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Broadband Spectrum Survey at San Francisco, California May-June 1995

Frank H. Sanders
Bradley J. Ramsey
Vincent S. Lawrence

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

Larry Irving, Assistant Secretary
for Communications and Information

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PREFACE

A spectrum survey often depends upon significant efforts by personnel not directly involved in the measurements. We wish to thank the following people and organizations who made the spectrum survey at San Francisco, California, a success: Watson Communications, who allowed us to use their site on Grizzly Peak as a measurement location; the U.S. Coast Guard, who allowed us to use their facilities on Yerba Buena Island as a measurement location; and the California State Parks Department, and Mr. James Burke of that Department, who allowed us to use the summit of Angel Island as a measurement location.

Certain commercial equipment and software are identified in this report to adequately describe the measurements. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration (NTIA), nor does it imply that the equipment or software identified are necessarily the best available for the application.

This report is available on the World Wide Web through the Institute for Telecommunication Sciences (ITS) home page. The ITS home page address is: http://www.its.bldrdoc.gov. Descriptions and availability of other NTIA reports are found on the ITS publications page. The publications page address is: http://www.its.bldrdoc.gov/pub/pubs.html.

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CONTENTS

Page

FIGURES

FIGURES (Continued)

Page

FIGURES (Continued)

Page

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BROADBAND SPECTRUM SURVEY AT
SAN FRANCISCO, CALIFORNIA
MAY-JUNE 1995

Frank H. Sanders, Bradley J. Ramsey, and Vincent S. Lawrence[1]

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA funds the Institute for Telecommunication Sciences (ITS) radio spectrum measurement system to collect data for spectrum utilization assessments. This report details such a data collection effort spanning all of the spectrum from 108 MHz to 19.7 GHz in the metropolitan area of San Francisco, California, during May and June 1995.

Key words: land mobile radio (LMR); radar emission spectrum; radio frequency environment; radio spectrum measurement system (RSMS); spectrum resource assessment; spectrum survey.

1. INTRODUCTION

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 may 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 been collecting data on Federal use of the radio frequency spectrum in support of the NTIA Spectrum Analysis Program. The radio spectrum measurement system (RSMS) is used by NTIA to provide technical support for several programs, such as, (1) Spectrum Resource Assessments (SRAs), (2) U.S. participation in the International Telecommunication Union (ITU) conferences and ITU Radiocommunication Sector (ITU-R) activities, (3) analysis of electromagnetic compatibility (EMC) conflicts, (4) interference resolution, and (5) systems review activity related to new Federal Government systems.

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[1]The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, Boulder, CO 80303-3328.

1.2 Authority

The RSMS is under the administrative control of the Director of ITS. The Deputy Associate Administrator of the Office of Spectrum Management (OSM) is responsible for meeting the spectrum management requirements of NTIA, as transmitted to him by the Associate Administrator of OSM. RSMS measurement activities are authorized by the Deputy Associate Administrator of OSM in consultation with the Director of ITS. Federal agencies with spectrum management needs can request support of the RSMS through the Deputy Associate Administrator of OSM.

1.3 Purpose

Under Departmental Organizational Order 25-7, issued October 5, 1992, and amended December 3, 1993, the Office of Spectrum Management is responsible for identifying and conducting measurements necessary to provide NTIA and the various departments and agencies with information to ensure effective and efficient use of the spectrum. As part of this NTIA measurement program, spectrum occupancy measurements are conducted using the RSMS. The spectrum occupancy data presented in this report do not include identification of specific emitters. The measured data are provided for the spectrum management community to:

- enable a better understanding of how telecommunication systems use the allocated spectrum;

- provide timely information on variations in frequency band usage, e.g., identify frequency bands becoming heavily used;

- support the NTIA system review process by providing information on the availability of spectrum for new systems; and

- assess the feasibility of promoting alternative types of services or systems that result in more effective and efficient use of the spectrum.

1.4 Extrapolation of Spectrum Occupancy Data

The spectrum survey measurements contained in this report cannot be used solely to assess the feasibility of using alternate services or systems in a band. Extrapolation of data in this report to general spectrum occupancy for alternative spectrum uses requires consideration of additional factors. These include spectrum management procedures, types of missions performed in the bands, and new spectrum requirements in the development and procurement stages. (See Appendix A for a broader discussion of systems that are not normally expected to appear in RSMS measurement data.) Also, measurement area, measurement site, and measurement system parameters should be considered.

The area chosen for a spectrum survey will affect measured spectrum occupancy. For example, measurements made in Denver, Colorado [2] are probably representative of metropolitan areas that do not have any maritime radionavigation or extensive military activity. A coastal city, such as San Diego, California [3] with major naval installations, will show higher levels of usage in bands that support such activities.

Choice of measurement site within an area also can affect measured spectrum occupancy. An area such as Seattle-Tacoma, Washington (rough terrain, heavy forestation, and widely dispersed transmitters) may require multiple measurement sites to adequately characterize usage.

Spectrum management procedures (such as band allotments for functions and missions) also affect spectrum utilization. For example, channels used for taxi dispatch might show heavy use whereas channels allocated for law enforcement or public safety may show less use. Regardless of usage, dedicated channels for these safety-of-life functions remain a spectrum requirement. Special events such as natural disasters, Olympic games, and Presidential inaugurations may also create unique spectrum requirements.

Spectrum measurements provide data on expected signal levels and probability of occurrences that are essential for assessing alternate uses of the spectrum. Such information is difficult to obtain from band allocation databases or an understanding of spectrum management procedures.

2. SAN FRANCISCO SPECTRUM SURVEY

2.1 Introduction

This section (1) describes the measurement sites selected for the San Francisco, California, spectrum survey, (2) briefly describes the data processing used to characterize spectrum occupancy across the 108-MHz to 19.7-GHz frequency range, (3) presents the measured data, and (4) provides band-by-band commentary on the survey results. Appendix A contains a thorough description of the spectrum survey measurement procedure. Appendix B provides details for interpretation of data presented in this report. Appendices C and D provide descriptions of the RSMS hardware and software used to make the measurements.

2.2 Measurement Site Description

The San Francisco metropolitan area is centered on, and largely surrounds, the San Francisco Bay, an estuarine body of water, measuring about 100 km north-to-south and about 30 km east-to-west, that is almost completely land-locked. A high ridge separates the west side of the bay from the ocean, and another high ridge occurs on the east side of the bay. The land around the south part of the bay is low-lying. Urban development in the area is especially dense on the west, south, and east sides of the bay, and it is this area that is targeted by the RSMS spectrum survey effort.

If topology were the only concern, the most desirable measurement location for the survey would be a high point on the west ridge, such as Mt. Sutro. Unfortunately, all topologically desirable measurement locations on the west ridge are already occupied by high-power transmitters, such as for television broadcast services, rendering these locations unusable for the purposes of RSMS broadband spectrum survey measurements. (See section A.2 for detailed requirements of RSMS spectrum survey measurement locations.) On the east side of the bay, the high ground affords excellent line-of-sight coverage of the bay area, but again the topologically desirable locations tend to already be occupied by high-power transmitters. A third possibility for RSMS measurement location would be an island in the bay, preferably one with a high summit not already occupied by high-power transmitters.

A detailed area reconnaissance suggested three strong candidates for measurement locations: Grizzly Peak, on the east ridge, Yerba Buena Island, in the middle of the bay, and Angel Island, about 32 km northwest of Yerba Buena Island. All three locations presented advantages and disadvantages for RSMS measurements, as shown in Table 1.

Table 1. Factors Considered in the Selection of Measurement Locations for the San Francisco Broadband Spectrum Survey.

