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Measured Occupancy of 5850-5925 MHz and Adjacent 5-GHz Spectrum in the United States

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PREFACE

This report was sponsored by the Federal Highway Administration (FHWA), McLean, Virginia, under the direction of J.A. Arnold, FHWA Contracting Officer Technical Representative. Institute for Telecommunication Sciences personnel who used suitcase measurement systems to acquire data presented in this report were Jeanne Ratzloff, Charlie Samora, Michael Terada, and John Ewan.

Certain commercial companies, equipment, instruments, and materials are identified in this report to specify adequately the technical aspects of the reported results. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is necessarily the best available for the applications described.

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EXECUTIVE SUMMARY

Intelligent Transportation Systems (ITS), utilizing dedicated short-range communication (DSRC) systems for electronic toll collection and other possible functions, have been proposed for operation at locations across the United States. Deployment of ITS depends upon the availability of spectrum for short-range wireless DSRC links between vehicles and roadside stations. It has been proposed that a spectrum allocation be made for such systems within the 5850- to 5925-MHz band. This is part of a larger band, 5250-5925 MHz ("5-GHz band" in this report), that is allocated to radiolocation (radar) and other services. Deployment of DSRC systems is contingent upon assurances that their operations will be electromagnetically compatible with existing and future systems in the 5-GHz spectrum. It is therefore desirable to understand as thoroughly as possible both existing and future occupancy of the 5-GHz spectrum to maximize electromagnetic compatibility between all systems.

This report summarizes the results of measurements by the Institute for Telecommunication Sciences (the Institute) to quantify 5-GHz band occupancy. Included in this summary are results of broadband spectrum surveys in several metropolitan areas. Also included are results of measurements performed on emissions from high-power radars and a 5-GHz earth station. The results are described to provide as complete a picture as possible of current types and patterns of occupancy in the 5-GHz bands in the United States. Future development of radar technology in this band is also discussed.

This report should not be used as the sole basis for assessing the feasibility of using new or alternative services in the 5-GHz spectrum; extrapolation of data in this report to general aspects of 5-GHz spectrum occupancy for alternative or additional spectrum uses requires consideration of additional factors. These include spectrum management procedures, types of missions performed in the band, and future spectrum requirements. The data presented in this report are intended to augment, rather than replace, consideration of these factors.

The systems in the 5250-5925 MHz band that generate the highest effective radiated power (ERP) levels are fixed-satellite service (FSS) earth stations in the 5850-5925 MHz band, but the maximum effective radiated power (ERP) values from such stations are directed at space, and not toward the terrestrial surface, where new DSRC systems are expected to be deployed. The Institute measured fields near such a station to determine the levels that might be expected in the vicinity of such a station. The result was found to be about +70 dBμV/m, substantially less than the maximum encountered near various radars, and comparable to the maximum levels of radar spurious emissions in the 5850-5925 MHz band. As is the case for radars, however, co-channel operations of DSRC’s and FSS earth stations should be avoided. This can be accomplished through existing frequency coordination mechanisms.

Spectrum survey results indicate that patterns of 5-GHz spectrum occupancy are similar for various metropolitan areas, coastal cities having the highest overall levels of usage. 5-GHz spectrum occupancy in these areas is dominated by emissions from high-power radiolocation systems (radars), although very low-power emissions from Part 15 devices and Part 18

Industrial, Scientific, and Medical (ISM) devices may escape survey detection under some circumstances. Aside from highly localized fields generated by Part 15 or Part 18 devices, the spectrum occupancy of the 5850-5925 MHz band is currently dominated by radar emissions, and most, but not all, of these emissions are spurious sidebands from radar transmitters, rather than emissions tuned to center frequencies in this band.

Because radars produce the majority of spectrum occupancy in the 5-GHz spectrum as measured from hilltop locations, and considering that high-level fields are generated in the vicinity of such radars, and further considering that such radars sometimes operate near roadways where ITS units could be deployed, the maximum 5-GHz fields occurring near such radars have been measured. The measurements show that such fields can reach values as high as +163 dBμV/m in the 5850-5925 MHz band. It has also been determined that at many locations, most radar signals in the 5850-5925 MHz spectrum are spurious emissions; most, but not all, of the currently deployed 5-GHz radars are tuned to frequencies below 5850 MHz, although future 5-GHz designs can operate above 5850 MHz.

Radar fields occur as pulsed emissions. The pulse widths are on the order of a few microseconds, the intra-pulse intervals are on the order of a millisecond, and the highest-level pulses occur in bursts of about 20 to 50 in a row, with an interval of 3 seconds to 20 seconds between bursts, depending upon the radar. DSRC system performance in such environments can be quite robust, as determined in tests by the Institute, but the Institute tests have also shown that co-channel operations at short distances must be avoided, and that therefore frequencies should be coordinated between DSRC assignments and radar assignments.

Future radar development is expected to occur in this portion of the spectrum, and such development will bring more radar center frequencies into this portion of the 5-GHz band. Radar pulse waveforms are also expected to become longer than at present, thereby increasing the average power produced by such transmitters; it is not known whether future radar development in the band will lead to higher peak radiated power levels. To minimize electromagnetic compatibility problems between future 5-GHz radars and Intelligent Transportation Systems, it is recommended that ITS designs take into account the need to share spectrum with higher duty-cycle radar systems than presently exist.

In summary, proposed 5-GHz DSRC systems will share spectrum with both co-channel and spurious emissions from radars. To avoid interference from co-channel radars, DSRC frequency assignments will need to be coordinated with local radar assignments to avoid co-channel operations at short separation distances. To avoid interference from radar spurious emissions, it is recommended that DSRC systems be designed for electromagnetic compatibility with radar spurious emissions from both existing radars and future radars that are expected to transmit longer pulses at higher duty cycles. Measurements described in [6] and [7] can serve as a guide for such evaluations. DSRC systems should also incorporate front-end preselection (bandpass filtering) to reject 5-GHz radar center-frequency emissions occurring at frequencies outside the DSRC band (below 5850 MHz).

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MEASURED OCCUPANCY OF 5850-5925 MHz AND ADJACENT 5-GHz SPECTRUM IN THE UNITED STATES

Frank H. Sanders[1]

Dedicated short-range communication (DSRC) systems have been proposed for operation at locations across the United States in the 5850- to 5925-MHz band. To establish electromagnetic compatibility between DSRC and other 5-GHz systems, it is necessary to understand current and future occupancy of this spectrum. This report summarizes results of measurements made in 5-GHz spectrum for the Federal Highway Administration (FHWA) of emissions from high-power radars and a fixed satellite service (FSS) earth station. Results of 5-GHz spectrum survey measurements in major metropolitan areas are also included. Measured spectrum occupancy in 5-GHz bands is typically dominated by radar systems. Radar spurious emissions are the major element of occupancy observed between 5850-5925 MHz, although future radar designs are expected to make more use of this band. Therefore, proposed 5-GHz DSRC systems will have to share spectrum with both spurious and on-tuned emissions from radars. DSRC frequency assignments will need to be coordinated with local radar assignments to avoid co-channel operations at short separation distances, and it is recommended that DSRC system designs be electromagnetically compatible with radar spurious emissions.

Key words: dedicated short-range communications (DSRC) systems; electromagnetic compatibility; electronic toll collection; fixed-satellite service; high-power radars; highway access control systems; intelligent transportation systems (ITS); interference; radar emissions; Radio Spectrum Measurement System (RSMS); spectrum measurements; spectrum occupancy; spectrum survey.

1. INTRODUCTION

This report describes measured types and patterns of occupancy between 5850-5925 MHz, and in lesser detail across the range of 5250-5925 MHz ("5-GHz band") within the continental United States. This description is accomplished by presenting the results of broadband spectrum surveys conducted in major metropolitan areas; measurements of high incident field strengths produced by 5-GHz radars; and measurements of the incident field strength in the vicinity of a 5-GHz earth-to-space fixed-satellite service (FSS) earth station.

The measurement results presented in this report cannot be used as the sole basis for assessing the feasibility of using new or alternative services in the 5-GHz spectrum;

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extrapolation of data in this report to general aspects of 5-GHz spectrum occupancy for alternative or additional spectrum uses requires consideration of additional factors. These include spectrum management procedures, types of missions performed in the band, and new spectrum requirements in the development and procurement stages. The data presented in this report are intended to augment, rather than replace, consideration of these factors by demonstrating the types and patterns of 5-GHz band occupancy that are actually observed at many locations in the continental United States, and to present the characteristics of transmitters that typically operate in the 5-GHz spectrum at many locations.

1.1 Background

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. Part of this responsibility is to establish policies concerning spectrum assignment, allocation, and use; and to provide the various departments and agencies with guidance to ensure that their conduct of telecommunications activities is consistent with these policies [1, part 8.3]. In discharging this responsibility, NTIA 1) assesses spectrum utilization; 2) identifies existing and/or potential compatibility problems among the telecommunication systems that belong to various departments and agencies; 3) provides recommendations for resolving any compatibility conflicts that exist in the use of the frequency spectrum; and 4) recommends changes to promote spectrum efficiency and improve spectrum management procedures.

Since 1973, NTIA has collected data on Federal use of the radio frequency spectrum in support of the NTIA Spectrum Analysis Program. The Institute for Telecommunication Sciences ("the Institute"), which constitutes the Boulder, Colorado laboratories of NTIA, operates the Radio Spectrum Measurement System (RSMS) and Compact Radio Spectrum Measurement Systems (CRSMS) to provide NTIA technical support for 1) Spectrum Resource Assessments (SRA); 2) U.S. participation in the International Telecommunication Union (ITU) conferences and ITU Radiocommunication Sector (ITU-R) activities; 3) analysis of electromagnetic compatibility (EMC) problems; 4) interference resolution; and 5) systems review activity related to new Federal Government systems.

The results of Institute spectrum surveys performed for NTIA have been published in an ongoing series of NTIA Reports beginning in 1995. These reports have presented the measured types and patterns of activity between 108 MHz to 19.7 GHz in Denver, Colorado [2], San Diego, California [3], Los Angeles, California [4], and San Francisco, California [5]. The results of those surveys in the 5-GHz bands are presented in this report, with comparisons and commentary regarding observed types and patterns of usage in this part of the 5-GHz spectrum in these cities.

