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SPECTRUM RESOURCE ASSESSMENT OF THE AERONAUTICAL MOBILE SERVICE BETWEEN 400 MHz AND 17.7 GHz

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ABSTRACT

This report is a spectrum resource assessment of the Aeronautical Mobile Service between 400 MHz and 17.7 GHz, which addresses the long-range planning of this service. It presents an assessment of 15 Federal Government frequency bands that are allocated to the Mobile or Aeronautical Mobile Services. Other bands containing aeronautical mobile activities are also reviewed. Included is information on allocations, technical standards, frequency assignments, and system characteristics. The future growth possibilities of the Aeronautical Mobile Service in the various bands is presented. The 4400-4900 MHz band was analyzed in detail to determine the sharing possibilities between the Fixed Service (point-to-point microwave and troposcatter communications systems) and aeronautical systems. The analysis indicates that sharing between such systems and aeronautical systems is feasible.

KEY WORDS

Spectrum Resource Assessment
Aeronautical Mobile Service
Spectrum Management
Spectrum Sharing
400 MHz-17.7 GHz

SECTION 1

INTRODUCTION

BACKGROUND

The National Telecommunications and Information Administration (NTIA) is responsible for managing the radio spectrum allocated to the U.S. Federal Government. Part of NTIA's responsibility is to "...establish policies concerning spectrum assignment, allocation and use, and provide the various Departments and agencies with guidance to ensure that their conduct of telecommunications activities is consistent with these policies" (Department of Commerce, 1978). In support of these requirements, NTIA has undertaken a number of spectrum resource assessments. The objectives of these studies are to assess spectrum utilization, identify existing or potential compatibility problems between systems of various departments and agencies, provide recommendations for resolving any compatibility conflicts, and recommend changes to improve spectrum management procedures.

This report presents a study of the Aeronautical Mobile Service between 400 MHz and 17.7 GHz, which addresses long-range planning issues. The systems operating under the Aeronautical Mobile Service allocation or under the more general Mobile Service allocation, but used in both ground and aeronautical environments, generally provide nonvoice communications and are usually referred to as telemetry, data, video, or command links. Typical applications are at test ranges where data is telemetered from a device undergoing tests to a central control or data recording area. Another application is military operations in tactical scenarios where information concerning the status of a system or externally collected information is transmitted over a communications channel, normally referred to as a data link.

Emerging technologies such as spread spectrum modulation and packet radio are either currently developed for airborne applications or most likely will be in the future. Some of this technology is being used in the multifunction types of systems that provide voice communications in digitized form and navigational data. An assessment is required to examine these emerging technologies, together with the appropriate frequency bands in order that the spectrum resource is used in the most judicious way possible.

The overall reason for undertaking this assessment is that aeronautical systems can be used in many bands above 400 MHz, some of which are becoming congested. It is necessary to study them as a whole to obtain a broad perspective and weigh the many facets of efficiently managing the spectrum and ensuring that adequate spectrum is available for the long-range planning of the Aeronautical Mobile Service. Aeronautical mobile systems can operate at high altitudes and consequently can cause potential interference problems to equipment within line-of-sight range of the airborne equipment. The more specific reasons are the following.

1. Some frequency bands currently used for aeronautical mobile are becoming increasingly congested.

2. Many different types of systems are being used for aeronautical mobile and new systems are currently under development. New technologies will result in new applications using the Aeronautical Mobile Service.

3. Aeronautical systems often present greater compatibility problems because of operation at high altitudes that present line-of-sight coupling conditions over very wide areas.

4. The 1979 World Administrative Radio Conference (WARC-79) made changes to the allocation tables dealing with the Aeronautical Mobile and Mobile Services between 400 MHz and 17.7 GHz.

OBJECTIVES

The overall objective of this assessment was to assist in the development of spectrum plans and policies for the Aeronautical Mobile Service between 400 MHz and 17.7 GHz. The specific objectives were to:

1. identify the frequency bands between 400 MHz and 17.7 GHz used for aeronautical mobile activities

2. identify and categorize existing and planned systems operating in the Aeronautical Mobile Service between 400 MHz and 17.7 GHz and those Mobile Service systems operating between 400 MHz and 17.7 GHz in the airborne mode

3. identify and document existing and potential spectrum management and electromagnetic compatibility problem areas that may have an impact on the efficient use of the spectrum.

APPROACH

In order to accomplish the objectives of the spectrum resource assessment, the following approach was taken.

1. Existing and planned systems and associated technical characteristics were identified by using the Government Master File (GMF), the non-Government Master File (NGMF), previous NTIA reports, and other reports to determine frequency assignments, assignment trends, and usage for Government and non-Government operations.

2. Future aeronautical mobile systems were identified by using the information submitted to the Interdepartment Radio Advisory Committee (IRAC) systems review process for Government equipment.

3. Existing reports that address aeronautical mobile spectrum management and electromagnetic compatibility issues were reviewed.

4. Potential spectrum management and compatibility problems of the Aeronautical Mobile Service were identified for further study.

5. New technologies that may impact future spectrum usage and that require spectrum planning were identified.

6. A technical basis for future planning of the spectrum was established using engineering solutions to potential problems.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

GENERAL CONCLUSIONS

An examination was made of the various frequency bands used for aeronautical mobile activities between 400 MHz and 17.7 GHz summarizing the associated rules and regulations and current usage. It also examined possible future uses of the bands. The sharing of the 4400-4990 MHz band between the Aeronautical Mobile Service and the Fixed Service was analyzed as a specific example.

The allocations of several bands that are related to the Aeronautical Mobile Service were changed as a result of WARC-79. Careful management and planning is necessary to ensure that efficient use is made of the spectrum. The long-range planning must take into consideration the WARC-79 changes, the impact on the bands where the changes were made, and the collective impact on the Aeronautical Mobile Service as a whole.

There is a trend towards increased aeronautical communications use of frequency bands that are allocated for other than communication services such as radionavigation and radiolocation. Examples are Joint Tactical Information Distribution System (JTIDS), Position Location Reporting System (PLRS), and the Air Force Wideband Data Link. Some of these systems have encountered lengthy coordination problems in obtaining spectrum support.

SPECIFIC CONCLUSIONS

The assessment of the Aeronautical Mobile Service above 400 MHz was conducted by examining frequency bands between 400 MHz and 17.7 GHz allocated to aeronautical mobile activities and by examining other bands where significant aeronautical mobile activities are taking place. TABLE 1 presents an assessment by comparison of the future growth possibilities of the Aeronautical Mobile Service in the various bands. The usage, allocations, potential interference situations, and the potential for expanded aeronautical activities are summarized in the following subsections.

406.1-420 MHz Band

The 406.1-420 MHz band is primarily used by fixed and land mobile communications. The airborne activities in this band are usually in support of land mobile activities. Other airborne activities include a limited amount of military use, such as flight termination and drone control. A previous spectrum resource assessment (Crandall, 1982) did not identify any problems specifically associated with the Aeronautical Mobile Service. Because of the extensive and growing use by Fixed and Land Mobile Services, accommodating increased use by unique aeronautical mobile activities is limited.

TABLE 1

BAND ALLOCATIONS AND EXPANSION POTENTIAL

BAND	Mobile or Aeronautical Mobile Allocation	Potential for Future Expansion of Aeronautical Mobile Activities	Comments
1. 406.1-420 MHz	Primary	Poor	Band is used extensively by Land Mobile and Fixed Service.
2. 902-928 MHz	Secondary	Poor to Moderate	Radiolocation and industrial, scientific, and medical (ISM) usage is increasing.
3. 1350-1400 MHz	Secondary	Poor to Moderate	Secondary allocation to radiolocation and radioastronomy activities limit growth potential.
4. 1429-1435 MHz	Primary	Good	Offers good potential, especially for telecommand functions.
5. 1435-1530 MHz	Primary	Moderate	Current use for Aeronautical telemetry is extensive, thus limiting future growth.
6. 1530-1535 MHz	Secondary	Poor to Moderate	Future maritime mobile-satellite usage limits growth potential.
7. 1710-1850 MHz	Primary	Moderate	Band is used extensively by various types of fixed, mobile, and space systems.
8. 2200-2290 MHz	Primary	Moderate	Current activities limit growth potential.
9. 2300-2310 MHz	Secondary	Poor	Footnote US253 protecting Amateur Service from Mobile limits growth.
10. 2310-2390 MHz	Primary	Good	Local coordination and good technical standards would enhance growth potential.for aeronautical telemetry and telecommand.
11. 4400-4990 MHz	Primary	Good	4400-4500 and 4800-4900 MHz portions offer good potential for future growth.
12. 14.4-14.5 GHz	Secondary	Poor	Secondary allocation and future satellite activities limit growth potential.
13. 14.5-14.7145 GHz	Secondary	Poor	Secondary allocation and emphasis on Fixed Service limit growth potential.
14. 14.7145-15.1365 GHz	Primary	Good	Primary allocation, low activity, and 422 MHz availability indicate good growth potential.
15. 15.1365-15.35 GHz	Secondary	Poor	Secondary allocation and expected growth of the Fixed Service limits growth potential.

902-928 MHz Band

The Mobile Service is allocated to the 902-928 MHz band on a secondary basis under the purview of U.S. Government Footnote G11. The 902-928 MHz band is used for the Radiolocation and Fixed Services and most likely will see expanded use by these services in the future. The frequency 915 ± 13 MHz is designated for industrial, scientific, and medical (ISM) purposes. These factors all tend to make this band unattractive for use by expanded aeronautical activities.

1350-1400 MHz Band

The 1350-1400 MHz band is allocated to the Radiolocation Service on a primary basis and to the Fixed and Mobile Services on a secondary basis. This band has 108 Federal Government assignments, 26 of which are radar systems. The 26 radar assignments represent many equipments. The military services are the main users of this band. This band has the potential for accommodating expanded aeronautical activities, although such use would be on a secondary basis to radar systems operating in this band.

1429-1435 MHz Band

The major user of the 1429-1435 MHz band is the Navy, with 74 of the 133 total assignments in the band. Those 74 are mainly for telecommand systems in support of missile programs. This band offers good potential for accommodating the future growth of military aeronautical mobile activities, especially for telecommand functions.

1435-1530 MHz Band

This band is used extensively for flight-test telemetry systems. There are over 600 telemetry-related assignments in this band with military services, Department of Energy, NASA, and non-Government being the major users. It is well managed, largely due to coordination effected through the joint efforts of the area frequency coordinators and the Aerospace and Flight Test Radio Coordinating Council (AFTRCC). Based on its extensive use, this band provides moderate opportunity for accommodating future growth of flight-test telemetry and other limited aeronautical mobile applications.

1530-1535 MHz Band

The 1530-1535 MHz band has 38 assignments, 31 of which are telemetry-related and used by the Air Force and Navy. The Mobile Service allocation has been downgraded to secondary, with the Maritime Mobile-Satellite Service being primary. This band may remain available for aeronautical mobile activities in the interior of the United States, away from the coastlines where maritime mobile-satellite systems would be expected to operate.

1710-1850 Mhz Band

This band is heavily used for the fixed microwave systems, aeronautical mobile, and space uses. Potential coordination problems have been encountered, and this band has been the subject of a previous assessment report. There has

been extensive growth in the band in recent years. The current rate of assignment growth is 10 percent annually and is increasing. This band has a moderate potential for accommodating the expansion of aeronautical activities. The Spectrum Planning Subcommittee (SPS) is addressing a recommendation to restructure this band through use of a channel plan or other methods.

2200-2290 MHz Band

This band is extensively used for aeronautical telemetry and has been the subject of a previous assessment. A real-time frequency coordination procedure has been implemented in some western states. Manned-flight-test telemetry is restricted from this band. Removal of the restriction would provide increased flexibility and could relieve some congestion in other bands over the long term.

2300-2310 MHz Band

The United States allocates the 2300-2310 MHz band to the Federal Government Radiolocation Service on a primary basis and to Federal Government Fixed and Mobile Services, and non-Government Amateur Service on a secondary basis. Applicable, also, to this band is U.S. Footnote US253 that states Fixed and Mobile Services shall not cause harmful interference to the Amateur Service. This footnote's specified limitations on the Mobile Service are the main reason that widespread aeronautical activities in the band would not be expected. Thus, this band has poor potential for accommodating future aeronautical mobile activities.

2310-2390 MHz Band

The U.S. input to WARC-79 for the addition of the Mobile Service on a primary basis to this band was generated in part by the requirements of aeronautical telemetry. The allocation change resulting from WARC-79 provides room for accommodation of the expansion of the aeronautical telemetry and associated telecommand functions.

4400-4990 MHz Band

This band is used for point-to-point microwave and troposcatter systems. The analysis indicates that sharing between such systems and aeronautical systems is feasible in some cases. Thus, this band offers potential for accommodating expanded use by aeronautical systems, particularly in the 4400-4500 and 4800-4990 MHz segments. The addition of the Fixed-Satellite Service allocation to the 4500-4800 MHz segment may present sharing problems near future earth stations using this band, although airborne activities could be conducted inland if the satellite earth stations are located in coastal areas.

14.4-14.5 GHz Band

There are no assignments associated with aeronautical mobile activities in the 14.4-14.5 GHz band. The U.S. allocation of the Mobile Service in this band has been reduced to secondary. This status, together with radio-astronomy observations at 14.489 GHz, will limit the growth of aeronautical mobile activities use in this band.

14.5-14.7145 GHz Band

The 14.5-14.7145 GHz band contains 154 assignments, the majority of which are to fixed stations (64 assignments) and experimental testing stations (69 assignments). The Mobile Service has a secondary allocation in this band. The Fixed Service, as the only primary allocation, will provide the framework for accommodating additional growth of fixed station activities in the band.

14.7145-15.1365 GHz Band

The United States allocates the 14.7145-15.1365 GHz band exclusively to the Federal Government, with the Mobile Service being the only primary allocation. There are 249 assignments in this band with the Fixed Service the heaviest user with 130 assignments. There are 87 experimental testing assignments in this band, some of which are associated with land mobile activities. This band is considered to have good potential for accommodating future expansion of aeronautical mobile activities.

15.1365-15.35 GHz Band

The 15.1365-15.35 GHz band contains 89 Federal Government assignments and 35 non-Government assignments. Forty-one Federal Government assignments are to fixed stations with 30 assignments to the FAA. This band is allocated to the Fixed Service on a primary basis and to the Mobile Service on a secondary basis. This band will most likely see increased use by the Fixed Service. Radio-astronomy observations, as provided for in U.S. Footnote US211, may also impede the growth of aeronautical mobile activities use. This band is considered to have poor potential for accommodating future expansion of aeronautical mobile activities.

Technical Standards

A review of the pertinent technical standards indicates that existing standards are adequate for the spectrum management of the bands examined.

RECOMMENDATIONS

The following are NTIA staff recommendations, based on the technical findings contained in this report. Any action to implement these recommendations will be accomplished under separate correspondence by modification of established rules, regulations, or procedures.

It is recommended that:

1. the 4400-4500 MHz, 4800-4990 MHz, and 14.7145-15.1365 GHz bands are the bands preferred for use by newly developing aeronautical communicatons systems, particularly those employing spread-spectrum modulation techniques

2. the 1429-1435 and 2310-2390 MHz bands be used for aeronautical telecommand and telemetry respectively, and incorporated into those portions of the NTIA Manual that provide for local coordination of the bands

3. because of the accelerated growth of Fixed Service usage, other bands should be considered for accommodating aeronautical mobile activities before the 1710-1850 MHz band is considered

4. long-range planning efforts should include consideration of the removal of the manned-flight telemetry restriction in the 2200-2290 MHz band in order to provide flexibility in frequency assignments and relieve congestion in other bands, which may be encountered in the future

5. future use by multifunction systems whose primary function is communications should only be developed in bands allocated to communications-types of services (IRAC committee Ad Hoc 182 is addressing this recommendation)

6. a list of preferred frequency bands for aeronautical mobile uses should be incorporated in the NTIA Manual. (See Recommendations 1 and 2.)

SECTION 3

RULES AND REGULATIONS

REGULATORY OVERVIEW

This section presents the rules and regulations pertinent to the Aeronautical Mobile Service above 400 MHz. The Federal Government radio spectrum activities are governed by the regulations and procedures as presented in the Manual of Regulations and Procedures for Federal Radio Frequency Management (referenced as NTIA (1982) and hereafter referred to as the NTIA Manual). The non-Government users (actually non-Federal Government users because states and municipalities are covered under the term "non-Government") are governed by the Federal Communications Commission in their Rules and Regulations.

This section presents the definitions, technical standards, and frequency bands that were analyzed. Regulatory aspects unique to the Aeronautical Mobile Service are also presented.

ALLOCATIONS

The international and national tables of frequency bands allocated to the Aeronautical Mobile Service above 400 MHz and below 17.7 GHz are presented in APPENDIX A. The tables also include those frequency bands where the Aeronautical Mobile Service is not specifically allocated, but which were identified as having signigicant airborne communications activities. Footnotes impacting, or pertaining to, aeronautical mobile activities are also included in APPENDIX A.

TABLE 2 presents the aeronautical mobile allocations, or the mobile allocations, in the range 400 MHz - 17.7 GHz. This report will concentrate on those bands that are allocated to the Federal Government, either on a shared or exclusive basis. Other bands where substantial aeronautical communications activity is evident are also addressed.

The entire frequency spectrum between 400 MHz and 17.7 GHz was reviewed for airborne communications activities. (Airborne satellite activities were not considered because they will be addressed in a separate assessment in the future.) Frequency bands, in addition to those presented in TABLE 2, are discussed in the text when significant airborne activity was identified.

UNIQUE REGULATORY ASPECTS

Area Frequency Coordination

The 1435-1535 MHz frequency band is used extensively for telemetry at aircraft test ranges. The local selection of frequencies by the particular test range frequency manager is permitted following the procedures delineated in Annex D, "Procedure for Field Level Selection and Coordination of the Use of Radio Frequencies," of the NTIA Manual. The purpose of this procedure is to provide for the local selection of frequencies and to minimize, through effective

TABLE 2

MOBILE OR AERONAUTICAL MOBILE ALLOCATIONS IN THE UNITED STATES
ABOVE 400 MHz AND BELOW 17.7 GHz

No.	Band (MHz)	U.S.	Allocation
1.	406.1-420*	G	Primary
2.	902-928	G	Secondary
3.	1350-1400	G	Secondary
4.	1429-1435	G,NG	Primary
5.	1435-1530	G,NG	Primary
6.	1530-1535	G,NG	Secondary
7.	1710-1850	G	Primary
8.	1990-2110	NG	Primary
9.	2200-2290	G	Primary
10.	2300-2310	G,NG	Secondary
11.	2310-2390	G,NG	Primary
12.	2450-2500	NG	Primary
13.	4400-4990	G	Primary
14.	6425-6525	NG	Primary
15.	6875-7075	NG	Primary
16.	7075-7125	NG	Primary
17.	12.7-12.75 GHz	NG	Primary
18.	12.75-13.25	NG	Primary
19.	14.4-14.5	G	Secondary
20.	14.5-14.7145	G	Secondary
21.	14.7145-15.1365	G	Primary
22.	15.1365-15.35	G	Secondary

Abbreviation Key:

G = Federal Government exclusive allocation
NG = non-Government exclusive allocation
G,NG = shared between Federal Government and non-Government

*Specific channels are designated for shared Government and non-Government use.

Note: See APPENDIX A to identify services other than mobile or aeronautical mobile that may also share these bands.

coordination, the possibility of harmful interference. Annex D of the NTIA Manual presents the names and addresses of the Area Frequency Coordinators (AFCs) and their area of responsibility.

The procedure is to conclude area coordination before the application for frequency assignment is submitted to the Frequency Assignment Subcommittee (FAS). Coordination is also required with the Aerospace and Flight Test Radio Coordinating Council (AFTRCC) currently located at the Northrop Corporation in California.

The AFTRCC has been recognized by the FCC as the frequency coordinating advisory committee for flight test frequencies authorized for use under Part 87, Subpart G of the FCC Rules. The AFTRCC is a trade organization of major entities engaged in the design and manufacture of aircraft and space vehicles and components thereof (AFTRCC, 1982). The AFTRCC members are Beech Aircraft, Bell Helicopter Textron, Boeing, E-S Systems, Grumman Aerospace, Hughes Aircraft, ITT Gilfillan, Lockheed, Martin Marietta, McDonnell-Douglas, Northrop, Rockwell International and Vought.

Figure 1 presents the geographical areas of responsibility of the Area Frequency Coordinators. The abbreviated AFCs are:

WAFC - Western AFC
EAFC - Eastern AFC
G - Gulf AFC
WSMR - White Sands Missile Range

Part 7.18 of the NTIA Manual permits military aeronautical activities in certain Radiolocation Service bands when such operations are an integral part of the radiolocation stations. Part 7.18 is included in APPENDIX B.

Part 7.19 of the NTIA Manual establishes policy on the use of the 406-550 MHz band by target drones. Part 7.19 is included in APPENDIX B.

DEFINITIONS

Radio systems that are capable of operating in aeronautical environments operate either under the Aeronautical Mobile Service allocation or the more general Mobile Service allocation. These services and related terms are defined in the 1982 edition of the ITU Radio Regulations (ITU, 1982) or the NTIA Manual. The source follows the definition.

> Aeronautical Mobile Service: A mobile service between aeronautical stations and aircraft stations, or between aircraft stations, in which survival craft stations may participate; emergency position-indicating radiobeacon stations may also participate in this service on designated distress and emergency frequencies (ITU and NTIA).

