NTIA Report 95-321

Broadband Spectrum Survey at Denver, Colorado

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report series

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U.S. DEPARTMENT OF COMMERCE
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PREFACE

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.

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BROADBAND SPECTRUM SURVEY AT DENVER, COLORADO

Frank H. Sanders and Vincent S. Lawrence[1]

NTIA is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the 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 Denver, Colorado, during September and October of 1993.

Key words: land mobile radio (LMR); radar emission spectrum; radio spectrum measurement system (RSMS); radio frequency environment; 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.[2] 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 1) Spectrum Resource Assessments, 2) U.S. participation in the International Telecommunication Union (ITU) conferences and ITU Radiocommunication Sector (ITU-R) activities, 3) analysis of complex electromagnetic compatibility (EMC) problems, 4) interference resolution, and 5) systems review activity related to new Federal Government systems.

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[2] *NTIA, Manual of Regulations and Procedures for Federal Radio Frequency Management,* Part 8.3, U.S. Department of Commerce, National Telecommunications and Information Administration, Washington, D. C., revised May 1992, January 1993 and May 1993.

1.2 Authority

The RSMS is under the administrative control of the Director of the Institute for Telecommunication Sciences (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 problems can request support of the RSMS through the Deputy Associate Administrator of OSM.

1.3 Purpose

Under Departmental Organizational Order 25-7, issued May 23, 1984, 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 Usage Data

The extrapolation of data in this report to general spectrum occupancy for consideration of other shared uses of the spectrum can only be assessed after considering a number of factors. These include measurement area, measurement site, measurement system, spectrum management procedures, types of missions performed in the bands, and new spectrum requirements in the development and procurement stages.

The area chosen for a spectrum survey will affect measured spectrum usage. For example, the Denver area should be representative of many major metropolitan areas that do not have any maritime radionavigation or heavy military activity. Other cities, such as San Diego, may show high levels of activity in these bands.

The measurement site location within an area can also affect measured spectrum usage. An area such as Seattle-Tacoma (rough terrain and widely dispersed transmitters) may require multiple measurement sites to adequately characterize usage.

Spectrum management procedures such as band allotments for functions and missions affect spectrum usage. 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 also create unique spectrum requirements.

In summary, spectrum usage measurements alone cannot be used to assess the feasibility of using alternate types of services or systems in a band. However, spectrum measurements provide data on expected signal levels and probability of occurrences that are essential for assessing alternate uses of the spectrum. Such information cannot be obtained from databases or an understanding of spectrum management procedures.

2. OVERVIEW OF BROADBAND SPECTRUM SURVEYS

2.1 Introduction

Procedures for conducting a broadband spectrum survey using the RSMS are outlined in this section. Site selection factors and significant measurement system parameters are discussed. The measurement system hardware and software configurations developed for the surveys are also described. Detailed information on the system hardware (vehicle, instrumentation, antennas, receiver front-end), calibration procedures, and other measurement capabilities are provided in Appendix A. The measurement system control software (called "DA" for data acquisition) is described in Appendix B.

2.2 Survey Site Selection

A successful spectrum survey (also called a site survey) requires careful selection of a measurement site. Maximum signal intercept probability and minimum logistic problems are the first considerations when locating a site for an RSMS spectrum survey.

The primary signal intercept factors are 1) maximum line-of-sight coverage to increase the probability of weak signal reception such as transmissions from mobile units; 2) limited number of near-by transmitters to prevent intermodulation or saturation problems that can arise even though preselection and/or filtering is used for survey measurements; and 3) limited man-made noise such as impulsive noise from automobile ignition systems and electrical machinery that can add to the received signals of interest and give misleading results.

The primary logistic factors are 1) commercial power to increase the probability of completing the spectrum survey (typically two weeks of 24-hr operation) without power interruptions; 2) commercial telephone for relatively inexpensive reliable communications, compared to the RSMS cellular telephone that could possibly contaminate the measurements when transmitting; and 3) security of personnel, vehicle, and electronic hardware.

The ideal site is a well-illuminated, fenced, and patrolled area that satisfies all of the primary site selection factors above and has reasonable access to lodging for the operating personnel.

2.3 Spectrum Survey Measurements

Spectrum surveys are normally conducted for two weeks using the RSMS in an automatic mode. The measurement system is preprogrammed to continuously run software algorithms tailored to the characteristics of the radio emitters that typically occupy measured frequency subbands. Two decades of making such measurements in cities across the United States suggest that general patterns of spectrum occupancy tend to be repeated from site to site. Emissions from the following sources are commonly observed during RSMS spectrum surveys:

> land-mobile, marine-mobile and air-mobile communication radios;

> terrestrial, marine and airborne radars, and airborne radio altimeters;

> radionavigation emitters, such as TACAN and VOR;

> cellular and trunked communication systems;

> broadcasting transmitters such as UHF and VHF television, and multipoint distribution systems (wireless cable TV);

> indusrial scientific and medical (ISM) sources, including vehicular tracking systems, welders, and microwave ovens; and

> common carrier (point-to-point) microwave signals.

Emissions that are <u>not</u> normally receivable during spectrum surveys are:

> satellite uplink and downlink emissions;

> astronomical emissions;

> some types of spread spectrum signals; and

> radio transmitters that are turned off.

Although the last category is self-evident, questions exist regarding the extent to which users who have assignments in the radio spectrum either do not operate, or operate very rarely, with those assignments. Appendix C discusses factors related to probability of intercept and addresses matters of measurement time vs. statistical significance of data.

As mentioned above, there are many different types of radio signals within the measurement frequency range. Each is measured with a hardware configuration and measurement algorithm specifically selected to give the most useful description of the particular type of signal(s) expected in a frequency subband. The measurement system parameters specially configured for each signal type include: antennas, signal conditioning, tuning speed, measurement bandwidth, detector mode, measurement repetitions, etc. The DA software automatically switches the measurement system to the proper configuration for each subband. The measurements are repeated in various subbands according to specifications established by consideration of signal intercept probability, signal variability, measurement significance, and expenditure of system resources.

For spectrum surveys, the RSMS normally performs measurements of general spectrum occupancy across a frequency range of 108 MHz to 19.7 GHz. To accomplish this task, measurements are conducted in an automatic mode with the RSMS configured as two measurement systems, identified as “System-1” for frequency measurements below 1 GHz, and “System-2” for simultaneous measurements above 1 GHz. The measurement software provides instructions to configure each receiver system, execute measurement routines, record measured data, and maintain a real-time log of the measurements and key parameters. Unattended operation of the measurement system for extended periods of time is made possible through this use of computer control. Remote control of the RSMS is also possible via a telephone modem linked to the computer. Standardized measurement instructions are used for each spectrum survey with the measured data stored for postmeasurement processing.

The measurement system configuration parameters used by the DA software are called “band events” and the automated band event execution procedures are called “band event schedules. ” The factors considered when selecting frequency subbands, receiver algorithms, and other parameters for the band events are discussed in detail in Appendix C.

2.3.1 Survey Band Events

The spectrum measured by the RSMS is divided into selected frequency ranges (survey bands), and each survey band is measured according to a computer-stored list of measurement parameters and instrument settings called a “band event. ” Each band event combines one of the measurement algorithms (“Swept/m3” for example, described in detail in Appendix C) with a particular set of signal input ports, front-end configurations, spectrum analyzer (SA) modes and settings, and data recording options. Spectrum survey “standard” band event parameters for System-1 and System-2 are shown in Tables 1 and 2, respectively.

Each line in the tables begins with an event number (evnt NO.) representing a specific receiver configuration in the RSMS. Instruction to run the event can come from an operator or from a computer-loaded band event schedule as explained in Section 2.3.2. The DA software, when instructed, sends the command parameters for an event to the system hardware and initiates measurements for the event. The tables (Table 1 and Table 2) are subdivided into four parts: 1) “Standard Events” identifies the event number and exact frequency range of interest, 2) “DA receiver parameters” shows input values for receiver configuration subroutines, 3)” DA spectrum analyzer parameters” lists configuration command values sent to the spectrum analyzer, and 4) “Antennas” identifies the type and gain of the antenna selected for the event. Sections B.2 and B.3 of Appendix B describe DA software configuration routines and the associated table parameters found in 2) and 3) above.

Table 1. Spectrum Survey Band Events for RSMS System-1

Standard Events		DA receiver parameters						DA spectrum analyzer parameters*						Antenna**	
evnt NO.	frequency band (MHz)	algor	start (MHz)	end (MHz)	scns #of	swps #of	steps #of	IFBW (kHz)	detec	VBW (kHz)	RL (dBm)	mh/va #swps	swp/stp tm(sec)	type	gain dBi
11	108-162	sw/m3	104	164	6	100	1	10	sampl	10	-10	1	0.3	LPA	5.5
12	162-174	sw/m3	160	180	2	500	1	10	sampl	10	-10	1	0.3	LPA	5.7
13	174-216	sw/m3	170	220	1	500	1	100	sampl	100	-10	1	0.02	LPA	5.8
14	216-225	sw/m3	216	225	3	60	1	3	sampl	3	-10	1	0.9	LPA	5.8
15	225-400	sw/m3	225	405	6	100	1	30	sampl	30	-10	1	0.09	LPA	5.9
16	400-406	sw/m3	400	406	2	60	1	3	sampl	3	-10	1	0.9	LPA	6.0
17	406-420	sw/m3	400	420	2	200	1	10	sampl	10	-10	1	0.9	LPA	6.0
18	420-450	step	420	450	1	1	30	1000	+peak	3000	-10	1	12	LPA	6.0
19	450-470	sw/m3	450	470	2	200	1	10	sampl	10	-10	1	0.9	LPA	6.1
20	470-512	sw/m3	470	520	5	100	1	10	sampl	10	-10	1	0.9	LPA	6.1
21	512-806	sw/m3	512	812	3	200	1	100	sampl	100	-10	1	0.02	LPA	6.2
22	806-902	sw/m3	806	906	10	60	1	10	sampl	10	-10	1	0.3	LPA	6.2
23	902-928	swept	900	930	3	1	1	10	MXMH	10	-10	600	0.1	LPA	6.1
24	902-928	step	900	930	1	1	30	1000	+peak	3000	-10	1	12	LPA	6.1
25	928-960	sw/m3	920	960	4	300	1	10	sampl	10	-10	1	0.3	LPA	6.1

*** For spectrum surveys, attenuation is set to 0 (default), display to 10 dB/div, and the analyzer in use must measure at least 1000 points/scan.**

**** For the Denver survey, all System-1 events were measured with a 0.1-1.0 GHz log periodic antenna (LPA) mounted at a 45°angle for slant polarization (see Section A.4 of Appendix A).**

Table 2. Spectrum Survey Band Events for RSMS System-2

Standard Events		DA receiver parameters						DA spectrum analyzer parameters*						Antenna**	
evnt NO.	frequency band (MHz)	algor	start (MHz)	end (MHz)	scns #of	swps #of	steps #of	IFBW (kHz)	detec	VBW (kHz)	RL (dBm)	mh/va #swps	swp/stp tm(sec)	type	gain dBi
05	960-1215	sw/m3	950	1250	1	500	1	300	+peak	3000	-10	1	0.02	omni	2.1
06	1215-1400	step	1200	1400	1	1	200	1000	+peak	3000	-10	1	12	omni	2.2
07	1350-1400	sw/m3	1350	1400	5	100	1	10	samp	10	-10	1	0.3	omni	2.2
08	1400-1530	sw/m3	1400	1550	5	200	1	30	sampl	30	-10	1	0.09	omni	2.2
09	1530-1710	sw/m3	1530	1710	6	500	1	30	sampl	30	-10	1	0.09	omni	2.2
10	1710-2300	swept	1700	2300	6	1	1	100	MXMH	100	-10	600	0.1	dish	17.5
11	2300-2500	swept	2300	2500	2	1	1	100	MXMH	100	-10	600	0.1	omni	2.5
12	2500-2700	swept	2500	2700	2	1	1	100	MXMH	100	-10	600	0.1	dish	19.8
13	2700-2900	step	2700	2900	1	1	200	1000	+peak	3000	-10	1	5+	omni	2.8
14	2900-3100	step	2900	3100	1	1	200	1000	+peak	3000	-10	1	12	omni	2.8
15	3100-3700	step	3100	3700	1	1	200	3000	+peak	3000	-10	1	12	omni	3.0
16	3700-4200	swept	3700	4200	5	1	1	100	MXMH	100	-10	600	0.1	dish	23.5
17	4200-4400	sw/m3	4200	4400	1	500	1	300	+peak	3000	-10	1	0.02	omni	3.0
18	4400-5000	swept	4400	5000	6	1	1	100	MXMH	100	-10	600	0.1	dish	25
19	5000-5250	sw/m3	5000	5300	1	500	1	300	+peak	3000	-10	1	0.02	omni	3.1
20	5250-5925	step	5250	5950	1	1	240‡	3000	+peak	3000	-10	1	12	omni	3.1
21	5925-7125	swept	5925	7125		1	1	300	MXMH	000	-1	600	0.1	sh	28

Continued

Table 2. Spectrum Survey Band Events for RSMS System-2 (continued)

Standard Events		DA receiver parameters						DA spectrum analyzer parameters*						Antenna**	
evnt NO.	frequency band (MHz)	algor	start (MHz)	end (MHz)	scns #of	swps #of	steps #of	IFBW (kHz)	detec	VBW (kHz)	RL (dBm)	mh/va #swps	swp/stp tm(sec)	type	gain dBi
22	7125-8500	swept	7100	8600	5	1	1	300	MXMH	1000	-10	600	0.1	dish	30
23	8500-10550	step	8500	10600	1	1	720[+]	3000	+peak	3000	-10	1	4	omni	3.1
24	10550-13250	swept	10550	13250	1	1	1	3000	MXMH	3000	-10	600	0.1	dish	33
25	13250-14200	step	13250	14250	1	1	340[+]	3000	+peak	3000	-10	1	4	omni	2.8
26	14200-15700	swept	14200	15700	1	1	1	3000	MXMH	3000	-10	600	0.1	dish	35
27	15700-17700	step	15700	17700	1	1	700[+]	3000	+peak	3000	-10	1	4	omni	2.7
28	17700-19700	swept	17700	19700	1	1	1	3000	MXMH	3000	-10	600	0.1	dish	37

* For spectrum surveys, attenuation is set to 0 (default), display to 10dB/div, and the analyzer in use must measure at least 1000 points/scan.

** A dish antenna is used for azimuth scanning, i.e., "rotating dish" measurements only. See Section A.4 of Appendix A for antenna descriptions and Section B.2 of Appendix B for a description of the Swept/az-scan (azimuth scanning) algorithm.

+A 22-s step-time (dwell) may be used if slow rotation emitters (e.g.,weather radars) are present.

The number of steps given is the minimum necessary to ensure full coverage in the measurement bandwidth selected for this event. Since this band has been well-characterized by previous RSMS measurements, fewer steps were used for the Denver survey to save measurement time for higher priority band events.

2.3.2 Band Event Schedules

Using DA software control, any band event can be executed by an operator at any time. For spectrum surveys, many band events are used to span several GHz of spectrum and each event requires a different amount of time to execute. Fortunately, DA software also includes an automated band event execution mode where any of the band events maybe programmed (scheduled) to execute in any sequence for any amount of time (within hardware limits on continuous operation of the measurement system).

Many variables are considered when developing a band event schedule; some are mentioned below, but a better understanding of band event selection and scheduling may be gained from the discussions of receiver response to measured signal characteristics in Appendix C.

There are two types of schedules used for spectrum surveys with the RSMS: a standard band event schedule of all the survey bands, or a special band event schedule for a few selected survey bands. For example, if a survey was conducted in a port city, a special schedule might include only survey bands with assignments for maritime communications. Any number of special schedules can be run during a survey.

Band event priority is an important consideration when scheduling standard band events; i.e., some frequency bands in a spectrum survey are of more interest to spectrum managers than others. In fact, an important part of the preparation for a spectrum survey is a review of local frequency assignments and allocations. From this preliminary information, measurement parameters may be modified and priority numbers (1, 2 or 3 with 1 being highest priority) assigned to each band event.

Highly dynamic bands (where occupancy changes rapidly) include those used by mobile radios (land, marine, and airborne) and airborne radars. These bands are measured often during a spectrum survey in order to maximize opportunities for signal interception. Bands that are not very dynamic in their occupancy (such as those occupied by commercial radio and television signals or fixed emitters such as air traffic control radars) need not be observed as often, because the same basic occupancy picture will be generated every time. Such bands are given a low priority and less measurement time. An extreme case is that of the common carrier bands, which are essentially nondynamic. Generally, these are only measured once during a survey and are not included in the band event schedules.

Tables 3 and 4 show standard band event schedules for RSMS System-1 and System-2, respectively. Tables 5 and 6 show special band event schedules for measurements in survey bands expected to show altered usage during adverse weather. The tables include: 1) schedule number;[3] 2) band event number (specifies which band event to "run" in the schedule); 3) priority number (value assigned to the band event data, with (1) being the highest priority); 4) event time (approximate time in minutes for the event to run); and 5) accumulative time (approximate time in hours that the sequence has run).

[3] This is a sequence number used by the DA scheduling subroutine; only 64 band events may be sequenced, but the operator may select how many times the sequence runs, even continuously.

Table 3. Standard Band Event Schedule for RSMS System-1

Schedule (number)	Band event (number)	Priority (number)	Event time (minutes)	Accumulative time (hours)
1	12	1	16.3	0.27
2	11	2	10.3	0.44
3	17	1	10.8	0.62
4	14	2	5.1	0.71
5	13	3	5.8	0.81
6	19	1	10.8	0.99
7	22	2	10.8	1.17
8	20	1	13.8	1.40
9	23	2	5.3	1.48
10	25	1	20.0	1.82
11	18	2	6.7	1.93
12	12	1	16.3	2.20
13	16	3	3.4	2.26
14	17	1	10.8	2.44
15	24	2	6.7	2.55
16	19	1	10.8	2.73
17	11	2	10.3	2.90
18	20	1	13.8	3.13
19	14	2	5.1	3.22
20	25	1	20.0	3.55
21	21	3	7.3	3.67
22	12	1	16.3	3.94
23	22	2	10.8	4.12
24	17	1	10.8	4.30
25	23	2	5.3	4.39
26	15	3	8.3	4.53
27	19	1	10.8	4.71
28	18	2	6.7	4.82
29	20	1	13.8	5.05
30	24	2	6.7	5.16
31	25	1	20.0	5.50

Table 4. Standard Band Event Schedule for RSMS System-2

Schedule (number)	Band event (number)	Priority (number)	Event time (minutes)	Accumulative time (hours)
1	05	3	5.6	0.09
2	06	3	42.0	0.79
3	07	2	8.6	0.94
4	08	2	12.7	1.15
5	09	1	37.2	1.77
6	11	3	3.0	1.82
7	13	3	18.0	2.12
8	14	2	42.0	2.82
9	15	2	42.0	3.52
10	17	3	5.6	3.61
11	19	3	5.6	3.71
12	20	2	49.0	4.52
13	23	2	49.0	5.34
14	25	1	25.0	5.76
15	27	1	52.0	6.62
16	05	3	5.6	6.72
17	09	1	37.2	7.34
18	17	3	5.6	7.43
19	19	3	5.6	7.52
20	25	1	25.0	7.94
21	27	1	52.0	8.81
22	05	3	5.6	8.90
23	07	2	8.6	9.04
24	08	2	12.7	9.25
25	09	1	37.2	9.87
26	11	3	3.0	9.92
27	14	2	42.0	10.62
28	15	2	42.0	11.32
29	17	3	5.6	11.42
30	19	3	5.6	11.51

Table 5. Adverse Weather Band Event Schedule for RSMS System-1

Schedule (number)	Band event (number)	Priority (number)	Event time (minutes)	Accumulative time (hours)
1	12	1	16.3	0.27
2	11	2	10.3	0.44
3	12	1	16.3	0.72
4	14	2	5.1	0.80

Table 6. Adverse Weather Band Event Schedule for RSMS System-2

Schedule (number)	Band event (number)	Priority (number)	Event time (minutes)	Accumulative time (hours)
1	09	1	37.2	0.62
2	23	2	49.0	1.44
3	05	3	5.6	1.53
4	17	3	5.6	1.62
5	20	2	49.0	2.44
6	14	2	42.0	3.14
7	13	3	18.0	3.44

The standard band event schedules are usually arranged to execute priority 1 events three times more often than priority 3 events. However, some adjustment to this arrangement may be necessary to accommodate total time required to complete the sequenced band event schedule. For example, if less than two weeks of measurement time were available, a time-consuming priority 1 event (such as Band Event 27) might not be run three times as often as priority 3 events to ensure that all bands would be measured.

Because of the many LMR bands below 1 GHz, System-1 scheduling reflects some preplanning for time-of-day analysis. The sequenced schedule is prepared so that all events will be run within eight hour period; such that, after a few days of 24-hr data collection certain LMR bands will be measured at least once during each hour.

3. DENVER SPECTRUM SURVEY

3.1 Introduction

This section 1) describes the measurement site selected for a spectrum survey in the Denver metropolitan area, 2) briefly describes the data processing used to characterize the spectrum occupancy across the 108 MHz to 19.7 GHz frequency range, and 3) presents the measured data.

3.2 Measurement Site Description

The RSMS was parked on Hackberry Hill, at 7991 W. 71st Avenue, Arvada, CO, about 12 km (7.3 mi) northwest of downtown Denver. The property was owned by the Lutheran Health Care Center. The site coordinates were 105°04'57.4" W, 39°49'35.4" N. Base altitude was 5610 ft MSL. The Lutheran Care Center buildings were to the west of the RSMS and generally one story high, low enough that they did not obstruct RSMS antennas when those antennas were raised to their full tower heights.

The site was reasonably removed from powerful RF transmitters but was within a few hundred feet of possible sources of random noise (heavy traffic on Wadsworth Boulevard and some construction activity with earth moving equipment just on the other side of Wadsworth Boulevard).

Figure 1 shows the location of the RSMS and its relationship to the Denver area. Figure 2 shows areas that were line-of-sight to the RSMS from six feet above ground (typical mobile antenna height) and those areas that were obstructed from the RSMS due to terrain.

Downtown Denver is in a wide valley along the east side of the South Platte River. Where the river passes through Denver, there are some low hills on the west side, but terrain is mostly flat on the east side. Generally, terrain elevation increases first slowly then sharply when moving west from Denver toward Golden. The sharp rise (foothills of the Rocky Mountains) is a continuous north-south barrier to line-of-sight coverage west of Golden.

3.3 Data Considerations

The Denver survey was performed as outlined in Section 2. The band event tables (Table 1 for System-1 and Table 2 for System-2) in Section 2.3.1 list the measurement system parameters used for each survey band. Appendix C contains explanations of the measurement algorithm selections. All survey bands for System-1 were measured with a 0.1-1.0 GHz log periodic antenna (LPA) mounted at a 45° angle (for slant polarization) on the small mast and aimed toward downtown Denver. The System-2 survey bands (except for azimuth-scanning bands[4]) were measured with a 0.5-18 GHz slant polarized biconical omni antenna mounted on the large mast. For the azimuth-scanning survey bands (event numbers

[4] The azimuth-scanning measurement routine is a special operator-interactive technique using a rotating dish antenna with the DA Swept measurement algorithm. See Sections B.2 and C.8 in Appendices B and C for more about scanning.

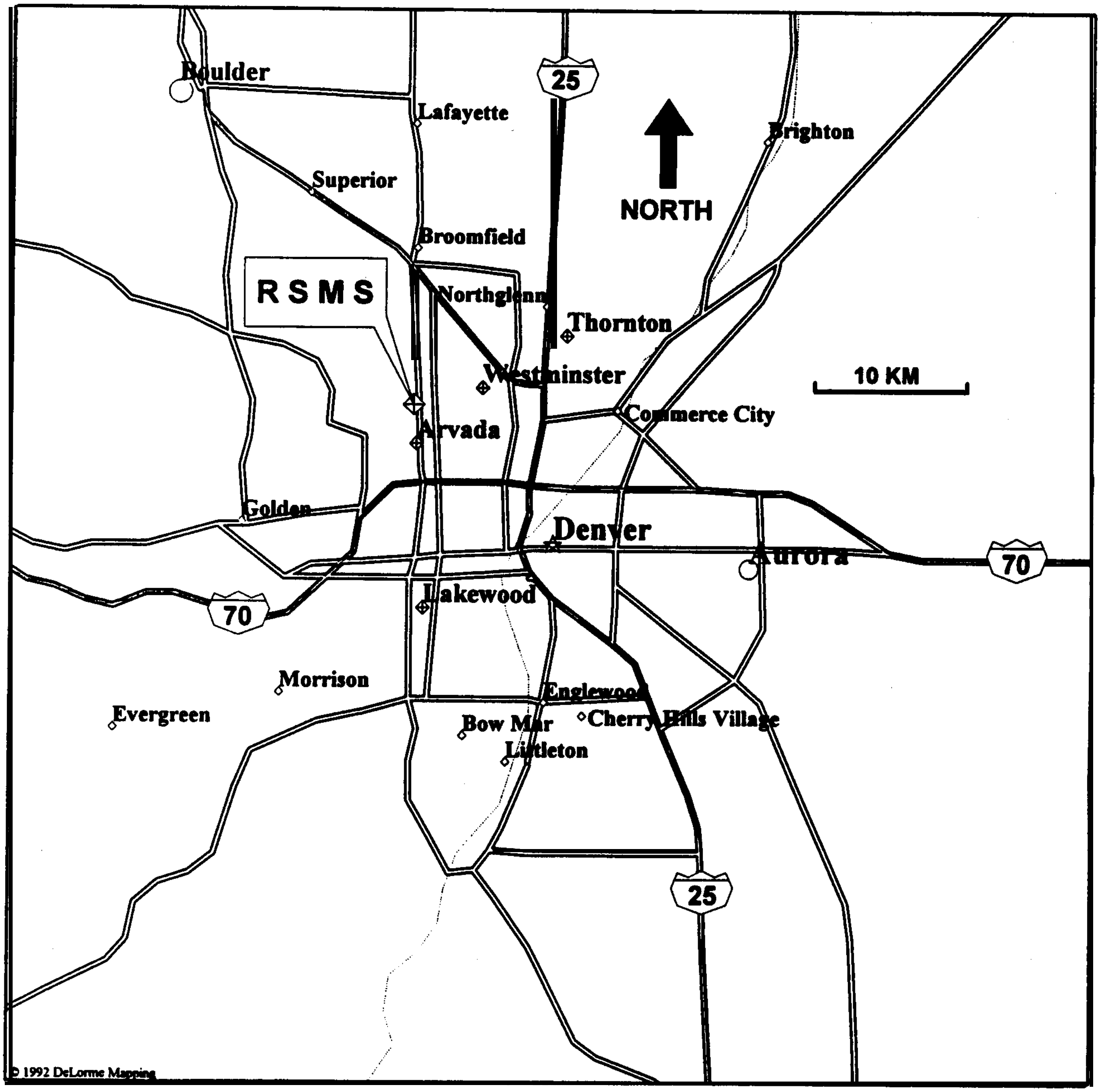

Figure 1. Area map of Denver showing location of the RSMS measurement site. Map produced with MapExpert™ software from DeLorme Mapping.

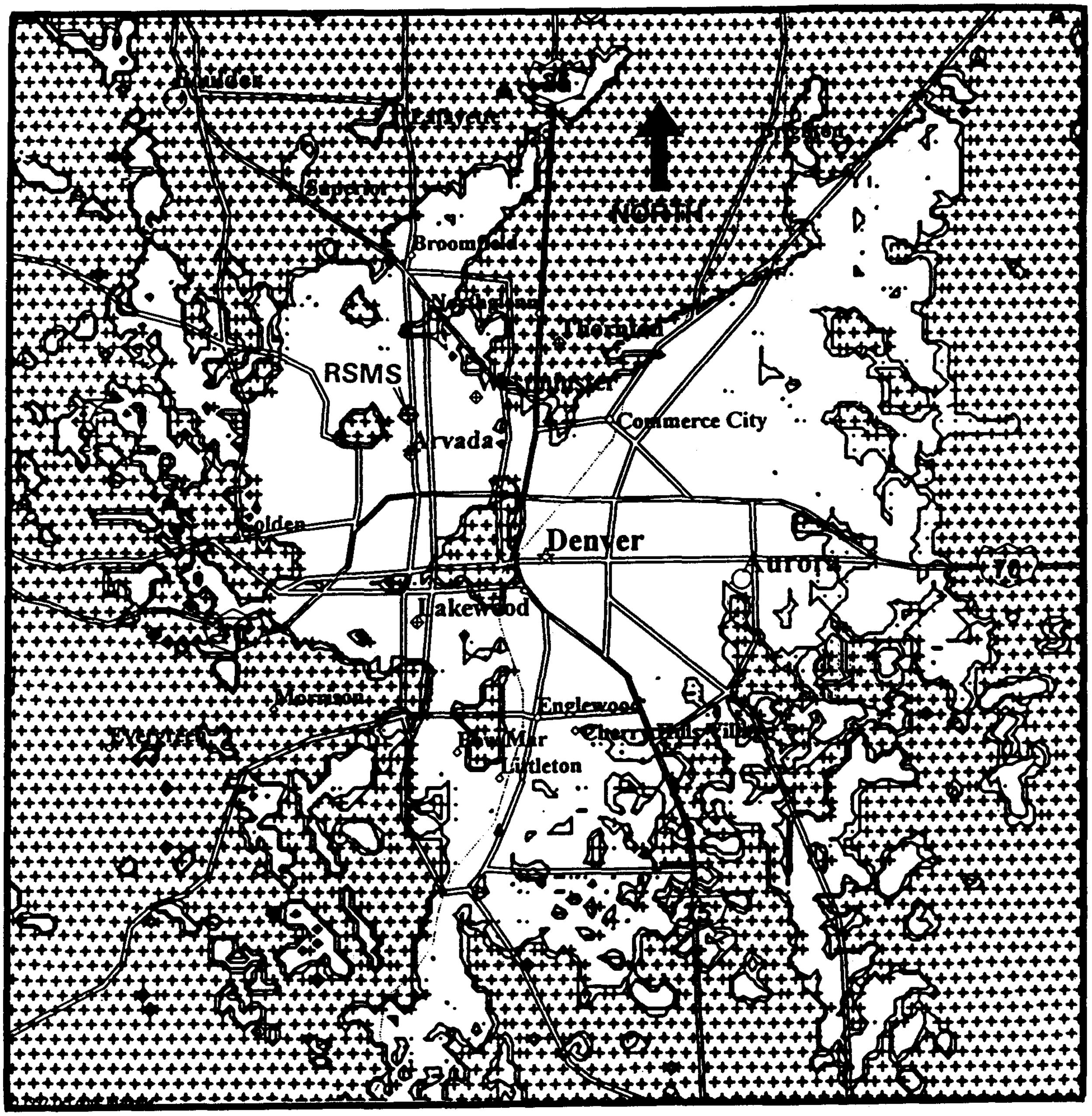

Figure 2. **Map of Figure 1 with a SHADOW overlay showing non-line-of-sight regions (from the RSMS raised antennas) as plus (+) signs. Overlay provided by Telecommunications Analysis Services, Institute for Telecommunication Sciences U.S. Department of Commerce, Boulder Co 80303-3328.**

10, 12, 16, 18, 21, 22, 24, 26, and 28) a rotating 1-meter Tecom dish (dual horizontal/vertical feed) antenna was used. See Appendix A for more on antennas and RF front-end hardware configurations.

All of the measured data, except the azimuth scanning measurements previously mentioned, underwent an additional cumulative processing (cuming) step before being displayed. Every frequency data point recorded for Swept/m3 measurements was cumulated (cumed) such that the graphed data points (received signal levels, RSLs) show the maximum of maximum RSLs, mean of mean RSLs, and minimum of minimum RSLs (see Section C.3.1 of Appendix C for a discussion of Swept/m3 cumulative processing). Cuming of Stepped and Swept measurements results in graphs showing maximum, mean, and minimum RSLs of all scans. On all graphs of cumed data, maximum and minimum curves are drawn with solid lines and mean curves with dashed lines.

System-1 adverse weather band event data (measured during a snowstorm) were cumed with the standard band event data. Also, the measurement rate for the Denver survey was increased by decreasing the number of steps used to measure some survey bands (specifically, band events 20, 23, 25, and 27). This change was made to assess the trade-off between reduced steps and accelerated measurement rate. The reduced-step results are comparable to those of RSMS surveys performed in these bands during the last twenty years.

Half-way through the measurements, a hardware failure in the System-1 HP 8566 SA forced data collection to continue with a substitute HP 8568 SA. Because of different internal processing, the analyzers' outputs could not be cumed together; only the 8566 data were cumed. Although RSMS spectrum surveys nominally last two weeks, one week of data is considered adequate for valid results; it is assumed that as much as half of the data in a band may be lost due to problems in the field. Thus, the Denver data from System-1 are considered to represent a valid set of survey results.

During measurement analysis, it was discovered that strong received signal levels from FM broadcast stations below 108 MHz had generated intermodulation products in the RSMS front end. These products caused false responses in the 108-114 MHz measurements. Therefore, data collected in the 108-114 MHz range were not reliable and were omitted.

3.4 Measured Data

Each survey band of measured data is graphically displayed on a single page along with corresponding frequency allocations and assignment information (Figures 3-41). Each survey band page shares an identical format. The principal band event parameters and measurement location are included in the figure caption. The survey band graphs in the middle of the page show frequency in MHz on the X-axis vs. received signal level marked at 5-dBm increments on the Y-axis. Noise level indicators (marked on the Y-axis) are explained in Appendix C along with suggestions for interpreting the graphed data.

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."[5] Briefly summarized: the names of primary services are printed in capital letters, secondary services are printed in normal upper and lower case, and where the allocated service is followed by a function in parenthesis, the allocation is limited to the function shown.

The vertical lines are placed according to frequency separations in the allocation tables. The frequencies are written at the lower end of the vertical lines and are always in MHz. 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., typical assignment usage notes for the Government or non-Government allocations that fall between the same vertical line delimiters also have a reference number if insufficient space is available . All notes are written in simple text format distinguishable from the allocated service entries that are entered according to convention as explained above.

It should be noted that the appearance of survey and data graphs is substantially affected by the measurement parameters and the analysis techniques employed. For example, System-1, band events 11 and 12 (Figures 3 and 4) were made with similar measurement techniques. Band Event 11 appears to show a more dense signal population than Band Event 12, but close examination shows that Band Event 11 covers a 54-MHz range and Band Event 12 covers a 12-MHz range. The apparently denser signal environment of Band Event 11 may be real or may be caused by the fact that it covers more than four times as much frequency range as Band Event 12. Similarly, various band events maybe plotted with different amplitude scales or are measured with different bandwidths and algorithms. This is the case for System-2, band events 6 and 7 (Figures 19 and 20). Band Event 7 covers the same frequency range as the upper 25% of Band Event 6, but the appearance of the two graphs is completely different. The signals in Band Event 7 appear (at first glance) to be much stronger and denser than those in the common part of Band Event 6.

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 summary observations of Section 3.5 should be of help with interpretation of the data graphs.