The Institute also performs spectrum measurements and technical tasks related to spectrum management for other Federal agencies on a reimbursable basis. The Federal Highway

Administration (FHWA)[2] has sponsored Institute measurements of particular transmitters in the 5-GHz band to better determine the impacts of particular transmitters on existing occupancy of this part of the spectrum. The results of those measurements are also presented in this report. These measurements have been performed with various types of Institute suitcase measurement systems.

1.2 Approach

The goal of this report is to describe types and patterns of usage in the 5850-5925 MHz band and adjacent 5-GHz bands as determined by measurements. The approach is as follows:

1) The Government Master File (GMF) was searched to determine all assignments in this part of the spectrum. Note that such a search will not identify Part 15 and Part 18 devices due to their unlicensed status, but it will identify all licensed users in the band. Knowledge of the types of transmitters in any given area was helpful in interpreting the results of the broadband spectrum surveys in major metropolitan areas. Knowledge of the transmitter parameters of these users was also used to identify particular transmitter systems that needed to be individually characterized through measurements of their emissions. The results of this search of the GMF are presented in Section 2.

2) Broadband spectrum surveys were performed in major metropolitan areas, and the results of those surveys are discussed in Section 3.

3) Spectrum emissions from radiolocation (radar) transmitters of particular technical interest were measured at various locations in the United States. Radars were selected for individual measurements based upon their likely impact on overall occupancy of the 5-GHz spectrum. Some radars that were measured utilized operational frequencies that fell below 5850 MHz; the emissions from these radars in the 5850-5925 MHz band were therefore spurious in nature. Measurements of both in-band and out-of-band 5-GHz radar emissions provided Institute personnel with the necessary technical information to perform tests on individual European-standard and Japanese-standard DSRC systems that were provided by FHWA for testing [6], [7]. Results for a high-power radar are presented in Section 4.

4) Spectrum emissions from an FSS earth station were measured to determine the maximum field strengths that would occur in the vicinity of such a station. Results of these measurements are presented in Section 5.

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[2]Federal Highway Administration (FHWA), McLean, Virginia, under the direction of J.A. Arnold, FHWA Contracting Officer Technical Representative.

5) Measurement results were synthesized into a summary of the types and patterns of spectrum occupancy measured in the 5850-5925 MHz and adjacent 5-GHz bands in the continental United States. These conclusions are presented in Section 6 of this report.

1.3 Interpretation and Extrapolation of 5-GHz Band Occupancy Measurements

No single methodology can be used to determine the complex technical characteristics of the systems that operate in the 5-GHz spectrum. Spectrum managers must utilize information from many sources, including measurement data, to determine the feasibility of introducing new systems or services in any given band. As stated above in the Introduction, the measurement results presented in this report cannot be used as the sole basis for assessing the feasibility of using new or alternative services in the 5-GHz spectrum. Additional factors that should be considered by spectrum managers include, but are not necessarily limited to, established spectrum management procedures, types of missions currently performed in the band, and new spectrum requirements in the development and procurement stages. The data presented in this report should augment, and not replace, consideration of these factors by presenting the characteristics of 5-GHz systems that were measured at many locations in the continental United States, and presenting the characteristics of transmitters that operate in the 5850-5925 MHz band spectrum at many locations.

2. U.S. ALLOCATIONS AND ASSIGNMENTS BETWEEN 5850-5925 MHz

2.1 Introduction

In the United States, the spectrum between 5850-5925 MHz is used on a primary basis by military radiolocation and by non-Government earth-to-space fixed-satellite services (FSS). Adjacent 5-GHz bands are also used by a variety of radiolocation and radionavigation services, as described below. This section describes the allocation rules and assignments within this part of the spectrum.

2.2 National Allocation Rules

In the United States, the band 5250-5350 MHz is allocated for Government radiolocation on a primary basis, as listed in Table 1. Non-Government radiolocation is secondary to Government radiolocation, and Government non-military radiolocation is secondary to Government military radiolocation.

The band 5350-5460 MHz is allocated to aeronautical radionavigation (airborne radars and associated airborne beacons) and Government radiolocation on a primary basis.

The band 5460-5470 MHz is allocated to radionavigation on a primary basis. The use of the band 5450-5650 MHz by the maritime radionavigation service is limited to shipborne radars.

The band 5470-5600 MHz is allocated to maritime radionavigation on a primary basis. The use of 5450-5650 MHz by the maritime radionavigation service is limited to shipborne radars.

The band 5600-5650 MHz is allocated to maritime radionavigation and meteorological aids on a primary basis. In this band, ground based radars used for meteorological purposes (weather radars) are authorized to operate on a basis of equality with stations of the maritime radionavigation service. The use of the band 5450-5650 MHz by the maritime radionavigation service is limited to shipborne radars.

The band 5650-5850 MHz is allocated on a primary basis to military Government radiolocation. The band 5725-5875 MHz (center frequency 5800 MHz) is designated for industrial, scientific and medical (ISM) applications. Radiocommunication services, including the amateur service, are secondary within this band and must accept harmful interference caused by these applications.

The band 5850-5925 MHz is allocated to military Government radiolocation and to non-Government fixed-satellite (earth-to-space) services on a primary basis. The 5850-5875 MHz range is designated for ISM applications under Federal Communications Commission (FCC) Part 18 rules. Part 18 devices in this band are not to be used for communication purposes. FCC Part 15 devices are permitted to operate between 5850-5875 MHz, but are unlicensed and unprotected. Amateur operations in the 5850-5925 MHz band are on a secondary basis.

Table 1. United States Frequency Allocations 5250-5925 MHz [1, Chapter 4].
(All-capital letter entries indicate primary allocations within a band; lower-case entries indicate secondary status within a band.)

Band (MHz)	PROVISIONS	GOVERNMENT	NON-GOVERNMENT
5250-5350	US110 713 G59 Also see Part 7.18 of the NTIA Manual [1].	RADIOLOCATION	Radiolocation
5350-5460	US48 799 G56	AERONAUTICAL RADIONAVIGATION RADIOLOCATION	AERONAUTICAL RADIONAVIGATION Radiolocation
5460-5470	US49, US65 799 G56 Also see Part 7.18 of the NTIA Manual [1].	RADIONAVIGATION Radiolocation	RADIONAVIGATION Radiolocation
5470-5600	US50, US65 G56	MARITIME RADIONAVIGATION Radiolocation	MARITIME RADIONAVIGATION Radiolocation
5600-5650	US51, US65 802 G56	MARITIME RADIONAVIGATION METEOROLOGICAL AIDS Radiolocation	MARITIME RADIONAVIGATION METEOROLOGICAL AIDS Radiolocation
5650-5850	664, 806, 808 G2 ISM 5800 ± 75 MHz	RADIOLOCATION	Amateur
5850-5925	US245 806 G2	RADIOLOCATION	FIXED-SATELLITE (Earth-to-space) Amateur

US Footnotes to Table 1

US48 The non-Government radiolocation service may be authorized in the bands 5350-5460 MHz and 9000-9200 MHz on the condition that it does not cause harmful interference to the aeronautical radionavigation service or to the Government radiolocation service.

US49 The non-Government radiolocation service may be authorized in the band 5460-5470 MHz on the condition that it does not cause harmful interference to the aeronautical or maritime radionavigation services or to the Government radiolocation service.

(Table 1, continued)

US50 The non-Government radiolocation service may be authorized in the band 5470-5600 MHz on the condition that it does not cause harmful interference to the maritime radionavigation service or to the Government radiolocation service.

US51 In the bands 5600-5650 MHz and 9300-9500 MHz, the non-Government radiolocation service shall not cause harmful interference to the Government radiolocation service.

US65 The use of the band 5450-5650 MHz by the maritime radionavigation service is limited to shipborne radars.

US110 In the frequency bands 3100-3300 MHz, 3500-3700 MHz, 5250-5350 MHz, 8500-9000 MHz, 9200-9300 MHz, 9500-10000 MHz, 13.4-14.0 GHz, 15.7-17.3 GHz, 24.05-24.25 GHz and 33.4-36 GHz, the non-Government radiolocation service shall be secondary to the Government radiolocation service and to airborne doppler radars at 8800 MHz, and shall provide protection to airport surface detection equipment (ASDE) operating between 15.7-16.2 GHz.

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

International Footnotes to Table 1

664 In the bands 435-438 MHz, 1260-1270 MHz, 2400-2450 MHz, 3400-3410 MHz (in Regions 2 and 3 only), and 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 No. 435). Administrations authorizing such use shall ensure that any harmful interference caused by emissions from a station in the amateur-satellite service is immediately eliminated 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.

713 In the bands 1215-1300 MHz, 3100-3300 MHz, 5250-5350 MHz, 8550-8650 MHz, 9500-9800 MHz and 13.4-14.0 GHz, radiolocation stations installed on spacecraft may also be employed for the earth exploration-satellite and space research services on a secondary basis.

799 The use of the band 5350-5470 MHz by the aeronautical radionavigation service is limited to airborne radars and associated airborne beacons.

(Table 1, continued)

802 Between 5600 MHz and 5650 MHz, ground based radars used for meteorological purposes are authorized to operate on a basis of equality with stations of the maritime radionavigation service.

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

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

Government Footnotes to Table 1

G2 In the bands 216-225, 420-450 (except as provided by US217), 890-902, 928-942, 1300-1400, 2310-2390, 2417-2450, 2700-2900, 5650-5925, and 9000-9200 MHz, the Government radiolocation is limited to the military services.

G56 Government radiolocation in the bands 1215-1300, 2900-3100, 5350-5650 and 9300-9500 MHz is primarily for the military services; however, limited secondary use is permitted by other Government agencies in support of experimentation and research programs. In addition, limited secondary use is permitted for survey operations in the band 2900-3100 MHz.

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

2.3 Assignments

As of the date of this report, the Government Master File lists 94 assignments within the 5850-5925 MHz portion of the spectrum in the United States. Of these, 78 are Government assignments and 16 are non-Government assignments. Non-Government assignments include antenna ranges, space communication (earth-to-space) systems, and telemetry systems. Government assignments include low-power calibration systems, telemetry systems, and high-power radars.

Government radars that utilize this band are used to track aircraft, balloons, and rockets, and include the FPS-6, FPS-16 and RIR-778C radars at locations shown in Figure 1.

