

JPL PUBLICATION 77-71

(NASA-CR-155268) SHARING THE 620-790 MHz  
BAND ALLOCATED TO TERRESTRIAL TELEVISION  
WITH AN AUDIO-BANDWIDTH SOCIAL SERVICE  
SATELLITE SYSTEM Final Report (Jet  
Propulsion Lab.) 104 p EC AC6/MF A01

N78-12261

Unclas  
63/32 53626

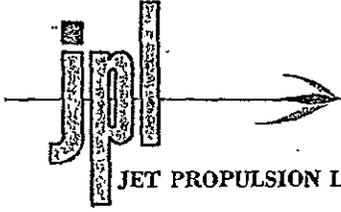
# Sharing the 620-790 MHz Band Allocated to Terrestrial Television With an Audio- Bandwidth Social Service Satellite System

Prepared for  
Department of Health,  
Education, and Welfare

by

Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California





JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

December 9, 1977

Refer to: 652-CAM:sc

NASA Scientific and Technical  
Information Facility  
P. O. Box 8757  
Baltimore-Washington International Airport  
Maryland 21240

Attention: NASA Representative (S-AK-RKT)

Gentlemen:

Attached are COSATI Technical Report Standard Title Pages for JPL Technical Documents released during October and November 1977.

Two copies each of the following JPL Publications are enclosed for your systems input and listing in the unlimited, unclassified, category of STAR:

- |                        |  |
|------------------------|--|
| *JPL Publication 77-36 | Comparison of Experimental and Theoretical Reaction Rail Currents, Rail Voltages, and Airgap Fields for the Linear Induction Motor Research Vehicle. |
| JPL Publication 77-54  | Evaluation of Coal Feed System Being Developed by ERDA.  |
| JPL Publication 77-55  | Proceedings of the Conference on Coal Feeding Systems. Held at the California Institute of Technology Pasadena, California, June 21-23, 1977.        |
| JPL Publication 77-59  | An Analysis of the back End of the Nuclear Fuel Cycle with Emphasis on High-Level Waste Management.  |
| JPL Publication 77-60  | High Efficiency Thin-Film GaAs Solar Cells.  |
| JPL Publication 77-61  | Monopropellant Thruster Exhaust Plume Contamination Measurements Final Report.   |
| JPL Publication 77-65  | Development of a Multiplexed Bypass Control System for Aerospace Batteries.  |
| JPL Publication 77-66  | Sampled Data Analysis of a Computer-Controlled Manipulator.  |
| *JPL Publication 77-68 | Investigation of Pressure Oscillations in Axi-Symmetric Cavity Flows. Final Report-Phase I.  |

NASA STIF

December 9, 1977

JPL Publication 77-71 ✓ Sharing the 620-790 MHz Band Allocated to Terrestrial Television with an Audio-Bandwidth Social Service Satellite System.

JPL Publication 77-72 Medical Ultrasonic Tomographic System.

\* The Standard Title page is included with the Publication as a part of the customer format.

Copies of the following report for which a Standard Title Page is enclosed, were released to NASA for unrestricted systems input and announcement at the time of initial distribution:

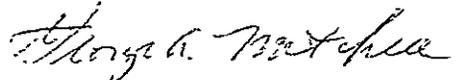
DSN PR 42-41 Deep Space Network Progress Report

Two copies of the following JPL Civil System Project Office Documents required under the terms of their particular contracts are enclosed and authorized for your systems input and listing in the unlimited, unclassified category of STAR:

5040-3 Building Application of Solar Energy, Study No. 2:  
Representative Buildings For Solar Energy Performance  
Analysis and Market Penetration.

5040-10 Building Application of Solar Energy, Study No. 4:  
Utilization of Solar Energy in Southern California Buildings.

Very truly yours,



for Joseph A. Wynecoop, Manager  
Information Support Section  
Technical Information and  
Documentation Division

Enclosures:

cc: Jerry Waldo, Acquisitions Branch

JPL PUBLICATION 77-71

# Sharing the 620-790 MHz Band Allocated to Terrestrial Television With an Audio- Bandwidth Social Service Satellite System

Ernest K. Smith  
Edward E. Reinhart

---

October 31, 1977

Prepared for  
Department of Health,  
Education, and Welfare

by

Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California

Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the Department of Health, Education, and Welfare by agreement with the National Aeronautics and Space Administration.

## PREFACE

This is the Final Report on a study carried out by the Telecommunications Science and Engineering Division, Jet Propulsion Laboratory, for the Office of Telecommunications Policy of the Department of Health, Education, and Welfare (DHEW). The intent was to provide technical assistance and advice to DHEW in the area of voice-bandwidth allocations for the dispensing of social services via satellites particularly with regard to the preparatory work under way in the U.S. for the General World Administrative Radio Conference in 1979.

It is a pleasure to acknowledge the generous assistance provided by many individuals in Government and industry and of the authors' colleagues at JPL.

## ABSTRACT

A social service satellite system ( $S^4$ ) is proposed for 620 to 800 MHz (UHF TV channels 39 through 68) to satisfy a need for thin-route, interactive, audio-bandwidth communication circuits between one or more sophisticated base stations and a large number of smaller fixed stations. Each  $S^4$  provides 126 simplex audio-bandwidth channels. Five  $S^4$  systems fill the available channels in a given geographic area. However, only three  $S^4$  systems can be accommodated in a single satellite owing to the need to provide adequate separation between uplink and downlink channels.

Basically, the  $S^4$  proposes to use the 2 MHz wide, 40 dB deep (relative to the luminance carrier) trough, which exists 1-3 MHz above the luminance carrier in the NTSC (National Television Systems Committee) color television system. Each 2 MHz segment is divided into 42 audio-bandwidth channels, each 47.2 kHz wide, operating with frequency modulation in a single channel per carrier mode. Six of these 2 MHz segments (3 downlink, 3 uplink) constitute one  $S^4$ .

Interference calculations indicate that the  $S^4$  can be accommodated in the UHF television band if restricted to power flux density values currently given in the International Telecommunications Union Radio Regulations under Footnote 332A, and to protection ratios specified by the CCIR (International Radio Consultative Committee) for non-synchronized CW interference. It is proposed to synchronize the  $S^4$  to the line-scan frequency of the television transmissions, but the  $S^4$  is engineered so that this synchronization is not required.

## CONTENTS

I.	SUMMARY -----	1-1
II.	INTRODUCTION -----	2-1
III.	MODEL OF A BASELINE SATELLITE SYSTEM -----	3-1
IV.	SYSTEM DESIGN CONSIDERATIONS -----	4-1
V.	INTERFERENCE ANALYSIS -----	5-1
	A.    TERRESTRIAL TELEVISION RECEIVERS -----	5-1
	B.    PROTECTION OF TV SERVICE AREAS AGAINST INTERFERENCE FROM SATELLITES -----	5-5
	C.    PROTECTION OF TV SERVICE AREAS AGAINST INTERFERENCE FROM EARTH STATIONS -----	5-7
	D.    PROTECTION OF THE S <sup>4</sup> SYSTEM AGAINST INTERFERENCE FROM TERRESTRIAL TELEVISION TRANSMITTERS -----	5-8
VI.	DISCUSSION -----	6-1
	A.    SPECTRUM AVAILABILITY: 620-800 MHz -----	6-1
	B.    NEEDED WORK -----	6-5
VII.	CONCLUSIONS -----	7-1
	REFERENCES -----	8-1
APPENDIXES		
A.	SURVEY OF PERTINENT HISTORY AND REGULATORY ASPECTS -----	A-1
	1.    INTRODUCTION -----	A-1
	2.    HISTORY OF APPLICATIONS SATELLITE EXPERIMENTS -----	A-1
	3.    FUTURE OF APPLICATIONS SATELLITES -----	A-2
	4.    REGULATORY ASPECTS -----	A-2

a.	The Domestic Preparatory Work -----	A-3
b.	The International Scene -----	A-3
5.	COMPETITION FOR SPECTRUM SPACE - THE SHARING PROBLEM -----	A-4
6.	THE FREQUENCY ALLOCATION TABLES AND THE NEED FOR SHARING -----	A-4
B.	BASELINE FUNCTIONAL REQUIREMENTS -----	B-1
1.	INTRODUCTION -----	E-1
2.	SOME EXPRESSIONS OF NEEDS -----	B-1
a.	Health -----	B-1
b.	Education -----	B-2
c.	Welfare -----	B-3
3.	BASELINE MODELS DERIVED FROM FUNCTIONAL REQUIREMENTS -----	B-4
a.	Model 1 - A Health Application -----	B-4
b.	Model 2 - An Educational Application -----	B-5
c.	Model 3 - Disaster Network -----	B-6
d.	Model 4 - Rural Health Consultation Service -----	B-7
e.	Model 5 - Interactive Old Age Program -----	B-8
4.	DESIGN OF A SATELLITE NETWORK -----	B-9
C.	BASELINE SYSTEM TECHNICAL PARAMETERS -----	C-1
1.	PERFORMANCE OBJECTIVES FOR DERIVED MODELS -----	C-1
a.	Noise Objectives -----	C-2
2.	TECHNICAL TRADEOFF PARAMETERS AS A FUNCTION OF FREQUENCY -----	C-3
a.	Modulation -----	C-3
b.	Antennas -----	C-4
c.	System Noise Temperature -----	C-7

d.	Transmitter Power and Frequency Stability -----	C-12
e.	Propagation Considerations -----	C-12
3.	SYSTEM POWER BUDGETS -----	C-14
D.	COST CONSIDERATIONS -----	D-1
1.	COST RELATIVE TO COMPETING MODES -----	D-1
2.	COST VERSUS FREQUENCY -----	D-1
a.	Some Technical Considerations -----	D-1
b.	Costs When Using the Model -----	D-6
E.	CONSIDERATIONS AND CRITERIA IN THE SELECTION OF FREQUENCY REGIONS AND BANDS -----	E-1
1.	OPTIMUM FREQUENCY FOR EXCLUSIVE ALLOCATION -----	E-1
2.	SHARING CONSIDERATIONS -----	E-2
F.	SELECTION AND EVALUATION OF CANDIDATE FREQUENCY BANDS -----	F-1
1.	PRESENT ALLOCATIONS -----	F-1
a.	The Broadcasting Satellite Service (Down) -----	F-1
b.	Uplink Bands in the Fixed Satellite Service (Region 2) -----	F-2
2.	DELINEATION OF A REGION OF THE SPECTRUM -----	F-2
a.	Propagation and Noise -----	F-2
b.	Characteristics of Components -----	F-3
c.	Costs -----	F-3
d.	Frequency Availability -----	F-3
e.	Regulatory Constraints -----	F-3
3.	CANDIDATE BANDS IN THE RANGE 300 TO 1000 MHz -----	F-4
a.	Categories of Services and Allocations -----	F-4
b.	Miscellaneous Provisions -----	F-5
4.	EVALUATION OF CANDIDATE BANDS -----	F-5

G.	TECHNICAL REFERENCE MATERIAL -----	G-1
1.	SYMBOLS USED IN THE STUDY -----	G-1
2.	MATHEMATICAL RELATIONS USED IN THE TEXT -----	G-5
a.	Antenna Relations -----	G-5
b.	Transmission Relations -----	G-6
c.	Thermal Noise -----	G-7
d.	Receiver Input Relations -----	G-8
e.	Post-Detection Signal-to-Noise Ratio for FM -----	G-9
f.	Companding -----	G-11

### Figures

3-1.	The Social Service Satellite System -----	3-2
3-2.	Frequency Plan Showing UHF Television Channels Utilized by S <sup>4</sup> -----	3-4
4-1.	Spectra of the NTSC 525 Line AM Vestigial Sideband Television System M -----	4-5
5-1.	Geometry of Wanted and Interference Signal Paths -----	5-2
5-2.	Protection Ratios for a 525 Line NTSC or PAL Color Television System When a CW Signal or Carrier of an Interfering Sound or Vision Signal Lies Within the Channel of the Wanted Transmission -----	5-6
6-1.	Television Stations in the Continental United States Operating or Under Construction as of September 1, 1976 -----	6-2
C-1.	Gain Versus D/A for Various Cases of $\delta/D = \text{Constant}$ , Where $\delta$ Is the RMS Surface Irregularity -----	C-6
C-2.	Background Noise Temperature Contributors Outside the Atmosphere of the Earth -----	C-9
C-3.	Total Sky Noise Temperature Outside the Atmosphere of the Earth -----	C-9
C-4.	Space-to-Earth Attenuation ( $L_T$ ) -----	C-10

C-5.	Total Sky Noise Temperature Seen From the Surface of the Earth -----	C-10
C-6.	External Noise Figure $F_a$ and Antenna Temperature $t_a$ due to External Noise Versus Frequency -----	C-11
D-1.	Idealized Curves of Gain and Beamwidth for Parabolic Reflectors Showing the Values Selected for Class I, II, and III Stations -----	D-2
D-2.	Frequency Variation of Earth Station Parameters Based on $F = -125$ dBW/m <sup>2</sup> -----	D-5
D-3.	Illustration of the Behavior of the Model for Antennas Shown in Figure D-1 as a Function of Frequency and G/T -----	D-7
D-4.	Variable Costs for Class I and II Earth Stations -----	D-8

### Tables

3-1.	Station Parameters Assumed for the Sharing Analysis -----	3-5
3-2.	Summary of Reception Parameters -----	3-6
4-1.	Frequency Plan for the 2 MHz Slot of a TV Channel -----	4-2
5-1.	Summary of Interference Effects -----	5-3
5-2.	U.S. and World Television Statistics -----	5-4
5-3.	TV Translator Statistics in the U.S. -----	5-4
5-4.	Separation Distances From TV Station Class B Service Contour Required of Class I and II Earth Stations in Order to Achieve Different Possible Protection Requirements -----	5-9
5-5.	Separation Distances From TV Broadcast and Translator Stations Required to Afford Protection to Class I and II Earth Stations -----	5-13
B-1.	Standardized Communications Systems -----	B-11
C-1.	Estimated Maximum Ionospheric Effects in the U.S. for Elevation Angles of About 30 deg, One-Way Traversal -----	C-13

- F-1. Review of Frequency Allocations 300 MHz  
to 1.0 GHz ----- F-6
- F-2. The Frequency Spectrum 470 to 890 MHz From the  
5th NOI FCC Docket 20271 ----- F-10

## SECTION I

## SUMMARY

Many social service needs require communication networks that mainly operate in a broadcast mode and are appropriate for transmission via geostationary satellites. Of these, a significant number are thin-route (one Erlang or less) in nature and involve interactive audio-bandwidth transmissions from a relatively sophisticated base station to many fixed stations at predominantly remote locations.

A social service satellite system ( $S^4$ ), providing about 126 simplex audio-bandwidth channels in a total RF bandwidth of about 12 MHz (6 MHz for uplink and 6 MHz for downlink), would accommodate many of these thin-route services.

Consideration of technical, environmental, and cost factors leads to a preference for the UHF band, particularly for frequencies between about 400 and 1000 MHz. In this range the band 620-790 MHz is the first choice as it is authorized in the International Telecommunications Union (ITU) Radio Regulations (RR) for "television stations using FM in the broadcasting-satellite service..." and offers interference protection to the existing terrestrial broadcasting service through a stringent power flux-density limit. In order to provide the same degree of protection, the downlink part of an  $S^4$  would be designed to meet a comparable power flux-density limit. Translator service areas deserve additional attention, but preliminary inspection indicates this sharing problem is also solvable.

In order to minimize mutual interference between  $S^4$  and the terrestrial broadcasting service, it is proposed that  $S^4$  follow a special frequency plan which takes advantage of the 2 MHz-wide, 40 dB-deep (relative to the luminance carrier) trough in the NTSC (National Television Systems Committee) television signal spectrum that exists over the range from 1 to 3 MHz above the luminance carrier frequency. Specifically, the proposed  $S^4$  would use only the trough portion in each of a pair of three adjacent 6 MHz, UHF TV channels. The upper three channels would be used for uplinks and the lower three for downlinks. The uplink triplet would be separated about 10% in frequency from the downlink triplet. Each 2 MHz trough would be divided into 42 voice-bandwidth channels of 47.2 kHz bandwidth in which frequency modulation would be used in a single channel per carrier (SCPC) mode. Thus, each  $S^4$  would have a capacity for 126 simultaneous simplex, or 63 duplex, circuits.

Earth stations would consist of class II (remote) stations of 100 W transmitter power feeding 3 m parabolic dish antennas and class I (base) stations of 5 kW feeding 5 m antennas. There would be about 100 class II stations for each class I station. The class I stations would have the capability of receiving, transmitting, and processing signals as well as controlling the network and originating programs. Class II stations would each transmit and receive only one voice-bandwidth signal. A single satellite could carry five  $S^4$  systems if the frequency band was extended

to cover 620 to 800 MHz. Service to other nations in the Americas might then be possible.

Power flux densities from the satellite signals are limited to  $-129$  dBW/m<sup>2</sup> up to elevation angles ( $\delta$ ) of 20 deg and to  $-129 + 0.4(\delta-20)$  dBW/m<sup>2</sup> for angles of  $20 \text{ deg} < \delta \leq 60 \text{ deg}$  for each 2 MHz group of 42 voice-bandwidth channels. Normal protection to TV station grade B contours is afforded by the S<sup>4</sup> earth stations. As a consequence of the low power flux densities proposed for the downlink and the remote locations of the S<sup>4</sup> earth stations, the prospects of satisfactory sharing appear good.

Interference calculations indicate that with the foregoing protection provided to the TV station grade B contour, and some consideration taken of TV translators, 95% of the spectrum-area product (defined as the product of the total bandwidth and the geographical area) for the continental U.S. is presently available for an S<sup>4</sup> service and 87% would be available by the year 2000 if the 160% growth prediction for terrestrial broadcasting service in this band is fulfilled.

## SECTION II

## INTRODUCTION

A study has been carried out for the Department of Health, Education, and Welfare (HEW) to identify optimum uplink and downlink frequencies for audio-bandwidth channels for use by a satellite system distributing social services. The study considered functional-user-need models for five types of social services and identified a general baseline system that is appropriate for most of them. A review of the technical aspects and costs of this system and of the frequency bands that it might use led to the identification of the 620-790 MHz band as a preferred candidate for both uplink and downlink transmissions for non-mobile applications. The study also led to some ideas as to how to configure the satellite system.

The use of the frequency band 620-790 MHz for the broadcasting-satellite service is presently authorized in Article 5 of the Radio Regulations through footnote 332A to the allocation table. This footnote applies to all three ITU regions, and allows assignments in this band to "television stations using frequency modulation in the broadcasting-satellite service, subject to agreement between administrations concerned." In ITU Region 2 (North and South America and Greenland), footnote 332A is attached to the band 470-890 MHz, which is otherwise allocated exclusively to the (terrestrial) broadcasting service. Sharing with the broadcasting service is treated in the ITU Radio Regulations in Recommendation Spa 2-10, entitled "Relating to the Criteria to be Applied for Frequency Sharing between the Broadcasting-Satellite Service and the Terrestrial Broadcasting Service in the Band 620-790 MHz."

In the draft table of allocations contained in the Fifth Notice of Inquiry, Federal Communications Commission (FCC) Docket No. 20271 (preparation for the General World Administration Radio Conference, 1979), footnote 332A is retained for Region 2. Interestingly enough, footnote 332A is open to interpretation as allowing uplink as well as downlink transmission. Moreover, the single deletion of the word "television" from the part of 332A quoted earlier may be adequate to allow future allocations by the FCC for the audio-bandwidth service described below, since at least some of the social service needs would appear to fall under the definition of community reception in the broadcasting-satellite service.

The preliminary analysis described here indicates that a satellite system for social service needs (S<sup>4</sup>) providing voice-bandwidth circuits can be overlaid on the existing terrestrial broadcasting service with negligible impact on listeners within the TV grade B contours (64 dBu) as defined in Section 73.683 of the FCC Rules and Regulations. Similarly, it is believed that the service would be compatible with that from television broadcasting translator stations as treated in Sections 74.701 through 74.784, FCC Rules and Regulations, although the impact of the restrictions of Section 74.702(c)(2) has not been examined in detail.

An additional passive user of this spectrum, namely, cable television (CATV), also deserves special attention. CATV systems frequently serve remote areas by picking up television broadcast stations with very elaborate antenna arrays at distances well beyond the grade B contour. A cursory examination of this problem indicates that the proposed service should not materially affect CATV off-the-air pickup of primary television stations. Even the projected 160% expansion of UHF usage by the year 2000 projected by the FCC Broadcasting Service Working Group could probably be accommodated.

The balance of the report is arranged as follows: Section III describes the general baseline satellite system, and Section IV treats some of the technical considerations leading to its selection. An interference analysis is offered in Section V. Section VI considers the S<sup>4</sup> and presents spectrum occupancy in the 620-790 MHz band. Conclusions appear in Section VII.

The supporting material is found in the appendices on regulatory aspects (Appendix A), baseline functional requirements (Appendix B), technical parameters (Appendix C), cost considerations (Appendix D), selection criteria (Appendix E), and, finally, the selection and evaluation of frequency bands (Appendix F). Symbols and equations used in the study are listed in Appendix G.

## SECTION III

## MODEL OF A BASELINE SATELLITE SYSTEM

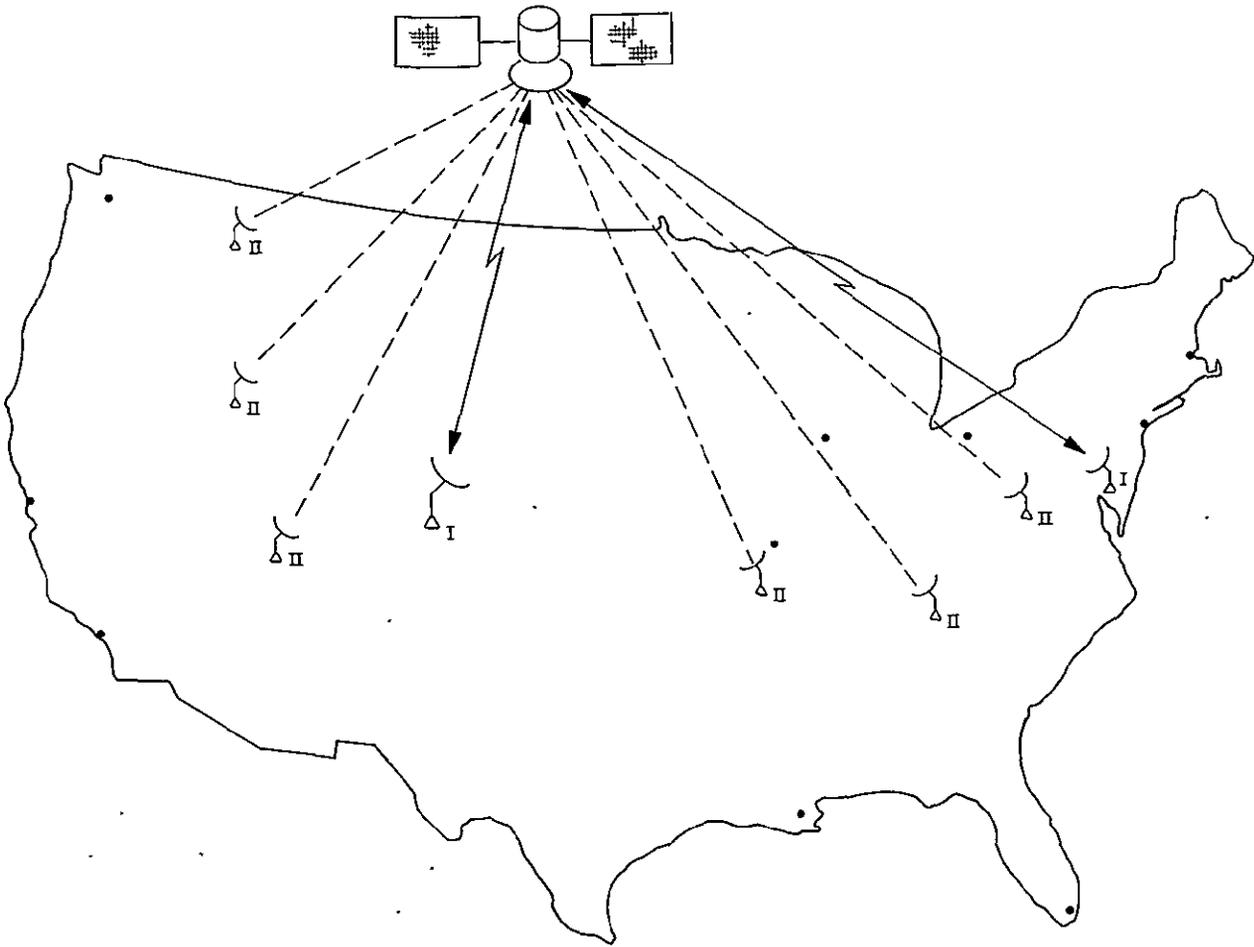
As conceived here, each  $S^4$  network would share a part of the spectrum in six adjacent terrestrial UHF television channels arranged in two sets of three contiguous bands, the bands themselves being separated by at least 72 MHz in accordance with transponder practice (about 10% separation in uplink and downlink frequencies). In each such channel, a 2 MHz band extending from 1 to 3 MHz above the luminance carrier would be used to provide 42 FM voice (or equivalent) single-channel-per-carrier (SCPC) links. Control of the system would be achieved through a computer at a base station. If the upper limit of the 620-790 MHz band were extended by 10 MHz, as described later, a single satellite might carry up to five such systems, for a total of 1260 one-way links (530 simplex channels). An artist's conception of the  $S^4$  system is shown in Figure 3-1a.

The class I, or base, stations are network focal points normally used for program origination and network control. They are relatively expensive and can handle a large number of channels. Frequencies for the remote stations are allocated by a computer at a base station.

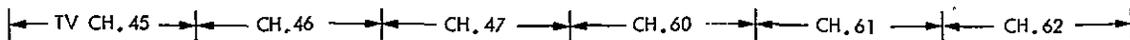
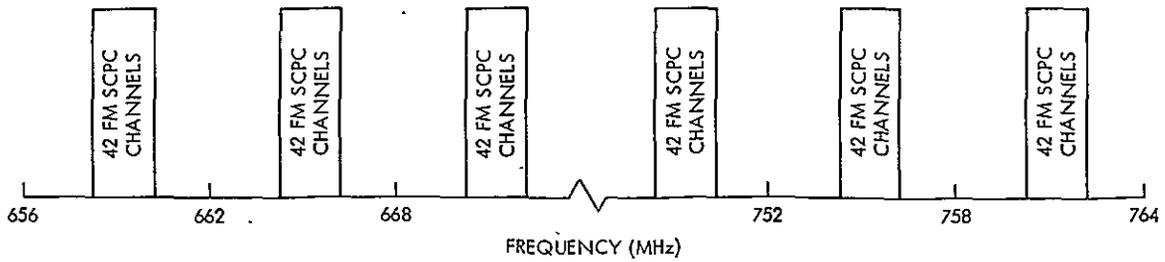
The class II, or remote, stations are much more numerous than the class I stations, and cost is considered to be a major factor in their design. While control may be effected through a time-division data channel, the principal communication mode is through a voice-bandwidth, SCPC transmission over a 47.2 kHz channel (deviation ratio of 6 for a 300-3400 Hz voice channel). At the satellite each SCPC signal from a remote station is translated in frequency and retransmitted downward and is available for reception by any station in the network. If this frequency does not happen to be open at the intended receiver, the desired signal can be switched at the base station and retransmitted to the satellite, where it would be returned to earth in a more suitable channel.

A possible frequency plan for a typical  $S^4$  system is shown in Figure 3-1b. The uplink channels would occupy the upper three of the six terrestrial television channels previously mentioned, and the downlink channels would occupy the lower three. The system is predicated on the need for interactive (i.e., two-way) information flow. For some of the social service uses such as broadcasting of academic courses and dissemination of information to the aged and handicapped, the data requirements on the return link are nominal. For other uses such as consultation on medical problems and access to diagnostic information at the base computer by paraprofessionals at remotely located clinics, the information flow may be almost equal in both directions.

The services are primarily needed at remote locations, which will tend to reduce interference with television broadcasting stations. Further, each remote location has the option to choose which pair of uplink/downlink UHF TV channels to use. If the system is fully loaded, then the choice of a channel in one direction will determine the radio frequency of the channel in the other direction. If the system is not



c) THE SATELLITE NETWORK SHOWING CLASS I (BASE) STATIONS AND CLASS II (REMOTE) STATIONS



b) THE FREQUENCY PLAN SHOWING HOW THE CHANNELS OF ONE TRANSPONDER OF THE S<sup>4</sup> SATELLITE NETWORK COULD BE CONFIGURED

Figure 3-1. The Social Service Satellite System (S<sup>4</sup>)

fully loaded, then switching can be provided by the base computer at the expense of an additional channel pair.

Shown in Tables 3-1 and 3-2 are the parameters of the space system and of the terrestrial stations with which sharing has been examined. The space station transmitter power (per 2 MHz channel) is modest (11.5 W) and assumes a power backoff to reduce intermodulation products. While this means that the transmitter must be sized for a somewhat larger output than actually used, the actual power consumed is small, so that the same satellite, if equipped with a primary power subsystem comparable to that of ATS-6 or CTS, could be used for, say, three systems (such as shown in Figure 3-1a), in a configuration such as that of Figure 3-2. If some liberties can be taken with the upper limit of the 620-790 MHz band (which fits poorly in Region 2, where 788 MHz is the boundary between channels 66 and 67) and extend it to 800 MHz, it would then be possible to divide the spectrum between 620 and 800 MHz into 10 bands of 18 MHz each (5 uplink and 5 downlink). Such a band could then accommodate five systems as described here, and possibly accommodate in two satellites the near-term social service needs of North and South America, thus alleviating the intersatellite coordination problem in the immediate future. The five systems of Figure 3-2 would occupy UHF-TV channels as follows:

- S<sup>4</sup> No. 1: 620-638 MHz (TV Channels 39, 40, 41), 3 x 2 MHz down  
710-728 MHz (TV Channels 54, 55, 56), 3 x 2 MHz up
- S<sup>4</sup> No. 2: 638-656 MHz (TV Channels 42, 43, 44), 3 x 2 MHz down  
728-746 MHz (TV Channels 57, 58, 59), 3 x 2 MHz up
- S<sup>4</sup> No. 3: 656-674 MHz (TV Channels 45, 46, 47), 3 x 2 MHz down  
746-764 MHz (TV Channels 60, 61, 62), 3 x 2 MHz up
- S<sup>4</sup> No. 4: 674-692 MHz (TV Channels 48, 49, 50), 3 x 2 MHz down  
764-782 MHz (TV Channels 63, 64, 65), 3 x 2 MHz up
- S<sup>4</sup> No. 5: 692-710 MHz (TV Channels 51, 52, 53), 3 x 2 MHz down  
782-800 MHz (TV Channels 66, 67, 68), 3 x 2 MHz up

NOTE

The 2 MHz part of a TV channel which is utilized in the S<sup>4</sup> system is 2.25-4.25 MHz above the lower band edge. Hence, for S<sup>4</sup> No. 1, above, the actual downlink frequencies are 622.25-624.25 MHz for channel 39.

