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SPECTRUM RESOURCE ASSESSMENT IN THE 1710-1850 MHz BAND

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ABSTRACT

This report describes the spectrum resource assessment of the 1710-1850 MHz band. The Phase I Report [Hurt and Crandall, 1980] provided information on frequency allocations, technical standards, spectrum usage, and identification of key spectrum management issues. The key problem areas identified were the sharing between fixed and aeronautical mobile services, coordination of earth stations, accommodation of the Packet Radio System and congestion of certain geographic areas in the Continental U.S. This report examines these potential problems and identifies improvements to the current spectrum management process to assure the efficient use of the limited available spectrum.

KEY WORDS

Spectrum Resource Assessment
Fixed Service
Space Ground Link Subsystem
Packet Radio System
Spectrum Management
Radio Frequency Interference
1710-1850 MHz Band

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 assure 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 and/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.

The band 1710-1850 MHz is currently allocated nationally as a Government band for the Fixed and Mobile Services on a primary basis and by footnote G42, in portions of it, for Earth-to-space satellite control systems on a co-equal basis. In the past, the moderate number of assignments in the band allowed the needs of most agencies to be accommodated without significant compatibility problems or restrictions on use. Moreover, the limited number of systems allowed the frequency assignment process within the Interdepartment Radio Advisory Committee (IRAC) to proceed with relatively straight forward management techniques.

Recent activities within the IRAC forum, particularly through the system review process, indicate that significant growth in band usage is likely. More importantly, the wide variety of systems being proposed for the band significantly complicates the frequency management procedures. The diverse nature of these systems and their various degrees of incompatibility indicated a need for an overall study of this band.

The following multiphase approach to this task has been taken:

<u>Phase I:</u> This phase involved the identification of the existing and planned systems in the band, determination of available technical and operational data for each system, identification of the potential interactions between systems, and the generation of a plan leading to an overall assessment of the band's sharing potential. Phase I was completed and a report was published [Hurt and Crandall, 1980].

<u>Spectrum Resource Assessment (SRA):</u> This final phase of the study provides a detailed examination of the key issues identified in the Phase I portion. A quantitative evaluation of the potential problems is provided along with specific recommendations for change in spectrum management regulations and procedures to better utilize the band. Potentially congested areas of the country are examined to identify trends and specific regional problems as they pertain to this band.

OBJECTIVES

To provide a technical basis for development of spectrum plans and policies, the following objectives are identified for this SRA.

1. Review and document the characteristics and deployment of existing and proposed systems, including those which may be developed as a result of the 1979 World Administrative Radio Conference (WARC), within the 1710-1850 MHz band.

2. Review the compatibility analyses of systems within the 1710-1850 MHz band made by other agencies and those analyses made in support of the system review process.

3. Identify and document the potential problem areas (including band-edge problems with systems in adjacent bands) which may have an impact on efficient use of the spectrum, and also evaluate the electromagnetic compatibility among existing and proposed systems.

4. Identify and outline specific problem areas, if any, which require additional measurement and/or analysis.

5. Identify the various alternatives relating to the spectrum management practices in the band and their potential impact, if adopted, on spectrum utilization.

APPROACH

The Phase I portion of this study [Hurt and Crandall, 1980] identified a number of areas where further investigation was necessary. For purposes of this report, these are grouped into four general categories:

a. Sharing between Fixed and Aeronautical Mobile Services

b. Coordination of earth stations

c. Accommodation of the Packet Radio system

d. Examination of congested geographic areas

The sharing of the 1710-1850 MHz band between the Fixed and Mobile Services has resulted in a number of spectrum management conflicts. Rather than undertaking a detailed compatibility analysis, based on specific equipment types, the investigation of these conflicts primarily addressed spectrum management alternatives that may improve sharing among these services. Three aspects of sharing between the Fixed and Mobile Services were examined: (1) technical, (2) spectrum planning, and (3) frequency assignment. In the technical areas the present standards which apply to the band were reviewed and possible shortcomings discussed. Alternative standards, definitions, and principles were examined and recommendations offered. Under the spectrum planning heading, the various functions and radiocommunication techniques used in the band were examined and alternative approaches reviewed. The application of a channel plan for the band was also examined. Potential improvements in the frequency assignment process that were examined include development of frequency coordination procedures and upgraded data requirements for the Government Master File.

Space operations including telemetry, tracking and command functions are accommodated in the 1761-1842 MHz band on a coequal basis with the Fixed and Mobile Services (footnote G42). Techniques for coordination between these services were examined and recommendations offered.

An examination of the Packet Radio system has been completed by Crandall [1980] which identified separation criteria required to avoid interference to other systems. These criteria were further examined in this report to evaluate the overall impact of the Packet Radio on the 1710-1850 MHz band environment. Several hypothetical deployments were examined.

The Phase I report suggested that certain regions of the country are more congested than the nation as a whole and deserve special study. These areas were defined and examined to identify assignment trends, special regional problems, and possible techniques to minimize compatibility issues.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

An examination has been completed of the 1710-1850 MHz band with regards to technical standards, procedures, compatibility issues, and overall spectrum planning. Based on this study the following conclusions and recommendations are drawn.

GENERAL CONCLUSIONS

The 1710-1850 MHz band was not found to be currently saturated; the various agency needs are being accommodated, as the requirements arise, following existing spectrum management procedures. However, the majority of stations in this band are located within a few regions of the country including the Pacific Northwest, the Southwest, the Northeast coastal, Gulf and Tennessee Valley Authority (TVA) regions. The growth in the number of assignments in this band, especially in these regions, is expected to continue. In order for NTIA to effectively assure that the band will be able to accommodate the various future Federal agency radiocommunication needs, improvements in the regulations and procedures for this band are necessary. If such changes are to be effective, they must be adopted well in advance of band saturation rather than after the fact. The following conclusions identify specific areas where such changes would be effective.

SPECIFIC CONCLUSIONS

1) Technical Standards. Several changes to technical standards and definitions which apply to this band would, if adopted, improve management of the Fixed and Aeronautical Mobile Services as follows:

a. An improvement in the frequency tolerance requirement for transmitters with a necessary bandwidth of 2 MHz or less from the present 10 ppm would improve sharing among these systems. The required carrier-to-interference protection ratio for cochannel operation would be reduced up to 7 dB by this change thus enhancing sharing. This tolerance value is commercially available from most, if not all, present equipment manufacturers.

b. The present antenna specifications for Fixed systems in this band effectively require the use of a 1.2 meter diameter antenna or larger. Increasing this requirement to a minimum of 1.8 meter in diameter for congested regions of the country would result in a theoretical improvment of up to 7 dB in sharing potential.

c. A clear and consistent approach in specifying the necessary and occupied bandwidths for frequency modulated (FM) systems. In particular, methods for calculating the necessary bandwidth for FM video, telemetry, telecommand, and data systems must be established. The Technical Subcommittee of the IRAC would be an appropriate forum for examining this issue. The occupied bandwidth of an emission is more useful when expressed in terms of the X dB bandwidth. Further study is necessary to establish this relationship for each of various FM emission classes.

When the specific relationship is not known, the -26 dB bandwidth can be used to approximate the occupied bandwidth as per CCIR Recommendation 443-1 (CCIR, 1978b).

d. The operation of systems in the 1710-1850 MHz band which are permanently fixed tuned at the factory with no provision for use of alternative frequencies impedes good spectrum management practices. A requirement that all operational systems in this band provide some minimal frequency selection capability, by crystal replacement or other means, would enhance the effective management of the band.

e. The standards for the Fixed Service in the NTIA Manual require that the receiver -3 dB bandwidth be "commensurate" with the associated transmitter authorized bandwidth. This requirement is ambiguous and ineffective. Expanding this specification to state that the receiver -3 dB bandwidth shall be <u>at most</u> twice the associated transmitter authorized bandwidth would be both achievable and enforceable, and would foster good spectrum management.

2) <u>System Planning.</u> Beneficial changes in system planning that were identified in this study are as follows:

a. The operation of low capacity fixed links (2-12 channel) in this band leads to inefficient use of the spectrum because of the limited commercial availability of receivers with bandwidths commensurate with the resultant narrowband emissions. The operation of these narrowband systems in other frequency bands, where narrowband receivers are available, would be desirable from a spectrum utilization standpoint. The receiver specification discussed above (1.e.) would be an effective enforcement mechanism to prevent the use of these non-commensurate systems.

b. The operation of air-to-ground telemetry links in the same band as fixed microwave links leads to potential problems because of the large distance separations required for compatible cochannel operation (up to 400 km). Other bands are available which have been specifically designated for use by flight testing and aeronautical telemetry, including 1435-1535, 2200-2290 and 2310-2390 MHz. Further development or assignment of flight testing telemetry stations in the 1710-1850 MHz band would appear to be neither necessary nor in the interest of good spectrum management. For similar reasons, airborne telecommand functions would be better accommodated in the 1427-1435 MHz band.

c. The development and widespread use of an airborne spread spectrum system in the 1710-1850 MHz band would have a major impact on existing assignments. The large distance separation required with existing assignments, inability to time share, and unavoidable cochannel operation leads to the inability of the band to accommodate this type of operation except under very isolated test conditions. Coordination of specific flight paths on a case-by-case basis and a non-interference status would appear necessary to accommodate this type of operation.

d. A channel plan has been developed which, if adopted, would eventually lead to more efficient utilization of the band. The plan separates narrowband and wideband systems into distinct portions of the band and identifies specific center frequencies and frequency pairs for use. A detailed rationale supporting the adoption of this plan is provided in the text.

e. A standard format for reporting technical justification of proposed frequency diversity links has been developed in an attempt to assist the decision making process for approval of frequency diversity when necessary.

3) Frequency Assignment. Several changes in the frequency assignment process have been identified which would improve spectrum utilization as follows:

a. Improvements in the Government Master File (GMF), have been identified which would assist in more effective management of the band including: 1) adding modulation parameters for FM systems (such as maximum modulating frequency and peak deviation) to the GMF transmitter nomenclature field in the same manner as pulse parameters are currently included for radars, 2) requiring maximum altitude data for all aircraft stations similar to the method currently required for mobile earth stations, and 3) providing a mechanism to distinguish experimental stations according to the specific application such as Fixed, Land Mobile, Aeronautical Mobile, etc.

b. The coordination of proposed fixed and mobile frequency assignments in the 1710-1850 MHz band has, sometimes, been based on worst-case decision processes. For fixed microwave systems, the Electronic Industries Association (EIA) in its Bulletin No. 10-C has developed detailed interference coordination criteria and procedures to assure compatible operation. Those procedures are widely accepted by microwave users and would prove useful if recognized in the NTIA Manual as an acceptable procedure for Federal Government users. An automated version of Bulletin No. 10-C has been developed as part of this study as described in Appendix A. This model for fixed microwave systems is useful by both spectrum analysts and agency frequency managers for investigating interference situations. Further study is necessary to establish a standardized criterion for interactions involving mobile systems.

c. The NTIA Manual identifies a number of frequency assignment principles which help promote effective spectrum management. Two additional principles are often applied but are not explicitly stated in the NTIA Manual as follows: 1) Within a given system or network, frequencies should be re-used to the maximum extent possible, and 2) a station should be designed so that the necessary bandwidth results in maximum efficiency in the use of the spectrum. Incorporation and emphasis of these principles into the NTIA Manual would help encourage efficient spectrum management.

4) Space Operations. Based on the analysis given herein, the existing EIRP limitations on terrestrial stations provide adequate protection to present Earth-to-space links in this band; no additional antenna or pointing angle restrictions are necessary. Use of the channel plan for terrestrial systems, as discussed in Section 4, would add further protection to these space functions. Earth station transmitters are currently employed in this band at four locations

within the US&P. Because of the high power, high antenna gain, and multiple channel operation of these earth stations, significant distance separations with terrestrial stations are required. Procedures are given in Section 4 which help to minimize those required distance separations.

5) Packet Radio. A communication system which employs spread spectrum and packet switching techniques is being developed for use in this band. Presently, there are two Packet Radio systems which differ in a number of ways including emission bandwidth. The Experimental Packet Radio (EPR) utilizes a 20 MHz portion of this band whereas the Upgraded Packet Radio (UPR) occupies the entire 1710-1850 MHz band. Theoretical sharing criteria necessary to assure compatibility with other band users have been developed for both systems. Measurements to support these criteria have not been performed. It is found, herein, that the impact on the band is highly dependent on the nature of the planned operational deployments. If deployed in a checkerboard manner with repeaters every 32 km across the nation, either system cannot be accommodated in this band as proposed. Similarly, if extensive airborne use is planned, compatible operation could only be achieved by significant flight restrictions, coordination of flights on a case-by-case basis and authorization only on a non-interference basis. A modest land mobile deployment, such as locally around U.S. military bases, could be accommodated but would require reassignment of a limited number of existing assignments. Accommodation of this Packet Radio System would be greatly enhanced if all operational UPR systems were provided with a narrowband (i.e., 20 MHz) mode, in addition to the planned wideband (140 MHz) mode, for assignment flexibility required in congested environments. It is found that a system review has not addressed the planned airborne deployment of the EPR. In addition the GMF does not reflect present testing sites of the EPR (namely Fort Bragg) and lists the EPR at locations where it is not presently deployed (namely, Washington, D.C., San Diego and Los Angeles, CA). Also, a stage 1 (planning stage) application to the SPS for the planned LCPR has not been submitted.

6) Congested Areas. An examination of the assignments to this band showed that the majority are concentrated into five regions of the country which can be described in general terms as follows: Pacific Northwest, Gulf Coast, Tennessee Valley Authority area, Northeast, and Southwest. In the first four of these designated areas, the use of good spectrum management, as described in this report, would allow the accommodation of future Federal agency near-term and intermediate-term radiocommunications needs. In addition, several measures were identified to improve the present frequency management process. In the Southwest region, the intermixing of the various fixed, mobile, and space functions results in complex frequency management problems. Of particular concern are the many wideband airborne systems. Within this overall southwest region, six specific "hotspots" were identified. Proposed assignments within 250 kilometers of these locations should be examined on a case-by-case basis to assure compatible operation.

7) RSMS Measurements. Additional study of increased sharing by time scheduling among intermittent airborne operations should be undertaken. The benefits of such sharing would be more efficient use of the spectrum and making available additional spectrum for other users. Measurements of this band, conducted by the NTIA Radio Spectrum Measurement System at a congested location (such as Point Mugu, CA) would provide key input to this study.

RECOMMENDATIONS

Based on the conclusions drawn from this study, the following are recommended. For numbers 1, 3, 4, 6 and 7 below, specific proposed wording is provided in Section 4 of the text.

1. The Technical Subcommittee of the IRAC should consider adoption of the following recommendations for inclusion into the NTIA Manual.

   a. The frequency tolerance requirement for transmitters in this band with bandwidths of less than or equal to 2 MHz should be improved to 10 ppm (see page 34).

   b. The antenna standards for fixed stations in this band should be improved to require a minimum of a 1.8 meter (6 foot) diameter antenna when located in congested areas (see page 37).

   c. The current standard for Fixed Service receivers should be improved to limit the receiver bandwidth to twice the authorized emission bandwidth (see page 48).

   d. Additional study should be undertaken to develop methods for calculating necessary bandwidth for FM video telemetry, telecommand, and data systems.

   e. Additional studies should be undertaken to establish the relationship between the occupied bandwidth and the X dB bandwidth for those emission classes not currently established. Until such studies are completed, the 26 dB bandwidth should be used to approximate the occupied bandwidth as per CCIR Recommendation 443-1.

   f. Future systems designed for operation in the 1710-1850 MHz band should include some minimal frequency selection capability, by crystal replacement or otherwise (see page 41).

2. The use of low-capacity (2-12 channel) fixed links should be avoided in the band unless appropriate narrowband receivers are used.

3. Further development and assignment of frequencies to telemetry and telecommand functions in the Aeronautical Mobile Service in this band should be avoided (see page 58).

4. A channel plan should be adopted for the band to improve efficient utilization of the band (see page 75).

5. Improvements should be made to the GMF to assist in more effectively managing the band including a) adding modulation parameters for FM stations, b) requiring maximum altitude data for all aircraft stations, c) expanding the station class symbols for experimental stations to indicate the specific application such as fixed, aeronautical mobile, land mobile, etc., and d) providing a standard format for reporting technical justification of frequency diversity links.

6. The procedures given in EIA Bulletin 10-C should be considered for adoption by the Federal Government for coordinating fixed microwave links. A similar procedure appropriate for mobile stations should be developed (see page 85).

7. Two additional frequency assignment principles should be considered for adoption in the NTIA Manual to help promote efficient spectrum management as follows: a) within a given system or network, frequencies should be re-used to the maximum extent possible and b) a station should use the lowest value of necessary bandwidth that results in the most efficient use of the spectrum (see pages 81 and 82).

8. The procedures discussed in Section 4 should be used when siting fixed microwave systems in the vicinity of earth station transmitters.

9. Any operational use of the Upgraded Packet Radio should be limited to Fixed and/or Land Mobile applications. Operational systems should be designed with a narrowband mode (20 MHz) for flexibility in congested environments.

10. An EMC measurement program should be undertaken to determine, experimentally, the impact of the Packet Radio transmitters on the existing environment. Measurement results not only would determine better sharing criteria for the packet radios but would assist in the refinement of interference prediction techniques used for spread spectrum and packet switching systems.

11. The EPR should be referred to the SPS for review to address planned airborne deployments and location changes of test sites.

12. The LCPR should be referred to the SPS for stage 1 (planning stage) review.

13. Proposed systems to be located within 250 kilometers of the six "hotspots" identified in Section 7 should be examined on a case-by-case basis to assure compatible operation.

14. Federal agencies, when reviewing their frequency assignments should obtain a link plot of their systems and put more emphasis on detecting erroneous data in the GMF.

15. The definitions of the station class parameter should be clarified to reduce ambiguous entries in the GMF.

16. Measurements should be conducted by the RSMS Van at Point Mugu, California of the 1710-1850 MHz band to establish representative spectrum usage of intermittent airborne transmissions.

SECTION 3

SUMMARY OF BACKGROUND STUDY

As a preliminary part of this overall spectrum resource assessment, a background and study definition phase was undertaken and a report was published (Hurt and Crandall, 1980). That report documented the frequency allocation rules and regulations which apply to the band and summarized the spectrum usage trends. Additionally, a preliminary examination of potential spectrum management problems was undertaken to identify areas where further detailed study was deemed necessary. This section provides a summary of that report.

The current national and international frequency allocation table for this band is given in TABLE 3-1. As seen, the fixed and mobile services as well as certain space operation functions (Earth-to-space) coequally share the band on a primary basis, nationally.

TABLE 3-2 is the international frequency allocation table as adopted in the Final Acts of the 1979 World Administrative Radio Conference. The indicated changes were U.S.-sponsored to provide further international protection to existing U.S. space systems.

TABLES 3-3 and 3-4 summarize the major systems operating in the band along with typical parameters. A pictorial representation of these systems is given in Figure 3-1. A short synopsis is given below of the major systems in the band which are important from a spectrum management standpoint.

> <u>Space Systems.</u> The major space system in the band is the Air Force Space Ground Link Subsystem. Its function is to provide tracking, telemetry, and control for Department of Defense orbiting satellites. Both geostationary and non-geostationary satellites are serviced from four Satellite Control Facility ground stations located in Guam, Hawaii, New Hampshire, and California. The RF links in this band are up-paths in the band 1761-1842. The down-paths are in the 2200-2900 MHz band.
>
> <u>Fixed (line-of-sight).</u> The dominant fixed systems in the band are for medium capacity FDM/FM point-to-point communications. Channel capacities typically vary from 24 to 600 channel with bandwidths from 0.5 to 10 MHz. Applications include law-enforcement networks, backbone trunking systems and control links for various power, land, water, and energy management systems. Commercial off-the shelf-equipment is normally used. Other specialized fixed links include video/data relay and timing distribution signals.
>
> <u>Land Mobile.</u> The Department of Defense Advanced Research Projects Agency (ARPA) has developed several packet radio systems to test the feasibility of new techniques and concepts for a network of fixed and mobile digital data terminals. The concept extends the ARPANET packet switching technology to radio communications. Both 20 MHz and 140 MHz spread spectrum bandwidth versions have been built for experimentation.
>
> <u>Aeronautical Mobile.</u> A number of air-to-ground links are used in this band for video communications. These are primarily used to provide

TABLE 3-1

CURRENT NATIONAL AND INTERNATIONAL FREQUENCY ALLOCATION TABLE

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
1700-1710 FIXED SPACE RESEARCH (Space-to-Earth) Mobile 354D	1700-1710 FIXED MOBILE SPACE RESEARCH (Space-to-Earth) 354D		1700-1710	G,	FIXED METEOROLOGICAL SATELLITE (Space-to-Earth) MOBILE SPACE RESEARCH (Space-to-Earth)	METEOROLOGICAL-SATELLITE (Space-to-Earth) SPACE RESEARCH (Space-to-Earth)
1710-1770 FIXED Mobile 352K 356	1710-1770 FIXED MOBILE 352K 356A		1710-1850	G US100 See also 4.2.2 (NTIA Manual Jan., 1979)	FIXED MOBILE G42	
1770-1790 FIXED Meteorological-Satellite 356AA Mobile 356	1770-1790 FIXED MOBILE Meteorological-Satellite 356AA 356A					
1790-2290 FIXED Mobile 356 356AB 356ABA 356AC	1790-2290 FIXED MOBILE 356A 356ABA 356AB					
			1850-1990	NG		FIXED NG8

Footnotes Applicable to the U.S.

US100 In the Additional Protocol to the Final Acts of the Space EARC, Geneva, 1963, a declaration on behalf of the USA states that the USA cannot accept any obligation to observe the exception claimed by Cuba in those footnotes to the Table of Frequency Allocations which were adopted by the EARC and which specifically named Cuba.

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.

NG8 Frequencies in this band will be selected for assignment in such a manner that, on an engineering basis, the lowest frequency in the band is assigned which will not cause harmful interference to stations in that area already assigned frequencies in accordance with the Table of Frequency Allocation.

FREQUENCY ALLOTMENTS

4.2.2 Allotments in the Band 1710-1850 MHz for Fixed Security Surveillance Systems

The frequencies 1720, 1740, 1760, 1780, and 1800 MHz are allotted for use in fixed security surveillance systems, on a secondary basis to other stations operating in accordance with the Government Table of Frequency Allocations.

TABLE 3-2

EXCERPTS FROM THE FINAL ACTS OF THE 1979 WARC

Allocation to Services		
Region 1	Region 2	Region 3
1 710 - 2 290 FIXED Mobile 3679A 3695/352K 3704/356AA 3707A 3707B 3707C	1 710 - 2 290 FIXED MOBILE 3703/356A 3695/352K 3679A 3704 356AA 3707A 3707B 3707C 3707D	

MOD 3695 352K The band 1 718.8 - 1 722.2 MHz is also allocated to the radio astronomy service on a secondary basis for spectral line observations. In making assignments to stations of other services to which the band is allocated, administrations are urged to take all practicable steps to protect 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. 3280/116 and 3281/116A and Article N33A).

MOD 3703 356A Subject to agreement obtained under the procedure set forth in Article N13A 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.

MOD 3704 356AA Additional allocation : in Bulgaria, Cuba, Hungary, Mali, Mongolia, Poland, the German Democratic Republic, Roumania, Czechoslovakia and the U.S.S.R., the band 1 770 - 1 790 MHz is also allocated to the meteorological-satellite service on a primary basis, subject to agreement obtained under the procedure set forth in Article N13A.

SUP 3702/356

NOTE: Above footnotes include only those applicable to the 1710-1850 MHz Band.

TABLE 3-3

SUMMARY OF MAJOR SYSTEMS IN THE 1710-1850 MHz BAND

1. SPACE SYSTEMS
    - a. Space Ground Link Subsystem (SGLS)
    - b. Space Shuttle
    - c. Other Satellite Links

2. FIXED
    - a. Line-of-Sight, Point-to-Point
        - (1) Vessel Traffic System
        - (2) Corps of Engr. District Comm.
        - (3) Tennessee Valley Auth.
        - (4) Bonneville Power Admin.
        - (5) U.S. Park Service
        - (6) Bureau of Land Management
        - (7) Dept. of Energy Nevada Test Site
        - (8) Test Ranging Timing Distribution Systems
        - (9) Numerous Others
    - b. Transhorizon
    - c. Tactical and Training Radio Relay
    - d. Air Combat Maneuvering Systems

3. RADIOLOCATION
    - a. Scoring Systems
        - (1) Strafing Target Scorer
        - (2) Gunnery Range Scorer
        - (3) Miss Distance Scoring System
        - (4) Vector Miss Distance Indicator
        - (5) Bullet Hit Indicator
        - (6) BIDOPS
        - (7) AN/DSQ-007
        - (8) Others
    - b. Distance Measuring Equipment
    - c. Security Systems
    - d. Airborne Radar

4. LAND MOBILE
    - a. ARPA Packet Radio

5. AERONAUTICAL MOBILE
    - a. Tactical Weapon Systems
    - b. SEEK SKYHOOK
    - c. Air-Ground Video Links
    - d. Air Combat Maneuvering Systems

6. RADIOASTRONOMY

7. EXPERIMENTAL
    - a. Design or Development of New Systems
    - b. Basic Research
    - c. Testing of Operational Systems

8. UPPER ADJACENT BAND
    - a. Non-Government Fixed

9. LOWER ADJACENT BAND
    - a. Meteorological Satellite

TABLE 3-4

SUMMARY OF KEY SYSTEM PARAMETERS

System	Agen.	Frequency (MHz)	Environment	# of Asgmts	PWR (Watts)	G_T (dBi)	G_R (dBi)	Emission
SGLS	AF	1761-1842	NH, CA, HA, GUM → Space	80	10K	43	3	M5F9
Space Shuttle	NASA	1761-1842	Space → Space	1				M5F9
Fixed, L-O-S	AF AGA	1710-1850	US & P	480	1-40	24-33	24-33	800F9 - M8F9
Tactical & Training	Army	1350-1850	Army Bases & Nat'l Guard Units	124	20-120	19	19	M1.2F9 - M26F9
AMCI/ACMR	AF Navy	1779-1840	AF & Navy Air Bases & at Sea	35	1-20	0-26	0-26	600F9, M3F9
NB Scoring Systems	Navy	1710-1850	AF & Navy Training Facility	62	2-5	-	-	≤ M2.5A9
VMDI Scoring System	AF	1750,	Gulf of Mexico & WSMR	1	40	3	3	M115P0
BHI Scoring System	AF	1750 or 1775	Gulf of Mexico & WSMR	1	5-1	0-4	0-4	M350P9
DME	DOE	1710,1721,1742		3	50	-	-	M1
Security Systems	AF	1720,1740,1760	AZ,AR,KS	9	2	12	-	1F0
ARPA Packet Radio	Navy	1710-1850	San Francisco, CA	1	10	-	-	M15.36F9 - M140F9
SEEK SKYHOOK	AF	1755,1820	Florida Keys	2	2	7	20	M60F9
Air/Grd Video Links	AF Navy	1710-1850	US & P (Mostly Test Ranges)	15	2-20	3	30	M16F9
Radio Astronomy	NSF	1720,1721	Radio Astronomy Fac.	-	-	-	-	-
Experimental	AGA	1710-1850	US & P	190	-	-	-	-
METSAT	C	1695-1710	Space→ VA,AK & Worldwide	1	5	4	47	M3F9
Non-Gov't Fixed	FCC	1850-1990	US & P	-	2-5	24-33	24-33	800F9 -M8F9

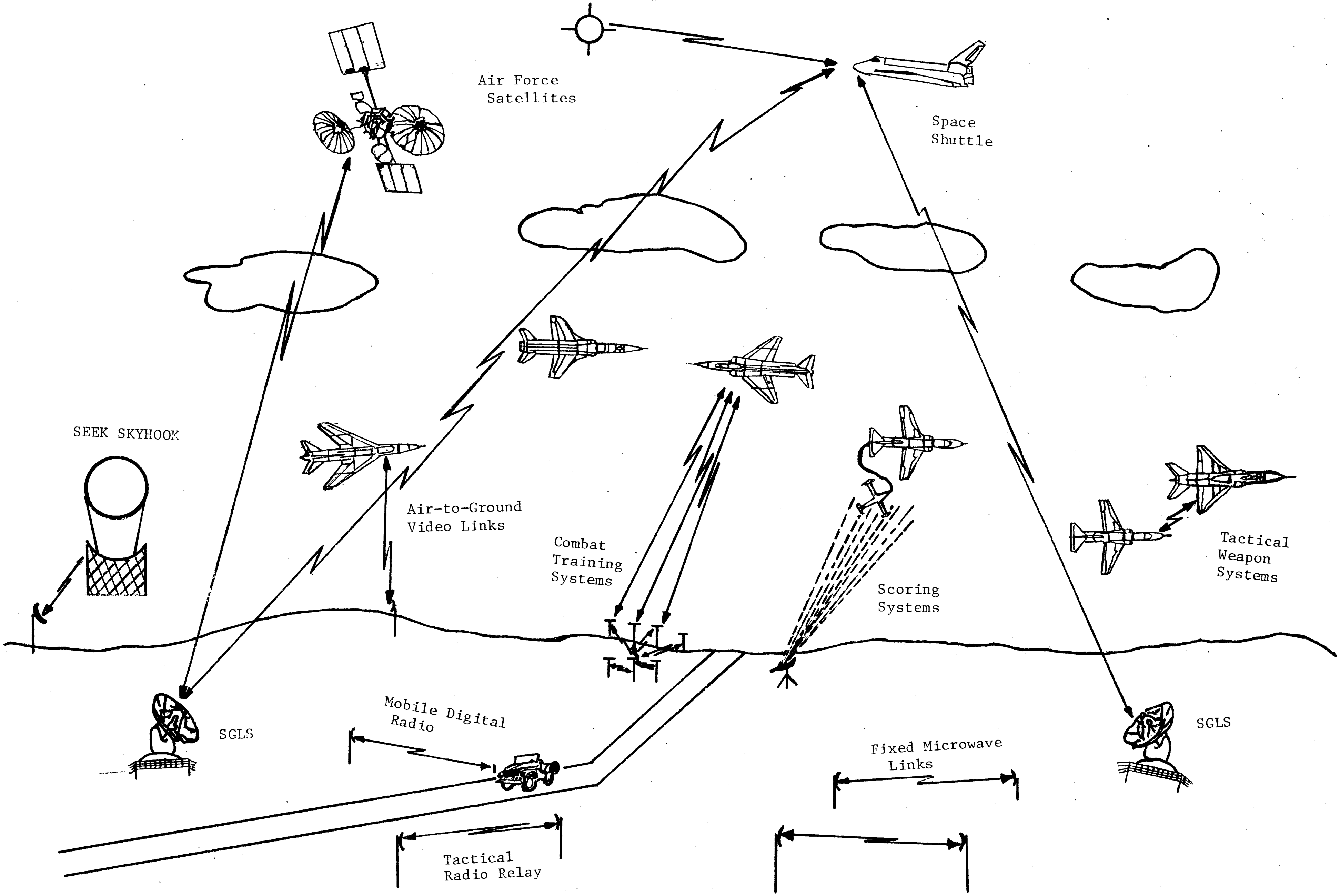


Figure 3-1. Pictorial Representation of Major Systems in the 1710-1850 MHz Band

real-time television displays from airborne cameras for ground reception. Functions include testing of remotely piloted vehicles and drones, flight testing of new aircraft, and airborne monitoring of civil disturbances. More limited aeronautical mobile functions include air-to-ground data relay, telemetry, and telecommand.

To illustrate the potential for conflicts among these systems, Figures 3-2, 3-3 and 3-4 show the tuning capabilities of the equipment, growth rate in band usage, and the geographical distribution of the assignments, respectively. Using relatively simple criteria, including geographic and frequency relationships, a preliminary matrix was developed in the Phase 1 report to identify potential frequency management problems as given in Figure 3-5. From the results of the Phase 1 assessment, including this interaction matrix, four general areas where more detailed study was deemed necessary are as follows:

1. Sharing between Fixed and Aeronautical Mobile Services.

2. Coordination of earth stations.

3. Accommodation of the Packet Radio System.

4. Examination of congested geographic areas.

The remaining sections of this report examine these issues in depth.