Location	**Advantages**	**Disadvantages**
Grizzly Peak	Excellent line-of-sight coverage of the metropolitan area	Some nearby land mobile radio base stations present potential for overload of the RSMS receiver in some bands
Yerba Buena Island (summit)	Moderately good line-of-sight coverage of the metropolitan area; no land mobile radio base station overload potential	X-band surface search radar at the summit might mask other x-band emissions; heavy vehicular traffic in the vicinity might generate substantial radio noise in VHF-UHF bands
Angel Island (summit)	Moderately good line-of-sight coverage; only one low-power UHF transmitter on the summit	More logistical problems, such as limited access to adequate commercial power; State Parks Department prefers that RSMS not stay on the summit for more than a few days

Because each of the three candidate measurement locations presented possible problems that would make spectrum measurements difficult in one or more bands, a final determination was made to perform measurements in most bands at more than one site. The data could be subsequently analyzed to extract usable data for every band from at least one measurement location. Except for fixed-terrestrial point-to-point microwave band measurements, all bands between 108 MHz and 19.7 GHz were measured at both Grizzly Peak and Yerba Buena Island. The measurements of the fixed point-to-point microwave bands were reserved for Angel Island, because that location provided the least-obstructed horizon (crucial for good azimuth-scan measurements), and the measurements could be done within the time constraints imposed for that location.

When all data were collected and analyzed, it became apparent that, although some overload had occurred in some bands, all three sites had yielded measurements that were presentable as final data. Additionally, it became apparent that the duplication of measurements at the Grizzly Peak and Yerba Buena Island locations had provided necessary data for determining the answer to a persistent question regarding the validity of RSMS broadband spectrum survey data: To what extent are measurement results for a given band at a given location representative of the spectrum occupancy in that band for an entire metropolitan area? The results of this spectrum survey, as described at length in the conclusions (Section 3), indicate in general that measured usage patterns were representative of the entire metropolitan area.

It was also apparent by the end of the measurements that the Angel Island location was probably the best location for a San Francisco broadband spectrum occupancy measurement survey, because of the lack of transmitters on the summit and the relatively good line-of-sight coverage of the metropolitan area. If future spectrum surveys are performed in San Francisco, it would be worth extraordinary effort to overcome the logistic problems and to obtain permission to keep the RSMS on the Angel Island summit long enough to complete a broadband spectrum survey.

The three San Francisco measurement locations are shown in Figure 1. The Grizzly Peak location was a fenced enclosure at 707 Sky Valley Drive in Berkeley, California. The property was owned by Watson Communications. Measurement site coordinates were 37.8822° N, 122.2328° W, and the site base altitude was 527 m MSL. Figure 2 shows areas that were line-of-sight (white areas) to the RSMS from 2 m above ground (typical mobile antenna height) and those areas that were obstructed (shaded with plus (+) signs in the Figure) from the RSMS due to terrain. The Grizzly Peak measurement location afforded the most extensive line-of-sight coverage of the San Francisco area.

The Yerba Buena Island location was at the summit of the island, within a Coast Guard communications facility. The site coordinates were 37.8101° N, 122.3650° W, and the site base altitude was 104 m MSL. Figure 3 shows areas that were line-of-sight to the RSMS and those areas that were obstructed from the RSMS due to terrain, in the same manner as Figure 2. The Yerba Buena Island measurement location afforded moderately good line-of-sight coverage of the San Francisco area.

The Angel Island location was at the summit of Mt. Caroline Livermore, part of the Angel Island State Park facility. The site coordinates were 37.8617° N, 122.4296° W, and the site base altitude was 238 m MSL. Figure 4 shows line-of-sight coverage for this site. This location afforded good coverage of the San Francisco area.

2.3 Data Considerations

The San Francisco spectrum survey, with the following few exceptions, was performed as described in Appendix A. For spectrum surveys, the RSMS is configured as two measurement systems operating simultaneously: one, identified as "System-1," for frequency measurements below 1 GHz; and the other, "System-2" for measurements above 1 GHz. All System-1 frequency bands were measured with a 100-MHz to 1-GHz log-periodic antenna (LPA) mounted

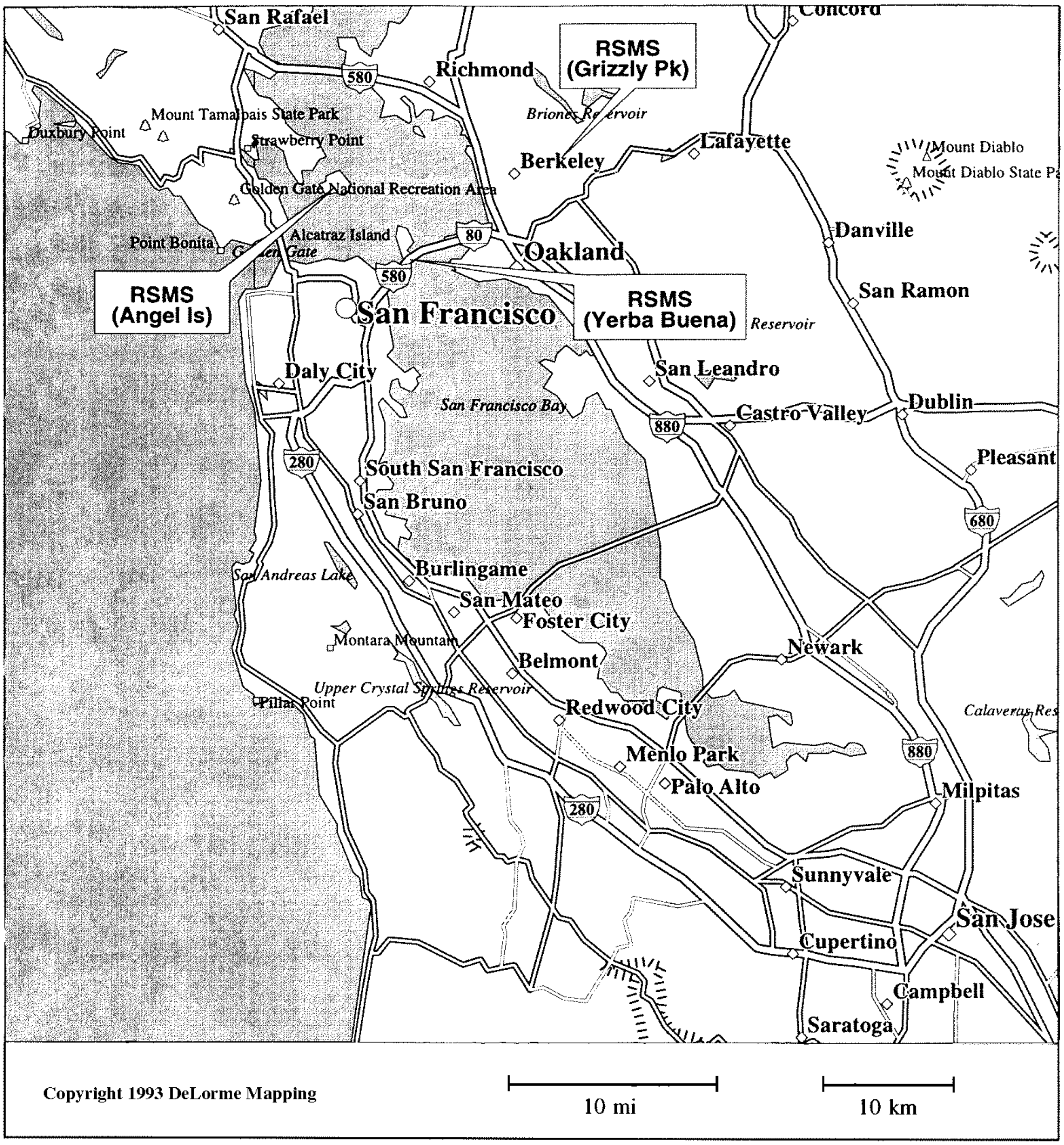

Figure 1. Regional map of San Francisco, California, showing the location of all three RSMS measurement sites. Map produced with MapExpert™ software from DeLorme Mapping, Freeport, Maine.