> Mobile Service: A radiocommunication service between mobile and land stations, or between mobile stations (ITU and NTIA).

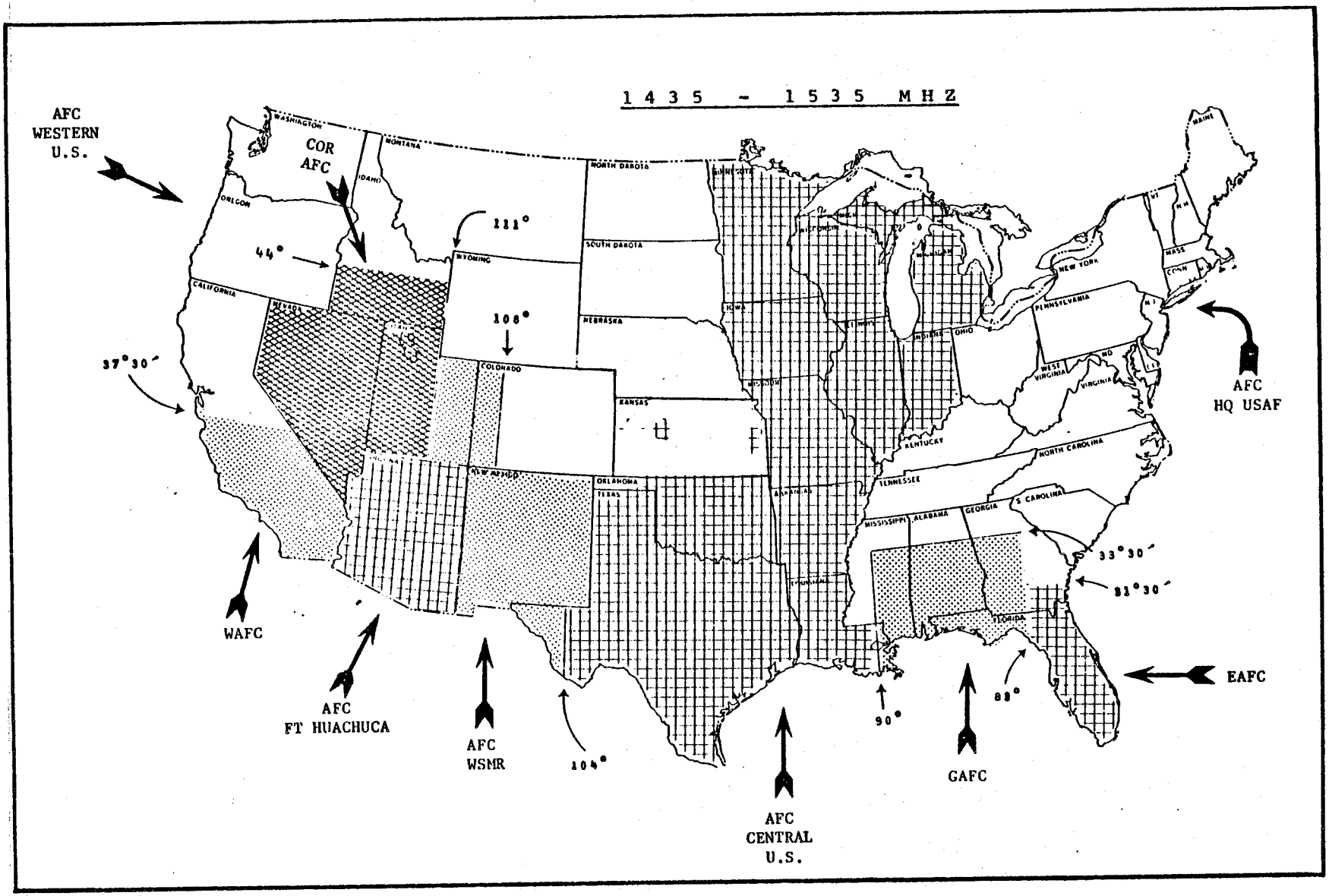


Figure 1. Area Frequency Coordination Responsibility
(Extracted from Annex D of the NTIA Manual)

Telecommand: The use of telecommunication for the transmission of signals to initiate, modify or terminate functions of equipment at a distance (ITU).

Terrestrial Telecommand: The use of radiocommunication for the transmission of signals to a terrestrial station to initiate, modify, or terminate functions of equipment directly associated with the station, including the station itself (NTIA).

Television: A system of telecommunication for the transmission of transient images of fixed or moving objects (ITU and NTIA).

Telemetry: The use of telecommunication for automatically indicating or recording measurements at a distance from the measuring instrument (ITU and NTIA).

Chapter 6 of the NTIA Manual includes definitions of stations used in the Federal Government frequency assignment process. The pertinent definitions and their data processing information retrieval abbreviations are presented herein:

SYMBOLS	DEFINITION
Aeronautical Stations	
FA	Aeronautical Station: A land station in the aeronautical mobile service. In certain instances an aeronautical station may be placed on board a ship or an earth satellite.
FAC	Airdrome Control Station: An aeronautical station providing communication between an airdrome control tower and aircraft.
FAT	Flight Test Station: An aeronautical station used for the transmission of essential communications in connection with the testing of aircraft or major components of aircraft.
Land Stations	
FL	Land Station: A station in the mobile service not intended to be used while in motion.
FLD	Telecommand Land Station: A land station the emissions of which are used for terrestrial telecommand.
FLE	Telemetering Land Station: A land station the emissions of which are used for telemetering.
FLEA	Aeronautical Telemetering Land Station: A telemetering land station used in the flight testing of manned or unmanned aircraft, missiles, or major components thereof.

FLEB Flight Telemetering Land Station: A telemetering land station the emissions of which are used for telemetering to a balloon; to a booster or rocket, excluding a booster or rocket in orbit about the earth or in deep space; or to an aircraft, excluding a station used in the flight testing of an aircraft.

Fixed Stations - (Included here only for later reference).

FX Fixed Station: A station in the Fixed Service.

FXD Telecommand Fixed Station: A fixed station the emissions of which are used for terrestrial telecommand.

FXE Telemetering Fixed Station: A fixed station the emissions of which are used for telemetering.

Aircraft Stations

MA Aircraft Station: A mobile station in the aeronautical mobile service on board an aircraft or an air-space vehicle.

Mobile Stations

MO Mobile Station: A station in the mobile service intended to be used while in motion or during halts at unspecified points.

MOD Telecommand Mobile Station: A mobile station the emissions of which are used for terrestrial telecommand.

MOE Telemetering Mobile Station: A mobile station the emissions of which are used for telemetering.

MOEA Aeronautical Telemetering Mobile Station: A telemetering Mobile station used in the flight testing of manned or unmanned aircraft, missiles, or major components thereof.

MOEB Flight Telemetering Mobile Station: A telemetering mobile station the emissions of which are used for telemetering from a balloon; from a booster or rocket, excluding a booster or rocket in orbit about the earth or in deep space; or from an aircraft, excluding a station used in the flight testing of an aircraft.

MOP Portable Mobile Station: A portable station operating in the mobile service.

Experimental Stations - (Included here only for later reference.)

XT Experimental Testing Station: An experimental station used for the evaluation or testing of electronics equipment or systems, including site selection and transmission path surveys, which have been developed for operational use.

The term "data link" is used very frequently in describing certain communications channels, particularly those associated with military tactical scenarios. The Department of Defense (DOD) has published a Data Link Handbook (DOD,1977) in which a data link is defined as follows:

> Data link: generically defined as that portion of a system which provides transfer of formatted information between an information source and an information sink.

Another definition of a data link is contained in the Institute of Electrical and Electronics Engineer (IEEE) Dictionary (IEEE, 1978):

> Data link: an assembly of data terminals and the interconnecting circuits operating according to a particular method that permits information to be exchanged between the terminals.

TECHNICAL STANDARDS

The general technical standards applicable to Federal Government radio electronic systems are presented in Chapter 5 of the NTIA Manual. These standards concern the frequency tolerance and spurious emissions of transmitters.

The frequency tolerance is the maximum permissable departure by the center frequency of the frequency band occupied by an emission from the assigned frequency or, by the characteristic frequency of an emission from the reference frequency.

A spurious emission is an emission on a frequency or frequencies which is outside the necessary band, and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions and intermodulation products, but exclude emissions in the immediate vicinity of the necessary band, which are a result of the modulation process for the transmission of information.

Tolerance Categories

The tolerance categories are defined in Section 5.2.3 of the NTIA Manual. The following notes were obtained from that section. References to non-mobile or non-aeronautical terms such as maritime mobile are omitted because they are not pertinent.

> TABLE 3 presents the spurious emission and frequency tolerances from 100 MHz to 30 GHz for aeronautical stations, aircraft stations and mobile stations. For this table, the various spurious emission categories are given below.
>
> Spurious Emission Category "D" ----
>
> The mean power of any emission supplied to the antenna transmission line, as compared with the mean power of the fundamental, shall be in accordance with the following:

TABLE 3

SPURIOUS EMISSION AND FREQUENCY TOLERANCES
(Frequency Tolerances are in parts per million)

Frequency Bands and Station Type	Tolerances	
	Spurious	Frequency
BAND: 100 to 470 MHz		
2.2 Aeronautical Stations	D,F	20
3.3 Aircraft Stations		
3.3.1 406-420 MHz	F	5
BAND: 470-960		
2. Land Stations	D	5
3.1 Mobile Stations 3 watts or less	D	50
3.2 Mobile Stations above 3 watts	D	5
BAND: 1215 to 2450 MHz		
2. Land Stations	E,I	30
3. Mobile Stations	E,I	30
BAND: 2450 to 4000 MHz		
2. Land Stations	E	30
3. Mobile Stations	E	30
BAND: 4000 MHz to 10.5 GHz		
2. Land Stations	E	50
3. Mobile Stations	E	50
BAND: 10.5 to 30 GHz		
2. Land Stations	E	100
3. Mobile Stations	E	100

1. On any frequency removed from the assigned frequency by more than 75 percent, up to and including 150 percent, of the authorized bandwidth, at least 25 decibels attenuation;

2. On any frequency removed from the assigned frequency by more than 150 percent, up to and including 300 percent, of the authorized bandwidth, at least 35 decibels attenuation; and

3. On any frequency removed from the assigned frequency by more than 300 percent of the authorized bandwidth, for transmitters with mean power of 5 kilowatts or greater, at least 80 decibels attenuation; and for transmitters with mean power less than 5 kilowatts, at least 43 plus 10 $\log_{10}$ (mean power of the fundamental in watts) decibels attenuation (i.e., 50 microwatts absolute level).

Spurious Emission Category "E" ----

The mean power of any emission supplied to the antenna transmission line, as compared with the mean power of the fundamental, shall be in accordance with the following:

1. On any frequency removed from the assigned frequency by more than 75 percent, up to and including 150 percent of the authorized bandwidth, at least 25 decibels attenuation.

3. On any frequency removed from the assigned frequency by more than 300 percent of the authorized bandwidth, for transmitters with mean power of 5 kilowatts or greater, at least 80 decibels attenuation; and for transmitters with mean power less than 5 kilowatts, at least 43 plus 10 $\log_{10}$ (mean power of the fundamental in watts) decibels attenuation (i.e., 50 microwatts absolute level).

Spurious Emission Categories "F" and "I " ----

The spurious tolerances of Category "F" are for FM stations in the 406.1-420 MHz band and are contained in Section 5.4.6 of the NTIA Manual. These address systems are generally operated as land mobile communications systems with occasional airborne use.

The spurious tolerances of Category "I" are for telemetering stations excluding those for space radiocommunications, in the bands 1435-1535 and 2200-2290 MHz are contained in Section 5.9 of the NTIA Manual. They consist of lengthy calculations and for the sake of brevity, are not presented here. Secondly, part of the calculations depend upon necessary bandwidth values which are being reviewed in a separate activity.

Standards Adequacy

The technical standards listed and discussed in this section were reviewed to determine if they are adequate when considering the systems being developed today. It was determined that the standards are adequate for such systems.

SECTION 4

SPECTRUM USAGE

GENERAL

This examination of the use of the spectrum between 400 MHz and 17.7 GHz for aeronautical mobile purposes emphasizes those frequency bands that are allocated to the Federal Government either exclusively or shared with non-Government. These bands are listed in TABLE 4.

The general technical characteristics of equipment are examined to develop an understanding of the interference potential. New technologies that may impact future spectrum use are examined to determine possible courses of action of spectrum planning efforts.

TABLE 5 presents the frequency band assignment statistics based on the various types of station classes associated with each assignment. It must be noted that some assignments have two or more station classes.

406.1-420 MHz BAND

Allocations

The 406.1-420 MHz band is allocated to the Federal Government for the Fixed and Mobile Services on a primary basis. The 406.1-410 MHz segment is also allocated to the Radio-Astronomy Service on a primary basis. The radio-astronomy allocation exists for both Government and non-Government.

Spectrum Usage

As presented in TABLE 5, the 406.1-420 MHz band assignment statistics indicate that this band is used mainly for land (FL), mobile (MO), and fixed (FX) stations. This band is used extensively for land mobile, fixed and base stations. This band is channelized into 556 channels and spaced at 25 kHz per Section 4.3.9 of the NTIA Manual. The main activities are narrowband FM (16 kHz bandwidth) land mobile operation and single channel (16-36 kHz bandwidth) fixed operation. Airborne voice communications are carried out when air-ground communications are desired that are in support of activities such as law enforcement. Telemetering activities are associated with the flying of drone aircraft.

The FCC license records indicate that there are 109 assignments to non-Government activities in this band. These are to aerospace firms with most of the activity concentrated in Southern California.

The 406.1-420 MHz band is used for controlling target drones. Under the provisions of Part 7.18 of the NTIA Manual, target drones may continue until December 31, 1987, in designated and controlled military test and training areas and firing ranges on land and at sea. Such operations shall be reaccommodated from the 406.1-420 MHz band by December 31, 1987.

TABLE 4

FEDERAL GOVERNMENT BANDS ABOVE 400 MHz
USED FOR AIRBORNE PURPOSES AND
TOTAL NUMBER OF ASSIGNMENTS
(January 1984)

No.	Band (MHz)	Federal Gov't Assignments	Non-Gov't Assignments
1.	406.1-420	10742	109
2.	902-928	254	43
3.	1350-1400	98	11
4.	1429-1435	91	6
5.	1435-1530	725	30
6.	1530-1535	34	0
7.	1710-1850	2590	5
8.	2200-2290	1624	26
9.	2300-2310	11	0
10.	2310-2390	61	2
11.	4400-4990	1028	17
12.	14.4-14.5 GHz	22	2
13.	14.5-14.7145 GHz	148	0
14.	14.7145-15.1365 GHz	286	6
15.	15.1365-15.35 GHz	85	35

TABLE 5

FREQUENCY BAND ASSIGNMENT STATISTICS*

	AERONAUTICAL STATIONS			LAND STATIONS					FIXED STATIONS			AIR-CRAFT STNS.	MOBILE STATIONS							
	FA	FAC	FAT	FL	FLD	FLE	FLEA	FLEB	FX	FXD	FXE	MA	MO	MOD	MOE	MOEA	MOEB	MOP	XT	OTHER
1. 406.1-420	92		1	728	76	5		4	3613	42	197	200	1652	32	3		8	53	68	9213
2. 902-928									80	20		1					1	2	51	195
3. 1350-1400				2					5				2				1		27	71
4. 1429-1435					5							22							92	14
5. 1435-1530						1	6				1	1			13	557	122		20	47
6. 1530-1535															1	25	6		1	5
7. 1710- 1850	8			2	6	10	14	16	2033		28	54	1	3	1	59	32		155	393
8. 2200-2290	5						14		154	2	50	15		9	93	487	267		322	479
9. 2300-2310																			6	7
10. 2310-2390						6			5		2	1			2				32	16
11. 4400-4990				9	24		1		673		29	13		67		8	3		97	132
12. 14.4-14.5 GHz									16										5	2
13. 14.5-14.7145 GHZ					3				64	1	2		2		2				69	11
14. 14.7145-15.1365 GHz				1					147		2	2			3				104	40
15. 15.1365-15.350 GHz									41										37	11

*Statistics as of January 25, 1984

The 406.1-420 MHz band has been the subject of a previous spectrum resource assessment (Crandall, 1982). The assessment identified increasing assignments for land mobile and fixed requirements. An annual growth trend of 15 percent was noted. The assessment presents conclusions and makes recommendations to improve the spectrum management of this band. The assessment makes a recommendation concerning the restructuring of the channel plan based on function rather than by Government agency. New technologies, such as amplitude compandored single sideband (ACSB), are noted in the assessment and recommended for further study. There are no results specifically directed towards aeronautical activities. No problems associated with aeronautical usage were identified in the assessment.

Future Planning

The 406.1-420 MHz band is primarily a land mobile and fixed station communications band. Aeronautical communications are usually carried out in support of the land mobile activity. Other aeronautical activities are military target drone operations through 1987. Based on the heavy use and continuing growth of this band for land mobile communications, it has poor potential for accommodating expansion of new aeronautical activities.

902-928 MHz BAND

Allocations

The 902-928 MHz band is allocated to the Federal Government for the Radiolocation Service on a primary basis. U.S. Footnote US215 provides for the use of 915 $\pm$ 13 MHz for industrial, scientific, and medical purposes. U.S. Government Footnote G11 provides for the Federal Government Fixed and Mobile Services, including low-power radio control operations in the 902-928 MHz on a secondary basis. Aeronautical mobile activities fall under the purview of U.S. Government Footnote G11.

Spectrum Usage

The data presented in TABLE 5 indicates that there are 80 Federal Government assignments to fixed station class. Therefore, 76 assignments for radiolocation application are not indicated in TABLE 5. The 51 experimental testing assignments are associated with radar systems. The aeronautical mobile activities are represented by several range measurement systems that are being operated or are planned for operation in 902-928 MHz by the three military services [Hurt, 1977 and Bulawka, 1980]. The first of these systems, developed by the Army, is called the Range Measurement System II (RMS-II) and operates at 918 MHz. It is operated at the Hunter-Liggett Military Reservation, California, the Yuma Test Range, Arizona, and the White Sands Missile Range, New Mexico. A derivative of this system is currently being deployed by the Air Force which is the High Accuracy Multiple Object Tracking System (HAMOTS) and is operated at the Hill, Wendover, and Dugway Test Ranges in Utah. Similar systems also are used by the Navy.

The purpose of these systems is to provide the capability of simultaneously displaying, recording, and tracking multiple land and/or air units (called B-units) with high accuracy. The tracking is accomplished by pulse ranging with each unit from multiple-fixed interrogators (called A and D units) located throughout the test area. Short formatted digital data messages can also be relayed between individual units and the central computer control (called the C unit).

Additional discussion and analysis on these systems are presented in a previous spectrum resource assessment (Bulawka, 1980).

Future Planning

The 902-928 MHz band is mainly used by radiolocation and fixed systems. It has been the subject of a separate spectrum resource assessment (Bulawka, 1980) where the key issues involved low-capacity Fixed Service requirements, sharing with radiolocation and ISM activities.

The possibility of expanded use of the band for Radiolocation Service, the use of the band for ISM devices and the secondary provision for the Mobile Service tends to give the band poor potential for accommodating the expansion of aeronautical activities.

1350-1400 MHz BAND

Allocations

The 1350-1400 MHz band is allocated to the Radiolocation Service on a primary basis and to the Fixed and Mobile Services on a secondary basis. U.S. Government Footnote G2 limit radiolocation, fixed and mobile activities to the military services. U.S. Government Footnote G113 provides for radio astronomy observations in this band and G114 addresses satellite activities in the space-to-Earth direction for the relay of nuclear burst data.

The aeronautical activities would fall under the purview of the mobile allocation.

Spectrum Usage

There are 108 Federal Government assignments in the 1350-1400 MHz band. Twenty-six of these assignments are associated with the Radiolocation Service. Twenty-seven are experimental testing assignments most of which are associated with radar activities. There are no assignments that are associated with aeronautical mobile activities.

Forty-three assignments are attributed to the Army, 18 to the Navy (accounting for 79 equipments) and 12 to the Air Force. There are 11 FCC license records that are attributed to individual firms doing Federal Government contract work on radar systems.

Future Planning

The 1350-1400 MHz band has the potential for accommodating some aeronautical activities, although such would be on a secondary basis to radar systems currently operating in the band. Hence, this band is judged to have moderate potential for accommodating the future expansion of aeronautical mobile activities.

1429-1435 MHz BAND

Allocations

The 1429-1435 MHz band is allocated to the Federal Government for Fixed and Mobile Services on a shared primary basis and to the non-Government Land Mobile (telemetering and telecommand) and Fixed (telemetering) Services on a secondary basis. U.S. Government Footnote G30 provides that operations in the Fixed and Mobile Services are limited primarily to the military services. International Footnote 722 states that passive research is being conducted by some countries in a program for the search for intentional emissions of extra-terrestrial origin.

Spectrum Usage

For Federal Government activity, the data presented in TABLE 5 indicate there are 22 aircraft station assignments and 92 experimental testing (XT) station assignments.

The main aeronautical activities in the 1429-1435 MHz band are by the military services. The Federal Government has a total of 133 assignments. Of these 133 assignments, the Navy has 74, the Air Force has 7 and the Army has 3. The Navy assignments are mainly for telecommand systems in support of missile programs. TABLE 6 presents band assignment statistics in the form of emission designators and the number of occurrences of each designator. Some assignments have up to three designators.