3.5 Observations on Measured Data and Spectrum Use

It is important to understand what aspects of spectrum use can be extrapolated from the RSMS data presented in this report, and also what aspects of spectrum use cannot be inferred from these data. First, the data acquisition was performed at a single location in the Denver metropolitan area during a two-week period spanning the end of September and the beginning of October, 1993. In most measured bands, the RSMS data presented in this report show maximum, minimum, and average measured power levels of received signals. In these bands,

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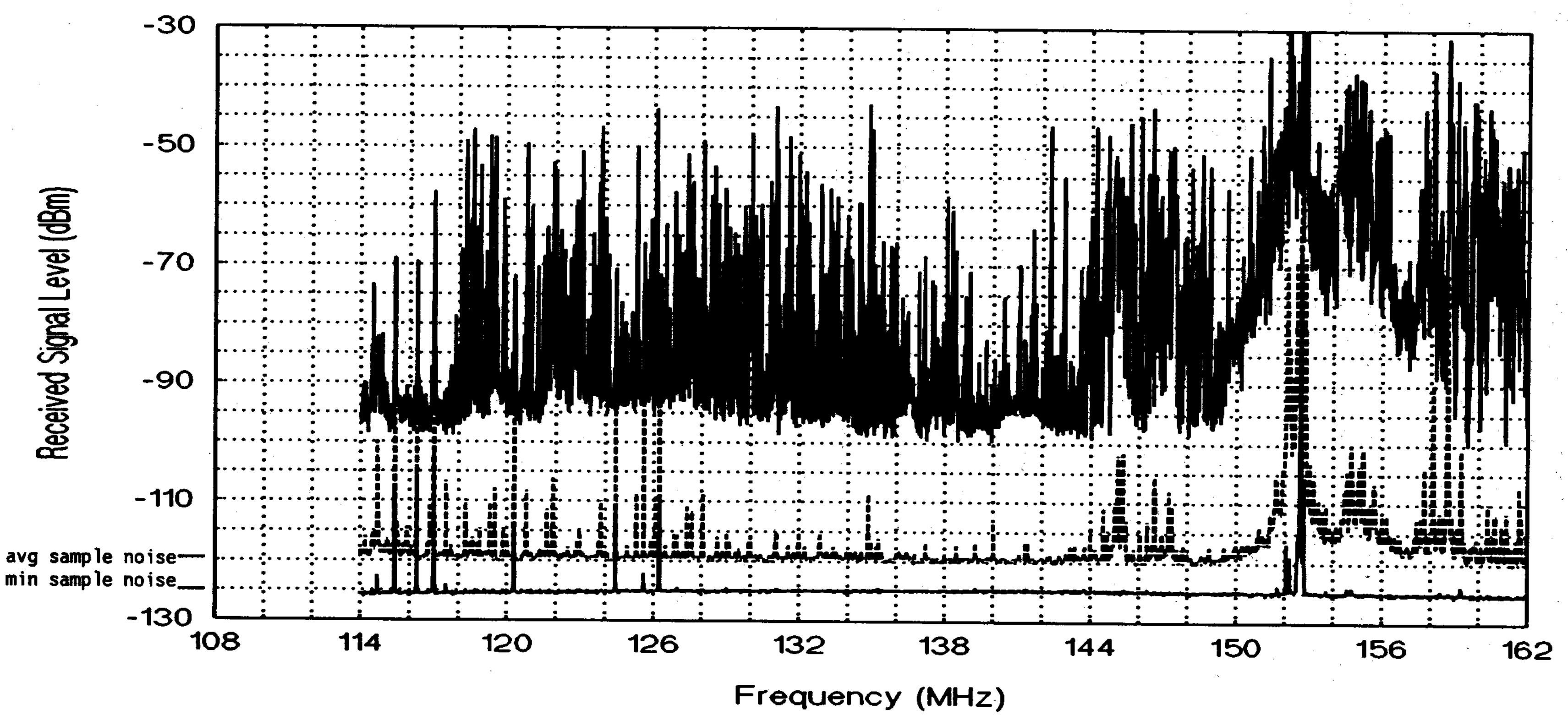
[5] *NTIA, Manual of Regulations and Procedures for Federal Radio Frequency Management* Part 4.1.3, U.S. Department of Commerce, National Telecommunications and Information Administration, Washington, D. C., revised May 1992, January 1993 and May 1993.

	108–117.975	117.975–137	137–138	138–144	144–148	148–162.0125
GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION.	AERONAUTICAL MOBILE.	2	MOBILE, FIXED.		FIXED, MOBILE, MARITIME MOBILE, RADIONAVIGATION-SATELLITE, 5.
NON-GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION.	AERONAUTICAL MOBILE.	2		AMATEUR, 4.	LAND MOBILE, MARITIME MOBILE, RADIONAVIGATION-SATELLITE, 6.
GENERAL UTILIZATION:	VHF Omnidirectional Range (VOR).	Air Traffic Control (ATC), ground control and aeronautical advisories, 1.	2	Non-tactical military, 3.		LMR, TIROS, TRANSIT-SAT, Maritime communications, 7.



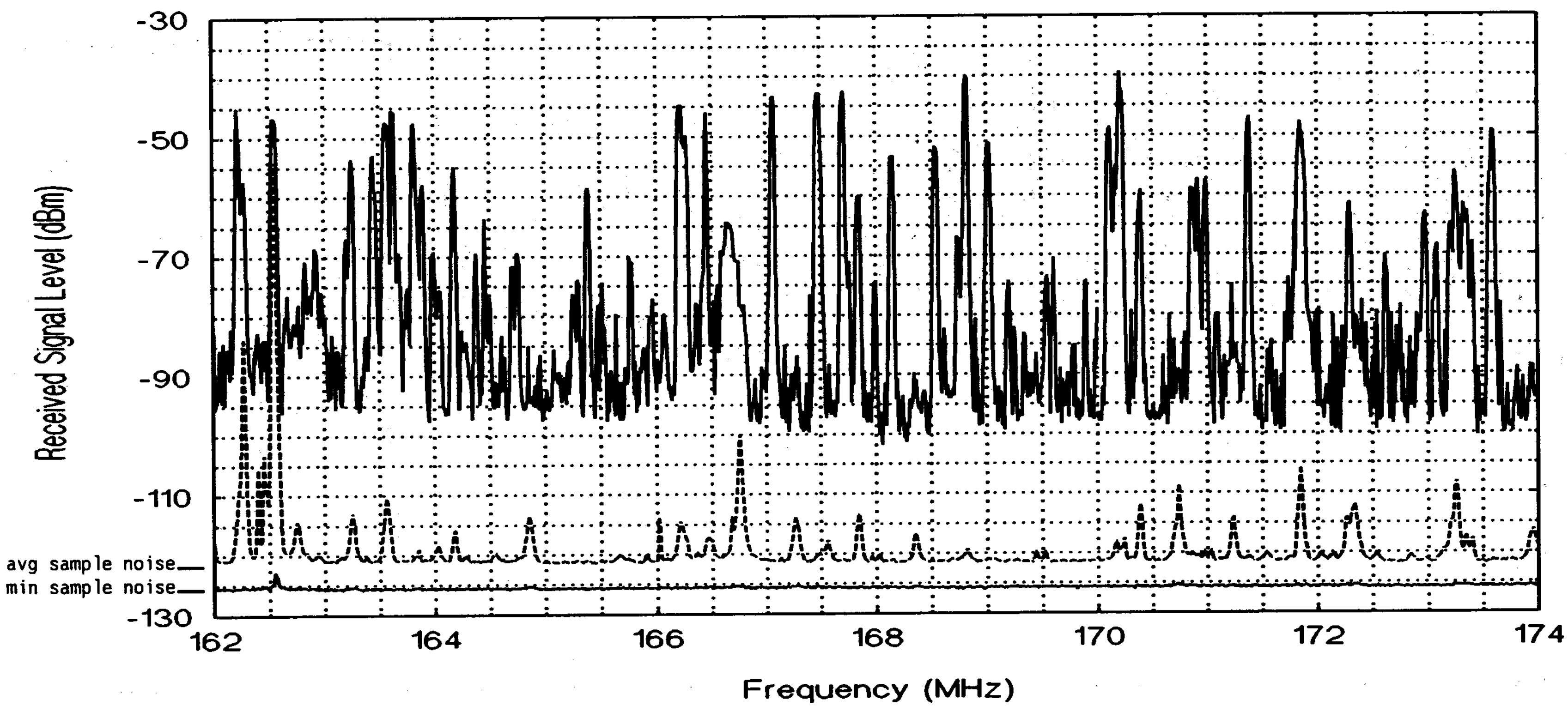
Note: Concerning 108-114 MHz data, see analysis comment in Section 3.3.

1. 121.9375-123.0875 MHz: private aircarft. 123.1 MHz: SAR (search and rescue) operations.
2. SPACE OPERATION/RESEARCH, METEOROLOGICAL/MOBILE-SATELLITE, Mobile-SateNite. Space-to-Earth; government use includes TIROS downlinks.
3. 143.75 MHz, 143.9 MHz: Civil Air Patrol.
4. 144-146 MHz: AMATEUR-SATELLITE.
5. 148-150.05 MHz: MOBILE-SATELLITE (Earth-to-space).
6. FIXED, MOBILE, MOBILE-SATELLITE (Earth-tc-space).
7. Land transportation, domestic public, industrial, public safety, etc.

Figure 3. **NTIA spectrum survey graph summarizing 8,600 sweeps across the 108-162 MHz range (System-1, band event 11, swept/m3 algorithm, sample detector, 10 kHz bandwidth) at Denver, CO, 1993.**

GOVERNMENT ALLOCATIONS:	FIXED, MOBILE		3.
NON-GOVERNMENT ALLOCATIONS:		1.	
GENERAL UTILIZATION:	Land Mobile Radio (LMR) including weather radio, public safety, and law enforcement.	2.	

162.0125 173.2-173.4 174

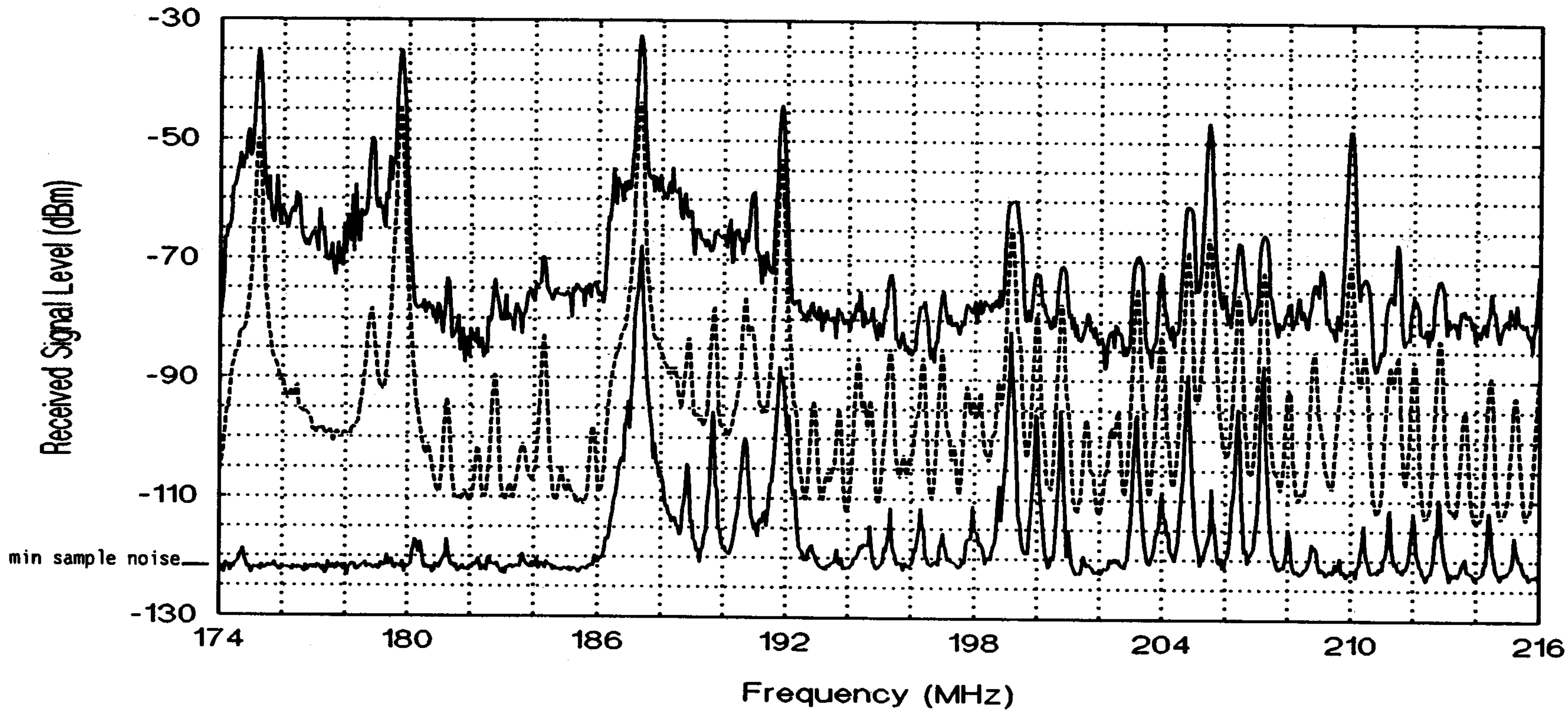


1. **FIXED, Land Mobile.**
2. **Industrial, public safety.**
3. **FIXED, MOBILE.**

Figure 4. NTIA spectrum survey graph summarizing 68,000 sweeps across the 162-174 MHz range (System-1, Band Event 12, swept/m3 algorithm, sample detector, 10-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:							
NON-GOVERNMENT ALLOCATIONS:	BROADCASTING (television broadcasting), 1, 2.						
GENERAL UTILIZATION:	Channel 7	Channel 8	Channel 9	Channel 10	Channel 11	Channel 12	Channel 13

174 180 186 192 198 204 210 216



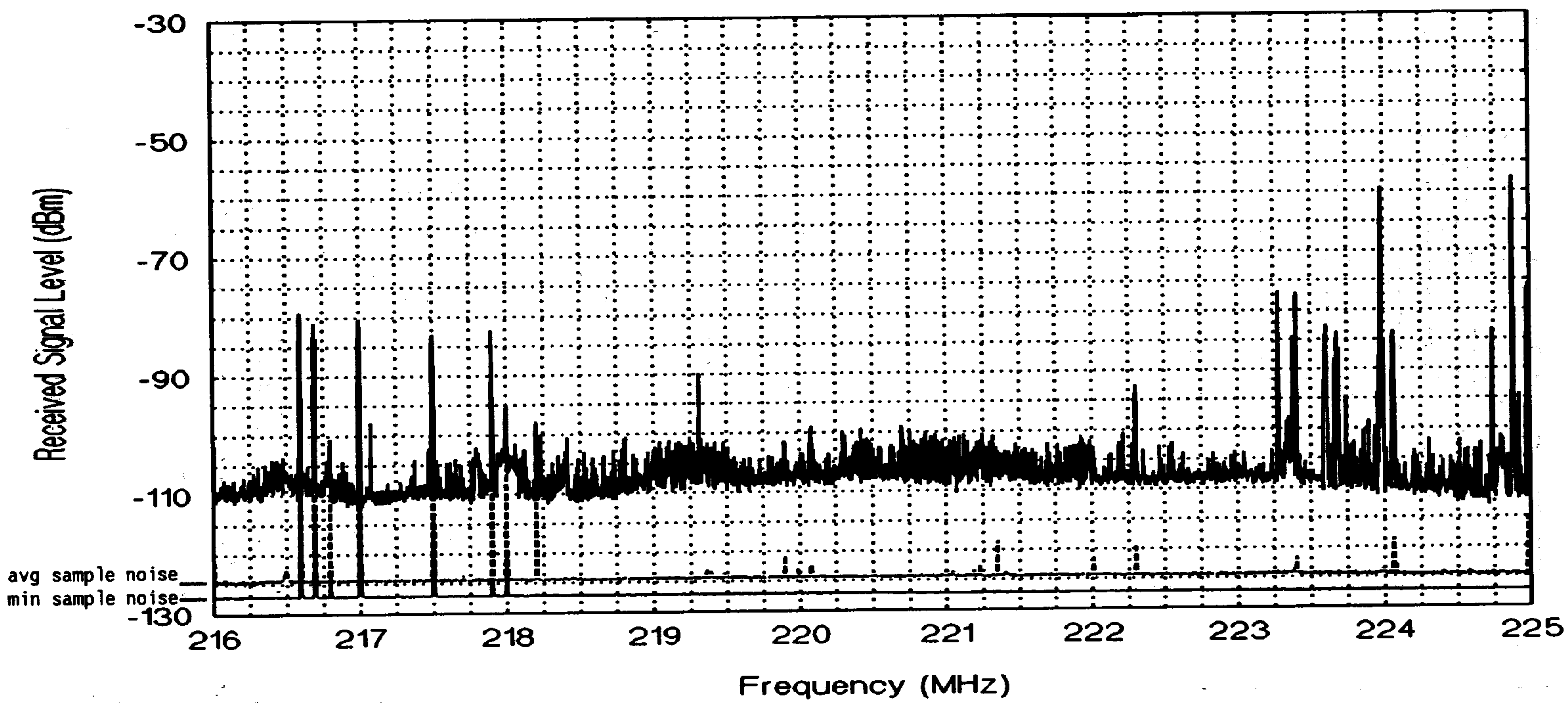
1. **Subscription television services and limited wireless microphone operations are also permitted in this band.**

2. **TV broadcast licencees are permitted to use subcarriers on a secondary basis for both broadcast and non-broadcast purposes.**

Figure 5. NTIA spectrum survey graph summarizing 16,500 sweeps across the 174-216 MHz range (System-1, band event 13, swept/m3 algorithm, sample detector, 100-kHz bandwidth) at Denver, CO, 1993.

	216–220 MHz	220–222 MHz	222–225 MHz
GOVERNMENT ALLOCATIONS:	MARITIME MOBILE, Radiolocation, Fixed, Aeronautical Mobile, 1, 2.	LAND MOBILE, Radiolocation, 1.	Radiolocation, 1.
NON-GOVERNMENT ALLOCATIONS:	MARITIME MOBILE, Fixed, Radiolocation, Aeronautical Mobile, 2.	LAND MOBILE.	AMATEUR.
GENERAL UTILIZATION:	Automated maritime telecommunications systems.	Trunked and conventional systems.	Amateur (1.25 meters).

216 220 222 225



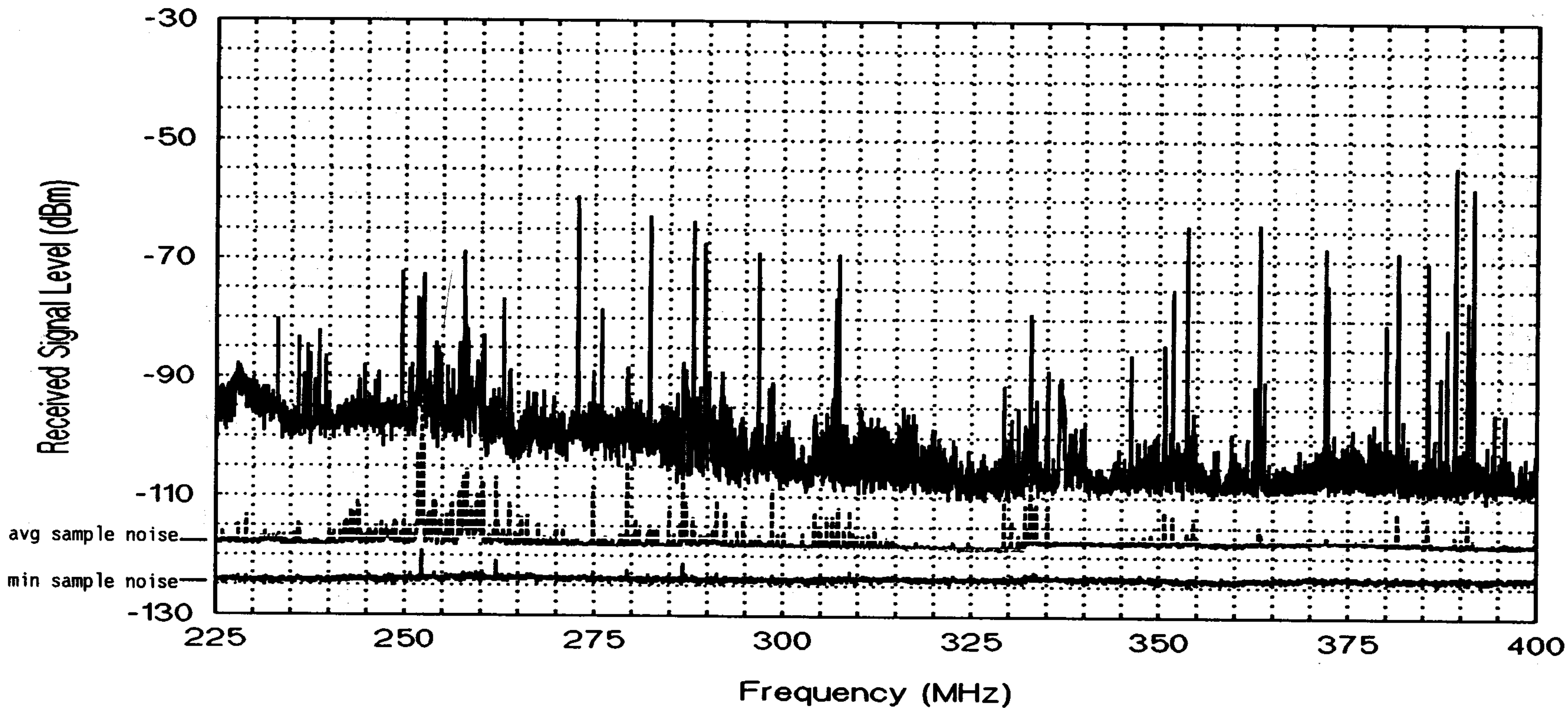
1. Radiolocation is limited to the military services.

2. Secondary services, other than radiolocation, are generally limited to telemetering and associated telecommand operations.

Figure 6. NTIA spectrum survey graph summarizing 4,980 sweeps across the 216-225 MHz range (System-1, band event 4, swept/m3 algorithm, sample detector, 3-kHz bandwidth) at Denver, CO, 1993.

	225–	328.6-335.4	–400.05
GOVERNMENT ALLOCATIONS:	FIXED, MOBILE, 1.	2.	FIXED, MOBILE, 3.
NON-GOVERNMENT ALLOCATIONS:		2.	3.
GENERAL UTILIZATION:	Military tactical and training communications including air traffic control (ATC).	2.	

225 328.6-335.4 400.05



1 Government usage is limited to the military services; additionally, 235-322 MHz is allocated on a primary basis to the mobile-satellite service. 243.0 MHz may be used for search and rescue operations.

2. AERONAUTICAL RADIONAVIGATION, instrument landing systems (ILS) only.

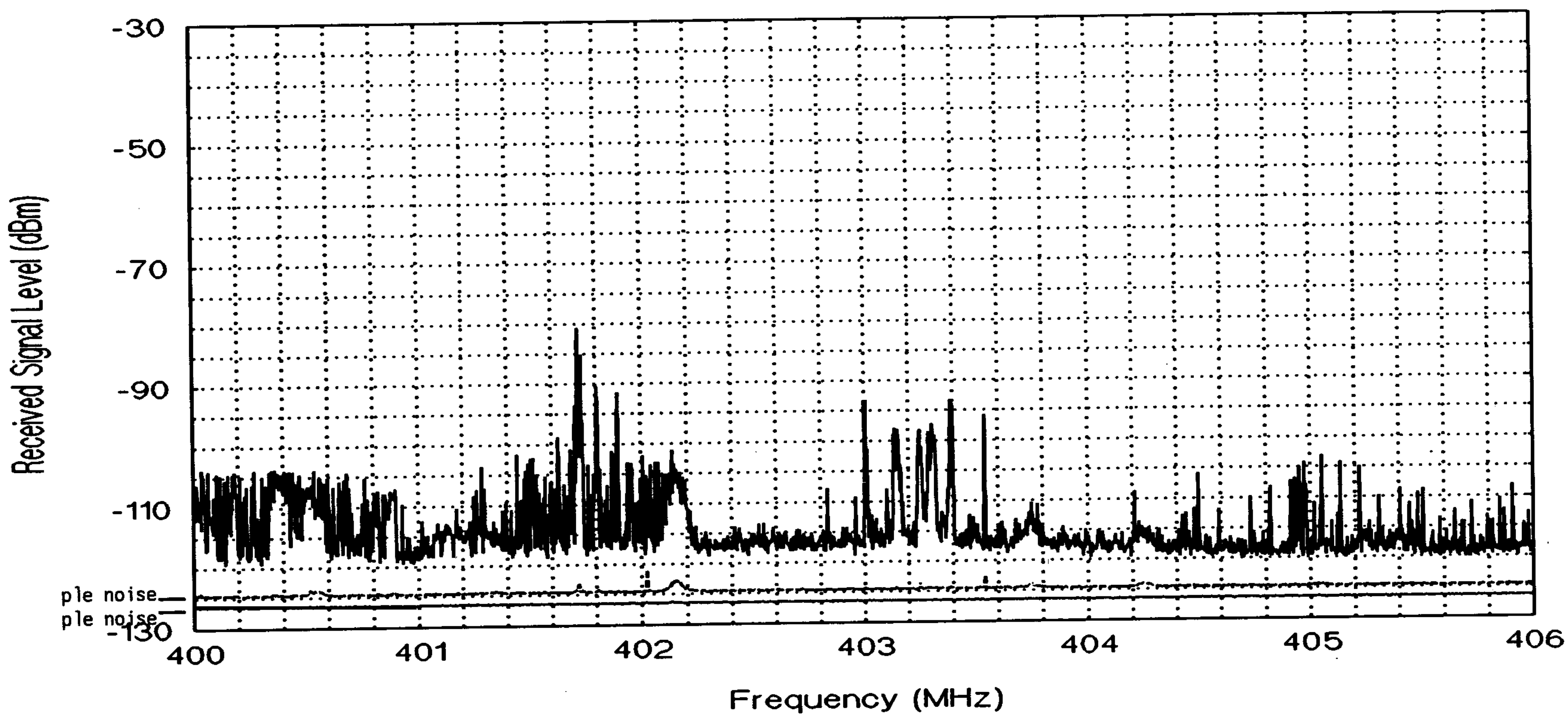
3. 399.9-400.05 MHz: RADIONAVIGATION-SATELLITE.

Figure 7. NTIA spectrum survey graph summarizing 2,900 sweeps across the 225-400 MHz range (System-1, band event 15, swept/m3 algorithm, sample detector, 30-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	1.	METEOROLOGICAL AIDS (Radiosonde), 2, 3, 4, 5.
NON-GOVERNMENT ALLOCATIONS:	1.	METEOROLOGICAL AIDS (Radiosonde), 3, 4, 5.
GENERAL UTILIZATION:	1.	Meteorological radiosondes and satellites including GOES and TIROS-N.

400.05-400.15

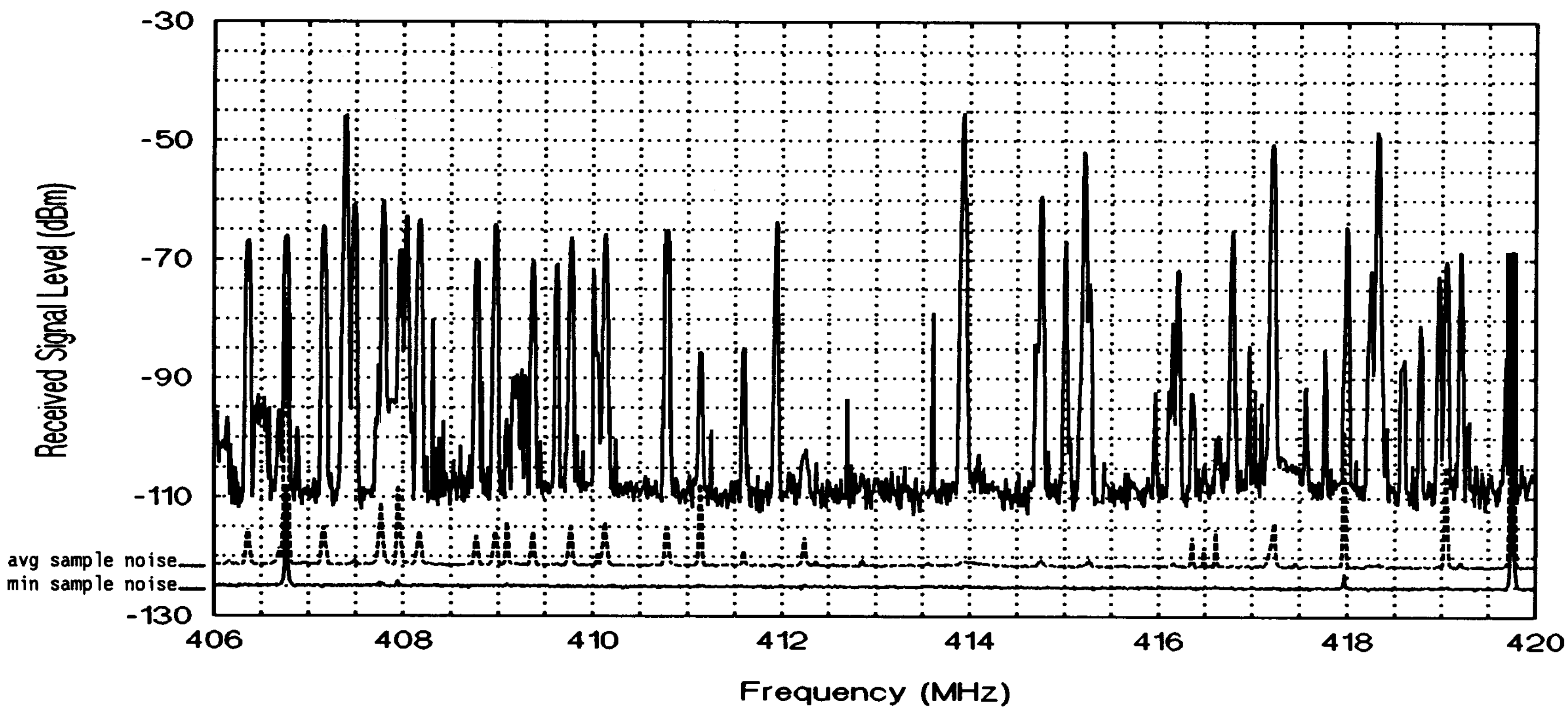
406



1. STANDARD FREQUENCY AND TIME SIGNAL-SATELLITE (400.1 MHz ± 25 kHz).
2. 400.15-401 MHz: METEOROLOGICAL-SATELLITE (space-to-Earth).
3. 400.15-401 MHz: SPACE RESEARCH (space-to-Earth), Space Operation (space-to-Earth).
4. 401-402 MHz: SPACE OPERATION (space-to-Earth), Earth Exploration-Satellite (Earth-to-space), Meteorological-Sat. (Earth-to-space).
5. 402-403 MHz: Earth Exploration-Satellite (Earth-to-space), Meteorological-Satellite (Earth-to-space).

Figure 8. NTIA spectrum survey graph summarizing 1,800 sweeps across the 400-406 MHz range (System-1, band event 16, swept/m3 algorithm, sample detector, 3-kHz bandwidth) at Denver, CO, 1993.

	406-406.1	406.1-410	410-420
GOVERNMENT ALLOCATIONS:	1	RADIO ASTRONOMY, FIXED, MOBILE, 2.	FIXED, MOBILE, 2.
NON-GOVERNMENT ALLOCATIONS:	1	RADIO ASTRONOMY.	
GENERAL UTILIZATION:	1	LMR, 2.	LMR, 2.



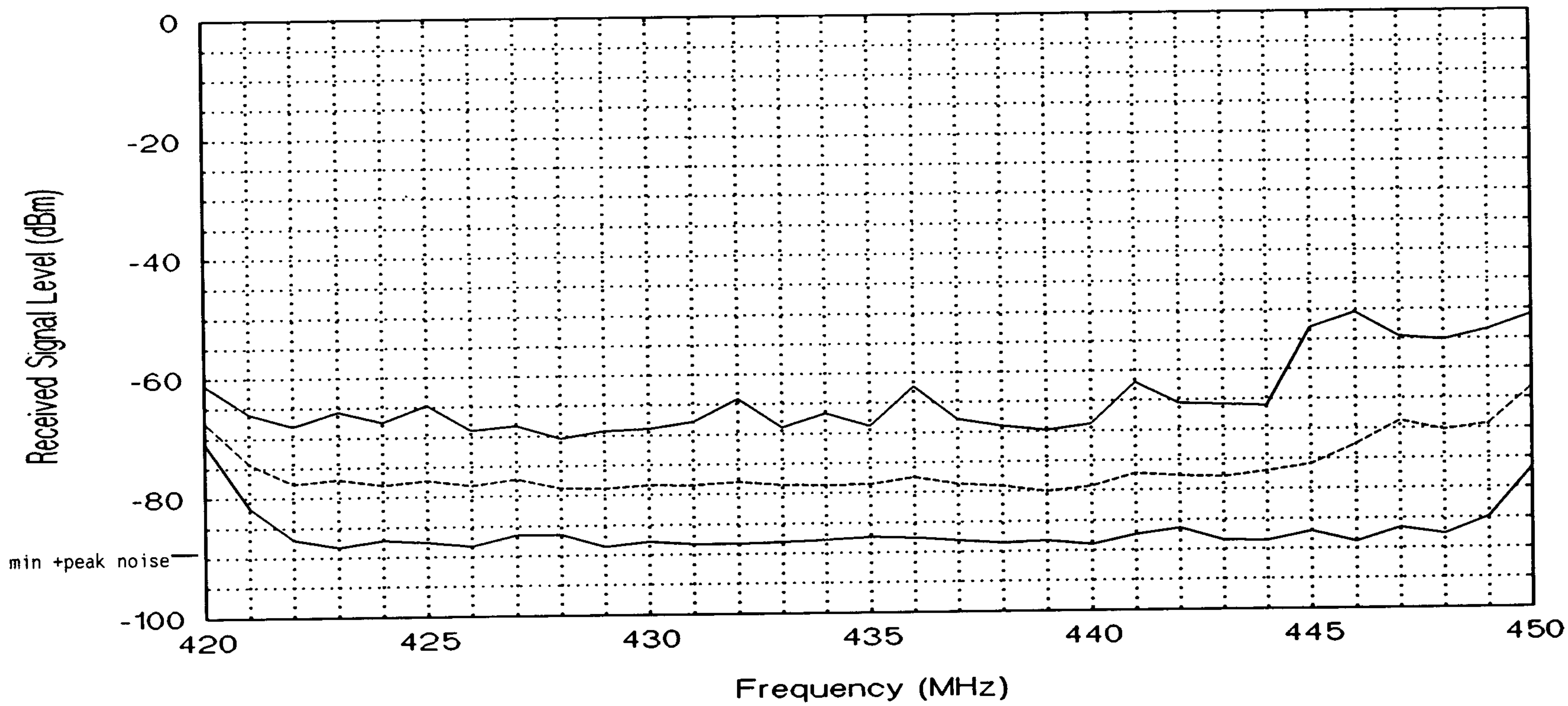
1. **MOBILE-SATELLITE (Earth-to-space). Low power satellite emergency position-indicating radiobeacons (EPIRB) only. Supported by the joint U.S. SARSAT/-Soviet COSPAS satellite network.**

2. **Fixed and mobile services are allocated for Government non-military agencies. Military use may be authorized on a local-coordinated, secondary, non-interfering basis.**

Figure 9. NTIA spectrum survey graph summarizing 14,200 sweeps across the 406-420 MHz range (System-1, band event 17, swept/m3 algorithm, sample detector, 10-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	RADIOLOCATION.
NON-GOVERNMENT ALLOCATIONS:	Amateur.
GENERAL UTILIZATION:	Long-range surveillance radars, 1, 2.

420 450



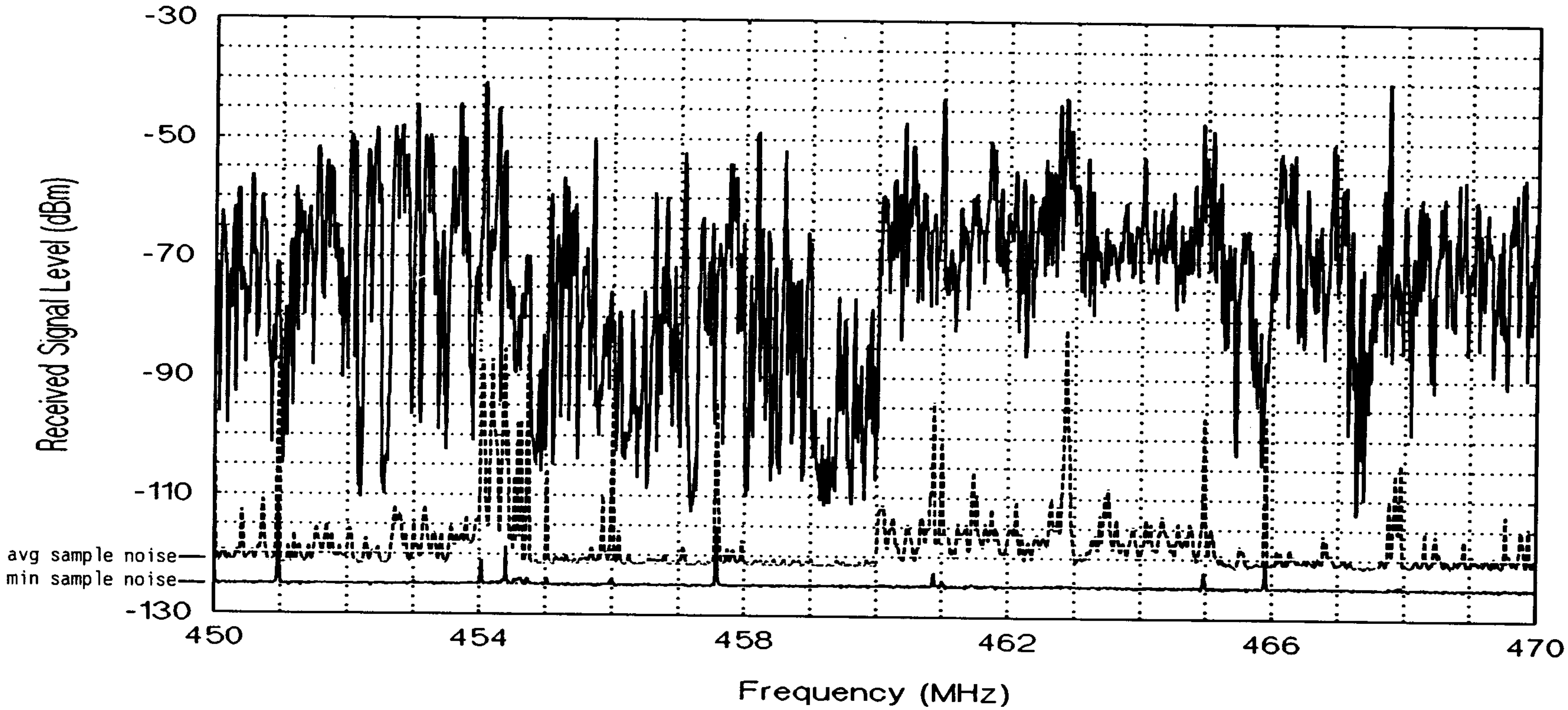
Radiolocation is limited to military services. Primarily, long-range radar systems essential to the nations early warning capability, law enforcement, and tracking objects in space. These systems use very high power and wide bandwidths. Low power radio control operations are permitted in the band. NASA and military use of telemetry and telecommand is also extensive.