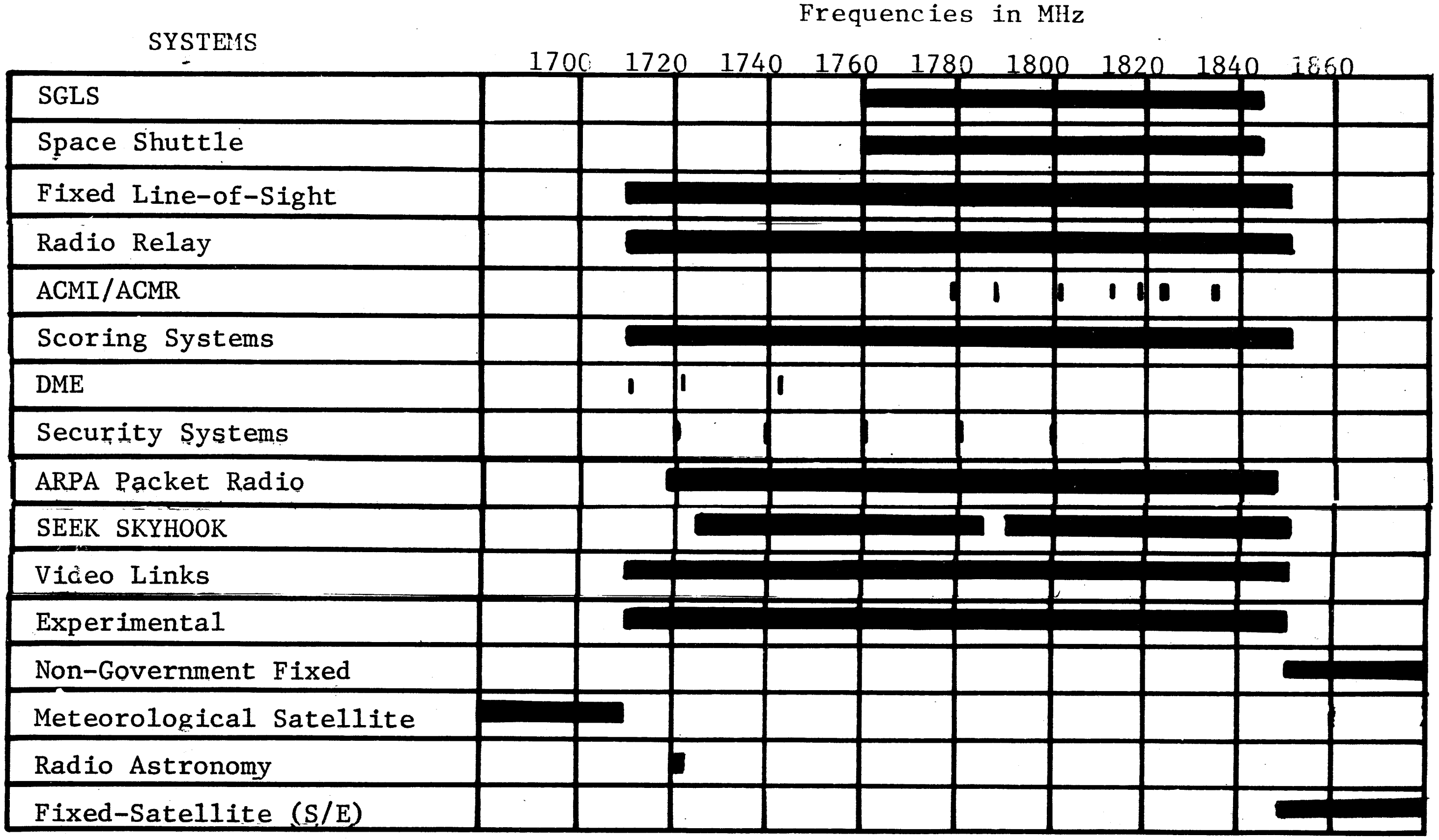


Figure 3-2. Tuning Range Capabilities of Major Systems

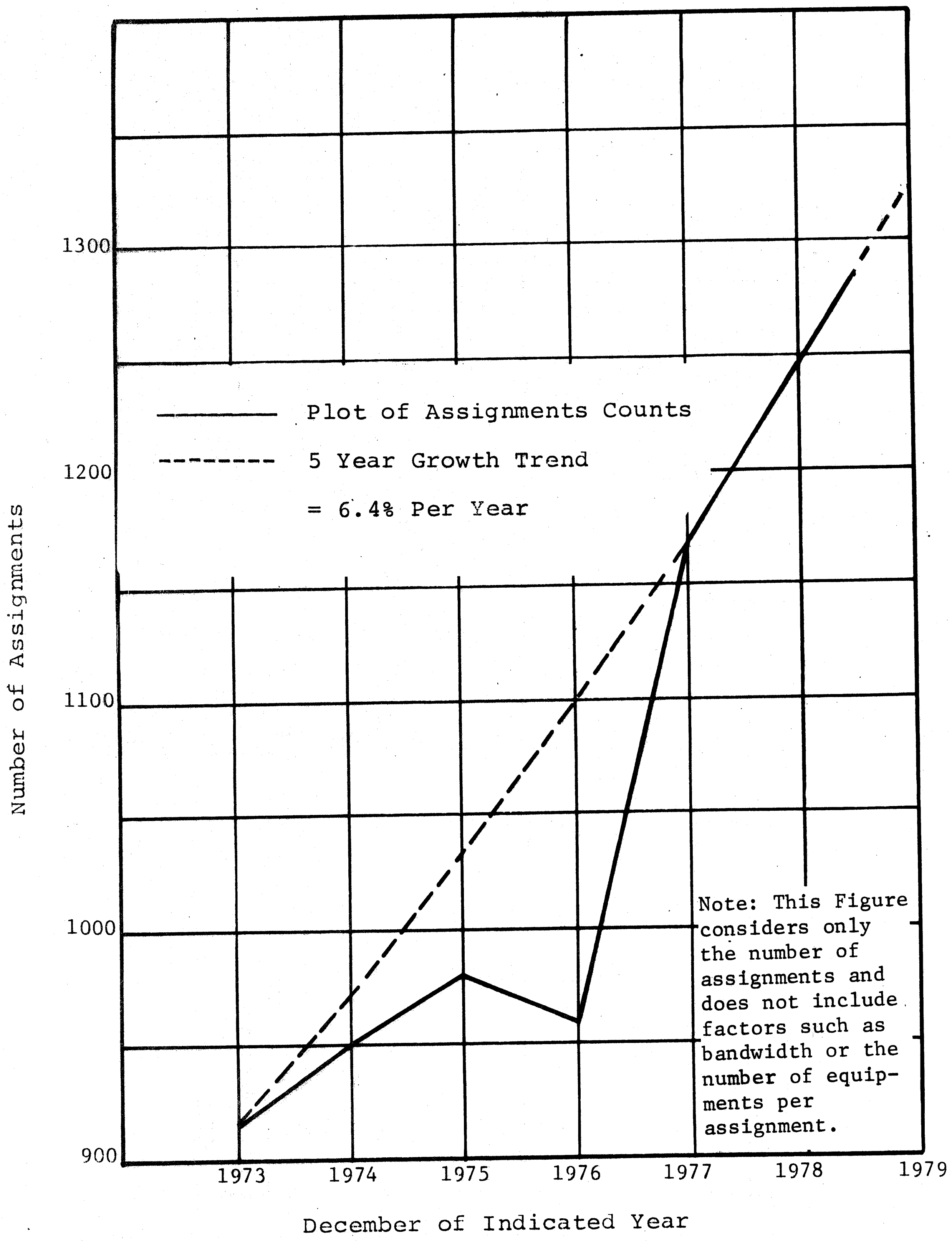


Figure 3-3. Growth Trends for 1710-1850 MHz Band

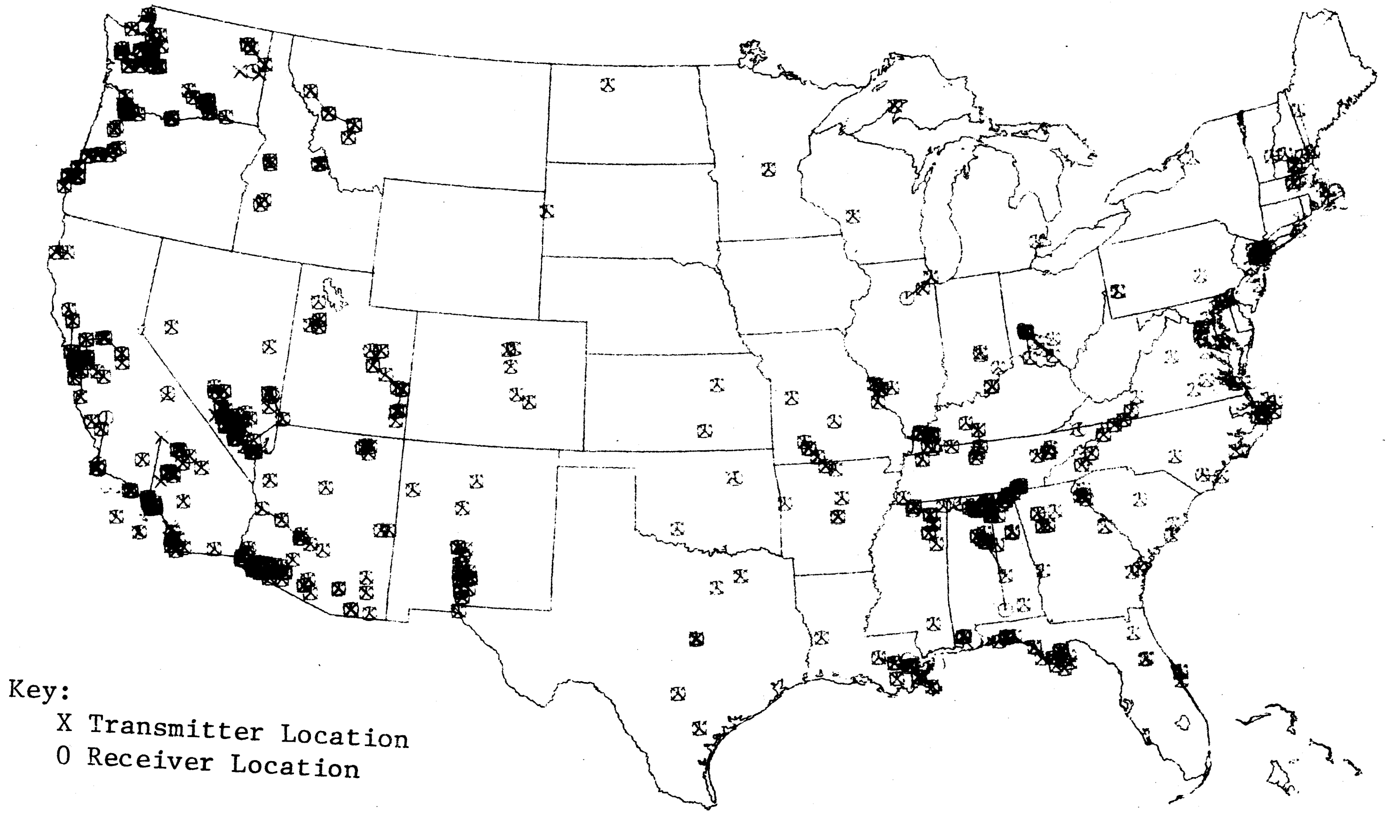


Figure 3-4. Geographic Distribution of Assignments in the 1710-1850 MHz Band

Receivers Transmitters	SGLS	Space Shuttle	Point-Point Fixed	Transhorizon	Radio Relay	NB Scoring System	WB Scoring System	Airborne Radar	Packet Radio	Tactical Airborne	SEEK SKYHOOK	A/G Video Links	ACMI/ACMR	MET SAT	N Gov't Fixed	Fixed-Satellite (S/E)
SGLS			☒		☒					☒		☒	☒			
Space Shuttle																
Point-Point Fixed			☒	☒	☒	☒				☒		☒	☒			
Transhorizon	☒	☒	☒													
Radio Relay			☒			☒				☒		☒	☒	☒		
NB Scoring System			☒		☒					☒		☒	☒			
WB Scoring System			☒		☒					☒		☒	☒	☒	☒	☒
Airborne Radar			☒		☒					☒		☒	☒		☒	☒
Packet Radio			✳		✳	☒				✳		☒	✳	✳		☒
Tactical Airborne			✳		☒					☒		☒		☒	☒	☒
SEEK SKYHOOK			☒													
A/G Video Links			☒		☒					☒		☒	☒			
ACMI/ACMR			☒		☒	☒				☒		☒				
MET SAT					☒											
N Gov't Fixed																

✳ Potential Problems

☒ Manageable Problems

☐ No Problems

Figure 3-5. Preliminary Interaction Matrix

SECTION 4

SHARING BETWEEN FIXED AND AERONAUTICAL MOBILE SERVICES

In the 1710-1850 MHz band, the majority of the assignments are to stations in the Fixed and Aeronautical Mobile Services. In general, potential band-sharing problems between these two services have not been the result of any specific individual system, but rather the cumulative effect of the many recently introduced systems. The issues to be addressed here, then, will not be specific electromagnetic compatibility interactions among the various systems. Instead, the overall spectrum management of the band as it relates to these two services will be addressed.

The issues have been organized into these areas: 1) technical, where possible improvements in technical standards and definitions are examined; 2) spectrum planning, where the various functional equipment types used in the band are discussed, alternative bands identified, and channelization of the band examined, and 3) frequency assignment, where possible improvements in the frequency assignment process are reviewed.

TECHNICAL STANDARDS

Technical standards have been adopted for certain Fixed stations operating in designated bands above 1710 MHz including 1710-1850 MHz. These standards address technical parameters including emission spectrum, frequency tolerance, receiver selectivity, etc. For other station classes used in the band, only standards for frequency tolerance and spurious emissions are specified. These standards were summarized in the Phase I study. In this portion of the section, these various requirements will be evaluated with a view towards possible improvements in the spectrum management of the band. The areas to be discussed are in order; frequency tolerance, antennas, frequency selection, bandwidth, receiver standards, and frequency diversity.

Frequency Tolerance

The frequency tolerance of a transmitter is its maximum departure of its carrier, or center frequency, from the assigned frequency. The frequency tolerance can have an effect on the efficient use of the spectrum in several ways. For very unstable transmitters, the resulting frequency drifting can cause interference to assignments on adjacent frequencies. This is, in general, not a problem in the 1710-1850 MHz band since the current standards call for a tolerance of no more than .003 percent for new fixed and mobile stations. This relates to a maximum frequency drift of approximately 60 kHz. Considering the bandwidths used in this band of typically 1 to 10 MHz, a drift of at most 60 kHz would be adequate to protect adjacent frequency operations.

Another effect of the frequency tolerance is more subtle and generally is a factor only among frequency division multiplex (FDM/FM) links which are nominally cochannel tuned. For cochannel tuned FDM/FM links, the protection criteria to assure interference-free operation is usually considered to be a combination of two factors; sideband beat and carrier beat interference. The former results from the interfering emission modulation sideband energy which falls within the baseband of the victim receiver. The degree of this interference is dependent primarily upon modulation parameters and is relatively independent of minor frequency drifts of the carrier. Carrier beat interference, as the name implies, results when the interfering and desired transmitter carriers are slightly separated in frequency such that beat frequencies are generated which fall within the desired signal baseband. The latter effect is highly dependent upon the frequency tolerance, and as such, the tolerance establishes which factor dominates.

The EIA [1976] has studied these protection criteria in detail and has derived C/I protection ratios required to preclude interference for various classes of systems. From the tables and procedures provided in that report, summarized results were generated and given in TABLE 4-1.

Various combinations of the different channel capacity systems could be included but are not important for the purposes herein. One result that is apparent from the results given on TABLE 4-1 is that the higher capacity (wider bandwidth) systems would not benefit from improved frequency tolerance since the sideband beat criteria predominates, whereas, the lower capacity (narrower bandwidth) systems would benefit. For the 24 channel example, an improvement in the frequency tolerance from the current 0.003 percent to 0.001 percent would reduce the required C/I protection ratio approximately 7 dB. Intermixing of 0.001 percent and 0.003 percent tolerances will obviously reduce this advantage. However, if narrowband systems were all assigned together in designated parts of the band, as proposed later herein, full benefit would result from this improvement. A review of available equipment indicated that a frequency tolerance of .001 percent is commercially available from most manufacturers.

A proposed change to the NTIA Manual to incorporate these results is as follows (underlining indicates added material):

Proposed Modification of Paragraph 5.10.1e (2)
of the NTIA Manual

1.7-4.0 GHz	30 ppm for 100 W or less transmitter power and having a necessary bandwidth >2 MHz
	10 ppm for transmitter power above 100 W or having a necessary bandwidth ≤ 2 MHz

Antennas

The use of quality antennas is a recognized technique in promoting efficient use of the spectrum. With radiated power minimized in all but the desired direction, transmitter power and coordination distances can be reduced. In the NTIA Manual, the only current limitations on antennas used in this band apply to the Fixed Service. Section 5.10.1 of the NTIA Manual specifies that directional antennas for the 1710-1850 MHz band shall be used with the following minimum specifications for antenna pattern.

Angle from axis	5°	10-15°	15-20°	20-30°	30-100°	100-140°	140-180°
Minimum dB down	3	14	16	18	23	24	30

TABLE 4-1

SUMMARIZED C/I PROTECTION RATIO
(FROM EIA [1976])

Desired and Interfering Transmitter Parameters		C/I Protection Ratio in dB	
Modulation	Freq. Tolerance	Sideband Beat	Carrier Beat
24 Voice Channel Unemphasized	0.003 %	66	73
	0.001 %	66	65
	0.0003%	66	55
120 Voice Channel Unemphasized	0.003 %	56	53
	0.001 %	56	46
	0.0003%	56	33
300 Voice Channel Unemphasized	0.003 %	59	53
	0.001 %	59	46
	0.0003%	59	33

NOTE: Sideband beat criteria was 25 pWOp and carrier beat criteria was 50 pWOp as per EIA recommendations for short-haul circuits.

These specifications correspond to a good quality parabolic dish antenna with a 1.2 meter (4') diameter. A review of the assignments in the GMF as part of the Phase 1 report revealed that very few assignments, even prior to the adoption of this standard, indicate antenna sizes less than 1.2 meters in diameter. The twenty frequency assignments which do list antennas of less than 1.2 meters (size being deduced from the gain) are primarily for very short hops with low power or for special applications. For the conventional type of microwave link used in this band, the above specifications for antennas do not, in effect, result in any limitation since essentially all would meet them. The predominant antenna size 1.8 meters (6') with 2.4 meters (8') and 3 m (10') antennas used to a lesser degree. An exception to these antenna requirements are those transportable systems used in tactical and training operations.

The question arises as to whether more restrictive antenna specifications, or specifications in a different form, would prove beneficial in the management of the Fixed systems in the band. The Federal Communications Commission (FCC) has had in force, for a number of years, specifications for antenna patterns similar to the newly adopted Federal standards just discussed. In these rules [FCC, 1975] Grade A and Grade B criteria are specified for portions of the adjacent 1850-2200 MHz band which correspond to the characteristics for a 2.4 meter and 1.8 meter diameter antenna, respectively. The more restrictive Grade A antenna must be used except in areas not subject to frequency congestion where the Grade B antenna may be used.

For the Federal Government, it is unlikely that justification could be made, based on current band congestion, for adoption of a 2.4 meter antenna standard in the 1710-1850 MHz band. However, the concept of a Grade A and B criteria does have merit. For example, a subsequent section of this report shows that certain regions of the country are more congested than others. Within these areas, specifications for 1.8 meter antennas rather than the currently required 1.2 meter antenna would lead to somewhat improved sharing in the band. Compare a microwave link which employs 1.8 meter antennas at each end versus a link with 1.2 meter antennas. The resulting increased antenna gain would be approximately 3.5 dB at each end. Thus the system with 1.8 meter antenna could, theoretically, employ 7 dB less transmitter power to achieve the same carrier-to-noise ratio at the receiver, for example, a reduction from a five-watt to a one-watt transmitter. The lower power and resultant lower sidelobes will obviously reduce the required distance separation for frequency re-use. For the less congested areas of the country, the present 1.2 meter standard would be adequate. Specific areas where a proposed Grade A and B criteria might apply are discussed in a subsequent section of the report. A proposed modification to the existing standards is given below to effect this result (underlined portions added). In order to use terminology compatible with the FCC, the terms Grade B (1.8 meter diameter) and Grade C (1.2 meter diameter) will be used here, i.e., the Grade B criteria would be identical for both FCC and proposed NTIA standards.

An alternative approach in specifying antenna patterns is given by the CCIR [1978d]. In that report a reference pattern for antennas used for radio relay purposes is described by the following equations:

$$G\ (\text{dBi}) = 38 - 25 \log \theta \qquad (\text{for } 1^\circ < \theta < 33^\circ)$$
$$G\ (\text{dBi}) = 0 \qquad (\text{for } 33^\circ < \theta < 90^\circ)$$
$$G\ (\text{dBi}) < 0 \qquad (\text{for } 90^\circ < \theta < 180^\circ)$$

Proposed Modification to Table B of

Section 5.10.3 of the NTIA Manual

ANTENNA PATTERN LIMITATIONS*

Frequency Band	Maximum Beam-width (3 dB point)	Minimum suppression at angle in degrees from center line of main beam (dB)						
		5-10°	10-15°	15-20°	20-30°	30-100°	100-140°	140-180°
1710-1850 MHz (Grade C)	10°	-	14	16	18	23	24	30
1710-1850 MHz (Grade B)	8°	5	18	20	20	25	28	36
2200-2400 MHz	8.5°	4	12	16	16	24	25	30
4.4-4.99 GHz	4°	13	20	23	24	29	31	31
7.125-8.5 GHz	2.5°	19	23	28	30	34	35	43
14.4-15.35GHz	1.5°	21	26	31	35	37	41	48

*In the band 1710-1850 MHz, Grade B antennas shall be used except in areas not subject to spectrum congestion where Grade C antennas are permitted.

where G is the off-axis gain in dB and θ is the off-axis angle in degrees. This equation limits neither the on-axis gain nor the 3 dB beamwidth of the pattern. An antenna pattern specification of this form is, not clearly, an improvement over the existing standards discussed above. This equation, however, can be quite convenient in analyzing frequency sharing problems involving fixed stations. This will be discussed later.

Requiring minimum antenna performance specifications for aeronautical mobile stations, is less practical than for fixed stations. The airborne components typically require either omnidirectional or hemispheric patterns. The ground-based components will normally require either an omnidirectional or a directional tracking antenna. Adopting an antenna pattern requirement for these land stations may significantly impact tracking capabilities. Specifying antenna patterns for such systems would require additional analysis and is not considered further herein.

Frequency Selection

The selection of frequencies for equipment used in this band is accomplished in several ways. The vast majority of equipments are capable of operating over the entire 1710-1850 MHz band, and are tuned to a specific frequency by crystal controlled oscillators. For a given station, the frequency that best suits its intended environment is, typically, designated at the time of purchase. The frequency often will remain the same during the life of the equipment, although the capability exists to change frequency by crystal replacement should circumstances dictate.

A more limited number of equipment types used in this band have the capability of operator selectable frequencies. These are predominantly intended for military tactical applications and used within the U.S. for testing, training and/or evaluation. Some, like the AN/GRC-50, have fully synthesized tuning in 1 MHz steps across the band (as well as additional bands). Other systems provide operator selection capability among three to five predetermined crystal controlled channels. Those channels may or may not be fixed at the factory. Such tuning capability can, if well controlled, be managed satisfactorily. For example, one or two of the channels may be authorized for use during peacetime. The specific channel(s) used may be varied geographically to best fit with existing spectrum usage.

Several systems have been introduced into the band which are fixed tuned at the factory with no provision for use of alternate frequencies within the band. For these systems the specific frequency used is "frozen" during the development stage and all subsequent operational equipments must use this same frequency regardless of spectrum management concerns. Such practice is done typically to save size and weight in airborne applications or simply to reduce costs. Such factory-fixed tuning can lead to difficulties in managing the band. For example, systems whose operations are intermittent with low duty cycles can efficiently use the spectrum by time-sharing the same frequency when used in the same environment. If systems are fixed tuned at the factory it becomes more difficult to coordinate the use of the same frequency. Thus, several channels may become committed at a given location when only one may be needed.

Permanent factory tuning of fixed stations can also lead to inefficiencies. For example, the current series of ACMI/ACMR equipments are identified in the Phase I study as being factory-fixed tuned. (Future versions may include a field tuning capability.) This system employs six to seven links to and from a central master station with predetermined frequencies spaced 5-22 MHz apart and a nominal necessary bandwidth of 1 MHz. Thus, in a given geographic area, a total of 56 MHz of spectrum is committed to the fixed links in this system. Although other frequency spacings between links may result in a smaller amount of total spectrum committed to the system, the factory-fixed tuning prohibits this possibility. Permanent fixed tuning also makes impractical the future adoption of channel planning for the band as well as makes difficult the resolution of frequency conflicts.

From a spectrum management standpoint, it is apparent that equipments should be designed such that frequencies can be chosen to best suit the intended environment. A requirement to this effect in Chapter 5 (Standards) of the NTIA Manual could enhance band utilization by permitting optimum sharing between systems by time and/or geographical sharing. While economic considerations may make permanent factory-fixed tuning desirable in certain instances, justification should be provided when application is submitted to NTIA for frequency assignment or system review. The following is a proposed addition to Chapter 8 of the NTIA Manual to effect this principle.

> 8.2.44 Tuning capability for stations operating in the 1710-1850 MHz Band
>
> The operation of stations in the 1710-1850 MHz band which are fixed tuned at the point of manufacture and which provide no capability for use of alternate frequencies within the band can lead to difficulties in the spectrum management process. As a result, the use of systems which are permanently fixed tuned at the factory shall be limited to only those cases where it can be operationally justified.

Bandwidth

The bandwidth of a system is one of the key factors in evaluating the potential compatibility with other systems. The need for accurate reporting of bandwidth information in both the spectrum planning and frequency assignment processes is well recognized. However, as described in the Phase I study, a consistent approach in specifying bandwidths has not always been taken. The following paragraphs discuss a proposed standard approach to specifying bandwidth parameters.

Three key terms that are important in considering the bandwidth associated with a particular system or station are the authorized, necessary, and occupied bandwidths which are defined in the NTIA Manual as follows:

> Authorized Bandwidth: Authorized bandwidth is, for purposes of this Manual, the necessary bandwidth (bandwidth required for transmission and reception of intelligence) and does not include allowance for transmitter drift or doppler shift.
>
> Necessary Bandwidth: For a given class of emission, the minimum value of the occupied bandwidth sufficient to ensure the transmission of information at the rate and with the quality required for the system employed, under specified conditions. Emissions useful for the good functioning of the receiving equipment as, for example, the emission corresponding to the carrier of reduced carrier systems, shall be included in the necessary bandwidth.
>
> Occupied Bandwidth: The frequency bandwidth such that, below its lower and above its upper frequency limits, the mean powers radiated are each equal to 0.5 percent of the total mean power radiated by a given emission. In some cases, for example multichannel frequency-division systems, the percentage of 0.5 percent may lead to certain difficulties in the practical application of the definitions of occupied and necessary bandwidth. In such cases a different percentage may prove useful.

The above definitions for necessary and occupied bandwidth are identical to current definitions given in the International Radio Regulations [ITU 1979]. Authorized bandwidth is not defined internationally. The Final Acts of the 1979 WARC adopted new definitions as follows:

> Necessary Bandwidth: For a given class of emissions the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and quality required under specified conditions.
>
> Occupied Bandwidth: The frequency bandwidth such that below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage B/2 of the total mean power emitted by a given emission. The percentage B/2 will be specified for each class of emission.

A third related definition was recommended by the CCIR but not adopted in the Final Acts of the 1979 WARC.

> X dB Bandwidth: A bandwidth such that beyond its lower and upper limits any discrete spectrum component or continuous spectral power density is attenuated by at least X dB relative to a given and predetermined zero dB reference level.

In the interest of spectrum conservation it is stated in the NTIA Manual, Part 5.5, that "All reasonable effort should be made .... to maintain the occupied bandwidth .... as closely to the necessary bandwidth as is reasonably practicable ...". In order to accomplish this goal, agencies need a practical method of establishing these parameters.

The determination of the occupied bandwidth for the various emission classes is, in general, a non-trivial problem. Since the definition has been given in terms of a percentage of power, the occupied bandwidth cannot be simply measured and usually is established through an integration process of either a measured or theoretical spectrum. A more convenient approach is to relate the occupied bandwith of an emission to the XdB bandwidth, the latter being a more easily measured value. Depending on the specific class of emission, the occupied bandwidth can typically vary from the -15 dB bandwidth to the -35 dB bandwidth. Various CCIR reports (CCIR, 1978a, CCIR, 1978b, CCIR,1978c) examine this relationship but more study is needed especially for the complex FM emissions such as video, telemetry, etc. As part of these studies, it would be necessary to establish appropriate values of B.

For practical reasons, it is sometimes desirable to approximate the occupied bandwidth with an X dB bandwidth, even though the specific dB value is not known. An example would be in recording the approximate occupied bandwidth of emissions at monitoring stations. Another example is where the occupied bandwidth is desired and only the envelope of the emission spectrum is known. For such cases, insufficient details of the emission would be available to accurately determine the occupied bandwidth through integration of the spectrum.

For such instances, the CCIR recommends that the -26 dB bandwidth be used as an approximation to the occupied bandwidth. Use of this approximation in lieu of other approximations occasionally used, e.g., -20 dB or -23 dB bandwidth, would result in a more consistent spectrum management procedure.

The necessary bandwidth is a key factor in identifying potential frequency conflicts when new assignments are proposed to the Frequency Assignment Subcommittee of the IRAC. A consistent approach is needed in specifying this parameter to permit effective management of the band. Incorrectly stated values can lead to inefficient use of the spectrum if stated too large, or potential interference situations if stated too small.

For multichannel telephony stations in this Fixed service, Chapter 5 of the NTIA Manual provides clear and specific methods for calculating necessary bandwidth. However, methods for calculating necessary bandwiths for several other common signals, including frequency modulated video, telemetry, telecommand, and data, are not explicitly defined. Because of this, there exist numerous conflicting values for necessary bandwidths for these systems. For example, the necessary bandwidth for FM modulated television is often calculated using the "Carson Rule" (Keenze, 1979) according to the following formula:

$$B = 2M + 2DK$$

where

B = Necessary bandwidth

M = Maximum Modulation Frequency

D = Peak Frequency Deviation

K = Multiplying Constant, usually 1

Using this equation for a typical FM video link having a 4.2 MHz maximum modulating frequency and a 4 MHz peak deviation results in calculated necessary bandwidth of 16.4 MHz. In the GMF, the stated necessary bandwidths for two identical video systems can be from 8 to 20 MHz depending on the particular method used by the submitting agency.

In some instances, the bandwidth indicated in the GMF for an assignment is the -3 dB bandwidth. This is the approach used for the telemetry and telecommand links of the ACMI/ACMR systems identified in the Phase 1 report. In general, the necessary bandwidth of a system is considerably larger than the -3 dB bandwidth and the use of the latter value may lead to confusion and possible interference situations.

For complex frequency modulated signals, more study is needed to establish appropriate methods of calculating necessary bandwidth. The Technical Subcommittee of the IRAC should further examine these techniques and adopt appropriate procedures for inclusion into the NTIA Manual which are applicable for both the Fixed and Mobile Services.