**ORIGINAL PAGE IS  
OF POOR QUALITY**

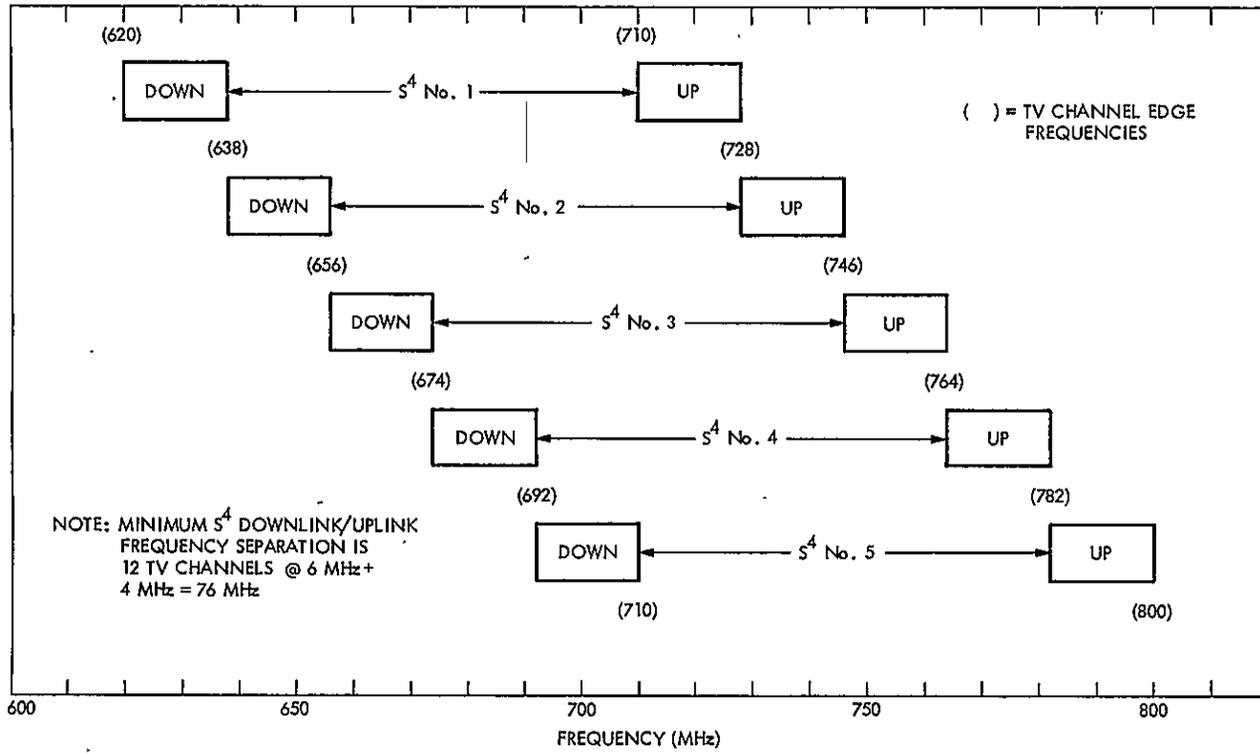


Figure 3-2. Frequency Plan Showing UHF Television Channels Utilized by  $S^4$

Table 3-1. Station Parameters Assumed for the Sharing Analysis

Facility Parameter	Public Service Space Station		Class I (Base) Earth Station	Class II (Remote) Earth Station	Terrestrial Television Stations	Terrestrial Translator Station	Receiver B Sensitive Terrestrial Television Receiver (noise fig- ure = 8 dB)	Receiver A Typical Terrestrial Television Receiver (noise fig- ure = 12 dB)
	Transmitting	Receiving						
Operating frequencies (MHz)	658.25-660.25 664.25-666.25 670.25-672.25	748.25-750.25 754.25-756.25 760.25-762.25	ditto (left, but reversed)	SCPC <sup>a</sup> in on duplex channel from left	Channels 49-54	Channels 49-54	Channels 49-54	Channels 49-54
Antenna beamwidth (°)	5 x 9	5 x 9	6	10	NA	NA	27.5	NA
Antenna description	CONUS beam	CONUS beam	5 m dish elevation angle 30°- 60°	3 m dish ele- vation angle 30°-60°	stacked bat- wings (omni- pattern)	hemi- spherical radiator	10-element Horiz. Yagi	hemispherical radiator (loop, bat- wings)
Antenna height (m above average terrain)	-	-	3.75	3.75	300	10	10	10
Antenna gain (dBi)	27	27	28.6	24	14 at -1° -7 above 30°	3	16 to 0 dBi after 60° off axis	3
Transmitting power (W)	11.5	-	5000	100	40,000	100	-	-
EIRP (dBi)	37.6	-	65.6	44	60.	28.	-	-
Receiver noise temp (K)	-	300	200	300	-	-	2000	2000
Antenna temperature (K)	-	290.	100	100	-	-	290.	290
System temperature (K)	-	590	300	400	-	-	1540 (noise figure 8 dB)	4310 (noise figure 12 dB)
G/T (dBi-dBK)	-	-0.71	3.8	-2.	-	-	-18.8	-33.6
PTD (wanted) <sup>b</sup> (dBW/m <sup>2</sup> )	-	-97.1 (I) -118.7 (II)	-125 axis -128 edge	-141.5 axis -144.5 edge	-	-	-	-
C/No (dB · Hz)	-	112.4 (I) 90.8 (II)	89.1 axis 86.1 edge	66.7 axis 63.7 edge	-	-	-	-
IF noise bandwidth (kHz)	-	2000	2000	40	-	-	-	-
Link (S/N) <sub>1</sub> (dB) (see Note 'c')	-	78.1 (from I) 71.1 (from II)	54.8 axis 51.8 edge	46.9 axis 43.9 edge	-	-	-	-

<sup>a</sup>SCPC = single channel per carrier, 47E3 emission.

<sup>b</sup>Power flux density values are given for "on-axis"/"edge of service area."

<sup>c</sup>(S/N)<sub>1</sub> is the signal-to-noise ratio before adding in the improvements for pre-emphasis, weighting and companding.

3-5 ORIGINAL PAGE IS OF POOR QUALITY

77-71

Table 3-2. Summary of Reception Parameters<sup>a</sup>

From \ To	S <sup>4</sup> Space Station				Class I (Base) Earth Station				Class II (Remote) Earth Station			
	Parameter	Units	Axis	Edge	Parameter	Units	Axis	Edge	Parameter	Units	Axis	Edge
S <sup>4</sup> Space Station					F <sub>2</sub> (δ = 30°)	dBW/m <sup>2</sup>	-125	-128	F <sub>3</sub> (δ = 30°)	dBW/m <sup>2</sup>	-141.2	-144.2
					C/N <sub>0</sub>	dB · Hz	89.1	86.1	C/N <sub>0</sub>	dB · Hz	66.7	63.7
					C/T	dBW/K	-139.5	-142.5	C/T	dBW/K	-161.9	-164.9
Class I (Base) Earth Station	F <sub>1</sub> (6 MHz)	dBW/m <sup>2</sup>	-97.1	-97.1								
	F <sub>2</sub> (2 MHz)	dBW/m <sup>2</sup>	-97.1	-97.1								
	F <sub>3</sub> (47.2 kHz)	dBW/m <sup>2</sup>	-113.3	-113.3								
	C/N <sub>0</sub> (47.2 kHz)	dB · Hz	96.2	93.2								
	C/T (47.2 kHz)	dBW/K	-132.4	-135.4								
Class II (Remote) Earth Station	F <sub>3</sub> (47.2 kHz)	dBW/m <sup>2</sup>	-118.6	-118.6								
	C/N <sub>0</sub> (47.2 kHz)	dB · Hz	90.8	87.8								
	C/T (47.2 kHz)	dBW/K	-137.8	-140.8								
<sup>a</sup> Worst case receiver location and δ = 30° assumed unless otherwise indicated. F <sub>1</sub> , F <sub>2</sub> , and F <sub>3</sub> refer to power flux densities for 6 MHz, 2 MHz, and 47.2 kHz bandwidths, respectively. C/N <sub>0</sub> is carrier power-to-noise power density; δ is the elevation angle of the satellite.												

3-6

77-71

SECTION IV  
SYSTEM DESIGN CONSIDERATIONS

The engineering model of the system derives from the recognition that the spectrum of the modulated carrier from TV broadcasting stations actually contains a 2 MHz trough of more than 40 dB depth relative to the luminance carrier, as discussed in detail later in this section. Utilization of this trough, for example, for satellite maritime mobile communications, has been suggested before in Study Group 8 of CCIR (International Radio Consultative Committee) U.S. National Committee. The frequency plan for the 42 voice-bandwidth channels in a typical 2 MHz portion of a TV channel is shown in Table 4-1.

In order to protect terrestrial broadcasting receivers to an extent commensurate with Recommendation Spa 2-10 of the 1971 Space World Administrative Radio Conference, the S<sup>4</sup> design also assumes the imposition of a power flux density (PFD) limit for each 2 MHz portion of:

-129 dBW/m <sup>2</sup>	for	$\delta \leq 20$ deg
-129 + 0.4 ( $\delta - 20$ )	for	20 deg < $\delta \leq 60$ deg
-113	for	60 deg < $\delta \leq 90$ deg

where  $\delta$  is the angle of arrival above the horizontal plane. The values shown in Tables 3-1 and 3-2 are based on a  $\delta$  of 30 deg as would be appropriate in the northern part of the continental U.S. (CONUS) for a satellite at 100°W lon. A  $\delta$  of 30 deg yields a PFD of -125 dBW/m<sup>2</sup>, which in turn determines the satellite effective isotropic radiated power (e.i.r.p.) of 37.6 dBW. A 5- x 9- deg elliptical satellite antenna beam is used to encircle CONUS, which defines the satellite antenna gain at 27 dBi and transmitter power of 11.5 W (which could be reduced by beam-shaping if the system were power limited, but it does not appear to be).

A system-noise objective of 10,000 pWOp (picowatts at a point of zero relative level, psophometrically weighted) would be achieved by a signal-to-unweighted noise ratio of 47.5 dB in the absence of interference.<sup>1</sup> The weakest link of the system is that from the satellite down to the class II (remote) station, where a link signal-to-noise ratio (S/N) of 43.9 dB (22,500 pWOp) is found. It will be assumed that pre-emphasis improvement is used, and an improvement of 6.3 dB is realized. If compandor improvement ( $\approx 17$  dB) is also utilized, a composite improvement of 23.3 dB over the value given above is realized (Ferguson, 1975),

---

<sup>1</sup>The psophometric weighting factor is 2.5 dB below flat random noise in a 3.1-kHz band. For comparison, 10,000 pWOp corresponds to a signal-to-unweighted noise ratio of 50 dB.

Table 4-1. Frequency Plan for the 2 MHz Slot of a TV Channel

SCPC Channel No.	Ratio of SCPC Carrier Frequency to TV Line Scan Frequency $f_H$	Difference Between SCPC Carrier Frequency and Luminance Frequency (Hz)
1	65.33	1,027,972.
2	68.33	1,075,174.
3	71.33	1,122,377.
4.	74.33	1,169,580.
5	77.33	1,216,783.
6	80.33	1,263,986.
7	83.33	1,311,188.
8	86.33	1,358,391.
9	89.33	1,405,594.
10	92.33	1,452,797.
11	95.33	1,499,999.
12	98.33	1,547,202.
13	101.33	1,594,405.
14	104.33	1,641,608.
15	107.33	1,688,811.
16	110.33	1,736,013.
17	113.33	1,783,216.
18	116.33	1,830,419.
19	119.33	1,877,622.
20	122.33	1,924,824.
21	125.33	1,972,027.
22	128.33	2,019,230.

Table 4-1. Frequency Plan for the 2 MHz Slot of a TV Channel  
(Continuation 1)

SCPC Channel No.	Ratio of SCPC Carrier Frequency to TV Line Scan Frequency $f_H$	Difference Between SCPC Carrier Frequency and Luminance Frequency (Hz)
23	131.33	2,066,433.
24	134.33	2,113,636.
25	137.33	2,160,838.
26	140.33	2,208,041.
27	143.33	2,255,244.
28	146.33	2,302,447.
29	149.33	2,349,649.
30	152.33	2,396,852.
31	155.33	2,444,055.
32	158.33	2,491,258.
33	161.33	2,538,461.
34	164.33	2,585,663.
35	167.33	2,632,866.
36	170.33	2,680,069.
37	173.33	2,727,272.
38	176.33	2,774,474.
39	179.33	2,821,677.
40	182.33	2,868,880.
41	185.33	2,916,083.
42	188.33	2,963,286.

resulting in  $S/N \approx 66.2$  (304 pWOp). Hence, the system is still within compatible voice-quality limits while still protecting terrestrial broadcasting receivers.

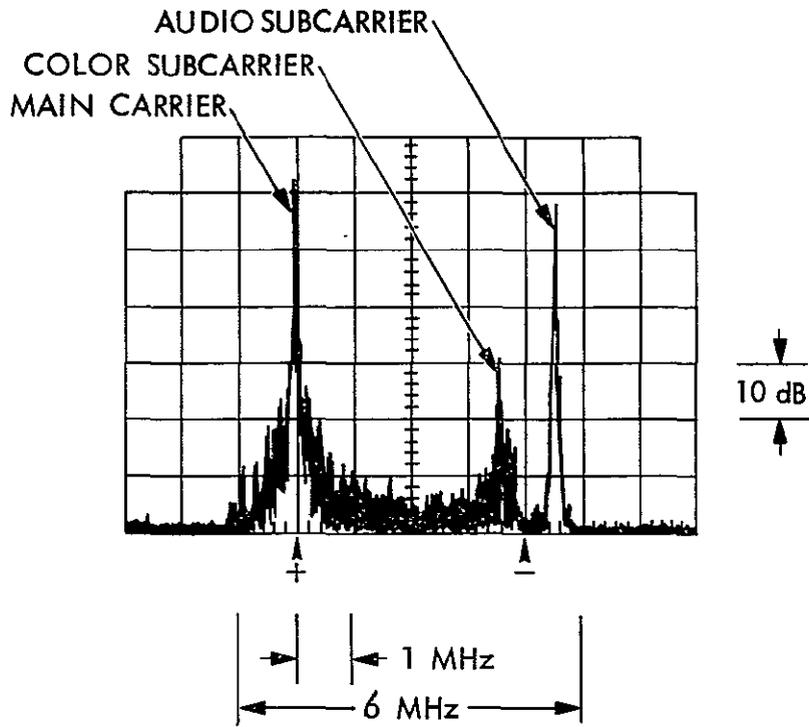
The model discussed here is designed to work with a base station equipped with a 5 m dish (gain = 28.6 dBi) and remote stations with 3 m dishes (gain = 24 dBi). With a power flux density limit of  $-125$  dBW/m<sup>2</sup>, the same system could not be used in mobile applications (ambulances or emergency vehicles), where the antenna gain would drop to the order of 3 dBi, because the carrier-to-noise ratios (C/N) would be below the FM threshold (C/N = 10 dB). However, a special configuration for emergency use is feasible; the transmitter power previously serving 20 channels could be used for 1 channel. (See Figure D-2, Appendix D.)

Spectra of the NTSC 525 line AM vestigial sideband (VSB) television system M as used in North America are portrayed in Figure 4-1. In Figure 4-1a we see a typical color spectrum as recorded off-the-air with a spectrum analyzer; Figure 4-1b illustrates the monochrome spectrum as measured for a gray scale and shows the basic structure of lines (harmonics of the line scanning frequency: 15,750 Hz for monochrome, 15,734.26 Hz for color). Figure 4-1c shows the fine structure around these harmonics due to harmonics of the field and frame scanning frequencies, while Figure 4-1d illustrates the effect of motion. The lines of the color subcarrier are interleaved into the intervals between these line clusters as shown in Figure 4-1e.

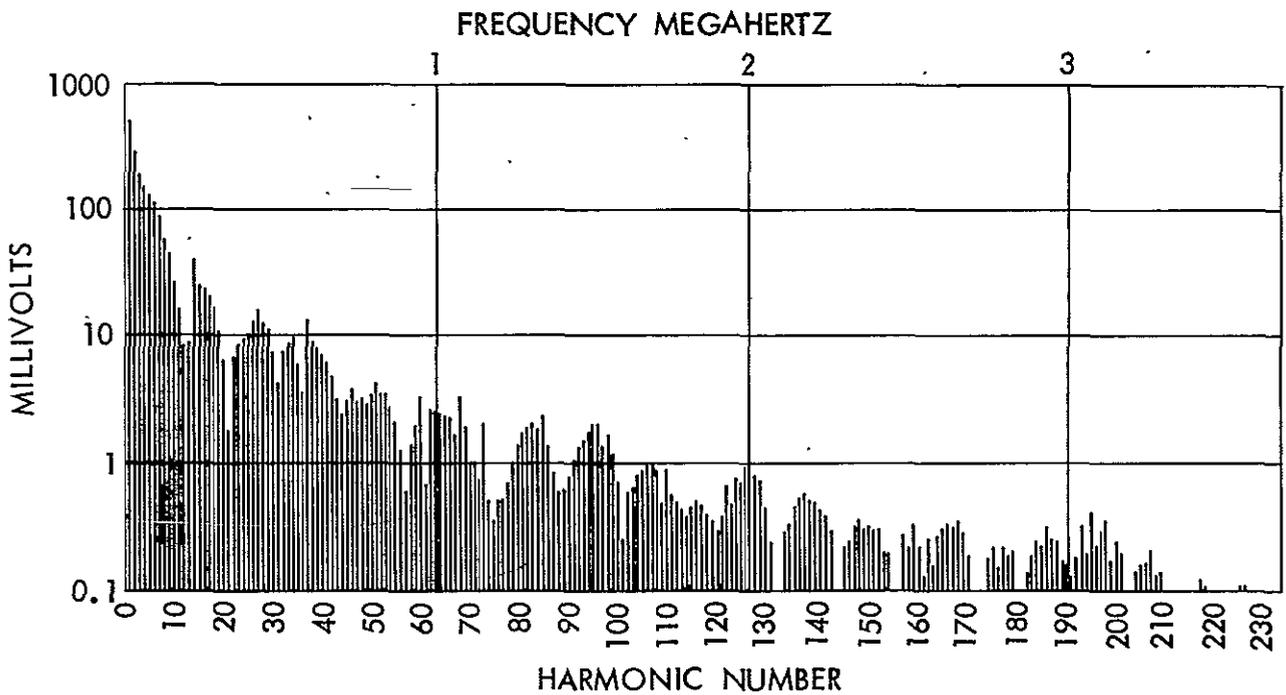
The effect of CW interference (which represents a worst case of SCPC) on the television picture is reduced if the unwanted carriers are positioned within these interharmonic spaces (e.g., Bell, 1970, p. 705). This is proposed for the social service satellite system and determines the proposed channel spacing of 47,203 kHz. This results in a transmitter stability requirement on the order of 1 kHz at the remote stations and in the satellite (or of about 1 part in  $10^6$ ). Figure 4-1f shows the idealized picture transmission amplitude characteristics, showing the extension of the I color signal (one of the orthogonal pair transmitted over the NTSC color subcarrier) into the channel proposed for S<sup>4</sup>. As the protection ratios used in engineering the S<sup>4</sup> are for CW interference to the color TV signal (see Figure 5-2), the inclusion of this piece of the band, where the I signal overlap occurs, is not expected to create a problem.

The protection ratios used in the interference analysis of the next section do not assume synchronization. This choice was made in order to illustrate that this satellite system can be overlaid on the existing terrestrial broadcasting assignments with little problem, even assuming "worst case" conditions.

Man-made noise is a significant consideration at these frequencies, and there is little data available in this part of the spectrum (A. D. Spaulding, private communication, 1977). At 620 MHz, extrapolation of the mean value of man-made noise power for a short vertical lossless grounded monopole antenna in CCIR Report 258-2 indicates 0 dB relative to thermal noise at 288 K for business areas, -4 dB for residential, -11 dB for rural, and -22 dB for quiet rural, but it is not clear whether

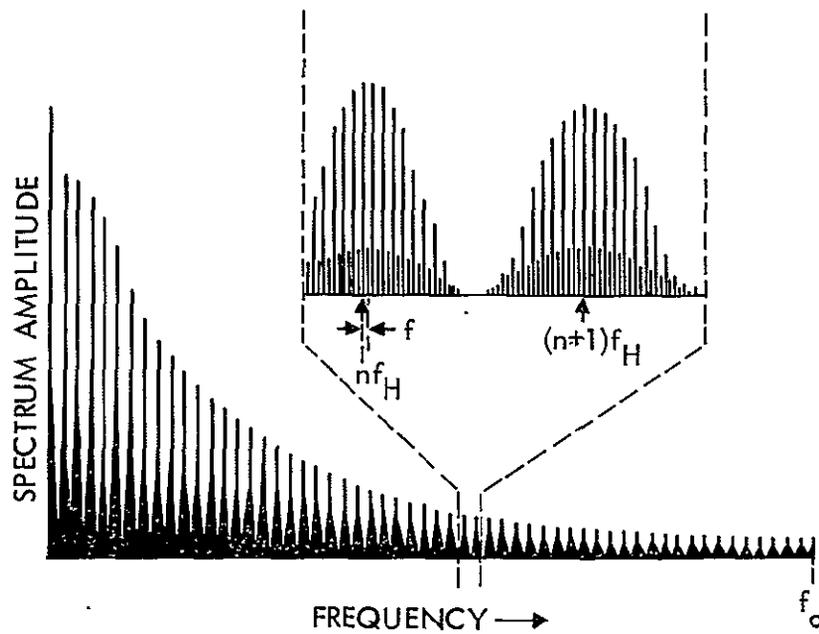


a) Typical Color Spectrum as Recorded Off-the-Air

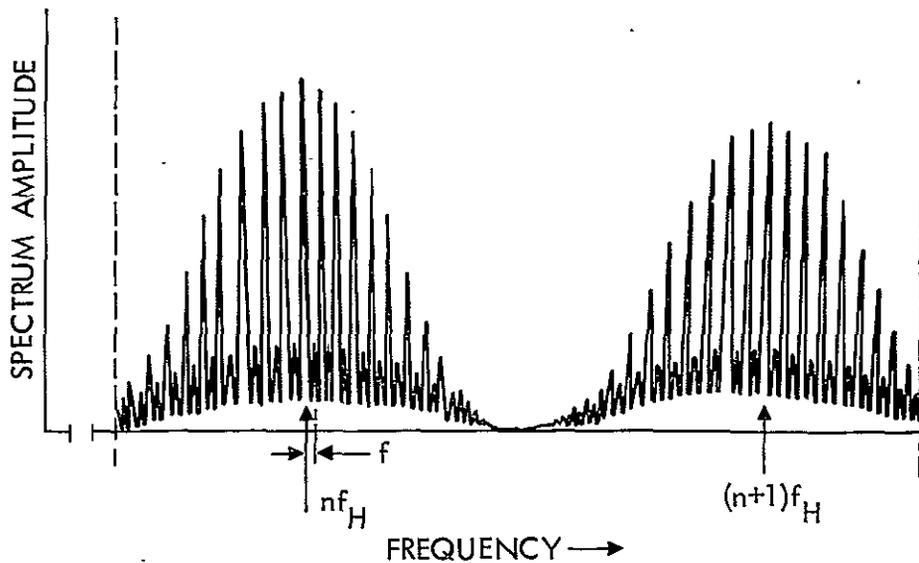


b) Computed Gray Scale Spectrum (Fink, 1957)

Figure 4-1. Spectra of the NTSC 525 Line AM Vestigial Sideband Television System M



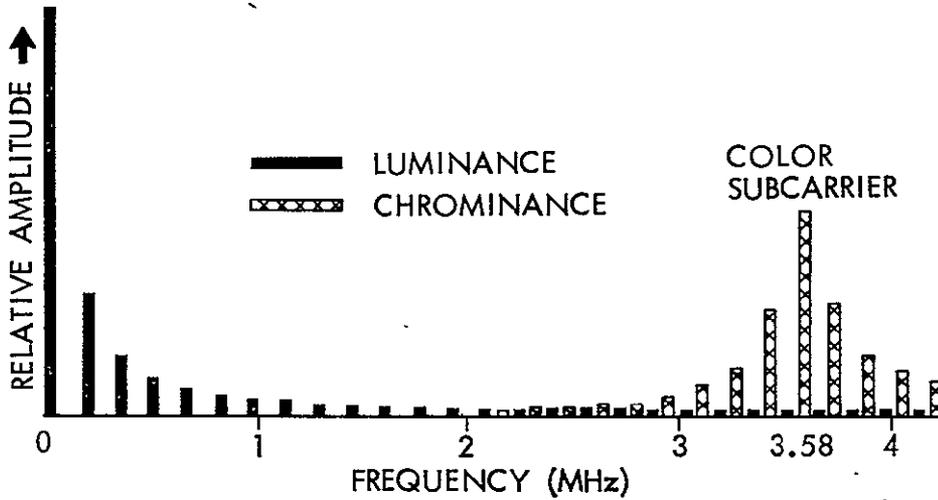
c) Fine Structure of the Video Spectrum



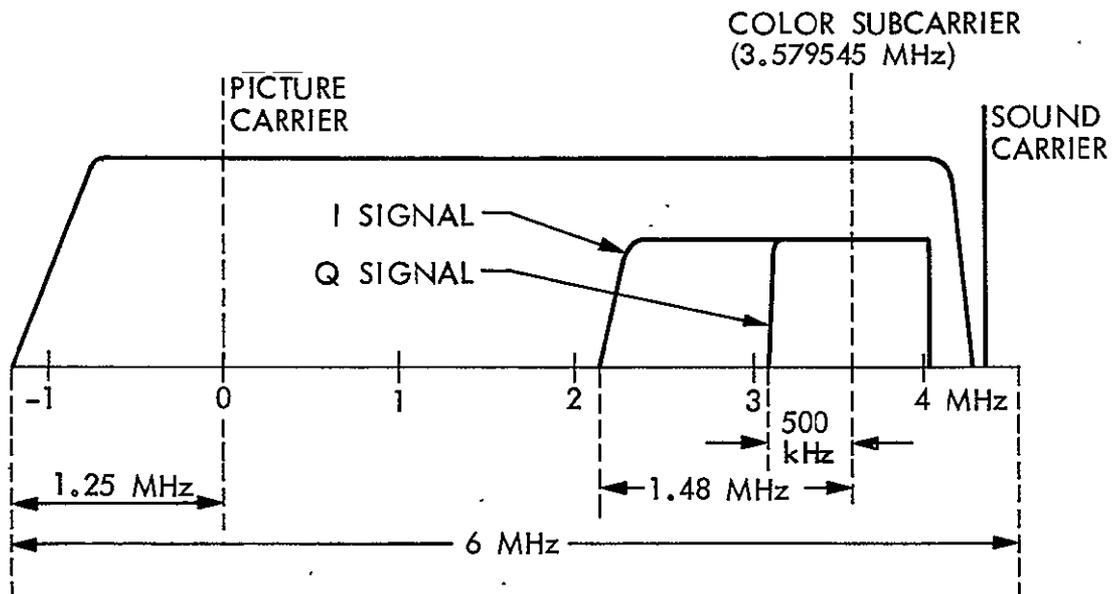
d) Effect of Motion on the Fine Structure

NOTE:  $f$ ,  $f_H$ , AND  $f_c$  ARE FRAME SCANNING, LINE SCANNING, AND VIDEO CUTOFF FREQUENCIES RESPECTIVELY (FINK, 1957)

Figure 4-1. Spectra of the NTSC 525 Line AM Vestigial Sideband Television System M (Continuation 1)



e) Manner in Which Subcarrier is Interleaved



f) Idealized Picture Transmission Amplitude Characteristic

Figure 4-1. Spectra of the NTSC 525 Line AM Vestigial Sideband Television System M (Continuation 2)

this extrapolation is justified. As man-made noise is reduced by antenna discrimination, it will be below thermal noise at 620 MHz for the worst 10% of the time for the earth stations considered here. Galactic noise is also adequately less than thermal noise. The sun may be a noise factor to earth station receivers for small percents of the time during the six months around the winter solstice.

Propagation anomalies on the earth-to-space path are expected to be less than 1 dB for the worst 1% of the time at these frequencies, although ionospheric scintillation may affect the north-east CONUS to slightly above this 1 dB level. Circular polarization is used to circumvent Faraday rotation problems.

## SECTION V

## INTERFERENCE ANALYSIS

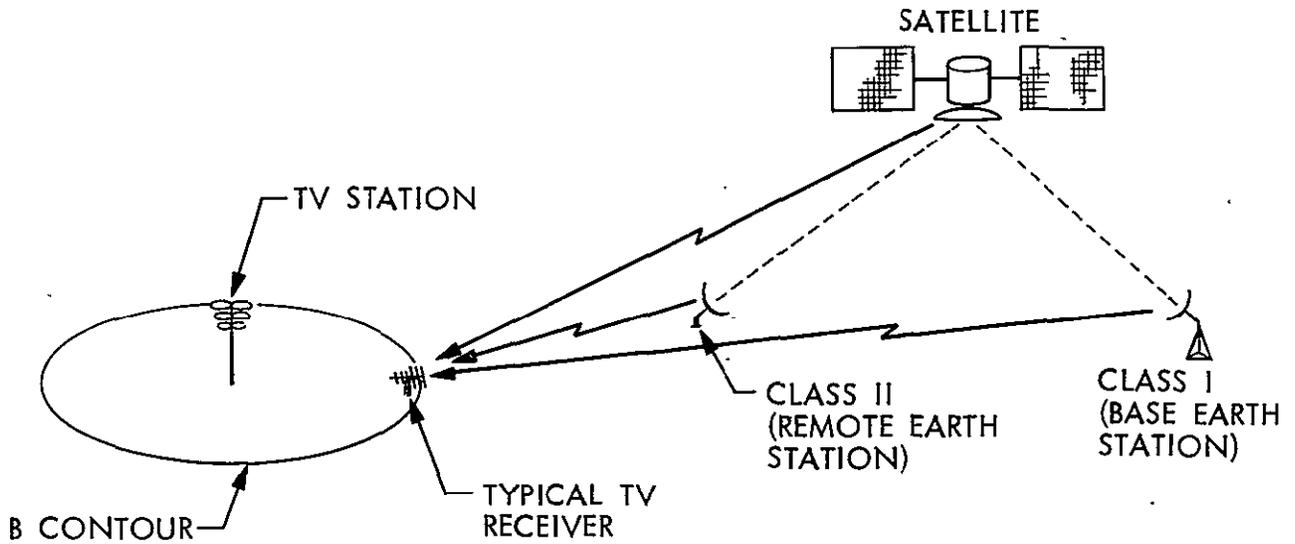
We divide consideration of interference into two categories: interference to the existing terrestrial television receivers (primarily those within and at the grade B contour defined by the FCC), and interference from the terrestrial TV broadcasting and translator stations to the proposed social service space systems. The geometry is illustrated in Figure 5-1 and the general conclusions of the interference analysis are summarized in Table 5-1. As we attempt to be realistic in this assessment, we examine the present occupancy of the TV channels under consideration and briefly consider the capabilities of UHF TV receivers.