2. There is some non-Government use of spread spectrum modes; also, amateur weak signal modes (432-433 MHz), television (420-432 & 438-444 MHz), repeaters (442-450 MHz), auxiliary links (433-435 MHz), and amateur satellite (435-438 MHz).

Figure 10. NTIA spectrum survey graph summarizing 49 scans across the 420-450 MHz range (System-1, band event 18, stepped algorithm, +peak detector, 1000-kHz bandwidth) at Denver, CO, 1993.

	450–455	455–460	460–465	465–470
GOVERNMENT ALLOCATIONS:			Meteorological-Satellite (Space-to-Earth).	
NON-GOVERNMENT ALLOCATIONS:	LAND MOBILE.		LAND MOBILE.	
GENERAL UTILIZATION:	LMR, 1, 2, 3. (base or mobile)	LMR, 1, 2, 3. (mobile only)	LMR, 2, 4, 5. (base or mobile)	LMR, 2, 4, 5. (mobile only)

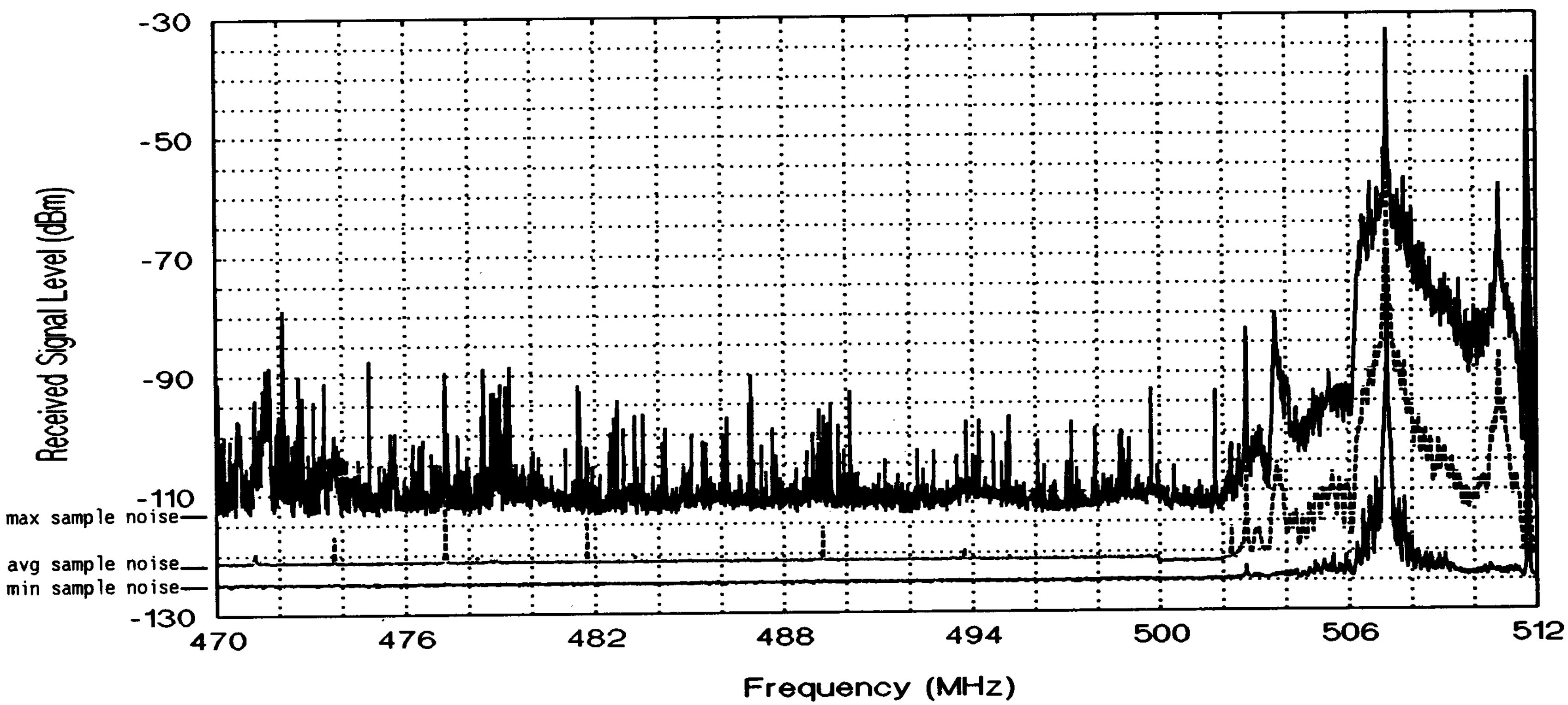
450 455 460 465 470



1. 450-451 MHz, 455-456 MHz: Remote pickup broadcast.
2. 451-454 MHz, 456-459 MHz, 460-462.5375 MHz, 462.7375-467.5375 MHz, 467.7375-470 MHz: Public Safety, Industrial, Land Transportation.
3. 454-455 MHz, 459-460 MHz: Domestic Public.
4. 462.5375-462.7375 MHz, 467.5375-467.7375 MHz: Personal.
5. 460-470 MHz: GOES and TIROS satellite downlinks.

Figure 11. NTIA spectrum survey graph summarizing 13,800 sweeps across the 450-470 MHz range (System-1, band event 19, swept/m3 algorithm, sample detector, 10-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:							
NON-GOVERNMENT ALLOCATIONS:	BROADCASTING, LAND MOBILE, 1, 2.						
GENERAL UTILIZATION:	Channel 14	Channel 15	Channel 16	Channel 17	Channel 18	Channel 19	Channel 20
	470	476	482	488	494	500	506 – 512



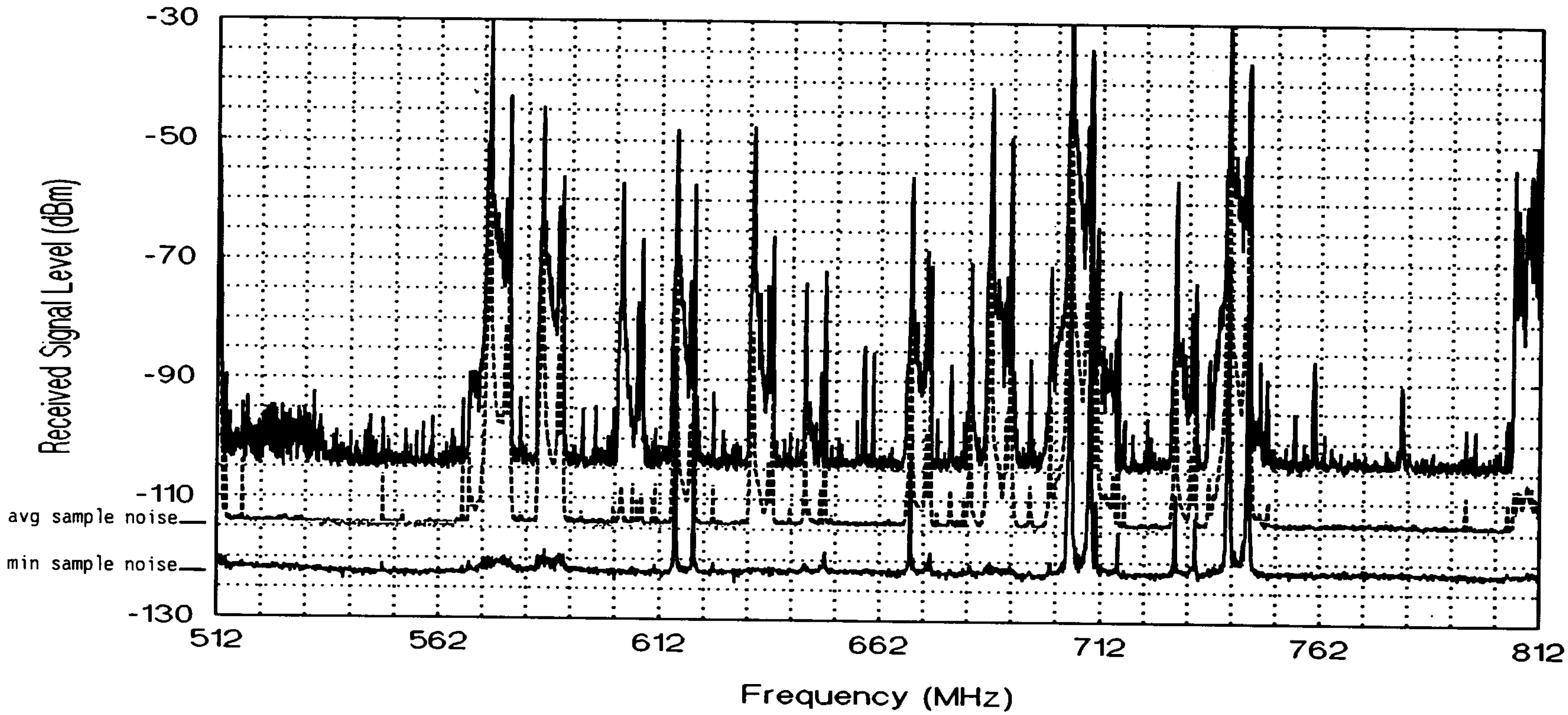
1. Land Mobile Radio Services include Public Safety, Domestic Public, Industrial, and Land Transportation assignments in specific urban areas.

2. The band is also allocated to the fixed service to permit subscription television operations.

Figure 12. NTIA spectrum survey graph summarizing 6,700 sweeps across the 470-512 MHz range (System-1, band event 20, swept/m3 algorithm, sample detector, 10-kHz bandwidth) at Denver, CO, 1993.

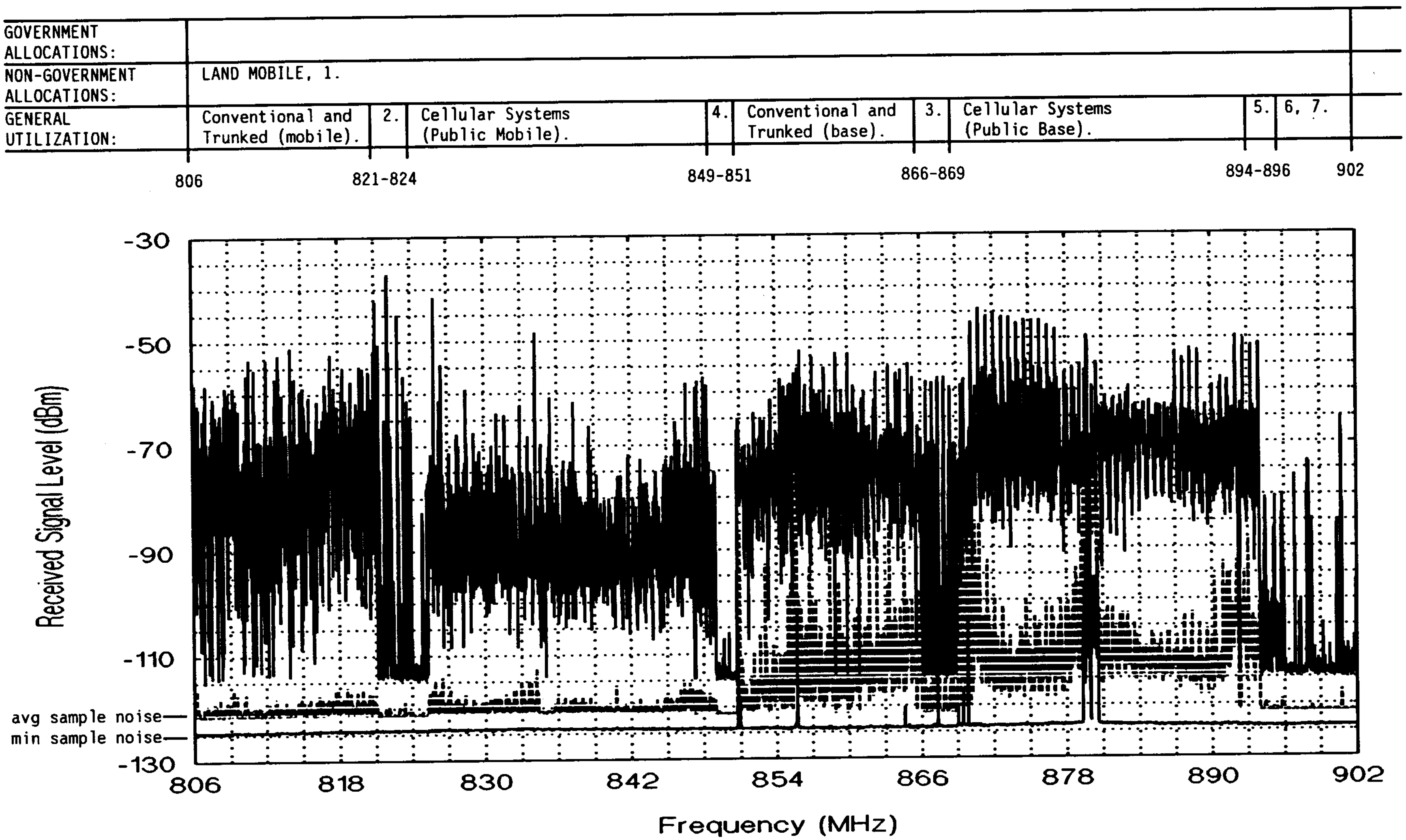
	512–608	608–614	614–806
GOVERNMENT ALLOCATIONS:		1.	
NON-GOVERNMENT ALLOCATIONS:	BROADCASTING.	1.	BROADCASTING.
GENERAL UTILIZATION:	TV Channels 21-36.		TV Channels 38-69.

512 608-614 806



1. RADIO ASTRONOMY. No stations are authorized to transmit in this band.

Figure 13. NTIA spectrum survey graph summarizing 5,600 sweeps across the 512-806 MHz range (System-1, band event 21, swept/m3 algorithm, sample detector, 100-kHz bandwidth) at Denver, CO, 1993.

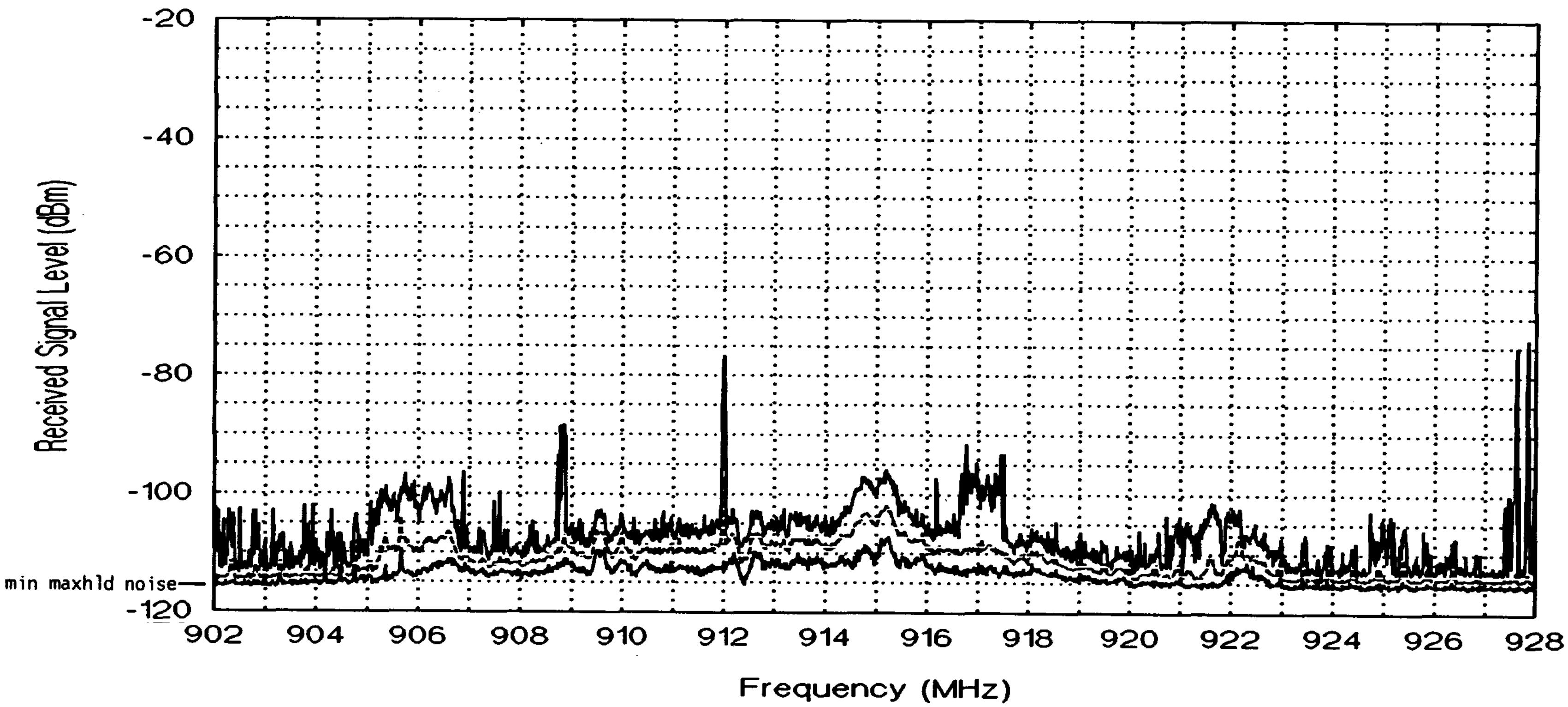


1. 806-890 MHz: Limited allocation is available for TV Channels 70-83.
2. Public Safety (mobile).
3. Public Safety (base).
4. Aeronautical Mobile (ground-to-air).
5. Aeronautical Mobile (air-to-ground).
6. 896-901 MHz: Private Land Mobile (paired with 935-940 MHz).
7. 901-902 MHz: General Mobile.

Figure 14. NTIA spectrum survey graph summarizing 2,880 sweeps across the 806-902 MHz range (System-1, band event 22, swept/m3 algorithm, sample detector, 10-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	RADIOLOCATION.
NON-GOVERNMENT ALLOCATIONS:	
GENERAL UTILIZATION:	Military radiolocation systems, Industrial Scientific and Medical (ISM), Automatic Vehicle Monitoring (AVM), spread spectrum devices, microwave ovens, digital communications, repeaters, 1.

902 928

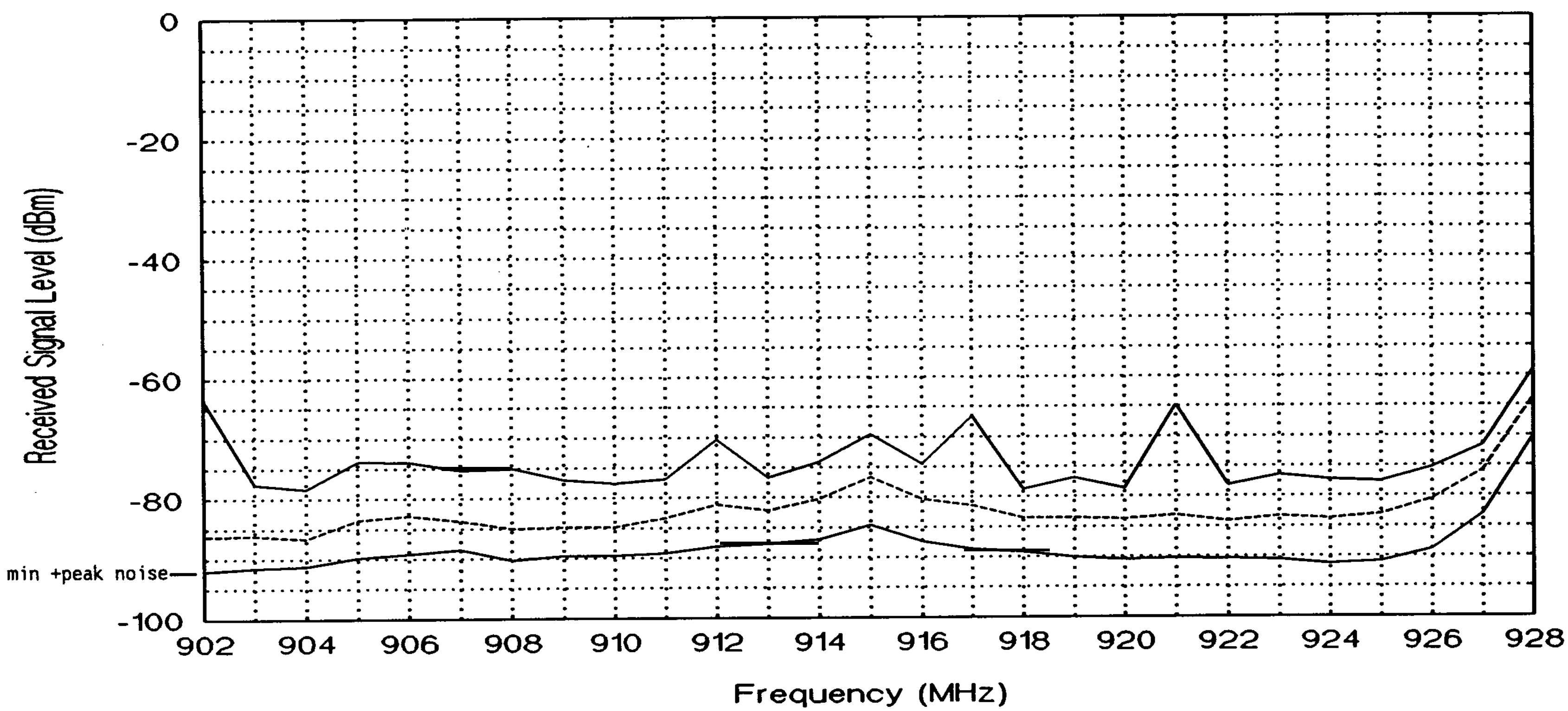


1. Fixed and Mobile radio services are permitted on a secondary basis; however, band utilization is increasing for non-Government ISM, spread spectrum and other modes, amateur, etc., as permitted in Region 2.

Figure 15. NTIA spectrum survey graph summarizing 23,400 sweeps across the 902-928 MHz range (System-1, band event 23, swept algorithm, maximum-hold detector, 10-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	RADIOLOCATION.
NON-GOVERNMENT ALLOCATIONS:	
GENERAL UTILIZATION:	Military radiolocation systems, Industrial Scientific and Medical (ISM), Automatic Vehicle Monitoring (AVM), spread spectrum devices, microwave ovens, digital communications, repeaters, 1.

902 928

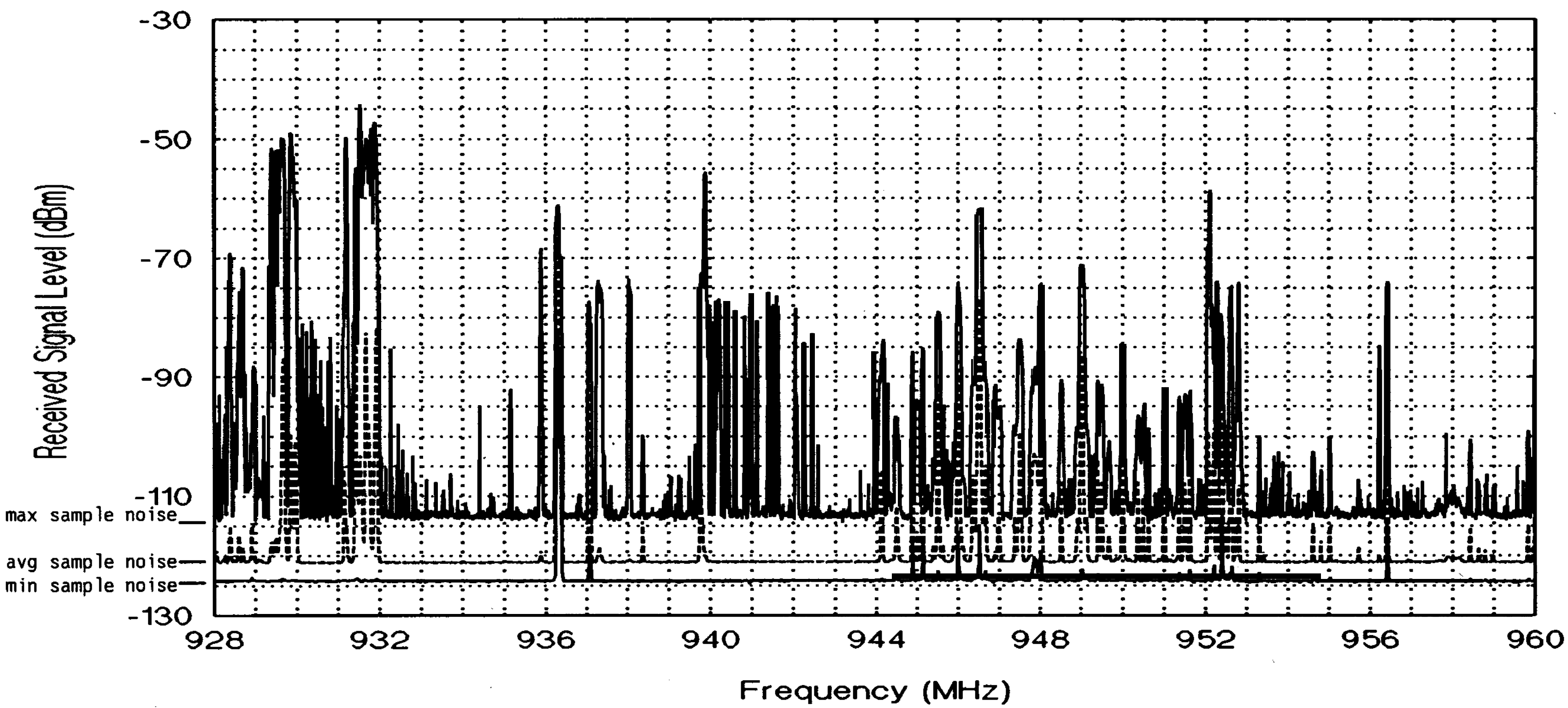


1. Fixed and Mobile radio services are permitted on a secondary basis; however, band utilization is increasing for non-Government ISM, spread spectrum and other modes, amateur, etc., as permitted in Region 2.

Figure 16. NTIA spectrum survey graph summarizing 48 scans across the 902-928 MHz range (System-1, band event 24, stepped algorithm, +peak detector, 1000-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:			FIXED.			FIXED.	
NON-GOVERNMENT ALLOCATIONS:	1.	LAND MOBILE	FIXED.	LAND MOBILE.	5.	FIXED.	FIXED.
GENERAL UTILIZATION:	1.	2.	3.	Private land mobile (base), 4.		3.	Auxiliary broadcasting, private fixed microwave, studio-to-transmitter links (STL's), 6.

928-929 932 935 940-941 944 960

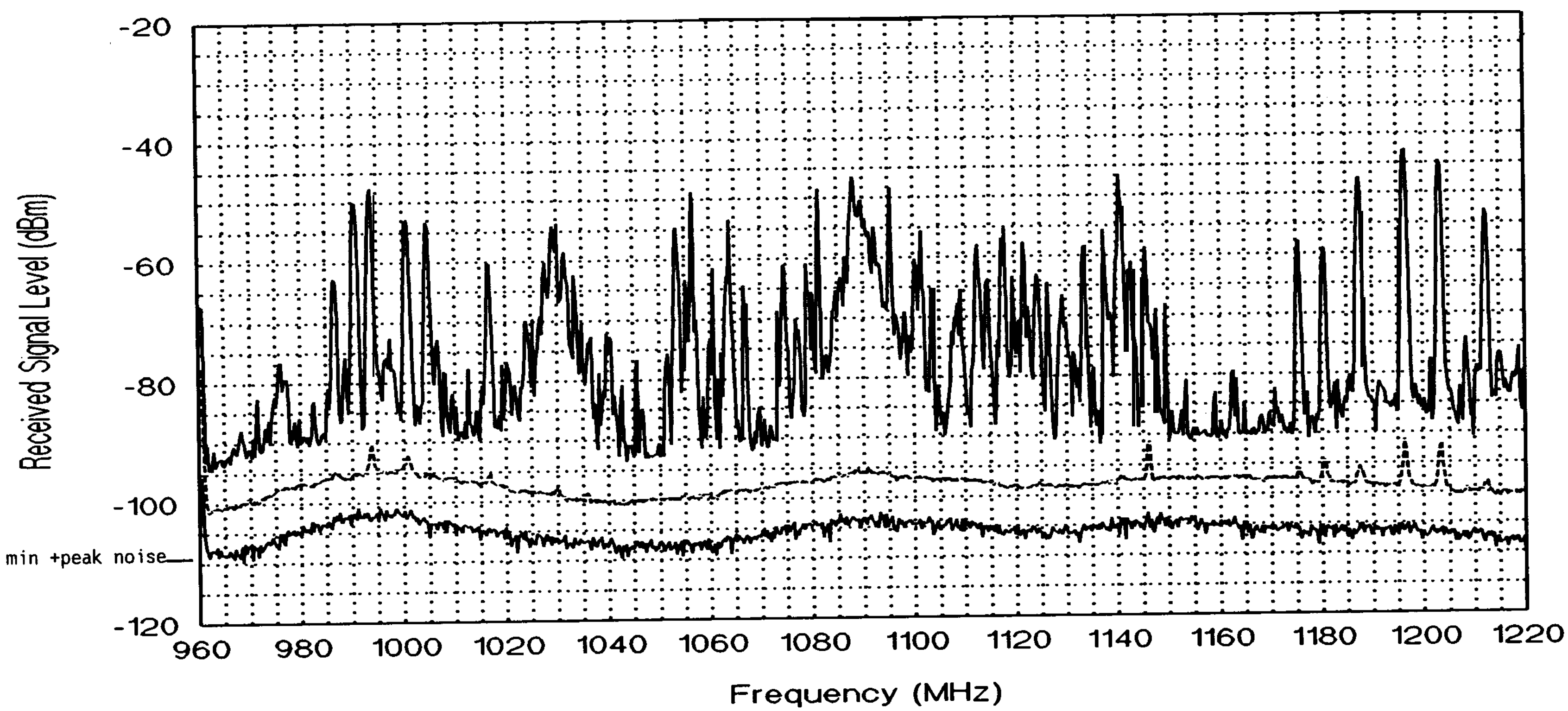


1. **FIXED.** Private fixed microwave, public and private land mobile, telemetry applications. Two-way services paired with 952-953 MHz.
2. Public and private land mobile.
3. Paired band for point-to-point and point-to-multipoint communications.
4. Trunked and conventional systems in 12.5 kHz channels (paired with 896-901 MHz).
5. MOBILE.
6. 944-952 MHz: Primarily STL's. 952-953 MHz paired with 928-929 MHz. 953-960 MHz: Primarily, fixed point-to-point communications.

Figure 17. NTIA spectrum survey graph summarizing 17,400 sweeps across the 928-960 MHz range (System-1, band event 25, swept/m3 algorithm, sample detector, 10-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION, 1.
NON-GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION, 1.
GENERAL UTILIZATION:	TACAN, DME, MLS, ATCRBS, MODE-S, T-CAS, JTIDS, 2.

960 1215

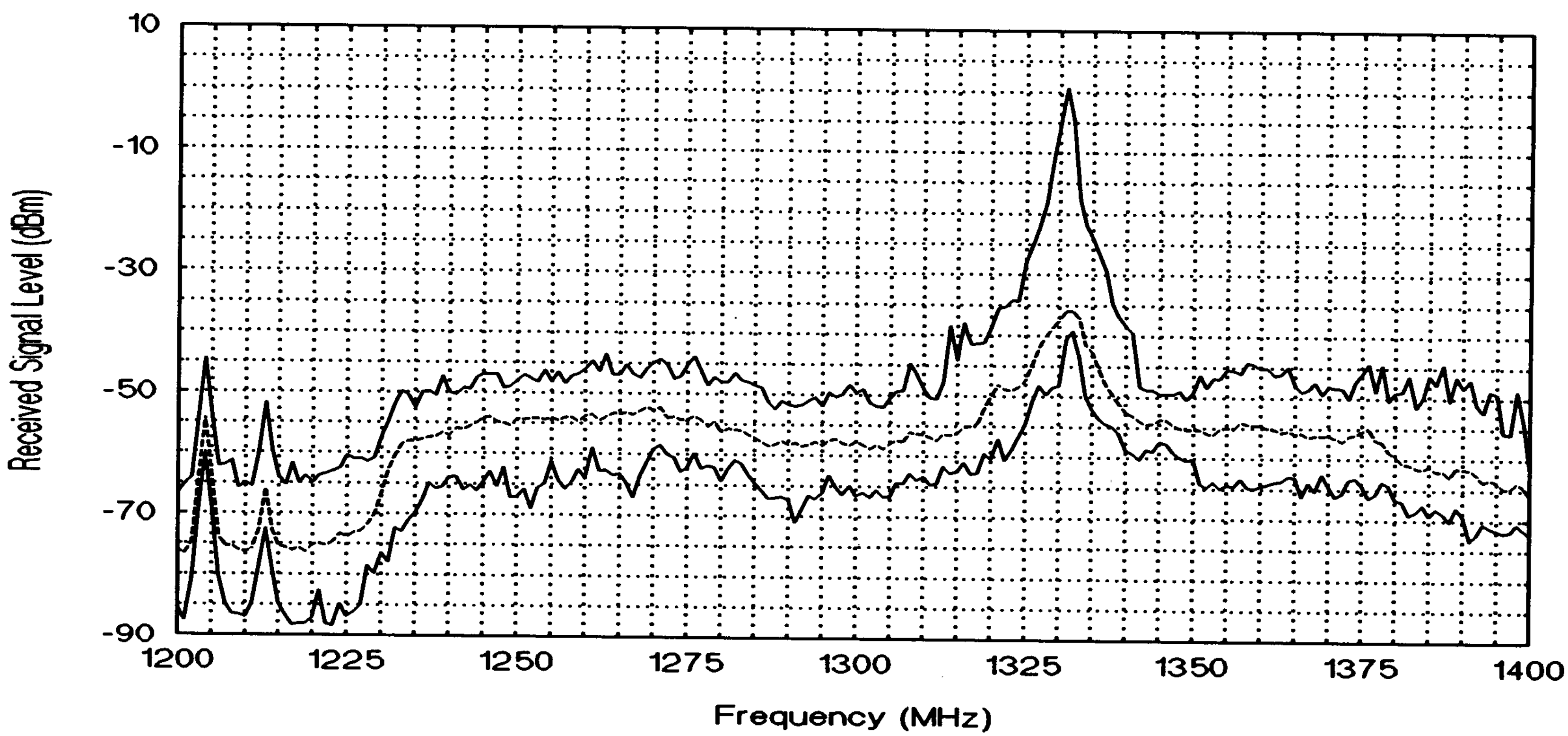


The 960-1215 MHz band is reserved on a worldwide basis for the use and development of electronic aids to air navigation. On a case by case basis, Government systems utilizing spread spectrum techniques for terrestrial communication, navigation and identification may be authorized on condition that aeronautical radionavigation services not experience harmful interference.

2. Tactical Air Navigation (TACAN). Distance Metering Equipment (DME). Microwave Landing System (MLS). Air Traffic Control Radar Beacon system (ATCRBS), (MODE-S, IFF, etc.). Collision Avoidance System (T-CAS). Joint Tactical Information Distribution System (JTIDS).

Figure 18. NTIA spectrum survey graph summarizing 22,000 sweeps across the 960-1215 MHz range (System-2, band event 05, swept/m3 algorithm, +peak detector, 300-kHz bandwidth) at Denver, CO, 1993.

	1215	1240	1300	1350	1400
GOVERNMENT ALLOCATIONS:	RADIOLOCATION, 1.	RADIOLOCATION.	AERONAUTICAL RADIONAVIGATION, Radiolocation.	FIXED, MOBILE, RADIOLOCATION.	
NON-GOVERNMENT ALLOCATIONS:		Amateur.	AERONAUTICAL RADIONAVIGATION.		
GENERAL UTILIZATION:	2, 3, 4.	3, 4, 5.	3, 4.	3, 6, Fixed and Mobile links.	