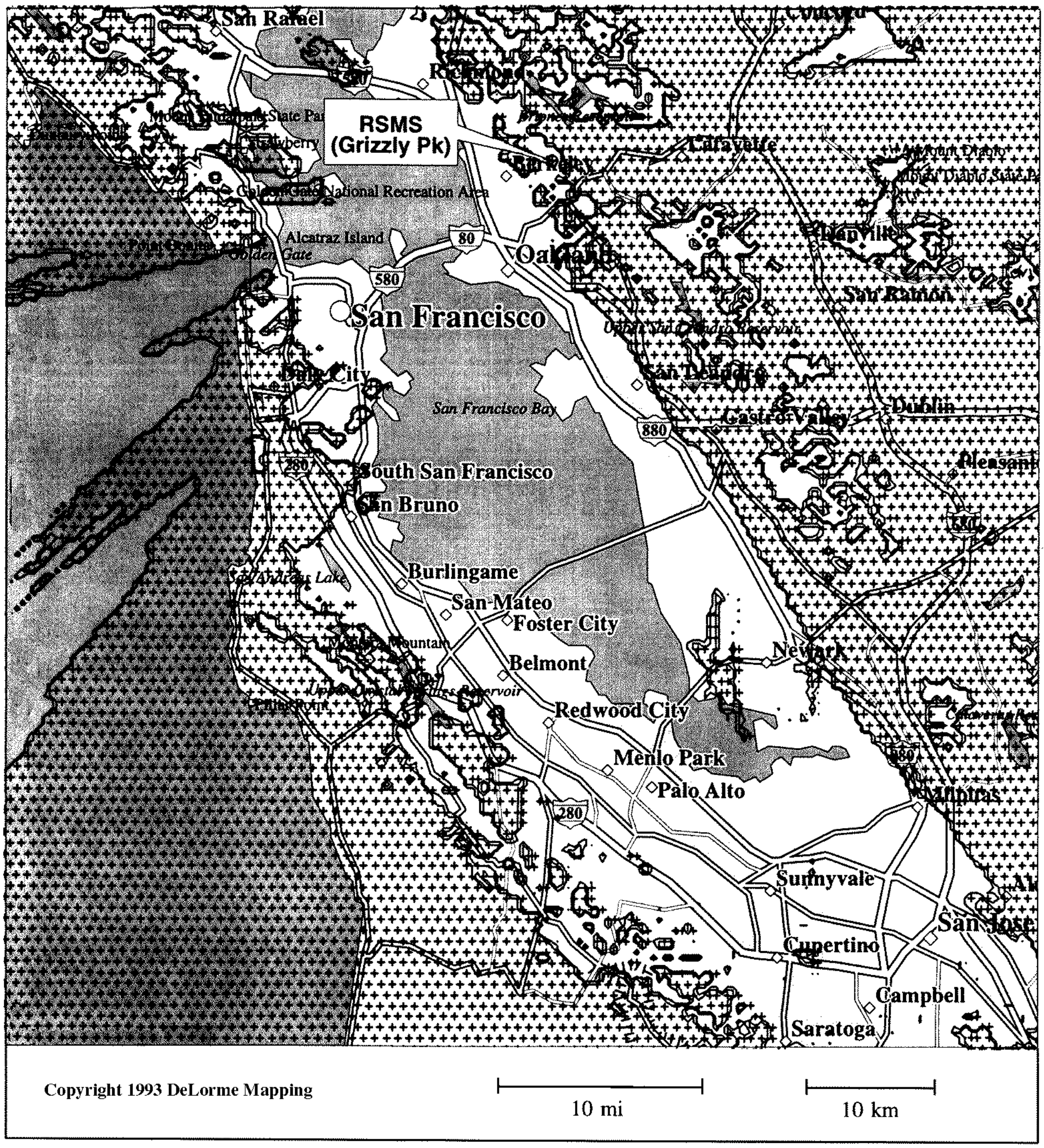

Figure 2. Regional map of San Francisco, California, showing areas that are line-of-sight (white) and terrain nonline-of-site (plus-sign shaded) from the measurement site at Grizzly Peak.

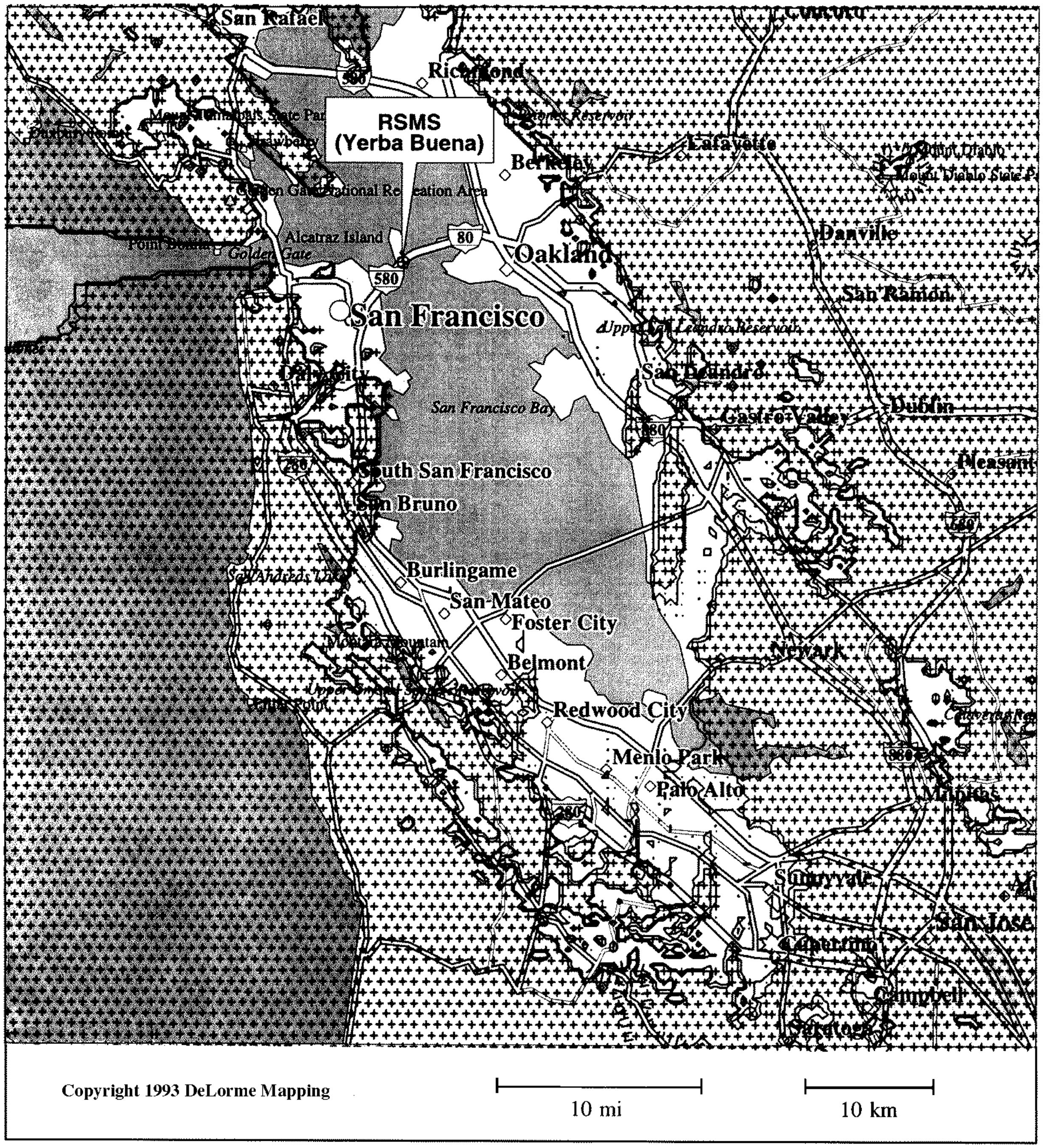

Figure 3. Regional map of San Francisco, California, showing areas that are line-of-sight (white) and terrain nonline-of-site (plus-sign shaded) from the measurement site at Yerba Buena.

