 and 6 GHz. Thus, either satellite EIRP or ground station A_e/T must be significantly increased. This is expensive.
- o The cost of low noise amplifiers is higher than the cost of the equivalent amplifiers at 4 and 6 GHz, and this cost disadvantage holds true for other RF components. Machining tolerances must be increased, thus increasing costs.
- o When higher frequencies are used, antenna beamwidths are considerably reduced; stations with antennas larger than 4.5 meters in diameter would require some form of tracking capability, significantly increasing costs.

The only significant advantage of 12 and 14 GHz for applications not involving spot beams is the reduced complexity of the required coordination.[18] When small spot beams are desired, the increased directivity of the higher frequency may be an advantage, but the significance of this advantage is problematical. In any case, the applications of satellites to thin-route services do not require small spot beams. Thus, for applications involving thin-route and television distribution use of the 12 and 14 GHz bands probably results in higher costs than use of the 4 and 6 GHz bands.[19]

Hence, use of the higher frequency bands is just another technique available for reducing the spectral crowding at 4 and 6 GHz. We believe that it should be evaluated in the manner that we have described, and that the higher frequencies should be used in a manner that minimizes the cost of dealing with the limited availability of orbit-spectrum.

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[18] The relaxed flux density limitation at 12 and 14 GHz is not an advantage in the U.S. since the flux limitation at 4 and 6 GHz is not exceeded by minimum cost systems. Direct broadcast services are not included in this assessment because it is highly unlikely that they would be deployed. A community receiver with a re-transmission or other local distribution system is always much cheaper.

[19] With the advantage of hindsight, we see that it might have been better to have allocated the 12 and 14 GHz band to the terrestrial microwave services and to have allocated 4 and 6 GHz to satellite use exclusively. The rain margin is not as large a problem for terrestrial microwave at these frequencies as it is for the satellite services since much of the margin that must be provided as either 6 GHz or 14 GHz is for multi-path fading. Further, the increased antenna gain would be a definite advantage for both the transmit and receive antennas of the terrestrial microwave. This is not the case with the satellite services because the need for larger collecting areas at the receiver results in a tracking requirement at 12 and 14 GHz.

Switching the allocations in this manner may be a realistic alternative in countries that do not already have an installed base of the older technology.

Critical data on the required rain margins and on costs are not readily available to us at this time. However, to us it seems likely that the trunk services could make most effective use of the higher frequencies when such use is desirable. The main reason is that the trunk services can reap the economies of utilization that the higher frequencies potentially offer, and the thin-route services cannot economically do so. These economies of utilization have three sources. First, one satellite can carry transponders for more than one frequency band, reducing costs per unit of bandwidth. Only the trunk route services can take advantage of the large amounts of bandwidth at the relatively low flux densities that would thus be created. Second, the higher frequencies are more amenable to spot beams than the 4 and 6 GHz frequencies, and spot beams may greatly increase both ground station and satellite utilization. Finally, the advantages of the very wide bandwidth (2.5 GHz) available at 20 and 30 GHz have been widely discussed, and clearly would result in greater satellite and ground station utilization.

RECAPITULATION

In this paper we have argued;

- Discussion of orbit-spectrum regulation should be confined to traditional spectrum management issues, such as minimization of extra costs due to spectral shortage and making allowances for technical change and traffic growth.
  Such issues as desirability of competition in provision of satellite service, the need to support the rate base of present carriers, and whether "private" satellite systems ought to be allowed should be discussed separately, on their merits.
- In a purely technical sense, given that all spectrum conservation technologies are used, there is no shortage of orbit-spectrum for any realistically conceivable level of demand.
- Thus, the only necessary consequence of the orbit-spectrum limitation is that communication costs may be higher than if there were no limitation.
- The goal of orbit-spectrum regulation ought to be to minimize the magnitude of these extra costs, with future costs discounted to present value at an appropriate discount rate.
- Spectrum is a resource, but it cannot be "saved" or conserved in the same sense that oil can be conserved. At any time, it can only be either used, or not used. Except for short term needs, it is uneconomic to reserve orbit-spectrum to allow for future demand growth. Rather, it ought to be used as freely as present need allows, with the understanding that conservation

measures will be required later. It is more economic to build cheaply initially and retrofit later, than it is to build an expensive system initially.

- When spectrum saving measures must finally be taken, the best measure to take is the one that minimizes the "normalized incremental cost," i.e.,

$$\frac{\text{incremental cost of the measure}}{\text{incremental spectrum saved}}$$

  Any other measure fails to achieve the goal of orbit-spectrum regulation: minimization of the additional costs imposed on society by the orbit-spectrum limitation.
- Satellite systems that carry heavy traffic with few ground stations can save spectrum with far less normalized incremental cost than satellite systems with less traffic and more ground stations. Consequently, "trunk-route" satellite systems ought to bear the brunt of spectrum conservation when conservation is necessary, simply because this minimizes the consumer cost.
- Indeed, even if spectrum were unlimited, trunk route systems would find it economic to take certain kinds of spectrum conservation measures just because they improve satellite utilization and thus reduce costs. (An example is the frequency re-use capability of the AT&T and RCA satellites.) These measures should be encouraged for their own sake.

- The ideal parameter for assessing who ought to take what spectrum conservation action is the above mentioned "normalized incremental cost." A parameter that is easier to measure, and that is reasonably accurate in ferreting out who ought to take spectrum conservation action, is the "intensity of investment" parameter:

$$\frac{\text{investment in satellite system hardware}}{\text{spectrum used}}$$

  The investments to be included in the numerator are all investments in hardware that are actually concerned with the space relay function. Modulators and antennas are included; access roads, terrestrial tails, and administration buildings are not.