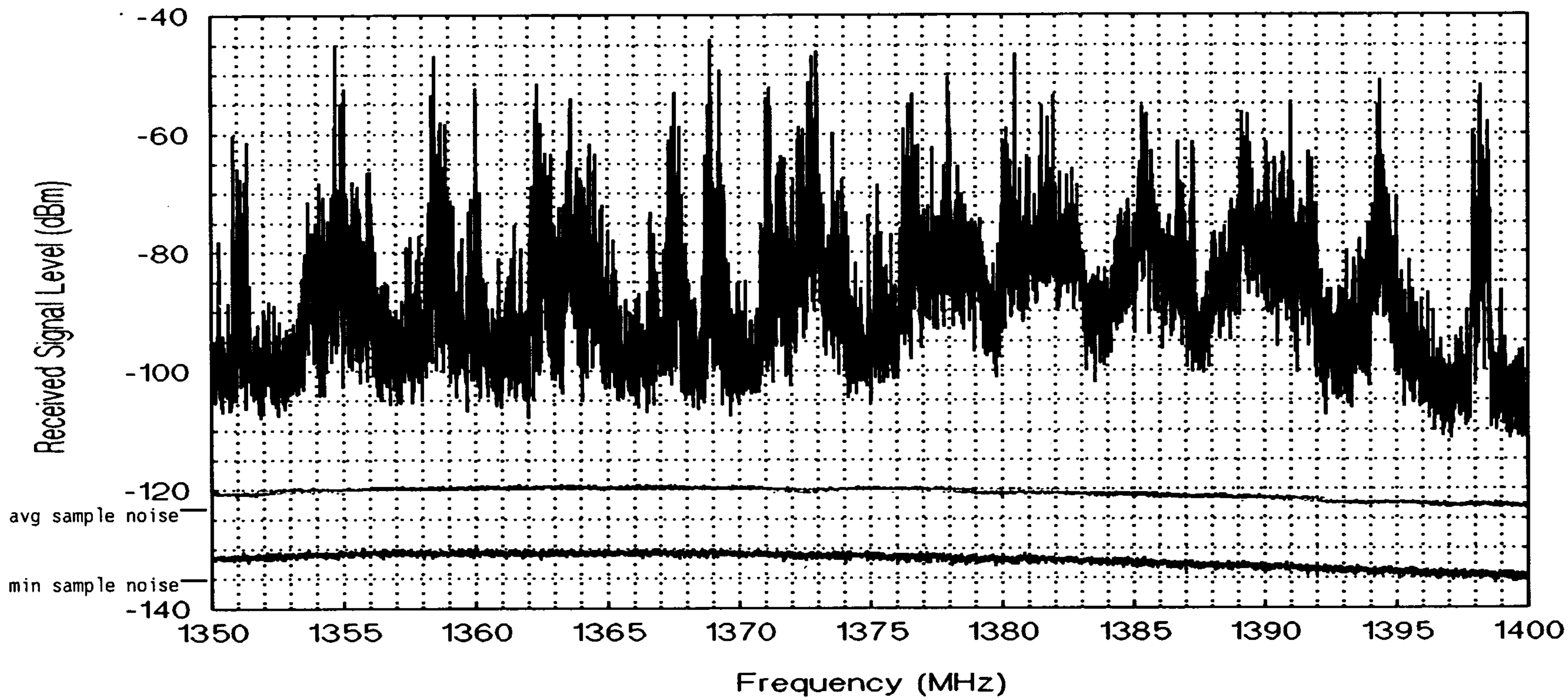


1. RADIONAVIGATION-SATELLITE (space-to-Earth).
2. 1227.6 MHz: Global Positioning System (GPS).
3. High-power long-range surveillance radars including FAA Air-Route Radar (ARSR).
4. Tethered balloon mounted radar for drug interdiction.
5. Amateur television. Amateur weak signal modes and other modes. Amateur satellite (Earth-to-space).
6. 1381.05 MHz: GPS data relay.

Figure 19. NTIA spectrum survey graph summarizing 27 scans across the 1215-1400 MHz range (System-2, band event 06, stepped algorithm, +peak detector, 1000-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	FIXED, MOBILE, RADIOLOCATION, 1.
NON-GOVERNMENT ALLOCATIONS:	1.
GENERAL UTILIZATION:	Military radiolocation, fixed and mobile links, GPS, aeronautical radionavigation, 2, 3.

1350 1400

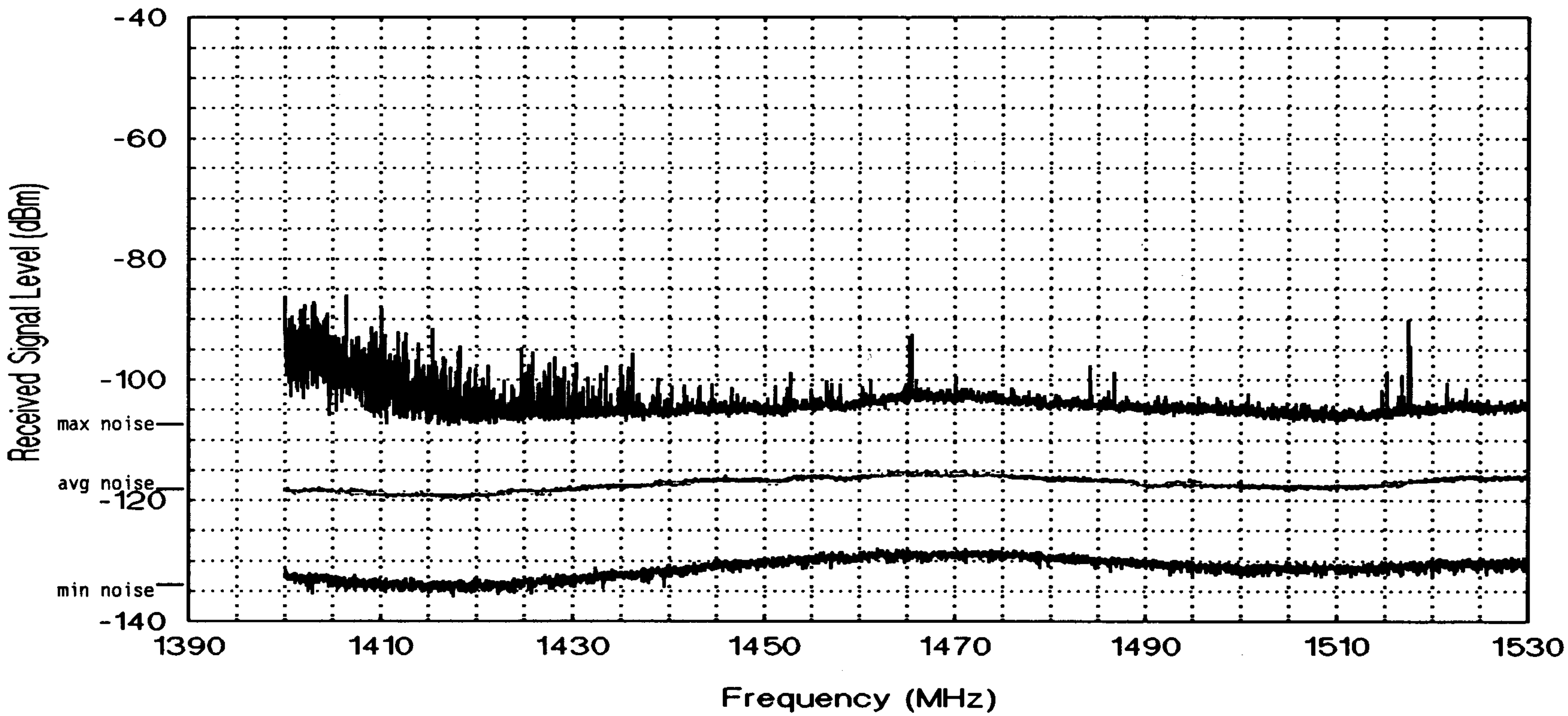


1. 1350-1370 MHz: AERONAUTICAL RADIONAVIGATION (allocation for U.S. and Canada only).
2. Military radiolocation applications are primarily high-power long-range surveillance radars.
3. 1369.05-1393.05 MHz: Fixed and mobile satellite services (space-to-Earth) for the relay of nuclear burst data. GPS operates at 1381.05 MHz to relay data detected by orbiting satellites.

Figure 20. NTIA spectrum survey graph summarizing 5,800 sweeps across the 1350-1400 MHz range (System-2, band event 07, swept/m3 algorithm, sample detector, 10-kHz bandwidth) at Denver, CO, 1993.

	1400–1427	1427–1429	1429–1435	1435–1530
GOVERNMENT ALLOCATIONS:	RADIO ASTRONOMY, 1.	2.	3.	MOBILE.
NON-GOVERNMENT ALLOCATIONS:	RADIO ASTRONOMY, 1.	4.	5.	MOBILE.
GENERAL UTILIZATION:	Passive.			Aeronautical telemetry and telecommand.

1400 1427-1429-1435 1530

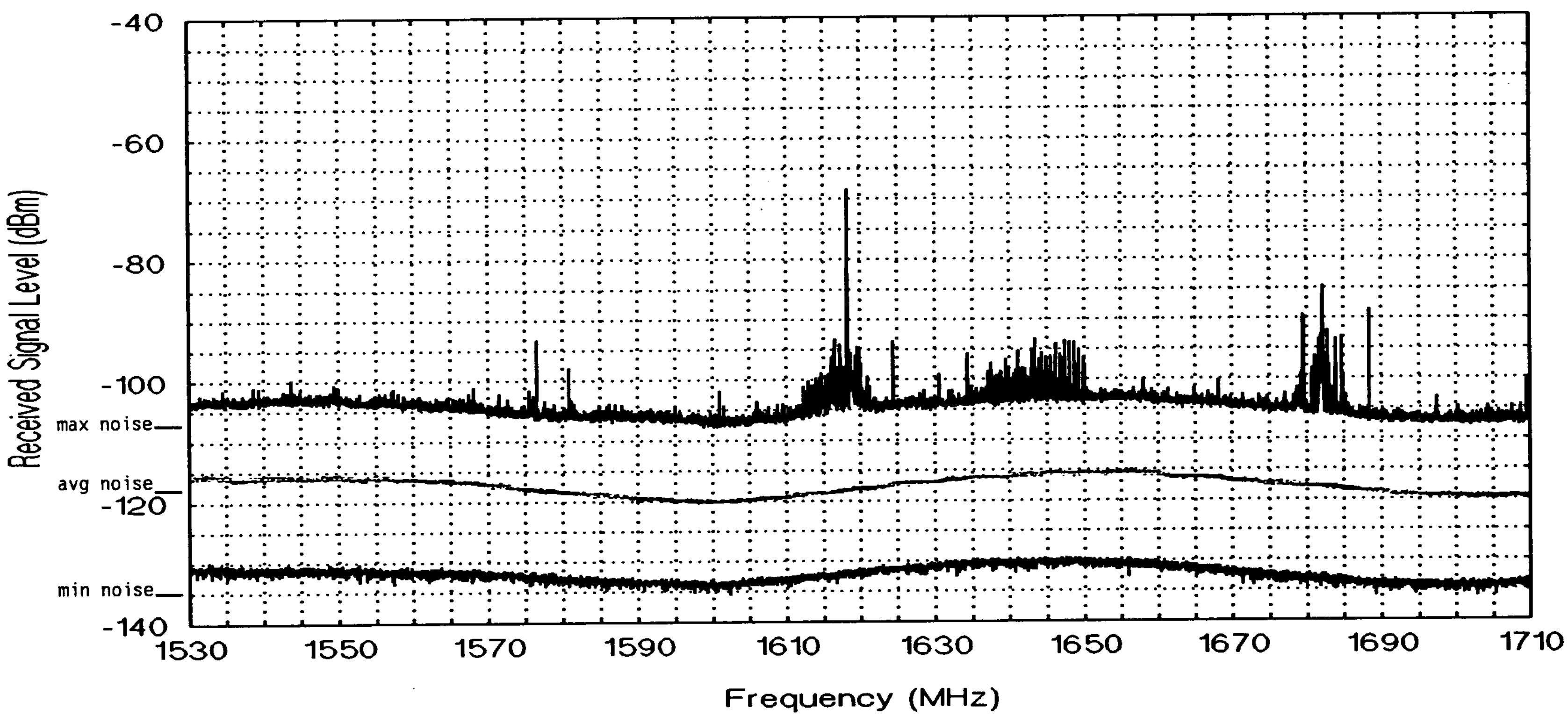


1. EARTH EXPLORATION-SATELLITE (Passive), SPACE RESEARCH (Passive).
2. FIXED, MOBILE (except aeronautical mobile), SPACE OPERATION (Earth-to-space).
3. FIXED, MOBILE.
4. SPACE OPERATION (Earth-to-space), Land Mobile (Telemetering and telecommand), Fixed (Telemetering).
5 Land Mobile (Telemetering and telecommand), Fixed (telemetering).

Figure 21. NTIA spectrum survey graph summarizing 11,600 sweeps across the 1400-1530 MHz range (System-2, band event 08, swept/m3 algorithm, sample detector, 30-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	1.	2.	AERONAUTICAL RADIONAVIGATION, RADIONAVIGATION-SATELLITE (space-to-Earth).	3.	4.	METEOROLOGICAL AIDS, 5.	FIXED, 6.
NON-GOVERNMENT ALLOCATIONS:	1.	2.	AERONAUTICAL RADIONAVIGATION, RADIONAVIGATION-SATELLITE (space-to-Earth).	3.	4.	METEOROLOGICAL AIDS, 5.	6, fixed.
GENERAL UTILIZATION:	INMARSAT.	AMS(R)S.	GPS, GLONASS, (1610-1626.5 MHz Airborne aids to air navigation, only).	INMARSAT.	AMS(R)S.	Radiosondes and satellite imagery.	7.

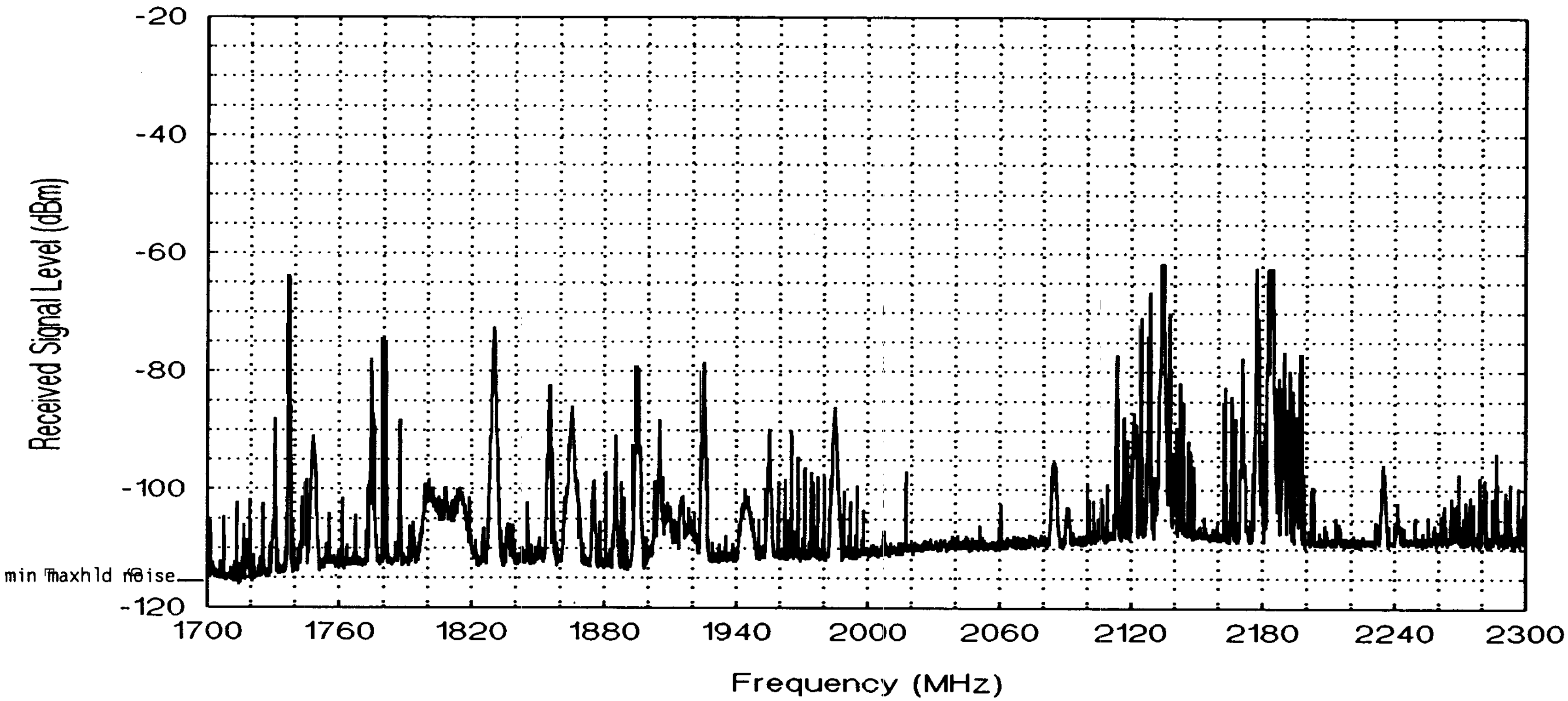
1530 1545 1559 1626.5 1646.5 1668.4 1700 1710



1. MARITIME MOBILE-SATELLITE (space-to-Earth), Mobile (1530-1535 MHz, Aeronautical telemetering), MOBILE-SATELLITE (1544-1545 MHz, space-to-Earth, distress and safety only, SARSAT).
2. AERONAUTICAL MOBILE-SATELLITE (R) (space-to-Earth), MOBILE-SATELLITE (space-to-Earth), Mobile-Satellite (space-to-Earth).
3. MARITIME MOBILE-SATELLITE (Earth-to-space), MOBILE-SATELLITE (1645.5-1646.5 MHz, Earth-to-space, distress and safety only).
4. AERONAUTICAL MOBILE-SATELLITE (R) (Earth-to-space), MOBILE-SATELLITE (Earth-to-space), RADIO ASTRONOMY, Mobile-Satellite (Earth-to-space), 1660-1668.4 MHz: RADIO ASTRONOMY, SPACE RESEARCH (passive).
5. RADIO ASTRONOMY, METEOROLOGICAL-SATELLITE (space-to-Earth).
6. METEOROLOGICAL-SATELLITE (space-to-Earth).
7. GOES, TIROS-N.

Figure 22. NTIA spectrum survey graph summarizing 42,500 sweeps across the 1530-1710 MHz range (System-2, band event 09, swept/m3 algorithm, sample detector, 30-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	FIXED, MOBILE.				FIXED, MOBILE, SPACE RESEARCH.	5
NON-GOVERNMENT ALLOCATIONS:		FIXED.	FIXED, MOBILE.	FIXED.		6
GENERAL UTILIZATION:	LOS fixed links, 1, telemetry, telecommand.	Private fixed microwave.	Auxiliary broadcasting, Cable TV, TDRSS, 2.	Control links, Cellular, 3.	TDRSS, SGLS, 4.	7
	1710	1850	1990	2110	2200	2290-2300

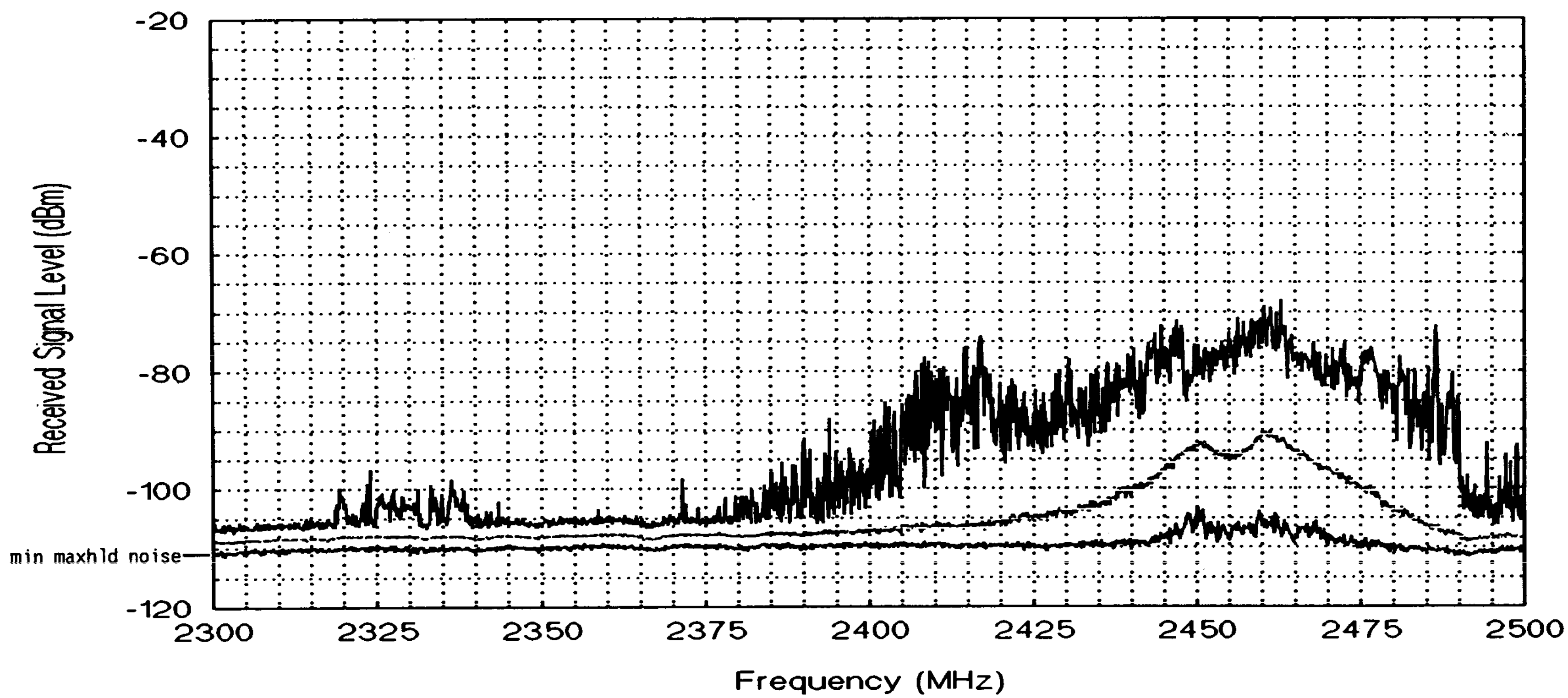


1. Predominantly federal medium-capacity LOS fixed service band.
2. GOES uplink. NASA's global ground network and TDRSS (2025-2110 MHz).
3. Paired fixed links (2110-2130 MHz and 2160-2180 MHz; 2130-2150 MHz and 2180-2200 MHz). Point-to-point and multipoint links (2150-2160 MHz). NASA space and Earth to space command links (2110-2120 MHz).
4. Space telemetry, telecommand and control systems. Fixed microwave.
5. FIXED, MOBILE (except aeronautical mobile), SPACE RESEARCH (space-to-Earth and Deep Space only).
6. SPACE RESEARCH (space-to-Earth and Deep Space only).
7. NASA deep space network space-to-Earth telemetry.

Figure 23. NTIA spectrum survey azimuth-scan graph of the 1710-2300 MHz range (System-2, band event 10, swept algorithm, maximum-hold detector, 100-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	1.	RADIOLOCATION, MOBILE, Fixed.	RADIOLOCATION, 5.		
NON-GOVERNMENT ALLOCATIONS:	2.	MOBILE.	Amateur, 5.		FIXED, MOBILE, Radiolocation, 5, 7.
GENERAL UTILIZATION:	3.	Telemetry, telemetry communications, aeronautical telemetry, 4.	6.	ISM, 6.	ISM, 8.

2300 2310 2390 2400 2450 2500

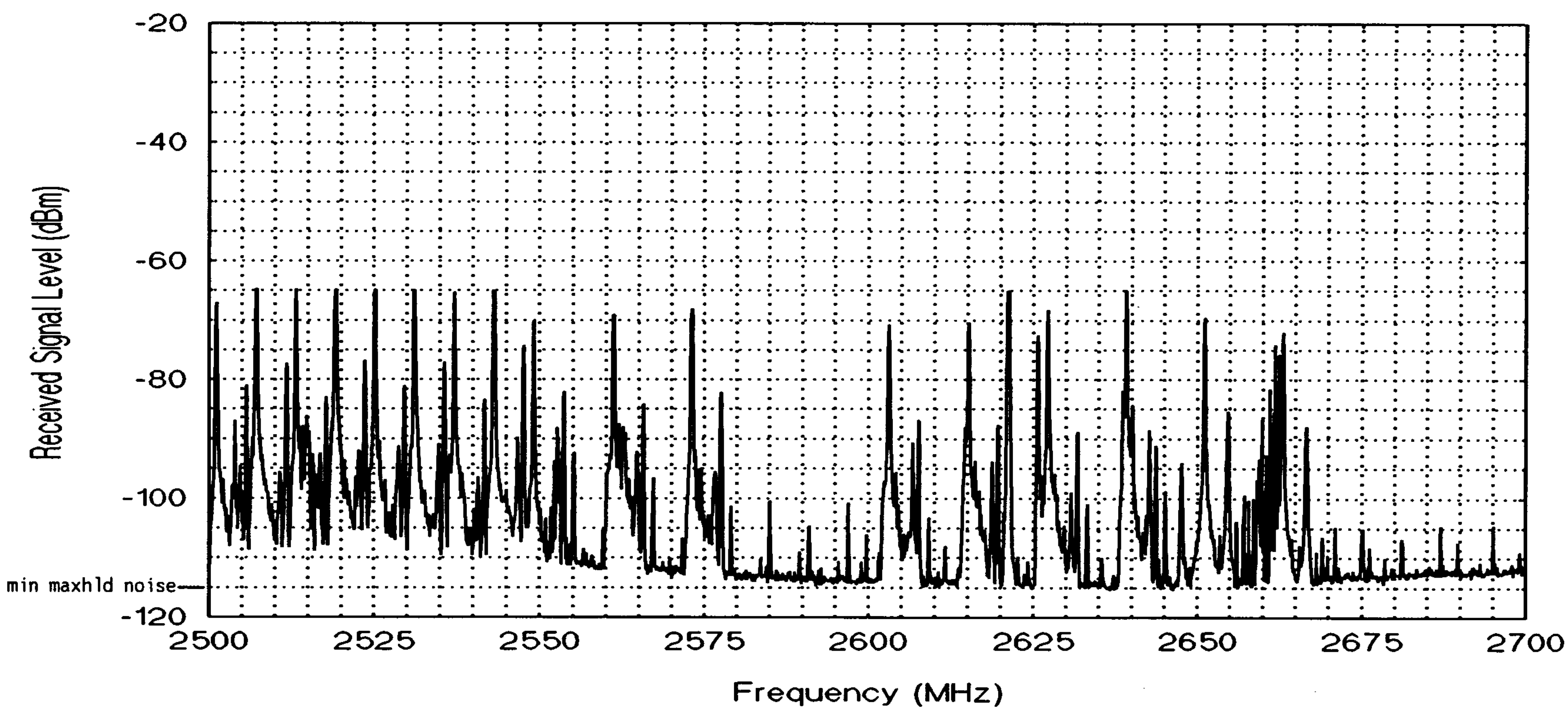


1. RADIOLOCATION, Fixed, Mobile.
2. Amateur.
3. Amateur weak signal modes and other modes.
4. AF High-power long-range surveillance radar and air traffic control radar. Venus Radar Mapper (VRM) synthetic aperture radar.
5. 2400-2500 MHz: Is designated for industrial scientific and medical (ISM) applications including microwave ovens.
6. Amateur mixed modes. Amateur satellite (space-to-Earth).
7. 2483.5-2500 MHz: RADIODETERMINATION-SATELLITE (space-to-Earth).
8. Fixed and portable video tranmission by TV broadcasters.

Figure 24. NTIA spectrum survey graph summarizing 34,800 sweeps across the 2300-2500 MHz range (System-2, band event 11, swept algorithm, maximum-hold detector, 100-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:		3.	4.	
NON-GOVERNMENT ALLOCATIONS:	BROADCASTING-SATELLITE, FIXED, 1.	BROADCASTING-SAT., FIXED, 1, 3.	4.	
GENERAL UTILIZATION:	Auxiliary broadcasting, pay television distribution, private video teleconferences, educational television (ITSF), 2.	Private fixed microwave, 2.		

2500 2655 2690 2700

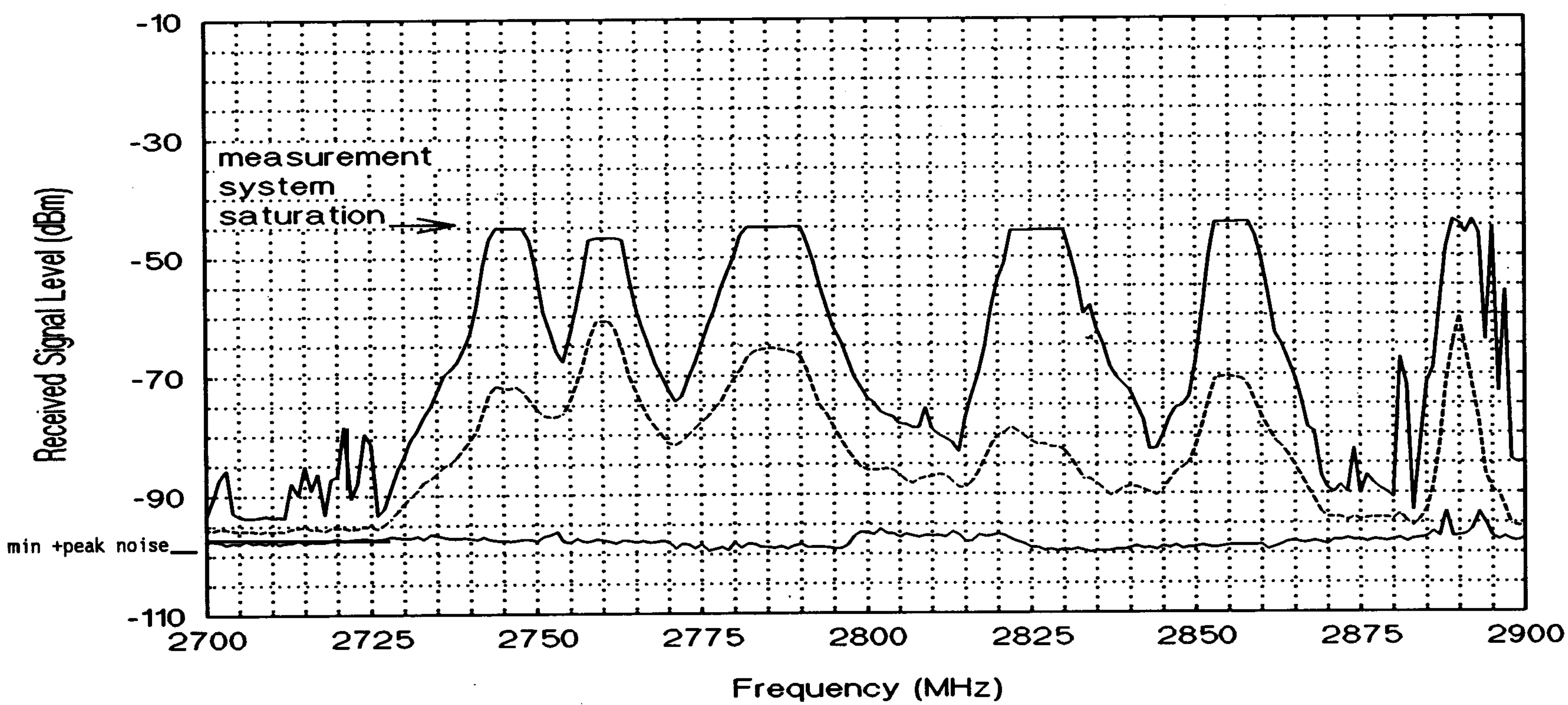


1. Broadcasting-satellite service is limited to community reception of educational and public service television programming.
2. 2500-2686 MHz: Omni transmission of Multipoint MDS that can be contained within 6 MHz channel bandwidths.
3. Earth Exploration-Satellite (Passive), Radio Astronomy, Space Research (Passive).
4. EARTH EXPLORATION-SATELLITE (Passive), RADIO ASTRONOMY, SPACE RESEARCH (Passive).

Figure 25. NTIA spectrum survey azimuth-scan graph of the 2500-2700 MHz range (System-2, band event 12, swept algorithm, maximum-hold detector, 10-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION, METEOROLOGICAL AIDS, Radiolocation, 1, 2.
NON-GOVERNMENT ALLOCATIONS:	
GENERAL UTILIZATION:	Airport Surveillance Radars (ASRs), military Ground Control Approach radars (GCAs), NWS weather radars (NEXRAD, etc.), Long-range surveillance radars and air traffic control radars.

2700 2900



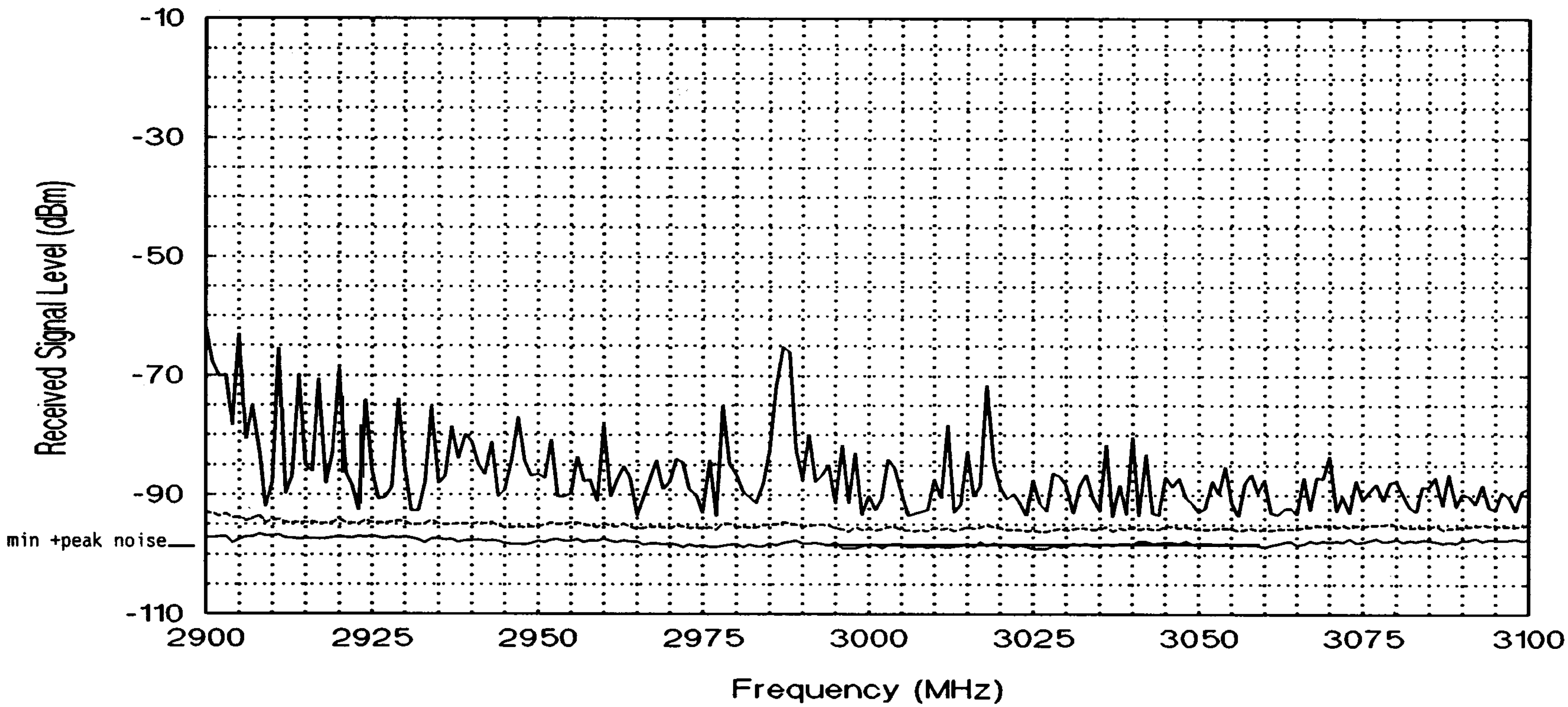
1. The aeronautical radionavigation service is restricted to ground-based radars and associated airborne transponders that transmit only in this band when actuated by these radars.

2. The secondary radiolocation service is limited to the military and must be fully coordinated with the primary services.

Figure 26. NTIA spectrum survey graph summarizing 31 scans across the 2700-2900 MHz range (System-2, band event 13, stepped algorithm, +peak detector, 1000-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	MARITIME RADIONAVIGATION, Radiolocation, 1, 2.
NON-GOVERNMENT ALLOCATIONS:	MARITIME RADIONAVIGATION, Radiolocation, 1, 2.
GENERAL UTILIZATION:	Maritime radars and radar beacons (racons), military high-power 3-D long-range surveillance radars and air traffic control radars.

