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RADIO FREQUENCY UTILIZATION IN THE BANDS OF PRINCIPAL INTEREST FOR AERONAUTICAL SATELLITES

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DECEMBER 1970

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GREENBELT, MARYLAND

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SECTION I

INTRODUCTION

1.1 PURPOSE

The purpose of this report is to examine the utilization in the United States of the Very High Frequency (VHF) Band and "L" Band allocations for aeronautical services. The results of this study will be inputs to continuing studies of the applications of space techniques to provide aeronautical communication services.

1.2 SCOPE

Radio frequencies examined are those allocated and assigned in the frequency bands 118.0 to 136.0 MHz (VHF) and 1535 to 1660 MHz (UHF or "L"-Band). These frequency areas have been considered as possible candidates for aeronautical communications using satellite techniques because of their current allocation to the aeronautical service. The study examines present utilization, future trends which would affect frequency availability with projected growth, and pertinent factors influencing frequency assignment for the time frame to 1980. Since the ability to meet increased utilization also depends upon channelization and performance characteristics, the study includes the parametric relation of these factors for a range of values.

The VHF aeronautical communications band currently provides the primary frequency support for domestic and international aeronautical communications. The factors concerning its utilization may be defined upon the basis of known systems, techniques, and operational experience. As it is the primary frequency area for present communications, it has been addressed in some detail.

The VHF system characteristics used in the VHF sharing analyses, including frequency plan, are compatible with the Mark I VHF SATCOM System as described by ARINC Characteristic 566. The transceiver described is designed to be eventually used in an operational VHF satellite system.

The "L" Band, on the other hand, presently does not include operational aeronautical communication systems, but there are a limited number of altimeters operating in the band. Because of the nebulous nature of the characteristics of future communication systems in this band, it is not possible to consider in detail the spectrum problems without an undue number of major assumptions. The study accordingly has been limited in its treatment of frequency utilization for this band.

1.3 SOURCES

The primary sources of information have been the Federal Aviation Administration, the Federal Communications Commission, and various other Government and industrial organizations. Numerous personal contacts were made during the course of this study. A complete list of the organizations contacted is included in Appendix E.

1.4 ORGANIZATION

The report organization provides a summary of the findings in Section 2. A general discussion of frequency allocations in the two bands of interest is contained in Section 3. Section 4 and 5 discuss in detail the utilization of the two bands. In Sections 3 and 4, the general philosophy of frequency allocation in the VHF band is discussed in some detail along with a description of the interaction between various organizations concerned. This is done for completeness and to provide background for readers not intimately involved in frequency matters. Section 6 describes a method of examining the problem of sharing the VHF band between satellite and terrestrial aeronautical mobile communication services. Specialized data and information pertinent to the study are contained in the Appendices.

SECTION 2

SUMMARY

2.1 GENERAL

Transoceanic air traffic presently uses VHF, extended range VHF and then HF communications facilities. At long ranges, HF is unreliable because of its dependence on ionospheric conditions and the resulting propagation variations. The application of line of sight communication using a satellite as a relay point promises to offer greatly improved communications to these aircraft and to others in sparsely settled areas of the world where adequate communication facilities are not available.

The selection of the frequency band in which this new service should be provided is currently a subject of much interest. Two primary candidates are VHF (118 to 136 MHz) and "L" band (1535 to 1660 MHz).

This study considers some particular factors which may influence this selection. These factors are:

a. Present utilization

b. Future trends in utilization

c. Known assignment constraints

d. Technical aspects of VHF band sharing

2.2 VHF FREQUENCY SITUATION

This study has concluded that:

a. The VHF ATC frequencies being utilized are congested. ATC communication requirements make efficient use of only some 190 frequencies. In 1968, on a national average basis, an ideal protection level of 20 dB theoretically required about 200 frequencies to meet ATC requirements at that time. New requirements are being satisfied by reductions in desired protection criteria. Nearly all of the 253 frequencies technically available would be assigned if it were not for restraints imposed by radio equipment in a large percentage of general aviation aircraft. The result is more frequency congestion on the 100 kHz channels and reduced air-air protection (down to as low as 7 dB). If local congestion problems at major airports were disregarded, and the high idealized condition of equal national loading was assumed, the protection ratio would now average about 13 dB. Projected increases in requirements and the resultant further sharing of frequencies will degrade the average protection ratio on the ATC channels to a highly questionable condition by 1972.

The protection ratio achievable at high concentrations of activity such as major terminal areas is considerably less than the national average.

A number of indicators of congestion present in the environment have been identified. These include:

1. Increased channel congestion and interference reports

2. Increased engineering time and computer assistance

3. Use of special channel assignments schemes

4. Chain-reaction frequency adjustments to meet a new requirement

5. A general degree of increased attention and sensitivity to frequency management in the band.

As an example of the chain-reaction indicator, a requirement for seven additional ATC channels was recently fulfilled in the New York area. To provide the seven frequencies, the best engineering plan which could be devised without causing intolerable interference required the rearrangement of 17 other frequency assignments. Implementation of these changes required 4 months.

b. The operational control portion of the VHF band is alsc congested in the area bounded by Boston, Massachusetts; Chicago, Illinois; and Washington, D. C. This is supported by the fact that ARINC (the carrier's communication operating agency) has recently petitioned the FCC to permit implementation of a 25 kHz channeling plan in the band 128.85 - 132.0 MHz. However, the ARINC Petition was not solely based upon present or contemplated future congestion in this band. Rather, this Petition was also designed to provide for expanded air/ground communication functions, the accommodation of data link, and a VHF aeronautical satellite service. It is the opinion of ARINC that the evolution of data link will replace many functional requirements now fulfilled by voice communications thereby insuring the availability of this band well into the future.

c. The major reasons for congestion are:

1. The growth of aviation during the past decade to over 2600 air carrier aircraft and nearly 124,000 authorized general aviation aircraft through April 1970.

2. The FAA's respect of the tuning limitations of a substantial portion (on the order of 35-40 percent) of general aviation's communication equipment and the long-life cycle of general aviation avionics. This results in about 190 of the 253 possible ATC frequency assignments being efficiently utilized.

3. Civil VHF frequencies must be assigned to many military airfields to accommodate civil aircraft using those facilities for various reasons.

d. The 190 frequencies which can be efficiently utilized under the present assignment plan (50 kHz channelization when subject to practical assignment restraints) will be sufficient to meet conventional air-ground requirements only through 1972-73 (assuming at least an 8-10 dB protection ratio is required). By then, (failing complete deployment) expanding communication needs will have further deteriorated protection ratios and will require further regulatory and/or technical solutions. Measures which may be required by 1973, or shortly thereafter, are considered to be as follows:

1. Reduce transmission needs, with particular emphasis directed to major metropolitan areas, by both technical and operational measures including data link.

2. Consider new concepts for frequency assignments including such operational concepts as aircraft single frequency designation, functional assignment approaches, and other means to distribute frequency loading.

3. Increase frequency availability by establishment of equipment programs to achieve fuller utilization of the 50 kHz channels and ultimately 25 kHz channelization.

e. Estimates of spectral density at the satellite through examination of frequency registrations and subsequent calculations contain many simplifying assumptions which are not a sound basis for systems design. For this purpose, actual frequency and signal level measurements by satellite should be conducted. Such a Radio Frequency Interference (RFI) experiment could provide a factual basis for frequency and propagation computations.

2.3 "L" BAND FREQUENCY SITUATION

The conclusions regarding the aeronautical "L" band are:

a. The "L" Band appears to offer frequency availability for aeronautical satellite use in today's crowded spectrum. Radionavigation and communication frequency requirements may be afforded radio spectrum space in the "L" band (1540 to 1660 MHz) subject to technology equipment measures and international coordination. The "L" band provides grouping of several aeronautical functions in one portion of the spectrum. This includes potential space techniques, communications, navigation, glide path control, and collision avoidance. It provides 120 MHz* of spectrum space which may be used to meet current and known future requirements.

b. The RFI aspects of close field coupling may require further examination during development phases. Measurement and studies of potential interference from the continued operation of existing radio altimeters in frequency proximity to the provisional aeronautical mobile downlinks should be examined further. Although the altimeter will eventually vacate this band, those continued in use in the interim represent potential frequency conflicts.

2.4 VHF BAND SHARING IMPLICATIONS

Section 6 shows:

a. Insufficient data is available regarding appropriate receiving system performance in an interference environment to permit a meaningful assessment of VHF band sharing.

b. A methodology has been developed which, given the required protection ratios, has the capability of evaluating the potential geographical constraints which VHF band sharing might impose. The results are critically dependent on these protection

* International allocations presently in effect.

ratios. These potential constraints are exemplified by a limitation in the service radius of coastal terrestrial stations and the emergence of a communications gap between service areas of the terrestrial and satellite systems.

SECTION 3

ALLOCATIONS AND ASSIGNMENTS

3.1 INTERNATIONAL ALLOCATIONS

To assure commonality of radio frequency uses and equipments in the various services and to assist in the control of interference, internationally agreed frequency allocations have been established. These agreements, by national ratification of radio conventions of the International Telecommunications Union (ITU), have treaty status and are binding upon frequency assignment activities of each administration. The allocations in the Radio Regulations, Edition of 1968, are those reached at the Geneva 1959 Conference as revised by the following:

a. The Extraordinary Administrative Radio Conference for Space Radiocommunications, 1963.

b. The Extraordinary Administrative Radio Conference for the Aeronautical Mobile (R) Service, 1966.

c. The World Administrative Radio Conference, Maritime Mobile Service, 1967.

The allocation to services are reached at international radio conferences by multilateral discussions, although preconference bilateral coordination may be conducted in seeking support for national proposals. Although the interests of government and industry users may offer differing frequency views during the conference preparatory cycle, the final responsibility for a unified United States position as presented internationally rests with the Department of State.

The allocations to aeronautical services pertinent to this study are shown by Tables 3-1 and 3-2. These tables reproduce the current frequency allocations with the appropriate footnotes rearranged for easy reference. To achieve maximum standardization

TABLE 3-1. INTERNATIONAL ALLOCATIONS TO THE AERONAUTICAL SERVICES IN THE VHF BAND

Allocation to Services		
Region 1	Region 2	Region 3
117·975—132	AERONAUTICAL MOBILE (R) 273 273A	
132—136 AERONAUTICAL MOBILE (R) 273A 274 275	132—136 FIXED MOBILE 273A 276 277 278 279	

273 The frequency 121.5 Mc/s is the aeronautical emergency frequency in this band; mobile stations of the maritime mobile service may communicate on this frequency for safety purposes with stations of the aeronautical mobile service.

273A Spa In the band 117·975-132 Mc/s and in the band 132-136 Mc/s where the aeronautical mobile (R) service is authorized, the use and development, for this service, of systems using space communication techniques may be authorized but limited initially to satellite relay stations of the aeronautical mobile (R) service. Such use and development shall be subject to co-ordination between administrations concerned and those having services operating in accordance with the Table, which may be affected

274 In certain countries of Region 1, the aeronautical mobile (OR) service will continue to operate for an unspecified period, on a primary basis.

275 Spa In Burundi, Ethiopia, Nigeria, Sierra Leone, Gambia, Portuguese Oversea Provinces in Region 1 south of the equator, Rhodesia and Nyasaland, Rwanda and the Rep. of South Africa and Territory of South-West Africa, the bands 132-136 Mc/s and 138-144 Mc/s are allocated to the fixed and mobile services.

276 In Region 2, in the band 132-135 Mc/s, the aeronautical mobile (R) service shall operate on a primary basis subject to co-ordination between administrations concerned and those having services operating in accordance with the Table, which may be affected.

277 In Region 3, in the band 132-136 Mc/s, which will eventually become exclusively allocated to the aeronautical mobile (R) service, frequency assignments to the aeronautical mobile service shall be co-ordinated between administrations concerned and shall be protected from harmful interference.

278 Spa In New Zealand, the bands 132-136 Mc/s and 138-144 Mc/s are allocated to the aeronautical mobile (OR) service.

279 Spa In Australia, the band 132-136 Mc/s is allocated to the aeronautical mobile service.

Note: These are the currently published allocations which are the subject of proposed changes in 1971.

TABLE 3-2. INTERNATIONAL ALLOCATIONS IN THE AERONAUTICAL "L" BAND

Allocation to Services		
Region 1	Region 2	Region 3
1 535—1 540		
	SPACE (Telemetering)	
	350A 351 352 352C	
1 540—1 660		
	AERONAUTICAL RADIONAVIGATION	
	351 352 352A 352B 352D	

350A Spa Space stations employing frequencies in the band 1 525-1 540 Mc/s for telemetering purposes may also transmit tracking signals in the band.

351 Spa In Italy, the band 1 535-1 600 Mc/s is also allocated to the fixed service until 1 January, 1970.

352 Spa In Albania, Bulgaria, Hungary, Poland, Roumania, Czechoslovakia and the U.S.S.R., the band 1 535-1 660 Mc/s is also allocated to the fixed service. As regards the category of the fixed service in the band 1 535-1 540 Mc/s, see Resolution NoSpa3

352A Spa The bands 1 540-1 660 Mc/s, 4 200-4 400 Mc/s, 5 000-5 250 Mc/s and 15·4-15·7 Gc/s are reserved, on a world-wide basis, for the use and development of airborne electronic aids to air navigation and any directly associated ground-based or satellite-borne facilities.

352B Spa The bands 1 540-1 660 Mc/s, 5 000-5 250 Mc/s and 15·4-15·7 Gc/s are also allocated to the aeronautical mobile (R) service for the use and development of systems using space communication techniques. Such use and development is subject to agreement and co-ordination between administrations concerned and those having services operating in accordance with the Table, which may be affected.

352C Spa In Morocco and Yugoslavia, the band 1 535-1 540 Mc/s is also allocated to the aeronautical radionavigation service.

352D Spa In Austria, Indonesia and the F. R. of Germany, the band 1 540-1 660 Mc/s is also allocated to the fixed service.

Note: These are currently published allocations which are the subject of proposed changes in 1971.

of frequency utilization, a worldwide allocation is desired. Howevery, nations in some parts of the world may have differing requirements and thereby differing frequency needs. Regional differences in allocations are recognized by three defined regions of the world. Additional national provisions may be indicated by footnotes officially part of the radio regulations (Reference 1).

3.2 ORGANIZATIONAL INFLUENCES UPON FREQUENCY PLANNING

Within the frequency bands internationally allocated to the aeronautical services by the ITU, several organizations influence the operational uses and frequency assignment plans made by national administrations. The close coordination among these organizations provides for the unusual degree of standardization in aeronautical radio frequency uses that is so important to the successful widespread operation of modern aircraft. As a result, families of frequencies are associated with specific world aeronautical routes and radio operations are highly standardized.

Among these specialized organizations, the International Civil Aviation Organization (ICAO) serves a primary coordinating function for its member states (i.e., government to government). The aviation carriers are represented by the International Air Transport Association (IATA). Within the U.S., representation to IATA is centered in the U.S. international air carriers aided by the Air Transport Association (ATA) and the communications organization of the airline industry, Aeronatuical Radio, Inc. (ARINC). ARINC is the FCC licensee and has operated ground facilities for the aircraft operating agencies since about 1929. ARINC performs communication systems development and the radio frequency engineering required by the aircraft operating agencies, and coordinates the avionics development and standardization of airborne systems. The Interagency Group on International Aviation (IGIA) serves to coordinate international aviation matters among U.S. governmental agencies and user groups. The Radio Technical Commission for Aeronautics (RTCA) serves as a means of coordinating government and industry, and recommends actions to the IGIA, user groups, and governmental agencies, as appropriate.

In the U.S., national aeronautical frequency assignments are controlled by a dual system. For all non-federal users, radio frequencies are licensed by the Federal Communications Commission (FCC). The staff element exercising this function is the Aviation and Marine Division of the Safety and Special Radio Services Bureau. For all federal users of the aeronautical mobile band, this function is exercised by the Office of Telecommunications Policy (OTP) using the coordination mechanism of the Interdepartment Radio Advisory Committee (IRAC). Most government departments and agencies having radio interest are members of the IRAC. The IRAC's substructure consists of the Spectrum Planning Subcommittee (SPS), Frequency Assignment Subcommittee (FAS), the Technical Subcommittee (TSC), and the Secretariat. The FAS has a subgroup concerned with aeronautical frequency assignments. This is the Aeronautical Assignment Group (AAG), which is chaired by the Federal Aviation Administration. The FAA thereby serves a significant role in radio frequency matters affecting aviation and the determination of frequency requirements, sharing criteria, and assignment concepts. The FCC, through direct coordination as well as through the Joint FCC-IRAC organization, reflects national aeronautical frequency planning in its licensing activities. (Reference 2)

3.3 NATIONAL ALLOCATION PLANS

Since each administration is free to determine frequency utilization within the framework established by the international allocation tables, national allocations are made responsive to particular interests or needs. In the U.S., such allocations plans are prepared by the Federal Aviation Administration and the Federal Communications Commission through the coordinating structure of the OTP and Joint IRAC-FCC.

This allocation is shown in Table 3-3 for the frequency spectrum 118.0 to 135.95 MHz (References 3 and 4).

TABLE 3-3. NATIONAL SUBALLOCATION PLAN FOR THE VHF AERONAUTICAL COMMUNICATIONS BAND

FREQUENCIES (MHz)	USE	CHANNEL SPACING	NON-ATC CHANNELS	ATC CHANNELS
118.0-121.4	Air Traffic Control	50 kHz		69
*121.5	Emergency	100 kHz	1	
121.6	Airport Utility	100 kHz below 121.6 MHz 50 kHz above 121.6 MHz	1	
121.65-121.95	Airport Utility	50 kHz	7	
122.0-123.05	Private Aircraft	50 kHz	22	
123.1	Search and Rescue	50 kHz	1	
123.15-123.25	Flight Test	50 kHz	3	
123.3	Flight Test - Flying School	50 kHz	1	
123.35-123.45	Flight Test	50 kHz	3	
123.5	Flight Test - Flying School	50 kHz	1	
123.55	Flight Test	50 kHz	1	
123.6-128.8	Air Traffic Control	50 kHz		105
128.85-132.0	Aeronautical Enroute (Air Carrier)	50 kHz	64	
132.05-135.95	Air Traffic Control	50 kHz		79
Number of channels other than Air Traffic Control			105	
Number of Air Traffic Control channels				253
		Total	358	

*The radio spectrum between 118.0 and 136.0 MHz on 50-kHz channeling could contain 360 channels. However, by affording 100-kHz protection indefinitely to the emergency channel 121.5 MHz, the maximum number available, by existing standards, is 358 channels.

The most recent U.S. proposals for "L" band are as follows (not internationally agreed upon at present).

1535.0 - 1537.5	Maritime Mobile
1537.5 - 1542.5	Aeronautical Mobile and Maritime Mobile
1542.5 - 1557.5	Aeronautical Mobile
1557.5 - 1567.5	Aeronautical Radionavigation
1567.5 - 1592.5	Aeronautical Radionavigation
1592.5 - 1622.5	Aeronautical Radionavigation
1622.5 - 1637.5	Aeronautical Radionavigation
1637.5 - 1640.0	Maritime Mobile
1640.0 - 1645.0	Aeronautical Mobile and Maritime Mobile
1645.0 - 1660	Aeronautical Mobile

As discussed further in Section 5, the above proposals are to be considered by the World Administrative Radio Conference for Space Telecommunications, 1971.

The national frequency table reflected in Part 2 of the FCC Rules and Regulations will be modified when appropriate as a result of international action. The current FCC allocations for this band were adopted in February 1970 (Docket 18550) prior to formulation of the above frequency plan through the subdivisions for navigation and communications are identical in both, the tables differ presently in priority or sharing aspects between aeronautical and maritime communication users. Pending implementation measures of frequency agreements resulting from the 1971 conference, frequency assignment plans must be evaluated against the possibility of potential adjustments.

SECTION 4

VHF AERONAUTICAL BAND

4.1 INTRODUCTION

A portion of the VHF band between 118 and 136 MHz provides the spectrum serving practically all the world's aviation. In the U.S., the national airways serve some 2600 air carrier aircraft and some 124,000 general aviation aircraft in this frequency band (Reference 5). The communication operations include both terminal and enroute activities.

ATC enroute operations in the U.S. are handled by Air Route Traffic Control Centers (ARTCC); each assigned a control area. The control areas are further divided into sectors within which a controller team has jurisdiction. The communication range of each ARTCC is extended to its entire control area by Remote Center Air/Ground (RCAG) radio facilities. Aircraft within or in transit must communicate with the appropriate sector controller on his designated frequencies. An aircraft must, therefore, make appropriate frequency changes as he passes through sectors and control areas (References 6 and 7).

The FAA Rules require that airlines be in continuous communication with planes aloft, since the responsibility for the safety is shared by the airline-licensed dispatcher and the pilot. The dispatcher controls the airline's traffic and maintains operational control. These services are provided by Aeronautical Radio, Inc. (ARINC) and are extended to all aircraft operators, large or small, U.S. or foreign, scheduled and supplemental, business, private, and government. The portion of the VHF aeronautical mobile (R) band, 128.825-132.025 MHz, is used exclusively by ARINC in providing these services. The ARINC domestic communications channels are used for the handling of operational communications as distinct from FAA air traffic services.

The relative position of the VHF aeronautical band and its suballocations is shown by Figure 4-1, which is a graphical presentation of the table in Section 3. Frequency assignments within the VHF spectrum space allocated to aviation have been channelized on specific center frequencies, a procedure common to the mobile services. Aircraft are given "blanket" assignments, which provide a wide choice of transmitting frequencies as related to particular needs or services provided by ground stations, either in accordance with a published plan or as directed by the ground station (Reference 3). The pattern of aircraft frequency use generally reflects the frequency plan of ground facilities, except for emergency or air-rescue frequencies.

Aircraft in flight over oceanic or sparsely settled areas use high frequency (approximately 3 to 20 MHz) radio when out of range of VHF. To provide VHF service as far as possible out along the overseas routes special high powered extended range stations are employed. These overseas services handle both company operational control and air traffic service communications. All communication flows directly through the extended range communication center to or from the airline dispatcher, FAA controller, or others directly involved with flight operations.

The frequency utilization philosophy is a functional approach. Various terminal and enroute flight services, or emergency functions are related to discrete frequencies in accordance with a plan disseminated to all users. Functional frequencies may differ with geography, such as enroute functions in various air control sectors, or among terminal areas to alleviate interference. Present functional uses are listed in Table 4-1.

Many functional frequencies may be engineered in broad usage terms because the nature of their use neither demands nor is applicable to rigid engineering criteria. Other frequencies, however, serve communication requirements which may be defined for use in

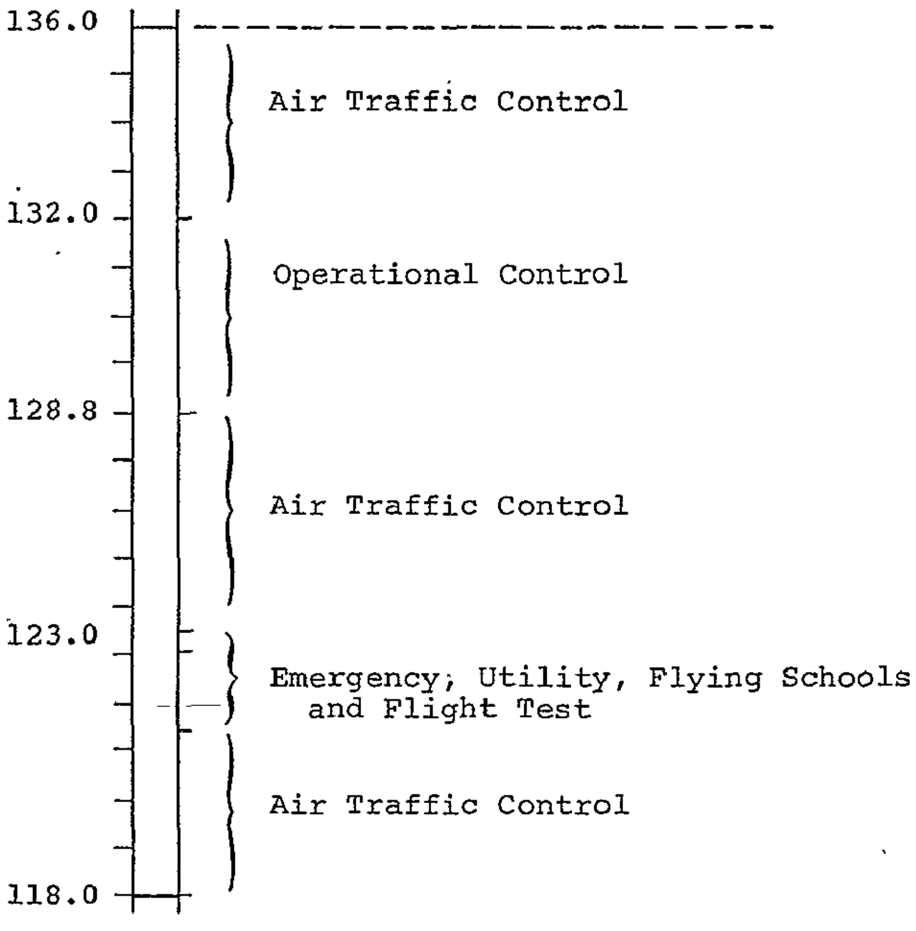


Figure 4-1. Relative Orientation of the VHF Aeronautical Band

TABLE 4-1. FUNCTIONS SERVED BY AERONAUTICAL COMMUNICATIONS IN THE VHF BAND

Emergency
Approach Control
Ground Control
Local Control
Departure Control
Clearance Delivery
Helicopter Control
Air Traffic Information Service (ATIS)
Precision Approach Radar (PAR)
Unicomm
Multicomm
Flight Service Station (FSS)
Low Altitude Enroute
High Altitude Enroute
VFR Radar Advisory
Air Operational Control

specific geographical areas where a protected grade of service is considered particularly important. This results in two categories of frequency utilization:

a. Engineered channels using rigid site criteria to assure a protected service volume for specific ground stations, control sectors, or functions (ATC and operational control).

b. Nonengineered channels to provide services, on demand, without significant efforts to protect a defined service area.

