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Land Mobile Radio Channel Usage Measurements at the 1996 Summer Olympic Games

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PREFACE

Successful completion of the land mobile radio channel usage measurements at the 1996 Summer Olympic Games in Atlanta, Georgia was partly due to efforts by individuals and organizations not associated with the National Telecommunications and Information Administration (NTIA). We wish to thank the following contributors: the Cobb County-Marietta Water Authority, who permitted us to use one of their water tank sites as a measurement location for the Institute for Telecommunication Sciences (ITS) radio spectrum measurement system (RSMS); the management of the Atlanta Financial Center building, who permitted us to use their rooftop as another measurement location; E. Lyons of the Army Information Directorate, who authorized us to install a measurement system at Fort McPherson, Georgia, and who assisted in installation of our equipment there; T. Sahara of the Atlanta Committee for the Olympic Games, who assisted in obtaining the Atlanta Financial Center location for our use; the Denver Museum of Natural History, which allowed us to use their rooftop for preliminary tests of the suitcase measurement systems; the Colorado Lutheran Home in Arvada, Colorado, which allowed us to use their property for preliminary tests of the RSMS; J. Malone of Total R.F. Marketing, Inc., who permitted us to use telephone lines at the Atlanta Financial Center; and D. Miller of the Powder Springs, Georgia, Federal Communications Commission office for providing valuable information on measurement locations in the Atlanta area (including the Atlanta Financial Center and Cobb County water tank sites), and names of contact persons at advantageous measurement locations. Mr. D. Miller also provided us with useful background information on spectrum activities in the Atlanta area.

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, nor does it imply that the equipment or software identified are necessarily the best available for the application.

EXECUTIVE SUMMARY

The 138-940 MHz radio spectrum is a critical resource for land mobile radio communications; aside from specialized applications between 30 MHz and 50 MHz, essentially all mobile radio communications (including, but not limited to, most public safety voice communications) occur in this so-called very high frequency to ultrahigh frequency (VHF/UHF) spectrum. As the number of users of these frequencies has increased, and as wideband communication technologies have been developed, increasing demands are placed upon the information carrying capacity of this portion of the spectrum. Spectrum managers and planners have been particularly concerned in recent years with the question of how much reserve spectrum is necessary to permit the efficient functioning of public safety agencies when natural or man-made emergencies occur.

To address this question, NTIA performed automated measurements of land mobile channel usage during the 1996 Summer Olympic Games in Atlanta, Georgia. The Games were believed to potentially require the same magnitude of reserve land mobile radio spectrum capacity as would be required to meet public safety emergency needs. The measurements were performed before, during, and after the Games, and included all mobile radio bands between 138 MHz and 940 MHz. The resulting channel usage statistics were analyzed to determine relative channel usage levels as a function of time of day, day of the week, overall average channel usage levels, and average channel usage for separate periods before, during, and after the Games. Comparison of the measured channel usage levels during these periods allows an estimation of the increase that may occur in land mobile radio bands during public emergencies.

As presented in the body of this report, the measurement results indicate that overall usage patterns in some land mobile radio bands were as much as two hundred to three hundred percent higher immediately before and during the Games than they were after the Games had ended. The most pronounced increase occurred in the 138-144 MHz band, which was used extensively for crowd control and public safety tactical communications during the Games. It is inferred that natural or man-made public emergencies could likewise be expected to double or possibly triple the communication capacity that would be required for public safety purposes in land mobile radio bands relative to non-emergency capacity required of such bands.

Not all land mobile radio bands exhibited this increase in channel usage during the Games; some bands showed little or no increase, and one band actually showed a decrease in channel usage, apparently due to a migration of regular users away from the downtown area during the Games. However, bands that showed little or no increase were those with spectrum held in reserve for communication systems that had been installed for the Games and that were only to be used in the event of a major disaster. Those systems were not activated during or after the Centennial Park bombing. Other frequencies were used; but, significant amounts of reserve spectrum capacity, probably similar to that required for the 138-144 MHz band, had to be available for those systems during the Games.

In summary, the results of the 1996 Summer Olympic Games channel usage measurements indicate that, in the event of natural or man-made public emergencies, a land mobile radio spectrum capacity capable of accommodating two to three times ordinary channel usage levels may be required to meet emergency needs.

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LAND MOBILE RADIO CHANNEL USAGE MEASUREMENTS AT THE 1996 SUMMER OLYMPIC GAMES

Frank H. Sanders, Gregory R. Hand, Vincent S. Lawrence[1]

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the ITS radio spectrum measurement system and portable measurement systems to collect data for spectrum utilization assessments. This report details an NTIA project to measure and analyze land mobile radio channel usage statistics in the metropolitan area of Atlanta, Georgia, before, during, and after the 1996 Summer Olympic Games.

Key words: channel usage; compact radio spectrum measurement system (CRSMS); land mobile radio (LMR); land mobile radio band usage; land mobile radio channel usage; radio spectrum measurement system (RSMS); spectrum survey.

1. INTRODUCTION

1.1 Background

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

Since 1973, NTIA has been collecting data on Federal use of the radio frequency spectrum in support of the NTIA spectrum analysis program. The ITS radio spectrum measurement system (RSMS) and compact radio spectrum measurement systems (CRSMS's) are used by NTIA to provide technical support for (1) spectrum resource assessments (SRAs), (2) U.S. participation in the International Telecommunication Union (ITU) conferences and ITU Radiocommunication Sector (ITU-R) activities, (3) analysis of electromagnetic compatibility (EMC) conflicts, (4) interference resolution, and (5) systems review activity related to new Federal Government systems.

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1.2 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 needs can request support from the RSMS through the Deputy Associate Administrator of OSM.

1.3 Purpose

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

- enable a better understanding of how LMR systems use the allocated spectrum;
- provide timely information on variations in frequency-band usage, e.g., identify LMR bands becoming heavily used;
- support the NTIA system review process by providing information on the availability of spectrum for new LMR systems and technologies; and
- assess the feasibility of promoting alternative types of LMR services or systems that might result in more effective and efficient use of the spectrum.

1.4 Interpretation of Measured LMR Channel Usage Statistics

As part of the above stated purpose, the Atlanta, Georgia, measurement data were collected to determine the relative impact that a spectrum-use crisis event would have on channel usage statistics in the 138-940 MHz mobile radio bands. Specifically, the measurements were performed to determine the differences in channel usage, on a band-by-band basis, in the time periods before, during, and after the 1996 Summer Olympic Games. The channel usage statistics presented in this report show the percentage of time that individual channels were used in each measured band at each measurement location during those periods. (For statistical data collected at each location, a measured channel was defined as used if the received power level exceeded minimum threshold at any time the channel was being measured.) We stress that these statistics are ***relative***, not absolute. That is, the statistics can be used to compare usage in a band during one time period against usage in the same band during another time period or at another location; but, the statistics do ***not*** indicate the absolute percentage of time that transmissions in each measured band channel show usage for the entire Atlanta, Georgia, area. Also, because of varying technologies and patterns of use in different bands, usage statistics cannot necessarily be compared between different bands, even during identical time periods.

The channel usage measurements contained in this report cannot be used solely to assess the feasibility of using alternate LMR services or systems in a band. Extrapolation of data in this report to general channel usage statistics for alternative spectrum uses require consideration of additional factors. These include spectrum management procedures, types of missions performed, and new spectrum requirements in the development and procurement stages of LMR systems. Also, measurement locations and measurement system parameters should be considered.

The location(s) and dates chosen for LMR channel surveys will affect measured channel usage. For example, measurements made in a city during a period of emergency conditions (as was the case for measurements in this report) are expected to show different results than measurements made during nonemergency periods. These 1996 Summer Olympic Games measurements in Atlanta, Georgia, should help determine the extent to which patterns of use may change during such emergency periods.

Choice of measurement sites within an area can also affect measured channel usage. An area such as Seattle-Tacoma, Washington (rough terrain, heavy forestation, and widely dispersed transmitters), may require multiple measurement sites to adequately characterize usage. This was the case during the Atlanta survey, and was the reason for selecting three measurement sites for the 1996 Summer Olympic Games data collection effort.

Spectrum management procedures such as band allotments for functions and missions affect spectrum utilization. For example, channels used for taxi dispatch might show heavier usage than channels allocated for law enforcement or public safety. Special events such as natural disasters, Olympic Games, and Presidential inaugurations create unique spectrum requirements of LMR band architectures. Regardless of measured usage levels, dedicated telecommunication routing for critical functions, such as safety-of-life, remain a spectrum requirement.

LMR channel usage measurements provide data on percentages of time that signal levels have exceeded amplitude thresholds at various measurement locations, on a channel-by-channel basis. When usage measurements in a band are compared to other measurements made in the same band, at the same location, but at different times, the relative amount of LMR band crowding that is occurring as a function of time can be assessed. When channel usage statistics for a band are compared between multiple measurement locations, a picture of typical channel loading levels within a band in a metropolitan area may emerge. Specifically, examination of channel usage levels in a given band at multiple metropolitan locations over a period of weeks will indicate the extent to which channels in that band may be expected to be available at any given time and location in the area. That information, in turn, may indicate the feasibility of using alternative spectrum technologies that may be more spectrally efficient in terms of channel usage than current assignment schemes. Such information cannot be obtained from band-allocation or channel-assignment databases, nor solely from an analysis of LMR band management procedures.

2. OVERVIEW OF LAND MOBILE RADIO CHANNEL USAGE SURVEYS

2.1 Introduction

Procedures for conducting an LMR channel usage survey using the RSMS/CRSMS are outlined in this section. Site selection factors, significant measurement system parameters, and hardware and software configurations developed for the surveys are described. Measurement system response to LMR signals is described in Appendix A. Detailed information on the system hardware (including the vehicle, instrumentation, antennas, and receiver front-end), and other measurement capabilities are provided in Appendix B.

2.2 Survey Site Selection

A successful LMR channel usage survey requires careful selection of a measurement site. High LMR signal intercept probability and minimal logistic problems are the first considerations when locating a survey site.

The primary LMR intercept factors considered are:

- line-of-sight coverage area, maximized to increase the probability of weak signal reception such as transmissions from mobile units;
- nearby transmitters, avoided to prevent intermodulation or saturation problems that can arise even though preselection and/or filtering is used by the survey measurement system; and
- impulsive noise sources, such as automobile ignition systems and electrical machinery that can add to the received signals of interest and give misleading results.

It is crucial that the measurement site not be colocated with any transmitter operating in an LMR band or an adjacent band at a sufficiently high received power level to cause overload in the RSMS/CRSMS front-end. The overload threshold for the RSMS/CRSMS is -25 dBm in the measurement circuitry. To provide a margin of system overload protection, the software overload threshold is set 5-dB lower, at -30 dBm. If, during any single measurement in an LMR band, any signal within the measurement band exceeds this threshold, then that particular measurement for that band must be excluded from the final data; in effect, overload contaminates all data taken during a single scan, and all data in such a scan must be discarded. Since a scan may represent 10 or 15 min of data collection, frequent overload can cause a very adverse impact on the survey results for a given band and measurement location.

To avoid substantial amounts of data loss due to overload problems, a preliminary survey is performed at all prospective measurement locations to determine whether overload signals frequently occur in any of the LMR bands to be measured at each location. If frequently occurring overload signals are discovered, then the prospective measurement site cannot be used for a spectrum survey.

The primary logistic factors to consider at each site are availability of (1) commercial power; (2) commercial telephone for relatively inexpensive reliable communications, compared to cellular telephone that could possibly contaminate the measurements when transmitting; and (3) adequate physical security for personnel, electronic hardware, and vehicles.

2.3 Land Mobile Radio Channel Usage Measurements

LMR channel usage surveys are normally conducted for 1-2 weeks at one or more locations in a metropolitan area using the RSMS/CRSMS in an automatic mode. The measurement system is preprogrammed to continuously run software algorithms tailored to determine the percentage of time that communication signals exceed preset thresholds in each measured LMR channel. Emissions from land-mobile, marine-mobile and air-mobile communication radios are the targets of RSMS/CRSMS channel usage surveys. Appendix A discusses factors related to probability of intercept and addresses matters of measurement time vs. statistical significance of data.

Each LMR band is measured with a hardware configuration and measurement algorithm specifically selected to accurately determine the percentage of measurement time that LMR channels are occupied. The measurement system parameters that are configured for each LMR band include: band channelization architecture, measurement antennas, signal-conditioning path and tuning speed in the RSMS/CRSMS, measurement bandwidth, measurement repetition rate, and signal-processing thresholds. The RSMS/CRSMS measurement software automatically switches the measurement system to the proper configuration for each LMR band. The measurements are repeated in LMR bands according to specifications established by consideration of signal intercept probability, signal variability, LMR band significance, and expenditure of measurement system time for each band measurement.

For LMR channel usage surveys, NTIA/ITS measurements are conducted normally in bands between 138 MHz and 940 MHz. LMR bands outside this range, such as 30-50 MHz, are sometimes measured at selected sites. Mobile radio bands measured during the 1996 Summer Olympic Games in Atlanta were: 138-144 MHz, 148-162 MHz, 162-174 MHz, 225-400 MHz, 406-420 MHz, 450-470 MHz, 806-821 MHz, 821-824 MHz, 851-866 MHz, 866-869 MHz, 896-901 MHz, and 935-940 MHz.

The RSMS/CRSMS data acquisition (DA) measurement control software provides automated instructions to configure the measurement system, execute measurement routines, record measured data, and maintain a real-time log of the measurements. The measurement system configuration parameters used by the software are called "band events" and the automated band event execution procedures are called "band event schedules." Unattended operation of the measurement system for extended periods of time is made possible through this use of computer control. LMR channel usage survey band events and band event schedules are described in the following sections.

2.3.1 Survey Band Events

The mobile radio spectrum measured by the RSMS/CRSMS is divided into selected frequency ranges (survey bands) that are measured according to a computer-stored list of measurement parameters and instrument settings called a band event. Each band event combines a measurement algorithm with an antenna, a particular signal input port, front-end configuration, receiver settings, spectrum analyzer mode, and data-recording options.

LMR channel usage survey band event parameters are shown in Table 1. Each row in the table, beginning with an event number, shows the measurement parameters for a specific receiver configuration in the RSMS/CRSMS. (Band event number 1 is reserved for special uses in the system software, and hence does not appear in Table 1.) Instructions to execute the event can come from an operator or from a computer-loaded band event schedule as explained in Section 2.3.2. The DA measurement system software sends the command parameters for an event to the system hardware and initiates measurements. Table 1 is subdivided into four parts: (1) "Measurement Events" identifies the event number and mobile radio frequency band to be measured, (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) "Antenna" identifies the type and gain of the antenna selected for the event. Appendix C describes DA software configuration routines and the associated table parameters found in (2) and (3) above. The measurement algorithm for LMR channel usage measurements, "Swept/m3/apd," is described in detail in Section A.3.1 of Appendix A.

2.3.2 Band Event Schedules

Using RSMS/CRSMS measurement control software, any band event can be executed by an operator at any time. For LMR channel usage surveys, each band event corresponds to a selected LMR survey band. DA software includes an automated band event execution mode whereby the band events may be programmed (scheduled) to execute in any sequence for any amount of time (within hardware limits on continuous operation of the measurement system).

The band event schedule for an LMR usage survey must balance the need to measure each LMR band as frequently as possible with the need to spend enough time within each band to obtain an adequate statistical sampling of channel usage activity. Table 2 shows the band event schedule for LMR channel usage measurements in Atlanta, Georgia. The table includes: (1) schedule number[2]; (2) band event number (specifies which band event to run in the schedule); (3) priority number (value assigned to the band-event data, with number 1 being the highest priority); (4) event time (approximate measurement time in minutes needed to run the event); and (5) accumulative time (approximate time in hours that the schedule has run). This schedule repeats approximately every eight hours.

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[2] Schedule numbers are assigned sequentially from 1 to 64. The system software supports only 64 band events in a single schedule; however, the schedule may be programmed to restart automatically and there is no limit on how many times the schedule executes during a survey.

Table 1. Band Event Parameters for Channel Usage Surveys

Measurement Events		**DA Receiver Parameters**[*]					**DA Spectrum Analyzer Parameters**[*]					**Antenna**[**]	
Event Number	**Freq. Band (MHz)**	**Algorithm**	**Start (MHz)**	**End (MHz)**	**Scans (# of)**	**Sweeps (# of)**	**IFBW (kHz)**	**Detector Type**	**VBW (kHz)**	**RL (dBm)**	**Swp/stp (sec)**	**Type**	**Gain (dBi)**
2	138-144	sw/m3/apd	138.0	150.5	3	90	15	sample	1	-30	2.0	omni	-4.0
3	148-162	sw/m3/apd	148.0	163.0	3	90	15	sample	1	-30	2.0	omni	-3.2
4	162-174	sw/m3/apd	162.0	174.5	3	90	15	sample	1	-30	2.0	omni	-2.1
5	225-400	sw/m3/apd	225.0	400.0	35	40	15	sample	1	-30	2.0	omni	1.5
6	406-420	sw/m3/apd	406.0	422.667	4	90	15	sample	1	-30	2.0	omni	2.8
7	450-470	sw/m3/apd	450.0	470.833	5	90	15	sample	1	-30	2.0	omni	2.3
8[***]	470-512	sw/m3/apd	470.0	520.0	5	90	15	sample	1	-30	2.0	omni	2.0
9	806-821	sw/m3/apd	806.0	821.0	3	90	15	sample	1	-30	2.0	omni	1.8
10	821-824	sw/m3/apd	821.0063	825.1729	1	90	15	sample	1	-30	2.0	omni	1.7
11	851-866	sw/m3/apd	851.0	866.0	3	90	15	sample	1	-30	2.0	omni	1.4
12	866-869	sw/m3/apd	866.0063	870.1729	1	90	15	sample	1	-30	2.0	omni	1.3
13	896-901	sw/m3/apd	896.0063	904.3396	2	90	15	sample	1	-30	2.0	omni	1.0
14	935-940	sw/m3/apd	935.0063	943.3396	2	90	15	sample	1	-30	2.0	omni	0.9

[*] Table parameters are defined in Appendix C.2.1 and C.3.1 respectively. For channel usage measurements, the IF bandwidth parameter (IFBW) is set to 30 kHz but a special 15-kHz channel filter is inserted into the spectrum analyzer IF path by ITS personnel, resulting in an effective IFBW of 15 kHz. Spectrum analyzer attenuation is set to 0 (default), display to 10 dB/div, and the analyzer measures 1001 points/scan.

[**] For the Atlanta channel usage survey, all band events were measured with a 0.02-1.0 GHz omnidirectional discone antenna (Antenna Research Associates (ARA) model 210/C, passive option), mounted vertically and providing slant polarization.

[***] For the Atlanta survey, the 470-512 MHz band was not measured. This band is only measured for channel usage statistics in metropolitan areas where 470-512 MHz is used for mobile radio. In Atlanta, this band is used for television broadcasting.

Table 2. Band Event Schedule for RSMS/CRSMS LMR Channel Usage Measurements

Schedule Number	Band Event Number	Priority Number	Event Time (minutes)	Accumulative Time (hours)
1	2	1	12	0.20
2	3	1	12	0.40
3	4	1	12	0.60
4	6	1	16	0.87
5	7	1	20	1.20
6	9	2	12	1.40
7	10	1	4	1.47
8	11	2	12	1.67
9	12	1	4	1.73
10	13	2	8	1.87
11	14	2	4	1.93
12	2	1	12	2.13
13	3	1	12	2.33
14	4	1	12	2.53
15	5	3	60	3.53
16	6	1	16	3.80
17	7	1	20	4.13
18	10	1	4	4.20
19	12	1	4	4.27
20	2	1	12	4.47
21	3	1	12	4.67
22	4	1	12	4.87
23	6	1	16	5.13
24	7	1	20	5.47
25	9	2	12	5.67
26	10	1	4	5.73
27	11	2	12	5.93
28	12	1	4	6.00
29	13	2	8	6.13
30	14	2	4	6.20
31	2	1	12	6.40
32	3	1	12	6.60
33	4	1	12	6.80
34	6	1	16	7.07
35	7	1	20	7.40
36	10	1	4	7.47
37	12	1	4	7.53

Band event priority is an important consideration when scheduling band events; i.e., some frequency bands in a spectrum survey are of more interest to spectrum managers than others. Band event priorities are based primarily upon the dynamics of channel usage in the band, and the length of time required to make a complete band measurement. For example, the 225-400 MHz band does not have high priority because of the current lack of allocation issues and the length of time (1 hr) required to measure the band. Most of the LMR bands are assigned priority-level 1 due to current interest in spectrum allocation issues.

The entire LMR channel usage band event schedule requires 8 hrs to execute. Within that cycle time, priority-1 events run 4 times (once every 2 hrs), priority-2 events run twice (once every 4 hrs), and priority-3 events run just once. Running every band event an integral number of times every 8 hrs facilitates time-of-day analysis. During an 8-hr period, about 2.7 s are spent measuring a single priority-1 channel.

3. 1996 SUMMER OLYMPICS CHANNEL USAGE SURVEY

3.1 Introduction

This section (1) describes the measurement sites selected for the LMR channel usage survey in Atlanta, Georgia, (2) briefly describes the data processing used to characterize the LMR channel usage statistics for frequencies within a range of 138-MHz to 940-MHz, (3) presents the measured data, and (4) provides a band-by-band evaluation of measured usage before, during, and after the 1996 Summer Olympic Games.

3.2 Measurement Site Descriptions

Three sites were selected for LMR channel usage measurements in the Atlanta, Georgia, area. The RSMS was deployed at one site, and a CRSMS was deployed at each of the other two sites. All three sites were selected to satisfy the criteria presented in Section 2.2.

One site was on the roof of the Atlanta Financial Center (AFC), 3343 Peachtree Road, in the Buckhead district of Atlanta. The building was about 10 km (6 mi) north of downtown Atlanta. A CRSMS was deployed on the building rooftop, at coordinates 84.3677° W, 33.8464° N. Base altitude was 304 m MSL, and the rooftop was 60 m AGL. Part of the building shielded the CRSMS antenna from the north, but otherwise the view from the rooftop, shown in Figure 1, was unobstructed. An RF cable (about 30-m long) connected the antenna on the roof to the CRSMS; located inside a utility room on the top floor of the AFC, as shown in Figure 2. This site was designated "Buckhead" and is so addressed for the remainder of this report.

Another CRSMS deployment was located at Fort McPherson (Building 205), about 6 km (4 mi) southwest of downtown Atlanta. The site coordinates were 84.4293° W, 33.7064° N. Base altitude was 317 m MSL, and the antenna height (on the roof of the building) was 5 m AGL. An RF cable (about 20-m long) connected the antenna to the CRSMS located inside the building. This site was designated "Fort McPherson."

Figure 1. Downtown Atlanta skyline viewed from the rooftop at the Buckhead measurement site.

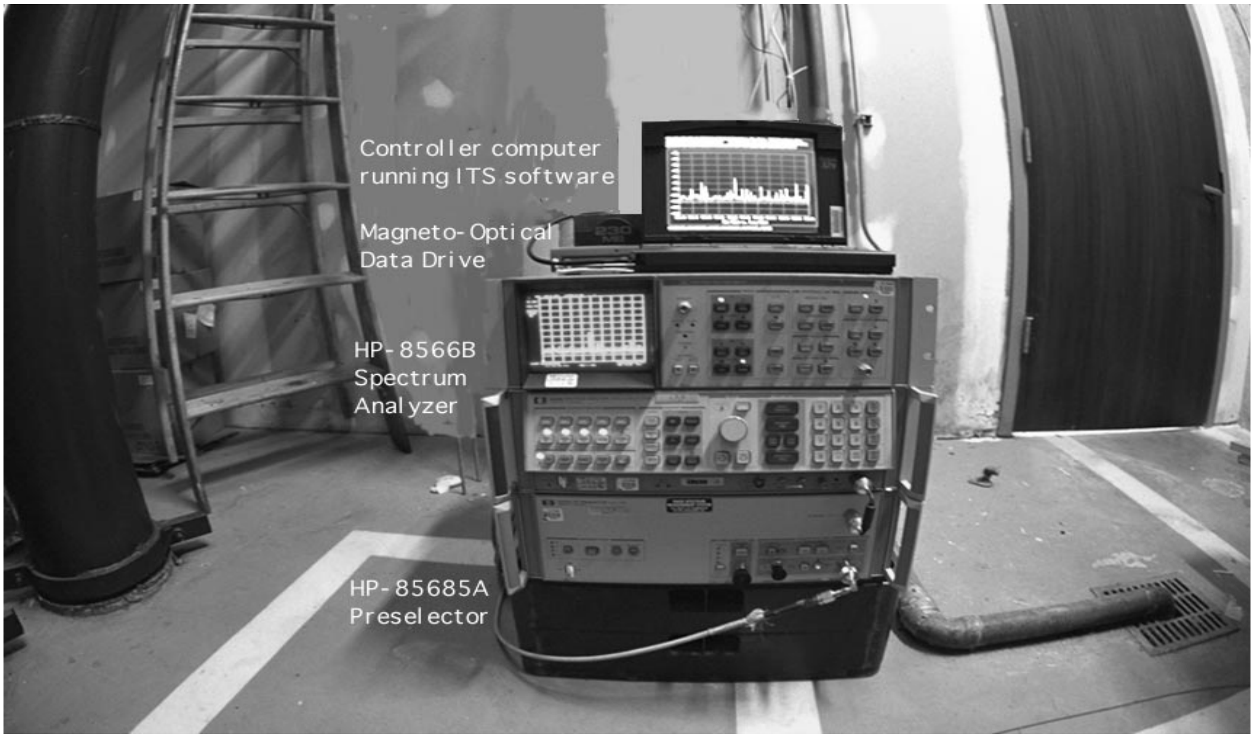

Figure 2. ITS compact radio spectrum measurement system operating in an equipment utility room below the rooftop at the Buckhead measurement site.