2900 3100

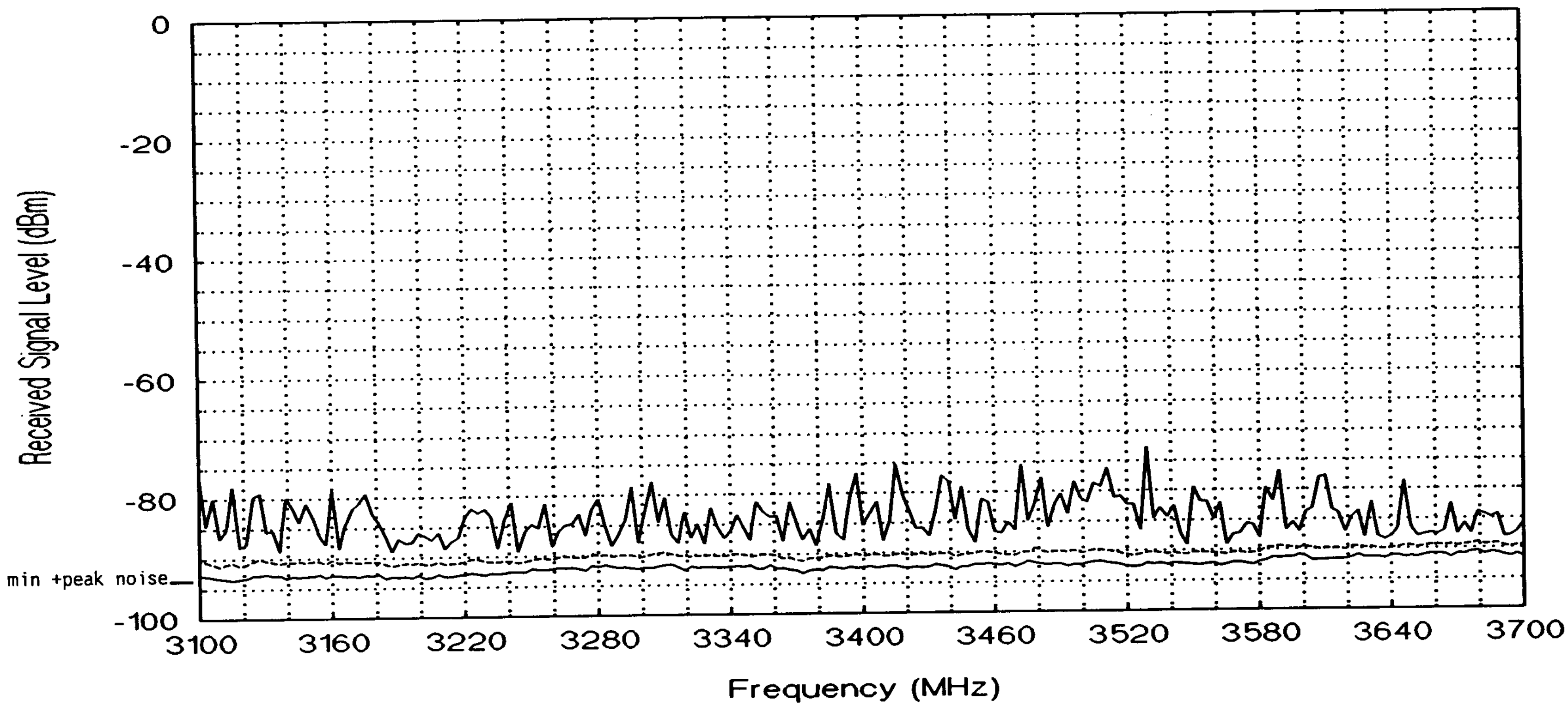


1. Radiolocation assignments are primarily for the military; however, other agency use is permitted for experimentation, research, and survey operations, if no harmful interference occurs.

2. 2900-3000 MHz: Also, allocated for next generation weather radar (NEXRAD) systems.

Figure 27. NTIA spectrum survey graph summarizing 57 scans across the 2900-3100 MHz range (System-2, band event 14, stepped algorithm, +peak detector, 1000-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	RADIOLOCATION.	RADIOLOCATION.	RADIOLOCATION, 1.	RADIOLOCATION, 1.
NON-GOVERNMENT ALLOCATIONS:	Radiolocation.	Amateur, Radiolocation.	Radiolocation.	FIXED-SATELLITE (space-to-Earth), 2.
GENERAL UTILIZATION:	3.	3.	3.	INMARSAT, INTELSAT.
	3100	3300	3500	3600–3700



1. AERONAUTICAL RADIONAVIGATION (Ground-based).
2. Radiolocation.
3. Primarily, military airborne, land-based, and shipborne defense radars.

Figure 28. NTIA spectrum survey graph summarizing 57 scans across the 3100-3700 MHz range (System-2, band event 15, stepped algorithm, +peak detector, 3000-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	
NON-GOVERNMENT ALLOCATIONS:	FIXED, FIXED-SATELLITE (space-to-Earth).
GENERAL UTILIZATION:	Common carrier microwave radio-relay and television receive only (TVRO) Earth stations.

3700 4200

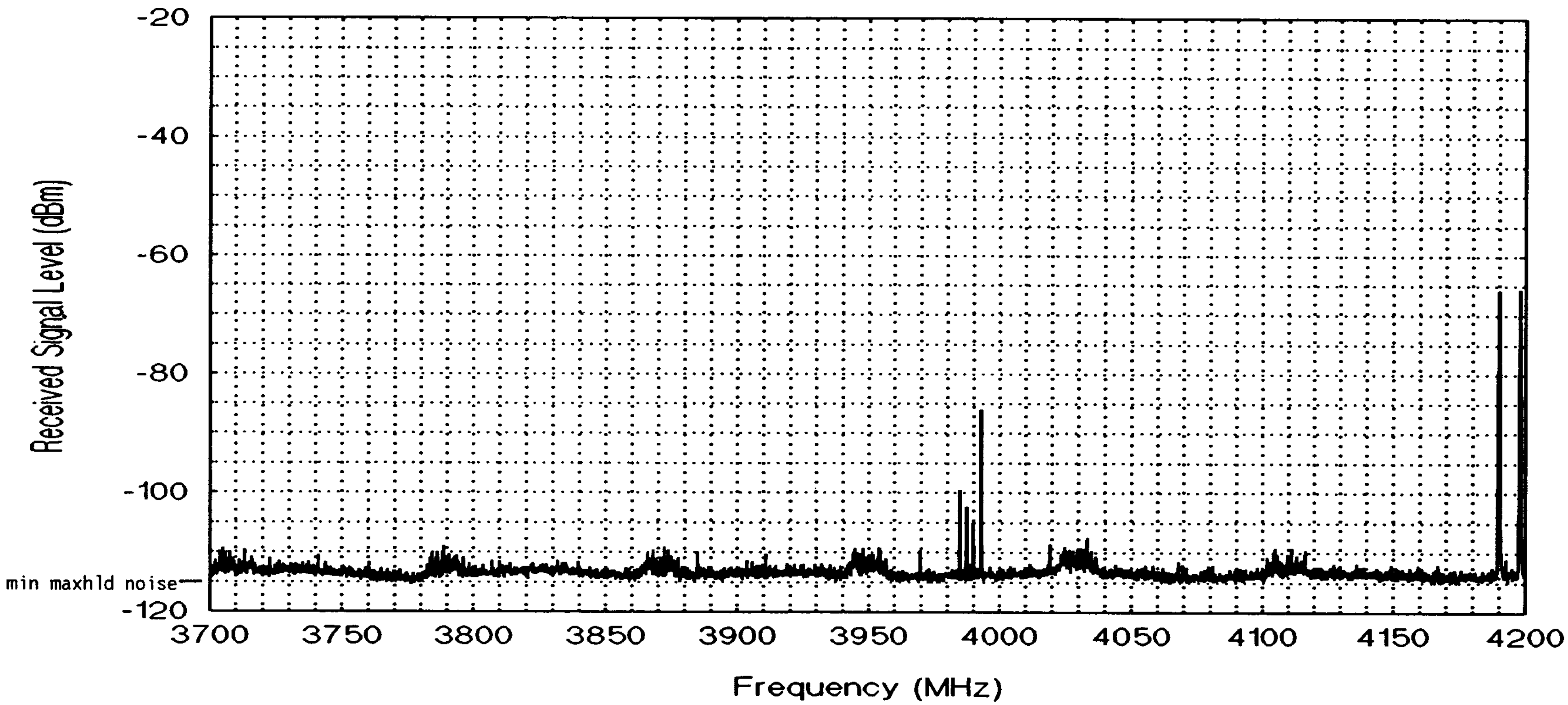
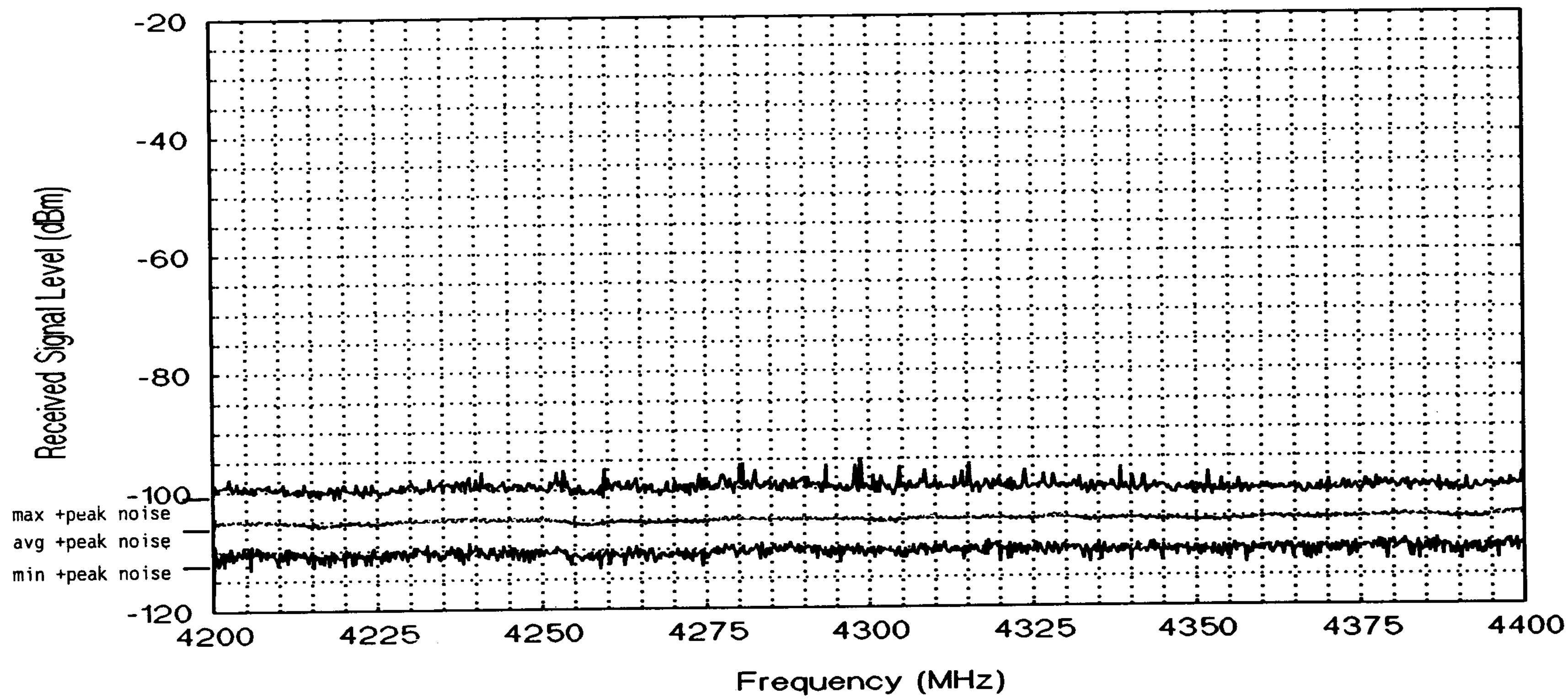


Figure 29. NTIA spectrum survey azimuth-scan graph of the 3700-4200 MHz range (System-2, band event 16, swept algorithm, maximum-hold detector, 100-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION, 1.
NON-GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION, 1.
GENERAL UTILIZATION:	Airborne radio altimeters.

4200 4400

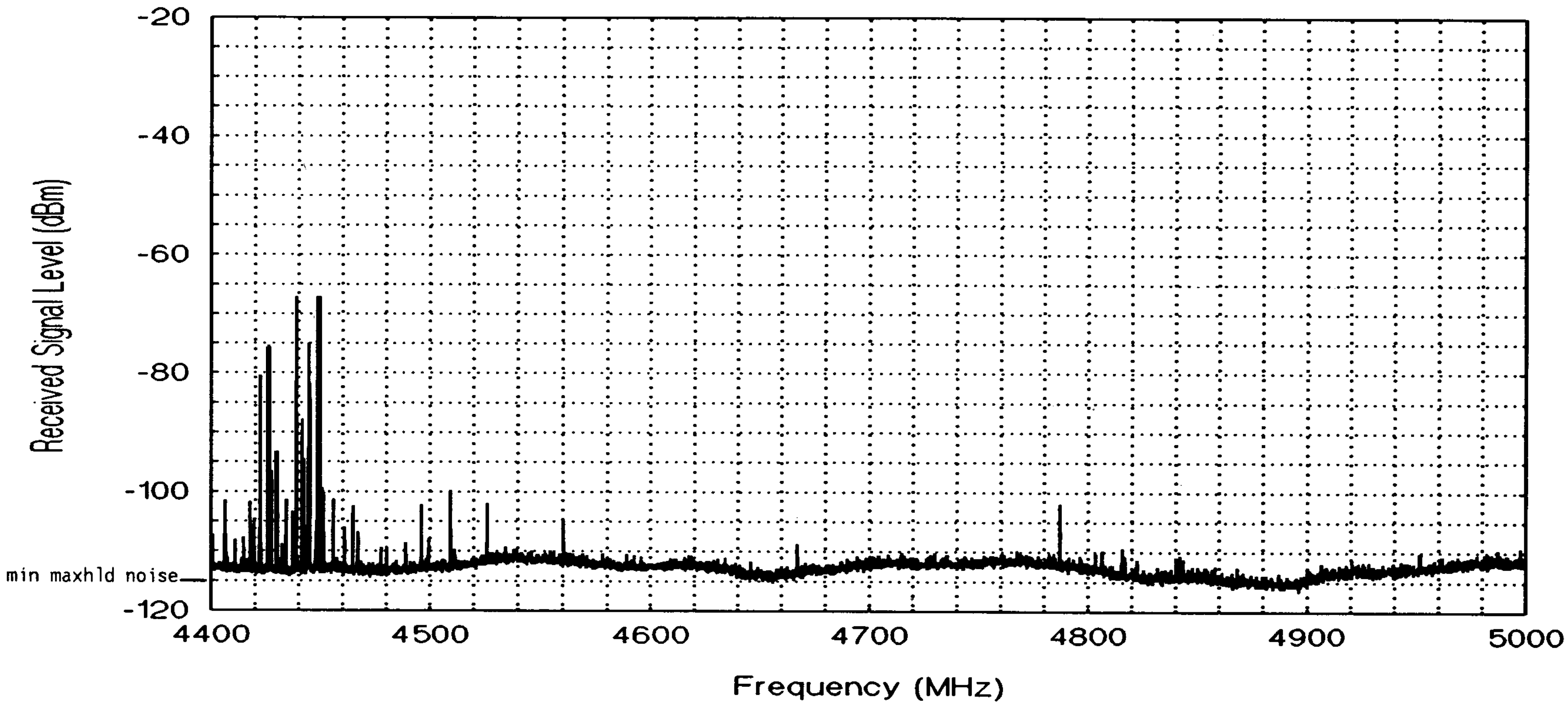


1. 4202 ±12 MHz: Standard frequency and time satellite service (space-to-Earth), permitted.

Figure 30. NTIA spectrum survey graph summarizing 32,500 sweeps across the 4200-4400 MHz range (System-2, band event 17, swept/m3 algorithm, +peak detector, 300-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	FIXED, MOBILE.		1.
NON-GOVERNMENT ALLOCATIONS:		FIXED-SATELLITE (space-to-Earth). 4500-4800 MHz.	1.
GENERAL UTILIZATION:	Military tactical communications, both line-of-sight and troposcatter.		

4400 — 4990-5000

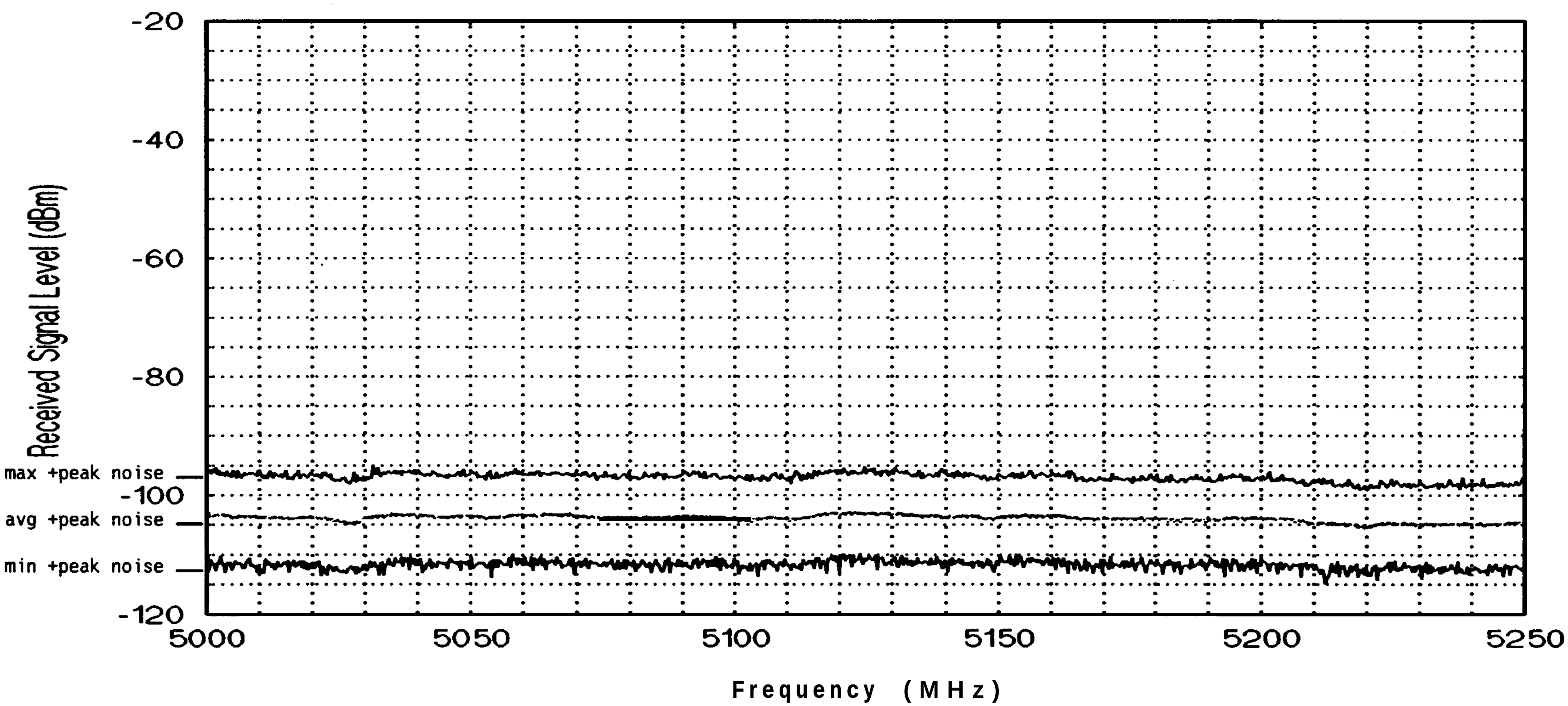


1. RADIO ASTRONOMY, Space Research (Passive).

Figure 31. NTIA spectrum survey azimuth-scan graph of the 4400-5000 MHz range (System-2, band event 18, swept algorithm, maximum-hold detector, 100-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION, AERONAUTICAL MOBILE-SATELLITE , 1.
NON-GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION . AERONAUTICAL MOBILE-SATELLITE. 1.
GENERAL UTILIZATION:	Microwave landing systems.

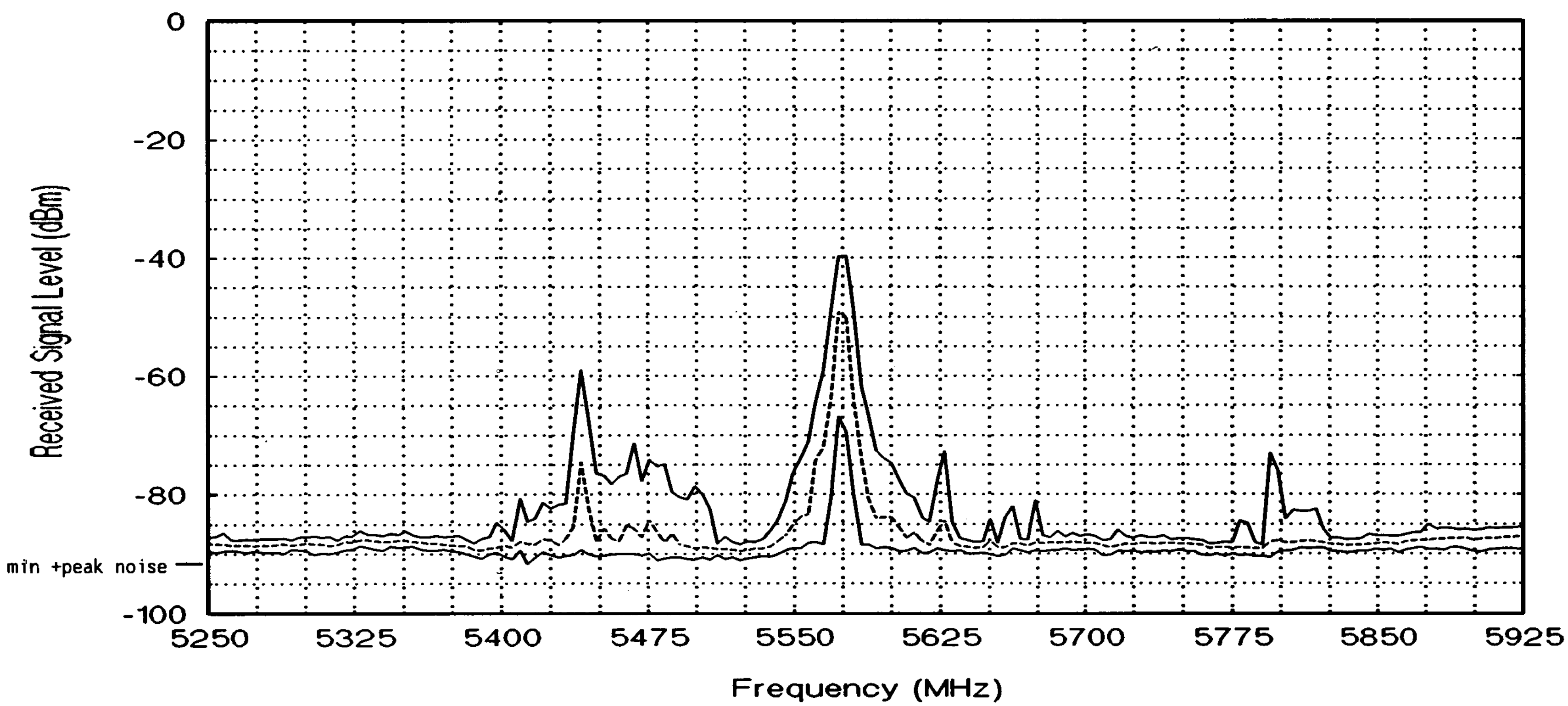
5000 5250



1. Also, 5150-5216 MHz: Fixed-Satellite service (space-to-Earth).

Figure 32. NTIA spectrum survey graph summarizing 42,000 sweeps across the 5000-5250 MHz range (System-2, band event 19, swept/m3 algorithm, + peak detector, 300-kHz bandwidth) at Denver, CO, 1993.

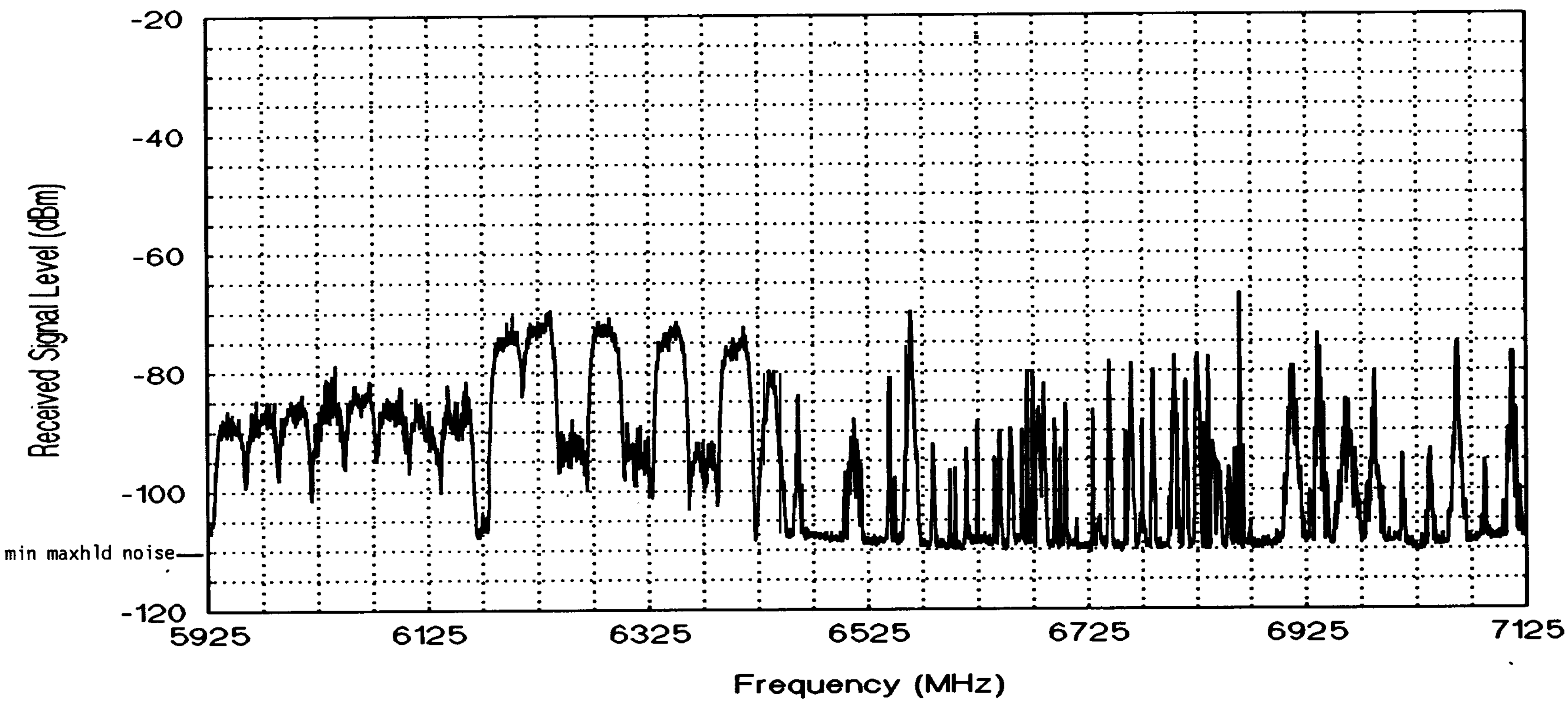
GOVERNMENT ALLOCATIONS:	RADIOLOCATION.	AERONAUTICAL RADIONAVIGATION, 1.	3	MARITIME RADIONAVIGATION, Radiolocation.	4.	RADIOLOCATION.	
NON-GOVERNMENT ALLOCATIONS:	Radiolocation.	AERONAUTICAL RADIONAVIGATION, 2.	3	MARITIME RADIONAVIGATION, Radiolocation.	4.	Amateur.	6.
GENERAL UTILIZATION:				Weather radars.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

Figure 33. NTIA spectrum survey graph summarizing 26 scans across the 5250-5925 MHz range (System-2, band event 20, stepped algorithm, +peak detector, 3000-kHz bandwidth) at Denver, CO, 1993.

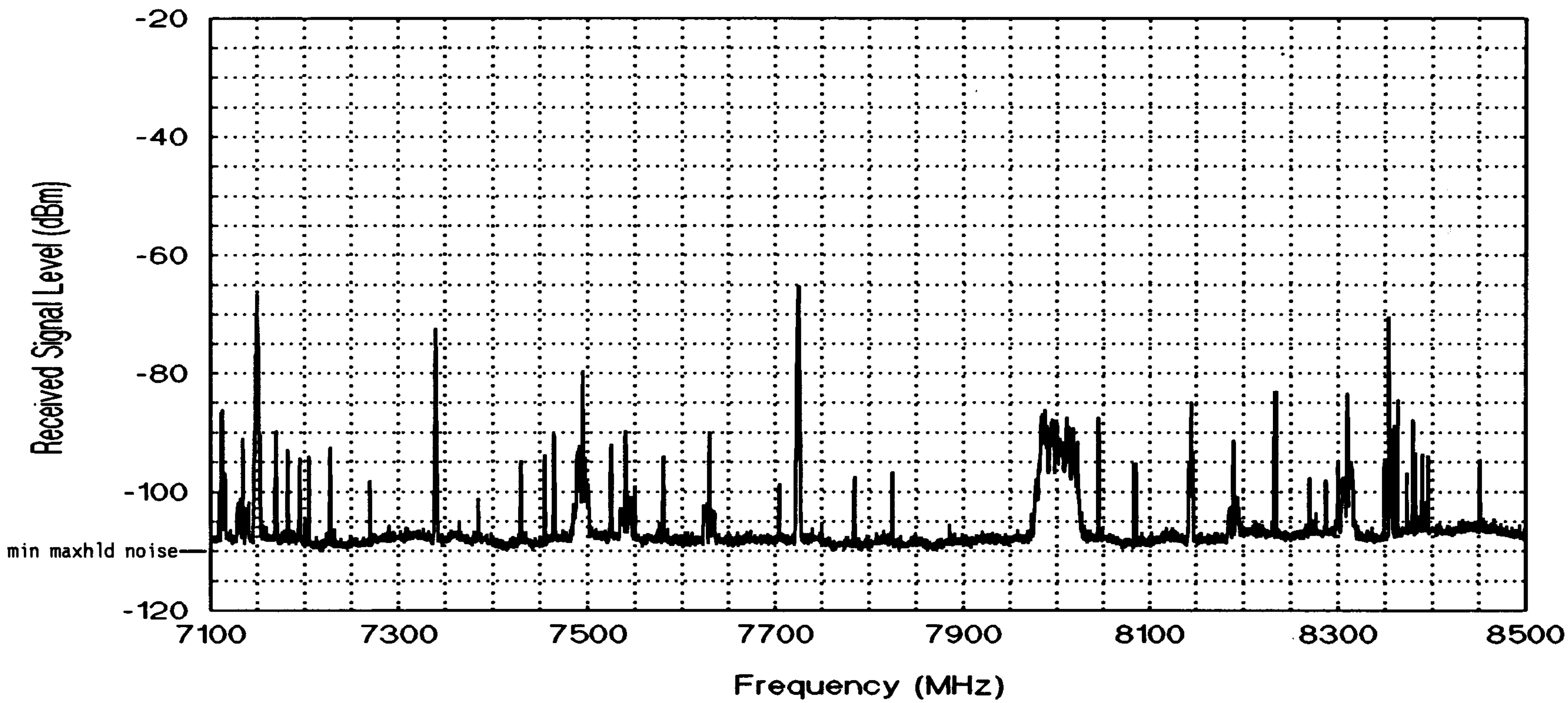
	5925–6425	6425–6525	6525–6875	6875–7075	7075–7125
GOVERNMENT ALLOCATIONS:					
NON-GOVERNMENT ALLOCATIONS:	FIXED, FIXED-SATELLITE (Earth-to-space).	2.	FIXED, FIXED-SATELLITE (Earth-to-space).	3, FIXED-SATELLITE (Earth-to-space).	3.
GENERAL UTILIZATION:	Common carrier, cellular, satellite uplinks for television and data, VSAT systems.		Public safety, common carrier, Auxiliary broadcasting.	Auxiliary broadcasting, 4.	



1. 6415-6439 MHz: Standard frequency and time signal (Earth-to-space).
2. FIXED-SATELLITE (Earth-to-space), MOBILE.
3. FIXED, MOBILE.
4. Studio-to-transmitter links (STL), intercity relays (ICR), electronic news gathering (ENG), cable TV pickup stations, TV translator relay stations permitted on a secondary basis.

Figure 34. NTIA spectrum survey azimuth-scan graph of the 5925-7125 MHz range (System-2, band event 21, swept algorithm, maximum-hold detector, 300-kHz bandwidth) at Denver, CO, 1993.

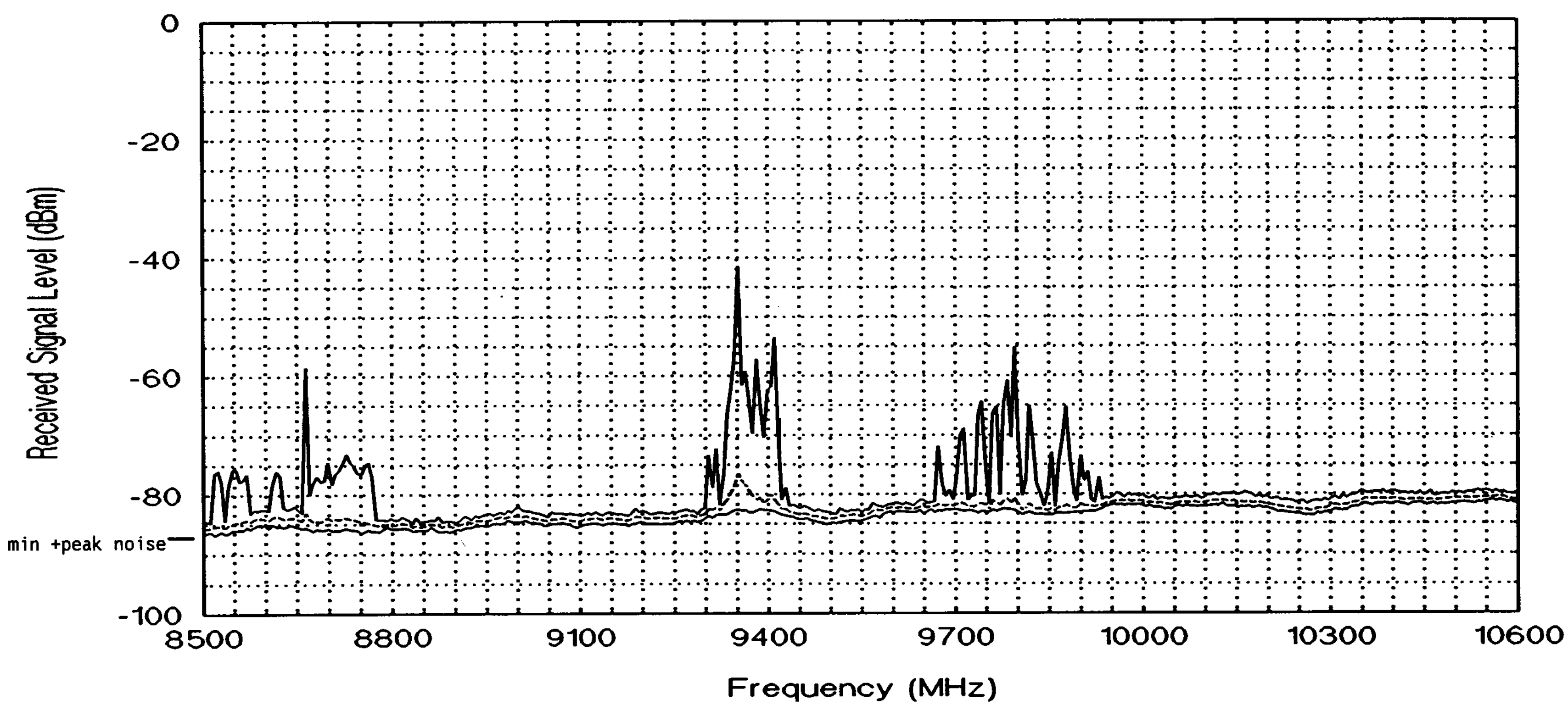
	7125	7250-7300		7750	7900	8400	8450 8500
GOVERNMENT ALLOCATIONS:	FIXED, 1.	3.	FIXED-SATELLITE (space-to-Earth), FIXED, Mobile-Sat. (space-to-Earth), 4.	FIXED.	FIXED-SATELLITE (Earth-to-space), 5, 6, 7.	FIXED, 8.	
NON-GOVERNMENT ALLOCATIONS:							8.
GENERAL UTILIZATION:	2.						



