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SPECTRUM RESOURCE ASSESSMENT IN THE 5650-5925 MHz BAND

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont.)

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The authors would like to acknowledge the contribution of the EM Environment Characterization Group of NTIA. This group under the direction of Robert Matheson conducted the spectrum measurements, using the Radio Spectrum Measurement System (RSMS) contained in this report. They coordinated the location, made the measurements and reduced the measured data to a usable form.

ABSTRACT

This report constitutes a Spectrum Resource Assessment of the 5650-5925 MHz band. Included is information on rules and regulations, allocations, technical standards, frequency assignments, system characteristics, and applicable compatibility analysis. Problems of concern to the U.S. Government usage of the band are identified, analyzed and recommendations made. Major issues concerned the introduction of a Fixed-Satellite Service (FSS) in the band and current usage of that portion of the band designated for Industrial, Scientific and Medical (ISM) purposes. It is concluded that power limitations for radars should be considered as an option to minimize potential interference problems with satellites which may become operational in the 5850-5925 MHz portion of the band. It is also concluded that in-band radiation limits be considered for the Industrial, Scientific and medical designated frequency at 5800 ± 75 MHz to help protect Government investment and future Fixed-Satellite Service usage.

KEY WORDS

Amateur Service
Electromagnetic Compatibility
5650-5925 MHz
Fixed-Satellite Service
ISM
Radiolocation Service
Restricted Radiation Devices

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" [United States 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 among the telecommunication systems which belong to various departments and agencies, provide recommendations for resolving any compatibility conflicts which may exist in the use of frequency spectrum, and recommend changes to improve spectrum management procedures. This spectrum resource assessment considers the 5650-5925 MHz frequency band.

In the United States the 5650-5925 MHz band has been a shared band with the primary allocation assigned to the Government radiolocation service with an industrial, scientific and medical (ISM) designation at 5800 $\pm$ 75 MHz. Radio communication services operating within the ISM band must accept any harmful interference that may be experienced from the operation of ISM equipment. There is a secondary allocation to the amateur service; the amateurs must operate on a non-interference basis. Government allocation is for military radiolocation and is used for air-surveillance radar, transponder tracking, and positive aircraft guidance, missile and rocket tracking, telemetry, and ground facilities for development and testing of associated radio and radar equipment. There are only 21 non-Government assignments in the band and these are mainly assigned to developers and manufacturers of equipment and systems which support the Government effort in the band for test and evaluation purposes.

At the World Administrative Radio Conference (WARC) held in 1979, the portion of this band from 5850 to 5925 MHz was reallocated to the fixed, fixed-satellite (Earth-to-space), and mobile on a primary basis with radiolocation and amateur on a secondary basis in Region 2. An ad hoc commitee (Ad Hoc 172) of the Interdepartment Radio Advisory Committee (IRAC) was tasked to assess and make recommendations concerning the impact of WARC-79 on Government allocations. The IRAC has recommended adding non-Government Fixed-Satellite Service (FSS) (Earth-to-space) in the 5850 to 5925 MHz portion of the band on a co-equal primary basis with the Radiolocation Service. The IRAC has recommended the addition of U.S. Footnote 245, which states that the FSS is limited to international systems and subject to case-by-case electromagnetic compatibility analysis. Because of this proposed change effecting the 5650-5925 MHz band a spectrum resource assessment of the band was warranted.

The IRAC, at its meeting on March 23, 1982 established Ad Hoc 183 with the following terms of reference:

"To develop and recommend to the IRAC spectrum management procedures that will allow implementation of the Fixed-Satellite Service in the frequency bands 3600-3700 MHz and 5850-5925 MHz, consistent with the National Table of Allocations as implemented as a result of WARC-79.

To consider technical sharing parameters among airborne, shipborne, and terrestrial radar operations, and the proposed satellite systems.

To recommend to the IRAC an acceptable coordination procedure to be employed in siting the two earth terminals that are to be allowed (one on each Coast). In arriving at the proposed coordinated procedure, this Group shall recommend:

(1) The equipment characteristics to be used for coordination purposes;

(2) the propagation mode to be used in the coordination procedures; and,

(3) the specific interference criteria to be used for the fixed-satellite and Radiolocation/Radionavigation systems."

The outputs from this Ad Hoc Group are expected to give needed guidance to the users of the 5850-5925 MHz band in resolving future compatibility problems.

OBJECTIVES

To assist in the development of spectrum management plans and policies, the following objectives are identified for this spectrum resource assessment.

1. Review and document the characteristics and deployment of existing and proposed systems within the 5650-5925 MHz band, including those which could be expected in response to the results of WARC-79 and other international or national agreements.

2. Evaluate electromagnetic compatibility (EMC) interactions to identify and document the potential problem areas which may have an impact on the efficient use of the spectrum, and evaluate the feasibility of sharing between existing and proposed services.

3. Recommend specific changes to the existing rules, regulations and frequency management practices which would improve overall management of the band.

4. Identify and outline specific problem areas requiring additional analysis, if any.

APPROACH

In order to accomplish the objectives of the 5650-5925 MHz Spectrum Resource Assessment, the following approach was used:

1. Identify WARC-79 changes and national recommendations that impact the band.

2. Identify the systems that are currently operating in the band, where they are deployed, and their technical characteristics by:

   a. Using the Government Master File (GMF), the non-Government Master File (NGMF), previous NTIA reports, Systems Review File (SRF), and other Government reports to identify frequency assignments and usage for Government and non-Government operations.

   b. Contacting Government frequency managers, using surveys of major equipment manufacturers, users, and measured data.

3. Identify future systems proposed for the band by using data in the IRAC/SPS system review process for Government systems and equipment, and information supplied by the Electromagnetic Compatibility Analysis Center (ECAC) of the Department of Defense.

4. Review the compatibility analysis of systems within the 5650-5925 MHz band accomplished by other Government agencies and those analyses made in support of the IRAC system review process.

5. Assess the present band utilization using the Radio Spectrum Measurement System (RSMS) van data obtained at certain locations in the United States.

6. Identify and analyze the potential EMC problems in the band.

7. Identify remaining key issues, that affect spectrum management of the band and make recommendations for their resolution.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The 5650-5925 MHz band is presently used mainly by the Government (Military) Radiolocation Service. The main usage is by the various missile and rocket test ranges, Navy shipboard radars, and various land sites for air and sea defense search radars. There are a few non-Government assignments used by companies who develop systems or subsystems for the Government.

The Systems Review File shows eleven new systems under development from 1979 through 1981. There has been an increase in frequency assignments from 88 assignments in 1972 to 461 assignments in 1982. There has been a steady increase in band usage and new systems introduced in the band each year. Systems used in the 5650-5925 MHz band are considered crucial to the national defense by the various DOD agencies. There are a little over 1200 operating units corresponding to the frequency assignments.

For mobile land based radars and fixed site radars other than missile or rocket test ranges the use of frequencies in the band are coordinated through frequency management personnel of the various departments and agencies of the Government as listed in the Director of Field contacts for the coordination of the Use of Radio Frequencies, Section 3 (FCC, NTIA 1982). Shipboard radar frequencies are coordinated by fleet frequency management officers for best interfleet and ocean area compatibility. Missile and rocket test range frequency assignments and usage are coordinated by the various regional Area Frequency Coordinators (AFC) under the direction of the Range Commanders Council (RCC). Frequencies for given range operations are assigned on a daily basis, both intrarange and inter-range, for best compatibility between the various operating systems to be used in the exercises of that day.

Allocation changes adopted by WARC-79 resulted in proposed changes to the national allocation tables that affect the portion of the band from 5850-5925 MHz. The proposed change added the FSS (International systems up-link only) on a coequal primary basis with the Radiolocation Service. This change introduced potential problem areas which were analyzed and the conclusions are presented below.

General Conclusions

1. The 5650-5925 MHz band is a very important band for the military and to national defense systems. As shown in Figure 4 the band usage by the Government Radiolocation Service has grown steadily with a 43% growth from January 1979 through January 1982. Care must be taken to assure that new services introduced in the band do not hinder development of new systems vital to national defense or to cause harmful interference to present systems.

2. The band is well managed by Military Area Frequency Coordinators (AFC) and Military and Civilian government Frequency Management personnel.

3. The systems used in the band (predominantly radars and transponder systems) have the capability of tuning across most of the band.

4. Although there is an allocation, on a secondary basis to the amateur service, no use could be found in the band by the amateurs as corroborated by the American Radio Relay League (ARRL).

5. There is an ISM frequency designation at 5800 $\pm$ 75 MHz, but no usage could be found in the band by ISM equipment. Since the most active frequency area in the band is between 5760-5775 MHz (as seen in Figure 2) a potential problem could exist if ISM usage were to proliferate in the future.

6. There is some potential usage of the band by restricted radiation devices, but at present they do not pose a significant interference problem.

7. Most usage of the 5850-5925 MHz portion of the band is by transponders and various test equipment, but only represents 8% of band assignments.

8. International Satellite Systems (Intelsat VI) may be coming into the band from 5850-5925 MHz. For two existing INTELSAT Earth station sites at Jamesburg, CA and Andover, ME there appears to be potential compatible operation with the present Radiolocation Service as shown in the analysis of Section 6.

9. The measurements made by the RSMS showed this band to be fairly active particularly around coastal areas and the various missile and rocket test ranges.

Specific Conclusions

10. The analysis of interference potential between a typical in-band radar and an INTELSAT VI receiver as given in Section 6 shows that co-channel operation is not possible without restriction on either the radar or the proposed satellite receiver.

11. The distance separation requirements for sharing between the FSS uplink transmissions and radiolocation transponders, as given in Section 6, are such for the Jamesburg, CA and Andover, ME sites that compatible operation should be possible.

12. Frequency separation between the FSS and many radars in the band can be an effective EMC management tool. Many radars can operate up to 5820 MHz with powers under 500 kW. For those radars that have megawatt pulse power capabilities the frequency separation will have to be in excess of 100 MHz.

13. Radar such as the AN/FPS-16 have spurious emissions, some 70 to 150 MHz above the fundamental which could possibly pose a problem even with frequency off-set from the satellite fundamental. A waveguide filter at the output of the radar transmitter may be an effective method to minimize this potential problem.

14. Radars whose tracking angles may cause mainbeam-to-mainbeam coupling with a communication satellite in the 5850-5925 MHz portion of the band would have to be limited to radiated powers of 69.8 dBW if the satellite transponder carries FM/TV or 92.4 dBW if the satellite transponder system is limited to FDM/FM or similar modulations for compatible operation.

15. The probability of a tracking radar mainbeam intercepting a communication satellite in geostationary orbit is on the order of 1.5×10^{-3}.

16. Figure 25 indicates the required separation distance between a field disturbance sensor (a restricted radiation device) and a typical radar receiver. The separation distances within the band are on the order of 26 to 29 km. This could pose a problem for some areas if the use of this type of device were to proliferate in the band.

17. Figure 26 indicates the required separation distance between low-power communications devices as used for the measurement of characteristics of materials and a typical radar receiver. The impact of such devices when operated within the given tolerances would pose little, if any, problems within the band.

18. Based on the potential use of restricted radiation devices in the band there is a need for adherence to the non-interference status of such devices to assume protection to vital defense systems.

19. To protect Government radiolocation operations a footnote similar to US 7 limiting the power that the amateur satellite service can transmit from a satellite in their allocated down-link at 5830-5850 MHz may be desirable.

20. The ISM designation from 5725-5875 MHz with unlimited radiated electric field within this designation poses a potential problem to radiolocation systems if new ISM equipments were designed for and heavily used in the band.

RECOMMENDATIONS

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

It is recommended that:

1. The Ad Hoc 183 working group, which has been established by the IRAC to examine sharing between the Radiolocation and Fixed-Satellite Services, look at the issue involved in this SRA and consider using the sharing criteria developed in this report.

2. The Ad Hoc 180 of IRAC should recommend establishing in-band radiation limits in the proposed new ISM standards for the 5800 ± 50 MHz ISM frequency designation to help protect the Government investment and future FSS usage.

3. Limits on transmitted power from amateur satellites which will allow compatible operation with the Radiolocation Service should be determined after the amateur-satellite system is specified.

SECTION 3

RULES AND REGULATIONS

ALLOCATIONS

Prior to WARC 79, nationally, the 5650-5925 MHz band was allocated to the radiolocation service on a primary basis with the amateur service as secondary. There is an ISM band from 5725 to 5875 MHz, but at present there is very little use of this band for ISM purposes and nothing new planned for the near future as verified through the FCC.

Internationally, the allocations differ in that, from 5670-5725 MHz, deep space research is also a designated service on a secondary basis; 5725-5850 MHz is allocated to fixed-satellite (Earth-to-space) and radiolocation on a primary basis with amateur secondary in Region 1; and 5850-5925 MHz is now allocated to fixed, fixed-satellite (earth-to-space) and mobile on a primary basis in regions 1 and 3 with radiolocation as secondary in region 3.

The International Telecommunication Union (ITU) Radio Regulations, 1982, showed the agreed changes to the International Allocation Table as an output of WARC 1979. The IRAC recommended a new national frequency allocation table reflecting the ITU impacts. The United States did not accept certain decisions made by the WARC 79 and added protocol No. 38 to the Final Acts of the WARC 79 which stated in item 3 concerning this band "In the operation of stations in the Radiolocation Service on a primary basis in the band 430-440 MHz; 5650-5850 MHz..., cannot guarantee protection to or coordination with others services;". Table 1 shows the pre-WARC-79 international and National Allocation Table for the 5650-5925 MHz band in effect in 1981. Table 2 shows the new international and national frequency allocation table for the band as recommended by IRAC to become effective in 1982. There has been a change in the numbering system for the international footnotes, i.e., old footnote 320A has been modified and is new footnote 3644, old footnote 391 is now new footnote 3760.

Internationally, the 5850-5925 MHz portion of the band was redesignated to the Fixed, Fixed-Satellite (Earth-to-space) and Mobile Service on a co-equal primary basis with amateur and radiolocation as secondary in Region 2. Nationally, the IRAC has recommended adding non-Government Fixed-Satellite Service (Earth-to-space) in the 5850-5925 MHz portion of the band on a co-equal primary basis with the Radiolocation Service. The IRAC has also recommended adding U.S. 245 which states that the Fixed-Satellite Service is limited to international systems and subject to case-by-case electromagnetic compatibility analysis. The IRAC has also recommended only two sites, one on each coast. The rationale for IRAC recommendations comes from the U.S. position as outlined in the Department of State correspondence to the Communications Satellite Corporation that is copied in Appendix C.

WARC-79 granted the following new amateur-satellite allocations; 5650-5670 MHz (Earth-to-space) and 5830-5850 MHz (Space-to-Earth). Within the United States there is little or no use of this band by the amateurs. There are plans to develop an amateur capability in this band, but a program similar to OSCAR (ARRL, 1982) is needed before this can be accomplished. Of course, any developments along this line imply non-interference to any system operating on a primary basis within the 5650-5925 MHz band.

TABLE 1

PRE WARC-79 FREQUENCY ALLOCATIONS FOR THE 5650-5925 MHz BAND

INTERNATIONAL			UNITED STATES			
Region 1 MHz	Region 2 MHz	Region 3 MHz	Band MHz 1	National Provisions 2	Government Allocations 3	Non-Government Allocations 4
5470-5650 MARITIME RADIONAVIGATION Radiolocation 386 387			5470-5600	G, NG US50 US65	MARITIME RADIONAVIGATION Radiolocation G56	MARITIME RADIONAVIGATION Radiolocation
			5600-5650	G, NG 387 US51 US65	MARITIME RADIONAVIGATION METEOROLOGICAL AIDS Radiolocation G56	MARITIME RADIONAVIGATION METEOROLOGICAL AIDS Radiolocation
5650-5670 RADIOLOCATION Amateur 388 389			5650-5925 (ISM 5800 ± 75 MHz)	G, NG 391 US 34 US 100	RADIOLOCATION G2	Amateur
5670-5725 RADIOLOCATION Amateur Space Research (Deep Space) 388 389 389A						
5725-5850 FIXED-SATELLITE (Earth-to-Space) RADIOLOCATION Amateur 354 388 390 391 391A	5725-5850 RADIOLOCATION Amateur 389 391 391A					
5850-5925 FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE 391	5850-5925 RADIOLOCATION Amateur 391	5850-5925 FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE Radiolocation 391				
5925-6425 FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE			5925-6425	NG		FIXED FIXED-SATELLITE (Earth-to-Space) NG41

Footnotes Applicable to the 5650-5925 MHz band in the U.S.

391 - The frequency 5800 MHz is designated for industrial, scientific and medical purposes. Emissions must be confined within the limits ± 75 MHz of that frequency. Radiocommunication services operating within those limits must accept any harmful interference that may be experienced from the operation of ISM equipment.

US34 - The only non-Government service permitted in the bands 220-225 MHz, 1215-1300 MHz, 2300-2450 MHz and 5650-5925 MHz is the amateur service. The amateur service shall not cause harmful interference to the radiolocation service.

G2 - In the bands 216-225, 420-425, 1300-1400, 2300-2450, 2700-2900, 5650-5925 and 9000-9200 MHz, the Government radiolocation is limited to the military services.

TABLE 2

PROPOSED POST WARC-79 FREQUENCY ALLOCATIONS FOR THE 5650-5925 MHz BAND

INTERNATIONAL			UNITED STATES			
Region 1 MHz	Region 2 MHz	Region 3 MHz	Band MHz 1	National Provisions 2	Government Allocations 3	Non-Government Allocations 4
5650-5725 RADIOLOCATION Amateur Space Research (Deep Space) 664 801 803 804 805			5650-5850 (ISM 5800 ± 75 MHz)	664 806 808	RADIOLOCATION G2	Amateur
5725-5850 FIXED-SATELLITE (Earth-to-Space) RADIOLOCATION Amateur 801 803 805 806 807 808	5725-5850 RADIOLOCATION Amateur 803 805 806 808					
5850-5925 FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE 806	5850-5925 FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE Amateur Radiolocation 806	5850-5925 FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE Radiolocation 806	5850-5925	806 US245	RADIOLOCATION G2	FIXED-SATELLITE (Earth-to-Space) Amateur

Footnotes Applicable to the 5650-5925 MHz band in the U.S.

664 - In the bands 435-438 MHz, 1260-1270 MHz, 2400-2450 MHz, 3400-3410 MHz (in regions 2 and 3 only), 5650-5670 MHz, the amateur-satellite service may operate subject to not causing harmful interference to other services operating in accordance with the Table (See new 435). Administrations authorizing such use shall insure that only harmful interference caused by emissions from a station in the amateur-satellite service is immediately estimated in accordance with the provisions of No. 2741. The use of the bands 1260-1270 MHz and 5650-5670 MHz by the amateur-satellite service is limited to the Earth-to-Space direction.

806 - The band 5725-5875 MHz (center frequency 5800 MHz) is designated for industrial, scientific and medical purposes. Communication services operating within this band must accept harmful interference which may be caused by these applications. ISM equipment operating in this band is subject to the provisions of No. 1815.

808 - The band 5830-5850 MHz is also allocated to the amateur-satellite service (space-to-earth) on a secondary basis.

G2 - In the bands 216-225, 420-450 (except as provided in US217), 890-900, 928-945, 1300-1400, 2300-2450, 2700-2900, 5650-5925, and 9000-9200 MHz, the Government radiolocation is limited to military services.

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

The major portion of this band is now occupied by Government radiolocation limited to the military service for radar tracking, to transmit command signals to airborne vehicles being tracked, and to receive status information from the vehicles. Military telemetering and terrestrial telecommand operations are authorized in the bands when conducted as an integral part of the operation of authorized stations in the radiolocation service. Such telemetering and terresterial command operations are conducted on a secondary basis to the authorized stations operating in accordance with the national table of frequency allocations.

SUMMARY OF WARC-79 CHANGES

The WARC-79 changes in the international allocations and resultant changes in the national allocations will have a significant impact on the development of future systems and planning for the 5650-5925 MHz band. In region 2, prior to WARC-79, radiolocation was the primary service. Nationally, the band was allocated exclusively to the Government (military) Radiolocation Service on a primary basis. Many of the radar systems in the band were designed to tune across the entire band. With the 5850-5925 MHz portion of the band now allocated to radiolocation and fixed-satellite service on a shared co-equal basis, essentially that 30 percent of the band may require restricted operations by the large power radars (500 kW and above). New radar systems with like powers may not be able to be designed to operate in this upper portion of the band because of EM incompatibility with the FSS. Section 6 analyzes the impact, and Section 7 discusses the resultant frequency management issues.

The WARC-79 allocations also show the amateur-satellite service at 5650-5770 MHz limited to the Earth-to-space direction and 5830-5850 MHz for the space-to-Earth direction, all on a secondary basis. Coordination by the amateur-satellite stations with, and under, conditions established by the DOD Area Frequency Coordinators in the area of certain test ranges may be necessary to protect Government radiolocation operations.

TECHNICAL STANDARDS

The general technical standards, which are more stringent than those specified in the ITU Radio Regulations, of Chapter 5 of the NTIA Manual contain minimum performance requirements and design objectives applicable to transmitters, receivers, and antennas used in Government radio services. As of January 1979, stations transmitting in the 5650 to 5925 MHz band are required by Section 5.2.3 to have frequency and spurious tolerances as follows:

STATION TYPE	FREQUENCY TOLERANCE (Parts per Million)	SPURIOUS TOLERANCES (See Notes)
1. Radionavigation Stations		
1.1 radar	1250	J
1.2 other than above	1250	E
2. Radiolocation Stations		
2.1 radar	1250	J
2.2 other than above	1250	E
3. Earth Stations	20	K
4. Space Stations	20	K

Existing systems in the space service, replacement equipment for those systems, and a new system designed or in process of being designed as of 11/24/70 may have a tolerance no greater than 50 ppm.

Spurious Tolerance

E The standards for spurious signals which limit the mean power of any emission supplied to the antenna transmission line, as compared with the mean power of the fundamental, shall be in accordance with the following:

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

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

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

J The spurious tolerances for radionavigation radars and radiolocation radars in the 5650-5925 MHz band are found in Sections 5.3.1 and 5.3.2 (Radar Spectrum Engineering Criteria) of the NTIA Manual.

K Development of spurious tolerances is pending.

RADAR STANDARDS

Radar Spectrum Engineering Criteria (RSEC) apply to Government radar systems. RSEC specifications are contained in Part 5.3 of the NTIA Manual [NTIA, Sept. 1981]. The specific technical requirements of RSEC for the 5650-5925 MHz band fall under the Group B and C categories of radars. The details for computing emission bandwidth and emission level, as well as the criteria for antenna pattern, frequency tolerance, tunability, rejection of spurious responses, and measurement accuracy, are given in Sections 5.3.1 through 5.3.3 of the RSEC.

Along with the above technical standards, other standards have been developed by the Inter-Range Instrumentation Group (IRIG) under the Range Commanders Council which are applicable to this band. Since the various rocket and missile test ranges are users of this band, they have organized groups under the Range Commanders Council to manage the radio frequency spectrum assigned for their use and to set standards for the major systems and subsystems which use that spectrum to insure compatibility.

Following is a list of some of the IRIG documents that have been issued as guidelines and/or standards for systems used in the 5400-5900 MHz band.

IRIG Document 101-65	"Frequency Standards for Radar Beacons."
IRIG Document 103-65	"IRIG Standard for PRF and Reference Oscillator Frequency for C-Band Radars."
IRIG Document 105-74	"IRIG Tracking Radar Compatibility and Design Standards for G-Band (4 to 6 GHz) Radars."
IRIG Document 114-69	"Doppler and Coherent Radar Standards."
IRIG Document 115-69	"Noncoherent C-Band Transponder Standards."
IRIG Document 116-69	"Inter-Range Radar Synchronization for Global Tracking."

Also MIL-STD-469 was adopted prior to the RSEC (Part 5.3 of the NTIA Manual). Therefore, the RSEC requirements were not considered in the design of some of the systems which came into existence earlier in the band. The Department of Defense uses MIL-STD-469 as a guide for compliance and a reference for procurement of its radars. The Navy is presently taking the lead in updating this Standard. This standard entitled "Radar Engineering Design Requirements, Electromagnetic Compatibility" sets forth engineering design requirements to control spectral characteristics of all new radars operating between 100 MHz and 40 GHz. The MIL-STD-469 also outlines the measurement procedures that are required. In general, the criteria outlined in the MIL-STD-469 are more stringent than those given in RSEC. One of the distinguishing features of MIL-STD-469 is that it requires measurements for compliance. The Technical Subcommittee of IRAC is presently investigating the utility of incorporating similar measurement requirements into the RSEC. It should be mentioned that the requirement of "measurement for compliance" discussed in the MIL-STD-469 is generally for the purpose of DOD procurement. However, the purpose of incorporating the measurement requirements into the RSEC is to develop recommended measurement procedures for each of the thirteen equipment parameters defined in the RSEC (Farrar, 1981).

AMATEUR STANDARDS

Prior to WARC-79 there were no specific international standards for spurious emissions from transmitters operating above 235 MHz. The Conference extended these standards for all services, including the Amateur and Amateur-Satellite Service, to 17.7 GHz. New transmitters installed after January 1, 1985, and all transmitters operating after January 1, 1994, will be required to have their spurious emissions suppressed as follows (where two limits are expressed, the more stringent of the two applies):

960 MHz to 17.7 GHz	
Mean power above 10 watts	50 dB or 100 mW
Mean Power 10 watts or less	100 μW

Frequency tolerance standards do not apply to amateur stations, because they are not assigned to specific channels. Instead, amateur stations simply are required to confine their emissions to the allocated band and to use the minimum bandwidth consistent with good engineering practice.

ISM STANDARDS

The technical standards for Industrial, Scientific, and Medical (ISM) equipment are specified in section 7.10 of the NTIA Manual of Regulations and Procedures and in Part 18 of the FCC Rules and Regulations (CFR 47, 1977a). For the frequency band 5650-5925 MHz the ISM frequency band assigned is: 5800 $\pm$75 MHz.

Although there are at present no known uses of this designated frequency, the following standards are applicable for any planned future use:

1. Industrial Heating equipment shall be adjusted to operate as close to the ISM frequency as practical. Outside of the assigned band, the average electric-field at a distance of one mile must be less than 10 μV/m; within the band there is no limit on the radiated electric field.

2. Medical Diathermy equipment may be operated on the 5800 $\pm$75 MHz frequency with no limit on the radiated electric field within the band. However, any harmonic or spurious radiation outside of the $\pm$75 MHz limits shall not exceed an average electric field of 25 μV/m at a distance of 1000 feet.