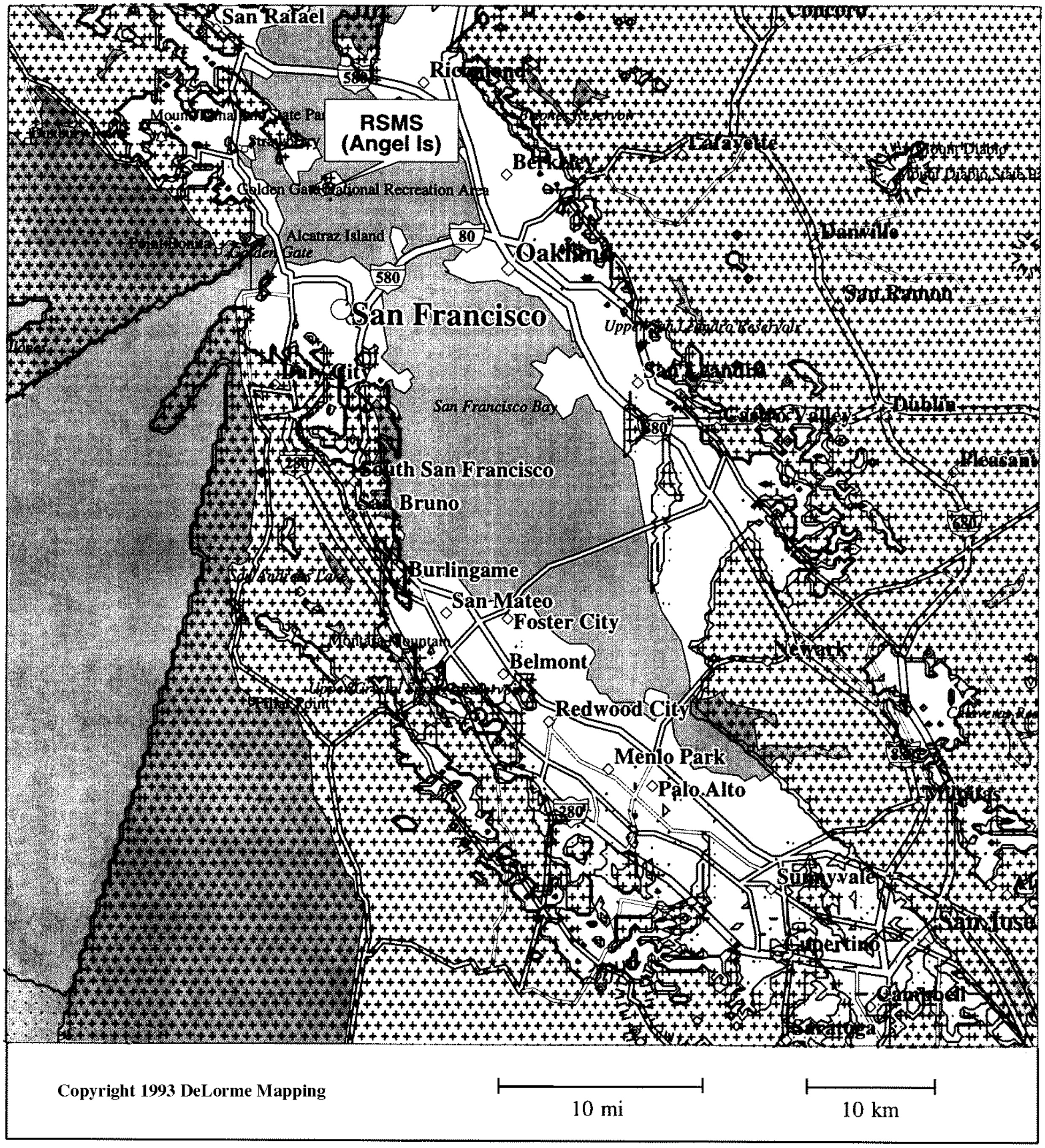

Figure 4. Regional map of San Francisco, California, showing areas that are line-of-sight (white) and terrain nonline-of-site (plus-sign shaded) from the measurement site at Angel Island.

at a 45° angle for slant polarization and aimed toward the downtown San Francisco area. This improved RSMS detection of emissions from the most densely developed part of San Francisco. The System-2 frequencies were measured with a 500-MHz to 18-GHz slant polarized biconical omni antenna, except for azimuth-scanned[2] bands that were measured with a rotating dish antenna (1-m parabolic reflector with dual horizontal and vertical feeds).

As detailed in Section 2.5 and Section 3, most bands were measured at two locations to determine the extent to which measured usage patterns were representative of usage patterns across the entire metropolitan area.

Some broadcast signals were received at sufficiently high levels at both the Grizzly Peak and Yerba Buena Island measurement locations to cause some frontend overload in the RSMS receiver. For the most part, these overload effects were mitigated by the use of rf attenuation in the bands occupied by these signals. Band-by-band comments on measurement results (Section 2.5.1) include discussion of overload effects in the three bands (108 to 114, 174 to 216, and 490 to 612 MHz) where rf attenuation was used.

All measured data, except the azimuth-scanning measurements, underwent a postmeasurement cumulative processing (cuming) step before being displayed. Every frequency data point recorded was cumulated (cumed) according to the measurement algorithm[3] used to collect the data. Swept and stepped measurements were cumed such that the graphed data points (received signal levels; RSLs) showed the maximum, mean, and minimum RSLs of all scans. Swept/m3 data already contained this information, so cuming resulted in graphs showing maximum of maximum RSLs, mean of mean RSLs, and minimum of minimum RSLs. Azimuth-scan data were not cumed, but horizontally and vertically polarized scans were combined in postmeasurement processing so the graphed data show only one resultant single-line curve.

2.4 Measured Data

Each survey band of measured data is displayed graphically on a single page along with corresponding frequency allocation information (Figures 5-75). Each survey band figure has an identical format. The survey band graph in the middle of the page shows frequency in megahertz on the x-axis vs. received signal level marked at 5-dBm increments on the y-axis. Noise level tick marks on the y-axis of some graphs (e.g., "max sample noise," "mean sample noise" and "min sample noise" on Figure 5) show measurement system noise limits. Measurement system response to different types of signals and system noise limits are described in Appendix B. The figure caption includes the survey location and principle measurement parameters.

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[2]The azimuth-scanning measurement routine is an operator-interactive technique using a rotating dish antenna with a swept measurement algorithm. See Section B.8 in Appendix B for more information about azimuth-scanning.

[3]Appendix B contains operational descriptions of the RSMS measurement algorithms, including swept, stepped, and swept/m3.

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The text above each graph (delimited by horizontal and vertical lines) shows the applicable U.S. Government and non-Government frequency allocations and corresponding typical user information (general utilization) for the survey band. The vertical lines delimit, by frequency, both the allocations and the measured survey band graph on the same page.

The frequency allocations (services) are entered according to convention just as they appear in the "U.S. Government Table of Frequency Allocations" [1, part 4.1.3]. Briefly summarized: the names of primary services are printed in capital letters; secondary services are printed in upper and lower case; and where the allocated service is followed by a function in parentheses, the allocation is limited to the function shown. Frequency allocations are continuously updated and some assignment information on the graphs may be out of date; however, the allocations shown were current at the time the measurements were performed.

The vertical lines are placed according to frequency separations in the allocation tables. The frequencies (in megahertz) are written at the lower end of the vertical lines. Any service entry that does not fit within the line-delimited space above the graph is given a number referencing the complete allocation text below the graph on the same page. If there is additional information pertinent to a specific Government or non-Government allocation, it is indicated by a number referencing a note below the graph. General utilization (i.e., a description of how the frequency allotment is typically used) also will show a reference number if insufficient space is available within the vertical line delimiters. All notes are written in simple text format distinguishable from the allocated service entries that are entered according to convention, as previously explained.