The RSMS was parked near a Cobb County-Marietta water tank at the intersection of Factory Shoals Road and Six Flags Drive, not far from the Six Flags amusement park. Located about 16 km (10 mi) west of downtown Atlanta, the site coordinates were 84.5754° W, 33.7783° N. Base altitude was 342 m MSL, and the antenna height was 8 m AGL. The water tank at the site partially blocked the RSMS antenna coverage northeast of the site; coverage of the downtown area was clear. This site was designated "Six Flags."

All three sites were well removed from fixed RF transmitters and man-made noise sources such as heavy vehicular traffic. Figure 3 shows the locations of the RSMS and CRSMS deployments in the Atlanta area. Figures 4, 5, and 6, show areas that were line-of-sight (white) or terrain obstructed (shaded with plus (+) symbols) from the RSMS/CRSMS antennas. Based on a terrain database[3], any clear straight-line path between the RSMS/CRSMS antennas and a point 2 m above ground (typical mobile antenna height) was considered to be a line-of-sight path.

The Atlanta metropolitan area is located among low, rolling hills that are heavily vegetated; the tree line is typically 10-20 m (30-60 ft) high. The terrain rises slightly to the north, northwest, and the west. Urban development in the area is extensive. A downtown area near the main stadiums used for the 1996 Summer Olympic Games contains many skyscrapers that serve as base stations for broadcast transmitters and mobile communication systems. Stone Mountain, a granite outcrop to the east of Atlanta, also provides a base for many broadcast and mobile radio systems. All three measurement locations provided line-of-sight signal reception of the Stone Mountain summit and skyscraper rooftop transmitters.

High tree lines, as exist in Atlanta, can substantially attenuate weak signals, such as transmissions from mobile LMR units, due to their lower antenna heights. However, this propagation signal loss was not a serious concern for these measurements because it would be relatively constant at each measurement site and would not alter measured channel usage as a function of time (before, during, and after the 1996 Summer Olympic Games; see Section 1.4, above).

Of the three sites, Buckhead provided the greatest overall line-of-sight reception area; it provided especially good coverage of the north, central, and east-central Atlanta metropolitan area. Buckhead coverage included Dobbins Air Force Base, which was the center of much logistical and emergency-response command-and-control activity during the Olympics. The Buckhead site was also closest to downtown Atlanta and Stone Mountain. As such, absolute usage levels measured at Buckhead were expected to be the highest of the three sites. This expectation is generally supported by examination of the measurement results.

The Six Flags site had the second largest line-of-sight coverage, and still included the downtown buildings and Stone Mountain. This site provided good coverage of the west and southwest parts of the Atlanta area, and some coverage of Dobbins Air Force Base. This site was expected to produce the second highest absolute usage levels, and generally, that was the case.

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[3] Time-shared propagation analysis computer programs, terrain databases, and technical assistance with problems involving sighting, design, and analysis of all types of radio telecommunications systems are available through ITS Telecommunications Analysis Services.

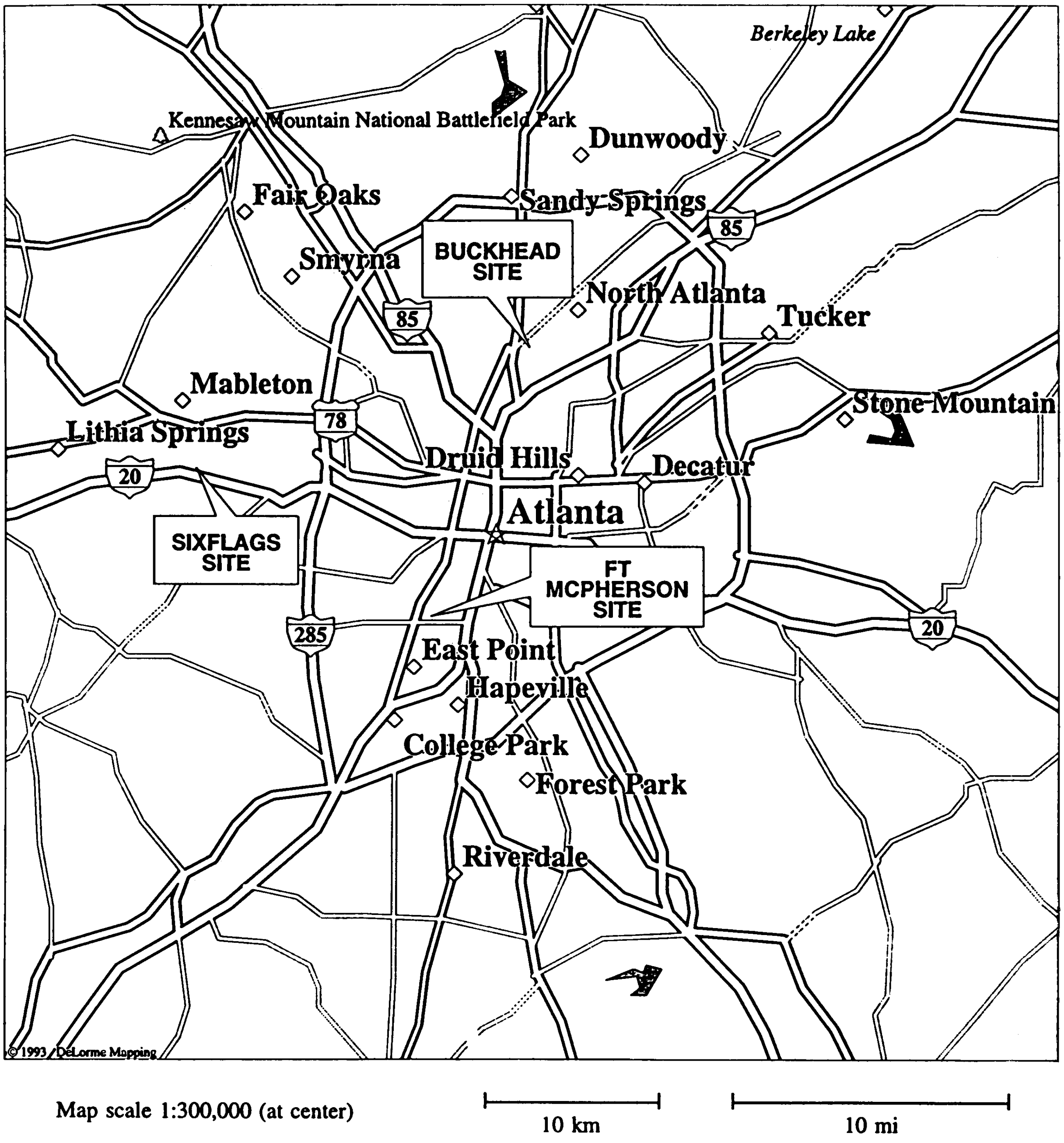

Figure 3. Area map of Atlanta, Georgia, showing the location of all three measurement sites. Map produced with MapExpert™ software from DeLorme mapping, Freeport Maine.

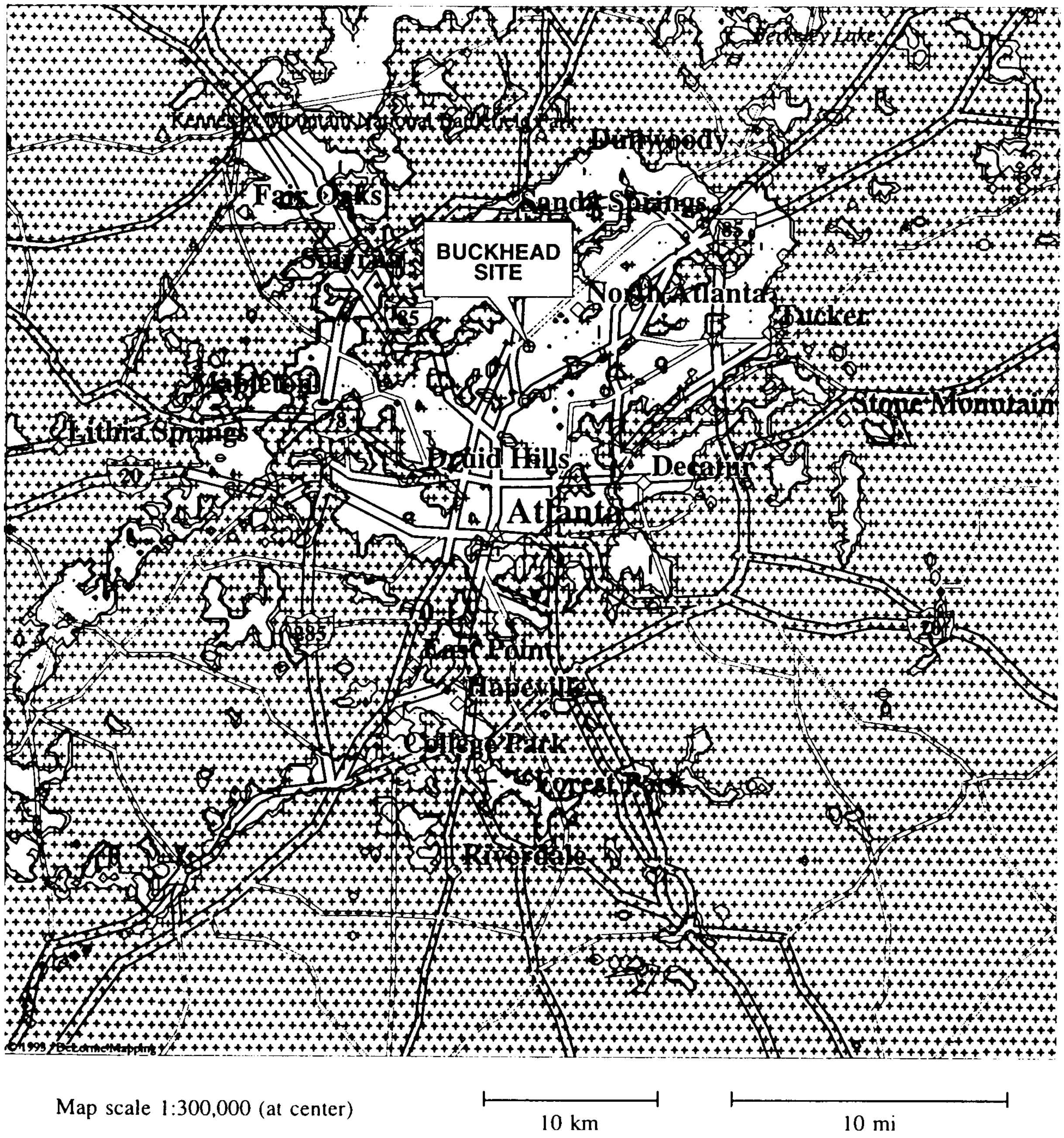

Figure 4. Map of Atlanta, Georgia, with an overlay showing terrain line-of-sight areas (unshaded) from the Buckhead measurement site.

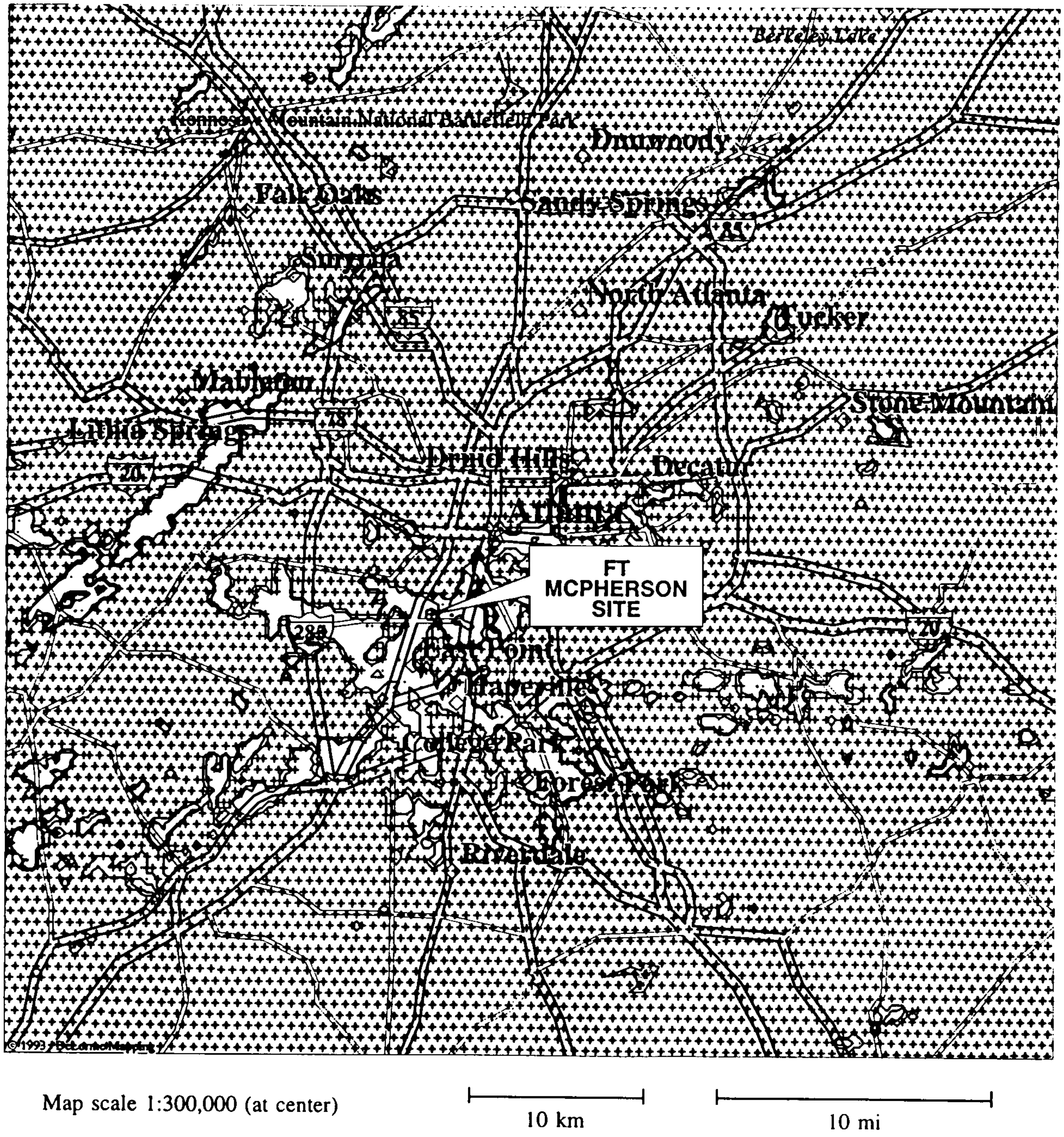

Figure 5. Map of Atlanta, Georgia, with an overlay showing terrain line-of-sight areas (unshaded) from the Fort McPherson Measurement site.

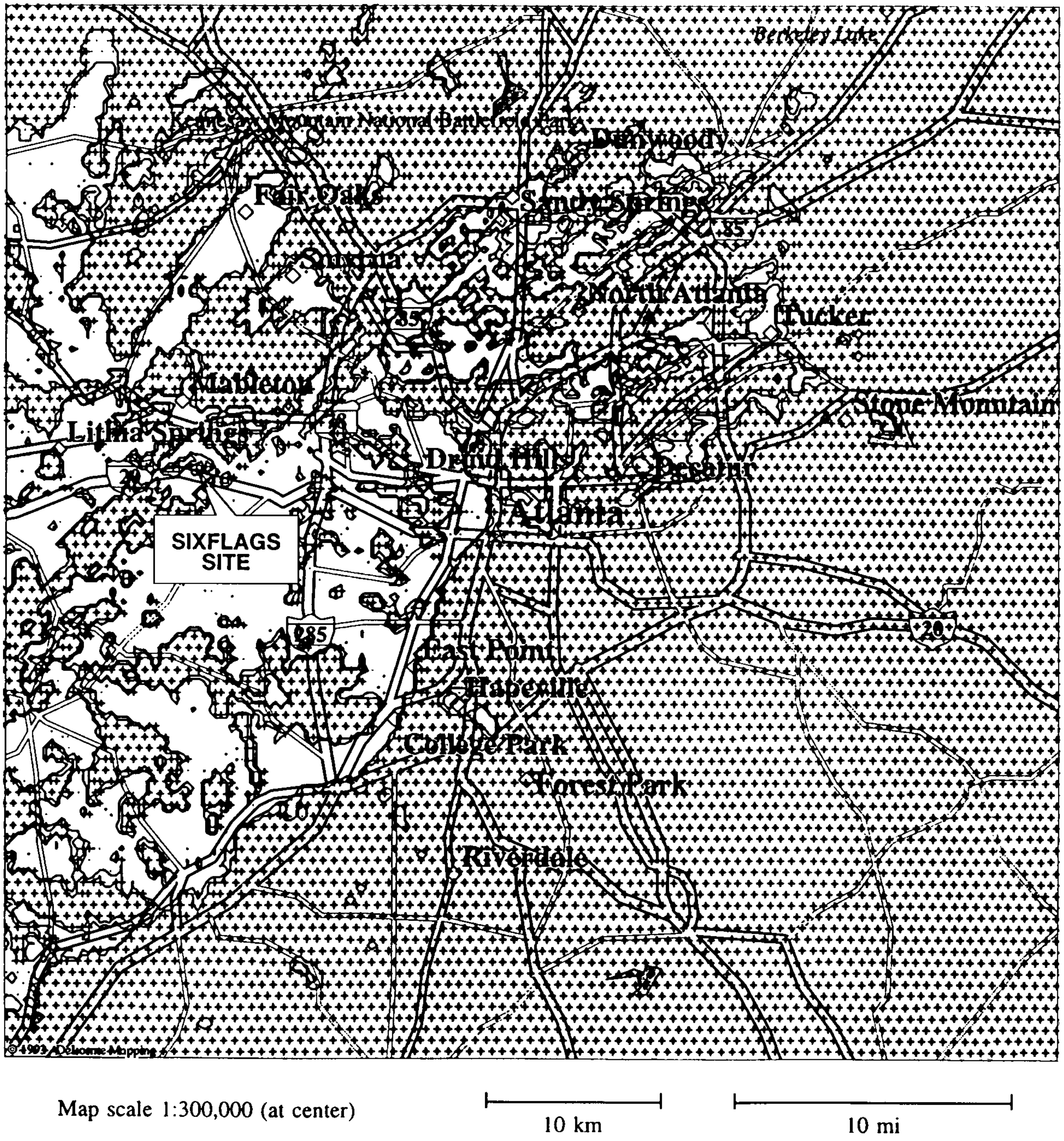

Figure 6. Map of Atlanta, Georgia, with an overlay showing terrain line-of-sight areas (unshaded) from the Six Flags measurement site.

The Fort McPherson site had the poorest line-of-sight coverage of the three measurement sites, both due to a low terrain elevation and low antenna height above the ground. But, the site filled a significant coverage gap in the south part of the Atlanta area, including the main airport. In addition, military band communications were expected to be better measured at Fort McPherson than elsewhere.

3.3 Measured Data Analysis

The Atlanta LMR channel usage survey was performed as outlined in Section 2. Table 1 (in Section 2.3.1) lists the measurement system parameters used for each survey band. Appendix A contains explanations of the measurement algorithm selections. All survey bands were measured with a 20-MHz to 1-GHz passive, omnidirectional discone antenna (Antenna Research Associates (ARA) model 210/C, passive option) mounted vertically. See Appendix B for more information on antennas and RF front-end hardware configurations.

Figures 7 through 9 show the distribution of band measurements in time at the three measurement sites. Each vertical line represents an intersection of a measured frequency range with the time the measurement took place. These lines represent the times and frequencies of recorded data; as such, they show large breaks between the before, during, and after, measurement periods and small breaks at times when the measurement system was stopped for such operator-initiated activities as checking the status of recorded data files.

All measured data underwent extensive cumulative processing before being recorded. Every channel usage data point plotted for Swept/m3/apd measurements was determined on the basis of, typically, 90 individual apd-threshold measurements. In addition to the apd data, the maximum, minimum, and mean (m3) occupancy power levels at all measured frequencies were recorded (see Section A.3.1 of Appendix A for a complete description of the Swept/m3/apd measurement algorithm).

Figure 10 is a graph of one maximum, minimum, and mean (m3) power-vs.-frequency scan that was recorded at the Buckhead site. Because the m3 data are not the primary concern of this survey's results, this is the only m3 graph presented in this report. Note that the graph shows a strong signal (at about 163.23 MHz) that exceeds the -30 dBm overload threshold.[4] Despite the number of preliminary checks at the three measurement locations, a few overload signals were received during the course of the survey. Most did not significantly reduce the total amount of data that were available for analysis. However, this signal-occurrence accelerated as the survey progressed and forced many of the Buckhead site 162-166 MHz data scans to be excluded from analysis.

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[4] The nominal overload threshold for the RSMS/CRSMS is -25 dBm. The software overload threshold is set 5 dB lower, at -30 dBm. If, during any single measurement scan, any signal exceeds this threshold, an overload condition exists and that particular measurement must be excluded from the final data; in effect, overload contaminates all data taken during a single scan, and all data in such a scan must be discarded.

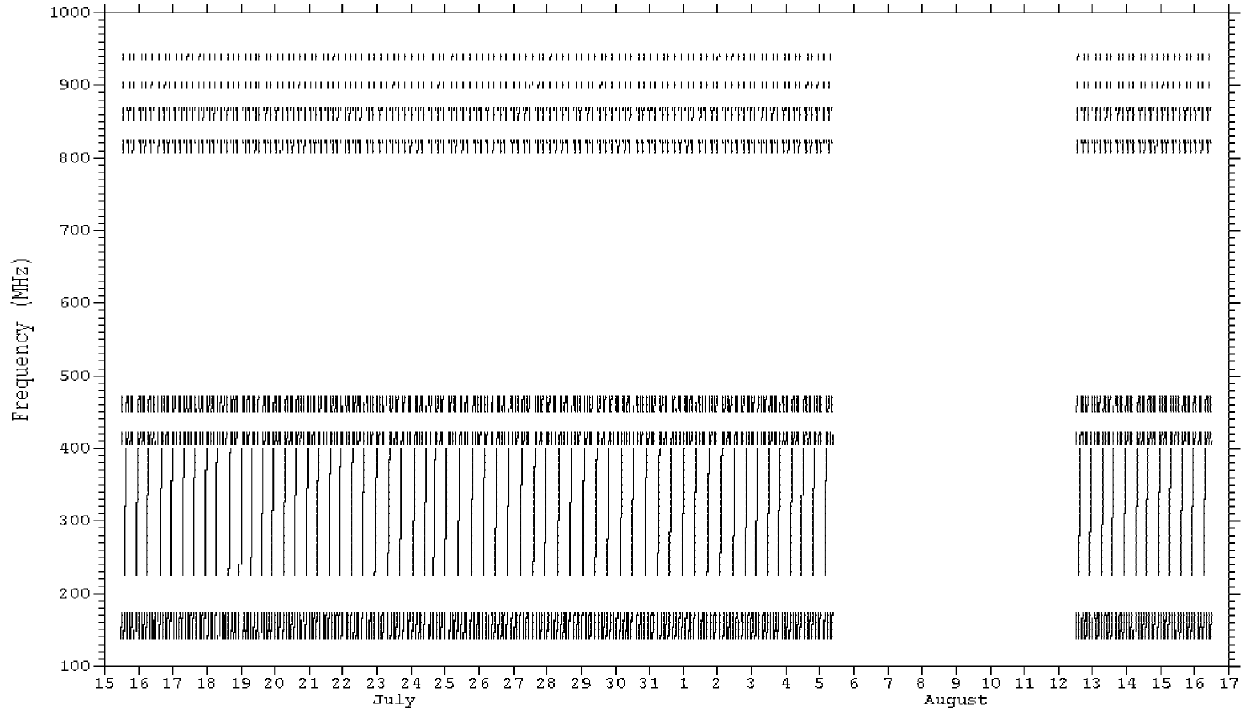

Figure 7. Frequency bands measured as a function of measurement time (24-hr days) at the Buckhead measurement site.