Receiver Standards

The standards for fixed stations cited in Part 5.10 of the NTIA Manual require certain minimum values for receiver selectivity. In particular, the -3 dB receiver bandwidth should be commensurate with the authorized emission bandwidth plus twice the frequency tolerance of the associated transmitter. Additionally, the -60 dB receiver bandwidth shall not exceed five times the -3 dB receiver bandwidth. A sampling of data for commercially available equipment given in Appendix B illustrates the degree to which these requirements are achieved. One problem is the interpretation of the word "commensurate" which is defined variously as equal, proportional, and comparable. A typical design goal is for the receiver -3 dB bandwidth to be approximately 1.0 to 2.0 times the authorized emission bandwidth of the desired signal. (See representative data in Appendix B.) In general, smaller bandwidths result in excessive intermodulation noise, and wider bandwidths result in excessive thermal noise. For modern equipment, the transmitter frequency tolerance is a relatively insignificent factor, except for very narrowband emissions.

Because a single equipment model may be capable of receiving a wide range of desired signal bandwidths, manufacturers generally provide several bandwidth options. However, it is economically impractical to manufacture a separate bandwidth capability matched to every possible desired signal, but rather two or more bandwidth options may be offered to cover a range of bandwidths. This tends to present problems, especially with relatively narrowband links. For example, a review of assignments from the GMF shows an equipment with a 3.5 MHz bandwidth receiving an emission of 150 kHz, a ratio of over 23. Review of the data given in Appendix B shows that it would be practical to adopt a specific definition of commensurate. Specifically, limiting the receiver -3 dB bandwidth to <u>at most twice</u> the associated transmitter authorized emission bandwidth, would be achievable for most commercially available equipments. This value would represent a reasonable compromise between good spectrum management and economic/availability considerations. The data provided in Appendix B may be found useful by the various frequency managers in determining compliance with such a standard. A proposed change to the NTIA Manual to implement this recommendation is as follows:

Proposed change to Section 5.10.2,
paragraph 1.2(2) of the NTIA
Manual. (Underlined portion
added.)

"The -3 dB receiver bandwidth should be commensurate with the authorized emission bandwidth plus twice the frequency tolerance of the transmitter specified in Section 5.10.1, paragraph 1.C. In no case shall the -3 dB receiver bandwidth exceed twice the authorized emission bandwidth."

Frequency Diversity

Although not used extensively, frequency diversity is a technique employed to improve the reliability of a fixed microwave link under the conditions of selective fading. This diversity technique, however, consumes twice the spectrum of a non-diversity link while other forms of diversity such as space or polarization do not. Section 8.2.25 of the NTIA Manual recognizes the necessity of some form of diversity in selected cases but places limits on the use of frequency diversity in Fixed Service bands above 1710 MHz. In particular, the use of frequency diversity is limited to those cases where its use can be justified from a requirements standpoint. Additionally, a statement must be provided that an engineering evaluation has been made that demonstrates that the required reliability necessitates frequency diversity. Providing the actual engineering evaluation to NTIA/IRAC is not required and would not appear to be currently necessary. However, in order for frequency managers to arrive at a valid decision regarding the approval for a proposed frequency diversity link, some additional data may prove useful. TABLE 4-2 provides a proposed standard form that could be submitted with any frequency diversity request. The specific parameters requested should be readily available to the submitting agency, since it is expected all would be available from the required engineering evaluation. Thus, little additional effort would be required by the submitting agencies other than transfering the data to the standardized form. It is expected that the decision making process for approval of frequency diversity requested would be improved with the use of this additional data.

SPECTRUM PLANNING

A goal of the spectrum planning process is to assure that the applicable frequency allocations, procedures, and regulations promote effective use of the radio spectrum. Additionally, these procedures, etc., must assure that the various classes of systems and functions performed in the band can operate together in a compatible manner.

In the following portions of this section the spectrum planning process for this band is examined from two viewpoints. The first subsection discusses the major functions used in the band. Insight is given as to how these functions are accommodated in the band and what, if any, alternatives (e.g., other bands) are possible to satisfy those needs. Recommendations are offered in instances where improved management of the band would result. The second subsection addresses the advantages and disadvantages of adopting a channel plan for this band.

TABLE 4-2

Proposed Data for Technical Justification for a Frequency Diversity Link

Agency __________ Bureau __________
Link Name __________ to __________
Frequency __________ Channel Capacity __________

		Transmitter		Receiver
1.	Site	______		______
2.	Latitude	______ N		______ N
3.	Longitude	______ W		______ W
4.	Site Elevation	______ m		______ m
5.	Tower Height	______ m		______ m
6.	Azimuth	______		______
7.	Equipment Type	______		______
8.	Path Length		______ km	
9.	Path Loss (Free space)		______ dB	
10.	Waveguide/Coax. Length	______ m		______ m
11.	Waveguide/Coax. Loss	______ dB		______ dB
12.	Other Fixed Losses	______ dB		______ dB
13.	Antenna Size	______ m		______ m
14.	Antenna Gain	______ dBi		______ dBi
15.	Transmitter Power		______ dBm	
16.	Total Antenna Gains		______ dBi	
17.	Total Link Losses (1)		______ dB	
18.	Med. Received Power		______ dBm	
19.	Practical Receiver Threshold (2)		______ dBm	
20.	Available Fade Margin		______ dB	
21.	Non-diversity reliability (3)		______ %	
22.	Frequency Diversity Imp. Factor (4)		______ dB	
23.	Space/Polar Diversity Imp Factor (4)		______ dB	
24.	Expected Equipment Reliability		______ %	
25.	Overall Freq. Div. Reliability		______ %	
26.	Overall Space/Polar Div. Reliability		______ %	
27.	Required Overall Reliability (5)		______ %	

Notes:

1. If link includes a passive reflector, provide additional data to derive total end-to-end path loss.
2. Based on 30 dB S/N in worst channel.
3. Based on Rayleigh Fading unless otherwise stated.
4. Provide specific references for derivations: __________
   ____
   ____
5. Provide justification for required high link reliability:
   ____
   ____
   ____
   ____
   ____
   ____
   ____

System Functions

Line-of-Sight Fixed Links. The 1710-1850 MHz band is the major Government band for accommodating medium channel capacity (or medium bandwidth) point-to-point microwave links. For multichannel telephony, typical capacity varies from 24 to 600 channel with most necessary bandwidths being in the range from 0.5 to 10 MHz. In general, microwave links with bandwidths considerably greater than 10 MHz can be better accommodated in portions of the 7.125-8.5 GHz and 14.4-15.35 GHz bands. The increased spectrum generally available in these bands is more conducive to accommodating the wider bandwidth systems.

Similarly, low capacity (or narrow bandwidth) links are often better accommodated in lower frequency bands such as 406.1-420 MHz or in the vicinity of 902-928 MHz. This follows from the fact that few commercial microwave receivers in the 1710-1850 MHz band employ bandwidths commensurate with narrowband emissions less than approximately 0.5 MHz (see Appendix B). Thus, these receivers would be unable to achieve the standards of Part 5.10 of the NTIA Manual as previously discussed. It is recognized that the use of the lower bands is not without problems. In the 406.1-420 MHz band, the multichannel links would be competing for spectrum space with the rapidly expanding use of single channel Fixed and Mobile stations. In the 902-928 MHz band, the Fixed Service is currently on a secondary basis and is the subject of a separate study [Bulawka, 1980].

For the medium capacity link bandwidths, in the range of 0.5-10 MHz, few alternatives exist to the 1710-1850 MHz band. For example, the 2200-2300 MHz band is allocated to the Fixed and Mobile Service but is presently dominated by the Mobile Service. This also is the subject of a separate study [Flynn, 1980]. The 4400-4990 MHz band is also allocated to the Fixed and Mobile Service, but is not currently used to a great extent by non-military Government operations [Kimball, 1974].

Tropospheric Scatter. Tropospheric scatter communications is a technique which takes advantage of scattering of radio waves from irregularities and disturbances in the lower troposphere. When sufficient power, antenna gains, and receiver sensitivity are employed, the high troposcatter propagation losses can be overcome to achieve point-to-point communications for distances of 400 kms or more. Thus, up to ten line-of-sight microwave hops could be replaced by one tropospheric scatter link. This proves to be an advantage in certain military tactical and other situations where maintenance of intervening line-of-sight stations may be impractical. The disadvantages are the significant increase in overall system costs as well as the consumption of a large amount of spectrum space.

For line-of-sight links, potential interference paths are nearly always limited to free space or diffraction mode propagation mechanisms resulting in relatively short interference distances. Because of the high power and gain used for the troposcatter link, tropospheric scatter propagation can become significant for potential interference paths as well. Thus, much larger interference distances are involved. Also, troposcatter links often employ frequency diversity and high frequency deviation ratios in the modulation in order to achieve acceptable reliability further adding to spectrum consumption.

In view of the large consumption of spectrum space and high interference potential, the decision has been previously made to exclude tropospheric scatter communications from the similarly allocated 2200-2300 MHz band. This was accomplished by adding a "line-of-sight only" restriction directly into the national allocation tables. An argument could be advanced for a similar restriction in the 1710-1850 MHz band. Both the 1710-1850 MHz and 2200-2300 MHz bands are allocated to the Fixed and Mobile Service and both are used for many of the same types of functions, albeit in different distributions. Presently, there are very few tropospheric scatter links and no current plans are known for any new tropospheric scatter communications systems for this band. The adoption of a line-of-sight only restriction for this band would preclude this possibility.

Tactical Radio Relay. A number of military radio relay equipments are assigned and operated in this band for tactical and training use. While some of these links are assigned specific frequencies and locations, many are class assignments which authorize their use but provide for the selection of specific locations and frequencies by field level frequency coordinators. Most of these equipments have field tuning capabilities over the 1350-1850 MHz or 1700-2400 MHz bands. The 1710-1850 MHz band is the principle band available over these ranges that can accommodate Fixed service operations on a primary basis. This field coordination of frequencies has apparently worked satisfactorily with few problems. One problem that exists in the assignment records for many of those class assignments concerns the reported bandwidth. On all assignments the AN/GRC-50 is listed as the equipment nomenclature and an emission designation of M26F9 is reported on many. This is in error since the AN/GRC-50 has a maximum bandwidth of 1.2 MHz. Correction of these data appear warranted.

Air-to-Ground and Air-to-Air Video/Data Links. The 1710-1850 MHz band supports a number of assignments for air-to-ground or air-to-air video/data links for testing, training, and limited operational links. The test and training applications are predominately for video information used for such purposes as munitions targeting, aerial reconnaissance, and vehicle testing. Bandwidths are commonly between 10 and 20 MHz.

The SPS [1976] has identified two frequency bands that were recommended for supporting these types of funtions to be 4400-4990 MHz as well as 1710-1850 MHz. While the higher band is available and used, some penalty is paid in system performance. For example, many of these links use omnidirectional (or hemispheric coverage) antennas in the airborne components and tracking antennas on the ground on the order of four to six feet in diameter. The use of the higher frequency band introduces additional path losses which cannot be easily compensated by increased antenna gains. The latter results from the tracking requirements. Thus, increased transmitter power would be required at increased cost. Also, commonality of equipments with the associated telemetry, tracking and/or command functions, which operate in the 1400-2300 MHz range is often desirable. This is easily achieved in the 1710-1850 MHz band but not in the 4400-4990 MHz band. In general, these types of systems operate on an intermittent basis with some uses being reported as few as several hours per week. In such cases time sharing among these systems is practical, and the same frequency may be assigned to several users in the same area. Coordination of the planned transmission periods with the local frequency coordinator can assure compatible operation. Thus, continued accommodation of this type of function appears warranted in this band. Later in this section a channeling plan is discussed which would limit this and similar wideband systems to specific portions of the band.

One specific class of air-to-ground data link that becomes difficult to accommodate in the band includes systems that are very wideband and operate on a continuous or long duration basis. One example is the SEEK SKYHOOK System identified in the Phase I study. The links in this band (two 60 MHz channels) are used for relaying wideband radar data from a tethered balloon to a ground receiver. Because of its continuous transmission and airborne operation, both time and geographic sharing with other band users becomes very limited. To assure protection from interference to other users, a distance separation of 100 to 200 miles may be required. Future systems of this type, which consume a large portion of the band and have limited sharing possibilities with other systems, should be considered for assignment in other more appropriate bands. One such possibility is 14.7145 to 15.1365 GHz. In a National Memorandum of Understanding (Probst, 1979), it was stated that this band will be designated nationally for the Mobile Service on a primary basis, and with the Fixed Service on a secondary basis.

<u>Telemetry and Telecommand.</u> A limited number of Aeronautical Mobile stations are assigned in this band for telemetry purposes. Such use would be permitted under the overall Mobile service allocation for the band. Accommodation of a limited number of these systems into the band has been accomplished in the past with minimal difficulty. As the band usage continues to grow, difficulty in coordinating the use of this airborne function will likewise grow, because of large required distance separations between airborne and land-based systems. These large required distances follow from the resulting line-of-sight ranges of typically 100 to 200 miles depending on altitude.

It is observed that alternative bands are available for use which have been specifically designated for flight testing and aeronautical telemetry, namely 1435-1535 MHz and 2200-2290 MHz. In a separate study [Flynn, 1980], the 2200-2290 MHz band is examined and the telemetry usage is discussed along with the extensive coordination procedures presently employed in that band to assure compatible operation. Using real-time regional frequency management, with time sharing used as required, spectrum efficiency is optimized for these intermittent operations. Similar time sharing among intermittent telemetry functions is also accomplished in the 1435-1535 MHz band in accordance with procedures given in Annex D of the NTIA Manual. With the recent adoption at the 1979 WARC of the 2310-2390 MHz band for telemetry functions, additional spectrum is available to support these needs. The latter band is expected to be implemented in the U.S. for flight testing telemetry.

In the 1710-1850 MHz band, extensive real-time coordination of these intermittent operations is not currently practiced nor planned. While time sharing among these intermittent airborne operations can result in relatively efficient use of the spectrum, sharing between fixed and aeronautical mobile operations tend to be less efficient. This follows from the inability of continuously operating Fixed stations to time share, and the reduced possibility for geographic sharing because of large required distance separations from airborne transmissions.

In view of the growing usage in the 1710-1850 MHz band and the more suitable alternative bands available for flight testing telemetry, exclusion of future flight testing telemetry operations in the 1710-1850 MHz band would appear to be a feasible and attractive policy option.

Similarly, some limited telecommand stations are assigned in the band. The SPS [1976] has previously noted that the 1427-1435 MHz band is recommended for supporting these functions. Since telecommand is inherently a relatively narrowband function the 8 MHz available should, in general, be adequate to support this function.

One specific example is the ACMI/ACMR system used by the Air Force and Navy which was discussed in the Phase I report. This system is used to monitor aircraft while engaging in simulated air combat. It is composed of multiple fixed links, an air-to-ground, and a ground-to-air link. The fixed links which are nominally of 1 MHz bandwidth are appropriate for assignment in the 1710-1850 MHz band. The two airborne links serve telemetry and telecommand functions with a closed loop CW ranging function also provided. These functions could be accommodated in the 1427-1435 and 1435-1535 MHz bands for the command and telemetry respectively. The tracking function essentially rides "piggy back" on top of the command and telemetry signal and would not normally require a separate and distinct station class indicator. Assignment of future functions of this type in other more appropriate bands would further ease potential congestion in the 1710-1850 MHz band.

A proposed modification to the NTIA Manual to effect such a policy to exclude futher telemetry and telecommand functions in this band is as follows:

Proposed Addition to Chapter 7 of the NTIA Manual

7.20 USE OF STATIONS IN THE AERONAUTICAL MOBILE SERVICE FOR TELEMETRY AND TELECOMMAND IN THE 1710-1850 MHz BAND

A limited number of stations in the Aeronautical Mobile Service for flight testing telemetry and telecommand functions have been accommodated in the past in the 1710-1850 MHz band. In view of the availability of more suitable alternative bands for these functions (e.g., 1427-1435 MHz, 1435-1535 MHz, 2200-2290 MHz, and 2310-2390 MHz) and the growing congestion in the 1710-1850 MHz band, future spectrum support in the latter band will be limited. In particular, the following policy is adopted.

1. Existing assignments for flight testing telemetry and telecommand stations in the Aeronautical Mobile Service and, such systems having been authorized by NTIA for development and/or operation, will continue to be supported in the 1710-1850 MHz band until January 1, 19XX.

2. No new assignments to flight testing telemetry and telecommand stations in the Aeronautical Mobile Service will be authorized in the 1710-1850 MHz band after January 1, 19XX. Extensions of existing systems after that date may be authorized on a case-by-case basis, subject to review and recommendations by the SPS/IRAC and to the limitations given in 1) above.

Airborne Spread Spectrum. The need is recognized for certain military applications to employ band spreading, or spread spectrum, techniques to assure adequate anti-jam margins in a hostile environment. In the future, possible non-military applications may also come into use as a potentially more efficient use of the spectrum as compared to conventional narrowband techniques. The use of a spread spectrum system in the band in a fixed and mobile application has been discussed by Crandall [1980]. The use of spread spectrum in airborne application has not, at present, been proposed for this band. However, to provide a technical evaluation prior to any proposal for such an application in the 1710-1850 MHz band, the following analysis is offered.

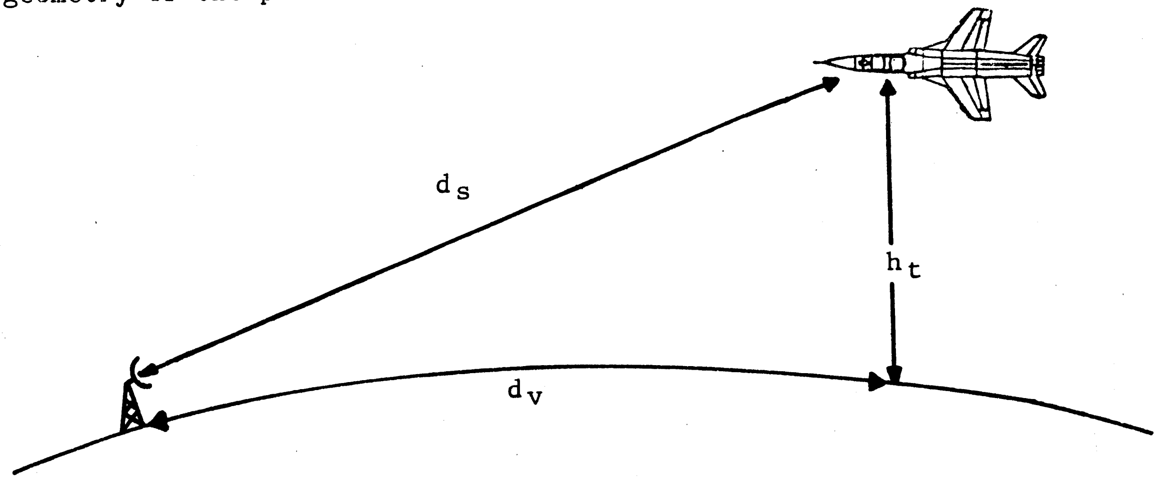
A hypothetical airborne spread spectrum system is assumed with the following parameters:

Transmitter Power	:	100 watts (50 dBm)
Antenna Gain	:	3 dBi
Bandwidth (3 dB)	:	100 MHz
Altitude	:	$\leq$ 6,000 meters
Duty Factor	:	1 to 100%

For initial calculations, a fixed microwave link will be used as the victim receiver with the following characteristics:

Channel Capacity	:	300
Noise Figure	:	7 dB
Receiver Noise Level	:	-96 dBm
Receiver Bandwidth(3 dB)	:	12 MHz
Antenna Gain	:	28 dBi
Antenna Beamwidth	:	6.5 degrees
Antenna Height	:	30 meters
Cable Losses	:	3 dB

The geometry of the potential interference link is illustrated below.



To determine the slant distance, d_s, at which the interference becomes unacceptable, a criterion will be used that the interference will increase the receiver noise level by not more than 1 dB. For an additive noise-like interfering signal, such as a wideband spread spectrum emission, this point occurs when the power within the receiver passband is approximately 6 dB below the receiver noise level. This can be expressed as follows:

$$P_T + G_T - L_P + G_R - L_C - 10 \log \left(B_t/B_r\right) = N_s - 6 \qquad (2)$$

where

P_T = Interfering transmitter power in dBm

G_T, G_R = Transmitter and receiver antenna gain in opposing directions in dBi

L_P = Propagation loss in dB

L_C = Losses due to cables, etc. in dB

B_t = Interfering transmitter 3 dB bandwidth in MHz

B_r = Victim receiver 3 dB bandwidth in MHz

N_s = Receiver noise level in dBm

Substituting the above assumed parameters into Equation 2 yields

$$50 + 3 - L_P + G_R - 3 - 10 \log (100/12) = -96 - 6$$

$$G_R - L_P = -142.8 \text{ dB}$$

Both the propagation loss and receiver antenna gain in the direction of the transmitter are dependent on antenna height, orientation, etc. TABLE 4-3 gives calculated values of slant range using Equation 2 for various conditions. In these calculations, the path loss is based on computer derived values given on Figure 4-1 for smooth terrain conditions. The off-axis antenna gain is based on the discussion given in Appendix A. Also, given in TABLE 4-3 are similar results for transmitter duty cycles of one percent. Measurements performed by ECAC [Newhouse, 1977] showed that the degradation caused by pulsed interference to FDM/FM systems depends on the average power of the offending signal. Thus, it is assumed that the interfering signal can be 20 dB higher for a one percent duty cycle. It must be noted that the distances indicated are for one single interfering equipment at its closest distance to the microwave link. For multiple interference, such as an airborne communications net, the interfering powers will tend to be directly additive, thus increasing the distance separation requirements. Specific scenarios would be necessary to fully examine the case of multiple interference.

While the calculations given here are based on hypothetical parameters, it is clear that the coordination of airborne spread spectrum systems in this band would become difficult. Time sharing with fixed systems is impractical for obvious reasons. Frequency sharing, i.e., designating a specific portion of the band for the airborne spread spectrum system, would not assist in the solution because of the typically wide bandwidths used. And finally, geographic sharing would require relatively large distance separations as indicated. In view of these difficulties, widespread use of airborne spread spectrum systems in this band would not be possible in many areas of the country. In a given geographic

TABLE 4-3

REQUIRED DISTANCE SEPARATION BETWEEN AIRBORNE SPREAD SPECTRUM TRANSMITTER AND FIXED MICROWAVE SYSTEMS

A. REQUIRED DISTANCE SEPARATION (KILOMETERS) FOR 100% DUTY CYCLE

FIXED ANTENNA * DISCRIMINATION ANGLE	MAXIMUM ALTITUDE (METERS) 300	600	1500	3000	6000
0	141 km	201 km	241 km	265 km	354 km
10	132	188	230	254	356
30	120	177	220	241	330
90	113	167	198	198	198
180	105	116	116	116	116

B. REQUIRED DISTANCE SEPARATION (KILOMETERS) FOR 1% DUTY CYCLE

FIXED ANTENNA * DISCRIMINATION ANGLE	MAXIMUM ALTITUDE (METERS) 1000	2000	5000	10000	20000
0	121 km	177 km	220 km	241 km	330 km
10	109	153	153	153	153
30	48	48	48	48	48
90	22	22	22	22	22
180	<10	<10	<10	<10	<10

*Azimuth Angle Between Fixed Antenna Boresight and Direction to Airborne transmitter

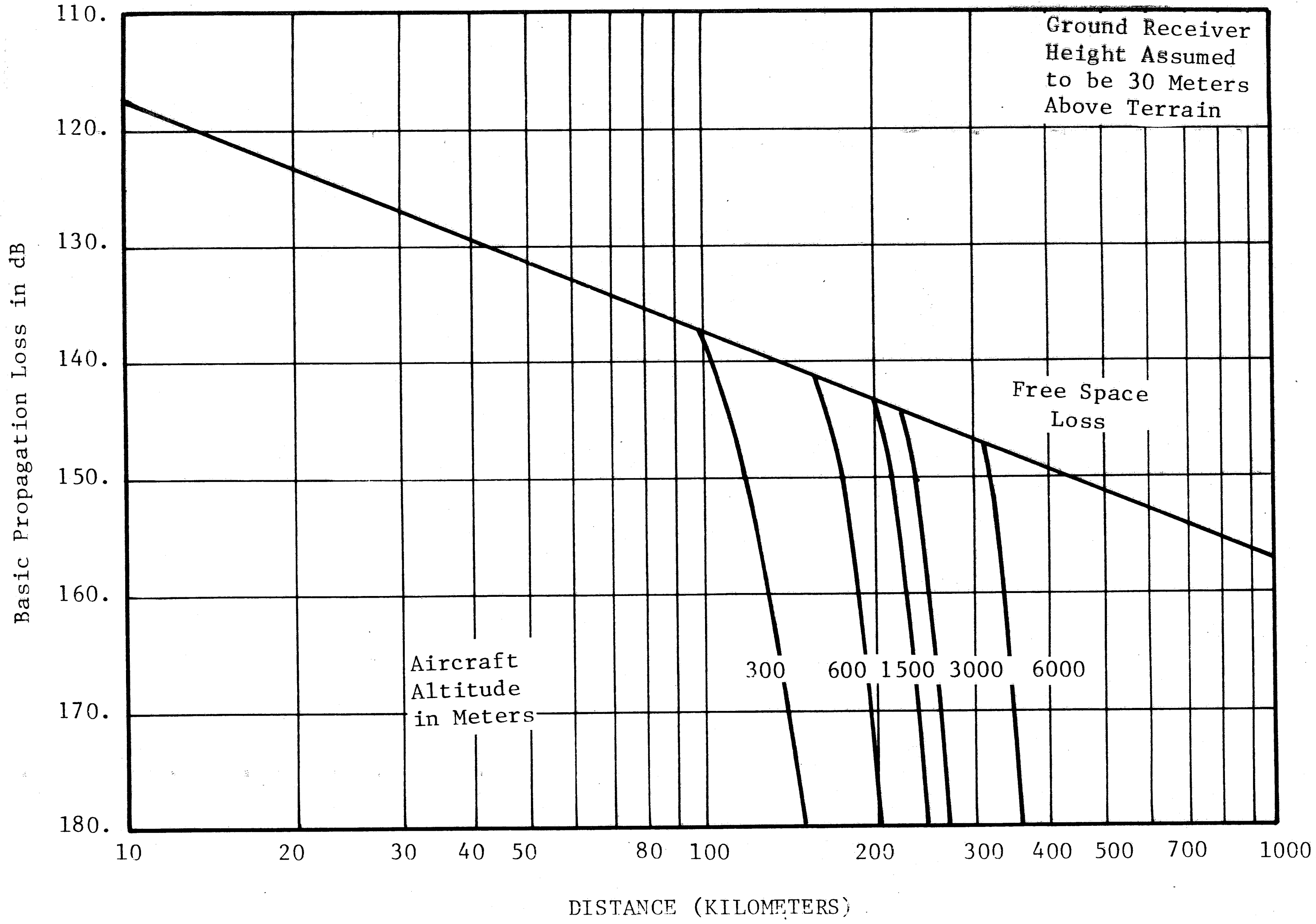


Figure 4-1. Air-to-Ground Propagation Loss at 1800 MHz

area, the use of one system that effectively excludes all other band users from the same area cannot be considered as effective use of the band. Any such planned use could only be permitted on a secondary non-interference basis, and would be limited to specific geographic areas as determined on a case-by-case basis. Such use should not limit the introduction or expansion of other conventional systems in the same area.

Channel Plan

A channel plan is not, at present, employed in the 1710-1850 MHz band. The users of fixed and mobile systems are free to choose any frequency in the band, subject of course, to any case-by-case restrictions imposed within the normal spectrum planning and assignment processes of the IRAC. The advantages and disadvantages of using a channel plan are discussed in the following paragraphs.

One goal in the spectrum management process is to develop regulations and procedures that are simple to administer while at the same time efficiently and economically accommodate the various requirements of band users. The use of a channel plan can serve as an aid in achieving this goal. Conversely, a plan that is overly rigid can impede the introduction of new or unique applications of the bands. Thus, at the outset any channel plan to be considered must allow for some flexibility in its application. Also, the 1710-1850 MHz band is not empty. A new plan for a band that has a large number of stations already assigned may be difficult to implement.

The spectrum management process becomes simplest to administer when a given band is used by a uniform class of similar systems, e.g., fixed microwave links all of the same bandwidth. The Federal Communications Commission (FCC) has applied this approach in managing a number of non-Government bands. In using this approach, the interference criteria, separation requirements, etc., can be simply defined and applied by frequency managers in a straightforward manner. It should be noted that such a management process is not necessarily the most efficient use of the band.

Due to increased spectrum congestion, sharing among various services has become a necessity in many bands. The 1710-1850 MHz band is occupied by a wide variety of system types with many varying characteristics as described in the Phase I study. The appropriate sharing criteria to be used among the various systems are, in general, not well defined and "worst-case" assumptions are typically used. Additionally, some combinations of systems tend to share frequencies much more compatibly than others. The following examples will illustrate how an ordered approach to assigning frequencies in this band can improve spectrum efficiency.

Consider first the random intermixing of systems with various bandwidths within the 1710-1850 MHz band. The FCC, in its channeling plans for the adjacent 1850-2200 MHz band, separates the narrowband and medium bandwidth microwave systems into distinct subbands. Wideband systems with bandwidths greater than 10 MHz are not permitted by the FCC in those bands. A simple hypothetical problem can be addressed to demonstrate that such an arrangement can, indeed, result in better use of the band. It is first assumed that the 1710-1850 MHz band is clear of assignments and new stations will be assigned to the band at random frequencies. The frequencies chosen will be subject only to the condition that the necessary bandwidth does not fall out of the band nor overlap other previously assigned stations. For simplicity, the stations will consist of 50 percent with one MHz bandwidth and 50 percent with 10 MHz bandwidth, the sequence also to be chosen at random. The process will stop and the band will be considered saturated when a clear frequency cannot be found for a chosen station.

Figure 4-2A shows the results of one trial of the experiment for the first 15 randomly chosen stations. The 16th station chosen was wideband and could not be accommodated based on the aforementioned rules. In real life the agency submitting such an assignment application would indeed feel that the band was saturated since the agency needs were not being met. Repeated trials using a simple computer routine showed that the average number of stations assigned under these given assumptions was 17.3.

Now consider changing the rules for this model slightly. Instead of completely random frequencies, the following is assumed. The narrowband systems will be confined to the 1710-1720 MHz portion in one MHz increments, and the wideband systems to the remainder using 10 MHz increments. Figure 4-2B is the result of one trial under these ground rules using the same random sequence of stations. In this example 21 stations were assigned before failing. Repeated trials using the computer routine showed an average of 19.5 assignments or a 13 percent increase in band utilization. The model also showed that for the assumptions used, the optimum division of the band would be to permit the narrowband systems to operate within a 20 MHz subband, as opposed to 10 MHz. With this change, the band utilization was increased 40 percent over the random assignment approach for a 50/50 mix of 1 MHz and 10 MHz bandwidths.

Any number of variations could be made to this assignment problem. Assignments could be made random at first. Then after X assignments the above channeling scheme could be introduced. This variation would attempt to consider the fact that any actual channel plan would not be initiated with an empty band. One could generalize the model to more realistic environments to include guardband requirements, a larger variety of bandwidths, etc. While these variations have not been attempted, it is postulated that while the specific numbers would change, the same trend is expected to prevail. While this example is obviously not a rigorous mathematical proof that a channeling plan improves band utilization, the results, as well as the experience gained from other bands, have strongly suggested such is the case.

An extension of this argument relates to the frequency separation requirement for equipments located in close proximity. The required frequency separation is determined for a given situation by calculating the carrier-to-interference ratio at the victim receiver and comparing this ratio with an appropriate criteria such as that developed by the EIA. Figure 4-3 shows representative C/I criteria for various combinations of 24 and 300 channel equipments.