- Thin route satellite systems generally have very high normalized incremental costs of spectrum saving. In this sense, they reap more economic benefit from spectrum use than trunk route stations. Thin route stations also have a much higher intensity of investment in spectrum use, as defined above. It is not economic to save spectrum through restrictions on thin route stations because the cost per unit of orbit-spectrum saved is so high.

- Finally, assignment of orbit-spectrum is not a moral issue, and does not involve questions of "fairness." Fairness to particular satellite system operators in any sense except due process is a specious concept. A spectrum assignment to a satellite system is like assignment of a concession to a concessionaire. The

interest being cared for is the public necessity and convenience. This necessity and convenience is maximized by minimizing the economic impact of the orbit-spectrum limitation through the techniques outlined above.

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[2] Swensen, Robert. "Inclusion of the Time Factor in Comparing the Costs of Terrestrial Telecommunication Transmission Systems." IEEE Transactions on Communications Technology, COM-19, No. 5, October 1972.

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APPENDIX L

ATTENDEES

OFFICE OF TELECOMMUNICATIONS POLICY
INTERDEPARTMENT RADIO ADVISORY COMMITTEE
Washington, D.C. 20005

ATTENDEES SMALL EARTH TERMINAL SEMINAR

NAME	AFFILIATION
Gomaa Abu-Taleb	Comsat
Jean G. Adams	OT/ITS
Lawrence Adams	Comsat
A. F. Arnt	Hughs Aircraft
C. Atkinson	I.T&T
Jeffrey Binckes	DCA
H. T. Blaker	Collins Radio
Lewis Bradley	OT
J. Brilliant	OTP
A. William Brook	RCA Global Communications
Samual A. Brunstein	Jet Propulsion Lab.
J. R. Burke	Joint Council on Educational Telecommunications
B. M. Chiswell	U.S. Coast Guard
H. K. M. Chitre	Intelsat
W. R. Coffman	Navy
W. L. Cook	Navy
R. B. Crowell	FCC
R. DeGoede	FCC
Harold Detlefs	General Electric
Kenneth S. Dewire	Consultant
Jack Dicks	Comsat
Edwin E. Dinkle	OT
Moe DiPietro	Army
E. Dyke	Radio Science Co.
R. M. Dyson	Navy
C. E. Faflick	GTE Sylvania
Billy J. Fansler	Army Satcom
M. E. Ferguson	California Microwave Inc.
O. C. Foster	AT&T
William E. Frazier	OT
J. Freibaum	NASA
William Gamble	OT
W. B. Garner	American Satellite Corp.
Joseph Gatti	FAA
Ernst Gehrel	Consultant
R. G. Gould	Satellite Systems
Richard E. Gray	GTE Sylvania
R. B. Greenwood	Navy-Tracor
Paul C. Groat	ECAC
Neil Helm	Comsat
G. F. Hempton	FCC
Tom Hewlett	Andrew Corp.
George Hickmatt	Western Union
Bruce Higgins	OT
H. L. Holthaus	OTP
S. H. Hubbard	NASA
Charles Hutchinson	OT
Ed Jacobs	FCC
Donald M. Jansky	OTP
Leo P. Joergensen	Western Union
Raymond Johnson	FAA
Harold Kimball	OT
Joseph M. Kittner	McKenna, Wilkinson and Kittner
Arthur Korff	IBEW
Jeffrey Krauss	American Satellite
Frank S. Kravitz	ECAC
D. L. Labanca	Army SatCom
G. S. Li	OT
Paul Locke	National Scientific Laboratories
William G. Long	DCA
L. L. Lucas	NSA
Bruce Lusignan	Stanford University
David Madison	ECAC
Fred Matos	ECAC
Ralph J. Metz	IBM
H. Meyerhoff	Comsat
Joseph G. Molnar	Air Force
J. R. Morin	Navy-Tracor
John P. Murray	OT/ITS
John H. Nagle	NOAA
Walter Owens	FAA
L. M. Palmer	FCC
James D. Parker	CBS
R. D. Parlow	OT
R. Parthasarathy	Intelsat
Joseph L. Pierzga	FAA
Benjamin Pontano	Intelsat
S. E. Probst	OTP
Jack Puerner	NOAA
L. R. Raish	Attorney
J. J. Renner	Advanced Technology Systems
Phillip Reuben	Corp. for Public Broadcasting
William Reytar	FAA
Warren G. Richards	USIA
M. D. Richardson	NASA
Carlos Roberts	FCC
Thomas L. Robertson	NASA
C. A. Runyon	Army
P. Sawitz	ORI
Carl Schmitt	Comsat
C. H. Schmitt	Comsat

John Sell	OT
Frederick Sera	Commerce
John Serafin	ABC
F. E. Sharer	Army
George L. Sharp	FCC
Robert H. Simmons	Air Force
Raymond E. Simonds	RCA
W. Russell Slye	ECAC
Arthur H. Solomon	Arthur O. Little, Inc.
Larry S. Solomon	American Petroleum Institute
J. D. Thompson	Army
Ming T. Tseng	Army
Raymond D. Ulrick	Booz-Allen Applied Research
C. L. Vance	Pierson, Ball and Doud
Walter G. Vient	Ford Corp.
T. M. Walsh	OT/SMSD
C. J. Waylon	Navy
Jack Weatherford	OTP
Donald F. Weiland	FCC
H. E. Weppler	A.T&T
A. Whalen	NASA
John L. Wibbe	Computer Sciences
Virginia M. Wightman	OT/SMSD
F. Williams	FCC
S. L. Windes	Department of Interior
William S. Wojanis	Navy
Lee B. Zahalaka	GTE Sylvania