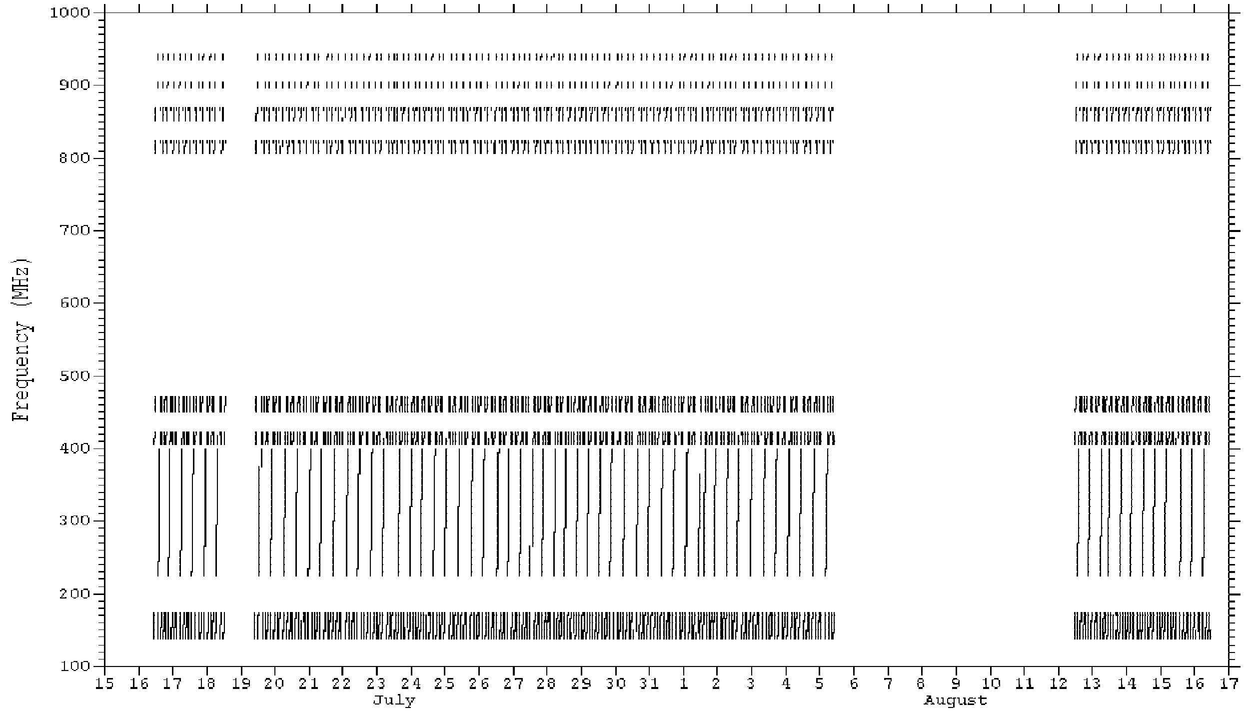

Figure 8. Frequency bands measured as a function of measurement time (24-hr days) at the Fort McPherson measurement site.

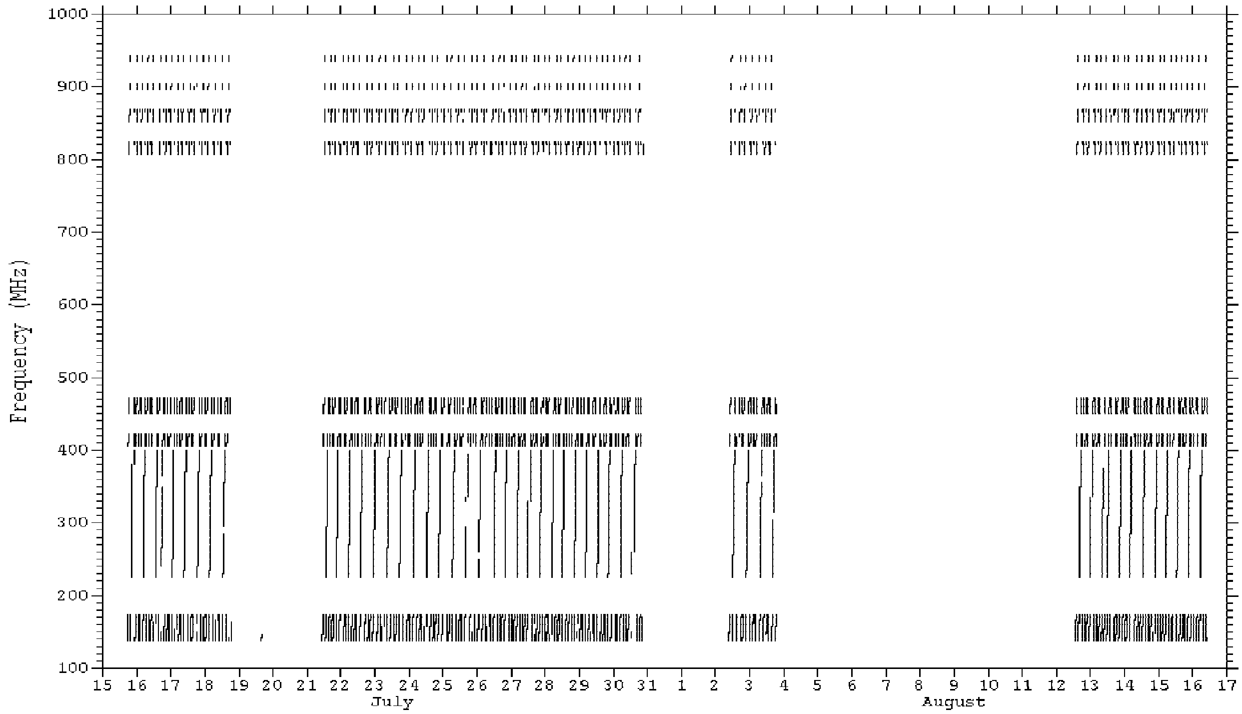

Figure 9. Frequency bands measured as a function of measurement time (24-hr days) at the Six Flags measurement site.

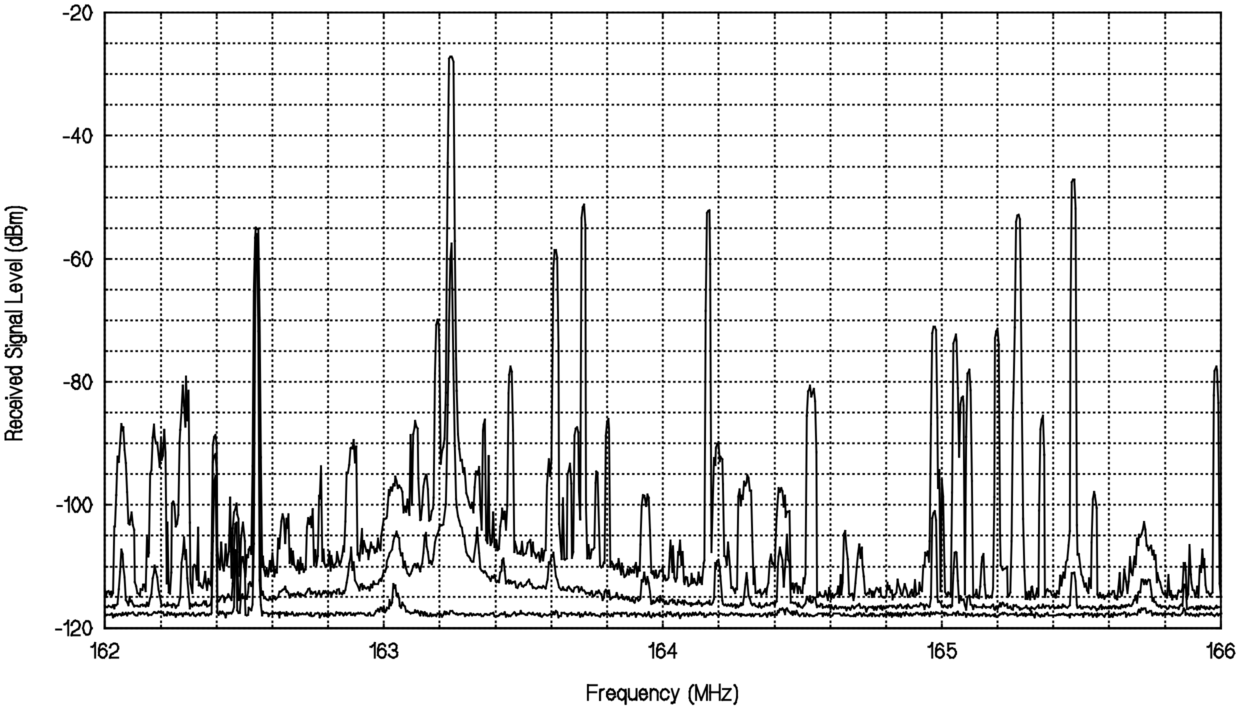

Figure 10. Swept/m3 measurement scan recorded at the Buckhead site.

3.4 Buckhead Site Channel Usage Statistics

This section presents graphs showing usage vs. time and usage vs. frequency for measurements at the Buckhead site. Each page contains graphs of analysis band channel usage statistics. Analysis bands are generally the same as survey bands (see Section 2.3.1); however, the 148-162 MHz survey band is split into two analysis-band plots to better show the LMR band channelization.

As explained in Section 2, measurements were accomplished as one or more frequency scans per survey band. For example, the 148-162 MHz survey band was measured in three 5-MHz scans of 148-153, 153-158, and 158-163 MHz. After post measurement processing, these data are presented as graphed analysis-band plots (in this case, two bands, 148-151 MHz and 150-162 MHz) of 148-162 MHz channelized LMR data. The plots are captioned for the analysis band, and displayed on one page. The graph at the top of each page shows percentage usage as a function of time (hereafter called a time plot), and the bottom graph shows percentage usage as a function of frequency (hereafter called a frequency plot). Each analysis graph has a header that is coded as follows:

▸ Measurement location	Site-identification codes for Atlanta are BUCKHEAD, FTMCPHSN, and SIXFLAGS;
▸ Frequency range	Survey band frequencies processed for the analysis graph (time plot or frequency plot);
▸ Date/time codes	Days included in graphed data are coded MTWTFSS; start/end dates are coded YYMMDD, e.g., 960715-960816, indicates measured data collected between July 15, 1996 and August 16, 1996; start/end times are coded HHMMSS (24-hr clock), e.g., 00000-240000 indicates data for all hours of the day are included;
▸ Total spans	For analysis, all or part of a measurement scan that was used to calculate usage was called a span (the number in brackets is a counter used only during analysis);
▸ Include/exclude	‘include’ data includes scans that exceeded the overload threshold, ‘exclude’ data does not, see explanation later in this section;
▸ Color bars	Different colors are used to graph the average usage for different thresholds (exact values are shown above each color bar). Note that the threshold levels may be different for each frequency band.

All of the analysis graphs (both time plots and frequency plots) are color coded to show usage as a function of measured power threshold (color bars in the graph header show the analysis band thresholds). Each vertical line on the time-dependence plot (upper graph) represents the average analysis band usage (i.e., average of all scans exceeding each color-coded threshold) at the time indicated. Each vertical line on the frequency plots shows the average usage for each threshold at the indicated frequency. Figures 11 through 40 are the time and frequency plots for all of the Buckhead analysis bands. Band-by-band observations on relative levels of LMR usage and comments on the extrapolation of all measured data are found in Section 3.9.

To further discuss results of the Buckhead measurements, Figures 15 and 16 are used as examples. The small amount of red on the bottom of Figure 15 indicates that on almost every measurement scan in the 150-162 MHz analysis band the -30-dBm threshold was exceeded. This occurred because a transmitter on one of the channels was too close to the measurement site (see Section 2.2). As a result, the spectrum analyzer was overloaded and the data collected was not used. Therefore, whenever a nonzero value appears in the -30-dBm threshold title, an additional figure is plotted with an **Exclude** title (Figures 17 and 18 in this case). These plots exclude any data scan that exceeded the -30-dBm threshold. In this example, Figure 15 shows that 872 spans were included in the analysis, while Figure 17 shows that only 313 spans were included. A close look at Figure 16 shows the specific frequencies that caused the problem: note the red line at 150.92 MHz and another at 157.71 MHz. The numbers below the ‘Frequency (MHz)’ label in Figure 16 show how many scans were included in the analysis band:

291	148-153 MHz scans;
291	153-158 MHz scans, and;
290	158-163 MHz scans.

When the -30-dBm threshold-exceeded data are **excluded** in Figure 18, the resultant scans are:

23	148-153 MHz scans;
0	153-158 MHz scans, and;
290	158-163 MHz scans.

Thus, every 153-158 MHz scan was corrupt, as were most of the 148-153 MHz scans.

The orange bar at the bottom of the frequency plots indicates which frequencies were included in the analysis. Figure 12 has a solid orange bar across the bottom indicating that every frequency in the 138-144 MHz survey band was included in the analysis. Figure 16 shows some white spaces where frequencies (assigned to services such as maritime mobile) were not considered pertinent Atlanta data and were excluded from the analysis.

The color bars in the title represent the total usage based on each of the thresholds exceeded. When plotted, the colors are stacked because data that exceeded the higher thresholds must have also exceeded the lower thresholds. In Figure 16, for example, a signal at 152.46 MHz has a **Blue** level of 85% (top of the vertical blue line). This shows that, during the times measured, this signal exceeded the -97-dBm threshold 85% of the time, indicating a strong transmitter that was almost always turned on.

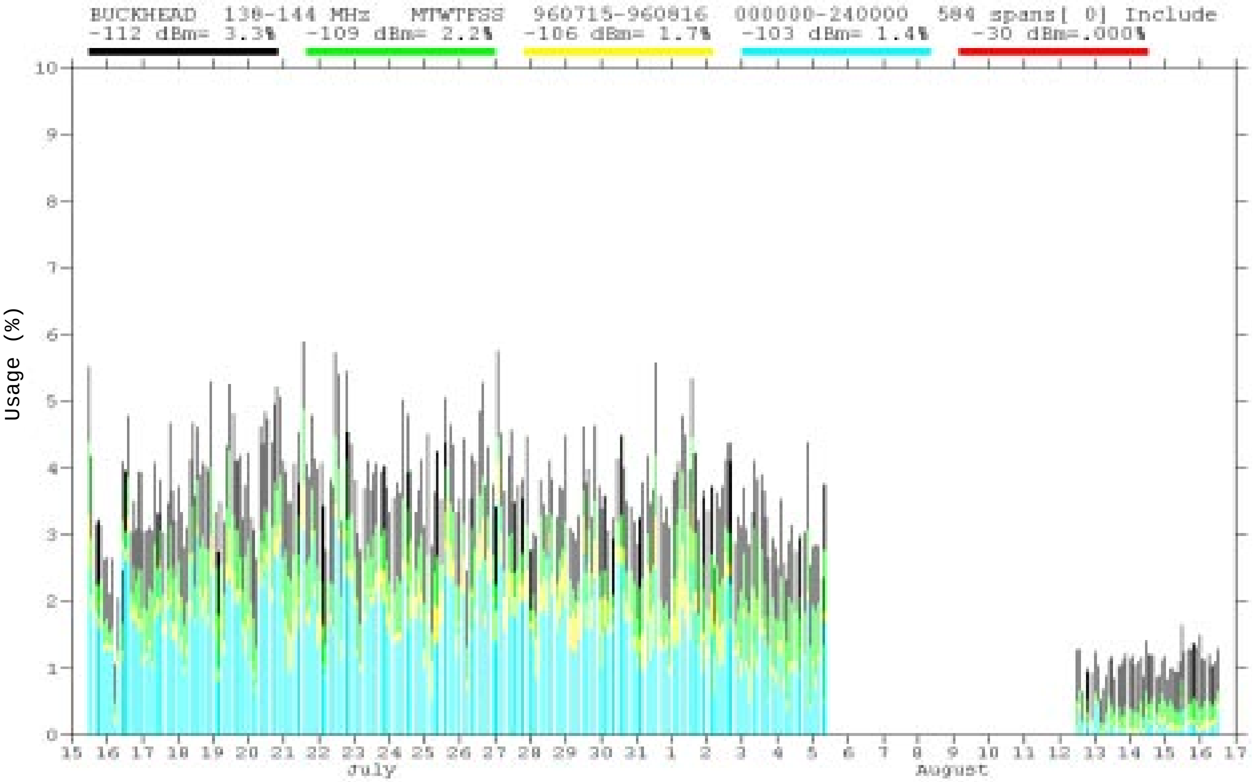

Figure 11. Usage vs. time plot of 138-144 MHz measurements at Buckhead.

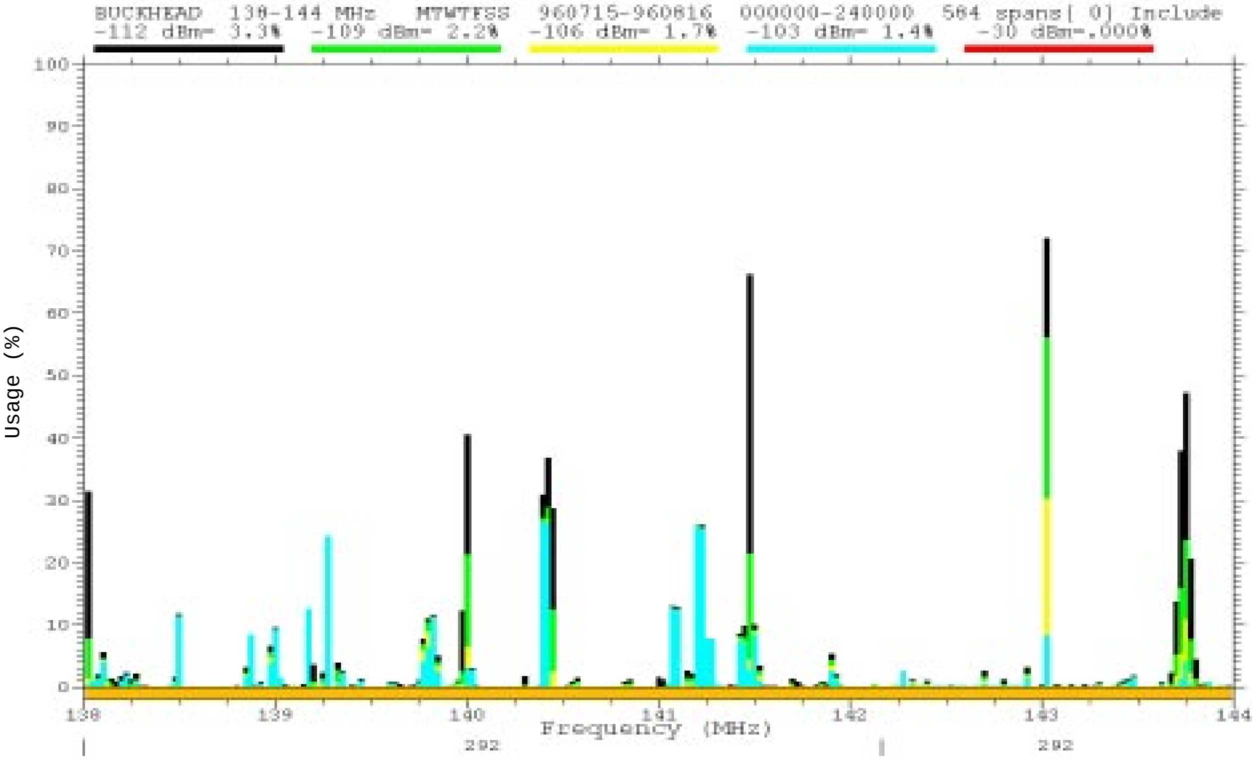

Figure 12. Usage vs. frequency plot of 138-144 MHz measurements at Buckhead.

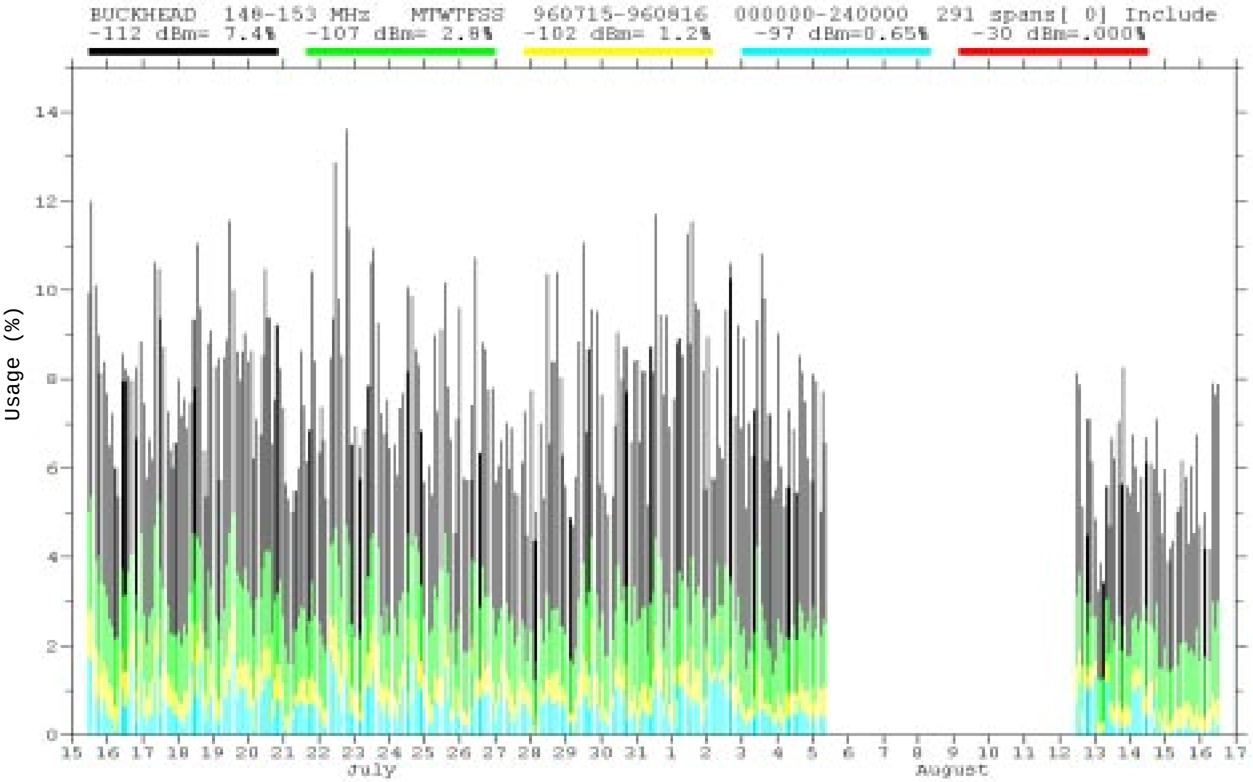

Figure 13. Usage vs. time plot of 148-151 MHz measurements at Buckhead.