The provision of nonengineered functional frequencies serves a necessary purpose and is highly utilized but their use, of course, detracts from the number of channels available in the ATC band for the engineered ATC requirements.

The following subsections discuss these categories and the factors affecting frequency utilization.

4.2 ENGINEERED AIR TRAFFIC CONTROL FREQUENCY UTILIZATION

The engineered frequencies consist of those bands allocated to air traffic control in Figure 4-1. The FAA has been engaged in a major effort to define frequency requirements for a national system (Reference 8). This effort has included contractual assistance by computer techniques considering service coverage, frequency sharing, and performance levels. This program is examining ATC frequency channel requirements for both enroute and terminal operations. It has included current refinements of sharing to the maximum extent between enroute and terminal needs, and the tailoring of protected service volumes to coincide with control sector geographical areas as well as projected growth requirements. Two necessary assumptions that were made during the study force the results to be interpreted in absolute minimum terms. These are:

a. Complete freedom exists to reassign existing frequencies

b. No co-site assignment constraints exist.

The portion of this report treating the theoretical frequency channel needs, or the minimum essential channels, includes selected data from "Analysis of Channel Requirements for Air Traffic Control Communications and Navigational Aid Systems," (Reference 8).

4.2.1 Service Volume Criteria

Whereas fixed or land services are engineered for a particular service area in relation to the transmitter, the aeronautical service deals in service volumes centered on a station. The radius and altitude of the service volume is related to the functions and airspace control category. This cylindrical volume is defined as the standard service volume. As a refinement to further reduce the essential number of frequency channels, the standard volumes are tailored to the air traffic control areas so as to disregard protection needs beyond the precise boundary of the geographical sector. This further engineering of frequency and service volumes is identified as the "Tailored Service Volumes." In this case, signals are protected from air-to-air interference only within the specific sector served, and coinciding with actual boundaries. The standard service volumes are tabulated in Table 4-2 (Reference 6).

4.2.2 Growth Projections

As an example of the type of basic information considered during the referenced on-going study, consider the following.

The FAA estimated the total number of general aviation aircraft to be 124,000 in January 1969, and forecasts this to increase to 178,000 by 1975 and 225,000 by 1980. Total air carrier aircraft in service in January 1969 was 2586 and this is projected to be 3600 by 1980.

The potential growth of radio communication requirements is illustrated by the projected increase in Remote Center Air-Ground (RCAG) assignments serving air traffic control centers. This is shown in Figure 4-2 along with the projected increases in air operations (Reference 9).

TABLE 4-2. STANDARD SERVICE VOLUMES*

Communications Function	Service Radius (nautical miles)	Altitude (thousand feet)
Low Altitude Enroute	60	18
High Altitude Enroute	150	45
Local Control	30	10
Approach Control	60	25
Departure Control	60	20
Clearance Delivery	25	5
Helicopter Control	30	5
ATIS	60	25
Precision Approach Radar	25	5

*Source: Reference 6

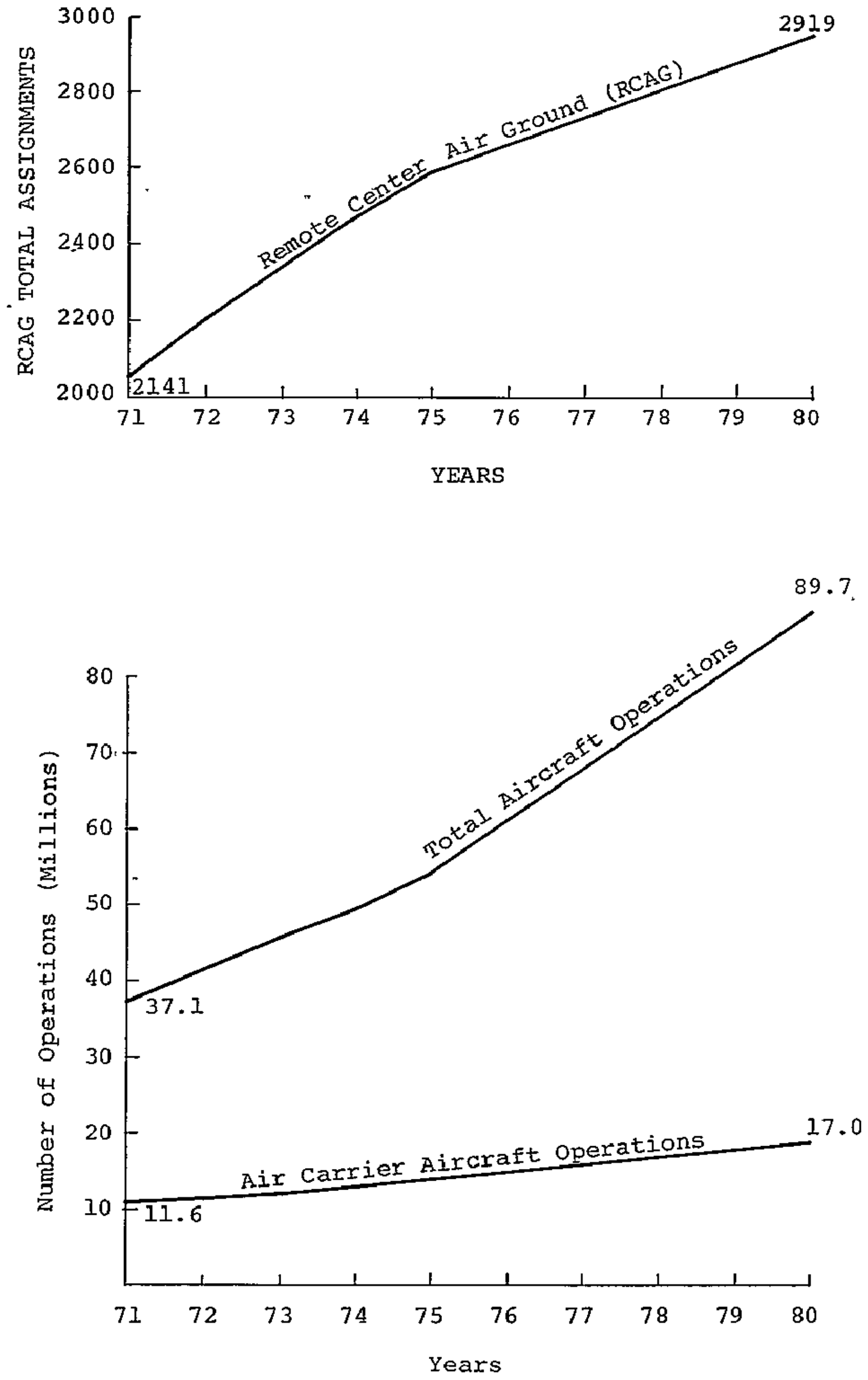


Figure 4-2. Growth Projections (Source: Reference 9)

4.2.3 Channel Requirement Computations

During the referenced study, the U.S. VHF air-ground communications system channel requirements, both enroute and present terminal functions, were computed for each of six levels of signal-to-interference protection. Only air-to-air interference by direct wave propagation was considered. Transmitter powers and antenna gains were considered identical in all cases.

The levels of protection against unwanted co-channel interference that were used were 20, 17, 14, 11, 8 and 5 dB. For each of these assumed protection ratios, the computations for the entire system considered feasible interfunction frequency sharing and geographical repeating schemes. Requirements were computed for high and low altitude enroute stations individually, as well as composites where some stations provided both services (Reference 8).

The results of the FAA study applicable to the VHF band have been extracted and are tabulated in Table 4-3. The results indicate the number of frequency channels required as a function of the protection ratio. If it is assumed, as discussion with the FAA indicates, that the same criteria is applied to present assignments, then the degree of congestion may be expressed in terms of available protection ratio and its degradation with time. Paragraph 4.2.5 discusses protection ratio and concludes that the predicted existance of an 8-10 dB protection ratio represents the point at which steps should be taken to alleviate the causes of the degradation.

With the increases in communication requirements which must be met by available frequencies, either the performance (protection ratio) will be degraded as sharing is increased, or frequency availability must be increased by operational or technical measures. Figures 4-3 and 4-4 illustrate these factors and show that if the total of 253 ATC frequencies under 50-kHz spacing were actually available to meet ATC requirements under an engineered concept, predicted increases in enroute requirements alone could be satisfied until about 1973 with 20 dB protection. Thereafter, with increased sharing of

TABLE 4-3. NUMBER OF REQUIRED FREQUENCY CHANNELS FOR ATC BASED ON AN IDEAL ENGINEERING PLAN*

REQUIREMENTS	LEVEL OF PROTECTION (dB)					
	20	17	14	11	8	5
Enroute functions, high and low: (Standard)						
Present	101	100	99	86	75	60
1975	171	171	171	152	133	114
Terminal functions:						
Present	123	123	120	99	93	85
1975	123	123	120	99	93	85
Enroute functions, tailored, high and low						
Present	86	86	82	74	62	50
1975	154	148	144	135	108	91
Total Requirements, enroute and Terminal						
Present Standard	200	200	193	160	152	136
1975 Standard	269	268	255	217	199	175

*Source: Reference 8

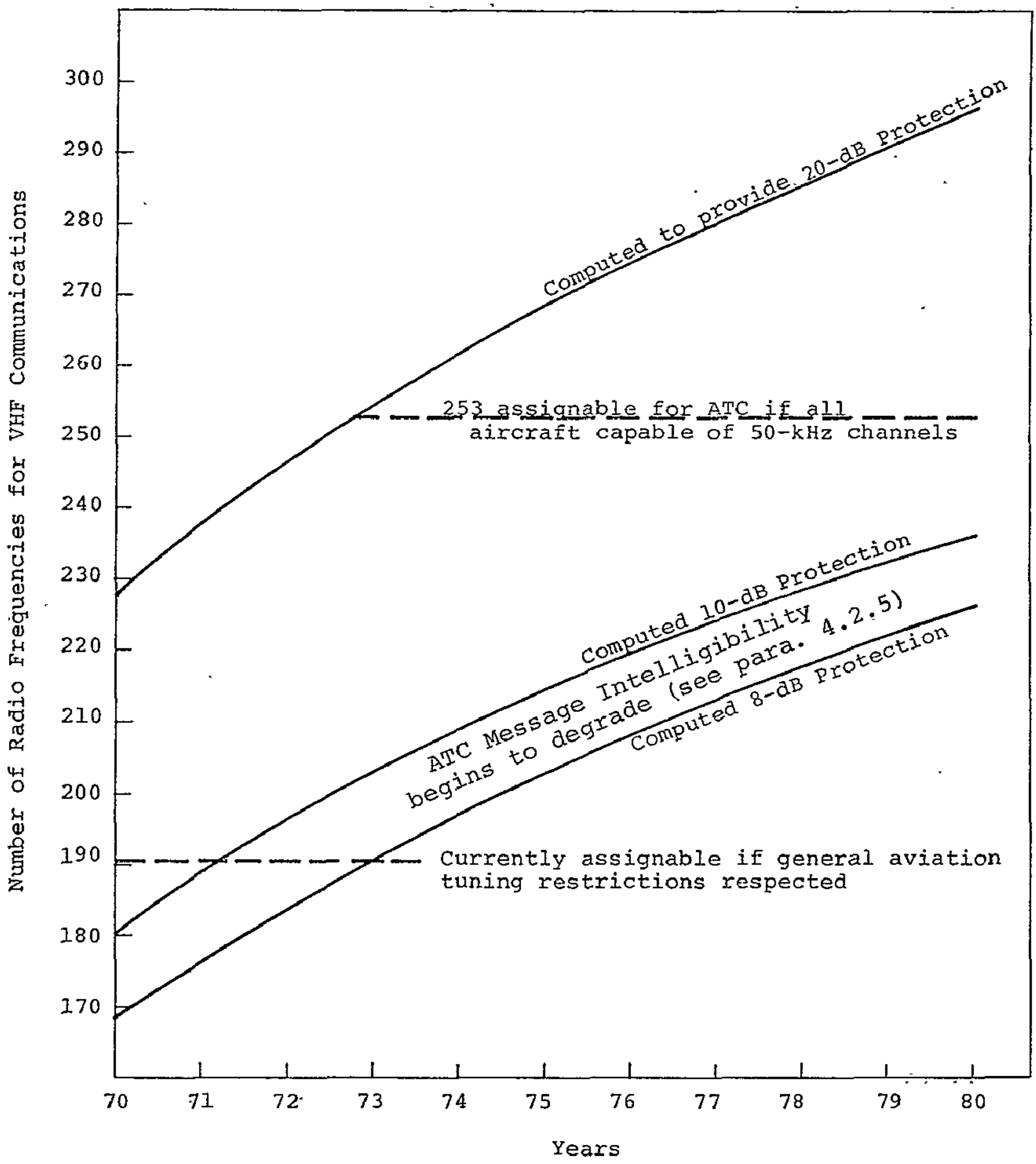


Figure 4-3. Absolute Minimum Number of Required Frequencies to Meet Predicted Increases in Communication Requirements (Data Source: Reference 8)

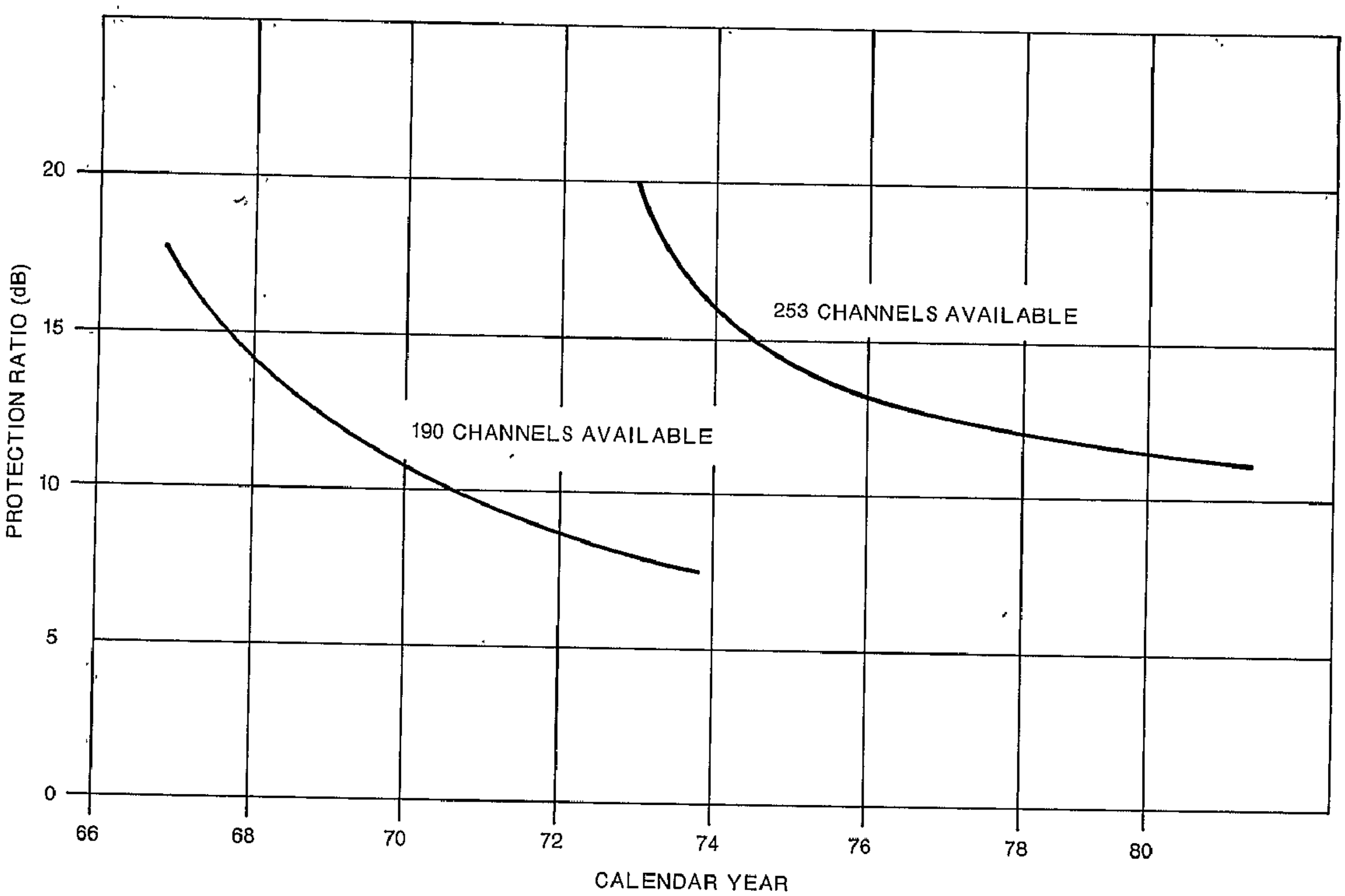


Figure 4-4. Available Ideal Protection Ratio Versus Time (Data Source: Reference 8)

253 frequencies, the protection ratio deteriorates to 14 dB by about 1975, and to an estimated 11 to 12 dB by 1980. It should be recognized that substantial growth of terminal requirements is not reflected in these conclusions.

The fallacy, however, is that several factors prevent the full utilization of all 253 frequencies possible in the assignment plan. A minor factor is that frequency interactions in collocated areas (co-site) inject restraints which may be solved only at the expense of flexibility in overall frequency assignments. The major factor, which is considered in detail in the next subsection, is that the tuning characteristics of equipment in the field govern the number of frequencies, or assignable channels, available. This is related to economics and equipment life and is a most serious restraint on available frequencies in the immediate time frame. Although the existing frequency plan provides 253 frequencies for ATC, only about 190 can be efficiently utilized if the large number of less selective receivers are to be respected in a national system. Again, based upon the engineering study ESD-TR-70-132, if today's ATC requirements are confined to 190 frequencies, then an 11-dB protection ratio is the best possible today on a national level and an even worse condition exists in localized congested areas. It appears that the near-future situation will get considerably worse unless more frequencies are made available.

4.2.4 Restraints to Full Utilization of Frequencies in the Plan

Based upon a 50-kHz channelization of the 118- to 136-MHz band, a total of 360 frequencies are assignable. However, by providing a guard band on each side of the emergency channel (121.5 MHz) the maximum number of assignable frequencies is 358. Pursuant to the existing national plan, the 358 frequencies are divided into 105 frequencies for non-ATC uses and 253 frequencies for ATC use. Utilization of all 253 frequencies to meet an engineered national system must consider the following:

a. Near-field or proximity considerations including interaction of frequency combinations.

b. User equipment characteristics which may not permit utilization of all assignable frequencies in the plan.

The near-field problem requires detailed study of each case considering the specific frequencies involved. The equipment characteristics are currently the most severe restraint upon total frequencies available. The FAA's responsibilities apply to all aircraft regardless of performance, size or equipment configuration. In seeking the system which best serves the airways user, the FAA cannot ignore limiting capabilities. This forces the system to either be responsive to limiting capabilities (rather than provide the optimum solution) or to further regulate the users to be served. At present, all general aviation aircraft are not able to utilize the 50-kHz channels.

The impact of this limitation by general aviation is demonstrated in the number of station assignments on the 100- and 50-kHz subdivisions. Table 4-4 presents an assignment count in the ATC bands as of February 1970. A figure of 50 percent in the table would indicated an equitable assignment balance on both the 100- and 50-kHz frequencies. The effect of limitations on general aviation equipment has less impact above 127 MHz, the upper tuning limit of much of the 100-kHz equipment. For example, between 132 and 136 the FAA has assigned stations to both 50- and 100-kHz channels on an equitable basis (47 percent); whereas, the 118- to 121.4-MHz band assignment ratio is only 6 percent and the 123.7- to 127-MHz band ratio is 7 percent. Likewise, the FCC assignments (excluding blanket coverage, aircraft, and operational control assignments) total 3621, of which 244 or 7 percent are made on the 50-kHz channels.

Specific data on the frequency tuning capabilities for all general aviation avionics installed does not appear to be centrally available. From a survey mailed to 145,689 members in 1969, the Aircraft Owners and Pilots Association (AOPA) has a unique and broad information base covering approximately 65 percent of the

TABLE 4-4. ATC FREQUENCY ASSIGNMENT BALANCE*

ATC FREQUENCIES	TOTAL ASSIGNMENTS		PERCENT OF ASSIGNMENTS ON 50-kHz CHANNELS
	100 kHz	50 kHz	
118.0 - 121.4	923	57	5.8
123.7 - 127.0	957	75	7.2
127.05 - 128.8	204	92	31.1
132.05 - 135.95	344	304	47.0

*Source: Reference 10

general aviation aircraft then in use. Although frequency selection capabilities were not included in the questionnaire, the data base provides some means for deriving the desired information, if the following reasoning is used.

The FAA requires any aircraft filing under instrument flight rules (IFR) to be able to tune to all 50-kHz channels. The AOPA data was examined to particularly identify configurations associated with IFR capabilities. While this may not include all aircraft with a 50-kHz channel capability, it does provide a lower bound estimate. The survey shows that 60 percent (50,021 aircraft) are equipped with dual VHF communications and dual VHF navigation avionics equipment, which is characteristic of IFR operation. It is concluded, therefore, that at least 60 percent have installed a 50-kHz channeling capability. Aircraft with single receiver installations (and therefore having no IFR capability but are not necessarily limited to 100-kHz channeling) represented 35 percent (28,857 aircraft) of the aircraft reported in the survey (Reference 11).

The FAA's respect of the tuning limitations of general aviation equipment results in the efficient use of only about 190 frequencies of the 253 that are actually available. The ATC system, therefore, absorbs the deficit of 63 frequencies in terms of a reduced protection ratio and frequency congestion. This constraint upon the national ATC system results from not over 35 to 40 percent of general aviation. However, without regulatory steps it may not improve. One major manufacturer of general aviation equipment, for example, reports (see Appendix A) that 40 percent of his sales in 1969 were for 100-kHz units (or 90-channel equipments). The individual price differences between the two versions is about $200 on a base price of about $1000.

4.2.5 Protection Ratio

If voice communications are to be effective, the voice signal must meet minimum intelligibility requirements in the face of interference and noise. ICAO, in their considerations affecting the deployment of VHF communication frequencies, assumed that a co-channel protection ratio (wanted-to-unwanted signal ratio) of 20 dB was required (approximately 90 percent modulation). It is believed that the FAA also endeavored to provide 20 dB of co-channel protection for ATC services until the VHF band became so crowded.

Today, it is generally felt that 20-dB protection is a luxury which the service cannot afford. However, derivation of a minimum acceptable protection ratio (as a standard) is virtually impossible because of the subjectivity involved. On the other hand, without some indication of the protection ratio at which communication service begins to degrade, no quantitative assessment of overall system performance can be made.

A recent study which investigated this subject is documented in Reference 48 [ESSA RL. 1968 (updated 1970)]. During this study measurements were made on conventional VHF facilities in the laboratory. Subjective performance evaluations of Modified Rhyme Tests (MRT) and ATC messages using experienced controllers were conducted, as well as objective sets of data obtained from a Speech Communication Index Meter (SCIM). The performance measurements were compared directly to derive a relationship between them, and to establish a quantitative grade of service at the receiver audio output that is a function of the ratio of the desired and interfering signals at the receiver input (protection ratio).

Figure 4-5 shows the pertinent results obtained during the referenced study. Six curves of percent intelligibility are shown: three using ATC messages typical of enroute communication traffic and three using the MRT. The three curves for each message type represent a single co-channel interferer on frequency, a single co-channel interferer off-tuned 600 Hz, and wideband Gaussian noise. The single interferer on-frequency curves are

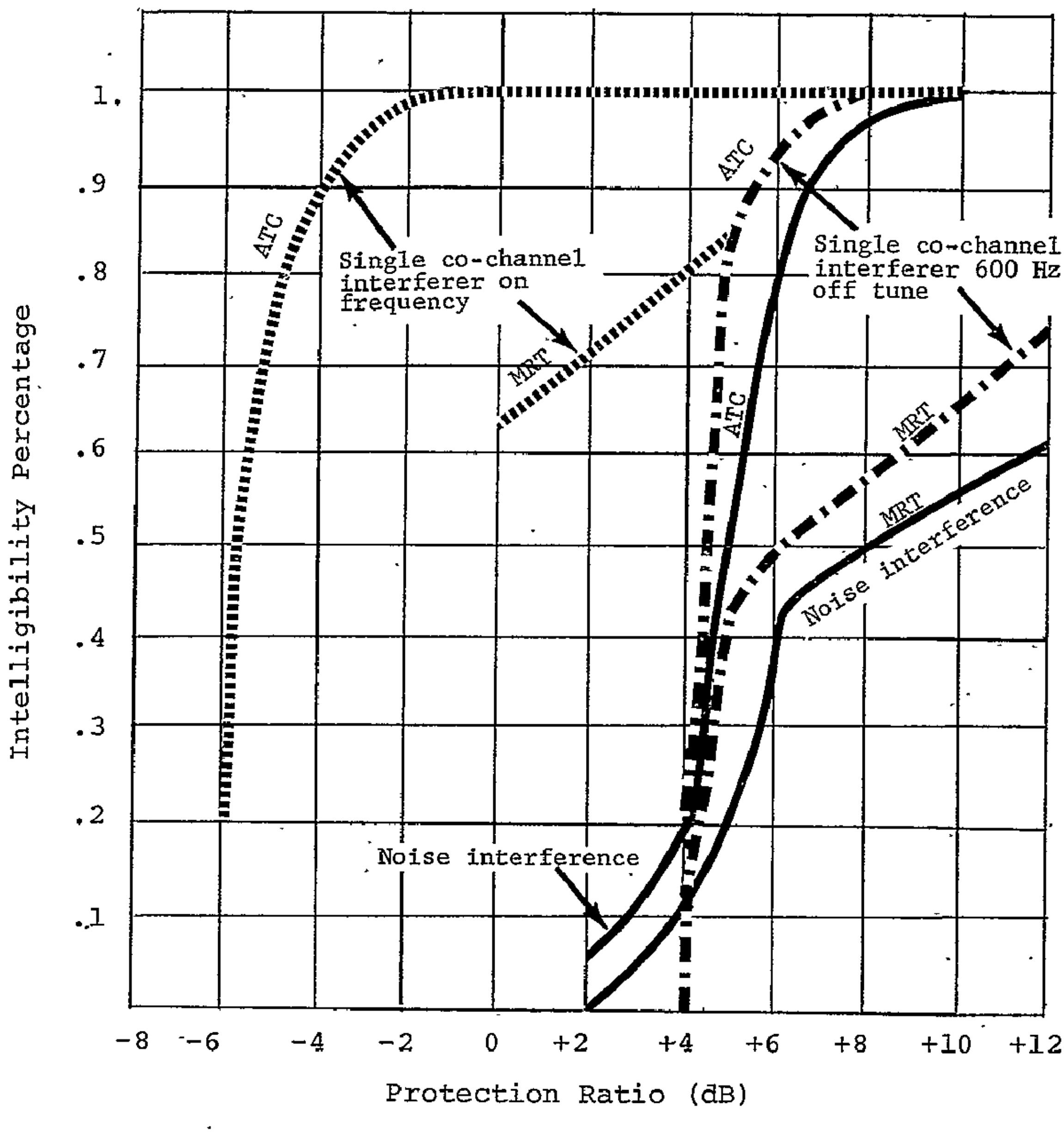


Figure 4-5. Intelligibility Percentage Versus Co-Channel Protection Ratio, (Source: Reference 48, 49)

considered to represent very specialized situations which may only rarely occur in practice. Two frequently occuring situations include multiple interferers, the effect of which approaches Gaussian interference as their number increases, and slightly detuned single interference giving rise to a heterodye effect in the audio. For a given message type, these effects are within 1 to 2 dB of each other.