The current status of television in the U.S. and of the rest of the world is shown in Table 5-2 (where it can be seen that the U.S. presently has over half of the world's color sets) and the status of U.S. translator stations in Table 5-3.

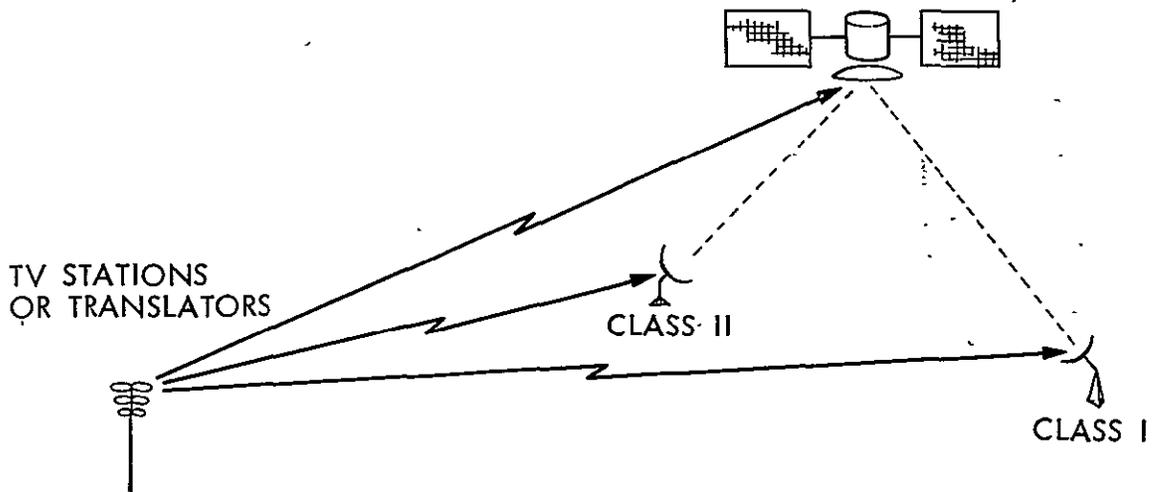
The television translator station situation in the U.S. is not nearly as much publicized as cable television, for example. Translators are, however, an important source of television service to rural communities and, hence, are apt to be located in the same sort of areas as a social service satellite would wish to serve. Fortunately, as we shall see, there do not appear to be major problems in the cohabitation of translator service areas (which receive no formal protection from the FCC vis-a-vis TV broadcasting stations).

## A. TERRESTRIAL TELEVISION RECEIVERS

The typical noise figure for the present generation of UHF receiver is probably about 13 dB, and the best individual sets run as low as 8 dB (Hall and Wetmore, 1973). We have chosen two model receivers, as shown previously in Tables 3-1 and 3-2. Receiver B is intended to be typical of future "fringe area" receivers located near the grade B contour of a television broadcasting station. Receiver A requires more signal to overcome thermal noise and is intended to be adequate within the grade A contour of a TV station (74 dBu). We use the sidelobe pattern of CCIR (SG-11) Recommendation 419, which assumes a gain of 0 dBi beyond 60 deg off axis for the high-gain antenna. Finally, we assume that 50% of the power in the TV carrier is in the synchronizing pulses. (This is an arbitrary value. A more accurate figure may be derived from the British Broadcasting Corporation determination that during active scanning the average video level is about 40% of the blanking to reference white voltage.)



a) From the Satellite Network to Terrestrial Television Receivers



b) From Terrestrial Television and Translator Stations to the Satellite Network

NOTE: - - - - - WANTED SIGNAL PATH  
 ———— INTERFERENCE PATH

Figure 5-1. Geometry of Wanted and Interference Signal Paths

Table 5-1. Summary of Interference Effects

From \ To	Social Service Space Station	Class I (Base) Earth Station	Class II (Remote) Earth Station	Terrestrial Television Receiving Station A (G/T = -18.8 dB · Hz)	Terrestrial Television Receiving Station B (G/T = -33.6 dB · Hz)
1. Social Service Space Station (S <sup>4</sup> )				Proposed PFD limits F = -129 dBW/m <sup>2</sup> , δ ≤ 20°; F = -129 + 0.4 (δ - 20) for 20° < δ < 60°	Protection equal or better than to B
2. Class I (Base) Earth Station				Separation from co-channel TV station will be ≤ 171 km (Rq = 50 dB at B contour for 50% of time)	Required separation distance will always be less than for receiver B.
3. Class II (Remote) Earth Station				Separation from co-channel TV station will be ≤ 119 km as above	Required separation distance will always be less than for B.
4. Terrestrial Television Broadcasting Station	C/I = 56.6 dB (Class I, 2 MHz) <sup>(a)</sup> where I = ΣF <sub>I</sub> = -156.7 dBW/m <sup>2</sup> C'/I = 51.3 dB (Class II, 47.2 kHz) <sup>(a)</sup> where I = ΣF <sub>I</sub> = -172.9 dBW/m <sup>2</sup>	Limiting distance is 78 km from TV station (70 dBu, 1% of time)	Limiting distance is 118 km from TV station (60.5 dBu, 1% of time)		
5. Terrestrial Television Translator Station	C/I = 59.6 dB (Class I, 2 MHz) <sup>(b)</sup> where I = ΣF <sub>I</sub> = -159.7 dBW/m <sup>2</sup> C'/I = 54.3 dB (Class II, 47.2 kHz) <sup>(b)</sup> where I = ΣF <sub>I</sub> = -175.9 dBW/m <sup>2</sup>	Limiting distance is 7 km from the translator station (70 dBu, 1% of the time)	Limiting distance is 3 km from the translator station (60.5 dBu, 1% of the time)		
6. Combined TV B/C and Translators	C/I = 54.8 dB (Class I, 2 MHz) where ΣF <sub>I</sub> = -154.9 dBW/m <sup>2</sup> C'/I = 49.5 dB (Class II, 47.2 kHz) where ΣF <sub>I</sub> = -171.1 dBW/m <sup>2</sup>				
<p><sup>a</sup>In computing aggregate interference power flux density ΣF<sub>I</sub> to S<sup>4</sup> space station, 10 co-channel terrestrial TV stations are assumed.</p> <p><sup>b</sup>In computing aggregate interference power flux density ΣF<sub>I</sub> to S<sup>4</sup> space station, 100 co-channel terrestrial translators are assumed.</p>					

5-3

77-71

ORIGINAL PAGE IS  
OF POOR QUALITY

Table 5-2. U.S. and World Television Statistics

Category	U.S.	Rest of World
TV Stations	965	3724
TV Sets		
Monochrome (millions)	66.6	201.8
Color (millions)	58.5	52.0
Source: TV Fact Book No. 46, Television Digest, Inc., Washington D.C., 1977		

Table 5-3. TV Translator Statistics in the U.S.

Category	Total	VHF	UHF
Licensed	3187	2194	993
Permittees	364	161	203
Applications	119	69	50
Source: TV Fact Book No. 46, Television Digest, Inc., Washington D.C., 1977			

## B. PROTECTION OF TV SERVICE AREAS AGAINST INTERFERENCE FROM SATELLITES

Report 631 of CCIR Study Groups 10 and 11 provides a general equation for determining the limit on power flux density from a broadcasting satellite for sharing with a terrestrial service:

$$F_s = F_{tpq} - R_q + D_d + D_p - M_r - M_i$$

where

- $F_s$  = maximum power flux density (dBW/m<sup>2</sup>) to be allowed at the protected station
- $F_{tpq}$  = minimum power flux density (dBW/m<sup>2</sup>) to be protected, i.e., the power flux density which, in the face of thermal noise only, yields the output signal quality q that is to be exceeded for some specified high percentage of the time p
- $R_q$  = protection ratio (ratio of wanted-to-interfering signal power at the receiver input) (dB) for barely detectable interference when the output signal quality has been degraded by thermal noise to q
- $D_d$  = discrimination (dB) against the interfering signal due to directivity of the receiving antenna
- $D_p$  = discrimination (dB) against the interfering signal due to polarization of the receiving antenna
- $M_r$  = margin (dB) for possible ground reflection of interfering signal
- $M_i$  = margin (dB) for possible multiple interference entries

The value of  $F_{tpq}$  considered here is the value  $F(50,50) = 64$  dBu used by the FCC to define the grade B contour (50% of locations for 50% of the time). For  $R_q$  we employ the values of CCIR Draft Recommendation AA/11 shown in Figure 5-2. These values of protection ratio range from 37 to 50 dB depending on the frequency of the interference in relation to that of the luminance carrier after demodulation. Values for  $D_d$ , the receiving antenna discrimination, are taken from CCIR Recommendation 419 (discrimination for bands IV and V) and assume 16 dB front-to-back ratio. The polarization discrimination is taken to be 3 dB as it is assumed that circular polarization will be used in the satellite system. We take  $M_i = M_r = 0$ . Substituting these numbers, we get at the 64 dBu (grade B) contour:

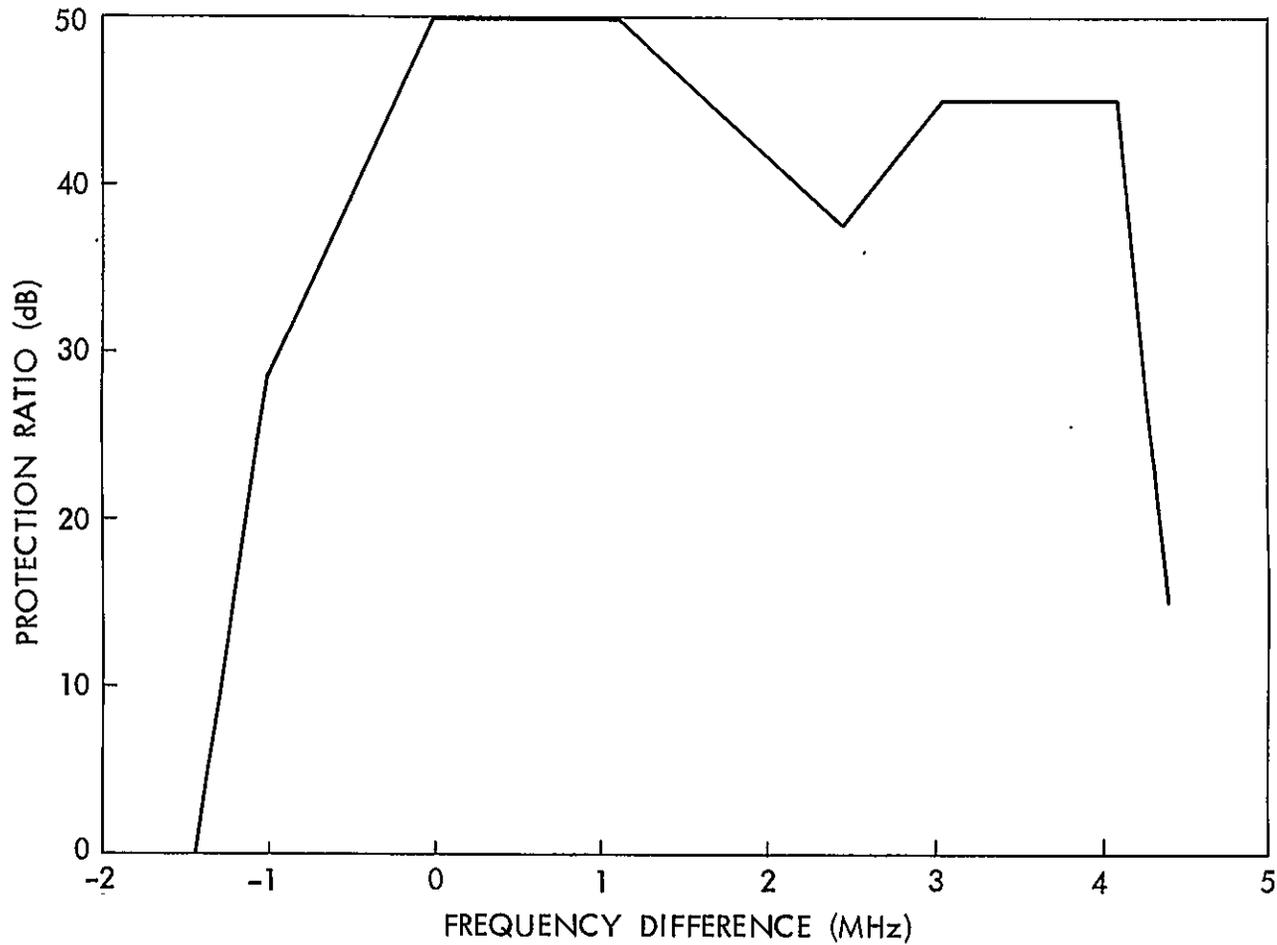


Figure 5-2. Protection Ratios for a 525 Line NTSC or PAL Color Television System When a CW Signal or the Carrier of an Interfering Sound or Vision Signal Lies Within the Channel of the Wanted Transmission (Draft Recommendation AA/11, CCIR 1976).

$$F_S = \begin{cases} -115.8 + D_d \text{ dBW/m}^2, & \text{for } R_Q = 37 \text{ dB} \quad \text{and} \quad 4 \leq D_d \leq 16 \text{ dB} \\ -128.8 + D_d \text{ dBW/m}^2, & \text{for } R_Q = 50 \text{ dB} \quad \text{and} \quad 4 \leq D_d \leq 16 \text{ dB} \end{cases}$$

Alternatively, these values can be expressed in terms of maximum allowed interfering field strength  $E_S$ :

$$E_S = \begin{cases} 30 + D_d \text{ dBu}, & \text{for } R_Q = 37 \text{ dB} \quad \text{and} \quad 4 \leq D_d \leq 16 \text{ dB} \\ 17 + D_d \text{ dBu}, & \text{for } R_Q = 50 \text{ dB} \quad \text{and} \quad 4 \leq D_d \leq 16 \text{ dB} \end{cases}$$

As the design limit for  $S^4$  is based on  $F_S = -125 \text{ dBW/m}^2$  at  $\delta = 30 \text{ deg}$ , protection will be afforded even beyond the  $R_Q$  range. This is due to the values assumed by  $D_d$ , the receiving antenna discrimination, so that  $F_S$  will range from  $-99.8$  to  $-111.8 \text{ dBW/m}^2$  for  $R_Q = 37 \text{ dB}$  and from  $-112.8$  to  $-124.8 \text{ dBW/m}^2$  for  $R_Q = 50 \text{ dB}$ . The proposed PFD limit is thus seen to allow presently protected service to continue unimpaired.

### C. PROTECTION OF TV SERVICE AREAS AGAINST INTERFERENCE FROM EARTH STATIONS

The FCC affords protection to the grade B contour (64 dBu) of the regular television broadcasting station, and, for 620-790 MHz, allows only the television service. For example, to protect one UHF TV station from another on the same channel, the FCC plan allocates UHF stations with a minimum spacing of 330 km (205 mi). For typical UHF stations (1 MW e.i.r.p. and 305 m (1000 ft) antennas) the grade B contour of the station would be located at a radial distance of 69 km (43 mi) from the station assuming normal terrain. The other co-channel station would produce an interfering field  $F(50,50) = 21.5 \text{ dBu}$  at this contour or  $F(50,10) = 32.5 \text{ dBu}$ . These figures are for receiving antenna heights of 9 m (30 ft), and  $F(50,50)$  refers to the field strength exceeded at 50% of the locations for 50% of the time. The values of  $R_Q$ , the protection ratio, implied by these figures are 42.5 dB in the first case and 31.5 dB in the latter. Interference is less objectionable under certain circumstances. For example, in Recommendation 418-2 of CCIR (SG-11), the suggested value of protection ratio for monochrome (AM VSB to AM VSB) is 45 dB when no special control of the frequency difference is made and 29 dB when the frequency difference between the wanted and unwanted carriers is a multiple of the line frequency (15.75 kHz) plus or minus one-third of the line frequency.

In order to be consistent with these possibilities, Table 5-4 has been prepared for two protection ratios (37 and 50 dB) and for 50, 10, and 1% of the time (for 50% of the locations and 50 m mean difference between the upper and lower deciles of terrain irregularity). As can be seen in Figure 5-2, these protection ratios can also be interpreted in terms of position in the spectrum as well as willingness to adopt synchronization; the latter, we propose, should be done in any event (as, for example, is done in Table 4-1) as it decreases the objectionability of the interference at little cost.

Table 5-4 shows the required separation distances for two values of  $\theta$ , the off-axis angle for the earth station antennae. A value of 30 deg is the worst possible case, in that it is the lowest elevation angle  $\delta$  expected in the system (applicable to the most northerly CONUS stations) and assumes that the receivers being interfered with are on the same azimuth as the horizontal projection of the earth station antenna axis. The value of 34 deg for class II stations represents the angle for which the sidelobe pattern of each antenna reaches 0 dBi gain (using the community antenna pattern -  $[10-25 \log \phi/\phi_0]$ , where  $\phi_0$  = angle between half-power points and  $\theta = (1/2)(\phi \cdot \phi_0)$ ). Path loss is based on terrain irregularity ( $\Delta h$ ) of 50 m between the upper and lower deciles of the irregularity distribution. Thus, if we take a protection ratio  $R_q = 50$  dB and protect the TV grade B contour for 50% of the stations for the worst 1% of the time, class I stations would need to be located no closer than 205 km and class II stations no closer than 88 km to the grade B contour for co-channel operation. If protection to translator service areas is to be required, further study is needed.

#### D. PROTECTION OF THE $S^4$ SYSTEM AGAINST INTERFERENCE FROM TERRESTRIAL TELEVISION TRANSMITTERS

The basic feature of the interference to the space system is that, while high TV power flux densities are incident at the satellite at the frequencies of the luminance carrier and FM voice channel, the spectral densities are 40 dB or more down in the interval of interest. The values shown in Table 5-1 for composite power flux densities are based on the characteristics of stations and translators listed in Tables 3-1 and 3-2 and assume 10 co-channel TV stations and 100 co-channel translator stations. As no significant antenna discrimination exists against terrestrial interference from within the satellite coverage area at the satellite, the incident fluxes are simply aggregated in power. Thus, the aggregate interference power flux density of  $-154.8$  dBW/m<sup>2</sup> for a 2 MHz band is well within tolerable limits.

A radio frequency (predetection) protection ratio of  $R_q = 25$  dB is used in this study for protection of the voice-bandwidth channel of the  $S^4$  against interference from the trough of an interfering TV signal (1 to 3 MHz above the luminance carrier). This value was arrived at following consideration of Miller and Myhre (1970), who suggest  $R_q = 16$  to 26 dB for FM TV (no voice channel) suffering interference from AM VSB TV; CCIR Recommendation 356-3 (1974), which suggests 10%

Table 5-4. Separation Distances From TV Station Class B Service Contour Required of Class I and II Earth Stations in Order to Achieve Different Possible Protection Requirements

Interfering Field F(x,y) where x is % locations and y is percent of time	Class I Earth Station		Class II Earth Station			
	Protection Ratio					
	$R_q = 37$ dB	$R_q = 50$ dB	$R_q = 37$ dB		$R_q = 50$ dB	
	Off-Axis Angle					
	$\theta > 30^\circ$	$\theta > 30^\circ$	$\theta = 30^\circ$	$\theta > 34^\circ$	$\theta = 30^\circ$	$\theta > 34^\circ$
F(50,50)	60 km	105 km	28 km	27 km	53 km	50 km
F(50,10)	73	145	30	28	62	58
F(50,1)	100	205	39	36	88	80
F(10,50)	105	180	50	48	92	85
F(10,10)	140	240	58	53	125	120
F(10,1)	195	330	83	75	170	160
F(1,50)	150	260	77	72	135	130
F(1,10)	210	330	105	96	190	180
F(1,1)	295	440	145	135	270	255

Note: Antenna gains for off-axis values of  $\theta$  in the above Table are;

Class I stations  $G(\theta) = 0$  dBi at  $\theta \geq 30^\circ$

Class II stations  $G(\theta) = 1.5$  dBi at  $\theta = 30^\circ$  and 0 dBi for  $\theta \geq 34^\circ$

- Propagation curves used are from CCIR Recommendation 370-2 for  $\Delta h = 50$  m,  $h = 37.5$  m

- Antenna discrimination of earth station from CCIR Report 631 (Rev. 76), Section 6.1.2

-  $R_q$  = protection ratio derived from CCIR Draft Recommendation AA/11

- Characteristics of facilities are as listed in Tables 3-1 and 3-2.

of the noise budget of CCIR Recommendation 353-2 (1974) be allocated to other station interference for the case of FM radio relay (by inference  $R_q \simeq 23$  dB); and, finally, CCIR Recommendation 412-1 (1974), which shows values of  $R_q$  ranging from 36 dB (0 frequency difference) to 16 dB (75 kHz frequency difference) for the case of steady interference for VHF monophonic FM broadcast service with a maximum frequency deviation of  $\pm 75$  kHz.

The figures shown in Table 5-1 in the vertical column titled social service space station were developed as follows.

It was assumed that the carrier-to-interference ratio (C/I) is equal to the power flux density of the desired signal (F) less 3 dB (for possible edge location) divided by the aggregate interference power flux densities:  $C/I = (F - 3) - \sum F_I$  dB. The values of F ( $F_1$ ,  $F_2$ , or  $F_3$ ) are given in Table 3-1. The values of interference were obtained from the parameters given in Table 3-1 using the relation:

$$\sum_{i=1}^n F_{I_i} = 10 \log_{10} n + W - D_d - D_s - 162.7 \text{ dBW/m}^2$$

where

- $F_{I_i}$  = interfering power flux density from one station
- $n$  = number of identical stations
- $W$  = maximum e.i.r.p.  
= 60 dBW for TV stations  
= 20 dBW for translators
- $D_d$  = decrease in gain at 30 deg elevation angle  
= 24 dB for TV stations  
= 0 dB for translators
- $D_s$  = discrimination due to spectral position  
= 40 dB for the 2 MHz trough in the TV channel  
= 56.2 dB for a 47.2 kHz channel in the trough

Thus, for TV station interference, if we assume 10 co-channel stations, we obtain

$$\begin{aligned} \sum_{i=1}^{10} F_{I_i} \Big|_{\text{(dB)}} &= 10 \log(10) + 60 - 24 - 40 - 162.7 \\ &= -156.7 \text{ dBW/m}^2 \end{aligned}$$

Similarly, for translator station interference assuming 100 co-channel translators, one obtains

$$\begin{aligned} \sum_{i=1}^{100} F_{I_i} \Big| \text{(dB)} &= 10 \log(100) + 23 - 0 - 40 - 162.7 \\ &= 159.7 \text{ dBW/m}^2 \end{aligned}$$

The composite interference, noting that the aggregate for TV stations is 3 dB above the aggregate for translators, is thus 1.5 times the total interfering power for TV stations (or +1.8 dB) for a power flux density of -154.9 dBW/m<sup>2</sup> for a 2 MHz trough or -171.1 dBW/m<sup>2</sup> for a 47.2 kHz part of the trough corresponding to one SCPC channel.

The resultant C/I values shown in Table 5-1 are seen to exceed the protection ratio ( $R_q = 25$  dB) adopted for this study by a wide margin (more than 24 dB).

The separation distances to protect the class I and II earth stations from objectionable interference from TV transmitters and translators are shown in Table 5-5 and are seen to be much less demanding than the reverse case. (This is due to the 40 dB reduction in power in the NTSC transmissions in the 2 MHz trough.) Hence, by siting stations on the basis of protecting the TV grade B contours, more than adequate protection is afforded the earth stations against interference from TV stations. Spacing from translator stations is computed to afford protection to earth stations and is seen to be 7 km for class I and 8 km for class II for the worst 1% of time.

It is recognized that some translator stations may have antennas with maximum gains up to 12.7 dBi (8 bay Bogner antennas). However, the effect of this will be to decrease the contribution of these stations at the geostationary orbit as the radiation at off-axis angles in excess of 30 deg decreases below the 3 dBi assumed here.

So far consideration has been given only to interference from U.S. transmitters at the geostationary orbit. Interference might also be expected from Japan and Europe. The easiest way to eliminate this would be to position the satellite such that both areas are below the horizon (roughly 95°W to 115°W in the geostationary orbit). If this cannot be done, then accepting interference from Japan would appear preferable to Europe. The reasons for this are that Japan also uses NTSC and relies on relatively low-power transmitters at UHF. In Europe the channel allocations are offset relative to the U.S., different standards are used, and higher e.i.r.p.'s are employed than in Japan. An additional advantage for placing the satellite west of its service area is that solar eclipses of the satellite by the earth occur after midnight, thus making it unnecessary for the satellite to carry batteries.

At grazing incidence the geostationary orbit receives close to the maximum radiated power from terrestrial TV transmitters. Antenna

discrimination at the satellite will tend to balance this, and sophisticated satellite antenna design may reduce the problem considerably. These problems remain to be examined in detail.

Table 5-5. Separation Distances from TV Broadcast and Translator Stations Required to Afford Protection to Class I and II Earth Stations (Worst Case Conditions; Source Data CCIR Recommendation 370-2, Figs. 9-11)

Situation	Distances in km to the Indicated Maximum Allowable Interference Signal Strength		
	F(50,50)	F(50,10)	F(50,1)
1. To protect Class I Earth Stations ( $F_s = 70 \text{ dBu} = -76 \text{ dBW/m}^2$ )			
a. From TV Broadcast Station*	60	65	78
b. From TV Translator Station*	7	7	7
2. To protect Class II Earth Stations ( $F_s = 60.5 \text{ dBu} = -85.3 \text{ dBW/m}^2$ )			
a. From TV Broadcast Station*	79	88	118
b. From TV Translator Station*	8	8	8
* See Table 3-1 for characteristics.			

ORIGINAL PAGE IS  
OF POOR QUALITY

## SECTION VI

## DISCUSSION

The most severe restrictions on the proposed S<sup>4</sup> lie in the separation distances (Table 5-4) required of earth stations to protect the grade B contours of television stations. In meeting these requirements the S<sup>4</sup> automatically achieves more than adequate protection from TV stations. The problem of serving an area with an S<sup>4</sup> that lies within the protection radius of a UHF TV station is not, in practice, expected to be difficult. The reason is illustrated in Figure 6-1, where one can see that for any given location there are few instances where two adjacent channels are voided. Therefore, as a consequence of the option in the S<sup>4</sup> for a class II station to choose a frequency between two or more channels, there should not be a problem in practice of providing service to the S<sup>4</sup> network. Even with the 160% growth predicted by the year 2000 by the Broadcast Service Working Group, it appears that the S<sup>4</sup> could be accommodated by simply avoiding co-channel operation close to the grade B contour of all UHF TV stations.

The spacing of S<sup>4</sup> satellites in the geostationary orbit is primarily determined by the antenna patterns of the space station and the class II (remote) stations of the S<sup>4</sup> and the geography of the earth. If one assumes that a pair of satellites might serve the Americas with five S<sup>4</sup> systems, then the immediate problem is one of protection to and from Europe and Japan. This class of problems remains to be examined in detail.

From the standpoint of the UHF TV broadcasters, sharing with S<sup>4</sup> appears to be relatively painless (and not only because S<sup>4</sup> would be many years off). The S<sup>4</sup>, with its emphasis on service to remote areas, offers a better joint geographical, frequency-spectrum usage than, say, mobile, where urban usage and somewhat higher powers would be involved.

#### A. SPECTRUM AVAILABILITY: 620-800 MHz

The present occupancy of channels 39 through 68 by 103 TV broadcast stations is shown in Figure 6-1 on a state-by-state basis for CONUS. A separate column on the far right shows the occupancy in Canada (5 stations as of September 1976).

A quantitative feeling for the spectrum availability in CONUS for an S<sup>4</sup> network can be obtained by the following first-order computation:

Let

$$\begin{aligned} S_{\max} &= (\text{Area of CONUS}) \times (30 \text{ UHF TV channels}) \\ &= 2.35 \times 10^8 \text{ km}^2 \text{ ch} (9.067 \times 10^7 \text{ mi}^2 \text{ ch}) \\ S &= (\text{Spectrum}) \cdot (\text{area open to S}^4). \end{aligned}$$

CH	MHz	ALABAMA	ARIZONA	ARKANSAS	CALIFORNIA	COLORADO	CONNECTICUT	DELAWARE	FLORIDA	GEORGIA	IDAHO	ILLINOIS	INDIANA	IOWA	KANSAS	KENTUCKY	LOUISIANA	MAINE	MARYLAND	MASSACHUSETTS	MICHIGAN	MINNESOTA	MISSISSIPPI	MISSOURI	MONTANA	NEBRASKA	NEVADA	NEW HAMPSHIRE	NEW JERSEY	NEW MEXICO	NORTH CAROLINA	NORTH DAKOTA	OHIO	OKLAHOMA	OREGON	PENNSYLVANIA	RHODE ISLAND	SOUTH CAROLINA	SOUTH DAKOTA	TENNESSEE	TEXAS	UTAH	VERMONT	VIRGINIA	WASHINGTON	WEST VIRGINIA	WISCONSIN	WYOMING	CONUS TOTAL	CH	
39...	620-626		1																									1										2										5	39		
40...	626-632	1	1	2			1					1	1					1								1	1																					12	1	40	
41...	632-638						1	1							1					1		1																											8	41	
42...	638-644	2		1																									1		1																		6	1	42
43...	644-650	2																												1						1												4	43		
44...	650-656		1				1			1								1																														5	44		
45...	656-662						1										1																																4	45	
46...	662-668		2				1	1							1																																		7	46	
47...	668-674		1							1																	1		1																				6	47	
48...	674-678	1																									1																						4	1	48
49...	680-686					1						1																																					4	49	
50...	686-692		1										1																																			4	50		
51...	692-698						1																																										2	51	
52...	698-704		1												1																																		4	52	
53...	704-710		1	1											1																																			5	53
54...	710-716		1												1																																		3	54	
55...	716-722																																																1	1	55
56...	722-728																																																3	56	
57...	728-734														1																																			4	57
58...	734-740		1																																														3	58	
59...	740-746																																																0	1	59
60...	746-752																																																0	60	
61...	752-758																																																	1	61
62...	752-764														1																																		2	62	
63...	764-770		1																																														1	63	
64...	770-776																																																0	64	
65...	776-782																																																1	65	
66...	782-788																																																0	66	
67...	788-794																																																2	67	
68...	794-800		1												1																																			2	68
		6	0	1	15	0	3	0	6	2	0	2	3	1	0	8	0	0	2	4	4	0	0	1	0	0	0	3	5	0	5	3	0	7	0	0	6	0	1	0	3	4	0	1	4	3	0	0	103	5	
		TOTAL NUMBER OF STATIONS																																																	

Figure 6-1. Television Stations (Channels 39 Through 68) in the Continental United States Operating or Under Construction as of September 1, 1976 (Source: Television Factbook 46, 1977).

$$S_v = (\text{Spectrum}) \cdot (\text{area voided by TV station and translator occupancy})$$

$$= S_{\max} - S$$

- (1) Percent of spectrum area voided by TV stations can be computed as follows. Let us provide protection to the grade B contour with a protection ratio  $R_q = 50$  for 99% of the time.