It should be noted that the appearance of survey band graphed data is affected substantially by the measurement parameters and the analysis techniques employed. For example, data in Figures 7 and 9 were measured with similar techniques; however, Figure 7 appears to show a denser signal population than Figure 9. Closer examination shows that Figure 7 covers twice the frequency range of Figure 9 and this may be a primary reason for the apparently denser signal environment of Figure 7. Similarly, various survey bands may be plotted with different graph scales or measured with different bandwidths and algorithms. This is the case for Figures 31 and 33. Both figures cover the same frequency range, but the bandwidths and measurement algorithms are completely different.

The previous two examples are given as a caution to the reader that each survey band is intended to best describe the signal environment within its frequency range and is not, generally comparable to other survey bands. The band-by-band summary observations of Section 2.5 should help in interpreting the data graphs.

2.5 Band-by-Band Evaluation of San Francisco Spectrum Survey Results

It is important to understand those aspects of spectrum use that can be extrapolated from the RSMS data presented in this report, and also those aspects of spectrum use that cannot be inferred from these data. Most bands were surveyed at two separate locations in the San Francisco area during two weeks of May, 1995. This was effectively a double survey, intended to determine the extent to which RSMS occupancy data from any given site are indicative of usage patterns across an entire metropolitan area. As described more fully in Table 2 and in Section 3, comparisons of survey results between the two sites show measured usage patterns that were truly indicative of overall spectrum occupancy across the metropolitan area for most bands, the major exception being the 902 to 928 MHz Industrial, Scientific, and Medical (ISM) band.

In most measured bands, the RSMS data presented in this report show maximum, minimum, and mean power levels of received signals. In these bands, the accumulative measurement time during the survey typically was several hours, spread uniformly over the diurnal cycle. Nondynamic bands that were measured with the azimuth-scanning technique show only a single occupancy curve representing a few minutes of sampling time. Appendix B details the sampling techniques and probability-of-intercept factors for RSMS spectrum surveys.

Based on the measurement and sampling techniques used, we believe that these data represent a good statistical sampling of the activity in the radio spectrum in the San Francisco metropolitan area. Maximum and minimum activity levels measured in the spectrum probably are representative of actual activity levels. The mean curves provide a qualitative estimate of the typical received power as a function of frequency. The maximum, minimum, and mean curves also can be used to qualitatively assess the relative density of channel occupancy on a band-by-band basis. Likewise in the azimuth-scan bands, the single plotted curve provides a density estimate of spectrum occupancy in the survey area.

However, while the data presented here can be used to infer the density of frequency occupancy, these data ***cannot*** be used to infer the statistical percentage of time that channels are occupied. A good analogy is to imagine counting houses while driving along a street: one can easily count the number of houses that have been built on each block (analogous to counting the number of frequencies that show activity in each band in the RSMS survey), but one cannot tell, on the basis of that count, what percentage of time the houses are occupied. Signals that are observed in 100% of the scans can be determined, because the minimum curve will show such activity. Other than 100% signals, the mean curves provide a qualitative, not quantitative, measure of occupancy for the measured frequencies.

There is an RSMS measurement technique for obtaining absolute channel occupancy statistics. Measurements of this type were performed (in mobile radio bands) in conjunction with the RSMS occupancy survey in San Francisco. Results of those measurements will be published separately.

Table 2 contains a band-by-band evaluation of spectrum occupancy in the San Francisco area. Comments and observations are based on examination of the RSMS data collected during the spectrum survey and frequency allocation information in the NTIA *Manual of Regulations and Procedures for Federal Radio Frequency Management* [1, Chapter 4].

Table 2. Comments on San Francisco Spectrum Survey Results

Survey Band (MHz)	Figures	Comments
108-138	5, 6	For measurements below 114 MHz, 20-dB rf attenuation was added at the RSMS frontend to prevent overload by signals in the adjacent 88 to 108 MHz commercial FM radio broadcast band. This raised the RSMS noise floor in this range by 20 dB relative to the rest of the band, and reduced RSMS sensitivity to signals in the 108 to 114 MHz range by the same amount. Instrument landing system (ILS) localizers transmit in the 108 to 112 MHz range, so detection of ILS localizers was degraded by the high RSMS noise figure in this range. Some ILS localizers, including San Francisco (SFO) airport, are nevertheless observed. Across 108 to 118 MHz, very-high frequency omnidirectional range (VOR) aeronautical navigation beacons are observed as 100% emitters. These are seen as vertical lines coming up from the minimum curve. Also, in the air traffic control (ATC) band across 118 to 136 MHz, automated terminal information service transmissions appear as high-average or 100% signals. Frequently used ATC frequencies also appear as high points on the mean curve. Air mobile frequencies that were used at least once during the survey are observed on the maximum curve. A large number of the available channels in the ATC band were used during the survey period. In the 137 to 138 MHz band, television infrared observation satellite (TIROS) signals are not usually receivable by the RSMS. However, three signals were received in this band, from either satellites or other meteorological-aids transmitters.
138-162	7, 8	A large number of mobile signals are observed in the 138 to 144 MHz portion of the spectrum, especially as measured from Grizzly Peak. The mean curve is significantly raised across the 144 to 148 MHz range, used by amateurs. From 148 to 162 MHz, a large percentage of available channels also show use. Transmitters between 152 MHz and 153 MHz were in operation continuously during the survey period. Maritime mobile signals occur between 156.2475 MHz and 162.025 MHz. All of these channels show some occupancy, consistent with expectations for the RSMS coverage of the San Francisco Bay area from the measurement locations.
162-174	9, 10	A variety of fixed and mobile signals are observed. The signal at 162.4 MHz is a public broadcast weather information channel. Approximately half of the channels in this band show some occupancy during the survey period, although most channels were not occupied often enough to affect the mean curve. Measured occupancy is similar for the Grizzly Peak and Yerba Buena Island locations.
174-216	11, 12	Television broadcast channels 7, 9, 11, and 13 are occupied by San Francisco stations. Channels 8, 10, and 12 are occupied by San Diego stations. 20-dB rf attenuation was used to prevent frontend overload in the RSMS. Measured occupancy is similar for the Grizzly Peak and Yerba Buena Island locations.

Table 2. Comments on San Francisco Spectrum Survey Results (Continued)

Survey Band (MHz)	Figures	Comments
216-225	13, 14	Maritime mobile signals and Government seismic stations are observed between 216 MHz and 220 MHz. A trunked-system base station occupies the spectrum between 220.0 MHz and 220.75 MHz. Amateur signals are observed above 222 MHz, and the relative density of channel occupancy slightly increases above 223.25 MHz. No military radiolocation occurs in this spectral range in the San Francisco area. Measured occupancy data were similar for the Grizzly Peak and Yerba Buena Island locations.
225-400	15, 16	Military ATC and other communications are observed at high density. Many of these signals are 100% transmissions from fixed locations, as is especially evident in the Yerba Buena data. Even signals that are less than 100% often are used enough of the time to significantly affect the mean curve. ILS glideslope signals from San Francisco and Oakland airports are observed. Measured occupancy is similar for the Grizzly Peak and Yerba Buena Island locations.
400-406	17, 18	Occupancy is dominated by non-Government meteorological-aids systems that show peaks that are each 50 to 100 kHz wide and 800 kHz apart. One such system was observed from Yerba Buena Island, and the same system and an additional system were observed from Grizzly Peak. Radiosonde signals were also observed at 401.9 and 404.02 MHz.
406-420	19, 20	Occupancy in this band appears to be relatively heavy in San Francisco as compared to San Diego [3] and Los Angeles [4], and the band shows more use than in Denver [2]. Not only do most of the channels show occupancy on at least one occasion during the survey, but the mean curve shows that many of those channels were in use for an appreciable fraction of the time during the survey. A number of trunked-radio systems are operative in this band in the San Francisco area, and this may partly explain why the measured occupancy in this band is relatively high. The emission spectra also show that many of the channels were carrying fm traffic. The channel at 412.8 MHz measured at Yerba Buena shows a possible digital signal. In addition to trunked-radio transmissions, this band also supports such dedicated-channel systems as the National Weather Service Automated Surface Observation System (constant-use signal at 410.075 MHz), Government scientific systems such as seismic sensors, and various law enforcement and military activities. Measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations.
420-450	21, 22	High-power air search radar signals produced all usage observed in this band. Some of these radar signal amplitudes, in excess of −30 dBm in 50 ohms, were near RSMS receiver saturation levels. The radars are mostly long-range, on naval ships and aircraft. Comparison of the high level of activity in this band in the San Francisco area and other coastal cities (San Diego and Los Angeles [3,4]) with practically nonexistent activity at a continental interior location (Denver, Colorado [2]) implies that this may be a nationwide pattern.