On the other hand, the ATC messages curves are specialized in that they are applicable only to highly trained and experienced controllers and pilots using the specialized enroute traffic ATC volcabulary. They may not be applicable to terminal traffic where the vocabulary and talkers are different and may vary. A group of general aviation pilots who are less experienced would be expected to require a greater protection ratio for a given intelligibility than the controllers used in the evaluation. Furthermore there is evidence to suggest and it has been conjectured that in times of stress, a higher protection ratio might be required due to a lessening of redundancy in the message content. (Ref. 50). For these conditions, the performance curve would be expected to be somewhere between those for the ATC and MRT tests.

It is evident that considerable work remains to be done in this area before protection ratio standards can be developed for the various situations present in an ATC system.

It must also be concluded (with the present knowledge available) that if the protection ratio available in the ATC system is predicted to gradually drop until it reaches 8-10 dB at some point in time, then steps to reverse the trend should certainly be taken before this point is reached.

4.3 Engineered Operational Control Frequency Utilization

The requirements of the aircraft operating agencies are generally accommodated through the utilization of facilities providing network, local area, ground operational control, extended range VHF (also relaying ATC information) and, additionally, communications in support of helicopter operations. All frequency assignments to stations serving aircraft operating agencies are engineered on 50 kHz channels using essentially the same protection criteria employed by the FAA. This is particularly true of network operations.

Frequency utilization is further enhanced in the network operations by the use of off-set carrier (CLIMAX) operation. All frequency assignments are shared by the aircraft operating agencies to the maximum extent possible with the objective of insuring efficient use and conservation of frequencies. Sharing of facilities, other than networks, is accomplished by the use of criteria employing peak flight hours per hour in the interference area based on existing and/or soon to be implemented schedules of the air carriers concerned. This has proved to be an effective method for the sharing of a particular channel by several airlines in such cases where the peak flight hours per hour do not coincide.

Assignments to air carriers may vary from a minimum of 8 assignments per channel for high level enroute networks to a maximum of 93 assignments for local area and/or ground operational control. It should be noted, however, that frequency assignments for network operations wherein off-set carrier operations are employed may indicate assignments to several stations on the same channel within any given interference area. However, interference and/or heterodyne effect is precluded by such off-set carrier operations thereby insuring more effective and efficient frequency utilization. (For example, 130.3 MHz, through the use of off-set carrier operations, is now providing 4 networks extending from Dallas through St. Louis to Detroit; through Denver to Seattle; through Kansas City to Minneapolis; and to Corpus Christi. These networks are comprised of a total of 23 stations operating on this frequency.) Within the operational control band, with the exception of that area bounded by Boston, Chicago and Washington, D.C., frequencies are generally available to accommodate future requirements of the aircraft operating agencies for the next decade. It should be recognized that frequency availability within the band concerned, within this particular North East area, has been limited due to the utilization of channels by Canada, precluding use of these channels within the so called "Golden Triangle." The current paucity of available channels in this particular area is also due to the fact that the airports concerned are primarily major international "Gateway" airports serving the European area and, therefore, have a higher density of air traffic than that normally found at airports throughout the remainder of the U.S. These are also high density airports with respect to strickly domestic air traffic.

Beyond the 1985 time frame, ARINC has estimated that a total of 195 channels must be made available to meet the future requirements for operational control communications by air carriers and general aviation (Reference 51). Although, the volume of communications from 1985 to the year 2000 and beyond may well exceed all present forecasts, it is believed by ARINC that the gradual introduction of data, telemetry and automation techniques may permit any increase projected beyond 1985 to be absorbed without the need for additional spectrum space. Considering the expected reallocation to permit 25 KHz channel spacing in the aeronautical mobile (R) VHF band, roughly 128 channels will be available to aircraft operating agencies for use until the early 1980 time period.

4.4 NONENGINEERED (FUNCTIONAL) FREQUENCY UTILIZATION

This category includes functional activities related generally to certain terminal services and private fields. In general, these frequencies are not assigned on the basis of engineered air volumes but are related to functions. However, some degree of engineering to meet congested areas may be applied to provide some distribution locally as a result of serious interference. Frequencies assigned for emergency guard and transmission are not included. Further, frequencies of a broad blanket use in a region or state, or those used for temporary sites, were not included.

Functional activities are currently assigned on 41 frequency channels based upon a 50-kHz plan. These frequency channels are used for some 10 functions assigned as required (two channels adjacent to the emergency channel as guards are not included).

Flight service stations, flying schools, Unicom/Multicom, air-rescue, and tower VFR functions are accommodated on over 5000 frequency assignments between 121.5 and 123.65 MHz.

Flight Service Stations (FSS) are operated by the FAA to serve all aircraft but are primarily used by general aviation. Simplex communications are on the primary frequencies of 122.0, 122.2, 122.3, 122.6, and 123.6 MHz. The total number of ground station authorizations for these frequencies is as follows (Reference 10):

122.0 MHz	15
122.2 MHz	202
122.3 MHz	115
122.6 MHz	375
123.6 MHz	314

Seven additional frequencies on the 50-kHz channels have been designated recently for FSS to meet the growth of general aviation aircraft. The present frequencies are heavily utilized, but measurement of activity is difficult since some aircraft operate crossband. For example, the aircraft may transmit on 122.1 MHz and receive replies from a navigational station (VOR or ILS) using superimposed voice (Reference 13).

At airfields not served by FAA facilities, a functional service is provided by FCC licensed stations identified as "aeronautical advisory" (or Unicomm). This service provides, on call, such local information as safety, fuel, or local assistance of an advisory nature. In addition to blanket provision to general aviation and temporary sites, the ground authorizations are as follows (Reference 10):

122.8 MHz	1697
122.85 MHz	20
122.95 MHz	4
123.0 MHz	327
123.05 MHz	95

The frequency channel 122.9 MHz is reserved for "Multicomm" functions with some 227 ground authorizations. The function of this channel is to satisfy needs for direct controls to aircraft engaged in specific tasks requiring coordination such as crop dusting, banners, air drops, et cetera (References 3 and 10).

4.5 FREQUENCY CONGESTION INDICATORS

In addition to the discussion and calculations regarding present and future utilization of the VHF band presented earlier, it is instructive to attempt to examine another factor bearing on the subject. This factor is the possible existence of certain indicators of very high utilization and their rate of growth. Possible indicators include:

a. Increased interference reports

b. Increased engineering time

c. Chain-reaction adjustments to meet a requirement

d. Deterioration of protection criteria

e. Special technical assignment schemes

f. Increased attention to frequency management

If these indicators exist and can be roughly quantified, some independent conclusions may be drawn regarding the degree of congestion in the band.

A quantitative analysis of these indicators over a period of time was not possible because of the lack of appropriate record data. Although personnel engaged in both the managerial and technical aspects of frequency assignments at the FCC and FAA confirm the increasing difficulties, apparently appropriate records do not contain data sufficient to quantify the actual changes. Related information for each indicator was gathered, however, and is discussed in the following paragraphs. Specific examples are cited where evidence was found.

Virtually everyone contacted on the subject agreed that interference cases and reports have increased. However, the reporting system is structured so that consolidated interference reports are not transmitted to the FAA or FCC level. The various regions or offices now receive local reports, but few are forwarded. This lack of interference data stems from the attempt to handle interference at the lowest echelon, and the fact that many pilots accept interference as normal and make few formal reports. With respect to those frequencies utilized by the aircraft operating agencies for operational control communications, ARINC indicates that very few cases of interference have been reported because of the quality control system they have instituted. Those cases which have been reported have been resolved by ARINC.

Increased time is required in frequency engineering efforts to meet new requirements. This has been shown in manpower surveys and personnel levels. In addition, increased uses of computers are being applied because of the increased complexity of assignment engineering.

Numerous instances have occurred in which multiple or chain-reaction frequency changes were required to meet a new ATC requirement. This results from efforts to fit each frequency assignment in a pattern which provides the greatest overall utilization. These cases were rarely experienced in previous years, but are considered routine at present.

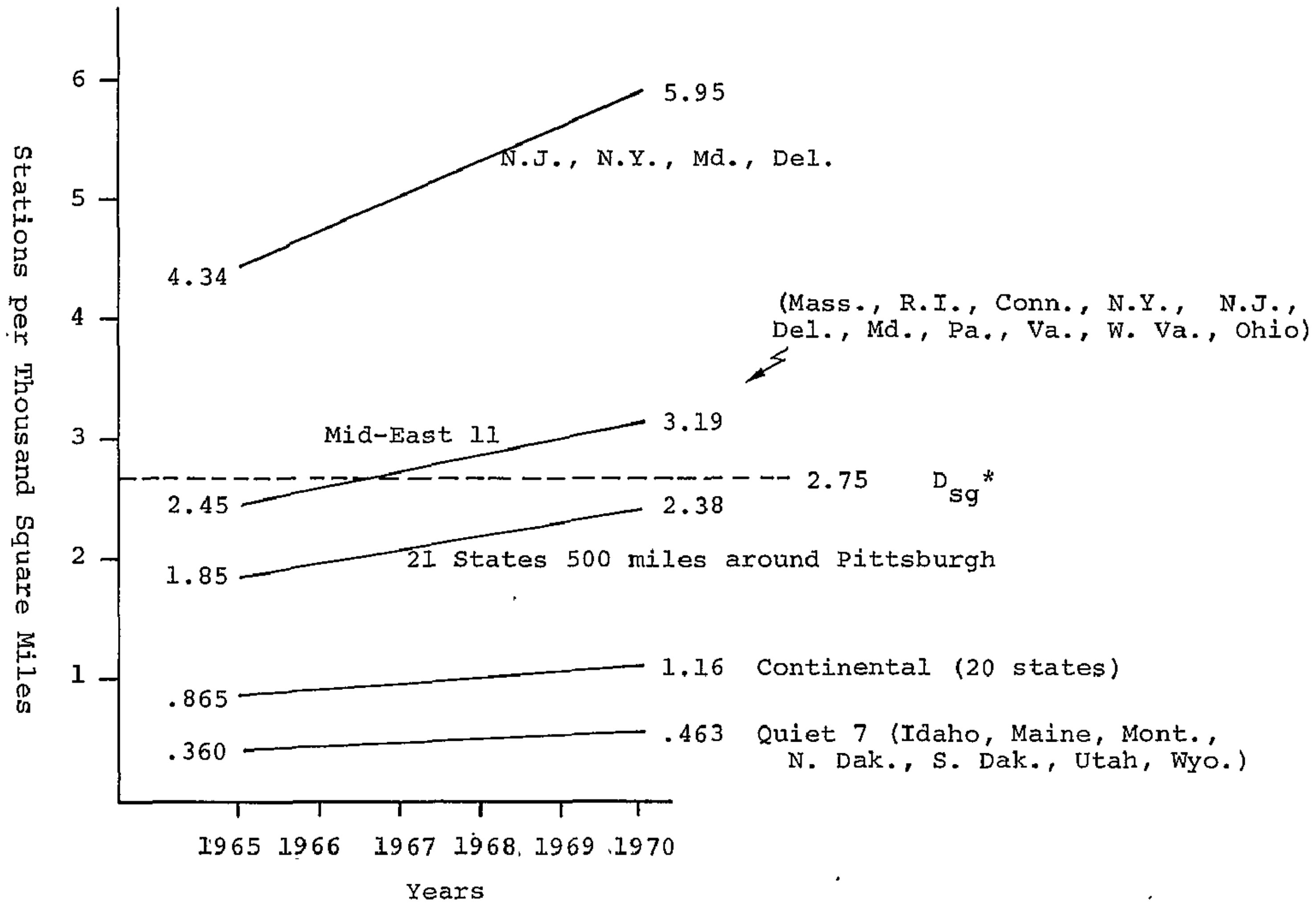
One particular example which can be cited is when a requirement for seven new channels was recently fulfilled in the New York area. To provide the seven frequencies, the best engineering plan which could be devised without causing excessive interference required the rearrangement of 17 other frequency assignments. Implementation of these changes required 4 months.

The deterioration of the protection ratio was found to be the most definable and was discussed in detail earlier in this section.

Another indicator of increasing congestion is the use of special assignment schemes. Although the basic approach to service areas involves protection for a defined service volume, it has been necessary because of surrounding assignments to make some assignments for specific approach corridors. In this case, protection is controlled only within an air corridor and any attempt to communicate outside the defined path can expect harmful interference.

Other indicators are reflected by organizational structures and increased policy level attention afforded frequency management. This has been evident at departmental levels and also in the President's Reorganization Plan concerning the Office of Telecommunications Policy. Frequency congestion throughout the spectrum has resulted in a substantial number of radio frequency compatibility programs estimated at about $7 million annually. These programs include specialized frequency studies by the Electromagnetic Compatibility Analysis Center (ECAC) at Annapolis.

The increasing frequency congestion situation is also indicated by the attention which it has received from professional groups. In the report of the Joint Technical Advisory Committee (JTAC) of the IEEE and EIA, studies included the VHF aeronautical communications band. The task group included FAA participants. The JTAC approach considered frequency assignments per thousand square miles in the U.S. by geographical regions. Figure 4-6 has been prepared from data extracted from the JTAC report, but rearranged in a format to show density changes. The level marked "Dsg" is the study group's judgment of a density level representing saturation, i.e., 2.75 stations per thousand square miles (Reference 15).



*D_{sg} - A quasi-arbitrary "saturation" level selected by the JTAC Subgroup

Figure 4-6. Station Density Trend for VHF Aeronautical Communications (Data Source: Reference 15)

4.6 FUTURE PLANNING FOR THE VHF BAND

Aeronautical Radio, Inc. (ARINC) recently petitioned the FCC to permit implementation of a 25 kHz channeling plan in the band 128.85 to 132.0 MHz. This Petition was predicated upon discussions in ICAO Regional Meetings (LIM/EUM 68/69) wherein it was generally considered that the implementation of 25 kHz channeling in the band 117.975-136 MHz would come about in the 1975-1978 time frame (the ICAO 7th Air Navigation Conference scheduled for the 2nd Quarter 1972 has included on its Agenda consideration of the need for the future introduction of narrow channel separation in the VHF Band 117.975-136 MHz). This petition was also designed to allow for the orderly implementation of data link and a VHF Aeronautical Satellite System. It is the opinion of ARINC that the evolution of data link will replace many functional requirements now fulfilled by voice communications, thereby insuring the availability of the band 128.85-132.0 MHz well into the future. This is addressed in FCC Docket 18931. At the present time, the FCC is preparing to release a Notice of Proposed Rule Making which will allow the "permissive" use of 25 kHz channel spacing throughout the band 117.075-136.0 MHz.

If all 253 ATC channels could be efficiently utilized, the predicted deterioration of protection ratios to accommodate Air Traffic Control needs does not become critical until around 1980 (assuming 10 dB minimum protection ratio). However, this situation is affected by the operational equipment currently included in the ATC bands, particularly the equipment used by general aviation. A sizable fraction of these equipments are channelized in 100 kHz increments which results in the efficient utilization of only 190 channels. This is predicted to cause concern regarding the maintenance of suitable (but degraded from today's) protection ratios as early as 1972-73.

Should all general aviation conform to 50 kHz channeling, the approximately 60 more ATC channels would, it is believed, provide for ATC services until about 1975 without reduction of protection ratios below that existing in 1969. If it is desired to maintain 1969 protection ratios beyond the mid-Seventies, steps must be taken to implement 25 kHz channel spacing before then.

There is no formal criterion of system performance applied to air/ground communications by FAA. FAA has attempted to honor the ICAO protection ratio of +20 dB desired/undesired in lieu of such a criterion, but the penalty imposed by utilizing this standard for the "worst case" aircraft configuration could not be tolerated. FAA has elected, therefore, to relax this standard to permit additional requirements to be introduced and has filed a difference covering this. The latitude to relax D/U ratios has been exhausted in the northeastern United States although the FAA continues to study frequency redeployment approaches to assure the most efficient frequency utilization under various assumed protection criteria and 253 VHF channels. In fact, an internal FAA study conducted after initial drafting of this report reexamined projected requirements through FY-1972. Based upon 14 dB protection, the most recent review indicated 253 VHF channels fell short of satisfying all air traffic control requirements by 243 assignments.

Recognizing this, on September 29, 1970, the FAA released an Advisory Circular, subject: "ATC Frequency Assignment Plan for VFR and IFR Communications." While pointing toward a full 360 channel communications capability (50 kHz channel spacing) this Advisory Circular also recognizes that the use of 720 channels (i.e., 25 kHz channel spacing) will be required at some future date. Accordingly, this Circular states that the purchase of such a capability would ensure full service for a greatly extended period.

The economics of converting all general aviation radio communications to 50 kHz channeling merit consideration. Assuming that a communications transceiver capable of 50 kHz channeling can be produced for $750, and that 50,000 general aviation aircraft do not now have this capability, the cost magnitude is $37,500,000 (50,000 x $750). The aircraft estimated not to possess any radio communications are included in the above total. If it is assumed that they would not be outfitted, the cost magnitude is $30,750,000 (41,000 x $750). This figure may be slightly lowered by a small percentage of aircraft with equipment designed for easy modification ($200) from 100 to 50 kHz capability. Assuming that a 25 kHz channeling transceiver could be produced in quantity for $1200, and that one receiver in each of 113,000 general aviation aircraft is replaced (assumes 7 percent without radio communications today would not convert), the cost magnitude would be $135,600,000 (113,000 x $1200). It should be noted, however, that engineering, producing, and installing a $1200 transceiver responsive to 25 kHz channeling for general aviation would require about five years.

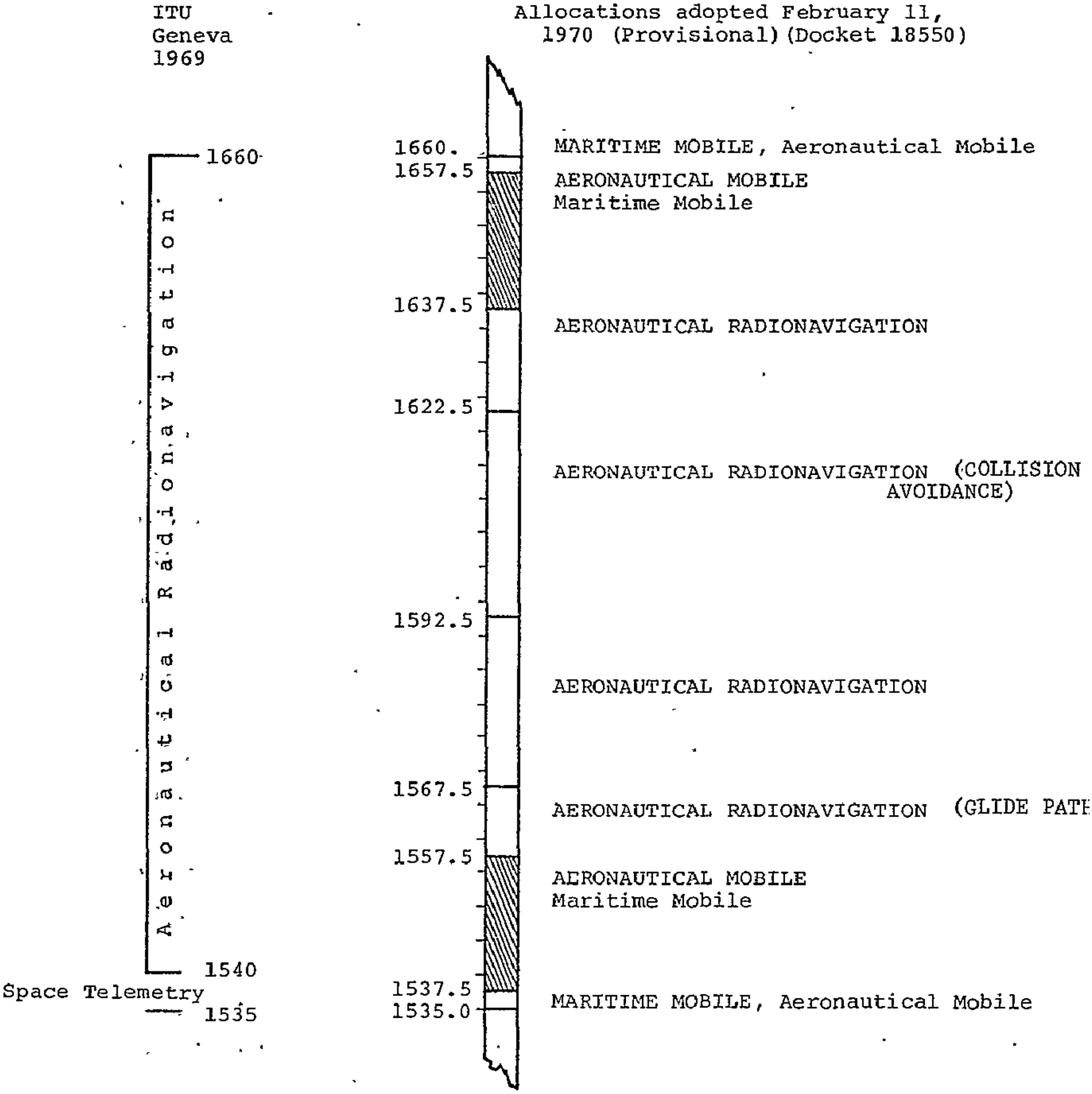
SECTION 5

AERONAUTICAL "L" BAND

5.1 BACKGROUND

The short title "L Band" stems from a World War II reference to the 1215- to 1700-MHz band. It therefore applies to the 1535- to 1660-MHz aeronautical band under consideration. This band was intended for use by an integrated system of electronic aids to air navigation and traffic control by the Atlantic City Radio Conference in 1947. It was utilized for radar altimeters with little change in allocation status until 1959. In the course of allocation hearings in the bands above 890 MHz (FCC Docket 11866, 1956-1959), the frequency requirements for future collision avoidance systems were first proposed for inclusion in this band. The Geneva (1959) Radio Conference continued the allocation of 1540 to 1660 MHz for aeronautical radionavigation. On September 15, 1967, ATA/ARINC petitioned the FCC for changes in the applicable frequency rules to provide for collision avoidance systems and space techniques. Following FCC-government discussions, and FCC-industry hearings, the FCC issued a Report and Order on February 13, 1970 (Appendix C) adopting the provisional allocations shown in Figure 5-1. The suballocations are within the framework of the present international allocations except for provisions for maritime mobile service and wording permitting communications in this band.

Coordination with industry and operators is in progress through a series of hearings by the FCC (Notice of Inquiry, Docket 18294) and between OTP-FCC. The principle of maintaining maximum flexibility of national frequency action suggests that proposed international allocations in this band should be defined in broad service terms. The introduction of maritime mobile under a shared arrangement in a frequency band "ear-marked" for aeronautical use requires clarification of what is being shared



Note: Secondary service in lower case letters

Figure 5-1. Frequency Allocations in "L" Band

and the impact upon each user. Since the sharing arrangement is on a primary and secondary basis between aeronautical and maritime, the controlling service appears clear. However, this viewpoint is not unanimous. A frequency arrangement which reduces the shared aspects between aeronautical and maritime is presented in the FCC Seventh Notice of Inquiry in a document entitled "Draft Proposals of the United States of America for the World Administrative Radio Conference for Space Telecommunications-Geneva 1971." The pertinent part of this proposal is presented in Figure 5-2. This provides for 2.5 MHz for exclusive maritime, the next 5 MHz shared, and the next 15 MHz exclusive aeronautical.

5.2 CURRENT SITUATION

Existing utilization of the "L" band by aviation is for altimeters using pulsed emissions. Equipment used is "type approved," and authorization for the aircraft operator is granted for the band upon application and conformance with eligibility requirements. The predominant user of the band for radio altimeters is the military with some use by general aviation. A higher frequency band, 4200 to 4400 MHz, also is allocated for altimeters, and considerable altimeter operations are in the higher band.

Altimeter equipment in the "L" band is designated upper and lower band limits rather than a specific frequency assignment. Manufacturing and operating adjustment practices place all emissions within the 1600- to 1660-MHz band with the transmitter centered at about 1630 MHz. The total equipment inventory is estimated at 2000 units for non-military use. Military aircraft uses total about 5000 units.