1. 7190-7235 MHz: SPACE RESEARCH (Earth-to-space).
2. 7125-8500 MHz: Government point-to-point microwave voice/data links, military satellite communications systems, miscellaneous space links.
3. FIXED-SATELLITE and MOBILE-SATELLITE (space-to-Earth), Fixed.
4. 7450-7550 MHz: METEOROLOGICAL-SATELLITE (space-to-Earth).
5. 7900-8025 MHz: MOBILE-SATELLITE (Earth-to-space), fixed.
6. 8025-8400 MHz: EARTH EXPLORATION-SATELLITE (space-to-Earth), FIXED, Mobile-Satellite (Earth-to-space) (no airborne transmissions).
7. 8175-8215 MHz: METEOROLOGICAL-SATELLITE (Earth-to-space).
8. SPACE RESEARCH (space-to-Earth) (8400-8450 MHz deep space only).

Figure 35. NTIA spectrum survey azimuth-scan graph of the 7125-8500 MHz range (System-2, band event 22, swept algorithm, maximum-hold detector, 300-kHz bandwidth) at Denver, CO, 1993.

	8500–9000	9000–9200	9200–9300	9300–9500	9500–10000	10000–10450	10450–10550
GOVERNMENT ALLOCATIONS:	RADIOLOCATION.	1.	2.	3.	RADIOLOCATION.		
NON-GOVERNMENT ALLOCATIONS:	Radiolocation.	1.	2.	3.	Radiolocation.	Amateur, Radiolocation.	5.
GENERAL UTILIZATION:	Military Ground Control Approach (GCA) radar.			4.			

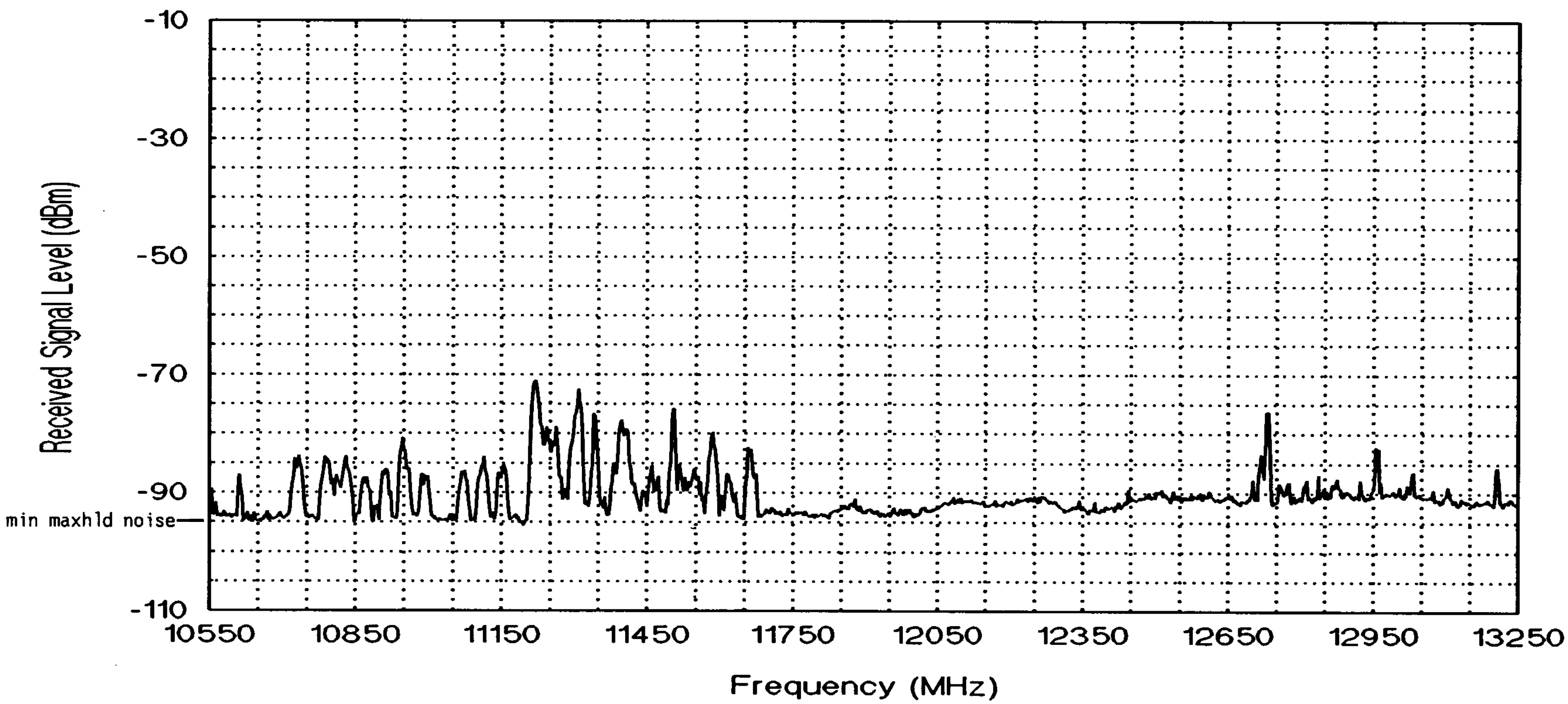


1. AERONAUTICAL RADIONAVIGATION, Radiolocation.
2. MARITIME RADIONAVIGATION, Radiolocation.
3. RADIONAVIGATION, Meteorological Aids, Radiolocation.
4. Maritime radionavigation radar, airborne weather radar.
5. RADIOLOCATION, Amateur, Amateur-Satellite.

Figure 36. NTIA spectrum survey graph summarizing 24 scans across the 8500-10550 MHz range (System-2, band event 23, stepped algorithm, +peak detector, 3000-kHz bandwidth) at Denver, CO, 1993.

	10550–10700	10700–11700	11700–12200	12200–12700	12700–13250
GOVERNMENT ALLOCATIONS:	1.				
NON-GOVERNMENT ALLOCATIONS:	2.	FIXED, FIXED-SATELLITE (space-to-Earth).	FIXED-SATELLITE (space-to-Earth), 4.	BROADCASTING-SATELLITE, FIXED.	FIXED, MOBILE, 5.
GENERAL UTILIZATION:	3.	Common carrier point-to-point microwave links, TV studio-to-transmitter links.		Private point-to-point microwave.	Cable Relay Systems (CARS), 6.

10550 10700 11700 12200 12700 13250

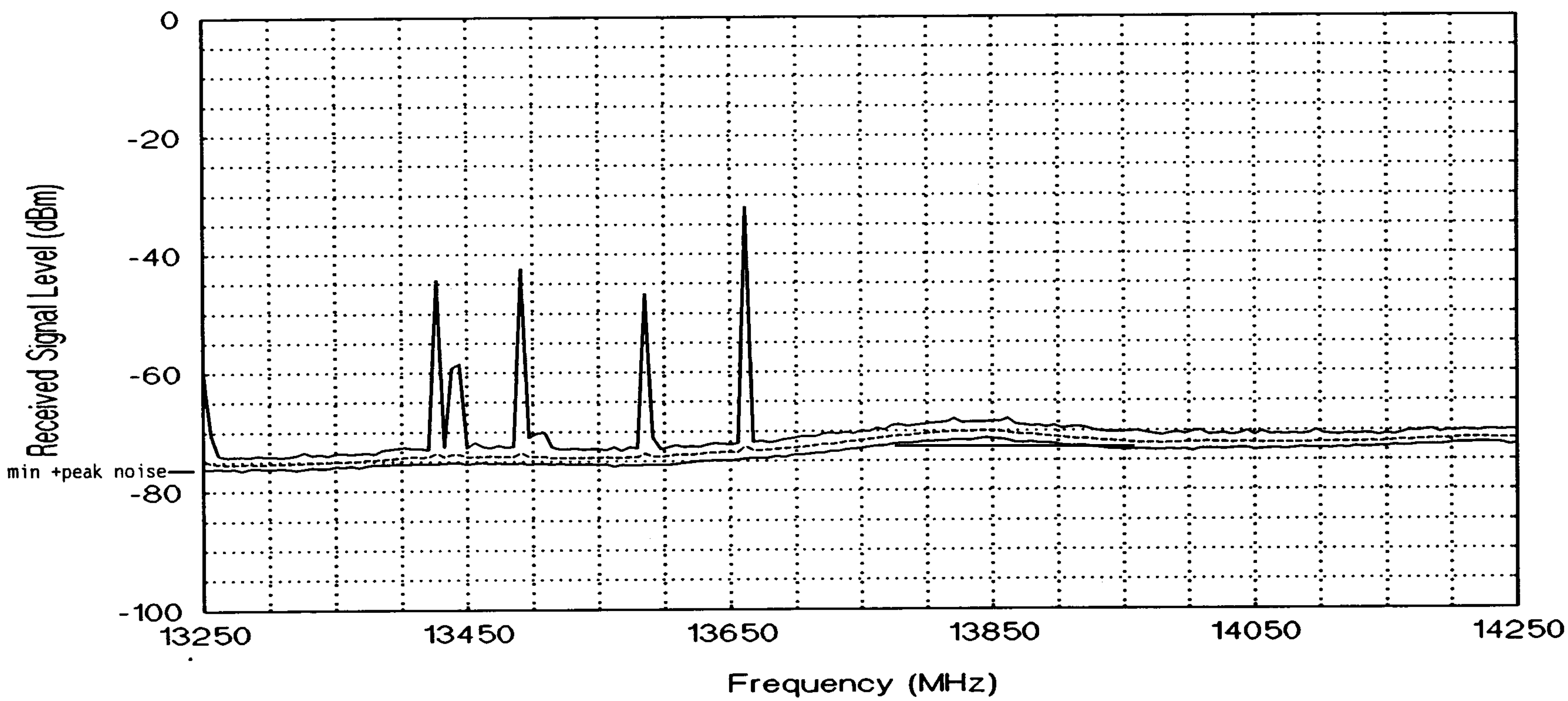


1. 10600-10700 MHz: EARTH EXPLORATION-SATELLITE (Passive), SPACE RESEARCH (Passive), RADIO ASTRONOMY (10680-10700 MHz).
2. FIXED (10550-10680 MHz, only), 10600-10700 MHz: EARTH EXPLORATION-SATELLITE (Passive), SPACE RESEARCH (Passive), RADIO ASTRONOMY (10680-10700 MHz, only).
3. Point-to-point microwave stations. Narrowband cellular links.
4. Mobile (except aeronautical mobile).
5. FIXED-SATELLITE (Earth-to-space).
6. TV auxiliary broadcasting (includes: SHL, STL, ENG, and ICR's).

Figure 37. NTIA spectrum survey azimuth-scan graph of the 10550-13250 MHz range (System-2, band event 24, swept algorithm, maximum-hold detector, 3000-kHz bandwidth) at Denver, CO, 1993.

	13250–13400	13400–14000	14000–14200	
GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION, 1.	RADIOLOCATION, Space Research, Standard Frequency and Time Signal-Satellite (Earth-to-space).	RADIONAVIGATION, Space Research.	
NON-GOVERNMENT ALLOCATIONS:	AERONAUTICAL RADIONAVIGATION, 1.	Radiolocation, Space Research, Standard Frequency and Time Signal-Satellite (Earth-to-space).	RADIONAVIGATION, Space Research, 2.	
GENERAL UTILIZATION:		Military airborne radars.		

13250 13400 14000 14200

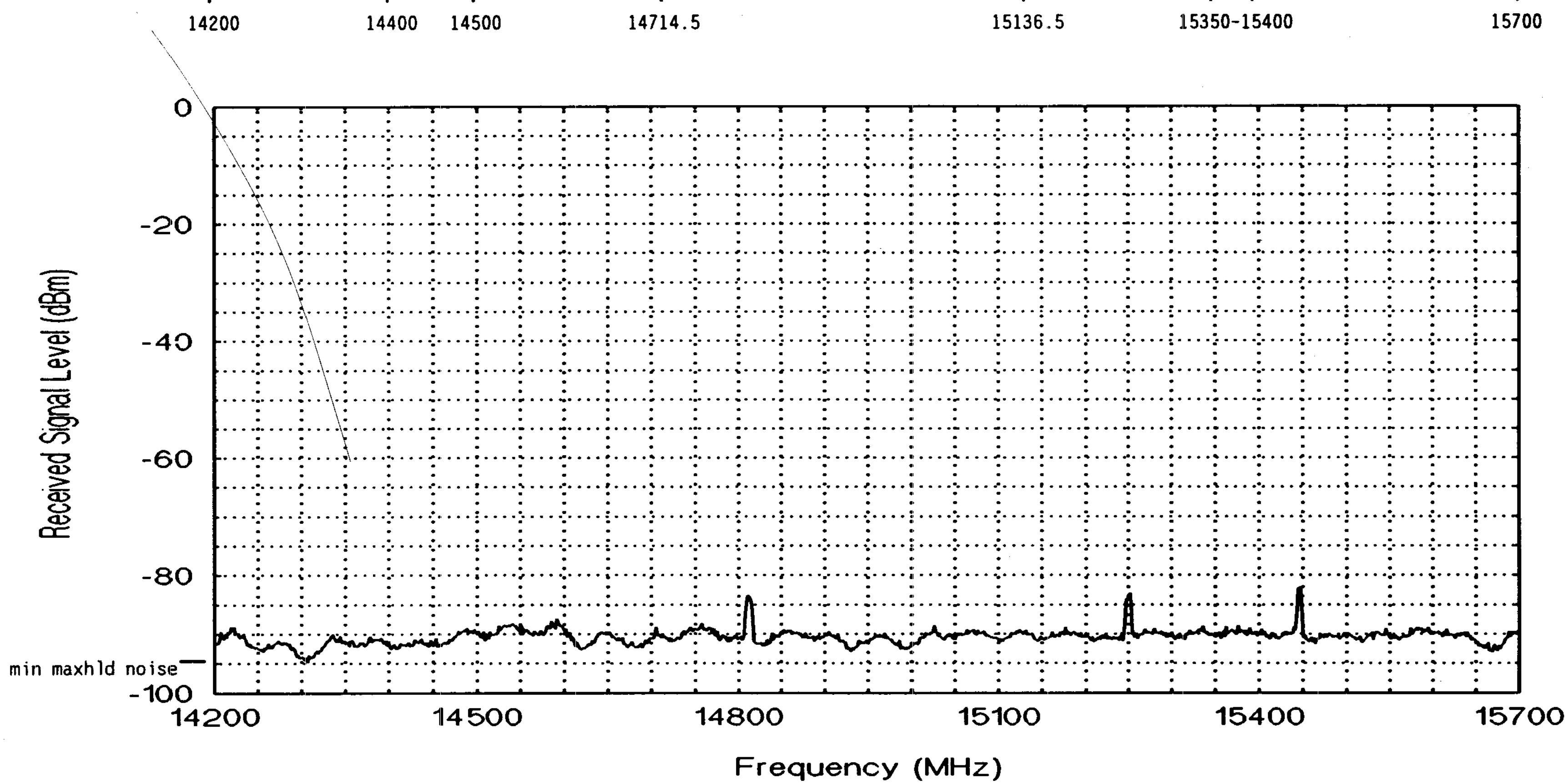


1. Space Research (Earth-to-space).

2. FIXED-SATELLITE (Earth-to-space).

Figure 38. NTIA spectrum survey graph summarizing 42 scans across the 13250-14200 MHz range (System-2, band event 25, stepped algorithm, +peak detector, 3000-kHz bandwidth) at Denver, CO, 1993.

	14200–14400	14400–14500	14500–14714.5	14714.5–15136.5	15136.5–15350	15350–15400	15400–15700
GOVERNMENT ALLOCATIONS:		Fixed, Mobile.	FIXED, Mobile, Space Research.	MOBILE, Fixed, Space Research.	FIXED, Mobile, Space Research.	2.	AERONAUTICAL RADIONAVIGATION.
NON-GOVERNMENT ALLOCATIONS:	FIXED-SATELLITE (Earth-to-sp.).					2.	AERONAUTICAL RADIONAVIGATION.
GENERAL UTILIZATION:			1.		1.		

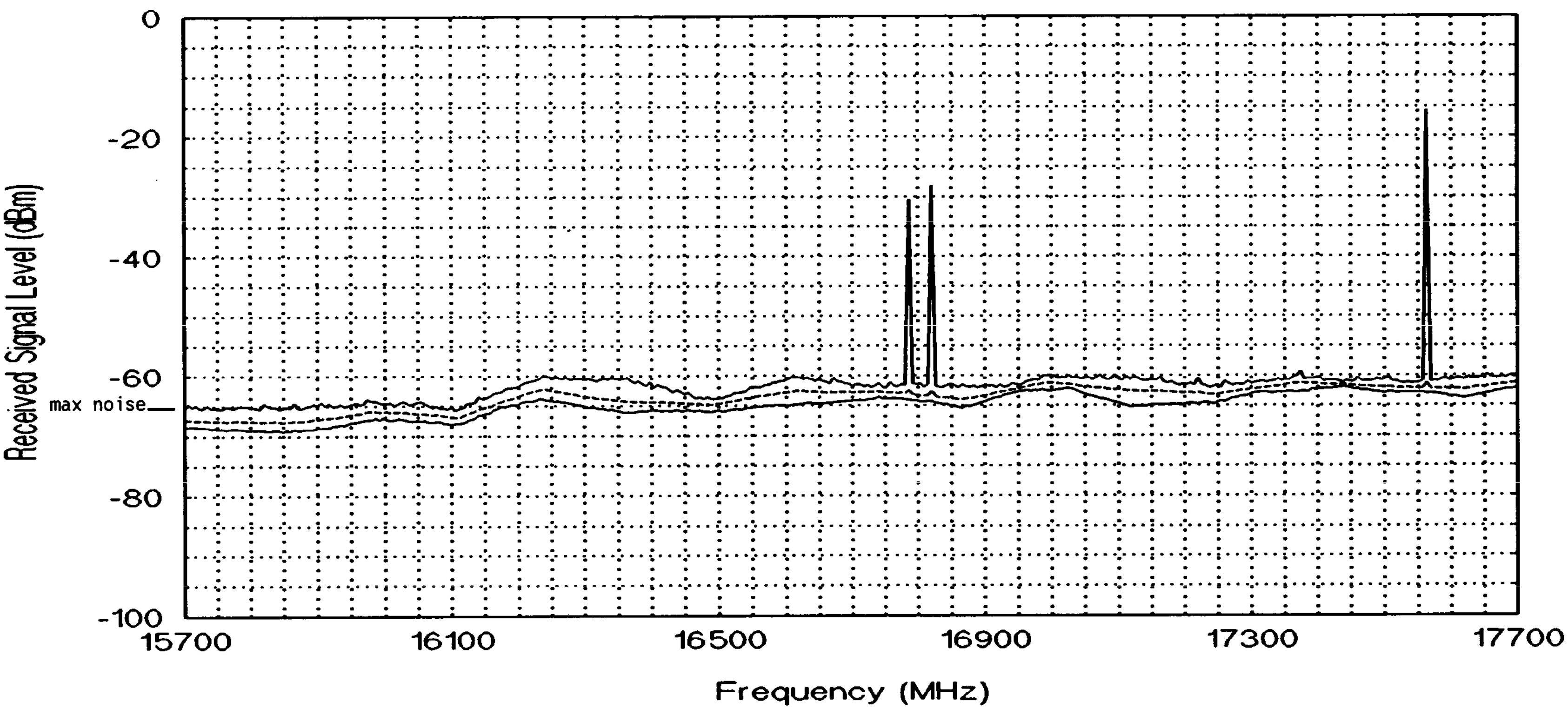


1. Military communication links and microwave links. Air traffic control links, including video data.
2. EARTH EXPLORATION-SATELLITE (Passive), RADIO ASTRONOMY, SPACE RESEARCH (Passive).

Figure 39. NTIA spectrum survey azimuth-scan graph of the 14200-15700 MHz range (System-2, band event 26, swept algorithm, maximum-hold detector, 3000-kHz bandwidth) at Denver, CO, 1993.

GOVERNMENT ALLOCATIONS:	RADIOLOCATION, Space Research (Deep Space) (Earth-to-space).	1.	Radiolocation.	
NON-GOVERNMENT ALLOCATIONS:	Radiolocation.	2.	FIXED-SATELLITE (Earth-to-space).	
GENERAL UTILIZATION:	Military airborne radars.			

15700 17200-17300 17700



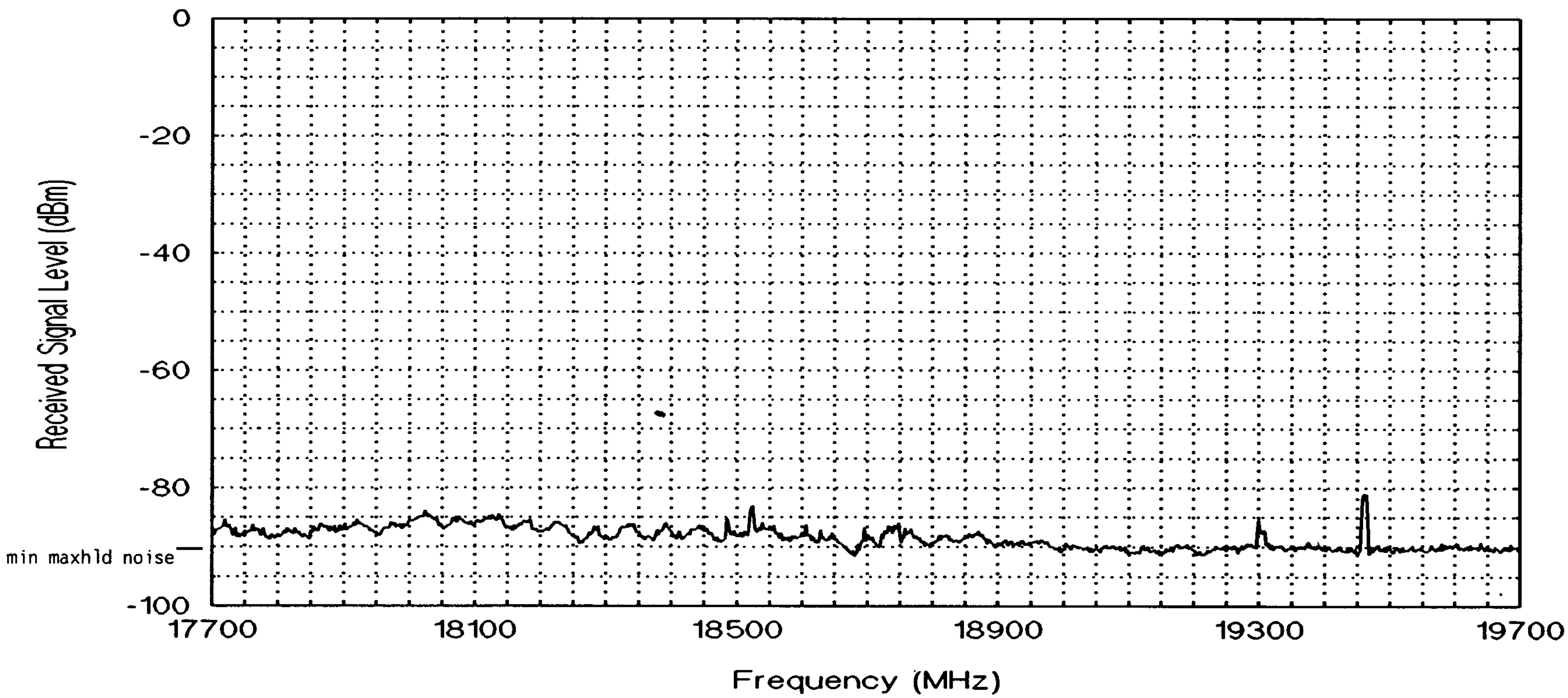
1. RADIOLOCATION, Earth Exploration-Satellite (Active}, space Research (Active).

2. Earth Exploration-Satellite (Active), Radiolocation, Space Research (Active).

Figure 40. NTIA spectrum survey graph summarizing 46 scans across the 15700-17700 MHz range (System-2, band event 27, stepped algorithm, + peak detector, 3000-kHz bandwidth) at Denver, CO, 1993.

	17700–18600	18600–18800	18800–19700
GOVERNMENT ALLOCATIONS:		2.	
NON-GOVERNMENT ALLOCATIONS:	FIXED, MOBILE, FIXED-SATELLITE (space-to-Earth), 1.	3.	FIXED, FIXED-SATELLITE (space-to-Earth), MOBILE.
GENERAL UTILIZATION:	General purpose point-to-point microwave band including private, common carrier, Cable TV relay systems (CARS), studio-to-transmitter (STL) TV links, Digital Electronic Message Services (DEMS), etc.		

17700 18600 18800 19700



1. 17700-17800 MHz: FIXED-SATELLITE (Earth-to-space).
2. EARTH EXPLORATION-SATELLITE (Passive), SPACE RESEARCH (Passive).
3. FIXED, FIXED-SATELLITE (space-to-Earth), EARTH EXPLORATION-SATELLITE (Passive), MOBILE (exc. aeronaut. mobile), SPACE RESEARCH (Passive).

Figure 41. NTIA spectrum survey aximuth-scan graph of the 17700-19700 MHz range (System-2, band event 28, swept algorithm, maximum-hold detector, 3000-kHz bandwidth) at Denver, CO, 1993.

the cumulative measurement time during the survey was typically several hours, spread uniformly over the diurnal cycle. In some bands, which are nondynamic and were measured with the azimuth-scanning technique, only a single occupancy curve is shown.

Based on the measurement and sampling techniques used, we believe that these data represent an extremely good statistical sampling of the activity in the ‘radio spectrum in the Denver metropolitan area. Maximum and minimum activity levels measured in the spectrum are probably very good representations of actual activity levels. The average curves provide a good qualitative estimate of the typical received power as a function of frequency. The maximum, minimum and average curves can also be used to qualitatively assess the relative density of channel occupancy on a band-by-band basis. In the azimuth-scan bands, the single curve which is shown likewise provides a good estimate of the density 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 average curves in these data provide a qualitative, not quantitative, measure of occupancy rates for the measured frequencies.

There does exist an RSMS measurement technique for obtaining absolute channel occupancy statistics. Measurements of this type have been recently performed in mobile radio bands in conjunction with RSMS occupancy surveys in California. However, this technique was not yet implemented when the Denver survey was performed, nor has a presentation format been developed for the release of the channel occupancy statistics data.

No emission sources are specifically identified in this report. RSMS crew members routinely measure emission parameters of selected transmitters, particularly radars, during occupancy surveys, but the notes on those parameters are not released here. The following paragraphs present general information about band occupancy that can be extrapolated from the survey band scans in this report; no reference is made to RSMS field notes on emitter characteristics to produce the comments below.

3.5.1 Band-by-band Observations on Spectrum Use

108-162 MHz: Measured data between 108 MHz and 114 MHz were contaminated by receiver-generated intermod products due to inadequate attenuation of adjacent band FM broadcast signals; those data are not presented here.

Between 108 MHz and 118 MHz, VOR (very high frequency omnidirectional range) aeronautical navigation beacons appear as 100’% emitters. These show on the occupancy scans as vertical lines coming up from the minimum curve. Also, in the air traffic control (ATC) band (up to 136 MHz) ATIS (automated terminal information service) transmissions appear as high-average or 100% signals. Frequently used ATC frequencies also show up as high points on the average curve, and ATC frequencies which were observed one or more times during the survey show on the maximum curve.

In the 137-138 MHz band, TIROS signals are not receivable by the RSMS. A variety of mobile signals were observed in the 138-148 MHz portion of the spectrum. The average curve increases noticeably at a number of frequencies from 144-148 MHz. In the 148-162 MHz range, a nearby fixed transmitter was observed at about 152.5 MHz. This transmitter came close to, but did not quite exceed, the overload threshold of the RSMS. The sloping average curve on either side of this signal represents a measurement of the noise sideband emission from this transmitter.

162-174 MHz: A variety of fixed and mobile transmitters are observed. The high-average signal at 162.55 MHz is a public broadcast weather information frequency.

174-216 MHz: Television broadcast channels 7 and 9 are readily apparent, Channel 12 and a channel 11 repeater are also evident.

216-225 MHz: A few 100% signals are observed in the 216-220 MHz (maritime mobile) part of this spectrum. Other than that, little signal activity is noted for that band. This is consistent with Denver's land-locked location. Little activity was measured in the 220-222 MHz band. Most of the maximum curve is receiver noise and locally generated noise, as from vehicular traffic. Some signals are observed between 222-225 MHz on the maximum curve, but only four of those have any impact on the average curve.

225-400 MHz: An increased noise level is noted on the maximum curve between 225-325 MHz. Many of the signals observed on the maximum curve also produced an increase on the average curve. Four signals were measured in 100% of the RSMS scans, as shown on the minimum curve.

400-406 MHz: The maximum curve shows occupancy by a number of signals. Most of these signals were apparently observed briefly, as inferred from the fact that the average curve is only affected at a few frequencies,

406-420 MHz: Fixed and mobile signals, many of them showing up on both the maximum and average curves, were observed. At least three of the signals were observed on 100% of scans, as inferred from the minimum curve.

420-450 MHz: Nothing identifiable as a radar signal appears in this band. The three curves are consistent with a measurement mainly of RSMS receiver noise. A few peaks on the maximum curve may represent nonradar signals. The rise in the three curves at 420 MHz and at 450 MHz is caused by signals just outside this band. The measurement bandwidth of 1 MHz is convolving these signals, and the convolution appears in the band. The signals, however, are outside the band. The rise at 420 MHz is probably due to the 100% signal seen in the previous band at 419.75 MHz, and the rise at 450 MHz is probably due to the 100% signal seen in the next band at 451 MHz.

450-470 MHz: A large number of mobile signals are observed in this band, and many of these signals show high levels on the average curve. Note that the allocated band edges at 455 MHz and 460 MHz show very distinctly in the measured data.

470-512 MHz: Some signals are observed between 470-506 MHz, but the average curve is not affected much, and the minimum curve shows no 100% signals. Between 506-512 MHz, television broadcast channel 20 is observed.

512-806 MHz: All of the signals observed in this part of the spectrum appear to be television broadcast. Five of them were observed 100% of the time (although one of those was at a low power level on at least one scan). The others were transmitting enough to significantly raise the average curve, but were off the air during at least one RSMS scan.

806-902 MHz: Cellular and trunked communications are clearly delineated. Note differences between mobile and base systems, and also the differences that delineate public safety and aeronautical mobile parts of this spectrum.

902-928 MHz: This band was measured with two different algorithms: swept/m3 and stepped. The results are shown in Figures 15 and 16. Note the differences that result from changing the bandwidth and the scan algorithm. The reason for doing two different scans is to accommodate the fact that this is both an ISM (industrial, scientific and medical) band and a radiolocation band. The swept/m3, 10-kHz bandwidth measurement is intended to show ISM activity. The stepped, 1 -MHz bandwidth measurement is intended to show radar activity. United States radars which utilize this band are not found in the Denver area. Consequently, while the swept/m3 measurement shows ISM activity, the stepped measurement only indicates RSMS receiver noise. Note that the stepped measurement does clearly show (as a single peak) the pair of signals just below 928 MHz.

928-960 MHz: A variety of mobile and fixed signals, many of them producing high average and minimum responses, are observed. Note the delineation of allocated band edges in the measurement data.

960-1215 MHz: This band shows activity from aeronautical navigation aids. The large features at 1030 MHz and 1090 MHz are air traffic control beacon signals. Interrogations are at 1030 MHz, and replies are at 1090 MHz. The low duty cycle, impulsive characteristics of the signals in this band are such that they affect the peak curve, but not the average or minimum curves. However, beacon signals are observed approximately 100% of the time during RSMS operations. This is a good example of why, with the exception of high duty cycle signals transmitting 100% of the time, the RSMS data shown in this report cannot be used to directly infer a percentage of time that signals use a frequency.

1215-1400 MHz: Aeronautical radionavigation signals are observed below 1215 MHz. Above 1215 MHz, the rest of the band shows occupancy by a radar. The radar center frequency is 1332 MHz. The radar center frequency peaks at O dBm, and was normally receivable at that amplitude. The lack of automatic attenuation routines in the RSMS software meant that most of the scans saturated at this frequency, resulting in an apparent average amplitude that is considerably less than O dBm. Radar spurious emissions are observed between about 1230-1400 MHz. The sharp spurious emission roll-off at 1230 MHz is typical of a bandpass filter characteristic.

1350-1400 MHz: The peak curve shows radar spurious emissions as measured by the swept/m3 algorithm in a 10 kHz bandwidth. These emissions do not affect the average or minimum curves, even though the radar in this measurement operates continuously. Compare these measurements to the 1350-1400 MHz portion of the preceding 1200-1400 MHz occupancy scans, which were made using a stepped algorithm in a 1-MHz bandwidth.

1400-1530 MHz: The radar spurious emissions from the center frequency at 1332 MHz are observed up to about 1440 MHz. Above that frequency, a few impulsive signals are observed (as evidenced by the fact that the average and minimum curves are not affected).

1530-1710 MHz: A few signals are observed in the 1610 -1626.5 MHz airborne aids to air navigation band. Other signals are observed in earth-to-space bands and in the meteorological aids band. None of these signals affect the average curve. They probably operated for brief durations, and some may have been impulsive.

1710-2300 MHz: This band was measured with the azimuth scan technique, and therefore only a single curve is shown. Analog links show up as narrow spectral features, and digital links are shown as wider spectral features.

2300-2500 MHz: The major spectral feature in this part of the spectrum is the prominent feature centered at about 2550 MHz. The band 2400-2500 MHz is ISM, and the feature shown here is generated by ISM devices, primarily microwave ovens. Other RSMS measurements have been performed in this band at various locations in the United States, and may be released in NTIA reports at a later date.

2500-2700 MHz: This azimuth scan shows a set of multipoint distribution system (MDS) television signals between 2500-2670 MHz. A few lower-amplitude signals are observed.

2700-2900 MHz: This band shows occupancy by radars. Due to lack of automatic attenuation in the RSMS software, the signals were amplitude-limited at -45 dBm received signal level. The radar at 2890 MHz probably rotated more slowly than the 5-sec step time of the scans in this band, leading to a slightly discontinuous envelope measurement.

2900-3100 MHz: The discontinuous envelope which is highest at 2900 MHz and then decreases at higher frequencies is probably produced by the radar at 2890 MHz in the previous band. This emission is not observed above 3000 MHz; above that frequency, only noise is observed. The envelope looks discontinuous because the radar's beam scanning interval is longer than the RSMS stepping interval. Another radar is apparent at 2987.5 MHz.

3100-3700 MHz: Only noise is observed in this radar band in the Denver area.

3700-4200 MHz: Terrestrial point-to-point microwave signals are observed in this band. The six low-amplitude, relatively wide spectral features observed in this azimuth scan are a set of digital links. The even spacing and uniform amplitude of these links implies that they were all located on a single tower. The other signals observed in this scan are analog communications. As with all other RSMS bands, satellite signals in this band (such as for television receive-only systems) are not receivable in RSMS spectrum surveys.

4200-4400 MHz: RSMS surveys can detect airborne radio altimeter signals in this band if aircraft flight patterns carry aircraft over the van. However, in Denver this was not the case, and so no signals were received in this band during the survey.

4400-5000 MHz: A few signals were received in this band. They appear to be analog. The RSMS can receive terrestrial point-to-point microwave in this band.

5000-5250 MHz: No signals were received in this band during the RSMS Denver spectrum survey.

5250-5925 MHz: The signals observed in this band are generated by radars. The radar at 5575 MHz was operating during every RSMS scan.

5925-7125 MHz: Terrestrial point-to-point microwave signals are observed in this band. All of the signals below 6425 MHz appear to be digital. The signals above 6425 MHz appear to be analog. The digital signals appear to fall into distinct groupings. This kind of behavior is the result of all of the transmitters in each group being located on the same tower.

7125-8500 MHz: Terrestrial point-to-point microwave signals are observed in this band. Mostly analog signals and a digital signal are observed.

8500-10550 MHz: The signals observed in this band are all radars.

10550-13250 MHz: The common carrier band between 10700-11700 MHz shows a number of terrestrial point-to-point microwave signals. These signals appear to all be analog.

The fixed band above 12700 MHz also shows a signal. Above 12 GHz, few signals are observed by the RSMS. There are several reasons for this: the RSMS noise figure increases, the typical transmitter power is low, and the transmitters typically use high-gain antennas, operate intermittently, and/or are mobile.

13250-14200 MHz: A few radar signals were received. The received signal comments made for the 10550-13250 MHz band (above) are also true for this band.

14200-15700 MHz: Three signals, probably analog, were observed in this band. The received signal comments made for the 10550-13250 MHz band (above) are also true for this band.

15700-17700 MHz: Three signals, probably radars, were observed in this band. The received signal comments made for the 10550-13250 MHz band (above) are also true for this band.

17700-19700 MHz: One signal, probably analog, was received. The received signal comments made for the 10550-13250 MHz band (above) also are true for this band.