Table 2. Comments on San Francisco Spectrum Survey Results (Continued)

Survey Band (MHz)	Figures	Comments
450-470	23, 24	A large number of land mobile signals are observed, and many of them sufficiently often to affect the mean curve. The band edges of the 460 to 465 MHz base station allocation are very distinct. The 454 to 455 MHz domestic public base stations are also distinctly observed. Much of the measured activity between 466 MHz and 470 MHz was due to overload in the RSMS receiver from television channel 14 transmissions (470 to 476 MHz), and does not represent true occupancy. Measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations.
470-512	25, 26	Television channels 14 and 20 are broadcast in San Francisco. Channel 14 overloaded the RSMS receiver system, and consequently an intermodulation product occurs at 480.3 MHz. The other occupancy observed in this band, (allocation for television channels 16 and 17) is generated by land mobile radio transmitters. Spectrum nominally allocated for television broadcast channels 16 and 17 shows use by the San Francisco T-band land-mobile-radio allocation, as defined in [5, Part 90.311], for ten major urban areas in the United States. Base stations operate in the lower half of each channel, and mobile stations operate in the upper half of each channel. Occupancy is a combination of Public Safety, Domestic Public, Industrial, and Land Transportation assignments. Measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations.
512-806	27, 28	All of the signals observed in this band are San Francisco-area UHF television broadcast. 20-dB rf attenuation was added between 512 MHz and 612 MHz to prevent overload of the RSMS receiver by particularly high-amplitude signals in this part of the band. Measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations.
806-902	29, 30	Cellular, trunked, and public safety portions of this part of the spectrum are clearly delineated. Mobile and base parts of the band are also easy to identify. The 806 to 821 MHz (mobile conventional and trunked) band segment is heavily occupied, as is the 821 to 824 MHz mobile public safety band and its base station counterpart between 866 MHz and 869 MHz. The 824 to 849 MHz cellular mobile band shows enough use by mobile units to affect the mean curve slightly. The 849 to 851 MHz ground-to-air allocation shows lower usage, but the probability-of-intercept for such signals by the RSMS is low. The 851 to 866 MHz base conventional and trunked band shows usage that significantly raises the mean curve. The 866 to 869 MHz base public safety shows usage on most channels, and the mean curve is affected. The 869 to 894 MHz band, occupied by cellular base stations, is distinctly observed. The 100% occupancy channels (879 to 881 MHz and 891 to 892 MHz) are probably system control channels. Air-to-ground signals between 894 MHz and 896 MHz are observed, confirming that low probability-of-intercept may prevent the RSMS from measuring corresponding ground-to-air signals. Many signals are observed in the 896 to 901 MHz private land mobile band, and a few signals (901 to 902 MHz general mobile allocation) are seen in the Grizzly Peak data. In this band overall, measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations.

Table 2. Comments on San Francisco Spectrum Survey Results (Continued)

Survey Band (MHz)	Figures	Comments
902-928	31, 32 33, 34	This band is measured in two ways: with the positive peak detector in maximum hold mode and 10-kHz IF bandwidth, as shown in Figures 31 and 32, and with the positive peak detector in stepped mode and 1-MHz bandwidth, as shown in Figures 33 and 34. The narrow-IF bandwidth, maximum-hold measurement is intended to show industrial, scientific and medical (ISM), and Part 15 device operations, while the wide-IF bandwidth, stepped algorithm is intended to optimize the RSMS for measurement of radar signals in the band. For the San Francisco area, both algorithms produced band usage data that show occupancy levels only slightly higher than were measured in the Denver, Colorado, survey [2], and not as high as measured in San Diego and Los Angeles, California [3, 4]. A wide variety of systems operate in this band. These include, but are not limited to, high-power naval radars (primary allocation in the band), ISM devices, Part 15 devices, wireless local area networks (required to either use spread spectrum or frequency-hopping transmitters), automatic vehicle monitoring, highway toll tag readers, location and monitoring service (LMS) systems (for commercial vehicle tracking), digital communication systems, and amateur radio (allocated on a secondary, non-interference basis). A number of assignments for railroads exist in this band for the San Francisco area. Figures 31 and 32 show the cumulative effect of nonradar devices on spectrum usage in this band. Radar emissions tend to be discriminated out of these data by the narrowband (10-kHz) IF. Maximum observed signal amplitude in this bandwidth is about −55 dBm on an omni antenna. Note that many of the signals are observed in 100% of RSMS data scans. The measured occupancy patterns, as measured with maximum-hold mode, differed substantially between the Grizzly Peak and Yerba Buena Island locations, implying that the patterns measured with this algorithm and bandwidth are probably highly dependent upon local ISM systems. This is consistent with the low-power emissions from these systems. Figures 33 and 34 show spectrum occupancy by high-power naval radars. These are long-range radars that were receivable at the measurement locations from ships in San Francisco Bay and ships on the open waters beyond the Golden Gate. The difference in measured occupancy, as measured from Grizzly Peak and Yerba Buena Island, probably represents the vagaries of transit by various military ships during different measurement periods.
928-960	35, 36	Paging systems are observed between 929 MHz and 932 MHz. No signals are observed in the paired 932 to 935 MHz and 941 to 944 MHz point-to-point and point-to-multipoint bands, and this could be due to low probability-of-intercept for such signals by the RSMS, but signals have been measured in this band in other localities, such as Los Angeles [4]. Base stations in the 935 to 940 MHz land mobile band show substantial occupancy. Most signals in the 944 to 960 MHz fixed band (auxiliary broadcasting, fixed private microwave, and studio-to-transmitter links) were present in 100% of RSMS data scans, a pattern that has been observed in Denver, San Diego, and Los Angeles [2, 3, 4]. Overall, measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations.

Table 2. Comments on San Francisco Spectrum Survey Results (Continued)

Survey Band (MHz)	Figures	Comments
960-1215	37, 38	Activity in this band is produced entirely by aeronautical navigation aids. These include tactical air navigation beacons (TACAN), distance-measuring equipment (DME), and air traffic control radar beacon system (ATCRBS) interrogators and transponders. Probable TACAN signals appear as bumps in the mean curve at (approximately) 961, 987, 1018, 1119, 1131, 1157, 1165, 1171, 1173, 1192, 1196, and 1202 MHz. DME airborne interrogations occur from 1025 to 1150 MHz; DME ground beacon replies occur between 962 MHz and 1025 MHz, and between 1150 MHz and 1213 MHz. Note the delineation that is visible at 1150 MHz. ATCRBS ground-based interrogations occur at 1030 MHz, and airborne replies occur at 1090 MHz. Both of these peaks are clearly visible in the data. Because the emissions in this band are primarily pulsed, the mean curve is essentially unaffected by all signals except TACAN. Overall, measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations.
1215-1400	39, 40	This band shows occupancy by high-power, long-range air search radars. Frequencies occupied by distinctly identifiable radar signals are 1310 MHz and 1345 MHz. Emission parameters for this type of radar vary, but values measured by the RSMS crew are typically as follows: mechanical beam rotation, 9 to 12 s rotation time, 1 to 6 μs pulse widths, and 300 to 600 pps transmitted. These radars usually are observed to emit staggered pulse trains to enhance doppler processing of target returns. Overall, measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations; although measured amplitudes in Grizzly Peak data are typically higher than at Yerba Buena Island.
1350-1400	41, 42	Unlike the measurements made in the 1215 to 1400 MHz band, measurements in this band are optimized to observe nonradar emissions. Nevertheless, much of the activity observed in this band is from radars. The prominent features observed in Grizzly Peak data are spurious emissions from the radars between 1215 MHz and 1400 MHz. At Yerba Buena Island, where the radars were received at lower amplitudes, the spurious emissions are below the measurement system noise floor, and consequently are not seen.
1400-1530	43, 44	No activity is observed in this band in the San Francisco area. But note that this band is heavily used by telemetry systems at test ranges, and measurement sites near such facilities, such as Los Angeles [4], do show activity in this band.
1530-1710	45, 46	Numerous signals are observed in the maritime mobile satellite earth-to-space band of 1626.5 to 1646.5 MHz. Some radiosonde signals are observed in the 1668.4 to 1700 MHz band. Overall, measured occupancy patterns are similar for the Grizzly Peak and Yerba Buena Island locations.
1710-2300	47	All signals observed in this band are terrestrial point-to-point communications, as measured with the RSMS azimuth-scanning technique. The measurement system noise floor varies across this frequency range, as evidenced by the dip centered at 2000 MHz. Note that all signals observed in this band in San Francisco are analog; in some other measurement locations, such as Los Angeles [4], some digital signals are observed.