3. ISM equipment of all other types may be operated on the ISM frequency provided any harmonic or other spurious radiation outside of the frequency limits is suppressed, i.e., so as not to exceed 15 μV/m at a distance of 1000 feet; or for a radiated power (P) of more than 500 Watts of RF power on the fundamental frequency, 15 μV/m times a factor equal to the square root of P/500, but not to exceed 10 μV/m at a distance of one mile.

Proposed Changes to ISM Standards

The FCC issued a Notice of Proposed Rule Making (NPRM) requesting comments for revising Part 18 governing industrial, scientific and medical equipment (FCC, 1978). There is a second NPRM being drafted at this writing based on comments from the first NPRM. The primary concern of the FCC NPRM is the effect of ISM operation on radio communication. Some of the reasons, identified by the FCC, for revising Part 18 are:

(a) ISM equipment is considered to be the largest source of man made radio noise.

(b) Present limits are inadequate to protect future communication needs. ISM limits are out of line with limits for other equipment.

(c) Requests for tighter limits have been made.

(d) Present ISM specifications are much more liberal than those imposed by other administrations.

(e) Present equipment approval procedure requires clarification.

(f) Responsibility for compliance requires clarification.

(g) Present test procedures are inadequate.

(h) Present equipment classifications are difficult to apply." (FCC, 1978).

The FCC proposed rules in the NPRM are based on the International Special Committee on Radio Interference (CISPR) recommendations on ISM (CISPR, 1975). Significant proposed changes deal with reduced frequency tolerances, in-band and out-of-band emission limits.

Restricted Radiation Devices

Technical standards for restricted radiation devices are included in Part 7.9 (NTIA, 1979) and Part 15 of the FCC Rules and Regulations (CFR 47, 1977b). This class of devices includes field-disturbance sensors and low-power communication equipment. Non-Government users operating such devices in accordance with the standards are exempt from license requirements and Government users do not require a frequency assignment. In any case, all operations of restricted radiation devices are on a non-interference basis to authorized services.

1. Field Disturbance Sensors: These devices may operate at 5800 MHz with a frequency tolerance of $\pm$15 MHz. The carrier frequency is recommended to be kept within the central 80 percent portion of the band. At 100 feet, the average field strength for 5800 MHz is not to exceed 50,000 μV/m.

2. Low-Power Communication: These types of devices in the frequency band 5725-5875 MHz may be used for measurement of characteristics of materials provided that the device shall not be used for voice communication or for the transmission of any other type of message; and the maximum level of emission from the device shall not exceed 500 μV/m at 100 feet on the fundamental frequency, 50 μV/m at 100 feet on harmonic frequencies, and 15 μV/m at 100 feet on any other frequency.

SATELLITE COMMUNICATIONS

In November of 1981, the FCC released a Notice of Proposed Rulemaking (FCC, 1981) to make revisions and additions to Part 25 which concerns Satellite Communications. These revisions and additions are intended to update definitions, available frequency bands and other technical standards to conform them to the current National Table of Frequency Allocations and International Radio Regulations. This new revision will speak to the International Satellite Systems to be implemented in the 5850-5925 MHz band. Further rulemaking will be performed in the course of implementation of the Final Acts of the 1979 WARC.

SECTION 4

MAJOR SYSTEMS AND SPECTRUM USAGE

INTRODUCTION

The major portion of the 5650-5925 MHz band has been allocated to the Government (military) Radiolocation Service. There is an ISM designated frequency at 5800 ±75 MHz which, at present, has no documented use. There is an allocation to the amateurs on a secondary basis but no documented use could be found. New allocations to the Amateur-Satellite Service have been proposed as a result of WARC-79 action. There is an up-path allocated at 5650-5670 MHz and a down-path at 5830-5850 MHz both on a secondary non-interference basis. Because this is a new service in the band there is no usage at this time and it will most likely be some years in the future before a satellite with amateur channel assignments will be operable in the 5650-5925 MHz band.

All military services have equipments operating in the band which are considered essential to their basic responsibilities to the national defense. NASA and DOE also have a few systems, primarily radiolocation, operating in this band. There are also a few experimental assignments to Government contractors who conduct research in support of systems development in the band.

The sources of data to identify users and uses within the band are primarily:

- The Government Master File (GMF)
- The Non-Government Master File (NGMF)
- The Systems Review File (SRV)
- Interdepartment Radio Advisory Committee (IRAC)
  - Records and Documents
- Electromagnetic Compatibility Analysis Center (ECAC)
  - Operational Platform Allocation File (OPAF)
  - Nominal Characteristics File (NCF)
  - Frequency Allocations File (FAL)
  - Reports and Documents
- American Radio Relay League (ARRL)
- Contacts with various agency personnel.

The new proposed national table of allocations reflect WARC-79 changes in this band and allocates the 5850-5925 MHz portion of the band to the Non-Government Fixed-Satellite Service on a co-equal primary basis with Government Radiolocation Service. This will change the present characteristics of the band since most of the systems operating in the band have the capability of tuning across the entire band as shown in Figure 1. Figure 1a. shows the unclassified radars in the band and their tuning ranges. New systems being developed for the band should now take the FSS into account while in the development stages so that compatibility can be achieved.

SPECTRUM USAGE

The present usage in the 5650-5925 MHz band is summarized in Table 3. The data used for this table and associated figures were taken from the Government Master File as of February 17, 1982. Of the 461 assignments shown, 222 are

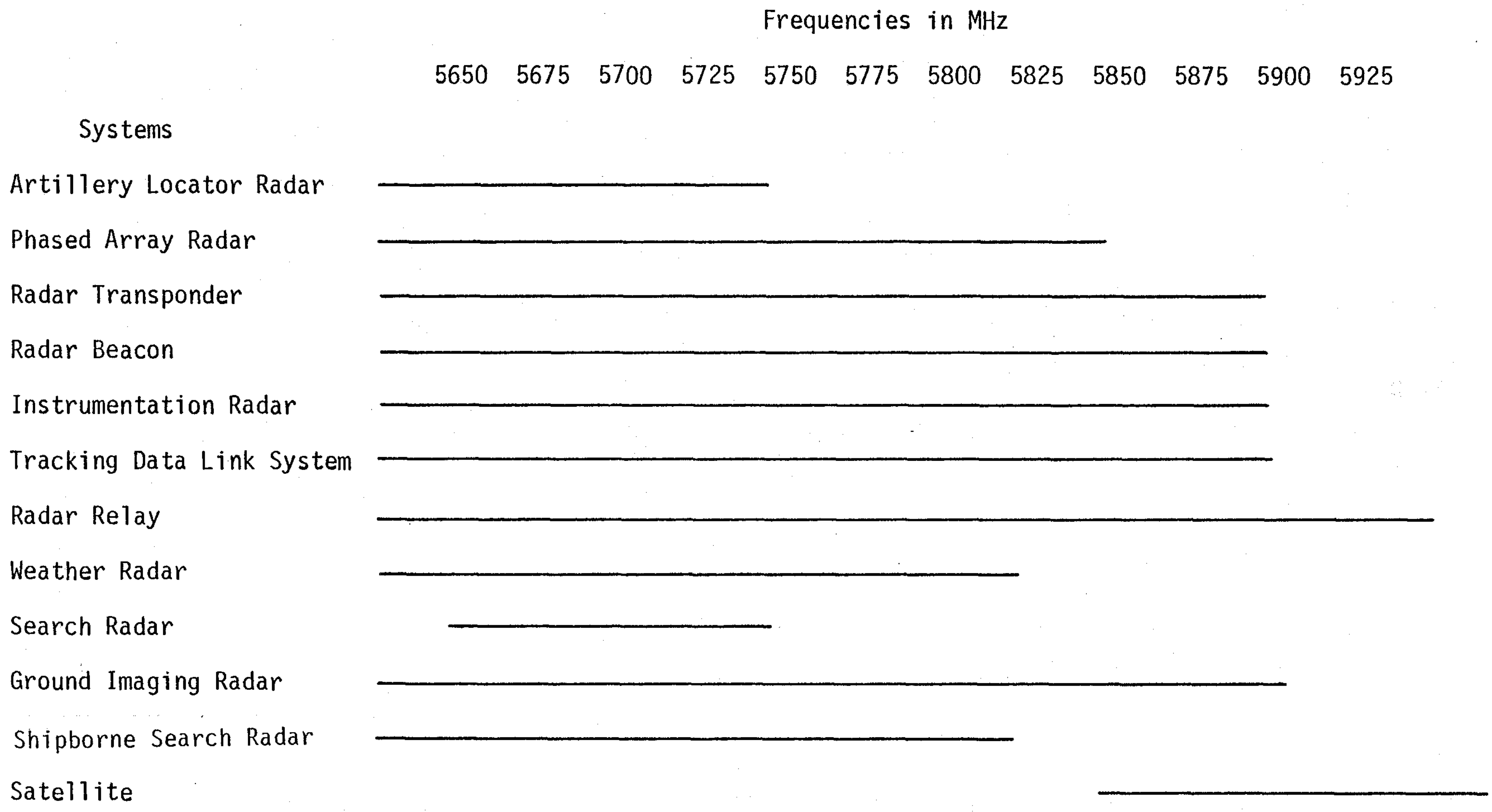


Figure 1. Tuning Range Capabilities of Typical Major Systems

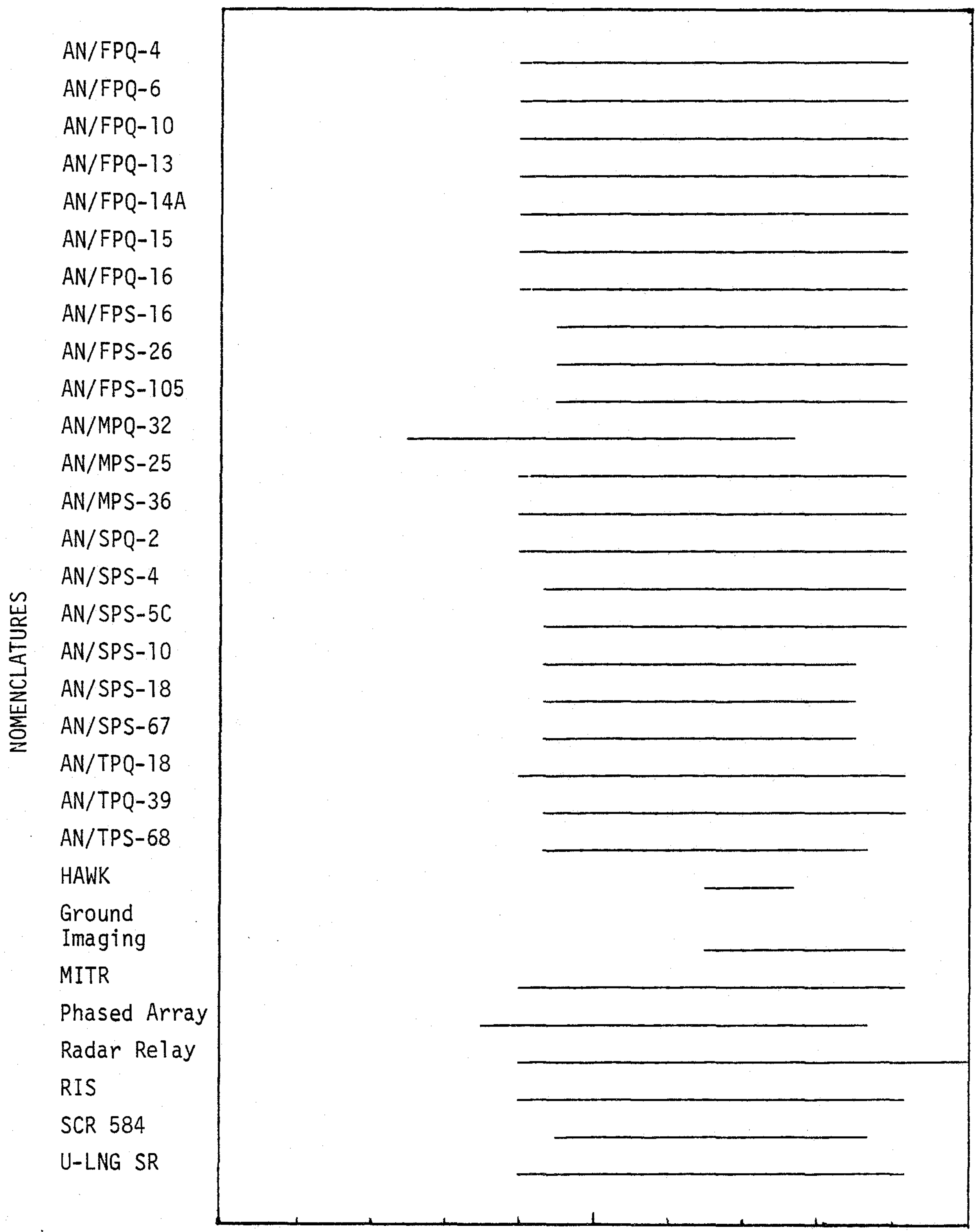


Figure 1a. Tuning Frequency Range for Unclassified Operational Radars in the 5650-5925 MHz band.

Table 3. Government and Non-Government Assignments in the 5650-5925 MHz Band*

AGENCY/SERVICE	STATION CLASS											NUMBER OF ASSIGNMENTS	PERCENTAGE OF ASSIGNMENTS
	LR	MR	RO	MOB	FLD	MOEA	RLS	XC	XD	XR	XT		
AIR FORCE	52	99		17	7	7		4		1	21	208	45%
ARMY	28	68	15				3	4		3	6	127	27.5%
DOE	2	15									5	22	5%
NAVY	24	29		1				1			18	73	16%
NASA	5	4								1		10	2%
NON-GOVERNMENT								6	8	7		21	4.5%
NUMBER OF ASSIGNMENTS	111	215	15	18	7	7	3	15	8	12	50	TOTAL 461	
PERCENTAGE OF ASSIGNMENTS	24%	47%	3%	4%	1.5%	1.5%	0.7%	3%	1.7%	2.6%	11%		

LR - Radiolocation Land Station
MR - Mobile Radiolocation Station
RO - Radionavigation Mobile Station
MOB - Radio Beacon Mobile Station

MOEA - Aeronautical Telemetering Mobile Station
RLS - Surveillance Radar Station
FLD - Telecommand Land Station

XC - Experimental Contract Dev.
XD - Experimental Dev. Station
XR - Exp. Research Station
XT - Exp. Testing Station

*The number of assignments does not represent the actual number of equipments in operation.

listed in the GMF in the 5250-5925 MHz band and can range tune or have assigned operational frequencies by the operating agency anywhere in the band. There are 239 actual assignments in the 5650-5925 MHz band given by GMF. Of the 461 total assignments, 50 are classified and 21 are non-Government contractors. As can be seen, the major users are the military for radiolocation purposes. The experimental assignments (those station classes with an X prefix) deal with research and development and/or test and evaluation of new or modified radiolocation equipment and system and represent 18% of the assignments. Internationally there are operational radars in this band would could include some foreign ships in U.S. waters.

The distribution of frequency assignments from the 5650-5925 MHz GMF, in 5 MHz increments, is shown in Figure 2. This figure does not reflect the 78 range tuned systems from the 5400-5900 MHz band. However, there is some useful information to be gained from such a figure. Of the 383 assignments 85% are between 5650 and 5800 MHz. This is important since the FSS to be operable in the 5850-5925 MHz portion of the band has a better chance for compatible operation with the Radiolocation Service, the larger the frequency separation from active radar systems. There are 55% of the assignments between 5725 and 5875 MHz which are within the ISM frequency designation of 5800 $\pm$ 75 MHz. The distribution of frequency assignments does not represent the total number of equipments or systems operational in the band. Although the location and numbers of some equipments and systems are not available, there are approximately 1200 systems that operate in the 5650-5925 MHz band in the United States.

Figure 3 shows the geographical distribution of the Government frequency assignments in the 5650-5925 MHz band including the range tuned systems from 5250-5925 MHz. The map does not show locations of mobile radars or reflect shipboard use. The major fixed site users are concentrated in the Southwestern portion of the country, mainly California, Nevada, Arizona, and New Mexico. Besides the Government assignments in CONUS there are a number of assignments on islands which constitute the Eastern Down Range Tracking Facility out of the Kennedy Space Flight Center, Florida, such as Grand Bahama Island, Grand Turk, and Bermuda Islands. There are other tracking facilities representing the Pacific Missile Range operations. Woomera, Australia and Pretoria, South Africa, are part of the worldwide space tracking network.

Figure 4 shows the 10 year growth trend for the 5650-5925 MHz band from January 1972 to January 1982. The number of assignments have increased steadily over this period with a 62% increase occurring over the last 5 years. Increased use by the U.S. Air Force accounted for most of this growth trend. This plot shows the trend and does not include range tuned equipments or represent numbers of equipment in operation, but is representative of assigned frequencies in the band 5650-5925 MHz. The SRV shows 12 new systems in development and/or test and evaluation stages in the band over the past 3 years. This includes the AN/TPS-68, Vega 374C, the Aircraft Security Radar System, and AN/SPS-67 systems. This is a band which continues to show growth in Government use, and in checking with the various agencies and departments involved, this trend should continue.

Use of the ISM band at 5725-5875 MHz is very uncertain since there is no licensing requirement by the FCC and no detailed records are kept. However, no documented use of ISM equipment in this band could be found and there is no indication that ISM equipment is being manufactured for the band. There is major use of these frequencies by the Government Radiolocation Service.

Restricted radiation devices may operate in the band as given in Section 3. However, due to the in-band emission limits and the non-interference basis, these systems must conform to standard spectrum management techniques and should keep interference potential to a minimum.

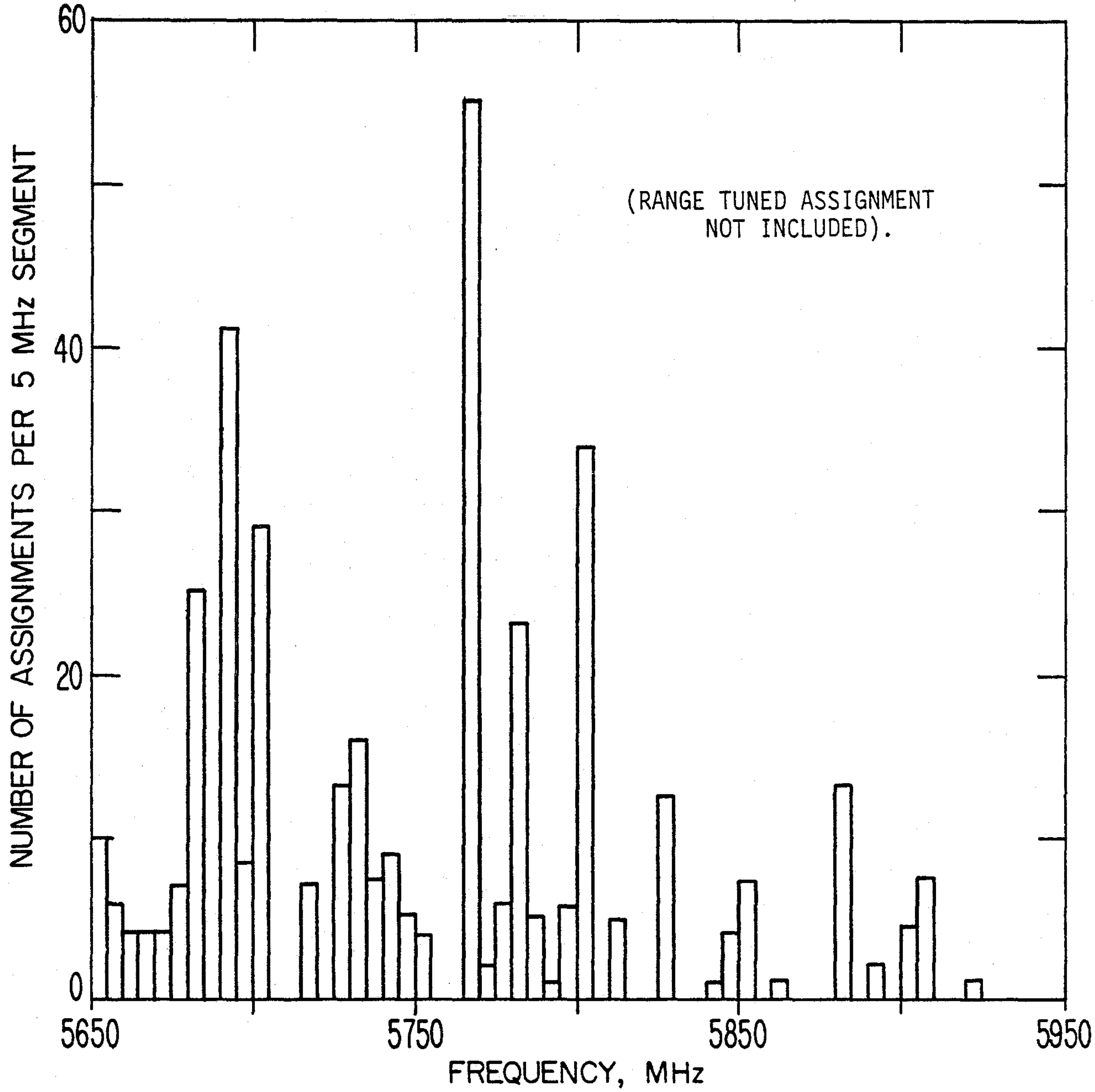


Figure 2. Distribution of Frequency Assignments and 5 MHz Increments between 5650-5950 MHz.

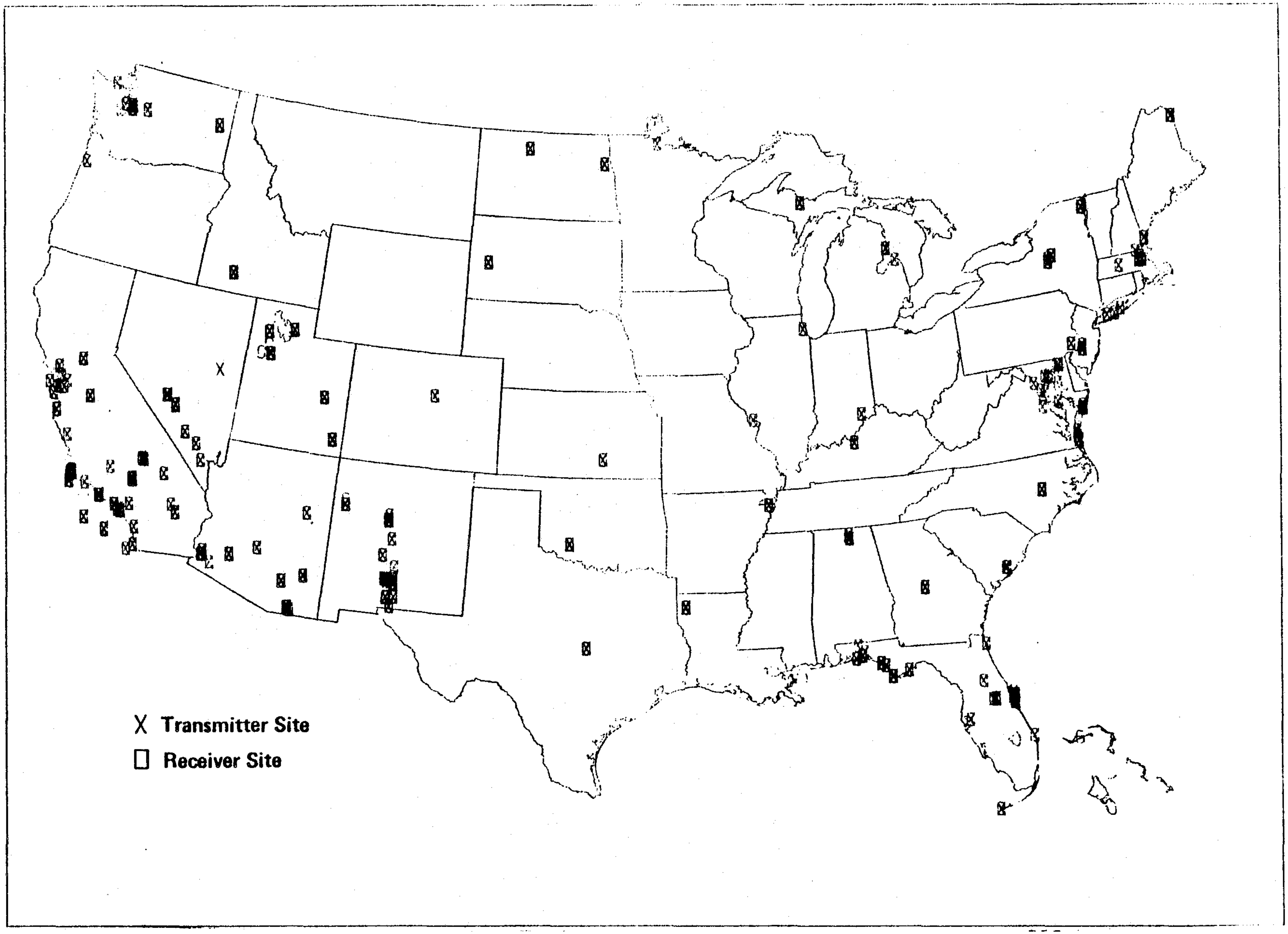


Figure 3. Geographic Distribution of Government Frequency Assignments in the 5650-5925 MHz Band.