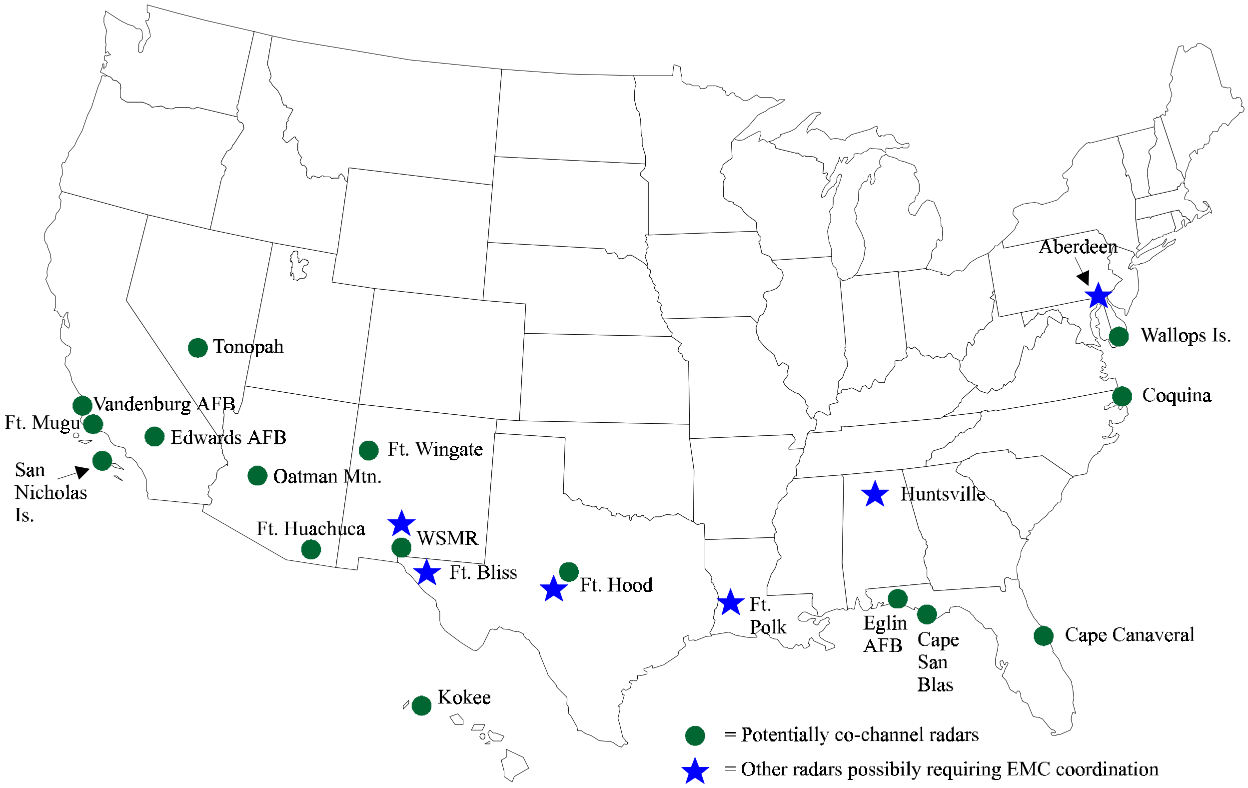


Figure 1. U.S. locations with high-power radars in the 5850-5925 MHz spectrum (dots). Such radars will require coordination to avoid co-channel operations with DSRC. Other locations (stars) identify radars that operate outside the 5850-5925 MHz band, but emissions from these radars need to be filtered out by RF front-ends of nearby DSRC systems.

3. 5250-5925-MHz BROADBAND SPECTRUM SURVEY RESULTS

3.1 Introduction

NTIA broadband spectrum surveys (108 MHz to 19.7 GHz) have been performed in a number of major metropolitan areas in the United States during the 1990's. Results of these spectrum surveys have been described for Denver, Colorado [2], San Diego, California [3], Los Angeles, California [4], and San Francisco, California [5]. As described in detail in these references, the spectrum survey measurements have been performed with hardware and software optimized for the interception of the particular types of signal that occur in each part of the spectrum. These spectrum surveys typically have been performed for periods of about two weeks at each measurement location. During that time, every measurement band has been sampled many times, the result being that statistically meaningful results have been determined for the types and patterns of occupancy in each band.

In the band 5250-5925 MHz, the measurements are optimized to intercept the signals produced by radars that occupy this portion of the spectrum. These include maritime surface search and navigation radars, weather radars, airborne radionavigation radars, and tracking radars. Other types of signals, such as for telemetry and earth-to-space FSS systems, can also be received, although the relatively lower effective radiated power (ERP) of these systems makes the probability-of-intercept for such signals generally lower than for radars. The reader is referred to the NTIA Report references [2], [3], [4], and [5] for additional technical details concerning the measurement hardware and software utilized to perform these measurements.

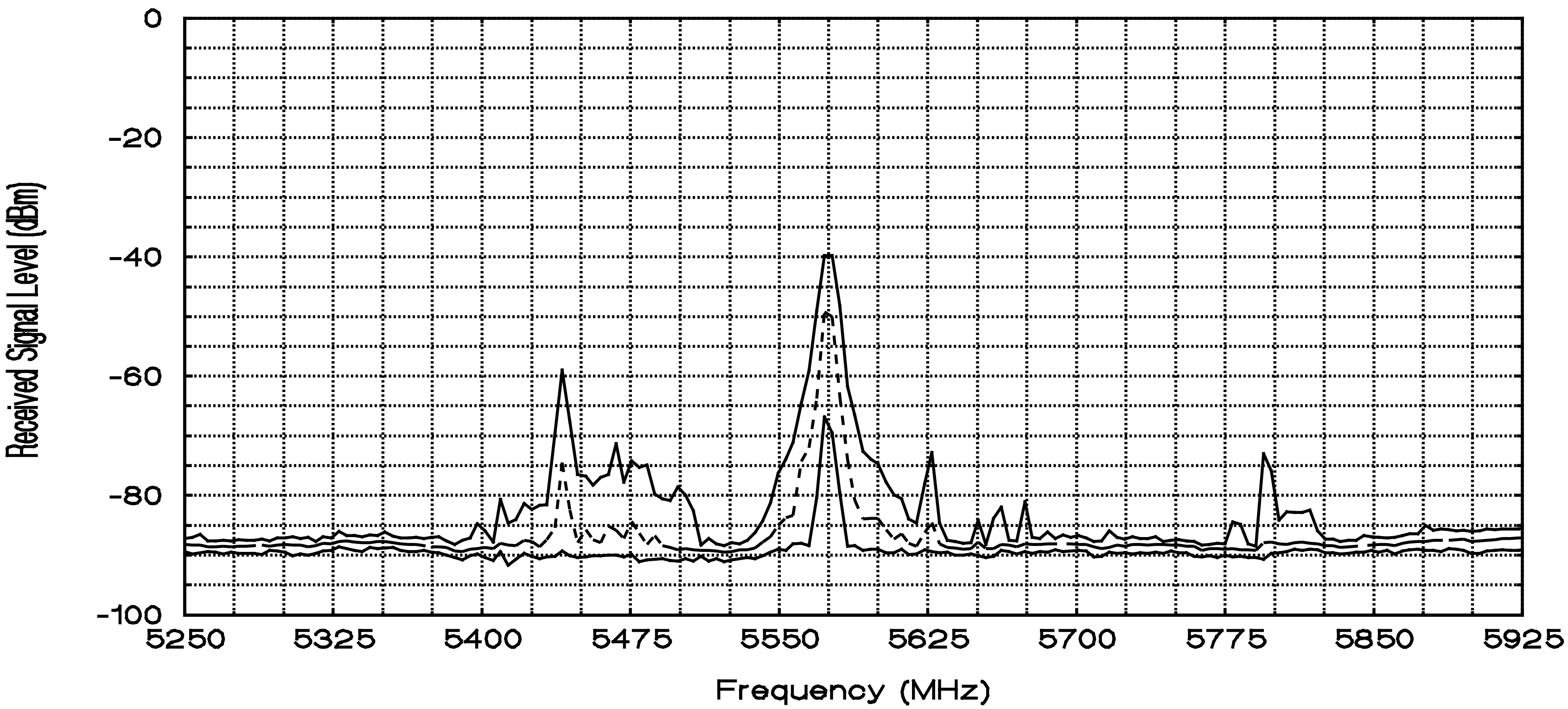
The results of these spectrum surveys cannot be extrapolated automatically to every major U.S. metropolitan area, nor are these results applicable to the environment found near various facilities that utilize (for example) high-power tracking radars. However, these survey measurements do represent spectrum occupancy types and patterns in metropolitan areas that are believed, based upon all available information, to be among the most heavily-used in the U.S., especially the two coastal cities of San Diego and Los Angeles.

This section addresses the question of what is essentially the background occupancy that exists in some major metropolitan areas. Sections 4 and 5 address the electromagnetic environment in the vicinity of particular high-power radars and an earth-to-space FSS communication station.

3.2 Denver, Colorado

Figure 2 shows the results of the Denver, Colorado spectrum survey between 5250-5925 MHz. This survey was performed from a high hilltop with line-of-sight coverage over the bulk of the metropolitan area during a two-week period in the fall of 1993 [2].

GOVERNMENT ALLOCATIONS:	RADIOLOCATION.	AERONAUTICAL RADIONAVIGATION, 1.	3.	MARITIME RADIONAVIGA-TION, Radiolocation.	4.	RADIOLOCATION.	
NON-GOVERNMENT ALLOCATIONS:	Radiolocation.	AERONAUTICAL RADIONAVIGATION, 2.	3.	MARITIME RADIONAVIGA-TION, Radiolocation.	4.	Amateur.	6.
GENERAL UTILIZATION:				Weather radars.	5.	Military radars, 7.	7.
	5250	5350	5460-5470		5600	5650	5850	5925



1. RADIOLOCATION.
2. Radiolocation.
3. RADIONAVIGATION, Radiolocation.
4. MARITIME RADIONAVIGATION, METEOROLOGICAL AIDS, Radiolocation.
5. Government weather radars, e.g., Terminal Doppler Weather Radar (TDWR).
6. FIXED-SATELLITE (Earth-to-space), Amateur.
7. 5725-5875 MHz: Industrial, scientific, and medical (ISM).

Figure 2. Maximum, minimum, and mean activity between 5250-5925 MHz at Denver, CO, 1993. Measured in 26 scans with positive peak detection and 3-MHz resolution bandwidth. Measurement system tuned from one frequency to the next every twelve seconds, to assure interception of signals from slowly scanning radar beams.