National frequency planning for altimeters is to place all operations in the 4200- to 4400-MHz band. This objective is reflected in the Report and Order of the FCC (Docket 18550) mentioned previously. In consonance with this objective, the

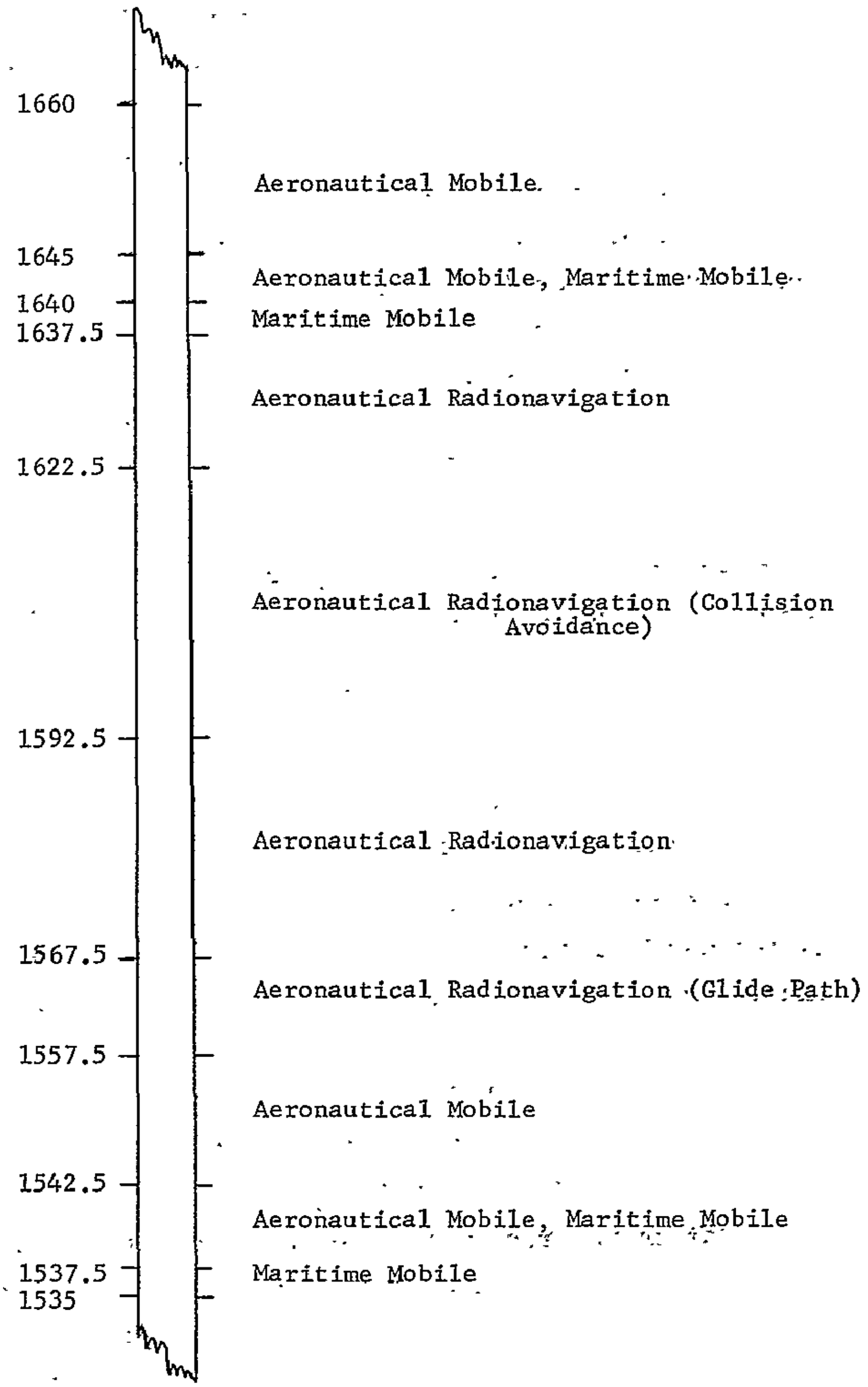


Figure 5-2. U.S. Proposed Frequency Allocations in "L" Band

military is no longer developing or procuring altimeters in "L" band. Some military procurement exists, but this is primarily for replacement purposes. Effective in April 1970, the FCC ceased issuance of type approvals for any new altimeter equipment in this band. In accordance with frequency planning, all future altimeter operations are to be in the 4200-4400 MHz region which is reserved exclusively for radio altimeters. The FCC Report and Order, Docket 18550, also gave notice that no new authorizations would be granted as of 1 January 1971. In response to a petition for reconsideration by one manufacturer, this date was extended to July 1971. Therefore, equipment may be continued to be manufactured and sold until that time. This is reported to represent 80 units per month. However, the Commission did not establish a termination date for the use of these altimeters, recognizing that any such date would have to be the subject of international agreement.

5.3 POTENTIAL FREQUENCY IMPACTS

The sub-bands provisionally designated for aeronautical mobile communications on a primary basis are 1537.5 to 1557.5 MHz and 1637.5 to 1657.5 MHz. These frequency bands are the shaded portions in Figure 5-1. The provisional allocation intended for downlink aeronautical mobile use extends downward 2.5 MHz into the currently international allocated space telemetry. Although worldwide allocation is reflected in the Table of Frequency Allocations for space or aeronautical operations, the band 1535 to 1660 MHz is subject to a footnote reservation (352) by the Soviet Bloc which also allocated the band to the fixed service (Reference 1). In Australia, Indonesia, and the Federal Republic of Germany, the band 1540 to 1660 MHz is also allocated to the fixed service. A check of international frequency registration records shows no operations are listed in the provisional aeronautical mobile bands.

However, above 100 MHz only those assignments requiring International protection are notified to the International Frequency Registration Board. Therefore, it must not be assumed that this band is void of fixed and mobile services. It should be noted, that one State, in preparation for the 1971 WARC-ST, has reiterated to the ICAO the difficulties which may be experienced within that State due to the fact that International Telecommunication Union Radio Regulations permit the utilization of the band 1540-1660 MHz for fixed services and that present users have already invested considerable funds for development and installation. A similar situation may exist in other States also having allocations in this band for fixed services under the provisions of Radio Regulations 352 and 352D.

The question of Radio Frequency Interference (RFI) among the several subdivisions sharing the band continues to be examined, and RFI control programs may be expected as specific designs are developed. The potential interference from the continued operation of radio altimeters centered at about 1630 MHz with collision avoidance systems (1592.5 to 1622.5 MHz) has received particular attention. These studies include efforts of ECAC, McDonnell Douglas, and Martin Marietta. The most probable interference condition concerns the altimeter burst and its "spikes" with the proposed collision avoidance systems. Since implementation is planned by about 1972, the frequency compatibility aspects are of timely concern. The potential frequency impact upon aeronautical mobile from altimeters similarly will require study as systems design progresses. However, the aeronautical mobile band nearest in frequency to the altimeter is the uplink, and its impact at satellite distances is not considered significant. The downlink is at least 72.5 MHz removed from the altimeter center frequency. The glide path is immediately above the frequencies for the proposed aeronautical mobile downlink and may require further examination. Frequencies immediately below the downlink frequencies are used for aircraft telemetry in many parts of the U.S. "Quiet Zones" near earth stations may be required to avoid interference from telemetry operations. The mechanism for such coordination exist at present in the Aeronautical Flight Test and Range Coordinating Committee (AFTRCC). However, technical solutions, i.e., power restrictions or operational constraints, are considered necessary for the frequency compatibility aspects.

Definitization of frequency compatibility of projected radio operations aboard the aircraft in this band relating to the aeronautical mobile service should be planned. System design of the satellite approach should consider the electromagnetic environment and include appropriate measures to control radio frequency interference.

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SECTION 6
FREQUENCY SHARING CONSIDERATIONS

6.1 INTRODUCTION

The concept of frequency sharing used in this report refers to the capability to employ the same spectral allocation for more than one system. The sharing problem addressed concerns only the band 118 to 136 MHz which now provides a worldwide aeronautical mobile communications service. The question involves the provision of frequencies for a new satellite system in this band to serve oceanic areas while continuing the existing system. According to ITU Regulations, the proposed satellite system may be established in the same band subject to coordination between the administrations concerned. The administrations therefore are obligated to view the new system in terms of its potential interference upon the existing communications system, particularly since the existing system may be required for an indefinite period into the future. In fact, the transition may extend over a period of time, and in some areas may never occur.

Favorable concurrence is therefore related to a showing that sharing of the frequency band between the present system and the future satellite system is compatible, and attainable within acceptable arrangements which pose minimum impacts upon the existing system. Of course, if the satellite system could not concurrently provide the performance desired, both from a service quality or quantity standpoint, sharing would not be forthcoming. This section treats both the sharing and adequacy of performance aspects of the situation. In view of the existing density of assignment in the band concerned and the difficulty of major reassignment to create exclusive satellite frequency space, any application of satellite techniques should first consider the possibility of interleaved frequencies between the two systems. (Ref. ARINC Plan (566), Reference 21)

The technical considerations of frequency sharing are primarily considered from the point of view that the wanted signal must exceed the potentially interfering signal by more than some known factor. When expressed in decibels, this factor is generally known as the protection ratio. In general, it depends upon the wanted and unwanted modulation types incident at the point of entry for the receiver under consideration and the statistical variability of those signals. Protection ratios are a function of receiver design and their technical characteristics in the environment, and the human factors which define intelligibility at the system output.

Unfortunately, the measurements for all desired parameters are not available at present. This is true of technical characteristics of all receivers currently employed, and also in subjective tests of user characteristics which can relate unsatisfactory intelligibility with measured technical criteria in a realistic environment. Accordingly, we have assumed parameters which will serve to demonstrate a method of analysis which, it is believed, will highlight the potential interference situations.

6.2 SATELLITE SYSTEM PERFORMANCE AND FLUX DENSITY

Implicit in a discussion of the frequency sharing problem in the band 118 to 136 MHz is the supposition that an acceptable space system can be designed and implemented within the constraints imposed by the sharing principles. This section briefly discusses the impact on the satellite of the flux densities appropriate to sharing.

In order to provide a usable voice communications channel in the aeronautical mobile satellite service employing a narrow band (about 11 kHz wide) FM system of the type frequently proposed, it will be assumed that a carrier-to-noise power density ratio of about 46 dB-Hz is required. A typical power budget for a VHF (125 MHz) link from a geostationary satellite which results in a -130 dBW/m^2 flux density (free space value at the subsatellite point) is shown in Table 6-1. The power in excess of that necessary to provide the desired performance under free space conditions is termed "power available for propagation anomalies."

Table 6-2 shows that approximately 360 watts of dc power must be provided on the satellite for each voice channel at $-130\ dBW/m^2$ flux density. It should be noted that the $-130\ dBW/m^2$ is chosen at this point for reference purposes only. Later analyses will consider this parameter over the range from -140 to $-130\ dBW/m^2$ and its impact on the sharing problem.

6.3 INTERFERENCE ANALYSIS

A VHF aeronautical synchronous satellite system has been proposed in the band with 118 to 136 MHz frequency assignments 50 kHz apart, interstitially related to those of the existing terrestrial system. The satellite system has been designed to provide oceanic coverage. Over land areas, aircraft will continue to use the existing terrestrial system. As an aircraft departs on or returns from an oceanic flight, it would switch, at the appropriate point in its flight, between the satellite (oceanic) system and the terrestrial (domestic) system. The ARINC 566 (Reference 21) receiver is an example of avionics equipment which provides this capability. The role which the extended range VHF stations will play is not clear. If they are maintained in operation, they could serve to create a "buffer" zone and possibly some interference situations, discussed later, could be avoided.

Appendix III of ARINC Characteristic 566 notes that "certain geographical constraints must be applied to avoid harmful interference to conventional operations from aircraft operating in the SATCOM mode." It is the purpose of this subsection to investigate a method whereby these potential geographical constraints which may have operational implications can be examined.

The steps to be followed are to define the potential interference situations, system parameter assumptions, protection ratio,

TABLE 6-1. ASSUMED VHF POWER BUDGET PER VOICE CHANNEL*

EIRP (peak)	32.0
Antenna off-axis loss	-1.0 dB
Free Space loss (@ 125 MHz)	-166.0 dB
Aircraft antenna gain	0 dB
Polarization loss	-1.0 dB
Received Carrier Power	-136.0 dBW
System Noise Power Density (1300°K)	-197.5 dBW/Hz
Carrier to Noise Power Density Ratio	61.5 dB-Hz
Required C/N_o (assumed)	46.0 dB-Hz
Power available for propagation anomalies	15.5 dB

*Providing -130 dBW/m^2 flux density

TABLE 6-2. SATELLITE POWER ALLOCATION PER VOICE CHANNEL*

EIRP (peak)	32.0 dBW
Transmitter to antenna loss	-1.5 dB
Antenna gain (peak)	+11.0 dB
Transmitter RF power	22.5 dBW (180)
dc power required (@ 50 percent efficiency)	360 watts

*Providing -130 dBW/m^2 flux density

propagation model and interference calculations. We conclude with a summary of the analysis and a particular method of displaying the results.

6.3.1 Potential Interference Situations

The interference situations which are examined in this report are shown in Figures 6-1 and 6-2. Cases I and II consider cross interference between two aircraft, one in the terrestrial system and one in the satellite system. Case III depicts cross interference between the satellite and terrestrial transmitters into an aircraft in the other system. Cases IV and V consider interference into the terrestrial receiver from the satellite and an aircraft in the satellite system, respectively. Case VI includes all interference from the terrestrial system (both aircraft and terrestrial transmitters) into the satellite receiver. This latter case is addressed in Paragraph 6.6.

All cases (except Case VI) consider only a single source of interference. It is recognized that sometimes multiple interferers may be present in which case the analysis must be modified. This will be particularly true on the North Atlantic tracks in the future, if separation standards are reduced. Cases I and II, aircraft-to-aircraft interference, are particularly affected.

In the analysis of Cases I and II, it will be assumed that the two aircraft and the terrestrial transmitter are located along a straight line. This is a practical assumption, particularly in the North Atlantic where a rigid track system is used, and in any case represents a worst case situation. Case V can be viewed as a best Case I (with the aircraft replaced by a terrestrial receiver) and is independent of the angular disposition of the two aircraft. All other cases considered (except Cases I and II) are also independent of their angular disposition.

Interference into and from the earth stations of the satellite service was not considered in this analysis. It is assumed that,

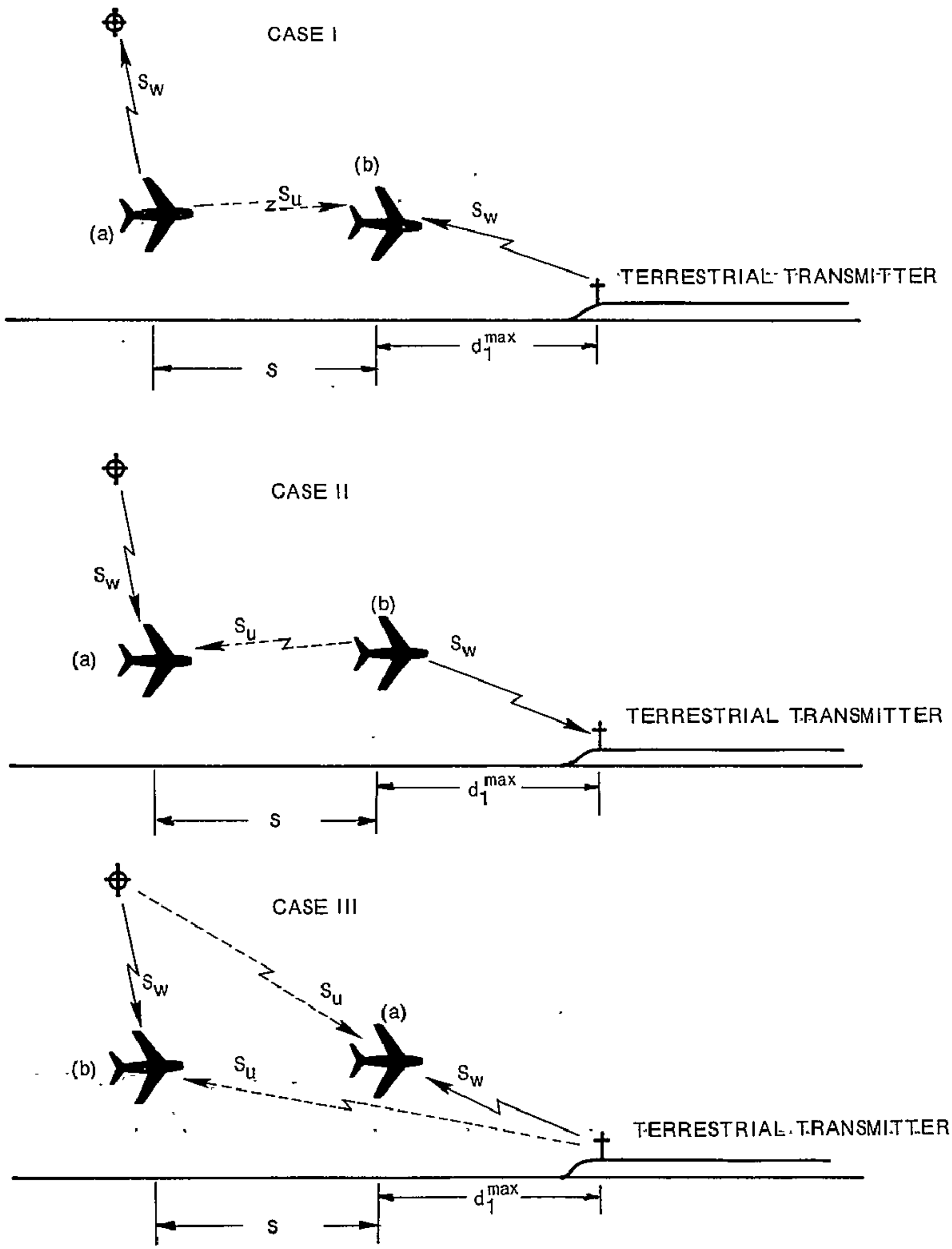


Figure 6-1. Interference Situations - Cases I, II and III

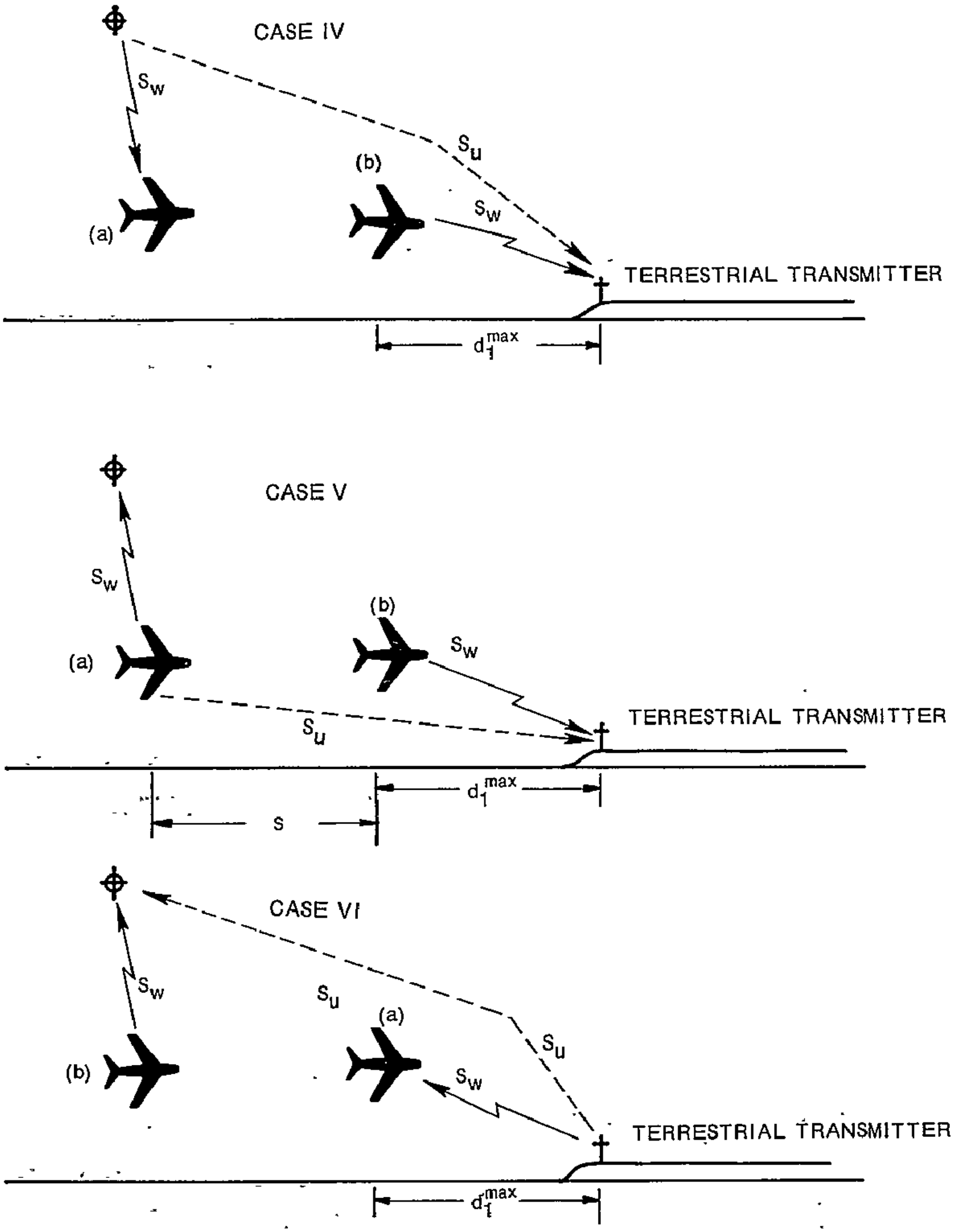


Figure 6-2. Interference Situations - Cases IV, V and VI

since there would be few of them required, they can be appropriately sited and/or designed so as not to operationally limit either the satellite or terrestrial systems. Possibilities for operational systems include use of other than VHF for these links, remote siting, good sidelobe control, antenna shielding, and use of large antennas and low transmitter power.

6.3.2 System Parameter Assumptions

In order to perform an interference analysis, certain parameters must be chosen. The assumed parameters are shown in Table 6-3.

TABLE 6-3. SYSTEM PARAMETERS
(All Antennas are Assumed Isotropic)

System Parameter	AM Terrestrial System		FM Satellite System	
	Terminal	Aircraft	Satellite	Aircraft
EIRP	14 dBW	14 dBW	**	24 dBW
Required Protection Ratio	(FM on AM) -10 dB and + 5 dB *		(AM on FM) -30 dB*	
Altitude	50 ft	40,000 ft.	Geostationary orbit	40,000 ft.

* See Paragraph 6.3.3.

** Related to the power flux density by EIRP (dBW) = -162 + (power flux density in dBW/m^2).

Flux densities between limits of -130 dBW/m^2 and -140 dBW/m^2 will be considered. The altitudes chosed are maximum for the operational conditions being considered.

The aircraft EIRP's are based on the use of the ARINC 566 VHF communications transceiver system. It is assumed that the 500 watt power amplifier is used in the FM mode, but not in the AM mode. Approximately 3 dB is assumed for dissipation and mismatch losses in each node. Although circular polarization is a likely candidate for the satellite system, interference propagation paths off the main beam axis are more likely to exhibit linear polarization. Consequently, for the purpose of this study, all signals are assumed to be vertically polarized. Aircraft antenna gain is assumed to be 0 dB for all signals. A more detailed analysis would use actual antenna patterns with possibly some variation in gain depending on signal angle of arrival. The basic method used, however, remains the same.

Appendix A shows that approximately 70 percent of terrestrial system VHF transmitters are 50 watts and 23 percent are 10 watts. The remaining seven percent are scattered between 10 and 30 watts (excluding the extended range stations at 1 kilowatt). Therefore, allowing 3 dB for losses, an EIRP of 14 dBW (identical to the aircraft value) is used. However, it should be noted that some ground transmitters in the operational control bands employ a higher power. For example, one approach places the up-link channels for a VHF satellite system in the subband 131-132 MHz used for operational control. In this particular subband some ground facilities employ 200 watt transmitters for high level aircraft communications.

6.3.3 Protection Ratio

The required protection ratio has a profound effect on the results of any interference analysis. It is, therefore, necessary to attempt to define this parameter for all combinations of transmissions and receiver types in both systems. The complexity of the present situation is demonstrated in Table 6-4, where each of the interference cases is discussed in terms of the interference situation (FM on AM or AM on FM), receiver type possibility, receiver mode, the interfering frequency band (as proposed by ARINC), the type of communications in which the terrestrial system element is involved and the interfering source possibilities. A somewhat similar, but greatly simplified, situation was encountered in Section 4.2.5 for the terrestrial system. There, however,

TABLE 6-4. INTERFERENCE SITUATIONS

Case	Interference Situation	Interference Band	Receiver Type	Receiver Mode/B.W.	Interference Source
I	FM on AM	131-132	ARINC 546 or 566	AM/36 kHz	Aircraft-566 transceiver
II	AM on FM	125-126	ARINC 566	FM/20 kHz	Aircraft - general aviation or 546 or 566 transceiver
III (a)	FM on AM	125-126	ARINC 546 or 566 or General Aviation	AM/36 kHz	Satellite
(b)	AM on FM	125-126	ARINC 566	FM/20 kHz	ATC station
IV	FM on AM	125-126	RV-9	AM/36 kHz	Satellite
V	FM on AM	131-132	*	AM/36 kHz	Aircraft-566 Transceiver

Notes:

Assumes ARINC frequency plan Uplink 131-132 MHz, Downlink 125-126 MHz
* assumed equivalent to the 546 receiver

co-channel interference in an all-AM system was at issue, a much easier (albeit still complex) situation since receiver parameters such as selectivity, frequency stability, and cross-modulation performance are not as important as in the adjacent channel environment of the interstitial plan. The latest and most comprehensive treatment of cross interference in FM and AM voice systems (Reference 52) does not provide all the data necessary for a complete interference analysis of the kind needed. Indeed, the investigation reported in this document was not intended to do so. Attempts to modify the data to account for the estimated performance of the various receivers which are appropriate to the analysis and allow for possible frequency instabilities in both transmitters and receivers were totally unsatisfying.

CCIR Report 1101 (Reference 53) provides one assessment of the protection ratio needed for FM on AM with an RV-9 receiver (36 kHz bandwidth) and only an 18 kHz interference to desired signal spacing (rather than 25 kHz) to allow for frequency instabilities in both transmitter and receiver. The +6 dB protection ratio obtained attests to the fact that the RV-9 did not provide appreciable rejection of the AM interference signal.