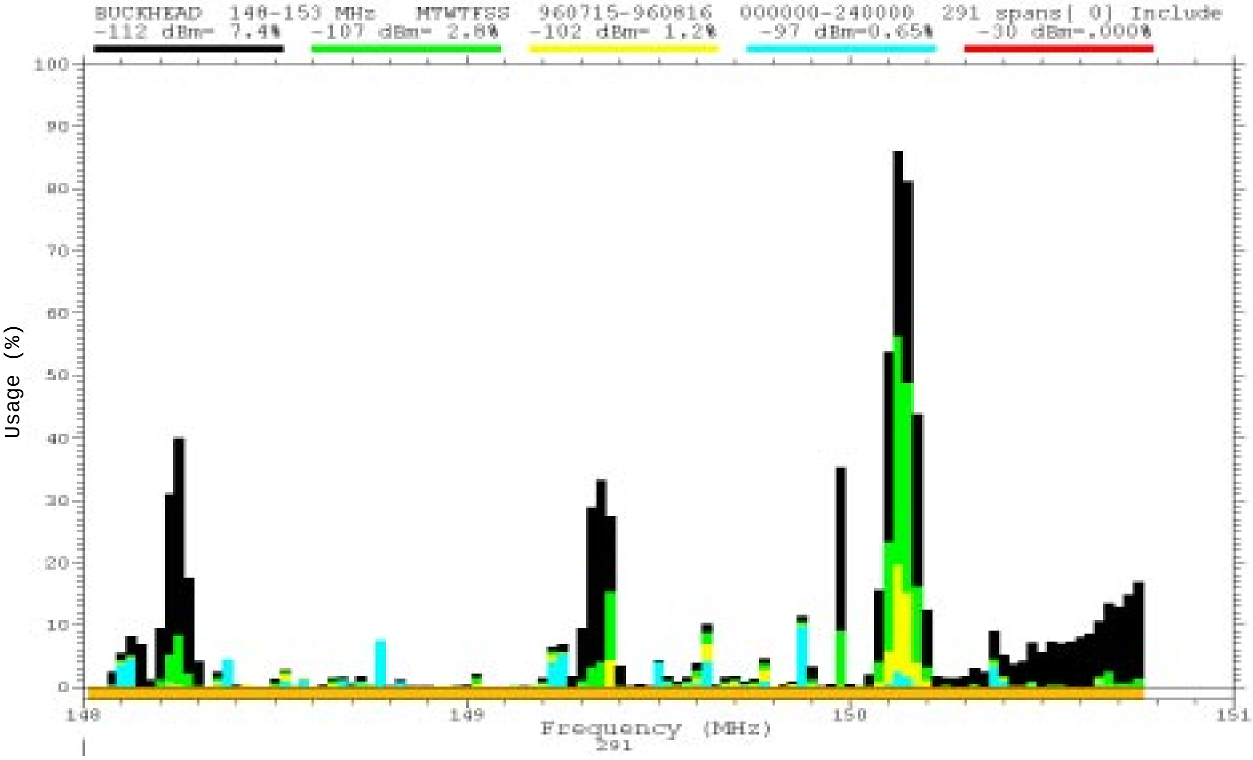

Figure 14. Usage vs. frequency plot of 148-151 MHz measurements at Buckhead.

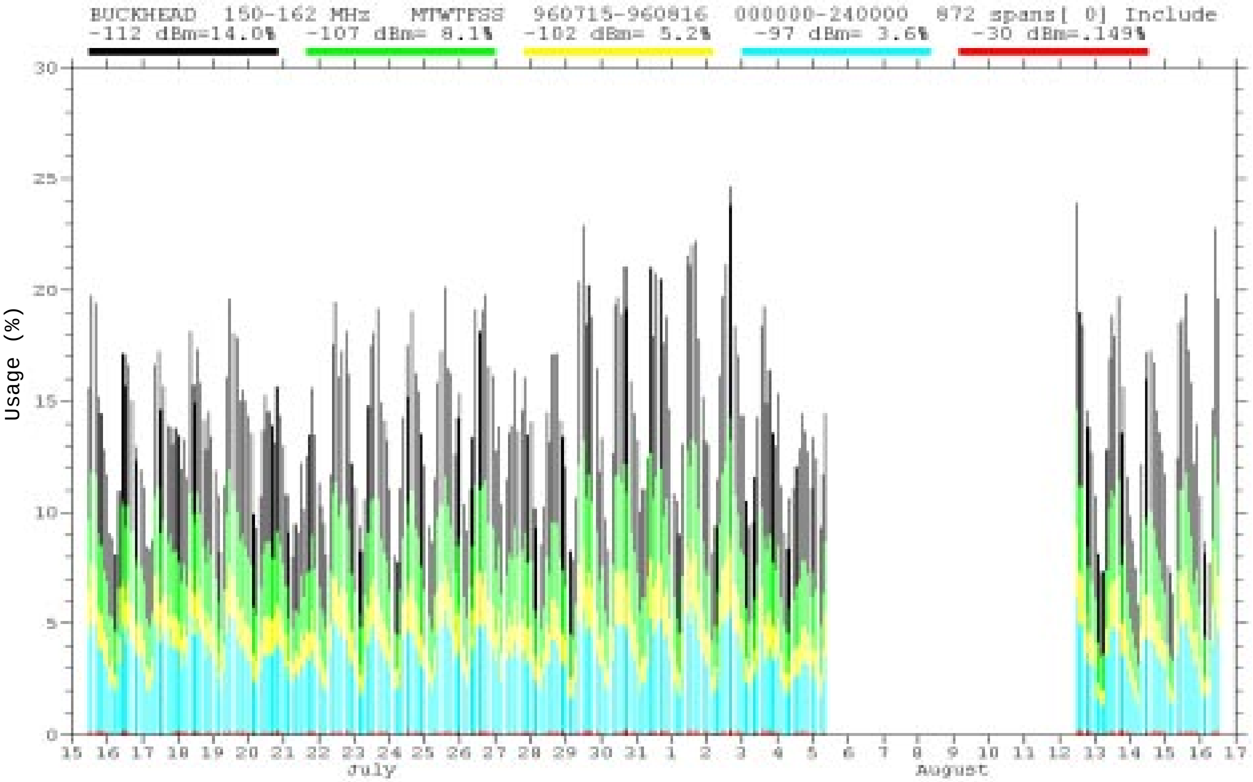

Figure 15. Usage vs. time plot of 150-162 MHz measurements at Buckhead.

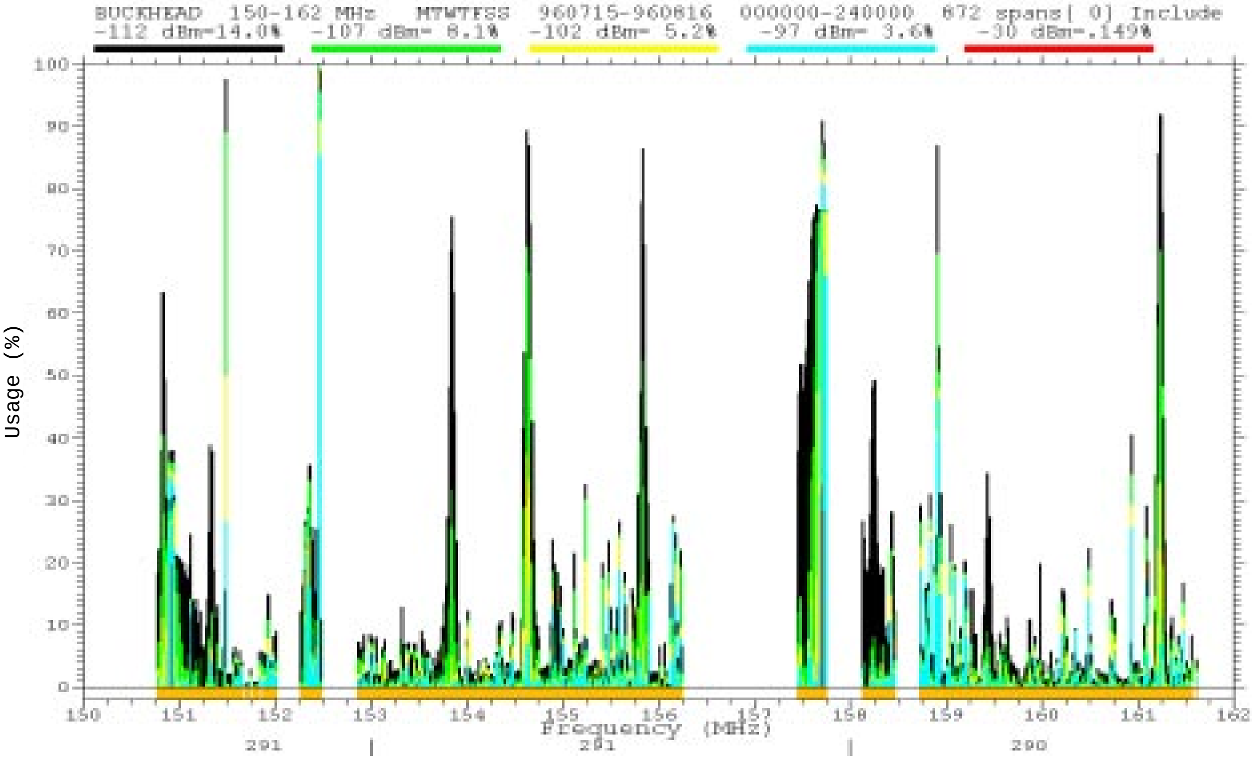

Figure 16. Usage vs. frequency plot of 150-162 MHz measurements at Buckhead.

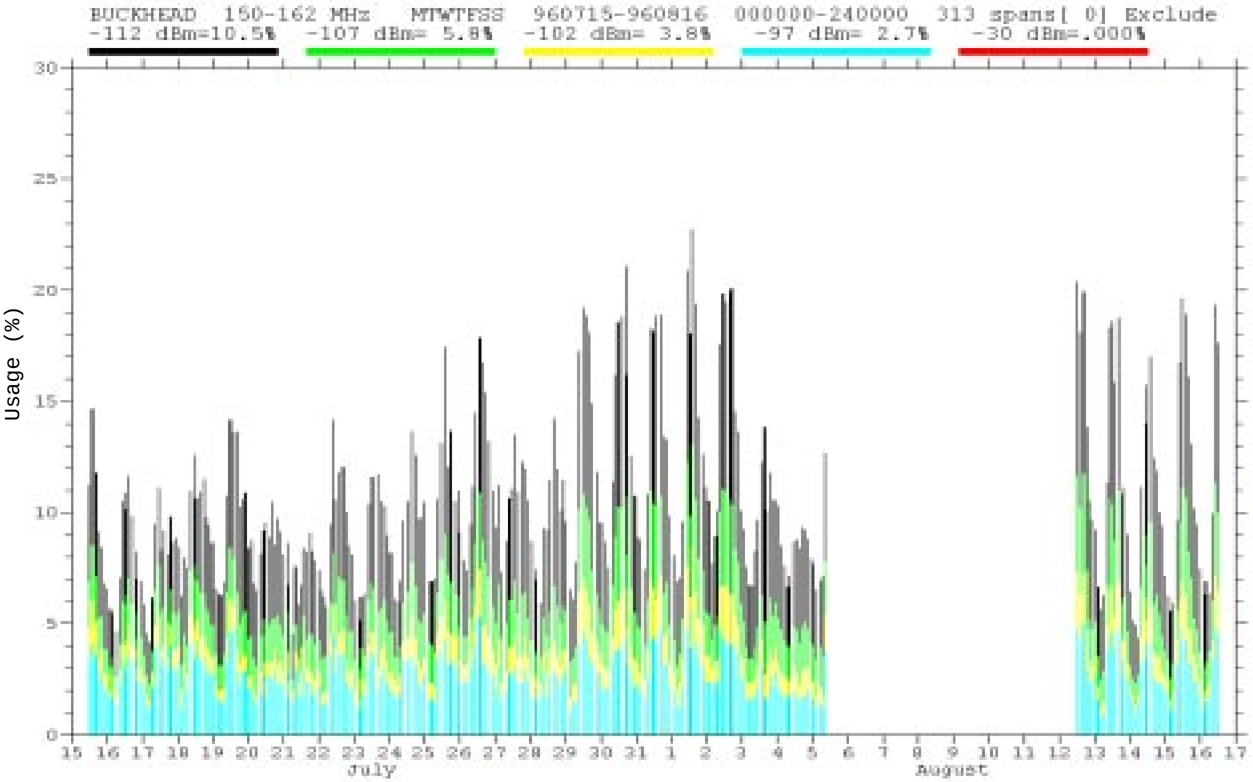

Figure 17. Usage vs. time plot of 150-162 MHz measurements at Buckhead (exclude data).

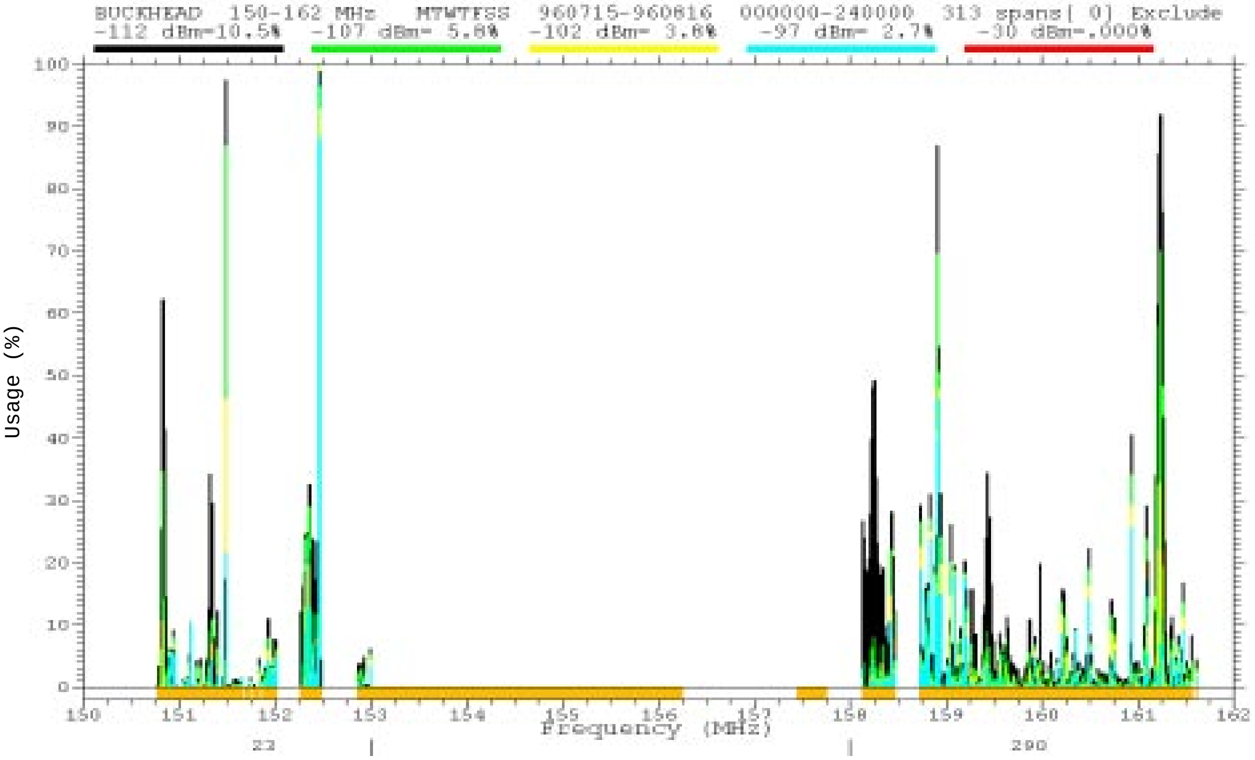

Figure 18. Usage vs. frequency plot of 150-162 MHz measurements at Buckhead (exclude data).

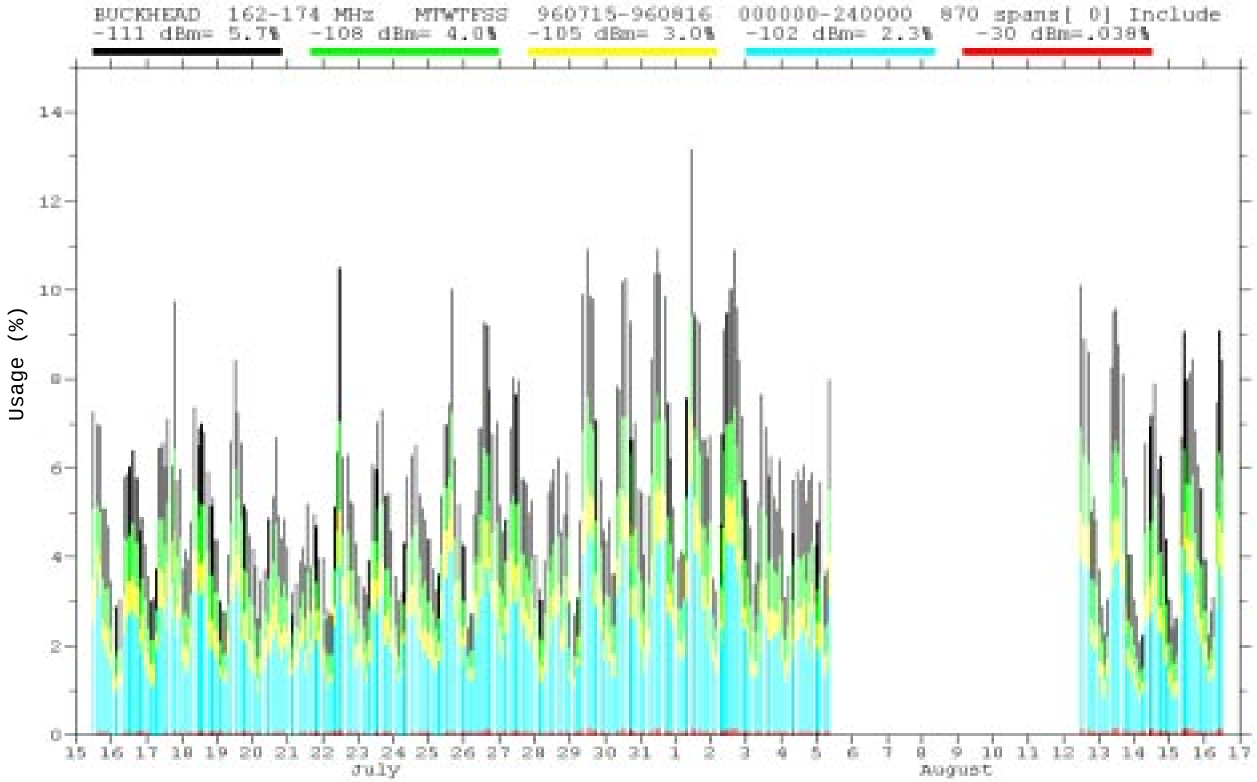

Figure 19. Usage vs. time plot of 162-174 MHz measurements at Buckhead.

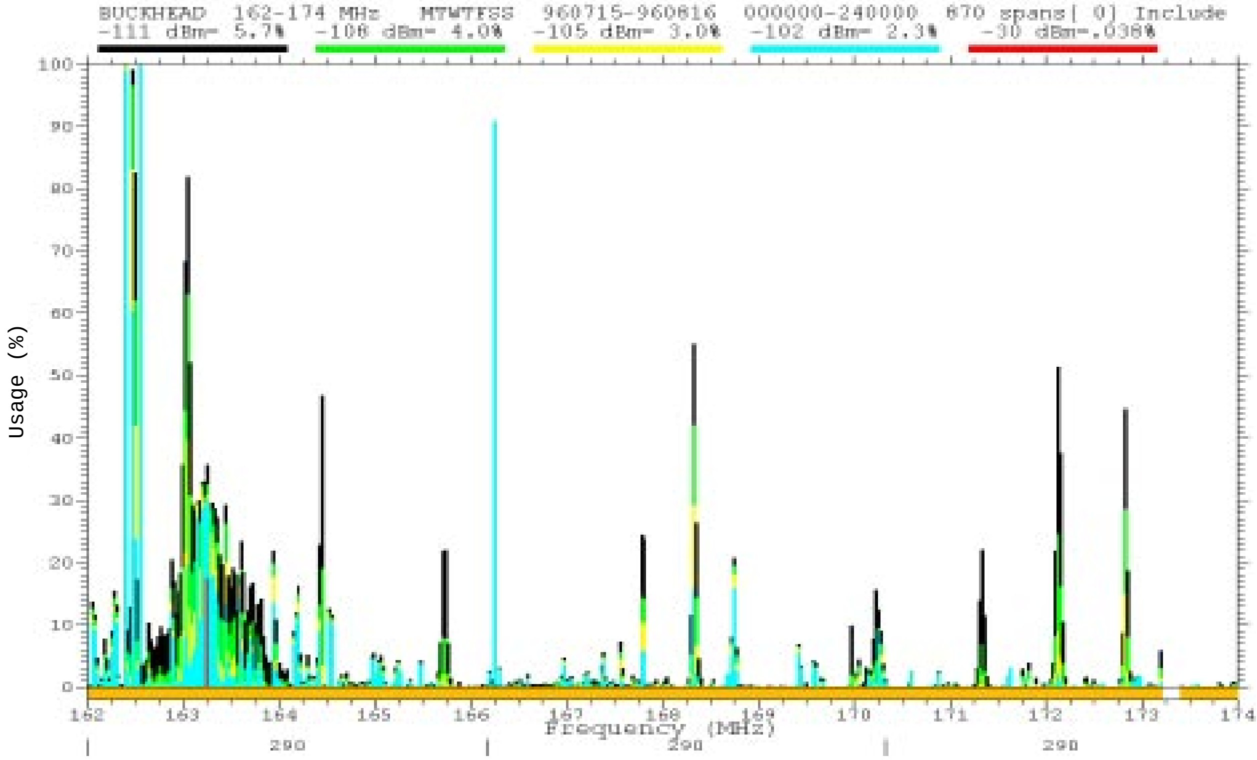

Figure 20. Usage vs. frequency plot of 162-174 MHz measurements at Buckhead.

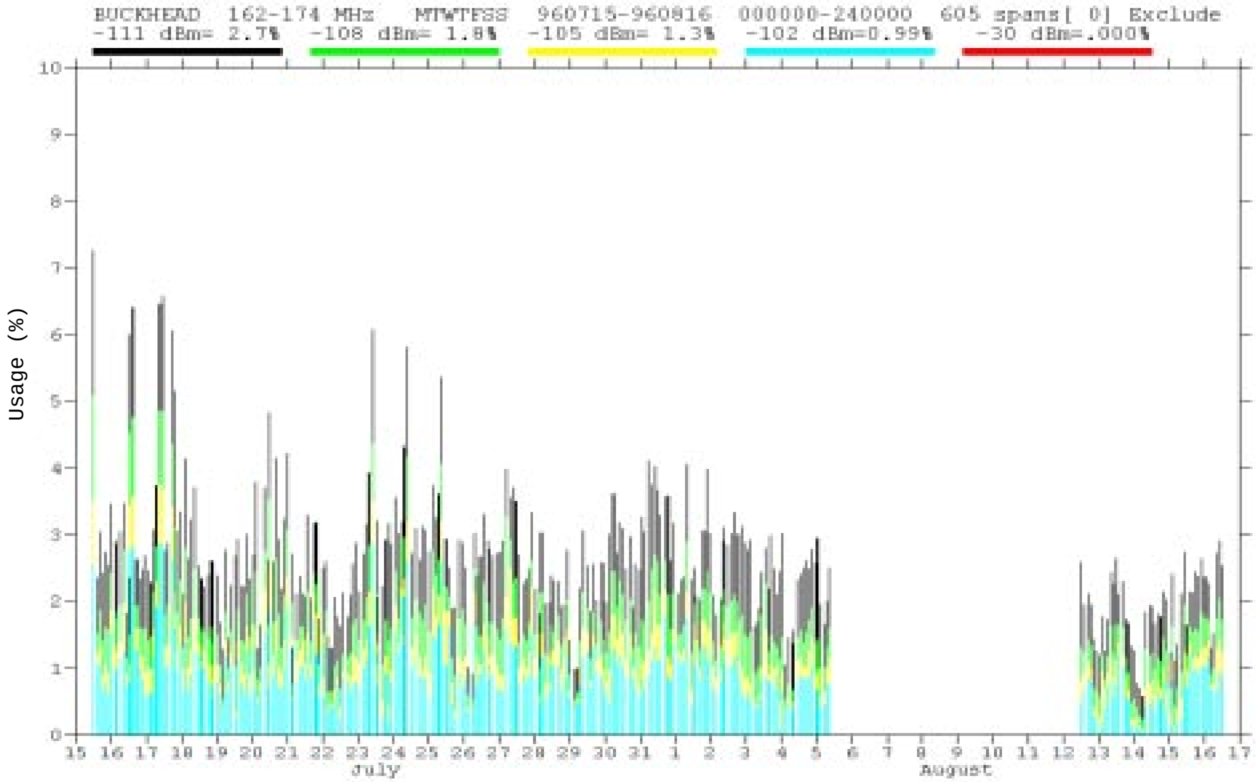

Figure 21. Usage vs. time plot of 162-174 MHz measurements at Buckhead (exclude data).