Twenty-six scans were performed through this band, each scan consisting of 200 individual fixed-frequency steps that were performed in a 3-MHz resolution bandwidth with positive-peak detection. At each step, the system was held fixed-tuned for 12 seconds, and the maximum signal strength received in each interval was recorded. Each scan took a total of 40 minutes to complete. The 26 scans made during the Denver survey therefore represent a total measurement time of 17.3 hours in this band. The total amount of time spent measuring the 5850-5925 MHz band is 0.11 times this total, or 1.9 hours. Because these measurements were spread evenly through both the diurnal cycle and through the measurement period, it is unlikely that high-power transmitters that were operated in this band in the Denver area during the measurement period would have escaped detection. Thus, this survey result represents the envelope of spectrum occupancy in this band in the Denver area at the time of the survey.

The Denver survey results in the 5-GHz band revealed the operation of four radars, with center frequencies at 5437 MHz, 5575 MHz, 5625 MHz, and 5795 MHz. No signals were received in the 5850-5925 MHz band during the spectrum survey. The signal at 5437 MHz was consistent with an airborne radionavigation signal. The signal at 5575 MHz is a weather radar, as is the signal at 5625 MHz. The signal at 5790 is an uncharacterized radar.

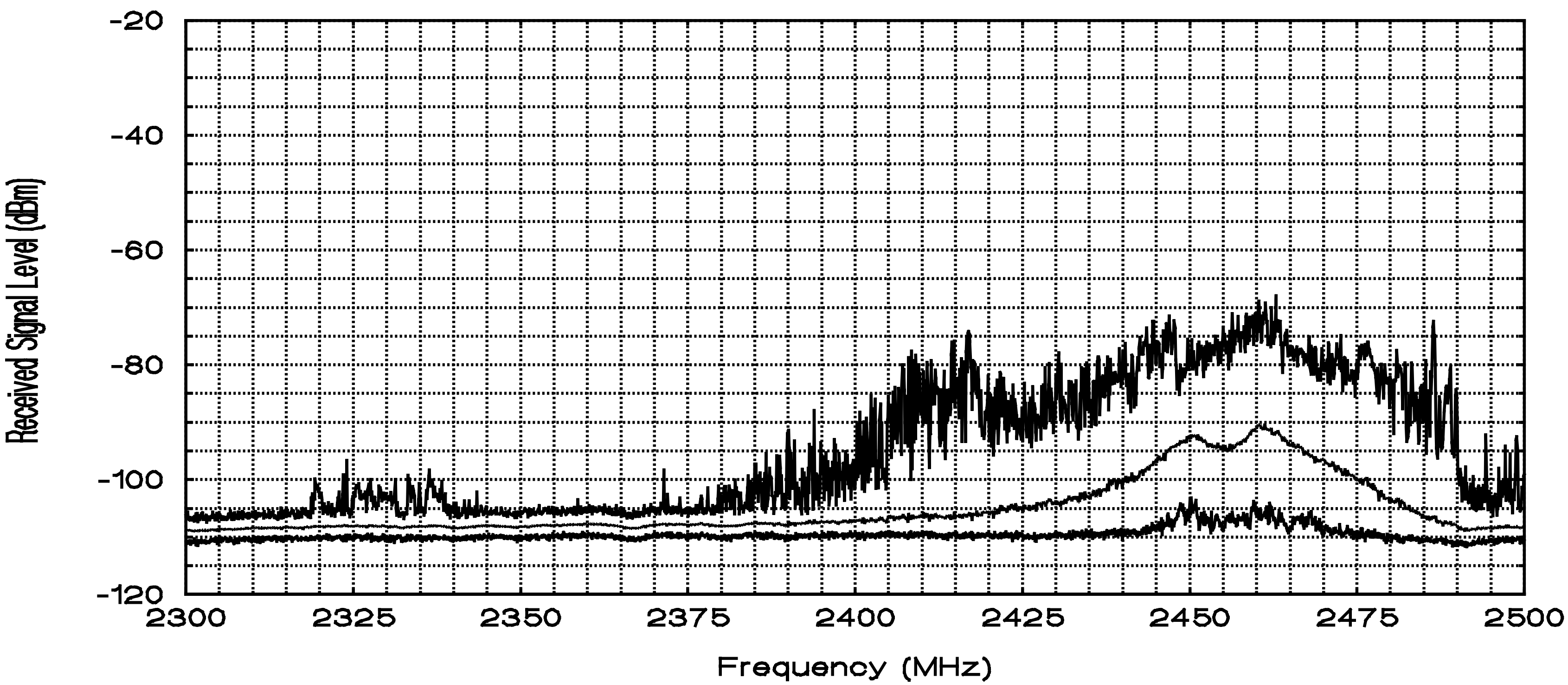
The salient characteristic of the Denver spectrum survey results is the absence of any signals, radar or otherwise, in the 5850-5925 MHz band as measured from a hilltop location with line-of-sight coverage over most of the metropolitan area. Neither center-frequency emissions nor spurious (sideband) emissions were observed in this portion of the 5-GHz spectrum in the Denver area during the survey period.

While some signals from Part 15 or Part 18 devices in the 5-GHz band could have possibly occurred in the Denver area without being detected during the survey, the fact that Part 18 microwave oven emissions were received at high amplitudes during the same survey in the 2400-2500 MHz portion of the spectrum, as shown in Figure 3, indicates that such emissions in the 5-GHz bands must have been either very low in amplitude or else very few in number during the measurement period. Other measurements of microwave oven emissions [8] indicate that Part 18 devices that produce even unintentional emissions at comparable levels ought to be easily observed during such spectrum surveys.

3.3 San Diego, California

Figure 4 shows the results of the San Diego, California spectrum survey between 5250-5925 MHz. This survey was performed from a high hilltop (Point Loma) with line-of-sight coverage over the bulk of the metropolitan area during a two-week period in the winter of 1995 [3]. Twenty-two scans were performed through this band, each scan consisting of 200 individual fixed-frequency steps that were performed in a 3-MHz resolution bandwidth with positive-peak detection. At each step, the system was held fixed-tuned for 12 seconds, and the maximum signal strength received in each interval was recorded. Each scan took a total of 40 minutes to complete. The scans made during the San Diego survey therefore represent a total

GOVERNMENT ALLOCATIONS:	1.	RADIOLOCATION, MOBILE, Fixed.	RADIOLOCATION, 5.			
NON-GOVERNMENT ALLOCATIONS:	2.	MOBILE.	6.	Amateur.	FIXED, MOBILE, Radiolocation.	8.
GENERAL UTILIZATION:	3.	Telemetry, telemetry communications, aeronautical telemetry, 4.		Amateur Satellite (space-to-Earth). Amateur mixed modes, 7.	7.	7, 9.
	2300	2310	2390	2400	2450	2483.5 2500

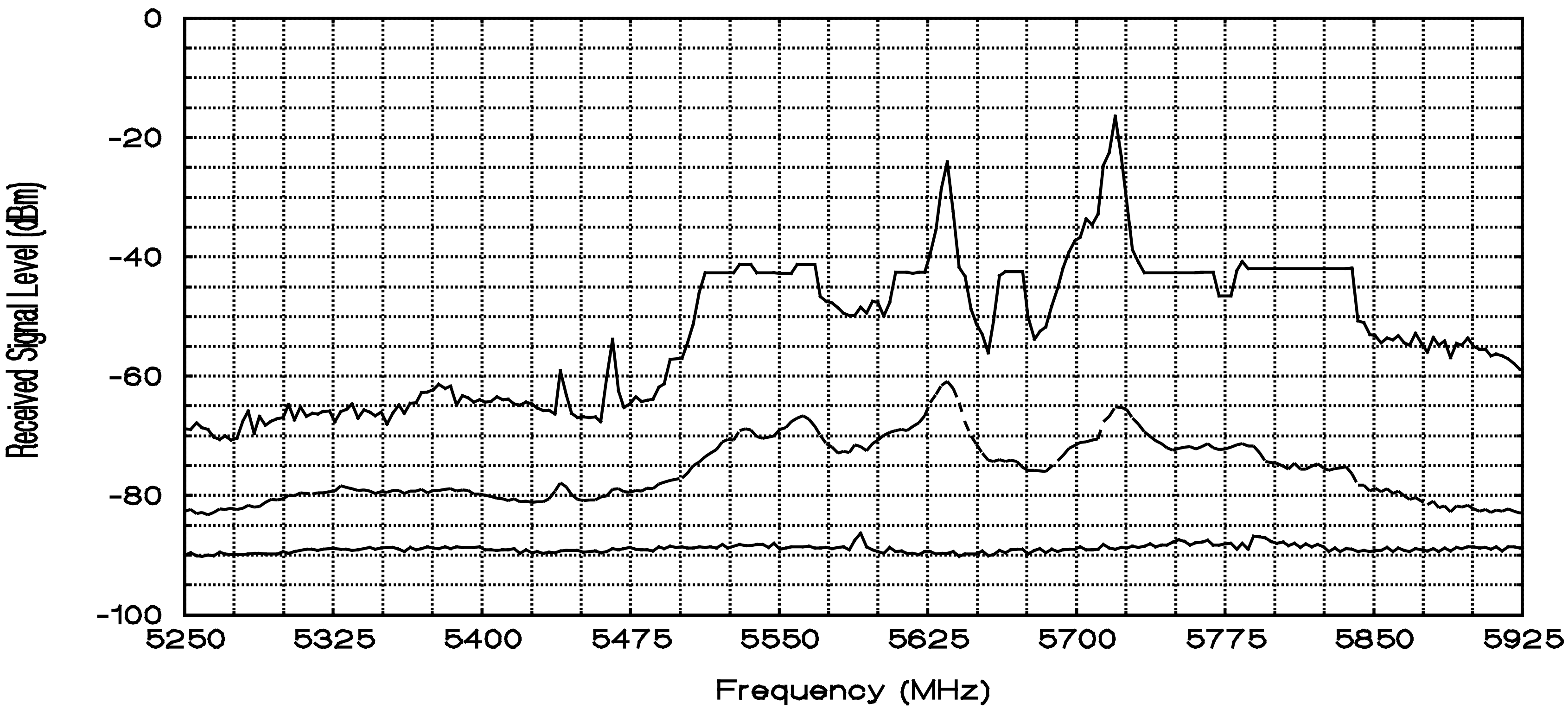


1. RADIOLOCATION, Fixed, Mobile.
2. Amateur.
3. Amateur weak signal modes and other modes.
4. AF High-power long-range surveillance radar and air traffic control radar. Venus Radar Mapper (VRM) synthetic aperture radar.
5. No Government allocations in this band after August 1995.
6. AMATEUR.
7. 2400-2500 MHz: Is also used for industrial scientific and medical (ISM) applications including microwave ovens.
8. RADIODETERMINATION-SATELLITE (space-to-Earth).
9. Satellite downlinks and multichannel fixed and portable video transmission by TV broadcasters.