Table 2. Comments on San Francisco Spectrum Survey Results (Continued)

Survey Band (MHz)	Figures	Comments
2300-2500	48, 49	Some observed signals (2305 to 2310 MHz, and 2355 MHz) were present for only brief periods; indicated by the lack of impact on the mean curve. Other than those signals, all of the observed activity is background radiation generated by ISM devices, and especially by aggregate emissions from microwave ovens in the San Francisco area. This background is observed at other RSMS spectrum survey locations [2], [3], [4]. See also Gawthrop, *et al.* [6], for further information on emission characteristics of microwave ovens.
2500-2700	50	At least 22 fixed transmitters are observed in this band. The individual signal spectra are standard NTSC television broadcast, indicating that these are multi-channel multipoint distribution system (MMDS, also called wireless cable television) transmitters. Fixed microwave links in this band, if any, are probably hidden by the more powerful MMDS transmitters. There is some variation in the RSMS system noise floor across this frequency range.
2700-2900	51, 52	All signals in this band are generated by high-power air-search radars. Nine frequencies (2705, 2745, 2765, 2790, 2825, 2835, 2850, 2885, and 2895 MHz) are easily discernable. Because automatic attenuation was not yet implemented in the RSMS, these radars saturated the RSMS frontend at their center frequencies during most of the measurements. However, a few manually attenuated scans were recorded to document the peak received power, and are shown as the maximum curve. So, the mean curve reflects the maximum, positive-peak detected amplitudes of the majority of scans (which were unattenuated), while the maximum curve shows the true envelope of radar emissions in this band. Radars in this band as measured by RSMS crew, typically have the following characteristics: mechanical rotation, no elevation scanning, 4.7 to 5.0 s rotation time, about 1 μs pulse width, and about 1000 pps emitted at a high-order stagger, presumably for doppler processing of target returns.
2900-3100	53, 54	In contrast to the spectrum survey measurements in San Diego and Los Angeles [3,4], no high-power air-search radars are observed in this band. This apparently reflects a relative paucity of activity by naval vessels in the vicinity of San Francisco during the measurement period. The high level of occupancy between 3000 MHz and 3100 MHz is generated by maritime and naval surface-search and navigation radars in the San Francisco Bay area. Most large vessels, both military and civilian, carry a surface-search radar that operates at or near 3050 MHz.
3100-3700	55, 56	In contrast to the spectrum survey measurements in San Diego and Los Angeles [3,4], very little spectrum occupancy is observed in the San Francisco area during the spectrum survey period. Occupancy observed between 3100 MHz and 3220 MHz is spurious emission activity from the 3050-MHz surface-search radars. One or two radar signals occur sporadically between 3220 MHz and 3500 MHz. Radar signals observed between 3500 MHz and 3600 MHz are generated by naval air-traffic control radars.

Table 2. Comments on San Francisco Spectrum Survey Results (Continued)

Survey Band (MHz)	Figures	Comments
3700-4200	57	RSMS azimuth scans show only a single, fixed, point-to-point microwave link in this band. The link's spectrum shows that it is analog. The low level of occupancy by fixed terrestrial links in this band in the San Francisco area correlates well with measurement results in Denver, San Diego, and Los Angeles [2,3,4]. Demand for fixed link assignments in this band is decreasing,[4] and results of this survey, as well as the RSMS spectrum surveys in Denver, San Diego, and Los Angeles [2,3,4] (which consistently show almost no terrestrial signals in this band), raise the question of whether there are nearly as many operational terrestrial links as are indicated by the number of existing licenses. The RSMS noise floor shows variation between 3860 MHz and 4000 MHz.
4200-4400	58, 59	Airborne radio altimeter signals, transmitted by aircraft on approach and departure from nearby airfields, are clearly observed between 4225 MHz and 4350 MHz in the Yerba Buena Island data. Observation of these signals depends upon location of the measurement system below aircraft flight patterns; the Grizzly Peak site was not under such flight patterns, and these signals were not recorded. Two signal modulations predominate: pulsed and FM/CW. Because the signals occur very intermittently, and some are pulsed, the mean and minimum curves are not affected.
4400-5000	60	Only a single fixed, point-to-point microwave link is observed in this band at 4681 MHz, as measured with the RSMS azimuth-scanning technique. Low observed occupancy in this band is consistent with the measured results from Denver and Los Angeles [2,4]. The band exhibited considerably more occupancy in San Diego [3].

[4]Most terrestrial point-to-point links in this band carry long-distance telephone traffic. These links are gradually being replaced by fiber-optic technology; as indicated by this graph showing the number of transmitter licenses issued, in the U.S., for the years 1987 through 1996.

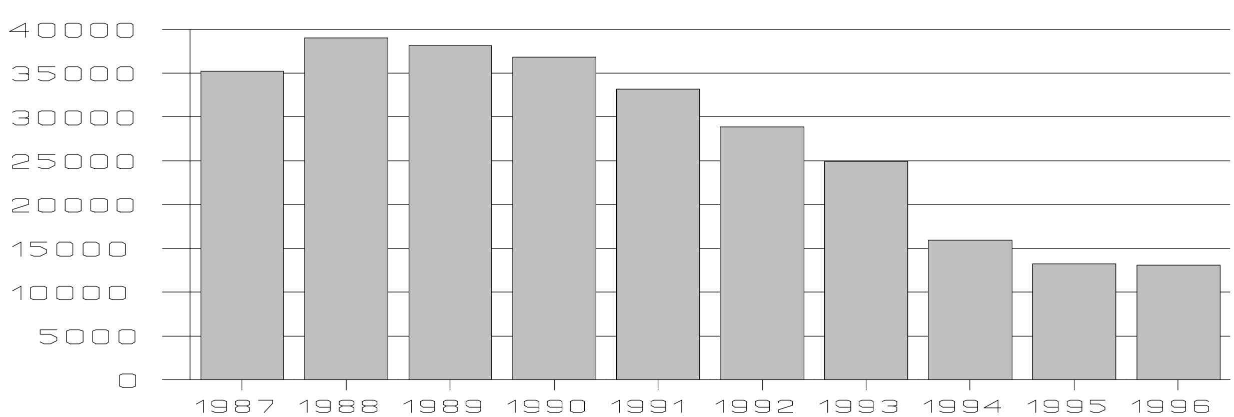

Table 2. Comments on San Francisco Spectrum Survey Results (Continued)