It is observed from the curves, that when the 24 channel equipments are intermixed together, relatively small frequency separations are required. Similarly, when the 300 channel radios are intermixed, larger frequency separations are required as expected. However, when the 24 and 300 channel equipments are intermixed, in particular a 24 channel transmitter and a 300 channel receiver, the wider separation requirement of the 300 channel receiver predominates. For example consider an environment that includes both 24 channel and 300 channel equipments. It is simple to show that the arrangement which

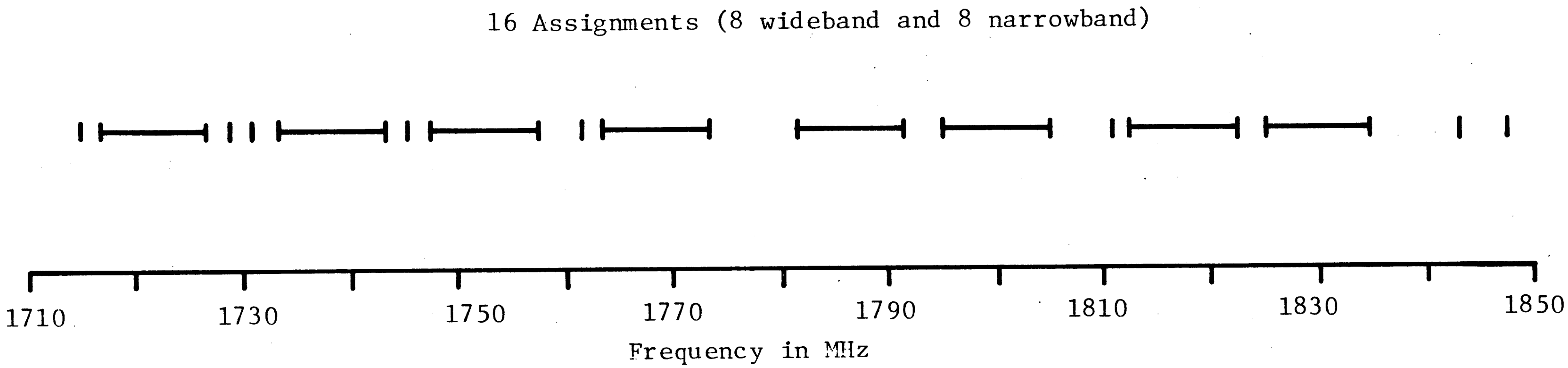


Figure 4-2A. Example of Random Frequency Assignment

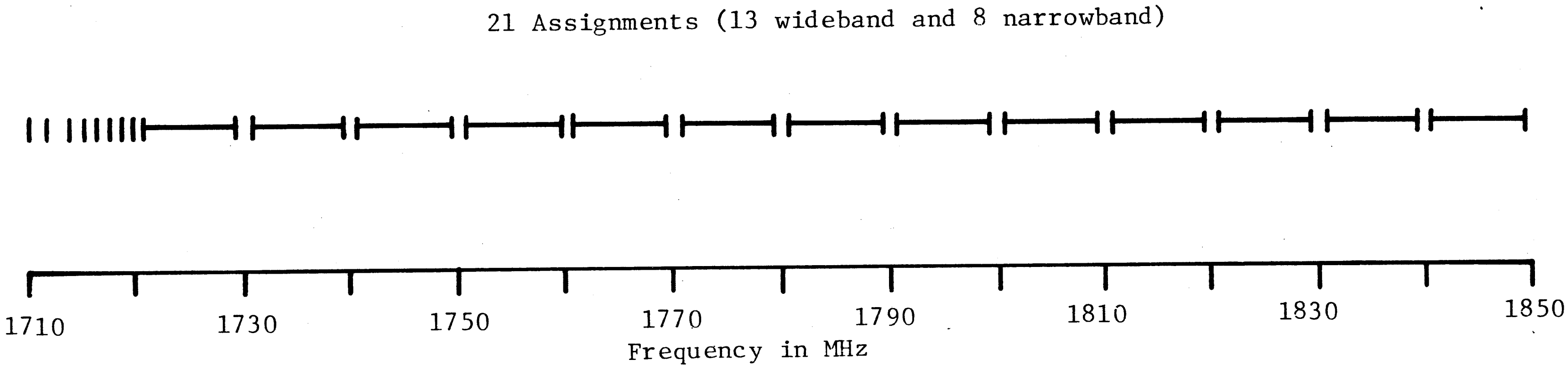


Figure 4-2B. Example of Ordered Frequency Assignment

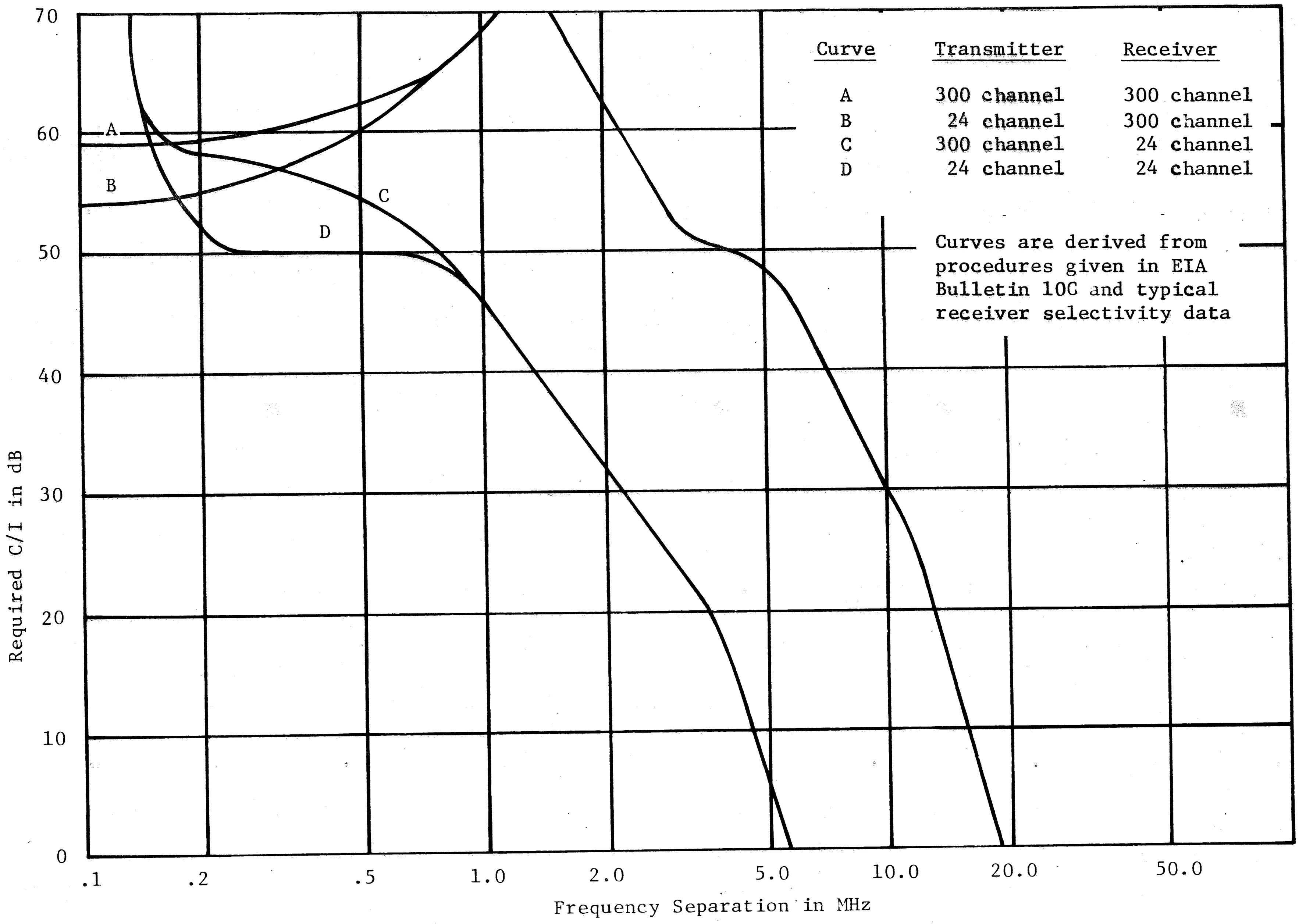


Figure 4-3. Representative C/I Protection Ratio

minimizes the total spectrum committed is where 24 channel and 300 channel systems are grouped separately. For an environment consisting of two each of 24 and 300 channel transmitters and receivers, the following shows the best and worst ordering of assignments.

Best Rx(24), Rx(24), Tx(24), Tx(24), Tx(300), Tx(300), Rx(300), Rx(300)

Worst Rx(24), Tx(300), Rx(24), Tx(300), Rx(300), Tx(24), Rx(300), T(24)

For the first case, only one large frequency separation is required which involves a 300 channel receiver, i.e., between the sixth and seventh assignment (transmitter-to-transmitter and receiver-to-receiver separation requirements are typically modest). For the second case four are present. This trend would hold for any combination of wideband and narrowband systems, i.e., the total spectrum committed is minimized when narrowband and wideband assignments are grouped separately.

Several additional factors can provide arguments for further subdividing the band into specific channels. The first also has to do with the frequency separation between assignments. The EIA [1976] has provided specific carrier-to-interference (C/I) criteria for use in coordination among fixed microwave systems.

An example will be used of a 300 channel receiver being interfered with by a 300 channel transmitter. The required C/I ratio between these equipments as a function of frequency separation, following EIA criteria, is shown in Figure 4-3. The sharp peak occuring at a frequency separation of approximately 1.3 MHz results from beats occurring between the desired and undesired carriers which fall within the desired signal baseband. For systems with different capacities, the peaks will have similar magnitudes but occur at different frequency separations. Such a high level of required protection results in quite large required distance separations, and thus less effective geographic sharing of frequencies. Clearly, these specific frequency separations should be avoided, which a channel plan can easily accomplish.

A final point is based on the spectrum management principle called out in Section 8.2.16 of the NTIA Manual. It states "... where feasible and consistent with frequency allocation and assignment plans, to assign the most heavily occupied channel before resorting to those less heavily occupied." In this way, the frequency assignments are made such that the increase in total spectrum space committed is as small as possible. Thus, the possible spectrum available for future radiocommunications requirements will be maximized. The mathematical basis for this policy is given by Zoellner [1973]. While this policy would be applicable across the spectrum, it has been applied to a very limited extent in the bands used by the Land Mobile Service. In general, no simple mechanism currently exists to implement this policy. Again, if a channel plan were developed in which there existed a priority ordering of channels, the intent of this principle could be achieved.

Based on the discussion presented, a channel plan for this band would significantly improve the utilization of the band to more effectively accommodate the various needs of the band users. At the same time the potential spectrum available for future radiocommunication needs for the band will be maximized.

As a first proposal, TABLE 4-4 identifies a possible channel plan which divides the band into segments for three classes of assignments, those with bandwidths less than or equal to 2 MHz; those with bandwidths between 2 and 10 MHz; and those with bandwidths greater than 10 MHz. This plan achieves the objectives desired for an ordered approach to frequency assignments, namely 1) flexibility to accommodate the various needs of the agencies 2) minimizes interactions between less compatible systems 3) maximizes interactions between the more compatible systems 4) avoids specific undesirable frequency separations between systems, and 5) provides a procedure for implementing Section 8.2.16 of the NTIA Manual.

The choice for the bandwidth limitation for the various sub-bands was based on characteristics of fixed and mobile systems currently used and expected for use in the band. The 10 MHz sub-bands will accommodate multichannel FDM/FM links up to 600 channels (with 140 kHz deviation per channel), the largest capacity expected for the band. The 2 MHz sub-bands can accommodate capacities up to 96 channels. These sub-bands are paired with 90 MHz separation, a convenient value for go and return paths of a microwave link. Wideband equipments, such as video links, generally do not employ two directional paths, thus not requiring a paired subband, and can be accommodated in the central 40 MHz portion. Spread Spectrum systems with bandwidths greater than 40 MHz must be treated separately.

It is, of course, recognized that existing assignments must be "grandfathered" into the band without change. The plan is aimed at future assignments to assure adequate spectrum will be available for these future needs.

FREQUENCY ASSIGNMENT

The frequency assignment of a station is generally the final stage in the overall spectrum management process. To assure efficient use of the spectrum it is essential that accurate data and effective procedures are used in this process. In the following paragraphs three areas of possible improvements are discussed which are particularly applicable to the 1710-1850 MHz band.

Government Master File Improvements

The Government Master File (GMF) is the principle tool used in managing the assignments used by the Federal Government. As such, complete and accurate data in the file are essential for an effective spectrum management process. As part of this study, a review of the parameters used in the GMF has been made to identify possible modifications and/or improvements in the GMF structure.

One area where additional data would be beneficial is the specification of modulation parameters for FM stations. Currently, the only parameter in the GMF for FM systems which relates to modulation is the authorized bandwidth. As a result of band congestion, more refined frequency management techniques become necessary requiring more detailed data. Providing modulation parameters for the GMF for FM stations would permit frequency managers to more effectively assure compliance with rules and regulations, choosing optimum interference criteria, coordination, etc.

The provision for additional modulation parameters in the GMF has already been implemented for pulsed radars in certain bands. For these radars, the pulse

TABLE 4-4

PROPOSED CHANNEL PLAN FOR FIXED AND MOBILE STATIONS IN THE 1710-1850 MHz BAND

The following channelization plan shall be followed for new Fixed and Mobile stations in the 1710-1850 MHz band granted assignments after ____. Equipment previously granted developmental or operational authority may continue to operate without regard to the requirements of this plan until ______. If existing assignments preclude the application of this plan for specific stations, alternative pairing arrangements of the identified center frequencies should be examined before using center frequencies not given.

OVERALL BAND CHANNELIZATION

Frequency Subband	Bandwidth Limitation
1710-1720 MHz	BW < 2 MHz
1720-1730 MHz	2 MHz < BW < 10 MHz
1730-1740 MHz	"
1740-1750 MHz	"
1750-1760 MHz	"
1760-1800 MHz	BW < 40 MHz
1800-1810 MHz	BW < 2 MHz
1810-1820 MHz	2 MHz < BW < 10 MHz
1820-1830 MHz	"
1830-1840 MHz	"
1840-1850 MHz	"

SPECIFIC CHANNELS

Stations with Bandwidths less than or equal to 1 MHz

1. 1710.5, 1800.5 MHz
2. 1711.5, 1801.5 MHz
3. 1712.5, 1802.5 MHz
4. 1713.5, 1803.5 MHz
5. 1714.5, 1804.5 MHz
6. 1715.5, 1805.5 MHz
7. 1716.5, 1806.5 MHz
8. 1717.5, 1807.5 MHz
9. 1718.5, 1808.5 MHz
10. 1719.5, 1809.5 MHz

Stations with Bandwidths greater than 1 MHz and less than or equal to 2 MHz

1. 1711, 1801 MHz
2. 1713, 1803 MHz
3. 1715, 1805 MHz
4. 1717, 1807 MHz
5. 1719, 1809 MHz

Stations with Bandwidths greater than 2 MHz and less than or equal to 5 MHz

1. 1725, 1815 MHz
2. 1730, 1820 MHz
3. 1735, 1825 MHz
4. 1740, 1830 MHz
5. 1745, 1835 MHz
6. 1750, 1840 MHz
7. 1755, 1845 MHz

Stations with Bandwidths greater than 5 MHz and less than or equal to 10 MHz

1. 1725, 1815 MHz
2. 1735, 1825 MHz
3. 1745, 1835 MHz
4. 1755, 1845 MHz

Stations with Bandwidths less than or equal to 40 MHz

1. 1760-1800 MHz

Notes:

1) In order to assign frequencies in accordance with Section 8.2.16 to the maximum extent, frequencies shall be chosen within each of the indicated categories from the highest available channel on each list.

2) Frequencies within the subband 1760-1800 MHz are available for use by any fixed or mobile station without regard to center frequencies or bandwidths, provided that the authorized bandwidth is totally confined within these limits. Stations which do not require paired frequencies should use this sub-band to the maximum extend possible.

duration and pulse repetition rate are required, which were adopted for the same reasons as given above.

For FM systems, the most meaningful parameters are the maximum modulating frequency and the peak frequency deviation. For systems employing FDM/FM modulation, an alternative set of parameters would be the number of channels and the rms deviation per channel. These parameters can be included in the GMF record in the same manner as pulse parameters are currently included for pulsed radars, namely as an appendage to the equipment nomenclature field. Specifically, a proposed procedure for including these data in the assignment record is as follows: As an appendage to the equipment nomenclature field of an FM assignment record, the following codes could be used. For FDM/FM systems, the symbol CH would be added followed by the number of voice channels and the symbol DEV followed by the rms frequency deviation per channel in kHz. For other types of FM systems, the symbol FM would be added followed by the maximum modulating frequency and the symbol FD followed by the peak deviation in kHz.

With the incorporation of these parameters into the GMF, the use of worst-case assumptions in spectrum management decisions could be reduced. The result would be a more effective frequency assignment process.

Another key parameter for systems in this band is the maximum altitude for airborne equipment. Such information is critical in establishing the interference range of an airborne transmitter since the radio line-of-sight is a function of altitude. Without altitude data it becomes necessary to assume a worst-case altitude of, for example, 6,000 to 12,000 meters, resulting in potential line-of-sight interference paths of up to 400 kilometers. If the station were in fact used only aboard low flying aircraft, such as helicopters, the worst-case assumptions would be overly conservative and the actual interference range limited to less than, for example, 160 kilometers. The area might appear congested when in fact additional stations could be accommodated.

Again inclusion of these parameters into the GMF record would not require any format changes since altitude data is already required for airborne earth stations. Including altitude data for all aircraft stations could be accomplished identically to that process as described in Chapter 9 of the NTIA Manual.

A significant portion (15%) of the GMF records in this band consists of experimental stations. These stations are designated by one of six station class codes as follows:

XC = Experimental Contract Developmental Station
XD = Experimental Developmental Station
XE = Experimental Export Station
XM = Experimental Composite Station
XR = Experimental Research Station
XT = Experimental Testing Station

While these symbols do distinguish between the various categories of experimentation such as research, developmental, etc., they do not indicate the nature of the radiocommunications service such as fixed, mobile, etc. Although all such stations are on a secondary non-interference basis, knowledge of the radio service is important in establishing when the non-interfering status must be invoked. Airborne stations obviously have a larger interference range than land based stations. An indication of the station's nature of service may or may not be in the textual part of the GMF record but is not required. Incorporation of additional data into the experimental station class codes is possible without format changes by observing that the existing experimental station class codes are limited to two letters while the GMF record format permits up to four. Adding a two-letter suffix to the existing codes to indicate the nature of service such as fixed (e.g., XTFX), or aeronautical mobile (e.g., XDMA), would significantly enhance usefulness of this field. While this would obviously rule out the use of the available three- and four-letter station codes as suffixes, the existing two-letter codes adequately cover most categories.

Frequency Assignment Principles

In the interest of effective spectrum management, a number of frequency assignment principles have been incorporated into the NTIA Manual. These principles have to do with such issues as the use of the minimum necessary transmitter power (NTIA Manual Section 8.2.19), assigning the most heavily used channel first (Section 8.2.16), maintaining the occupied bandwidth as close as possible to the necessary bandwidth (Part 5.5), etc. Two additional principles of good spectrum management have been used in the past but are not currently explicitly stated in the NTIA Manual.

The first has to do with re-use of frequencies within a system. It is generally accepted that frequencies within a network of fixed microwave stations should be re-used to the maximum extent possible. A recent study [Matos, 1979] has shown that considerable spectrum can be saved, and thus remain available for future assignments, by application of this principle. For many instances, it is possible to operate an entire multiple-hop microwave network on four frequencies by good site engineering and frequency re-use. Networks in which three or more paths converge to a central point will obviously require more than four frequencies. Frequency conflicts with other networks may also require deviating from a four-frequency plan.

This principle applies equally as well to mobile stations, especially those which are intermittently used. For example, many of the airborne stations operated in this band are used for testing or tactical/training applications. Actual transmissions may be as low as a few hours per week. For such cases, re-use of the same frequency by time-sharing becomes a feasible option. In the military test areas, time-sharing is accomplished by the area or local frequency coordinator.

Because of the advantages offered, it is proposed that a statement be adopted in the NTIA Manual to further encourage this practice. The following is a possible wording of this proposal:

Proposed Addition to Chapter 8 of the NTIA Manual

> 8.2.44 Re-use of Frequencies Within a System
>
> In the interest of efficient use of the spectrum, frequencies within a network of fixed or mobile stations should be re-used to the maximum extent possible. In this way, the total spectrum commited to any given

system will be minimized. For multi-hop fixed microwave systems, a four frequency plan should be considered unless existing assignments and/or system design require the use of additional frequencies. Mobile systems which are intermittent in nature can efficiently re-use frequencies by time-sharing or operational scheduling. This technique should be considered where practical.

A second principle deals with the authorized bandwidth of a station. It is stated in Part 5.5 of the NTIA Manual that the occupied bandwidth of an emission should be maintained as closely as practical to the necessary bandwidth. While this principle does provide a guideline on minimizing the occupied bandwidth, no current guidelines or regulations exist to limit or minimize the necessary bandwidth except for specific cases. For example, Chapters 4 and 5 of the NTIA Manual place restrictions on the necessary bandwidth for certain land mobile applications. For the majority of system types, no limitations are imposed.

Consider a frequency modulated video link. A typical maximum modulating frequency of 4.2 MHz and a peak deviation of ± 4 MHz might be used for such a link resulting in a necessary bandwidth of 16.4 MHz (using the Carson Rule as previously described). However, under present regulations, it would be permissible to employ any value of frequency deviation, for example, ± 10 MHz. This would result in a necesary bandwidth of 28.4 MHz. Unless dictated by system requirements, such a use is wasteful of spectrum.

For many frequency modulated systems, considerable flexibility is possible in the choice of the peak deviation. TABLE 4-5 shows a number of typical parameters for FDM/FM links. As seen, the use of the higher frequency deviations does improve sensitivity but at the expense of larger spectrum occupancy. Take for example the choice between using 100 kHz or 200 kHz rms per channel deviation for a 120-channel link (third and fourth column from right in TABLE 4-5). The use of 200 kHz results in a 1 dB improvement in sensitivity but a 60 percent increase in necessary bandwidth. As bands become more congested, the choice in favor of spectrum conservation is the preferable option.

In order to encourage such a policy, the following is a proposed addition to the NTIA Manual:

Proposed Addition to Section 8.2.45 of the NTIA Manual

8.2.45 Use of Lowest Practical Value of Necessary Bandwidth

In the design of a radiocommunication system, the necessary bandwidth should be used which maximizes the efficient use of the spectrum. For frequeny modulated signals, this entails the use of the lowest practical value of frequency deviation which is consistent with the quantity and quality of information being transmitted. For systems using band-spreading techniques, e.g., spread spectrum, other factors must also be considered such as anti-jam requirements or power-flux density limitations.

Coordination of Frequency Assignments

New assignments proposed by a Federal agency are reviewed and coordinated

TABLE 4-5. TYPICAL PARAMETERS FOR FDM/FM LINKS

PARAMETER		UNITS	OPERATING BANDS																						
			DOMESTIC (MHz) Private MW-Operational Fixed: 1850-1990, 2130-2150, 2180-2200 U.S. Government: 1710-1850, 2200-2290 Public, Fixed: 2110-2130, 2160-2180															INTERNATIONAL (MHz)							
																		CCIR REC. 283-2								CCIR REC. 382-2
FREQUENCY BANDS		MHz	2130-2150, 2180-2200						2110-2130 2160-2180		1850-1990							1700-1900, 1900-2100, 2100-2300								1700-2100, 1900-2300
EMISSION DESIGNATOR/NECESSARY BW		MHz	800F9			1600F9			3500F9		5000F9			10000F9				.70	1.36	2.12	3.70	2.00	2.85	4.60	7.23	11.63
RECEIVER IF BANDWIDTH		MHz	1.3			2.5			5.6		8.0			20.0				1.3	2.5	5.6	5.6	5.6	5.6	8.0	12.0	20.0
CHANNEL CAPACITY		NO. OF CHANNELS	24	36	48	48	72	96	132	252	132	252	312	312	480	600	612	24	60	60	60	120	120	120	300	600
TOP BASEBAND FREQUENCY		KHz	108	156	204	204	300	408	552	1052	552	1052	1300	1300	2044	2660	2540	108	300	300	300	552	552	552	1300	2540
RMS/CH TT DEVIATION		KHz/CH RMS	41.8	33	26	79.8	63	46.9	134	65	200	136	100	200	200	142.8	148	35	50	100	200	50	100	200	200	200
PILOT FREQUENCY		KHz	119	331	331	331	331	607	607	1159	607	1159	1499	1499	3200	3200	3200	119	331	331	331	607	607	607	1499	3200
PILOT DEVIATION		KHz/CH RMS	20	16	13	40	31	24	67	33	100	68	50	140	140	100	100	20	25	50	100	25	50	100	100	140
EMPHASIS	CCIR	—	OPT	OPT	OPT	OPT	OPT	OPT	STD	STD	STD	STD	STD	STD	STD	STD	STD	OPT	STD	STD	STD	STD	STD	STD	STD	STD
	FLAT FM	—	STD	STD	STD	STD	STD	STD	OPT	OPT	OPT	OPT	OPT	OPT	OPT	OPT	OPT	STD	OPT	OPT	OPT	OPT	OPT	OPT	OPT	OPT
RECEIVER THRESHOLD (30dB S/N flat wtd. @ receiver port with std. emphasis)		—dBm	93.6	88.3	83.9	93.0	88.2	83.0	90.3	81.0	90.4	87.4	82.9	85.2	83.9	79.8	80.5	92.1	90.0	91.5	93.5	84.4	89.4	90.4	86.7	83.1

with members of the Frequency Assignment Subcommittee (FAS) of the IRAC to identify potential frequency conflicts with existing stations. For the majority of cases, sufficient distance and/or frequency separation is available to existing stations to clearly indicate compatible operation. In other cases, the compatibility issue is not as clear. In general, a standard approach to identifying frequency conflicts among various classes of stations is not followed. Due to time considerations and lack of adequate data, worst-case assumptions which are often applied, lead to inefficient spectrum management. For example, an agency may maintain a minimum distance separation of 150 miles between cochannel fixed assignments regardless of equipment characteristics, antenna orientation, etc. Such a practice would typically prevent interference (except for very high site elevations) but would be overly conservative in many cases.

For coordination among fixed microwave systems employing FDM/FM, the EIA in its Bulletin 10-C [EIA, 1976] has developed a detailed coordination procedure based on recognized techniques. This procedure is described in the CCIR and elsewhere (for example [Panter, 1972]). Bulletin 10-C provides techniques for calculating carrier-to-interference ratios for acceptable performance of a link based on a given level of interference power in a single voice channel. Although based on somewhat conservative protection criteria, EIA procedures are recognized and used throughout much of the microwave industry.

It would appear to be in the interest of good spectrum management to recognize the EIA procedures given in Bulletin 10-C as a standardized approach in resolving frequency conflicts among fixed microwave links using FDM/FM modulation. A proposed statement to this effect for inclusion into the NTIA Manual is given below:

> 8.2.46 Frequency Coordination Among Fixed Microwave Systems Using FDM/FM
>
> Conflicts occasionally arise over the use of a radio frequency which involves fixed microwave links using FDM/FM modulation. For such cases, it is desirable to employ a standard procedure for identifying the conflicts in a manner that is both spectrally efficient and provides the degree of interference protection necessary. The procedures described by EIA's Bulletin 10-C are widely recognized by the microwave industry and should be used by Federal agencies to the extent possible.

Adoption of a standardized coordination procedure for other types of fixed and/or mobile stations is a more complex issue and is beyond the scope of this report. Special consideration required for space and spread spectrum systems is given in Sections 5 and 6, respectively, of this report.

A preliminary fixed microwave interference automated model has been developed as part of this study. The model can be used as both an engineering aid for analysis purposes as well as an assignment tool by frequency managers. The model in its present form is simply an automated version of the interference criteria developed by the EIA in Bulletin 10-C (1976). As such, it is limited to evaluation of interactions among FDM/FM fixed links only. Future effort may expand the model to include other types of systems.

The model selects environmental systems from the GMF based on frequency band (currently limited to 1710-1850 MHz, but expandable to other bands) and distance culls (typically 200 km). Data on proposed links are entered via computer terminal and include only parameters currently required for frequency assignment on Form NTIA-19A. The model examines interactions involving environmental transmitters to new proposed receivers as well as new proposed transmitters to environmental receivers. The carrier-to-interference (C/I) ratio is computed at each receiver using link parameters, free space propagation loss, and CCIR (1978) antenna gain patterns. The computed C/I values are compared against tabulated C/I threshold values based on EIA noise performance criteria. Since certain parameters required by the EIA procedure are not available from the GMF, assumptions are incorporated into the model. These include channel loading, emphasis/de-emphasis, frequency tolerance, and receiver selectivity. Although the assumptions are conservative (i.e., worst-case), the model provides a significant cull of potential interference interactions. The links that fail the cull, that is, the computed C/I is less than the tabulated threshold values, can be examined manually by considering terrain dependent propagation loss (both short and long-term), actual antenna gain patterns, receiver selectivity, operational signal-to-noise and interference requirements, etc.

The model will accept multiple proposed links so that frequency managers can examine the suitability of alternative sites, and/or frequency schemes. If a channel plan is adopted for this band, such as that proposed previously herein, the model could be expanded into a frequency assignment model as an aid for frequency managers in choosing optimum frequencies.

Appendix A discusses the model in more detail giving input parameters and operating information.

SECTION 5

SPACE SYSTEMS

In the NTIA Manual, Government footnote 42 of the National Table of Frequency Allocations, provides for certain space functions in the 1710-1850 MHz band as follows:

> 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.

This footnote accommodates the Air Force Space Ground Link Subsystem (SGLS) which employs up-paths in this band and down-paths in the 2200-2290 MHz band. This system is used to provide tracking, telemetry and command services to a wide variety of geostationary and non-geostationary military satellites.

At present, the SGLS and related test systems are the only space assignments in the 1710-1850 MHz band. The DoD/NASA Space Shuttle vehicle includes an SGLS compatible transmitter/receiver and is considered a part of the overall SGLS system.

In this section, two subjects will be addressed; the characteristics and operation of the SGLS and the compatibility/coordination requirements with terrestrial systems.

SGLS CHARACTERISTICS AND OPERATION

Satellite Control Facility (SCF) stations are located at four sites within the United States and Possessions with nominal characteristics as given in TABLES 5-1 and 5-2. The SGLS processes various combinations of up-path data to develop the baseband components and modulation indices required in the RF up-path to the SGLS-instrumented spacecraft. The generalized composite up-path spectrum is shown in Figure 5-1. TABLE 5-3 provides a typical up-path link analysis.