Figure 3. Maximum, minimum, and mean activity between 2300-2500 MHz at Denver, CO, 1993. Measured in 34,800 scans with positive peak detection and 100-kHz resolution bandwidth. Individual sweeps were each 0.1 second. Measurement period was two weeks.

	5250–5350	5350–5460	5460–5470	5470–5600	5600–5650	5650–5850	5850–5925
GOVERNMENT ALLOCATIONS:	RADIOLOCATION.	AERONAUTICAL RADIONAVIGATION, 1.	3.	MARITIME RADIONAVIGA-TION, Radiolocation.	4.	RADIOLOCATION.	
NON-GOVERNMENT ALLOCATIONS:	Radiolocation.	AERONAUTICAL RADIONAVIGATION, 2.	3.	MARITIME RADIONAVIGA-TION, Radiolocation.	4.	Amateur.	6.
GENERAL UTILIZATION:				Weather radars.	5.	Military radars, 7.	7.

5250 5350 5460-5470 5600 5650 5850 5925



1. RADIOLOCATION.
2. Radiolocation.
3. RADIONAVIGATION, Radiolocation.
4. MARITIME RADIONAVIGATION, METEOROLOGICAL AIDS, Radiolocation.
5. Government weather radars, e.g., Terminal Doppler Weather Radar (TDWR).
6. FIXED-SATELLITE (Earth-to-space), Amateur.
7. 5725-5875 MHz: Industrial, scientific, and medical (ISM).

Figure 4. Maximum, minimum, and mean activity between 5250-5925 MHz at San Diego, CA, 1995. Measured in 22 scans with positive peak detection and 3-MHz resolution bandwidth. Measurement system tuned from one frequency to the next every twelve seconds, to assure interception of signals from slowly scanning radar beams.

measurement time of 14.7 hours in this band. The total amount of time spent measuring the 5850-5925 MHz band is 0.11 times this total, or 1.6 hours. Because these measurements were spread evenly through the diurnal cycle, it is unlikely that high-power transmitters that were operated in this band in the San Diego area during the measurement period would have escaped detection. Thus, this result represents the spectrum occupancy envelope in this band in San Diego at the time of the survey.

The San Diego survey results in the 5-GHz band revealed the operation of numerous radars between 5475-5850 MHz. These included maritime surface search and navigation radars, weather radars, and some airborne radionavigation radars. No center-frequency signals were received in the 5850-5925 MHz band during the spectrum survey. Measurable radar spurious emissions (sideband emissions from radars tuned to frequencies below 5850 MHz) were received between 5850-5925 MHz.

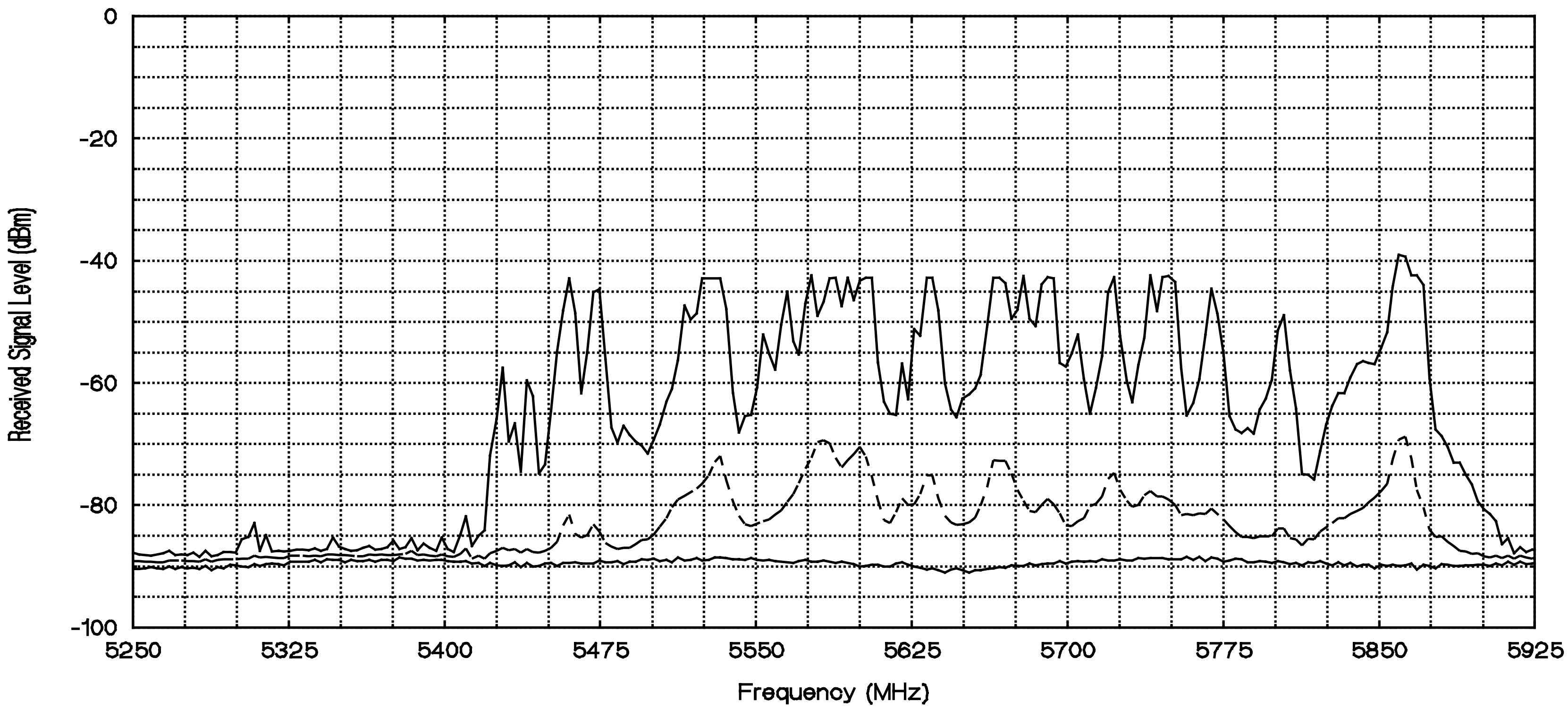
The salient characteristic of the San Diego 5-GHz spectrum survey is the occurrence of radar spurious emissions in the 5850-5925 MHz band. While no center-frequency emissions were observed in this portion of the 5-GHz spectrum, the spurious emissions from lower-frequency radars do represent electromagnetic energy in this band, and such emissions are detailed in Section 4. Part 15 and Part 18 device emissions in this band, if any, were received at levels below the envelope of the radar emissions.

3.4 Los Angeles, California

Figure 5 shows the results of the Los Angeles, California spectrum survey between 5250-5925 MHz. This survey was performed from a high hilltop with line-of-sight coverage over the bulk of the metropolitan area during a two-week period in the spring of 1995 [4]. A total of 35 scans were performed through this band, each scan consisting of 200 individual fixed-frequency steps that were performed in a 3-MHz resolution bandwidth with positive-peak detection. At each step, the system was held fixed-tuned for 12 seconds, and the maximum signal strength received in each interval was recorded. Each scan took a total of 40 minutes to complete. The scans made during the Los Angeles survey therefore represent a total measurement time of 23.3 hours in this band. The total amount of time spent measuring the 5850-5925 MHz band is 0.11 times this total, or 2.6 hours. Because these measurements were spread evenly through the diurnal cycle, it is unlikely that high-power transmitters that were operated in this band in the Los Angeles area during the measurement period would have escaped detection. Thus, this survey result represents the envelope of spectrum occupancy in this band in the Los Angeles area at the time of the survey.

GOVERNMENT ALLOCATIONS:	RADIOLOCATION.	AERONAUTICAL RADIONAVIGATION, 1.	3.	MARITIME RADIONAVIGA-TION, Radiolocation.	4.	RADIOLOCATION.	
NON-GOVERNMENT ALLOCATIONS:	Radiolocation.	AERONAUTICAL RADIONAVIGATION, 2.	3.	MARITIME RADIONAVIGA-TION, Radiolocation.	4.	Amateur.	6.
GENERAL UTILIZATION:				Weather radars.	5.	Military radars, 7.	7.

5250 5350 5460-5470 5600 5650 5850 5925



1. RADIOLOCATION.
2. Radiolocation.
3. RADIONAVIGATION, Radiolocation.
4. MARITIME RADIONAVIGATION, METEOROLOGICAL AIDS, Radiolocation.
5. Government weather radars, e.g., Terminal Doppler Weather Radar (TDWR).
6. FIXED-SATELLITE (Earth-to-space), Amateur.
7. 5725-5875 MHz: Industrial, scientific, and medical (ISM).

Figure 5. Maximum, minimum, and mean activity between 5250-5925 MHz at Los Angeles, CA, 1995. Measured in 35 scans with positive peak detection and 3-MHz resolution bandwidth. Measurement system tuned from one frequency to the next every twelve seconds, to assure interception of signals from slowly scanning radar beams.

The Los Angeles survey results in the 5-GHz band revealed the operation of numerous radars between 5400-5875 MHz. These included maritime surface search and navigation radars, weather radars, and some airborne radionavigation radars. A radar center-frequency signal was received in the 5850-5925 MHz band during the spectrum survey, and some spurious radar emissions were observed at frequencies as high as 5912 MHz.

The salient characteristic of the Los Angeles 5-GHz spectrum survey is the occurrence of a radar center-frequency emission in the 5850-5925 MHz band, and also some spurious emissions in the same band. Such emissions are detailed in Section 4, and the likely maximum level of any such emission that is likely to be encountered by highway systems in the U.S. is described in that section. Part 15 and Part 18 device emissions in this band, if any, were received at levels below the envelope of the radar emissions.