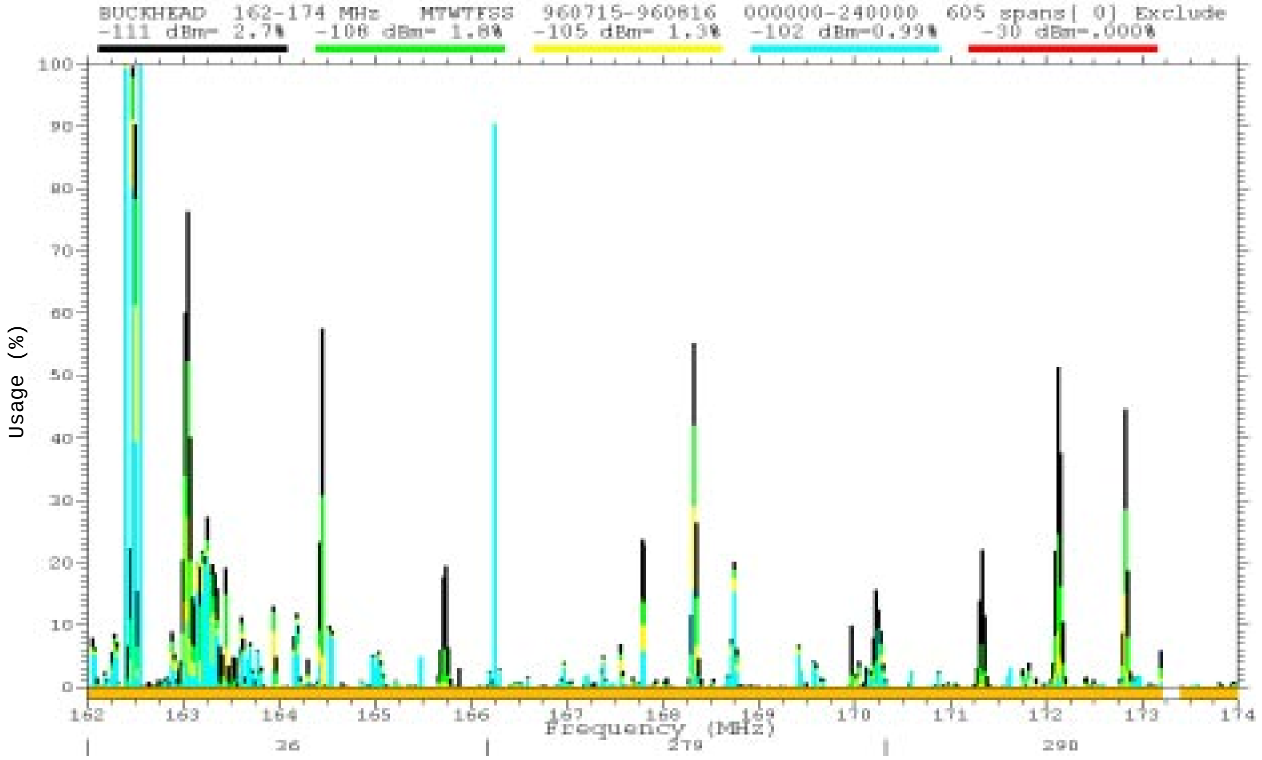

Figure 22. Usage vs. frequency plot of 162-174 MHz measurements at Buckhead (exclude data).

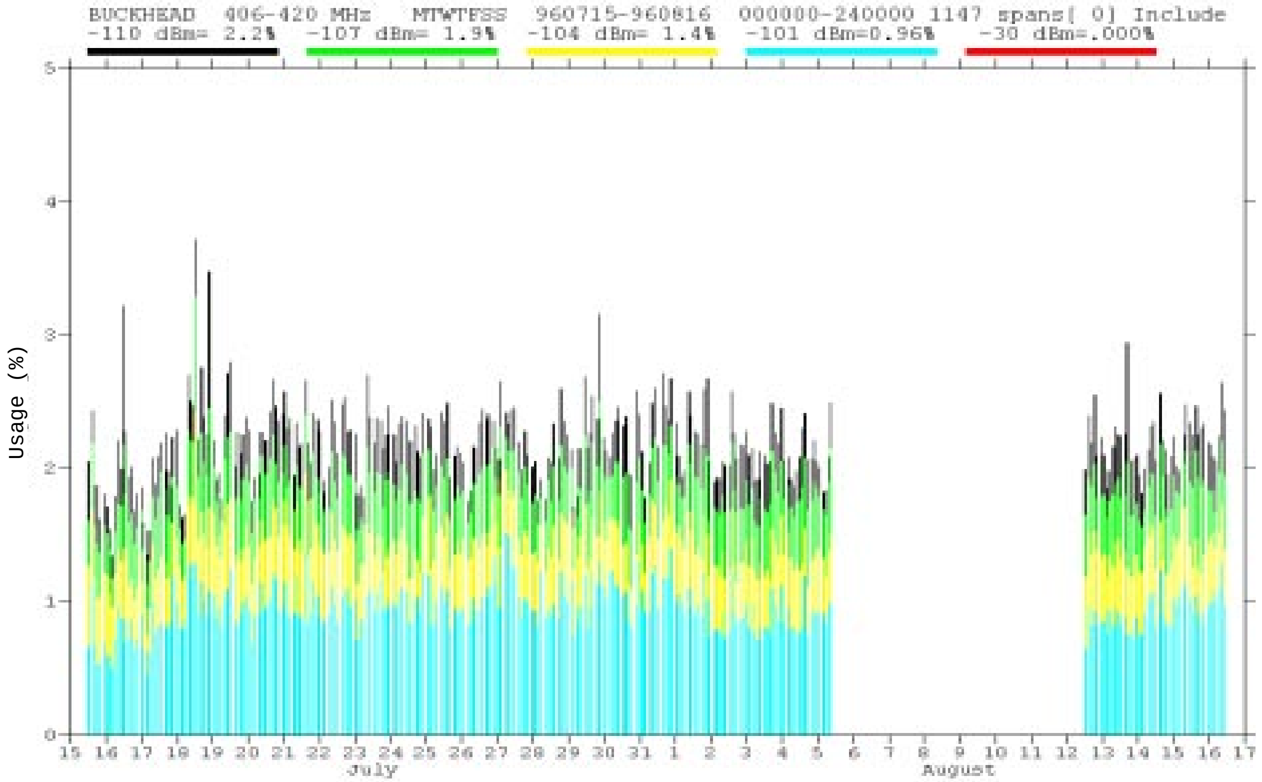

Figure 23. Usage vs. time plot of 406-420 MHz measurements at Buckhead.

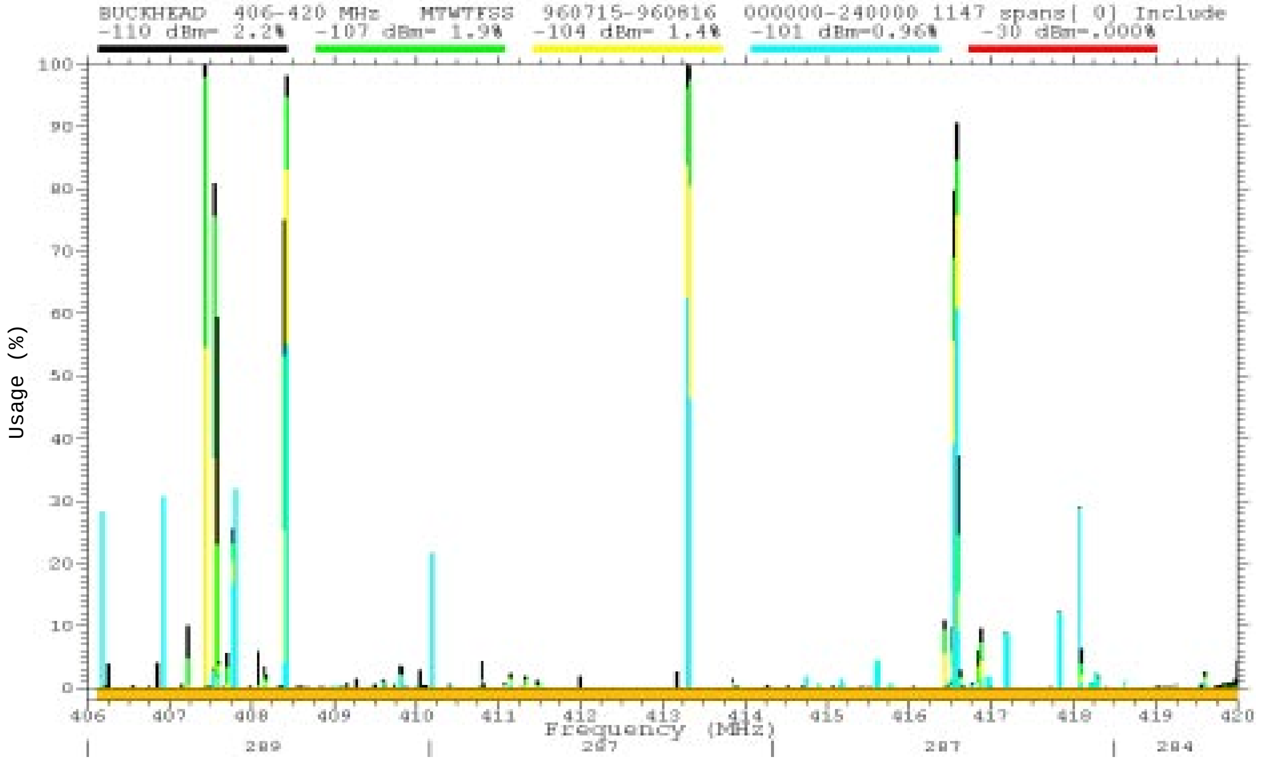

Figure 24. Usage vs. frequency plot of 406-420 MHz measurements at Buckhead.

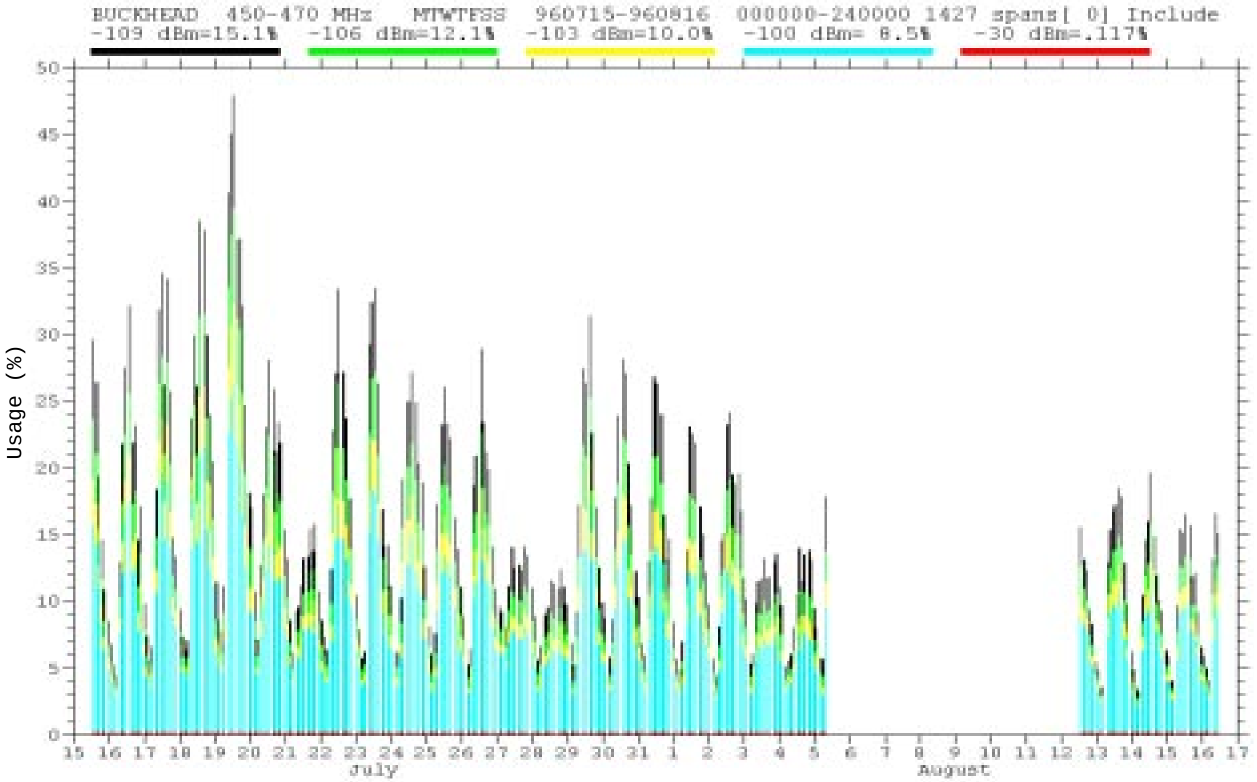

Figure 25. Usage vs. time plot of 451-470 MHz measurements at Buckhead.

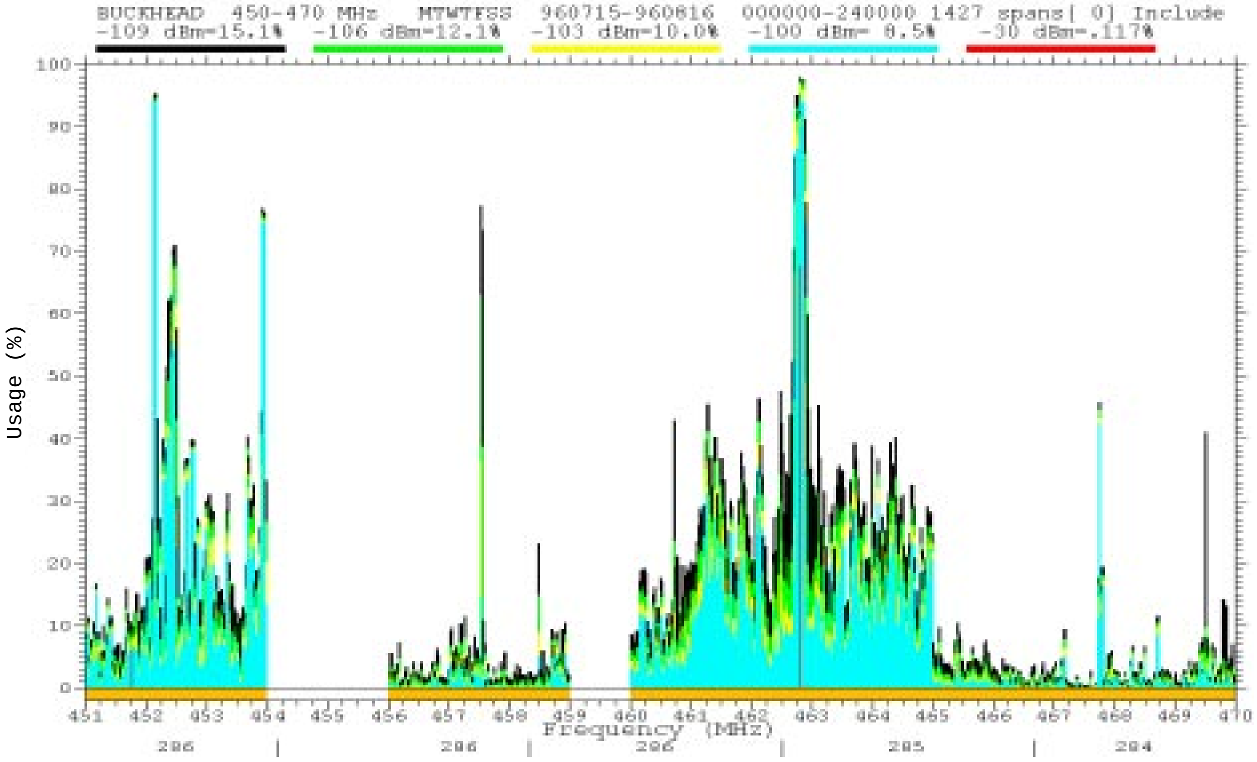

Figure 26. Usage vs. frequency plot of 451-470 MHz measurements at Buckhead.

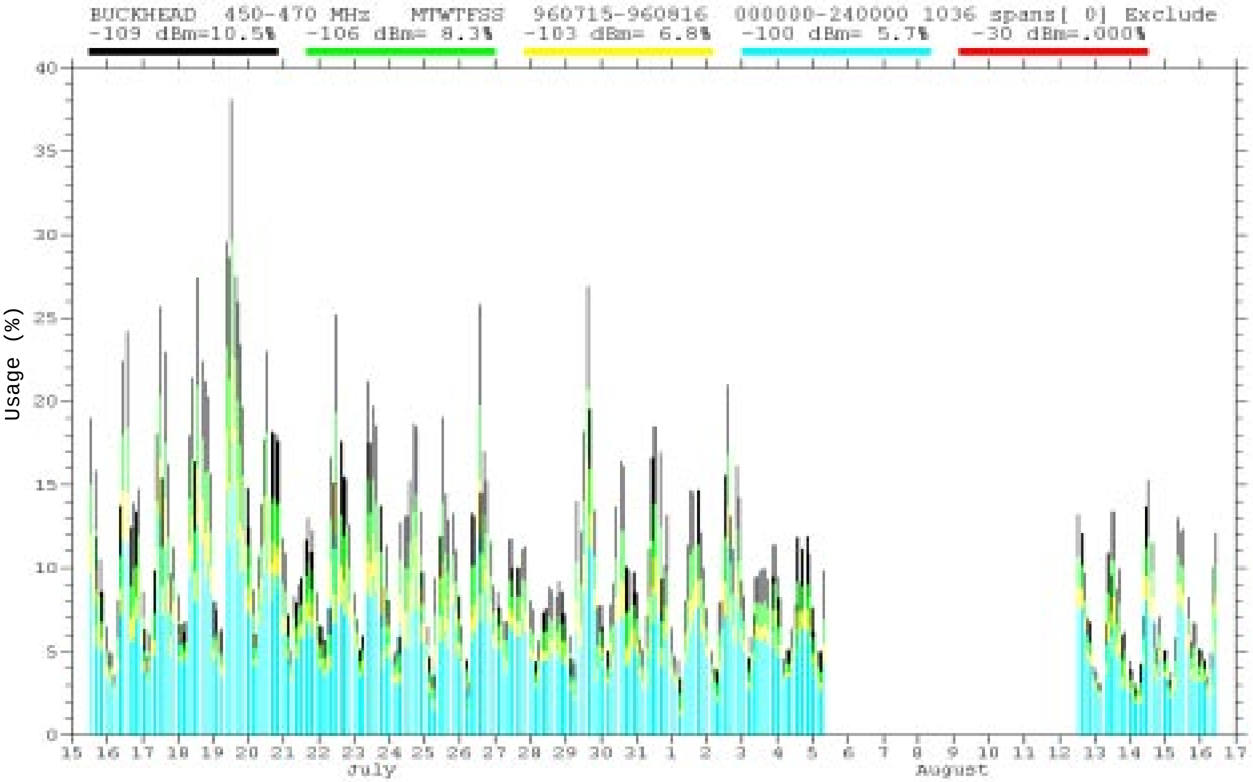

Figure 27. Usage vs. time plot of 451-470 MHz measurements at Buckhead (exclude data).

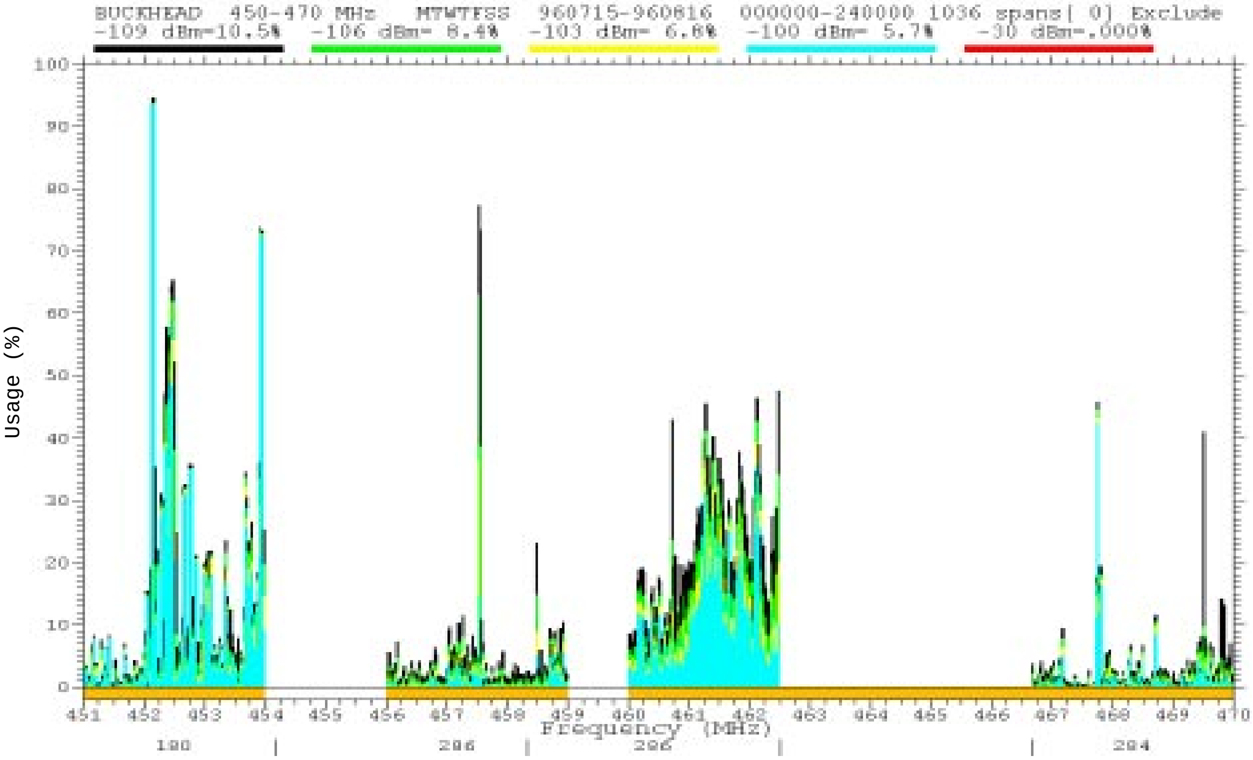

Figure 28. Usage vs. frequency plot of 451-470 MHz measurements at Buckhead (exclude data).

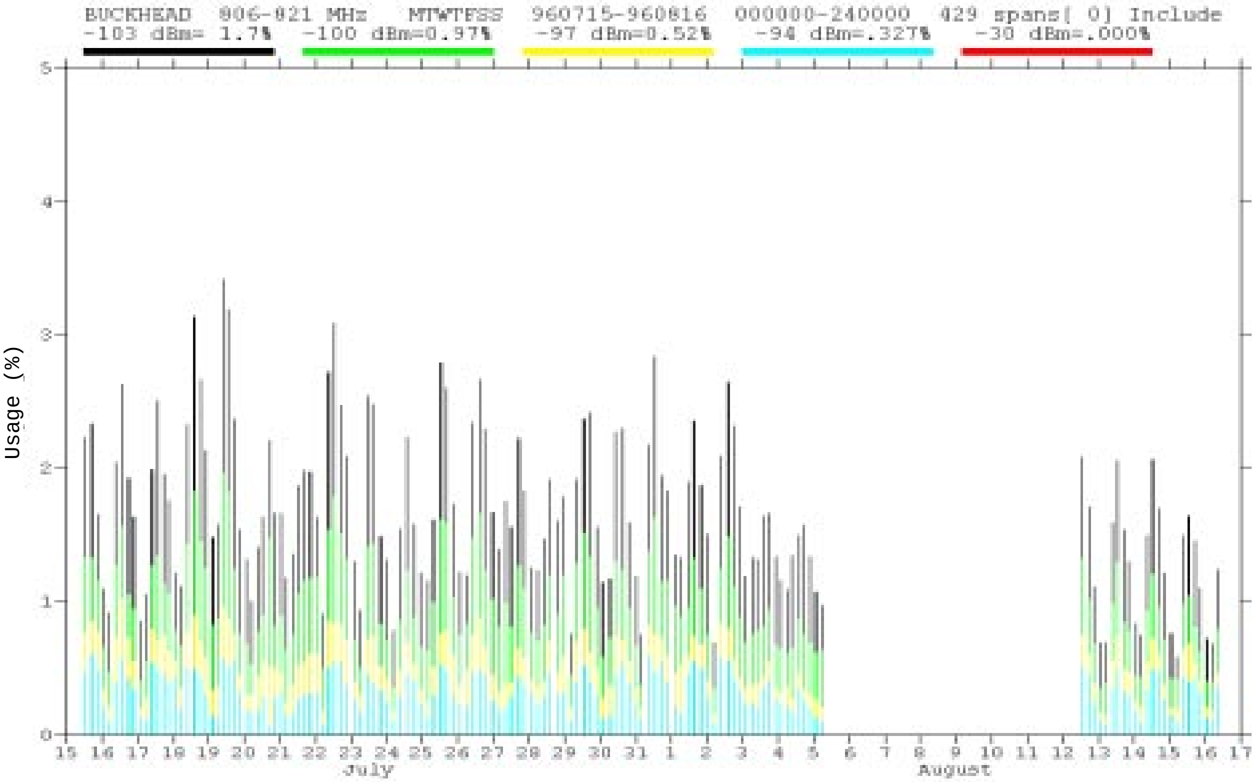

Figure 29. Usage vs. time plot of 806-821 MHz measurements at Buckhead.