SGLS COMPATIBILITY AND COORDINATION

Terrestrial Transmitter to Space Receiver

Using the nominal system parameters as well as geometric considerations, the worst signal-to-interference (S/I) ratio at the SGLS space station can be calculated as follows.

$$S/I = (P_S + G_S) - (P_I + G_I) - 20 \log (D_S/D_I) \qquad (1)$$

where

P_S, P_I = Desired, undesired transmitter power in dBm

TABLE 5-1

SGLS NOMINAL UP-PATH CHARACTERISTICS

Transmitter Power	Variable to 10kW, maximum. Operation is normally confined to power levels ≤ 1 kW
Frequency	Twenty pre-set channels (see TABLE 5-2).
Frequency Accuracy	±0.002%
Spurious Outputs	-40 dB @ ±8 MHz -45 dB @ ±8 to ±50 MHz -50 dB @ > ±50 MHz
Modulation (command)	Keyed tones of 65, 76, & 95 kHz switched at 1 or 2 kb/s rate. Modulation index - 0.3 or 1.0.
(command sync)	Amplitude modulation of the command tones with triangular waveform. Bit rate - 0.5 or 1.0 kb/s Modulation index - 0.5
(ranging)	Direct sequence pseudo random noise modulation at 1 MHz rate. Modulation index - 0.125 or 0.3
Antenna Size	14 meters
Gain	42.7 dBi
Polarization	RHCP
Minimum Elevation	5 degrees
Spacecraft Gain	0 dBi Typical
Line Losses	6 dB Typical
Sensitivity	-113.8 dBm Commanding -105.4 dBm Carrier Sensing -105.4 dBm Ranging
Distribution of Power	Carrier 87% (-0.6 dB) Command 4% (-14.0 dB) Ranging 9% (-10.8 dB)

TABLE 5-2

SGLS RF Frequencies

SGLS CHANNEL	UPLINK TRANSMISSION FREQUENCY	DOWNLINK RECEPTION FREQUENCIES CARRIER I	CARRIER II
1	1763.721 MHz	2202.500 MHz	2197.500 MHz*
2	1767.725 MHz	2207.500 MHz	2202.500 MHz
3	1771.729 MHz	2212.500 MHz	2207.500 MHz
4	1775.733 MHz	2217.500 MHz	2212.500 MHz
5	1779.736 MHz	2222.500 MHz	2217.500 MHz
6	1783.740 MHz	2227.500 MHz	2222.500 MHz
7	1787.744 MHz	2232.500 MHz	2227.500 MHz
8	1791.748 MHz	2237.500 MHz	2232.500 MHz
9	1795.752 MHz	2242.500 MHz	2237.500 MHz
10	1799.756 MHz	2247.500 MHz	2242.500 MHz
11	1803.760 MHz	2252.500 MHz	2247.500 MHz
12	1007.764 MHz	2257.500 MHz	2252.500 MHz
13	1181.768 MHz	2262.500 MHz	2257.500 MHz
14	1815.772 MHz	2267.500 MHz	2262.500 MHz
15	1819.775 MHz	2272.500 MHz	2267.500 MHz
16	1823.779 MHz	2277.500 MHz	2272.500 MHz
17	1827.783 MHz	2282.500 MHz	2277.500 MHz
18	1831.787 MHz	2287.500 MHz	2282.500 MHz
19	1835.791 MHz	2292.500 MHz*	2287.500 MHz
20	1839.795 MHz	2297.500 MHz*	2292.500 MHz*
21	Frequency synthesizer providing continuous tuneability for downlink signals having frequencies ranging from 2202.5 MHz to 2292.5 MHz.		

* Frequencies not authorized in Table of Allocations.

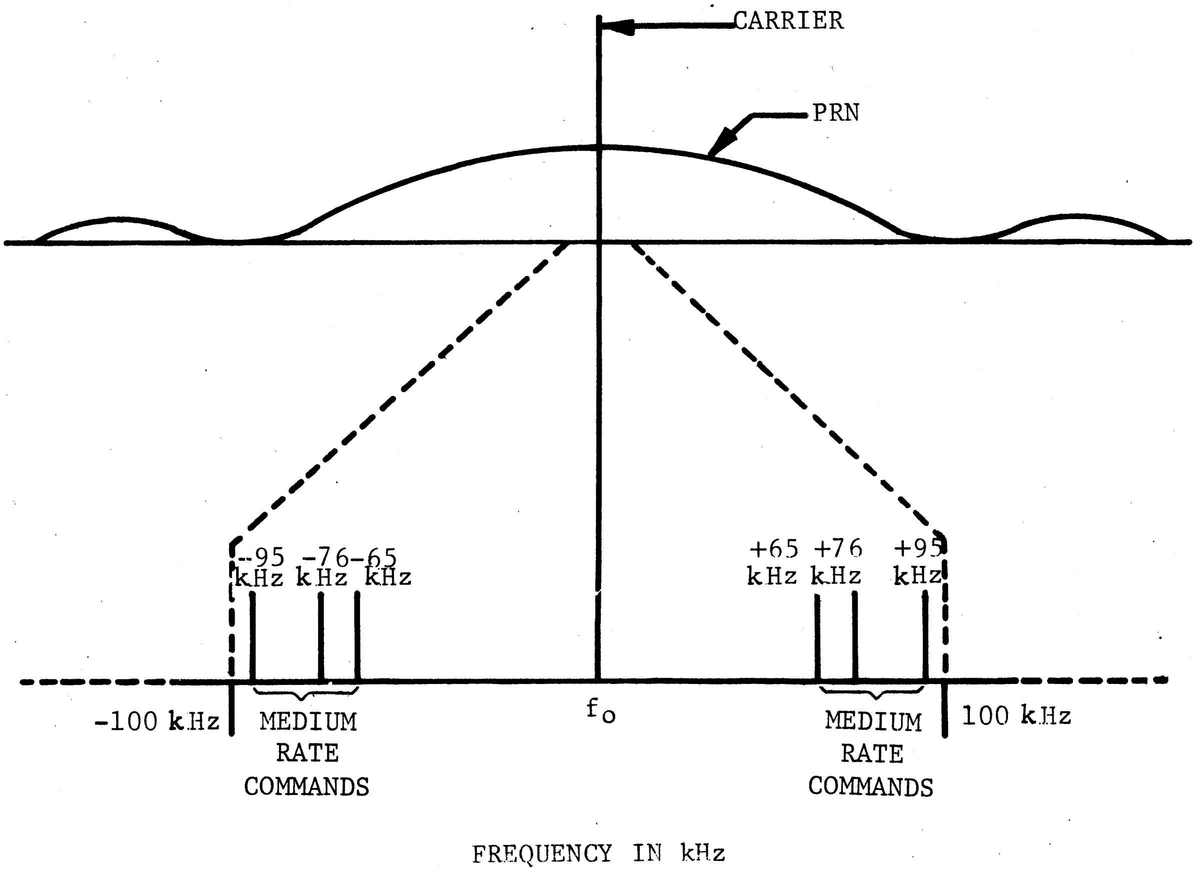


Figure 5-1. Typical Up-Path Carrier Spectrum

TABLE 5-3

TYPICAL RF UP-PATH ANALYSIS

Transmitter Power (1 kW)	+ 60 dBm
Ground Antenna Gain (14 m. antenna)	+ 42 dBi
Space Loss (' 2650 kms, 5 degrees Elevation)	-166.3 dB
Polarization Loss (RHCP)	0.0 dB
Atmospheric Attenuation	- 1.0 dB
Spacecraft Antenna Gain	0.0 dBi
Spacecraft Line Loss	- 6.0 dB
Total Spacecraft Received Power	- 70.6 dBM

Individual Service Power Service	Commanding	Carrier	Ranging
Modulation Index	0.3	N/A	0.3
Service/Total Power	- 14.0 dB	- 0.6 dB	- 10.8 dB
Net Service Power	- 84.6 dBm	- 71.2 dBm	- 81.4 dBm
Receiver Sensitivity by Service			
Required Min Service Power:	-113.8 dBm	-105.4 dBm	-105.4 dBm
Service Margin	29.3 dB	34.2 dB	24.0 dB
Receiver Noise Level	unk	unk	-105 dBm/1 MHz

G_S = Desired transmitter antenna gain in dBi

G_I = Undesired transmitter antenna gain in the direction of the satellite in dBi

D_S, D_I = Desired, undesired distance separation to the satellite in kilometers.

From an interference standpoint, fixed links represent the worst-case interference because of the typically higher EIRP involved. A tropospheric scatter link may have an EIRP on the order of 110 dBm; a line-of-sight fixed link will have an EIRP of 60-80 dBm and a mobile system may have an EIRP on the order of 50 dBm.

Since a troposcatter link may have an EIRP of a similar magnitude as the SGLS transmitter, it is simple to show that under certain geometric relationships the S/I at the satellite can be equal to or less than 0 dB for cochannel tuning; this would be clearly unacceptable. Thus coordination of any new proposed troposcatter links must be undertaken to assure compatibility with SGLS space transponders. Development of such a coordination procedure is beyond the scope of this report.

For line-of-sight microwave links, various possible interfering geometrics are shown in Figure 5-2. In TABLE 5-4, computed S/I values are given for these various conditions. For those calculations the microwave antennas were assumed to be aligned to 0 degrees elevation, employing 80 dBm EIRP (47 dBm of power and 33 dBi gain), and an off axis antenna gain (G) pattern as described by the following equation:

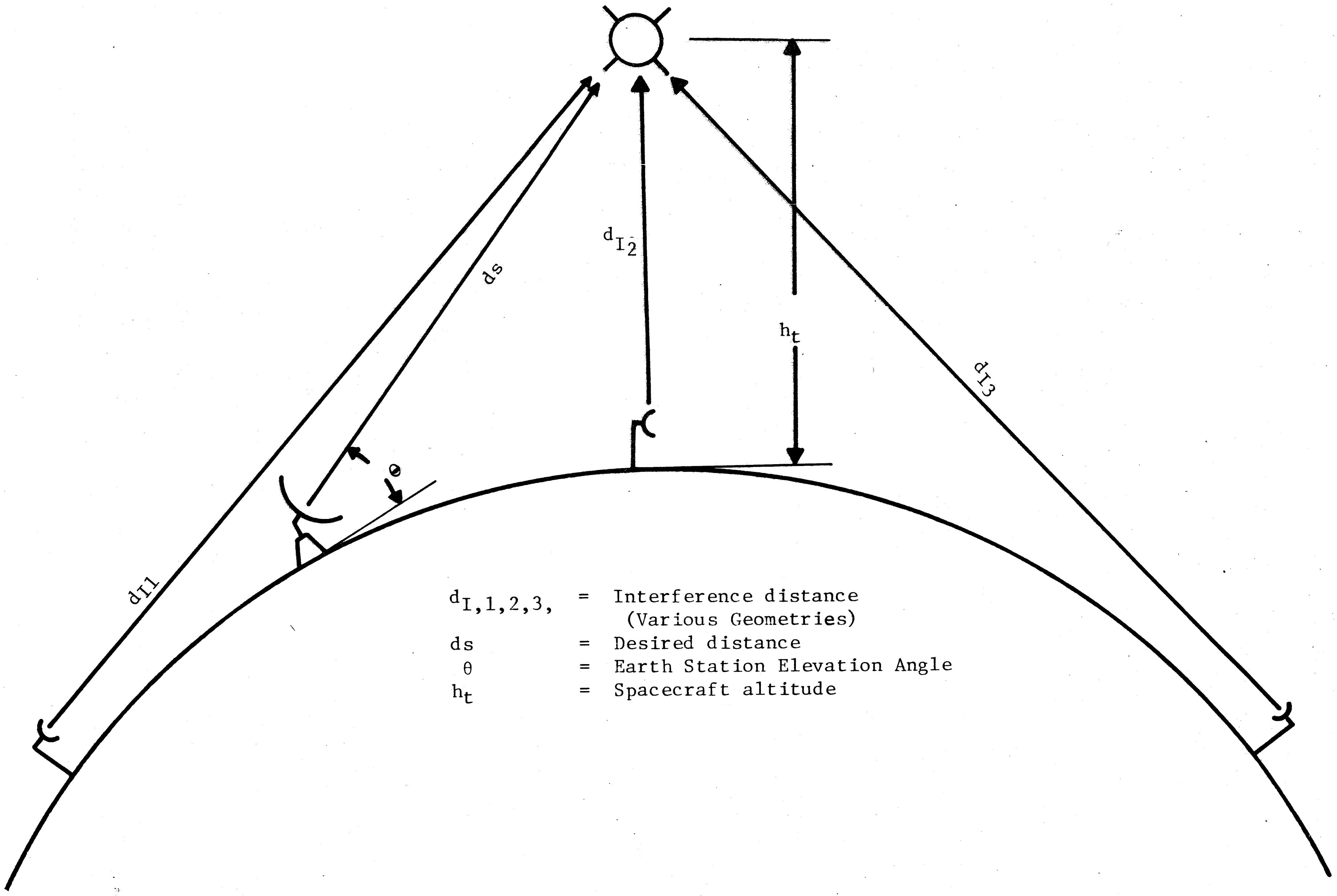
$$\begin{aligned} G(\text{dBi}) &= 38 && \text{for} \quad 0^\circ \leq \theta < 1.8^\circ \\ G(\text{dBi}) &= 38 - 20 \log \theta && \text{for} \quad 1.8^\circ \leq \theta < 33^\circ \\ G(\text{dBi}) &= 0 && \text{for} \quad 33^\circ \leq \theta < 180^\circ \end{aligned} \tag{2}$$

It is easily seen from Figure 5-2, that the interfering power level does not depend on the proximity of the terrestrial and earth station transmitters, but rather on the distance DI and the off-axis gain of the terrestrial transmitter antenna. Thus a terrestrial transmitter located thousands of miles from the earth station could result in the same received levels as one located immediately adjacent.

For the calculations in TABLE 5-4 two extreme situations were assumed; maximum terrestrial antenna gain and minimum interfering distance represented by paths DI_1, and DI_2 respectively, on Figure 5-2. Refraction effects of the atmosphere were not considered in these calculations.

TABLE 5-4 shows that the worst case (lowest) expected C/I ratio for this interaction is 23 dB. By examining, individually, the three up-path functions, i.e., commanding, carrier sensing, and ranging, it can be shown that no degradation to the SGLS up-path is expected.

First, consider the ranging signal. As given in TABLE 5-1 the ranging signal comprises only nine percent (-10.8 dB) of the total uplink power. The effective C/I considering only the ranging signal is then reduced from 23 dB to 12 dB. Because of the processing gain provided by the pseudo-random coding, the



$d_{I,1,2,3,}$ = Interference distance (Various Geometries)
d_s = Desired distance
θ = Earth Station Elevation Angle
h_t = Spacecraft altitude

Figure 5-2. Geometry of SGLS Interference

TABLE 5-4

Calculated C/I Ratios for SGLS Receiver

EARTH STATION ELEVATION ANGLE	SATELLITE ALTITUDE = 161 KILOMETERS		SATELLITE ALTITUDE = 36,500 KILOMETERS	
	MINIMUM DISTANCE	MAXIMUM ANT. GAIN	MINIMUM DISTANCE	MAXIMUM ANT. GAIN
5	C/I = 37.7 dB	C/I = 22.7 dB	C/I = 54.3 dB	C/I = 22.7 dB
90	= 55.7	= 40.7	= 55.7	= 24.1

ranging signal can function satisfactorily with a signal-to-noise ratio of 0 dB as indicated by the parameters given in TABLE 5-1. Since interference will appear as additional noise in the receiver due to the spreading effect of PRN processing (even an unmodulated carrier will appear as broadband noise after processing), the available C/I will be more than adequate to preclude degradation.

Interference to the carrier sensing function of the SGLS is likewise not expected. Since the carrier of the SGLS signal comprises 87 percent (-0.6 dB) of the total up-path signal, the worst-case C/I would be 23 - 0.6 = 22.4 dB. This level is expected to be sufficient to protect this function. This is especially true if the channel plan proposed in Section 4 is followed, since the interfering carriers would be sufficiently removed from the SGLS carrier frequencies.

Finally, consider the command function. The command signal comprises only four percent of the total up-link power so that the resulting worst case C/I for this function would be 23 - 14 = 9 dB. Again it is observed that if the channel plan proposed in Section 4 is adopted, sufficient frequency separation is present to avoid any interactions between the interfering carriers and the command tones. The minimum separation under these conditiions would be at least twice the maximum baseband frequency (95 kHz) of the SGLS command signal. The specific C/I value for acceptable performance has not been determined for this study. In interactions between frequency-modulated signals, significant problems are typically avoided when interfering signals within the desired signal baseband are avoided. For this reason compatible operation is expected.

Thus, if the channel plan for the proposed Fixed and Mobile Stations is adopted, compatible operation is expected. Without the channel plan, the interfering carrier could conceivably fall on one of the command tone frequencies. For such cases, the worst-case C/I of 9 dB may result in marginal performance. These worst case conditions are very low probability events. For example, no fixed (line-of-sight) station assigned in the band uses the maximum permitted value of 80 dBm EIRP, with 60-70 dBm being typical. Worst-case antenna assignments for both SGLS and fixed stations were also used in the calculations. If these conditions do occur, the SGLS has up to 10 dB more power (10 kW) available which is more than adequate to assure satisfactory service.

Earth Station Transmitter to Terrestrial Receiver

Because of the high power, high antenna gain, and multiple channel operation of the SGLS, an obvious potential exists for interference to terrestrial receivers located near the sites. However, it must not be assumed that the SGLS transmitters completely "sterilize" the environment around the sites for all other users of the 1710-1850 MHz band. The following shows that with adequate coordination and site engineering, other users can be accommodated in the vicinity of the earth stations.

In TABLE 5-2, the channel plan used by the SGLS is given. Under existing rules and regulations, terrestrial systems do not employ a channel plan and can use any frequency in the band. Analysis of such interactions would be somewhat complex and must be accomplished on a case-by-case basis which is beyond the scope of this report. If, however, the channel plan proposed in Section 4 of this report is adopted, the analysis and coordination of such interactions is greatly simplified since the two channel plans can be compared and conflicts more easily identified.

TABLE 5-5

C/I PROTECTION RATIOS IN dB FOR SGLS TO FIXED MICROWAVE INTERFERENCE

FIXED RECEIVER FREQUENCY (MHz)	MAX. BW (MHz)	NUMBER OF CHANNELS					
		24	48	96	120	300	600
1725	10				-18	-18	-18
1730	5				-10		
1735	10				- 6	- 6	- 6
1740	5				3		
1745	10				14	14	14
1750	5				28		
1755	10				44	44	44
Note (1)							
1800.5	1	50	50				
1801	2		50	50			
1801.5	1	50	50				
1802	2		50	50			
1802.5	1	50	50				
1803	2		50	50			
1803.5	1	50	*64				
1804	2		50	50			
1804.5	1	50	50				
1805	2		50	50			
1805.5	1	50	50				
1806	2		50	50			
1806.5	1	50	50				
1807	2		50	50			
1807.5	1	50	*64				
1808.5	2		50	50			
1808.5	1	50	50				
1809	2		50	50			
1809.5	1	50	50				
1815	10				*65	*66	*71
1820	5				*57		
1825	10				50	*70	*75
1830	5				50		
1835	10				50	*66	*71
1840	5				*53		
1845	10				50	50	50

Note 1: Frequency use between 1760 and 1800 MHz is not considered in this table.

Note 2: Values indicated with an asterisk are possible interactions involving carrier beat.

* = Interactions involving carrier beat

First consider interactions between the SGLS earth station transmitters and fixed microwave receivers. The protection criteria necessary to assure interference free operation of the microwave receivers can be derived from previously discussed procedures given in Section 4. It has been shown that interference to microwave receivers can result from three mechanisms: carrier beat, sideband beat, and receiver desensitization. The carrier beat and receiver desensitization are not functions of the interfering modulation waveform and can be treated in the same manner as discussed in Section 4 and Appendix A. The criteria for sideband beat interference is more difficult to establish but can be derived from equations provided in EIA [1976].

Evaluation of those equations using the emission spectrum shown in Figure 5-1 for the SGLS and typical fixed microwave spectrums given by the EIA [1976], shows that in all cases of interest either the carrier beat or receiver desensitization criteria dominates.

Recognizing this, it is possible to construct a table of the required C/I protection criteria for SGLS to fixed microwave receiver interactions for each of the individual channels in the previously proposed channel plan. TABLE 5-5 shows the calculated criteria for the various channels and typical channel capacities for the microwave links based on the above criteria.

It is observed from TABLE 5-5 that, due to the available frequency separation, the lower frequencies can be shared (i.e., lower required C/I ratios) much more easily than the higher frequencies which are cochannel or adjacent channel. Thus a strategy for more effective sharing between the SGLS and fixed microwave receivers would be as follows:

a. Terrestrial links should follow the channel plan identified in Section 4.

b. Avoid the use of those channels which result in carrier beat interactions (indicated with an asterisk on TABLE 5-5) to the extent possible.

c. In a given microwave link (two-way), the receiver antenna which is aimed toward the SGLS site should use the lowest frequency possible.

Following these practices, a sample calculation can be made to illustrate the degree of compatibility as follows:

$$C/I = P_d + G_{dt} + G_{dr} - L_d - (P_i + G_{it} - G_{ir} - L_i) \tag{3}$$

where

C/I = required C/I protection ratio assumed to be 50 dB

P_d, = Desired transmitter power in dBm assumed to be 5 watts (37 dBm)

G_{dt} = Desired transmitter antenna gain in dBi assumed to be 28 dBi

G_{dr} = Desired receiver antenna gain in dBi assumed to be 28 dBi

L_d = Desired path propagation loss in dB calculated to be 130 dB (for 1800 MHz and 25 miles separation assumption)

P_i = Interfering transmitter power equal to 70 dBm (10 kW maximum)

G_{it} = Interfering transmitter antenna gain equal to 15 dBi worst case (based on five degree minimum elevation)

G_{ir} = Receiver antenna gain in the direction of the interfering transmitter in dBi

= assumed to be 0 dBi (discrimination angle greater than 33 degrees)

L_i = Interfering path propagation loss in dB

Substitution of the assumed values yields

$$50 = (37 + 28 + 28 - 130) - (70 + 15 + 0 - L_i)$$

$$L_i = 172 \text{ dB}$$

For typical terrain and antenna heights, this amount of propagation loss can be achieved with a distance separation of approximately 65 km (40 miles).

While any proposed assignment for a microwave link in the vicinity of the SGLS earth station must be evaluated on a case-by-case basis, the above example indicates that relatively small distance separations are required relative to the established coordination contours [NTIA, 1980].

SECTION 6

PACKET RADIO

Packet Radio is a system developed by the Defense Advanced Research Projects Agency (DARPA) as a test-bed for various packet switching communication studies. Packet switching is a technology that was developed for digital networks of point-to-point communication links. Common carrier telephone networks were designed for voice traffic and are not ideally suited for digital data transmission, especially computer originated. Packet switching, on the other hand, is a natural mode of communication for computers. Computer generated traffic is characterized by a very low duty cycle in which a short burst of data is sent or received followed by a longer quiescent interval after which additional traffic will again be present. With this low duty cycle, multiple users could time share a single communications channel efficiently. Packet Radio extends this packet switching technology to the domain of radio communications. Packet Radio employs a communications architecture whereby a number of geographically distributed users can communicate among themselves by packets of digital information. The basic structure consists of randomly distributed mobile user terminals and one or more central stations (usually fixed). The functions of a central station are associated with management of the radio net. The central station determines the route to each of the radios in the net and plays an active role in initializing, organizing, and maintaining the operational network. Using a common wideband channel and spread spectrum multiple access techniques, the system attempts to demonstrate an overall increase in spectrum efficiency as well as end-to-end survivability of information. The Packet Radio concept and its capabilities are still primarily in the research stage, but significant progress has already been achieved in the development of three systems: the Experimental Packet Radio (EPR), the Improved Packet Radio (IPR), and the Upgraded Packet Radio (UPR). Another system, the Low Cost Packet Radio (LCPR), is in the planning stage.

The EPR system has been under experimentation since 1975 using a 20 MHz portion of the 1710-1850 MHz band. The EPR has been approved by the IRAC for experimental operation at six locations in the U.S. These locations are: San Francisco, Los Angeles and San Diego, CA, Washington, D.C., Boston, MA and Dallas, TX. Presently there are 28 EPR sets located a Fort Bragg, N.C. with a few at Rockwell International in Dallas, TX for maintenance. The testing of the EPR primarily concerns the implementation of the various concepts incorporated into this radio. The problems of maintaining connectivity of a mobile packet-switched spread spectrum system have been overcome. In the 1979-1980 time frame, experiments were made at Fort Bragg (18th Airborne Corps) in a fixed mode where the concept of using the EPR for various military computer based equipment was investigated. In the 1980-1982 time frame (fall 1980 initially) mobile operation in a tactical environment will be studied. The EPR will be deployed on jeeps and rotary-wing aircraft.

The IPR is identical to the EPR but with a different processor. There are 27 IPR sets deployed at Stanford Research Institute in the San Francisco Bay area. The station portion of the radio net is under development here. Since the radio portions of the IPR and EPR are identical, both systems will be identified, henceforth, in this report as the EPR.

A more recent development is the UPR. The UPR is a spread spectrum system utilizing the entire 1710-1850 MHz band (i.e., 140 MHz bandwidth) and differs from the EPR design only by its enhanced electronic-counter counter-measures (ECCM), low probability of intercept and position location capabilities for tactical environments. Presently, there are three UPR sets located at the Rockwell plant in Dallas where the several ECCM techniques are undergoing tests. The UPR was not listed in the GMF during this study, but spectrum support for experimental operation (stage 2) was recommended by the Spectrum Planning Subcommittee (SPS) of the IRAC with certain conditions. These conditions include, among others:

1. No aeronautical mobile operation except in support of coordinated tests.

2. Prior to stage 3 operation application, DoD in consultation with NTIA, as required, undertake a test program to more completely define the EMC aspects of introducing this spread spectrum system into the band.

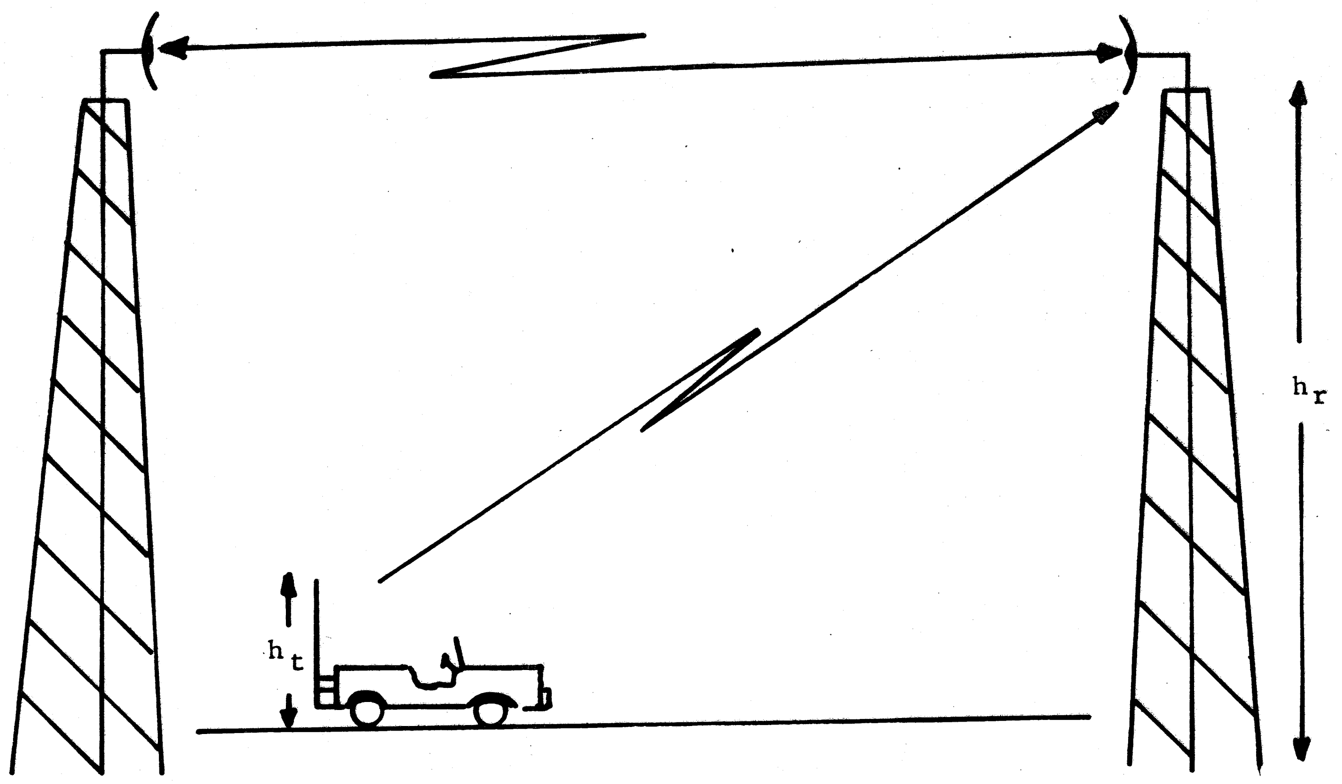
3. Any request for spectrum support for aeronautical mobile operations, identified during stage 3, be supported with an analysis and test data demonstrating that compatibility can be achieved with other agency operations.

There are no plans at present to deploy the UPR elsewhere or in an airborne configuration.

The LCPR is a proposed spread spectrum system utilizing a 20 MHz bandwidth and some ECCM techniques developed by the UPR tests. It will be smaller (0.0033 cubic meters (200 cu.in.) as opposed to 0.028 cubic meters (1 cu. ft.) for the EPR and 0.085 cubic meters (3 cu. ft.) for the UPR) and less expensive than the other systems. As stated before, this radio is still in the design stage but the planned deployment for experimentation involves both airborne and strategic C^3 reconstruction. To date, no spectrum support from the SPS for the planning stage (stage 1) has been requested for the LCPR.

PACKET RADIO EMC

The Packet Radio systems because of their spread spectrum operation should be able to tolerate other users in the 1710-1850 MHz band, although their impact on these other users, especially the fixed point-to-point microwave equipment, has been identified as a potential problem area. In an effort to assess the impact of the potential interference of these Packet Radio systems, two theoretical EMC analyses have been completed: one for the EPR [Newhouse, 1977] and one for the UPR [Crandall, 1980]. Both analyses assumed a land mobile deployment for the Packet Radio transmitters (Figure 6-1) and were performed following a procedure developed for analyzing interference caused by spread spectrum signals [Newhouse, 1978]. A summary of salient procedures and results of each study is presented next.



h_t = Packet Radio Transmitting Antenna Height
h_r = Victim Receiver Antenna Height

Figure 6-1. Configuration of the Packet Radio Assumed in the EMC Analyses

Experimental Packet Radio

A preliminary EMC analysis was performed to evaluate the impact of the EPR transmitter on typical receiving systems in the 1710-1850 MHz band in five initial locations the EPR was to operate experimentally. The measure of compatibility employed was the level of the Interference-to-Noise ratio (INR) at the IF amplifier output of the victim receiver. The distance separation that yielded an INR equal to a predetermined threshold value was presented for the following conditions: two propagation paths (smooth-earth and cluttered), three transmitter-receiver antenna couplings (main-beam, side-lobe, and back-lobe) and cochannel and adjacent channel operation considered for each of the four representative receiving systems. The EPR transmitter characteristics used for this analysis are listed in TABLE 6-1 and the representative microwave receiver technical characteristics are listed in TABLE 6-2. The threshold peak INR was determined to be equal to 10 dB for the first three receivers listed in TABLE 6-2 and -6 dB for the last. The resulting required distance separations between the EPR and the victim receivers are shown in TABLE 6-3. The results presented in TABLE 6-3 included only those for smooth-earth paths.

Upgraded Packet Radio

An identical procedure was employed for the EMC study of the UPR's impact on the existing environment. This study addressed the parameter difference between the EPR and UPR (i.e., emission bandwidth, chip rate, packet length, and duty cycle). Instead of considering specific locations (as done for the EPR study), a more general environment was addressed. The UPR was identified as a potential source of interference to tactical radio relay links, air-to-ground video links, ACMI/ACMR receivers and meteorological satellite downlink receivers as well as the fixed microwave links. The required distance separations were calculated for various antenna height combinations as well as for three antenna couplings. Smooth-earth propagation paths that are clear of obstacles were assumed. Since the UPR uses the entire 1710-1850 MHz band, only cochannel operation was considered for the victim receivers. Adjacent channel operation was considered for the meteorological satellite downlink receiver which operates in the 1690-1710 MHz band. Since the duty cycle of the UPR system is variable, results are presented for the two extreme values in order to bracket the required distance separations for all cases. The UPR transmitter characteristics shown in TABLE 6-4 and the victim receivers characteristics shown in TABLE 6-5 were used. The threshold INR was determined to be -6 dB for all of the victim receivers in this study. The resultant required distance separations between the UPR transmitter and the five receivers are shown in TABLE 6-6. The results presented here were condensed from those presented in the UPR report to include just the two antenna height combinations that represented the range of distance separations. Similar results were obtained by another approach [Matos, 1980] to determine relative compatibility of the UPR to its environment. The interference criteria used for this approach was based on a permissible interference power level of -130.8 dBW in a 4 kHz reference bandwidth for analog receivers and -104.9 dBW in a 1 MHz reference bandwidth for digital. The results from Matos' application required distance separation on the order of 50 to 70 kilometers. Under some terrain conditions, sharing may be feasible at distances of 6 kilometers.