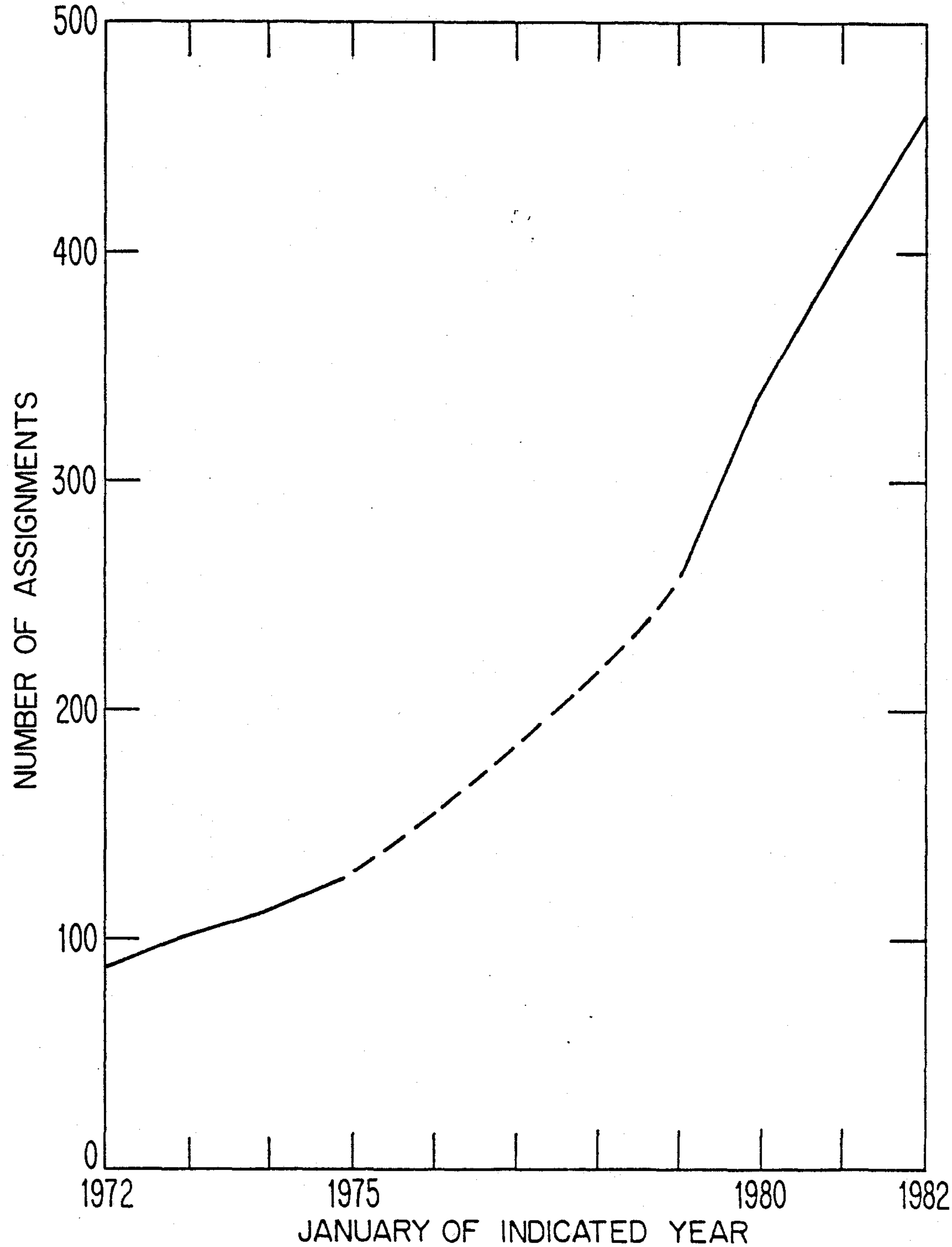


Figure 4. Growth Trend for the 5650-5925 MHz Band

RSMS MEASUREMENTS

There were measurements made by the RSMS Van in the 5650-5925 MHz band in 10 different areas of CONUS. Measurements were made from December 1974, in the Los Angeles, California area to various places including the East Coast and the latest at Seattle, Washington in 1982. There were active radars measured at San Diego, Seattle, Los Angeles, San Francisco, and WSMR sites. The WSMR is by far the most active measured area in the band. Most port areas such as San Diego, Los Angeles, and San Francisco measured Navy shipboard radars such as the AN/SPS-10 and AN/SPS-4. Figures 5 through 8 show typical occupancy measurements in San Diego, White Sands, and Seattle area for the frequencies from 5600-5925 MHz. In Figure 5 the first peak at 5513 MHz is an AN/SPS-10 shipboard radar. The peak at 5630 MHz is a weather radar and the other larger peaks are shipboard radars. Figure 9 is another AN/SPS-10 radar showing its measured antenna pattern which is useful in the type of analysis as given in Section 6 of this report.

The antenna pattern measurement program measures the peak energy received from the radar in 500 equally-spaced measurement periods. These 500 periods are timed so that the total measurement time matches a measurement time selected by the operator. The operator chooses a measurement period and starts the system, so that the measurements are made over an interval beginning just before the mainbeam of the radar is seen and ending slightly after the succeeding mainbeam has passed. These two mainbeams are assumed to be 0° and 360°, and the rest of the measurement points are assigned an antenna angle by interpolation. Similarly, the elapsed time for the block of 500 measurements is precisely measured, and the time between mainbeams is computed.

Several statistics are measured for the antenna pattern, including the average level for the entire pattern (between 0° and 360°), the average level for the sidelobes (between 3° and 25° and between 335° and 357°), and the average for backlobes (between 25° and 335°). In addition, the measurement frequency is printed out and the time elapsed between the mainbeams is calculated and printed.

The antenna patterns are plotted relative to the power received at 0°, so the pattern is actually plotted in terms of dB below mainbeam gain. In addition, a statistical antenna pattern, Figure 10, is plotted, which shows how much of the time the antenna pattern is suppressed certain amounts below the mainbeam. This sort of plot furnishes an EMC figure of merit for the antenna, since it tends to show what chance there would be for the antenna to radiate or receive interference on its sidelobes or backlobe if it were operated in a multi-radar environment.

Figure 11 shows the emission spectrum (short pulse mode) for the AN/SPS-10 a common shipboard radar. Figure 12 shows the same radar emission spectrum using long pulse mode. Figure 13 shows the emission spectrum for the AN/FPS-16, a common radar on the various missile and rocket test ranges. The measured emission spectrum shows a spurious emission (TE 121 mode) in the satellite band 5850-5925 MHz which is only 50 dB below the peak power of the carrier. Figure 14 is the radar signature of the WSR 74-C weather radar at Boston. This pattern shows spikes between 5720 and 5750 MHz which slightly exceed the RESC suggested limit. This has not been a problem in the 5650-5925 MHz band, but is given here to show the utility of the van measurements. The analysis in Section 6 uses the above military radar measured spectrum to accomplish levels of interference potential.

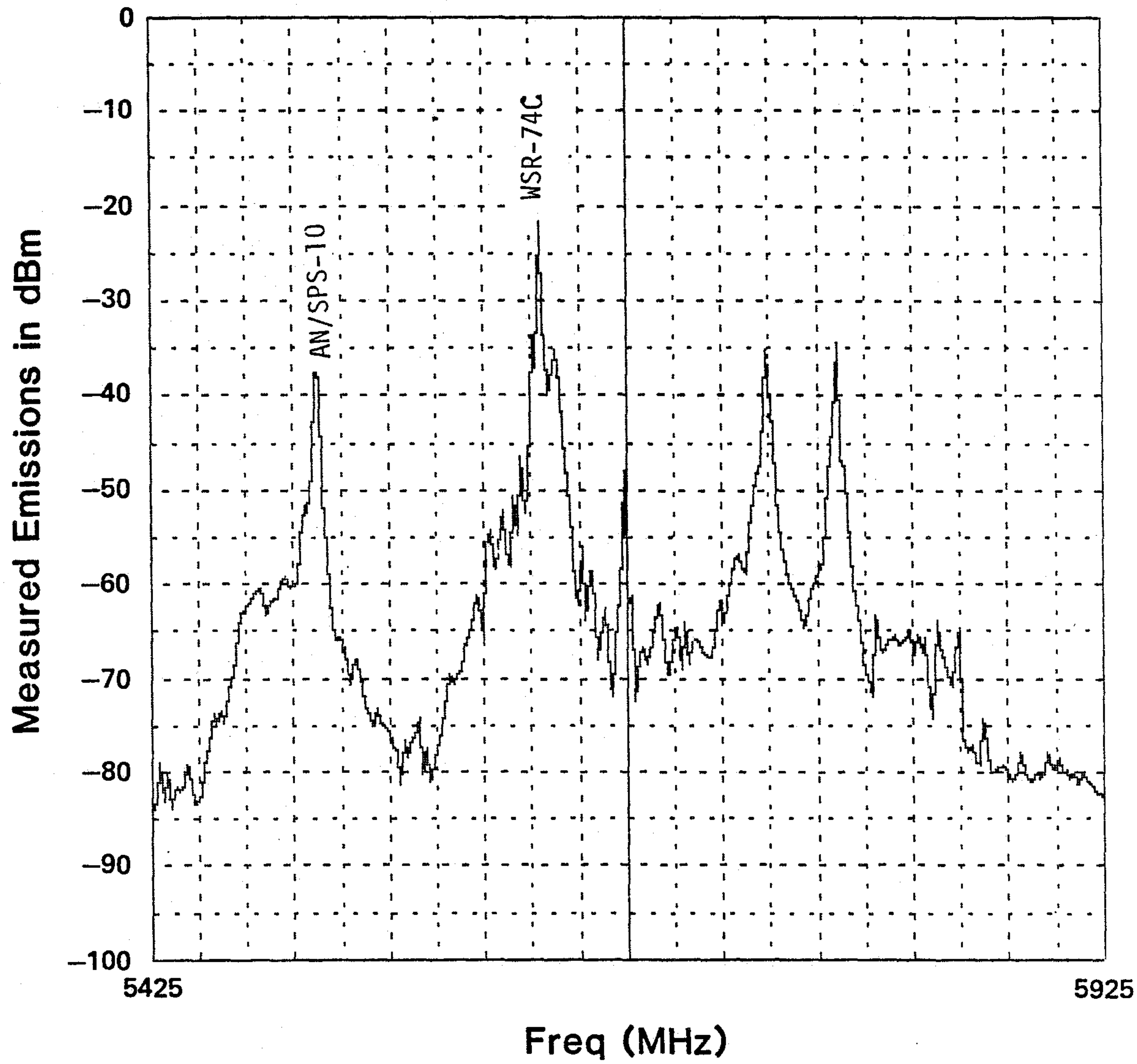


Figure 5. Occupancy Measurement for 5425-5925 MHz Band in the San Diego, CA Area.

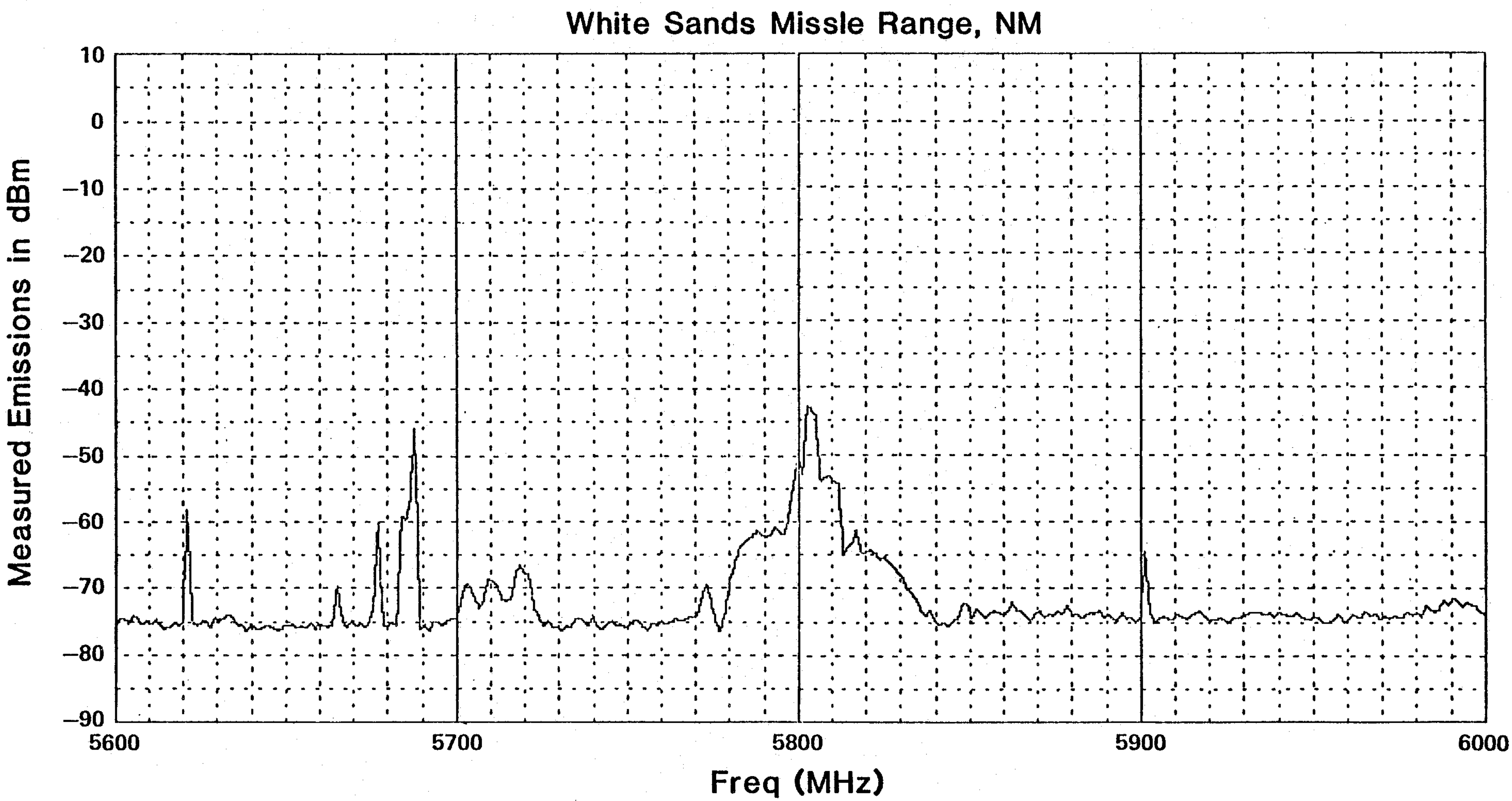


Figure 6. Spectrum Occupancy Measurements at White Sands Missile Range, NM (January 1977).

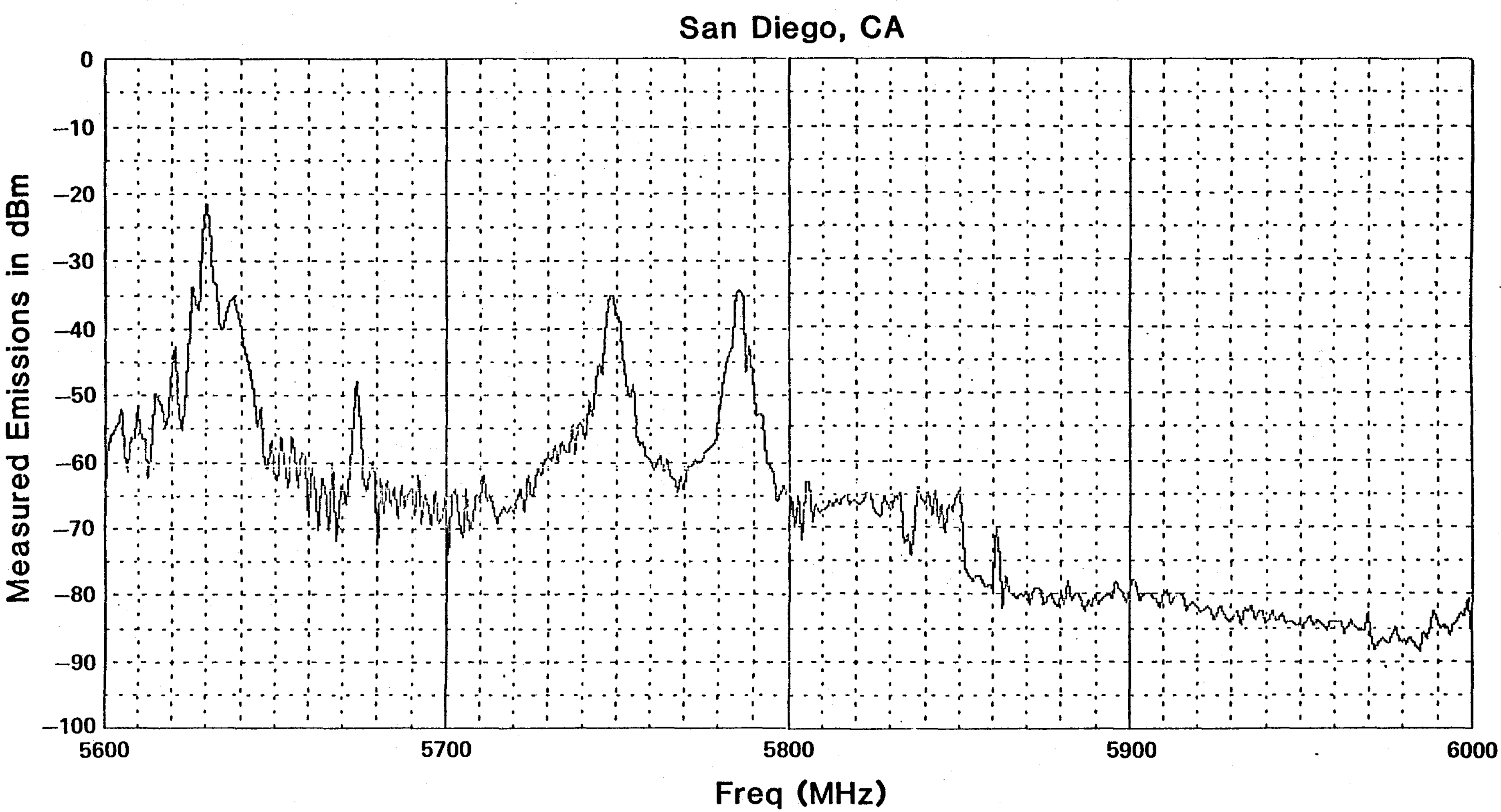


Figure 7. Spectrum Occupancy Measurements at San Diego, CA (April 1981).

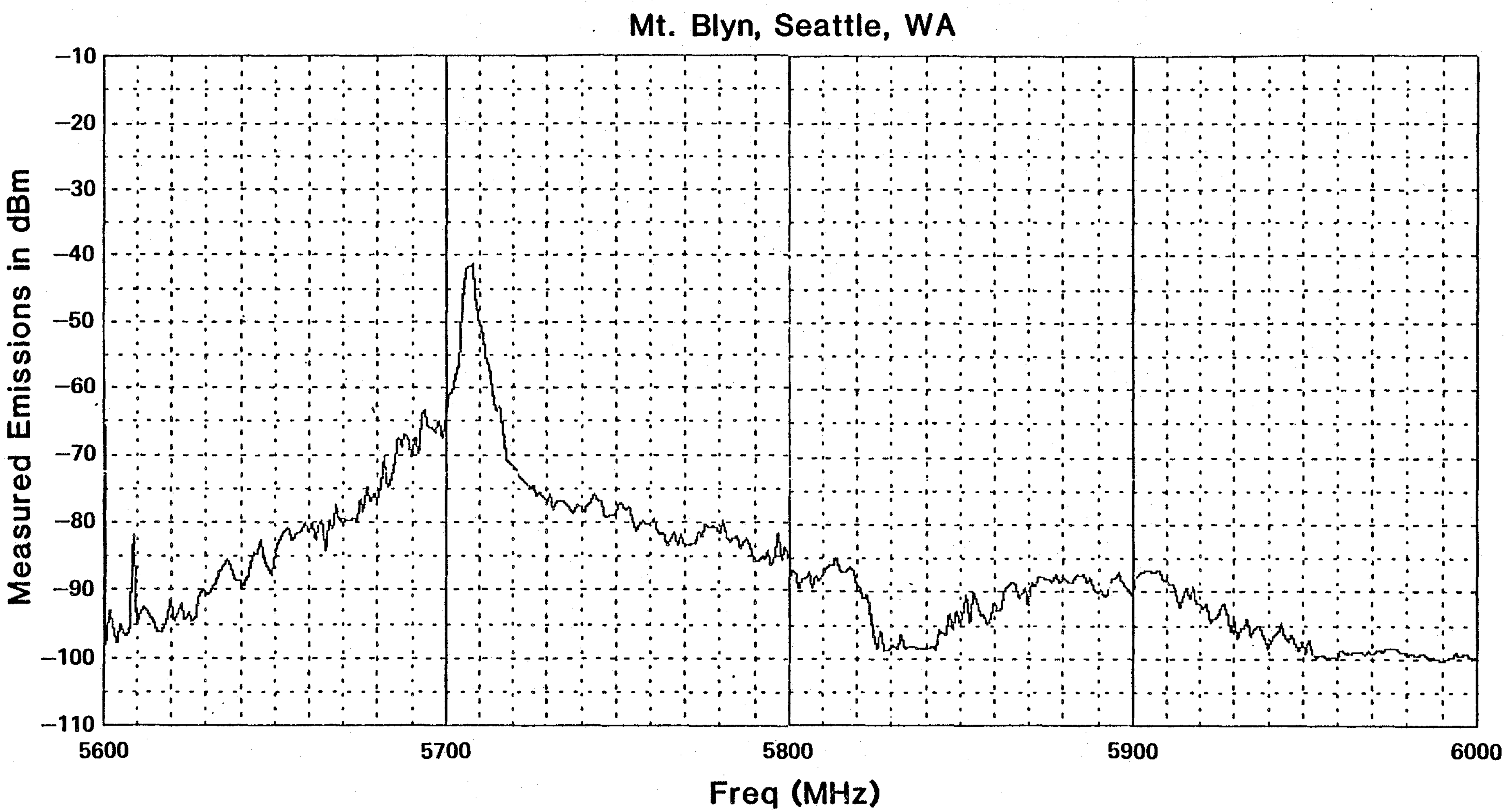


Figure 8. Spectrum Occupancy Measurements at Seattle, WA (June 1982).

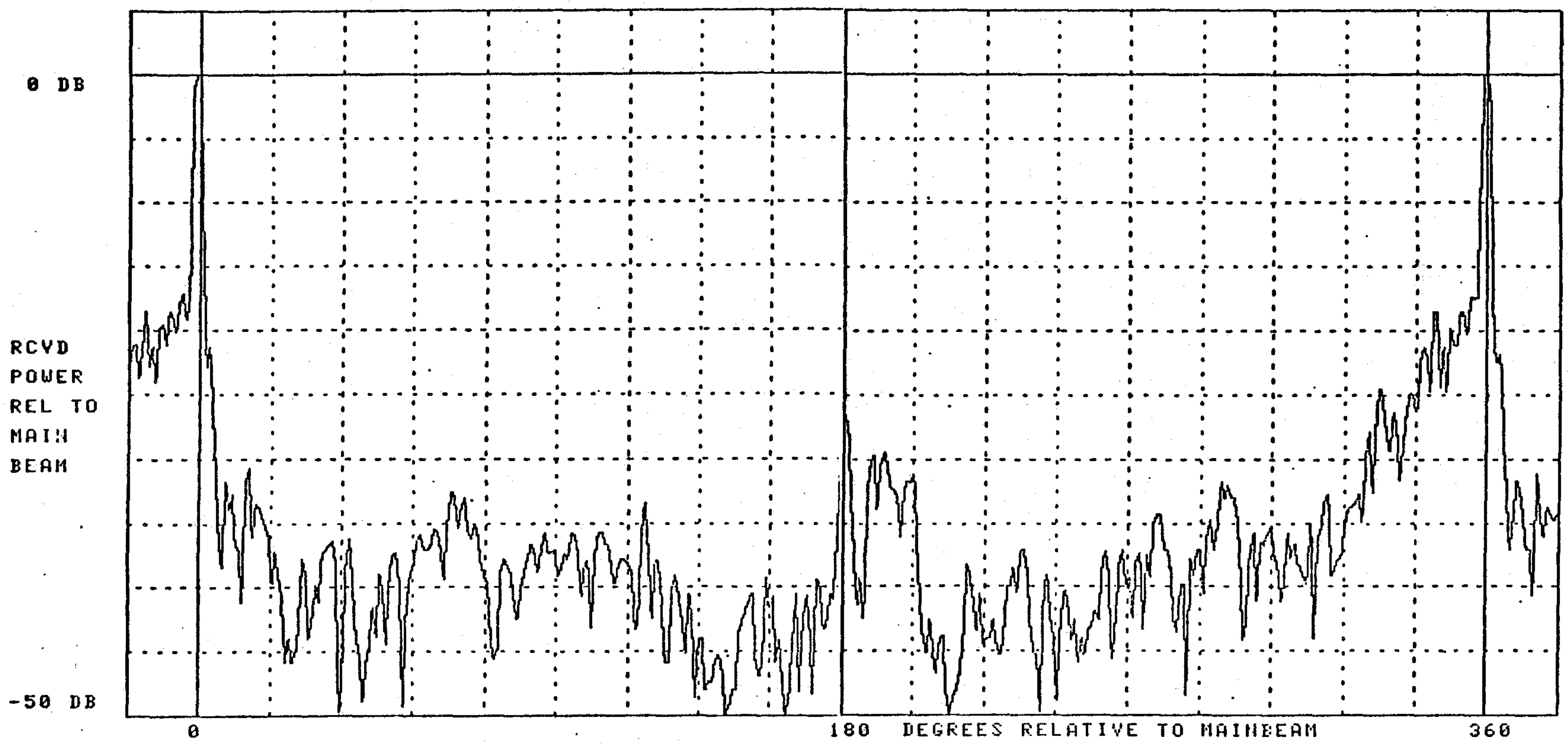


Figure 9. Measured AN/SPS-10 Antenna Pattern.

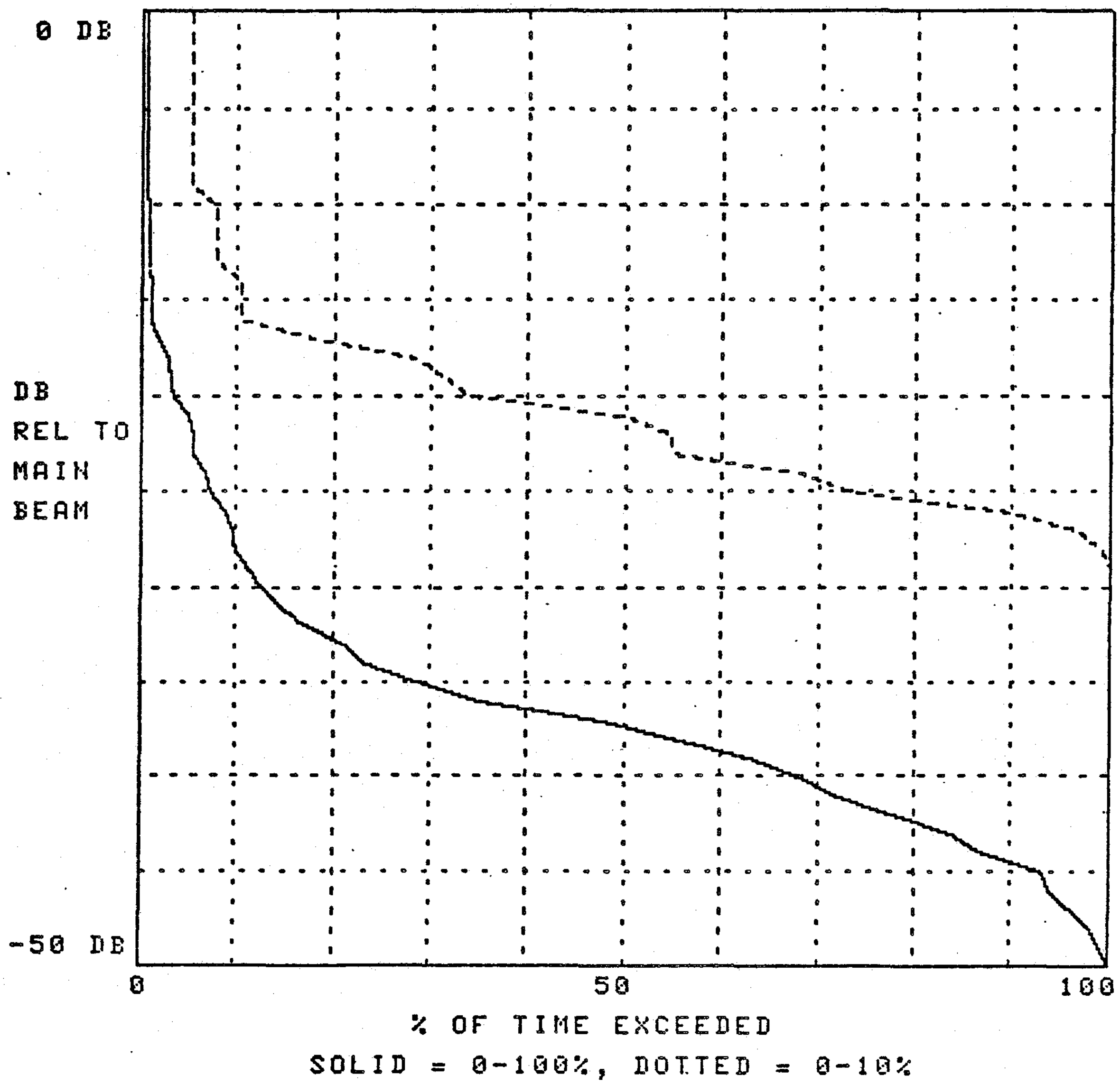


Figure 10. Statistical Antenna Pattern Distribution for AN/SPS-10.