In order to complete the presentation of the analysis method, however, specific protection ratios must be assumed. They are shown in Table 6-5.

Two FM on AM ratios are assumed to account for different types of AM receivers in the system and to show the sensitivity of the results obtained to this parameter.

Measurements should be made using the ARINC 546 and 566 receivers as well as "typical" general aviation and ATC ground station receivers under all conditions of relative frequency stability likely to be encountered. Until this is done, a realistic assessment of the interference potential cannot be made.

TABLE 6-5. PROTECTION RATIOS ASSUMED IN ANALYSIS

CASE	PROTECTION RATIO
I	-10 and +5 dB
II	-30 dB
III(a)	-10 and +5 dB
III(b)	-30 dB
IV	-10 and +5 dB
V	-10 and +5 dB

6.3.4 Propagation Model

6.3.4.1 General

For terrestrial propagation paths (air-to-air or air-to-ground) the analysis in this report is based upon an assumed two-path line-of-sight model, i.e., a direct path and a sea-reflected path. The two-path model was chosen because the interference analysis in this situation is more concerned with sharing at ranges nearer the radio horizon rather than response below the horizontal plane. At the ranges of analysis, the two-path model is more representative than a propagation model considering only free space transmission. A discussion of the validity of the two-path model is contained in the next subsection. In any case, the assumption should be verified by additional multipath experimentation with candidate antennas for an operational VHF satellite system.

In the two-path model, the resultant signal at the receiver is the vector sum of the signals propagated along both paths with proper account taken of the relative phase due to the difference in path lengths and the phase shift introduced by sea reflection. Along each path, attenuation is introduced due to geometric expansion of the spherical wavefront. The sea-reflected ray is additionally attenuated by the nonunity reflection coefficient (calculated in the model from Fresnel's formula) and spherical divergence of the wavefront due to the nonplanar reflecting surface. Because propagation loss within the band 118 to 136 MHz is not strongly frequency dependent, the frequency of 125 MHz was selected for computations. Propagation is assumed to be above sea water for all cases. Vertical polarization is also assumed.

Propagation results for the parameters used in the analysis are presented in Figures 6-3 and 6-4. Before employing these figures, a few comments regarding them may be made. First, the four lines plotted on each graph represent the expected value of path loss (the oscillating line), the free space loss experienced by the direct path (the middle monotonic line), and the loci of the minima and maxima of the expected path loss. These loci are especially important because, if the height of either terminal changed by only a few wavelengths (meters in the band 118 to 136 MHz), the maxima and minima of the oscillating line would shift in position, but would essentially still be located along the loci shown. Second, it is evident by inspection that many minima and maxima do not touch the curve of their loci. This is due to the finite step size between successive calculations and the method of computer plotting where by successive calculations are simply connected together by a straight line. Smaller increments would improve the graphical quality, but would also result in excessive computer time. Finally, one can observe (especially for Figure 6-4) that the oscillations rapidly increase in frequency as the distance first decreases from its line-of-sight maximum. Further decrease in distance, however, eventually results in a decrease of the frequency of oscillations. This will not be observed in practice, for an actual propagation path the oscillations will continue to increase in frequency with decreasing distance. The apparent paradox is easily resolved by means of the sampling theorem - successive increments selected for calculations by the

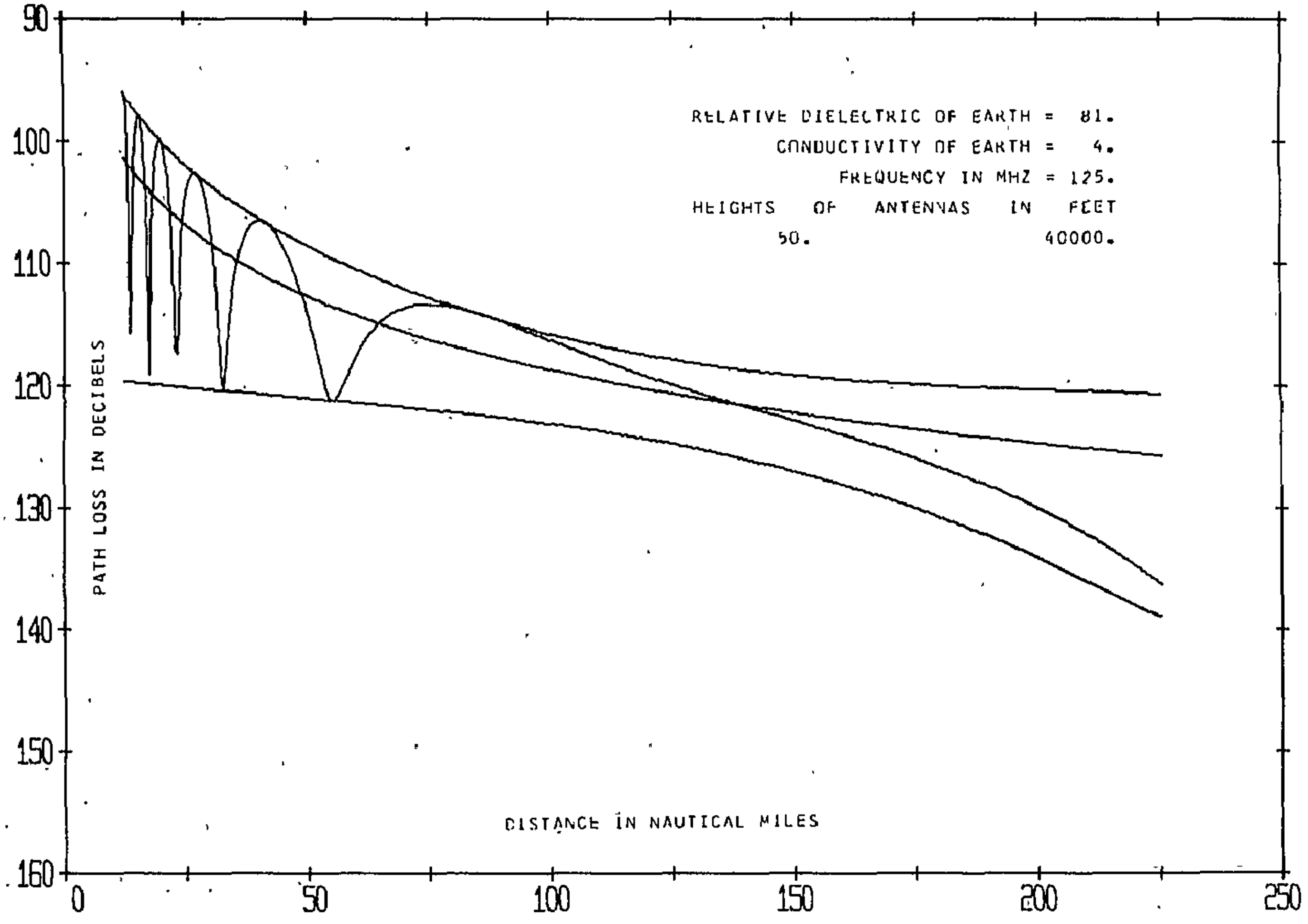


Figure 6-3. Loss versus Distance for a Two-Path Propagation Model
(Antenna Heights: 50 Feet and 40,000 Feet)

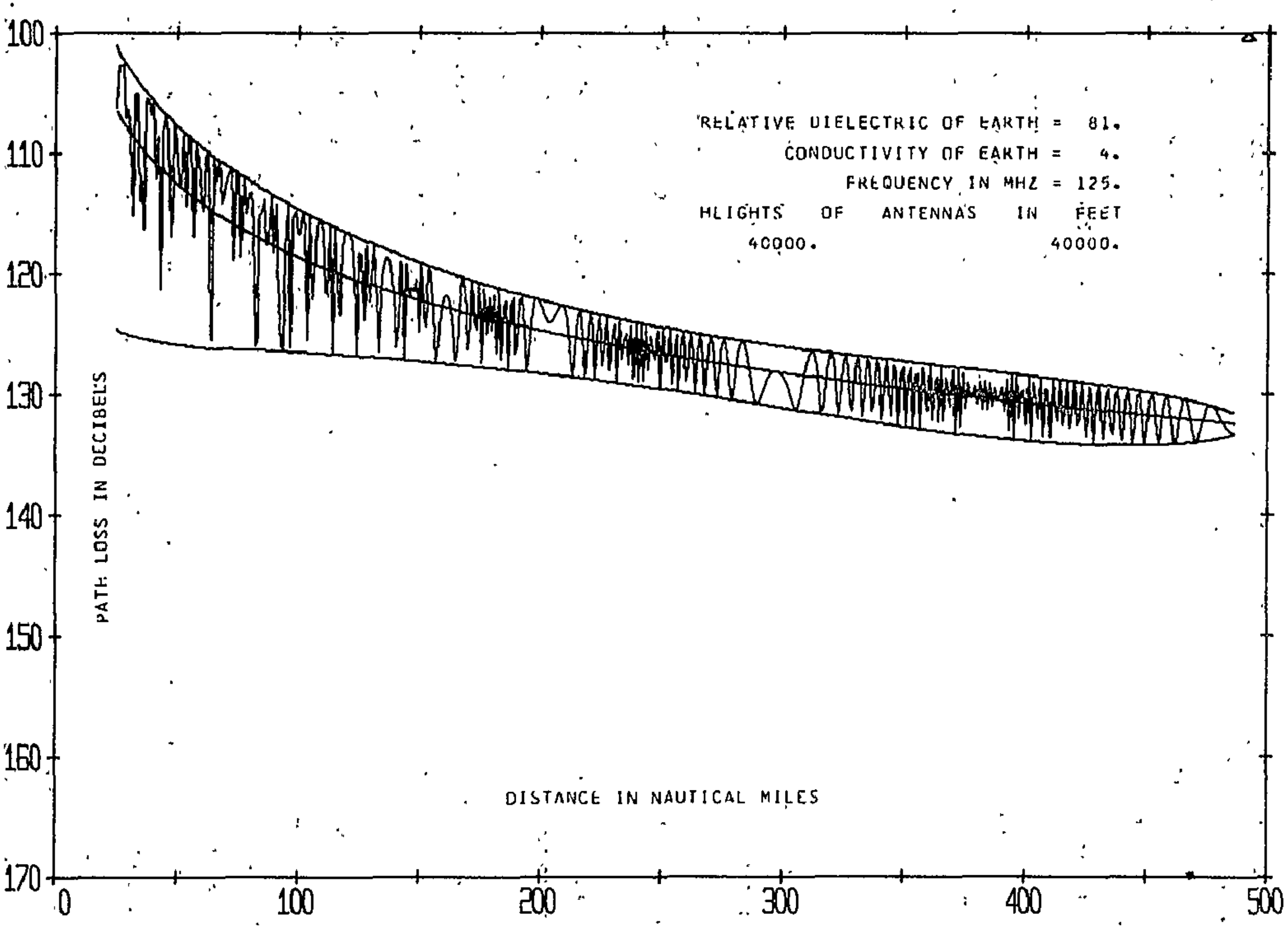


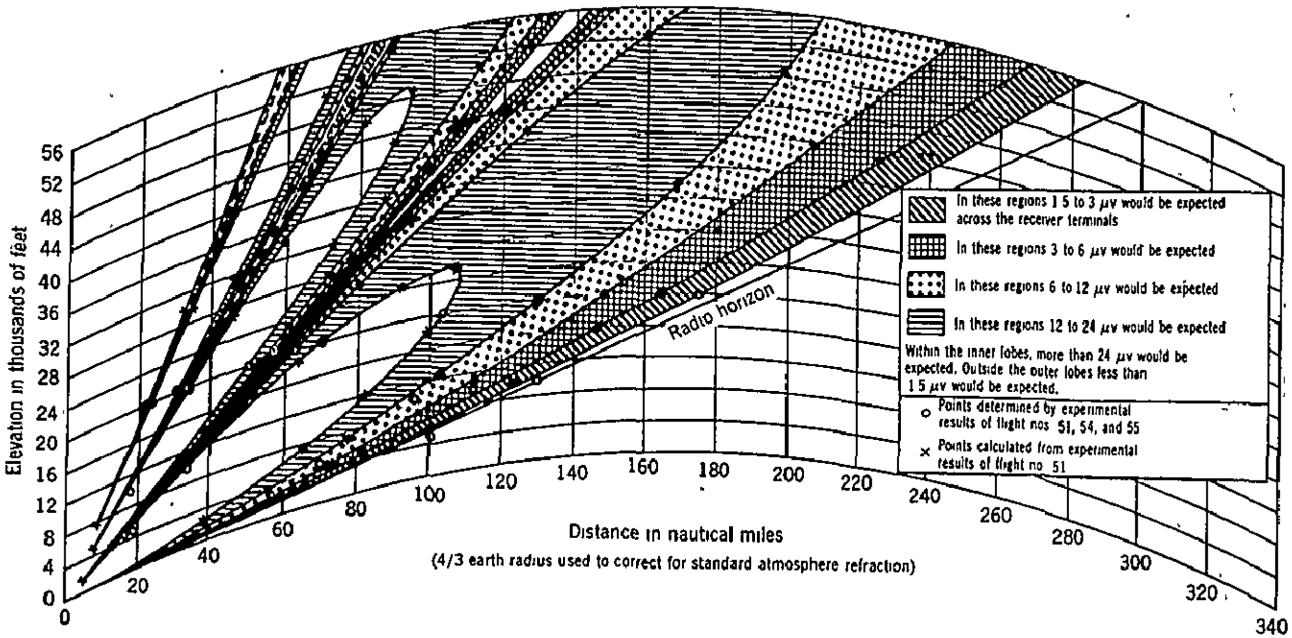
Figure 6-4. Loss versus Distance for a Two Path Propagation Model
(Antenna Heights: 40,000 Feet and 40,000 Feet)

computer are not spaced closely enough to represent sampling (in distance) at twice the highest frequency of the oscillating path loss. Consequently, the reduced frequency of oscillation can actually be attributed to an aliasing phenomenon of the oscillation spectrum. In this situation, only the three remaining monotonic curves have any true validity.

In general, the oscillation frequency noted above increases as the fixed station altitudes increase. This can be observed by comparing Figures 6-3 and 6-4. For the situation in which the fixed terminal is a satellite, the oscillation frequency will be much more rapid than that shown in either of the figures.

6.3.4.2 Demonstration of Validity

Before discussing in detail the results derived from the two-path propagation model, some discussion of its validity appears in order. One comparison between the theoretical two-path model and experimental results for ground-to-air propagation is provided by Figure 6-5, taken from Reed and Russell (Reference 22). With the exception that horizontal polarization has been employed instead of vertical polarization, the parameters of transmitting station height, frequency, and sea water conductivity surface are reasonably near to those employed for the interference situations of this study. From this figure, it can be seen that the observed values of field strength (or equivalently, propagation loss) demonstrate good agreement with the theoretically derived dependence. It is also evident from this figure that the variations in signal strength observed by an aircraft, and related to height variations of several hundred feet experienced by that aircraft, will not be appreciable when the airplane is within the vicinity of the lower (or first) lobe. Equivalently, for an aircraft near the radio horizon, but within line-of-sight of the transmitter, field strength does not vary appreciably with aircraft height. Another demonstration of the validity of the two-path propagation



Transmitting antenna: Half-wave horizontal dipole
Receiving antenna: Half-wave horizontal dipole

Effective height ground antenna: 70.5 feet
Corrected communication system loss: 6 dB
Corrected power output: 6 watts

Free space maximum range for 6-watt transmitter and 1.5 μv at receiver terminals: 878 n.mi.

Figure 6-5. Experimental VHF Radiation Pattern, Air-to-Ground Communication Over Sea Water - 139.14 MHz (Source: Reference 22) model is provided by Figure 6-6, taken from Ince and Williams (Reference 23), in which vertical polarization overland is considered. Again, reasonable agreement between theory and experiment can be observed for the two-path propagation model.

The propagation model employed in this study is similar to, but not identical with, the model described by Gierhart and Johnson in their report, "Transmission Loss Atlas for Select Aeronautical Service Bands from 0.125 to 15.5 GHz" (Reference 24). In their report the expected transmission loss between an aircraft and a ground station or some other aircraft is presented as a function of distance with height as a parameter. Three regions with respect to distance from the transmitter are delineated: beyond-the-horizon region, horizon-lobe region, and a region extending from the horizon-lobe region to the transmitter. In the beyond-the-horizon region the transmission loss mechanism is either diffraction or tropospheric scatter (or some combination of the two). The method employed by Gierhart and Johnson for the calculation of these losses follows the procedures described in NBS Technical Note 101 (Revised) (Reference 25). Except for anomalous propagation phenomena (such as ducting on surface-to-surface paths), the transmission loss within this region decreases rapidly with distance and, to a first approximation, need not be considered. For this reason the beyond-the-horizon region has not been considered in the model used in this interference analysis.

Within the horizon-lobe region Gierhart and Johnson employed a two-ray interference model. The model used in this interference analysis also employs a two-ray model in this region.

At distances nearer to the transmitter Gierhart and Johnson did not use the two-ray interference model because the lobing structure obtained from it as the path length shortens becomes very dependent on surface characteristics, atmospheric conditions, antenna characteristics, and other factors. Instead, free-space transmission loss between transmitter and receiver was employed

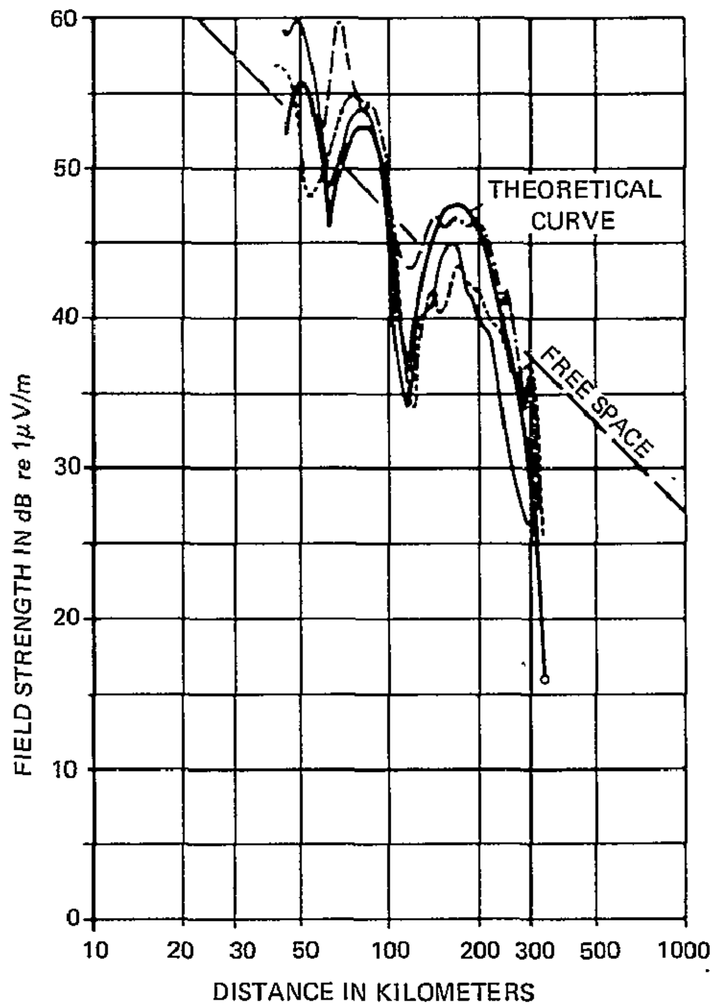


Figure 6-6. Comparison Between Theoretical and Measured Results (Source: Reference 23).

in this region. For the estimation of long term median transmission loss this is a valid assumption. However, for interference calculations it is the simultaneous difference between wanted and unwanted signals which is of interest and not the difference of their long term medians.

For the interference situations examined in this study (viz., coastal coverage by both space and terrestrial services), the reflection surface may be assumed to be sea water. Sea surface roughness need not be considered, since, for interference studies, quasi-worst case situations are of interest. Further, since most interference situations result in line-of-sight propagation paths to the receiver of interest, the gross atmospheric conditions along all propagation paths are likely to be the same. Thus, in contradistinction to the curves presented by Gierhart and Johnson, which are most useful for predicting the absolute transmission loss that might be expected above unknown terrain, the two-path model appears to provide a more realistic estimate of path loss differences between wanted and unwanted signals for interference analyses. Even this model has its disadvantages; however, it seems adequate for the study discussed below.

6.3.4.3 Application of the Model

Consider now the application of the two-path propagation model to the interference situations illustrated in Figures 6-1 and 6-2. As noted previously, the oscillations in field strength with distance will be very rapid for the situation in which one terminal is a satellite. For the case of satellite-to-aircraft transmissions, the motion of the aircraft will cause the signal received at the aircraft to fluctuate rapidly with time. Although satellite system performance calculations must take this rapid fluctuation in account for several reasons, interference analyses can (unless extremely worst-case predictions are required) use the free-space loss as a reasonable estimate for the median of the rapidly fading signal. Small scale fluctuations in the atmospheric refractive index also lead to rapid signal fluctuations. For this reason, the satellite-to-ground station propagation path also employs only the free-space value for path loss.

For aircraft-to-aircraft propagation paths, a similar situation involving rapidly fluctuating signals often occurs because of relative motion between the two aircraft. Because of this situation one is tempted to employ the free-space loss for the reason noted in satellite propagation paths. However, for interference studies one must consider the worst case situations. Such a situation could arise if there were no, or at least very little, relative motion between aircraft. This occasion could occur, for example, if aircraft were being maintained at fixed separations for purposes of air-traffic control. Since air-traffic control is the primary function of the communication systems considered, the worst case will be assumed for these interference studies by assuming that an interfering signal from another aircraft is not rapidly varying. Therefore, the reflected ray along the interfering path is assumed to add in-phase, so as to increase the resultant unwanted signal. This assumption requires that the upper envelope of the curve in Figure 6-4 (minimum loss) be employed for the unwanted signal between two aircraft.

For ground-to-aircraft propagation paths, a somewhat different situation exists than in the two cases noted immediately above. Referring to Figure 6-3, one sees that for an aircraft height of 40,000 feet, the field strength exhibits a slow variation with distance relative to the previously noted cases. Further, at distances less than about 50 n.mi., slight variations in height can result in field strength levels (or propagation losses) associated with either constructive or destructive interference between the direct and reflected rays. Considering these observations free-space loss is employed for interference situations involving air-to-ground propagation for distances less than about

50 n.mi. Because the field strength within the lowest lobe is not particularly sensitive to height variations by the aircraft, the theoretically derived field strength curves (or propagation losses) are directly employed for greater distances.

6.4 INTERFERENCE CALCULATIONS

This subsection presents representative calculations for a few of the interference cases discussed.

Consider first the interference situation of Case I. Here, aircraft (b) is receiving a wanted signal S_W from a terrestrial transmitter and a potentially interfering unwanted signal S_u from aircraft (a) that is transmitting to the satellite. Using a -10 dB protection ratio, the difference between these signals must satisfy the inequality:

$$S_u - S_W \le 10 \text{ dB}.$$

Because all antennas are isotropic, this inequality may be restated in terms of propagation loss by employing the known EIRPs. Hence:

$$\left(24 - L_u\right) - \left(14 - L_W\right) \le 10 \text{ dB}$$

or

$$L_u \ge L_W.$$

Where:

L_u = propagation loss of unwanted signal

L_W = propagation loss of wanted signal.

Assume that the receiving aircraft is 100 n.mi. distant from the terrestrial station, the propagation curve of Figure 6-3 shows that the path loss likely to be experienced (on the basis of the two-path propagation model) is 116 dB. This corresponds to the minimum/actual wanted signal at that range. In order that the unwanted signal should experience a propagation loss not less than that of the wanted signal, Figure 6-4 indicates that a separation between aircraft of at least 125 n. mi. is required. Proceeding in this manner for other ranges, the wanted separation between aircraft can be found as a function of the wanted signal path length and the results plotted, as in Figure 6-5 (Case I). Naturally, only those distances d_1 less than the service range in the absence of interference of the terrestrial system need be examined. This range is typically 150 n. mi. Case V follows in a similar manner.

Next, consider Case II. This situation is similar to but much simpler than that previously examined, because now the required separation that must be maintained between aircraft is independent of the distance d_1. If free space transmission loss can be assumed as a reasonable average for the rapidly fading multipath propagation loss between aircraft (a) and the satellite, as discussed in Paragraph 6.4.4, the following inequality can be derived in a manner similar to Case I for a flux density of -130 dBW/m^2:

$$\left(14 - L_u\right) - \left(32 - L_w\right) \leq 30 \text{ dB.}$$

Because the free space transmission loss at 125 MHz between an aircraft and a synchronous satellite is about 167 dB, the following result is easily obtained:

$$L_u \geq 119 \text{ dB.}$$

From Figure 6-4, the minimum allowable separation between aircraft is 140 n. mi.

Cases III (a) and (b) are nearly trivial. For Case III (a) the maximum distance d_1^{max} must be determined for which conventional coverage cannot be achieved in the presence of the unwanted signal emitted by the satellite. As in the previous cases, an inequality can be established in terms of the path loss; here one obtains:

$$(32 - 167) - \left(14 - L_w\right) \leq 10 \text{ dB}$$

or

$$L_w \leq 159 \text{ dB}.$$

From Figure 6-3, one finds that $d_1 \leq 250$ n. mi. Case IV follows in a similar manner.

For Case III (b) a similarity with Case II is observed. The only difference is that here the propagation loss curve of Figure 6-4 is employed. Thus:

$$L_u \geq 119 \text{ dB}$$

so that the minimum distance to which an aircraft operating in the satellite mode may approach a transmitter of the terrestrial service in $d_2^{\ min} = 150$ n.mi. This requirement can be represented in Figure 6-5 as the inequality $S + d_1 \geq 110$ n.mi.

The controlling interference situation can be identified if the results from Cases II and III are noted on the graph obtained from Case I as done in Figure 6-5. Shading has been used to indicate those portions of the graph resulting in an unacceptable interference situation for the case considered.

6.5 RESULTS AND CONCLUSIONS

The results obtained for the assumed protection ratios and satellite flux densities from -140 dBW/m^2 to -130 dBW/m^2 are presented in Figures 6-7 through 6-9.