3.5 Summary of Broadband Spectrum Survey Results

The results of the Denver, San Diego, and Los Angeles 5-GHz spectrum surveys demonstrate that, while there may be little or no measurable occupancy of the 5850-5925 MHz band in some areas, the band does show two types of occupancy in other areas: spurious emissions from radars tuned below 5850 MHz, and some radar emissions tuned to frequencies within the 5850-5925 MHz band.

The survey results also demonstrate that emissions from Part 15 and Part 18 devices are not commonly found at amplitudes that exceed the occupancy envelope of emissions from high-power radars. That is, emissions from high-power radars have been observed to dominate the measured spectrum occupancy in the 5-GHz portion of the spectrum in the metropolitan areas that have been so far surveyed. Thus, radar center-frequency emissions and spurious emissions are among the most important sources of energy to examine when considering electromagnetic compatibility issues in the 5850-5925 MHz spectrum. These emission characteristics are considered in detail in Section 4.

4. HIGH-POWER RADAR INCIDENT FIELD STRENGTHS BETWEEN 5850-5925 MHz

4.1 Introduction

As described in Section 3, measured occupancy in the 5-GHz bands is dominated by emissions from high-powered radars, based upon the results of NTIA broadband spectrum surveys in major metropolitan areas. It is also known that such emissions can be the major factor in 5-GHz spectrum occupancy in the vicinity of various military and other Government facilities.

Two types of radar emissions are significant in the 5850-5925 MHz band, as demonstrated by the results of the San Diego and Los Angeles 5-GHz spectrum surveys: spurious emissions from radars tuned below 5850 MHz, and emissions from radars tuned to frequencies within the 5850-5925 MHz band. Both types of emissions are considered in this Section.

4.2 In-band Radar Maximum Measured Incident Field Strengths

Radars that produce the highest field strengths in the 5850-5925 MHz band are used for tracking balloons, aircraft, and rockets at various test range facilities in the United States, as shown in Figure 1. Radars in adjacent 5-GHz spectrum have tactical applications. The emission characteristics and effective isotropic radiated power (EIRP) of the 5850-5925 MHz band radars are similar, and the Institute performed measurements on one of these radars to determine the highest field strength that might be encountered by any system in proximity to such a radar.

To perform this measurement, the Institute measurement antenna was positioned at multiple heights ranging from 1 m to 3 m above the ground. The measurement team looked for, but did not detect, variation in signal strength as a function of antenna height above the ground (a multipath effect). This did not occur, probably because both the radar and the RSMS were using high-gain antennas, and multipath effects were thus mitigated. The distance to the radar, the minimum permitted by the facility, was 3.0 km. For this measurement, the radar was boresighted on the Institute measurement system. The measurement system schematic is shown in Figure 6.

The highest frequency that this radar model can tune is 5875 MHz, and that frequency was selected for the maximum incident field strength measurement. The measurement result was a peak value of +163 dBμV/m at 3.0 km (the closest distance permitted by the facility) in a 1-MHz resolution bandwidth. The measurement bandwidth was selected to maximize the energy coupled from the radar into the measurement system. (Radar pulse width of 1.0 microsecond was used for this measurement, matching the measurement bandwidth.)

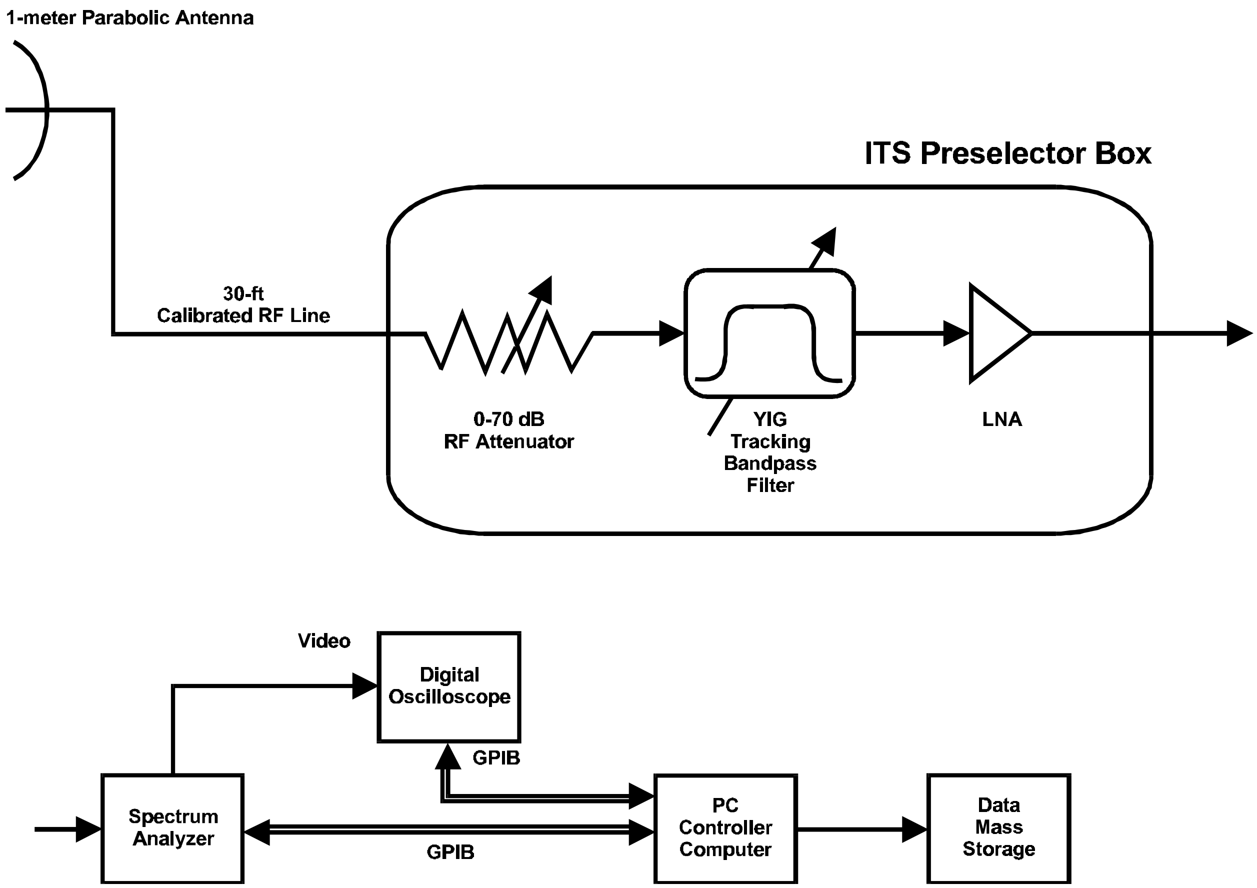


Figure 6. Block diagram of NTIA Radio Spectrum Measurement System (RSMS) radar spectrum measurement configuration. Yttrium-iron-garnet (YIG) tunable filter preselection, low-noise preamplification, and stepped-tuned software control ensure dynamic range of 110 dB to 120 dB in NTIA radar spectrum measurements.

No other radars known to utilize the 5850-5925 MHz band produce EIRP values as high as those measured; the measured values are thus believed to represent the maximum power level that can be encountered by a system operating in this part of the spectrum. The number of locations where such radars are deployed is small at the present time (Figure 1).

4.3 Spurious Radar Maximum Measured Incident Field Strengths

Other radar emissions known to occur in the 5850-5925 MHz band are produced by systems center-tuned below 5850 MHz. These systems produce measurable spurious emissions between 5850-5925 MHz. Chief among such systems are weather radars, maritime surface search radars, and some military radars and test-range radars (Figure 7). The Institute performed measurements on radars of each of these types, with the following results:

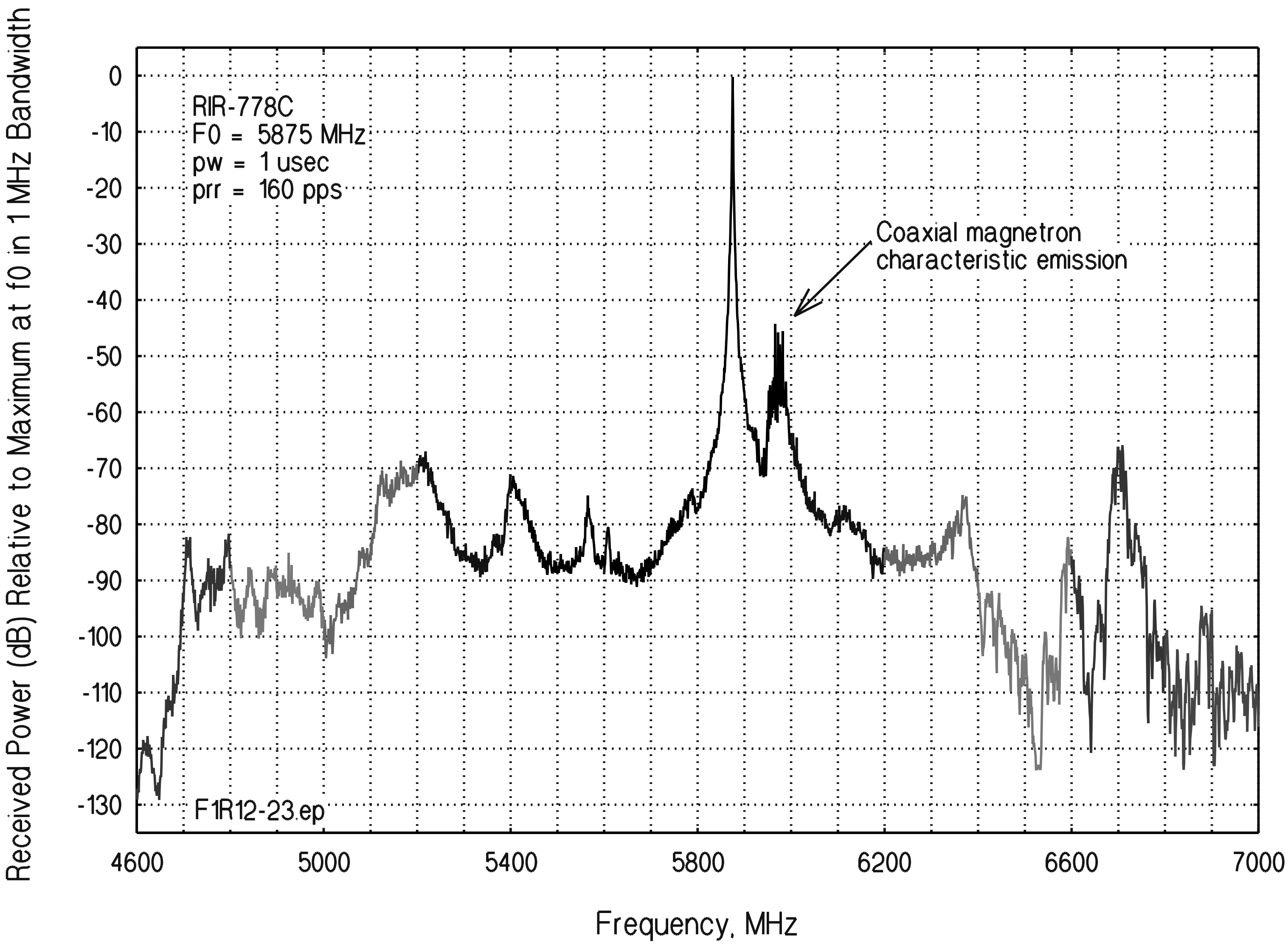


Figure 7. RIR-778C radar spectrum. Peak level at 5875 MHz is +163 dBuV/m at a distance of 3.0 km. This spectrum is typical of coaxial magnetron radars [9].