TABLE 6-1

EPR TRANSMITTER PARAMETERS USED FOR THE EMC ANALYSIS

FREQUENCY (Tunable)	1710-1850 MHz
POWER	10 watts
CHIP RATE	20 Mchips/sec
TYPE OF MODULATION	MSK differentially coherent spread spectrum
PACKET LENGTH	1 ms
PACKET SPACING	100 ms
DUTY CYCLE	1 percent
RF BANDPASS 3 dB BANDWIDTH	40 MHz
ANTENNA GAIN	9 dBi (omni-directionally)
ANTENNA HEIGHT	3 meters

TABLE 6-2

PARAMETERS OF VICTIM RECEIVERS USED IN EPR ANALYSIS

Nomenclature	IF Bandwidth (MHz)	Noise Figure (dB)	Antenna Gain (dBi)
AN/GRC-50	3	17	17 (mainbeam) 10 (sidelobe) 0 (backlobe)
WESCOM 200	1.6	9	25 (mainbeam)[a] 10 (sidelobe) 0 (backlobe)
Farinon Electric SS2200	4	11	25 (mainbeam)[a] 10 (sidelobe) 0 (backlobe)
Microwave TV Link	25	10	25 (mainbeam)[a] 10 (sidelobe) 0 (backlobe)

---

[a] Radiation pattern assumed to be similar to Andrew Corporation, Type P4-19 antenna (1.2 meters dish, 1.7 to 1.85 GHz).
sidelobe based on 9 off of mainbeam
backlobe based on 30 off of mainbeam
receiver antenna height = 30 meters

[b] Assumed value.

TABLE 6-3

REQUIRED DISTANCE SEPARATIONS IN KILOMETERS BETWEEN EPR TRANSMITTER AND THE VICTIM RECEIVERS (1% DUTY CYCLE)[1]

Victim Receiver	Antenna Coupling			Degree of Off-Tuning (ΔF)
	Mainbeam	Sidelobe[2]	Backlobe[3]	
AN/GRC-50	21.5 kms 10	17.5 kms 7	11.5 kms 4	< 5 MHz 15 MHz
WESCOM 200	34 19	22 10.5	16 6.5	< 5 MHz 15 MHz
Farinon Electric SS2000	32 18	20.9 10	14.5 6	< 5 MHz 15 MHz
MICROWAVE TV Link	40.5 25	31.5 15.5	23.5 10	0 20 MHz

[1] Based on smooth-earth propagation path.

[2] Based on 9° off of mainbeam.

[3] Based on 30° off of mainbeam.

TABLE 6-4

UPGRADED PACKET RADIO TRANSMITTER TECHNICAL CHARACTERISTICS

FREQUENCY RANGE	1710-1850 MHz
CENTER FREQUENCY (FIXED)	1780 MHz
EMISSION TYPE	M140F9 (140 MHz at 99.5% POWER)
TYPE OF MODULATION	Direct Sequence Spread Spectrum with Minimum-Shift Keying (MSK)
SPREAD SPECTRUM SIGNAL BANDWIDTH	92.5 MHz
POWER	0.001 to 10 Watts (10 Watts used for this analysis)
CHIP RATE	92.5 MHz
INFORMATION RATE	90 kbps or 360 kbps
PACKET LENGTH	0.7 to 40 ms (10 ms typical)
DUTY CYCLE	1% to 90%
ANTENNA GAIN	9 dBi (Omnidirectional in Azimuth)
ANTENNA HEIGHT	3 m and 46 m (for this analysis)

TABLE 6-5

PARAMETERS OF THE VICTIM RECEIVERS USED IN THE UPR ANALYSIS

TYPE OF SERVICE	REPRESENTATIVE EQUIPMENT	IF BANDWIDTH B_R (MHZ)	NOISE FIGURE F_R (dB)	ANTENNA GAIN(1) G (dBi)
POINT-TO POINT FIXED	GTE LENKURT 779 F1	22	8	28.7 0 -15.3
RADIO RELAY	AN/GRC-50	1.2	9	19 0 (2) -10 (2)
AIR-TO-GROUND VIDEO	REMOTELY PILOTED VEHICLE	12	9 (2)	31.2 0 (3) -10 (3)
ACMI/ACMR	ACMI	1.5	9 (2)	26 -1 (3) -8 (3)
METEOROLOGICAL SATELLITE	TIROS-N	1.5-20	1.4	47 -10 -10

(1) - Antenna Gains are Listed in the Order of Main-Beam, Sidelobe (90 degrees off boresight), and Backlobe Gains

(2) - Assumed

(3) - Obtained from typical antenna Radiation Pattern Envelopes

TABLE 6-6

REQUIRED DISTANCE SEPARATIONS IN KILOMETERS BETWEEN UPR TRANSMITTER AND THE VICTIM RECEIVER

VICTIM RECEIVER	$h_T = 3$ m $h_R = 46$ m		$h_T = 46$ m $h_R = 137$ m		ANTENNA COUPLING
	1% Duty Cycle	90% Duty Cycle	1% Duty Cycle	90% Duty Cycle	
POINT-TO-POINT FIXED	32.5 kms	51.5 kms	76 kms	95 kms	mainbeam
	12	25	34	68	sidelobe
	5.6	14.5	7.5	51.5	backlobe
RADIO RELAY	23.5	40.5	66	84.5	mainbeam
	11.5	24	31	67	sidelobe
	7.5	17	11.5	58	backlobe
AIR-TO-GROUND VIDEO	33	52.3	77.5	95	mainbeam
	11.5	24	31	67	sidelobe
	7.5	17	11.5	58	backlobe
ACMI/ACMR	29	47	72.5	92	mainbeam
	10.5	23.5	27.5	66	sidelobe
	8	19.5	14	59.5	backlobe
METEOROLOGICAL SATELLITE	----	----	----	----	mainbeam
	0.8	5.6	0.8	5.6	sidelobe
	0.8	5.6	0.8	5.6	backlobe

Summary

The conclusion of these analyses is that there is a sharing problem between the operation of the Packet Radio systems and the existing environment in the 1710-1850 MHz band. This problem can be minimized or eliminated by the provision of protected areas around the identified receiver sites which are determined by the required distance separations given in TABLES 6-3 and 6-6. Significant reduction of the required distance separations can be accomplished by frequency separation for the EPR as shown in TABLE 6-3. Frequency separation is not possible with the UPR in the 1710-1850 MHz environment. Avoiding mainbeam antenna couplings can also reduce the required distance separation as can be seen on both tables. These protected areas, are considered conservative due to the various worst-case assumptions made in these analyses. A measurement program to determine the effect of the Packet Radio systems on the identified receivers, especially the fixed microwave links, should be accomplished. Measurement results not only would determine a better criteria for the implementation of the Packet Radio into its intended environment, but could be used in the refinement of the prediction and analytical techniques presently used for spread spectrum systems as a whole.

PACKET RADIO DEPLOYMENT

The Packet Radio technology is undergoing continuing research and development. This technology and the capability inherent to packet switching provides for many of the future tactical needs of the military. Secure and reliable voice and digital communications and survivability due to packet switching are two important capabilities of the Packet Radio. Some examples of future applications are found in numerous publications. Of particular interest is the potential checkerboard deployment described in an article in Aviation Week and Space Technology [Klass, 1979] and the potential airborne deployment described in this and other articles [Fossum and Cerf, 1979]. The checkerboard deployment of the Packet Radio would involve the installation of 5,000 to 10,000 small Packet Radio repeater stations throughout the continental U.S., spaced within line-of-sight range, roughly 32 kms from one another. The philosophy behind this deployment is to provide survivability of communications in a wartime environment. Even if many communication repeaters were destroyed or incapacitated by nuclear missile attack, there would still be many surviving radios that could by circuitous routing maintain connectivity across the U.S. The concern here is that if the Packet Radio is deployed in the 1710-1850 MHz band, a Packet Radio transmitter will be well within the protection area of many receivers identified in the previous EMC studies, such as to cause severe degradation to these other services. Many of these other services, such as the fixed microwave links for dam control or tactical weapon systems are vital in a wartime environment. Thus, a checkerboard deployment of the Packet Radio cannot be accommodated in this band as proposed. Accommodation could be made by the deployment of a limited number of Packet Radios around military bases in conjunction with either packet-switched land lines or point-to-point communications to complete the checkerboard network. Also, using only the narrowband Packet Radios or the provision of a narrowband mode on the UPR could be used to obtain frequency separation as well as distance separation to avoid interference to the other users in the 1710-1850 MHz band.

The airborne deployment of the Packet Radio is also of particular concern. As mentioned before, the EMC studies performed addressed the land mobile operation of the two Packet Radio systems. Any airborne use would increase the presented constraints (required distance separations) due to the greater line-of-sight visibility of the Packet Radio transmitter (see Airborne Spread Spectrum in Section 4 of this report). Also, the inability to time share and unavoidable cochannel operation would make accommodating widespread use of airborne Packet Radios difficult in this band. Compatible operation could only be achieved by flight restrictions such as coordination of flights on a case-by-case basis and authorization only on a secondary non-interference basis. At the present time, no airborne tests are planned for the UPR. A limited number of airborne tests are planned for the EPR in late 1980 and 1981. The EPR tests are to take place at Fort Bragg, North Carolina. To accommodate both the testing of the EPR and compatible operation of the existing environment in the 1710-1850 MHz band, it is recommended that these flight restrictions be incorporated into the EPR test plan. It is also recommended that a systems review of the EPR be performed so that any new planned deployments (airborne and location, in particular) could be addressed by the SPS. A stage 1 system review for LCPR would also appear warranted to allow guidance toward proper deployment of this system to the existing environment.

SECTION 7

STUDY OF CONGESTED AREAS

As of January 1980, there were 1380 frequency assignments listed in the Government Master File (GMF) for the 1710-1850 MHz band. The geographic distribution of these assignments is shown in Figure 7-1. From this figure, it can be seen that some areas exhibit a higher density of frequency assignments than the U.S. as a whole. While the total number of assignments in this band is not excessive, it will be these areas that will be impacted the most as spectrum usage increases. Therefore, in an attempt to identify future problems and to develop possible solutions and guidance towards good frequency management of this band, several of these apparently congested regions were examined in some detail.

Five general areas were identified for this study. They are: the Northeast coastal region, the Tenessee Valley Authority (TVA) region, the Gulf area, the Southwest region and the Pacific Northwest. The boundaries that define these areas were chosen, somewhat arbitrarily, to coincide with existing frequency management districts wherever possible. State boundaries were used for the Pacific Northwest Region and the Boston-New York-Washington corridor was used for the Northeast coastal region. After the regions were defined, the assignments within them were classified into various categories. These categories include station class, users, type of service, and equipment characteristics. The categories selected for discussion were those which would give the reader an appreciation of how the band in each of the congested areas is presently used and in what quantity. For each region, potential problem areas, if any, were identified, and recommendations were provided for future assignments as well as some modifications to existing frequency management procedures.

NORTHEAST COASTAL REGION

The Northeast coastal region includes portions of the states of Maryland, Delaware, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine as shown in Figure 7-2. Within this area, there are 151 frequency assignments. The assignments in this area are used predominately by the military services with 115 assignments versus 36 for non-military use. In this breakdown the Coast Guard and Corps of Army Engineers were considered to be non-military agencies due to their peace-time function and type of equipment used. The breakdown of the assignments into station class is as follows: 69 for the fixed service, 39 for space telecommand and tracking, 31 for experimental testing, and 12 for the mobile service. There are 16 assignments associated with airborne operations. The agencies involved and their respective number of assignments are: Army (59), Air Force (49), Navy (15), GSA (14), and the Coast Guard (14).

Of the 59 Army assignments, 24 are devoted to an experimental testing link between Fort Monmouth and Fort Dix in New Jersey. A fixed communication link in the New York Harbor area involves 16 assignments using the AN/GRC-50 radio set. There are four land mobile assignments located at Aberdeen Proving Ground, Maryland. All of the mobile assignments in this region are located in Maryland with the exception of a Navy scoring system in New Jersey. There are eight assignments for fixed communications used by the Corps of Army Engineers: four are located at the Chesapeake and Delaware Canal and four are located in

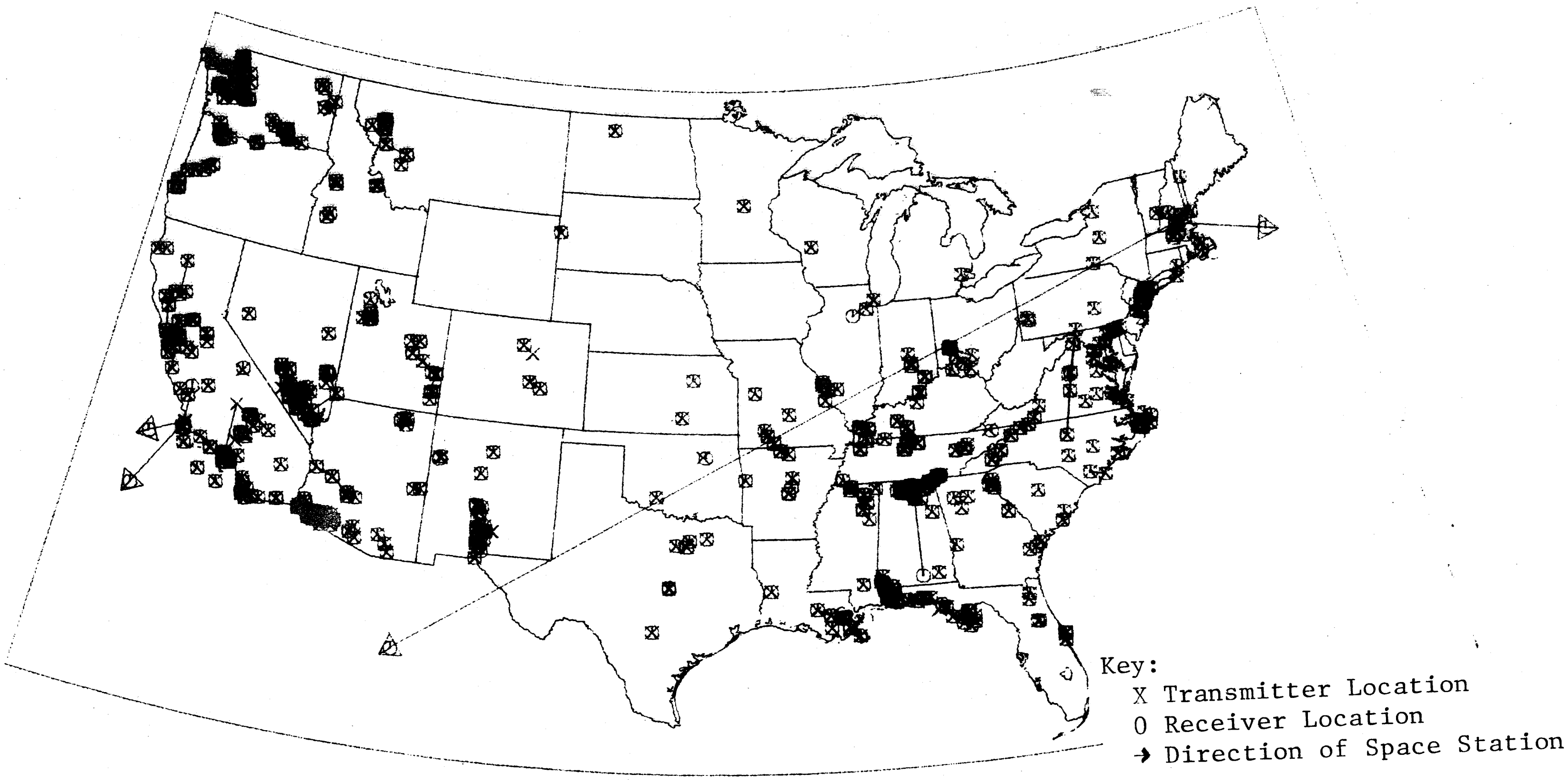


Figure 7-1. Geographic Distribution of Frequency Assignments in the 1710-1850 MHz Band

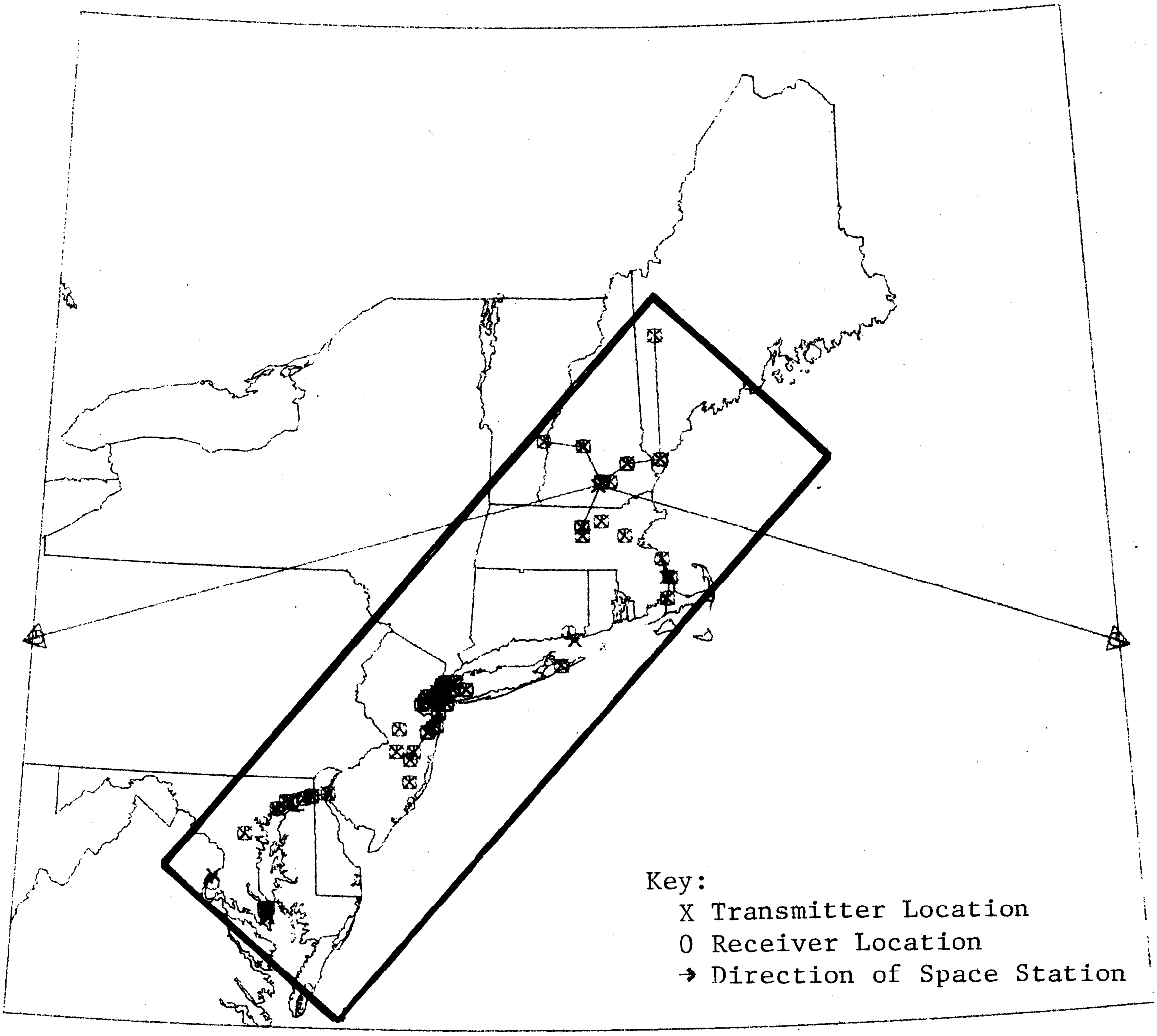


Figure 7-2. Distribution of Frequency Assignments In The Northeast Coastal Region

Massachusetts. The remaining seven Army assignments are for the AN/GRC-50 radio located at Army bases throughout the region. Of the 49 Air Force assignments, 39 are devoted to the space tracking and telecommand station at New Boston, New Hampshire. This station is seen in Figure 7-2 with the extended arrows on either side of the plot which indicate the direction to the two associated geostationary space stations. Of the remaining ten Air Force assignments, four are devoted to the experimental testing service, four to the fixed service, and two to the mobile service. Nine of these ten Air Force assignments involve airborne operations located throughout the region. Of the 15 Navy assignments, 12 are located at or near the Patuxent River Naval Air Station, Maryland. These assignments are used for various test range operations. One assignment is for the Experimental Packet Radio located in Boston, Massachusetts, one is for a fixed communication link between Fisherman's Island, New York to New London, Connecticut, and the remaining assignment is the miss-distance scoring system in New Jersey mentioned before. The 14 GSA assignments comprise a fixed point-to-point communication system for a life and property alarm which links together sites in Maine, New Hampshire, Vermont and Massachusetts. The 14 Coast Guard assignments comprise two Vessel Traffic Service (VTS) systems. One involving four assignments located in Massachusetts and the other system is located around the New York Harbor area. Both VTS systems utilize the Motorola MR-200 radio set.

One location in the region which exhibits some degree of congestion is the New York Harbor area which includes an Army communication link and a Coast Guard VTS system jointly using 26 frequencies. Since all of these assignments in this region are ground based, the complexity of the frequency management process is minimized. However, plans for additional stations in the New York Harbor area should include efficient spectrum management practices. These include use of minimum transmitter and receiver bandwidths, highly directional antennas, and other principles identified in Section 4 of this report. Use of an automated interference model such as that described in Appendix A would assist in assuring compatible operation. A second location where growth may be limited is in the New Boston, New Hampshire area where the SGLS earth station is located. Thirty-nine assignments across the 1762-1841 MHz band are authorized for this station. Coexisting in the same general area, is part of the GSA microwave link involving six assignments. Following procedures described in Sections 4 and 5 of this report, limited additional assignments to other stations are possible in this area.

TVA REGION

The boundaries of the TVA region, as defined in the NTIA Manual, are: bounded on the west by the Mississippi River, on the north by the parallel of latitude 37° 30' N, and on the east and south by that arc of the circle with the center at Springfield, Illinois, and radius equal to the airline distance between Springfield and Montgomery, Alabama, subtended between the foregoing west and north boundaries. The area contains 131 frequency assignments as illustrated in Figure 7-3. All of the assignments except one are devoted to the fixed service. The one exception is an Army airborne experimental developmental station at Redstone Arsenal, Alabama used for testing the Terminal Homing Project. Of the 131 assignments, 25 are military (all Army) versus 106 for the non-military agencies. For this breakdown the Corps of Army Engineers are considered to be non-military based on their non-tactical mission and type of equipment used (i.e., fixed line-of-sight). Of the 25 Army assignments 24 are for the AN/GRC-50

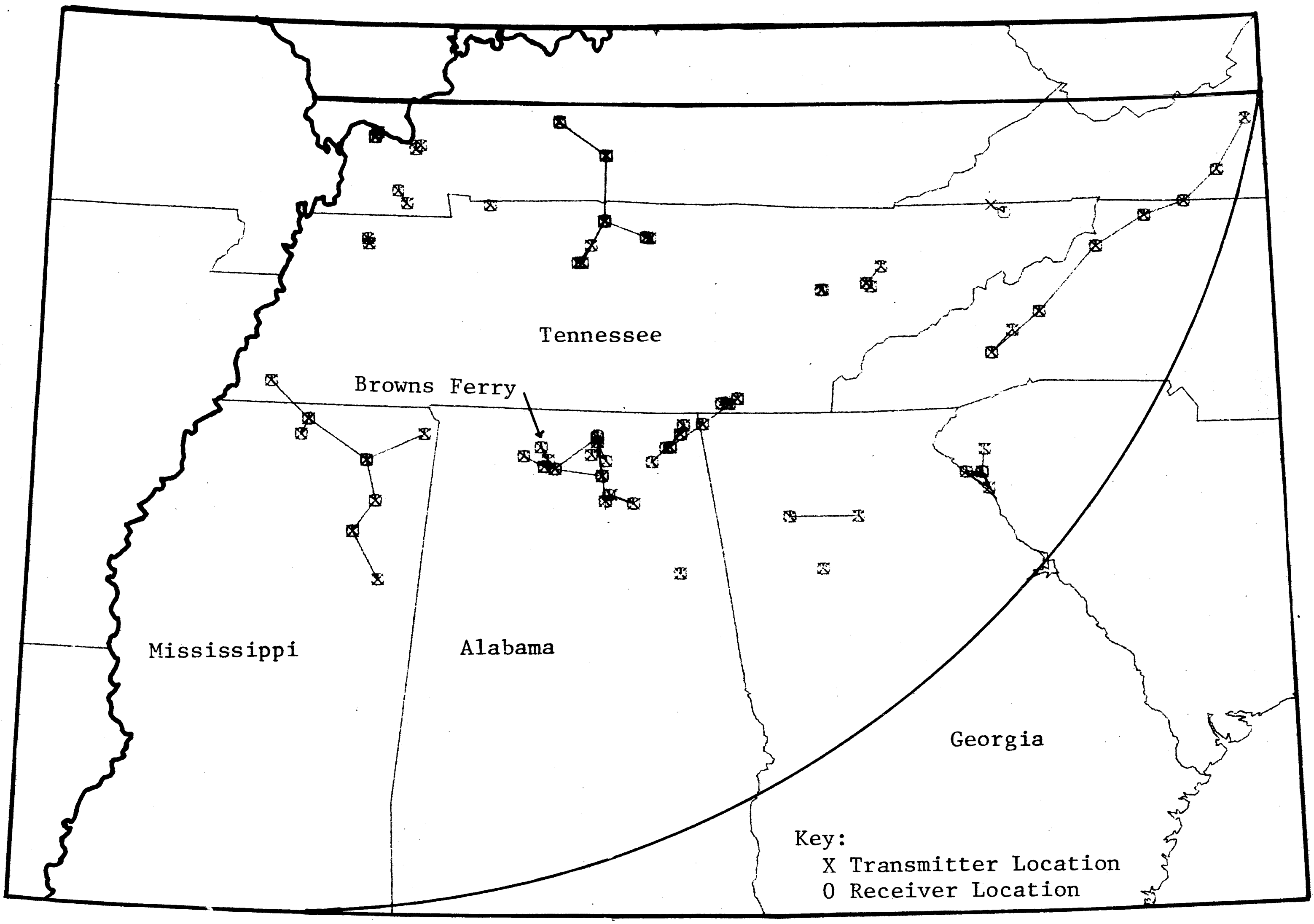


Figure 7-3. Distribution of Frequency Assignments In the TVA Region

radio (4 are located at four Army bases within the TVA region and 20 assignments are devoted to a radio relay net located in north central Alabama used for tactical training operations by the National Guard). Commercial off-the-shelf equipment as typified in Appendix B is used by all of the non-military agencies. Of the 106 non-military assignments, 76 belong to the TVA. Presently, 20 of these compose 5 frequency diversity links. This number will be reduced to eight assignments (corresponding to two links) in 1981 when some of the older equipment will be replaced with non-diversity equipment.

Agencies which have assignments in the TVA region are listed in TABLE 7-1 and are broken down into number of assignments per state to show general locations of assignment concentrations. Alabama and Tennessee contain over half of the number of assignments collectively.

From Figure 7-3, it can be seen that the northern part of Alabama is the only location within the TVA region which shows any significant congestion. Of particular concern, is the Browns Ferry nuclear power plant network which is adjacent to the National Guard radio relay net. Any proposed new assignments in this location, or expansion of either system should employ the frequency management principles described in Sections 4 and 5. The Department of Interior, which manages the radio frequency selections for the TVA, manages 90 of 131 frequency assignments in the TVA region. There are no new Interior/TVA systems planned for this area other than spurs to existing networks. Therefore, this area should not experience any difficult frequency management problems in the near future provided that good spectrum management principles are followed.

GULF AREA

The boundaries of this area were chosen to coincide with the area under the purview of the Gulf Area Frequency Coordinator at Eglin AFB, Florida. This area is bounded on the north by the latitude 33° 30' N, on the east by the longitude 83° W and on the east by the longitude 90° W. Within this area, there are 92 frequency assignments listed in the GMF. Their relative density and locations are shown in Figure 7-4. The assignments in this area are used predominately for military testing and training. The agencies involved and the number of assignments per agency are as follows: 35 for Army, 48 for Air Force, six for Navy, and three for the Coast Guard. The breakdown of these assignments by station class is: 57 for the fixed service, 21 for mobile, and 14 for experimental testing stations.

Of the 35 Army assignments, 31 use the AN/GRC-50 radio set (three at three Army bases and 28 comprise a radio relay net in the Mobile, Alabama area). The other four assignments are for a Corps of Army Engineers link utilizing the Motorola MR-200 radio also in the Mobile, Alabama area. Of the 48 assignments for the Air Force, 28 are located at Eglin, AFB. The functions of these assignments include test links for air-to-air video systems, air-to-ground video links, and scoring systems as well as an AN/GRC-50 radio. The other 20 are comprised of assignments necessary for an ACMI system and various scoring systems in the vicinity of Tyndall AFB. The six Navy assignments include three for a missile testing program at Eglin, one scoring system (AN/DSQ-40) and two for gathering oceanographic data. The Coast Guard assignments in this area are part of the New Orleans VTS system (located at the extreme left in Figure 7-4).