Here the distance required between two aircraft to prevent interference (one in the satellite service and one in the terrestrial service) is plotted as a function of the distance between the latter aircraft and the terrestrial station communicating with it. All interference cases, except Case VI, are shown in this way.

A geometric condition lying within the area on the shaded side of each curve produces an unacceptable interference situation of some kind.

Examples of the type of conclusions which can be drawn from presenting the analysis results in this manner are:

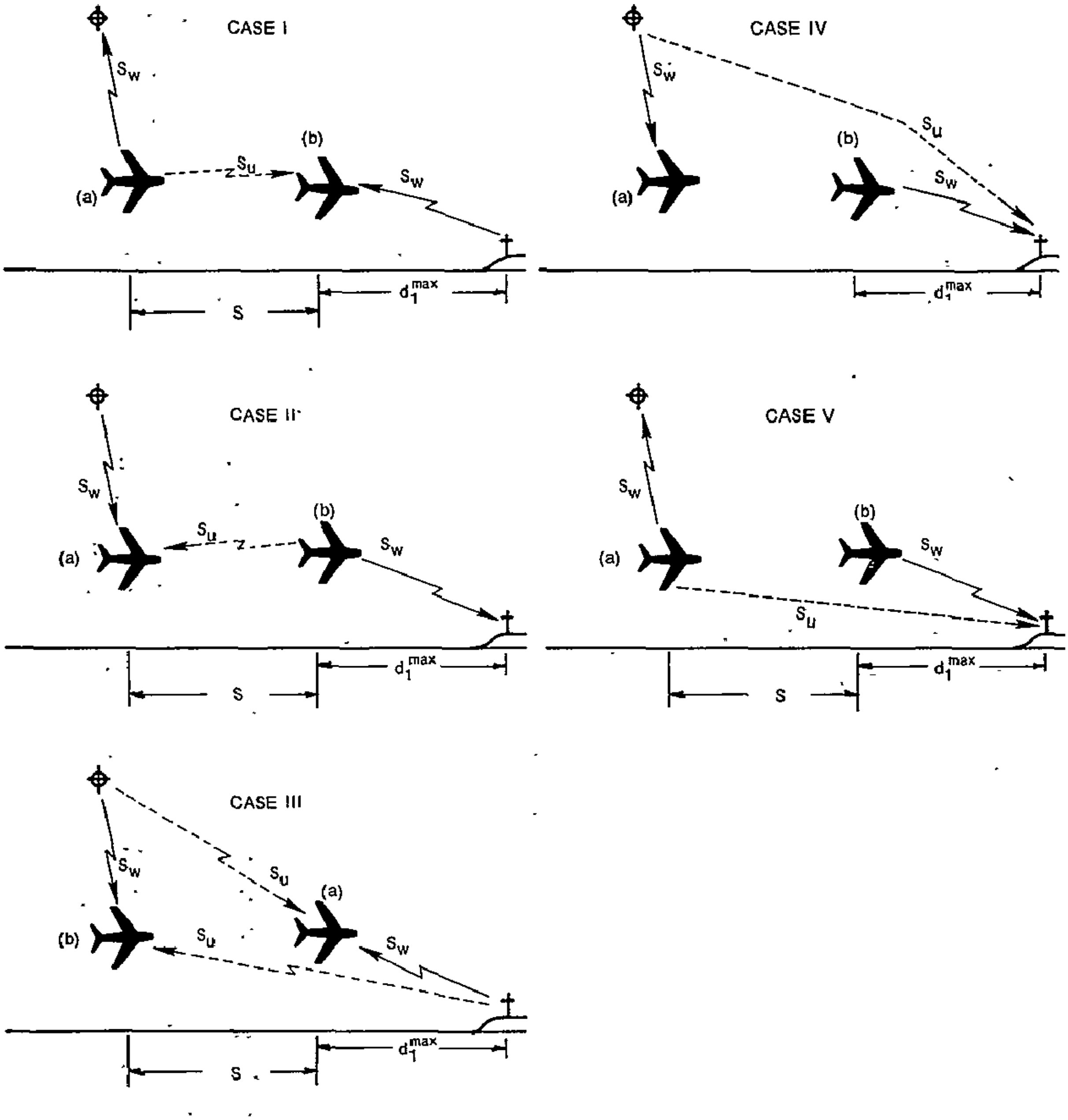
a. The results obtained are very sensitive to the values of protection ratio used.

b. A non-operational or "dead" zone S_{min} may exist within which interference-free coverage cannot be derived from either the satellite or the terrestrial system. The minimum width of this communication gap critically depends upon the flux density from the satellite which effects Case II (interference from terrestrial aircraft into satellite aircraft), and the FM on AM protection ratio which affects Case I (interference from satellite aircraft into terrestrial aircraft).

c. If a 5 dB FM on AM protection ratio is required, then Case I will limit in all cases. The two aircraft must be greater than line-of-sight distance apart (500 n.mi. at 40,000 feet) to prevent interference.

d. For the assumed protection ratios, Cases III (a) and IV, i.e., those where the satellite interferes with either element of the terrestrial system, never limit operation. Line-of-sight operation can always be achieved even at the flux density limit.

e. Case V results in only a trivial interference situation.


CASE I
S_w
(b)
S_u
(a)
S_w
d_1^{max}
S
CASE II
S_w
(b)
S_u
(a)
S_w
d_1^{max}
S
CASE III
S_w
S_u
(a)
(b)
S_u
S_w
d_1^{max}
S
CASE IV
S_w
S_u
(b)
(a)
S_w
d_1^{max}
CASE V
S_w
(b)
S_w
(a)
S_u
d_1^{max}
S

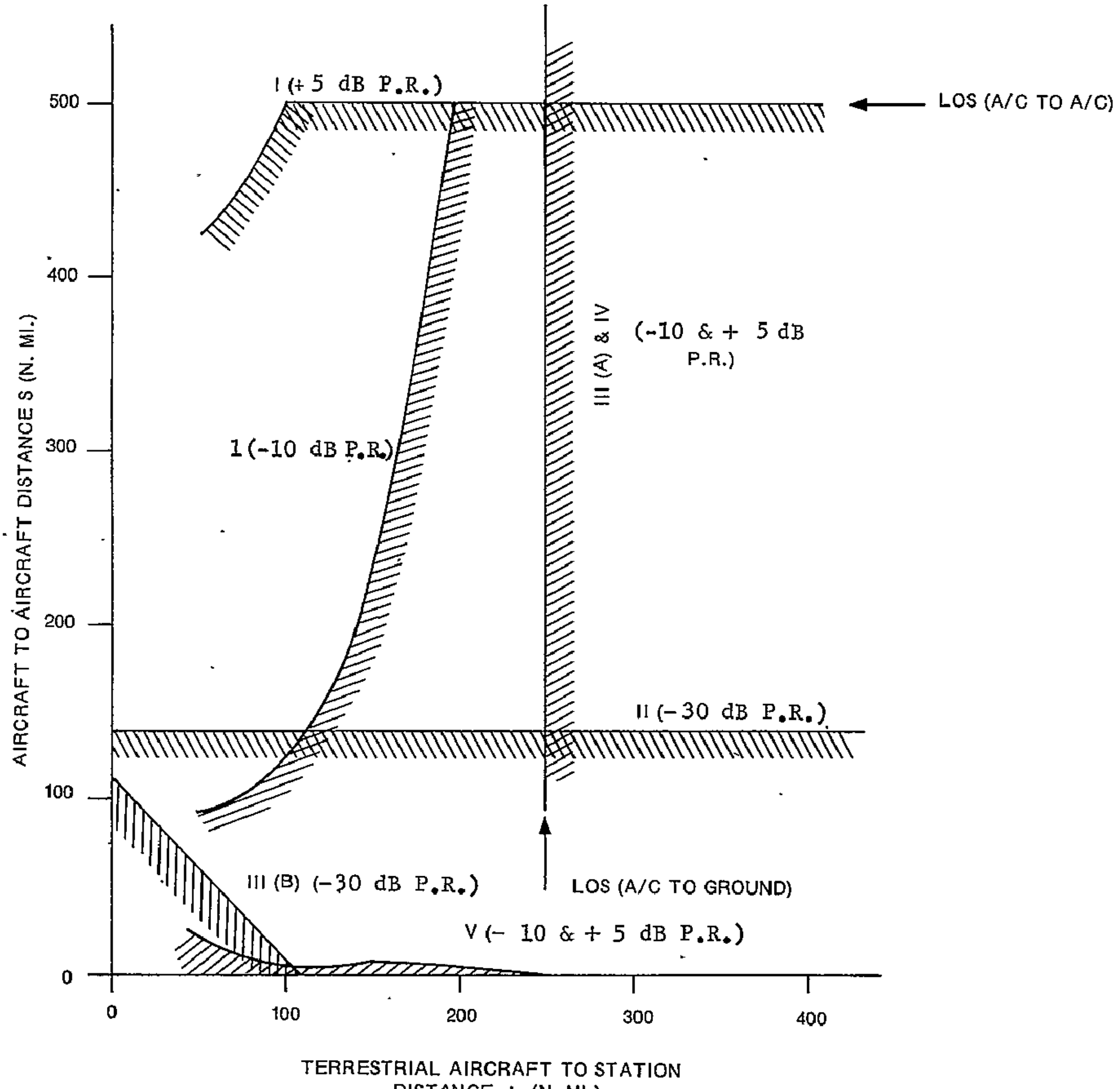
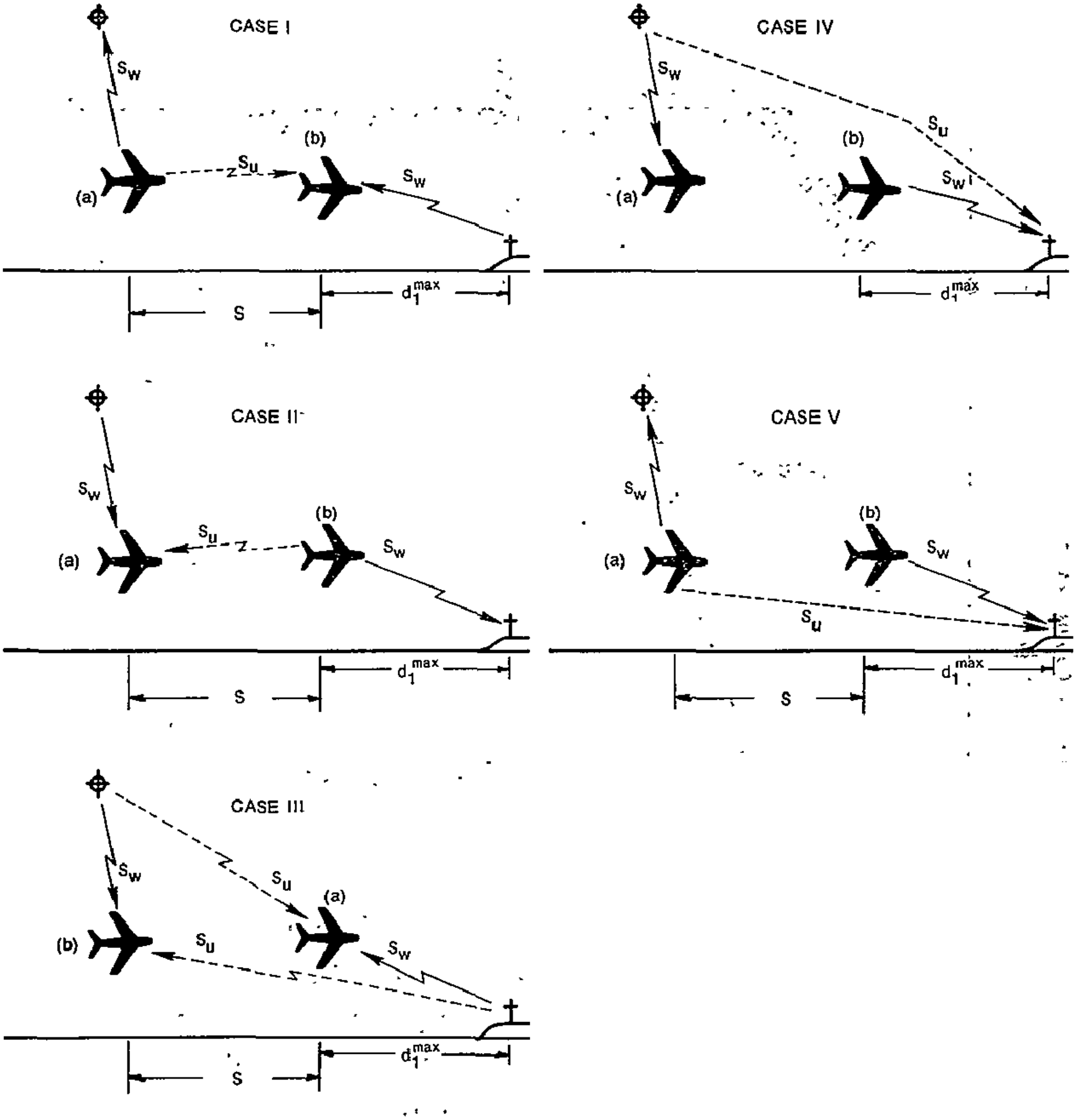


Figure 6-7. Interference Situation Tradeoff at -130 dBW/m^2 Flux Density


CASE I
S_W
S_u
S_W
(a)
(b)
S
d_1^{max}
CASE II
S_W
S_u
S_W
(a)
(b)
S
d_1^{max}
CASE III
S_W
S_u
S_u
S_W
(a)
(b)
S
d_1^{max}
CASE IV
S_W
S_u
S_W
(a)
(b)
d_1^{max}
CASE V
S_W
S_W
S_u
(a)
(b)
S
d_1^{max}

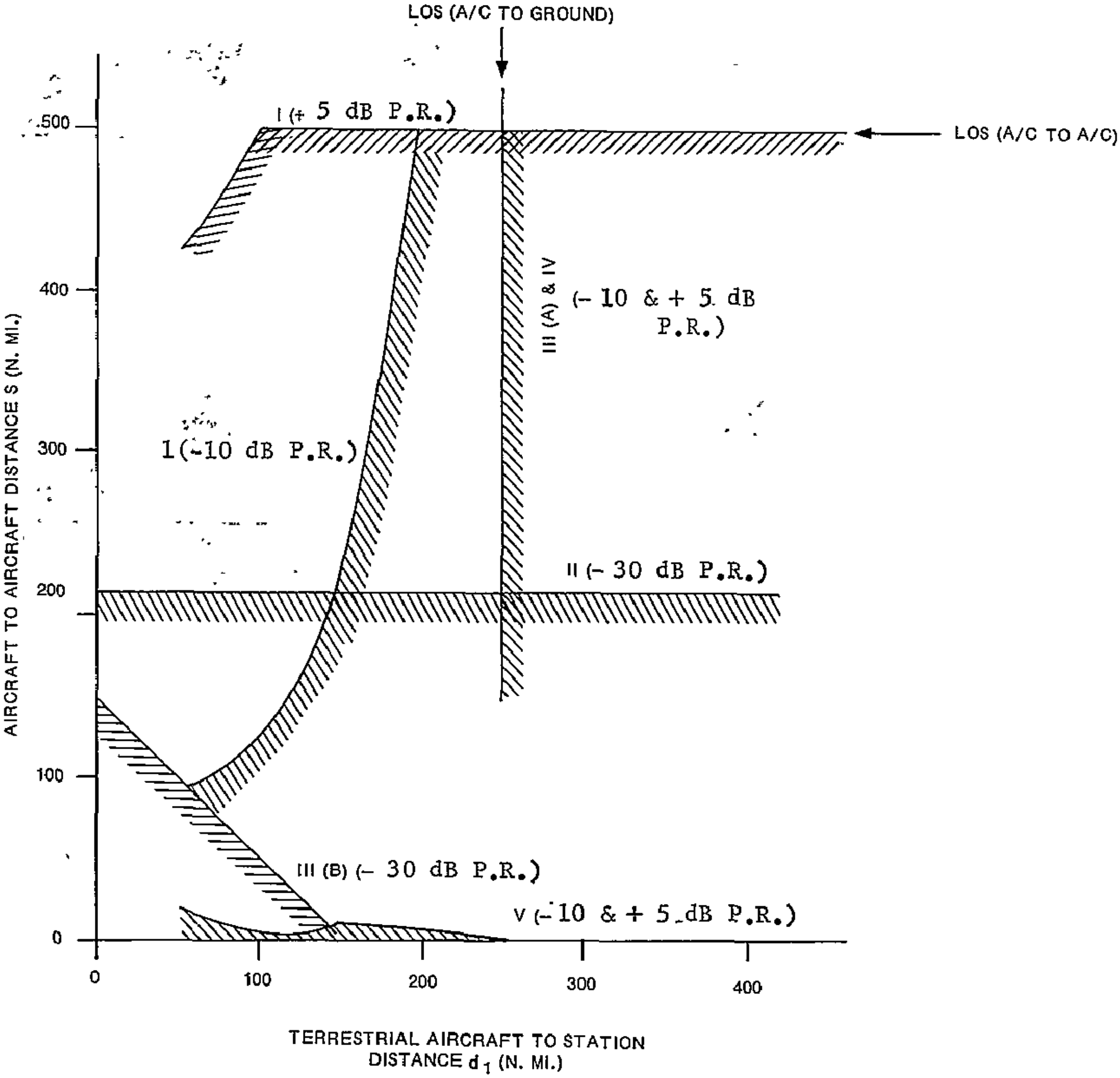
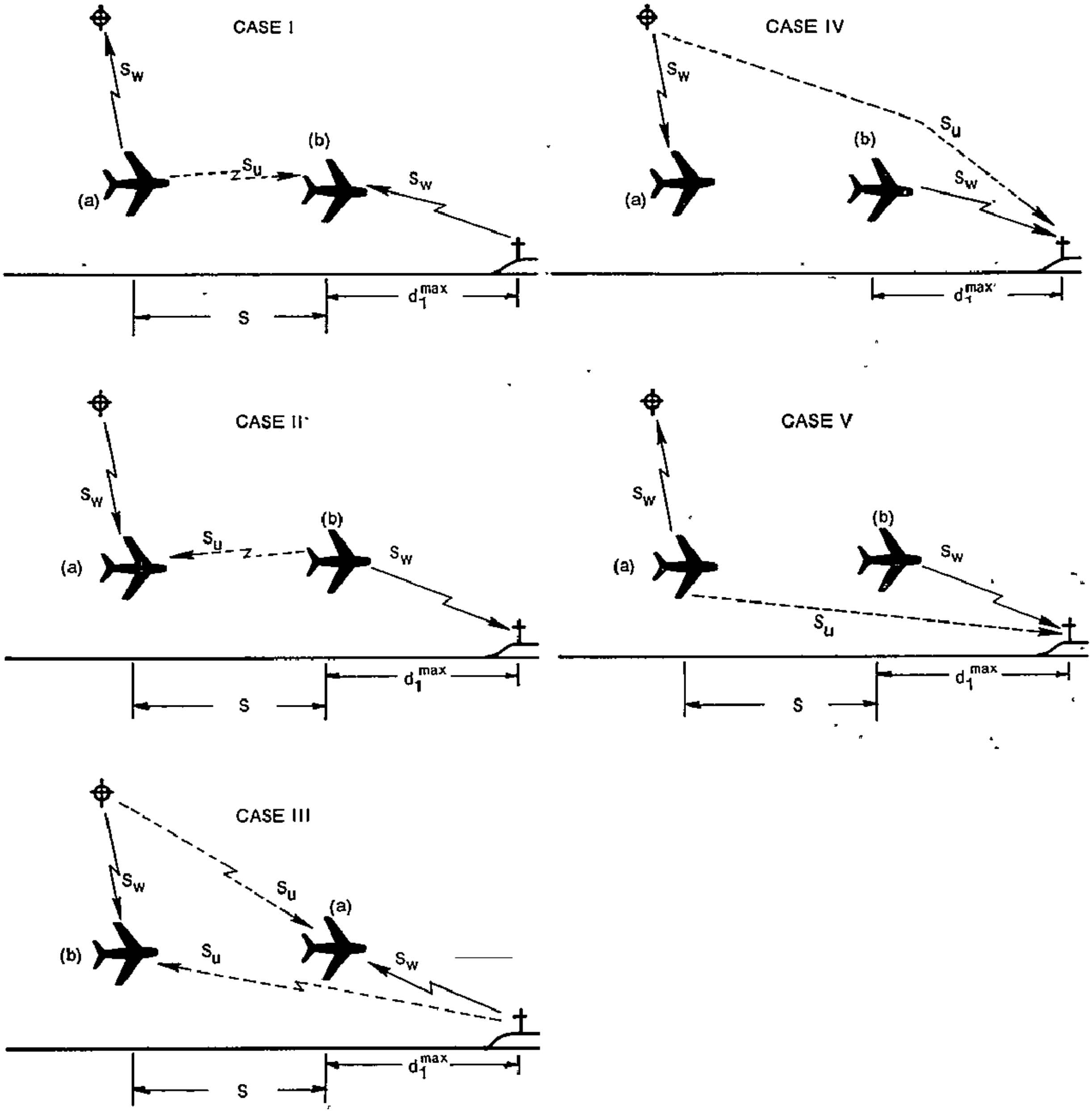


Figure 6-8. Interference Tradeoff at -135 dBW/m^2 Flux Density


CASE I
CASE II
CASE III
CASE IV
CASE V
(a)
(b)
S_w
S_u
S
d_1^{max}

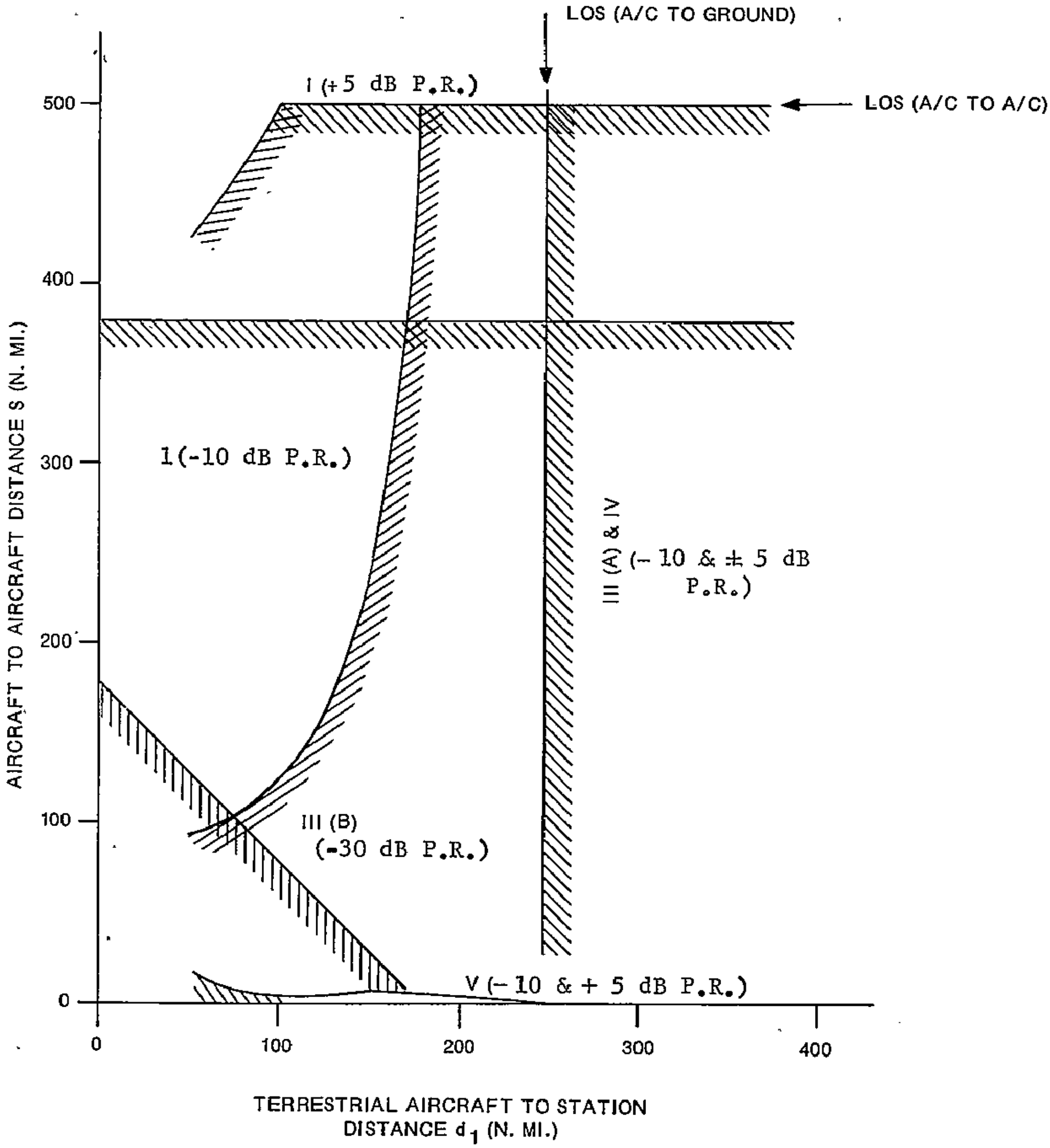


Figure 6-9. Interference Situation Tradeoff at -140 dBW/m^2 Flux Density

f. Case III (b), i.e., a terrestrial station interfering with a satellite aircraft, never limits operation because Case II always requires a larger S at all d_1's and flux densities.

g. Case II, i.e., an aircraft in the satellite service being interfered with by one in the terrestrial service, is most sensitive to the flux density provided by the satellite. It may not be desirable to use a low flux density even if the FM signal reliability requirement is met, since this may result in an excessive interference situation from other aircraft in the terrestrial system.

Figure 6-10 was constructed by assuming that it is desirable from an operational viewpoint to simultaneously minimize the communication gap and maximize the service radius of the terrestrial station. Here all the pertinent results of this section are presented. Both the minimum potential communication gap and maximum terrestrial service radius are shown as functions of flux density for the +5 and -10 dB protection ratios. Also indicated on the abscissa are the signal strength reliability and dc power required on the satellite per voice channel based on the power budgets of Paragraph 6.2.