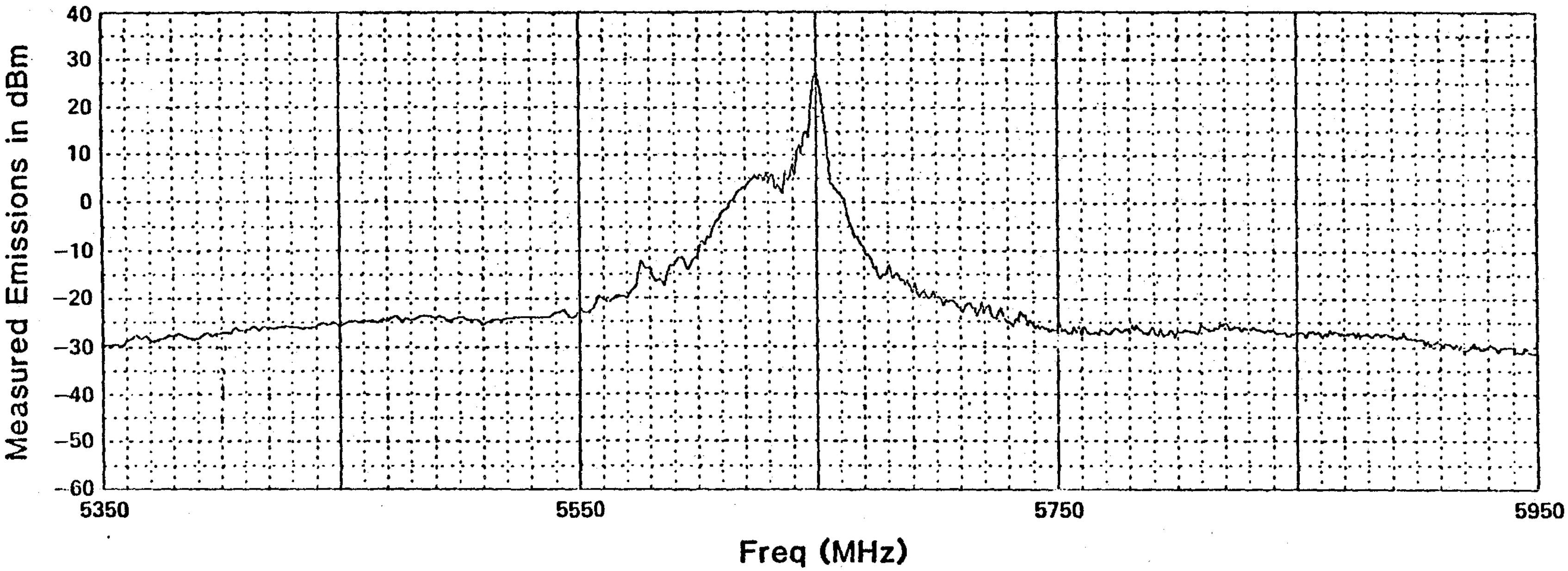


Figure 11. Measured AN/SPS-10 Emission Spectrum (Short Pulse Mode).

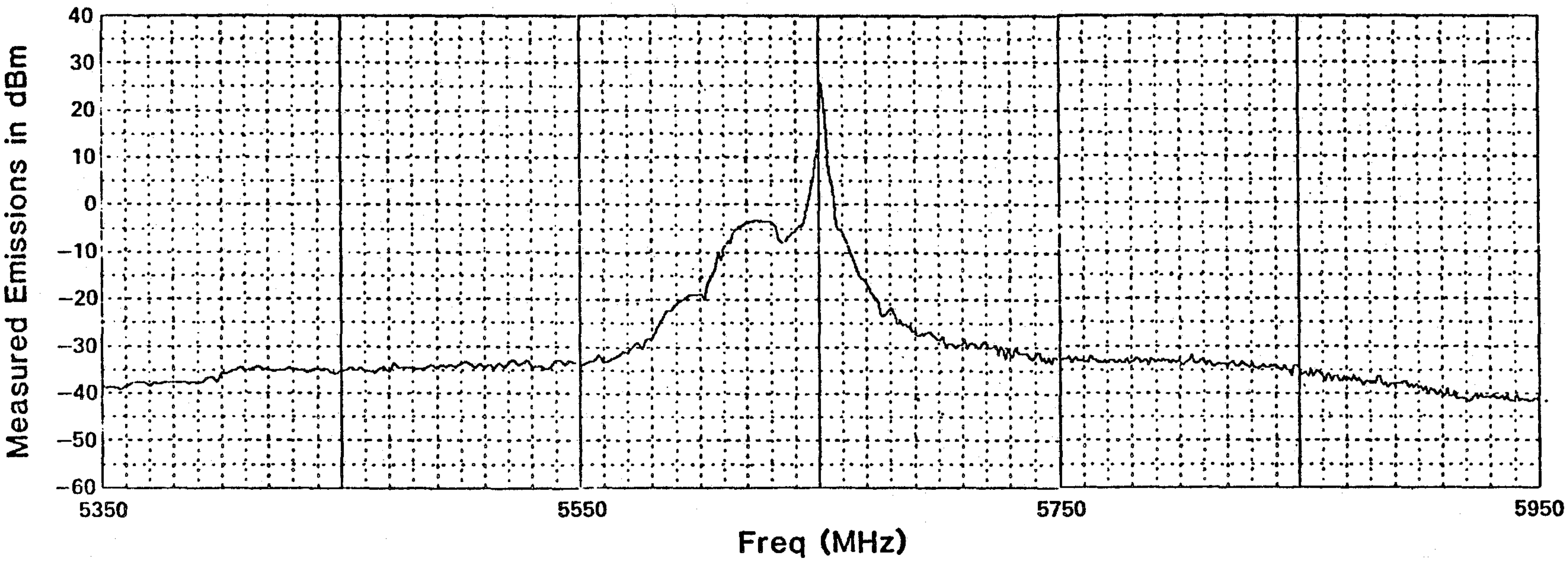


Figure 12. Measured AN/SPS-10 Emission Spectrum (Long Pulse Mode).

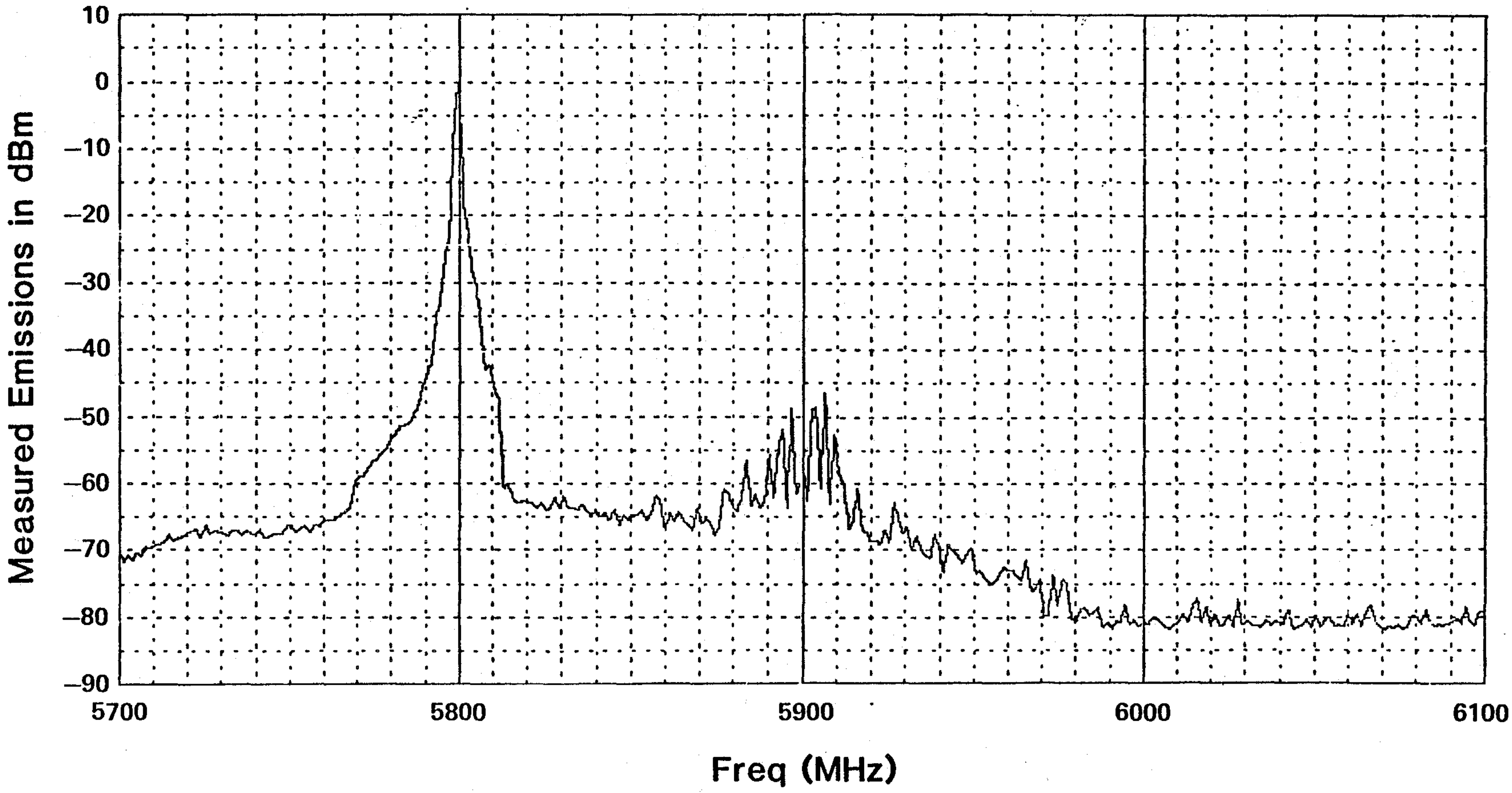


Figure 13. Measured AN/FPS-16 Emission Spectrum.

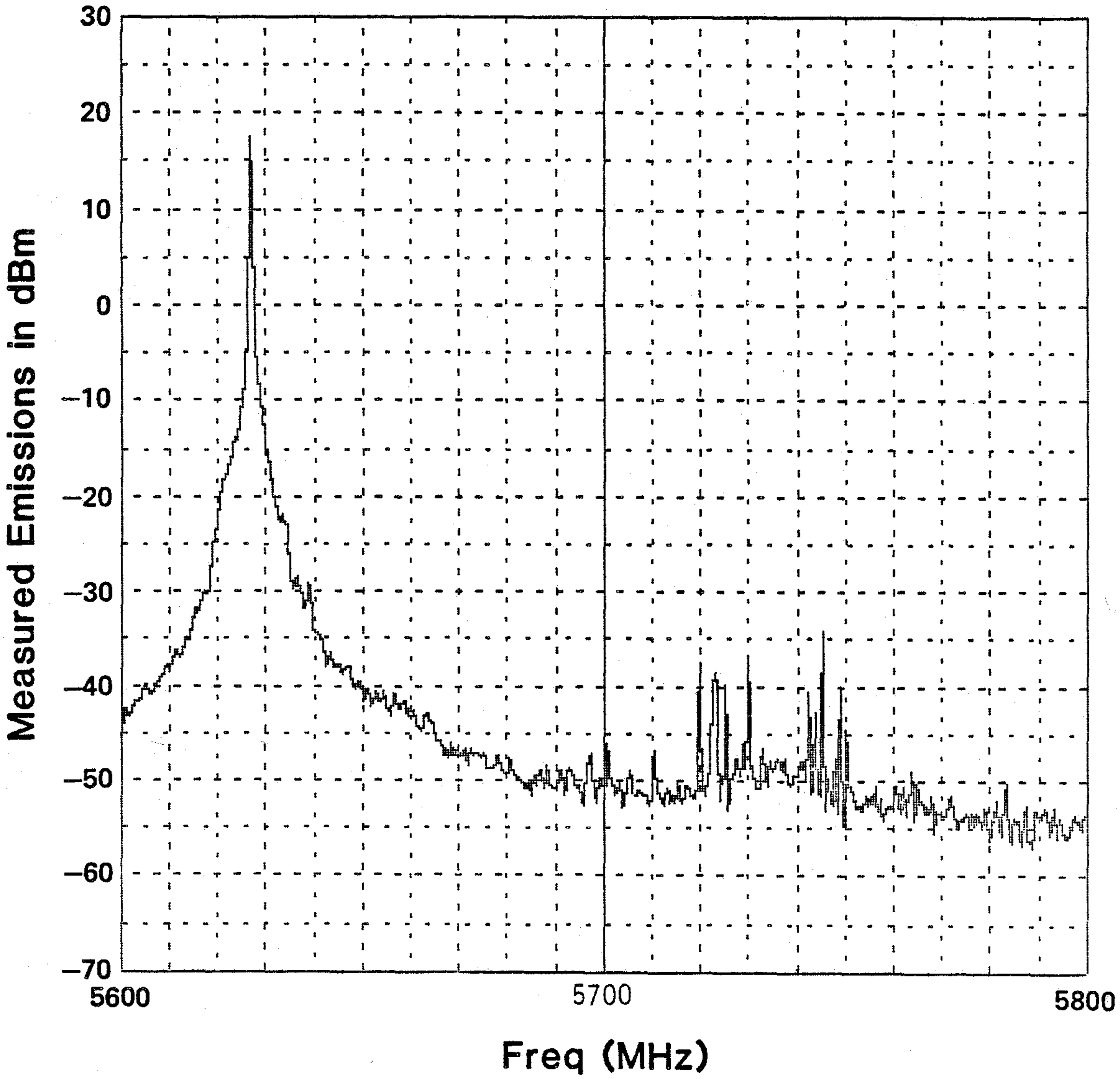


Figure 14. WSR 74-C Western Radar Boston.

When measurements are made in a given band such as 5650-5925 MHz there are often spikes such as these from a lower adjacent band that must be identified. Many of the radars in the band are not easily measured when in a tracking mode because of the narrow beam antennas, the position of the RSMS with respect to the radar when general measurements are being conducted in a given area, or the amount of power transmitted. In general, a radar band such as the one under study here will show less use than actual due to the inability of the RSMS to capture all transmitted signals. This is particularly true at ranges such as the White Sands Missile Range in New Mexico.

MAJOR SYSTEMS AND SELECTED TECHNICAL CHARACTERISTICS

This portion of the 5650-5925 MHz Spectrum Resource Assessment will identify the major systems and summarize selected technical characteristics. These sources include the GMF, NGMF, an ECAC FAL, and MIL-HDBK-162B. The majority of the systems used in the 5650-5925 MHz band can broadly be classed as radars and radar activated transponders. A pictorial representation of system usage including the new satellite usage is shown in Figure 15. There are a few assignments used for experimental development of new Government systems and antenna testing.

One feature common to these systems is the necessary bandwidth of the transmitted pulse waveform. This is defined in the NTIA manual as

$$BW_N(-20 \text{ dB}) = \frac{1.79}{\sqrt{t_r t}} \text{ or } \frac{6.36}{t},$$

whichever is less, where t_r is the pulse rise time and t is the pulse length. In most cases, the pulse rise time, t_r, is not immediately available, therefore, $BW_N = 6.36/t$ will be used in the tables to follow. This will yield a comparative number for the majority of the systems considered in this report.

RADIOLOCATION

Shipborne Radar Systems

The U.S. Navy has a number of shipborne radars at sea with an area of operation specified as "World Wide Use". The technical characteristics of most of these radars are readily available in the sources named above. The two principal categories of Navy radars in this band are surface search and missile guidance control. The AN/ nomenclature of these systems is discussed below.

Surface Search

AN/SPS-4. The AN/SPS-4 is a medium power surface and zenith search radar. It has a special dual antenna which permits observation of either targets on and near the surface of the water or limited observation of approaching aircraft overhead.

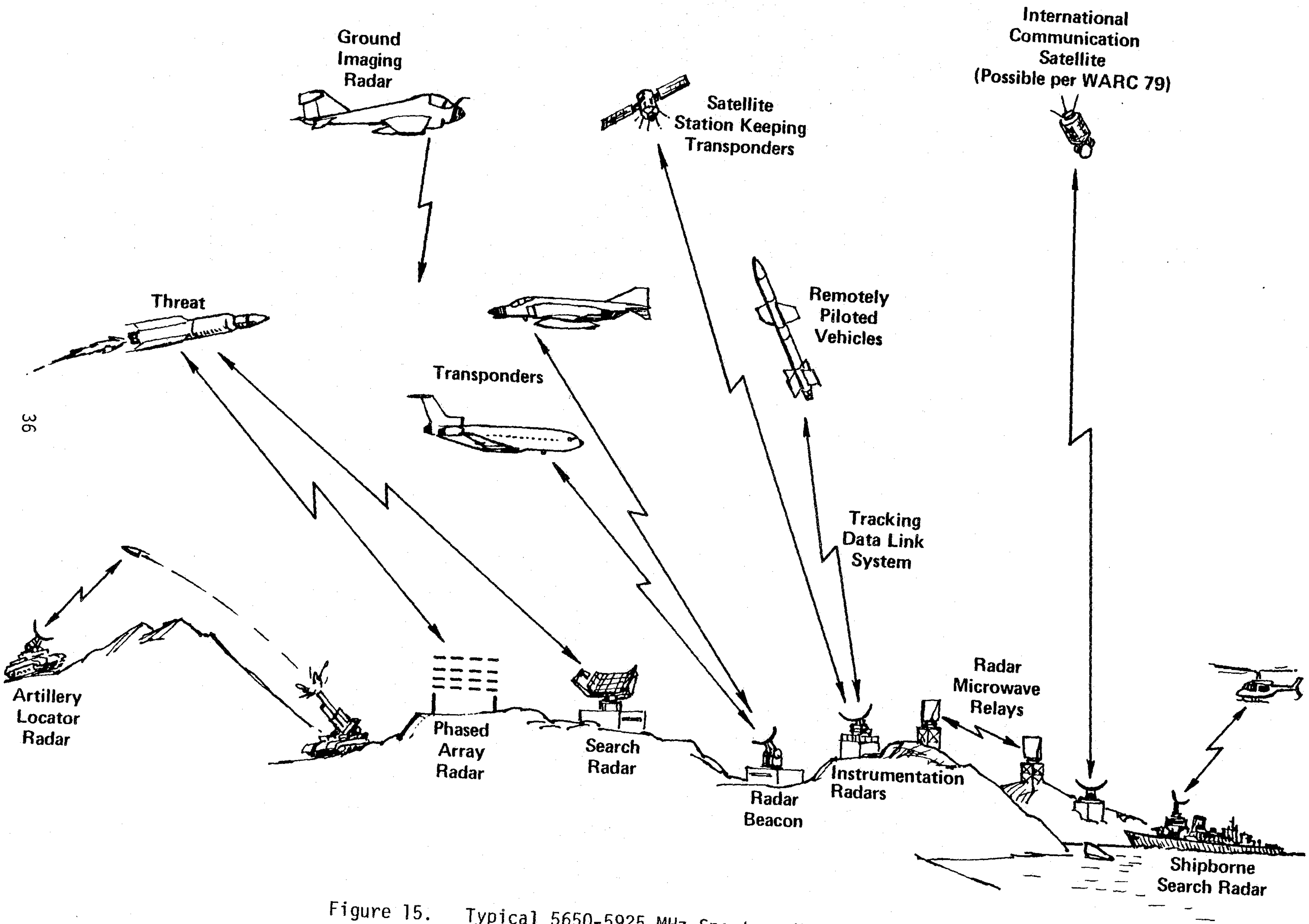


Figure 15. Typical 5650-5925 MHz Spectrum Usage.

Table 4. AN/SPS-4 Technical Characteristics

Frequency Range:	5450-5900 MHz
Power Output:	180 kW peak
Pulse Width:	0.37 to 1.3 μs
Necessary Bandwidth:	17.2 MHz
Pulse Repetition Rate:	625 to 650 pps
Antenna Data:	
Gain:	32 dB
Rotation:	5 or 15 rpm cw in automatic, manual in either direction
Beamwidth (Half-Power Points)	
Surface Reflector	
Horizontal Plane:	1.7 to 2.3°
Vertical Plane:	14 to 16°
Zenith Reflector	
Horizontal Plane:	Approx. 3.0°
Vertical Plane:	Fanshaped with max radiation at 21° above the horizon

AN/SPS-5. The AN/SPS-5 is designed as a medium-power, light-weight, surface-search radar for installation on light vessels.

Table 5. AN/SPS-5 Technical Characteristics

Frequency Range:	5450 to 5900 MHz
Power Output:	250 to 350 kW peak
Pulse Width:	0.5 μs
Necessary Bandwidth:	12.7 MHz
Pulse Repetition Rate:	683.03 pps
Antenna Data:	
Gain:	39 dB
Rotation:	17 rpm
Beamwidth (Half-Power Points)	
Horizontal Plane:	1.7°
Vertical Plane:	15°
Polarization:	Horizontal
High Angle Coverage:	Approx. CSC^2 + 7 to 22°

AN/SPS-10. There is a large family of the AN/SPS-10 series radars beginning as -10, -10B, ..., -10G. All these systems are basically the same radar with minor external system performance changes in antenna patterns. The AN/SPS-10's are designed for shipboard installation but may also be employed at a shore station. They are used for detection, ranging and tracking of surface targets, and to a limited extent, air targets. Means are also provided for Beacon and IFF operation.

Only the technical characteristics of the SPS-10G will be listed in Table 6 as they will adequately describe all SPS-10's. Measured emission spectrum and antenna patterns for the AN/SPS-10G are shown in Figures 9 to 12.

Table 6. AN/SPS-10G Technical Characteristics

Frequency Range:	5450 to 5825 MHz
Power Output:	190 to 285 kW peak
Pulse Width:	0.25 or 1.3 μs
Necessary Bandwidth:	25.4 MHz
Pulse Repetition Frequency:	635 to 660 pps
Antenna Data:	
Gain	32 dB
Rotation:	15 rpm cw
Beamwidth (Half-Power Points)	
Horizontal Plane:	1.5°
Vertical Plane:	14°
Polarization:	Horizontal
Beacon	
Frequency Range:	5450 ± 2 MHz
Power Output:	
Pulse Width:	2.25 μs
Pulse Repetition Frequency:	312 to 350 pps
Antenna Data:	
Rotation:	15 rpm cw
Beamwidth (Half-Power Points)	
Horizontal Plane:	6°
Vertical Plane:	22°

AN/SPS-67. The AN/SPS-67 is designed as a medium-power, light-weight, surface-search radar designed for variable range and variable pulse duration.

Table 7. AN/SPS-67 Technical Characteristics

Frequency Range:	5450-5825 MHz
Power Output:	285 kW peak
Pulse Width:	0.1, 0.25, 1.0 μs
Necessary Bandwidth	63.6 MHz
Pulse Repetition Rate:	2400, 1200, 750 pps

Missile Guidance Control

AN/SPQ-5. The AN/SPQ-5 is designed to supply TERRIER (beam rider type) missile guidance and/or precise gun laying information. The only information given in MIL-HDBK-162B is that the system is pulse modulated (PO) and tunable over the 5400-5900 MHz range.

AN/SPG-49, -55, and -55B. These radar systems are used in the TALOS, TARTER, and TERRIER Weapons systems, respectively. The function of all these systems is similar to that of the AN/SPQ-5; i.e., target detection and missile guidance.

Ground Based Radar Systems

The ground based radar systems operating in the 5650-5925 MHz frequency band are a sophisticated mixture of tracking and/or instrumentation radars. The majority of these systems are located at the various missile test ranges within CONUS. The common features of all these radars are that they are characterized by:

(a) high peak pulse power of 150 kw to 5000 kW,

(b) short pulse widths ranging from 0.1 to the order of 10 μsec,

(c) variable pulse repetition rates,

(d) P0 and/or P9 modulation designators,

(e) pencil beam antennas of the order of 1° and gains of the order of 35 to 45 dBi, and

(f) antenna pointing capabilities which usually cover the complete upper hemisphere above the radar location.

A brief list of ground based radar systems with their use and peak power outputs is shown in Table 8. The last entries in Table 8, although not designated as an AN/ system, are representative of a number of similar systems deployed throughout the world. Systems such as the VEGA 6104 are used by the various military agencies for control of Remotely Piloted Vehicles (RPV's) for reconnaissance and/or training purposes. It is worthy of note that, although the VEGA systems are not radars in the usual sense of the meaning, most of the instrumentation radars are capable of operation in an IF translation mode which is very similar to the operation of the VEGA systems. The SCR-584 radar listed in Table 8 is somewhat unique in that it is a modified World War Two system originally designed to operate around 3 GHz.