- (a) Distance from UHF TV station to B contour = 69 km
- (b) Class I station to B contour (Table 5-4)  
for F(50,1) = 205 km
- (c) Class II station to B contour (Table 5-4)  
for F(50,1) = 88 km

Assume 100 class II stations exist for each class I in the  $S^4$  network.

- (a) Mean radius of voided area  $r_m$

$$= \left[ \frac{(274)^2 + 100(157)^2}{101} \right]^{1/2} = 158.58 \text{ km}$$

- (b) Co-channel area voided per TV station = 79,004 km<sup>2</sup>
- (c) Adjacent channel areas (2) voided = 29,914 km<sup>2</sup>
- (d) Spectrum-area voided per TV station = 108,918 km<sup>2</sup> ch
- (e) Spectrum-area voided by 103 TV stations = 11,218,554 km<sup>2</sup> ch
- (f) Percent  $S_{\max}$  voided by TV stations

$$= 100 \left( \frac{11,218,554}{2.35 \times 10^8} \right) = 4.77\%$$

- (2) Assume that 500 UHF translator stations occupy channels 39 through 68 and that protection to class II earth stations is desired for 99% of the time. Then, from Table 5-5, we obtain for F(50,1) a separation distance of 8 km. We assume 400 of the translator stations to be of this variety (i.e., per Table 3-1). We assume 100 translators are of the high-power variety with 12.7 dBi antennas instead of the 3 dBi of Table 3-1. The corresponding separation distance is then 13 km. For simplicity we assume each translator voids an area defined by this same radius on each adjacent channel.

$$\begin{aligned}
 \text{(a) Spectrum-area voided by translators} &= 3[400\pi(8)^2 + 100\pi(13)^2] \\
 &= 3(133,518 \text{ km}^2) \\
 &= 400,554 \text{ km}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{(b) Percent } S_{\text{max}} \text{ voided by translators} &= 100 \left( \frac{400,554}{2.35 \times 10^8} \right) \\
 &= 0.17\%
 \end{aligned}$$

(3) Total spectrum area  $S_v$  voided is thus

$$\text{(a) } S_v = 11,218,554 + 400,554 = 11,619,108 \text{ km}^2$$

$$\text{(b) Percent } S \text{ voided} = 100 \left( \frac{11,619,108}{2.35 \times 10^8} \right) = 4.94\%$$

$$\text{(c) Spectrum-area available to } S^4 = 100 - 4.94 = 95.1\%$$

(4) Assume 160% growth by year 2000

$$\text{(a) Future percent spectrum-area voided} = 2.6(4.94) = 12.86\%$$

$$\text{(b) Spectrum-area available to } S^4 \text{ in year 2000} = 87.1\%$$

(5) If we assume the same co-channel protection be afforded to translator service areas as to the service area of TV broadcasting stations (if we assume 10 km to the B contour), then a parallel computation to that of (1) above yields

$$\begin{aligned}
 \text{(a) Mean radius of voided area } r'_m & \\
 &= \left( \frac{(215)^2 + 100(98)^2}{101} \right)^{1/2} = 99.8 \text{ km}
 \end{aligned}$$

$$\text{(b) Co-channel area voided per translator} = 31,311 \text{ km}^2$$

$$\text{(c) Spectrum-area voided by 500 translators} = 15,655,473 \text{ km}^2 \text{ ch}$$

$$\begin{aligned}
 \text{(d) Percent } S_{\text{max}} \text{ voided by translators} &= 100 \left( \frac{1.5655 \times 10^7}{2.35 \times 10^8} \right) \\
 &= 6.66\%
 \end{aligned}$$

(e) Total spectrum-area presently voided (TV stations plus translators) in percent of  $S_{\text{max}}$ :

$$100 \frac{S_v}{S_{\max}} = 4.94 + \frac{2}{3} (0.17) + 6.66 = 11.71\%$$

(f) Percent of spectrum-area available to S<sup>4</sup> = 88.3%

The capacity of S<sup>4</sup> is not as great as could be obtained if the power flux density limitation were to be relaxed, yet the service could be a very useful one while sharing the spectrum with terrestrial TV broadcasting.

#### B. NEEDED WORK

Technical aspects that warrant additional study if an S<sup>4</sup> system is to be given serious consideration include:

- (1) Interference to (and from) the S<sup>4</sup> satellite from (and to) terrestrial stations outside North America (particularly from Japan and Europe) and the resultant restrictions on S<sup>4</sup> position in the geostationary orbit (see Section V-D).
- (2) Rejection of the TV luminance carrier in the S<sup>4</sup> terrestrial and space receivers. (At what relative amplitude (S/I) of the S<sup>4</sup> SCPC signal relative to the unwanted luminance signal does the S<sup>4</sup> system become workable in the light of possible front end saturation?)
- (3) Propagation analysis based on information extending the data available in the FCC Rules and Regulations and CCIR Recommendation 370-2 to allow more accurate estimates of interference when both transmitting and receiving antennas are below 37.5 m (see Section V-C).
- (4) The frequency reuse question based on various possible antenna and power options for base and remote stations and satellite.
- (5) Optimizing the design of the S<sup>4</sup> network, for example, through the use of multibeam plus spot beam antennas.
- (6) More extensive consideration of protection to TV translator service areas and CATV headends.

## SECTION VII

## CONCLUSIONS

Many social service needs require communications networks that mainly operate in a broadcast mode and are appropriate to transmission via geostationary satellites. A review of many considerations leads to a preference for the 620-790 MHz band for both uplink and downlink transmission.

A satellite system for social service needs (dubbed S<sup>4</sup>) would accommodate many of the proposed services. It can be overlaid on the existing UHF television broadcasting service with adequate protection to the television broadcast service. Translator service areas deserve additional attention but preliminary inspection indicates this sharing problem is also solvable.

The features of the S<sup>4</sup> that make the scheme workable are the use of the 2 MHz wide trough between the luminance carrier and the color subcarrier of the television signal for transmission of the S<sup>4</sup> voice-bandwidth signals, limitation on the power spectral flux density from the satellite, and separation requirements between the earth stations and the TV grade B contour.

The S<sup>4</sup> is tailored to thin-route use, particularly to remote areas, and could provide many needed services while meeting reasonable sharing criteria.

## REFERENCES

- Akima, H. (1975): Modulation Studies for Direct Satellite Communication of Voice Signals, OT Report 76-108, Office of Telecommunications, U.S. Department of Commerce, Boulder, Colorado.
- Ball, J. E. D., and Wetmore, R. E. (1973): "The Key Aspect of Signal-to-Noise in TV Viewing," NCTA 22nd Convention Transcript.
- Bell Laboratories (1971): Transmission Systems for Communications, Fourth Edition, Western Electric Co., Inc., Winston-Salem, North Carolina.
- Burt, J. E., et al. (1973): Technology Requirements for Communication Satellites in the 1980's, Final Report, NASA CR 114680, Lockheed Missiles and Space Co., Inc., September 1973.
- Carlson, A. B. (1968): Communication Systems, McGraw-Hill Book Co., New York.
- CCIR Draft Recommendation AA/11 (1976): "Ratio of Wanted-to-Unwanted Signal for Colour Television," Document 11/298-E, pp. 58-70, 19 June 1976, ITU Geneva, Switzerland.
- CCIR Recommendation 353-2 (1974): "Systems in the Fixed Satellite Service for Frequency-Division Multiplex Telephony. Allowable Noise Power in the Hypothetical Reference Circuit," CCIR XIIIth Plenary Assembly, Vol. IV, pp. 64-65, Geneva, Switzerland.
- CCIR Recommendation 356-3 (1974): "Systems in the Fixed Satellite Service and Line-of-Sight Radio-Relay Systems Sharing the Same Frequency Bands. Maximum Allowable Values of Interference from Terrestrial Radio Links in a Telephone Channel of a System in the Fixed Satellite Service Employing Frequency Modulation," CCIR XIIIth Plenary Assembly, Vol. IX, pp. 360-361, Geneva, Switzerland.
- CCIR Recommendation 412-1 (1974): "Standards for Frequency-Modulation Sound Broadcasting in Band 8 (VHF)," CCIR XIIIth Plenary Assembly, Vol. X, pp. 109-112, Geneva, Switzerland.
- CCIR Report 215-3 (Rev. 1976): "Systems for the Broadcasting-Satellite Service (Sound and Television)," Document 10/246, 11/297, 10 June 1976. Conclusions of the Interim Meetings of Study Groups 10 and 11, 3-18 May 1976, Part 2 (SG 10), Part 2 (SG 11), Geneva, Switzerland.
- CCIR Report 258-2 (Rev. 1976): "Man-Made Radio Noise," Document 6/177, pp. 133-136, Conclusions of the Interim Meeting of Study Group 6, 16 February - 3 March 1976, ITU, Geneva, Switzerland.
- CCIR Report 263-3, (1974, Rev. 1976): "Ionospheric Effects upon Earth-Space Propagation," CCIR XIIIth Plenary Assembly, Vol. VI, pp. 223-236, Geneva, 1974; and Conclusions of the Interim Meeting of Study Group 6, pp. 86-117, 15 February - 3 March 1976, Geneva, Switzerland.

- CCIR Report 473-1 (1974): "Characteristics of Ground Receiving Equipment for Broadcasting-Satellite Systems," CCIR XIIIth Plenary Assembly, Vol. XI, pp. 208-210, Geneva, Switzerland.
- CCIR Report 631 (1974; Rev. 1976): "Broadcasting Satellite Service: Sound and Television; Frequency Sharing Between the Broadcasting-Satellite Service and Terrestrial Services," CCIR XIIIth Plenary Assembly, Vol. XI, pp. 212-231, Geneva, Switzerland.
- CPA (1977): Private communication from James Janky to Edward E. Reinhart of a draft report on satellite costs prepared for DHEW.
- Crane, R. K. (1977): "Ionospheric Scintillation," Proc. IEEE, Vol. 65, pp. 180-199, February 1977.
- EOP/OTP (1975): Manual of Regulations and Procedures for Radio Frequency Management: Tables of Frequency Allocations, pp. 4-1 through 4-130. Executive Office of the President, Office of Telecommunications Policy, Superintendent of Documents, Washington, D.C.
- FCC (1976): Rules and Regulations, Part II, Federal Communications Commission, Washington, D.C.
- Ferguson, M. E. (1975): "Design of FM Single Channel per Carrier Systems," 1975 IEEE/ICC Record, Vol. 1, Section 12, p. 11.
- Fink, D. G. (1957): Television Engineering Handbook, McGraw-Hill Book Co., New York.
- Fremouw, E. J., and Rino, C. L. (1973): "An Empirical Model for Average F-Layer Scintillation at VHF/UHF," Radio Science, Vol. 8, pp. 213-222.
- Hupe, H. H. (1974): "An Education Satellite: Cost and Effects on the Educational System," Educational Technology, pp. 48-52, October 1974.
- Hupe, H. H. (1975): "Cost-Effectiveness of an Interactive Broadcast Satellite," Astronautics and Aeronautics, pp. 63-67, January 1975.
- ITU-RR (1976): Radio Regulations, Edition of 1976, General Secretariat of the International Telecommunications Union, Geneva, Switzerland.
- Miller, E. F., and Myhre, R. W. (1970): "Frequency Sharing Between FM and AM-VSB Television Transmission Systems," in Communication Satellite Technology for the '70s, III, AIAA, Progress in Astronautics and Aeronautics, Academic Press.
- Miya, K., Ed. (1975): Satellite Communications Engineering, Lattice Co. Ltd., Tokyo, Japan.
- NASA Goddard (1972): ATS-F and -G Data Book Educational Television Experiment, Goddard Space Flight Center, October 1971, revised September 1972, pp. VII-38--VII-43.

- PISA (1977): Toward a Public Dividend: A Report on Satellite Telecommunications and the Public Interest Satellite Association, Interim Report Commissioned by the Public Interest Satellite Association, 55 West 44th Street, New York, New York.
- PLEN/2 (1976): Possible Broadcasting-Satellite Systems and Their Relative Acceptability, CCIR Interim Working Party PLEN/2, Final Report, June 1976.
- Reinhart, E. E. (1974): Orbit-Spectrum Sharing Between the Fixed-Satellite and Broadcasting-Satellite Services with Applications to 12 GHz Domestic Systems, RAND Report R-1463-NASA.
- Russell, S. P. (1977): Technical, Economic and Political Factor in System Planning for Public Service Satellite Systems, EDUTEL Communications and Development Inc., under subcontract from NIAS.
- Spaulding, A. D., and Disney, R. T. (1974): Man-Made Noise, Part I, Estimates for Business, Residential and Rural Areas, Report OT 74-38, Office of Telecommunications, Department of Commerce, Boulder, Colorado.
- USSG FM2/507 (1977): Preferred Frequency Bands for a Search for Extraterrestrial Intelligence, United States of America CCIR Study Group 2, Draft New Report, 14 February 1977.
- Wand, R. H., and Evans, J. V. (1975): "Morphology of Ionspheric Scintillation in the Auroral Zone," Proceedings of the IES Symposium, Naval Research Laboratory, Arlington, Virginia.
- Wolff, E. A. (1976): Public Service Communications Satellite Users Requirements Workshop, Draft Final Report, October 19, 1976, Communications and Navigation Division, Goddard Space Flight Center, Greenbelt, Maryland.

**ORIGINAL PAGE IS  
OF POOR QUALITY**

## APPENDIX A

## SURVEY OF PERTINENT HISTORY AND REGULATORY ASPECTS

## 1. INTRODUCTION

The object of the study covered in the main text and these appendices is to support the Office of Telecommunication Policy of the Department of Health, Education, and Welfare (DHEW/OTP) in preparation for the forthcoming World Administrative Radio Conference in 1979 (WARC 1979). In particular, this study is intended to identify the frequency bands that might be used for certain broadcasting-satellite systems used to dispense social services. The networks of interest are audio-bandwidth, interactive, satellite systems of the community reception type including fixed and portable earth stations. The social services include medical teleconferencing and consultation, education at the secondary, university, and continuing levels, and communications prior to and during emergency and disaster situations.

With this object in mind, this Appendix reviews some of the pertinent background in satellite networks and the regulatory framework through which preparations for the forthcoming WARC 1979 are undertaken.

## 2. HISTORY OF APPLICATIONS SATELLITE EXPERIMENTS

The satellites most germane to the current study are the applications satellites officially classified as "experimental." The Applications Technology Satellites (ATS) of NASA were a technological extension of the SYNCOM series of 1963 and 1964 (NASA, 1972).

ATS-1, a spin-stabilized satellite, was launched on December 7, 1966 and assumed a position in the geostationary orbit over the Pacific, where it has remained and is still operating under the name PEACESAT serving the islands of the Pacific (PISA, 1977). While not designed for social service uses, this satellite, in fact, did yeoman service during the Alaskan flood.

ATS-2 was launched on April 6, 1967. Due to a failure in the Agena rocket, it did not achieve its intended orbit but instead went into a highly elliptical orbit and reentered the earth's atmosphere and was destroyed on September 2, 1969.

ATS-3, also a spin-stabilized satellite, was placed into geostationary orbit over the Atlantic on November 6, 1967, and has been operating as expected ever since.

ATS-4 was launched on August 10, 1968. However, due to a failure in the second stage ignition, separation was not achieved, and the spacecraft, with apogee motor and rocket attached, was left in a low eccentric orbit. It reentered the earth's atmosphere and was destroyed on October 17, 1968.

ATS-5 was launched on August 12, 1969 and achieved geostationary orbit successfully. However, despinning of the antenna was not achieved so that the polar diagrams rotate with a period less than 1 second.

ATS-6 was successfully launched into geostationary orbit on December 30, 1974 and has been operating according to expectations ever since. The largest and most versatile of the ATS series, it has been the backbone of social service experiments to date. After one year at 94°W lon, it was repositioned to 35°E lon. After approximately 1 year ATS-6 was again repositioned to 135°W lon. Each repositioning maneuver took about 3 months.

CTS, the joint United States and Canada Communications Technology Satellite (now called Hermes in Canada), was successfully launched into geostationary orbit on January 17, 1976. Primarily aimed at exploring the communications potential of the 12/14 GHz region, CTS carries a broad spectrum of social service experiments conducted by both U.S. and Canadian experimenters.

### 3. FUTURE OF APPLICATIONS SATELLITES

The U.S. applications series has no approved new starts as of this writing. However, considerable interest has been evidenced in a proposed Public Service Communications Satellite (PSCS), which is under study at the NASA Goddard Space Flight Center (GSFC). A Users Requirements Workshop was held in October 1976 (Wolff, 1976) and NASA is reviewing its intention, announced January 5, 1973, to withdraw from communications satellite research and development in favor of the private sector.

### 4. REGULATORY ASPECTS

The U.S. is a charter member of the Radio Telegraph Union, which was founded in 1906 to undertake international agreements on the use of radio waves. In 1931 the Radio Telegraph Union merged with the International Telegraph Union to form the present International Telecommunications Union (ITU). The details of frequency allocations and usage are contained in the Radio Regulations of the ITU, of which the U.S. is one of the signatories. The Radio Regulations are revised by Administrative Radio Conferences of the ITU. The last Administrative Conference, which looked broadly at the Radio Regulations, took place in 1959. The next one is scheduled for a 10-week period in 1979. Since 1959, there have been two ITU Administrative Conferences that have looked at satellite telecommunications in isolation. The first of these conferences took place in 1963 (Spa 1), and the second in 1971 (Spa 2). The conclusions of both conferences were submitted to the U.S. Senate prior to taking effect in the U.S.

In the United States the Radio Spectrum is allotted to the civil and Federal Government sector and to bands shared by both. The administration of frequencies allotted to the civil sector was initially entrusted to the Secretary of Commerce; then, under the Communications Act of 1934, to the

Federal Communications Commission (FCC), an independent regulatory agency located in the Executive Branch but responsible to Congress. The Government frequencies are administered by the Interdepartmental Radio Advisory Committee (IRAC), which dates back to 1922. IRAC is presently chaired by a representative of the Office of Telecommunications Policy (OTP), located in the Executive Office of the President, while the IRAC secretariat is located in the Office of Telecommunications in the Department of Commerce. The shared frequencies involve both the FCC and the IRAC: non-Government applications are filed with the FCC, Government requests with the IRAC.

International treaty matters are the responsibility of the U.S. Department of State, and this responsibility is exercised by its Office of Communications Policy. The actual management of the U.S. delegation to the conferences of the ITU is handled by this Office. This includes not only World Administrative Radio Conferences, which fall under the ITU General Secretariat headed by the Secretary General of the ITU, but also those of three other ITU organs: the International Frequency Registration Board (IFRB) formed after World War II, the International Radio Consultative Committee (CCIR) dating from 1927, and the International Telephone and Telegraph Consultative Committee (CCITT) founded in 1924. The CCIR and CCITT render advice on technical aspects and in the area of tariffs. In the case of the CCIR, there is a U.S. National Committee directed and managed by the U.S. Department of State, OICP.

a. The Domestic Preparatory Work

The preparation for the 1979 World Administrative Radio Conference is a tripartite activity in the U.S. involving the State Department, the IRAC, and the FCC. Government planning is centralized in Ad Hoc 144 in a committee of the IRAC. The public has had an opportunity to participate through a specially organized set of committees, the Service Working Groups, and to submit comments and reply comments to Docket 20271 of the FCC. Finally, contributions to the 1977/1978 Final Meetings and 1978 Special Joint Meeting (SJM) of the CCIR Study Groups have been under preparation through the various U.S. Study Groups of the CCIR under the aegis of the U.S. National Committee for the CCIR. Coordination is effected between the U.S.-CCIR Study Group and the IRAC, and between the IRAC and the FCC. A public view of U.S. planning has been released by the FCC under the Third Notice of Inquiry, Docket 20271, and the Fifth Notice of Inquiry. The U.S. has traditionally followed the procedure of circulating its views internationally prior to ITU conferences.

b. The International Scene

The pertinent ITU conference schedule as it appears at present is:

September-October 1977 - Final Meetings of CCIR Study Groups,  
Block A

January-February 1978 - Final Meetings of CCIR Study Groups,  
Block B

May 1978 - CCIR XIVth Plenary Assembly

Fall 1978 - Special Preparatory Meeting (SPM) of the CCIR in preparation for the 1979 World Administrative Radio Conference

2nd half of 1979 - World Administrative Radio Conference

1980 - Interim Meetings, CCIR Study Groups.

1981 - Final Meetings, CCIR Study Groups.

Also scheduled in 1978 is a WARC for the Aeronautical Mobile (R) Service.

As the U.S. preparatory work is nearly complete for the CCIR Final Meetings, this particular report will be aimed for possible use in connection with the SPM scheduled for 1978.

#### 5. COMPETITION FOR THE SPECTRUM - THE SHARING PROBLEM

As will be demonstrated in the examples worked in Appendix C, the downlink is characterized by limited power flux densities, while the uplink from either the mobile or remote stations to the satellite requires low interfering fields in order to achieve the required C/I ratios. Both of these factors make sharing of either downlink or uplink bands difficult. At frequencies below 1 GHz the problem is additionally exacerbated by poor antenna directivity, while at frequencies above 1 GHz the problem of achieving an adequate absorbing aperture to the receiving antenna becomes critical.

#### 6. THE FREQUENCY ALLOCATION TABLES AND THE NEED FOR SHARING

The International Frequency Allocations are found in Article 5 of the ITU Radio Regulations (ITU-RR, 1975). Allocations of the Federal Government (the IRAC) are found in Chapter 4 of the Manual of Regulations and Procedures for Radio Frequency Management issued by the Office of Telecommunications Policy, Executive Office of the President (EOP/OTP, 1977); and those of the Federal Communications Commission in Section 2.106 (Part 2, Volume II) of its Rules and Regulations (FCC, 1976).

It is now widely recognized that sharing between services is the way of the future and that the technical considerations in this sharing are of paramount importance.

## APPENDIX B

## BASELINE FUNCTIONAL REQUIREMENTS

## 1. INTRODUCTION

By baseline functional requirements we mean the ends or purposes for which an operation is performed. One source of material for this Appendix is a Lockheed study carried out by Burt et al. on Technology Requirements for Post-1985 Communications Satellite (Burt et al., 1973). Another is the report on the Public Service Communications Satellite User Requirements Workshop held in October 1976 (Wolff, 1976).

Requirements levied on one mode of telecommunications, such as communications satellites, are of two types. First, there are those requirements dictated by the needs. Second, there is the requirement to equal the cost of competing modes, i.e., what service can be obtained for what cost from alternative communication modes. The competition is first and foremost to better the services and costs of the commercially available telephone system. For a person-to-person circuit the satellite is commonly considered to become cost effective for distances over 1610 to 2415 km (1000 to 1500 mi). A commercial telephone circuit may already be made by satellite so the advantages of a satellite in the social services field must be based on other factors, notably:

- (1) The possibilities for getting around the cost of switching involved in terrestrial telephone networks.
- (2) Certain economies for thin-route networks (less than one Erlang per station) through single channel per carrier techniques.
- (3) The broadcast feature of satellites where each customer can receive everything intended for all customers in the network.
- (4) Certain advantages in packet data transmissions.

## 2. SOME EXPRESSIONS OF NEEDS

## a. Health

Under health we include person-to-person consultation and teleconferencing by health personnel and the transmission of records and data. (Some medical education is included below under education.)

A biomedical requirement for 6000 voice/data 4 kHz channels for document and data handling has been proposed by Burt et al. (1973) for the 1975-1985 time frame. Beyond 1985 this national requirement is expected to reduce to 1400 four kHz channels as the advent of automated data-retrieval systems brings about the substitution of 1500/50 kbits/s for the voice grade circuits. Included in these figures are two-way voice consultations and instructions between doctors, dentists, paramedics,

nurses, students, and patients and the transmission of analog and digital records and data for remote processing and analysis for these people.

The Public Service Satellite Workshop (Wolff, 1976) emphasized the need for satellite communications particularly in the areas of:

- (1) Emergency medical services.
- (2) Teleconsultation.
- (3) Remote patient care (telediagnosis).
- (4) Basic and continuing medical education.
- (5) Supervision of allied health care workers.
- (6) Management and administration of health care resources.

b. Education

Elementary and secondary education needs have been reviewed by Burt et al. (1973) who find that for public and private schools and for handicapped at home the following needs will exist for the 1975-1985 period (4 kHz lines):

- (1) Computer-aided instruction (CAI) and program distribution.
- (2) Computer services: remote batch processing, information retrieval.
- (3) Interactive, time-shared multiple access computer services.

For higher education (colleges and universities, vocational schools, universities without walls and continuing education at home) Burt et al. (1973) suggest the following sorts of needs:

- (1) Instructional audio distribution.
- (2) CAI and program distribution.
- (3) Computer services as above.
- (4) Interactive uses as above.

For the 1985-1995 period both categories of education were forecast to need all the services of the prior period plus expanded services to homes and remote areas. A new type of service anticipated is that of global education, i.e., the provision of services to the Third World as well as to industrialized nations.

For the 1985-1995 period the Burt et al. (1973) study estimated a requirement for 2600 voice and slow-speed data channels to fulfill the

elementary and secondary school needs for the U.S. and 160 channels (again 4 kHz) for higher education.

The Public Service Workshop (Wolff, 1976) itemized a rich spectrum of requirements for the nation's 65,000 elementary and secondary schools, including audio transceiver computer terminals, two-way color video (slow scan TV), telecopiers, and teletype for use in instruction. Similar needs were expressed for teleconferencing between teachers and for in-service courses for teachers and other educators. In their recommendations the users in the education area included the following two items in the technology area:

- (1) Develop a high-powered satellite so that inexpensive earth terminals can be made available.
- (2) Develop low-cost mobile and fixed terminals. (This might be done by either public or private means.)

c. Welfare

The Burttt study (1973) does not explicitly address such social services as the needs of the aged, so the only relevant categories under welfare treated above are library services and emergency and disaster.

Libraries include all types, and their functions include:

- (1) Subject and abstract searches.
- (2) Electronic browsing.
- (3) Automated location and retrieval of books, papers and reports.
- (4) Remote reproduction of library reference data.
- (5) Interlibrary communications.
- (6) Communications with library from home, office, aircraft, train, ship, etc.

These needs are estimated by Burttt et al. (1973) to require over 500 voice-grade channels for total coverage during the 1985-1995 period.

Emergency and disaster needs include civil defense and disaster relief agencies and their requirements to communicate with the population at large. These needs are of two types: emergency warning to all households (Burttt et al. (1973) assume that this will be by cable for the 1985-1995 time period); and emergency communication, after the disaster has struck, with police, fire, and medical units. The estimated need is for 100 channels of voice or 200 bit/s data.

The Public Service Workshop (Wolff, 1976) was not explicit with regard to library service needs but suggests that a variety of areas exist.

The Workshop was more specific in the area of public safety communications systems, which consists of intra-agency systems, wide-area systems, and training systems. The intra-agency systems require mobile-to-fixed voice and slow speed data (<4800 bauds) and 95% can be contained within a 320 km diameter (per system). Potential users include 200,000 local law enforcement systems, 5000 fire units, 10,000 ambulance units and others. The wide-area systems include rapid access to national fingerprint and auto-license files and coordination of Red Cross and search and rescue units in time of major disaster. Communication to mobile units was felt to be a key factor.

### 3. BASELINE MODELS DERIVED FROM FUNCTIONAL REQUIREMENTS

This study is specifically concerned with community reception. However, the models discussed below are considered representative of general needs. All involve community reception to some extent. The stations involved are defined as follows:

- Class I: Base station, the hub of a network. It has high e.i.r.p. in transmitting and high G/T in receiving. It may have an associated computer.
- Class II: Remote fixed station, associated with a school, clinic or nursing home. Equipment is professionally installed and maintained but cost is a major consideration.
- Class IIA: Remote fixed station for individual reception in a home. The equipment may consist simply of a box with a vertical whip antenna.
- Class IIB: Portable remote station. This facility will have characteristics at least as good as a class II station.
- Class III: Mobile station such as ambulance, police car, or fire truck. Antenna gain is assumed to be 5 dBi or less (omnidirectional antenna).

Community reception (and transmission) is considered to take place between class I, II and IIB stations, but not where class IIA and III stations are involved.

#### a. Model 1 - A Health Application

1) Functional Requirements. The State of Washington equips 1000 ambulances with transponders for communication via satellite with a state emergency center and with 100 hospitals which will be the destinations of the ambulances. At least one specialist in each normal emergency problem will be on duty at one of the hospitals at any given time. Provision for voice and data (such as EKGs) from the ambulance and x-rays and voice between hospitals is required. Life and death matters are involved so voice transmission should be excellent and data and picture errors very few. The number of stations and channels are:

- Class I: 1 (maximum channels in simultaneous use: 20)
- Class II: 100 (2 channels)
- Class III: 1000 (1 channel)

2) Traffic Analysis. Of 1000 ambulances, 200 will be operating at any one time. Of those operating 30% will be engaged with a patient i.e., 60 ambulances will be interested in conversing, of which 30 will have their circuits in operation either transmitting or receiving. Of these 30, 10 will be transmitting data and talking to central, 20 to destination hospitals. In addition, five of the destination hospitals will be talking to central.

This is a demand access situation (ambulance to central). A frequency division multiplex/single channel per carrier (FDM/SCPC) system would be wasteful as only 100 circuits would be needed for better than 99% of the time. It would seem appropriate for each ambulance to have a calling code and be assigned an open channel upon interrogating the computer at central. Alternatively, there could be a time division digital polling channel that could keep in touch with each ambulance.