TABLE 7-1

FREQUENCY ASSIGNMENT USAGE BY AGENCY IN THE TVA REGION

STATE	ARMY	CORPS OF ARMY ENGINEERS	DEPT. OF ENERGY	TVA	INTERIOR (PARK SERVICE)	TOTAL
Kentucky	1		4	18		23
Tennessee		2	2	30		34
Mississippi				13		13
Alabama	22			13		35
Georgia	1	3		2		6
South Carolina	1	5				6
North Carolina					9	9
Virginia					5	5
	25	10	6	76	14	131

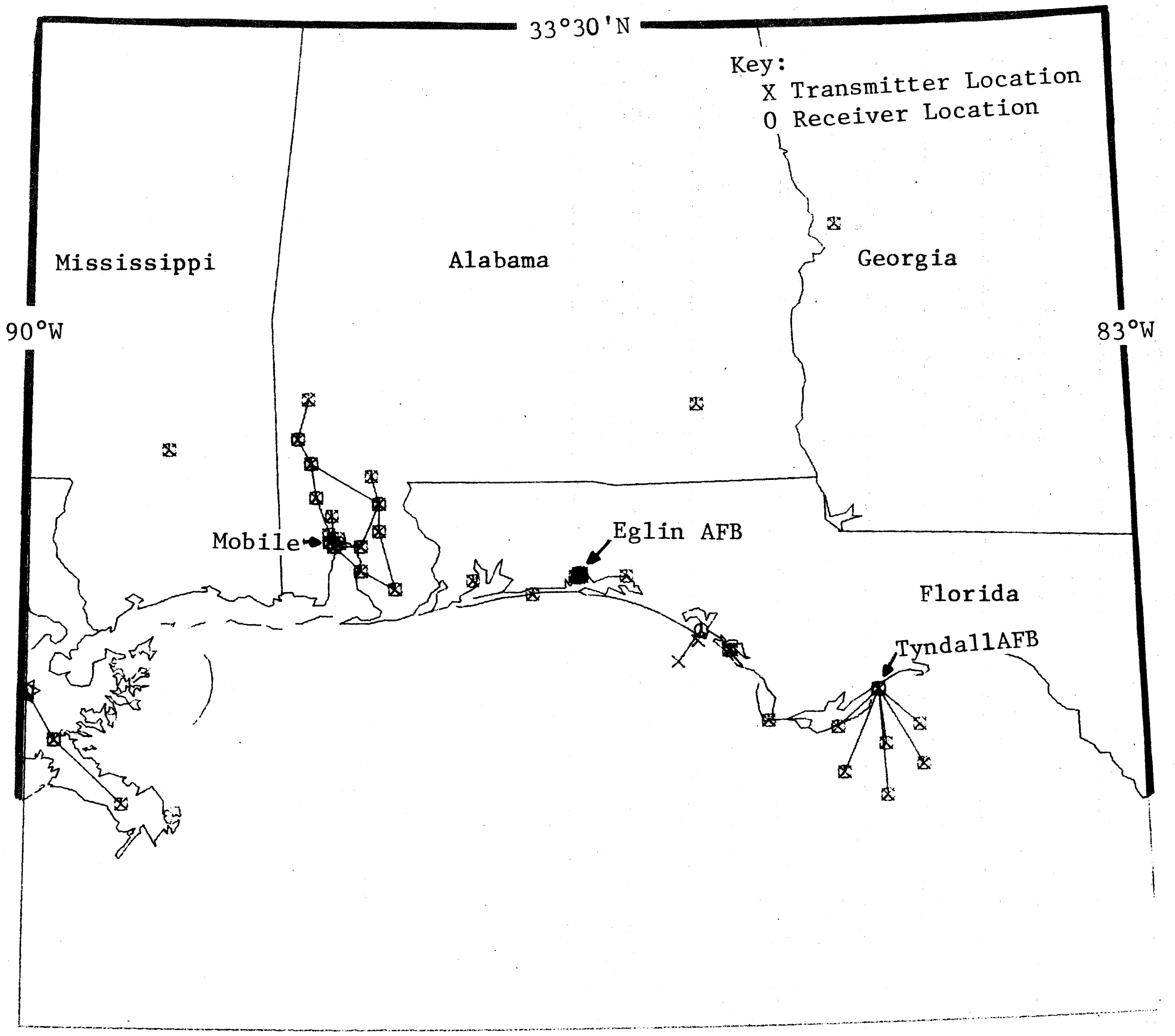


Figure 7-4. Distribution of Frequency Assignments In The Gulf Area

The concentration of assignments in this area occurs in the Mobile, Alabama area and the Eglin AFB area. The assignments in the Mobile area are all fixed stations. Employing efficient spectrum management practices on future assignments in this area such as described in Section 4, will ensure compatible operation. The complexity of equipment types, including airborne functions, used in the Eglin AFB area may result in difficult management of the band. In general, the assignments at this base are under the jurisdiction of the Gulf AFC at Eglin and are somewhat geographically isolated from stations of other agencies. Thus interagency frequency conflicts will be minimized.

PACIFIC NORTHWEST

The Pacific Northwest region is defined here as consisting of the states of Washington and Oregon. Contained in this area are 114 frequency assignments belonging to six Government agencies, most of which are for the fixed point-to-point service for the non-military agencies. The geographic distribution of these assignments is shown in Figure 7-5. There are 102 assignments for the fixed service, the remainder being experimental testing and contract development stations and one space telecommand earth station. There are no mobile stations in this area. There are 98 assignments for the non-military agencies versus 16 for the military. Commercial off-the-shelf equipment is used by the non-military agencies. The agencies and their respective number of assignments (in parentheses) are as follows: Department of Energy (43), Coast Guard (34), Army (21), Air Force (13), Department of Interior (2), and Navy (1). The Department of Energy assignments are distributed throughout the region and are used in support of the Bonneville Power Administration (BPA) for control, operation and management of the various BPA power transmission systems. The 34 Coast Guard assignments are all used by the Puget Sound VTS system in the Seattle, Washington area for communications and remote control of radar sites in support of harbor radar advisory ship control. Of the 21 Army assignments, 19 are used by the Corps of Army Engineers for various backbone communication networks. The remaining two are for the AN/GRC-50 located at two Army posts in Washington. Ten of the 13 Air Force assignments are located in the Seattle area: six are for experimental testing of antennas being developed for AF missiles and aircraft, and four are experimental contract development stations used for factory checkout of the inertial upper stage for the SGLS and Space Shuttle programs. The remaining three assignments located in the Spokane, Washington area, are used for a fixed point-to-point link and space telecommand earth station in support of the Defense Meteorological Satellite Program (DMSP). The two Department of Interior assignments are located in Portland, Oregon and are used for transmission of hydrologic and meteorological data. The Navy assignment is an experimental testing station at Port Angeles, Washington used for equipment checkout and antenna calibration.

In this region, the largest concentrations of assignments occur in the Puget Sound, Washington and Portland, Oregon areas. In the former, there are Coast Guard and Corps of Army Engineers microwave networks, and Air Force and Navy experimental stations. In the Portland area, there are BPA, Corps of Army Engineers and Interior networks in close proximity. Since all these are ground based assignments, following spectrum management practices as described in Section 4 would assure the availability of spectrum for future needs.

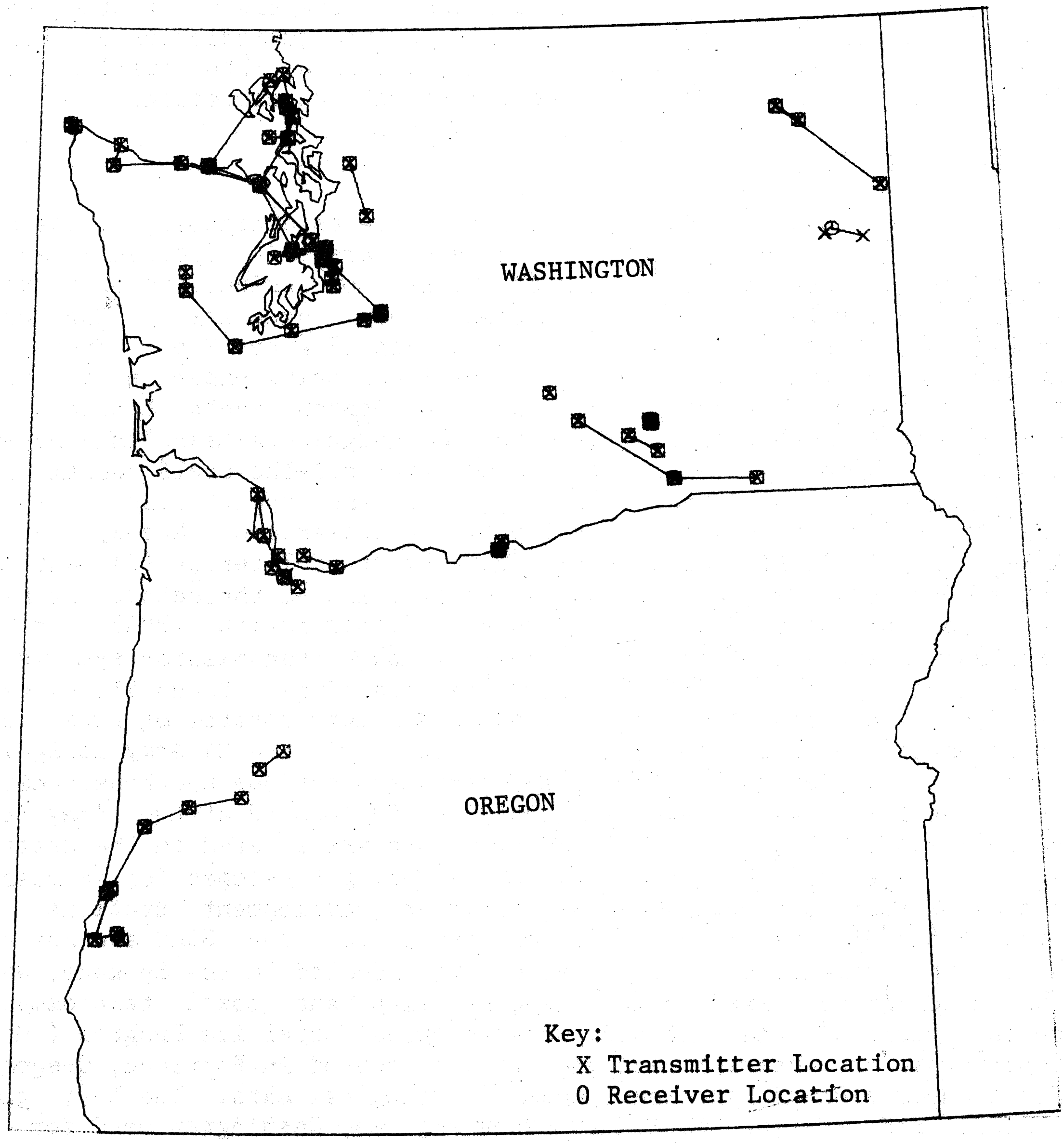


Figure 7-5. Distribution of Frequency Assignments In The Pacific Northwest

SOUTHWEST REGION

The boundaries of this region were chosen to include two military frequency coordination districts. One is the Naval Eleventh District-South which includes the area of California south of the latitude 36° N, Nevada south of the latitude 37° 30' N and the state of Arizona. The other district is the Army frequency coordination area of White Sands Missile Range (WSMR) which includes New Mexico, the U.S. territory within a 240 km radius of WSMR (includes Fort Bliss, Texas), plus the area of Utah and Colorado that lies between the longitudes of 108° and 111° W. These two districts and the distribution of frequency assignments contained within them are shown on the map of the Southwest Region (Figure 7-6). Within this region, there are 395 frequency assignments administered by 12 Government agencies. The breakdown of the number of assignments per agency as well as per state and district is given on TABLE 7-2. As can be seen on this table, military assignments predominate in this region. Of the 395 frequency assignments, 320 are used by the military versus 75 for the non-military agencies. Typically, these assignments represent numerous military test and training operations coexisting with various land, water, and power management systems. The number of assignments as well as the variety of systems used in this region, precludes an itemized description of each as was attempted for the other congested areas. A general discussion of groups of assignments will be presented here for the sake of brevity and clarity.

Of the 395 assignments, 209 are used by the fixed service, 77 for the mobile service, 70 represent experimental testing or developmental stations and 39 are used for a space telecommand and tracking earth station. Although the breakdown of the assignments by station class is convenient and easily tabulated, an appreciation of what the general use is of this band in this area is not gained. A better breakdown would be by function. Five general functional groupings which adequately cover all of the assignments in this area are as follows: (1) point-to-point microwave communications, (2) tactical and/or training operations, (3) test range operations, (4) experimental equipment and (5) satellite telecommand and tracking operations. The point-to-point microwave grouping is made up of 88 assignments. This grouping includes all of the non-military assignments which are used for the various land and power management sytems located throughout the region. The remaining assignments are used by the military on the various test ranges for point-to-point communications. The tactical and/or training grouping includes the Army AN/GRC-50 radio relay set, naval command data links, the ACMI/ACMR systems, and the various scoring systems. This grouping is made up of 135 assignments of which 60 are for the three ACMI/ACMR systems in the region and 49 are for the various scoring systems. The test range operations grouping includes systems used for testing the various experimental equipment (tactical air-to-air data links, weapon systems, etc.) air-to-ground video links for target drone control, and the test range central timing systems. This grouping includes 122 assignments, the majority being used for factory checkout and flight testing of various equipment. The experimental equipment includes the packet radio, signal generators for antenna evaluation and development and equipment developed to be used in the flight tests of other experimental systems. There are 21 assignments for this grouping. The last grouping includes the 39 assignments to the Air Force at Vandenburg, California. These assignments are used for the SGLS uplink command and control.

The Southwest region as defined here is the most complex frequency management region in the United States in the 1710-1850 MHz band. The

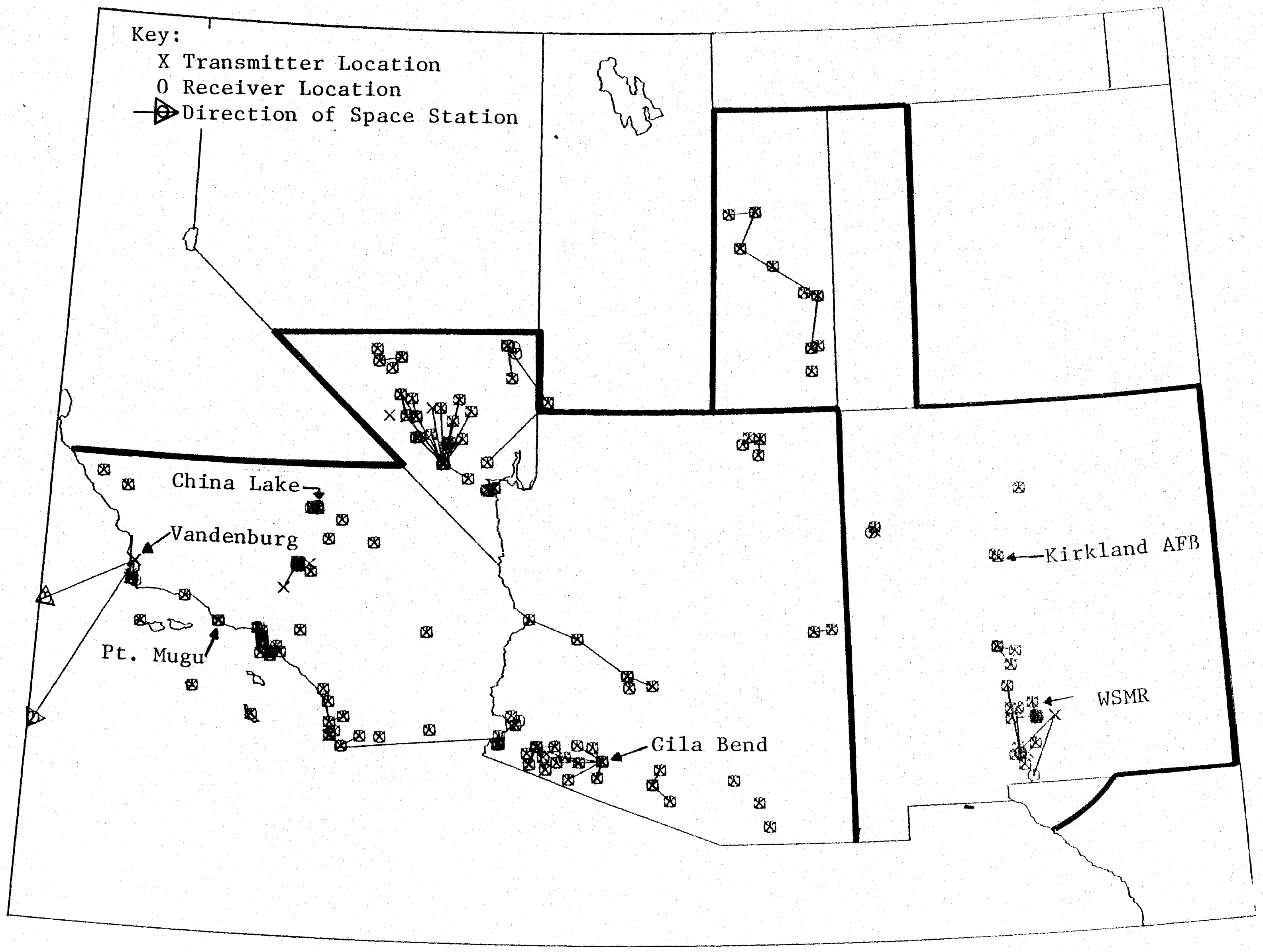


Figure 7-6. Distribution of Frequency Assignments in the Southwest Region

TABLE 7-2

FREQUENCY ASSIGNMENT USAGE IN THE SOUTHWEST REGION BY AGENCY, STATE, AND DISTRICT

	Military Agencies					Non-Military Agencies							
	AF	AR	N	A	C	DOE	FAA	FCC	HEW	I	J	NASA	Totals
Cal	80	6	77		2		1	1			4	1	172
Nev	39					27				4			70
Ariz	20	7	27	2				6	6	8			76
11th District	139	13	104	2	2	27	1	7	6	12	4	1	318
NMex	21	25	12			1							59
Utah	4	2								12			18
WSMR	25	27	12			1				12			77
Totals	164	40	116	2	2	28	1	7	6	24	4	1	395

KEY:

AF = Air Force
AR = Army
N = Navy
A = Department of Agriculture
C = Department of Commerce
DOE = Department of Engergy
FAA = Federal Aviation Administration
FCC = Federal Communications Commission
HEW = Department of Health, Education, and Welfare
I = Department of the Interior
J = Department of Justice
NASA = National Aeronautics and Space Administration

intermixing of the various fixed, mobile, and space applications leads in some cases to difficult sharing situations. Of particular concern are the assignments for aircraft or earth stations. In both of these instances, required distance separation with other users may be large in order to reuse a given frequency. TABLE 7-3 lists several key areas within this region that have major concentrations of these two types of stations. Since these identified areas are associated with specific military bases and/or test ranges in the region, the same trend will likely continue for future assignments. To assure compatibility of future stations in the vicinity of these sites, a case-by-case examination of any proposed stations within 250 kilometers of these sites in the 1710-1850 MHz band is recommended.

SUMMARY

The number of assignments reviewed for this congested area study totaled 878, or approximately 64 per cent of the assignments listed in the GMF for the 1710-1850 MHz band. The total area of these five regions represent about 20 per cent of the total area of the U.S. In addition to the large concentration of assignments, the diverse nature of the use of this band in these areas tends to complicate the frequency management process. There are certain measures that can be taken, however, in addition to the present management process to ensure future spectrum in these areas as follows:

1. Avoid frequency diversity - Frequency diversity uses up at least twice the available spectrum that a non-frequency diversity link would. The guard bands and associated denied frequency bands of harmonics of the four frequencies may combine in such a way as to reduce the bandwidth of an otherwise useful center frequency; further reducing the available spectrum to other users in a given area.

2. Minimize bandwidth - For these congested areas where future spectrum may become scarce, the use of the minimum practical bandwidth would provide more spectrum for future use and would facilitate spectrum planning (see Section 4 on channeling plan).

3. Improved technical standards - Proposed new station assignments in these areas should conform to stringent technical standards to assure the efficient use of the available spectrum. In particular, transmitters should have the lowest practical frequency tolerance, receivers should employ bandwidths commensurate with the associated emission bandwidth, and antennas should have reflectors of adequate size to sufficiently reduce sidelobe emissions. Refer to Section 4 for specific values.

4. Automated Frequency Assignment Model - The advantage of a frequency assignment model is that it can account for all transmitter-receiving pairing quickly and print-out the denied frequency ranges for link assignments. The use of such a model would assist the frequency assignment process at both the agency and IRAC levels.

In addition to these frequency management techniques several other steps could be taken to assist the present process.

TABLE 7-3

CRITICAL AREAS WITHIN THE SW AREA IDENTIFIED WHERE CASE-BY-CASE REVIEW IS NECESSARY FOR NEW ASSIGNMENTS

NAME	LOCATION	NUMBER OF AIRBORNE ASSIGNMENTS	NUMBER OF EARTH STATION ASSIGNMENTS
WSMR N MEX	32°51'N 106°06'W	24	
KIRKLAND AFB N MEX	35°02'N 106°36'W	10	
GILA BEND ARIZ	32°26'30"N 112°56'30"W	7	
CHINA LAKE CALIFORNIA	35°41'N 117°41'W	15	
PT MUGU CALIFORNIA	34°07'N 119°07'W	45	
VANDENBURG CALIFORNIA	34°49'24"N 120°31'54"W		38

1. Review assignments for technical accuracy - Of the frequency assignments reviewed for this study, the errors ranged from obviously erroneously listed coordinates to the not-so-obvious erroneous equipment parameters. Effective spectrum management requires that the data used be complete and accurate. If a receiver in Birmingham, Alabama is to receive the required protection from a proposed transmitter in that same area, it cannot be done if it is listed in the GMF 300 kilometers south of Birmingham. One way to alleviate this problem would be for each agency to acquire geographic plots of their assignments when they periodically review them. Power, antenna information, and emission data (not to belittle other information) are also important to the frequency assignment process not only for new assignments but to ensure the protection of the existing systems.

2. Proper listing of the Mobile systems - For example, of the six ACMI/ACMR systems listed presently in the GMF, four were reviewed for this study: the ACMI systems located at Nellis AFB, NV, Gila Bend, AZ and Tyndal AFB and one ACMR system located at Yuma, AZ. Although each system is identical (the ACMR system uses one less frequency), they are listed in the GMF four different ways using different station classes and various numbers of assignment to describe them. Since two of the nine stations (eight for the ACMR), use common frequencies, 16 frequency assignments is all that is necessary to describe the system. For example, since the master-to-remotes uses one frequency, this assignment could be listed with one transmitter and seven receivers in one assignment listings instead of using seven listings. This would make access of the system from the file easier and distinguishable from other ACMI/ACMR systems in the GMF file. Additionally, as stated in the Phase I effort of this resource assessment, a more consistent approach should be followed in entering the station classes of the various components. The following is suggested:

a. Air-to-Remote - MOEB, Flight Telemetering Mobile Station

b. Remote-to-Air - FLDR, Telecommand Land Station
(Repeater)

c. Remote-to-Master - FXER, Telemetering Fixed Station
(Repeater)

d. Master-to-Remote - FXD, Telecommand Fixed Station

3. Redefine the experimental station classes (XC, XD, XM, XR and XT) - The general usage of these station classes implies that the definition of each is unclear. The station class XT is used predominately for both test equipment and equipment being tested. For example, the Experimental Packet Radio (EPR) is listed in the GMF as an experimental testing station (XT). By definition, this station is an experimental station used for the evaluation or testing of electronics equipment or systems which have been developed for operational use which the EPR is not. The EPR, more properly, should be either listed as an XR or XM station. An experimental research station (XR) is one used in basic studies concerning scientific investigations, looking toward the improvement of the art of radiocommunications for which the EPR

qualifies. The EPR also qualifies as an experimental composite station (XM) which is used in experimental operations of a complex nature not readily specified (i.e., packet switching in the domain of radio communications and spread spectrum multiple access techniques). The experimental station classes are also apparently confused with the stage of review as defined in the NTIA Manual part 8.3.4). An equipment or system operating in the experimental stage (stage 2) is not necessarily an experimental station. One way to alleviate the problem would be to clarify the definitions to reduce the number of ambiguities. It is also suggested that the station class parameter, provided on a system review application to the SPS, be checked by NTIA and corrected as necessary before it is entered in the GMF. Since the station class field in the GMF provides for four characters, it also would be more meaningful to utilize the remaining two characters to describe the equipment or system deployment (see discussion under BMF improvements). For example, the EPR could be listed as XRML. This provides for the experimental nature of the EPR as well as tells of its land mobile capability.

4. Provision of future spectrum use - Planning is an important part of management. If early in the frequency management process, types and numbers of equipment the user community has on the drawing board were made known, space for these future systems could be provided for. In addition, with the knowledge of these future systems, steps could be taken in advance to alleviate potential problems. An example of this type of provision is given in TABLE 7-4. This type of information given by the Department of Interior is very useful not only to the frequency manager (who accounts for the user community as a whole) but to individual agencies interested in the knowledge that these future systems can be accommodated in the spectrum when still in the planning stage. These future plans do not have to be adhered to or implemented at all, but if every agency submitted their intended use in advance, future accommodation can be assured. Information such as that provided in TABLE 7-4 should be submitted for Stage 1 review, in accordance with Part 8.3 of the NTIA Manual.

5. Spectrum Management Site Survey and Measurements - one of the proposals of this report, see Section 3, is that stations whose emissions are intermittent can more efficiently utilize the band by time scheduling their use on common frequencies. This is especially true among certain airborne test operations. The frequencies used for these operations are often clear of other users within a 100-200 mile radius, although actual transmissions may last for as little as a few hours per week. For a given location, many frequencies may be committed to these operations, whereas, through effective time scheduling significant reduction in committed frequencies may be possible.

One such area is Point Mugu, California where 45 assignments on 33 different frequencies are currently authorized for airborne operations. When considering the bandwidths associated with each of these assignments the entire 1710-1850 MHz band is committed to these airborne operations.

Two mechanisms for further examining the feasibility of improved time scheduling among intermittent operations would be the NTIA Spectrum

TABLE 7-4

SUMMARY OF EXPECTED MICROWAVE SYSTEMS IN THE 1710-1850 MHz BAND TO BE PROPOSED BY THE DEPARTMENT OF INTERIOR FOR THE EARLY 1980'S

SYSTEM NAME	ESTIMATED NUMBER OF HOPS	SYSTEM CHANNEL CAPACITY	AREA AND GENERAL DESCRIPTION
Lower Colorado River	11	240	Along Colorado River from Yuma, AR to Boulder City, Nev.
Central Valley Project	8	120	North-Central Cal., from Shasta, to Sacramento, and from Gustine to Sacramento.
Snake River	4	24	Snake River area around Boise, Idaho.
North Platte	5	60	East-Central Wyo., Guernsey, to Medicine Bow.
South Platte	7	60	North-Central Colo., Blueridge, to Loveland area.
Kansas River	4	12	Northwestern Kansas from Stockton to McCook, Nebraska.

Management Survey and Spectrum Measurement Programs discussed in Paragraph 8.2.6 of the NTIA Manual. Through the use of the NTIA Radio Spectrum Measurement System Van, the 1710-1850 MHz band could be monitored in the Point Mugu area to establish relative spectrum usage. In conjunction with these measurements, a spectrum survey could be undertaken in cooperation with the Western Area Frequency Coordinator to obtain further insight into spectrum usage in this band. Results of these two efforts should jointly show the spectrum savings possible from improved time scheduling techniques.

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APPENDIX A

Fixed Microwave Interference Cull Model

Section 4 of the text provides a general description of a preliminary fixed microwave interference cull model. This appendix describes the model in detail including input and output parameters. Figure A-1 shows the basic flow chart for the model. Tables A-1 and A-2 describe the input and output data. Basic cull parameters are described in the following paragraphs.

PARAMETER CHECKING

At present the model is designed to consider only point-to-point fixed microwave links using FDM/FM modulation in the 1710-1850 MHz band. Assignments that do not meet the following criteria are listed in the output but with no calculations performed.

Frequency	(FREQ)	$1710 \leq FREQ \leq 1850$ MHz
Power	(PWR)	$0 \leq PWR \leq 50$ Watts
Transmitter Gain	(GT)	$10 < G < 37$ dBi
Receiver Gain	(GT)	$10 \leq G \leq 37$ dBi
Bandwidth	(BW)	500 kHz $\leq BW \leq$ 10 MHz
Station Class	(STC)	STC = FX or FXR
Modulation Type	(MOD)	MOD = F9
Path Length	(L)	$1 \leq L \leq 50$ Miles
Polarization	(POL)	POL = V or H

ANTENNA GAIN

The antenna gain patterns are based on the CCIR [1978] model as well as typical antenna patterns as follows

PARALLEL POLARIZED

$$\text{GAIN (dBi)} = \text{minimum } [G_{MB} \; ; \; 38 - 25 \log \theta] \quad \text{for } \theta \leq 35$$

$$= 0 \quad \text{for } 35 < \theta \leq 180$$

CROSS POLARIZED

$$\text{GAIN (dBi)} = 0 \quad \text{for } \theta \leq 15$$

$$= -10 \quad \text{for } 15 < \theta \leq 180$$

The cross polarized pattern, when applicable, is applied to whichever antenna that maximizes the total interference path antenna gains.

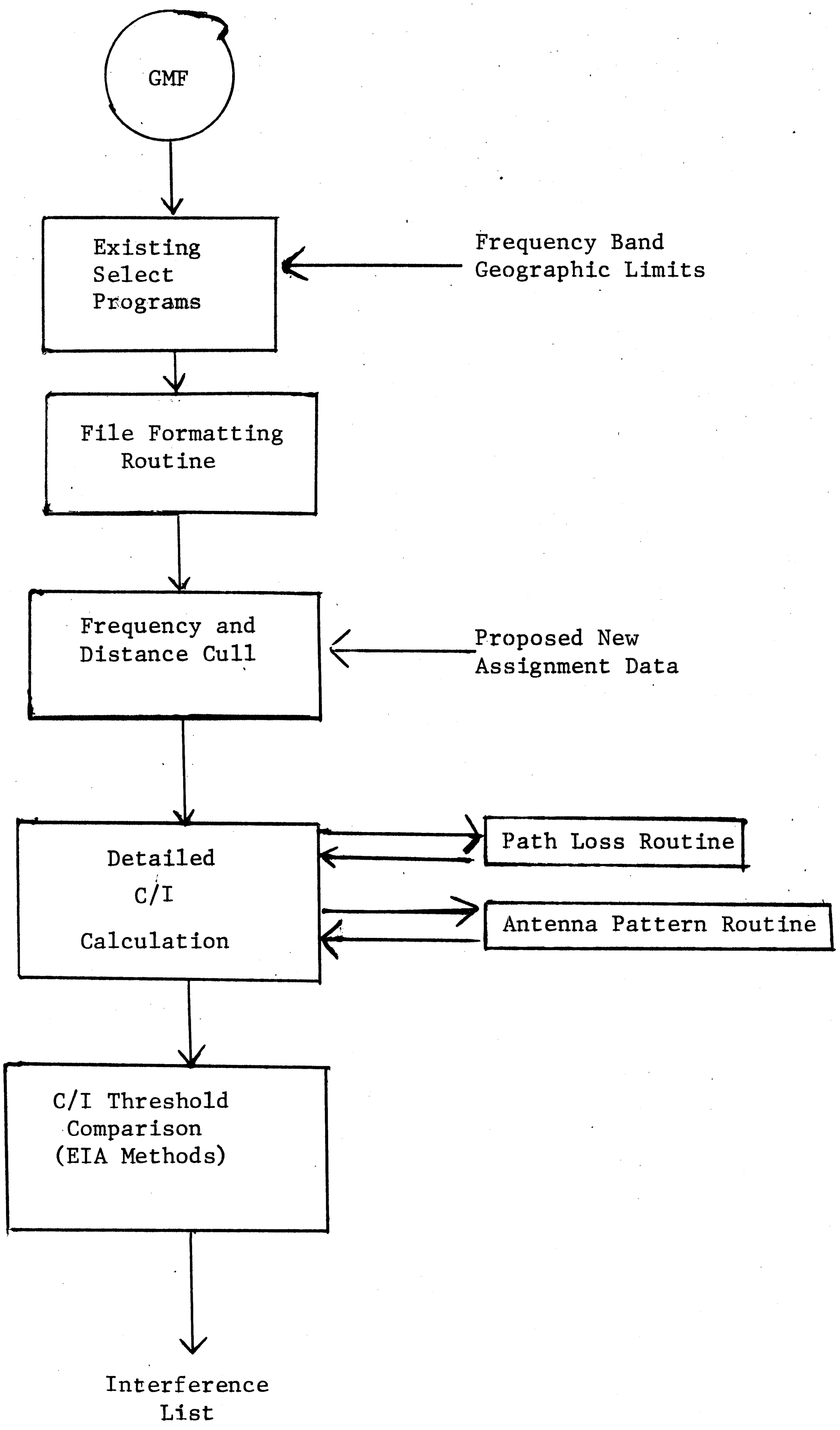

Figure A-1. Basic Flow Chart for Interference Cull Model

TABLE A-1

INPUT PARAMETERS FOR FDM/FM INTERFERENCE MODEL

Environment Selection

Frequency Range	(MHz)
Distance Cull	(Miles)
Center Location	(Latitude and Longitude)

Equipment Parameters

Tuned Frequency	(MHz)
Authorized Bandwidth	(kHz)
Modulation Type	(F9)
Transmitter Power	(Watts)
Transmitter Latitude and Longitude	(deg, min, sec)
Receiver Latitude and Longitude	(deg, min, sec)
Transmitter Antenna Gain	(dBi)
Receiver Antenna Gain	(dBi)
Station Class	(FX or FXR)
Antenna Polarization	(V or H)

TABLE A-2

OUTPUT PARAMETERS

1. TX No. - A sequential number assigned to each environmental and proposed transmitter for identification.

2. PWR - Transmitter power in watts.

3. B-TR - Transmitter antenna discrimination angle in degrees (bearing from transmitter to victim receiver relative to transmitter boresight)

4. G-TX - Gain of interfering transmitter in the direction of victim receiver in dBi

5. BWT - Authorized bandwidth of interfering transmitter in kHz

6. TX MOD - Modulation type of interfering transmitter

7. TX STC - Station class for interfering transmitter

8. RX No. - Victim receiver identification number

9. B-RT - Receiver antenna discrimination angle in degrees (bearing from receiver to interfering transmitter relative to receiver boresight.