Table 8. Typical Ground Based Radar Systems, Uses, and Powers

Radar	Use	Peak Power (KW)	Necessary Bandwidth MHz
AN/FPQ-4	Instrumentation	3000	25.4
AN/FPQ-6	"	2800	25.4
AN/FPQ-10	"	1000	25.4
AN/FPQ-13	"	5000	4.2
AN/FPQ-14	"	2800	25.4
AN/FPQ-15	"	5000	6.4
AN/FPS-16	"	≤ 5000	25.4
AN/FPS-105	"	1000	25.4
AN/MPQ-32	Artillery Locator	5000	12.7
AN/MPS-19	Tracking	250	8.0
AN/MPS-25	Instrumentation	1000	25.4
AN/MPS-26	Tracking	250	25.4
AN/MPS-36	Instrumentation	1000	25.4
SCR-584	"	250	8.0
AN/TPQ-18	"	2800	25.4
AN/TPQ-39	"	250	4.2
AN/TPS-68	Weather	150	3.2
VEGA 6104	Control of Remotely Piloted Vehicles	3.5	25.4
VEGA 657	" " "	1.5	31.8
VEGA 811C	" " "	1.2	21.2

The commonality of the radars listed do not warrant a detailed listing of all their individual specifications; thus, only the AN/FPS-16 (AN/MPS-25), AN/TPQ-39, and VEGA 6104 are listed in detail in the following Tables.

Table 9. AN/FPS-16 (MPS-25) Technical Characteristics

Type	Instrumentation
Frequency	5450-5900 MHz
Power	1 MW Peak 1 kW Average
Ant. Size	3.66 or 4.88 Meter Diameter
Ant. Gain	44.5 or 47 dB
Beam Shape	Pencil
Type Scanner	Mechanical
No. Beams	1
Beamwidth	1.1° or 0.8° EL and AZ
Angular Coverage	-10° TO + 190° EL 360° AZ
Scan Rate	25°/SEC EL 45°/SEC AZ
PRF	145 to 1364/ (12 Values)
Pulse Width	0.25, 0.50, 1.0 μs
Necessary Bandwidth	25.4 MHz
Transmitter Tube	Magnetron or Coaxial Magnetron
Noise Figure	11 dB Max
Range	278 km ($1m^2$) 334 km Detection 222 km Accurate Track
Polarization	Linear and/or Circular
Receiver BW	8.0 or 1.6 MHz

A measured emission spectrum of an AN/FPS-16 with a coaxial magnetron is shown in Figure 13.

Table 10. AN/TPQ-39 Technical Characteristics

Type:	Digital Instrumentation Radar
Frequency Range:	5400-5900 MHz
Power Output:	250 kW peak
Pulse Width:	1.5 μs
Necessary Bandwidth:	4.2 MHz
Pulse Repetition Frequency:	640 pps
Antenna Data:	
Shape:	Parabolic
Gain:	37 dBi
Angular Coverage:	0° to + 90° EL 360° Azimuth

Table 11. VEGA 6104 Target Tracking Control System

Type:	Control of RPV's
Frequency Range:	5400-5900 MHz
Power Output:	3.5 kW peak
Pulse Width:	0.25-0.45 μs
Necessary Bandwidth:	25.4 MHz
Pulse Repetition Frequency:	320 or 500 pps
Emission Designator:	P9
Antenna Data:	
Elevation:	-10° to + 80° Fan Beam
Azimuth:	360° scan

Transponders

Transponders are a unique group of devices in the 5650-5925 MHz frequency band:

(a) they do not transmit until they receive a radar pulse,

(b) in some cases they will not transmit until they receive a series of coded pulses,

(c) they may reply in code at a frequency different than that of the interrogation frequency,

(d) their power output may range from 0.1W to 1 kW depending upon the mission, and

(e) their antennas are mostly omnidirectional.

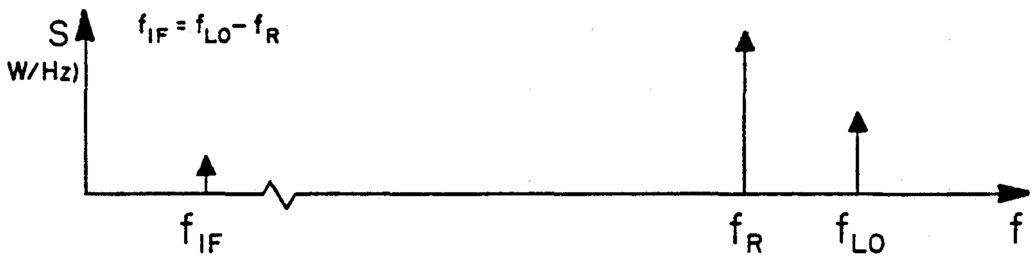
There are at least three distinct configurations of radar-transponder systems which may be utilized in various applications. These configurations are best described by Figures 16, 17, and 18 which display both the frequency usage and timing diagrams for the systems. The following symbols are used in the figures:

f_{IF} = intermediate frequency,
f_R = radar frequency,
f_{LO} = local oscillator frequency,
S = power spectral density (W/Hz),
τ = radar delay time to target echo,
T = radar pulse repetition period,
A = signal amplitude,
d = fixed transponder delay time,
f_T = transponder reply frequency,
f_{OLO} = offset local oscillator frequency,
BW_{IF} = IF bandwidth,
PPC = pulse position code.

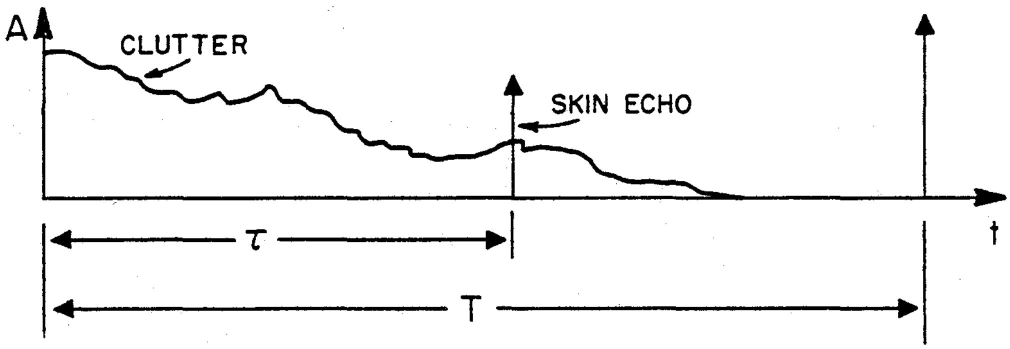
Figure 16 illustrates the usual radar system with the addition of a transponder to the target for enhanced skin tracking. Note that the addition of the transponder into this system will not change the distribution of frequencies depicted in Figure 16(a). The transponder delay time, d, is predetermined and fixed thus making the true target range simple to either calculate or measure by adding a delayed trigger in the radar range display. The primary reason for the delay time is to prevent the transponder from receiving and transmitting at the same time and possibly shocking itself into sustained oscillation.

Figure 17 illustrates the operation of a radar in operation with a transponder which replies at a frequency, f_T, not equal to the radar frequency, f_R. The radar local oscillator is offset to a frequency, f_{OLO}, so it beats f_T into the radar IF bandwidth. Since this offset is made larger than the IF bandwidth, the normal radar echoes are not detected and the radar time display is clutter free.

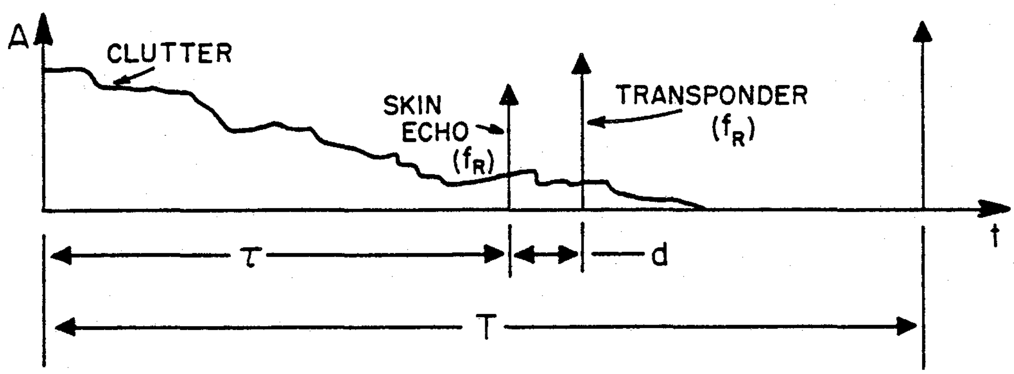
Figure 18 typifies a Target Tracking Control System (TTCS) such as the VEGA 6104. Note that the VEGA 6104 is not designed as a skin tracking radar and does not suffer an R^{-4} range loss; thus, it can perform adequately with the relatively low 3.5 KW peak power. The basic function of this type of system is control of Remotely Piloted Vehicles (RPV's) which are used for military reconnaissance and/or training purposes. Similar control systems may also be added to radars such as the FPS-16 or TPQ-39. Figure 18(b) shows the PPC command message towards the end of the radar pulse timing interval, T. This is convenient for radars such as the FPS-16 or TPQ-39 which may also act as skin trackers. Figure 18(c) shows the nature of a coded reply received from the transponder. The reply can carry information about acceptance of the previous command, platform elevation, platform status, range, etc.



(a) RADAR FREQUENCIES

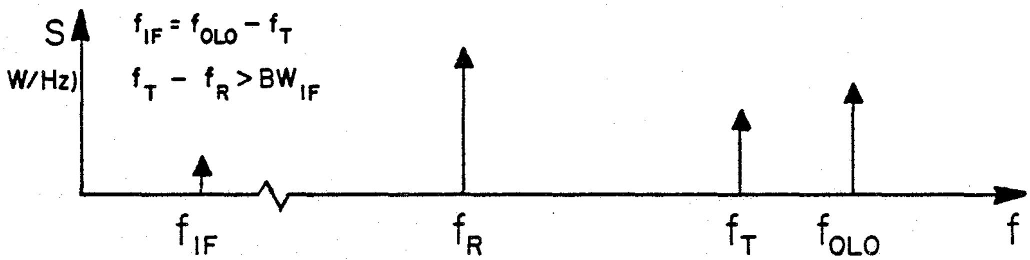


(b) RADAR TIMING

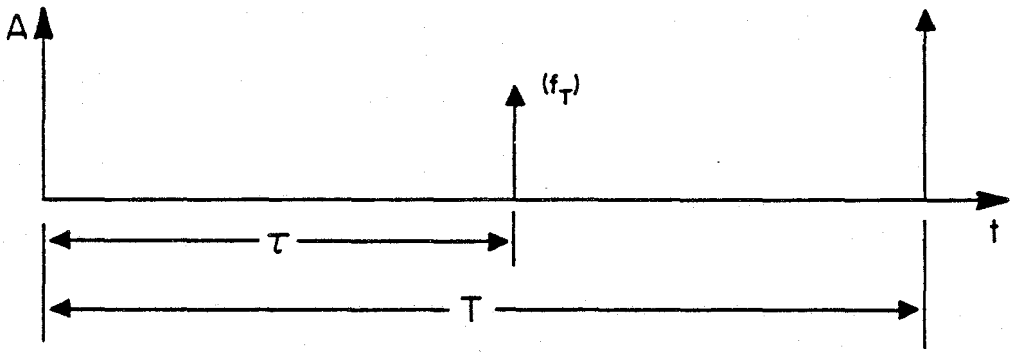


(c) RADAR TIMING WITH TRANSPONDER AT DELAY TIME ($\tau + d$) AT FREQUENCY f_R

Figure 16. Normal Radar with Added Transponder.



(a) RADAR/TRANSPONDER SYSTEM FREQUENCIES



(b) RADAR/TRANSPONDER TIMING

Figure 17. Radar and Offset Transponder.

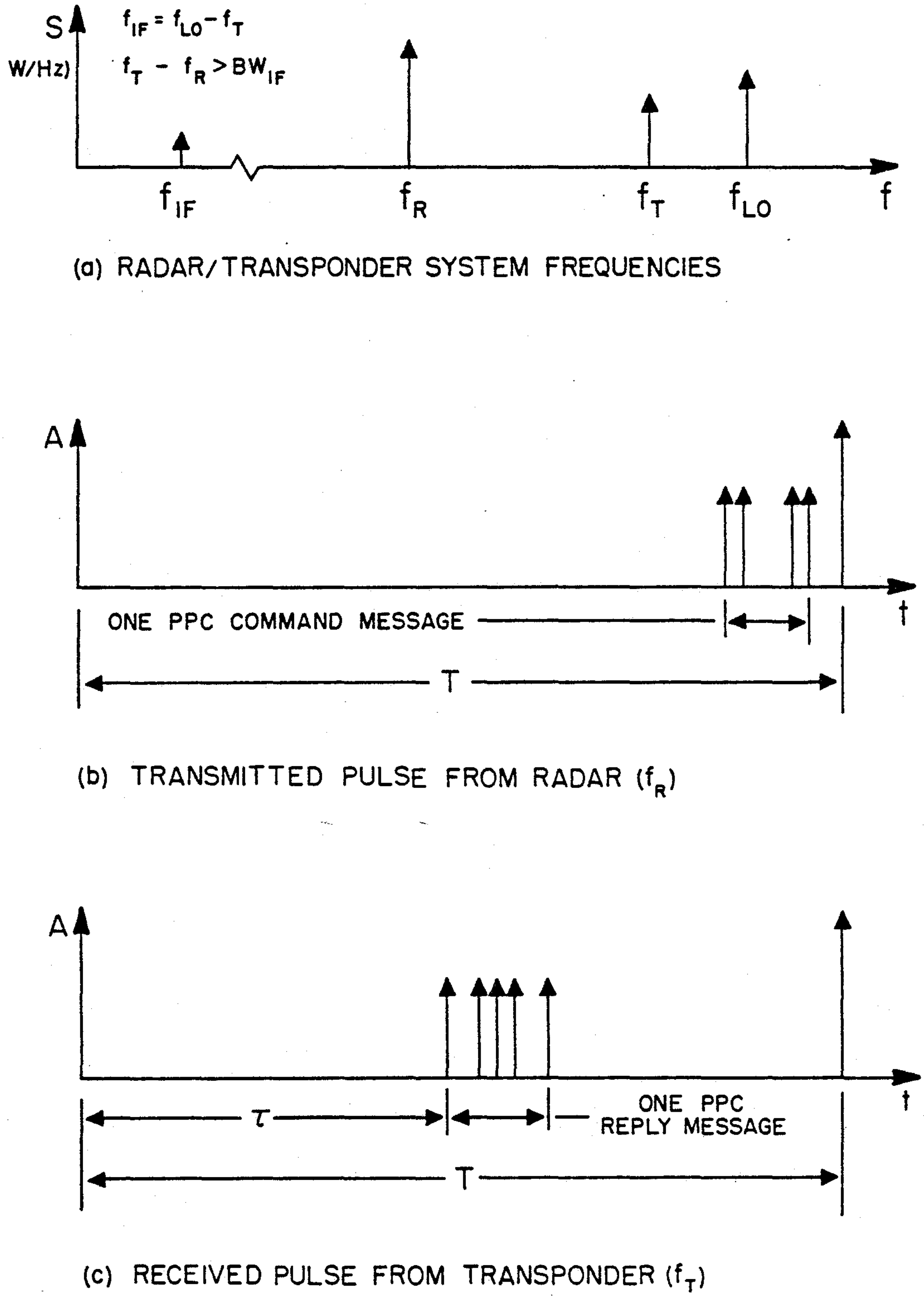


Figure 18. VEGA Target Tracking Control System (TTCS) (no skin track).

A list of the many types of radar transponders known to have been in use or currently in use is shown in Table 12. The peak powers listed are, in most cases, the largest peak powers found in the various sources of information. In several instances it appears the peak power of a transponder is tailored to fit the mission being undertaken.

Table 12. Transponder Types and Powers

Transponder	Peak Power (KW)	Necessary Bandwidth (MHz)
AN/DPN-31	0.05	16.0
AN/DPN-42	0.10	9.8
AN/DPN-55	0.40	31.8
AN/DPN-63	0.40	8.6
AN/DPN-66	0.50-1.0	25.4
AN/DPN-71	≤ 0.4	8.5
CSI 550C	0.50	12.7
MOT SST 131C	0.50	10.6
MOT SST 171C	1.05	15.9
MOT SST 174C	0.10	15.9
MOT SST 175C	0.10	14.1
MOT SST 176C	1.00	15.9
MOT SST 271C	0.40	15.9
MOT 10-22390	0.10	7.1
PD4	0.005	25.4
VEGA 207C	0.40	25.4
VEGA 228C	0.005	25.4
VEGA 302C	≤ 0.70	31.8
VEGA 306C	0.40	12.7
VEGA 321C	0.30	15.9
VEGA 345C	0.05	15.9
VEGA 349C	≤ 0.05	21.2
VEGA 355C	0.10	14.1
VEGA 366C	0.05	13.5
VEGA 616C	≤ 0.50	12.7
VEGA SA 2255	≤ 1.00	12.7
VEGA SA 2772	0.10	15.9
VEGA 303530	0.25	12.7

Here again, the commonality of these systems does not warrant a detailed listing of all their individual specifications. Their emission designators are either P0 and/or P9; many transponders are switchable to either mode of operation. As the majority of these systems are mounted on airborne platforms which may have more than one possible mission termination, the antennas used are some form of an omnidirectional antenna (∿3 dBi). The MOT SST 171C, VEGA 302C, and VEGA 366C are listed in detail in the following Tables as an indication of the diversity of transponders currently in use.

Table 13. MOT SST - 171C (AN/DPN-81) Technical Characteristics

Transmitter	
Frequency	5400-5900 MHz
Power	400 W peak
Pulse Width	0.5 $\pm$ 0.1 μs
PRF	-
Pulse Code	Single or double
Receiver	
Bandwidth	11 $\pm$ 3 MHz
Sensitivity	-70 dBm

Table 14. VEGA 302C-8 Technical Characteristics

Transmitter	
Frequency	5400-5900 MHz
Power	700 W Peak
Pulse Width	0.3 $\pm$ 0.1 μs
PRF	100 to 4160
Pulse Code	Single or multiple with external modulation
Receiver	
Bandwidth	11 $\pm$ 3 MHz
Sensitivity	-70 dBm
Telemetry out	
Amplitude	1.5 V min. (50 ohms)
Pulse width	0.4 $\pm$ 0.1 μs

Table 15. VEGA 366C Technical Characteristics

Transmitter	
Frequency	5400-5900 MHz
Power	50 W peak
Pulse Width	0.47 to 0.53 μs
PRF	100 to 2600/sec
Pulse Code	Replies to single or multiple radars
Receiver	
Bandwidth	11 $\pm$ 5 MHz
Sensitivity	-65 dBm

OTHER MAJOR EQUIPMENT

Radiolocation

AN/MPQ-32. This system is a mobile artillery locator radar used to determine the origin of hostile artillery fire. The exceptionally high transmitter power (5 MW) is required for detecting and tracing the ballistic trajectory of the small targets involved in a tactical situation.

Patriot Radar and Other Phased Array Systems. The patriot radar and other experimental phased array systems in the band have, in general, classified performance characteristics. It can be stated that the performance of most phased array systems are very similar: (1) the antenna beam and pattern is computer controlled and capable of tracing many targets simultaneously without mechanical motion of the antenna; (2) the tracing beams are of the order of 1°; (3) they may be capable of controlling a counter strike mission and (4) the transmitted power and pulse length is of the order of 100 kW and 10's of microseconds. Many of these systems have pulse compression capabilities for enhanced range resolution.

Radar Transponders. Transponders are, in general, low power ($\leq$ 1 kW) pulse devices utilized on airborne platforms for separating the target from clutter and hand-off to other tracking radars.

Radar Beacons. Beacons are, in principle, very similar to transponders except they are intended for the interrogation and collection of information from cooperative aircraft. This information is then utilized for control of the air corridors.

The remaining equipments used in the 5650-5925 MHz band are primarily used for experimental development of new Government systems, antenna testing, or routine ground tests of missiles before firing. A few systems are used for calibration of shipboard equipment. In general, it is noted that these diverse equipments are of moderate power ($\leq$ 2 kW), have directive antennas, and are generally directed towards a surface target receiver located nearby or within the 4/3 earth radius view of the transmitter.

Industrial, Scientific and Medical. There were no equipments found operating in the band which would fit the ISM category. Typically, the kinds of ISM equipment would be like Industrial Heating Equipment, Medical Diathermy Equipment and RF Stabilized Arc Welders. These devices, although not required to be licensed, do have to be certified attesting to compliance with spurious and harmonic emissions specified in Part 18 of the FCC Rules and Regulations. No certification for equipment in this band was found on file with the FCC.

Restricted Radiation Devices. The FCC Rules and Regulations, Part 15, states that certain restricted radiation devices may operate in the designated frequency 5800 $\pm$ 75 MHz. Specifically, the devices named are Low Power Communication Devices used for the measurement of the characteristics of materials, Radio Control Transmitters used for a door opener, and Field Disturbance Sensors which typically are microwave intrusion sensors, and devices that use RF energy for production line counting and sensing. There were no such systems found to be certified for, or operating in the 5650-5925 MHz band, but since licensing is not a requirement, positive identification of equipment is difficult.

Fixed-Satellite Service. The FSS may operate international communication satellite uplink systems in the band. These would be like the INTELSAT VI series now planned to be operational by the mid-1980s. At present there are transponders aboard a number of Satellites such as GOES-F, SPOT, RCA-C1, D,E &F, Westar-D,E etc. that use 5690 MHz as an up-link frequency and 5765 MHz as down-link. These transponders are used for station keeping and tracking purposes. They are interrogated by a radar and respond upon interrogation. The information returned is used for ephemeris up-date and positive tracking by Earth based radars.

Amateur. The amateur service may use the band 5650-5925 MHz on a secondary basis. There are two specific sub-bands given to the amateur-satellite service, 5650-5670 MHz (earth-to-space) and 5830-5850 MHz (space-to-earth). At present, no use of the band by the amateurs could be documented. The ARRL had no input from its members concerning use of this band.

SECTION 5

PROBLEM DEFINITION

INTRODUCTION

The preceding sections have defined frequency usage, the various classes of systems, and major systems operating in the 5650-5925 MHz band. This section presents potential interference problems in the form of a matrix which identifies the relative degree of compatibility between services using the band. The potential problems identified are analyzed in a more in-depth study in the following sections.

PROBLEM ASSESSMENT MATRIX

The matrix of Figure 19 is based on data presented in this report and represents potential interference problems in the 5650-5925 MHz band. Three categories of compatibility problems are used in the matrix and are defined as follows:

No problem implies that the systems involved are separated sufficiently in frequency, distance or time such that no interference would be expected.

Manageable problem is defined as an interaction where interference is possible, under worst-case conditions, but which can be avoided by using standard frequency management techniques.

Potential problems are defined as a category that requires additional study to fully define and resolve compatibility issues. The resolution of these problems may require operational restrictions of systems involved, system design changes, technical standards revision, and/or new operations procedures.

POTENTIAL PROBLEMS

The one potential problem area that merits further study in the 5650-5925 MHz band is the impact of radiolocation on the newly allocated fixed-satellite service (FSS) from 5850-5925 MHz. Some of the radar systems used in the Radiolocation Service have large peak power capability (including megawatt pulse power). This amount of power, in-band, presents an incompatible interference problem to satellite receivers of the INTELSAT type when the radar beam intercepts the satellite receiving antenna.

MANAGEABLE PROBLEMS

Compatibility problems in this category are considered manageable by standard spectrum management techniques and do not require further analytical study.

Interactions between the various systems operating in the Radiolocation Service are considered manageable. As mentioned in previous sections most of the radar systems operating in the band are on vessels at sea, on military test ranges in CONUS or perimeter radars used in the national defense. The various area frequency coordinators under the direction of the range commanders council manage the frequency spectrum assigned to the DOD test ranges. Along with the test range area frequency coordinators, there are various regional frequency coordinators for each DOD department or agency. Through this sytem there is very tight management of the band as well as EMC analysis of many systems in the band carried out by ECAC and responsible DOD agencies. Standard frequency management techniques should apply here.

Transponders aboard satellites used for station keeping and positive tracking purposes are very similar to transponders used for other positive tracking situations such as missile and rocket launches. Generally the same type of radars are used such as the AN/FPS-16. These types of transponders have been operating compatibility with other systems in the band for some years and should not pose a new problem with the introduction of the FSS.

There are possible interactions between FSS up-link transmission and radar receivers in the band. However, as pointed out in Section 6, this would seem to be a manageable problem with a combination of distance separation and frequency separation.

The Radiolocation Service, as primary, would not seem to have a particular problem with restricted radiation devices which must operate on a secondary non-interference basis. However, hypothetically if an unlicensed and popular device were to be designed for the 5650-5925 MHz band and a large percentage of the population were to own such a device, great pressure could come to bear on the Government if the large radars in the Radiolocation Service caused unacceptable interference. This is considered a manageable problem if steps are taken now to assure that no such devices are developed and allowed to proliferate in the band.

Interactions between earth station transmitters in the Fixed-Satellite Service and radiolocation transponders are remotely possible. However, as pointed out in Section 6 for the Jamesburg, CA, and Andover, ME, sites as candidates for the FSS up-path transmitter locations on either coast, possible interaction should be manageable.

Restricted radiation devices in the 5650-5925 MHz band operate on a non-interference basis. No reported incidents of interference with authorized service could be found. However, because of the importance of the military Radiolocation Service, the impact of such devices should be analyzed for new systems or services in the band. The restricted radiation devices should share compatibly with the Fixed-Satellite-Service in the band using standard spectrum management techniques.

At present there is no known use of the 5650-5925 MHz band by the amateur service. However, there is a new amateur-satellite allocation for an up-link at 5650-5670 MHz, and a down-link at 5830-5850 MHz. This allocation is on a secondary non-interference basis, but as use of this band is developed by the amateur-satellite-service, an analytic assessment would be required.

As previously mentioned, no present use of the ISM band (5800 $\pm$ 75 MHz) could be found. However, since the Radiolocation Service has a large number of assignments in the ISM band and ISM equipment has no restrictions on <u>in-band</u> radiated fields, possible interactions could present a problem at a future date. This is considered a manageable problem if the potential is recognized and coordination between the FCC, manufacturers of ISM equipment and the IRAC is maintained in this area.