The band is de facto channelized every 500 kHz beginning at 1429 MHz. The most extensively used frequencies are 1430 MHz with 26 assignments, 1432 MHz with 21 and 1434.5 MHz with 19. All of the remaining channels have six or less assignments. TABLE 6 presents the number of assignments per channel. There appears to be room for additional frequency assignments on some channels because of their limited use when compared to the other channels.

The non-Government FCC records indicate six licenses in the 1429-1435 MHz band. The use is by industrial firms for telemetry systems with typical emission bandwidths of 1 MHz and 3 MHz. Use can be expected at the laboratories and test facilities of these firms.

Future Planning

The most extensive user of the 1429-1435 MHz band is the Navy with 87 percent of the assignments primarily used for telecommand applications. The band appears to provide a good opportunity for accommodating the expanded use of telecommand links. The 1429-1435 MHz band is recommended for channelization via

TABLE 6

1429-1435 MHz BAND ASSIGNMENT STATISTICS AND CHANNEL ASSIGNMENTS*

BAND ASSIGNMENT STATISTICS

DESIGNATOR	NO. OF OCCURRENCES **
1M20F2F	44
1M40F2F	21
340K00F2F	21
21K00F2F	21
500K00F9	5
400K00F9	4
500K00F9	4
400K00F1D	3
100K00F9	3
1M00F9	2
200K00F8D	2
1M20F9	1
1M24F2F	1
200K00F9	1
TOTAL	133

CHANNEL ASSIGNMENTS

FREQUENCY (MHz)	NO. OF ASSIGNMENTS
1429.5	1
1430.0	26
1430.5	1
1431.0	5
1431.5	6
1432.0	21
1432.5	1
1433.0	5
1433.5	1
1434.0	19
1434.2	1
1434.5	2
1434.7	1
1434.9	1
TOTAL	91

*As of January 1984.
**Total number of occurrences is larger than the number of assignments because some assignments have multiple entries.

incorporation of a channel plan into the NTIA Manual. Such channels should be 0.5 MHz in width and begin on 1429.5 MHz and end on 1434.5 MHz. It also is recommended that local coordination be conducted through the use of area frequency coordinators.

1435-1530 MHz

Allocations

The 1435-1530 MHz band is allocated to the Mobile (aeronautical telemetering) Service on a primary and exclusive basis for both the Federal Government and the non-Government. U.S. Footnote US78 states that 1435-1485 MHz will be assigned primarily for flight testing of manned aircraft or major components thereof. The 1485-1535 MHz band will be assigned primarily for the flight testing of unmanned aircraft, missiles or major components thereof. Additional provisions of U.S. Footnote US78 are for 1435-1535 MHz stations for telemetry associated with the launching and reentry of space vehicles.

Channel Plans

The NTIA Manual, Section 4.3.4, provides for a channelization plan for the 1435-1535 MHz band. In the band 1435-1485 MHz, 50 one-megahertz narrowband channels are designated, centered on 1435.5 MHz and each one-megahertz increment thereafter, through and including 1484.5 MHz. The use of emission bandwidths greater than 1 MHz is permitted, provided the assigned frequencies are centered on the center frequencies of narrowband channels. These channels are available for aeronautical telemetering a) primarily for the flight testing of manned aircraft or major components thereof and b) secondarily for the flight testing of unmanned aircraft and missiles or major components thereof.

In the band 1485-1535 MHz, 50 one-megahertz narrowband channels are designated, centered on 1485.5 MHz and each one-megahertz increment thereafter, through and including 1534.5 MHz. The use of emission bandwidths greater than 1 MHz is permitted, provided the assigned frequencies are centered on the center frequencies or narrowband channels. These channels are available for aeronautical telemetering a) primarily for the flight testing of unmanned aircraft and missiles or major components thereof and b) secondarily for the flight testing of manned aircraft or major components thereof.

Included as permissible usage for aeronautical telemetering stations in the band 1435-1535 MHz is telemetry associated with launching and reentry into the Earth's atmosphere, as well as any incidental orbiting prior to reentry, of manned or unmanned objects undergoing flight tests.

For the purpose of this plan, flight testing telemetry is defined as telemetry which is used in support of research, development, test, and evaluation, and which is not integral to the operational function of the system.

In the band 1525-1535 MHz, the channels designated for aeronautical telemetering are also available for space telemetering on a shared basis.

Spectrum Usage

As shown in TABLE 5, the majority of the Federal Government assignments in the 1435-1530 MHz band are to the MOEA station class and 541 assignments and MOEB having 109 assignments. Both MOEA and MOEB are associated with airborne telemetering mobile stations. The MOEB assignments are not in accordance with the Table of Frequency allocations. Proposed changes to U.S. Footnote US78 will correct this situation.

The Navy with 284 assignments and the Air Force with 257 assignments are the heaviest Federal Government users of the 1435-1530 MHz band. The Army has 48, Department of Energy has 47 and NASA has 32 assignments. The assignment growth trend over the past five years has been at a rate of seven percent per year.

The non-Government usage is reflected in the FCC license files and those FCC assignments that have been coordinated with the Federal Government are contained in the GMF. Aerospace firms such as Grumman, and McDonnell-Douglas form the majority of activity. Geographically, activity can be expected where these firms have major test facilities or where the military has test facilities.

Some industrial firms operate systems in the band under Government assignment authority. The assignments are very often contained in the GMF.

The 1435-1530 MHz frequency band is the most important aeronautical test telemetry band in the United States. The current frequency assignment procedure includes coordination via the Area Frequency Coordinators (AFCs) as shown in Figure 1; and on the Aerospace and Flight Test Radio Coordinating Council (AFTRCC). (The AFTRCC has been recognized by the FCC as the frequency coordinating advisory committee for flight test frequencies authorized for use under Part 87, Subpart G of the FCC Rules.) Figure 2 presents the geographical distribution of the GMF data encompassing Federal Government assignments and those non-Government assignments coordinated in the IRAC.

A review of the GMF data indicates that frequency assignments exist every 1 MHz beginning with 1435.5 MHz. Figure 3 presents the distribution of GMF records within this band. Emission bandwidths typically fall within 1, 3, or 5 MHz.

A typical telemetry equipment is the model CTS/CTL-500 manufactured by the Conic Data Systems division of the Loral Corporation. This transmitter operates in the 1435-1540 MHz frequency band with a nominal output of 18 watts and a FM carrier deviation of $\pm$ 600 kHz. The typical receiver has a noise figure of 4.5 dB and an IF bandwidth of 1.5 MHz resulting in a sensitivity based on noise threshold of -108 dBm. The data is usually pulse-code-modulated at a rate up to 1 Mbps, which is frequency modulated onto the RF carrier.

A typical link budget equation for telemetry systems in the 1435-1530 MHz band can be developed from the following parameters (AFTRCC, 1982) presented in TABLE 7.

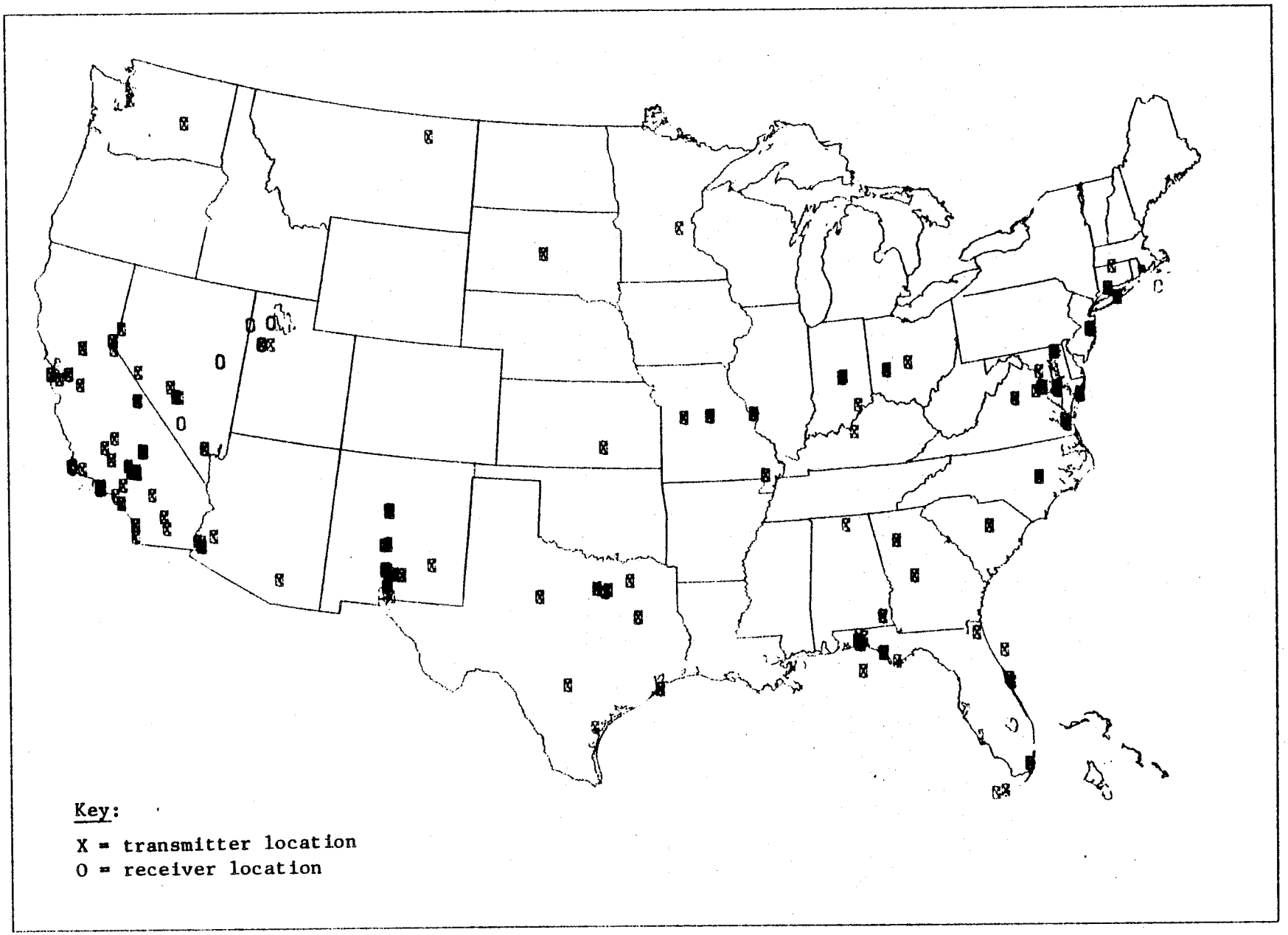


Figure 2. Geographic Distribution of Government Assignments in the 1435-1530 MHz Band.

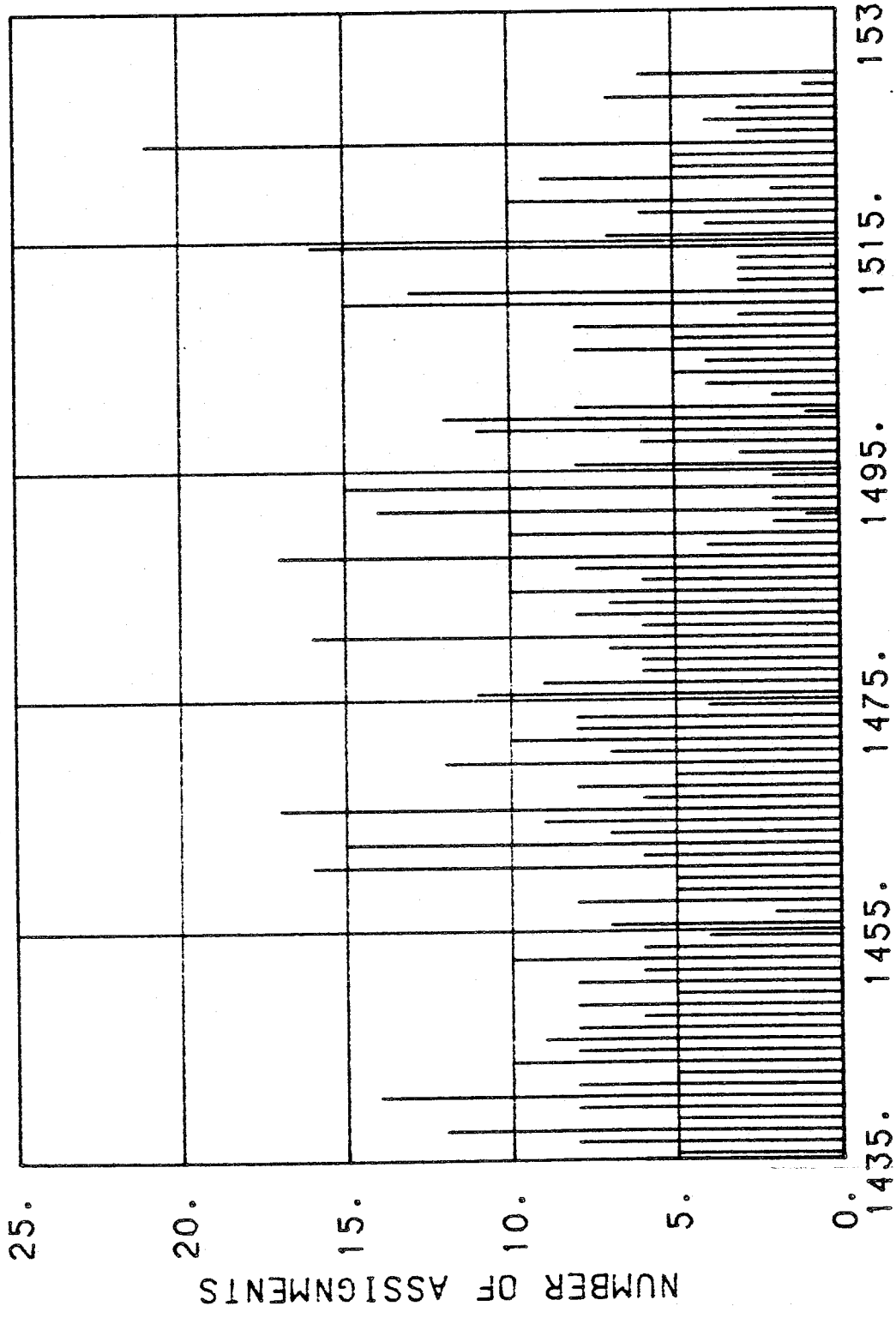


Figure 3. Federal Government Frequency Assignment Distribution in the 1435-1530 MHz Band.

TABLE 7

TYPICAL TELEMETRY LINK BUDGET EQUATION

Transmitter power (25 watts)	=	44 dBm
Vehicle antenna gain (typical omniblade)	=	0 dBi
Path loss (180 km)	=	142 dB
Receiver antenna gain	=	20.5 dBi
Transmission line loss	=	0.5 dB
Received signal level	=	-78.0 dBm
Receiver noise level		108 dBm
Nominal carrier-to-noise ratio (C/N)		30 dB
Minimum acceptable C/N		9 dB
Fade Margin Is		21 dB

Recent Activities

The AFTRCC has petitioned the FCC to make revisions to the FCC Rules to expand the frequencies available for aeronautical flight test telemetry and modify and clarify the technical criteria governing such uses (AFTRCC, 1982). One of the concepts being advocated in the petition is the amendment of U.S. Footnote US78 that subdivides the 1435-1535 MHz band into two 50 MHz subbands, one for manned aircraft flights and the other for unmanned aircraft flight testing. The proposed amendment would delete the subdivisions and permit manned or unmanned flight in the entire band. In addition, the frequencies 1522.5, 1525.5, 1528.5, 1531.5 and 1534.5 MHz are proposed to be shared with flight telemetering mobile stations. These latter frequencies would be used for telemetering other than for flight test purposes, including balloons, boosters, rockets (other than deep space), or an aircraft that is not being utilized for flight testing. The proposed new footnote as contained in the AFTRCC petition is:

> "US78 - The frequencies between 1435-1535 MHz and 2310-2390 MHz will be assigned for the aeronautical telemetering associated with flight testing of manned or unmanned aircraft and missiles, or major components thereof. The frequencies 1522.5, 1525.5, 1528.5, 1531.5 and 1534.5 MHz are shared with Flight Telemetering Mobile Stations. Included as permissible usage for aeronautical telemetering in these bands is telemetry associated with launching and reentry into the Earth's atmosphere, as well as any incidental orbiting prior to reentry of manned or unmanned objects undergoing flight test."

The IRAC has established a special committee (Ad Hoc 185) and chartered it to review the AFTRCC petition and to provide comments to the FCC on the draft Notice of Proposed Rulemaking (NPRM) that is being developed as a result of the

petition. As of January 1984, the NPRM was in draft form. The FCC will consider the IRAC comments and will issue an NPRM to the public. The public and Government agencies can then submit comments to the FCC.

The Ad Hoc 185 has developed recommendation comments regarding the draft NPRM. The following are new proposed definitions and the current definitions:

Proposed New MOEA Aeronautical Telemetering Mobile Station - a telemetering mobile station used for transmitting data directly to the airborne testing of the vehicle (or major components thereof) bearing the station.

Existing MOEA Aernautical Telemetering Mobile Station - A telemetering mobile station used in the flight testing of manned or unmanned aircraft, missiles, or major components thereof.

Proposed New MOEB Telemetering Mobile Station - A telemetering mobile station used for transmitting data from an airborne (excluding space) vehicle, which is not related, excluding data used in testing of the vehicle itself or major components thereof.

Existing MOEB Flight Telemetering Mobile Station - a telemetering mobile station the emissions of which are used for telemetering from a balloon, from a booster or rocket, excluding a booster or rocket in orbit about the Earth or in deep space; or from an aircraft, excluding a station used in flight testing an aircraft.

Ad Hoc 185 is also proposing to add another new definition as follows:

Proposed Flight Telemetering Telecommand Station - a station used for telecommand of flight telemetering mobile stations to allow telecommand to MOEB as well as to MOEA stations.

The Ad Hoc 185 committee has recommended that U.S. Footnote US78 be revised to read as follows:

US78- The frequencies between 1435 and 1535 MHz will be assigned for the aeronautical telemetry and associated telecommand operations for flight testing of manned or unmanned aircraft and missiles, or major components thereof. Permissible usage includes telemetry associated with launching and reentry into the earth's atmosphere as well as any incidental orbiting prior to reentry of manned or unmanned objects undergoing flight tests. The following frequencies are shared with flight telemetering mobile stations: 1444.5, 1453.5, 1501.5, 1515.5, 1524.5 and 1525.5 MHz. In the band 1530-1535 MHz, the Maritime Mobile-Satellite Service will be the only primary service after January 1, 1990.

The Ad Hoc 185 version of U.S. Footnote US78 differs from the revised U.S. Footnote US78 proposed in the AFTRCC petition. The final revised version of U.S. Footnote US78 will be developed in late 1984 following the FCC review of the

comments received in response to the NPRM and following coordination with the NTIA. The adoption of new definitions and other changes to the FCC Rules is also expected in late 1984 with the issuance of a Report and Order.

Future Planning

The 1435-1530 MHz band appears to be well managed largely due to the coordination conducted through the Area Frequency Coordinators and the AFTRCC. This coordination should be continued in the future.

Federal Government usage is heaviest in Southern California. A new footnote, Ad Hoc 185 version of U.S. Footnote US78, could provide increased flexibility to Federal Government users. The proposed new footnote, if it follows NTIA policy guidelines, should be incorporated into the U.S. Table of Allocations. Section 4.3.4 of the NTIA Manual should then be changed to reflect the new footnote.

The current use of the band for the Aeronautical Mobile Service is extensive thereby limiting the band to a moderate potential for future expansion of aeronautical mobile activities.

The upper adjacent band of 1530-1535 MHz will cease to be a primary telemetry band in 1990, having been reallocated to the Maritime Mobile-Satellite (space-to-Earth) Service on a primary basis with the Mobile Service (Aeronautical Telemetry) downgraded to secondary. Continued use of this band for aeronautical mobile purposes after 1990 is possible until satellites are authorized. After satellite use of this band is assured, and in order to minimize adjacent band interference to the shipborne earth terminals, plans should be made to use 1529.5 MHz as the highest telemetry channel and to have only those systems with an emission bandwidth of 1 MHz or less on the channel. That is, systems with emission bandwidths on the order of 3 MHz may have enough energy input to the satellite terminals to produce interference.

1530-1535 MHz BAND

Allocations

The WARC-79 added the Maritime Mobile-Satellite (space-to-Earth) Service to the 1530-1535 MHz band. This change has been incorporated into the U.S. Table of Allocations. Also, the Mobile Service has been downgraded from primary to secondary.

U.S. Footnote US272 states that the allocation to the Maritime Mobile-Satellite Service shall be effective from January 1, 1990. Up to that date, the allocation to the Mobile Service will be on a primary basis. U.S. Footnote US78 has also been amended by the addition of a sentence reflecting the fact that the Maritime Mobile-Satellite Service will be the only primary service after January 1, 1990.

Spectrum Usage

The GMF contains 38 assignments in the 1530-1535 MHz band. Thirty-one of these assignments are telemetry with MOEA (Aeronautical Telemetering Mobile

Station) or MOEB (Flight Telemetering Mobile Station) station classes. These are primarily operated by the Air Force and Navy at their test ranges. Following the NTIA Manual (see 1435-1530 MHz subsection), the assignments are spaced every 1 MHz ending with 1534.5 MHz.