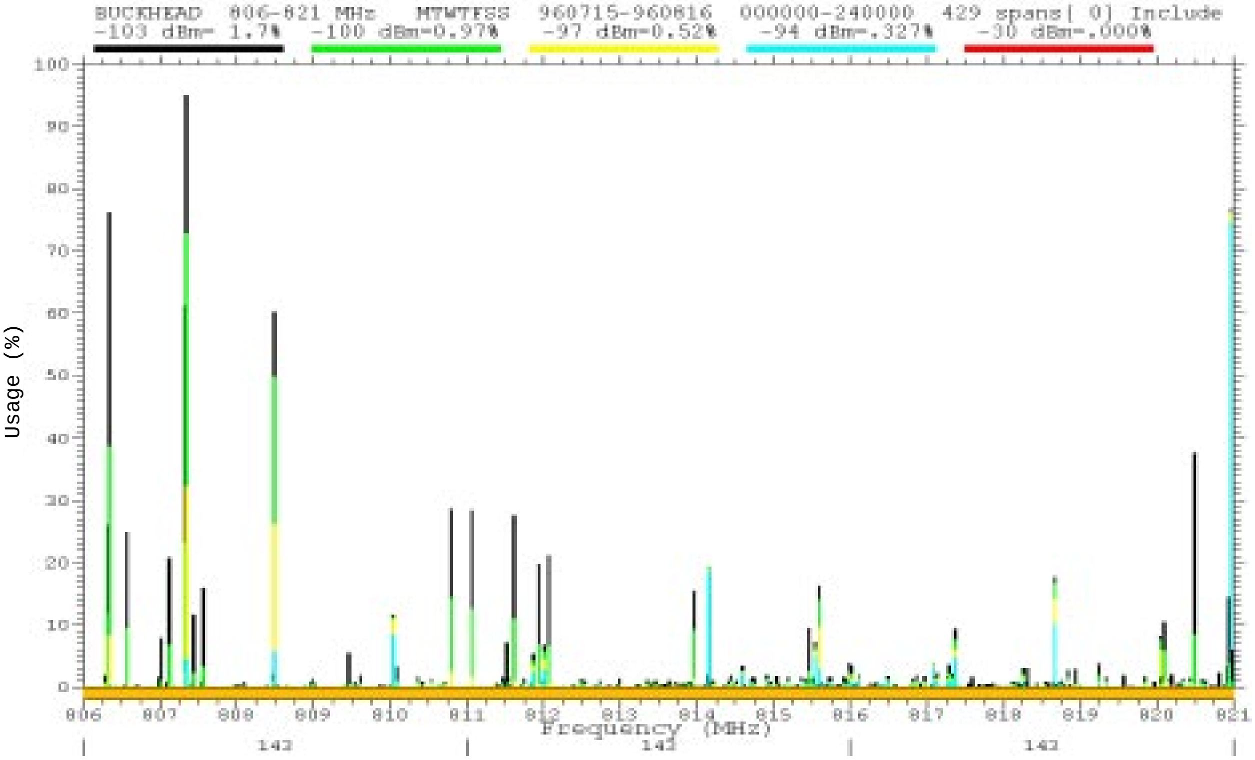

Figure 30. Usage vs. frequency plot of 806-821 MHz measurements at Buckhead.

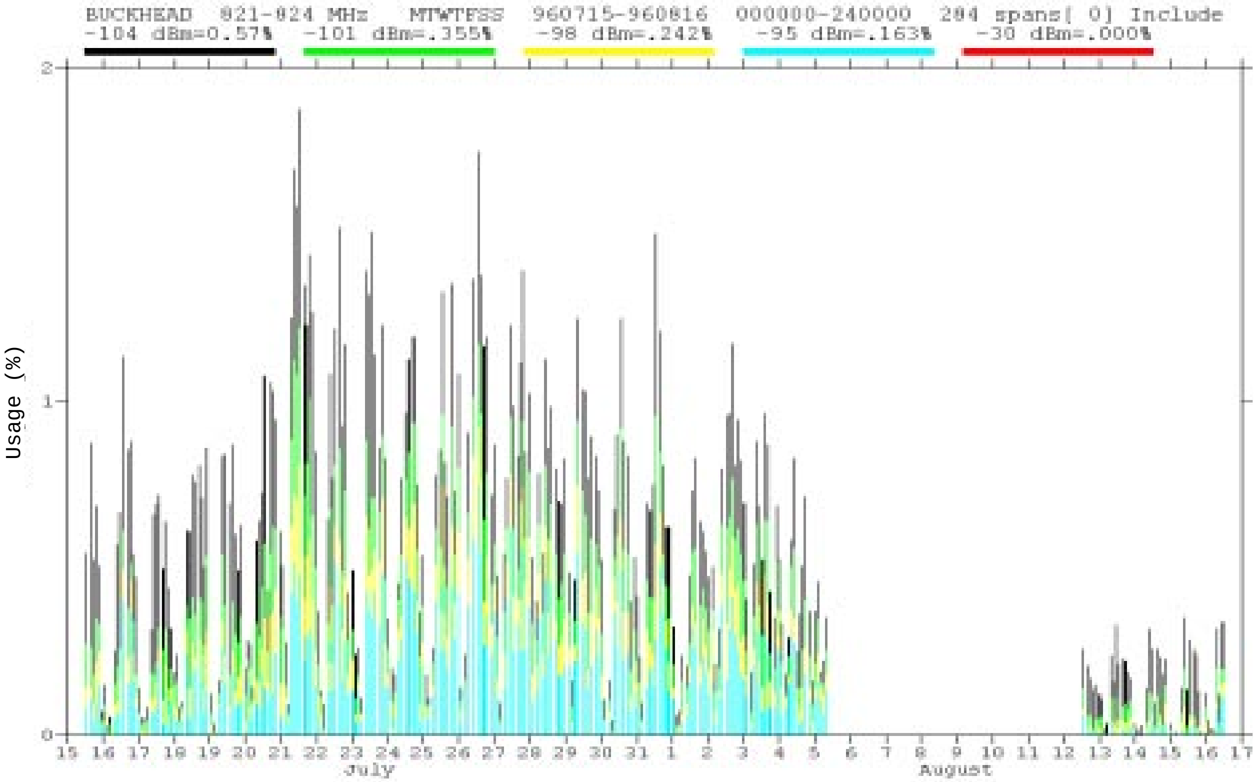

Figure 31. Usage vs. time plot of 821-824 MHz measurements at Buckhead.

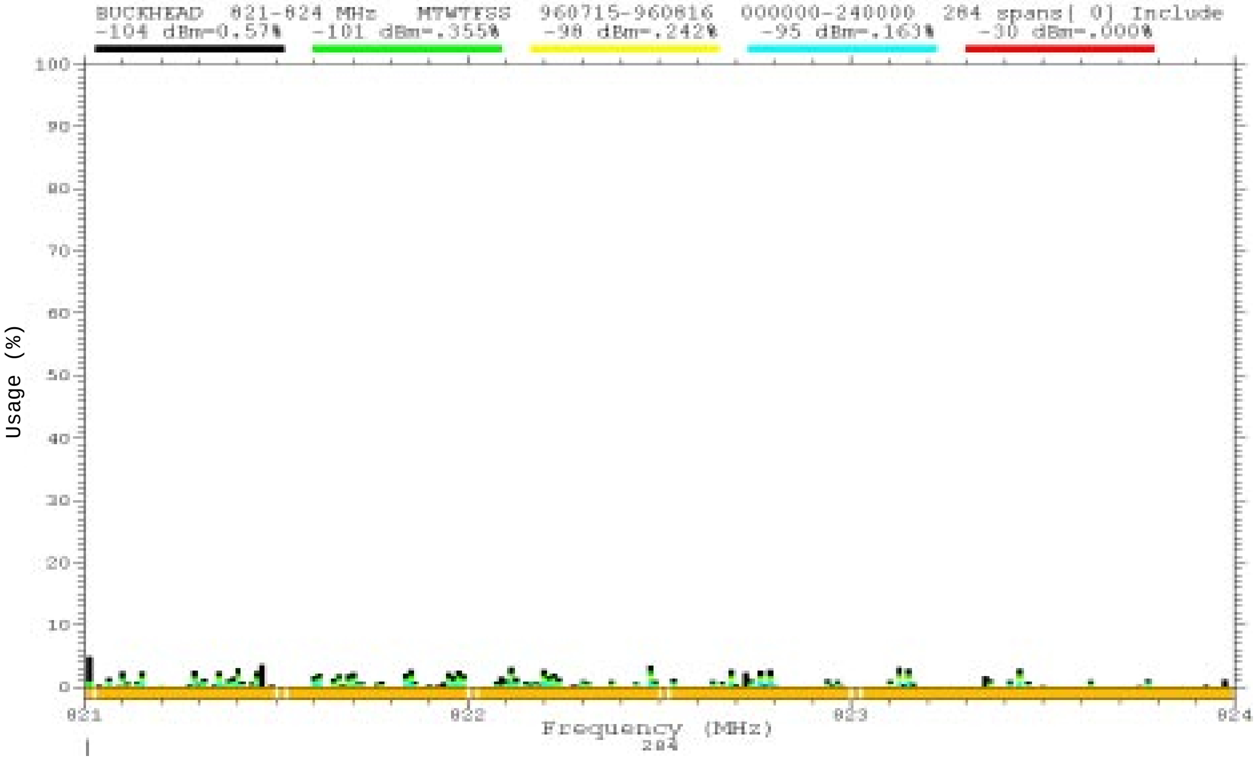

Figure 32. Usage vs. frequency plot of 821-824 MHz measurements at Buckhead.

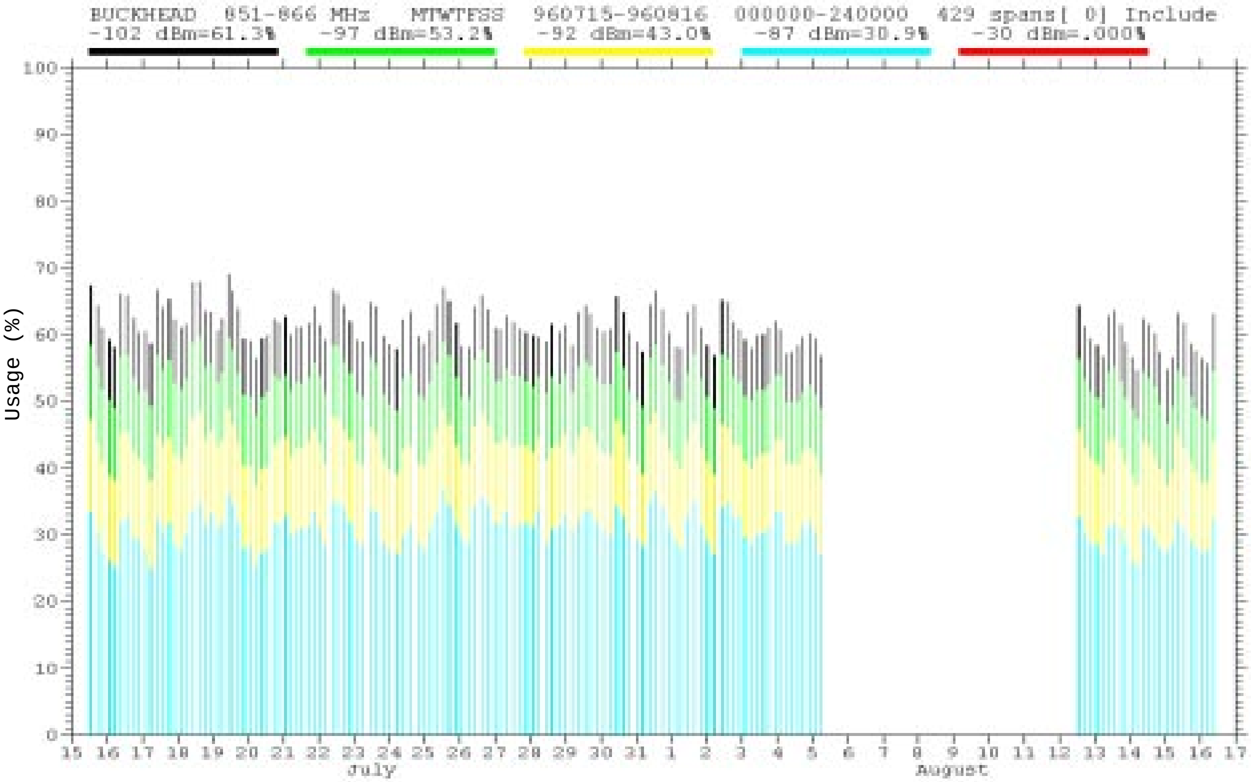

Figure 33. Usage vs. time plot of 851-866 MHz measurements at Buckhead.

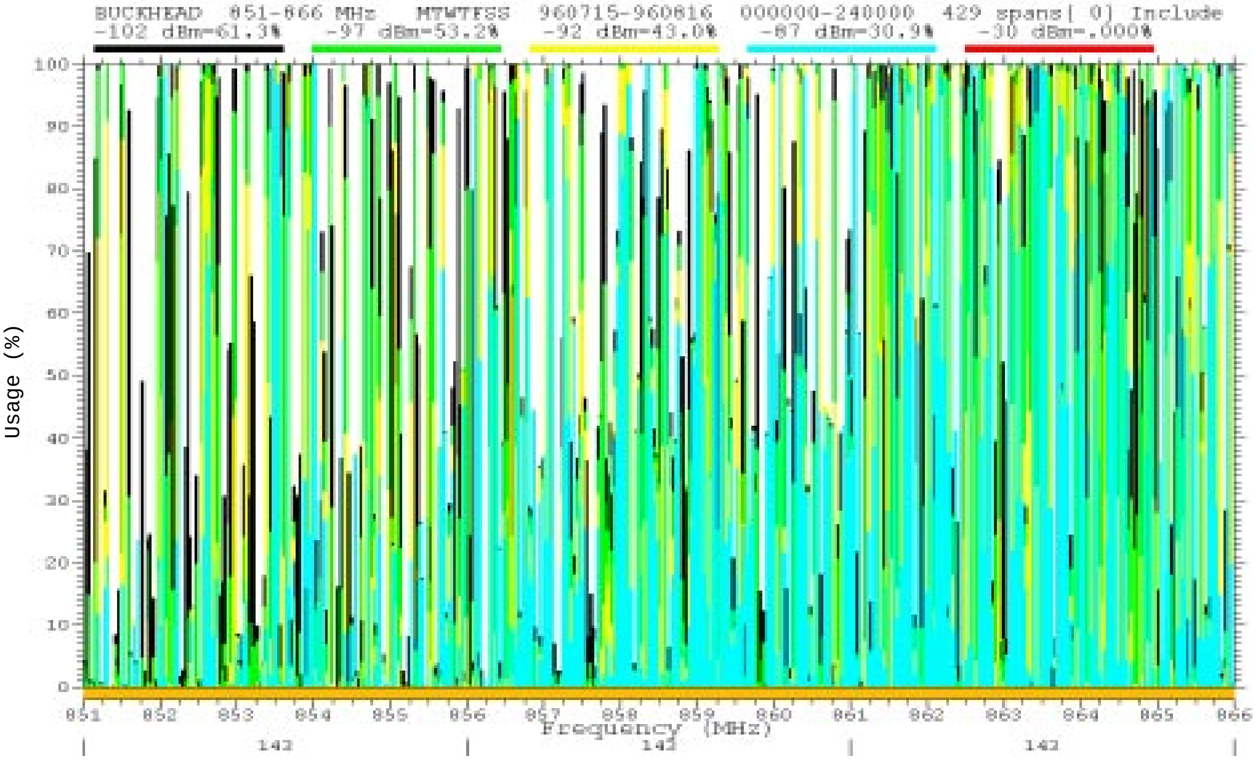

Figure 34. Usage vs. frequency plot of 851-866 MHz measurements at Buckhead.

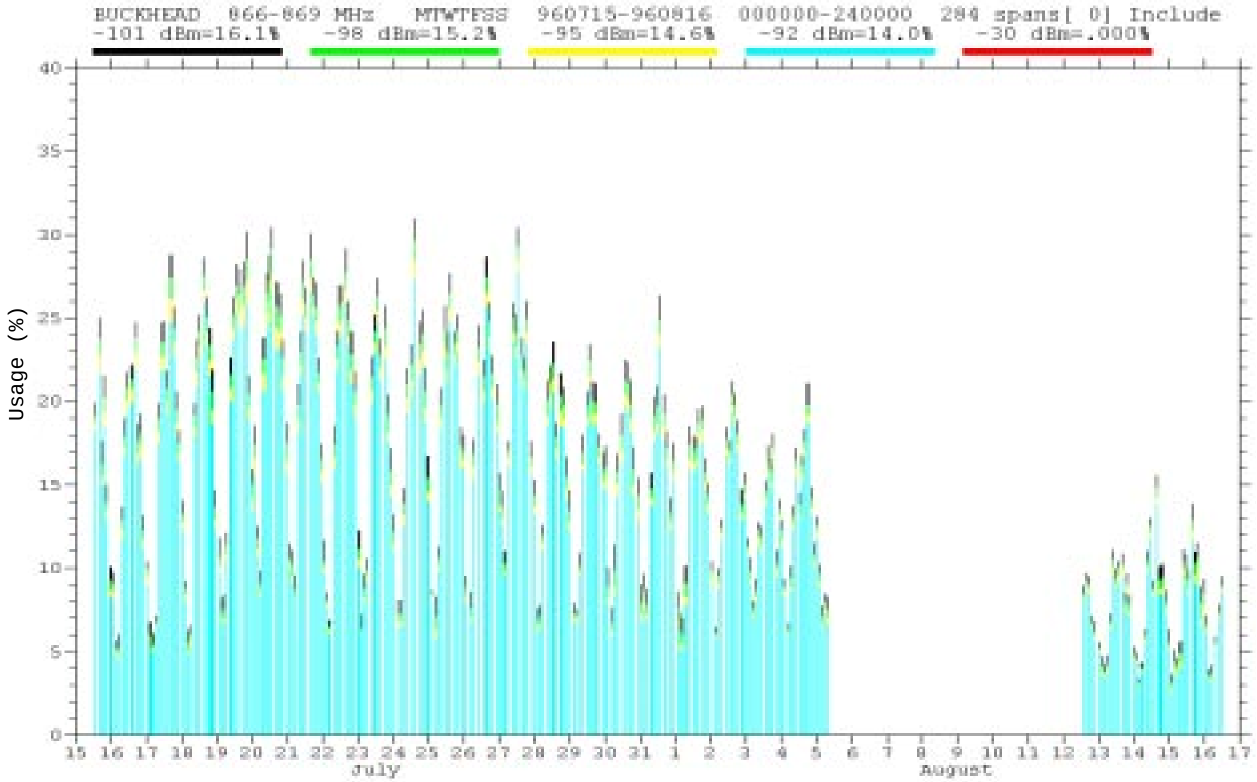

Figure 35. Usage vs. time plot of 866-869 MHz measurements at Buckhead.

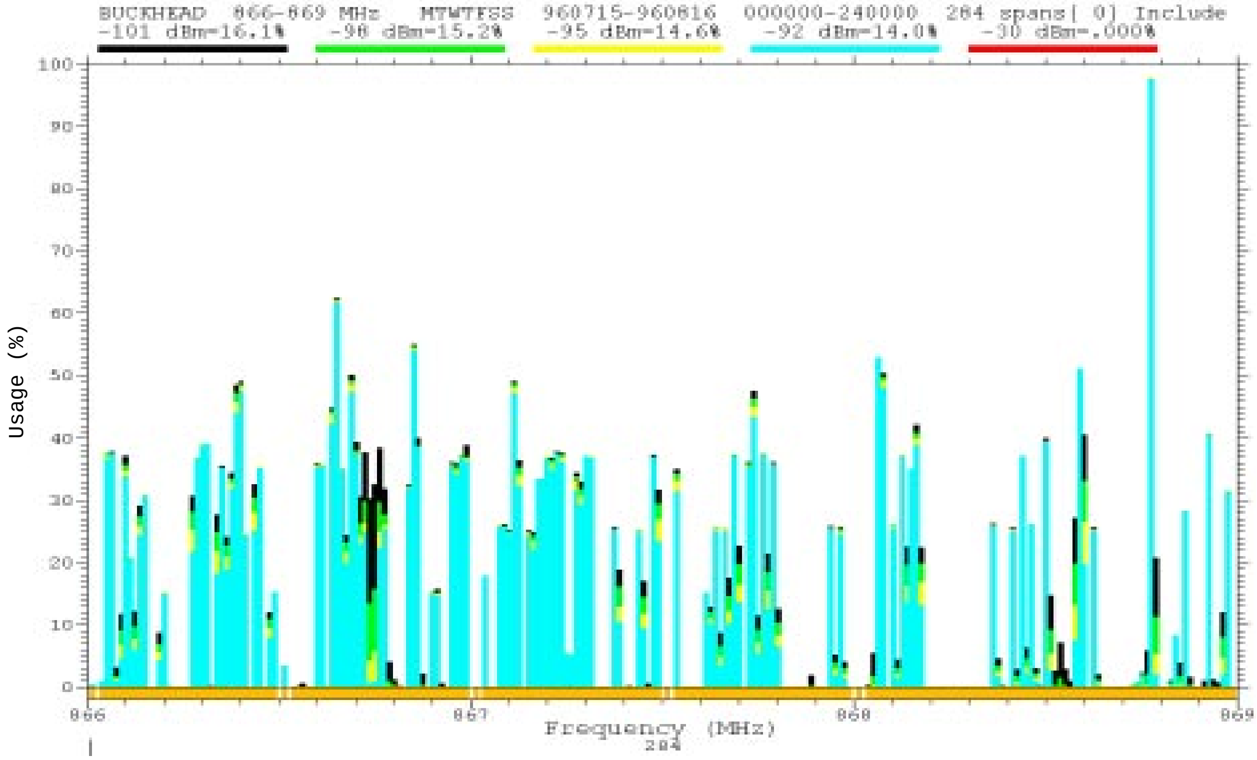

Figure 36. Usage vs. frequency plot of 866-869 MHz measurements at Buckhead.

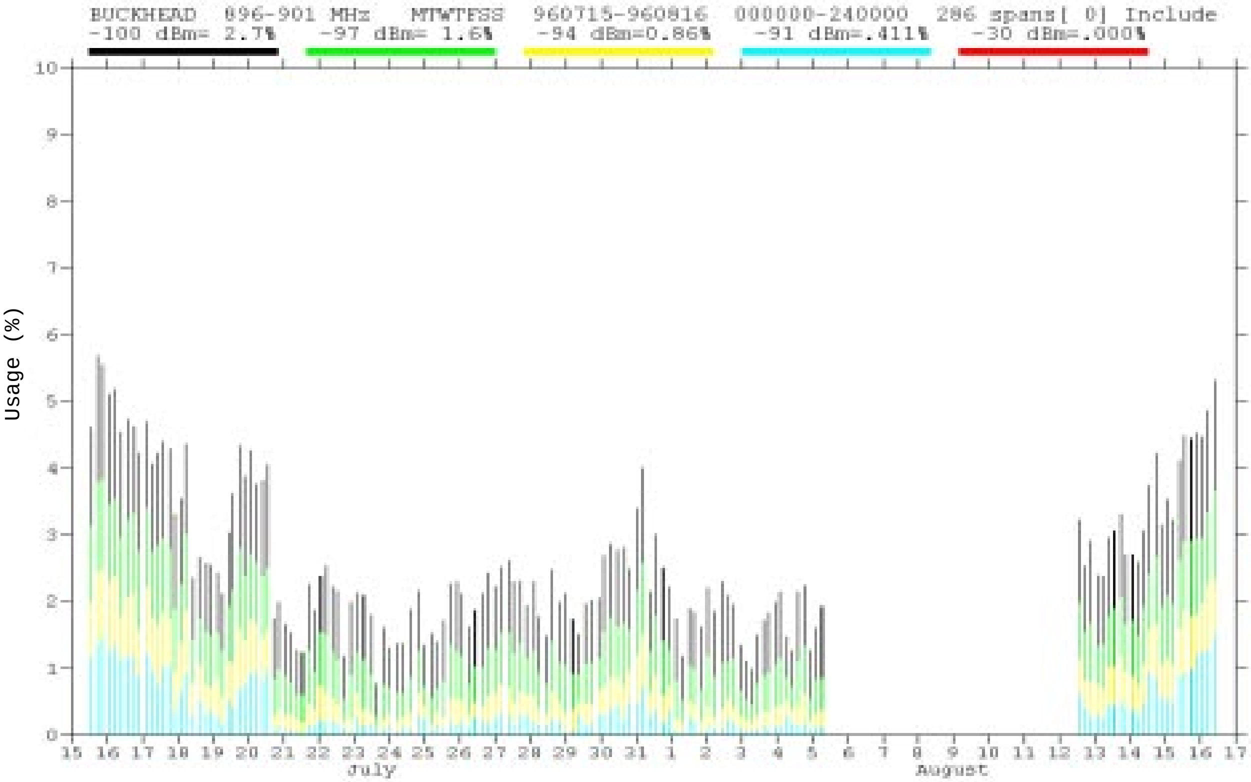

Figure 37. Usage vs. time plot of 896-901 MHz measurements at Buckhead.