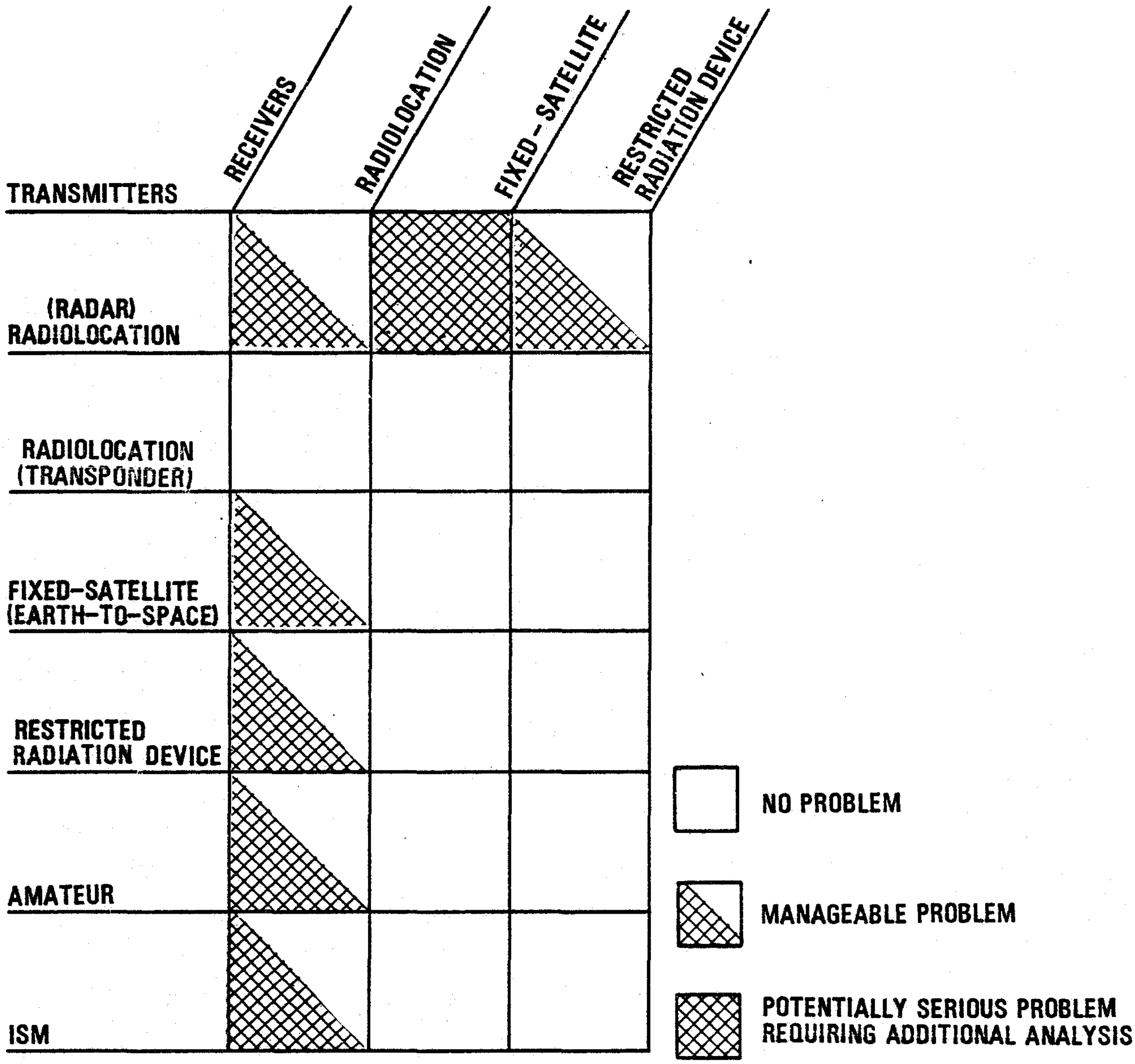


Figure 19. Problem Assessment Matrix.

NO PROBLEM

Transponders in the Radiolocation Service are generally low power transmitter/receivers used in tracking stages of missiles and rockets, or for positive guidance of aircraft. They should pose no problem for the Fixed-Satellite-Service, and their use and frequency assignments within the allocated band are well managed by the area frequency coordinators.

The remaining interactions in this category, as given in the problem matrix of Figure 19, are wholly within the jurisdiction of the FCC or services that operate on a secondary/non-interference basis such as the amateur service or restricted radiation devices. These interactions pose no direct problems to government spectrum management of the 5650-5925 MHz band.

SECTION 6

ELECTROMAGNETIC COMPATIBILITY ANALYSIS

INTRODUCTION:

From a spectrum management standpoint, the major issue of this particular frequency band study is the need to accommodate the Fixed Satellite Service uplink assignment in the 5850-5925 MHz portion. At present the 5650-5925 MHz band is a Government Radiolocation Service occupied by the Army, Navy, Air Force, NASA, and DOE users along with a few manufacturers of equipment and systems used in the band by the Government. The main problem dealt with in this section is the interference potential of high power radars with international communication satellites in Geosynchronous orbit (GEO) of the INTELSAT type which may come into the band in the mid 1980's.

The current proposal calls for two satellite uplink terminals probably one located on each coast within CONUS. As shown in Figure 4 even though the greatest density of assignments is on the coastal areas, there would be many locations where uplink terminals could be located well away from current radar sites. In addition, terrain topology could be utilized to minimize interference potentials between uplink transmitters and radar wide band receiver front ends.

RADIOLOCATION-AND-FIXED SATELLITE SERVICE SHARING

Radiolocation Transmitter to Satellite Receiver Coupling

Probability of Radar Mainbeam Intercept of Satellite

The problem of terrestrial tracking radar interfering with a geostationary satellite presents the major concern of this study. Although the areas of operation of the terrestrial radiolocation systems are generally known, the pointing angle of the radar antennas will depend upon the relationship of the mission and radar-target geometry. Here the problem of the radar intercepting a geostationary satellite becomes complex enough, it can only be treated by probability for worst case situations.

The probability of a tracking radar intercepting a satellite within the hemisphere that can be viewed by the radar has been discussed by H. Ng. et al., (1980). Their analysis of the problem is repeated in Appendix A of this report. From the simplified geometry of Appendix A, the assumption is made that the radar may track a target located at any arbitrary point in the hemisphere above the radar site and that targets are uniformly distributed in that hemisphere zone. From the simplified geometry of Appendix A, the probability of a tracking radar mainbeam intercepting a geostationary satellite is then given by:

$$P = [D_1 - D_2 \cos \phi]/H \qquad \text{(A-5)}$$

where D_1 = radar to satellite distance in Km

D_2 = distance from radar antenna beam 3 dB point on geostationary orbit in Km

ϕ = one-half the 3 dB beam width of the radar antenna.

H = 35,881 km = difference between radar and satellite altitude.

Where D_1 and D_2 may be calculated for various radar elevation angles, θ, and 3 dB beamwidths, 2ϕ, from equation A-4 of the Appendix.

Considering the fact that most tracking radars will have a 3 dB beamwidth of 1° or less, the probability of intercepting a GEO satellite at radar antenna elevation angles between 5° and 15° (the angles from coastal sites that the INTELSAT VI will most likely be visible) is computed from the following parameters:

θ	D_1 (Km)	D_2 (Km)
5°	41,226	41,172
15°	40,167	40,116

Substituting these parameters into equation (A-5) yields

$$P(5°) = 1.5 \times 10^{-3}$$
$$P(15°) = 1.4 \times 10^{-3}$$

based on 2ϕ = 1°.

For coastal and shipborne search radars particularly those with antennas which produce a fan beam such as the AN/SPS-10 where the 3 dB beamwidth is 1.5° in the horizontal plane and 14° in the vertical plane, the beam may scan the satellite once per revolution of the antenna. This is assuming the present planned orbit location of the two INTELSAT VI satellites will make them visible only approximately 5° above the horizon to the West Coast Earth Station and about 10° above the horizon to the East Coast Earth Station. For this situation the satellite will be in the radar 3 dB antenna beamwidth 0.4% of the time.

Note that the model of intercept does not allow for the time of radar mainbeam-satellite intercept. A minimum time of intercept can be estimated from the scan rates of the radars. For example, the AN/FPS-16 is capable of scanning at 25°/sec in elevation, and 45°/sec in azimuth. The respective dwell times are 40 ms and 22 ms when the radar antenna is moving at a maximum rate. The dwell time on the satellite could well be longer than this depending on the radar - transponder target mission geometry and target velocity in a tracking situation. A more detailed analysis of the probability of intercept would require detailed information about past and future test range tracking scenarios which is beyond the scope of this report. There is some difficulty in assessing the mainbeam-to-mainbeam coupling problem since satellite antenna patterns are shaped to receive transmissions from almost every possible terrestrial direction (Fuenzalida et al., 1977).

Radar Mainbeam-to-Satellite Mainbeam Coupling

Another point of difficulty is encountered when attempting to find an agreed upon criteria or an acceptable definition of "harmful radar-to-satellite interference". This is one of the problems being taken up at present by Ad Hoc 183 as mentioned earlier in this report and the outputs from this group should be of great help to studies involving radar/satellite interference. Hernandez (1978) gives some results for low channel voice circuits which have been incorporated into a recent CCIR report (CCIR, 1980) along with those of Wachs and Arroyo (1978) and the analysis of Bryon and Berry (1978). All of these studies are for FDM/FM systems. The INTELSAT V, as an example, permits the use of FDMA/FM, FDMA/PSK, or TDMA/PSK transmission as well, therefore, the results of radar/satellite interaction given in the CCIR report can be used only as a general guideline.

The NASA Measurements reported in a recent CCIR document (CCIR 1980) indicated that the carrier-to-interference ratio (C/I) of 11 to 17 dB is necessary to protect analog FM TV from incoherent interference from radar signals. The COMSAT measurements (Wachs and Arroyo, 1978) indicated that the C/I of -10 dB to 6.5 dB are required to protect FDM/FM Carriers from interfering radar emissions. For analysis purposes in this report based on the types of radars involved, two values of C/I will be used to bound the problem:

C/I = 15 dB for FM/TV

C/I = -7.5 dB for FDM/FM.

Another reference point for the evaluation of interference from radar may be taken as the saturation level at the satellite receiver input. Table 16 gives the saturation flux density for the INTELSAT VI used in this report. For power flux densities which meet or exceed the saturation flux density of the satellite receiver, non-linear regions of the front end may be reached and intermodulation products begin to appear at the receiver output. This nonlinear distortion may appear at frequencies other than that of the interfering signal and be demodulated into unpredictable voice channels (Pawula et al., 1971).

Table 16. INTELSAT VI Communication Satellite Technical Characteristics

Earth station transmitter
- Power - 1Kw   ERIP   90 dBW
- Polarization - Left hand circular
- Antenna Gain - 60 dB

Satellite Transponder Receiver
- Saturation Power Flux Density
  - -79 dBW/m^2/80 MHz beam edge
  - -82.6 dBW/M^2/80 MHz within beam
- G/T = -8.5 dB/k beam edge
- G/T = -5.5 dB/k within beam
- Out-of-band receiver filter response
  - -30 dB at 5840 MHz
  - -40 dB at 5830 MHz

The AN/FPS-16 is representative of typical search and tracking radars used in the band and is the most widely used radar at the various tracking ranges in CONUS. The AN/SPS-10 characteristics will be used as representative of typical shipboard radars in the band for analysis purposes. The technical characteristics of these two radars are given in Tables 6 and 11 and will be used in the following analysis. It must be noted that the AN/SPS-10 does not tune into the 5850-5925 MHz portion of the band. However, there is more information and measurements available for analysis than other shipboard radars and most characteristics other than the frequency range are typical. The basic characteristics of this radar will be used here for analysis example only. Peak power transmitted by the radars will be used in all analysis here.

For mainlobe-to-mainlobe coupling

$$C/I = P_T + G_T - P_I - G_I + G_{SE} - G_{SR} - (L_T - L_I) - M + FDR \quad (1)$$

Where: P_I = Radar transmitter power, dBW

G_I = Radar antenna gain, dBi

P_T = Earth station transmitter power, dBW

G_T = Earth station antenna gain, dBi

G_{SE} = Satellite antenna gain in the direction of the earth station, dBi

G_{SR} = Satellite antenna gain in the direction of the radar, dBi

L_T = Path loss between earth station and satellite, dB

L_I = Path loss between radar transmitter and satellite, dB

M = Path loss margin for the earth station signal, dB (assumed to be equal to 1.2 dB).

FDR = Frequency dependent rejection of receiver, dB.

The maximum differential path loss of two points on the surface of the earth to a satellite is 1.3 dB. $L_T - L_I$ = 1.0 dB will be used in the calculations here as an approximation. For the worst case analysis, it could be assumed that the earth-station is located at the 3-dB satellite beam contour and the radar is located at the beam center. Hence,

$$G_{SE} - G_{SR} = -3.0 \text{ dB} \quad (2)$$

is a good approximation and will be used in this analysis.

Substituting equations (2) above into (1) gives

$$C/I = P_T + G_T - P_I - G_I + (-3) -(1) -(1.2) + 0$$

$$= P_T + G_T - P_I - G_I -5.2 \quad (3)$$

(Note, FDR = 0 for cochannel case)

Substituting values from Tables 8 and 15

$$C/I = (30 + 60) - (60 + 47) -5.2$$

$$= -22.2 \text{ dB}$$

For the shipboard AN/SPS-10 type radars with less power and wider beamwidths the calcuation becomes:

$$C/I = 90 - (54.5 + 30) -5.2$$

$$= 0.3 \text{ dB.}$$

Using the C/I criteria as discussed earlier, the AN/FPS-16 radar would then fail to meet the C/I = -7.5 dB criteria by 14.7 dB and 37.2 dB for the C/I = 15 dB criteria. The AN/SPS-10 type radars would have a safe margin of 7.8 dB for the co-channel case using the C/I = -7.5 dB criteria and would fail to meet the C/I = 15 dB criteria by 14.7 dB.

Radar Sidelobe To Satellite Mainbeam Interaction

For the case of the radar sidelobe to satellite mainbeam interactions the worst case will be pursued here which would involve the first sidelobe of the radar. The actual earth station antenna to be used with the INTELSAT VI was not totally specified at this writing but the gain and patterns may be estimated from knowledge given by COMSAT Labs by private communication and ITU recommendations (1982). ITU Appendix 29, Annex III gives a method for calculating radiation patterns as given in Appendix B.

Assuming the earth station antenna has a diameter of 32 m, the gain pattern of the antenna may be calculated by method (a) in Appendix B and is listed in Table 17. In contrast, a typical tracking radar antenna approximately 4.88 m diameter (AN/FPS16) is calculated by method (b) of Appendix B. These results are listed in Table 18.

Table 17. Gain for 32 m Diameter Antenna at Selected Angles Off Boresight

$\phi°$	G(dB)	Remarks
0	60.0	Main lobe
0.12-0.33°	44.1	First Side Lobe
5°	14.5	
10°	7.0	
20°	- 0.5	
40°	- 8.1	
$48° < \phi < 180°$	-10.0	

Table 18. Gain for 4.88 m Diameter Antenna at Selected Angles Off Boresight

$\phi°$	G(dB)	Remarks
0	47.0	Main Lobe
0.84 to 1.07	31.5	First Side Lobe
5	14.8	
10	7.3	
20	-0.2	
40	-7.6	
$48 \leq \phi \leq 180°$	-9.7	

For the radar sidelobe-to-satellite mainbeam coupling case equation (3) can be rewritten in a more convenient form as

$$C/I = P_T + G_T - P_I - G_I\ (\theta)\ -5.2 \tag{4}$$

where

$G_I(\theta)$ = radar antenna gain in the direction of the satellite mainlobe as a function of pointing angle, θ.

For the tracking radar case the AN/FPS-16 radar characteristics will be used giving for the first sidelobe from CCIR Annex III

$$G_I = 2 + 15 \log \frac{D}{\lambda} = 31.5 \text{ dBi}$$

$$C/I = 90 -(60 + 31.5) -5.2 = -6.7 \text{ dB}$$

which fails to meet the C/I criteria of 15 dB by 21.7 dB but is just within the C/I criteria of -7.5 dB by 0.7 dB.

For the minimum angle, θ, that the radar must be pointed away from the geostationary orbit position for C/I = 15 dB

$$P_T + G_T - P_I - G_I\ (\theta)\ -5.2 = 15 \tag{5}$$

$$G_I(\theta) = 9.8 \text{ dB}$$

$$52 -10 \log \frac{D}{\lambda} -25 \log \theta = 9.8$$

$$\theta = 7.9°$$

Earth Station Transmitter-To-Radar Receiver Coupling

The power at a radar receiver may be calculated using

$$P_r = P_T + G_T + G_I - L_p - FDR \tag{6}$$

where:

P_r = Power received at the input of the radar receiver, dBW

P_T = Power transmitted by the earth station, dBW

G_T = Transmitter antenna gain, dBi

G_I = Radar receiver antenna gain, dBi

L_p = Propagation loss between two isotropic antennas, dB

FDR = Frequency Dependent Rejection, dB

If P_r is set equal to the radar receiver noise level (N_s), then L_p will represent the minimum required propagation loss between the earth station and radar site for permissible operation.

Then

$$L_p = P_T + G_T + G_I - N_s - FDR \qquad (7)$$

and

$$N_s = 10 \text{ Log } KTB_r + F \qquad (8)$$

where: N_s = receiver noise level, dBW

F = radar receiver noise figure, dB

K = Boltzmann's constant (= 1.38×10^{-23} Jules/Kelvin)

T = reference temperature (290° Kelvin)

B_r = radar receiver bandwidth, MHz

N_s = -124 dBW for the AN/FPS 16 radar receiver.

Assuming FDR = 0 for co-channel, equation (7) becomes

$$L_p = P_T + G_T(\phi) + G_I(\phi) + 124 \qquad (9)$$

Using information from Tables 17 and 18, values for L_p were derived for permissible operation of earth station transmitter and radar receiver for various angles off boresight for each antenna and are tabulated in Table 19.

Table 19. Summary of Minimum Required Propagation Loss in dB Between Earth Station Transmitter and Tracking Radar Receiver for Interference Free Operation

EARTH STATION	RADAR RECEIVER						
ANGLE OFF BORESIGHT	MAIN BEAM	FIRST SIDELOBE	5°	10°	20°	40°	48<θ<180°
FIRST SIDELOBE	245	229.6	212.9	205.4	197.9	190.5	188.4
5°	215.5	200	183.3	175.8	168.3	160.9	158.8
10°	208	192.5	175.8	168.3	160.8	153.4	151.3
20°	200.5	185	168.3	160.8	153.3	145.9	143.8
40°	192.5	177.4	160.7	153.2	145.7	138.3	136.2
48°<θ<180°	191	175.5	168.8	151.3	143.8	136.4	134.3

Figure 20 shows the basic transmission loss versus distance using NTIA path-loss model QKAREA (modified Longley, Rice model) where terrain effects are taken into consideration. Four existing COMSAT earth station sites and one planned were used in the model to generate the curves. The sites used and coordinates are:

Andover, ME	44.37.59N, 70.41.52W
Roaring Creek, PA	40.53.35N, 76.26.23W (Planned)
Etam, WV	39.16.50N, 79.44.13W
Jamesburg, CA	36.24.10N, 121.38.48W
Brewster, WA	48.08.49N, 119.41.28W

The five curves of Figure 20 are for five COMSAT earth-stations located as labeled. The distance from each site was extended radially in small steps until an area of 150 km in radius around each site was encompassed. For each area of radius up to the 150 km, the corresponding basic transmission loss curves for 50% of the locations and 50% of the time in the area around the site is shown on the graph. A free space basic transmission loss curve is shown on the graphs for reference. The curves can be used to find the distance that the earth station and radar must be separated to give interference free operation using Table 24. For example; the case of earth station first sidelobe interaction with the radar first sidelobe. The required transmission loss would have to be 229.6 dB for interference free operation. From Figure 20 using the curve for Jamesburg, CA, gives a distance of at least 70 km separation to accomplish interference free operation. The worst case situation would be earth station first sidelobe interaction with the mainbeam of the radar. From the table and the curve for Roaring Creek, PA, the minimum distance of separation would be over 200 km.

However, for many of the sites, there are terrain features such as mountains that would help shield radar sites in the 150 km area. Since a statistical model is used and locations are randomly selected within the 150 km radius from the earth-station transmitter, actual terrain features in the direction of a given radar site are not specifically addressed.

It is highly unlikely that there will ever be earth-station transmitter first sidelobe to radar receiver mainlobe coupling except for ships at sea. It is hard to visualize first sidelobe to first sidelobe coupling for land-based tracking radars and earth-station transmissions as well. For the Jamesburg, CA, site, the Earth-station/radar interactions would seem to be minimal. The Andover, Maine site, with only a cursory look, would seem to be the most promising site of existing COMSAT sites on the East Coast for compatible operation with radiolocation in this band.

Since there would seem to be a manageable problem with earth-station transmission interaction with radar receivers in-band, there would be even less likelihood for interaction if the radars are operated out-of-band (below 5850 MHz). Therefore, out-of-band analysis for this situation will not be given here.

Satellite-Radar Sharing Criteria

The greatest sharing problem as identified in this report is the mainbeam-to-mainbeam coupling between radar transmissions and satellite receivers. In developing a sharing criteria the following analysis is performed:

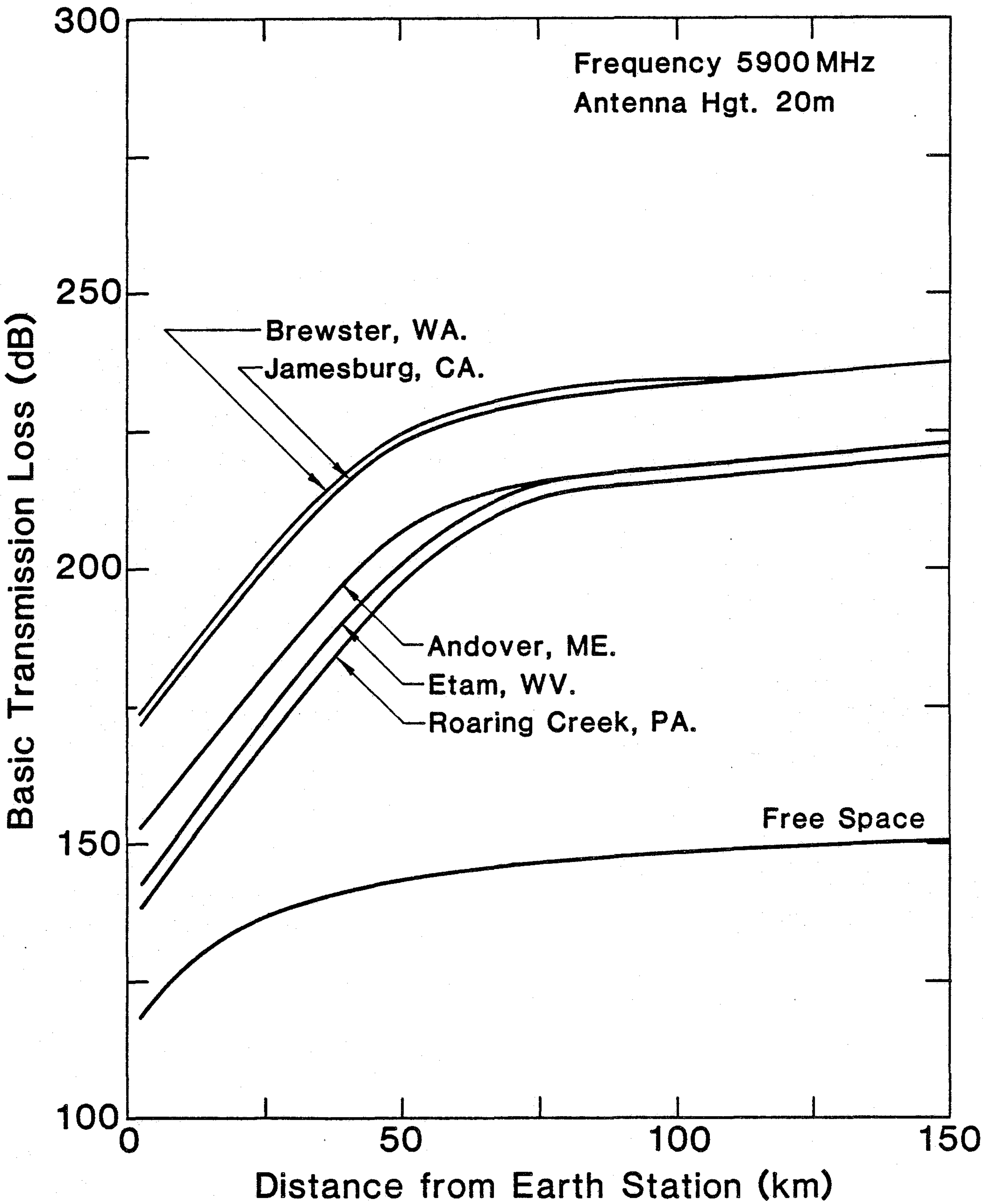


Figure 20. Basic Transmission Loss Versus Distance from Existing COMSAT Transmitter Sites.

The uplink carrier-to-noise ratio is given by

$$C/N = P_T + G_T + G/T_{sat} - L_T - L_m - 10 \log B_r - K \tag{10}$$

where: P_T = Earth station transmitter power, dBW

G_T - Earth Station Antenna Gain, dBi

G/T_{sat} = Satellite system figure of merit, mid beam, dB/k

L_T = propagation loss between earth station and satellite, dB

L_m = miscellaneous losses assumed to be 1.2 dB

B_r = satellite receiver bandwidth, Hz

K = Boltzmann's constant in dB

$C/N = 90 - 5.5 - 200 - 1.2 - 79 + 228.6 = 32.9$ dB

Letting $P_{TR} = P_T + G_T$ the Earth Station radiated power and $P_{IR} = P_I + G_I$ the radar radiated power then Equation (4) is rewritten to be

$$P_{TR} = C/I + P_{IR} + 5.2 \tag{11}$$

Setting $C/I = 15$ dB

$$P_{TR} = P_{IR} + 20.2$$

and $C/I = -7.5$ dB

$$P_{TR} = P_{IR} - 2.3$$

Substituting back into (11)

$$C/N = P_{IR} + 20.2 - 5.5 - 200 - 1.2 - 79 + 228.6$$

$$P_{IR} = C/N + 36.9$$

$$P_{IR} = 32.9 + 36.9 = 69.8 \text{ dBW } (C/I = 15 \text{ dB})$$

and

$$C/N = P_{IR} - 2.3 - 5.5 - 200 - 1.2 - 79 + 228.6$$

$$P_{IR} = C/N + 59.4$$

$$P_{IR} = 32.9 + 59.4 = 92.3 \text{ dBW } (C/I = -7.5 \text{ dB})$$

The maximum radiated power in-band that radars can transmit using the C/I = 15 dB and C/I = -7.5 dB bounds is 69.8 dBW and 92.3 dBW respectively.

The radiated power for the two radars used as typical in the band are: For the AN/FPS-16, P_{IR} = 107 dBW, and for the AN/SPS-10, P_{IR} = 84.5 dBW.