Requirement: 100 channels at SCPC/FM, 1 channel digital polling or 100 channels at DAMA/SCPC/PCM/QPSK (demand assigned multiple access/single channel per carrier/pulse code modulation/quadrature phase shift keying).

b. Model 2 - An Educational Application

1) Functional Requirements. A class specifically for blind students is offered nationally for credit by the National Braille Institute, Midland Park, New York. There are 100 participating centers and 200 students altogether, each with his own console and no more than 5 consoles per center. Each console has a keyboard with 6 buttons for: yes, no, understand, uncertain, very confused, and please repeat. The first half of the class consists of a 20 min lecture followed by a 10 min quiz. The second half would start with 20 more minutes of lecture and finish with the aural transmittal of homework. The voice quality must be very good and the errors in transmitting keyed responses very low.

2) Traffic Analysis. A total of 200 students will be receiving identical material for the two 20-min lecture periods of the class hour. Also, during the lecture period, they will be sending one of six possible signals back to the lecturers. These responses will be polled and the lecturer presented with a continuous aggregate "understanding" level of the class. During the interlecture period the class will be quizzed and their responses collected serially on a set of questions. The responses will be "yes" or "no," and each student's response will be recorded separately. After both lecture sections a homework assignment will be transmitted.

The transmission channel for the lecture can be analog FM or digital. If the former, then BW, the channel bandwidth requirement, would be that given by Carson's Rule,  $BW = 2 f_m (\Lambda^{1/2} m + 1)$ , where  $f_m$  (maximum baseband frequency) = 5 kHz,  $\Lambda$  (peak to average amplitude) = 9,  $m = 2.5$ , yielding  $BW = 57.8$  kHz. We will use 47.2 kHz, which, in practice, will be quite adequate. Polling the class would necessarily be a digital process but could be done quite speedily with a 10 kHz bandwidth. Using 16 kbits/s, the 200 terminals could be addressed with an 8 bit address and 8 bit buffer in  $200(8 + 8)/16,000 = 0.2$  s. The responses would need to be spaced to account for the various propagation delays (differences up to 5 ms). By simply ordering the addresses of the terminals by distance (nearest first), it would be possible to receive the polled signals without their overlapping. A minicomputer at the origination terminals would aggregate the polled information for CRT display to the lecturer and also tabulate the quiz scores by student.

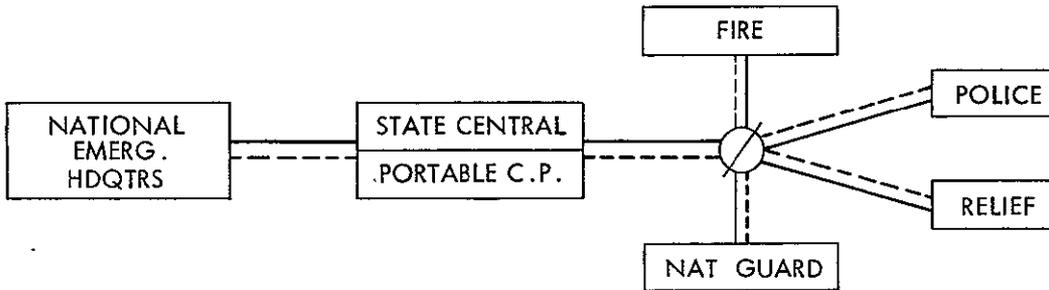
If the voice and data channel were digital, the digitized voice might be 64 kbits/s as in SPADE. The principal advantage of the digital channel would lie in its ability to also serve as the polling channel. At 64 kbits/s each polling burst would require only  $200(8 + 8)/64,000 = 0.05$  s. The instructor could poll the class for reaction at the press of a button and have the results without pausing in his delivery.

c. Model 3 - Disaster Network

1) Functional Requirements. A network is needed for during- and post-hurricane relief on the east coast of the United States. It will be assumed that phones and power are disrupted and that communication will take place from national headquarters to state headquarters (State Central) and from state headquarters to National Guard and to local fire, police, and public service facilities of fixed (100 units) and portable command post (2) varieties. Transmission will be primarily voice, but maps and written material will also be transmitted to and from the fixed stations. The facilities are essentially standby in nature but must be effective when needed.

2) Traffic Analysis. This emergency and disaster network is basically a standby facility that needs to be kept in a high state of readiness during the hurricane season (August through November). In order to keep the network in working order, and to demonstrate that the frequency band is being used, training lectures are offered for two hours each week day, and full-scale simulated disasters are called twice a year.

A basic decision required for this network is whether all information is to be funnelled through the state headquarters (which might be called the centralized command mode) or whether the state central office would wish to act simply as a switching center to tie local fire, police, and Red Cross units together (diffuse command mode). Let us suppose that the system is set up so either State Central or a portable command center can exercise full control over the network at the option of State Central, but that most message traffic would take place directly between local units. The experience gained on Anik indicates that



traffic from remote-to-remote is best handled on a single-hop rather than on a two-hop relay basis. This can be done on an SCPC basis with channel allocation controlled from State Central.

Written material could be sent over voice-bandwidth facsimile with provision for a broadcast mode or over dedicated teletype circuits. For simplicity we will assume the latter. There is no particular requirement for digital service so we will assume FM/DAMA/SCPC.

During an emergency the total traffic intensity is expected to maximize at 100 Erlangs. As all this traffic will be going through the satellite, it will need 100 voice channels (2 frequencies per channel) plus an equal number of DAMA/TWX circuits.

d. Model 4 - Rural Health Consultation Service

1) Functional Requirements. A national diagnostic and emergency consultation facility is operated by DHEW for the benefit of rural medical practitioners concentrated in the Rocky Mountain States and Appalachia. There are 500 locations in 4 time zones connected into the network with one or more nurses or paramedics at each remote location. DHEW maintains a 24 hour staff of doctors, nurses, and computer diagnostic specialists. Each remote location has a time-share teletype console for interfacing a DHEW computer (and card reader for less urgent requests) and a voice channel for direct consultation with a doctor or nurse at the national facility.

2) Traffic Analysis. There is a need for a low-speed data link, such as teletype, with a high probability of getting through. Communication with the computer and arrangements for voice channel would be over this line.

Twenty voice channels will be needed if 10 staff members are available at the base station; the other 10 channels would be used between remote locations. The voice quality would need to be comparable to commercial standards, and the bit error rate (BER) on the data circuit should not exceed  $10^{-4}$ .

Each of the 47.25 kHz voice-grade channels could carry 64 kbits/s of data. One such channel could marginally fulfill the data needs if used in time division multiple access mode over a quadrature phase shift keyed circuit (TDMA/QPSK). Two voice-grade circuits would be a conservative assignment. The total needs would, therefore, total 22 voice-grade circuits or 44 channels.

e. Model 5 - Interactive Old Age Programs - Two Examples

1) Model 5A

a) Functional Requirements. Some of the distressing aspects of life in the U.S. are loneliness, isolation, and societal rejection of its aged. If we take 65 years as the dividing line, then the life expectancy in the U.S. is that 74% of those born will reach age 65, and of these the average life expectancy will be 15.6 years. Thus, we may expect 15% of the future population to be over 65, a total of more than 30 million people. Let us assume that 3 million of these live in isolation and could well benefit from the most minimal form of daily contact: a button to be pressed once to signify that all is well, to be pressed two or more times to signify that help is needed. This information would then need to be relayed to the roughly 3000 county social service offices in the continental U.S.

b) Traffic Analysis. The maximum length of time from distress signal to transmittal of the information to the county should not exceed one hour. The home terminal should be very simple, foolproof, and not require an outside antenna. It would respond to an interrogation signal, which would then be transmitted by the satellite to the county as a high-speed data burst. The county facility would record this burst on tape, which could then be printed out at leisure. Let us assign 12 bits of the address to identify the 3000 counties. Thus, 12 bits could sensitize the terminals in one county. If this were Los Angeles county, it might contain as many as 60,000 terminals, so it would undoubtedly be further subdivided into, say, 10 subunits, each containing no more than 10,000 terminals, and each county subunit would be directly addressed from the satellite and would be among the 3000 units. A 14 bit address for each individual terminal would then be needed. If we now assign two bits for parity and 10 bits for message, we find for the downlink:

- (1) 3000 county level addresses of  $12 + 2 = 14$  bits.
- (2) 3 million individual addresses of 28 bits ( $14 + 2 + 10 + 2$ ).
- (3) Propagation time variation per county (200 km) =  $1.5 \times 10^{-3}$  s.

If we allow 2 ms per respondent, then surveying 3 million terminals will take 6000 s or 100 min. This is not unreasonable as it stands, and the mean signalling information rate is about 14 kbits/s with 25% duty cycle so the return rate is 56 kbits/s. Unless we arrange the respondents in terms of time delay, we cannot beat this by much but let us try. Let us order each regional area in terms of 100  $\mu$ s time delay intervals

(equivalent to equidistance contours from the satellite). Let us further specify that each message take no longer than 100  $\mu$ s to transmit. The interrogation signal can go no faster so it would have a mean rate of 140 kbits/s.

The antenna at the receiver would be omnidirectional,  $\lambda/4$  over a ground plane (11 cm over 11 cm ground plane for 700 MHz). Such an antenna would have a gain of about 1.5 dBi at  $\theta = 30$  deg. The transmitter would be required to operate for only 100  $\mu$ s and would produce 100 W during that period, giving a net e.i.r.p. of 21.5 dBW.

## 2) Model 5B

a) Functional Requirements. While the situation of Model 5A is real, it is also difficult and expensive to implement. A more manageable old-age program with different objectives could be achieved through the use of institutions where professional assistance is available and economies of scale exist. Examples would be retirement communities which have their own interactive cable systems and nursing homes. The services provided by satellite would consist of voice broadcasts provided by DHEW of material of concern to the aged: Medicare, Medicaid, Social Security, and appropriate recreational topics. Pamphlets could be ordered by insertion of a card with the individual's social security number on it into a card reader at the appropriate time in the program.

b) Traffic Analysis. Broadcasts would take place on five programs simultaneously, thus committing five channels on the uplink from base station to satellite and five channels on the downlink from satellite to remote stations. If we assume 1000 participating institutions, these could be polled in 2 s (allowing 2 ms per respondent as before). It would, therefore, be possible to use the broadcast channel for the downlink polling signals and the same uplink channel as used by the base station for the return signals (i.e., the base transmitter would shut off for 2 s after emitting the polling signal). The total needs would, therefore, be five uplink and five downlink channels.

## 4. DESIGN OF A SATELLITE NETWORK

The 2 MHz (approximately) slot in a TV channel is configured in 42 voice-grade FM channels of 47.2 kHz apiece. This specific bandwidth and placement of the carrier frequency is designed to be three times the line scanning frequency of the NTSC television signal ( $\approx 15,734$  Hz) in order to reduce the interference effects on the television receiver. In a network such as model 4, one or two channels would be dedicated to data and network synchronization, while 20 channels would be available for single channel per carrier assignment through the base computer. The two data channels could be configured in a time division digital data stream for greater capacity and flexibility if the additional cost in terminal equipment can be justified.

Similarly, the same configuration can be used for that part of model 1 involving communications between the base station (class I) and the hospitals (class II). In the case of model 2, the class for the blind, the entire system can be carried over our suggested configuration. Similarly, the disaster network could be fitted in one S<sup>4</sup> (6 x 42 channel system - 126 channels each direction), thus falling just two short of the requirement for a grade of service of 1 in 1000 (probability of failing to find an idle circuit in the first attempt) as shown in Table E-1. Model 5A exceeds the ability of our suggested configuration and is not within the community reception scope of this report. However, model 5B, a more feasible network for the aged, could be entirely contained within the configuration suggested above.

Table B-1. Standardized Communications Systems

Scenario & Model No.	Description	Number of Stations				Voice Circuits			5 kbits/s data ccts			≤200 Hz TWX ccts			Computer Required
		I	II	IIA,B	III	Erlangs	No ccts	Config. <sup>a</sup>	Erlang	No ccts	Config. <sup>a</sup>	Erlang	No ccts	Config. <sup>a</sup>	
1	Ambulance Assistance Service	1	100	-	1000	35	53 <sup>b</sup>	A/B	10	21 <sup>b</sup>	B/A	-	-	-	No
2	Class for the blind	1	100	-	-	1	1	B/A	-	-	-	50	50	B/A	No
3	Disaster network	1	1000	2	-	100	128	A/B	-	-	-	100	128 <sup>b</sup>	B/A	No
4	NIH Diagnostic and Consultative Service	1	500	-	-	17	20 <sup>b</sup>	A/B	10	21 <sup>b</sup>	B/A	50	71 <sup>b</sup>	B/A	Yes
5	Network for the aged: A	1	3x10 <sup>3</sup>	3x10 <sup>6</sup>	-	-	-	-	-	-	-	e	3x10 <sup>6</sup>	B	Yes
	B	1	1000	-	-	5	5	A/B	-	-	-	e	1000	B	Yes

<sup>a</sup> Configuration A: Single channel per carrier -- analog FM/DAMA, 6 MHz, 126 channels  
47.25 kHz each 40 kHz RF bandwidth

B: TDMA/PCM/QPSK, 64 kbits/s, 126 channels, 8 bit, 10<sup>-4</sup> bit error rate

<sup>b</sup> Grade of Service: 1 in 1000 (probability of not finding an idle circuit in the first attempt)

B-11

77-71

ORIGINAL PAGE IS  
OF POOR QUALITY

## APPENDIX C

## BASELINE SYSTEM TECHNICAL PARAMETERS

## 1. PERFORMANCE OBJECTIVES FOR DERIVED MODELS

The concern in this study is primarily with speech transmission but also with data.

Speech performance objectives are almost universally related to telephone practice. The signal-to-noise ratio (S/N) is defined at the output of a telephone channel, where S is the power of a test tone representing a speaker, and N is the noise power psophometrically weighted to represent the frequency response of the human ear. If the test tone power is established at 1 mW at some point in a transmission channel and S/N referred back to that point, then telephone signal quality can be expressed in terms of noise power in pWOp (picowatts =  $10^{-9}$  mW psophometrically weighted referred to the point of zero relative level).

When dealing with radio transmission, one is concerned with a modulated RF carrier. Following Reinhart (1974) we write  $[C/N]'$  for the carrier-to-noise ratio which is simply related to S/N (once the FM improvement threshold is exceeded for FM or PM). The proportionality factor R is called the receiver transfer characteristic

$$S/N = R [C/N]' \quad (C-1)$$

In a satellite circuit (earth station to earth station through a satellite repeater) the composite- $[C/N]'$  is related to that defined at the space and earth station receiver inputs by

$$[C/N]' = \frac{1}{(C/N)_{up} + (C/N)_{down}} \quad (C-2)$$

or, combining (C-1) and (C-2), the output noise-to-signal is

$$N/S = (1/R) [(N/C)_{up} + (N/C)_{down}] \quad (C-3)$$

If S is referred to 1 mW, we can now define the total noise at the channel output  $N_c$  as

$$N_c = N_{up} + N_{down}$$

where

$$N_{up} = (10^9/R) (N/C)_{up} \text{ pWOp} \quad (C-4)$$

$$N_{down} = (10^9/R) (N/C)_{down} \text{ pWOp} \quad (C-5)$$

a. Noise Objectives

Telephone usage defines noise objectives in Recommendation 353-2 of the CCIR for an earth station-to-earth station circuit (via a geostationary satellite) as not exceeding:

- (1) 10,000-pWOp mean power in any hour.
- (2) 10,000-pWOp 1-min mean power for more than 20% of any month.
- (3) 50,000 pWOp 1-min mean power for more than 0.3% of any month.
- (4) 1,000,000 pW unweighted (with an integration time of 5 ms), for more than 0.03% of any month.

In telephone usage unwanted signal interference and signal distortions are allocated as noise and assigned a fraction of each of the above values. For example, CCIR Recommendation 356-2 assigns 10% of the first two and 100% of the third (but for one-tenth of the time) to interference noise power between communication satellite relay systems and terrestrial radio relay systems. This telephone-related practice represents one pole of possible noise objectives. Note that 10,000 pWOp may be viewed as a signal-to-noise ratio of 47.5 dB, and  $10^6$  pWOp as  $S/N = 27.5$  dB. (At the end of a complete system, CCIR Recommendation 339-3 specifies 15 dB as the limiting  $S/N$  for marginal commercial voice quality.)

The other pole is in the mobile services (land, air and maritime), where the concern is with intelligibility. Mobile usage (and broadcasting, which occupies an intermediate position) specifies performance relative to noise in  $S/N$  and interference in terms of protection ratios. The protection ratio is defined for AM sound broadcasting in Recommendation 447. The distinction between audio frequency values (post-detection) and radio frequency value (receiver input) is made. In both cases the definition is in terms of minimum signal-to-interference ratios in decibels. For stable signals an RF protection ratio of 26 dB for AM broadcasting and 8 to 20 dB for mobile usage is typical. As all of these values fall in the millions of picowatts in the telephone terminology, one can see why a different representation evolved.

Akima (1976), in a careful study of voice quality required for direct satellite communication to homes for natural disaster warning, recommends a post-detection signal-to-psophometrically weighted noise ratio of 20 to 25 dB.

For the purpose of this report a lower threshold quality to be achieved by a post-detection signal-to-noise ratio will be specified [which is designated  $(S/N)_1$ ] of 37.5 dB ( $10^5$  pWOp) for the sum of the earth-to-space and space-to-earth links. Of this, 20,000 pWOp is distributed to the uplink and 80,000 to the downlink.

## 2. TECHNICAL TRADEOFF PARAMETERS AS A FUNCTION OF FREQUENCY

This section considers the different technical parameters that the design engineer has at his disposal and how (and if) they vary with frequency.

### a. Modulation

Modulation may be defined as the systematic alteration of a carrier wave in accordance with the message (modulating signal) and may include coding (Carlson, 1968). Modulation is required to match the signal to the transmission medium. Modulation is divided into analog and digital. The three basic forms of analog modulation are amplitude modulation (double sideband with transmitted carrier, double sideband suppressed carrier, single side band, vestigial sideband), frequency modulation (narrow band, wide band), and phase modulation.

Digital modulation has the same three basic ways in which the digital information can be impressed upon (modulate) the carrier wave. These are amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). Coding is the process in which the information is matched to the digital channel in order to achieve maximum reliability in the transfer process. It can be thought of as in series with the modulation of the carrier (e.g., pulse code modulation, quadrature phase shift keying: PCM/QPSK).

A useful principle is to opt for the simplest way to do a job unless there are compelling reasons to the contrary (such as the military digitization of voice circuits for security reasons). By this principle, if you start with an analog signal, be it voice or television, it is reasonable to look for an analog mode of transmission. Similarly, if you are transmitting data, and particularly if it is to a computer, you may wish to use digital modulation. For the "simplicity" principle to work, analog and digital systems must be fairly competitive in signal-to-noise ratio (or bit error rate).

A first impression may be that modulation and choice of operating frequency are separable. In a sense this is so. The joker is that in both digital and analog methods one can improve the signal-to-noise ratio (bit error rate) at the expense of bandwidth, and bandwidth is more available at higher frequencies than it is at lower ones. Hence, AM is used for broadcasting near 1 MHz and FM for broadcasting near 100 MHz, where a channel spacing 20 times that of AM broadcasting is used for a baseband signal with frequency excursion only 3 times that of AM broadcasting. At the frequencies with which we are dealing (primarily

300 to 1000 MHz), most practice assumes that the threshold between AM and FM has been passed for narrow-band signals (<50 kHz).

There is, however, another practical reason for preferring an exponential modulation (FM or PM) over AM in connection with communication satellites. This has to do with the nonlinear distortion encountered in the satellite. FM and PM are relatively immune to distortion products so that a frequency division multiplexed signal of many FM carriers (FDM-FM) can be transmitted through a satellite whose final amplifier is operating near saturation, while for the same resultant signal-to-noise ratio the final amplifier might have to reduce power (back off) to achieve linearity by 5 to 10 dB. For these reasons an exponential system is to be preferred. FM is the choice over PM due to the fact that PM is limited to phase swings of  $\pm \pi$  radians, which tends to restrict its usefulness to digital modulation.

Optimum coding in digital modulation is an elegant and complex subject (in which practice lags behind theory) in which the system is selected on the basis of the information rate, the noise background, the available bandwidth, and the required bit error rate. We will assume a work horse system, pulse code modulation using quadrature phase shift keying (PCM/QPSK). Its primary competitor is Delta modulation in one of its modern forms.

1) Multiplexing. The requirements under study here mostly indicate "thin-route" systems, namely, systems in which the traffic between a typical earth station and the space station is of the order of an Erlang or less. With such systems the trend is to use single channel per carrier (SCPC) systems, either analog FM or digital. A good recent discussion of thin-route systems may be found in Russell (1977). We accept the validity of his arguments and assume that the analog voice system will use pre-emphasis. Ferguson (1975) suggests a 6.3 dB advantage to signal-to-noise if this is done, which we here call  $(S/N)_2$  [Bell (1971) suggests a 4.77 dB limit]. Pre-emphasis is the scheme by which the highs of the FM signal spectrum are emphasized 6 dB per octave to match the triangular noise spectrum at the receiver discriminator output. A de-emphasis filter at the receiver reverses this process. Companding refers to the means of coping with the wide dynamic range in the average talker, estimated at 19 dB (peak-to-average power) by Akima (1976). At the sending end a compressor boosts the low-level parts, while at the receiving end an expander drops them back into the right relationship. This scheme is a little easier to comprehend in the digital version. Ferguson (1975) attributes an advantage of 17 dB to signal to noise under companding. We designate the pre-emphasized companded signal-to-noise ratio  $(S/N)_3$ .

b. Antennas

It is sensible to consider the behavior of an antenna separately for the transmitting and receiving case, reciprocal though they may be.

When transmitting, the gain of an antenna is conveniently defined in terms of the isotropic radiator, i.e., an antenna that radiates uniformly in all directions. A 10 m parabolic dish antenna with a gain of 38 dBi at 1 GHz ( $D/\lambda \sim 33$ ) scales down to a 1 m parabolic dish at 10 GHz with the gain still 38 dBi ( $D/\lambda$  still  $\sim 33$ ). Hence, for transmitting there is a nice advantage in size (for a given pattern and gain) by choosing the higher frequency.

The receiving situation is otherwise. The absorbing area  $A_i$  of the isotropic radiator is given by

$$A_i = \lambda^2 / (4\pi) \quad (C-6)$$

and that for a parabolic dish of gain  $G$  (over isotropic) by

$$A = G\lambda^2 / (4\pi) \quad (C-7)$$

Hence, for constant gain, there is a 20 dB advantage for the 10 m antenna at 1 GHz over the 1 m antenna at 10 GHz when used for receiving. These are the major factors involved in the behavior of antennas as a function of frequency.

There are some other more subtle effects. One cannot simply take a 10 m parabolic antenna designed for use at 1 GHz and use it at 10 GHz. The beamwidth of a parabolic antenna ( $d_0$  between 3 dB points) is given by

$$d_0 \approx 70 (\lambda/D) \text{ deg} \quad (C-8)$$

so at 10 GHz,  $D/\lambda$  is 333 and  $d_0 \approx 0.21$  deg, which has now become significantly smaller than the 1 deg box, which, until recently, was standard for satellite station keeping. In addition to tracking there will be problems of pointing and maintaining direction in the face of wind and ice loading.

The other part of the story is that gain  $G$  of the ideal parabolic antenna, i.e.,

$$G = k\pi^2 (D/\lambda)^2 = 7.35 + 20 \log (D/\lambda) \text{ dBi} \quad (C-9)$$

where  $k$ , the aperture efficiency, normally taken as 0.55, is limited by surface irregularities. The effect may be seen in Figure C-1, where loss in realized gain compared to the perfect reflector ( $\delta/D = 0$ ) is illustrated for various values of rms surface irregularity  $\delta$ .

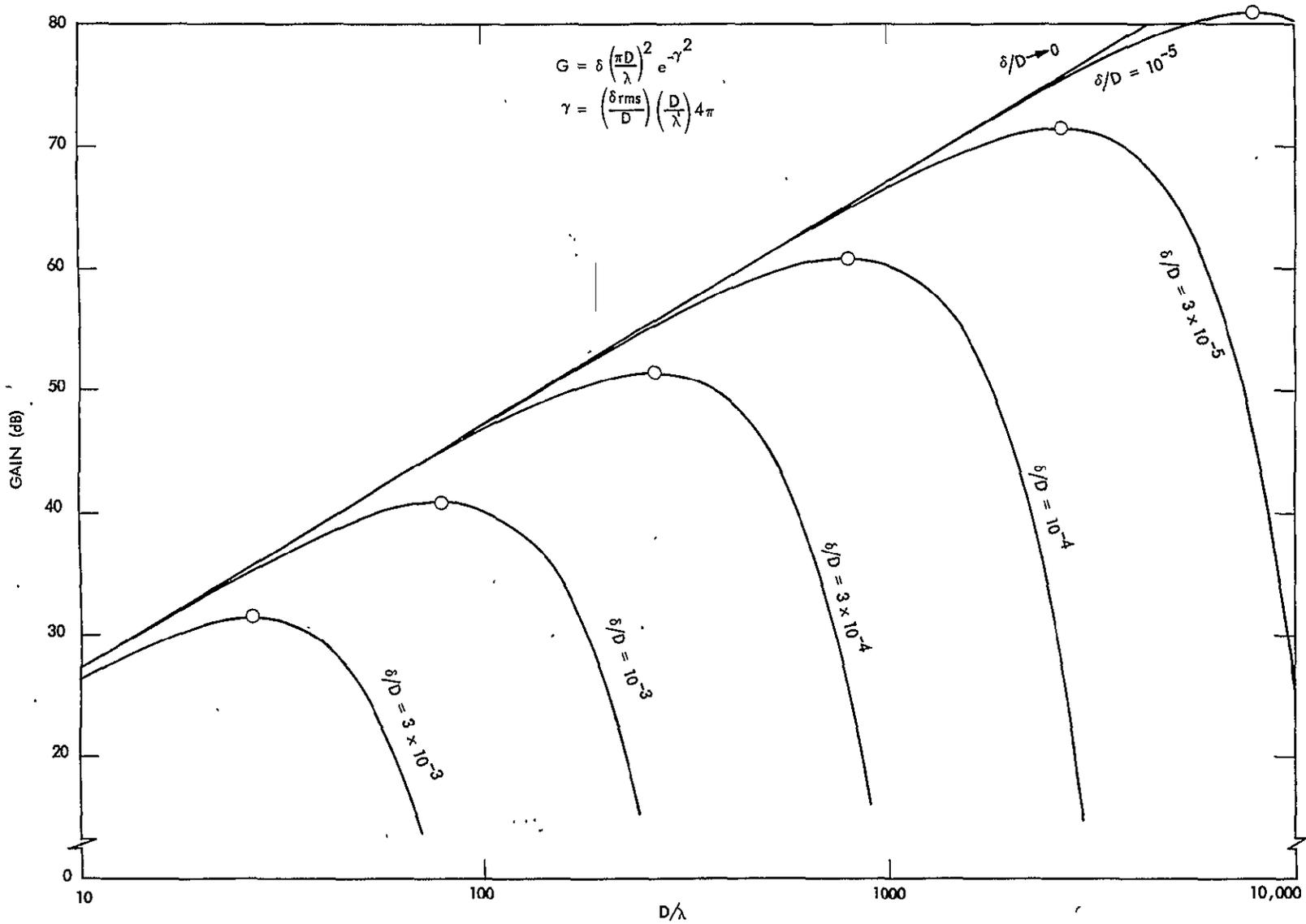


Figure C-1. Gain Versus  $\bar{D}/\lambda$  for Various Cases of  $\delta/\bar{D} = \text{Constant}$ , Where  $\delta$  Is the RMS Surface Irregularity (courtesy L. B. Paulos)

At the other end of the spectrum when the frequency is below 1 GHz, it is possible to achieve a large effective absorbing area with very economical antennas: yagis, corner reflectors, quads, and helixes. These will achieve a gain  $\approx 15$  dBi by themselves and can be arranged in arrays with an increase of 3 dB with each doubling of the number of antennas. There are also very economical parabolic dishes for use above 500 MHz. (There is a rule of thumb which suggests that a parabolic dish becomes worth considering when  $D/\lambda \geq 5$ .)

c. System Noise Temperature

The system noise temperature ( $T_S$ ) consists of the sky noise temperature  $T_a$  "seen" by the antenna, the feed line temperature ( $T_0$ ), and the equivalent noise temperature seen looking into the receiver ( $T_R$ ), which is normally expressed by the receiver noise factor  $F_a$  or noise figure  $F_b$  ( $F_b = 10 \log F_a$ ), where

$$T_R = T_0(F_a - 1) \quad \text{kelvin (K)} \quad (\text{C-10})$$

The system temperature is then given by:

$$T_S = \alpha T_a + T_0(1 - \alpha) + T_R \quad (\text{C-11})$$

where  $\alpha$  is the transmission coefficient.

If the feed line loss decreases to zero,  $\alpha \sim 1$ , as can be approached by mounting a preamplifier on the antenna, then (C-11) becomes simply

$$T_S = T_a + T_R \quad (\text{C-12})$$

This is the expression we will use as one which can be readily approached in practice.

System (or effective noise) temperature has the convenience that contributions can simply be added. As a consequence it is sometimes used as a catchall area for including modest margins for non-noise effects.

1) Receiver Noise Temperature. The receiver input consists of a down converter preceded by one or more preamplifier stages. One CCIR report (PLEN/2, 1976) suggests that  $F_b = 4$  to 6 dB is achievable for community reception at no great cost from 700 MHz to 12 GHz. Transistors or tunnel diodes are used in the lowest priced preamplifiers followed by uncooled and cooled parametric amplifiers. The most demanding systems, such as used in the Deep Space Network (DSN), use liquid-cooled maser amplifiers. At 2 GHz,  $T_S$  for DSS 14, the 64 m dish at Goldstone, California, approaches 16 K (e.g., see USSG-2 FM2/505, 24 March 1977).

2) Sky Noise Temperature. The irreducible minimum in sky noise is presently thought by radio astronomers to be 2.7 K, an isotropic background component that exists at all frequencies.

For an earth-based antenna looking skyward, the noise temperature it sees will be due to contributors shown in Figure C-2, which have the composite effect shown in Figure C-3. Absorption in the earth's atmosphere plays a similar role to attenuation in a transmission line so that to a first approximation

$$T_a = \beta T_b + T_d (1 - \beta) \quad (C-13)$$

where

$\beta(\Delta)$  = atmospheric transmission at the elevation angle  $\Delta$

$T_b$  = noise temperature outside the atmosphere

$T_d$  = temperature of the atmosphere where absorption is taking place

Thus, the atmosphere through its effect on the increase in sky noise temperature may play a more deleterious role than it does in the absorption of the transatmospheric radio signal in satellite communications. Rain may also contribute to sky noise in much the same way. This is illustrated in Figures C-4 and C-5. The dotted lines representing rain and atmosphere are the worst 0.01% of the time for rain climate 4, appropriate to most of California. These figures are taken from a JPL contribution to USSG-2 (USSG FM2/507, 1977).