APPENDIX A: RADIO SPECTRUM MEASUREMENT SYSTEM (RSMS)

A.1 Introduction

The NTIA RSMS is a mobile, self-contained computer-controlled radio receiving system capable of many measurement scenarios over a frequency range of 30 MHz to 22 GHz. This appendix contains particulars on the vehicle, instrumentation, and operation of the RSMS when it is deployed for broadband spectrum survey measurements.

A.2 Vehicle

For maximum effectiveness, the spectrum measurement system must be readily transported to near or distant locations that may not be easily accessible, e.g., open fields or hilltops without an access road. To meet this need, the measurement system, including antennas and support hardware, is carried in a shielded, insulated, climate-controlled shell mounted on a Chevrolet truck cab and chassis. The assembled measurement system and vehicle unit is called "the RSMS. " The vehicle has a high power-to-weight ratio, four-wheel drive, and a low-geared transmission for use on rough terrain and steep grades. The RSMS is still sufficiently small and light to fit on C-130 or larger aircraft for rapid transport over long distances. The chief disadvantage of a smaller unit is the loss of operating room inside the shell. Figure A-1 is a photograph of the RSMS with antennas mounted on partially extended masts.

Figure A-2, shows the internal layout of the RSMS. Four full-height equipment racks are located transversely above the rear axle. These racks divide the box-like equipment compartment into two parts, one in front and one behind the racks. The forward area comprises the operator's compartment with access to the equipment front panels, the main power panel and breaker box, work counters, two chairs, telephone, fax machine, and a cellular fax/modem. A built-in safe below the equipment racks provides storage for classified materials. A full-height cabinet in the forward driver's side corner provides for storage of small, frequently used items. A compartment for the smaller of two telescoping masts is located behind this cabinet, and is accessed from outside the van.

Additional storage cabinets are available to the rear of the racks for larger and less-used items. Compartments for the large mast and the external-tap power cable and its electrically driven reel are located behind these cabinets, with outside access. The weight of the mast-rotator, power cable and reel are counterbalanced on the driver's side by the 10-kW generator and two air conditioners. The rear area provides access to the back of the equipment racks. The generator compartment is accessed via an outside lift-up panel. The air conditioners are not readily accessible.

The tightly-shielded, windowless measurement compartment shell provides good radio frequency (RF) isolation between the measurement system and the outside environment. The small working compartment also reduces requirements for air conditioning and heating. Both of the telescoping masts are installed on rotators at their bases and will raise the antennas to a little over 8 meters above ground.

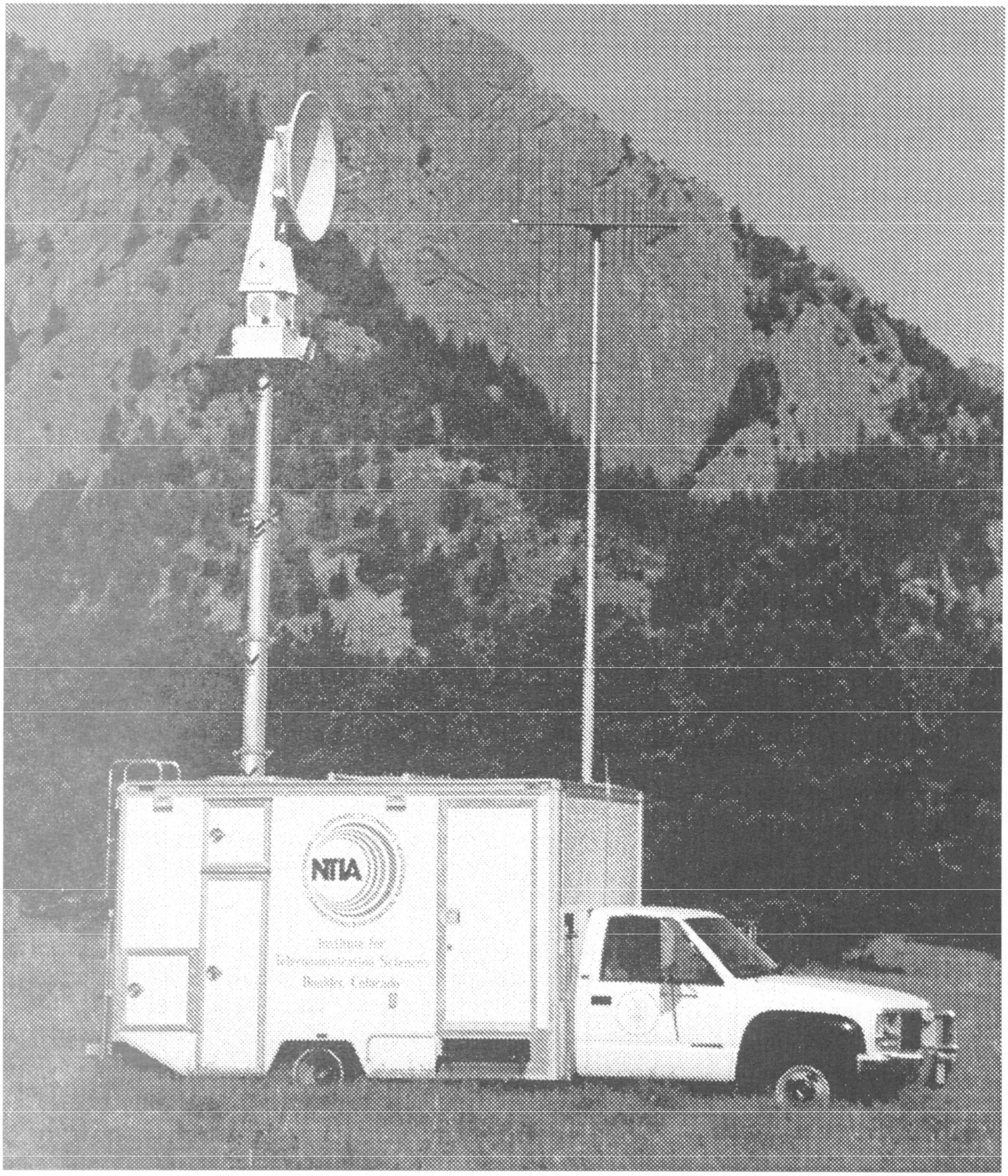
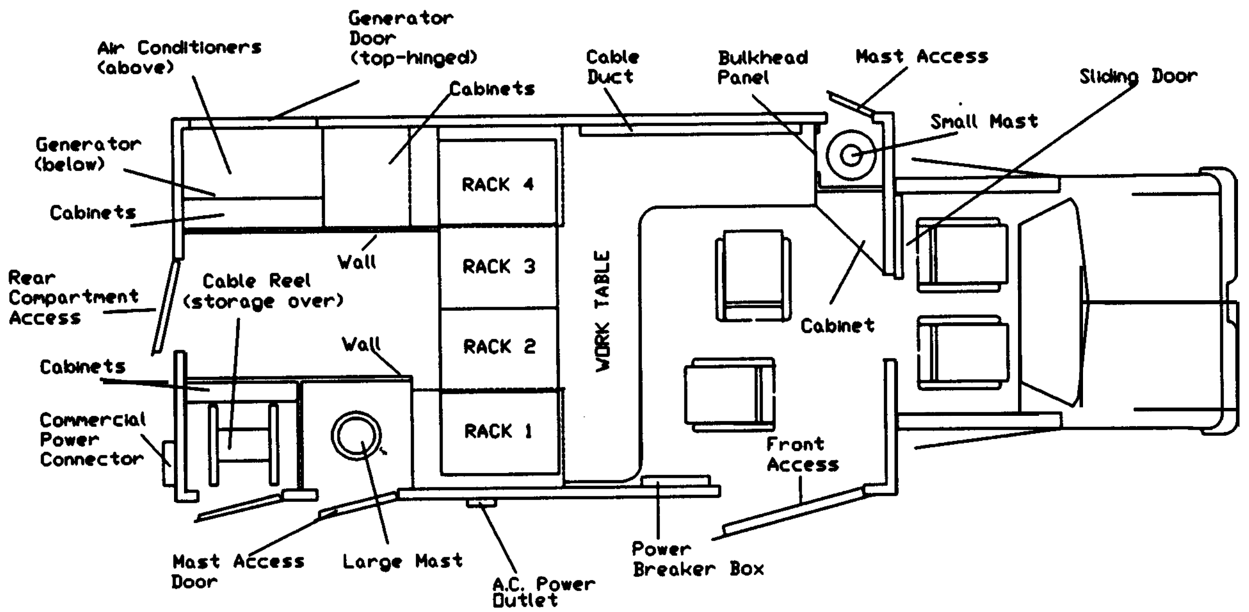


Figure A-1. External view of the RSMS.



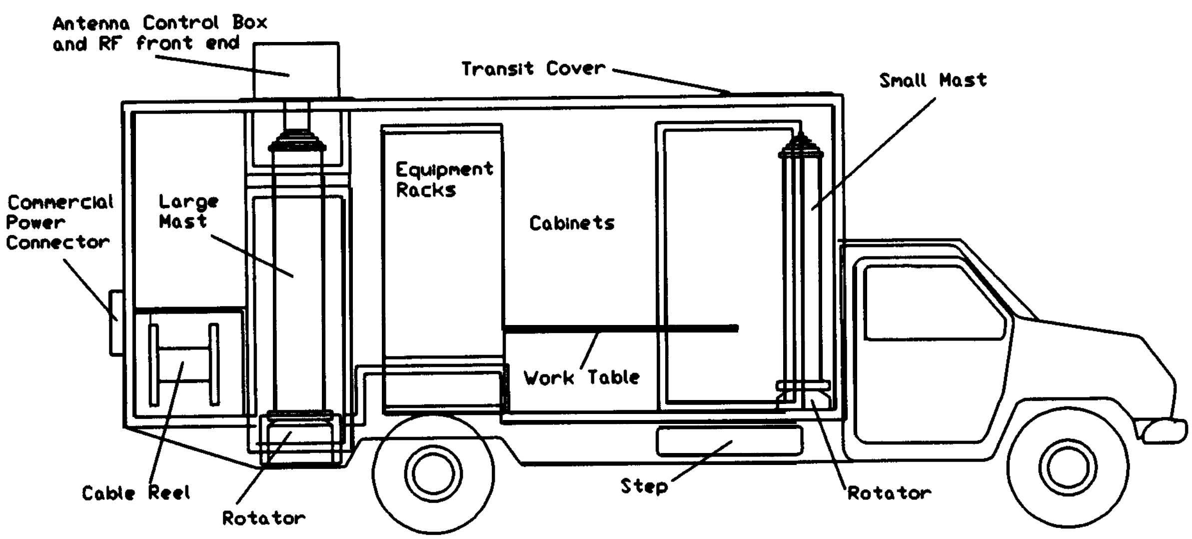


Figure A-2. Top and side view drawings of the RSMS.

A.3 Instrumentation

The RSMS receiver is depicted as a block diagram in Figure A-3. As the diagram shows, the receiving system is normally configured as two independent spectrum measurement systems, one optimized to measure lower frequency portions of the spectrum (System-1), and the other to measure higher frequencies (System-2) with some frequency overlap between the two systems. Both systems use RF front-ends that incorporate dynamic RF attenuation, low noise preamplification and tunable frequency preselection. These features allow the RSMS to achieve the best possible combination of dynamic range, sensitivity, and off-tuned signal rejection in its measurements. Figure A-4 is a photograph showing a front panel view of the rack mounted instrumentation.

Both the high and low frequency systems are designed around a O-22 GHz Hewlett-Packard 8566B spectrum analyzer, although the RSMS software will control other spectrum analyzers, such as the HP-70000 series. For spectrum surveys, the low-frequency system is usually operated between 100 MHz and 1 GHz, with its antenna(s) mounted on the smaller forward mast and its RF front-end located inside the operator's compartment. The high-frequency system is used for the remaining survey frequencies from 1 GHz-19.7 GHz, with its antenna(s) mounted on the larger mast and its RF front-end located at the top of that mast to overdrive the higher line losses that occur above 1 GHz. The selection of 1 GHz as the break point between the two systems in a site survey mode is determined primarily by the availability of antennas, which often begin or end their frequency response at 1 GHz.

Each of the measurement systems can be controlled in fully automatic, semiautomatic, and fully manual modes. In fully automatic operation, each system is controlled by ITS-written software (named DA, for Data Acquisition) that runs under Microsoft-DOS on 80486 -based computers. Spectrum surveys are normally conducted in the fully automatic mode. RSMS operators are able to interrupt automatic measurements to perform work in semi-automatic and manual modes. These modes allow special measurements with varying degrees of automated assistance.

The two measurement systems utilize independent antennas, RF front-ends, masts, spectrum analyzers and computers, but share the use of auxiliary equipments for special measurements, analysis, and troubleshooting. Support equipments include a digital oscilloscope, pulse train analyzer, demodulator, modulation domain analyzer, rotator controllers, signal generators (frequencies range from a few kilohertz to 18 GHz), power supplies, low noise amplifiers, cables, connectors, and hand tools. Data from the oscilloscope can be downloaded to the controller computers. Data from the auxiliary devices are often used to determine specific characteristics of selected emitters during the-course of a spectrum survey or other measurement.

The RF operational characteristics of the two measurement systems are shown as a function of frequency in Table A-1. The lower-frequency system can be operated across a frequency range of 100 Hz to 2 GHz, with fixed bandpass and varactor preselection at frequencies below 500 MHz and tracking yttrium-iron-garnet (YIG) preselection between 500 MHz and 2 GHz. This system includes 0-50 dB of dynamically selectable RF attenuation in the front-end, and achieves a typical overall noise figure of 10 dB across its entire frequency range. The higher-frequency system can be operated across the range of 500 MHz-22 GHz, with YIG preselection between 2 and 20 GHz. This system incorporates 0-70 dB of dynamically selectable RF attenuation in the front-end, and uses low noise preamplifiers to

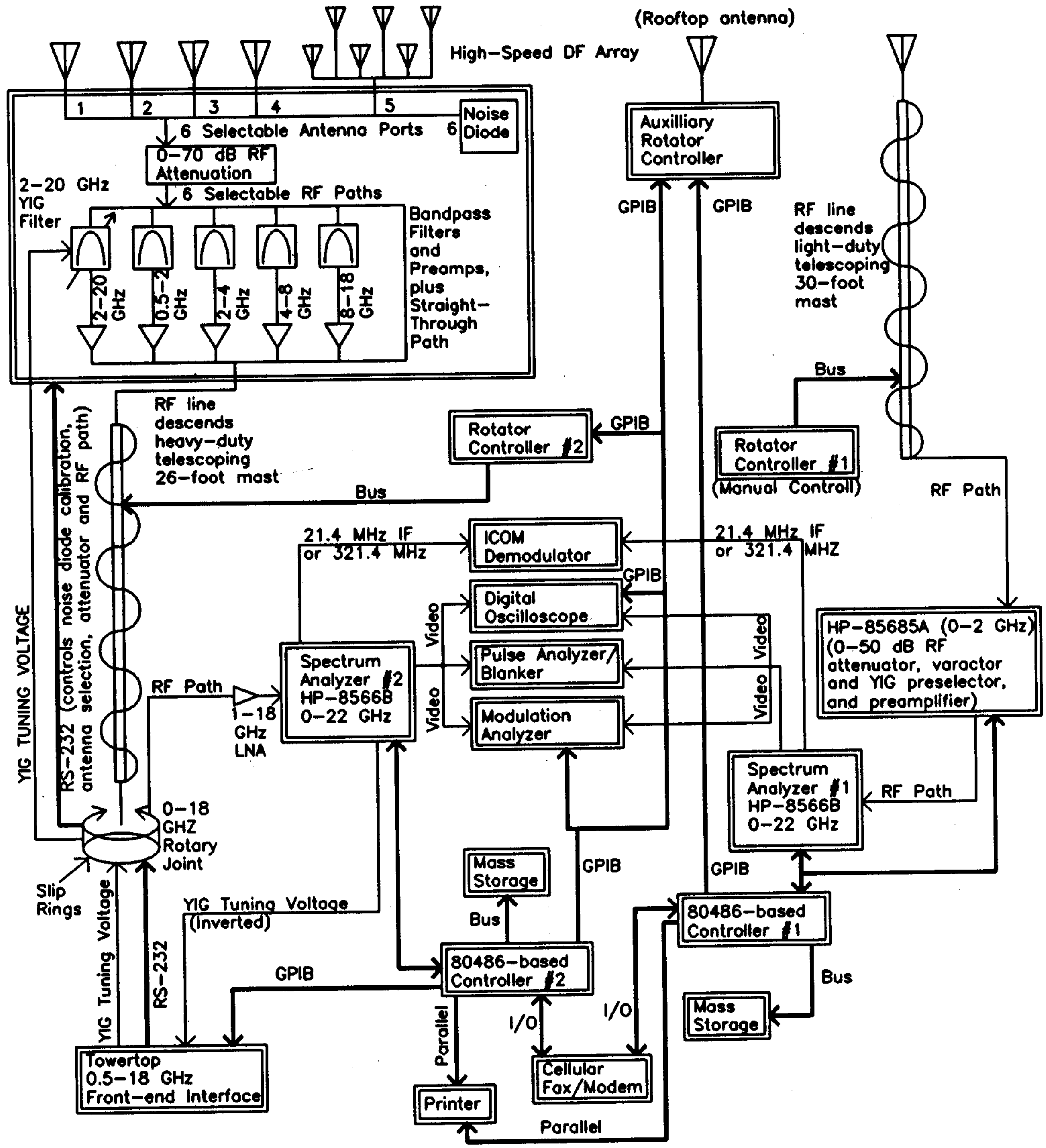


Figure A-3. Block diagram of the RSMS receiver.

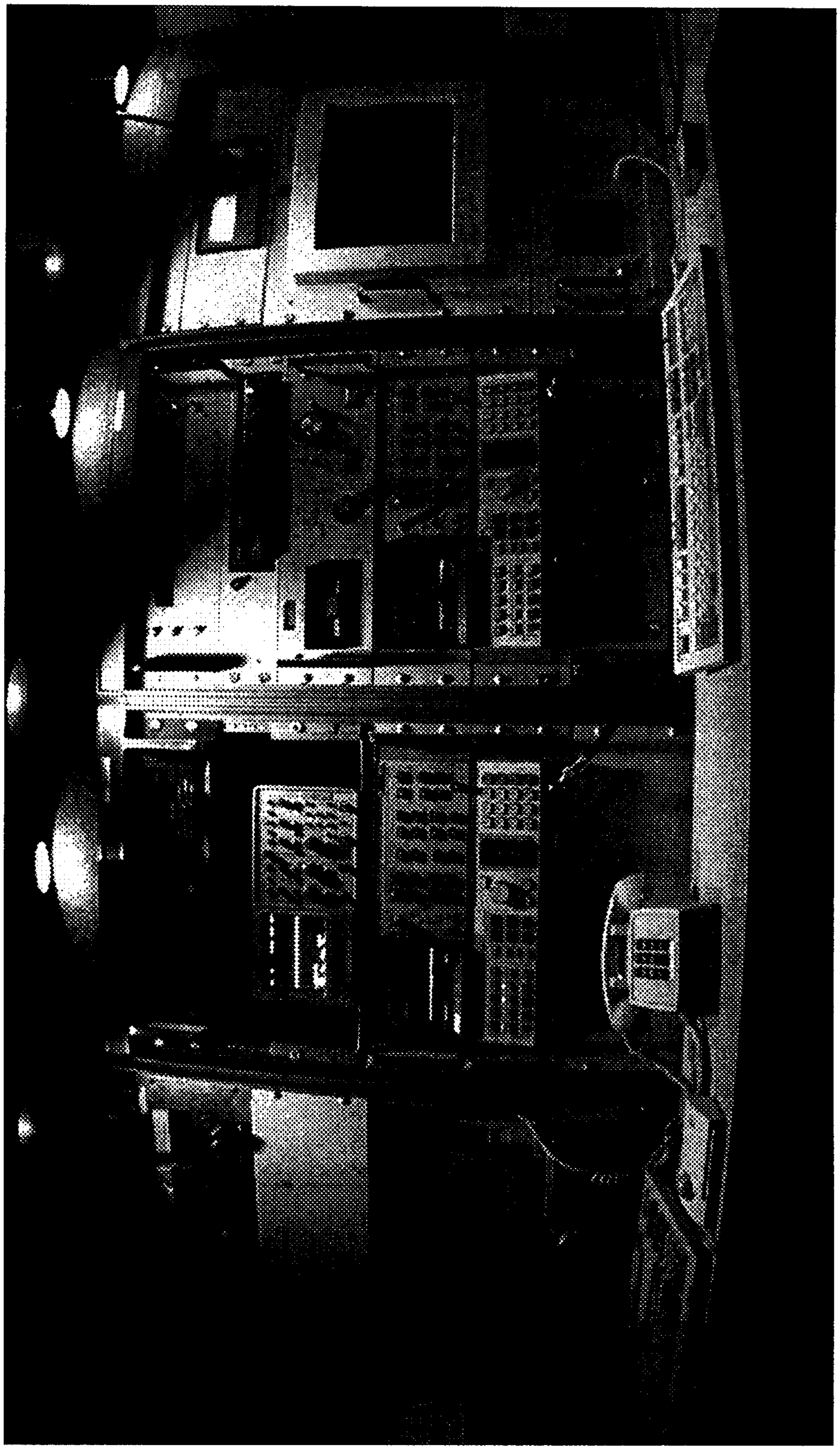


Figure A-4. Front panel photograph of the RSMS instrument racks.

achieve a typical noise figure of 10-15 dB up to about 10 GHz, and a noise figure which increases from 15 to 25 dB at frequencies between 10-20 GHz. Better noise figures can be obtained by using the fixed bandpass filters for preselection instead of the YIG, but that arrangement is tenable only if there are no in-band signals strong enough to overload the preamps.

Table A-1. Available RSMS RF Signal-processing Paths

Frequency Range	RSMS System	Dynamic RF Atten. (dB)	Type of Preselection and Low-noise Preamplification	Noise Fig.* (dB)
100 Hz-2 MHz**	1	0-50	Fixed Bandpass; HP-85685A preamps+	10
2 MHz-20 MHz**	1	0-50	5% Varactor; HP-85685A preamps+	10
20 MHz-100 MHz**	1	0-50	5% Varactor; HP-85685A preamps	10
100 MHz-500 MHz	1	0-50	5% Varactor; HP-85685A preamps	10
500 MHz-2 GHz	1	0-50	Tracking YIG; HP-85685A preamps	10
500 MHz-2 GHz	2	0-70	Fixed Bandpass; 0.5-2 GHz preamp±	10
2 GHz-4 GHz	2	0-70	Fixed Bandpass; 2-4 GHz preamp±	10
4 GHz-8 GHz	2	0-70	Fixed Bandpass; 4-8 GHz preamp±	10-15
8 GHz-18 GHz	2	0-70	Fixed Bandpass; 8-18 GHz preamp±	15-25
2 GHz-20 GHz	2	0-70	Tracking YIG; 1-20 GHz preamp≤	15-25

* Noise figure is measured using a +25 dB ENR noise diode and Y-factor calibration. Calibration is performed at the antenna terminals.

** Due to the shortage of storage space for large antennas, this frequency range is not normally measured as part of an RSMS spectrum survey.

\+ The low-frequency input on the HP-85685A preselector must be used.

± Generally, this path is only used to perform azimuth-scans or special measurements during an RSMS spectrum survey, but may be used for normal survey bands if no high-amplitude signals are anticipated in the measured frequency range.

≤ This path is normally used for all spectrum survey bands (except azimuth-scans, see note 4 above) in the 1 GHz-19.7 GHz frequency range. The YIG and preamplifier nominally operate in the 2-18 GHz frequency range, but have demonstrated adequate performance across a 1-20 GHz range.

A.4 Antennas

The RSMS normally carries a complement of broadband antennas that cover a frequency range of 100 MHz-20 GHz. Other antennas necessary for measurements at higher or lower frequencies are stored at the ITS laboratory. Omnidirectional, slant-polarized biconical antennas are most frequently used for site surveys. These antennas provide a good response to circular, vertical, and horizontal signal polarizations. At frequencies from 100 MHz-1 GHz, a slant-polarized log periodic antenna (LPA) may be used if (as in the Denver survey) most of the radio activity in the area is confined to an area subtending 180° or less relative to the RSMS and a satisfactory omni antenna is not available. Besides the 100-MHz to 1 -GHz LPA, the following omnidirectional slant-polarized biconical antennas are also carried: 0.5-20 GHz, 1-12 GHz, 2-8 GHz, and 8-20 GHz.

In addition to the LPA and omnidirectional antennas, a variety of broadband cavity-backed spiral (CBS) antennas are carried. These have antenna patterns which are most useful for direction-finding using differential methods at relative observation angles of 600 or 900. They are also useful as auxiliary antennas for manual monitoring of emitters or spectrum of special interest and for use on side excursions to measure specific emitters of interest in the area of a site survey. The frequency ranges of these CBS antennas are 1-12 GHz, 8-18 GHz, and 400 MHz-2 GHz. The latter is not normally carried due to its size.

A 1-meter parabolic dish antenna with a linear cross-polarized feed of 2-18 GHz is normally carried. This antenna may be used to perform azimuth-scanning measurements in the common carrier (point-to-point microwave) bands, but is primarily used for measurements on specific emitters (e.g., selected radars).

The receiving antennas are the only components of the RSMS that are not calibrated in the field. Because most RSMS measurements are performed to acquire relative emission levels, rather than absolute incident field strength values, the main requirement for RSMS antennas is that they have a fairly flat gain response as a function of measured frequency. If absolute incident field strengths must be determined for received signals, then the gain factors (or, equivalently, the antenna correction factors) for the applicable antennas are looked up from manufacturer-generated tables and curves, and the RSMS measurements are corrected in a post-acquisition analysis phase.

A.5 Attenuators, Preselectors, and Preamplifiers

All RSMS measurements are made using the RF front-ends depicted in Figure A-3. These front-ends incorporate dynamically switched RF attenuation, preselection, and preamplification. The Hewlett-Packard 85685A is used for frequencies below 2 GHz, and a unit designed and fabricated by ITS is used at frequencies between 2-20 GHz. The two boxes (HP 85685A and ITS designed unit) are functionally similar, but differ in significant details. For example, the 85685A provides 0-50 dB of RF attenuation, and the ITS box provides 0-70 dB of RF attenuation. This active attenuation allows the total dynamic range of the RSMS to be extended to as much as 130 dB.

Effective bandpass preselection is required if low noise preamplifiers (LNAs) are used; this is the case for essentially all RSMS measurements. preselection prevents strong off-tuned signals from overloading the front-end LNAs. At frequencies below 500 MHz, preselection in the HP-85685A is provided by fixed filtering, up to 2 MHz, and by 5% tracking varactors from 2-500 MHz. Tracking YIG filters are used in the frequency ranges of 500 MHz-2 GHz and 2-20 GHz. YIG filters provide the narrowest preselection (15 MHz wide at 500 MHz to about 25 MHz wide at 20 GHz), but at a cost of about 6 dB of insertion loss. Using fixed bandpass filters can reduce the preelection insertion loss to about 1 dB; fixed bandpass filters in an approximately octave progression are available in the ITS front-end (see Figure A-3). These can only be used if no signals are present in the band which are strong enough to overload the" LNAs.

LNAs are used to achieve the best possible sensitivity, coupled with (ideally) just enough gain to overdrive the noise figure of the rest of the measurement system. Operationally, at frequencies below 1 GHz, line losses are sufficiently low to allow placement of the RF front-end inside the operator's compartment with an RF line to the antenna mounted on the mast. At frequencies above 1 GHz, however, the line loss is 10 dB or more, and thus the LNAs (and the rest of the RF front-end) must be positioned at the top of the mast. (Consequently, the mast must be sturdier than the lower-frequency system mast.) If a single LNA at the top of the mast were used, it would have to overdrive about 10 dB of RF line loss, and 25-40 dB of spectrum analyzer noise figure. Thus, to achieve an overall noise figure of 10 dB, (including 6 dB of YIG insertion loss ahead of the LNA) a single LNA would have to have a noise figure of about 4 dB, and a gain of as much as 46 dB. Therefore, low noise preamplification is provided by cascaded preamplifiers located at two points in the high-frequency system: one at the top of the mast (overdriving 10 dB of line loss and about 4-dB noise figure of the second LNA) and one at the input to the spectrum analyzer (to overdrive the analyzer noise figure).

A.6 Calibration

RSMS calibrations are performed with noise diodes and Y-factor excess noise ratio (ENR) techniques described in detail in Section B.5 of Appendix B (Calibration Subroutine). Typically, a noise diode ENR source is used to calibrate an entire signal path for measurements about to be performed. Resultant frequency-dependent noise figure and gain calibration curves are used to automatically correct the measured amplitudes of all received signals. This calibration technique has proven very successful for field-deployed systems. It is a fast way to determine sensitivity and gain correction values for a measurement system, and it is also very useful for isolating the gain and loss factors of individual system components.

A.7 Additional Measurement Capabilities

When deployed for general spectrum occupancy measurements (broadband spectrum surveys), the RSMS is also equipped to perform other measurements. Following are brief descriptions of other measurement capabilities currently available.

Extended Emission Spectra: Measurements of radiated and in-guide emission spectra of individual radio transmitters, particularly radars, are a major strength of the RSMS program. A combination of high sensitivity and interactive front-end RF attenuation make impossible to routinely measure the emission spectra of radio emitters across several gigahertz of spectrum. Specialized RSMS measurement techniques and algorithms support spectrum measurements of intermittently received emitters, such as scanning radars, without the need to interrupt or interfere with their operations. The RSMS uses a stepped measurement routine that allows for measurements that are faster, have more dynamic range, and are more repeatable than swept measurements. Accurately tracked YIG and varactor-tuned preselection make stepped measurements highly resistant to problems of overload from strong center-frequency signals while measuring low-amplitude emissions in adjacent parts of the spectrum.

Azimuth Scan: This special measurement routine is used to determine the receivability of selected signals at particular locations, even if those signals propagate via unconventional (non-line-of-sight) routes. The RSMS dish antenna is rotated through 3600 on the horizon while recording received signal strength. This results in data showing the receivability of signals at all azimuths, and reveals non-line-of-sight propagation routes, if any exist. Azimuth scanning may be used to support spectrum surveys.

Transmitter Equipment Characteristics: The RSMS is capable of measuring and recording signal characteristics of multiple transmitter types. As part of any measurement scenario, certain received signals may be singled out for monitoring and detailed analysis. These special measurements may be used to determine radiated emission characteristics of known transmitters or identify the source of unknown transmissions. Measured transmitter (signal) characteristics include: tuned frequency or frequencies, beam scanning method (regular rotation, sector scan, etc.), beam scan interval, radiated antenna pattern, modulation type (AM, chirped, etc.), pulse width, pulse repetition rate, pulse jitter, pulse stagger, and intra-pulse modulation. Although the RSMS can observe the presence of phase coding in pulsed signals, no phase measurement capability is explicitly included in RSMS capabilities.

APPENDIX B: DATA ACQUISITION (DA) SOFTWARE

B. 1 Introduction

The RSMS is designed to identify and characterize usage at certain frequencies or in selected bands, and to perform in-depth analysis of factors such as system compatibilities with each other or with spectrum assignments. Because of the diverse signal types encountered when measuring an extended spectrum, the measurement system must be able to detect all or at least most of the signals and to display or record as much information about them as possible. Obviously, a general purpose measurement system cannot receive every signal type; however, the RSMS receiver detects almost every signal type encountered. As shown in Appendix A, the RSMS hardware can be configured as a receiver for practically all signal types occurring within an extended frequency range spanning 100 Hz to 19.7 GHz.

The key to efficient use of this extended measurement capability is rapid reconfiguration. The RSMS uses software developed by ITS to control all measurement system functions via computer. This control program, called "DA" (for Data Acquisition), runs on any DOS-based computer with sufficient memory. It interfaces via general-purpose interface bus (GPIB) with the measurement system at rates limited only by the computer's operating speed and functional speed of the managed hardware (interfaces, switches, components, etc.). DA will support any available combination of RF front-ends, spectrum analyzers, and auxiliary analysis equipment. DA also controls noise diode calibration of the RSMS and characterizes the noise figure and gain for individual components and entire measurement signal paths.

The DA program is basically four control subroutines that direct operation of multiple subroutine kernels that in turn control every function of the measurement system. This appendix includes descriptions of the four control subroutines (receiver algorithm, spectrum analyzer, RF front-end, and calibration) and the resultant system functions. As DA program development continues to meet new measurement demands, these functional descriptions may change with time.

B.2 Receiver Algorithm Subroutine

The DA receiver algorithm subroutine provides software management for up to 32 measurement algorithms (called program kernels in DA or band events for RSMS operations, see Section 2.3. 1). Any one of these algorithms, when coupled with spectrum analyzer and front-end selections (described later in this appendix), becomes a customized measurement system for receiving certain signals or signal types. Because the characteristics of emitters and the requirements for data on those emitters vary considerably, many different algorithms have been developed. However, all of the algorithms are based upon either a frequency sweep across the spectrum of interest, or a series of discrete steps across that spectrum.

For spectrum surveys, sweeping algorithms are generally used to examine spectral bands occupied by high duty cycle emitters such as mobile radios and television transmitters, and stepping algorithms are used to monitor spectral bands occupied by low duty cycle emitters such as radiolocation equipments (radars). Following are brief descriptions of the algorithms used during the Denver survey.

Swept: This algorithm controls a conventional spectrum analyzer[1] sweep across a selected portion of spectrum. Any type of detection available in the analyzer (i.e., positive peak, sample, etc.) can be used. Repeated sweeps may be programmed, and multiple sweeps incorporating the maximum-hold spectrum analyzer mode may also be performed. This algorithm also allows for sweeping a spectral band in several sub-bands (scans). This feature is important if a narrow bandwidth (e.g., 10 kHz) must be used to measure a spectral band that is more than 1000 times the width of the measurement bandwidth, e.g., measuring 900-930 MHz with a 10-kHz bandwidth requires at least three scans to ensure no loss of data.

Swept/m3: This is a swept measurement (as described above) that produces three data traces across a measurement range. At each of the 1000. frequencies measured on each individual spectrum analyzer sweep, the maximum, minimum, and (linear) mean received signal levels are measured. Repeated sweeps are made across the spectrum of interest, and for each of the measurement points returned from each sweep, the three registers for current maximum, minimum and mean are updated. This process continues until it is halted programmatically. The total amount of time for each sweep, and the total number of sweeps to be performed, are specified in advance by the operator. The duration of each individual sweep may be a few milliseconds, with a typical Swept/m3 measurement (hundreds of sweeps) lasting a total of several minutes. These cumulative three-trace Swept/m3 measurements are saved on magnetic media, and may themselves be cumed (see Section 3.3) in the analysis, phase of a site survey to yield long-term Swept/m3 curves. Typical RSMS site surveys use Swept/m3 measurements for mobile radio bands.

Stepped: Stepping measurements consist of a series of individual amplitude measurements made at predetermined (fixed-tuned) frequencies across a spectrum band of interest. The measurement system remains tuned to each frequency for a specified measurement interval. This interval is called step-time, or dwell. The frequency interval for each step is specified by an operator, and is usually about equal to the IF bandwidth of the measurement system. For example, measurements across 200 MHz might use 200 steps at a 1-MHz step interval and a 1-MHz IF bandwidth. Computer control of the measurement system is needed for this (step, tune, and measure) process to be performed at maximum speed.

Stepped measurements are usually performed to capture peak signals occurring on an intermittent basis. A prime example is a periodically scanning radar. If the step-time (dwell) is set slightly longer than the interval between visitations of the radar beam, then the maximum receivable level from the beam will illuminate the RSMS at some time during that interval. The RSMS, which is fixed-tuned for the entire dwell period, records each peak-detected point during that interval and the maximum amplitude recorded is saved for that frequency. The RSMS then tunes to the next frequency (one step), and repeats the process until the entire specified spectrum has been measured.

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[1] For spectrum surveys and most RSMS operations with DA software control, any GPIB interfaced spectrum analyzer that processes at least 1000 points (frequencies) per display sweep may be used.

For intermittently received signals, such as scanned-beam radars, the stepped algorithm has advantages over swept measurements. Stepping is faster, allows more dynamic range (attenuation can be added and subtracted as a function of measured frequency to extend the total available dynamic range of the measurement system), and has better repeatability than swept measurements.

The RSMS uses stepped measurements to gather data in radiolocation bands where measurements can be tailored to transmitter characteristics; i.e., dwell times, IF bandwidths, step widths, etc. are determined as a function of the parameters of the radiolocation equipments which normally operate in the band.

Swept/az-scan: This is not currently a selectable algorithm in DA, but is a hybrid routine using the Swept algorithm (above) with a rotating dish antenna. The dish is targeted on the horizon then rotated 360° while the Swept algorithm is running with positive peak detection and Maximum-Hold screen mode on the spectrum analyzer. The result is an analyzer display that shows the maximum activity across a band in an omnidirectional receiver sense, but with the effective gain of a dish antenna. This routine is most useful for nondynamic bands where received signal levels tend to be weak. Good examples are the common carrier (point-to-point) microwave bands; their transmitters are fixed-tuned, operate continuously, and do not move. The transmitters are also low-powered, and use high-gain antennas which further reduce their probability of intercept.