Radar Off-Tune Analysis

Since it is not practical to restrict the power of existing radars in the 5850-5925 MHz band, the other alternative would be to operate the radars out-of-band (below 5850 MHz). Following is the radar out-of-band analysis based on the current receiver filter response characteristics for the INTELSAT VI. Figures 21 and 22 show the received C/I at the INTELSAT VI receiver based on the satellite receiver out-of-band filter response characteristics given in Table 16 and the emission spectra of the AN/FPS-16 and AN/SPS-10 radars used in the example here. The curves were arrived by using a method described by Newhouse (Newhouse, 1969, 1974).

The curve of Figure 21 shows that if the center frequency of the AN/FPS-16 is off-tuned from the satellite receiver frequency by approximately 50 MHz (5840 MHz), the C/I = -7.5 dB criteria can be met. If it is off-tuned approximately 132 MHz (5758 MHz), the C/I = 15 dB criteria can be met. The perturbation around -100 MHz corresponds to the spurious emissions of the AN/FPS-16 measured emission spectrum as shown in Figure 13. If this spurious emission was suppressed by a waveguide filter at the output of the radar transmitter, this would reduce the amount of off-tuning needed to meet the C/I = 15 dB criteria.

For the AN/SPS-10, the curve of Figure 22 shows no frequency offset is needed for the C/I = -7.5 dB criteria since it is met by this radar. If the center frequency of this radar is off-tuned approximately 55 MHz, the C/I = 15 dB criteria can be met. However, the AN/SPS-10 radars normally are not tuned above 5825 MHz which is already 65 MHz away as shown by the vertical line in Figure 22. Thus the AN/SPS-10 radars should meet the C/I criteria bounds as given in this report.

EARTH STATION SIDELOBE-TO-RADIOLOCATION TRANSPONDER COUPLING

Many of the radiolocation scenarios surrounding the missile test ranges involves the tracking of transponders on aircraft, missiles, RPVs, etc. The interaction of earth station sidelobes with the radiolocation transponders would be a very possible situation. For this problem the following situation is assumed;

G_r = 3 dBi (omni directional)

N_s = -74 dBm (transponder receiver)

where: G_r = transponder receiver antenna gain, dB

N_s = transponder receiver noise level

Then the equation for propagation loss, L_p, becomes

$$L_p = P_T + G_T(\theta) + G_r - N_s \qquad (12)$$

Assuming no earth station mainbeam to transponder coupling, the worst case interaction would occur between the first sidelobe of the earth station emitter to radar transponder receiver. The minimum loss for interference free operation becomes

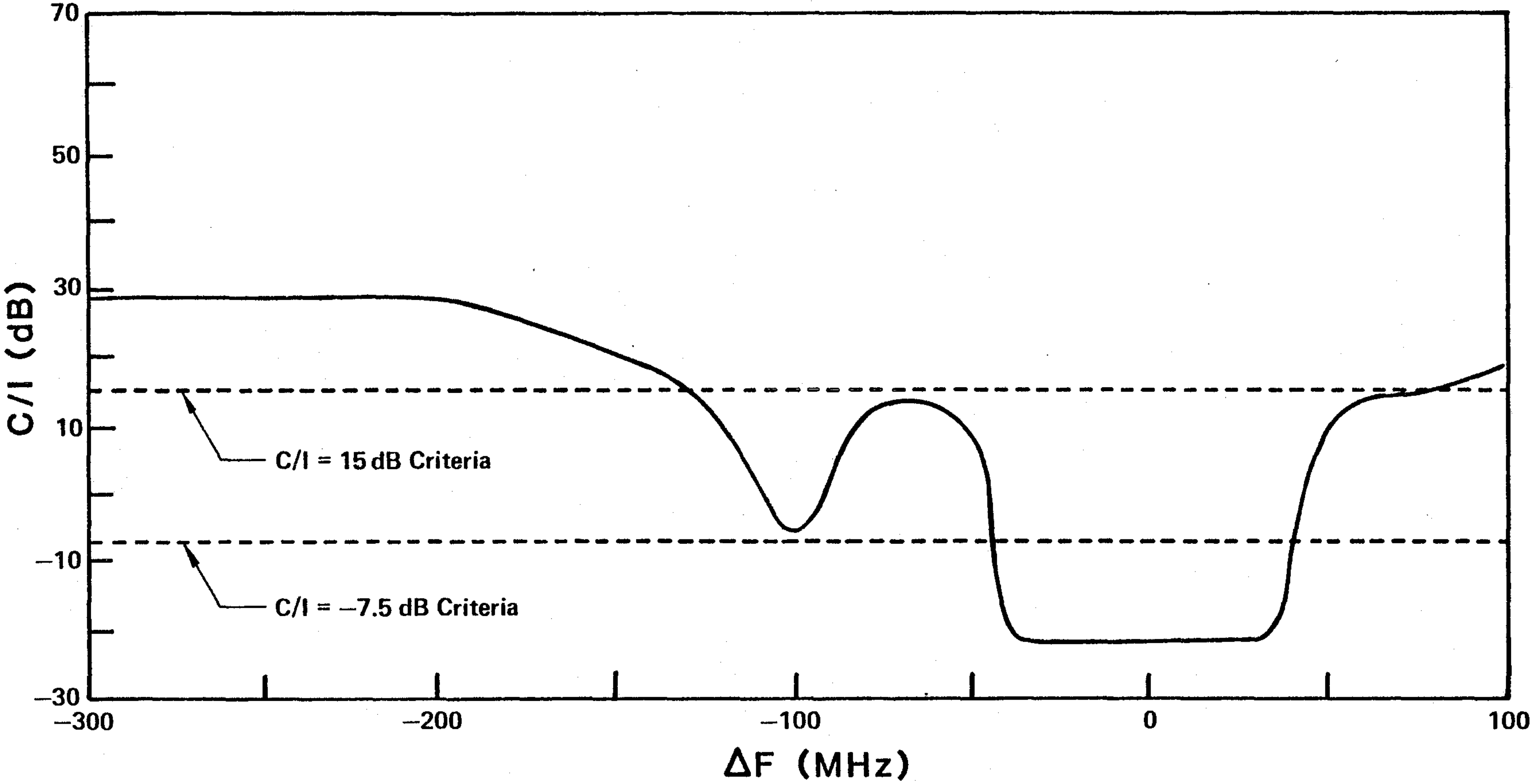


Figure 21. Receiver Carrier-to-Interference Ratio at Satellite for AN/FPS-16 Radar.

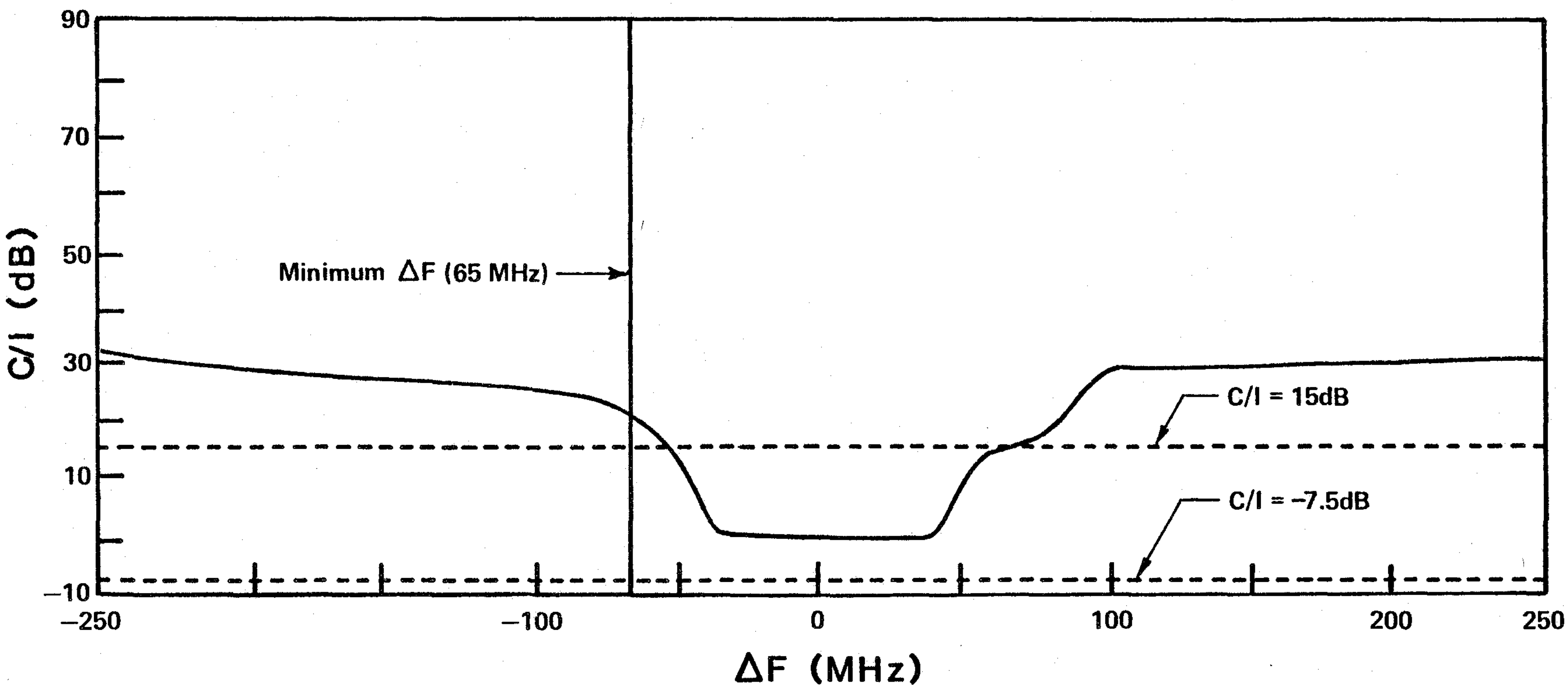


Figure 22. Received Carrier-to-Interference Ratio at Satellite for AN/SPS-10 Radar.

$L_p = 30 + 44.1 + 3 + 74 = 151.1$ dB.

Using the ground-to-air propagation loss curves of Figure 23 [which are computer derived from the Integrated Propagation System, (IPS), Smooth Earth Model] the slant range distance corresponding to transponder altitude for interference free operation is:

Transponder Altitude Meters	Slant Range km
300	83
600	105
1500	160
3000	210
6000	280

All other sidelobe conditions give slant range distances of under 10 km for interference free operation which should not pose a problem. Because of the narrow beam of the uplink antenna, the possible intercept with transponders seems unlikely for both the Jamesburg, CA, and Andover, ME sites.

For the case of the radiolocation transponder to satellite receiver interaction, there should be no compatibility problems since the transponder transmitters generally transmit low power (.1 to 1 kW) with an EIRP from 23 to 33 dBW.

ISM AND RESTRICTED RADIATION DEVICES/RADAR INTERACTIONS

Figure 24 gives the separation distances between ISM devices and a radar receiver. Here the AN/FPS-16 radar receiver is used as an example. It is assumed that the ISM devices radiate the maximum allowable out-of-band fields to the AN/FPS-16 receiver for 1.6 MHz and 8.0 MHz radar bandwidth (depending on track mode), and assuming the interfering signal is along the bore sight of the radar antenna (worst case). However, there is no restriction on in-band (5725-5875 MHz) radiated fields for ISM equipment which could pose a problem at some future date if ISM equipment were to use this band in large numbers.

The interactions between ISM and restricted radiation devices with radars was analyzed similar to a method used by Bulawka (1980) in a previous SRA. Given some value of electric field-strength at a specified distance from an ISM device, e.i. 25 μVm at 1000 ft for diathermy equipment, the objective is to calculate the received power level at the radar receiver. The electric field-strength can be calculated using the proportionality relationship of:

$$\frac{E_1}{E_2} = \frac{D_2}{D_1} \qquad (12)$$

where E_1 = electric field-strength at separation distance D_1,
E_2 = electric field-strength at separation distance D_2,
D_1 = separation distance at which electric field-strength is E_1,
D_2 = separation distance at which electric field-strength is E_2.

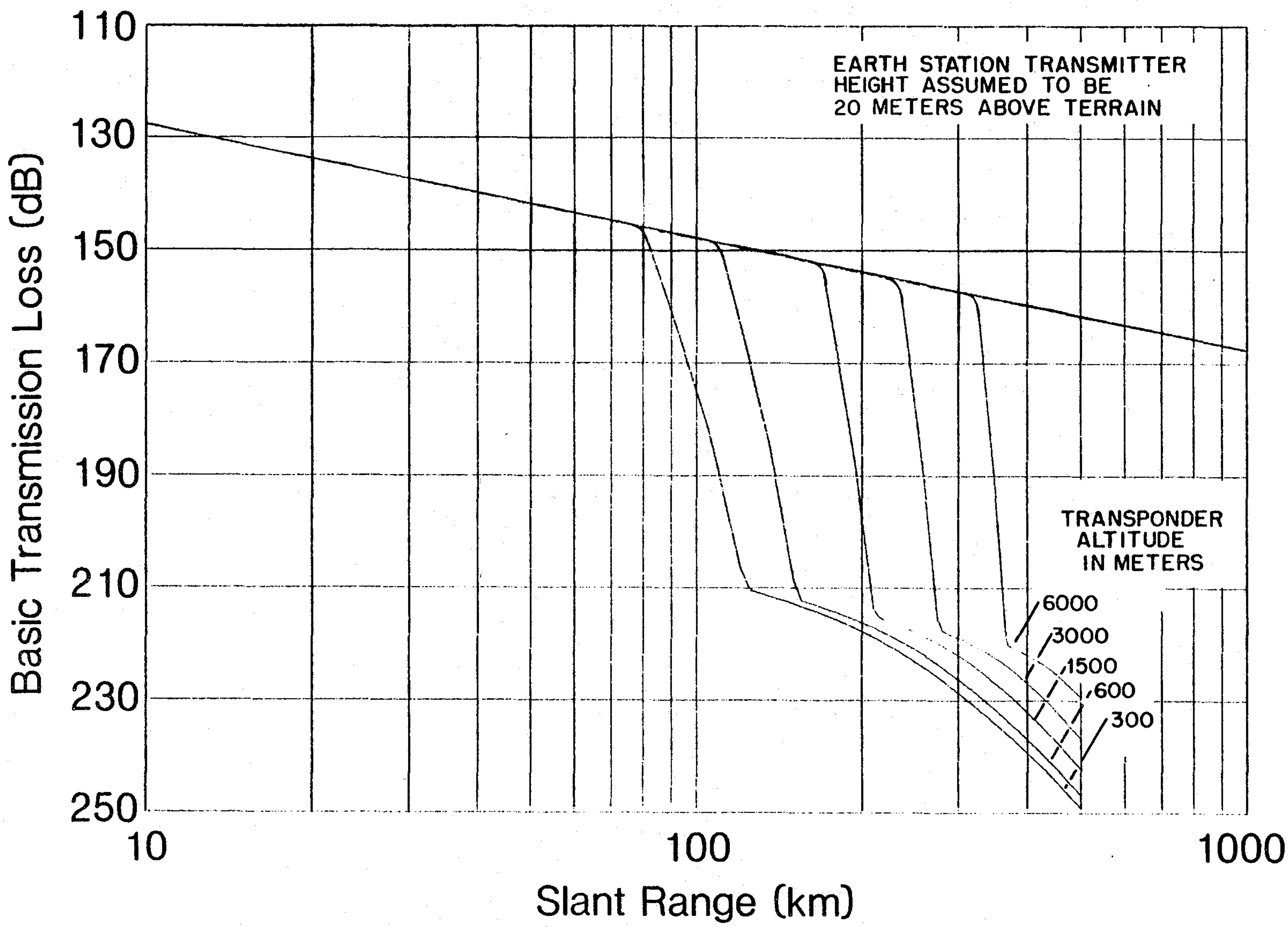


Figure 23. Ground-to-Air Propagation Loss at 5800 MHz.

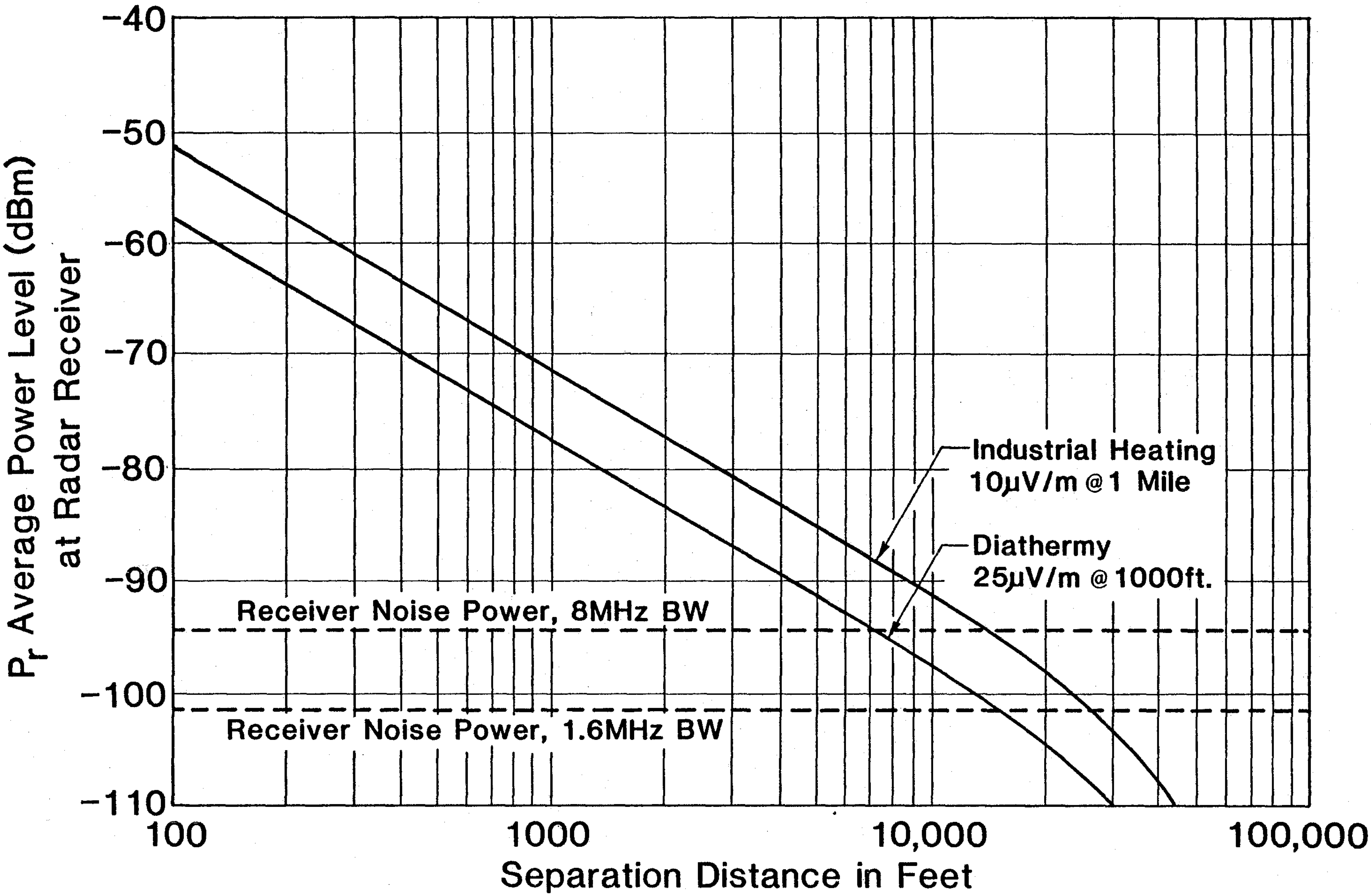


Figure 24. ISM/Radar Receiver Separation Distances Based on Out-of-Band Specifications. Radar Receiver Sensitivity Shown for Two Bandwidths (BW).

For this particular case the received power at the radar receiver as a function of separation distance may be expressed as:

$$P_r = P_d + A_e - OTR \qquad (13)$$

where

P_r = radar receiver average power in dBm,

P_d = average power density in dBm/m^2,

A_e = effective antenna aperture in dB,

OTR = on-tune rejection which is 0 in the cases analyzed here where the receiver bandwidth is larger than the interfering signal bandwidth.

The power density may be written as:

$$P_d = \frac{E_2^2 \ D_2^2}{D_1^2 \ R} \qquad (2)$$

where P_d is expressed in watts/m^2

E_2 is expressed in V/m

R is free space impedance, 377 Ω

Simplifying and rearranging terms

$$P_d = 20 \log (E_2D_2) -20 \log (D_1) - 116$$

where

P_d = average power density in dBm/m^2,

E_2 = average electric field strength in μV/m,

D_2 = distance in feet corresponding to E_2,

D_1 = variable separation distance in feet.

The effective antenna aperture is calculated by:

$\frac{G\lambda^2}{4\pi}$, converting wavelength into frequency and taking the logarithm

$$A_e = G -20 \log (f) + 38.5 \text{ (effective antenna aperture in dB)}$$

$$= 47 - 75.3 + 38.5 = 10.2 \text{ dB.}$$

The receiver noise level (N_s) was calculated for the two receiver bandwidths of the AN/FPS-16 corresponding to two operating modes using equation 8. These levels are shown on the Figures 24 through 26 by the dashed lines.

The average power level P_r at the radar receiver was plotted in Figure 24 for Industrial Heating and Diathermy equipments versus separation distance. From the 10,000 foot separation distance and beyond, the OKAREA path loss model was used to give a more realistic power loss. The radar antenna height was assumed to be 20 meters.

Figure 25 shows the separation distances between Field Disturbance Sensors (FDS), a restricted radiation device, and the AN/FPS-16 radar. This assumes the FDS devices radiate the maximum allowable fields in-band along the bore sight of the radar antenna. As can be seen, distances of 18 to 20 miles would have to be maintained to be below the receiver noise level. Figure 26 shows the separation distances between Low Power Communication (LPC) devices and the AN/FPS-16 radar receiver. These devices are used for measurement of the characteristics of materials. Although no such devices were found operating in the band, the provision for their use is given in Sub-part 15.214 of the FCC Rules and Regulations. Again, the "worst case" condition of the interfering signal along the bore sight of the radar antenna was assumed. The two curves, as labeled, represent the power at the radar receiver versus separation distance for the fundamental and 2nd harmonic.

The FDS and LPC are restricted radiation devices and must not cause harmful interference to systems operating within the band. The devices should be able to operate within the band on a non-interference basis using distance separation as a spectrum management technique.

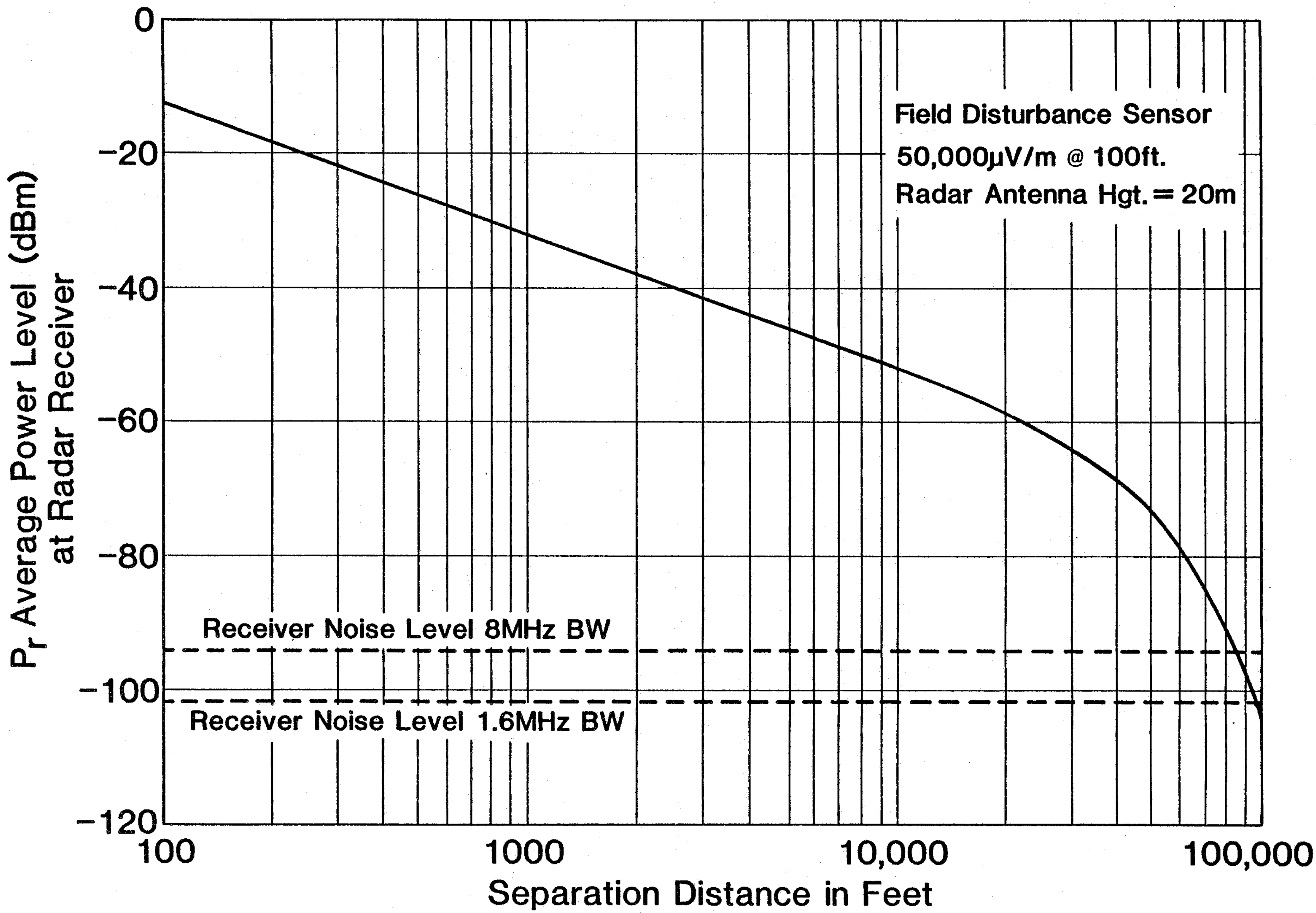


Figure 25. Field Disturbance Sensor/Radar Receiver Separation Distance Based on In-Band Specifications. Radar Receiver Sensitivity Shown for Two Bandwidths (BW).