1) The military radar spurious emissions in the 5850-5925 MHz band were the lowest of the three types. When the radar in question was tuned to the high end of its band, the resulting spurious emission levels in the 5850-5925 MHz band were more than 95 dB below the power level at the center frequency of the radar; measured power levels at distances that vehicular traffic could approach under reasonable circumstances were +30 dBµV/m, comparable to those the Institute has previously measured from microwave ovens in the 2400-2450 MHz band [8].

2) The weather radar spurious emissions in the 5850-5925 MHz band were approximately 70 dB below the measured power level at the center frequency of the radar. Maximum incident field strengths were +65 dBµV/m.

3) Spurious emissions from a maritime surface search radar were the highest measured in the 5850-5925 MHz band. At a location where such a radar illuminated a parking lot directly, the highest spurious emission level within the 5850-5925 MHz band was +70 dBµV/m. This level occurred every 3.75 seconds as the radar antenna rotated in a regular scan pattern. The nominal radar pulse width was 1 microsecond, and the average pulse repetition rate was 715 pulses per second. Note, however, that the spurious emission pulse width is not actually 1 microsecond, but rather occurs as a pair of shorter pulses separated by an interval of 1 microsecond. This so-called rabbit ears effect results from not convolving the radar center frequency emission within the measurement system bandwidth, as shown in Figure 8. It replicates the signal that will be coupled into a receiver that is limited to the 5850-5925 MHz band, with the radar tuned outside that band.

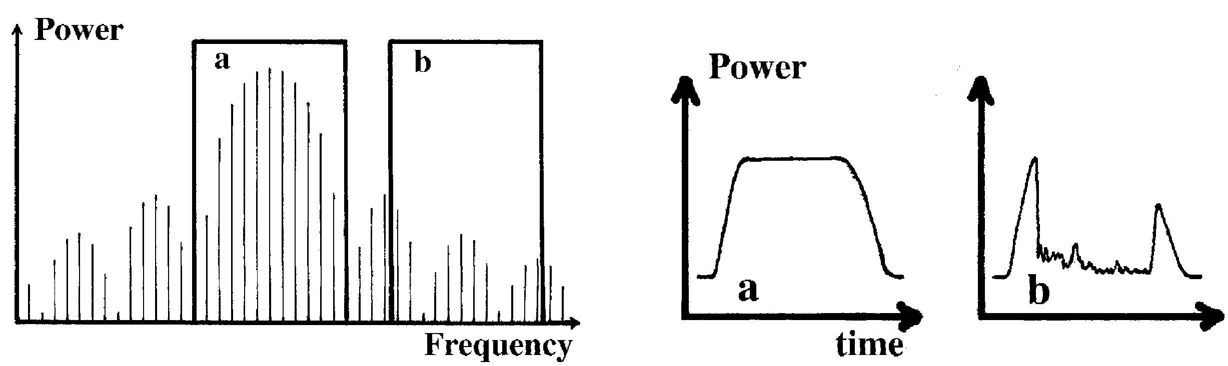


Figure 8. Variation in pulse shapes as a function of tuned frequency in an extended radar emission spectrum. Frequency domain: Receiver is tuned to the center frequency of a radar spectrum (a) and is tuned off-center (b), above.

Time domain: The convolution of lines near the center frequency results in a well-formed pulse in the receiver (a); lines convolved in the extended spectrum result in rabbit ears in the receiver (b).

4.4 Summary of Radar Maximum Measured Field Strengths 5850-5925 MHz

Measurements performed on 5-GHz radars to determine the maximum field strengths that such radars produce at the locations of nearby systems indicate that the highest field strength that ever occurs in the United States is about +163 dBµV/m, and at the present time this level will only occur at a limited number of test range facilities. High-power radars in this band are not known to tune above 5875 MHz, although future development efforts could presumably produce radars that tune to higher frequencies.

Other than these center-tuned emissions in the 5850-5925 MHz band, the highest levels known to occur are produced by maritime surface search/navigation radars, which direct their beams downward and can illuminate shoreline locations directly. However, these radars can only tune as high as 5825 MHz, and their spurious emissions represent the energy that is observed between 5850-5925 MHz. The highest levels of these emissions have been measured at +70 dBµV/m.

Radar emissions in this band utilize pulse widths on the order of 0.25 to 1 microsecond in length that occur at pulse repetition rates of between 160-1300 pulses per second. Range tracking radars maintain steady beam coverage on targets above the horizon, although the radar beams of these systems can be directed at the ground. Maritime surface search radars direct their beams downward and can illuminate shoreline locations during normal operation. They rotate at a rate of about 2 to 4 seconds per rotation. Spurious emissions from maritime surface search radars will thus be observed every few seconds as they operate, and the time waveforms of these pulses will be received in the 5850-5925 MHz band as pairs of "rabbit ears" spaced at an interval equal to the pulse width.

The Institute has conducted tests on proposed DSRC systems utilizing time waveforms and field strengths representative of the radar emissions measured in this part of the spectrum. These tests are detailed in two NTIA Reports, [7] and [8].

With reference to Figure 1, measurements of spurious emission levels from the military radar system (starred locations in the figure) indicate that it is unlikely that such locations will require coordination with systems operating between 5850-5925 MHz. This is due to the fact that spurious emissions from these radars are more than 95 dB below the center frequency energy between 5850-5925 MHz.

4.5 Anticipated Future U.S. Radar Development in 5-GHz Spectrum

It is not currently known what new radar systems, if any, will be developed for use in the 5-GHz bands in the next few decades. But the limited amounts of spectrum available for future radar development make it likely that some new systems will be developed for use in the 5-GHz bands. Current trends in advanced radar design can provide some guidance as to the likely emission characteristics of such radar systems. To the extent that these new designs can be anticipated, new services such as DSRC should be designed to be electromagnetically compatible with future radar systems.

Advanced radar designs are tending toward increased use of modulated, compressed-pulse waveforms. These approaches include various types of phase coding (Barker codes, minimum-shift keying, etc.) and frequency modulation. Assuming that this trend toward incorporating larger amounts of information in radar pulses continues, it can be expected that even compressed pulse lengths will increase. Already, some S-band radars are emitting pulse lengths on the order of 50 μs, and 100 μs pulses are foreseeable. Longer pulses will tend to increase the average power output of advanced radar transmitters. Advanced radar transmitters in the 5-GHz bands are expected to eventually be designed with center frequencies in the 5850-5925 MHz band.

Trends toward longer pulse lengths, higher average power levels, and center frequencies in the 5850-5925 MHz band for future radars do not necessarily preclude operation of DSRC devices in this band, but additional electromagnetic compatibility studies may have to be performed to determine the requirements for such compatibility. References [6] and [7] may be a blueprint for such future studies.

In view of such likely future trends for advanced 5-GHz radars, it is desirable that current DSRC designs be as resistant as possible to longer radar pulse lengths, higher average power levels, and in-band radar center frequencies.

5. FIXED SATELLITE SERVICE MEASURED INCIDENT FIELD STRENGTHS

5.1 Introduction

As part of the effort to determine the maximum field strength values occurring between 5850-5925 MHz at locations in the United States, ITS personnel performed measurements of emission levels from a 5-GHz earth station at Mt. Jackson, VA. This Section summarizes the results of those measurements.

5.2 Measurement Description and Results

The earth station at Mt. Jackson, VA was identified as being a good candidate for this measurement due to its operation in the desired frequency range, and its physical accessibility for measurements. The operating company agreed to permit ITS personnel to enter the earth station property for the purpose of performing measurements of maximum incident field strength.

It was determined that the optimum method for performing the measurements would be to transport a suitcase measurement system to the earth station site and operate it from a rented mini-van. The van was used to move the measurement system to various locations in the vicinity of the earth station, so that the highest value of maximum field strength could be obtained by the measurement personnel.

The measurement system used for Mt. Jackson is shown in block-diagram form in Figure 6; an Emco 3115 double-ridged waveguide horn antenna was used instead of a parabolic antenna. The system consisted of the microwave horn antenna (calibrated for conversion of power in a 50 ohm circuit at the antenna outputs to incident field strength at the antenna aperture), followed by a preamplifier and a portable spectrum analyzer. The antenna was linearly polarized, so that incident field strength could be determined in both horizontal and vertical orientations.

The measurement system was calibrated using noise diodes. The calibration determined both the noise figure and the gain of the measurement system. Amplifier gain was 33 dB at the frequency of the earth station emissions, and the overall system noise figure was 10 dB. All measured power values were corrected for the 33 dB gain of the amplifier (thus determining the corrected power in 50 ohm measurement circuitry), and then corrected for the antenna correction factor of the horn antenna (thus yielding the incident field strength, in decibels relative to a microvolt per meter, at the antenna aperture).

