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.