It should be emphasized that these conclusions pertain only to the protection ratios assumed. A more definitive set of protection ratios is required before an operationally meaningful analysis can be done.

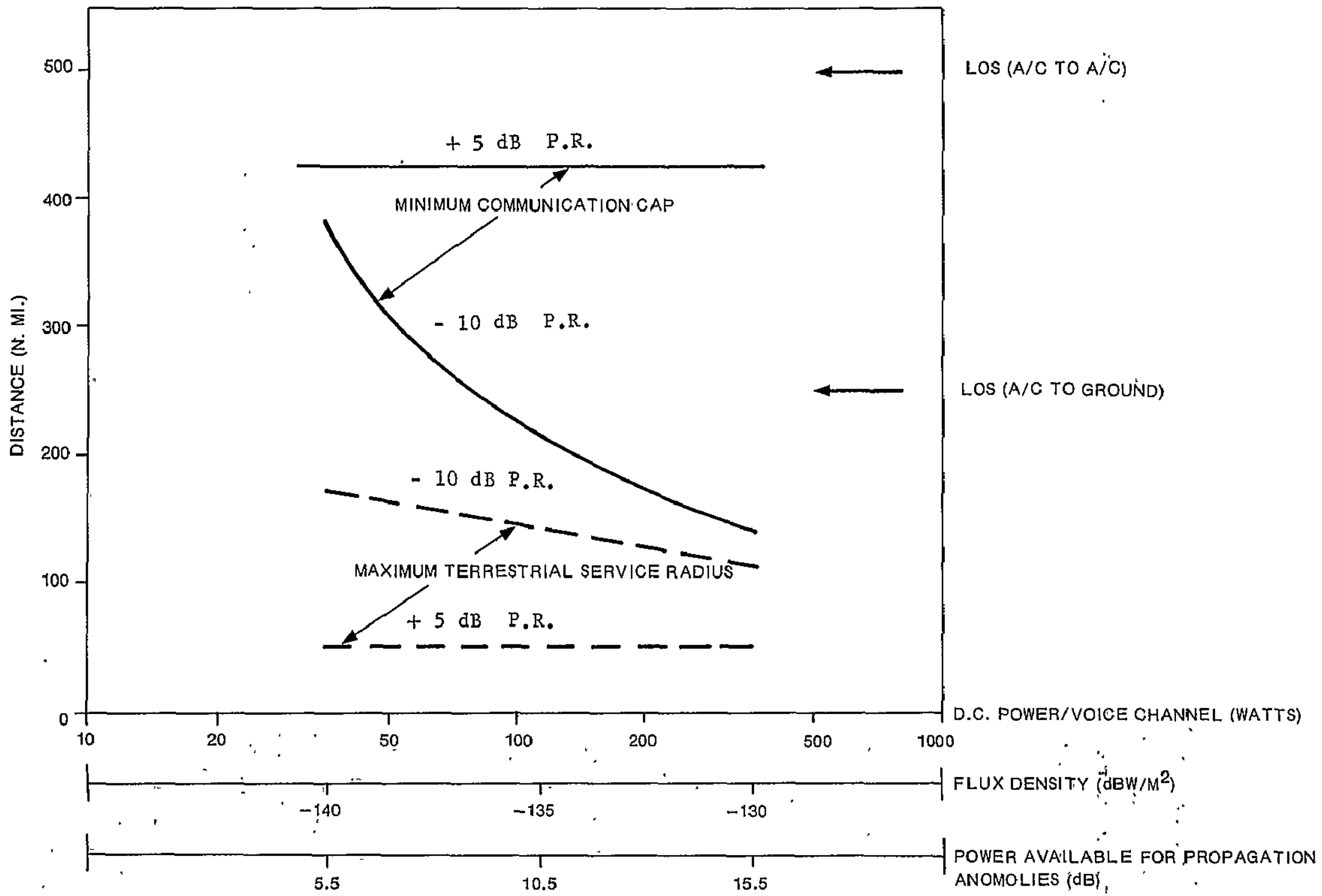


Figure 6-10. VHF Band Sharing Implications

6.6 EXTERNAL NOISE AT A SATELLITE IN THE VHF AERONAUTICAL SERVICE

The total of all unwanted emissions received by the satellite constitutes external noise. At VHF the sources of these unwanted emissions include:

a. Natural terrestrial sources (thunderstorms and thermal radiation)

b. Extra-terrestrial sources (galactic and solar emissions)

c. Broadband, man-made sources (ignition noise and electrical machinery)

d. Narrow band, man-made sources (transmitters in the conventional VHF aeronautical service)

Because the noise sources a. through d. are noncoherent, their noise powers add linearly. The received energy from the narrow band noise sources (Subparagraph d. above) can be distinguished, as occasion demands, by the term interference and is presented as the Case VI discussed in Paragraph 6.4.1.

Studies employing the ATS-1 and 3 have been carried out for the purpose of identifying the noise levels contributed by the above mentioned sources. According to Boeing's studies (Reference 26), the dominant external noise as measured in a 90-kHz bandwidth near 150 MHz by the ATS-1 was narrow band, man-made emissions from 2 to 5 watt handi-talkie mobile and fixed transceivers. However, the absolute level of neither these signals, nor the spectral density of the broadband noise sources also present, can be assessed from these studies.

Any analysis undertaken that attempts to estimate the total interference at the satellite must make so many assumptions that it is apt to be unsatisfying. Uncertainties in the channel filter selectivity, the oscillator stabilities, the spectra and number of the noise sources in view, and the other unaccounted for system vagaries cause this to be a factor of major concern in system design.

Although adjacent channel noise can be rejected to some extent by filtering, broadband external noise from sources a. through c. will still be present within the reception bands. Limited ground measured experimental evidence indicates that automotive ignitions will be the dominant source of this in-band noise. Unfortunately, no experimental data regarding the expected level of such noise at the satellite has been found. In fact, the only quantitative data available which was not measured by receivers at the surface of the earth comes from low altitude airborne measurements taken above Seattle by Boeing. Although a rationale has been developed for determining the effect of man-made noise upon airborne receiver (Reference 27), the dearth of experimental data on the geographic and temporal variability of the noise sources does not permit its extension to the estimation of noise at a satellite. Consequently, because of the lack of experimental data regarding noncoherent, man-made noise, no estimates can be made with any confidence regarding its level at the satellite.

An interference and noise-measuring satellite experiment, similar to those designed by NASA (Reference 28) in the 4 to 6 GHz bands for the ATS-F program, and by Lincoln Laboratory in the 250 to 300 MHz band for LES-5 and -6 programs could obtain the data required for man-made noise estimation. Such a satellite interference experiment would also find application in the measurement of the noise level due to the narrow band, coherent sources discussed previously and would lead to a more confident system design.

APPENDIX A

SOME TECHNICAL CHARACTERISTICS OF VHF COMMUNICATION EQUIPMENT

A.1 MODULATION AND BANDWIDTH

All transmissions in the VHF aeronautical bands for communication are amplitude modulated double sideband. The modulation depth is to be at least 70 percent but not to exceed 100 percent. In fact, equipment subject to "type approval" by the FCC which has more than 10 watts must include integral circuitry to prevent modulation peaks in excess of 100 percent (Reference 3).

Voice transmission requirements emphasize transfer of basic intelligence rather than fidelity of waveform. Air carrier transceiver specifications call for sharp cutoffs below 300 and above 3750 Hz (Reference 29). In equipment subject to the FCC rules, the transmitted signal must not occupy greater than a 50-kHz bandwidth. This is recognized as being in excess of actual transmission needs, and the FCC points out that this bandwidth "is temporary and this fact should be considered in the design of VHF radio equipment for future use." The FCC has continued this relatively wide bandwidth authorization mainly to provide for emergency "downed aircraft" communication sets.

Transmission in the communication band (118 to 136 MHz) are voice with selective calling (SELCAL) tones also utilized in the air carrier subband. Where selective calling is used, the highest audio frequency tone is 1047.1 Hz.

Equipment approved by the FCC for licensees in this service requires that emissions meet the following attenuation characteristics, referred to mean power of the assigned frequency (transmitters) (Reference 3):

a. On any frequency removed from the assigned frequency by more than 50 percent up to and including 100 percent of the authorized bandwidth: at least 25 dB.

b. On any frequency removed from the assigned frequency by more than 100 percent up to and including 250 percent of the authorized bandwidth: at least 35 dB.

The above FCC criteria for the VHF band requires all emissions 25 kHz and more removed from the assigned frequency to be attenuated by at least 25 dB. Although the FCC rules are applicable only to stations subject to FCC licensing, it is noted that the above engineering principles are observed by government stations. The slope of the emission characteristics appear relatively standardized but the greater emission bandwidth permitted by the Commission's rules reflects the relatively wide bandwidth authorized. FCC rules do not address the selectivity of receivers. The air carriers on the other hand have reached a common specification for receiver selectivity. This is contained in ARINC Characteristics Number 546 (Reference 29) and 566 (Reference 21) issued in October 1961 and October 1968, respectively.

The ARINC receiver characteristics provide two representative examples of selectable characteristics as shown in Figures A-1 and A-2. The "normal" selectivity is used to receive conventional terrestrial stations and the "sharp" selectivity must be used to receive a satellite transmission using the proposed "interleaved" frequency plan. The ARINC specifications apply only to air carrier equipment.

Bandwidths of representative general aviation receivers display a range of passband characteristics. A composite estimate is shown in Figure A-3.

Some of these receivers can tune into the VOR band and provide navigation signals. Therefore, their design minimum is for a 20-kHz passband plus stability allowances. The new NARCO solid-state receiver is 35 kHz wide at the 6-dB points. The selectivity

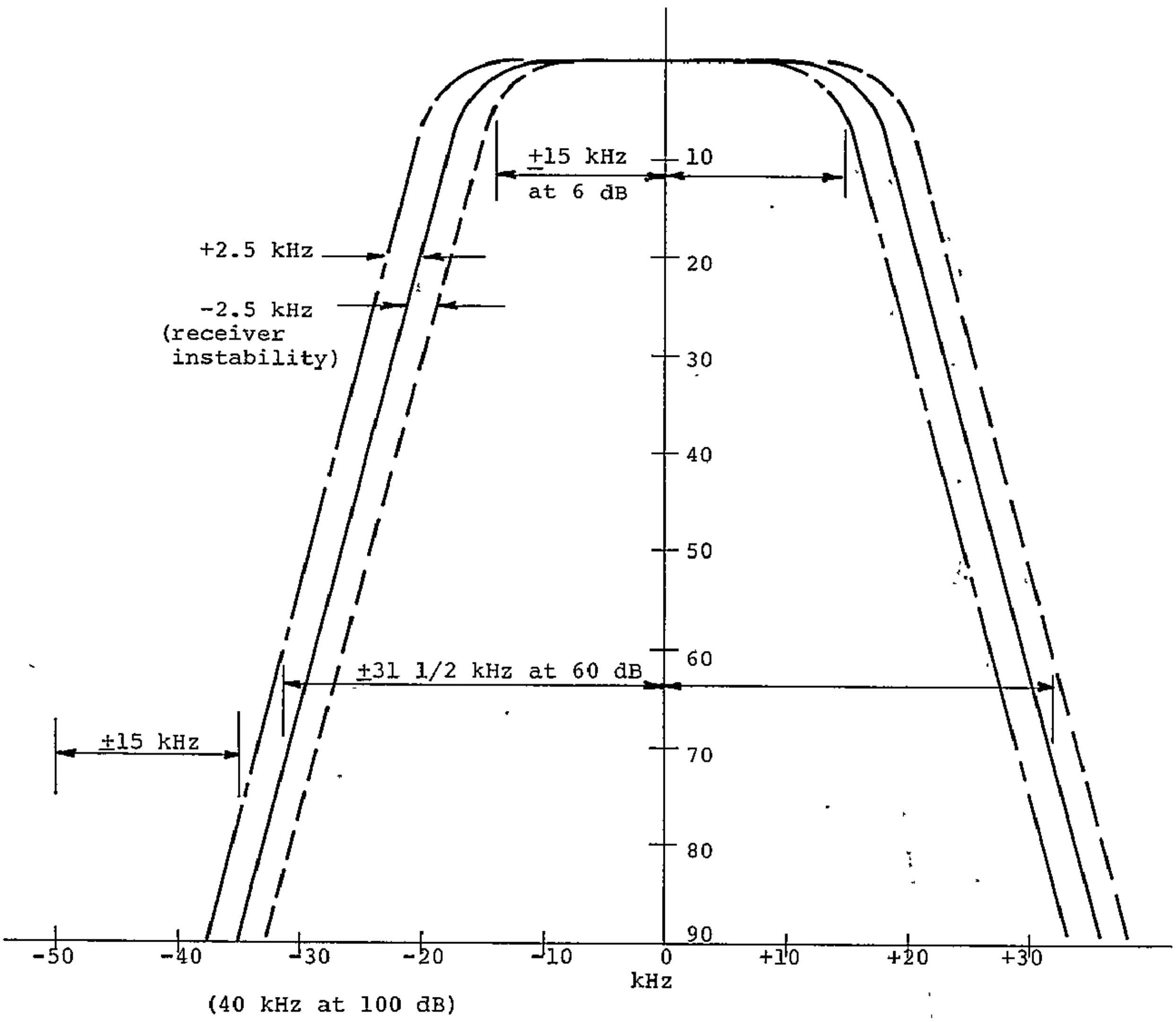


Figure A-1. Commercial Carrier Receiver Selectivity-"Normal"
(Data Sources: References 21 and 29)

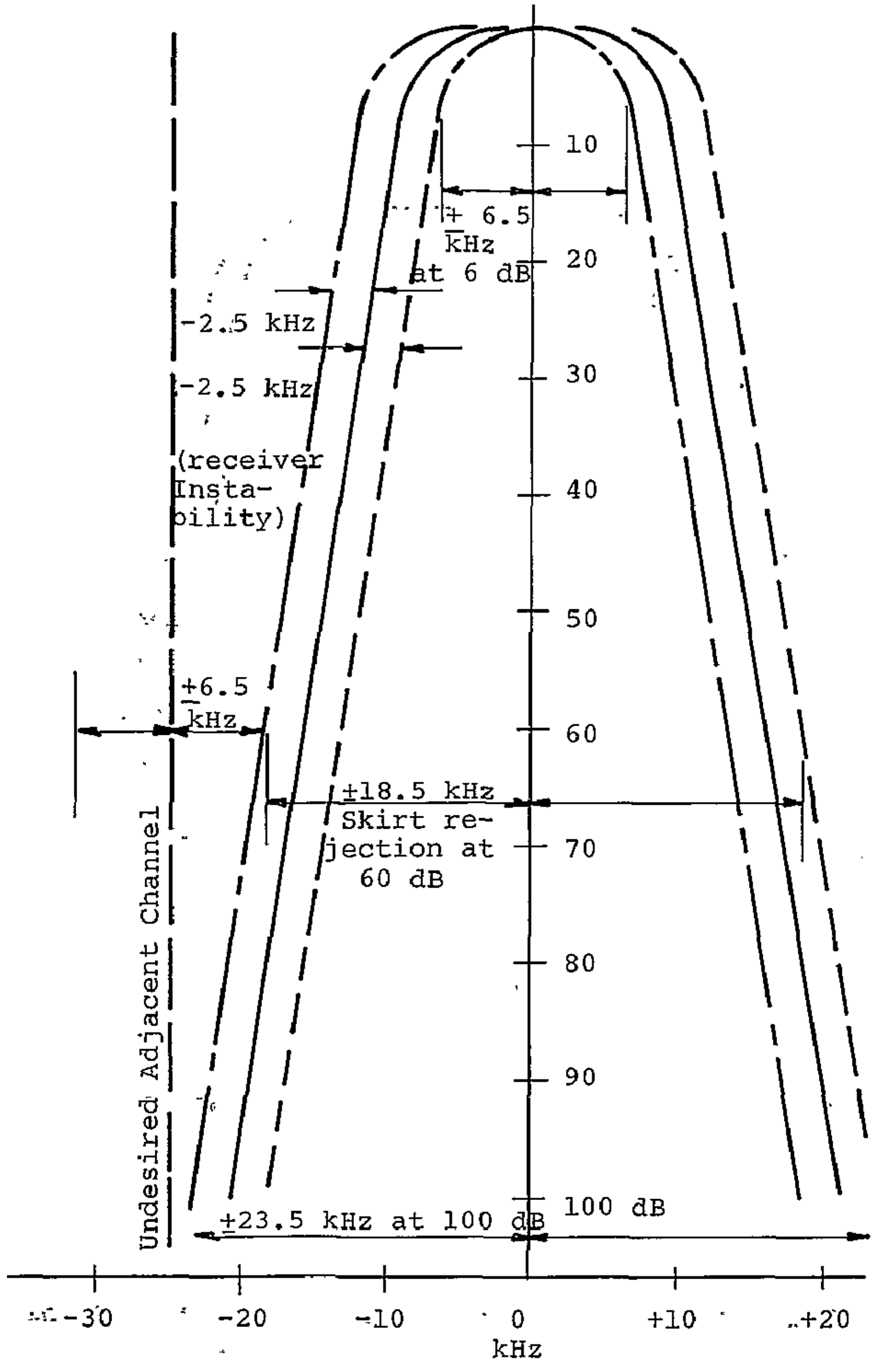


Figure A-2. Commercial Carrier Receiver Selectivity-"Sharp"
(Data Sources: References 21 and 29)

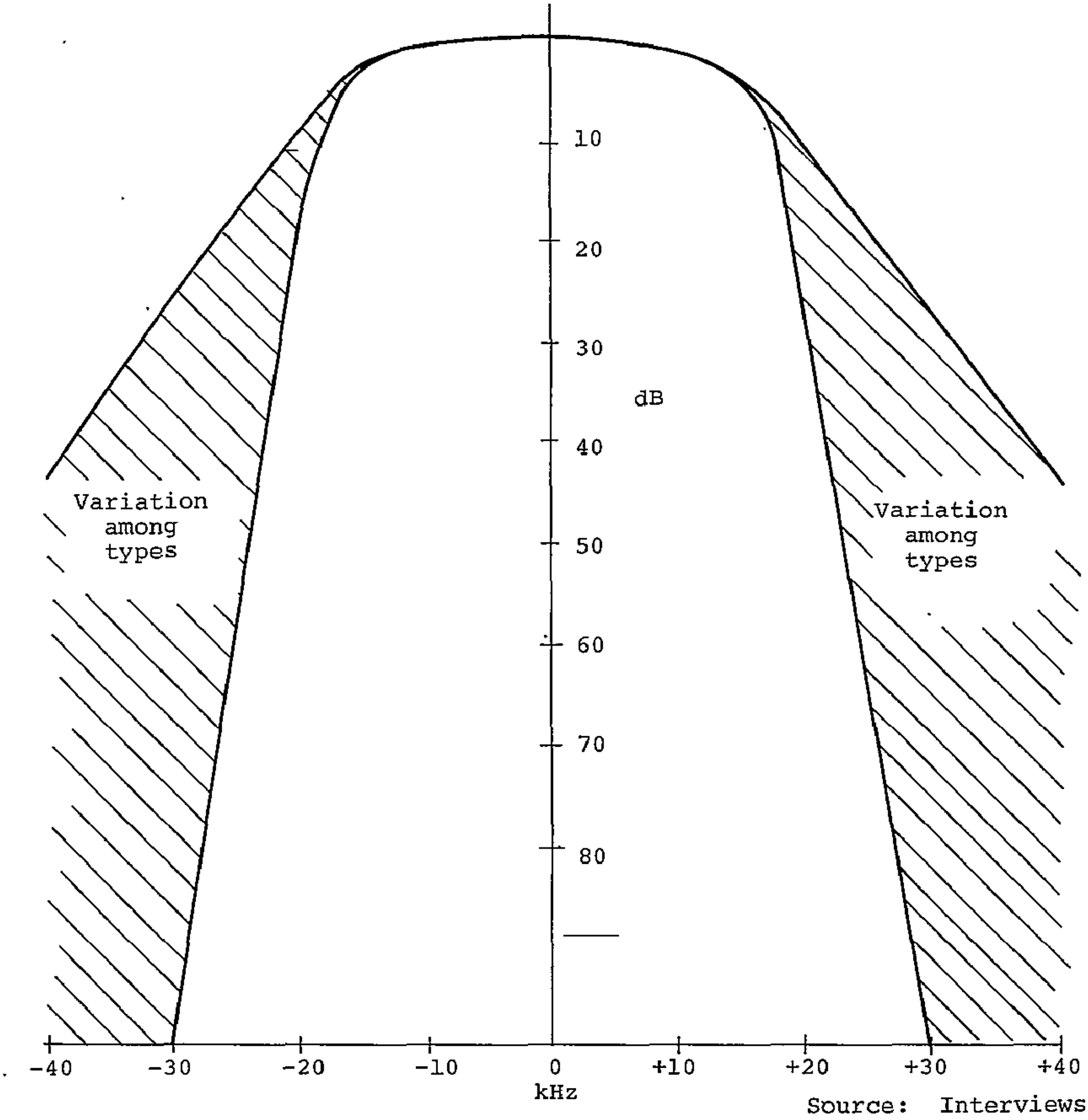


Figure A-3. Estimated Receiver Selectivity Characteristics of Some Typical General Aviation Receivers of the receivers being sold to general aviation at present ranges from 50 kHz wide at the 60-dB points to 100 kHz wide at the 60-dB points for some of the 100-kHz channeled equipment. The RTCA Report of SC 116A recommends minimum operating characteristics for general aviation, but it does not establish the receiver selectivity characteristics which are essential to more closely spaced frequency channels. For example, at 25 kHz away from the center frequency the response of good receivers is 60 dB down and that of the less expensive worst case receivers is only 20 dB down.

A.2 FREQUENCY CHANNELIZATION AND POWER

The aviation frequency assignments in the early forties were influenced by military equipment designed to 180-kHz channelization in the VHF band. The temporary nature of this early channelization was reflected by licensing footnotes, which indicated its interim use pending future study. As a result of government-industry agreement, particularly the work of Committee 11 of the Radio Technical Planning Board, the channelization was changed to a 100-kHz basis by March 1945. The frequency band available for aeronautical communications was then 118 to 132 MHz, with the segment from 127 to 132 MHz being utilized by air carriers. This allocation was continued in the Radio Regulations of Atlantic City (1947). As a result of a series of meetings between industry and the FAA in the 1958-1959 period, the air carrier's frequency space was shifted as part of a national plan to provide space for the developing air traffic control system. As part of this program, the Radio Regulations adopted at Geneva (1959) extended the aeronautical band to 136 MHz by allocations or by footnotes. As part of the implementing actions of the Geneva (1959) Radio Regulations, the channelization was established on a 50-kHz basis.

These actions were significant in the present situation because they resulted in a portion of air traffic control communications being activated on frequencies above 127 MHz. As a "grandfather clause" to existing general aviation, the FAA agreed to attempt "to the maximum extent" to adhere to the provision of IFR air traffic control for general aviation below 127 MHz, and on the 100-kHz channels. The difficulty appears to be in general aviation's long term interpretation of the transitional period and the lack of regulatory steps forcing a mandatory date for termination of 100-kHz channelization.

The air carriers, however, implemented the capability in 1960 for 50-kHz channelization; in fact, they are now able to go to a 25-kHz channelization.

Of the nine leading makes/models being purchased at present by general aviation, six are capable of 50-kHz channeling and three are 100-kHz channeling models. The only attraction in the 100-kHz channeling appears to be its cheaper price (approximately $200 on a base price of about $1000). Of these three, two are advertised as being convertible to 50-kHz channelization with simple modification (Reference 30).

The manufacturer of the popular NARCO series of aviation equipment states that 40 percent of his sales during 1969 was for the 100-kHz channelized version of his equipment.

Transmitter power of ground stations in the VHF aeronautical band are distributed as follows (Reference 31):

70 percent are 50 watts

23 percent are 10 watts

0.3 percent are less than 10 watts

1.4 percent are 25 watts

0.7 percent are 30 watts

0.5 percent are 15 watts

0.01 percent are 1 kilowatt (extended range)

Transmitter powers for aircraft are not specified except for judgment of reasonable and necessary power to maintain communications. Examination of "Equipment Acceptable for Licensing"* for type approval for aeronautical mobile use indicates the predominant power class as being 5- to 18-watts output with a few equipments available with up to 55 watts (e.g., Collins 17M-1).

A.3 FREQUENCY STABILITY

Frequency stability of the carrier frequency of each station in the Aviation Service licensed by the FCC must be maintained within the following percentage of the assigned frequency (Reference 3):

Land	0.003 percent
Aircraft	0.005 percent

The "Radio Equipment List of Equipment Suitable for Licensing"* contains 395 models which have been type approved for operation in the 108- to 136-MHz band subject to Part 87. (Separate power amplifiers were not included.). Of the equipment developing more than 100 watts, three have a listed tolerance of 0.002 percent and one has a tolerance of 0.003 percent.

Of the remaining 391 models of 50 watts or less, the following distribution of tolerances is listed:

Tolerance	Number of Equipment Types
0.0005	22
0.001	2
0.0015	8
0.002	31
0.003	42
0.004	12
0.005	274

*FCC, Office of the Chief Engineer, published March 13, 1970.

The equipment (50 watts or less) providing better than 0.005-percent tolerance comprises 30 percent of type approvals. Type equipment which equals or exceeds the tolerance of land stations (0.003) represents 26 percent of the total acceptable.

APPENDIX B

FREQUENCY ASSIGNMENT DATA

The frequency assignment data on the following pages was tabulated from records as of February 1970. The tabulation does not include Hawaii or blanket authorizations related to broad geographical areas. Aircraft frequency authorizations permit aircraft utilization of all channels as required by the aircraft, aircraft operating agency, or for Air Traffic Control. The aircraft licensed for radio transmissions total some 122,956, which would be distributed among these frequency channels.