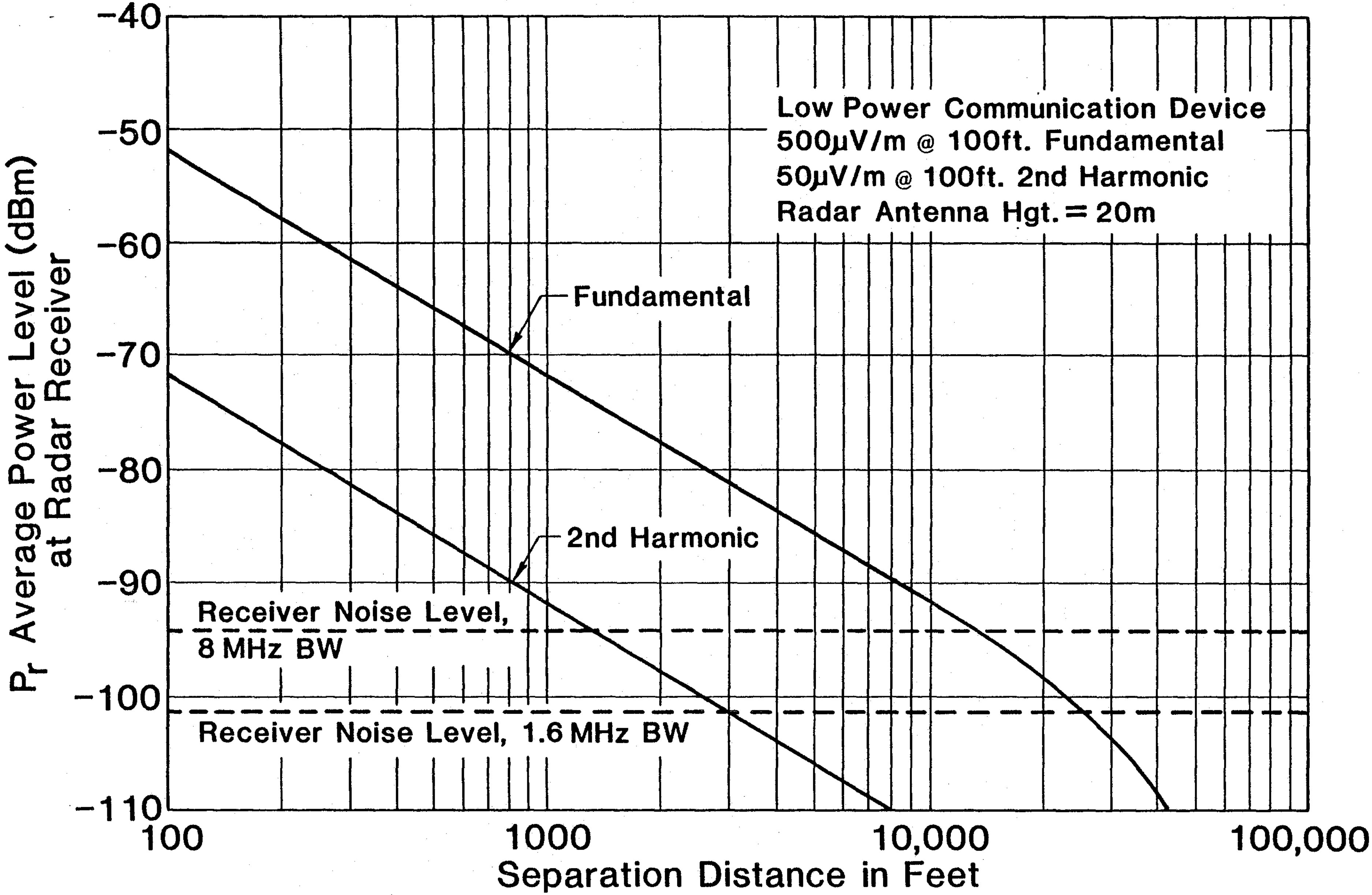


Figure 26. Low Power Communications Device/Radar Receiver Separation Distance Based on In-Band Specifications. Radar Receiver Sensitivity Shown for Two Bandwidths (BW).

SECTION 7

SPECTRUM MANAGEMENT ISSUES

The effects of WARC-79 on the 5650-5925 MHz band are significant. The band which previous to WARC-79 was military radiolocation in the United States must now share the upper portion of the band (5850-5925 MHz) with the non-Government Fixed-Satellite Service. There is also heavy use of the ISM band (5725-5875 MHz) by the radiolocation service. The character of the band could change significantly in the next decade. The major spectrum management issues are discussed in the following paragraphs.

RADIOLOCATION AND THE FIXED-SATELLITE SERVICE

International communication satellite systems such as the INTELSAT VI series have the option to become operational in the 5850-5925 MHz portion of the band under study here in the 1985-86 time frame. As shown in Section 6 the interference potential to the satellite receiver system from in-band radar energy presents an incompatible situation. The earth station transmitter could also pose some compatibility problem for transponder systems in the Radiolocation Service sharing this portion of the band. However, only the first sidelobe provides enough energy to be a problem. There are existing COMSAT sites on either coast which seem to be desirable for minimizing the potential problem.

Measurement by the RSMS show this band to be heavily used by military test ranges and shipboard radars. However, few radars were measured above 5850 MHz. Transponders were found to operate above 5850 MHz and as mentioned previously, would experience possible interference from the FSS. As given in Section 6 there are existing COMSAT Earth-station sites that seem to provide possibility of limited sharing between the Radiolocation and Fixed-Satellite Services. However, radars whose tracking angles may cause mainbeam-to-mainbeam coupling with the satellite would have to be limited to radiated powers of 69.8 dBW if the satellite transponder carries FM/TV or 92.3 dBW if the satellite transponder system is limited to FDM/FM or similar modulations. Since it is not practical to limit the power of existing radars in the band, off-tuning the radars from the 5850-5925 MHz portion of the band is another viable option.

RADIOLOCATION AND ISM

Figure 2 in Section 4 shows that a large number of assignments (44%) in the Radiolocation Service fall within the 5725-5875 MHz portion of the band designated to ISM use. Although there was no use of the ISM band found by equipments classified as ISM, the potential for interference at some future time always exists. This could be of importance to the national defense if ISM equipment which is permitted unlimited conducted and radiated energy in the 5725-5875 MHz band were to proliferate. As stated earlier in this report, at least 27% (5850-5925 MHz) of the band will require some sort of restricted use by the high power radar systems to be compatible with the FSS. Even more spectrum would be unusable if off-tuning is used as shown in Section 6 the AN/SPS-16 tuning to no higher than 5760 MHz to maintain a C/I criteria of 15 dB. If the ISM band were to be heavily used by ISM equipments, it is possible that the portion of the band from 5725-5850 MHz would also have only limited use by the military who are the prime users. As stated above, this is also the frequency range where a large number of radiolocation assignments exist.

There have been proposed changes to ISM standards considered over the past few years. The FCC issued a NPRM requesting comments for revising Part 18 which governs ISM equipment [FCC, 1978]. After receiving comments and suggestions from various manufacturers of ISM equipment, concerned government agencies, and other sources based on the first NPRM, a new NPRM is now being drawn up which is significantly different than the first. Although the second NPRM has not been issued at this report writing it will still deal with reduced frequency tolerances and stricter in-band and out-of-band emission limits.

RADIOLOCATION AND THE AMATEUR

The amateur-satellite service has new allocations in the 5650-5925 MHz band. The allocations are 5650-5670 MHz up-link and 5830-5850 MHz down-link. There is presently no known use of this band by the amateurs. However, even though the Amateur and Amateur Satellite Services operate secondary to radiolocation, interference potential particularly from the down-link can exist. Restrictions on the Amateur Satellite Service through the use of geographic location and power limitations could provide some protection to the radiolocation service. This method has been used previously, i.e., Footnote US7 used in the 420-450 MHz band which limits the power transmitted by amateur stations to 50 Watts near certain military test ranges. Also a National Memorandum of Understanding was established in the 902-928 MHz band which stated that the band was available for use by amateur stations only after coordination with and under conditions established by the DOD Frequency Coordinators in the stated areas. It is stated in the FCC Rules and Regulations, Part 97, Subpart C, that amateur stations shall not cause interference to the Government radiolocation service, however, a footnote would be beneficial both to the U.S. Government and the amateurs who would potentially use the band in that it would spell out definite coordination efforts and/or power levels to be used.

RADIOLOCATION AND RESTRICTED RADIATION DEVICES

The FCC Rules and Regulations, Part 15, states that certain restricted radiation devices may operate in the band 5725-5875 MHz. No use of the band was found by restricted radiation devices or reported incidence of interference from such devices. In light of the importance of this band to the U.S. Government, the FCC's assistance and cooperation would be needed to manage the growth of such devices in the private sector. Three specific areas of assistance would be needed as follows:

1. Change the band which can be used for such devices from 5800 ±75 MHz to 5800 ±50 MHz to help keep the possible interference potential to the smallest frequency subband as possible since radiolocation is already losing valuable flexibility in operating frequency within the 5650-5925 MHz band.

2. Make manufacturers aware of the importance of this band to the Government and request their support in helping to keep any devices considered for the band compatible.

3. Strict enforcement of the non-interference basis these devices must operate under per Part 15.311(b) for the 5750-5850 MHz subband.

APPENDIX A

PROBABILITY OF RADAR MAINBEAM-TO-SATELLITE ANTENNA COUPLING

The radars considered here are generally used for target tracking. The mainbeam of the antennas may be directed toward the target which is located at any arbitrary point in the hemisphere above the radar site. Since the geostationary orbit is visible to all the points on the earth except two small regions around the poles of the earth, it is easy to believe that, occasionally, in target tracking the mainbeam of the radar will be directed toward the satellite antenna. Here the probability, P, of the radar mainbeam-to-satellite antenna coupling is defined by

$$P = \frac{S}{S_t} \tag{A-1}$$

where S_t is the area of the spherical zone above the radar site and S is the area generated at the intersection of radar antenna mainbeam and the surface S_t, see Figure A-1.

The assumption in Equation A-1 is that the radar targets are uniformly distributed in the spherical zone above the radar site. The surface area of the spherical zone is given by

$$S_t = 2\pi R\, H \tag{A-2}$$

where H = R-r and the parameters R and r are described in Figure A-1. Considering the geometry shown, the surface area S may be expressed by

$$S = (D_1 - D_2 \cos \phi)\, 2\pi R \tag{A-3}$$

where the parameters D_1 and D_2 are defined in Figure A-1 and ϕ is one-half the 3 dB beamwidth of the radar antenna pattern.

D_1 and D_2 are related to the elevation angle of the radar by the expression

$$D_i = R \cos [\theta_i + \text{arc sin } (r/R \cos \theta_i)]/\cos \theta_i \qquad i = 1,2 \tag{A-4}$$

where:

$\theta_i \neq 90°$

θ_1 = Radar elevation angle, and θ_2 = radar elevation angle plus ϕ.

Substituting Equations A-2 and A-3 in Equation A-1, we obtain

$$P = [D_1 - D_2 \cos \phi]/H. \tag{A-5}$$

Equation A-5 may be used to calculate the probability P for different values of radar beamwidth. Figure A-1 is a simplified model which was used in the derivation of Equation A-5. More sophisticated models require more detailed information beyond this report.

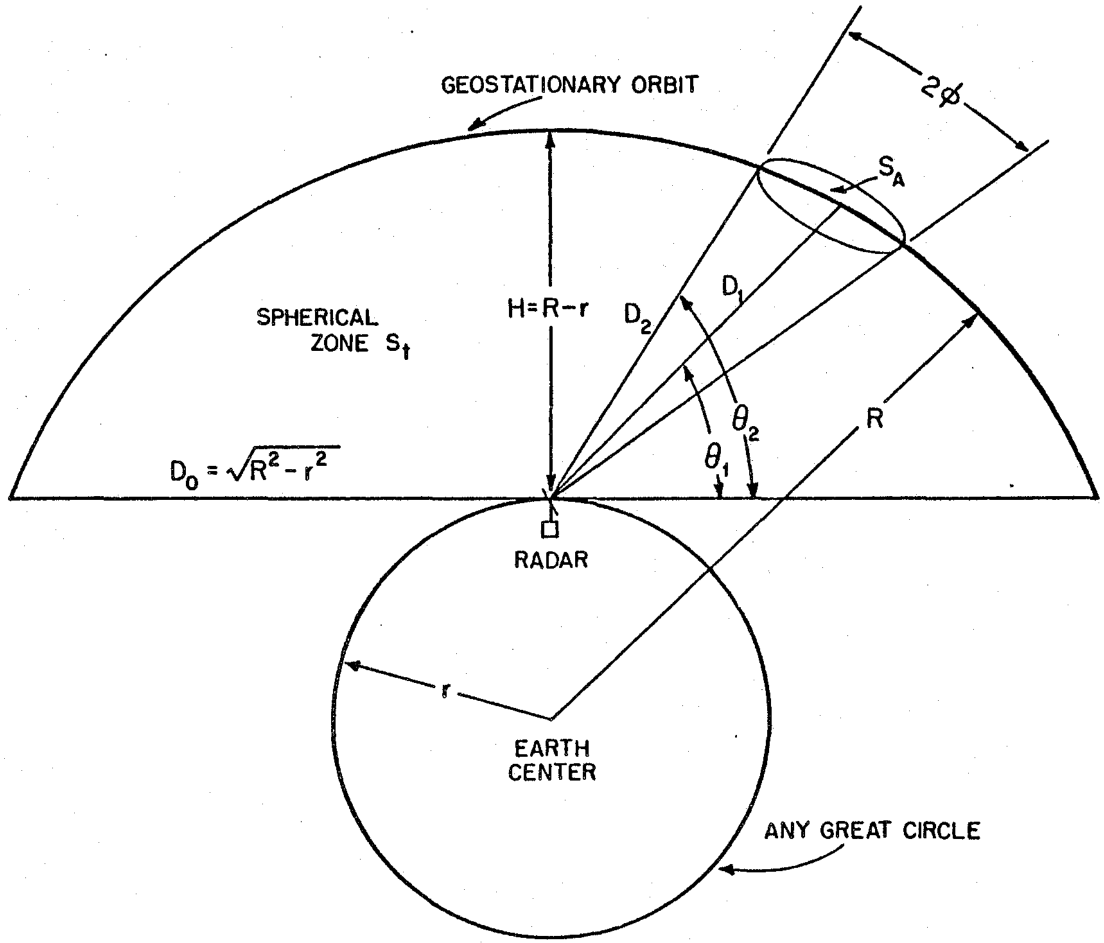


Figure A-1. Geometry for Probability of Radar Mainbeam to Satellite Coupling.

APPENDIX B

ANNEX III

Radiation Patterns for Earth Station Antennae
to Be Used When They Are Not Published

When neither measured data nor relevant CCIR Recommendations accepted by the administrations concerned are available, then administrations should use the reference patterns as described below (dB):

a) for values of $\frac{D}{\lambda} > 100$* (maximum gain > 48 dB approx):

$$G(\phi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \phi \right)^2 \quad \text{for } 0<\phi<\phi_m$$

$$G(\phi) = G_1 \quad \text{for } \phi_m<\phi<\phi_r$$

$$G(\phi) = 32 - 25 \log\phi \quad \text{for } \phi_r<\phi<48°$$

$$G(\phi) = -10 \quad \text{for } 48°<\phi<180°$$

where:

D = antenna diameter
λ = wavelength
(expressed in the same unit)
ϕ = off-axis angle of the antenna
G_1 = gain of the first sidelobe = $2 + 15 \log \frac{D}{\lambda}$

$$\phi_m = \frac{20\lambda}{D} G_{max} - G_1 \quad \text{(degrees)}$$

$$\phi_r = 15.85 \left(\frac{D}{\lambda}\right)^{-0.6} \quad \text{(degrees)}$$

b) for values of $\frac{D}{\lambda} < 100$* (maximum gain < 48 dB approx.):

$$G(\phi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \phi \right)^2 \quad \text{for } 0<\phi<\phi_m$$

$$G(\phi) = G_1 \quad \text{for } \phi_m \leq \phi \leq 100 \frac{\lambda}{D}$$

$$G(\phi) = 52 - 10 \log \frac{D}{\lambda} - 25 \log \phi \quad \text{for } 100 \frac{\lambda}{D} \leq \phi < 48°$$

$$G(\phi) = 10 - 10 \log \frac{D}{\lambda} \quad \text{for } 48° \leq \phi \leq 180°$$

The above patterns may be modified as appropriate to achieve a better representation of the actual antenna pattern.

---

*In cases where $\frac{D}{\lambda}$ is not given, it may be estimated from the expression $20 \log \frac{D}{\lambda} = G_{max} - 7.7$, where G_{max} is the main lobe antenna gain in dB.

DEPARTMENT OF STATE

Washington, D.C. 20520

June 10, 1980

Mr. Irving Goldstein
Vice President and General Manager
International Communications
Communications Satellite Corporation
950 L'Enfant Plaza, S.W.
Washington, D.C. 20024

Dear Mr. Goldstein:

The 1979 World Administrative Radio Conference modified the International Radio Regulations, including the Table of Frequency Allocations (Article N7), in order that administrations may satisfy their existing and future telecommunications requirements. In many frequency bands the specific allocations provide for two or more services on a coequal primary basis. In our opinion, there are some bands or portions thereof in which the indicated primary services are not technically compatible. In these cases it may be necessary for each administration to choose which of the primary services it will implement. The United States fully supports the right of all administrations to determine, according to their own national interest, which service allocations they will implement.

Of concern to the U.S. Government and of particular interest to ComSat and INTELSAT are specific allocations to the Fixed Satellite Service below 10 GHz. Some of the most intense and difficult negotiations during the Conference took place with respect to the bands 3.4.-3.7 GHz and 4.5-4.8 GHz. In order to consummate an acceptable compromise, the United States, along with several other administrations, agreed to and signed a formal Declaration. A copy of that Declaration is enclosed.

We believe it is necessary that ComSat and INTELSAT be fully aware of the United States Government interpretation of the Declaration, as well as our current national policy as set forth in sub-paragraphs 1) and 2) below with respect to, and domestic implementation of, the revised allocations. ComSat and INTELSAT must be equally aware of technical incompatibilities among the various services in question.

1) <u>3.4-3.7 GHz Band</u>

The United States will continue to operate vital radiolocation systems for worldwide use in the band 3.4-3.6 GHz. These sytems will be operating in accordance with the ITU Radio Regulations, and it should be understood that the U.S. Government cannot accept operational constraints. Although the United States will not withhold support for the implementation of the Fixed Satellite Service in the band, by INTELSAT, by reason of allocation table footnotes 3736 and 3736A, we will not guarantee protection from harmful interference to the Fixed Satellite Service from the Radiolocation Service. We are, however, prepared to participate in future studies and to make reasonable efforts to accomodate the Fixed Satellite Service, consistent with footnotes 3736 and 3736A and sound technical, operational and system financial planning by INTELSAT.

The 3.6-3.7 GHz can be made available for international systems in the Fixed Satellite Service in the United States on a very limited basis. The exact locations for implementation and the conditions which may be applicable to both the Fixed Satellite Service and to other services sharing this band will be subject to case-by-case electromagnetic compatibility studies.

2) <u>4.5-4.8 GHz Band</u>

The band 4.5-4.8 GHz can be made available for international systems in the Fixed Satellite Service in the United States on a limited basis. The exact locations for implementation and the conditions which may be applicable to both the Fixed Satellite Service and other services sharing this band will also be subject to case-by-case electromagnetic compatibility studies.

We wish to draw to your attention the fact that, by virtue of footnote 3748B, this band will not be available in all countries which are members of INTELSAT. Furthermore, the United States Government may find it necessary to discourage certain countries, particularly in Europe, from using this band for the Fixed Satellite Service in view of common national security interests.

3) In your capacity as United States Signatory, you are instructed to describe this U.S. national policy at all meetings of INTELSAT where this matter is discussed. You should remain in the closest possible contact with the State Department during consideration of these bands in such meetings. Following each session's consideration of these bands, but prior to the final session on this matter of any such meeting, you are further instructed to provide a verbal report on the relevant discussions; upon conclusion

of the meeting, we ask that you provide a written report.

4) You should explain, in a manner you deem expedient, this U.S. national policy to the Director General and his staff.

5) If there are any questions regarding the U.S. policy and the instructions contained in this letter, we will be pleased to arrange for any needed clarification.

Sincerely,

Arthur L. Freeman
Director
Office of International
Communications Policy

Attachment:

As stated.

ANNEX 3

DECLARATION

The Administrations of the USA, Canada, UK, Netherlands, Australia, Belgium, which are member-countries of INTELSAT, recognizing the importance of the bands 3.4 - 3.6 GHz and 4.5 - 4.8 GHz for use by the fixed-satellite service (FSS), agree as follows :

(1) They shall not by reason of footnotes 3736, 3736A and 3748B withhold support for the implementation of the FSS in these bands by INTELSAT either as to the space segment, or as to the use of the band 4.5 - 4.8 GHz in any country other than those listed in footnote 3748B.

(2) They shall make reasonable effort to accommodate FSS consistent with footnotes 3736, 3736A and 3748B and the normal procedures of the INTELSAT Organization.

The above mentioned Administrations will advise their Signatories to the INTELSAT Agreement accordingly.

USA - [signature]
AUST. [signature]
BEL [signature]
UK [signature]
CAN [signature]

HOL [signature]

The foregoing Declaration shall be effective upon the adoption of the proposals contained in Annexes 1 and 2 without substantial modifications.

29 November 1979

DEPARTMENT OF STATE

Washington, D.C. 20520

December 19, 1980

Mr. Irving Goldstein
Vice President and General Manager
International Communications
Communications Satellite Corporation
950 L'Enfant Plaza, S.W.
Washington, D.C. 20024

Dear Mr. Goldstein:

Your letter of July 28, 1980 requested a more precise definition of the provisions of our June 10, 1980 policy statement regarding the use of certain frequency bands adopted by the 1979 World Administrative Radio Conference (WARC-79) as they impact upon INTELSAT planning for future international satellite facilities. That policy was developed in consultation with all appropriate authorities of the United States Government in accordance with the normal instructional process and is hereby reaffirmed as our national policy in this matter. This letter is intended to provide additional details that should allow ComSat to proceed with any urgent planning activities and to perform its role as U.S. INTELSAT Signatory in an informed manner.

As you are aware, the 3.4-3.7 GHz and 4.4-4.7 GHz bands have been allocated to the Fixed Satellite Service in the International Table of Frequency Allocations since 1963, but these allocations have never been included in the U.S. National Table of Frequency Allocations. However, in light of the policy stated in our June 10 letter, it is possible that, after domestic implementation of the WARC-79 results, the U.S. Table will include the Fixed Satellite Service in the bands 3.6-3.7 GHz and 4.5-4.8 GHz with footnotes limiting their use to international systems.

In the United States the band 3.4-3.6 GHz will continue, for the foreseeable future, to be available to radiolocation on a primary basis. At least part of this band may also be required by aeronautical radionavigation systems for which alternative spectrum accommodation cannot be provided. It should be re-emphasized that United States military forces will continue to operate mobile radiolocation systems worldwide in this band, well beyond the 1985 date referred to in footnote 3736A, due to the lack of suitable alternative bands. Because of the nature of mobile radiolocation operations, it is not considered possible now or in the future to establish and enforce operating discipline which would either guarantee or give assurances through intent that the Radiolocation Service would not cause interference to the Fixed Satellite Service. For these reasons, it is virtually impossible that the 3.4-3.6 GHz band will be allocated to the Fixed Satellite Service in the U.S. National Table. Because of our critical military requirements for radiolocation in the European (NATO) area, the United States will press its allies in that area for continued protection of radiolocation in this band for as long as requirements exist.

To emphasize our position in regard to the band 3.4-3.6 GHz, the United States will not withhold support for INTELSAT's use of the band by reason of footnotes 3736 and 3736A or of our own national defense requirements. At the same time it must be clearly understood that for the foreseeable future, we will not include the allocation in the U.S. National Table and we can neither guarantee protection to the Fixed Satellite Service nor accept any operational constraints on existing or future radar systems. Therefore, it appears to be essential that any INTELSAT consideration for use of the band 3.4-3.6 GHz must include a complete assessment of areas of the world where the band may not be domestically allocated as well as the probable interference and other risks which may exist under these given circumstances.

In the band 3.6-3.7 GHz the United States will continue to operate radiolocation and aeronautical radionavigation (terrestrial) systems on a primary basis for an indefinite period of time beyond 1985. To the extent that stations in the international Fixed Satellite Service can coordinate their proposed frequency assignments with radar operations in this band at specific U.S. sites, the Fixed Satellite Service would enjoy the protection afforded a primary service in the U.S. It is not possible to identify the specific location or number of earth stations where favorable coordination might be feasible since future requirements are subject to change and case-by-case EMC analysis of each proposed site will be required. At this time it is anticipated that one earth station on each coast can be successfully coordinated. However, it must be recognized that no guarantee for additional earth stations exist. Finally, it should be noted that the band 3.6-3.7 GHz is not included in the formal Declaration attached to my June 10 letter.

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

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

In summary, the U.S. fully intends to honor its commitments with respect to the Final Acts of WARC-79 and we believe that the clarifications contained in this letter are consistent with the letter and intent of the Acts and the formal Declaration. It is not expected that the U.S. Government would seek action in the Board of Governors to prevent INTELSAT from planning to use the full 3.4-3.7 GHz and 4.5-4.8 GHz bands in its satellite systems, especially if the service they are proposing is to areas outside of the areas and/or frequency bands of critical concern, but we would be unable to provide guaranteed protection from interference. The policy stated in my letter of June 10, 1980 and the instructions contained therein are reaffirmed. We remain, however, prepared to participate in future studies and to make reasonable efforts to accommodate the Fixed Satellite Service, consistent with the National and International Tables of Frequency Allocations and sound technical, operational and system financial planning by INTELSAT.

Sincerely yours,

Arthur L. Freeman
Director
Office of International
Communications Policy

EB/TD:FESnrum:sp

Clearances: State - Huffcutt
NTIA - Bremat, Darnat
FCC - Torak, Greenburg
DOD - Cook May Phillips

SECTION 8

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

This report constitutes a Spectrum Resource Assessment of the 5650-5925 MHz band. Included is information on rules and regulations, allocations, technical standards, frequency assignments, system characteristics, and applicable compatibility analysis. Problems of concern to the U.S. Government usage of the band are identified, analyzed and recommendations made. Major issues concerned the introduction of a Fixed-Satellite Service (FSS) in the band and current usage of that portion of the band designated for Industrial, Scientific and Medical (ISM) purposes. It is concluded that power limitations for radars should be considered as an option to minimize potential interference problems with satellites which may become operational in the 5850-5925 MHz portion of the band. It is also concluded that in-band radiation limits be considered for the Industrial, Scientific and Medical designated frequency at 5800 ± 75 MHz to help protect Government investment and future Fixed-Satellite Service usage.

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

Amateur Service; Electromagnetic Compatiblity; 5650-5925 MHz; Fixed-Satellite Service; ISM: Radiolocation Service; Restricted Radiation Devices

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