As can be seen the sky noise temperature increases at frequencies under about 1 GHz. However, it takes a fairly good receiver to realize much difference. A receiver with 5 dB (uncooled) noise figure would have  $T_R = 865$  K; the extra 10 K from sky noise at 700 MHz would make  $T_S = 875$  K, a negligible change.

Sky noise temperature will also be affected by noise from the sun and from the surface of the earth coming in on the sidelobes of the antenna.

3) Man-Made Noise. Man-made noise is a controlling consideration in the frequency range 100 MHz to 1 GHz. The largest body of data on man-made noise is at the Institute for Telecommunication Sciences (ITS) of the Office of Telecommunications in Boulder, Colorado. The data reported in the IEEE Joint Technical Advisory Committee (JTAC) study in 1968 was supplied by ITS. The JTAC results are used, for example, in Figure 1 of CCIR Report 215-3 (1976). ITS subsequently revised its "urban" curves (Spaulding and Disney, 1974), and the new "business" curves given in CCIR Report 258-2 (1976) reflect a reduction of nearly 18 dB in the mean value of noise power. Figure C-6 reflects the most recent submissions from the ITS group to the US-CCIR preparatory effort.

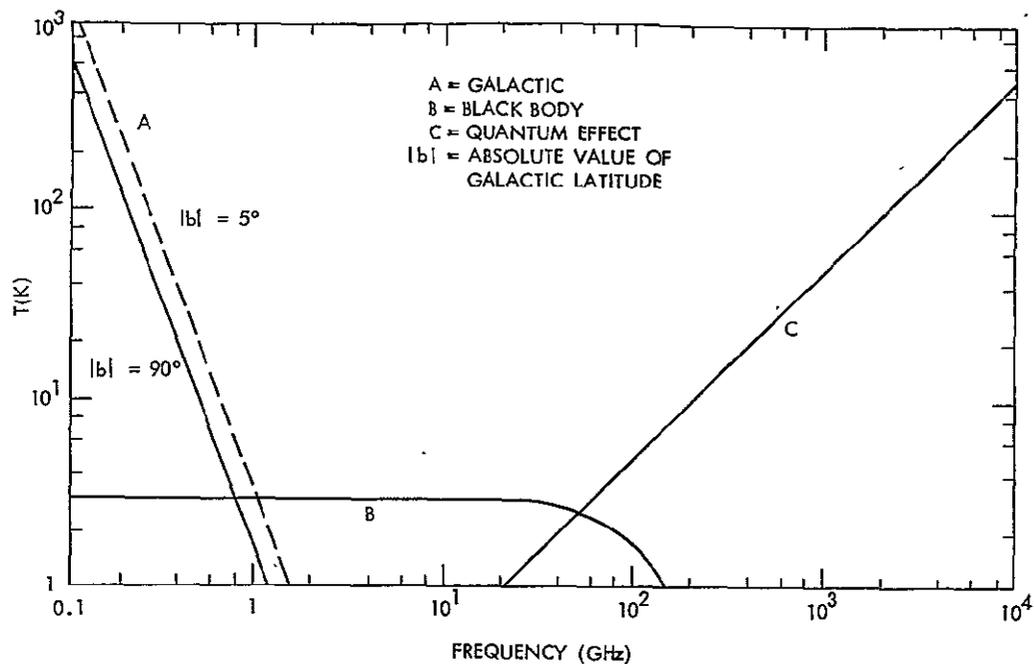


Figure C-2. Background Noise Temperature Contributors Outside the Atmosphere of the Earth

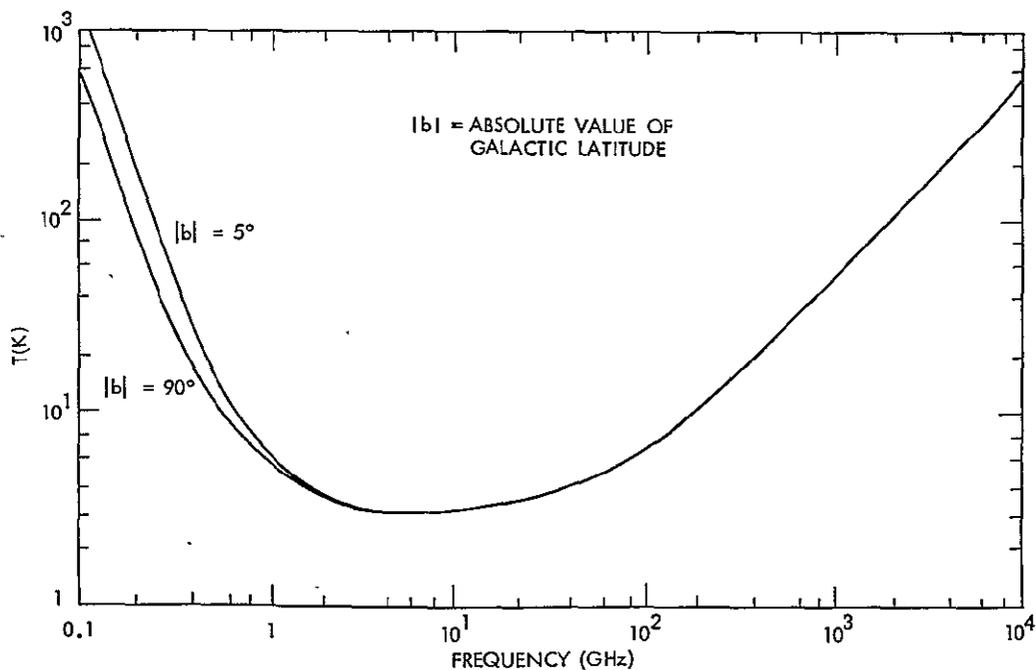


Figure C-3. Total Sky Noise Temperature Outside the Atmosphere of the Earth

ORIGINAL PAGE IS  
OF POOR QUALITY

C-10

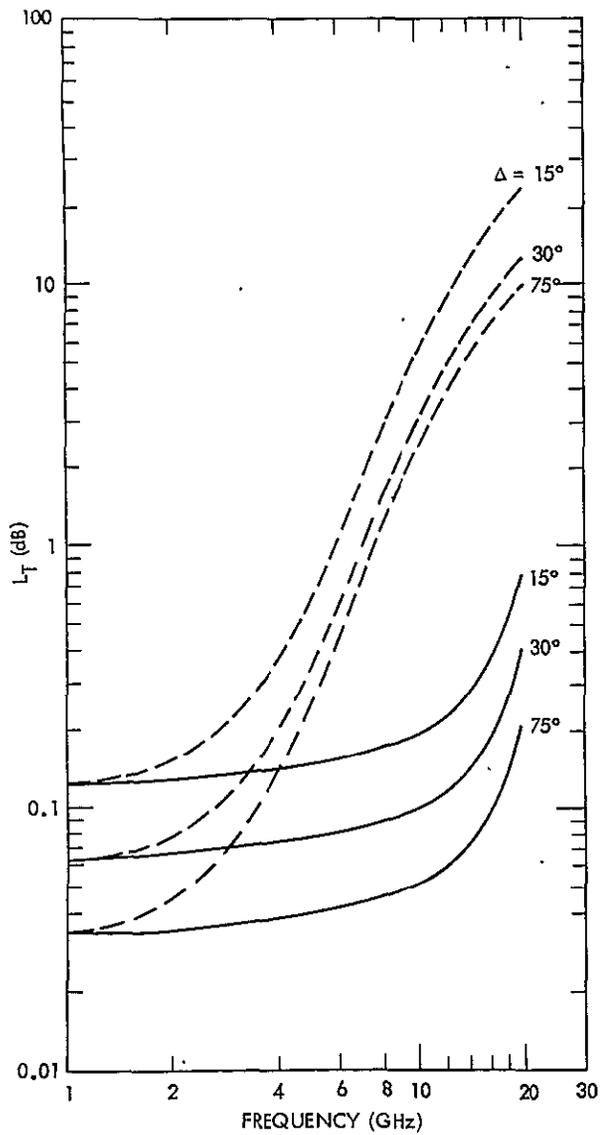


Figure C-4. Space-to-Earth Attenuation ( $L_T$ )

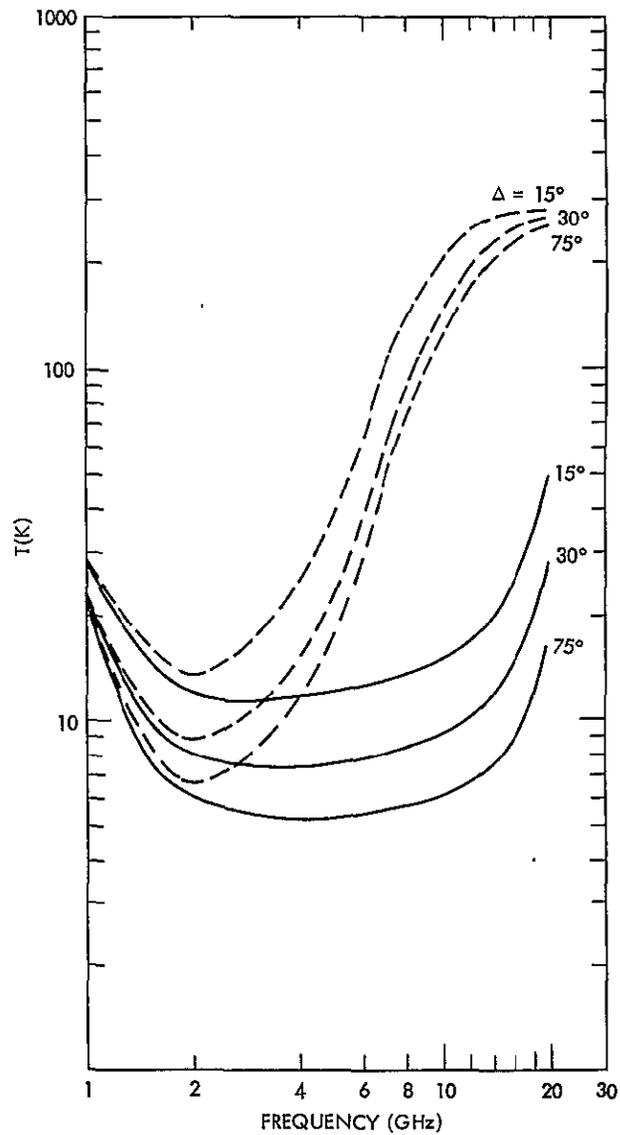


Figure C-5. Total Sky Noise Temperature Seen From the Surface of the Earth

--- rain and atmosphere    — clear weather, atmosphere only     $\Delta$  elevation of earth station antenna

77-71

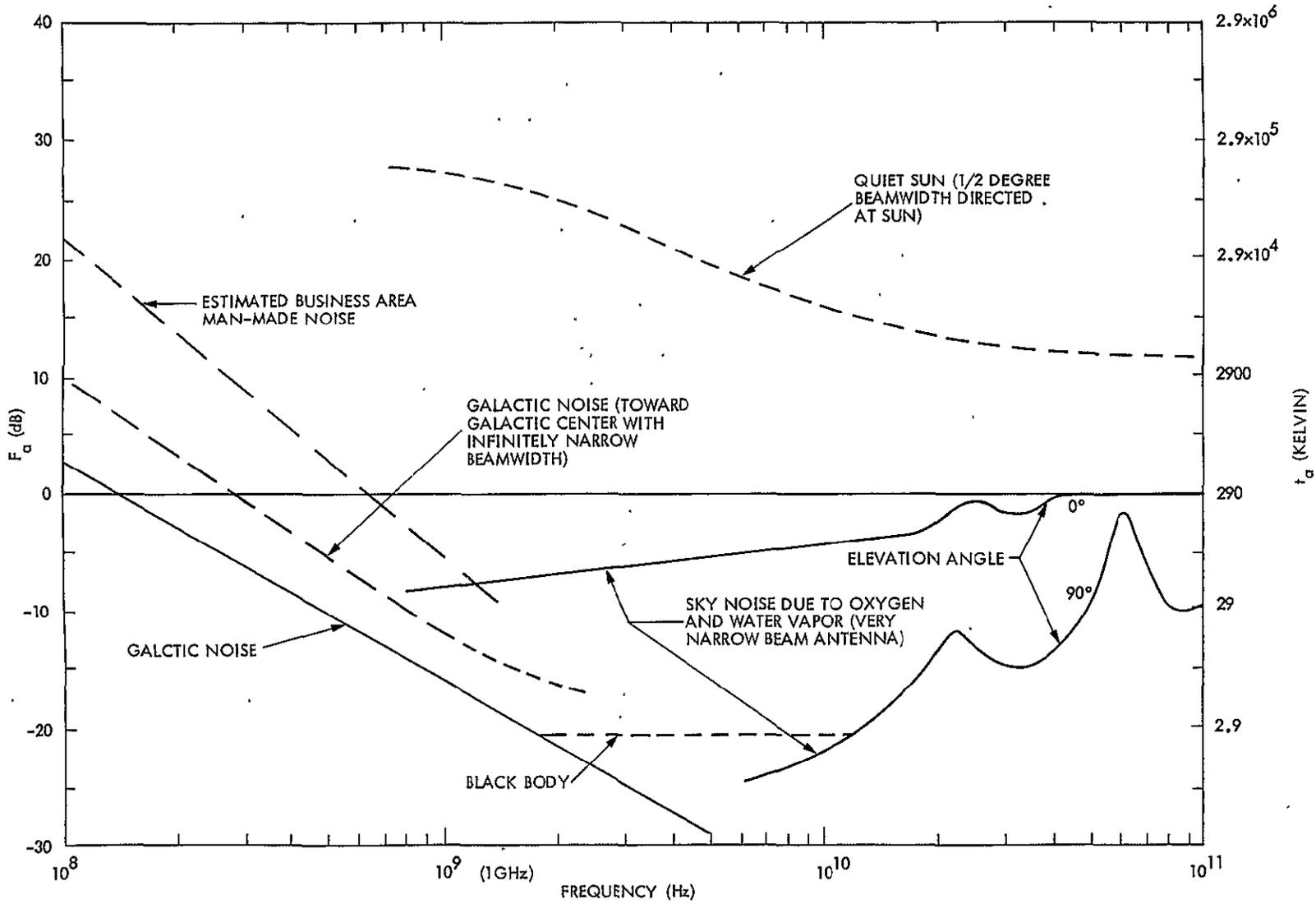


Figure C-6. External Noise Figure  $F_a$  and Antenna Temperature  $t_a$  due to External Noise Versus Frequency ( $10^8$  to  $10^{11}$  Hz) (Courtesy A. D. Spaulding)

d. Transmitter Power and Frequency Stability

The question of transmitter power will also be discussed under costs. Traveling wave tubes have been used in the final amplifier of ATS-6 (10 W) and CTS or Hermes (200 W). There is a limit in the spacecraft as to how much power can be produced by the solar cells and whether batteries will be carried to power the satellite during those periods when the satellite falls in the earth's shadow. This happens for two periods, one from March 1 to April 14 (around the vernal equinox), and the second from September 1 to October 15 (around the autumnal equinox). At the equinoxes themselves, the eclipses, which occur around the local midnight for the subsatellite point, reach a maximum duration of 70 min (Miya, 1976). Locating the satellite to the west of the area one wishes to serve pushes the eclipse period to after midnight local time at the earth stations and makes eclipse interruptions less of a problem. However, for the purposes of this study, the satellite is assumed to be located at 100°W lon. Eclipse outages thus would come at around 10:30 p.m. local sun time in California, and about 1:45 a.m. in Washington, D.C.

Frequency variations of the transmitted signal need to be small compared to  $f_H$  (15,734 Hz, the NTSC line scanning frequency) for the  $S^4$ , say,  $\pm 250$  Hz. This requirement translates to a frequency stability of  $\pm 4 \times 10^{-7}$  at 700 MHz,  $\pm 10^{-7}$  at 2.5 GHz, and  $\pm 2 \times 10^{-8}$  at 12 GHz.

e. Propagation Considerations

The low end of the frequency spectrum under consideration will experience some ionospheric effects, which, for the most part, vary as the inverse square of the radio frequency. Most of the important effects of ionospheric origin are shown in Table C-1 for half decade intervals of frequency. The values are drawn primarily from CCIR Report 263-3.

Ionospheric scintillation is the most bothersome effect (which cannot be compensated for), if one is concerned with high reliability. Most of the U.S. is in the middle-latitude zone for most of the time and, hence, gets minimal high-latitude scintillation and misses all of the most virulent kind, namely, equatorial scintillation. However, New England and upper New York State are in the subauroral zone and may be somewhat more affected. Since we assume in this study that reliabilities of 1% of the time will be adequate, it is not expected that scintillations will be significant above 500 MHz. Good applicable discussions of ionospheric scintillation may be found in Report 263-3 (1974) of CCIR Study Group 6, in Crane (1977), in Fremouw and Rino (1973), and in Wand and Evans (1975).

At the upper end of the frequency spectrum the effects of the non-ionized atmosphere come into play. Absorptions by the gaseous constituents (oxygen and water vapor) make themselves felt in low noise earth stations through the increase in noise temperature well before the absorptive effects become significant. The reverse is true of systems with high noise temperature. The effect of rain in attenuation may be seen in Figure C-4, where it can be seen to become significant above about 6 GHz for 0.01% of the time.

Table C-1. Estimated Maximum Ionospheric Effects in the U.S. for Elevation Angles of About 30 deg, One-Way Traversal

Effect	Frequency Dependence	100 MHz	300 MHz	1 GHz	3 GHz	10 GHz
Faraday Rotation	$1/f^2$	30 rot.	3.3 rot.	108°	12°	1.1°
Propagation delay	$1/f^2$	25 $\mu$ s	2.8 $\mu$ s	0.25 $\mu$ s	0.028 $\mu$ s	0.0025 $\mu$ s
Refraction	$1/f^2$	$\leq 1^\circ$	$< 7'$	$\leq 0.6'$	$< 4.2''$	$\leq 0.36''$
Variation in the direction of arrival	$1/f^2$	20 min of arc	2.2 min of arc	12 sec of arc	1.32 sec of arc	0.12 sec of arc
Absorption (auroral and polar cap)	$1/f \times 1 < x \leq 2$	5 dB	1.1 dB	0.2 dB	0.04 dB	0.008 dB
Absorption (mid latitude)	$1/f^2$	$< 1$ dB	0.1 dB	$< 0.01$ dB	0.001 dB	$< 10^{-4}$ dB
Dispersion	$1/f^3$	0.4 ps/Hz	0.015 ps/Hz	0.0004 ps/Hz	$1.5 \times 10^{-5}$ ps/Hz	$4 \times 10^{-7}$ ps/Hz
Scintillation <sup>a</sup>	—					

<sup>a</sup>Scintillation affects the amplitude, phase, and direction of arrival of transionospheric signals and varies with geographical location and time. To quote Crane (1977), "Scintillation has been observed at frequencies from 10 MHz to 6 GHz. At 137 MHz, scintillation with fades in excess of 6 dB occurs on zenith paths for less than 20% of the time near the geomagnetic equator, less than 2% of the time in the auroral regions, and less than 0.1% of the time at middle latitudes."

## 3. SYSTEM POWER BUDGETS

A useful relation for the system power budget is the ratio of the carrier power to noise density ( $C/N_0$ ). The total noise contribution  $N$  is given by

$$N = k T_S B \quad (C-14)$$

where

$$k = \text{Boltzmann's constant} = 1.38 \times 10^{-13} \text{ J/K} = -228.6 \text{ dB/K}$$

$$B = \text{predetection or IF equivalent rectangular bandwidth for noise in hertz}$$

The noise density  $N_0$  is  $N$  normalized to 1 Hz:

$$N_0 = k T_S \quad (C-15)$$

The ratio  $C/N_0$  is safer to work with than just  $C$  as one avoids the question of how power is actually delivered from the antenna into the first stage of the receiver:

$$\frac{C}{N_0} = \frac{P_T G_T G_R}{k T_S} \left( \frac{\lambda}{4\pi d} \right)^2 = \frac{F}{4\pi} \frac{G_R}{T_S} \left( \frac{0.2998}{f} \right)^2 \quad (C-16)$$

$$\left[ \frac{C}{N_0} \right] (\text{dB}) = 207.14 + F + \left( \frac{G_R}{T_S} \right) - 20 \log f(\text{GHz}) \text{ dB}$$

where

$$F = \text{power flux density}$$

$$= \frac{W}{4\pi d^2} \frac{1}{M} \quad (C-17)$$

$$= W](\text{dB}) - 11.0 - 20 \log d(\text{m}) - M$$

$$= W](\text{dB}) - 162.71 - M \text{ dBW/m}^2 \quad (C-18)$$

for  $d = 38,500$  km, where  $W$  is the effective radiated power of the transmitting station, and  $M$  is the margin for fading and other propagation effects.

Combining (C-16) and (3-18), we get

$$C/N_0](dB) = 44.43 + W - 20 \log f(\text{GHz}) + (G_R/T_S) - M \text{ dB} \quad (\text{C-19})$$

Expression (C-19) is useful in that it expresses the power budget in terms of the principal adjustable parameters before the question of modulation and noise bandwidth is considered.

In an FM system, such as we will be primarily concerned with, the simple signal-to-noise ratio ( $S/N$ ) (assuming the FM predetection threshold is exceeded) is given by

$$\left(\frac{S}{N}\right)_1 = \left(\frac{C}{N_0}\right) \frac{3}{2} \frac{\Delta F^2}{(f_u^3 - f_l^3)} \quad (\text{C-20})$$

where

$\Delta F$  = peak frequency deviation

$f_u, f_l$  = upper and lower limits of the baseband frequency (taken here to be 3400 and 300 Hz, respectively); Equation (C-20) is derived for a test tone, and, hence, the rms signal power is taken as 1/2 the peak amplitude

We may now combine (C-19) and (C-20) in decibel notation:

$$(S/N)_1 = (C/N_0) - 104.2 + 20 \log \Delta F(\text{Hz}) \text{ dB} \quad (\text{C-21})$$

which may be combined with (C-19):

$$(S/N)_1 = -59.8 + W - 20 \log f(\text{GHz}) + 20 \log \Delta F(\text{Hz}) + (G_R/T_S)](dB) - M \text{ dB} \quad (\text{C-22})$$

Through (C-20) we have introduced the actual bandwidth occupied by the signal so that (C-22) includes the improvement factor obtained by increasing the FM frequency deviation  $\Delta F$ . One may estimate the magnitude of  $\Delta F$  for a given assigned bandwidth  $BW$  from Carson's rule written in the form

$$\Delta F = (BW/2) - f_u \quad (C-23)$$

A lucid discussion of the significance of Carson's rule may be found in Carlson (1968), p. 243.

Examples: We will take the channel bandwidth at 47.25 kHz and assume voice frequencies of 300-3400 Hz:

$$\Delta F = (47,250/2) - 3400 = 20,225 \text{ Hz}$$

$$\Delta F^2 = 4.09 \times 10^8 \text{ Hz}^2$$

$$\Delta F_u = 3400 \text{ Hz} \quad f_u^3 = 3.93 \times 10^{10} \text{ Hz}^3$$

$$F_l = 300 \text{ Hz} \quad F_l^3 = 2.70 \times 10^7 \text{ Hz}^3$$

From (C-16), we have

$$(C/N_0) = 207.14 + F + (G_R/T_S) - 20 \log f(\text{GHz}) \text{ dB}$$

from C-22,

$$(S/N)_1 = \frac{3}{2} \frac{\Delta F^2}{(f_u^3 - f_l^3)} = \left( \frac{C}{N_0} \right) \frac{3}{2} \frac{4.09 \times 10^8}{3.93 \times 10^{10}}$$

$$(S/N)_1 = (C/N_0) (1.56 \times 10^{-2}) = (C/N_0)(\text{dB}) - 18.1 \quad (C-24)$$

$$(S/N)_1 = 189.07 + F + (G_R/T_S) - 20 \log f(\text{GHz}) \text{ dB} \quad (C-25)$$

Now let  $(G_R/T_S) = 2 \text{ dB}$ ,  $f = 0.7 \text{ GHz}$ , and  $F = -141.2 \text{ dBW/m}^2$ . Then,

$$(S/N)_1 = 189.07 - 141.2 - 2 + 3.1 = 48.97 \text{ dB} \quad (C-26)$$

## APPENDIX D

## COST CONSIDERATIONS

This section is concerned with a first-order look at costs using the general purpose model developed from the models considered in Section III. This model approach is used primarily to keep the discussion realistic. Cost information used include Hupe (1974, 1975), a draft CPA report (1977), and two CCIR documents: Report 473-1 (Rev. 1976) and the Final Report of Interim Working Party Plen/2 (1976). Where extrapolations beyond what could be found in these reports are necessary, these need to be recognized as reasoned guesses. Four computer programs of possible use for future work for "system configuration, synthesis, and cost evaluation" are listed in the appendix to CCIR Report AH/10-11 (1976).

## 1. COST RELATIVE TO COMPETING MODES

There are two aspects which bear consideration when examining competing modes:

- (1) Can the desired voice-response (interactive) part of the Space System be equally or more economically carried by a dial-up (e.g., WATS) or leased phone circuit? Can the data needs be achieved with the Teletypewriter Exchange Service (TWX) using a teletypewriter (TTY-TWX), "Customer provided terminal" (CPT-TWX) or "Customer equipment" (CE-TWX)? While there is a rule of thumb that a satellite is cheaper than surface beyond 1610 or 2415 km (1000 or 1500 mi), this rule is based on commercial traffic at 4 and 6 GHz.
- (2) In the case of interference to, say, CATV receptions of off-the-air programs, could these programs be carried commercially or by microwave line-of-sight (LOS) links purchased by the CATV company?

## 2. COST VERSUS FREQUENCY

## a. Some Technical Considerations

Attention is restricted to the standardized model. For simplicity, we specify  $C/N \geq 12$  dB, a conservative estimate of the FM threshold, and  $(S/N)_1 \geq 40$  dB. It is assumed that where better quality is required it will be obtained via pre-emphasis and companding.

The antenna types and sizes chosen for the estimates are shown in Figure D-1, where it can be seen that minimum gain is set at 22 dBi for both class I (base) and class II (remote) stations. After achieving the diameter equal to the 5 wavelength criterion, the class I stations use 5 m dishes up to 2.5 GHz, after which a dish with a fixed gain of 40 dBi (beamwidth just under 2 deg) is assumed. Similarly, the class II station starts at 22 dBi and shifts to a 3 m dish at 540 MHz. Then, at 2200

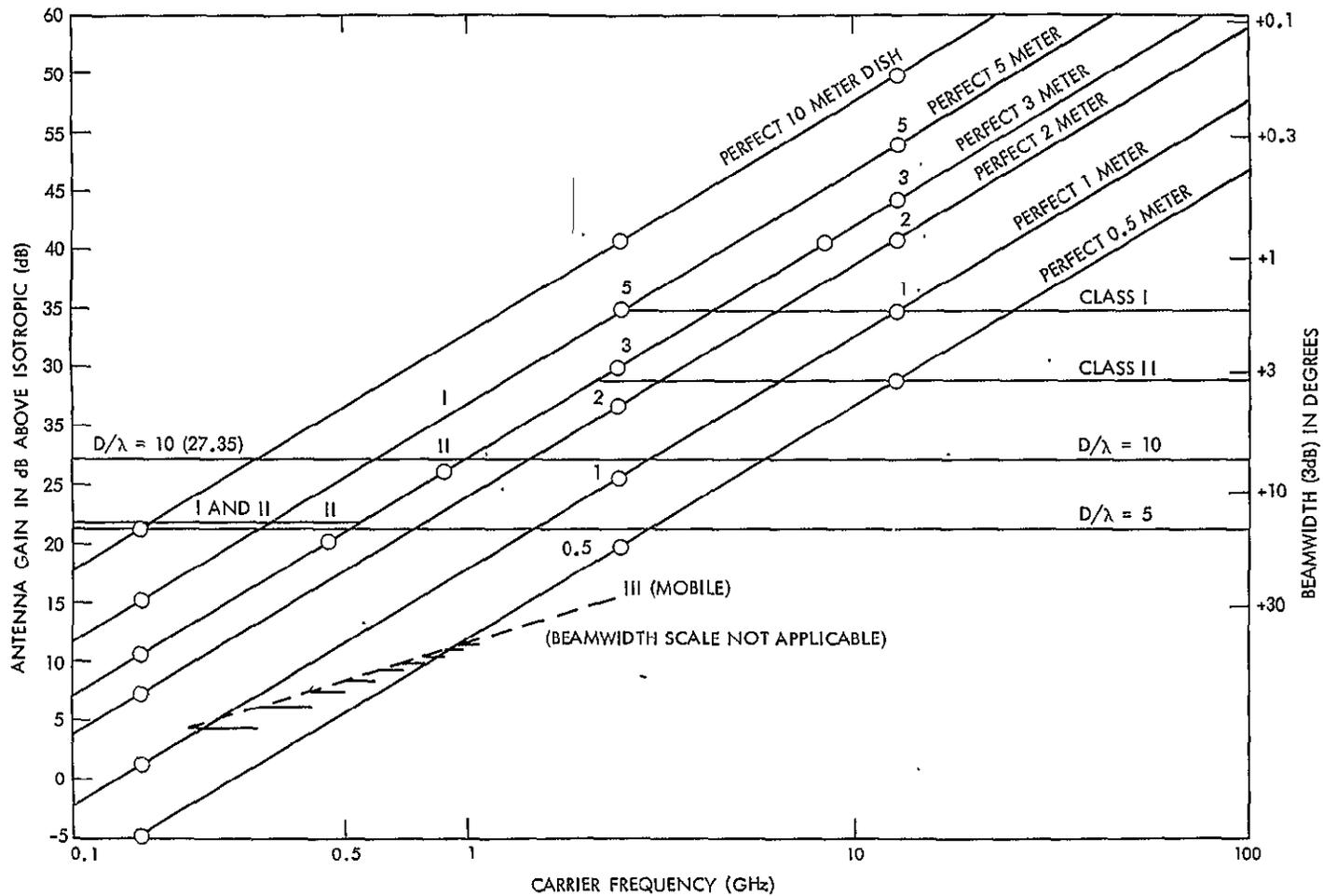


Figure D-1. Idealized Curves of Gain and Beamwidth for Parabolic Reflectors Showing the Values Selected for Class I, II, and III Stations

MHz, a second shift is made to a constant gain dish with gains of 34 dBi and constant beamwidth ( $\phi_0 \sim 3.2$  deg). From (C-19) we may write

$$C/N_0 = F + (G_R/T_S) - 20 \log f(\text{GHz}) + 207.4 \text{ dB} \quad (\text{D-1})$$

$$C/N_0 = (W-M) + (G_R/T_S) - 20 \log f(\text{GHz}) + 44.4_3 \text{ dB} \quad (\text{D-2})$$

We make the further specifications:

- (1) Power flux density  $F = -125$ ; hence,  $W-M = 37.7$  dBW, and, if  $F'$  is the PFD per carrier,  $F' = 125 - 10 \log 42 = 141.2$  dBW/m<sup>2</sup>
- (2) Peak frequency deviation  $\Delta F = (BW/2) - f$  is  $\sim 20$  kHz
- (3) Noise bandwidth =  $2 \Delta F = 40$  kHz (for 1 channel) =  $N_{II}$
- (4) Noise bandwidth = 2 MHz (for 42 channels) =  $N_I$

With these assumptions (D-1) becomes

$$\text{In } 47.25 \text{ kHz: } (C'/N_0) = 66.17 - 20 \log f(\text{GHz}) + (G_R/T_S) \quad (\text{D-3a})$$

$$\text{In } 2 \text{ MHz: } (C/N_0) = 82.4 - 20 \log f(\text{GHz}) + (G_R/T_S) \quad (\text{D-3b})$$

$$N_{II} = N_0 + 10 \log (4.0 \times 10^4) = N_0 + 46.0 \text{ dB} \quad (\text{D-4})$$

$$N_I = N_0 + 10 \log (2 \times 10^6) = N_0 + 63.0 \text{ dB} \quad (\text{D-5})$$

From (D-3), (D-4), and (D-5), it follows that

$$(C'/N_{II}) = 20.2 - 20 \log f(\text{GHz}) + (G_R/T_S)_{II} \text{ dB} \quad (\text{D-6})$$

$$(C/N_I) = 19.4 - 20 \log f(\text{GHz}) + (G_R/T_S)_I \text{ dB} \quad (\text{D-7})$$

If we set  $(C/N_{II}) = (C/N_I) \geq 12$  dB (the FM threshold),

$$(G_R/T_S)_{II} \geq 20 \log f(\text{GHz}) - 8.2 \text{ dB} \quad (\text{D-8})$$

$$(G_R/T_S)_I \geq 20 \log f(\text{GHz}) - 7.4 \text{ dB} \quad (\text{D-9})$$

This is the requirement for the carrier-to-noise ratio to equal or exceed the FM threshold. Similarly, the specification of  $(S/N)_1$  can be obtained from (C-25) to yield

$$(G_R/T_S) = (S/N)_1 - F + 20 \log f(\text{GHz}) - 189.1 \quad (\text{D-10})$$

and, substituting  $F = -141.2 \text{ dBW/m}^2$  (the single channel PFD),

$$(G_R/T_S)_{II} = (S/N)_I + 20 \log f(\text{GHz}) - 47.9 \text{ dB} \quad (\text{D-11})$$

The relations with which we will be working in cost comparison are (D-8), (D-9), and (D-11), all adjusted to represent the edge of the service area, i.e.,

$$C_{\text{edge}} = C - 3 \text{ dB}$$

With this change, we write two relations expressing  $C/N \geq 12 \text{ dB}$ :

$$(1) \quad \text{Class II } (G_R/T_S) \geq 20 \log f(\text{GHz}) - 5.1 \text{ dB/K} \quad (\text{D-13})$$

$$(2) \quad \text{Class I } (G_R/T_S) \geq 20 \log f(\text{GHz}) - 4.4 \text{ dB/K} \quad (\text{D-14})$$

and one relation for use with  $(S/N)_1$  for any one channel:

$$(3) \quad \text{Class I or II } (G_R/T_S) \geq (S/N)_1 + 20 \log f(\text{GHz}) - 47.9 \text{ dB/K} \quad (\text{D-15})$$

These three relations are given in Figure D-2. It can be seen that the system we have assumed is fairly well optimized for high voice quality as the post-detection signal-to-noise ratio falls very near the 12 dB FM threshold requirement for the class I (base) and class II (remote) stations.