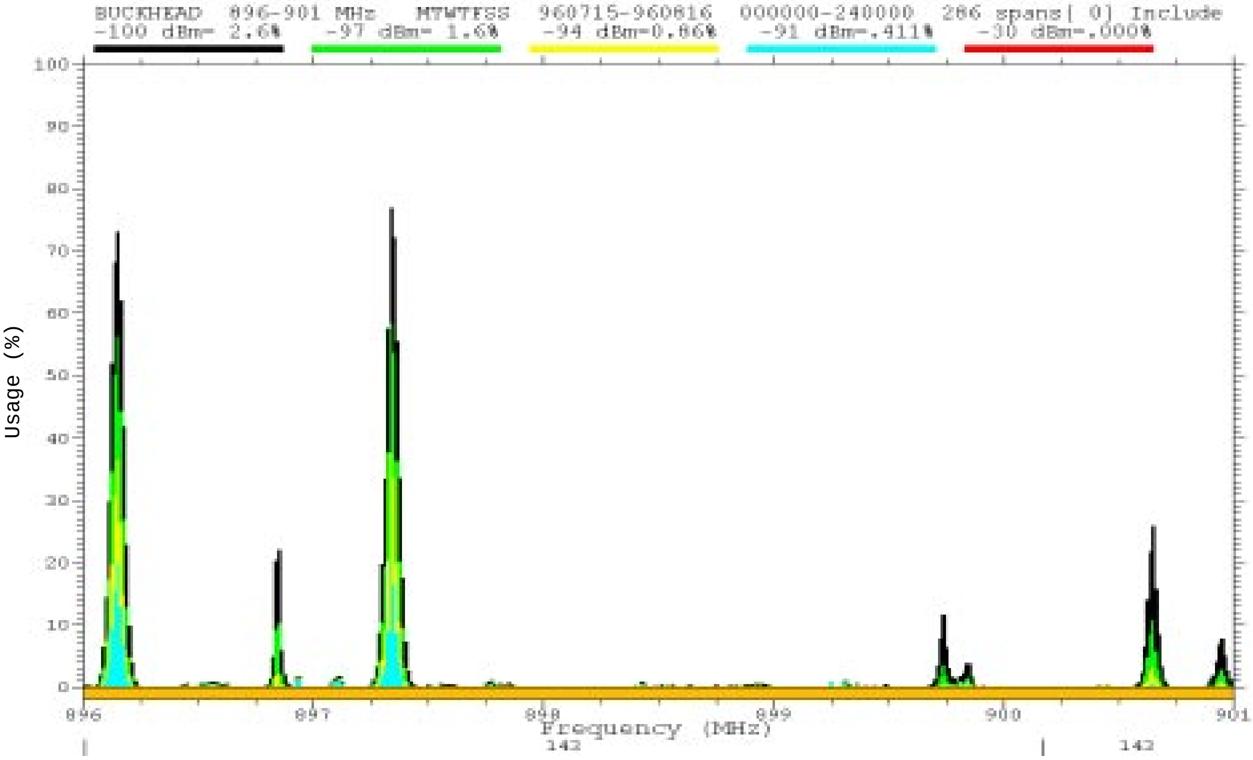

Figure 38. Usage vs. frequency plot of 896-901 MHz measurements at Buckhead.

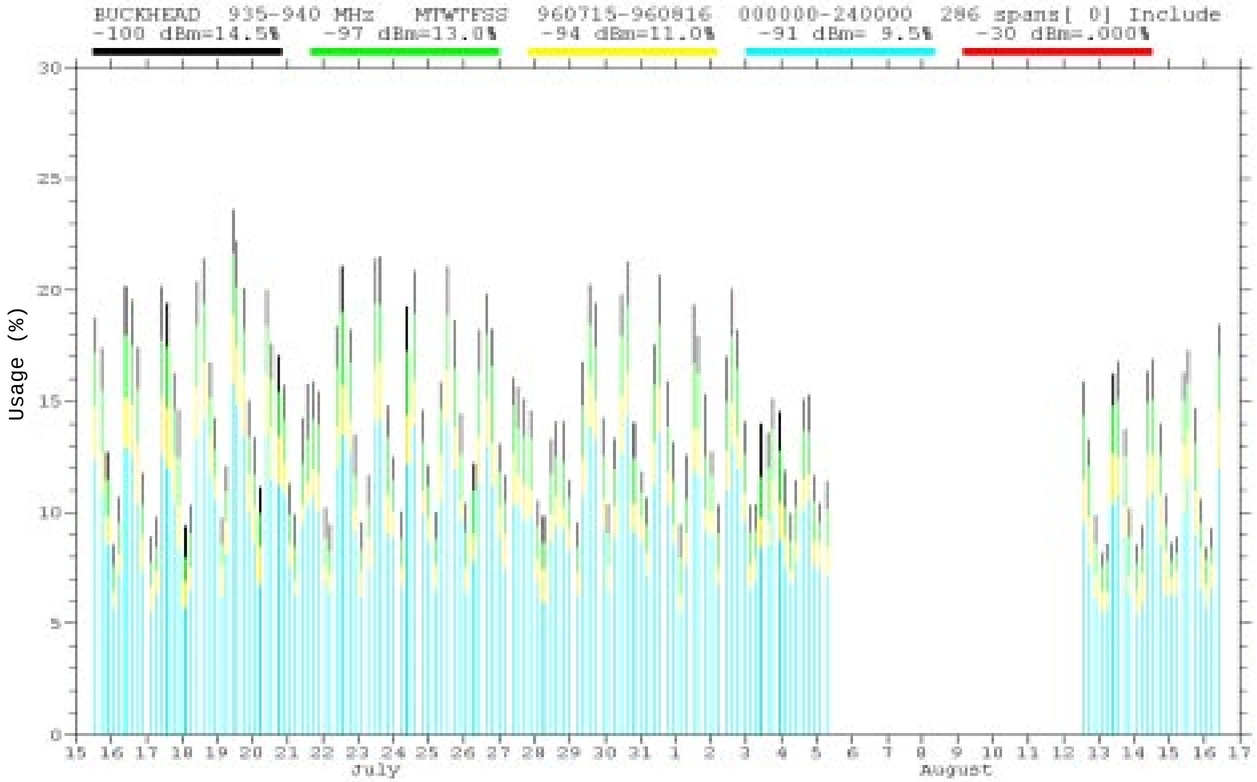

Figure 39. Usage vs. time plot of 935-940 MHz measurements at Buckhead.

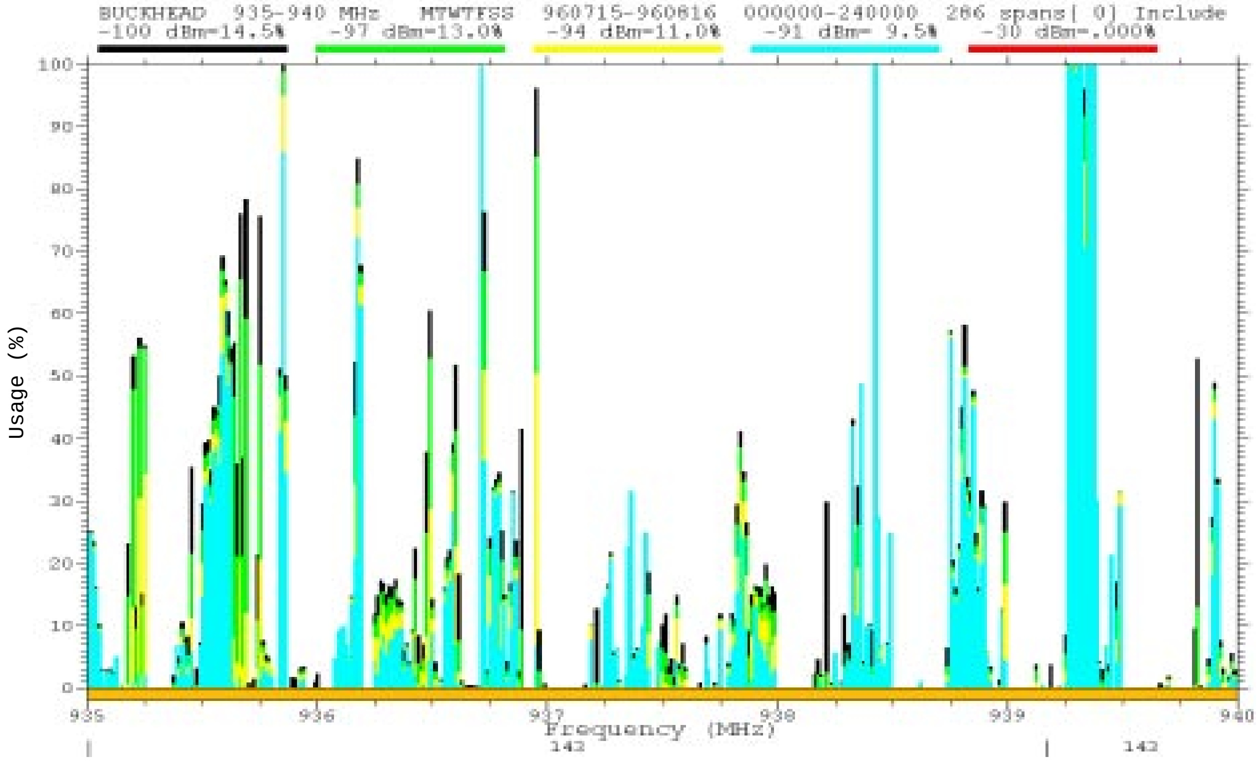

Figure 40. Usage vs. frequency plot of 935-940 MHz measurements at Buckhead.

3.5 Fort McPherson Site Channel Usage Statistics

This section presents graphs showing usage vs. time and usage vs. frequency for measurements at the Fort McPherson site. The graphed analysis plots in this Section are formatted the same as the plots previously described in Section 3.4; so, that description is not repeated here. The data are presented as two graphed analysis plots of channelized LMR data displayed on one page. The graph at the top of the page shows percentage usage as a function of time (time plot), and the bottom graph shows percentage usage as a function of frequency (frequency plot).

All of the usage graphs (both time plots and frequency plots) are color coded to show usage as a function of measured power threshold (color bars in the graph header show the analysis band thresholds). Each vertical line on the time-dependence plot (upper graph) represents the average analysis band usage (i.e., average of all scans exceeding each color-coded threshold) at the time indicated. Each vertical line on the frequency plots shows the average usage for each threshold at the indicated frequency. The orange bar at the bottom of the frequency plots indicates which frequencies were included in the analysis.

The color bars in the header represent the total usage based on each of the exceeded thresholds. When plotted, the colors are stacked because data that exceeded the higher thresholds must have also exceeded the lower thresholds.

Figures 41 through 64 are the time and frequency plots for all of the Fort McPherson analysis bands. Band-by-band observations on relative levels of LMR usage and comments on the extrapolation of all measured data are found in Section 3.9.

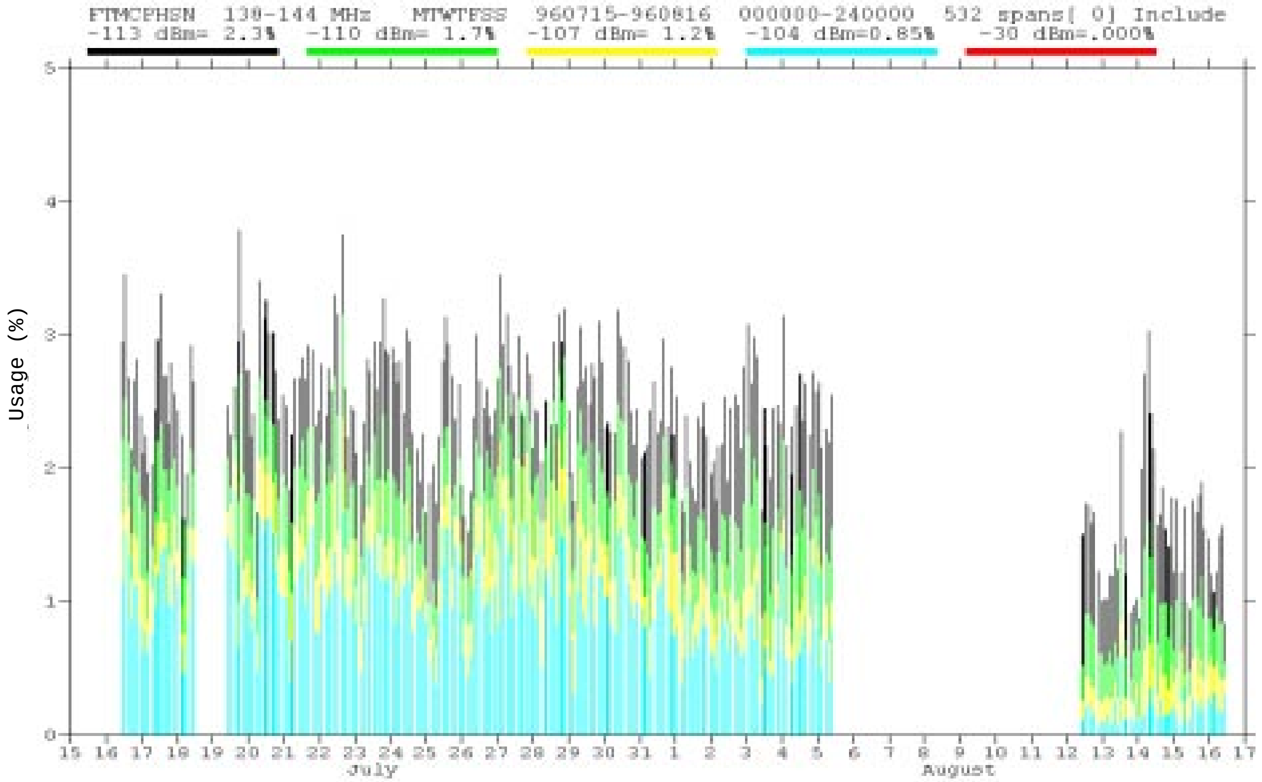

Figure 41. Usage vs. time plot of 138-144 MHz measurements at Fort McPherson.

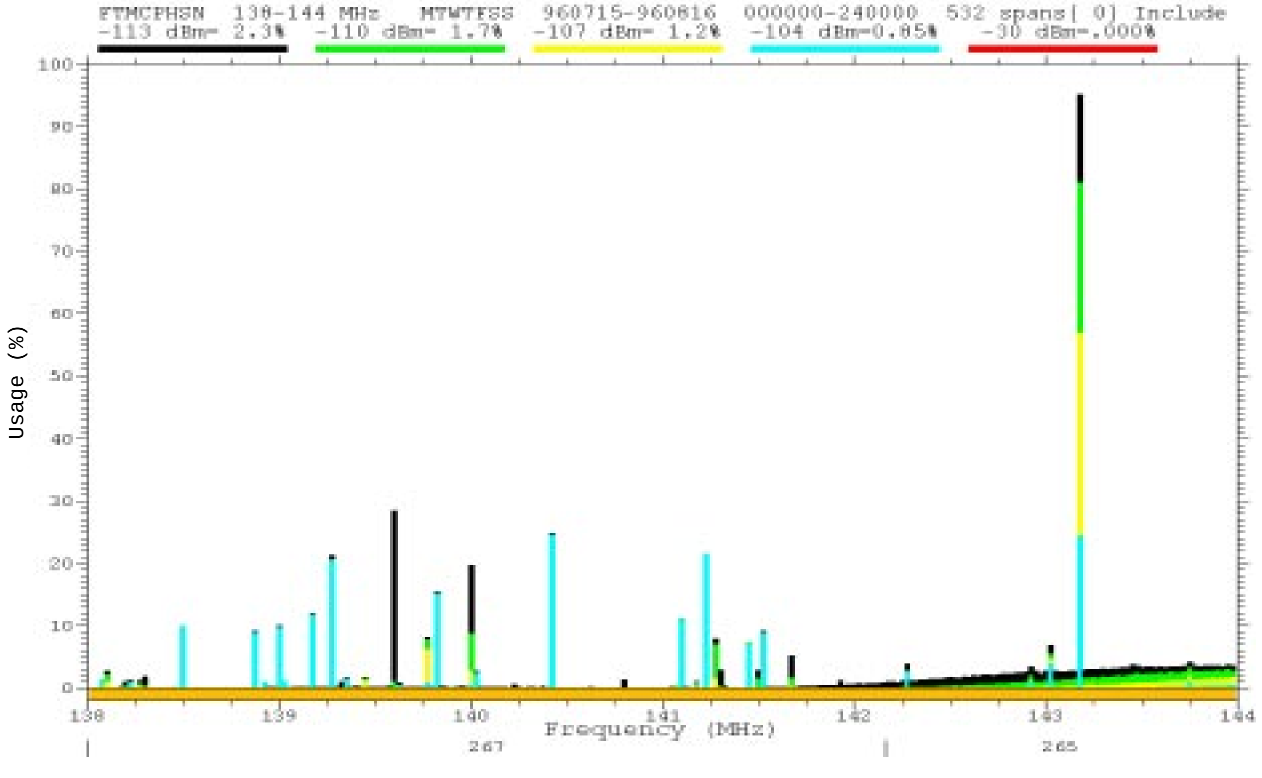

Figure 42. Usage vs. frequency plot of 138-144 MHz measurements at Fort McPherson.

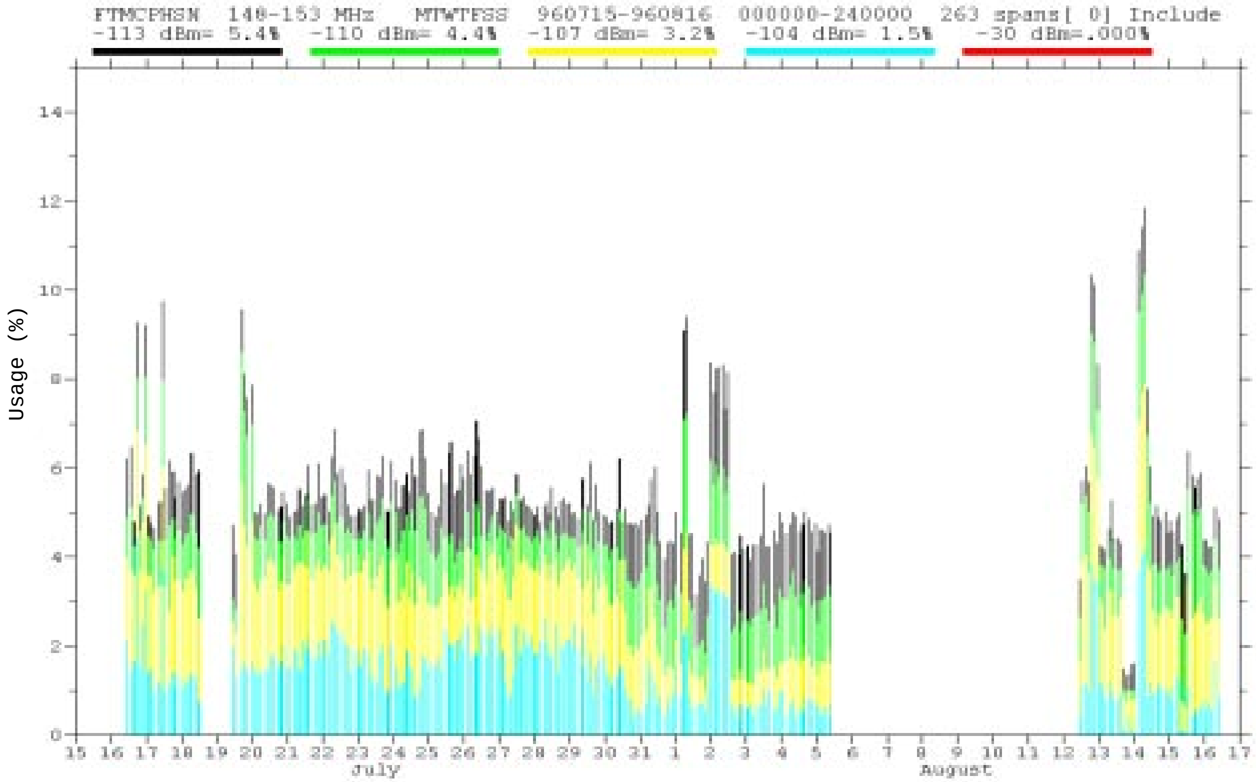

Figure 43. Usage vs. time plot of 148-151 MHz measurements at Fort McPherson.

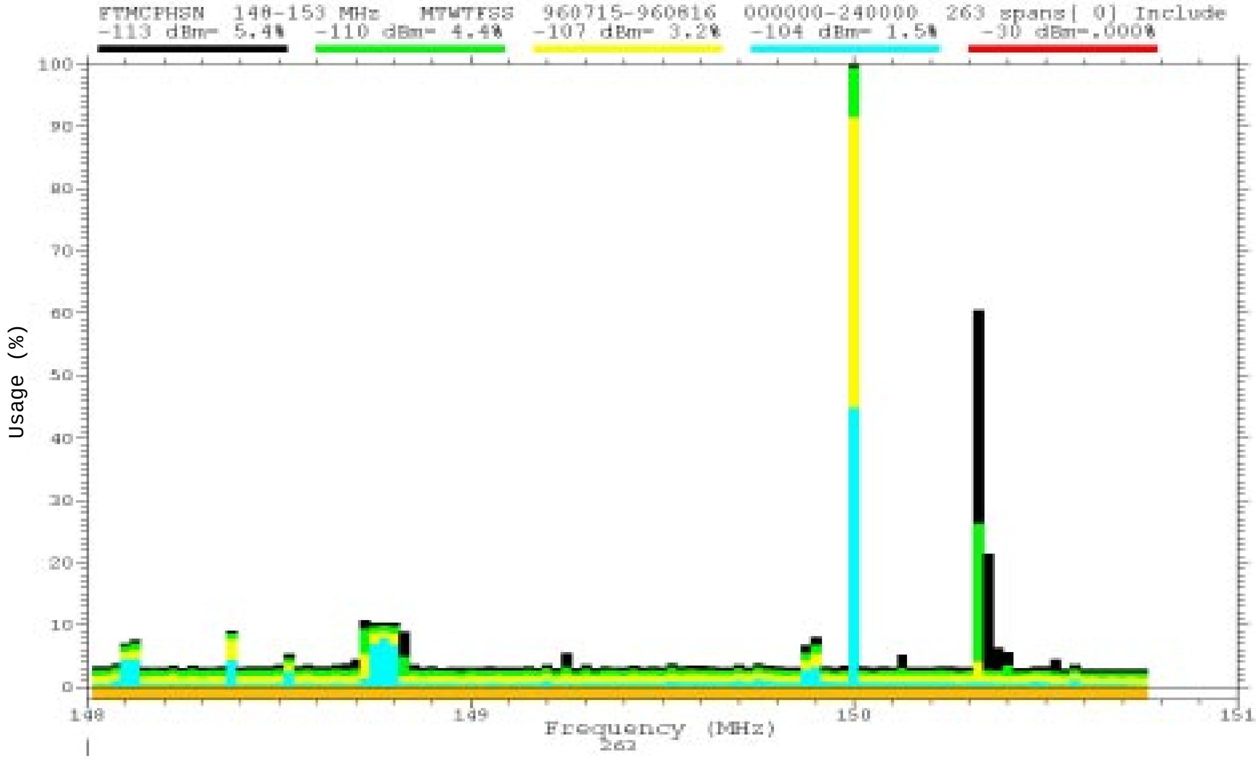

Figure 44. Usage vs. frequency plot of 148-151 MHz measurements at Fort McPherson.