There are no non-Government assignments in the 1530-1535 MHz band.

Future Planning

The maritime mobile-satellite activity is the space-to-Earth segment that would involve many shipborne terminals in the post-1990 time frame. Since airborne activity could involve very high altitudes, a wide area would be susceptible to interference. Consequently, sharing would be difficult along the coastlines. Therefore, it is recommended that those agencies currently using the 1530-1535 MHz segment make appropriate plans to cease activity in this band along the U.S. coastlines.

The 1530-1535 MHz band may be used for aeronautical mobile systems in the interior of the United States, away from the coastlines where maritime mobile-satellite systems would be expected to operate. Figure 4 presents an example of exclusion areas along the coastlines of the continental United States. This figure is based on a separation distance of about 320 km (200 miles) assuming a smooth curved earth propagation path loss.

The potential sharing problems with maritime mobile-satellite along the coastlines limit the growth potential of this band for aeronautical mobile activities. Overall, this band is judged to have poor-to-moderate potential for accommodating the future growth of aeronautical mobile activities.

1710-1850 MHz BAND

Allocations

The 1710-1850 MHz band is allocated to the Fixed and Mobile Services on a shared primary basis. U.S. Government Footnote G42 provides for space command, control, range and range-rate systems for earth station transmission on a co-equal basis with the Fixed and Mobile Services in the 1761-1842 MHz band.

The U.S. allocation for 1710-1850 MHz is to the Federal Government on an exclusive basis.

Spectrum Usage

As presented in TABLE 5, the frequency band assignment statistics reflected in the GMF indicate that MA (aircraft station), MOEA (Aeronautical Telemetering Mobile Station), and MOEB (Flight Telemetering Mobile Station) are the station classes pertinent to aeronautical activities that have the most assignments. The most extensive activity in the 1710-1850 MHz band is the Fixed Service having over 1800 assignments.

TABLE 8 presents the assignments by Government agency. The military services are heavy users of the band together with the Departments of Agriculture, Interior, and Energy.

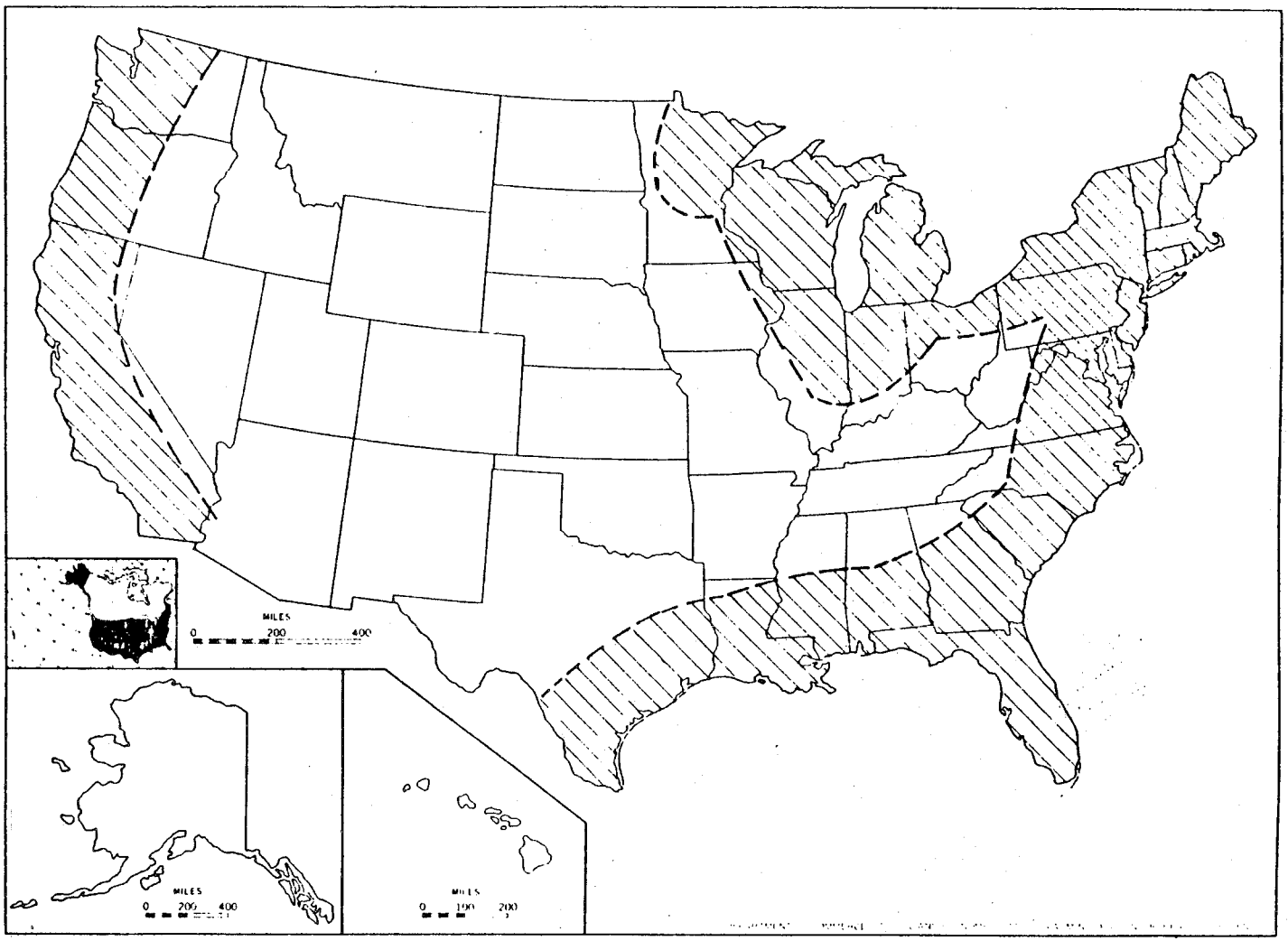


Figure 4. Hatched Areas Represent Coastal Exclusion Areas for Airborne Telemetry (1530-1535 MHz).

TABLE 8

TOTAL FEDERAL GOVERNMENT AGENCY ASSIGNMENTS
IN THE 1710-1850 MHZ BAND*

AGENCY	NUMBER
Agriculture	607
Air Force	419
Army	437
Commerce	8
Coast Guard	90
Energy	294
FAA	72
FEMA	17
GSA	14
HHS	6
Interior	174
Justice	46
Navy	245
NASA	22
NG	11
NS	2
NSF	2
Treasury	16
Transportation	33
TVA	75
Total	2590

*Statistics as of January 1984.

The military aeronautical activities in the band are exemplified by the operational (nontactical) telemetry links used in the flight training Air Combat Maneuvering Range (ACMR) and Air Combat Maneuvering Instrumentation (ACMI). Other uses are for scoring systems, air-to-ground video links and tactical weapons systems. The assignment growth trend for the past eight years has been at a rate of 6.4 percent. However, the 1981-1984 timeframe has seen an increase in the growth rate to 10 percent and even greater in 1982-83.

Future Planning

Various spectrum management problems have been encountered with the 1710-1850 MHz band prompting a separate spectrum resource assessment (Hurt and Crandall, 1980). Regarding aeronautical activities, the report noted that the operation of air-to-ground telemetry links in the same band as fixed microwave links leads to potential coordination difficulties because of the large distance separations required for compatible cochannel operation (up to 400 km); and that future development or assignment of flight test telemetry stations in this band would appear to be neither necessary nor in the interest of good spectrum management.

Regarding the possibility of airborne systems using spread spectrum modulation techniques, the SRA report stated that the development and widespread use of a wideband airborne spread spectrum system in the 1710-1850 MHz band would have a major impact on existing assignments. Such systems, when operated in this band, deny to other users both a large portion of the available band and, simultaneously, a large geographical area. Additionally, time sharing with the existing fixed microwave stations is typically not possible because of the communication reliability requirements of the latter. Coordination of specific flight paths on a case-by-case basis and a noninterference status was stated to be necessary to accommodate this type of operation.

In conclusion, this band has only moderate potential for accommodating the expansion of aeronautical activities. Recommendations were made in a previous study to discourage flight test telemetry, terrestrial telecommand, and wideband airborne links in this band. The aeronautical use of this band is currently being studied by Working Group 6 of the Spectrum Planning Subcommittee.

2200-2290 MHz BAND

Allocations

The 2200-2290 MHz band is part of the 1790-2290 MHz band that is allocated by the ITU to the Fixed and Mobile Services on a shared primary basis. International Footnote 750 provides that the band may also be used for space-to-Earth and space-to-space transmissions in the Space Research, Space Operations and Earth Exploration-Satellite Services.

The United States allocates the 2200-2290 MHz band to the Fixed and Mobile Services on a shared primary basis. The Fixed Service is for line-of-sight applications only. The Mobile Service, also line-of-sight only, is designated for aeronautical telemetering, but excludes flight testing of manned aircraft. The United States also allocates the band to the Space Research (space-to-Earth)

Service on a primary basis. U.S. Government Footnote G101 provides communications from operational space stations be accommodated on a co-equal basis with the Mobile and Space Research Services.

Channel Plans

Part 4.3.4 of the NTIA Manual provides for the channelization of this band for the Aeronautical Mobile Service. In the band 2200-2290 MHz, 90 one-megahertz narrowband channels are designated, centered on 2200.5 MHz and each one-megahertz increment thereafter, through and including 2289.5 MHz. The use of emission bandwidths greater than 1 MHz is permitted, provided the assigned frequencies are centered on the center frequencies of narrowband channels. These channels are available for a) telemetering from space research space stations irrespective of their trajectories and b) aeronautical telemetering, including telemetry associated with launch vehicles, missiles, and upper atmosphere research rockets. Such use is on a co-equal shared basis with fixed and mobile line-of-sight operations in the band conducted in accordance with the Government Table of Frequency Allocations.

Unique Coordination Procedures

A real-time coordination network has been established for the 2200-2300 MHz portion of the spectrum. This network is under control of the Western Area Frequency Coordinator and includes the Air Force Satellite Control Facility (Sunnyvale), NASA, the Air Force Space and Missile Test Center (SAMTEC) at Vandenburg; the Air Force Flight Test Center (AF/FTC) at Edwards Air Force Base, the Naval Weapons Center (NWC) at China Lake, CA, and the NASA/JPL deep-space earth station at Goldstone, CA. Positive operational control is used to affect frequency use time-sharing. All frequency use periods are coordinated and established in advance and changes in the plan may only be made after coordination with all users. Additional information on the network and the procedures can be found in Flynn (1980) or White (1977).

Spectrum Usage

As indicated in TABLE 4, there are 1624 assignments in the 2200-2290 MHz band. TABLE 5 presents the number of assignments in the various station classes associated with aeronautical activities. The majority of the activities are in the station class of MOEA (Aeronautical Telemetering Mobile) with 487 assignments; XT (Experimental testing) with 322 assignents; MOEB (Flight Telemetering Mobile) with 267 assignments; and MOE (Telemetering Mobile) with 93 assignments. A previous NTIA spectrum resource assessment report (Flynn, 1980) provides additional data on the spectrum usage.

The Air Force with 707 assignments is the heaviest user of the 2200-2290 MHz band. The Navy has 520, Department of Energy 231, and the Army 204 assignments.

The Air Force also uses the band for the Space Ground Link Subsystem (SGLS) in conjunction with various DOD satellites. This system uses the band for space-to-Earth tracking, telemetry and operational data. The Air Force channelizes the band every 5 MHz beginning with 2202.5 MHz. (The uplinks are in the 1710-1850 MHz band.)

The 2200-2290 MHz band is also used, and planned for use, for tracking and telemetry of other non-DOD satellites such as the Tracking and Data Relay Satellite System (TDRSS), NIMBUS, LANDSAT, SEASAT and the Space Shuttle. NASA maintains a worldwide system of ground tracking stations to provide tracking, telemetry, and command to all authorized user-spacecraft missions. The set of ground stations presently supporting the low earth-orbiting spacecraft and the high, eccentric, or synchronous orbit spacecraft, together with the communication links connecting NASA centers with the ground stations, is referred to as the Spacecraft Tracking and Data Network (STDN).

Future Planning

Consideration should be given to permitting telemetry use in support of manned flight testing in the 2200-2290 MHz band in long range planning efforts. Such testing could be done in areas under positive operational control. The frequency coordination procedures would ensure that no interference would occur. The overall effect would be beneficial because of the increased flexibility provided. The removal of the unmanned restriction could relieve congestion in other bands that may be encountered in the future.

The 2200-2290 MHz band is considered to have a moderate potential for accommodating the future growth of the Aeronautical Mobile Service. This evaluation is based largely on the current activities in this band and the problems encountered thus far, necessitating unique spectrum management procedures in the west coast areas.

2300-2310 MHz BAND

Allocations

The international allocation for the 2300-2450 MHz band resulting from WARC-79 is Fixed, Mobile and Radiolocation all on a shared primary basis with Amateur secondary. The United States subdivides the 2300-2450 MHz band into three subbands, one of which is 2300-2310 MHz. The U.S. allocation is Federal Government Radiolocation primary with Federal Government Fixed and Mobile and non-Government Amateur all secondary. The United States also adds U.S. Footnote US253 stating that Fixed and Mobile Services shall not cause harmful interference to the Amateur Service. This presents difficulty with respect to coordination procedures because of the uncertain nature of the amateur operations.

Spectrum Usage

TABLE 3 indicates that there are 11 Federal Government assignments in the 2300-2310 MHz band. These assignments are divided among the Federal Government agencies and include experimental types of station classes.

Future Planning

The fact that the Mobile Service shall not cause interference to the Amateur Service is the main reason that widespread aeronautical activities in this band would not be expected. Thus, this band has poor potential for accommodating future aeronautical mobile activities.

2310-2390 MHz BAND

Allocations

The international allocation for the 2300-2450 MHz band resulting from WARC-79 is Fixed, Mobile and Radiolocation, all on a shared primary basis, with Amateur a secondary allocation. The United States subdivides the 2300-2450 MHz band into three subbands, one of which is 2310-2390 MHz. The U.S. allocation is Government Radiolocation and Government and non-Government Mobile on a primary basis, with Government Fixed on a secondary basis. Furthermore, the United States adds U.S. Footnote US276 limiting mobile service use to aeronautical telemetering and associated telecommand operations, with all other mobile telemetering services being secondary. The Goverment radiolocation activities are addressed in U.S. Government Footnote G2, limiting the operation to the military services.

Spectrum Usage

The 2300-2450 MHz band was the subject of a separate spectrum resource assessment (Watson, 1981). Much of the following discussion was obtained from this previous assessment.

The Air Force uses the band for a limited number (less than six) of the AN/FPS-27 SAGE Air Defense System radars that operate in the 2322-2670 MHz band with 15 MW peak power output. These are scheduled for eventual phaseout.

The NASA Deep Space Network has assigned frequencies at 2310-2390 MHz for use in planetary radar imaging experiments. The National Science Foundation operates the Arecibo, Puerto Rico, observatory at 2380 MHz.

There are 61 assignments to Federal Government agencies in the 2310-2390 MHz band.

Recent Activities

The AFTRCC has petitioned the FCC to amend U.S. Footnote US78 to provide for the flight testing of manned and unmanned vehicles in 2310-2390 MHz (see the 1435-1535 MHz section of this report for the proposed footnote). The new footnote, if adopted, would also apply to Federal Government activites because the band is shared between non-Government and Federal Government. The proposed new version of U.S. Footnote US78 should be finalized in late 1984.

Future Planning

The U.S. input to WARC-79 for the addition of the Mobile Service on a primary basis to 2310-2390 MHz was generated in part by the requirements of the flight test telemetry community. Therefore, the band is seen as providing room for expansion of the Aeronautical Mobile Service and is considered to have good potential for accommodating future growth.

The previous assessment concluded that:

(1) Few radar systems currently are assigned in the 2300-2400 MHz band and no new radar systems were identified during this study. However, if future radiolocation systems are developed for this band, the exclusion of high-powered airborne radar transmissions in the 2310-2390 MHz portion would enhance compatible sharing between Radiolocation and Mobile (Telemetry) Services.

(2) In other bands designated for use by aeronautical or flight test telemetry, extensive local coordination procedures are required. Similar procedures may be required in this band if extensive telemetry operations evolve.

(3) The telemetry standards given in Part 5.9 of the NTIA Manual would be appropriate for applying to the newly proposed telemetry operations in the band 2310-2390 MHz. Additional standards may be proposed by user organizations.

4400-4990 MHz BAND

Allocations

The WARC-79 deleted the Fixed-Satellite Service allocation from the 4400-4500 MHz band, leaving the Fixed and Mobile Services as the services allocated on a primary basis. The U.S. table follows the international table in that the Government Fixed and Mobile Services are the primary services.

The 4500-4800 MHz band is allocated to the Fixed, Mobile, and Fixed-Satellite (space-to-Earth) Services on a primary basis. The U.S. allocation is to Government Fixed and Mobile on a primary basis together with the non-Government Fixed-Satellite (space-to-Earth) that is also on a primary basis. The United States also incorporates U.S. Footnote US245 limiting the Fixed-Satellite Service to international systems and subject to case-by-case electromagnetic compatibility analysis.

The WARC-79 added the Radio Astronomy Service to 4800-4990 MHz on a secondary basis to the already existing Fixed and Mobile Service primary allocations. The United States allocates the band to the Government Fixed and Mobile Service on a primary basis. The United States adds footnote US203 and US257 pertaining to radio astronomy observations in 4825-4835 and 4950-4990 MHz at specific astronomy observatories. The United States also adopts international footnotes 720 and 778. Footnote 720 provides for Space Research (passive) and Earth Exploration Satellite (passive) Services on a secondary basis in 4950-4990 mHz. Footnote 778 calls attention to radio astronomy observations in the 4825-4835 MHz band and that emissions from space or airborne stations can be particularly serious sources of interference to the Radio Astronomy Service. Footnote US203 provides for the observations of the formaldehyde spectral line at 4825-4835 MHz at specific observatories.

A "declaration" was signed at WARC-79 by the United States and a number of other developed countries, pledging that these INTELSAT member countries would not withhold support for INTELSAT's use of the 4500-4800 MHz band for fixed-satellite applications.

Spectrum Usage

TABLE 4 indicates that there are 1028 Federal Government assignments, as of July 1982, in the 4400-4990 MHz band. As shown in TABLE 5, 673 of these assignments are to the fixed station class. There are 190 assignments associated with mobile or experimental testing station classes. Ninety-seven of the 190 are Navy assignments, 56 Army, and 37 for the Air Force.

Sixty-nine of the 97 Navy assignments are associated with drone control systems, many of these with the AN/DKW-1 nomenclature. These drone control assignments are either in the MOD (Telecommand Mobile) or XT (Experimental Testing) station classes. The assignments are distributed throughout the entire 4400-4990 MHz band.

The Army aeronautical activity assignments are for video target scoring on aircraft armament, command links for missile testing, air-to-ground video data links, air-to-ground telemetry, and drone control.

The Air Force aeronautical mobile activities are for missile testing, aircraft-to-ground video links, target drone control, radar bomb scoring, and B-1 aircraft testing.

The 4400-4990 MHz band is used extensively for fixed stations in line-of-sight and troposcatter modes. These are represented by the 673 assignments to the FX (Fixed) station class. TABLE 9 presents the technical parameters of typical line-of-sight radio equipment, and TABLE 10 presents the parameters of typical beyond-the-horizon (troposcatter) radio equipment. TABLE 11 presents the typical aeronautical mobile systems in the band and their technical characteristics.

Canada is planning to install a point-to-point, line-of-sight microwave system in the 4400-4990 MHz band. This system is a long-haul, high-capacity, digital-relay system across Canada, that in some places runs along and very close to the U.S.-Canadian border. Canada has submitted information to the United States to initiate discussions to "clearly understand the potential constraints of frequency coordination" (SPS, 1981a). The Canadian information was analyzed by the NTIA (SPS, 1981b) to determine among other things the possible impact on the system by aeronautical mobile systems. The analysis results indicated that although some aeronautical mobile activities could cause interference to the Canadian microwave system, interference could be avoided by placing height restrictions on the U.S. operations or by frequency separation. (A more extensive fixed-aeronautical mobile analysis, based on probabilistic aspects, is presented in Section 6.)