FREQUENCY ASSIGNMENT DATA

Frequency Channel	Function & Allocation Notes	Ground Station Assignments	
		FAA	FCC
118.0	ATC, Enroute and Terminal	20	
118.05	"	1	
118.1	"	47	
118.15	"	3	
118.2	"	19	
118.25	"	1	
118.3	"	62	
118.35	"		
118.4	"	20	
118.45	"		
118.5	"	49	2
118.55	"	1	
118.6	"	17	
118.65	"	3	
118.7	"	48	
118.75	"	4	
118.8	"	19	2
118.85	"	2	
118.9	"	27	2
118.95	"	5	
119.0	"	17	
119.05	"		
119.1	"	33	
119.15	"		
119.2	"	24	
119.25	"	1	
119.3	"	33	
119.35	"	1	
119.4	"	17	
119.45	"	3	
119.5	"	39	
119.55	"	3	
119.6	"	13	
119.65	"	3	
119.7	"	29	
119.75	"	2	
119.8	"	16	
119.85	"	2	
119.9	" (1 KW,P.R.)	34	3
119.95	"	3	
120.0	"	28	1
120.05	"	3	
120.1	"	30	2
120.15	"	2	
120.2	"	20	
120.25	"		
120.3	"	27	
120.35	"	2	

FREQUENCY ASSIGNMENT DATA

Frequency Channel	Function & Allocation Notes	Ground Station Assignments	
		FAA	FCC
120.4	ATC, Enroute and Terminal	16	
120.45	"	1	
120.5	"	26	
120.55	"		
120.6	"	19	
120.65	"	2	
120.7	"	31	1
120.75	"	3	
120.8	"	15	1
120.85	"	2	
120.9	"	26	1
120.95	"		
121.0	"	14	
121.05	"	2	
121.1	"	34	
121.15	"		
121.2	"	18	1
121.25	"		
121.3	"	32	4
121.35	"	2	
121.4	"	4	
121.45	(Unassigned, Guard)		
@ 121.5	Emergency Frequency		
121.55	(Unassigned, Guard)		
@ 121.6	Utility, clearance & ground	20	34
@ 121.65	"	6	10
@ 121.7	"	122	168
@ 121.75	"	5	9
@ 121.8	"	31	98
@ 121.85	"	1	9
@ 121.9	"	264	373
@ 121.95	Utility, flight test West of Mississippi	3	10
@ 122.0	Flight service, simplex	15	
@ 122.05	"	2	
@ 122.1	FSS, receive (reply on VOR)		
@ 122.15	Flight service		
@ 122.2	Flight service	202	
@ 122.25	"		
@ 122.3	"	115	
@ 122.35	"		
@ 122.4	Tower receive, local		
@ 122.45	Flight service		
@ 122.5	Tower receive, local		
@ 122.55	Flight Service Station		
@ 122.6	FSS, simplex, general	375	
@ 122.65	Flight Service		
@ 122.7	Towers, receive		

@ non-ATC Channel

FREQUENCY ASSIGNMENT DATA

Frequency Channel	Function & Allocation Notes	Ground Station Assignments FAA	FCC
@ 122.75	Flight Service	1	
@ 122.8	Unicomm		1697
@ 122.85	Unicomm		20
@ 122.9	Multicomm		160
@ 122.95	Unicomm		4
@ 123.0	Unicomm		327
@ 123.05	Unicomm		95
@ 123.1	Flight test & Schools	3	94
@ 123.15	Flight test (manufacturers)		18
@ 123.2	Flight test	3	67
@ 123.25	Flight test		13
@ 123.3	Flight test & schools	6	272
@ 123.35	Flight test	1	18
@ 123.4	Flight test	2	
@ 123.45	Flight test	1	
@ 123.5	Flight test	7	
@ 123.55	Flight test	1	
123.6	Flight Service Stations	314	
123.65	Flight Service Stations	21	
123.7	ATC, Enroute & Terminal *	15	
123.75	" *	3	
123.8	" *	20	
123.85	" *	3	
123.9	" *	25	
123.95	" *	1	
124.00	"	21	
124.05	"	1	
124.1	"	22	
124.15	"	4	
124.2	"	18	
124.25	"	1	
124.3	"	14	
124.35	"	4	
124.4	"	19	
124.45	"	2	
124.5	"	18	
124.55	"	2	
124.6	"	25	
124.65	"	1	
124.7	"	22	
124.75	"	3	
124.8	"	17	
124.85	"	2	
124.9	"	19	
124.95	"	2	
125.0	"	18	
125.05	"	2	
125.1	"	21	
	* Exclude Extended Range		

@ non-ATC Channel

FREQUENCY ASSIGNMENT DATA

Frequency Channel	Function & Allocation Notes	Ground Station Assignments	
		FAA	FCC
125.15	ATC, Enroute & Terminal	5	
125.2	"	17	
125.25	"	1	
125.3	"	18	
125.35	"	3	
125.4	"	14	
125.45	"	2	
125.5	"	17	
125.55	"	1	1
125.6	"	16	
125.65	"	2	
125.7	"	14	
125.75	"	1	
125.8	"	27	
125.85	"	2	
125.9	"	19	
125.95	"	3	
126.0	"	20	
126.05	"	3	
126.1	"	14	
126.15	"		
126.2	Terminal	337	11
126.25	ATC, Enroute & Terminal		
126.3	"	20	1
126.35	"	1	
126.4	"	13	
126.45	"	4	
126.5	"	22	1
126.55	"	3	
126.6	"	20	
126.65	"	2	
126.7	"	16	
126.75	"	3	
126.8	"	13	
126.85	"	2	1
126.9	"	25	
126.95	"	6	
127.0	"	11	
127.05	"	7	
127.1	"	15	
127.15	"	5	
127.2	"	14	
127.25	"	7	
127.3	"	14	
127.35	"	5	
127.4	"	13	
127.45	"	5	
127.5	"	12	
127.55	"	7	

FREQUENCY ASSIGNMENT DATA

Frequency Channel	Function & Allocation Notes	Ground Station Assignments	
		FAA	FCC
127.6	ATC, Enroute & Terminal	11	
127.65	"	2	
127.7	"	17	
127.75	"	2	
127.8	"	9	
127.85	"	4	1
127.9	"	15	
127.95	"	3	
128.0	"	7	
128.05	"	6	
128.1	"	10	
128.15	"	7	
128.2	"	12	
128.25	"	3	
128.3	"	5	
128.35	"	4	
128.4	"	17	
128.45	"	5	
128.5	"	6	
128.55	"	9	
128.6	"	10	
128.65	"	5	
128.7	"	8	
128.75	"	6	
128.8	"	9	
@ 128.85	Air Carriers (ARINC)		5
@ 128.9	"		22
@ 128.95	"		13
@ 129.0	"		15
@ 129.05	"		21
@ 129.1	"		12
@ 129.15	"		9
@ 129.2	"		35
@ 129.25	"		7
@ 129.3	"		83
@ 129.35	"		4
@ 129.4	" (plus multi-carrier network, Alaska)	6	26
@ 129.45	Air Carriers (ARINC)		7
@ 129.5	"		43
@ 129.55	"		23
@ 129.6	"		40
@ 129.65	"		19
@ 129.7	"		18
@ 129.75	"		31
@ 129.8	"		73
@ 129.85	"		36
@ 129.9	"		36

@ non-ATC Channel

FREQUENCY ASSIGNMENT DATA

Frequency Channel	Function & Allocation Notes	Ground Station Assignments	
		FAA	FCC
@ 129.95	Air Carriers (ARINC)		11
@ 130.0	"		75
@ 130.05	"		47
@ 130.1	"		86
@ 130.15	"		4
@ 130.2	"		20
@ 130.25	"		8
@ 130.3	"		25
@ 130.35	"		10
@ 130.4	"		45
@ 130.45	"		10
@ 130.5	"		43
@ 130.55	"		17
@ 130.6	"		26
@ 130.65	"		7
@ 130.7	"		93
@ 130.75	"		6
@ 130.8	"		4
@ 130.85	"		9
@ 130.9	"		36
@ 130.95	"		15
@ 131.0	"		17
@ 131.05	"		6
@ 131.1	"		23
@ 131.15	"		12
@ 131.2	"		12
@ 131.25	"		64
@ 131.3	"		4
@ 131.35	"		6
@ 131.4	"		11
@ 131.45	"		9
@ 131.5	"		11
@ 131.55	"		3
@ 131.6	"		26
@ 131.65	"		8
@ 131.7	"		18
@ 131.75	"		51
@ 131.8	"		30
@ 131.85	"		37
@ 131.9	"		44
@ 131.95	"		12
@ 132.0	"		44
132.05	ATC, Enroute & Terminal	10	1
132.1	"	10	
132.15	"	13	
132.2	"	9	
132.25	"	8	
132.3	"	13	1

@ non-ATC Channel

FREQUENCY ASSIGNMENT DATA

Frequency Channel	Function & Allocation Notes	Ground Station Assignments FAA	FCC
132.35	ATC, Enroute & Terminal	4	
132.4	"	9	1
132.45	"	6	
132.5	"	11	
132.55	"	9	
132.6	"	8	
132.65	"	9	
132.7	"	10	
132.75	"	5	
132.8	"	5	
132.85	"	8	
132.9	"	5	
132.95	"	11	
133.0	"	13	
133.05	"	6	
133.1	"	4	
133.15	"	7	
133.2	"	6	
133.25	"	8	
133.3	"	6	
133.35	"	6	
133.4	"	11	
133.45	"	7	
133.5	"	7	
133.55	"	9	
133.6	"	6	
133.65	"	10	
133.7	"	7	
133.75	"	8	
133.8	"	9	
133.85	"	8	
133.9	"	6	
133.95	"	6	
134.0	"	2	
134.05	"		
134.1	Military	(68)	
134.15	ATC, Enroute & Terminal	3	
134.2	"	3	
134.25	"	11	
134.3	"	8	
134.35	"	9	
134.4	"	8	
134.45	"	10	
134.5	"	5	
134.55	"	8	
134.6	"	8	
134.65	"	12	
134.7	"	8	

FREQUENCY ASSIGNMENT DATA

Frequency Channel	Function & Allocation Notes	Ground Station Assignments FAA	FCC
134.75	ATC, Enroute & Terminal	13	
134.8	"	6	
134.85	"	8	
134.9	"	7	
134.95	"	10	
135.0	"	6	
135.05	"	5	
135.1	"	5	
135.15	"	8	
135.2	"	3	
135.25	"	10	
135.3	"	4	
135.35	"	4	
135.4	"	6	
135.45	"	9	
135.5	"	5	
135.55	"	9	
135.6	" (+ temp space test)	13	
135.65	"	11	
135.7	"	8	
135.75	"	6	
135.8	"	10	
135.85	Flight test terminals *		19
135.9	ATC, Enroute + tests #	8	
135.95	Flight test terminals *		19
	* Temp experimentals # NAFEC Tests with 2 KW		

APPENDIX C

G
FCC 70-163
43503

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D. C. 20554

In the Matter of Amendment of Parts 2, 81, 83 and 87 of the Commission's Rules and Regulations to sub-allocate, provisionally, the frequency band 1535-1660 MHz in the interest of fostering developmental programs for aeronautical and maritime purposes.	)	DOCKET NO. 18550
In the Matter of A petition for amendment of Parts 2 and 87 of the Commission's Rules and Regulations to provide for the use and development of an airborne collision avoidance system.	)	RM-1201

REPORT AND ORDER

Adopted: February 11, 1970; Released: February 13, 1970

By the Commission: Commissioner Johnson concurring in the result.

1. The Commission, on May 19, 1969, released a Notice of Proposed Rule Making in the above captioned proceeding which was published in the Federal Register on May 23, 1969 (FCC 69-512, 34 FR 8122). In response to a telegraphic request dated June 19, 1969 from Bonzer, Inc. the time for filing comments and reply comments was extended to July 7, 1969 and to July 17, 1969 respectively. No further requests for extension have been received.

2. Comments were filed by the following respondents:

Aeronautical Radio, Inc. and the Air Transportation Association of America (ARINC/ATA)
Aerospace and Flight Test Radio Coordinating Council (AFTRCC)
Bonzer, Inc. (Bonzer)
Communications Satellite Corporation (Comsat)
McDonnell Douglas Corporation (MDC)
TRW Systems Group of TRW, Inc. (TRW)

Reply comments were filed by ARINC/ATA and, on February 9, 1970, by In-Flight Devices Corporation (In-Flight).

3. The proceeding was initiated in response to a petition filed jointly by ARINC/ATA on September 15, 1967 requesting amendment of pertinent portions of Parts 2 and 87 of the Commission's Rules and Regulations to provide for the development and use of an aircraft collision avoidance system. Briefly, the Notice proposed provisional allocations for the use of space techniques in the bands 1535-1557.5 and 1637.5-1660 MHz; for glide slope operations in the band 1557.5-1567.5 MHz; and for development and operation of a collision avoidance system (CAS) in the band 1592.5-1622.5 MHz, with the remaining portions of the 1540-1660 MHz band continuing to be available for the aeronautical radionavigation service under presently prevailing national and international rules and regulations. It was pointed out also that, in the Fourth Notice of Inquiry, Docket 18294,1/ the Commission is proposing to expand the 1540-1660 MHz band to 1535-1660 MHz and to sub-allocate the band so that the segments 1535-1557.5 MHz and 1637.5-1660 MHz would be available exclusively for the application of space techniques. If, within a reasonable period of time, systems develop as expected in the bands, the "provisional" connotation would be removed.

4. Comments in response supported the proposal to provide exclusive portions of the 1535-1660 MHz band in which the different systems could be developed and to accommodate development of the collision avoidance system in the 1592.5-1622.5 MHz portion, allowing time for transition of existing systems to new bands. MDC, in view of its past experience with numerous frequency changes and heavy investment in the EROS (Eliminate Range Zero System) and EROS II Aircraft Collision Avoidance Systems, wishes to be assured the Commission will provide a more permanent status to a more fully developed CAS than the term "provisional" implies.

5. Bonzer, Inc., a manufacturer of radar altimeters in the 1630 MHz band, does not believe an interference problem exists between its system and the present CAS band of 1567.5-1597.5 MHz; therefore it expressed some doubt regarding the need for the reallocation proceeding. However, admitting its lack of expertise with respect to the glide slope and space programs, Bonzer is willing to accept the proposed change for radio altimeters to the 4200-4400 MHz band on an exclusive basis contingent upon a reasonable time to develop solid state devices in the higher band.

6. The area of greatest controversy was centered on the use of the bands 1535-1557.5 and 1637.5-1660 MHz for space techniques. ARINC/ATA comments, supported by AFTRCC and MDC, continue to oppose (as set forth in responses to the Third, Fourth and Fifth Notices of Inquiry in Docket 18294) the sharing by other radio services of frequency bands allocated to the aeronautical services. Consequently, the proposal to share the 1535-1557.5 and 1637.5-1660 MHz bands, reserved for space

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1/In the Matter of:
An Inquiry relating to preparation for a World Administrative Radio Conference of the International Telecommunication Union on matters pertaining to the radio astronomy and space services.

techniques, between the aeronautical and maritime mobile services, was opposed. Instead, ARINC/ATA, recognizing a possible need in the band for maritime space communication techniques, proposed exclusive allocations between 1535-1537.5 and 1637.5-1640 MHz for the maritime mobile service.

7. Comsat, on the other hand, and, consistent with their comments filed in Docket 18294, believed that maximum flexibility should be afforded development of the space systems in the 1535-1660 MHz band and that further sub-division or restrictions imposed on the 1535-1557.5 and 1637.5-1660 MHz bands would serve no useful purpose. Comsat further indicated that, if it were determined that such sub-designations were necessary, a common satellite translation frequency should be provided in order to avoid a complicated satellite design problem. To provide such a common frequency, Comsat proposed an exchange of the aeronautical and maritime up-link bands. This would have the added advantage of providing greater protection to the CAS receiver in the event it were operating in a CAS/satellite environment simultaneously. Comsat also requested clarification of the proposed footnotes 352E and 352F to permit transmission of both ground to satellite communication and radiodetermination signals.

8. TRW Systems supported the proposal to remove the availability of the 1540-1660 MHz band for radio altimeters and recommended that transition to the 4200-4400 MHz band be made expeditiously unless the deadline were set after 1973. TRW also cited design studies relating to satellite-based navigation and control systems and recommended that separate sub-bands be allocated for satellite to aircraft and aircraft to satellite transmissions in view of the low power margins feasible in a navigation satellite system.

9. In their Reply Comments, ARINC/ATA, although recognizing that the subject was not germane to the forthcoming WARC of the ITU, recommended that negotiations be initiated to achieve international acceptance and compatibility of the CAS. ARINC/ATA, while agreeing with Comsat's proposal regarding a common translation frequency, continue to reiterate their opposition to sharing between the aeronautical and maritime mobile services of the two bands proposed for allocation for space techniques.

10. In-Flight Corporation filed comments with the Commission on February 9, 1970, nearly seven months after the deadline for filing comments had passed. In-Flight requested the Commission hold a public hearing in order to receive information relative to the possibility of interference being created by other proposed services to radar altimeters in the 1540-1660 MHz band and to the marketing impact which the proposed action would have on general aviation aircraft operations.

11. On review and analysis of the comments, as well as other relevant information, the Commission believes adoption of the original proposals with minor modifications, would be in the public interest. Comments from the aviation industry overwhelmingly support the opportunity to develop an airborne collision avoidance system in an interference-free environment in the 1592.5-1622.5 MHz band. No opposition was expressed to accommodation of the glide slope in the band 1557.5-1567.5 MHz.

12. With respect to reaccommodating the radio altimeter function, no problems are foreseen so long as ample time is permitted to make the transition to the 4200-4400 MHz band. In this connection, it is believed appropriate that no new altimeters be authorized in the band 1540-1660 MHz after January 1, 1971,[2/] however, those devices already authorized should be permitted to operate. Such operation will be permitted to continue for an unspecified period, recognizing that it may be necessary to establish a termination date for such devices in the future. Footnote US-39 is retained unchanged except to reflect the greater overall band 1535-1660 MHz in lieu of 1540-1660 MHz.

13. With regard to the proposed reservation of the 1535-1557.5 and 1637.5-1660 MHz bands for space techniques, we do not find the arguments of ARINC/ATA opposing the sharing by other radio services of frequency bands allocated to the aeronautical service to be persuasive. No technical justification or rationale has been submitted nor is the Commission aware of any study or other data at this time which would support such a position. As stated in paragraph 24 of the Fifth Notice of Inquiry, Docket 18294 relative to the same general comments, "...If sweeping unsupported objections such as these were permitted to prevail, and all services voiced similar objections such as these the Table of Frequency Allocations would be a static description of services to which the radio spectrum had been allocated initially, rather than the dynamic structure it must be to meet the changing needs of all services..."

14. In this connection, the Commission concurs with the comments of Comsat that maximum flexibility should be retained for space systems in the proposed bands and proposes no subdivisions at this time other than those set out in the original notice. When viable space systems have been developed and sufficient experience has been gained to determine the extent of compatibility and/or requirements of the maritime and aeronautical mobile services, the matter may be reconsidered. A uniform translation could then be utilized if a joint satellite were launched; conversely, if exclusive satellites were used, no translation commonality would be required. Accordingly, the Commission believes the 1535-1557.5 and 1637.5-1660 MHz bands should be reserved for space techniques as proposed in this proceeding and as set forth in the Preliminary Views of the U.S.A. with respect to the 1971 Space Conference.

2/ After the effective date of this Report and Order, applications for type acceptance of new altimeters to operate within the frequency range 1540-1660 MHz will not be accepted.

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15. With regard to the proposed footnotes 352E and 352F, the Commission agrees with Comsat that clarification is in order. These notes, which are included in the Appendix, have been rewritten to make it clear that use between ground stations and satellites, as well as between mobile stations and satellites is intended. Provision has also been made for direct ground-to-aircraft communication where all stations concerned are part of the "space technique" system or interface therewith.

16. Aside from the fact that the request by In-Flight was neither timely filed nor did it contain any substantiating data, it should be pointed out that the question of interference has been considered not only by ARINC/ATA in an experimental program extending back to 1956 and which resulted in the original petition, but, since the band 1540-1660 MHz is shared jointly between the Government and non-Government services, by Executive Branch Agencies as well. Ample evidence has been amassed to resolve to our satisfaction the question of potential harmful interference during the transition period.

17. As pointed out earlier, Bonzer, Incorporated, a competitor of In-Flight, apparently anticipates no marketing problems subject to adequate time to develop devices in the 4200-4400 MHz band. In view of the above, the request for public hearing would appear to serve no useful purpose since it does not appear that information not already considered would be added. Accordingly, the request is denied.

18. In view of the foregoing, IT IS ORDERED, That pursuant to the authority contained in Sections 4(i) and 303(c), (e) and (r) of the Communications Act of 1934, as amended, Parts 2, 81, 83 and 87 of the Commission's Rules ARE AMENDED effective April 1, 1970, as set forth in the attached Appendix.

19. IT IS FURTHER ORDERED, That the proceedings in Docket 18550 ARE HEREBY TERMINATED.

FEDERAL COMMUNICATIONS COMMISSION

Ben F. Waple
Secretary

Attachment: Appendix

NOTE: Rules changes herein will be covered by T.S. II(69)-2, T.S. IV(64)-17, and T.S. V(70)-1.

APPENDIX

§ 2.106 [Amended]

1. Section 2.106, Table of Frequency Allocations, is amended with respect to columns 5 through 11, in the frequency band 1535-1660 MHz, to read as follows:

Band (MHz) 5	Allocation 6	Band (MHz) 7	Service 8	Class of Station 9	Frequency (MHz) 10	Nature (OF (SERVICES (of stations 11
1535-1537.5	G, NG. (352E)(US39)	1535-1537.5	MARITIME MOBILE. Aeronautical mobile (R).	Satellite-borne.		MOBILE using space techniques. (Provisional)
1537.5-1557.5	G, NG. (352E)(US39)	1537.5-1557.5	AERONAUTICAL MOBILE (R). Maritime mobile.	Satellite-borne		MOBILE using space techniques. (Provisional)
1557.5-1567.5	G, NG. (352A)(352B) (US39)	1557.5-1567.5	AERONAUTICAL RADIONAVIGATION.	Radionavigation land.		Glide path. (Provisional)
1567.5-1592.5	G, NG. (352A)(352B) (US39)	1567.5-1592.5	AERONAUTICAL RADIONAVIGATION.			
1592.5-1622.5	G, NG. (352A)(352B) (US39)(US39A)	1592.5-1622.5	AERONAUTICAL RADIONAVIGATION.	Radionavigation land. Radionavigation mobile.		Collision avoidance. (Provisional)
1622.5-1637.5	G, NG. (352A)(352B) (US39)(US39A)	1622.5-1637.5	AERONAUTICAL RADIONAVIGATION.			
1637.5-1657.5	G, NG. (352F)(US39) (US39A)	1637.5-1657.5	AERONAUTICAL MOBILE (R). Maritime mobile.			MOBILE using space techniques. (Provisional)
1657.5-1660	G, NG. (352F)(US39) (US39A)	1657.5-1660	MARITIME MOBILE. Aeronautical mobile (R).			MOBILE using space techniques. (Provisional)

2. In the list of Geneva Footnotes following the Table, modify the texts of 352A and 352B to read as follows:

352A The bands 1540-1660, 4200-4400, 5000-5250 MHz and 15.4-15.7 GHz are reserved on a worldwide basis, for the use and development of airborne electronic aids to air navigation and any directly associated ground-based or satellite-borne facilities. [The Fifth Notice of Inquiry, Docket No. 18294, proposes reducing the band 1540-1660 MHz to 1557.5-1637.5 MHz. This will be reviewed after the 1971 ITU Space Conference.]

352B The bands 1540-1660, 5000-5250 MHz and 15.4-15.7 GHz are also allocated to the aeronautical mobile (R) service for the use and development of systems using space communication techniques. Such use and development is subject to agreement and coordination between administrations concerned and those having services operating in accordance with the Table, which may be affected. [The Fifth Notice of Inquiry, Docket No. 18294, proposes reducing the band 1540-1660 MHz to 1557.5-1637.5 MHz. This will be reviewed after the 1971 ITU Space Conference.]

3. Add new footnotes 352E and 352F, reading as follows:

352E Limited to transmissions from satellite-borne stations to stations in the aeronautical mobile (R) and maritime mobile services for communication and/or radiodetermination purposes. Transmissions from terrestrial aeronautical stations directly to aircraft stations in the aeronautical mobile (R) service are also permitted when such aeronautical stations are utilized to augment and/or interface with the satellite-to-aircraft links. [The Fifth Notice of Inquiry, Docket No. 18294, proposes international adoption of this new footnote. This will be reviewed after the 1971 ITU Space Conference.]

352F Limited to transmissions from stations in the aeronautical mobile (R) and maritime mobile services to satellite-borne stations for communications and/or radiodetermination purposes. Transmissions from aircraft stations in the aeronautical mobile (R) service directly to terrestrial aeronautical stations are also permitted when such aeronautical stations are utilized to augment and/or interface with the aircraft-to-satellite links. [The Fifth Notice of Inquiry, Docket No. 18294, proposes international adoption of this new footnote. This will be reviewed after the 1971 ITU Space Conference.]

4. In the list of US Footnotes, modify the text of US39, add US39A and modify the text of US47, respectively, to read as follows:

US39 Within the band 1535-1660 MHz, radio altimeters are permitted to use only the portion 1600-1660 MHz and then only until such time as international standardization of other aeronautical radionavigation systems or devices require the discontinuance of radio altimeters in this band.

US39A The band 1592.5-1622.5 MHz is allotted provisionally, but on a primary basis, for the collision avoidance function, noting the continued use of existing altimeters in the band 1600-1660 MHz.

US47 **The band 4200-4400 MHz is reserved exclusively for radio altimeters.**

APPENDIX D

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APPENDIX E

ORGANIZATIONAL CONTACTS

National Aeronautics and Space Agency (NASA)

Federal Aviation Administration (FAA)

Federal Communications Commission (FCC)

Radio Technical Commission for Aeronautics (RTCA)

Interagency Group on International Aviation (IGIA)

Department of the Air Force, Frequency Office

International Civil Aviation Organization, Frequency Office

Office of Telecommunications Policy (OTP)

Electromagnetic Compatibility Analysis Center (ECAC)

Aircraft Owners and Pilots Association (AOPA)

General Aviation Manufacturers Association

Electronic Industries Association

National Business Aircraft Association

Aircraft Electronics Association

National Aeronautical Corporation