10. G-RX - Gain of victim receiver in the direction of interfering transmitter in dBi

11. BWR - Authorized bandwidth of the desired signal for victim receiver in kHz

12. RX MOD - Modulation type of desired signal for victim receiver

13. RX STC - Station class of desired signal for victim receiver

14. DIST - Distance separation between interfering transmitter and victim receiver in kilometers

15. DELF - Frequency separation between desired and interfering transmitter carriers in MHz

16. CTOI - Calculated carrier-to-interference ratio in dB. (Median free space value)

17. C50 - Long-term (median or 50 percent) C/I protection criteria, based on EIA Bulletin 10-C, in dB

18. C01 - Short term (.01 percent) C/I protection criteria, based on EIA Bulletin 10-C, in dB (used only when subsequent detailed analysis including terrain dependent propagation loss is used.

RECEIVED POWER

Received power, both interfering and desired, is calculated using the following equation

$$Pr = P_T + G_T(\theta) + G_R(\theta) - 20 \log (D) - 20 \log (F) -36.6$$

C/I THRESHOLD VALUES

The C/I threshold values are determined based on procedures developed by the EIA for the following conditions: sideband beat interference, carrier beat interference, and threshold desensitization. Values for both long term (50 percent) and short term (.01 percent) criteria are provided. The long term value is used in the initial cull using free space propagation. If the results are supplemented with terrain dependent propagation calculations, both long and short term values should be applied. Short term criteria are chosen to be 10 dB below carrier and sideband beat long term values. Short term criteria are not applicable to threshold desensitization. The following shows which interference mode predominates.

$0 = \Delta F$	Sideband beat or carrier beat
$0 < \Delta F \leq FM$	Carrier beat
$FM < \Delta F \leq \text{Max BW}$	Sideband beat or threshold desensitization
$\text{Max BW} \leq \Delta F \leq 30\text{ MHz}$	Threshold desensitization
$30\text{ MHz} < \Delta F$	None

where

ΔF = Frequency separation
FM = maximum modulating frequency in victim receiver

Max BW = maximum of the authorized frequency of interfering or desired transmitters

Sideband beat interference can occur in cochannel and adjacent channel conditions when the emission sidebands of the desired and interfering signal beat together in the receiver, resulting in intermodulation products which fall within the desired receiver baseband. For cochannel situations, tabulated data from from the EIA are used for various combinations of modulation types as shown in Table A-3. Some extrapolation of the data was necessary for specific combinations not covered. Also since channel loading information is not available in the GMF, the parameters given in TABLE A-4 are assumed, based on reported authorized bandwidth.

For adjacent channel conditions, sideband beat interference is based on procedures in Annex B of EIA Bulletin 10-C using the following formulas:

$$C/I = 86.4 + LF(v) - 10 \log [f (v)-f (v)] - 10 \log P$$

$$+ 10 \log \ 1 + 10^{-[R_D(i) - R_D(v)]/10} - R_D(v)$$

For $F_m < 2 f_m$

TABLE A-3

Cochannel Sideband Beat Criteria (1710-1850 MHz)

Interfering Necessary Bandwidth (MHz)	Desired Necessary Bandwidth (MHz)					
	0.5 - 1.0	1.0 - 2.0	2.0 - 4.0	4.0 - 6.0	6.0 - 8.0	8.0 - 10.0
0.5 - 1.0	66	58	60	54	54	53
1.0 - 2.0	69	61	60	54	54	53
2.0 - 4.0	65	65	62	54	54	53
4.0 - 6.0	60	64	61	56	54	53
6.0 - 8.0	58	62	60	60	59	58
8.0 -10.0	58	62	60	58	62	60

Values in Table given in dB.

TABLE A-4

ASSUMED CHANNEL LOADING

Necessary Bandwidth		No. of Channels	Max. Mod Freq.	RMS per Channel Dev.
0.5 < BW ≤ 1 MHz	(Min)	24	124 kHz	35 kHz
	(Max)	48	204	25
1 < BW ≤ 2	(Min)	48	204	100
	(Max)	96	396	50
2 < BW ≤ 4	(Min)	120	552	140
	(Max)	240	1020	100
4 < BW ≤ 6	(Min)	120	552	200
	(Max)	300	1300	100
6 < BW ≤ 8	(Min)	300	1300	200
	(Max)	480	2044	140
8 < BW ≤ 10	(Min)	480	2044	200
	(Max)	600	2540	140

$$R_D(v) = 20 \log [(F_m - f_m(v))/f_m(v)]$$

$$\underline{\text{For} \quad F_m > 2\, f_m(v)}$$

$$R_D(v) = [12 - 20 \log (\delta f(v) L(v)/f_m(v))] \quad [(F_m - 2\, f_m(v))/f_m(v)]$$

$$\underline{\text{For} \quad F_m < (f_m(v) + f_m(i))}$$

$$R_D(i) = 20 \log (\delta f(v)/\ f(i)) + 20 \log [(F_m - f_m(v))/f_m(i)]$$

$$\text{For} \quad F_m > (f_m(v) + f_m(i))$$

$$R_D(i) = 20 \log (\delta f(v)/\ f(i))$$
$$+ [12 - 20 \log (\delta f(i) L(i)/f_m(i))] \, [(F_m - (f_m(v) + f_m(i)))\ f_m(i)]$$

where

C/I,	Desired carrier power to undesired carrier power ratio in dB.
P_i,	Interference criteria in pW0p. (25 pW0p used in sibeband criteria)
$\delta f(v)$,	Per channel rms deviation of the victim system in kHz.
$\delta f(v)$,	Per channel rms deviation of the interfering system in kHz.
F_m,	Minimum frequency difference which can exist between the RF carrier frequencies of the victim system and the interfering system in kHz.
LF(v),	White noise loading factor for victim system expressed in dB.
L(v),	White noise loading factor for the victim system expressed as a voltage ratio.
L(i),	White noise loading factor for the interfering system expressed as a voltage ratio.
$f_m(v)$,	Maximum baseband frequency of the victim system in kHz.
$f_m(i)$,	Maximum baseband frequency of the interfering system in kHz.

Carrier beat interference results when the desired and interfering carriers are slightly off tuned from each other, such that the resulting intermodulation beat frequency falls within the desired receiver passband. The following equation is used as per Annex C of EIA [1976]..

$$C/I = 87.5 - 10 \log Pi - 20 \log (\Delta f(v)/Fm)) - (\text{Burble Factor})$$

The burble factor refers to the reduction in the interfering and victim carrier levels as compared to the unmodulated carrier. A value of 5 dB is assumed if both necessary emissions bandwidths are less than or equal to 2 MHz, 10 dB if both are greater than 2 MHz, and 7.5 dB if a combination thereof.

Receiver desensitization results from interfering signals that are separated from the desired signal by greater than the maximum baseband frequency, but still within the IF selectivity of the receiver. During fading conditions of the desired signal, an interfering signal of sufficient level can have a desensitization effect, which effectively reduces the link fade margin. A 1 dB reduction in fade margin is chosen as the criteria. The following equation is used as per Annex D of EIA [1976].

$$C/I = FM + 10. - S$$

where

FM = link fade margin in dB

= median signal level/practical threshold

S = effective receiver selectivity in dB

For purposes of this model, a fade margin of 40 dB is assumed for all links. Links with higher fade margins will be considered by the model, but may experience slightly higher reduction in fade margin (1-2 dB) if this C/I is not achieved.

Short term criteria are not applicable to threshold desensitization. This follows from the fact that full fading of the desired signal and short term enhancement of the interfering signal are uncorrelated short term events with negligible probability of simultaneous occurance.

The selectivity of the receiver is highly dependent on the specific manufacturer and model. From the data provided in Appendix B, a reasonable bound on receiver selectivity is given by the following:

$S = 0$	for $F\Delta < 1.75$ MHz	for authorized
$= 100 \log (\Delta F/1.75)$	otherwise	bandwidths ≤ 2 MHz
$s = 0$	for $F\Delta < 8$ MHz	for authorized
$100 \log (\Delta F/8)$	otherwise	bandwidth > 2 MHz and ≤ 10 MHz

APPENDIX B

This appendix contains parameters representative of equipments used in the 1710-1850 MHz band.

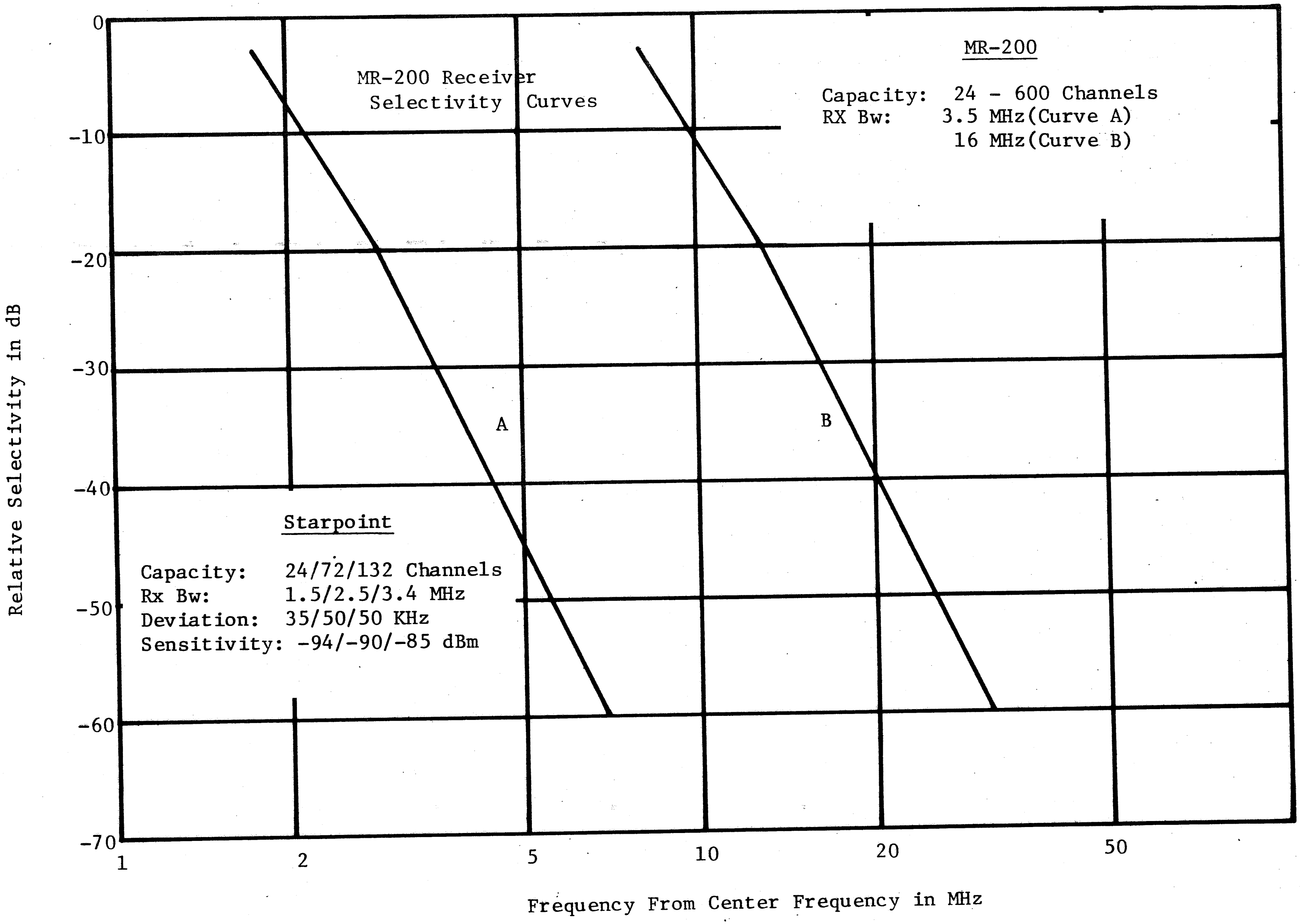

Figure B-1. Parameters for Motorola MR-200 and Starpoint Receiver

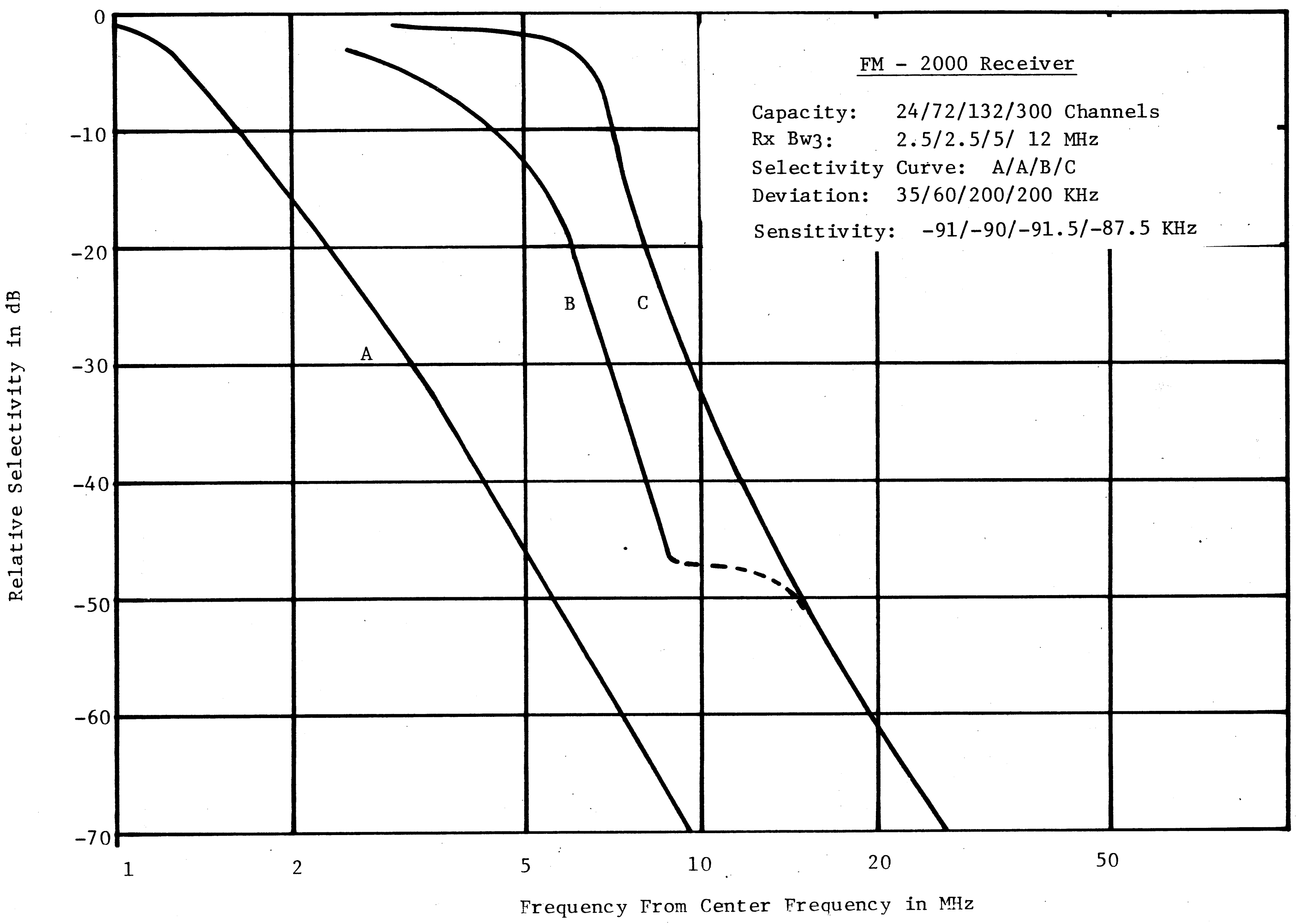

Figure B-2. Parameters for Farinon FM - 2000 Receiver

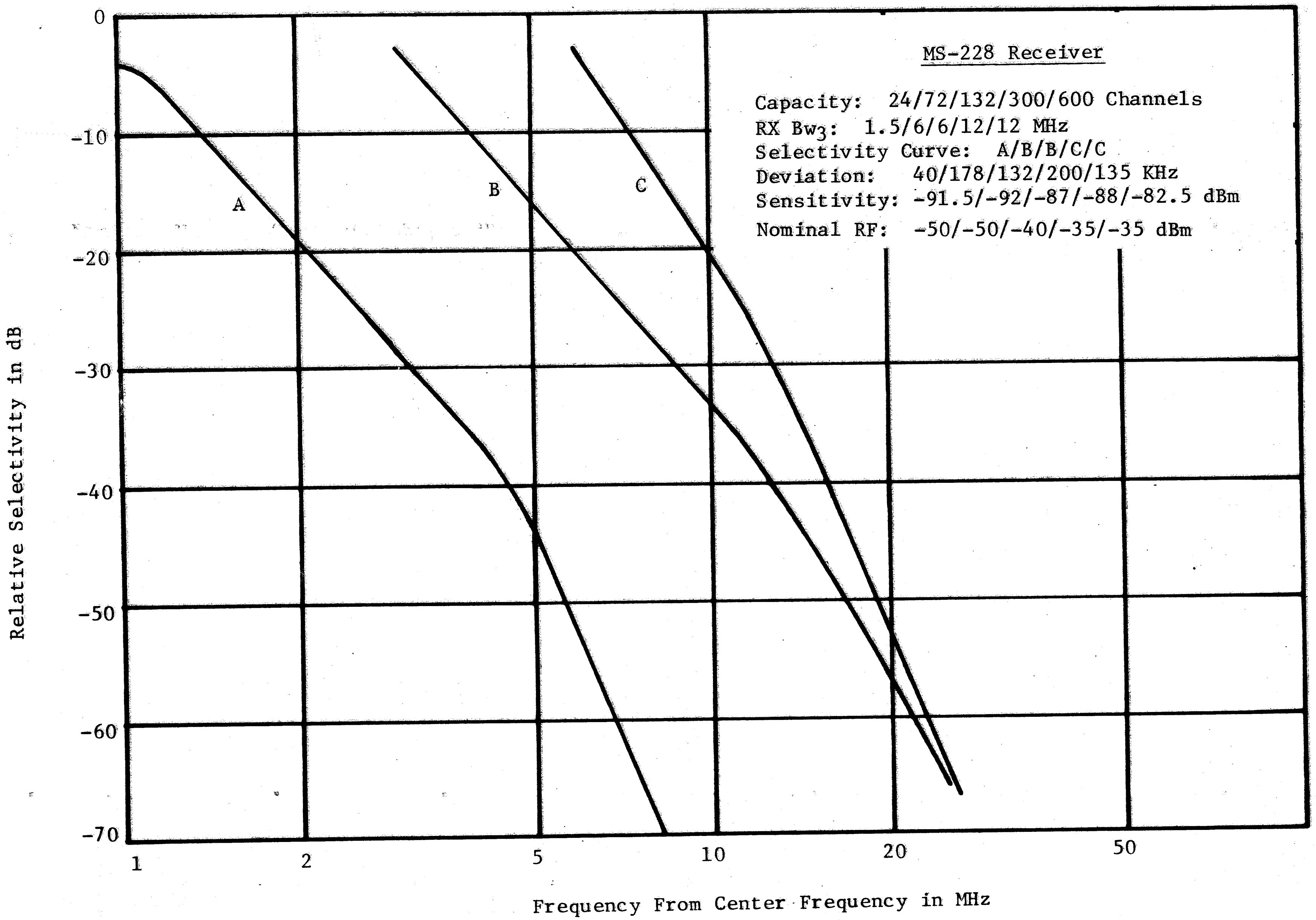

Figure B-3. Parameters for Collins MS-228 Receiver

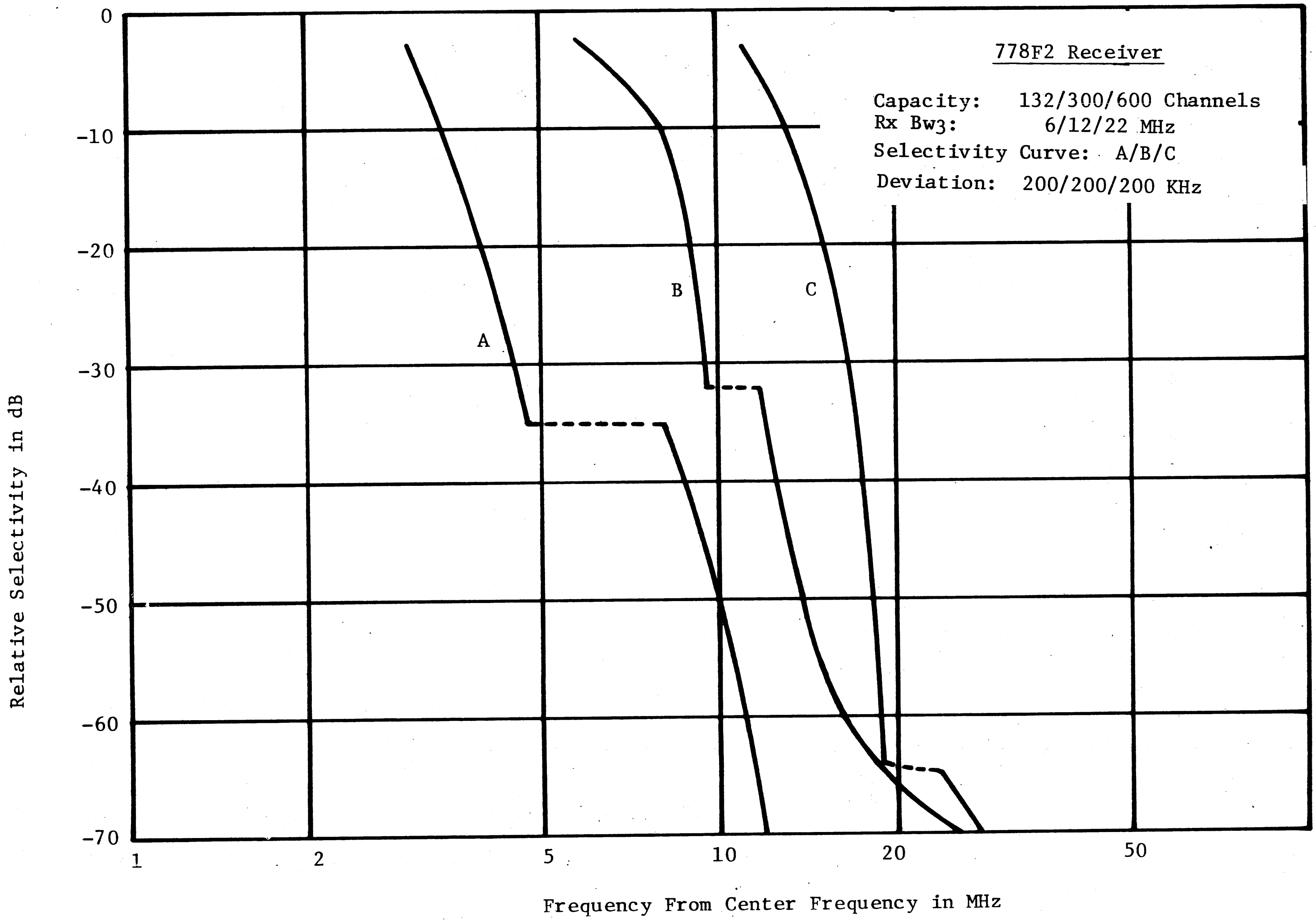

Figure B-4. Parameters for Lenkurt 778F2 Receiver

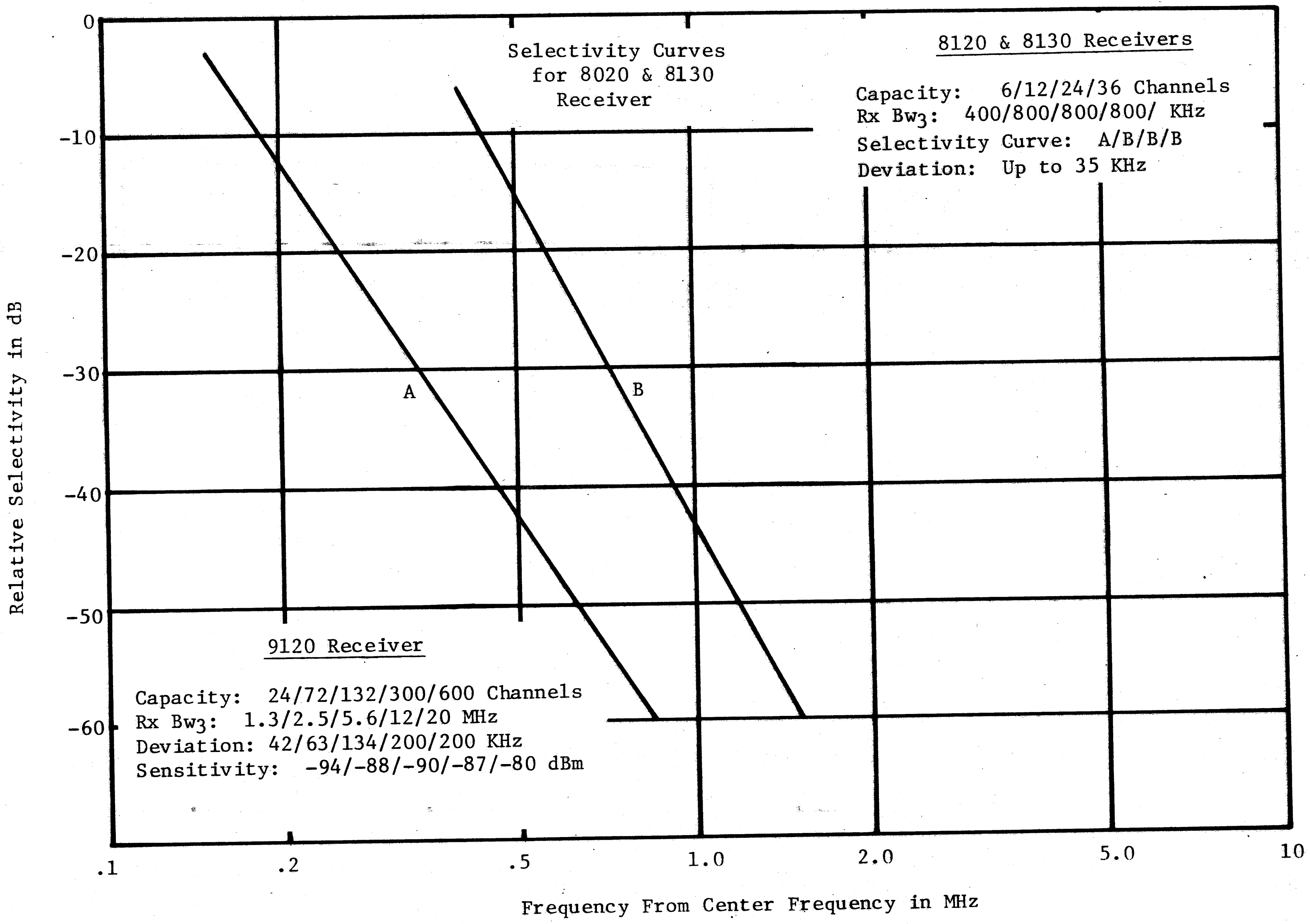

Figure B-5. Parameters for Cardion 8120, 8130, and 9120 Receivers

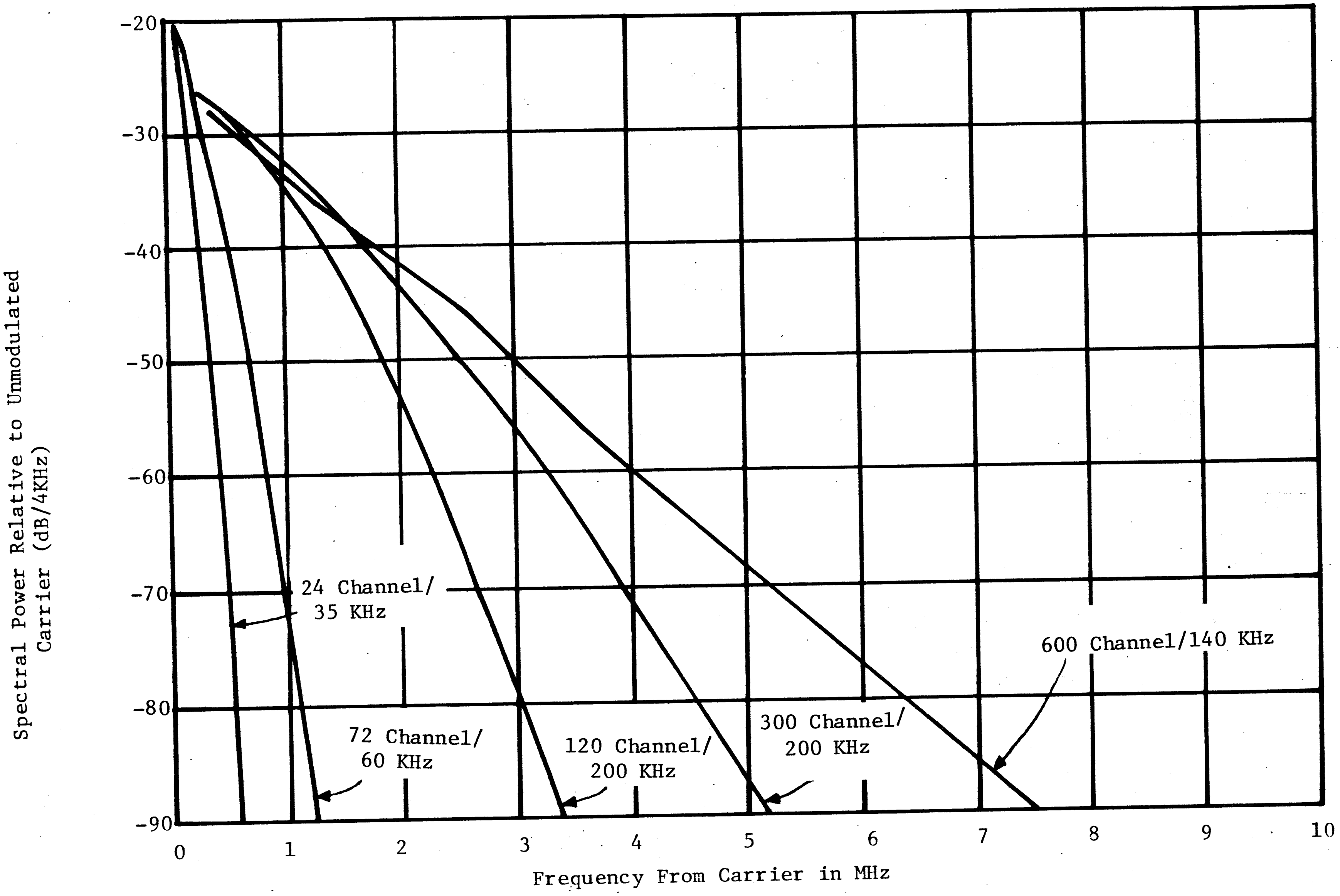

Figure B-6. Emission Spectrum for Various FDM/FM Modulations

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This report describes the spectrum resource assessment of the 1710-1850 MHz band. The Phase I Report provided information on frequency allocations, technical standards, spectrum usage and identification of key spectrum management issues. The key problem areas identified were the sharing between fixed and aeronautical mobile services, coordination of earth stations, accommodation of the Packet Radio systems, and congestion of certain geographic areas in the Continental U.S. This report examines these key issues and identifies improvements to the current spectrum management process to assure the efficient use of the limited available spectrum.

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