TABLE 9

TYPICAL LINE-OF-SIGHT RADIO RELAY EQUIPMENT IN THE BAND 4400-4990 MHZ

Equipment Nomenclature	Transmitter		Emission Bandwidth (MHz)	Receiver	
	Power (Watts)	Antenna Gain (dBi)		Noise Figure (dB)	Antenna Gain (dBi)
AN/TRC-97	15.0	38.0	1.0	5.0	38.0
AN/GRC-144	2.0	33.0	4.1	11.0	33.0
AN/TRC-027	3.0	30.0	10.0	13.0	30.0
AN/GSQ-120	0.5	37.0	1.0	—	37.0
AN/TRC-66	1.0	44.0	1.0	4.0	44.0
TERTCM 602	1.0	33.0	36.0	8.5	33.0
AN/TRC-144	0.1	33.0	3.0	—	33.0

TABLE 10

TYPICAL TROPOSPHERIC SCATTER EQUIPMENT IN THE BAND 4400-4990 MHZ

Equipment Nomenclature	Transmitter		Emission Bandwidth (MHz)	Receiver	
	Power (kW)	Antenna Gain (dBi)		Noise Figure (dB)	Antenna Gain (dBi)
AN/TRC-97( )	1.0	38.0	1.0	5.0	38.0
AN/TRC-66	10.0	47.0	7.0	4.0	47.0
AN/TRC-132A	10.0	49.0	5.0	9.0	49.0
AN/GRC-143	1.0	40.0	2.3	4.0	40.0
AN/TRC-170(V1)	6.6	36-45	3.5 or 7	3.0	36-45
-170(V2)	1.85	36-45	3.5 or 7	3.0	36-45
-170(V3)	2.0/0.65	36-45	3.5 or 7	3.0	36-45

TABLE 11

TYPICAL AERONAUTICAL MOBILE SYSTEMS IN THE BAND 4400-4990 MHz

EQUIPMENT NOMENCLATURE	POWER (W)	ANTENNA GAIN (dBi)	EMISSION BANDWIDTH (MHz)	USER	FUNCTION
AN/DKW-1	2.5	35 *	1	Navy	Integrated Target Control System (ITCS)
CM602	25	5	20	Army	Video target scoring on aircraft armament
FSIFS-9R	1	0	4	Navy	Telemetering lightning data
VEG8325	10	30 (ground) 2 (air)	400 kHz	Army	Air-to-ground telemetry link
BABBCT-57	10	2	100 kHz	Air Force	Drone Control
AN/TSW-10	800	33 *	1	Navy	Drone Control

* ground terminal antenna gain

Future Planning

The 4400-4990 MHz band was the subject of a previous spectrum resource assessment (Ng, 1981). The assessment presented an analysis of the effects of the implementation of the Fixed-Satellite Service on the terrestrial services in the United States. Particular emphasis was placed on the 4500-4800 MHz portion of the band and on the interaction between both the Fixed Service (troposcatter systems), and aeronautical equipments and the satellite receiving earth station. The assessment concluded that sharing is difficult and any implementation of the Fixed-Satellite Service in the United States may have a significant impact on important existing and future military operations.

More specifically, the previous assessment showed that the required radio-horizon separation is relatively large in order to provide protection for the receiving earth station from aeronautical mobile transmitters. Furthermore, the assessment indicated that the implementation of receiving earth stations in this band should avoid those areas that have aeronautical mobile assignments. On the other hand, the implementation of earth stations in the mid-Atlantic or California coastal regions could restrict the present and future operation of aeronautical mobile stations in these areas.

Regarding the 4800-4990 MHz portion of this band, the Fixed and Mobile Services are the only primary allocations. Potential sharing between the Fixed and Aeronautical Mobile Services are analyzed in Section 6.

The United States policy regarding satellite system use of the 4500-4800 MHz band has been stated in the Department of State letter to COMSAT. The most recent letter was written in February 1982, (Huffcutt, 1982). This letter stated "the 4500-4800 MHz band will be available on a limited basis for international Fixed-Satellite Service (not domestic service) in the United States subject to certain conditions." A Department of State letter to COMSAT in December 1980 contained detailed information regarding the use of the 4500-4800 MHz band (Freeman, 1980). The most significant paragraphs regarding the 4500-4800 MHz band are included herein.

From the Freeman letter:

> "The band 4.5-4.8 GHz will continue to be available in the United States to the Fixed (including tropospheric scatter operations) and Mobile Services on a primary basis. To the extent that stations in the international Fixed-Satellite Service can coordinate sites with other authorized users, the Fixed Satellite Service will be afforded the protection of a primary service in the United States. In this regard, you should understand that the introduction of any space service in this band in the United States will have a significant adverse impact on important existing and future fixed and mobile operations. However, consistent with our Declaration, we will try to accommodate the international Fixed-Satellite Service on a case-by-case basis in the new band. At this time it is anticipated that one earth station on each coast can be successfully coordinated. However, it must be recognized that no guarantee for additional earth stations exists. It is not possible to identify specific locations since

future requirements are subject to change and case-by-case EMC analysis of each proposed site will be required.

In NATO Europe in the band 4.5-4.8 GHz, there are extensive fixed (including tropospheric scatter) and mobile operations of critical importance that are implemented or planned by the United States and our allies, for which no suitable alternative frequency bands are available. We have recommended to our allies that they continue to exclude satellite communications from this band within their borders for the foreseeable future. As you are aware, the position of some of these countries has already been made known to the Board of Governors. Additionally, because of the universality of our military systems, the United States will make similar requests to certain countries outside of Europe where we have critical military operations in the band 4.5-4.8 GHz."

14.4-14.5 GHz BAND

Allocations

Prior to WARC-79, the 14.4-14.5 GHz band was allocated internationally to the Fixed, Fixed-Satellite and Mobile Services on a primary basis. It was also allocated via footnotes to space research (space-to-Earth) and for radio astronomy line observations at 14.489 GHz. The WARC-79 added the clause "except aeronautical mobile" to the Mobile Service allocation. This was not added to the U.S. Table. However, the U.S. Table has the Fixed and Mobile Services on a secondary basis. The U.S. Table has the Fixed-Satellite (Earth-to-space) to the non-Government as the only primary allocation.

The U.S. Table contains International Footnote 862, dealing with the protection of radio astronomy spectral line observations. This footnote states that emissions from space or airborne stations can be particularly serious sources of interference to the Radio Astronomy Service. The U.S. Table also contains U.S. Footnote US203 that lists the astronomy observatories where observations are taking place.

U.S. Footnote US287 provides for non-Government Land Mobile-Satellite Service (Earth-to-space) on a secondary basis in 14-14.5 GHz. U.S. Footnote US234 concerns Government fixed and land mobile stations being reduced to secondary status with certain station locations retaining primary status until December 31, 1986.

Spectrum Usage

There are 23 assignments to Federal Government stations in the 14.4-14.5 GHz band. These stations are primarily associated with the MOEC (Surface Telemetering Mobile Station) and FLEC (Surface Telemetering Land Station) station classes. There are no assignments associated with aeronautical telemetering in the 14.4-14.5 GHz band.

Future Planning

The U.S. allocation of the Mobile Service in 14.4-14.5 GHz has been reduced to secondary. In addition, aeronautical mobile is prohibited in the International Table of Allocations. This prohibition does not exist in the U.S. Table. This status, together with the radio astronomy observatories, will limit the growth of the aeronautical mobile activities in the 14.4-14.5 GHz band. The major activity in the band in the future is expected to be the Fixed-Satellite (Earth-to-space) Service. The combination of these activities results in a conclusion that the 14.4-14.5 GHz has poor potential for accommodating future expansion of the aeronautical mobile band.

14.5-14.7145 GHz BAND

Allocations

The ITU allocation of the 14.5-14.8 GHz band is to the Fixed, Fixed-Satellite (Earth-to-space), and Mobile Services all on a primary basis with Space Research secondary. The Fixed-Satellite Service is addressed in International Footnote 863 that limits the activity to feeder links for the Broadcasting-Satellite Service outside Europe and for Malta.

The U.S. Allocation Table divides the 14.5-15.35 GHz band into three parts, one of which is 14.5-14.7145 GHz. The 14.5-14.7145 GHz portion is allocated exclusively to the Federal Government with the Fixed Service having primary status and Mobile and Space Research both secondary.

The 14.5-14.71 GHz band has been channelized for all assignments in the Fixed Service. The channel plan is presented in Part 4.3.12 of the NTIA Manual. The channels are on every 2.5 MHz beginning with 14501.25 MHz. The 14500.0-14710.0 MHz band is to be used for emission bandwidths equal to, or greater than, 3.5 MHz and the 14710.0-14714.5 MHz band is to be used for bandwidths of less than 3.5 MHz. The 14710.0-14714.5 MHz portion is not channelized.

Spectrum Usage

TABLE 4 indicates that there are 148 assignments in the 14.5-14.7145 GHz band, all of which are made to Federal Government agencies. The majority of the assignments are made to fixed stations that have 64 assignments and to experimental testing stations that have 69 assignments. The Air Force has 45 assignments, the Army 17, DOE 16, FAA 14, and the Navy 12. As indicated in TABLE 5, there are only three assignments associated with aeronautical activities.

NASA is planning to use the a portion of this band for the Tracking and Data Relay Satellite System (TDRSS). This frequency band will be used for the earth station-to-TDRSS communications link (SPS, 1982). The TDRSS system is composed of two geostationary satellites, a ground station at White Sands, New Mexico, and an undetermined number of orbiting spacecraft at various altitudes. The TDRSS operates in the Space Research Service, a secondary allocation in the band.

The coupling situation of interference from a data link to the TDRSS geostationary satellite has been analyzed in a previous Spectrum Resource Assessment (Frazier, 1979). The analysis recognized that interference from a ground station transmitter to the TDRSS was a potentially serious problem. The ground station was transmitting to an airborne receiver; hence, the aeronautical mobile categorization. The assessment concludes that the TDRSS may receive interference from ground stations in North America, depending upon their antenna pointing direction. The worst problem occurs in the vicinity of White Sands, New Mexico, and includes much of the southwestern United States.

Future Planning

The secondary allocation to the Mobile Service will impede the growth of mobile activities in this band. The Fixed Service, as the only primary allocation, will provide the framework for additional growth of fixed station activities in this band. The secondary allocation to mobile and the emphasis on Fixed Service, indicate that the 14.5-14.7145 GHz band has a poor potential for accommodating the future expansion of aeronautical mobile activities.

14.7145-15.1365 GHz BAND

Allocations

The 14.7145-14.8 GHz band is part of the 14.5-14.8 GHz band that is allocated by the ITU to the Fixed, Fixed-Satellite (Earth-to-space), and Mobile Services all on a primary basis with Space Research secondary. Fixed-Satellite activities outside Europe and for Malta are limited to feeder links for the Broadcasting-Satellite Service.

The 14.8-15.1365 GHz band is that part of the 14.8-15.35 GHz band allocated by the ITU to the Fixed and Mobile Services on a primary basis and to Space Research on a secondary basis.

The U.S. allocates the 14.7145-15.1365 GHz band exclusively to the Federal Government with the Mobile Service being the only primary allocation. Fixed and Space Research are secondary services.

Spectrum Usage

TABLE 4 indicates that there are 286 assignments to Federal Government stations in the 14.7145-15.1365 GHz band. TABLE 5 indicates that there are 147 assignments for the fixed station (FX) class, 104 for experimental testing (XT) and one for the aircraft station (MA) class. A large majority of the XT assignments are associated with nonairborne activities.

The FAA is the heaviest user of this band with 97 assignments, all fixed stations. The Air Force has 71 assignments followed by the Army with 46, DOE with 22, NASA 14, and the Navy 14.

The Air Force uses this band for a data link on the low-cost decoy system operating with the AN/TPS-43E radar under the XT station class assignment. The Department of Agriculture uses this band for aircraft transmission of images of forest fires under the MA station class.

NASA is planning to use the 14.896-15.121 GHz band for the Tracking and Data Relay Satellite System (TDRSS). The TDRSS system is comprised of two geostationary satellites, a ground station at White Sands, New Mexico, and an undetermined number of orbiting user spacecraft at various altitudes. The 14.896-15.121 GHz band will be used for the user satellite-to-TDRSS communications link. One application is for the Space Shuttle, where the Shuttle is the user spacecraft. The TDRSS operates in the Space Research Service, a secondary allocation in the band.

The potential problem of interference to the user satellite-to-TDRSS was analyzed in a previous Spectrum Resource Assessment (Frazier, 1979). The analysis concluded that interference may be received from a ground based transmitter in the Aeronautical Mobile Service. However, interference is highly dependent on antenna pointing directions. The result is that the percentage of time the interference would occur is very small, probably less than one percent of the TDRSS operating time.

Future Planning

The 14.7145-15.1365 GHz band is 422 MHz wide. It is a band that can be used for more aeronautical mobile activities in the future. Since the Mobile Service is the only primary allocation, and the band is allocated exclusively to the Federal Government, this band is available for accommodating the future growth of the Aeronautical Mobile Service. The band is considered to have a good potential for accommodating the future expansion of aeronautical mobile activities.

The Army has recently sponsored research and development projects involving solid-state power amplifiers in the 15 GHz band and in the 12-16 GHz band. The 15 GHz project concerned the development of a multicell Field-Effect Transistor (FET) capable of delivering 3.5 watts of output power at 15 GHz with an instantaneous (1 dB) bandwidth of 1500 MHz. A second project considered the 14-16 GHz band and involved incorporating pairs of FETs delivering 1.2 watts with a 1-dB bandwidth of 2.4 GHz. The goal was a 4 MHz 1-dB bandwidth.

The research and development into such solid-state components has relevance to spectrum management because such efforts are primarily conducted to fulfull the systems requirements generated by other units. For example, the application may be for the data link of remotely piloted vehicles (RPVs). Since the components are being developed to operate with a very wide bandwidth, the communications requirement is most likely one involving spread spectrum modulation techniques when a very wide RF bandwidth is required.

15.1365-15.35 GHz BAND

Allocations

The 15.1365-15.35 GHz band is that part of the 14.8-15.35 GHz band allocated by the ITU to the Fixed and Mobile Services both on a primary basis with Space Research secondary. International Footnote 720 provides for Space Research (passive) and Earth-Exploration-Satellite (passive) Services on a secondary basis in 15.20-15.35 GHz.

The U.S. allocation in 15.1365-15.35 GHz is exclusively to the Federal Government, with the Fixed Service the only primary allocation. The Mobile and Space Research Services are allocated on a secondary basis. The United States adopts International Footnote 720. In addition, U.S. Footnote US211 specifies that applicants in the 15.1365-15.35 GHz band for airborne or space station assignments are urged to take all practicable steps to protect radio astronomy observations in the adjacent bands from harmful interference. U.S. Footnote US211 also states that U.S. Footnote US74 applies. U.S. Footnote US74 addresses extra-band radiation and protection to the Radio Astronomy Service.

The 15,140.0-15,350.0 MHz frequency band has been channelized for all assignments in the Fixed Service. The channeling plan is presented in Part 4.3.12 of the NTIA Manual. The channeling plan begins at 15,141.25 MHz and is on every 2.5 MHz thereafter ending with 15,348.75 GHz. The assignments are to be used for systems with emission bandwidths equal to, or greater than, 3.5 MHz. Fixed Service systems with emission bandwidths of less than 3.5 MHz are to use the 15,136.5-15,140.0 MHz segment that is not channelized.

Spectrum Usage

As indicated in TABLE 4, there are 61 Federal Government frequency assignments in the 15.1365-15.35 GHz band and 35 non-Government assignments. Thirty-seven of the 61 Federal Government assignments are to fixed stations, with 30 of the 37 being FAA assignments. The Army and the Air Force each have 11 assignments, with nine of each belonging to the experimental testing station class. NASA has three assignments, with two being experimental testing and the other fixed. There were no assignments for Space Research or Earth-Exploration (passive) Satellites.

Future Planning

The 15.1365-15.35 GHz band is allocated to the Fixed Service, it being the only primary allocation and to the Mobile Service on a secondary basis. The band most likely will grow as a Fixed Service band because of the primary allocation. The fact that Mobile is secondary may impede future growth of aeronautical activities in this band. The radio astronomy U.S. Footnote US211, may also impede the growth of aeronautical activities. Because of these factors, the 15.1365-15.35 GHz band is considered to have poor potential for accommodating the future expansion of aeronautical mobile activities.

OTHER FREQUENCY BANDS

420-450 MHz Band - Position Location Reporting System (PLRS)

The Position Location Reporting System (PLRS) is a joint Army and Marine Corps tactical system that provides position location and navigation information. The PLRS is considered to be a multifunction system. The term "multifunction" is used herein to define a communications-electronics system or service that is used for more than one purpose. It is relevant to the aeronautical mobile assessment because communications data links are employed, and because airborne units are used. The system is currently in the developmental stage. The major PLRS elements are ground and airborne. The PLRS supports both helicopter and fixed wing aircraft. The PLRS is categorized as a multifunction system, radionavigation and radiolocation, and operates in the 420-450 MHz band, a band allocated to the Radiolocation Service on a primary basis.

The system is essentially a computer communications network, with the master unit containing a computer and video display terminals. The system architecture consists of time-ordered spread-spectrum transmissions, with integrated relaying capability between units, frequency multiplexing, and cryptographically secure data. Communications path rerouting adaptability and path redundancy are automatic. The waveform and signal processing consists of pseudonoise spread spectrum, frequency hopping, error detection and correction coding, and time-slot scrambling. An asynchronous time-division multiple access (TDMA) system is employed. The time is organized into fixed cyclic intervals divided and subdivided into epochs, frames, and time slots, respectively. The PLRS transmitter power output is 100 watts, which is spread over a bandwidth of 3 MHz.

960-1215 MHz Band - Joint Tactical Information Distribution System (JTIDS)

The Department of Defense (DOD) is developing the JTIDS, which is planned to provide an airborne integrated communication, navigation and identification (ICNI) function in the 960-1215 MHz band. The JTIDS is a multifunction system. The JTIDS requirement specifies the need for an integrated system capable of distributing digital information among airborne and surface-based elements in a tactical theater. The Air Force has indicated that placement of JTIDS in the 960-1215 MHz band is essential in view of the proposed application of the ICNI concept. Operation of JTIDS in the 960-1215 MHz band is indicated by the need to simultaneously satisfy the requirements for a minimum of 190 MHz bandwidth, 500 nautical mile communications range with omnidirectional antennas, integral Tactical Air Navigation (TACAN) and Identification-Friend-or-Foe (IFF) capability, and lowest possible cost, size, and weight.

In accordance with Federal Government procedures, the Air Force requested spectrum support for the Phase I version of JTIDS in the 960-1215 MHz band, which is allocated worldwide for the Aeronautical Radionavigation Service on a primary basis. This band is allocated for aeronautical radionavigation; and thus, the introduction of JTIDS required extensive testing to determine the electromagnetic compatibility of JTIDS with the aeronautical radionavigation systems.

The JTIDS design is heavily influenced by a recognized need to minimize interference to other systems within the 960-1215 MHz frequency band. JTIDS employs a time-division multiple access (TDMA) technique using spread-spectrum modulation. Within a JTIDS/TDMA network, only one user transmits at any instant, and enough time is provided for propagation of the transmission across the coverage volume before another transmission can occur. Phase I JTIDS also includes an integral TACAN capability.

The basic JTIDS pulse consists of a carrier modulated by a 5 Mb/s binary sequence. The pulsewidth is limited to minimize interference to TACAN receivers that could be sensitive to long single pulses. The continuous phase-shift modulation (CPSM) confines the spectrum and limits the number of TACAN channels potentially affected by a single JTIDS pulse.

Following the extensive testing and coordination discussed previously, the JTIDS Phase I TDMA was given spectrum approval for a Stage 4 (operational) system. Further development of the JTIDS system continues. The DOD has submitted material for NTIA spectrum approval of a Distributed TDMA JTIDS system. This version is currently being evaluated in the system review procedures of the Spectrum Planning Subcommittee. The U.S. Table of Frequency Allocations was amended by the addition of footnote US224. This footnote allows Government systems utilizing spread spectrum techniques for terrestrial communications, navigation and identification to operate in the 960-1215 MHz band on the condition that harmful interference will not be caused to the Aeronautical Radionavigation Service. The FCC officially amended the table effective April 30, 1979, and changed Part 87 of the FCC Rules.

9200-9300 MHz Band

The 9200-9300 MHz band is seeing increased usage for data links, particularly for tactical applications such as control of drones and remotely piloted vehicles. Data records in the GMF indicate use of the AN/TPW-2, AN/APW-25 and AN/APW-26 series of equipments for microwave command guidance of drones and other aircraft. These systems are listed as operating at 9285 MHz at Davis Montham AFB, Oat Mountain, Arizona, and at Seattle, Washington. Operation is at low-power using a pulsed emission with a 2 MHz emission bandwidth.

The Air Force also operates the AN/UPQ-3 drone command guidance sysem at Hill AFB, Utah. The equipment complement here may also consist of the aforementioned AN/TPW-2 and AN/APW-25. The emission bandwidth in this data record is listed as 10 MHz.

The Air Force is developing a tactical data link system called the Multiple Drone Control/Strike System (MDC/SS) for operation in the 9250-9800 MHz band. The development is being undertaken to fulfill an Air Force operational requirement for the AN/AQM-34V and AN/BGM-34C RPVs in performing such missions as electronic warfare and reconnaissance. The Air Force envisions that as many as eight RPVs may be airborne simultaneously in a tactical environment and the MDC/SS will provide data to determine positions for positive control. The control function enables corrective commands to be transmitted to control the vehicle or terminate the mission. The control and data collection interface with the RPVs may be from an air or ground-based director station.

The MDC/SS will utilize the existing AN/APW-25 or AN/APW-26 type transponders. Commands are received on 9285 MHz and data pertaining to the flight status is transmitted back to the director stations at 9330 MHz. The broader operating frequency bands are 9250-9800 MHz for transmitting to the RPV and 9330-9800 MHz for the RPV-to-director link, although actual operation is at the fixed frequencies. The command guidance system will employ the AN/TPW-2, AN/TPW-2A, AN/TPW-3, and AN/TPW-3A. All systems will employ pulse code modulations. These may be gradually phased out and replaced with more modern equipment.