Survey Band (MHz)	**Figures**	**Comments**
5000-5250	61, 62	No signals are observed in this band during the period of the San Francisco spectrum survey. There is no microwave landing system (MLS) deployed in the San Francisco area. The small peaks that appear in the occupancy graph for Yerba Buena Island are noise, generated by adjacent-band maritime surface-search radars operating between 5250 MHz and 5925 MHz. This band was similarly measured with no signal occupancy in Denver, San Diego, and Los Angeles [2,3,4]. This lack of observed occupancy is expected, since until recently MLS has been virtually the only system assigned to this band, and MLS is deployed at a very limited number of locations in the United States. Differential global-positioning system (DGPS) services for aircraft navigation are currently being activated between 5000 MHz and 5150 MHz, but such service was not yet active at the time of this spectrum survey.
5250-5925	63, 64	Occupancy by maritime surface-search and navigation radars is observed between 5250 MHz and 5350 MHz. Weather radar emissions occupy the band between 5400 MHz and 5650 MHz. A military navigation radar is observed between 5650 MHz and 5675 MHz. Radar spurious emissions from the aggregate occupancy are observed up to 5800 MHz.
5925-7125	65	Numerous fixed links, both analog and digital, are observed in the San Francisco area. The digital links occupy spectrum between 5925 MHz and 6370 MHz, and other digital links occur at 6680 MHz and 7020 MHz. Measurement of significant occupancy by fixed-terrestrial and earth-to-space links in this band demonstrates the ability to observe such signals with the RSMS, and indicates that lack of observed occupancy in other bands, such as 3700 to 4200 MHz, probably indicates that such bands are, in fact, not occupied in the metropolitan area.
7125-8500	66	Only a few fixed links, all of them analog, are observed in the RSMS azimuth-scan measurement. Substantially less occupancy is observed in this band in San Francisco than in either the Denver or San Diego surveys [2,3]. The dip between 7850 MHz and 8000 MHz is due to a decrease in the RSMS noise floor across that range.
8500-10550	67, 68	All signals observed in this band are generated by maritime surface-search radars and airborne radars. The observed occupancy at Yerba Buena Island is higher than that observed at Grizzly Peak because the surface-search radars are in closer proximity to Yerba Buena Island, and their main-beam antenna patterns illuminate the island more effectively than they illuminate the high peak. Essentially all surface-search radars carried by small vessels operate in this band; larger vessels also frequently carry radars that operate in this band. Typical operational parameters of the surface search radars, as measured by RSMS, are: mechanical rotation, 2 to 4 s rotation, less than 300 ns pulse width, pulse repetition rates of several thousand pps, no pulse staggering present. Airborne radars have similar pulse characteristics, but employ mechanical sector scans.
10550-13250	69	No signals are observed in this band in San Francisco. Observed occupancy is similar to San Diego and Los Angeles [3,4], and lower than was observed in Denver [2].

Table 2. Comments on San Francisco Spectrum Survey Results (Continued)

Survey Band (MHz)	Figures	Comments
13250-14200	70, 71	A single radar is observed at 13450 MHz in only one RSMS measurement scan. Radars in this band are short-range, often used for fire control.
14200-15700	72	One signal, an earth-to-space link, is observed at 17350 MHz. In general, the probability-of-intercept by the RSMS for signals in this band is low. See Appendix B.
15700-17700	73, 74	No signals are observed in the RSMS azimuth scan. In general, the probability-of-intercept by the RSMS for signals in this band is low. See Appendix B.
17700-19700	75	A few signals are observed near 19450 MHz. These are terrestrial links. The change in the RSMS noise floor at 19300 MHz is due to a band edge in the spectrum analyzer. In general, the probability-of-intercept by the RSMS for signals in this band is low. See Appendix B.

3. CONCLUSIONS

RSMS spectrum survey measurements are intended to provide spectrum engineers and spectrum managers with data that show patterns of spectrum occupancy at selected metropolitan locations across the United States. It has been implicitly assumed during previous RSMS spectrum surveys that the occupancy patterns observed at a well-chosen measurement location in a metropolitan area are indicative of the overall occupancy patterns for the entire area. In San Francisco, that assumption was tested by performing most of the spectrum survey measurements at two measurement locations. To the extent that spectrum occupancy results are replicated at the two locations for any given band, the assumption is considered to be true for this metropolitan area. Table 3 summarizes the comparison between measured band occupancy for all survey bands measured at the two locations in the San Francisco area.

Table 3. Comparison of Measured Spectrum Occupancy at Two Locations

Survey Band (MHz)	Qualitative degree of similarity	Comments on any observed occupancy pattern variation between the two measurement locations
108-138	High	
138-162	High	
162-174	High	
174-216	High	
216-225	High	
225-400	High	
400-406	High	
406-420	High	

Table 3. Comparison of Measured Spectrum Occupancy at Two Locations (Continued).

Survey Band (MHz)	Qualitative degree of similarity	Comments on any observed occupancy pattern variation between the two measurement locations
420-450	Moderate	Transitory nature of naval high-power radars in this band significantly changes occupancy as a function of time.
450-470	High	
470-512	High	
512-812	High	
806-902	High	
902-928 (nonradar)	Low	Prevalent use of low-powered devices in this band causes measured occupancy to be dominated by nearby devices.
902-928 (radar)	High	
928-960	High	
960-1220	High	
1200-1400	High	
1350-1400	High	
1400-1530	High	
1530-1710	High	
2300-2500	High	
2700-2900	Moderate	Reduced line-of-sight coverage for these radars at one measurement location.
2900-3100	High	
3100-3700	High	
4200-4400	Low	Reception of directive, low-power airborne radio altimeters dependent upon location of measurement system relative to local flight paths.
5000-5250	High	
5250-5925	Moderate	Line-of-sight coverage for these radars significantly better at one measurement location.
8500-10600	High	
13250-14250	High	
15700-17700	High	

As shown in Table 3, almost every measured band shows highly similar occupancy patterns between the two measurement locations, with some microwave bands showing only moderate similarity in measured occupancy. Variation between the measured occupancy in the microwave bands is believed to be due to the criticality of line-of-sight coverage at those frequencies, and generally the location with the largest line-of-sight coverage area shows higher measured occupancy levels.

The two bands that show low correlation in measured occupancy between the two measurement sites (902 to 928 MHz, nonradar, and 4200 to 4400 MHz) may do so because their use is dominated by devices that are only receivable for short distances. In the case of the 902 to 928 MHz nonradar occupancy, this results from prevalent use of low-power devices in the band. In the case of 4200 to 4400 MHz, this results from the low power and high directivity of airborne radio altimeter signals.

The results of the multiple-location measurements in San Francisco provide proof that the occupancy patterns measured by the RSMS at any well-selected measurement location are, for the most part, accurate representations of the spectrum occupancy for the entire metropolitan area (assuming, of course, that the measurement location is selected with due regard for the criteria presented in Section A.2 of Appendix A). The only significant exception to this generalization seems to be in the ISM band (902 to 928 MHz), where usage is dominated by low-power transmitters of limited signal intercept range.

The dependence of measured occupancy data on line-of-sight coverage in the microwave bands does suggest that future RSMS spectrum surveys should perform the azimuth-scan measurements for the point-to-point bands at multiple locations, as well.

4. REFERENCES

[1] *Manual of Regulations and Procedures for Federal Radio Frequency Management*, revised Jan. and May. 1996, NTIA Office of Spectrum Management, U.S. Government Printing Office, Stock No. 903-008-00000-8.

[2] F.H. Sanders and V.S. Lawrence, "Broadband spectrum survey at Denver, Colorado," NTIA Report 95-321, Sep. 1995.

[3] F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, "Broadband spectrum survey at San Diego, California," NTIA Report 97-334, Dec. 1996.

[4] F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, "Broadband spectrum survey at Los Angeles, California," NTIA Report 97-336, May 1997.

[5] *Title 47 Code of Federal Regulations, Telecommunications*, Part 80 to End, revised Oct. 1994, (U.S. Government Printing Office, Superintendent of Documents, Mailstop: SSOP, Washington, DC 20402-9328).

[6] P.E. Gawthrop, F.H. Sanders, K.B. Nebbia, and J.J. Sell, "Radio Spectrum Measurements of Individual Microwave Ovens," NTIA Report 94-303, Vol 1 & 2, Mar. 1994.

This is a placeholder for Appendix A, B, C, and D.