Mobile stations will clearly be limited by the FM threshold effect rather than by post-detection signal-to-noise ratio, and a modest tradeoff between the two is possible. The limit achievable by reducing noise bandwidth would be the baseband signal bandwidth (300 to 3400 Hz) or 3100 Hz, which would correspond to single-sideband suppressed-carrier transmission. In the limit, then,  $(C/N)$  can be reduced by 11.1 dB (for 40 kHz to 3.1 kHz). The trouble with doing this with an FM system is that  $(C/N)$  improves inversely as the bandwidth, while  $(S/N)_1$  and  $(S/N)_2$  decrease as the square of the bandwidth. Hence, if one were willing to drop  $(S/N)_1$  from a 40 dB objective to 26 dB (for mobile

ORIGINAL PAGE IS  
OF POOR QUALITY

D-5

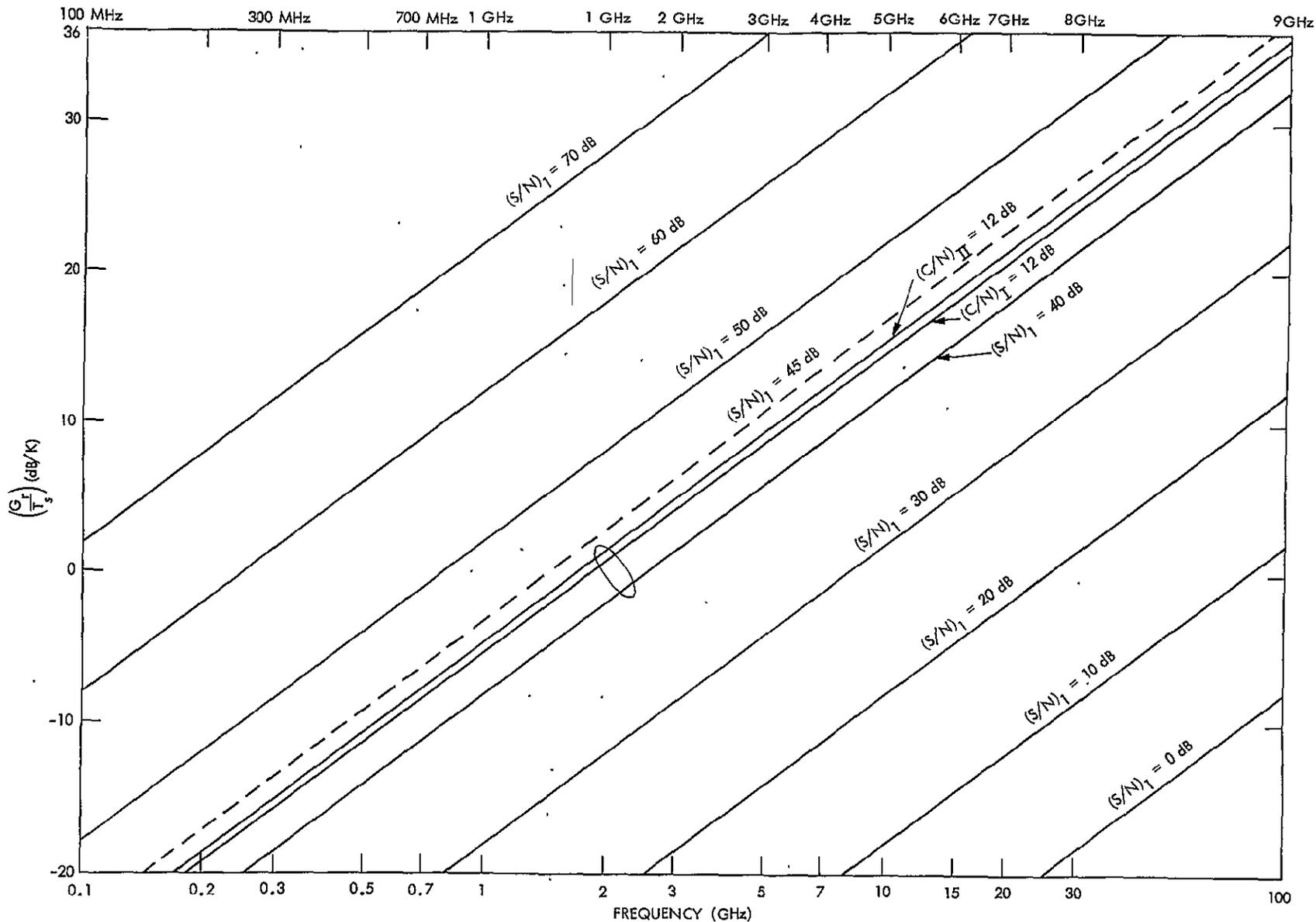


Figure D-2. Frequency Variation of Earth Station Parameters  
Based on PFD  $F = -125$  dBW/m<sup>2</sup>; where  
 $F = W - M - 162.7$  dBW/m<sup>2</sup>

77-71

applications) or a net of 14 dB, it would be appropriate to reduce the frequency deviation  $\Delta F$  by 7 dB in frequency from 20 to 4 kHz.

b. Costs When Using the Model

The antennas chosen for the costing study are indicated on Figure D-1. As was pointed out earlier, 5 m parabolic dishes were used for class I (base) stations between a lower limit at 330 MHz, where the aperture diameter equals 5 wavelengths, and an upper limit, where the gain reaches 40 dB and the beamwidth drops below 2 deg and tracking becomes a problem.

Similarly, the class II (remote) stations use a 2 m parabola between 550 Mhz and 2.2 GHz..

A mobile antenna configuration is shown in Figure D-1, but, as can be seen on Figures D-2 and D-3, it is very difficult with mobile omniazimuthal antennas to surmount the FM threshold of  $(C/N) \geq 12$  dB with a power flux density limit of  $125 \text{ dBW/m}^2$  with voice transmission. Teletype and data circuits can be managed, but voice is very marginal [unless spacecraft power were arbitrarily increased in the mobile channels and the radio frequency bandwidth reduced for a net 10 dB improvement in  $(C/N)$ ].

For simplicity in Figure D-2, we have included the various margins (propagation, deterioration, etc.) in the power flux density F. In other words, if a decibel of absorption is experienced on the path, it is assumed that the spacecraft e.i.r.p. W would be increased by 1 dB.

On Figure D-3 can be seen the consequences of the antenna selections shown on Figure D-1. Values to the left of the diagonal line exceed the FM threshold.

The cost information shown in Figure D-4 (variable costs) is taken primarily from CPA (1977), which in turn reflects recent proposals to the State of Alaska. We have based the class II (remote) stations on equipment cost in lots of 1000 units, while the class I (base) station costs are in units of 100. The total cost is the sum of the variable costs shown in Figure D-4 plus certain fixed costs covering the telecommunications package that are frequency independent. The fixed cost is \$75,000 for class I stations and \$12,000 for class II stations.

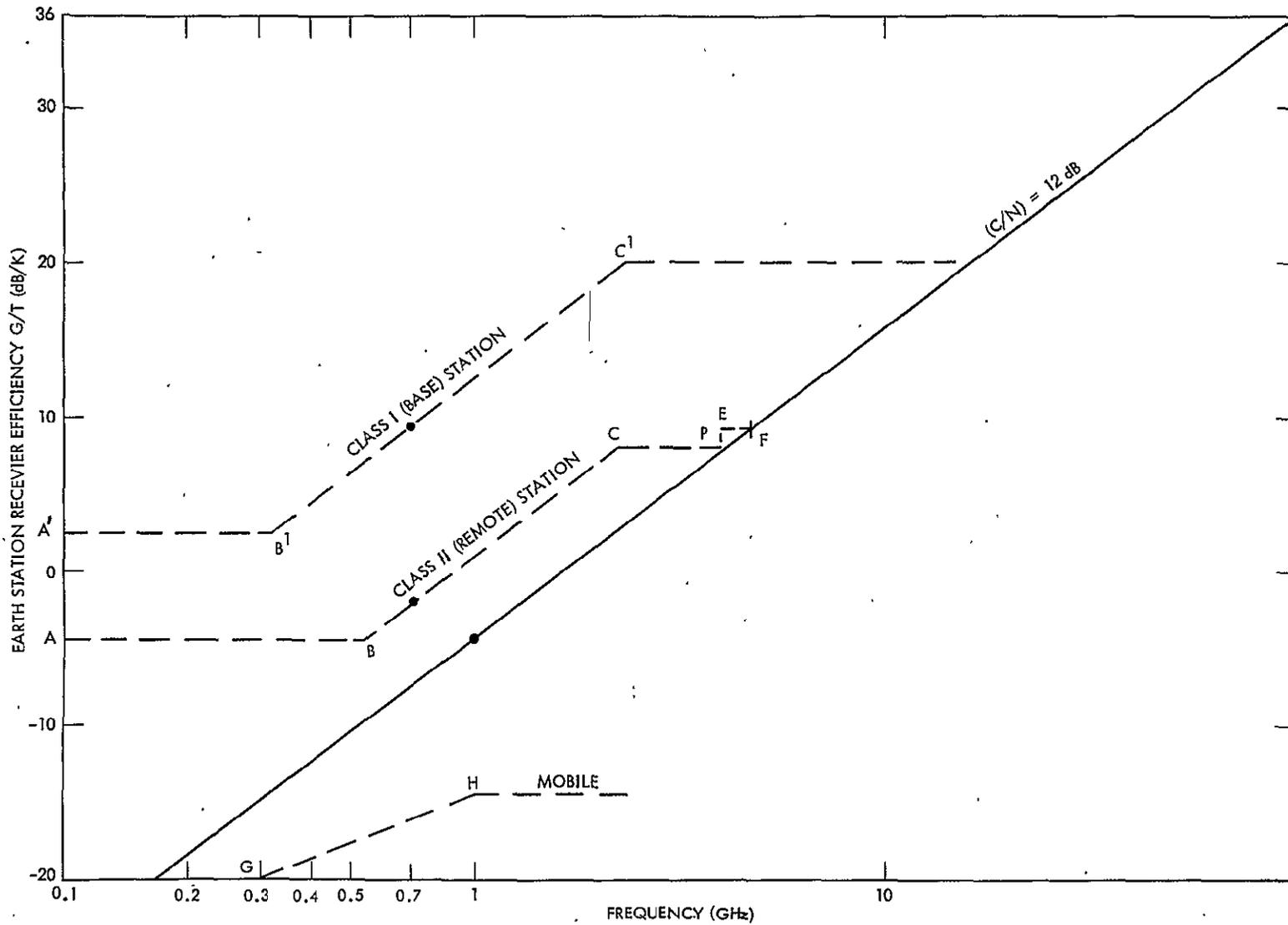


Figure D-3. Illustration of the Behavior of the Model for Antennas Shown in Figure D-1 as a Function of Frequency and G/T.

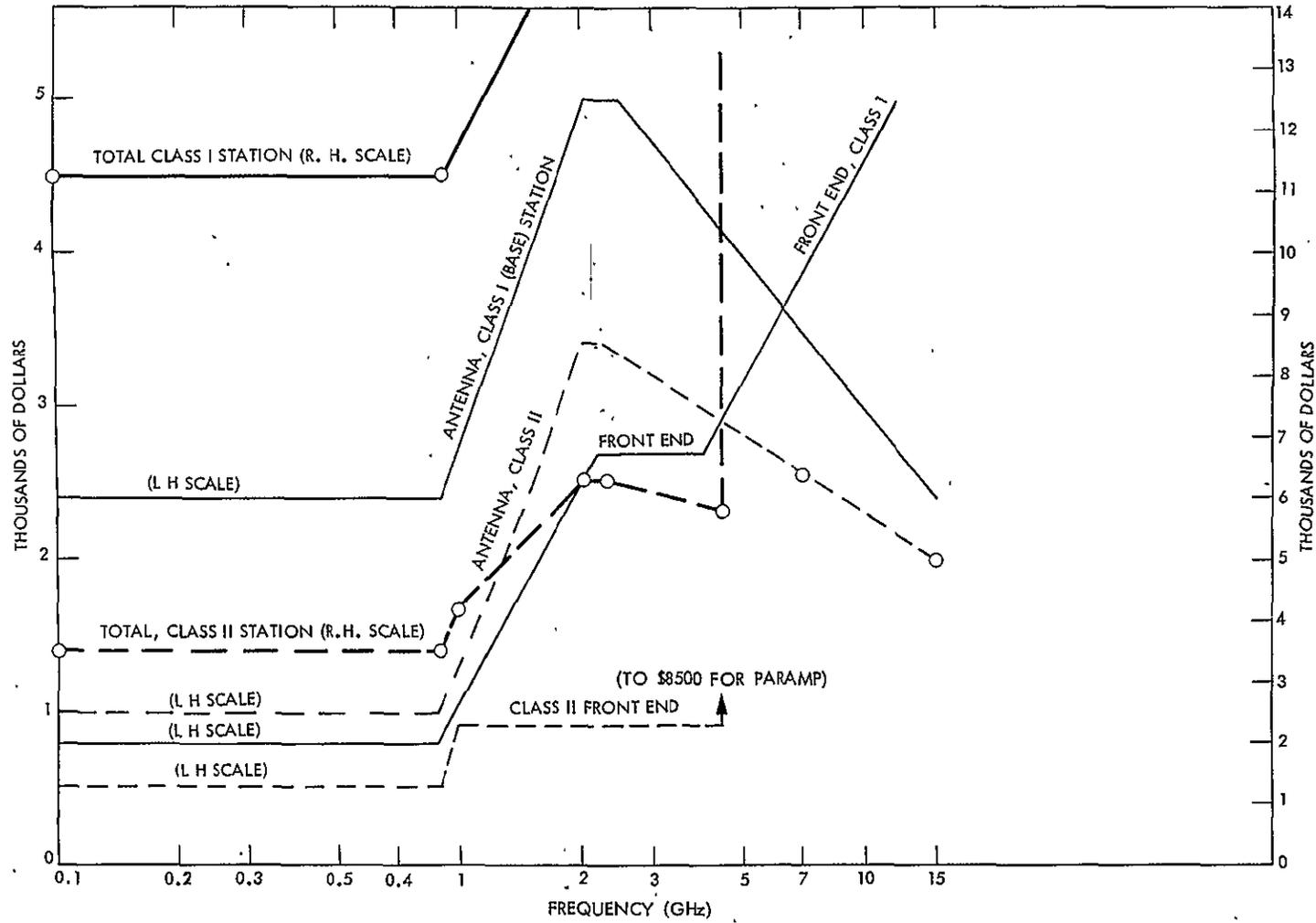


Figure D-4. Variable Costs for Class I and II Earth Stations

A sample of the costing is shown below:

Item	Class I (Base)		Class II (Remote)	
	700 MHz	2 GHz	700 MHz	2 GHz
Antenna	\$ 2,400	\$ 5,000	\$ 1,000	\$ 3,400
Front end	800	2,500	500	920
Telecommunications package	75,000	75,000	12,000	12,000
Totals	\$78,200	\$82,500	\$13,500	\$16,320

Example. Cost of 100 base stations and 1000 remote stations:

700 MHz: \$7.82 million (base) + 13.5 million (remote) = \$21.32 million

2 GHz: \$8.25 million (base) + 16.32 million (remote) = \$24.57 million.

As can be seen, there are modest but no compelling economic reasons for staying below 1 GHz. We assume \$30 million for the space segment in both cases.

**ORIGINAL PAGE IS  
OF POOR QUALITY**

## APPENDIX E

CONSIDERATIONS AND CRITERIA IN THE SELECTION OF  
FREQUENCY REGIONS AND BANDS

The approach used in this study has been to narrow down the frequency range to be considered based on rather general considerations and then to look at specific possibilities in the selected frequency range.

The general considerations include:

- (1) Propagation and noise.
- (2) Characteristics of components (antennas, receiver front ends).
- (3) Costs.
- (4) Frequency availability.
- (5) Regulatory constraints (allocations, power flux density limitations).

The more specific considerations once the frequency band is narrowed down are:

- (1) Sharing possibilities.
- (2) Regulatory environment (what proposals are conceptually possible internationally and domestically).
- (3) Capacity: 100 duplex voice channels is taken as a general guide.
- (4) Power flux density limitation at the surface of the earth and existing and anticipated power flux densities incident on the geostationary orbit.
- (5) Suggestions from the sponsor as to bands deserving attention.

#### 1. OPTIMUM FREQUENCY FOR EXCLUSIVE ALLOCATION

Propagation considerations indicate an ideal decade of frequencies between 0.5 and 5 MHz, in which there are no significant propagation problems at the 1% level at middle latitudes if circular polarization is used. Below this range ionospheric effects become increasingly important, while above this range margins for rain and atmospheric absorption need to be considered. Propagation factors are a mild constraint.

Noise, particularly man-made, is a significant constraint and, as shown earlier, leads to a preference for frequencies above 0.5 GHz. At the upper end of the spectrum, sky noise due to atmospheric absorption

will first enter as a limitation to the class I (base) stations, where low-noise front ends may be justifiable. However, sky noise is not a strong factor in the possible networks for this study.

Characteristics of components appear to be a strong factor only in the area of antennas. Here, the 20 dB per decade increase in absorbing aperture of the isotropic antenna is a dominant factor in reception, leading to a preference for frequencies below about 1.5 GHz. Additionally, if a specific aperture is required, the fact that the antenna beamwidth will, with increase in frequency, ultimately decrease to a point where tracking becomes a problem constitutes an additional constraint. These factors are offset to some extent by the transmitting situation. Here, for a given gain, the diameter of a parabolic antenna decreases a factor of 10 per decade increase in frequency.

Costs have not been analyzed in depth. There is an advantage in the availability of low cost components in certain frequency bands, particularly the UHF television band from 470 to 890 MHz. There is an additional advantage in the tradeoff of antenna aperture for transmitter power, particularly for class II (remote) stations, which leads to an advantage for frequencies below about 1.5 GHz.

Frequency availability is generally greater as one goes higher in frequency. However, an unusual situation exists in the UHF television band which tends to counteract this principle.

The regulatory picture is a complex one, and oversimplification is a danger. However, it is fair to say that the way of the future is toward progressively more sophisticated ways of sharing the spectrum between various services. Even this principle needs to be stated guardedly as the driving consideration should be to maximize the overall utility of the frequency spectrum, and, at times, this is better done with exclusive allocations.

## 2. SHARING CONSIDERATIONS

The first principle adopted for this study is that considerations will be limited to the civil and shared bands (i.e., exclude the exclusively government bands).

The CCIR has in recent years paid significant attention to the sharing problem. In particular Report 631 of Study Group 11 treats frequency-sharing between the broadcasting satellite service and terrestrial services and has served as the basic reference for this study.

While Report 631 deals primarily with television, Section 2.1 states some conditions for sharing of sound broadcasting, which have been of use in this study, to wit:

"Frequency-sharing between the sound broadcasting service and terrestrial services may be feasible under one or more of the following conditions:

- considerably lower protection ratios than those contained in Recommendation 412-1 are applied;
- field strength having values considerably lower than those required of terrestrial stations as shown in Recommendation 412-1 are utilized by the broadcasting satellite service;
- power flux density limitations are placed on emissions from either satellite and/or terrestrial stations within areas where interference may occur, noting that a satellite may produce interference over geographical areas of continental size;
- confinement of the potential zone of coverage for the broadcasting satellite service to those areas where emissions from co- and adjacent-channel terrestrial stations do not exist at present and where the satellite service could be protected from interference due to terrestrial stations that might be installed in the future (primarily rural or sparsely settled areas)."

These four conditions have all been applied in this study. In addition, Equation (1) of Section 2.2, CCIR Report 631 (1974), which relates to determining the limit on power flux density  $F$  as a function of thermal noise, protection ratio, antenna discrimination, polarization discrimination, required signal quality, and percent in time, has been used for interference levels in development of the sharing possibilities in the 620 to 790 MHz region.

ORIGINAL PAGE IS  
OF POOR QUALITY

## APPENDIX F

## SELECTION AND EVALUATION OF CANDIDATE FREQUENCY BANDS

## 1. PRESENT ALLOCATIONS

The present understanding in the broadcasting satellite service is that uplinks will be in the regular fixed satellite service bands. The present allocations available and potentially available for use are:

## a. The Broadcasting Satellite Service (Down)

- (1) 620 to 790 MHz, which is mainly used for fixed, mobile, and terrestrial broadcasting services. In region 2 it is limited to broadcasting where footnote 332A of the Radio Regulations (RR) relates to space use in the broadcasting satellite service.<sup>3</sup>
- (2) 2500 to 2690 MHz to be shared with the fixed, fixed satellite, and mobile services; 361B<sup>4</sup> (470NH-470NK).
- (3) 11.7 to 12.2 GHz (11.7 to 12.5 in Region 1) to be shared with the fixed, fixed satellite (in Region 2 only), mobile, and terrestrial broadcasting service; 405BA (Region 1); 405BB, 405BC Region 2; 405BA Region 3.
- (4) 22.5 to 23 GHz in Region 3 only, where it is to be shared with the fixed and mobile services, 410B.

---

<sup>3</sup>RR Footnote 332A (Spa 2). "Within the frequency band 620-790 MHz, assignments may be made to television stations using frequency modulation in the broadcasting-satellite service subject to agreement between the administrations concerned and those having services, operating in accordance with the Table [of Frequency Allocations], which may be affected (see Resolution Nos. Spa 2-2 and Spa 2-3). Such stations shall not produce a power flux density in excess of the value  $-129 \text{ dBW/m}^2$  for angles of arrival less than 20 deg. (see Recommendation No. Spa 2-10) within the territories of other countries without the consent of the administrations of those countries." (ITU Radio Regulations, published by the General Secretariat, International Telecommunications Union, Geneva.)

<sup>4</sup>RR Footnote 361B (Spa 2) restricts the use of the 2500-2690 MHz band by satellite broadcasting to national and regional systems for community reception, subject to agreements between administrations. It requires, moreover, that the power flux density must not exceed the values given in the ITU Radio Regulation Nos. 470NH-470NK ( $-152 \text{ dBW/m}^2$  from 0 to 5 deg elevation in any 4 kHz bandwidth rising to  $-137 \text{ dBW/m}^2$  between 25 and 90 deg elevation for any 4 kHz bandwidth).

(5) 41 to 43 GHz, exclusive.

(6) 84 to 86 GHz, exclusive.

b. Uplink Bands in the Fixed Satellite Service (Region 2)

(1) 2655 to 2690 MHz, shared with fixed, mobile, and broadcast (see NG102 in U.S.5).

(2) 4400 to 4700 MHz, shared with fixed and mobile internationally, assigned to Government use in U.S.

(3) 5925 to 6425 MHz, shared with fixed and mobile.

(4) 7900 to 7975 MHz, shared with fixed and mobile internationally, assigned to Government use in U.S.

(5) 14.0 to 14.5 GHz, shared in bands with radio navigation, radio navigation-satellite and fixed satellite and mobile.

(6) 27.5 to 29.5 GHz, shared with fixed and mobile.

(7) 29.5 to 31 GHz, exclusive.

(8) 50 to 51 GHz, exclusive.

(9) 102 to 105 GHz, exclusive.

(10) 150 to 152 GHz, exclusive.

2. DELINEATION OF A REGION OF THE SPECTRUM

A review of the criteria outlined in Appendix E leads to the following conclusions.

a. Propagation and Noise

If one adopts circular polarization, then Faraday rotation will not be a factor. Table C-1 indicates that for mid-latitudes scintillation

---

<sup>5</sup>FCC Footnote NG102. "The frequency bands 2500-2535 MHz (space-to-earth) and 2655-2690 MHz (earth-to-space) are allocated for use in the fixed satellite service as follows: (a) For common carrier use in Alaska, for intra-Alaska Service only, and in the mid and Western Pacific area including American Samoa, the Trust Territory of the Pacific Islands, Guam and Hawaii; (b) For educational use in the contiguous United States, Alaska and the mid and Western Pacific area including American Samoa, the Trust territory of the Pacific Islands, Guam and Hawaii."

will be the only major concern above 300 MHz (and that probably not too serious at the 1% of the time service level).

Man-made noise is more of a concern and leads to a preference for frequencies above 300 MHz, and, to some extent, above 500 MHz.

b. Characteristics of Components

The frequency dependence of the absorbing aperture of the isotropic radiator ( $\lambda^2/4\pi$ ) leads to a preference for frequencies below 1.5 GHz and preferably below 1 GHz.

c. Costs

While there does not appear to be much difference in costs between the UHF TV spectrum (470 to 890 MHz) and the ITFS (Instructional Television Fixed Service: 2500 to 2690 MHz), there is more flexibility of choice at the lower frequencies as to antenna designs and transmitter powers. Costs reflect mildly in favor of the UHF TV band.

d. Frequency Availability

As apparent from Figure 6-1 of the main text and the accompanying analysis, there is spectrum available in the UHF TV band for the sort of service needs contemplated here.

e. Regulatory Constraints

These are complex and not easily generalized. The NASA ATS series of satellites are classified as experimental and, therefore, are not subject to the same regulatory constraints as are the satellite networks under consideration here. As a general rule power flux density limits are relaxed with increasing frequency. As a selection strategy we have given preference to a band if (a) the ITU Radio Regulations contain some recognition of a relevant space use of the band, and, to a lesser extent, if (b) the U.S. proposes, in its current preparatory work, to recommend a relevant space use for the band.

In addition to the general criteria suggested above, suggestions from the sponsor affected the limits chosen, in that 420-450 MHz had been suggested for first consideration at the study's inception, and consideration of 407-608 MHz, 614-806 MHz, and 806-890 MHz suggested in a memo dated September 17, 1976.

In view of sponsor request, we extended the lower limit of the frequency region for intense search from 500 to 300 MHz and chose 1000 MHz for the upper limit. Hence, the region for detailed frequency search for this study is the region 300 to 1000 MHz.

## 3. CANDIDATE BANDS IN THE RANGE 300 to 1000 MHz

The terminology and approach used in allocations is important to its understanding. We excerpt below the pertinent provisions from the ITU Radio Regulations.

## a. Categories of Services and Allocations (RR 5-3)

RR 138. "Permitted and primary services have equal rights, except that, in the preparation of frequency plans, the primary service, as compared to the permitted service, shall have prior choice of frequencies."

RR 141. Permitted and primary service may derive from a footnote if the words "primary basis" or "permitted basis" appear.

RR 139. Stations of a secondary service:

- (1) Shall not cause harmful interference to stations of the primary or permitted service to which frequencies are already assigned or to which frequencies may be assigned at a later date.
- (2) Cannot claim protection from harmful interference from stations in the primary or permitted service to which stations are already assigned or may be assigned at a later date.
- (3) Can claim protection, however, from harmful interference from stations of the same or other secondary services to which frequencies may be assigned at a later date.

RR 140. (Footnote indicating allocation "on a secondary basis" is a secondary service.)