The Spectrum Planning Subcommittee (SPS) of the Interdepartment Radio Advisory Committee (IRAC) has reviewed the MDC/SS under the provisions of the NTIA manual. This review process has been established to ensure availability of frequency support for major systems prior to the commitment and expenditure of large amounts of resources. The MDC/SS was reviewed in the Stage 4 phase, a preproduction phase, in September 1977 (Probst, 1977). The MDC/SS was analyzed as operating in the testing and training environment consisting primarily of geographical areas such as the Pacific Missile Range, China Lake NAS, California, Nellis Range, Nevada, and Eglin AFB, Florida Test Range. Since the MDC/SS made use of existing equipment, the SPS review concluded that the MDC/SS represented no new spectrum utilization.

The SPS review pointed out the Air Force has current frequency assignments for 9285 and 9330 MHz for RPV operations. However, these assignments are annotated with S144 (a special note of the NTIA Record Notes in Annex A of the NTIA Manual) which specifies that they are not in complete conformity with the Table of Allocations and, therefore, are secondary to assignments that are in accordance with such.

9.5-10.0 GHz BAND

There is a trend on the part of the military towards developing communications systems for the 9.5-10.0 GHz band. The DOD Handbook of Data Link Systems (DOD, 1977) is an attempt towards commonality, being a compilation of data links that are to be reviewed and considered before development of a new system is begun. Since three, and possibly four, systems capable of operating in the 9.5-10.0 GHz are listed, the handbook encourages the use of the band for communications-type services. Except for International Footnote 826, addressing specific countries (the United States is not addressed), there is no allocation to the Fixed Service in the band. The systems must operate on a noninterference basis (NIB). In the United States, an allocation is provided by Part 7.18 (see APPENDIX B) of the NTIA Manual for telemetry and telecommand only when such communications are conducted with the radar signals. The systems listed in the DOD Handbook of Data Link Systems are the Air Force Wideband Data Link (WDL) System operating with RPVs, and the Air Force TRDL, a wideband data link designed for high-performance aircraft with capabilities to transmmit jam-resistant data over 500 km. These systems may be out of the scope of Part 7.18.

The WBDL apparently has been renamed the multiple drone control strike system (MDC/SS) and has been submitted for SPS review. The subsequent review results reiterated the NIB status.

The TRDL system may eventually operate in the 8-10 GHz or 10-20 GHz band according to the aforementioned handbook. The system is in development.

15.7-17.7 GHz BAND

The Air Force has frequency assignments for their WDL at 15.825 and 16.950 GHz. The 15.7-17.7 GHz band is allocated to the Radiolocation Service on an exclusive primary basis.

SUMMARY

A summary is provided in TABLE 1 giving an initial assessment of each of the 15 major bands and their capability of supporting future growth for the aeronautical mobile activities.

SECTION 5

IDENTIFICATION OF PROBLEM AREAS FOR STUDY

The requirements for spectrum for aeronautical mobile activities, particularly in support of military systems, are expected to increase substantially in the future. The previous section identified the aeronautical mobile growth potential of 15 frequency bands. The 4400-4990 MHz band was identified as having expansion potential for aeronautical mobile activities. However, the 4400-4990 MHz band is a shared band involving the Fixed, Mobile, and Fixed-Satellite Services. It is necessary to identify the potential spectrum management problems associated with sharing this band.

PROBLEM ASSESSMENT MATRIX

Using relatively simple criteria, a first step can be made to identify the issues involving spectrum management of the 4400-4990 MHz band in the future. The intent is not to develop solutions to the problems, but rather to indicate the area of the problems to be addressed in the next section.

The criteria for this initial cull are frequency, space and time. When two services share all these elements, interference problems become possible. Conversely, if the two services are mutually exclusive in any one element, compatible sharing is feasible. Using these criteria, a preliminary interaction matrix has been developed (see Figure 5) that indicates the relative degree of expected compatibility between each category of stations. Three levels of compatibility are indicated.

No Problem: No interactions or interactions where no interference is expected even under worst-case conditions.

Manageable Problem: Interactions where interference is possible under worst-case conditions, but which can be avoided using standard spectrum management techniques.

Potential Problem: Interactions where potential compatibility and/or spectrum congestion problems are possible and a more detailed examination is required.

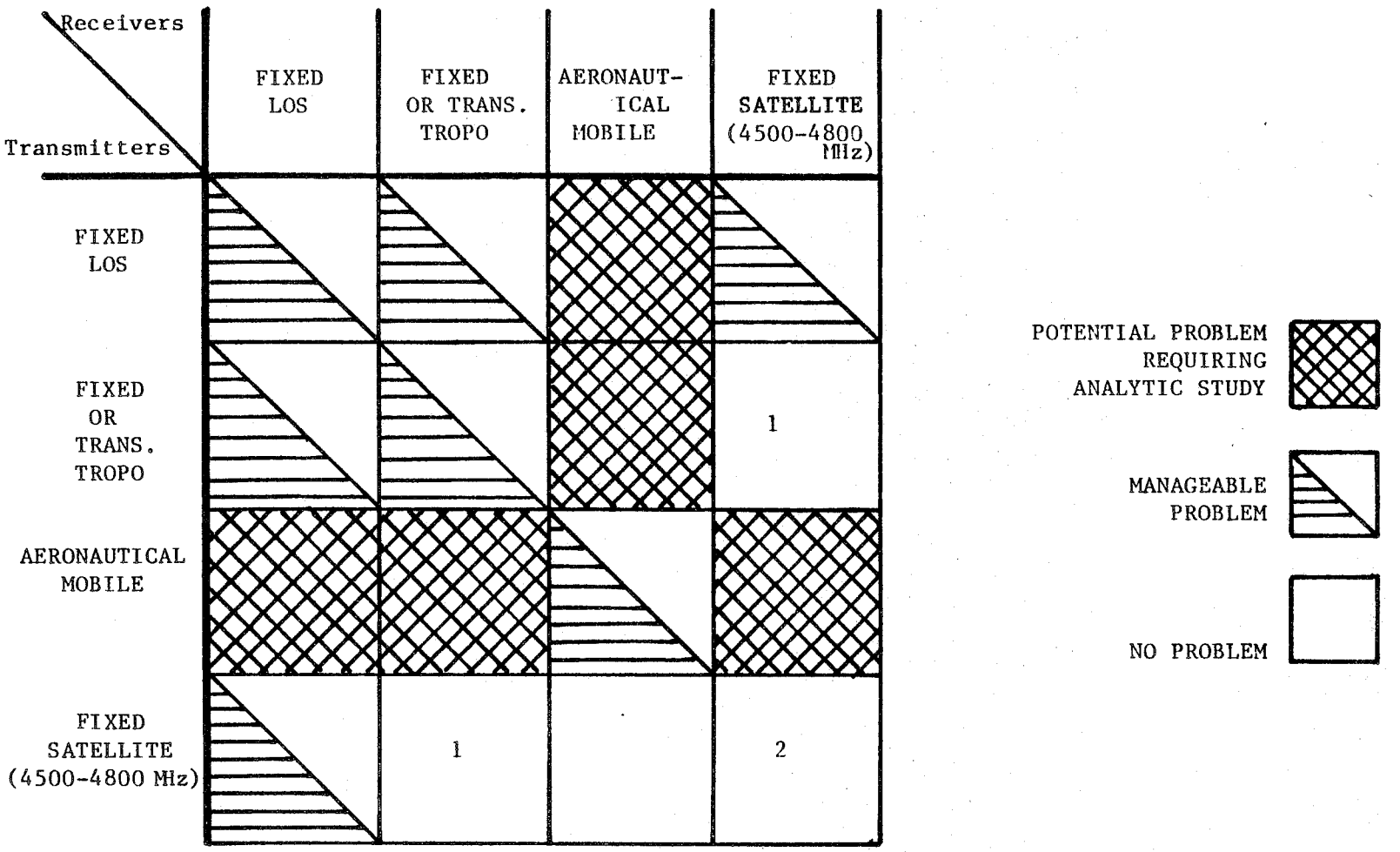
POTENTIAL PROBLEMS

The potential problem areas involving the aeronautical mobile activities that merit further study are:

1) spectrum sharing between the Aeronautical Mobile Service and the Fixed Service line-of-sight (LOS) systems

2) spectrum sharing between the Aeronautical Mobile Service and the Fixed-Service troposcatter systems

3) the impact of the Aeronautical Mobile Service on Fixed-Satellite earth stations in the 4500-4800 MHz.



Notes: 1 = Problem addressed in NTIA Report 81-82 (Ng, 1981)
2 = Interactions involving only non-Government systems are not addressed in this report.

Figure 5. Problem Assessment Matrix for the 4400-4900 MHz Band.

The first key issue is the sharing between the Aeronautical Mobile Service and the line-of-sight (LOS) microwave communications systems. In the United States, the 4400-4990 MHz LOS systems are operated by the military services in training exercises. The equipment is primarily transportable enabling the forces to move entire units and to then set up communications links. Although the data collection efforts did not identify any permanent LOS links in the United States, there are some in Canada. Thus, the analysis results may be applicable in examining transborder problems.

A second key issue is the sharing between the Aeronautical Mobile Service and troposcatter communications systems. These troposcatter (or tropo for brevity) systems are used by the military systems and are transportable. New digital systems are being developed and deployed. An analysis is required that will determine the sharing possibilities between these systems.

The third major issue is the impact of the aeronautical systems on receiving earth stations in the Fixed-Satellite Service. The WARC-79 rearranged the band limits and the satellite transmission directionss. The sharing problem was analyzed in a previous assessment (Ng, 1981).

MANAGEABLE PROBLEMS

The sharing of aeronautical mobile systems with other aeronautical mobile systems is considered to be a manageable problem. Various sharing criteria are discussed in the following section that would enhance the sharing possibilities.

The sharing between the Fixed Service 4400-4990 MHz LOS and the tropo systems is a manageable problem. Sharing criteria have been well established. Since it does not involve the Aeronautical Mobile Service, it is not addressed further in this report.

SECTION 6

SHARING ANALYSIS

GENERAL

The previous sections identified potential congestion and frequency management problems in various bands. Some of these bands have been the subject of previous assessments where many of the frequency management problems were addressed. Largely unanswered in previous assessments, however, are the following questions.

1. In what frequency bands should new aeronautical systems, using spread spectrum modulation techniques, operate?

2. What is the interference potential of aeronautical systems using spread spectrum modulation techniques?

In general, the bands where aeronautical mobile activities are taking place are shared bands including both Fixed and Mobile Services. Occasionally other services are included. The problem assessment matrix for the 4400-4990 MHz band identified LOS and tropo communications systems as those systems warranting additional analysis.

A review of the trends of military activities regarding the Aeronautical Mobile Service indicates that spread spectrum modulation techniques are being used more frequently.

SHARING CRITERIA

This subsection presents some typical sharing criteria that are used when considering the Fixed and Aeronautical Mobile Services.

Receiver Sensitivity

The basic sensitivity in receivers over 400 MHz is a function of the basic noise power. The basic noise power in a system can be defined as:

$$P_N = kTB \qquad (1)$$

where

P_N = basic noise power, in Watts

k = Boltzman's constant, 1.38×10^{-23} Joules/Kelvin

T = system noise temperature, in Kelvins

B = bandwidth, in Hertz

To compute noise power in the receiver or the thermal noise sensitivity, the

receiver noise figure must be included. Converting to logarithmic terms:

$$R_S = P_N + NF \quad (2)$$

where

R_S = receiver thermal noise sensitivity, in dBm

P_N = basic noise power, in dBm

NF = receiver noise figure, in dB

In some cases, sharing criteria can be based on the receiver thermal noise sensitivity. A sharing criterion equal to R_S can often be used, or 10 dB below R_S where receiving systems are operating at or near their basic sensitivity values. The terminology used herein is the interference-to-noise ratio (INR) of INR = 0 or INR = -10 dB.

Carrier-to-Interference Ratio (C/I)

In some cases it is appropriate to use a desired signal level (carrier) to undesired signal (interference) level ratio. In these cases, the level of the interfering signal is generally above the basic receiver sensitivity. The receiver output is not seriously degraded at the prescribed carrier-to-interference ratio (C/I) and good system performance is obtained.

For point-to-point communications of both the LOS and tropo types, the minimum acceptable C/I value is generally about 60 dB. Higher values become necessary when considering carrier beat interference.

Digital Systems Criteria

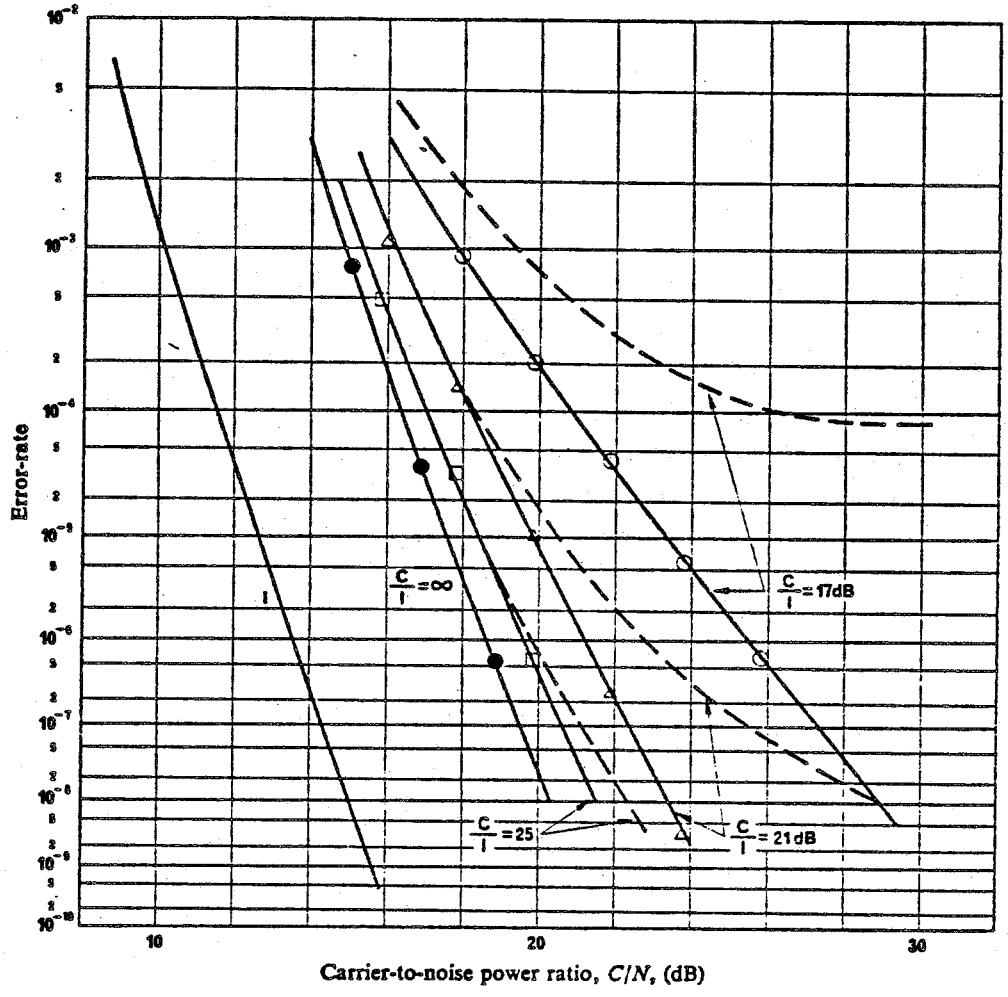
Figure 6 presents the error rate performance of digital systems for the case of cochannel interference (CCIR, 1978). These values were obtained from digital radio-relay systems used in fixed LOS systems. No error correction techniques are employed in the development of the performance curves. The lower performance bound of digital systems is generally accepted to have an error rate of 10^{-6}. At an error rate of 10^{-3}, the system synchronization is generally lost resulting in a drastic increase in the number of errors.

SPREAD SPECTRUM SYSTEMS

More and more aeronautical mobile systems are being developed that employ spread spectrum modulation systems. It is appropriate to examine such systems and how they share the spectrum.

Technical Characteristics

Spread spectrum systems are generally defined as those systems where the radio-frequency (RF) bandwidth is not a function of the information bandwidth and where the RF bandwidth is much greater than the information bandwidth. An "intelligent" receiver is also usually associated with spread spectrum systems.



I: Ideal theoretical value without band limitation

○ △ ● □ : Measured values

—— —— : Calculated values (Gaussian assumption)

C/I: Carrier-to-interchannel interference ratio

Figure 6. Typical Digital System Performance Curves.

One advantage of spread spectrum systems over conventional systems is in the processing gain (Dixon, 1976). This is defined as the difference (in dB) between the processor output and input signal-to-noise ratios. In general, the upper bound on the amount of processing available can be estimated by:

$$G_P = 10 \log (BW_{RF}/R_{INFO})$$

where

G_P = available processing gain, in dB

BW_{RF} = radio-frequency bandwidth, in Hertz

R_{INFO} = data rate in the information baseband channel, in b/s

Although variables such as the RF bandwidth, the basic information bandwidth, and the sampling rate must be considered when determining the available processing gain, the RF bandwidths usually available are between 20 and 100 MHz. For various types of information and sampling rates, the available processing gain will typically range from 20 to 40 dB.

Spread spectrum systems often have a performance margin associated with them. This is sometimes referred to as a "jamming" margin because the terminology originated from tactical military systems where the performance is measured in the presence of intentional interference. The general expression for a performance margin is:

$$\text{Performance Margin} = G_P - [L_{sys} + S/N_{out}]$$

where

Performance Margin is expressed, in dB

G_P = available processing gain, in dB

L_{sys} = system implementation losses, in dB

S/N_{out} = signal-to-noise ratio at the information output, in dB

A typical system may have a 30 dB processing gain, an $(S/N)_{out}$ of 10 dB, and system losses of 2 dB. This results in a performance margin of 18 dB meaning that the interference could exceed the desired signal level by amounts up to 18 dB without seriously degrading performance.

A typical data link system must be developed in order to proceed with the analysis. The data link system developed herein is one that can be expected in the future using state of the art equipment. This is so that the analysis results will be usable in long-range spectrum planning.

Solid State Technology. Figure 7 presents the current state-of-the-art in Galium-Arsenide (GA) Field Effect Transistor (FET) power output versus frequency

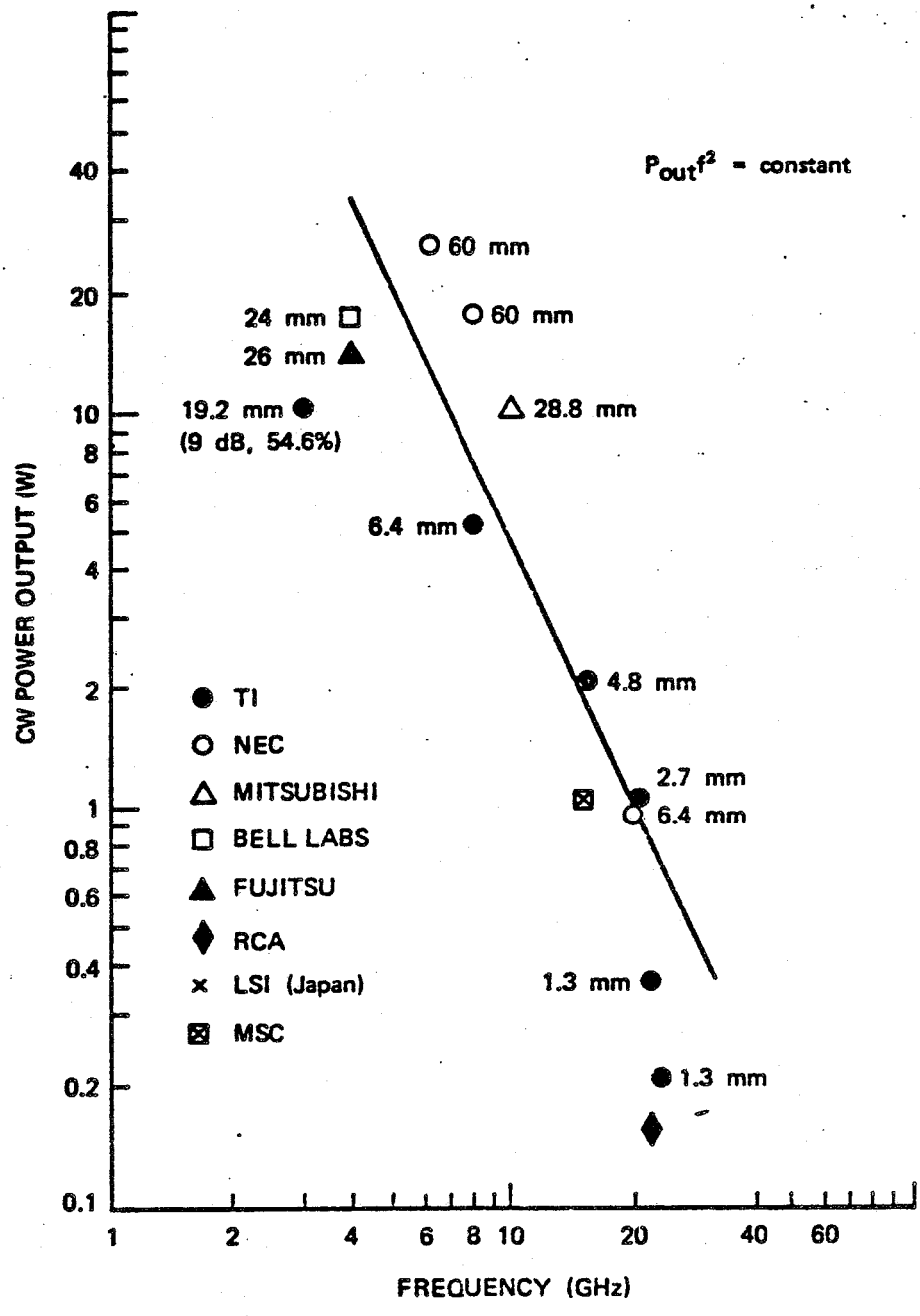


Figure 7. GA FET power output versus frequency. From H.G. Tserng, "Advances in Microwave GA Power FET Devices and Circuit Technology," 1981 European Microwave Conference, London. State of the art as of September 1981.