During the course of the measurements, the Institute personnel used both a global positioning system (GPS) receiver and a USGS 7.5’ topographic map to determine their position relative to the earth station. At each measurement point, Institute personnel stopped the measurement van, set up the horn antenna on a phenolic tripod, oriented the horn aperture toward the earth station, and recorded the following information:

1) Position relative to the earth station, correlated to a numbered point in the data log
2) Antenna polarization (horizontal or vertical)
3) Frequencies at which measurements were performed
4) Received power measured in the 50-ohm circuitry of the spectrum analyzer

The earth station antenna was linearly polarized, but was tilted relative to the earth's surface, so that the polarization of received signals was slanted. Because the received signals were slant-polarized, incident power was measured for both horizontal and vertical polarizations. Several power values were measured at each location, to reduce the impact of chance fluctuations of power at any given measurement location.

At the Institute's Boulder laboratory, the measured power values were converted to incident field strength in dBμV/m and in μV/m. This allowed Figure 9, a plot of incident field strength values as a function of distance from the station, to be constructed.

The average incident field strength values in the vicinity of the Mt. Jackson earth station at frequencies of 5875 and 5922 MHz are plotted in Figure 9. At the Mt. Jackson site, the measurements made at the closest distances were in the near field of the antenna. Also, the natural and man-made obstacles were present. These factors nullified the possibility of free-space propagation, and therefore the curves shown on the graph should roll off at a rate differing from ($1/r^2$). This, in fact, was the reason for making the Mt. Jackson measurements: to determine empirically the field strength and rate of roll-off of field strength as a function of distance from the earth station antenna, including factors of near-field conditions and propagation obstacles.

The empirically measured curves roll-off at a rate greater than ($1/r^2$) at near distances, while at larger distances, the roll-off rate decreases to less than ($1/r^2$). The measured field strength values range from about +68 dBμV/m at a distance of 80 meters (the nearest distance at which measurements could be performed without running into the earth station main building), to about +38 dBμV/m at a distance of almost 1500 meters. The low values of the measured incident field strength at a distance of 190 meters (see attached table and graph) may have been due to either multipath propagation or else blocking by natural or man-made obstacles.

5.3 Summary of Fixed Satellite Service Measurements

The Mt. Jackson data indicate that an empirical data set is required to determine the incident field strength as a function of distance from a 5-GHz earth station. The data show that the maximum incident field strength at the nearest possible approach to an earth station by a motor vehicle is about +70 dBμV/m at frequencies of about 5.9 GHz.

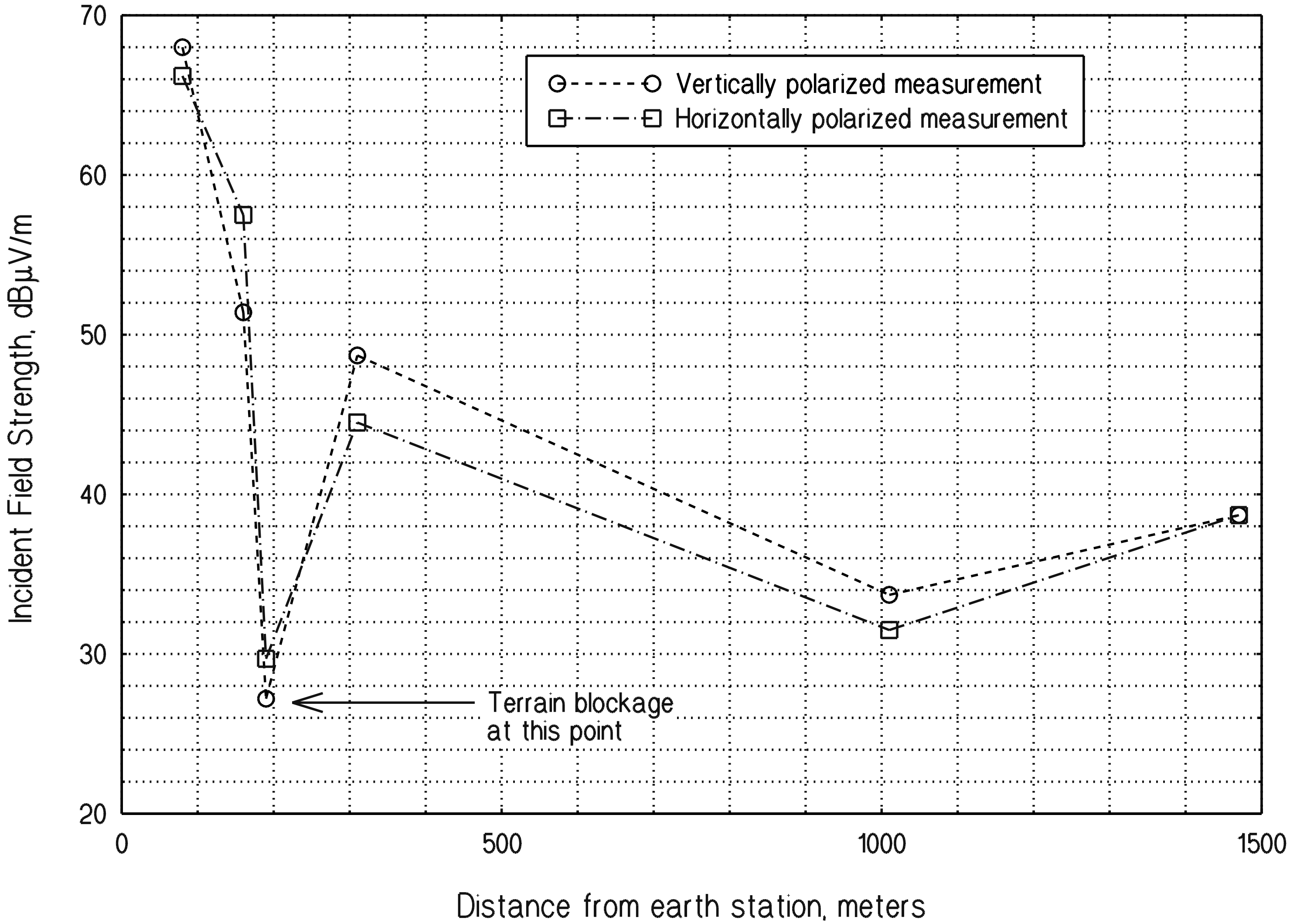


Figure 9. Incident field strength as a function of distance from the Mt. Jackson fixed satellite service (FSS) earth station.

6. CONCLUSIONS AND RECOMMENDATIONS

Measured occupancy of the 5-GHz bands (5250-5925 MHz) is dominated by Government radar emissions in major metropolitan areas, as indicated by NTIA spectrum surveys at Denver, Colorado, San Diego, California, and Los Angeles, California. Emissions from Part 15 and Part 18 devices at these locations were not measurable, either because they were few in number (as indicated by the Denver results) or because they were at levels below the envelope of radar occupancy (as was likely the case in San Diego and Los Angeles).

Within the 5850-5925 MHz portion of the spectrum, measured occupancy at hilltop locations has been observed to range between effectively none, as in Denver, to spurious emissions from Government radars tuned below 5850 MHz, as in San Diego, to some center-tuned emissions within the band, as observed in Los Angeles. Radars known to be tunable within the 5850-5925 MHz band are believed to have a maximum tunable frequency of 5875 MHz. However, future radar development could presumably result in the production of radars that could tune to higher frequencies, as high as the upper band edge of 5925 MHz.

The maximum field strength due to radars that has been measured in the 5850-5925 MHz band is +163 dBμV/m. This value, measured at the distance of closest permissible approach (3.0 km) to a high-power tracking radar (boresighted on the measurement system), is believed to be the highest field strength that can be encountered in this band at locations where other systems such as DSRC can be deployed in the future. The number of locations utilizing this type of radar is limited (Figure 1). This field strength occurs as a pulsed emission at a number of test range facilities in the United States, as detailed in Sections 2 and 4 of this report.

The systems in the 5250-5925 MHz band that generate the highest effective radiated power (ERP) levels are fixed-satellite service (FSS) earth stations in the 5850-5925 MHz band, but the maximum effective radiated power (ERP) values from such stations are directed at space, and not toward the terrestrial surface, where new DSRC systems are expected to be deployed. The Institute measured fields near such a station to determine the levels that might be expected in the vicinity of such a station. The result was found to be about +70 dBμV/m, substantially less than the maximum encountered near various radars, and comparable to the maximum levels of radar spurious emissions in the 5850-5925 MHz band. Co-channel operations of DSRC systems and FSS earth stations should be avoided. This can be accomplished through existing frequency coordination mechanisms.

Radar spurious emissions in this band occur widely. They are produced by military, weather, and maritime surface search radars. But the highest levels that these emissions are believed to reach in a highway environment in the 5850-5925 MHz band is +70 dBμV/m.

Weather radar spurious emissions have been measured at levels slightly lower than the maritime radar spurious emissions, and military radar spurious emissions have been measured at substantially lower levels. The low levels of the military spurious emissions in the 5850-5925 MHz band make it less likely that new operations in the 5850-5925 MHz band will need to coordinate with these radars, as suggested in an earlier NTIA Report [6].

Maximum measured radar field strengths and time waveforms have been used to test DSRC systems intended to operate between 5850-5925 MHz, and the results have been documented in NTIA Reports [6], [7]. Additional tests may be performed on other DSRC systems. Such tests will presumably continue to be performed against worst-case radar signals, since those signals apparently dominate the occupancy of this portion of the spectrum at most locations in the United States.

Because radars currently dominate 5-GHz band usage on a nationwide basis, and will be likely to dominate it for the foreseeable future, it is important to consider the characteristics of new radars in this portion of the spectrum. Trends for advanced 5-GHz radars will be likely to include longer pulse lengths, higher average power levels, and center frequencies in the 5850-5925 MHz band. It is recommended that DSRC systems be designed to be as resistant as possible to interference from future radars with such emission characteristics.

In summary, proposed 5-GHz DSRC systems will have to share spectrum with both co-channel and spurious emissions from radars. To avoid interference from co-channel radars, DSRC frequency assignments will need to be coordinated with local radar assignments to avoid co-channel operations at short separation distances. To avoid interference from radar spurious emissions, it is recommended that DSRC systems be designed for electromagnetic compatibility with radar spurious emissions from both existing radars and future radars that are expected to transmit longer pulses at higher duty cycles. Measurements described in [6] and [7] can serve as a guide for such electromagnetic compatibility evaluations. DSRC systems should also incorporate front-end preselection (bandpass filtering) to reject 5-GHz radar center-frequency emissions occurring at frequencies outside the DSRC band (below 5850 MHz).

7. REFERENCES

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