B.2.1 Receiver Parameters

Following are brief descriptions of the DA program input parameters needed to run the above subroutines (algorithms). Brackets identify the corresponding column headings as they appear in the band event tables of Section 2.3.1. For example, [algor] in the tables shows which of the above described subroutines (algorithms) is controlling the band event.

Start and Stop Frequencies [start (MHz)] [end (MHz)]: The value in MHz of the first and last frequency point to be measured. These numbers must be equal to or fall outside the event frequency band range.

Passes: The number of times the algorithm iterates for each run command. This value is always one for spectrum surveys.

Scans [scns #of]: The number of measurement sub-bands to occur between the start and stop frequencies. This value is usually determined by comparing measurement bandwidth and frequency range. For example, a 30-MHz frequency range measured with a 100-kHz IF bandwidth would ensure sampling of all frequencies (1001 points) in one scan. However, if a 10-kHz IF bandwidth were used in the above example, three scans would be required to ensure sampling of all frequencies.

The Sweeps [swps#of]: The number of sweeps in each scan. DA processes each sweep so increasing this number can add greatly to measurement time; however, increasing this value also increases the probability of intercept for intermittent signals.

Steps [steps #of]: The number of frequency steps to occur between the start and stop frequencies. This parameter is only used with stepped algorithms.

Graph Min and Graph Max: The minimum and maximum values in dBm for the graphical display of measured amplitude data.

B.3 Spectrum Analyzer Subroutine

The DA spectrum analyzer subroutine manages configuration control strings (via GPIB) for the spectrum analyzer. The operator selects spectrum analyzer parameters (listed in the following subsection) from menus in the DA program. Generally, parameters are selected that will configure the analyzer to run with a receiver algorithm for a desired measurement scenario. DA protects against out-of-range and nonlinear configurations but the operator can control the analyzer manually for unusual situations.

B.3.1 Spectrum Analyzer Parameters

When the DA program sends command strings to the analyzer, all signal path parameters are reset according to the operator selections for the measurement scenario. Following are brief descriptions of the analyzer parameter choices controlled by DA. Brackets identify the corresponding column headings as they appear in the band event tables of Section 2.3.1.

Attenuation: May be adjusted from 0-70 dB in 10-dB increments. The spectrum analyzer subroutine determines whether or not RSMS front-end attenuators are available and if so will set them to the selected value. Spectrum analyzer attenuation is set to zero when RSMS attenuation is active, if however, RSMS attenuators are not available the spectrum analyzer attenuation will be set to the selected value.

IF Bandwidth [IFBW (kHz)]: May be selected from 0.01-3000 kHz in a 1, 3, 10 progression.

Detector [detecl: Normal, positive peak, negative peak, sample, maximum hold, and video average modes are available. See Appendix C for discussions on detector selection for receiver algorithms.

Video Bandwidth [VBW (kHz)]: May be selected from 0.01-3000 kHz in a 1, 3, 10 progression.

Display: Amplitude graticule choices in dB/division are: 1, 2, 5, and 10. This parameter selection applies to both the analyzer and the system console displays.

Reference Level [RL (dBm)]: May be adjusted from -10 to -70 dBm in 10-dB increments.

Sweeps [mh/va #swpsl: Number of analyzer processed sweeps per scan. This parameter is only used with maximum hold or video averaged detection.

Sweep Time [swp/stp tm(sec)]: This parameter (entered in seconds) specifies sweep (trace) time if used with swept algorithms, or specifies step-time (dwell) if used with a stepped algorithm.

B.4 RF Front-end Subroutine

The DA software handles the RF front-end path selection differently than other routines. Most of the RF-path parameters are predetermined by the measurement algorithm so operators need only select an antenna and choose whether preamplifiers are turned on or off. preselection is also controlled by the antenna selection.

The antenna selection is made from a list of antenna choices that is stored in a separately maintained library file called by the RF Front-end Subroutine. Antenna information stored in the file includes:

- antenna type (omni, cavity-backed, etc.);
- manufacturer (may include identification or model number);
- port (tells the computer where signals enter the RSMS and includes particulars on any external signal conditioning such as special mounting, additional amplifiers, or extra path gain or loss);
- frequency range;
- vertical and horizontal beam widths;
- dB gain;
- front to back ratio; and
- side lobe levels.

B.5 Calibration Subroutine

The calibration subroutine may be run at any time the operator chooses, but measurements must be interrupted. The software is interactive and flexible, allowing the operator to. choose any calibration path desired. RSMS calibrations are performed with noise diodes and Y-factor excess noise ratio (ENR) techniques. Typically, an entire signal path is calibrated with a noise diode ENR source; a noise diode-is connected at the point where the RF line attaches to the receiver antenna. The connection may be accomplished manually or via an automatic relay, depending upon the measurement scenario. The noise level in the system is measured across the desired frequency range with the noise diode turned on (diode on) and turned off (diode off). The measured difference between the conditions of diode on vs. diode off is compared to the known ENR of the diode (typically +25 dB for RSMS diodes). From these measured values, noise figure and gain calibration curves for the entire signal path are stored in the computer. These frequency-dependent curves are used to automatically correct the measured amplitudes of all received signals in subsequent measurements. This calibration

technique has proven very successful for field-deployed systems. It is a fast way to determine sensitivity and gain correction values for a measurement system, and it is also very useful for isolating the gains and losses through individual components of the measurement system, such as RF lines and amplifiers.

APPENDIX C: INTERPRETATION OF SPECTRUM SURVEY DATA

C.1 Introduction

RSMS spectrum survey measurements are performed with a variety of receiver algorithms (see Section B.2 of Appendix B). These algorithms provide various combinations of frequency sweeping or frequency stepping, positive peak or sample detection, and data processing capabilities during the data acquisition phase of the spectrum survey. Additional processing is performed on the data after the acquisition phase. Measurement algorithms are assigned on an individual basis to optimally measure spectrum use in each band.

Each algorithm has a particular response to noise and signal activity. It is critical to understand the noise and signal response of each algorithm if the RSMS data are to be used accurately. This appendix describes the algorithms currently used for RSMS site surveys. The noise and signal response of each algorithm is described, along with the types of spectrum occupancy it is best suited to measure. Some of the data processing techniques are also discussed to fully explain the measurement algorithms.

C.2 Signal Probability of Intercept Factors

RSMS measurements are intended to achieve a high probability of intercept for the types of signal activity occurring in each spectral band. Factors that are considered include:

> the types of emitters allocated to the band (e.g., land mobile radio, radiolocation, or broadcasting);

> the percentage of time individual transmitters in the band typically operate (e.g., 100% on-air time by broadcasters vs. intermittent radio dispatch messages);

> the dependence (or nondependence) of band activity on diurnal and other cyclic occurrences (e.g., radionavigation beacons with no time dependence vs. marine mobile activity which varies as a function of time-of-day and day-of-week);

> the time interval that individual transmissions usually occupy (e.g., air traffic control communications vs. cellular telephone communications);

> the periodicity, if any, of individual transmissions (e.g., a highly periodic search radar beam that completes a rotation every 4 seconds vs. mobile communications that occur in a random distribution over time);

> the directional gain, if any, of antennas used by the transmitters (e.g., an omnidirectional navigation beacon vs. a point-to-point microwave link);

> the typical peak and average power outputs of transmitters in the band (e.g, 4 megawatts peak power from a radar vs. perhaps a fraction of a watt from a typical land mobile radio);

> the signal duty cycle (e.g., a 30 dB duty cycle for a typical radar vs. a near 0 dB duty cycle for a two-way radio transmission);

> the relative abundance or paucity of systems using the band (e.g., a band used largely by airborne fire-control radars vs. a band used by thousands of local voice-communication radios); and

> the polarization of typical transmitted signals in the band.

These factors are used to optimize the receiver parameters for the selected band, select the measurement algorithm, and determine how measurement time should be allocated. The relative amount of time devoted to measure each band is roughly proportional to the dynamics of band usage. For example, point-to-point microwave bands are not very dynamic, because the transmitters in these bands normally operate 24 hours/day, 365 days/year, at uniform power levels, fixed modulations, and fixed beam. directions. Their operations are not normally affected by external factors, such as weather or local emergencies. Consequently, these bands are measured only once during a spectrum survey. In contrast, activity in land mobile radio bands is highly dynamic, varying significantly with time-of-day, day-of-week, and other factors such as local emergency conditions. Consequently, these bands are measured frequently throughout a site survey, so that a maximal number of time-dependent signals will be intercepted. Slightly less dynamic bands, such as those used by tactical radars, are measured less frequently than the mobile bands, but more frequently than the point-to-point microwave bands. Bands whose use varies with local weather, such as those used by weather radars, are measured on different clear-weather and foul-weather schedules.

Swept-spectrum measurement techniques are used in highly dynamic bands. Stepped-spectrum techniques are used in bands occupied by periodic emitters, such as radars. A slow dish antenna sweep of the horizon coupled with simultaneous swept-spectrum measurements is used in point-to-point microwave bands. These measurement techniques are detailed in the following subsections.

A parabolic antenna is used to measure signals from fixed-beam, highly directional transmitters in the point-to-point microwave bands (see the description of azimuth scanning in Section C.8). For bands in which signals are expected to originate primarily from a single quadrant as seen from the RSMS location, a moderately directional antenna (such as a cavity-backed spiral or a log-periodic antenna) is used. For bands in which signals are expected to originate from any direction with an approximately constant probability, such ‘as bands used by airborne beacon transponders and air-search radars, the RSMS uses omnidirectional antennas.

Slant (antenna) polarization is used for all RSMS measurements except those in the point-to-point microwave bands. Slant-polarized biconical omnidirectional antennas are usually used above 1 GHz, and slant-oriented log periodic or conical omni antennas are usually used below 1 GHz. Slant polarization provides adequate response to all signals except those having a slant direction orthogonal to the RSMS antennas. Orthogonally-oriented slant-polarized signals are rare. In the point-to-point microwave bands, the transmitted signals are always vertically or horizontally polarized, and thus RSMS receive polarization in those bands is alternately vertical and horizontal, with the results being combined into a composite scan.

The end result of these selections (number of measurements made in each band, selection of antenna type and polarization, and selection of measurement algorithm) is to optimize the probability of intercept for signals present during the course of the RSMS site survey. Inevitably, some signals will be missed; however, the standard RSMS spectrum survey data set should provide a good measure of the relative number, levels, and types of signals in each of the bands between 100 MHz and 19.7 GHz.

C.3 Overview of Swept Measurement Techniques

To fully understand the measurement algorithms described in this appendix, it is necessary to describe how the spectrum analyzers perform swept-frequency measurements.

The HP-8566B spectrum analyzers used in the RSMS sweep across the spectrum in individual segments called spans. The frequency range of each span is in turn broken into 1001 individual frequency bins. When the spectrum analyzers perform sweeps across a selected span, they spend a finite amount of time measuring received power in each of the 1001 bins. For example, a 20 ms sweep time divided by 1001 measurement bins per sweep yields a 20-us measurement time in each frequency bin. Within each bin measurement interval (in this example, 20 us), the power measured in the waveform may take on multiple values. However, the spectrum analyzer can only provide a single power measurement per bin.

The single value derived from the multiple values occurring within each bin sampling interval depends upon which spectrum analyzer detector mode has been selected. The detector modes available in the RSMS spectrum analyzers are positive peak, negative peak, sample, and “normal.” (Note: positive peak detection is different from the maximum-hold display mode discussed in Section C.6.) Positive peak detector mode will latch to the highest power value assumed by the measured waveform during the sampling interval (continuing the example above, this would be 20 us) for each bin. Similarly, the negative peak detector mode latches to and displays the lowest power level measured during each bin interval. In sample detector mode, the value displayed is the power level that the input waveform has assumed at the end of the bin measurement interval. If the bin sampling interval is uncorrelated with respect to the input waveform, then this value can be considered to be randomly selected from the input waveform. Finally, in “normal” detection mode, alternate bins use positive peak and negative peak detection.

If the analyzer’s video bandwidth is substantially narrower than the IF bandwidth, and if a white noise source (such as thermal electron noise in a circuit or a noise diode) is being measured, then the root mean square (RMS) value of the noise will be displayed, irrespective of the detector mode which has been selected.

If the analyzer’s video bandwidth is equal to or greater than the IF bandwidth, and if a white noise source is being measured, then the displayed power level will vary as a function of the detector mode. Positive peak detection will display noise values approximately 10-12 dB higher than the RMS noise level, and negative peak will display values about 10-20 dB below the RMS noise level. “Normal” detection used on such a noise source will display an illuminated band about 20-30 dB wide, with an average value equal to the RMS level of the noise. Normal detection mode is useful for estimating the duty cycle of a signal (the wider the illuminated band underneath a signal peak, the lower the duty cycle of the signal).

C.3.1 Description of the Swept/m3 Measurement Algorithm

The Swept/m3 algorithm, developed by ITS, is an extension to the swept measurements just described. In Swept/m3 mode, frequency-domain data traces are measured repeatedly across a band on the spectrum analyzer. Each sweep is returned individually to the PC controller, but the data traces are not individually recorded. Instead, for each of the 1001 frequency bins that the analyzer returns in each sweep, the PC sorts the returned values as follows: the value in each bin is compared to the highest and lowest values so far observed in that bin, and if the new value represents a new maximum or minimum' in that bin, then it is saved as such. (This is, in effect, a software-implemented version of maximum-hold and minimum-hold trace mode.) Also, the current value of each bin is included in a running average of all the values returned for that bin in previous sweeps. This is an average of measured power in the selected detector mode (that is, the antilogs of the returned decibel values are averaged). Thus, the maximum, minimum, and mean (m3) signal levels in a band are simultaneously obtained over the time interval (typically several minutes) that the spectrum analyzer continues sweeping.

Swept/m3 measurements compress data volume by several orders of magnitude by performing real-time cuming. This compression causes loss of the original data sweeps, and thus precludes the possibility of processing the data with different algorithms during postmeasurement analysis. Figure C-1 shows how the Swept/m3 cumulative processing is integrated with the normal RSMS processing path. All other cumulative processing is accomplished during postmeasurement analysis.[1] In the diagram, all measured data identified as "RSMS data output for lab analysis" is considered to be postmeasurement data.

C.4 Description of Swept/m3/Sample Data Collection

If the Swept/m3 algorithm (described in Subsection C.3.1) is performed using the sample detector (see Section C.3 for a description of the sample detector in the RSMS analyzers), then the data are referred to as "Swept/m3/sample."

C.4.1 Interpretation of Noise Responses in Swept/m3/Sample Data

The noise level displayed by a measurement system using the sample detector will be equal to [kTB + (measurement system noise figure)].[2] With a 1 -MHz IF bandwidth and a 10-dB measurement system noise figure, for example, the average noise level would occur at -104 dBm.

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[1] All band events measured more than once during the same survey are cumed. As explained in this appendix, stepped and swept data records are processed for maximum, mean, and minimum received signal levels. Swept/m3 data scans already contain this information so a maximum of maximums, mean of means, and minimum of minimums is extracted for survey graphs.

[2] kTB is derived from the Nyquist Theorem for electron thermal noise, where: k is Boltzmann's constant ($1.38*10^{-20}$ mW*s/K), T is system temperature (290 K for these measurements), and B is measurement IF bandwidth in Hz. At room temperature, kTB = -174 dBm/Hz. In a 1-MHz IF bandwidth, kTB = $-174 + 10\log(10^6) = -114$ dBm.

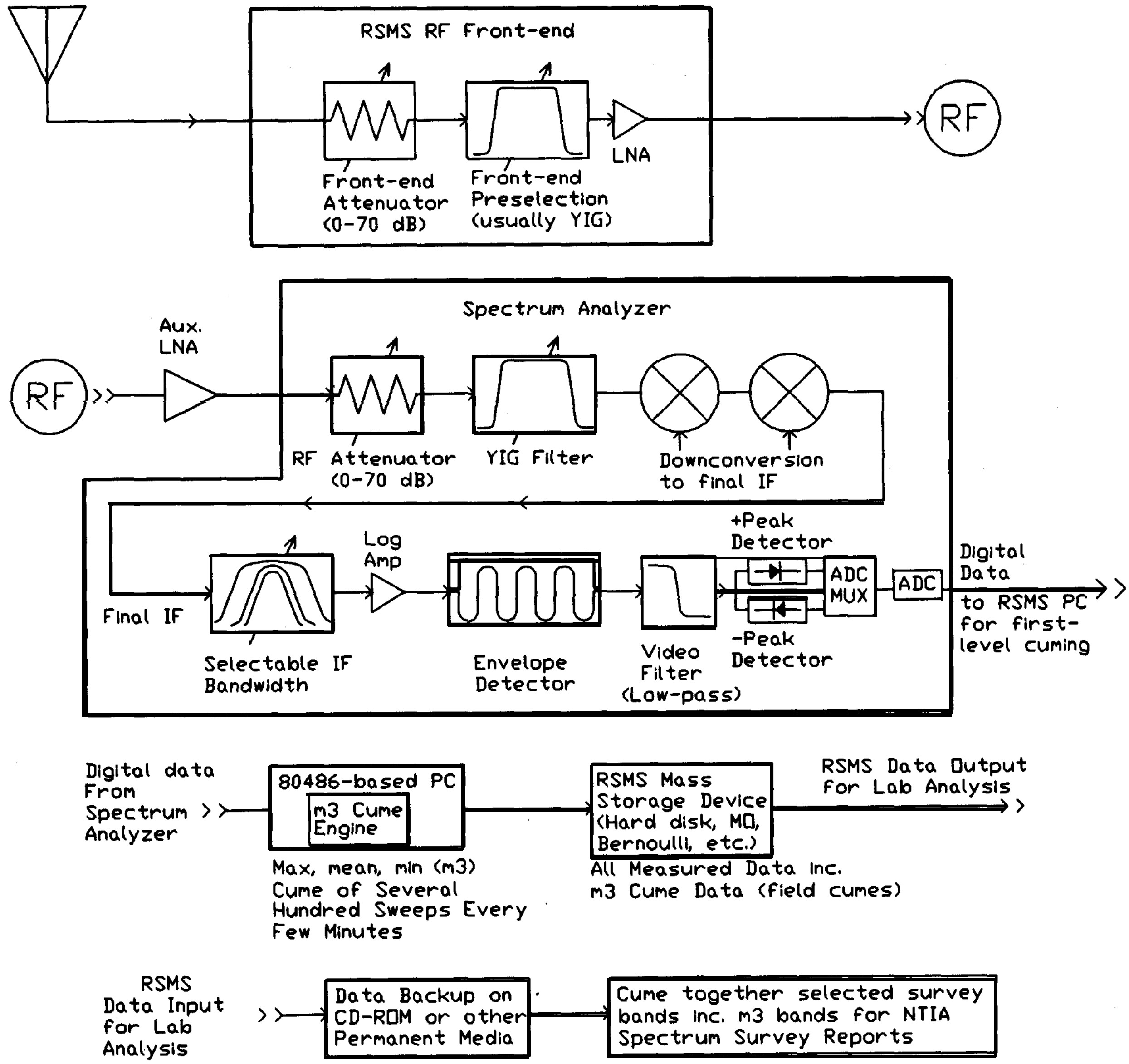

Figure C-1. Functional diagram of the RSMS signal processing path for cumulated data.

If the video bandwidth (that is, the post-envelope detector, low-pass filtering bandwidth) is significantly narrower than the IF bandwidth, then the variance in the measured average noise will be very small (approximately 1 dB). This mode is normally used only for calibrations in the RSMS.

However, if the video bandwidth is set to a value equal to or greater than the IF bandwidth (which is the case for RSMS spectrum survey measurements), the the maximum level sample on thermal noise will be about 10-12 dB above the average, and the minimum level sample on thermal noise will be about 10-20 dB below the average.

During the Denver survey, during some scans, the spectrum analyzer reference level was set too high. As a result, the minimum traces on some Swept/m3 data were gain-compressed. In such cases, the minimum trace is less than 10 dB below the average trace. Noise reference levels are marked on the Y-axis of many survey data scans in Section 3.4.

C.4.2 Interpretation of Signal Responses in Swept/m3/Sample Data

Because the sample detector value displayed for each bin is the value of the waveform at the end of each bin interval, the value displayed for a signal with a duty cycle of 100% will be equal to the peak power of the signal (if the signal was present for the entire bin interval). However, if a signal has less than a 100% duty cycle (and is not present during the entire bin interval), then the probability that the signal will be sampled is less than one. For example, if the signal is only present for half of the bin interval, there is only a 50% chance that the sample detector will capture the value of the signal (and a 50% chance that the measurement system's thermal noise will be measured and displayed). For typical radar signals, which operate with a duty cycle of about 1:1000, the probability that a bin will display the radar signal value is only about 1/1 000 (0.1%). The same rationale holds for impulsive noise; sample detection mode tends to display high-duty cycle signals, but not low-duty cycle signals such as radars and impulsive noise. This makes sample detection a desirable option for measurements in bands handling mobile communications, where the signals of interest have high-duty cycles, and where measurement of impulsive noise is not desirable for the purposes of the RSMS project.

For Swept/m3/sample data, the highest curve shows the maximum signal ever captured by the sample detector on any trace at each measured frequency. This represents the highest value ever attained by high-duty cycle signals at each measured frequency; impulsive energy could have been present at even higher values, but would have been discriminated against by the sample detector. At frequencies where no signal was ever measured, the maximum curve will have a value of kTB + measurement system noise figure + (nearly) 10 dB. This value will be 10 dB higher than the average noise (middle) curve. Since a signal displayed on the maximum curve can occur with different amplitudes at different times, there is no way to determine, solely from examination of the maximum curve, how frequently the displayed signals were measured.

The middle curve of Swept/m3/sample data shows the power-average (average of the antilogs of the measured decibel values) of all of the raw data traces gathered in the band. Qualitatively, the closer this curve comes to the maximum curve at any given frequency, the higher the percentage of scans in which the signal was observed. Quantitatively, it is not possible to derive an actual percentage of scans in which the signal was present. This is because the signal may not have always been received at the same level, and the level received on raw scans is not recorded. If, however, the average curve comes close to touching the maximum curve, then the signal was probably present in nearly 100% of the raw data traces. Conversely, if the maximum and mean curves are far apart, then the signal was probably observed in a lower percentage of raw data scans. If no signals were ever measured at any given frequency, then the middle curve will show measurement system noise at a value of kTB + measurement system noise figure, about 10 dB below the maximum noise curve.

Finally, the lowest curve shows the minimum power level ever measured in any raw data trace, at each measured frequency bin. If no signal is measured in a bin during any sweep, then this curve will have a value of: kTB + measurement system noise figure - (10-20 dB). This is 10-20 dB lower than the average curve. If a signal is present in 100% of the measurement sweeps, then a bump will occur in the minimum curve at that frequency. The amplitude of the bump will be equal to the minimum power measured for the signal. Thus, this curve serves the purpose of showing signals which are continuously present during the spectrum survey. (Note: During the Denver spectrum survey, the reference level for the spectrum analyzer was sometimes set too high, and as a result the minimum curve for Swept/m3 data was gain-compressed at a level which is less than 10 dB below the average curve.)

C.5 Description of Swept/m3/ + peak Data Collection

If the Swept/m3 algorithm is performed using the positive peak (+ peak) detector (see Section C.3 for a description of the + peak detector in the RSMS spectrum analyzers), then the data are called "Swept/m3/ + peak."

C.5.1 Interpretation of Noise Responses in Swept/m3/ + peak Data

The average noise level displayed by a measurement system using a + peak detector will be equal to kTB + measurement system noise figure + approximately 10-12 dB. With a 1-MHz IF bandwidth and a 10-dB measurement system noise figure, for example, the average + peak noise level would occur at -174 dBm/Hz + 10log(10^6 Hz) + 10 dB noise figure + 10 dB peak detector offset = -94 dBm.

If the video bandwidth (the post-envelope detector, low-pass filtering bandwidth) is equal to or greater than the IF bandwidth (which is the case for RSMS site survey measurements), and if the sweep time is short (a few tens of microseconds per bin), then the maximum level sampled on thermal noise will be about 10 dB above the average; the minimum level of thermal noise will be about 10 dB below the average. Note that this + or - 10 dB value for maximum and minimum levels of + peak noise is the same as the + or - 10 dB offset levels for sample detection, but that the maximum, mean, and minimum peak-detected levels are 10 dB higher than the corresponding sample-detected levels.

Positive peak detection shows less than a + or - 10 dB difference between the maximum, mean, and minimum as sample times increase (i.e., as sweep times become longer). This is because the positive peak detector will have a higher probability of latching to a high noise level if it samples the noise for a relatively long interval. In this case, the minimum and average noise levels will approach the maximum noise level to within a few dB. The maximum will be 2-3 dB higher than the short sweep-time values.

C.5.2 Interpretation of Signal Responses in Swept/m3/ + peak Data

Because the + peak detector latches to the highest value that the waveform assumes during each bin interval, the value displayed for a signal will be equal to the peak power of the signal (assuming that the measurement system is not bandwidth-limited in its response) regardless of the signal's duty cycle. This makes + peak detection mode useful for measuring impulsive activity such as radar signals. (This also means that + peak detection will also record impulsive noise in the spectrum.) Thus, the + peak detector is used in RSMS spectrum surveys to measure radiolocation bands and other bands where activity is dominated by impulsive (low-duty cycle) transmissions.

For Swept/m3/+ peak data, the highest curve shows the maximum signal ever captured by the + peak detector on any trace in each measured frequency bin. At frequencies at which no signal was ever measured, the maximum curve will have a value of kTB + measurement system noise figure + about 10-dB peak detector offset + 10 dB. If the sweep time is short (a few tens of microseconds per bin), this will be about 10 dB higher than the average peak detector response. If the sweep time is much longer, the average will be higher, coming to within a few dB of the maximum. There is no way to determine, solely from examination of the maximum curve, how frequently the displayed signals were observed.

The middle curve of Swept/m3/ + peak data shows the power-average (average of the antilogs of the measured decibel values) of all the data traces that were gathered in the band. Qualitatively, the closer this curve comes to the maximum curve at any frequency, the higher the percentage of scans in which the signal was observed. Quantitatively, it is not possible to derive a percentage of time the signal was present, because the signal may not always be received at the same level. If, however, the average curve nearly touches the maximum curve, then the signal must have been present in nearly all of the raw data traces. Conversely, if the maximum and mean curves are far apart, then the signal was probably observed in a low percentage, of scans. If no signals were measured at a frequency, and if sweep time is a few tens of milliseconds, the middle curve will show measurement system noise at a value of kTB + measurement system noise figure + about 10 dB peak detector offset. This value will be nearly 10 dB higher if the sweep time is appreciably longer.

Finally, the lowest curve shows the minimum power level measured with the + peak detector in any sweep, in each frequency bin. If no signal is measured at a frequency, and if the sweep time is a few tens of milliseconds, this curve will have a value of: kTB + measurement system noise figure + about 10 dB peak detector offset - 10 dB, which is 10 dB lower than the mean peak detector curve. If the sweep time is longer, the minimum curve will approach the maximum and mean curves. If a signal is observed at a frequency in every data sweep, then a bump will occur in the minimum curve at that frequency. Thus, this curve shows signals that are continuously present during the spectrum survey.

C.6 Description of Swept/Max-Hold Data Collection

If a frequency-sweeping algorithm is performed using the + peak detector (see Section C.3 for a description of the + peak detector in the RSMS spectrum analyzers) while the spectrum analyzer display is being operated in the Maximum-Hold mode[3], then the data are referred to as "Swept/max-hold"

[3] In Maximum-Hold mode, the spectrum analyzer repeatedly sweeps a portion of spectrum, and saves the highest value measured in any sweep in each screen display bin. Thus, Maximum-Hold mode generates a maximum-level trace which is analogous to the maximum-level trace generated by RSMS software in the Swept/m3/ + peak mode.

The measured data are peak-detected, maximum-hold scans. Each scan represents an interval of a few minutes of maximum-hold running on the measurement system. The scans do not contain mean or minimum information. They are intended only to show the presence of intermittent, low-duty cycle signals, and therefore no additional information is obtained.

The individual scans are cumed for the site survey report, and as a result, the final graphs show maximum, minimum, and mean curves. However, the distribution of maximum-hold data is narrow when noise is being measured, and so the difference between these curves is only about + or - 3 dB on noise, instead of the + or - 10 dB difference which usually characterizes Swept/m3 data.

C.6.1 Interpretation of Noise Responses in Swept/max-hold Data

The maximum, mean, and minimum curves displayed by a measurement system will be nearly identical if the hold time is more than a few tens of microseconds per bin. If white noise is measured, the three curves will all have a value of about kTB + measurement system noise figure + about 10-dB peak detector offset + 10 dB. With a 1-MHz IF bandwidth and a 10-dB measurement system noise figure, for example, the noise level is about -174 dBm/Hz + 10log(10^6Hz) + 10 dB noise figure + 10-dB peak detector offset + 10dB = -84 dBm.

If the video bandwidth is equal to or greater than the IF bandwidth, then the maximum level sampled on thermal noise in maximum-hold mode is about 2 dB above the mean, and the minimum level sampled on thermal noise is about 2 dB below the mean.

C.6.2 Interpretation of Signal Responses in Swept/max-hold Data

Swept/max-hold measurement mode is ideal for capturing low-duty cycle signals from intermittently operating systems. It can be used in bands occupied by impulsive emitters that operate intermittently (e.g., airborne radars). A Swept/max-hold measurement displays the maximum activity observed in a band for an interval of a few minutes. No information is collected to indicate mean or minimum activity during that interval.

For cumed Swept/max-hold data, the highest curve shows the maximum signal ever captured by the + peak detector on any maximum-hold trace at each measured frequency. Since a signal displayed on the maximum curve could have occurred with different amplitudes at different times, there is no way to determine, solely from examination of the maximum curve, how frequently the displayed signals were actually observed.

The middle curve of cumed Swept/max-hold data shows the power-average (average of the antilogs of the measured decibel values] of all individual maximum-hold data traces that were measured in the band. Qualitatively, the closer this curve comes to the maximum curve at a frequency, the higher the percentage of scans in which the signal was observed. Quantitatively, it is not possible to derive an actual percentage of time that the signal was present, because the signal may not have always been received at the same level. If the mean curve nearly touches the maximum curve, then the signal must have been present in most of the. raw data traces. If no signals were ever measured at any given frequency, then the middle curve will be about 3 dB lower than the maximum curve.

Finally, the lowest curve shows the minimum power level ever measured with the + peak detector in any maximum-hold data trace, at each measured frequency. If a signal was present in every scan, then the curve shows a bump at that frequency. Otherwise, the curve will show noise 3 dB below the mean curve. Thus, this curve serves the purpose of showing signals that were present in all of the scans.

C.7 Description of Stepped/+ peak Data Collection

Although most spectrum analyzers are routinely operated by sweeping in the frequency domain, this is not the most efficient method for the measurement of spectral emissions from pulsed emitters like radars. An alternative method, called stepping, is usually faster and can provide measurement results with wider dynamic range than is possible with sweeping.

Stepping is performed by tuning the measurement system to a frequency in the radar spectrum, and then performing a time-scan at that frequency over a span of zero hertz. Positive peak detection is always used. For rotating radars, the interval (called dwell time) for a single time-scan is set equal to or greater than the radar rotation time. (For electronically beam-scanning radars, this interval is selected on the basis of the typical recurrence of the radar beam at the measurement site.) For example, if a radar has a 10-second rotation time, then the dwell time at each measured frequency might be set to 12 seconds. Thus, the emitter's rotating main beam would certainly be aimed in the direction of the measurement system at some moment during the 12-second time-scan. At the end of the dwell period, the highest-amplitude point that was measured is retrieved, corrected for calibration factors, and stored. This process of waiting at a frequency in a O-Hz span and recording the highest point measured during a radar rotation (or beam-scanning) interval is called a "step." When each step is completed, the measurement system is tuned to another, higher frequency, and the process is repeated.

The spectrum interval between adjacent measured frequencies is approximately equal to the IF bandwidth of the measurement system. For example, if a 1-MHz IF bandwidth is being used, then the frequency interval between steps will be about 1 MHz. The IF bandwidth is determined from the inverse of the emitter pulse width. For example, if 1 us is the shortest pulse width expected from emitters in a band, then a 1 -MHz measurement (IF) bandwidth is used. In this manner, the entire spectrum is convolved with the measurement bandwidth across the band of interest.

Stepped measurements are used for all dominantly radiolocation (radar) bands. IF bandwidth and dwell times are optimized for typical radars in the band. The individual stepped measurement scans are cumed for spectrum surveys and the final graphs show a maximum, minimum, and mean value for each dwell time at each measured frequency during the entire survey.

C.7.1 Interpretation of Noise Responses in Stepped/+ Peak Data

The mean noise level displayed by the measurement system in the + peak detector stepped mode will be equal to kTB + measurement system noise figure + 10 dB peak detector offset. With a 1-MHz IF bandwidth and a 10-dB measurement system noise figure, for example, the mean + peak noise level is -174 dBm/Hz + 10log(10^6Hz) + 10 dB noise figure + 10 dB peak detector offset = -94 dBm.

The difference between the maximum and minimum levels measured for noise in the stepped mode is small; the maximum and minimum curves will be about + or - 2 dB relative to the mean curve.

C.7.2 Interpretation of Signal Responses in Stepped/ + Peak Data

Stepped/ + peak measurement mode is ideal for capturing low-duty cycle signals from systems that direct energy at the measurement site at regular intervals (e.g., rotating radars). If the dwell time is greater than or equal to the rotation time of the radar, then the stepped algorithm will completely fill the emission envelope.

The maximum curve on each site survey graph for stepped measurements depicts the maximum envelope of the spectral emissions of the emitters observed in the band. The result is a representation of the spectrum occupancy when emissions (usually radar beams) are directed at the measurement site.

The minimum curve represents the lowest signal ever measured at each frequency step during the survey. If an emitter is turned off during a single scan, then this curve will be at the system noise level for that emitter. At frequencies where this curve is above the noise level, but well below the maximum curve, the difference represents either varying emitter power output levels, varying emitter scanning modes, varying propagation between the emitter and the measurement site, or a combination of these factors.

The mean curve represents the linear mean (the average of the antilogs of the decibel values of received signal level) for each frequency step in the band of interest during the site survey. This is not necessarily the same as the mean signal level transmitted by a radar to the measurement location. For example, a radar that was turned on during half the stepped scans, and turned off during the other half would appear, after cuming, with a maximum curve that is its emission envelope, a minimum curve that is the measurement system noise floor, and a mean curve roughly midway between the radar envelope and the noise. However, the radar would never have been measured at the amplitudes shown on the average curve.

C.8 Description of Swept/az-scan Data Collection

In bands dominated by point-to-point fixed microwave communication systems, the main beams of the transmitters are seldom pointed towards the RSMS. To enhance the probability of intercepting signals from these sources, a dish antenna is used. However, the site survey data must include signals received from all points on the horizon. These two apparently contradictory requirements are reconciled by performing azimuth scanning with the dish antenna. The RSMS dish antenna is pointed at the horizon and slowly rotated through 360°. Simultaneously, a spectrum analyzer sweeps the band of interest with positive peak detection and maximum-hold scan mode. Such measurements are called “Swept/az-scan.”

The dish antenna is rotated at approximately 6 degree/s (1 rpm), while the sweep time across the band is set at 20 ms. At the highest frequencies, where the dish beamwidth is about 1 degree, the dish rotates through one beamwidth in 1/6 of a second (170 ms). This is long enough for 7 or 8 Sweeps (170 ms/20 ms) within the beam width. Thus, every point on the horizon is sampled at least 7 or 8 times across the entire band of interest. Maximum-hold mode and positive peak detection ensure that any signal that arrives at the RSMS site is retained on the scan.

The dish is rotated twice around the horizon: once with horizontal polarization and once with vertical polarization. The purpose is to observe signals from point-to-point links utilizing either polarization. The two polarization scans are combined to show the maximum envelope of both scans on a single data curve.

The single data curve is corrected for noise diode calibration factors and recorded. Unlike other RSMS site survey measurements, this measurement is only performed once at each survey location and no cuming is performed on this data. Activity in these bands does not vary much with time and little information is gained by measuring these bands repetitively.

C.8.1 Interpretation of Signal Responses in Swept/az-scan Data

Swept/az-scan data show the presence of a signal at some point or points on the horizon. The data curve does not reveal the direction of any signals, but does show the aggregate occupancy of the spectrum by all point-to-point signals detected omnidirectionally on the horizon.

Generally, two types of signals will be noted in the az-scan graphs: those having narrow emission spectra, and those having wider emissions. The narrow signals are analog links, and the wider signals are digital links. Because a single transmitting tower (a single point on the horizon) may have many channels in operation (often located next to each other in the spectrum), clusters of signals with uniform amplitudes will be observed. Space-to-earth and earth-to-space links in these bands are not normally detected by the RSMS.

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