(AGED, 1981). At 4400-4990 MHz, the current state of the art is 20 watts CW output. Some digital systems in a network configuration have pulsed or bursts of output. Thus, a duty cycle may be associated with the output power values. A 20 dB duty cycle will be used in the analysis calculation.

Various research projects into microwave solid-state amplifiers have been sponsored by the branches of the Department of Defense. One project saw the development of silicon bipolar transistor amplifiers in the 3.1-3.5 GHz band. A peak power output of 200 watts was obtainable. Similar results could be expected in the 4400-4990 MHz band.

Another research project into silicon bipolar power amplifiers in the 4.4-5.0 GHz band resulted in a device that is capable of generating 12 watts of continuous power. The device bandwidth was 600 MHz.

Research into GA FET amplifiers indicates that a device can be developed that is capable of producing a 200 watt peak power output in the 3.0-3.5 GHz band. Similar results could be expected in the 4400-4990 MHz band.

DOD sponsored research into IMPATT diodes has produced an amplifier capable of producing 1 kw peak power output in the 8-10 GHz band. Similar or higher outputs can be expected in the 4400-4990 MHz band.

Data Link Technical Performance. In one case, the data link receiver is located on the ground and with the transmitter being airborne. This is the scenario where tactical remotely piloted vehicles (RPVs) would be the platforms using the data link. A second scenario exists wherein both transmitters and receivers are airborne and networking is achieved.

The data link system bandwidth using spread spectrum modulation techniques can be either moderate (20 MHz) or wide (100 MHz or greater). The digital data may be digitized voice, video, or other information. With a 20 watt transmitter power, this yields CW power spectral densities of -30 dBm/Hz and -37 dBm/Hz, respectively.

The antenna gain on the moving platform is considered to be 0 dBi, although some slotted arrays may be higher. The antenna gain of the ground station is considered to be 34 dBi, that being the gain of a parabolic antenna 1.5 meters in diameter.

The receiver sensitivities are related to the basic noise power and to their noise figure. When considering the thermal noise in 20 or 100 MHz, the kTB calculation yields P_N as -101 dBm at T=290K and B=20 MHz. At 100 MHz, the P_N is -94 dBm. With a 5 dB noise figure, the receiver sensitivities for 20 and 100 MHz bandwidths are -96 and -89 dBm, respectively. This calculation ignores the processing gain of spread spectrum process. When considering processing gain, a 30 dB value will be used as typical.

A typical link budget equation can be developed for the data link systems.

TABLE 13

TYPICAL DATA LINK BUDGET EQUATION

	Air-to-Air	Air-to-Ground
Peak transmitter power (20 watts average with 20 dB duty cycle)	+63 dBm	+63 dBm
Vehicle antenna gain	0 dBi	0 dBi
Path loss (4600 MHz at 200 km)	152 dB	152 dB
Receiver antenna gain	0 dBi	34 dBi
Transmission line and other losses	3 dB	3 dB
Received Power	-92 dBm	-58 dBm

TABLE 13 indicates that the air-to-air receiver may expect a -92 dBm signal level. When considering basic receiver sensitivity of -89 and -96 dBm, the expected performance is only marginal because fading may occur providing some additional path loss. When considering the receiver spread spectrum processing gain, acceptable performance can be achieved particularly if the processing gain is 30 dB or more.

FIXED SERVICE SYSTEM EXAMPLE

Since the desired result of this analysis is to be useful in long-range planning, a modern troposcatter equipment should be considered that would be expected to be used in the future. The AN/TRC-170 is a digital troposcatter system that is being procured by the Air Force Joint Tactical Communication Office and will be used in the future. This analysis can also be applied to fixed point-to-point LOS microwave systems.

The AN/TRC-170 operates in the 4400-5000 MHz band with an occupied bandwidth of 3.5 or 7.0 MHz. Data rates between 128-4096 Kbps are used in the system. The nominal service range is 160-330 km. The receiving antenna is one of three different sizes from 1.8 to 4.5 meters in diameter with gains ranging from 36.5 to 44.5 dBi.

The antenna sidelobe pattern of the AN/TRC-170 will be considered to conform to the CCIR antenna reference radiation pattern for radio relay systems, (CCIR 1982). In this pattern, the gain values are:

$$G = 38 - 25 \log \theta, \quad 1^\circ < \theta < 33$$

and

$$G = 0, \quad 33^\circ \leq \theta \leq 180^\circ$$

where

G is the gain in dBi

θ is the angle from the axis of the mainbeam

The 3 dB beamwidths of the 4.5 and 1.8 meter diameter antennas are approximately one and three degrees respectively.

The receiver bandwidth that will be used is 3.5 MHz with a 3 dB noise figure yielding a sensitivity of about -105 dBm. Systems operating in the Fixed Service as point-to-point, line-of-sight systems may have receiver bandwidths on the order of 1 MHz and noise figures of 5 to 13 dB.

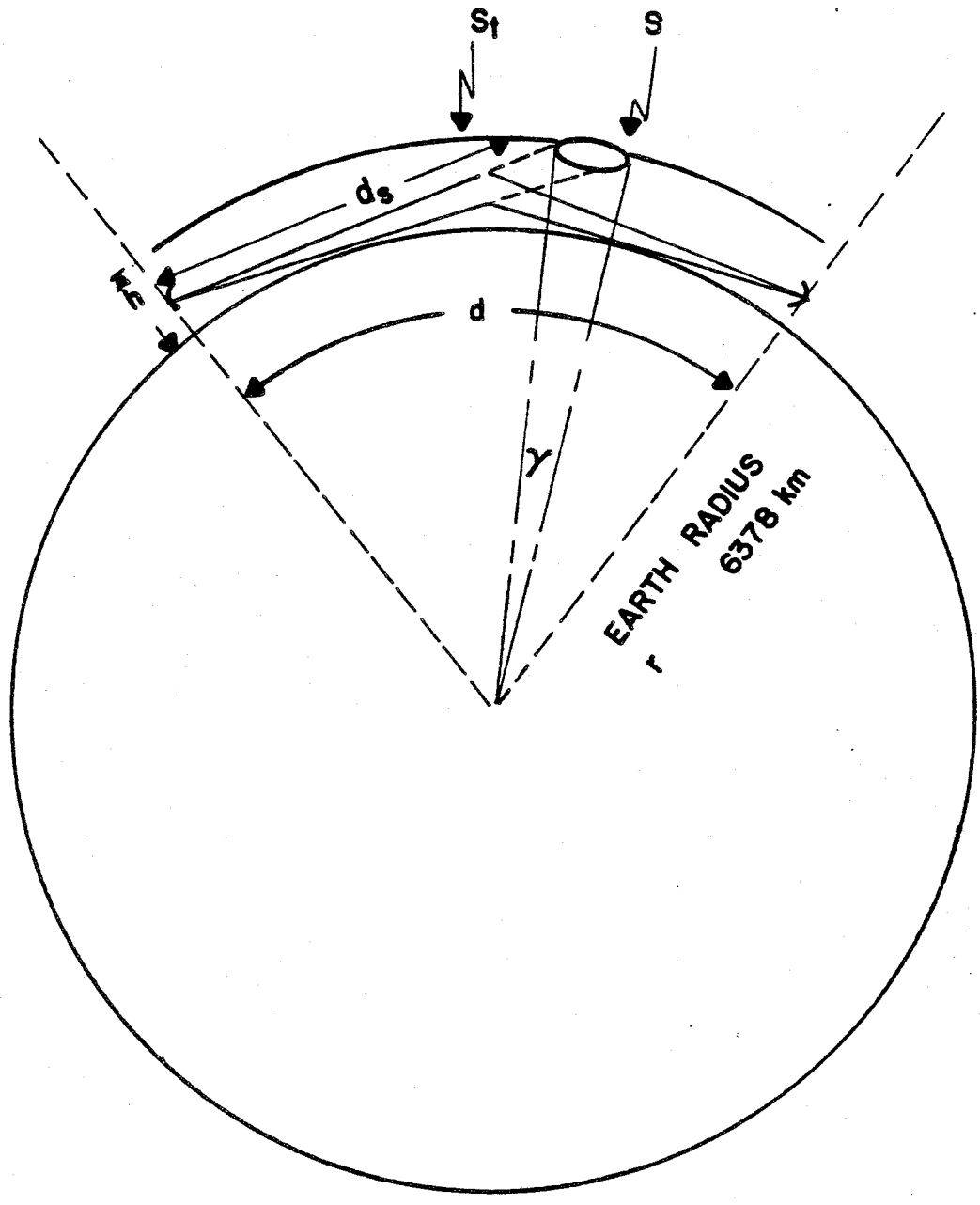
SHARING ANALYSIS

The analysis of the interference from an airborne transmitter to a fixed receiving station must address the probability that interference will occur. This is based on the fact that the fixed antenna is pointed to a fixed point in space and the airborne transmitter may be located anywhere in the space surrounding the fixed station.

Figure 8 presents the geometry for the probability of mainbeam coupling into a troposcatter system from an aircraft carrying a transmitter operating in the aeronautical mobile service. For this example, an AN/TRC-170 will be used as the typical troposcatter system and the AN/DKW-1 as the aeronautical mobile system. Additionally, it is assumed that the operating diameter of the airborne system is identical to the operating area of the troposcatter system. The operating distance of the troposcatter system is considered to be 300 km. A 2.5 Watt airborne transmitter with a 0 dBi gain antenna operating at 4800 MHz will produce a signal level of approximately -91 dBm at the receiver input that is above the receiver sensitivity of typically -105 dBm.

The probability of interference from the aircraft to the troposcatter receiver can be approximated

$$P = S/S_t$$



r = Earth radius ≈ 6378 km

h = Aircraft altitude ≈ 7 km

d = Troposcatter communication range ≈ 300 km
= Diameter of aircraft operating area (assumed)

S_t = Total operating area of aircraft

S = Portion of aircraft operating area subtended by troposcatter mainbeam

σ = Elevation angle of troposcatter mainbeam ≈ 1.5°

β = Beamwidth of troposcatter mainbeam ≈ 3°

γ = Geocentric angle of troposcatter mainbeam projected on operating area

Figure 8. Typical Troposcatter and Aircraft Coupling Geometry.

where

P = is the probability of interference

S = portion of operational area of aircraft subtended by mainbeam

S_t = total area of operation of aircraft

The aircraft is considered to be capable of being anywhere within the region of operation on an equal likelihood basis. Since the assumed operational diameter for the aircraft is small compared to the diameter of the Earth, the total area S_t can be approximated (within 1%) using plane geometry by

$$S_t \approx \pi d^2/4$$

$$\approx \pi(300)^2/4$$

$$\approx 70686 \text{ km}^2$$

Establishing the area subtended by the mainbeam is more difficult since the area cannot, in general, be represented by a circular section of a sphere. Again using a plane geometry approximation, the area can be approximated as an elipse with a major axis, d_1, given by

$$d_1 \approx (r + h) \quad \gamma \text{ (radians)}$$

where r, h, and γ are defined on Figure 8. The minor axis d_2 can be approximated by

$$d_2 \approx d_s \quad \beta \text{(radians)}$$

$$\approx 300 \beta \text{ (km)}$$

The area S is then

$$S \approx \pi d_1 d_2/4$$

Using standard trigonometric identities to solve for γ yields

$$\gamma \approx 0.029 \text{ radians}$$

$$d_1 \approx (6378 + 7)(0.029) = 185.2$$

$$d_2 \approx (300)\ (.0523) = 15.7$$

$$S \approx \pi d_1 d_2/4$$

$$\approx (3.14)\ (185.2)\ \ (15.7)/4$$

$$\approx 2282 \text{ km}^2$$

The probability of mainbeam coupling is then, for this example,

$$P = S/S_t \approx 2282/70686$$

$$\approx 3.2\%$$

Additional interference coupling via the troposcatter antenna sidelobes may result when the aircraft is overhead.

The analysis has shown that when operating in the same area, aeronautical mobile systems may interfere with troposcatter systems on the order of 3% of the time which would probably be unacceptable in most operational cases, but may be acceptable for tactical and training exercises. In cases where this level of interference is unacceptable, separation of these services on different channels or portions of the band may be a satisfactory procedure.

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APPENDIX A

EXCERPTS FROM TABLE OF ALLOCATIONS

This appendix presents excerpts from the Table of Allocations (see TABLE A-1) including those frequency bands between 400 MHz and 17 GHz where aeronautical mobile activities are permitted. The allocation is either to the Mobile Service or to the Aeronautical Mobile Service. The Table of Allocations was extracted from the NTIA Manual revised as of May 1983.

TABLE A-1

EXCERPT FROM TABLE OF ALLOCATIONS

INTERNATIONAL			UNITED STATES				
Region 1 *MHz*	*Region 2* *MHz*	*Region 3* *MHz*	*Band* *MHz* *1*	*National Provisions* *2*	*Government Allocation* *3*	*Non-Government Allocation* *4*	*Remarks* *5*
406.1–410	FIXED MOBILE except aeronautical mobile RADIO ASTRONOMY 648 650		406.1–410	US13 US74 US117	FIXED MOBILE RADIO ASTRONOMY G5 G6	RADIO ASTRONOMY	The Channeling Plan for assignments in this band is shown in Section 4.3.9 of the NTIA Manual.
410–420	FIXED MOBILE except aeronautical mobile		410–420	US13	FIXED MOBILE G5		
890–942 FIXED MOBILE except aeronautical mobile BROADCASTING 703 Radiolocation	890–902 FIXED MOBILE except aeronautical mobile Radiolocation 705	890–942 FIXED MOBILE BROADCASTING Radiolocation					
704	902–928 FIXED Amateur Mobile except aeronautical mobile Radiolocation 705 707	706	902–928	US215 US218 US267 US275 707	RADIOLOCATION G11 G59		(ISM 915 ± 13 MHz)

TABLE A-1 (CONTINUED)

INTERNATIONAL			UNITED STATES				
Region 1 MHz	*Region 2 MHz*	*Region 3 MHz*	*Band MHz* 1	*National Provisions* 2	*Government Allocation* 3	*Non-Government Allocation* 4	*Remarks* 5
1350-1400 FIXED MOBILE RADIOLOCATION 718 719 720	1350-1400 RADIOLOCATION 714 718 720		1350-1400	714 718 720	RADIOLOCATION Fixed Mobile G2 G27 G114		
1429-1525 FIXED MOBILE except aeronautical mobile 722	1429-1525 FIXED MOBILE 723 722		1429-1435	722	FIXED MOBILE G30	Land Mobile (Telemetering and telecommand) Fixed (Telemetering)	
			1435-1530	US78 722	MOBILE (Aeronautical telemetering)	MOBILE (Aeronautical telemetering)	

TABLE A-1 (CONTINUED)

INTERNATIONAL			UNITED STATES				
Region 1 *MHz*	*Region 2* *MHz*	*Region 3* *MHz*	*Band* *MHz* *1*	*National Provisions* *2*	*Government Allocation* *3*	*Non-Government Allocation* *4*	*Remarks* *5*
1525–1530 SPACE OPERATION (Space-to-Earth) FIXED Earth Exploration-Satellite Mobile except aeronautical mobile 724 722 725	1525–1530 SPACE OPERATION (Space-to-Earth) Earth Exploration Satellite Fixed Mobile 723 722	1525–1530 SPACE OPERATION (Space-to-Earth) FIXED Earth Exploration-Satellite Mobile 723 724 722					
1530–1535 SPACE OPERATION (Space-to-Earth) MARITIME MOBILE-SATELLITE (Space-to-Earth) Earth Exploration-Satellite Fixed Mobile except aeronautical mobile 722 726	1530–1535 SPACE OPERATION (Space-to-Earth) MARITIME MOBILE-SATELLITE (Space-to-Earth) Earth Exploration-Satellite Fixed Mobile 723 722 726		1530–1535	US78 US272 722	MARITIME MOBILE-SATELLITE (Space-to-Earth) Mobile (Aeronautical telemetering)	MARITIME MOBILE-SATELLITE (Space-to-Earth) Mobile (Aeronautical telemetering)	

TABLE A-1 (CONTINUED)

INTERNATIONAL			UNITED STATES				
Region 1 MHz	*Region 2 MHz*	*Region 3 MHz*	*Band MHz 1*	*National Provisions 2*	*Government Allocation 3*	*Non-Government Allocation 4*	*Remarks 5*
1710-2290 FIXED Mobile	1710-2290 FIXED MOBILE		1710-1850	US256 722	FIXED MOBILE G42		
			1850-1990			FIXED	
			1990-2110	US90 US111 US219 US222		FIXED MOBILE NG23 NG118	
722 744 746 747 748 750	722 744 745 746 747 748 749 750		2110-2200	US111 US252		FIXED NG23	
			2200-2290		FIXED (LOS*only) MOBILE (LOS only including aeronautical telemetering, but excluding flight testing of manned aircraft) SPACE RESEARCH (Space-to-Earth) (Space-to-space) G101		*Line of sight

TABLE A-1 (CONTINUED)

INTERNATIONAL			UNITED STATES				
Region 1 MHz	*Region 2 MHz*	*Region 3 MHz*	*Band MHz* *1*	*National Provisions* *2*	*Government Allocation* *3*	*Non-Government Allocation* *4*	*Remarks* *5*
2300-2450 FIXED Amateur Mobile Radiolocation 664 752	2300-2450 FIXED MOBILE RADIOLOCATION Amateur 664 751 752		2300-2310	US253	RADIOLOCATION Fixed Mobile G2	Amateur	
			2310-2390	US276	RADIOLOCATION MOBILE Fixed G2	MOBILE	
			2390-2450	664 752	RADIOLOCATION G2	Amateur	(ISM 2450 ± 50 MHz)
2450-2500 FIXED MOBILE Radiolocation 752 753	2450-2500 FIXED MOBILE RADIOLOCATION 752		2450-2500	US41 752		FIXED MOBILE Radiolocation	(ISM 2450 ± 50 MHz)

TABLE A-1 (CONTINUED)

INTERNATIONAL			UNITED STATES				
Region 1 MHz	*Region 2 MHz*	*Region 3 MHz*	*Band MHz 1*	*National Provisions 2*	*Government Allocation 3*	*Non-Government Allocation 4*	*Remarks 5*
4400–4500	FIXED MOBILE		4400–4500		FIXED MOBILE		
4500–4800	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE 792		4500–4800	US245	FIXED MOBILE	FIXED-SATELLITE (Space-to-Earth)	
4800–4990	FIXED MOBILE 793 Radio Astronomy 720 778 794		4800–4990	US203 US257 720 778	FIXED MOBILE		

TABLE A-1 (CONTINUED)

INTERNATIONAL			UNITED STATES				
Region 1 MHz	*Region 2 MHz*	*Region 3 MHz*	*Band MHz* *1*	*National Provisions* *2*	*Government Allocation* *3*	*Non-Government Allocation* *4*	*Remarks* *5*
5925-7075	FIXED FIXED-SATELLITE (Earth-to-space) MOBILE 791 809						
			6425-6525	791 809		MOBILE FIXED-SATELLITE (Earth-to-space) NG122	
			6875-7075	809		FIXED FIXED-SATELLITE (Earth-to-space) MOBILE NG118	
7075-7250	FIXED MOBILE 809 810 811		7075-7125	809		FIXED MOBILE NG118	

TABLE A-1 (CONTINUED)

INTERNATIONAL			UNITED STATES				
Region 1 GHz	*Region 2 GHz*	*Region 3 GHz*	*Band GHz 1*	*National Provisions 2*	*Government Allocation 3*	*Non-Government Allocation 4*	*Remarks 5*
12.5–12.75 FIXED-SATELLITE (Space-to-Earth) (Earth-to-space) 840 848 849 850	12.7–12.75 FIXED FIXED-SATELLITE (Earth-to-space) MOBILE except aeronautical mobile 840	12.5–12.75 FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE except aeronautical mobile BROADCASTING-SATELLITE 847 840	12.7–12.75	840		FIXED FIXED-SATELLITE (Earth-to-space) MOBILE NG53 NG118	
12.75–13.25	FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Space Research (Deep Space) (Space-to-Earth)		12.75–13.25	US251		FIXED MOBILE FIXED-SATELLITE (Earth-to-space) NG53 NG104 NG118	
14.4–14.47	FIXED FIXED-SATELLITE (Earth-to-space) 858 MOBILE except aeronautical mobile Space Research (Space-to-Earth) 859		14.4–14.5	US203 US234 US287 862	Mobile Fixed	FIXED-SATELLITE (Earth-to-space)	
14.47–14.5	FIXED FIXED-SATELLITE (Earth-to-space) 858 MOBILE except aeronautical mobile Radio Astronomy 859 862						

TABLE A-1 (CONTINUED)

INTERNATIONAL			UNITED STATES				
Region 1 GHz	*Region 2 GHz*	*Region 3 GHz*	*Band GHz* *1*	*National Provisions* *2*	*Government Allocation* *3*	*Non-Government Allocation* *4*	*Remarks* *5*
14.5-14.8	FIXED FIXED-SATELLITE (Earth-to-space) 863 MOBILE Space Research		14.5-14.7145		FIXED Mobile Space Research		
			14.7145-15.1365		Fixed MOBILE Space Research G119		
14.8-15.35	FIXED MOBILE Space Research 720		15.1365-15.35	US211 720	FIXED Mobile Space Research		

INTERNATIONAL FOOTNOTES ADOPTED BY THE UNITED STATES

707-In Region 2, the band 902 - 928 MHz (centre frequency 915 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815.