RR 142. Additional Service. Where a band is indicated in a footnote to the Table as "also allocated" to a service in an area smaller than a region, or in a particular country, this is an "additional" service, i.e., a service which is added in this area or in this country to the service or services indicated in the Table.

RR 143. (If the footnote contains no additional restrictions, equality with other services exist.)

RR 144. (Any restrictions on an additional service will appear in the footnote.)

RR 145. Alternative Allocations. "Where a band is indicated in a footnote to the Table as "allocated" to one or more services in an area smaller than a region, or in a particular country, this is an "alternative" allocation, i.e., an allocation which replaces, in this area or in this country, the allocation indicated in the Table (see RR 146)."

RR 146. "If the footnote does not include any restriction on stations of the service or services concerned, apart from the restrictions to operate only in a particular area or country, these systems shall have an equality of right to operate with stations of the service or services, the names of which are printed in "small capitals" in the Table, and to which the band is allocated in other areas or countries."

RR 147. (If these area restrictions are imposed on the "alternative service," these show in the footnote.)

b. Miscellaneous Provisions

RR 148. "Where it is indicated in these Regulations that a service may operate in a specific frequency band subject to not causing harmful interference, this means that the service cannot claim protection from harmful interference caused by other services to which the band is allocated under Chapter II of these Regulations."

RR 152. (Services are listed in alphabetical order according to format.)

RR 153. (Footnotes below a service or services refer to whole allocation.)

RR 154. (Footnotes to the right of a service refer to it alone.)

The actual allocations in the 300 to 1000 MHz region are shown in Table F-1. The column titled ITU RR shows listings from Section IV (Table of Frequency Allocations-- 10 kHz to 275 GHz) of Article 5 of the 1976 Edition of Radio Regulations. The next column FCC R&R is taken from Section 2.106 of the FCC Rules and Regulations, August 1976 Edition. The column marked OTP Manual of R&P is taken from the Manual of Regulations and Procedures for Radio Frequency Management of the Office of Telecommunications Policy, Executive Office of the President, January 1976 Edition. The final heading FCC 3rd NOI is taken from the Third Notice of Inquiry released December 6, 1976 of FCC Docket No. 20271 (GWARC preparation). Table F-2 reflects the Fifth Notice of Inquiry of the same docket and was released in June 1977.

4. EVALUATION OF CANDIDATE BANDS

The circled numbers in Table F-2 indicate our order preference for different bands for a community reception and transmission service. While it is not necessary, nor normally even considered desirable, to have the uplink and downlink frequencies in the same band, there is adequate precedent that it can be done.

First Choice: 620-790 MHz. The presently existing footnote 332A already countenances FM TV in the broadcasting satellite service for these frequencies (internationally but not domestically). We believe we can demonstrate that a satisfactory voice-bandwidth service can be introduced

Table F-1. Review of Frequency Allocations 300 MHz to 1.0 GHz

Frequency Bands	ITU RR	FCC R&R	OTP Manual of R&P	FCC 3rd NOI
273-328.6 MHz*	<p>FIXED MOBILE</p> <p>308A { 240-328.6 also OK for mobile sat. serv.</p> <p>310 { 322-328.6 is Rad Astrm in some count.</p> <p>310A { 322-328.6 alloc Rad Astr. in India</p>	<p>G</p> <p>US98 { 243 MHz is Govt. &amp; NG survival craft</p>	<p>G</p> <p>G30 { Primary operation by military services</p> <p>G100 { Mobile satellite serv. lim to military</p> <p>The FAA provides Air traffic control comm. to the military on selected freqs. in these bands</p>	<p>FIXED MOBILE</p> <p>308A, 310, 310A "Requirements unchanged"</p>
335.4-399.9 MHz*	<p>FIXED MOBILE</p> <p>308A: Mob. Sat Serv</p>	<p>G</p> <p>308A</p>	<p>G</p> <p>G30</p> <p>G100</p>	<p>(Same)</p> <p>"Req. remain unchanged"</p>
420-450 MHz*	<p>RADIOLOCATION Amateur</p> <p>318 { Radio altimeter may also be authorized</p> <p>319A { 449.75-450.25 may also be used for space telecommand and research</p>	<p>GNG Amateur</p> <p>Amateur-Satellite</p> <p>US217 { Pulse ranging radio location may be used</p> <p>US87 { 450±.25 may be used for telecomm.</p>	<p>RADIOLOCATION</p> <p>320A</p> <p>US7</p> <p>US35</p> <p>US87</p>	<p>420- (RADIOLOCA- 435 TION Amateur</p> <p>435- (Amateur 438 RADIOLOCA- TION</p> <p>438- (RADIOLOCA- 450 TION Amateur</p>
<p>* Possible with some difficulty</p> <p>** Good prospect</p>		<p>G Government allocation</p> <p>NG Non-Government allocation</p>		

Table F-1. Review of Frequency Allocations 300 MHz to 1.0 GHz (Continuation 1)

Frequency Bands	ITU RR	FCC R&R	OTP Manual of R&P	FCC 3rd NOI
470-890 MHz**	319B France and Guyana 434±.25 also E→S	US7 { Am DC Pt. Power ≤ 50 watts in design areas	NG Broadcasting Land Mobile	318, 319B, 323, 324 Note: SB-SWG requested 6 MHz in this band. FCC added this as a req. to 470- 806 MHz band
	320A { Am. Sat. Ser. OK 435-438 on NI basis			
	323 { Indonesia, band also al. (2nd) to F&M	320A		US35 { (Only NG expected to be amateur)
	324 { Australia band also fixed service			
	BROADCASTING	470-512		Specific Allo- cation not proposed
	329A { Argentina and Uruguay	BROADCASTING LAND MOBILE		
	332 { 608-614 reserved for R.A. until 1979	NG66 { Describes LMS Assign.		
	332A { 620-790 can be used for TV using FM in B/C Sat Service	NG114 { 488-494 to DPR of La.		
		512-806		512-806
		BROADCASTING		BROADCASTING
	NG630 { 716-890 MHz OK for Fixed in N. Fla.	NG 30 etc 806-902	806-890	
	821-825 LAND MOBILE (Reser)	Land Mobile (NGs only)	MOBILE ADD 329B Band	
	845-851 LAND MOBILE (Reser)		also allocated to use and develop of sys. us. space Radio com. techniques	

F-7

ORIGINAL PAGE IS  
OF POOR QUALITY

77-71

Table F-1. Review of Frequency Allocations 300 MHz to 1.0 GHz (Continuation 2)

Frequency Bands	ITU RR	FCC R&R	OTP Manual of R&P	FCC 3rd NOI
890-942 MHz	<p>FIXED RADIOLOCATION</p> <p>339A { Parts of 900-960 OK for Exp/Space Res.</p> <p>340 { Region 2 915±13 for ISM purpose (1)</p>	<p>866-870 LANDMOBILE (Reserve)</p> <p>890-902 LANDMOBILE (Reserve)</p> <p>920-928 G US36 ISM dom NG 915±13 US115 915± des. for ISM US218 AVM 2nd ISM</p> <p>928-947 NG LANDMOBILE</p> <p>NG64 { B/C Aux. St. can cont. op. in 942-947 pending ruling</p>	<p>902-928 RADIOLOCATION</p> <p>G11 { Govt fixed &amp; mobile perm on 2nd basis</p> <p>G59 { non mil 2nd to mil. radioloca- tion</p> <p>928-947 NG (LANDMOBILE)</p>	<p>890-896 MOBILE</p> <p>339A { Portions of 900- 960 OK for Exp.Sp.Res</p> <p>896-902 MOBILE 339A</p> <p>902-928 FIXED RADIO- LOCATION Amateur Mobile 339A (see above) Ind/Sc/Med MOD 340 915±13 WW</p> <p>928-941 FIXED RADIOLOCATION MOBILE</p> <p>339A { Portions of 900- 960 may be used on a secondary basis for Sp. Com. Res.</p>

Table F-1. Review of Frequency Allocations 300 MHz to 1.0 GHz  
(Continuation 3)

Frequency Bands	ITU RR	FCC R&R	OTP Manual of R&P	FCC 3rd NOI
942-960 MHz	FIXED 339A { Portions of 900-960 OK for Exp. Sp. Res.	947-952 NG FIXED N69 { Non intert basis awal B/C relay NG40 { OK NG fixed in 890-940 to 947-952 NG58 { OK B/C Aux on the fixed NI 952-960 NG 10	947-960 NG FIXED	941-942 MOBILE 339A 942-947 FIXED MOBILE 339A { 900-960 OK for 2nd basis Sp. Res. 947-952 FIXED 339A 329B 952-960 FIXED MOBILE 339A

Table F-2. The Frequency Spectrum 470 to 890 MHz From the 5th NOI FCC Docket 20271

MHz		
Region 1	Region 2	Region 3
470-582 BROADCASTING	470- <u>512</u> (4) BROADCASTING <u>MOBILE</u>	470-585 BROADCASTING
582-606 BROADCASTING RADIONAVIGATION	<u>512-608</u> (3) BROADCASTING	335 585-610 RADIONAVIGATION
325 327 328 329	329A	330B 336 337
606-790 BROADCASTING	<u>608-614</u> <u>RADIO ASTRONOMY</u>	610-890 FIXED MOBILE BROADCASTING
329 330 330A	<u>614-806</u> (1) BROADCASTING	
331 MOD 332 332A	332A	
790-890 FIXED BROADCASTING	<u>806-890</u> (2) BROADCASTING <u>MOBILE</u>	
329 331 333	<u>329B*</u> <u>329C</u>	330B MOD 332
334		332A 338 339

"REASON: See paragraphs \_\_\_\_ through \_\_\_\_ in the narrative portion. Footnote suppressions are consequential to allocation proposals."

\*ADD 329B In Region 2, the band 806-890 MHz is also allocated to the mobile-satellite service for the use and development of systems

Table F-2. The Frequency Spectrum 470 to 890 MHz From the 5th  
NOI FCC Docket 20271 (Continuation 1)

using space radiocommunications techniques. Such use and development is subject to agreement and coordination between the administrations concerned and those having services, operating in accordance with the table, which may be affected.

REASON: To provide spectrum allocation for possible development and use of a mobile satellite system for public services.

ADD 329C Special agreements between administrations concerned shall determine the conditions for implementations of broadcasting in the proximity of international boundaries to preclude harmful interference being caused to the mobile service.

REASON: To provide some protection to the mobile service operating in this band.

MOD 332 In Region 1, except the African Broadcasting Area\*, the band 606-614 MHz and in Region 3, the band 610-614 MHz may be used by the radio astronomy service. Administrations shall avoid using the band concerned for the broadcasting service as long as possible, and thereafter, as far as practicable, shall avoid the use of such effective radiated powers as will cause harmful interference to radio astronomy observations.

REASON: Consequential to allocation proposals.

ORIGINAL PAGE IS  
OF POOR QUALITY

and still allow adequate protection for the terrestrial UHF TV service. We investigate this band in some detail.

Second Choice: 806-890 MHz. Here the U.S. proposal for footnote 329B, which, while directed to the mobile satellite service, might be interpreted to cover a community service, makes this band a likely choice.

Third Choice: 512-602 MHz. Footnote 329A reads, "In Argentina and Uruguay, the band 602-608 MHz is allocated to the radio astronomy service," so we have deleted that piece. This band contains TV channels 21-35, which are not as densely populated with TV stations as are channels 14-20 (470-512 MHz), which are our final choice.

Fourth Choice: 470-512 MHz. This band, which contains TV channels 14-20, is proposed in the 5th NOI to be shared with the mobile service. For a community service, the interference levels will be higher in this band but sharing is possible.

## APPENDIX G

## TECHNICAL REFERENCE MATERIAL

## 1. SYMBOLS USED IN THE STUDY

The same symbol is frequently used for the magnitude of a quantity and the magnitude in decibels relative to a reference.

A	absorbing area (or aperture) of a parabolic antenna
$A_i$	absorbing area of the isotropic radiator, normally in $m^2$
b	galactic latitude, deg
B	predetection or IF equivalent rectangular bandwidth for noise, Hz
BW	bandwidth as derived from Carson's rule, Hz
C/I	carrier-to-interference ratio (predetection), normally in dB
C/N	carrier-to-noise ratio, normally in dB
$C/N_0$	carrier-to-noise per hertz (noise density), normally in dB
$[C/N]'$	effective carrier-to-noise ratio
C/T	carrier-to-system temperature ratio, dB/K
$C_{edge}$	C - 3 dB, normally used in a ratio, where C is carrier power
d	distance to geostationary satellite, taken to be $3.85 \times 10^7$ m
$d_0$	beamwidth between half-power points of a parabolic antenna, deg
$D/\lambda$	ratio of diameter of a parabolic antenna to wavelength
$D_d$	(a) discrimination against the interfering signal due to directivity of the receiving antenna, dB, or (b) decrease in gain at off-axis angle, dB
$D_p$	polarization discrimination, dB
$D_s$	discrimination due to position in the spectrum, dB

EIRP or e.i.r.p.	effective isotropic radiated power, normally taken in direction of maximum gain, dB
E, $E_S$	field strength of the electric vector, normally in dBu (decibels above 1 $\mu$ V/m) or mV/m
f	radio wave frequency, GHz
$f_l$	lower voice-band frequency, normally 300 Hz, Hz
$f_u$	upper voice-band frequency, normally 3400 Hz, Hz
$f_3$	de-emphasis frequency (3 dB down), $f_3 = (2\pi RC)^{-1}$ Hz
$f_H$	television line-scan frequency, 15,734.26 Hz for NTSC color
F	Power flux density of desired signal, dBW/m <sup>2</sup>
F'	power flux density of a single SCPC carrier, dBW/m <sup>2</sup>
$F_a$	receiver noise factor
$F_b$	receiver noise figure ( $F_b = 10 \log F_a$ ), dB
$F_S$	maximum power flux density to be allowed at the pro- tected station, dBW/m <sup>2</sup>
$F_1$	power flux density in 6 MHz, made up of 3 bands each 2 MHz wide as in the S <sup>4</sup> downlink, dBW/m <sup>2</sup>
$F_2$	power flux density in 2 MHz band as in uplink signal. from a class I (base) station, dBW/m <sup>2</sup>
$F_3$	power flux density in an SCPC channel of 47.2 kHz, dBW/m <sup>2</sup>
$F_{tpq}$	minimum power flux density to be protected in the face of thermal noise only, to yield an output signal of quality q to be exceeded for a specified high percent of time p, dBW/m <sup>2</sup>
F(x,y)	field strength required to serve x percent of the locations y percent of the time, normally in decibels above 1 $\mu$ V/m, dBu
F(50,50)	field strength required to serve 50% of locations 50% of the time, dBu
G	gain of an antenna relative to an isotropic radiator, dBi
$G_R$	gain of receiving antenna, dBi

$G_T$	gain of transmitting antenna, dBi
$G_R/T_s$	figure of merit, dB/K
$k$	efficiency of parabolic antenna, normally 0.55
$k$	Boltzmann's constant, $1.38 \times 10^{-23}$ J/K or -228.6 dBJ/K
$L$	path loss, normally in dB
$L_b$	basic transmission loss (= $L$ ), normally in dB
$L_T$	space-to-earth attenuation (exceeding free space), dB
$m$	rms modulation index
$M$	margin for fading and propagation effects, normally in dB
$M_i$	margin for possible multiple interference entries, dB
$M_r$	margin for possible ground reflection of interfering signal, dB
$n$	number of identical stations contributing to the interference
$N$	noise power within a designated band, dBW
$N_0$	noise power density, noise power within 1 Hz bandwidth, dBW/Hz
$N_G$	total noise in a satellite channel including uplink and downlink, dBW
$N_I$	noise power in 2 MHz band, dBW
$N_{II}$	noise power in 40 kHz band, dBW
$P_T$	transmitter output power, W
PF <sub>D</sub>	power flux density, dBW/m <sup>2</sup>
$r_m$	mean radius of spectrum area voided by TV stations, km
$r_m'$	mean radius of spectrum area voided by translator stations, km
$R$	receiver transfer characteristics, non-dimensional ratio
$R_Q$	protection ratio of wanted-to-unwanted signal level required to provide a specified grade of service, dB

S	desired signal power, used as a ratio, dBW
S	Spectrum area: (bandwidth voided) $\times$ (geographical area), where channel width is known, also (number of channels voided) $\times$ (geographical area), $\text{km}^2 \text{ Hz}$ or $\text{km}^2 \text{ ch}$
$S_{\text{max}}$	maximum possible value of spectrum area product, $\text{km}^2 \text{ Hz}$ or $\text{km}^2 \text{ ch}$
$S_V$	voided spectrum area product
$S(t)$	amplitude of signal under consideration
$(S/N)_1$	post-detection signal-to-noise ratio, normally in dB
$(S/N)_2$	post-detection signal-to-noise ratio with pre-emphasis, dB
$(S/N)_3$	post-detection signal-to-noise ratio with pre-emphasis and companding, dB
$t_a$	antenna temperature due to external noise, K
T	temperature, usually system temperature $T_S$ of a receiving system, K
$T_a$	sky noise temperature, K
$T_b$	noise temperature outside the earth's atmosphere, K
$T_d$	temperature of the atmosphere where absorption is taking place, K
$T_0$	feed-line temperature, K
$T_R$	noise temperature seen looking into a receiver, K
$T_S$	system noise temperature, K
W	effective isotropic radiated power of a transmitting station, dBW
$\overline{x^2}$	total average power normalized so that $ s(t)  \leq 1$
z	baseband signal-to-noise ratio = $C[N_0 f_u]^{-1}$ , dB
$\alpha$	transmission coefficient
$\beta(\Delta)$	atmospheric transmission at angle $\Delta$ , deg
$\delta$	angle of arrival above horizontal plane, deg

$\Delta$	elevation angle, deg
$\Delta F$	peak frequency deviation, Hz
$\Delta h$	terrain irregularity based on the difference between upper decile and lower decile of terrain irregularity distribution
$\eta$	impedance of free space, $\eta = 120\pi \approx 377$ ohms
$\theta$	off-axis angle for an antenna, deg
$\lambda$	wavelength, m
$\Lambda$	peak-to-average signal amplitude
$\sum_{i=1}^n F_{I_i}$	aggregate power flux density from n interfering sources, dBW/m <sup>2</sup>
$\phi$	off-axis angle, community antenna, deg
$\phi_0$	angle between half-power points, community antenna, deg

#### MATHEMATICAL RELATIONS USED IN THE TEXT

Mathematical relations used in the main text and Appendices are gathered here.

#### Antenna Relations

- (1) Power absorbed,  $A$ , by a receiving antenna. The effective absorbing area for a Hertzian dipole,  $A_H = 3\lambda^2/(8\pi)$ . This can be shown to have a gain of 3/2 over an isotropic radiator,  $A_i$ . Hence,

$$A_i = \frac{2}{3} \left( \frac{3}{8} \frac{\lambda^2}{\pi} \right) = \frac{\lambda^2}{4\pi}$$

Thus, an antenna of gain  $G$  over isotropic has an absorbing area  $A = G\lambda^2/(4\pi)$ .

- (2) Gain of parabolic antenna,  $G$ , relative to the isotropic radiator

$$\begin{aligned} G &= k(4\pi A/\lambda^2) = k(\pi^2 D^2/\lambda^2) \\ &= 7.3 + 20 \log_{10} D - 20 \log_{10} \lambda, \end{aligned}$$

ORIGINAL PAGE IS  
OF POOR QUALITY

$$\begin{aligned} \text{where } k &= 0.55, f(\text{GHz}) = 0.2998 / \lambda(\text{m}) \\ &= 17.80 + 20 \log_{10} D(\text{m}) + 20 \log_{10} f(\text{GHz}) \text{ dBi} \end{aligned}$$

- (3) Beamwidth,  $d_0$ , of a paraboloid

$$d_0 \approx 21/[f(\text{GHz})D(\text{m})] \text{ deg} \approx 70(\lambda/D) \text{ deg}$$

- (4) Community reception antenna discrimination,  $D_d$ , for off-axis-angle  $\phi$

$$D_d = 10.5 + 25 \log_{10} (\phi/\phi_0) \text{ dB, for } 0 \leq D_d \leq G$$

b. Transmission Relations

- (5) Power flux density,  $F$ , for a given e.i.r.p.,  $W = P_T G$  in free space

$$\begin{aligned} F_{\text{max}} &= W/(4\pi d^2) = W \Big|_{\text{(dB)}} - 11.0 - 20 \log_{10} d(\text{m}) \text{ dBW/m}^2 \\ &= W - 162.7 \text{ dBW/m}^2 \text{ (} d = 38,500 \text{ km)} \end{aligned}$$

- (6) Field strength,  $E$ , in free space due to an antenna of gain  $G$  over isotropic. From (5), we get

$$F = \frac{W}{4\pi d^2} = \frac{E^2}{\eta} = \frac{E^2}{120\pi}$$

where  $E$  is the field strength (rms value of the amplitude), and  $\eta$  is the impedance of free space. We may solve for  $E$ :

$$\begin{aligned} E &= [W/(4\pi d^2)]^{1/2} [120\pi]^{1/2} = [30 W/d^2]^{1/2} \\ &= 173 W^{1/2}_{(\text{kW})}/d(\text{km}) \text{ mV/m} \end{aligned}$$

$E(\text{dBu})$  is related unambiguously to  $F$  by

$$E(\text{dBu}) - 120 = F + 10 \log_{10} (120\pi) = F + 25.76$$

Hence,

$$E(\text{dBu}) = F(\text{dBW/m}^2) + 145.76 \approx F + 146$$

where dBu refers to dB above  $1 \mu\text{V/m}$ .

- (7) Path loss,  $L$ , or basic transmission loss,  $L_b$ , incorporates the isotropic absorbing area in its definition

$$L = L_b = (4\pi d^2) (4\pi/\lambda^2) = (4\pi d/\lambda)^2$$

$$L_b = 20 \log_{10} (4\pi d/\lambda)$$

$$= 92.45 + 20 \log_{10} f(\text{GHz}) + 20 \log_{10} d(\text{km}) \text{ dB}$$

- (8) Carrier power,  $C$ , at the input of the receiver. By the definition of path loss from (7), this is  $C = W G_R/L$ , where  $W$  = e.i.r.p. and  $G$  the gain. The carrier power  $C$  can also be related to the power flux density  $F$ , but the antenna aperture now appears. For example, from

$$C = W G_R/L, \quad L = (4\pi d^2)(4\pi/\lambda^2), \quad F = W/(4\pi d^2)$$

we may write

$$L = (W/F)(4\pi/\lambda^2)$$

which leads to

$$C = [\lambda^2/(4\pi)] F G_R = [(0.3)^2/(4\pi)] [F G_R/f^2(\text{GHz})]$$

or

$$C(\text{dB}) = -21.46 - 20 \log_{10} f(\text{GHz}) + F + G_R \text{ dBW}$$

$$= -8.54 - 20 \log_{10} f(\text{GHz}) + F + G_R \text{ dBm}$$

$$= -167.26 - 20 \log_{10} F(\text{GHz}) + E \text{ (dBu)} + G_R \text{ dBW}$$

### c. Thermal Noise

- (9) Noise power,  $N$ , from a resistor available to a matched load is given by:

$$N = k T_0 B \text{ watts}$$

$$= N_0 B$$

where

$$k = \text{Boltzmann's constant} = 1.38 \times 10^{-23} \text{ J/K}$$

$$T_0 = \text{ambient temperature of the resistor, K}$$

$$B = \text{bandwidth, Hz}$$

$$N_0 = \text{noise density} = k T_0$$

In a receiving system all predetection noise is referred to the receiver input terminals as though from a matched resistance across the input terminals. The pertinent noise temperature is  $T_S$ , the system noise temperature.

- (10) System noise temperature,  $T_S$  (ignoring feed-line losses).  
 $T_S = T_a + T_R$  kelvin (antenna temperature  $T_a$  and receiver temperature  $T_R$ ), where  $T_R = T_0 (F_a - 1)$ , and the noise factor,  $F_a$ , is related to the noise figure,  $F_b$ , by  $F_b = 10 \log_{10} F_a$ , and  $T_0$  is the ambient temperature (taken as 290 K on earth). For example, if  $T_a = T_0 = 290$  K and the noise figure is 8 dB (noise factor = 6.3), then  $T_R = (6.3 - 1)290 = 1537$  K and  $T_S = 1827$  K, or if the noise figure is 12 dB (noise factor = 15.85), then  $T_R = 4306$  K and  $T_S = 4596$  K.

d. Receiver Input Relations

- (11) Ratio carrier power to system temperature,  $C/T_S$

$$\frac{C}{T_S} = \frac{P_T G_T G_R}{T} \left( \frac{\lambda}{4\pi d} \right)^2 = \frac{F}{4\pi} \frac{G_R}{T_S} \left( \frac{0.2998}{f(\text{GHz})} \right)^2$$

$$= -21.46 + F + (G/T_S) - 20 \log_{10} f(\text{GHz}) \quad \text{dBW/K}$$

or

$$\frac{C}{T} = \frac{W G_R}{L T} = \frac{W G_R}{L} \frac{k B}{N} = \frac{W G_R}{L} \frac{k}{N_0}$$

where  $N$  is the noise in the RF bandwidth  $B$  (from  $N = kTB$ ,  $N_0 = kT$ ), where  $k$  is Boltzmann's constant ( $1.38 \times 10^{-23}$  J/K or -228.60 dB). Expressing the relations in decibels, we get

$$\begin{aligned} \left. \frac{C}{T} \right|_{(\text{dB})} &= W + G_R - L - T = W + G_R - L - N_0 + k \\ &= -92.45 - 20 \log_{10} f(\text{GHz}) - 20 \log_{10} d(\text{km}) + W + G_R - T \\ &= -92.45 - 20 \log_{10} f(\text{GHz}) - 20 \log_{10} d(\text{km}) + W + G_R - N_0 \\ &\quad + 228.6 \\ &= 136.15 - 20 \log_{10} f(\text{GHz}) - 20 \log_{10} d(\text{km}) + W + G_R - N_0 \end{aligned}$$

- (12) Ratio carrier power-to-noise density  $C/N_0$  ( $N_0 = kT_S$ )

$$C/N_0 = (C/T_S) + 228.6 \quad \text{dB Hz}$$

and

$$\begin{aligned} C/N &= C/(kT_s B) \quad (\text{carrier-to-noise power}) \\ &= C/N_0 - 10 \log_{10} B(\text{Hz}) \quad \text{dB} \end{aligned}$$

From (8) we may write

$$\begin{aligned} C/N_0 \Big|_{(\text{dB})} &= W + G_R - L - T + k \\ &= 136.15 - 20 \log_{10} f(\text{GHz}) - 20 \log_{10} d(\text{km}) \\ &\quad + W + G_R - T \end{aligned}$$

or

$$\frac{G_R W}{T} = \frac{LC}{T} = \frac{L C k}{N_0}$$

which in decibels is

$$W + (G/T)(\text{dB}) = (C/N_0)(\text{dB}) + L - 228.6$$

and from (8) and (9)

$$\begin{aligned} C/N_0 &= 61.34 - 20 \log_{10} f(\text{GHz}) - 10 \log_{10} T + E(\text{dBu}) \\ &\quad + G_R \quad \text{dB Hz} \\ &= 61.34 - 20 \log_{10} f(\text{GHz}) + (G_R/T_s)(\text{dB}) + E(\text{dBu}) \\ &= 207.14 - 20 \log_{10} f(\text{GHz}) + (G_R/T_s)(\text{dB}) + F(\text{dBW/m}^2) \end{aligned}$$

- (13) Permitted power flux density,  $F_s$ , to avoid interference (Section V-A)

$$F_s = F_{\text{tpq}} - R_q + D_d + D_p - M_r - M_i \quad \text{dBW/m}^2$$

#### Post-Detection Signal-to-Noise Ratio for FM

The predetection signal-to-noise ratio ( $C/N$ ) needs to exceed about 0 (13 dB) for safety (Carlson, 1968), but 10.5 dB is a frequently used value.

Without de-emphasis filtering, the post-detection signal-to-noise ratio is given by

$$\left(\frac{S}{N}\right)_1 = 3 \left(\frac{C}{N_0}\right) \frac{(\Delta F)^2}{f_u^3 - f_l^3} \cdot \overline{X^2}$$

where

$\Delta F$  = maximum deviation frequency

$\overline{X^2}$  = total average power normalized so that  $|s(t)| \leq 1$ ;

for a test tone  $\overline{X^2} = 1/2$

Adding an RC de-emphasis filter ( $f_3 = (2\pi RC)^{-1}$ , where  $f_3 \ll f_u$ ), reduces output noise. The principle is that interference effects in FM are greater the farther from the carrier frequency and interference occurs. Hence, the transmitted signal is boosted in power at the transmitter such that the product of the de-emphasis filter characteristics is unity. The S/N expression for de-emphasized FM (which we call  $(S/N)_2$ ) is

$$\begin{aligned} \left(\frac{S}{N}\right)_2 &= \frac{3 D^2 \overline{X^2}}{3(f_3/f_u)^2} \frac{C}{N_0 f_u} \\ &= \frac{1}{3} (f_u/f_3) (S/N)_1 \end{aligned}$$

For commercial FM,  $\Delta F = 75$  kHz,  $f_u = 15$  kHz,  $D = 5$ ,  $f_3 = 2.1$  kHz

(corresponding to  $75 \mu s = RC$ ). Let  $\overline{X^2} = 1/2$ , then

$$(S/N)_1 = 3 D^2 \overline{X^2} z$$

where  $z = C/(N_0 f_u)$  is baseband S/N

$$= 3 \cdot 25 \cdot (0.5) \cdot z = 37.5 z \text{ or } 15.74 \text{ dB over } z$$

$$(S/N)_2 = (1/3) (15/2.1)^2 (S/N)_1$$

$$= 17.01 (S/N)_1 = (S/N)_1 + 12.31 \text{ dB}$$

$$= 638 z \text{ or } 28.05 \text{ dB} \cdot z$$

## f. Companding

Companding (compressing - expanding) does absolutely nothing to the S/N improvement of a test tone. As a test tone is what is assumed for most signal-to-noise improvement calculations, it is misleading to add the companding improvement to the signal-to-noise ratio based on a test tone. What companding does is to allow you to realize the signal-to-noise improvement calculated with a test tone.

For example, assume a soft talker is speaking such that  $\overline{X^2} = 0.05$  or 10 dB down. From our previous example, we now have

$$(S/N)_1 = 3 D^2 \overline{X^2} z = 3.75 z \text{ or } 5.74 \text{ dB over } z$$

$$(S/N)_2 = 17.01 (S/N)_1 = 63.79 z \text{ or } 18.05 \text{ dB over } z$$

Most of this 10 dB reduction could be recovered by companding.

ORIGINAL PAGE IS  
OF POOR QUALITY