714-Additional allocation: in Canada and the United States, the bands 1 240 - 1 300 MHz and 1 350 - 1 370 MHz are also allocated to the aeronautical radionavigation service on a primary basis.

718-In making assignments to stations of other services, administrations are urged to take all practicable steps to protect the spectral line observations of the radio astronomy service from harmful interference in the band 1 330 - 1 400 MHz. Emissions from space or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 343 and 344 and Article 36).

720-The bands 1 370 - 1 400 MHz, 2 640 - 2 655 MHz, 4 950 - 4 990 MHz and 15.20 - 15.35 GHz are also allocated to the space research (passive) and earth exploration-satellite (passive) services on a secondary basis.

722-In the bands 1 400 - 1 727 MHz, 101 - 120 GHz and 197 - 220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extra-terrestrial origin.

745-Subject to agreement obtained under the procedure set forth in Article 14 and having particular regard to tropospheric scatter systems, the band 1 750 - 1 850 MHz may also be used for space operation (Earth-to-space) and space research (Earth-to-space) services in Region 2, in Afghanistan, Australia, India, Indonesia, Japan and Thailand.

752-The band 2 400 - 2 500 MHz (centre frequency 2 450 MHz) is designated for industrial, scientific and medical (ISM) applications. Radio services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815.

778-In making assignments to stations of other services, administrations are urged to take all practicable steps to protect the spectral line observations of the radio astronomy service from harmful interference in the bands 3 260 - 3 267 MHz, 3 332 - 3 339 MHz, 3 345.8 - 3 352.5 MHz and 4 825 - 4 835 MHz. Emissions from space or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 343 and 344 and Article 36).

791-The standard frequency and time signal-satellite service may be authorized to use the frequency 4 202 MHz for space-to-Earth transmissions and the frequency 6 427 MHz for Earth-to-space transmissions. Such transmissions shall be confined within the limits of $\pm$ 2 MHz of these frequencies and shall be subject to agreement obtained under the procedure set forth in Article 14.

809-In the band 6 425 - 7 075 MHz, passive microwave sensor measurements are carried out over the oceans. In the band 7 075 - 7 250 MHz, passive microwave sensor measurements are carried out. Administrations should bear in mind the needs of the earth exploration-satellite (passive) and space research (passive) services in their future planning of this band.

840-For the use of the band 11.7 - 12.75 GHz in Regions 1, 2 and 3, see Resolutions 31, 34, 504, 700 and 701.

862-In making assignments to stations of other services to which the band 14.47 - 14.5 GHz is allocated, administrations are urged to take all practicable steps to protect spectral line observations of the radio astronomy service from harmful interference. Emissions from space or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 343 and 344 and Article 36).

UNITED STATES NATIONAL FOOTNOTES

US13-For the specific purpose of transmitting hydrological and meteorological data in cooperation with agencies of the Federal Government, the following frequencies may be authorized to non-Government fixed stations on the condition that harmful interference will not be caused to Government stations:

MHz	MHz	MHz	MHz
169.425	170.275	171.125	406.175
169.450	170.300	171.825	409.675
169.475	170.325	171.850	409.725
169.500	171.025	171.875	412.625
169.525	171.050	171.900	412.675
170.225	171.075	171.925	412.725
170.250	171.100	406.125	412.775

Licensees holding a valid authorization on June 11, 1962, to operate on the frequencies 169.575, 170.375, or 171.975 MHz may continue to be authorized for such operations on the condition that harmful interference will not be caused to Government stations.

US41-The Government radiolocation service is permitted in the band 2450-2500 MHz on the condition that harmful interference is not caused to non-Government services.

US74-In the bands 25.55-25.67, 73-74.6, 406.1-410, 608-614, 1400-1427, 1660.5-1670, 2690-2700, and 4990-5000 MHz and in the bands 10.68-10.7, 15.35-15.4, 23.6-24, 31.3-31.8, 86-92, 105-116, and 217-231 GHz, the radio astronomy service shall be protected from extraband radiation only to the extent such radiation exceed the level which would be present if the offending station were operating in compliance with the technical standards or criteria applicable to the service in which it operates.

US78-In the band 1435-1535 MHz, the frequencies between 1435 and 1485 MHz will be assigned primarily for the flight testing of manned aircraft, or major components thereof; the frequencies between 1485 and 1535 MHz will be assigned primarily for the flight testing of unmanned aircraft and missiles or major components thereof. Included as permissible usage for aeronautical telemetering stations in the band 1435-1535 MHz is telemetry associated with launching and re-rentry into the earth's atmosphere, as well as any incidential orbiting prior to re-entry, of manned or unmanned objects undergoing flight tests. In the band 1530-1535 MHz the maritime mobile-satellite service will be the only primary service after 1 January 1990.

US90-In the band 2025-2110 MHz earth-to-space and space-to-space transmissions may be authorized in the space research and earth exploration-satellite services subject to such conditions as may be applied on a case-by-case basis. Such transmissions shall not cause harmful interference to non-Government stations operating in accordance with the Table of Frequency Allocations. All space-to-space transmission reaching the earth's surface shall adhere to a power flux density of between -144 and -154 dbw/M^2/4 kHz depending on angle of arrival in accordance with ITU Radio Regulations, 2557 NE through 2560 NGA and shall not cause harmful interference to the other space services.

US111-In the band 1990-2120 MHz, Government space research earth stations may be authorized to use specific frequencies at specific locations for earth-to-space transmissions. Such authorizations shall be secondary to non-Government use of this band and subject to such other conditions as may be applied on a case-by-case basis.

Corpus Christi, Tex., 27° 39' N 097° 23' W.
Fairbanks, Alaska, 64° 59' N 147° 53' W.
Goldstone, Calif., 35° 18' N 116° 54' W.
Greenbelt, Md., 39° 00' N 076° 50' W.
Guam, Mariana Is., 13° 19' N 144° 44' E.
Kauai, Hawaii, 22° 08' N 159° 40' W.
Merritt Is., Fla., 28° 29' N 080° 35' W.
Rosman, N. C., 35° 12' N 082° 52' W.
Wallops Is., Va., 37° 57' N 075° 28' W.

US117-In the band 406.1-410 MHz, all new authorizations will be limited to a maximum 7 watts per kHz of necessary bandwidth; existing authorizations as of November 30, 1970 exceeding this power are permitted to continue in use.

New authroizations in this band for stations, other than mobile stations, within the following areas are subject to prior coordination by the applicant with the Radio Spectrum Manager, National Science Foundation, Washington, D. C. 20550 (202-357-9696):

Arecibo Observatory:
Rectangle between latitudes 17° 30' N and 19° 00' N and between longitudes 65° 10' W and 68° 00' W.

Owens Valley Radio Observatory:
Two contiguous rectangles, one between latitudes 36° N and 37° N and longitudes 117° 40' W and 118° 30' W and the second between latitudes 37° N and 38° N and longitudes 118° W and 118° 50' W.

Sagamore Hill Radio Observator:
Rectangle between latitudes 42° 10' N and 43° 00' N and longitudes 70° 31' W and 71° 31' W.

Table Mountain Solar Observatory (NOAA)
Boulder, Colorado (407-409 MHz only)
Rectangle between latitudes 39° 30' N and 40° 30' N and longitudes 104° 30' W and 106° 00' W or the Continental Divide whichever is farther east.

The non-Government use of this band is limited to the radio astronomy service and as provided by footnote US13.

US203-Radio astronomy observations of the formaldehyde line frequencies 4825-4835 MHz and 14.470-14.500 GHz may be made at certain radio Astronomy Observatories as indicated below:

Bands to be observed		Observatory
4 GHz	14 GHz	
X		National Astronomy and Ionosphere Center Arecibo, Puerto Rico
X	X	National Radio Astronomy Observatory Green Bank, W. Va.
X	X	National Radio Astronomy Observatory Soccorro, New Mexico
X	X	Hat Creek Observatory (U of Calif.) Hat Creek, California
X	X	Haystack Radio Observatory (MIT-Lincoln Lab) Tyngsboro, Mass.
X	X	Owens Valley Radio Observatory (Cal. Tech.) Big Pine, California
	X	Five College Radio Astronomy Observatory, Quabbin Reservoir (near Amherst) Massachusetts

Every practicable effort will be made to avoid the assignment of frequencies to stations in the fixed or mobile services in these bands. Should such assignments result in harmful interference to these observatrions, the situation will be remedied to the extent practicable.

US211-In the bands 1670-1690, 5000-5250 MHz, and 10.7-11.7,15.1365-15.35, 15.4-15.7, 22.5-22.55, 24-24.05, 31.0-31.3, 31.8-32, 40.5-42.5, 84-86, 102-105, 116-126, 151-164, 176.5-182, 185-190, 231-235, 252-265 GHz, applicants for airborne or space station assignments are urged to take all practicable steps to protect radio astronomy observations in the adjacent bands from harmful interference; however, US74 applies.

US215-Emissions from microwave ovens manufactured on and after January 1, 1980, for operation on the frequency 915 MHz must be confined within the band 902-928 MHz. Emissions from microwave ovens manufactured prior to January 1, 1980, for operation on the frequency 915 MHz must be confined within the band 902-940 MHz. Radiocommunciations services operating within the band 928-940 MHz must accept any harmful interference that may be experienced from the operation of microwave ovens manufactured before January 1, 1980.

US218-The band segments 902-912 MHz and 918-928 MHz are available for Automatic Vehicle Monitoring (AVM) Systems subject to not causing harmful interference to the operation of Government stations authorized in these bands. These systems must tolerate any interference from the operation of industrial, scientific, and medical (ISM) devices and the operation of Government stations authorized in these bands.

US219-In the band 2025-2120 MHz Government Earth Resources Satellite Earth Stations in the Earth Exploration-Satellite Service may be authorized to use the frequency 2106.4 MHz for earth-to-space transmissions for tracking, telemetry, and telecommand at the sites listed below. Such transmissions shall not cause harmful interference to non-Government operations:

Sioux Falls, S. D., 43° 32' 03.1" N 96° 45' 42.8" W.
Fairbanks, Alaska, 64° 58' 36.6" N 147° 30' 54.2" W.

US222-In the band 2025-2120 MHz Geostationary Operational Environmental Satellite Earth stations in the Space Research and Earth Exploration-Satellite Services may be authorized on a coequal basis to use the frequency band 2025-2035 MHz for earth-to-space transmissions for tracking, telemetry, and telecommand at the sites listed below:

Wallops Is., Va., 37° 50' 48" N 75° 27' 33" W.
Seattle, Wa., 47° 34' 15" N 122° 33' 10" W.
Honolulu, Ha., 21° 21' 12" N 157° 52' 36" W.

US234-In the band 14.4-14.5 GHz, all Government fixed and mobile stations, effective December 31, 1981, shall be on a secondary basis to stations in the non-Government fixed-satellite service. Exceptionally, the Government operations listed below, which were in existence on December 31, 1981, may continue to operate on a coequal primary basis with stations in the non-Government fixed-satellite service until December 31, 1986.

Operation	Points of Communication
Point Mugu, CA	From 34° 07' N 119° 07' W to 34° 00' N 119° 38' W
Fort Bragg, NC	From 35° 08' N 79° 05' W to 35° 10' N 79° 01' W
Vandenberg, CA	Transportable terminals within 25 km radius of 34° 44' N 120° 35' W

US245-The Fixed-Satellite Service is limited to International Systems and subject to case-by-case electromagnetic compatibility analysis.

US251-The band 12.75-13.25 GHz is also allocated to the Space Research, (Deep Space) (Space-to-Earth) Service for reception only at Goldstone, California. 35° 18' N - 116° 54' W.

US253-In the band 2300-2310 MHz, the fixed and mobile services sh not cause harmful interference to the amateur service.

US257-Radio astronomy observations may be made in the 4950-4990 MHz band at certain Radio Astronomy Observatories indicated below:

Hat Creek Observatory Hat Creek, California	Rectangle between latitude 40°00'N and 42°00'N and between longitude 120°15'W and 122°15' W.
Owens Valley Radio Observatory Big Pine, California	Two contiguous rectangles, one between latitudes 36°00'N and 37°00'N and longitudes 117°40'W and 118°30'W and the second between latitudes 37° 00'N and 38°00'N and longitudes 118°00'W and 118°50'W.
Haystack Radio Observatory Tyngsboro, Massachusetts and Five College Radio Astronmy Observatory Quabbin Reservoir (near Amherst, MA)	Rectangle between latitudes 41°00'N and 43°00'N and between longitudes 71°00'W and 73°00'W.
National Astronomy and Ionosphere Center Arecibo, Puerto Rico	Rectangle between latitudes 17°30'N and 19°00'N and between longitudes 65°10'W and 68°00'W.
National Radio Astronomy Observatory Socorro, New Mexico	Rectangle between latitudes 32°30'N and 35°30'N and between longitudes 106°00'W and 109°00' W.
National Radio Astronomy Observatory Green Bank, West Virginia	Rectangle between latitudes 37°30'N and 39°15'N and between longitudes 78°30'W and 80°30'W.

Every practicable effort will be made to avoid the assignment of frequencies in the band 4950-4990 MHz to stations in the fixed and mobile services within the geographic areas given above. In addition, every practicable effort will be made to avoid the assignment of frequencies in this band to stations in the aeronautical mobile service which operate outside of those geographic areas, but which may cause harmful interference to the listed observatories. Should such assignments result in harmful interference to these observatories, the situation will be remedied to the extent practicable.

US267-In the band 902-928 MHz, amateur radio stations shall not operate within the States of Colorado and Wyoming, bounded by the area of: latitude 39° N to 42° N and longitude 103° W to 108°W.

US272-The allocation to the Maritime Mobile-Satellite Service in the band 1530-1535 MHz shall be effective from 1 January 1990. Up to that date the allocation to the Mobile Service will be on a primary basis.

US275-The band 902-928 MHz is available to stations in the amateur service subject to not causing harmful interference to the operations of Government stations authorized in this band. Stations in the amateur service must tolerate any interference from the operations of industrial, scientific and medical (ISM) devices and the operations of Government stations authorized in this band.

US276-Use of the band 2310-2390 MHz by the mobile service is limited to aeronautical telemetering and associated telecommand operations.

US287-The band 14-14.5 GHz is also allocated to the non-Government land mobile-satellite service (Earth-to-space) on a secondary basis.

FEDERAL GOVERNMENT FOOTNOTES

G2--In the bands 216-225, 420-450 (except as provided by US217), 890-902, 928-942, 1300-1400, 2300-2450, 2700-2900, 5650-5925, and 9000-9200 MHz, the Government radiolocation is limited to the military services.

G5--In the bands 162.0125-173.2, 173.4-174, 406.1-410 and 410-420 MHz, the fixed and mobile services are all allocated on a primary basis to the Government non-military agencies.

G6--Military tactical fixed and mobile operations may be conducted nationally on a secondary basis; (1) to the meteorological aids service in the band 403-406 MHz; and (2) to the radio astronomy service in the band 406.1-410 MHz. Such fixed and mobile operations are subject to local coordination to ensure that harmful interference will not be caused to the services to which the bands are allocated.

G11--Government fixed and mobile radio services, including low power radio control operations, are permitted in the band 902-928 MHz on a secondary basis.

G27--The fixed and mobile services are limited to the military services.

G30--In the bands 138-144, 148-149.9, 150.05-150.8, 225-328.6, 335.4-399.9, 1427-1429 and 1429-1435 MHz, the fixed and mobile services are limited primarily to operations by the military services.

G42--Space command, control, range and range rate systems for earth station transmission only (including installations on certain Navy ships) may be accommodated on a co-equal basis with the fixed and mobile services in the band 1761-1842 MHz. Specific frequencies required to be used at any location will be satisfied on a coordinated case-by-case basis.

G59--In the bands 902-928 MHz, 3100-3300 MHz, 3500-3700 MHz, 5250-5350 MHz, 8500-9000 MHz, 9200-9300 MHz, 13.4-14.0 GHz, 15.7-17.7 GHz and 24.05-24.25 GHz, all Government non-military radiolocation shall be secondary to military radiolocation, except in the sub-band 15.7-16.2 GHz airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military departments.

G101-In the band 2200-2290 MHz, space operations (Space-to-Earth) and (Space-to-space), and earth exploration-satellite (Space-to-Earth) and (Space-to-space) services, may be accommodated on a co-equal basis with fixed, mobile and space research service.

G114-In the band 1350-1400 MHz, the frequency 1381.05 MHz with emissions limited to $\pm$ 12 MHz is also allocated to Fixed and Mobile Satellite Services (space-to-Earth) for the relay of nuclear burst data.

NON-GOVERNMENT FOOTNOTES

NG23-Frequencies in the band 2100-2200 MHz may also be assigned to stations in the international fixed public radio service located south of 25°30' north latitude in the State of Florida and in U.S. Possessions in the Caribbean area, provided, however, no new assignments in the band 2150-2162 MHz will be made to such stations after February 25, 1974.

NG53-In the band 12.7-13.15 GHz, television pickup stations and CARS pickup stations shall be assigned channels on a co-equal basis and shall operate on a secondary basis to fixed stations operating in accordance with the Table of Frequency Allocations. In the 13.15-13.20 GHz band television pickup stations and CARS pickup stations shall be assigned on an exclusive basis in the top one hundred markets, as set out in Section 76.51.

NG118-Television translator relay stations may be authorized to use frequencies in this band on a secondary basis to stations operating in accordance with the table of frequency allocations.

NG122-Television Pickup stations may be authorized in the 6425-6525 MHz band on a secondary basis to stations operating in accordance with the Table of Frequency Allocations.

APPENDIX B

Parts 7.18 and 7.19 of the NTIA Manual

Parts 7.18 and 7.19 of the NTIA Manual are concerned with aeronautical mobile activities in certain frequency bands. They are reproduced herein for reference.

7.18 MILITARY TELEMETERING AND TERRESTRIAL TELECOMMAND IN RADIOLOCATION BANDS

In order to transmit command signals to airborne vehicles being tracked and to receive status information from the vehicles, Military telemetering and terrestrial telecommand operations are authorized in the bands 3100–3700, 5250–5925, 8500–10,000 MHz, 13.4–14.0 and 15.7–17.7 GHz when conducted as an integral part of the operation of authorized stations in the radiolocation service. Such telemetering and terrestrial telecommand operations shall be on a secondary basis to authorized stations operating in accordance with the National Table of Frequency Allocations.

7.19 POLICY ON THE USE OF THE FREQUENCY BANDS BETWEEN 406 AND 550 MHz BY TARGET DRONES

The following policy is established with respect to use of the bands between 406.1 and 550 MHz by target drones:

1. Target drones may be supported in the 420–450 MHz band on a continuing basis;

2. Operations of all target drones in the band 450–550 MHz will cease not later than December 31, 1982. Extensions of existing assignments may be made on a nonrenewable basis to expire December 31, 1982; no extensions of this authority will be considered;

3. Target drones may continue to operate in the 406.1–420 MHz band until December 31, 1987 in designated and controlled military test and training areas and firing ranges on land and at sea. Target drones will operate in this band on a nonprotected, noninterference basis to current and future operations conducted in accordance with the National Table of Allocations;

4. Target drone operations will be limited to designated military ranges and training areas;

5. Target drone operations shall be reaccommodated from the 406.1–420 MHz band by December 31, 1987 and from the 450–550 MHz band by December 31, 1982 into the 420–450 MHz band or other appropriate bands. No extension of authority to use 406.1–420 MHz and 450–550 MHz bands will be considered.

6. No new procurement of transmitting and Receiving equipment in support of target drones in the band 406.1–420 MHz and 450–550 MHz will be initiated.

FORM NTIA-29
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U.S. DEPARTMENT OF COMMERCE
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SPECTRUM RESOURCE ASSESSMENT OF THE AERONAUTICAL MOBILE SERVICE BETWEEN 400 MHz and 17.7 GHz

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

This report is a spectrum resource assessment of the Aeronautical Mobile Service between 400 MHz and 17.7 GHz, which addresses the long-range planning of this service. It presents an assessment of 15 Federal Government frequency bands that are allocated to the Mobile or Aeronautical Mobile Services. Other bands containing aeronautical mobile activities are also reviewed. Included is information on allocations, technical standards, frequency assignments, and system characteristics. The future growth possibilities of the Aeronautical Mobile Service in the various bands is presented. The 4400-4900 MHz band was analyzed in detail to determine the sharing possibilities between the Fixed Service (point-to-point microwave and troposcatter communications systems) and aeronautical systems. The analysis indicates that sharing between such systems and aeronautical systems is feasible.

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

Spectrum Resource Assessment; Aeronautical Mobile Service;
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