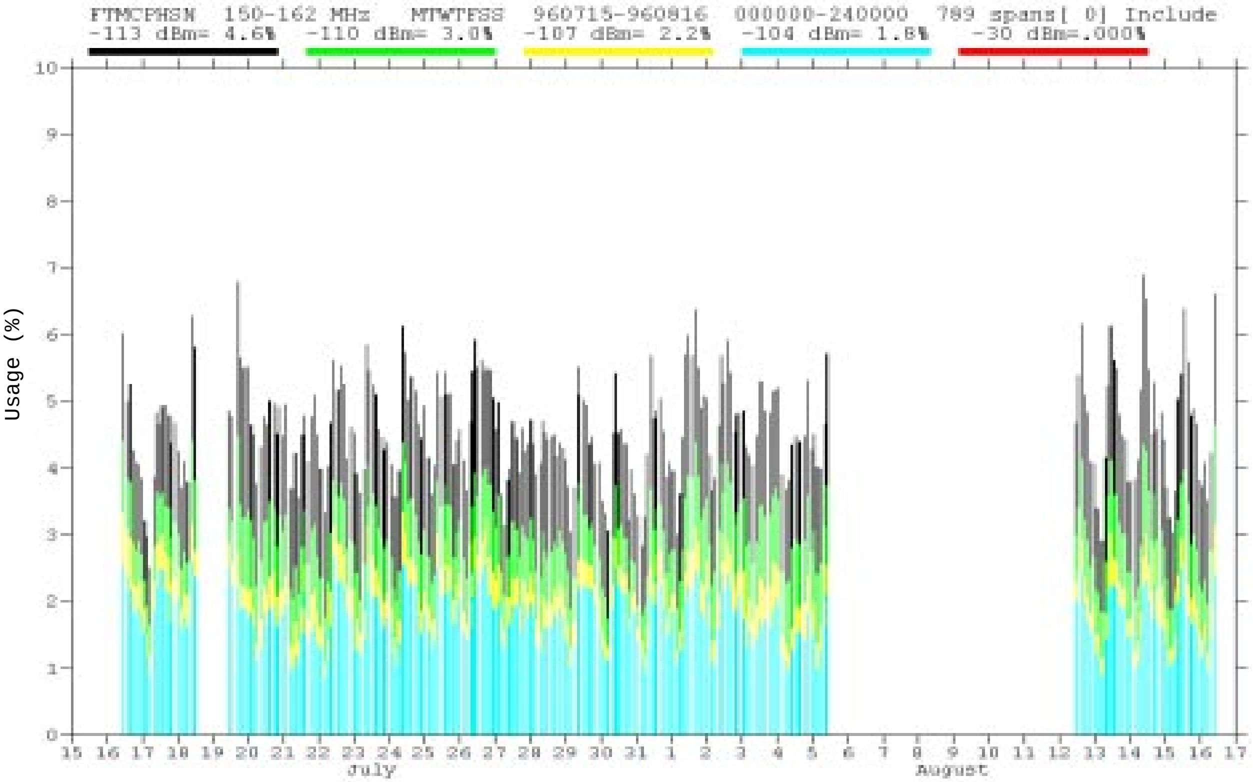

Figure 45. Usage vs. time plot of 150-162 MHz measurements at Fort McPherson.

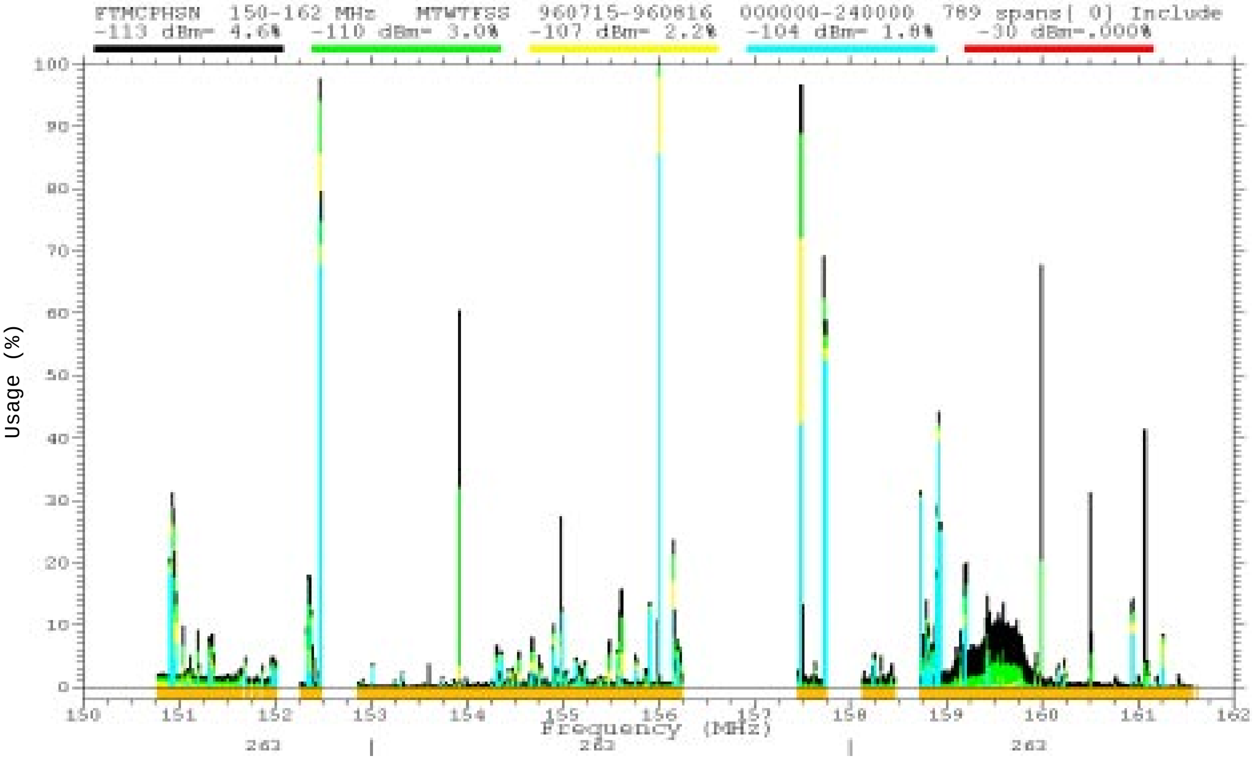

Figure 46. Usage vs. frequency plot of 150-162 MHz measurements at Fort McPherson.

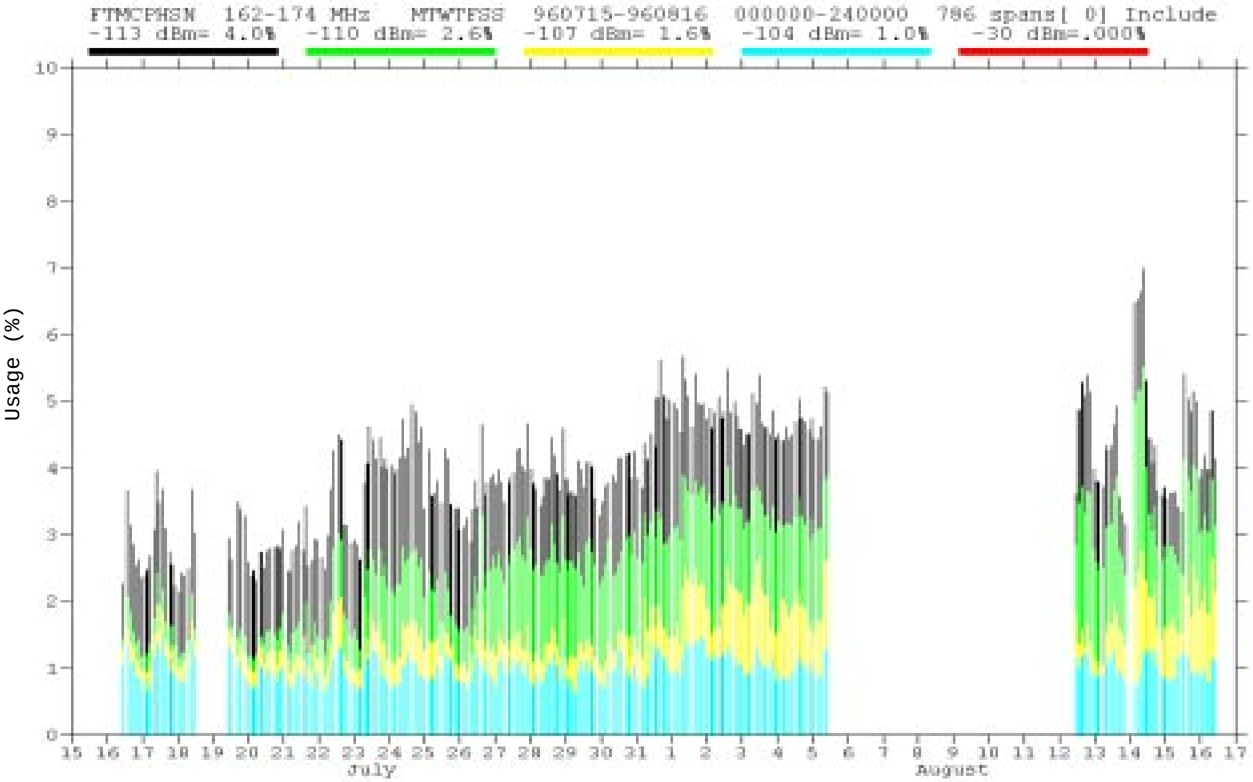

Figure 47. Usage vs. time plot of 162-174 MHz measurements at Fort McPherson.

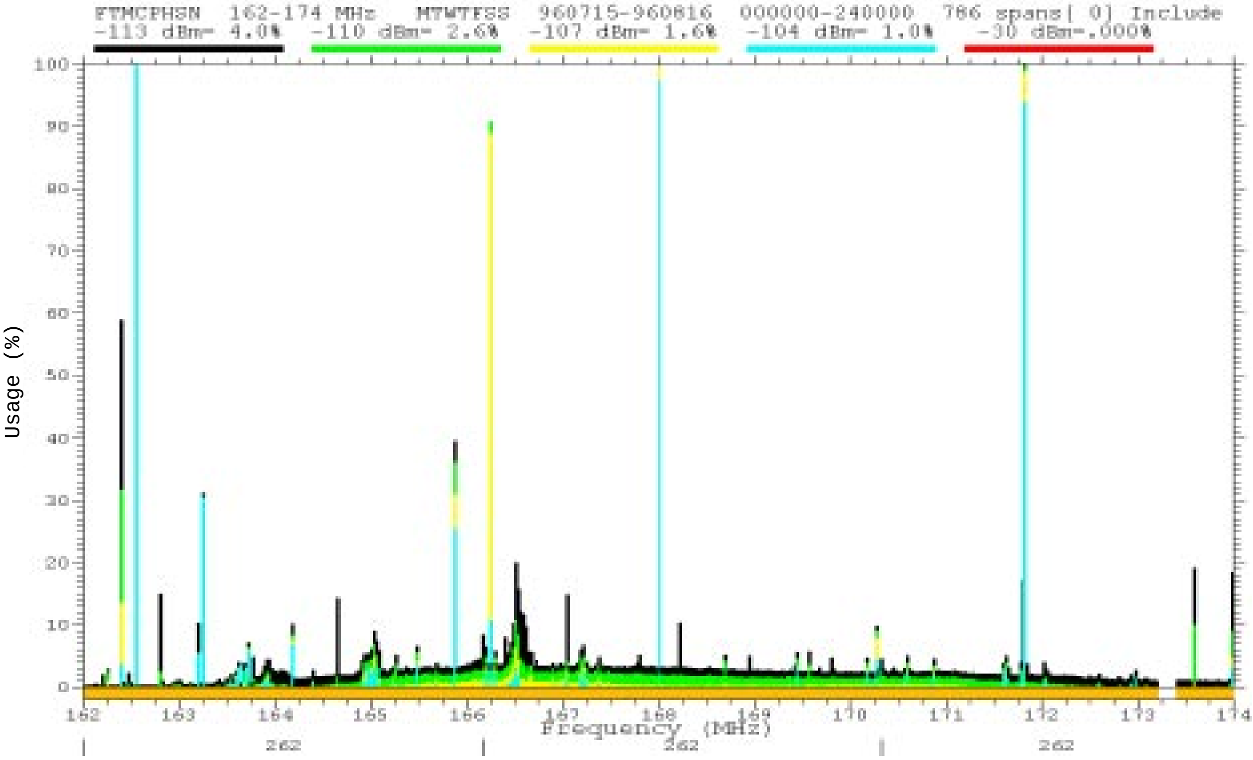

Figure 48. Usage vs. frequency plot of 162-174 MHz measurements at Fort McPherson.

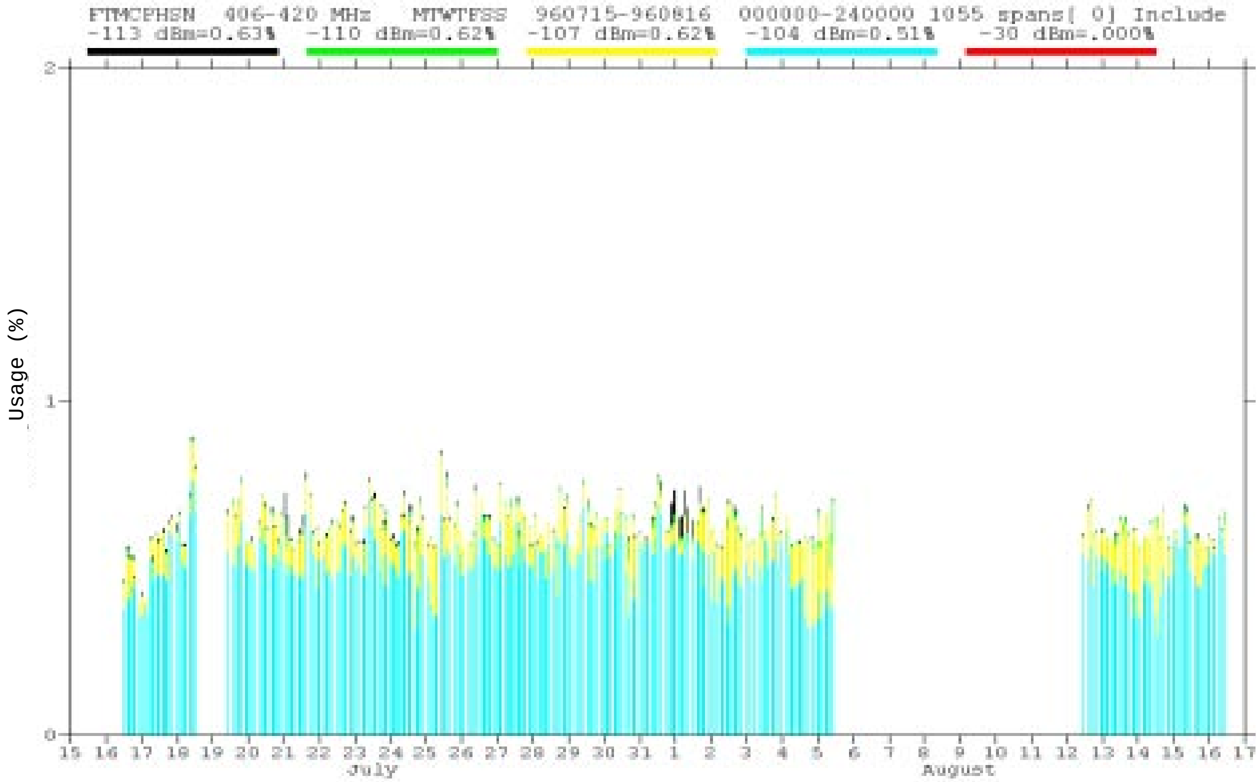

Figure 49. Usage vs. time plot of 406-420 MHz measurements at Fort McPherson.

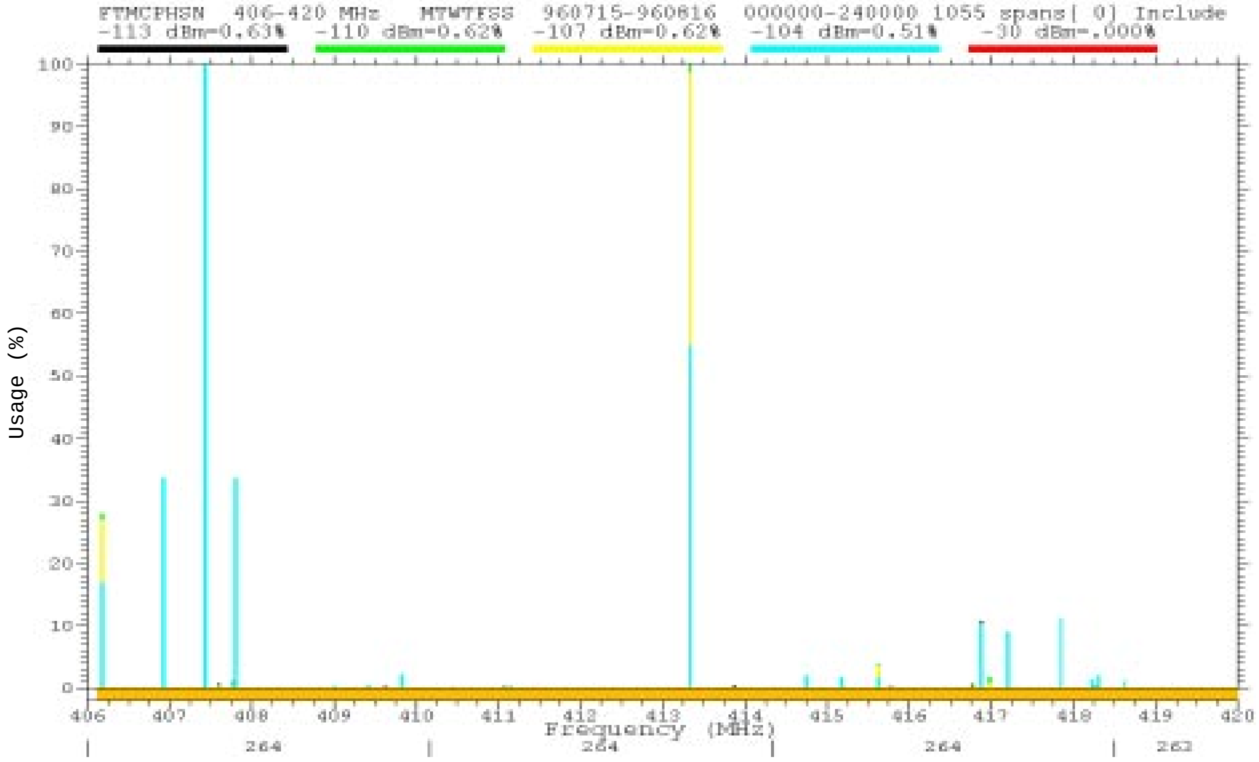

Figure 50. Usage vs. frequency plot of 406-420 MHz measurements at Fort McPherson.

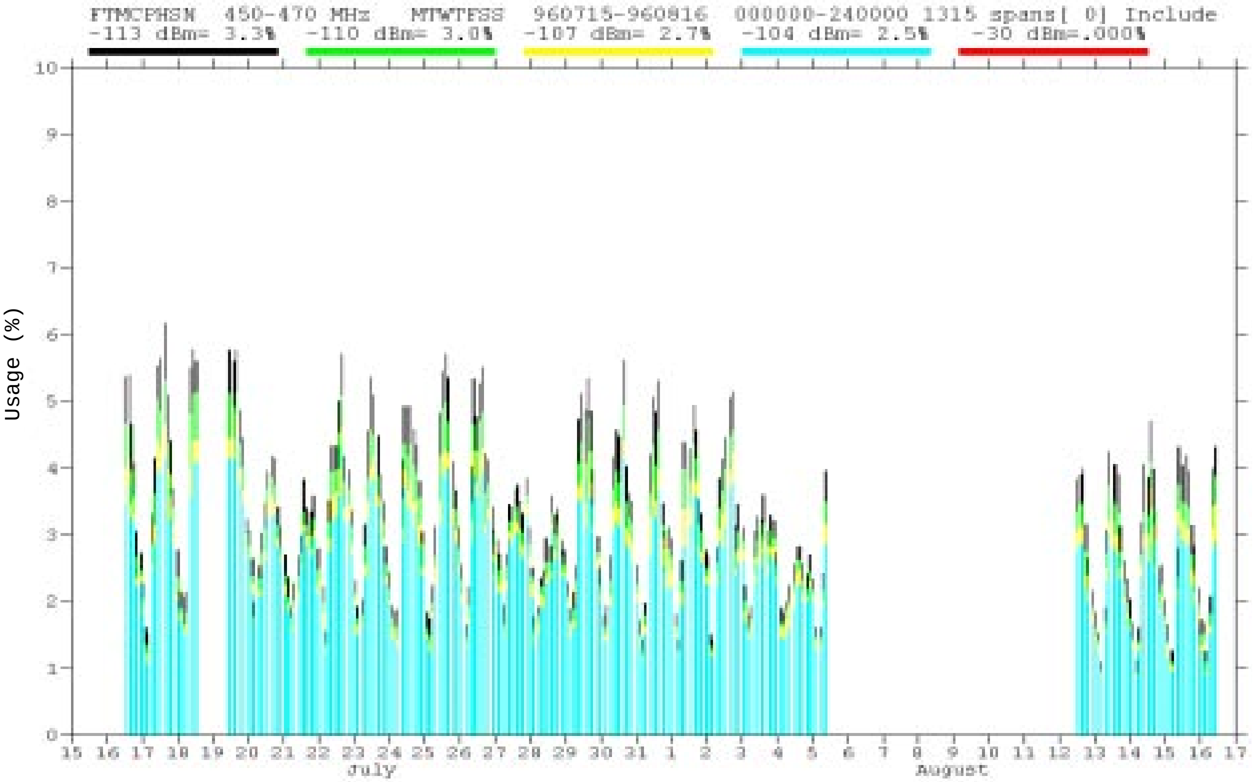

Figure 51. Usage vs. time plot of 451-470 MHz measurements at Fort McPherson.

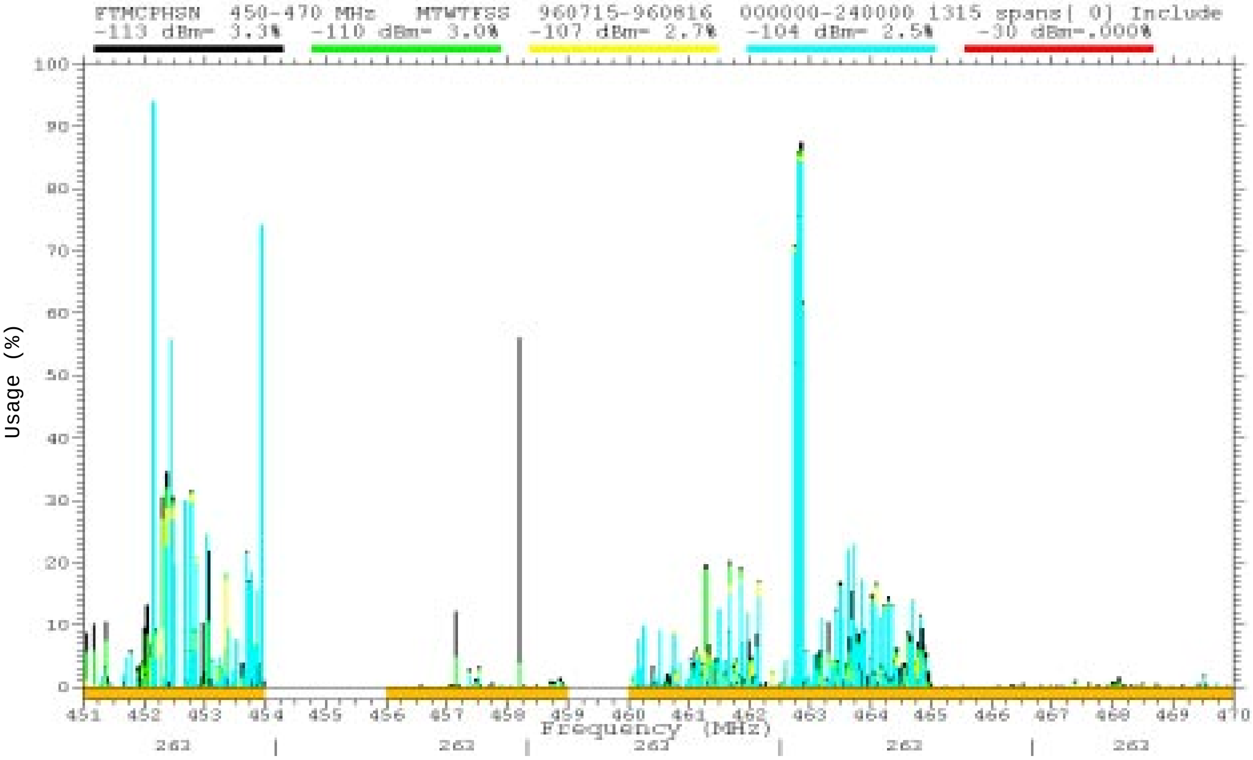

Figure 52. Usage vs. frequency plot of 451-470 MHz measurements at Fort McPherson.

Figure 53. Usage vs. time plot of 806-821 MHz measurements at Fort McPherson.

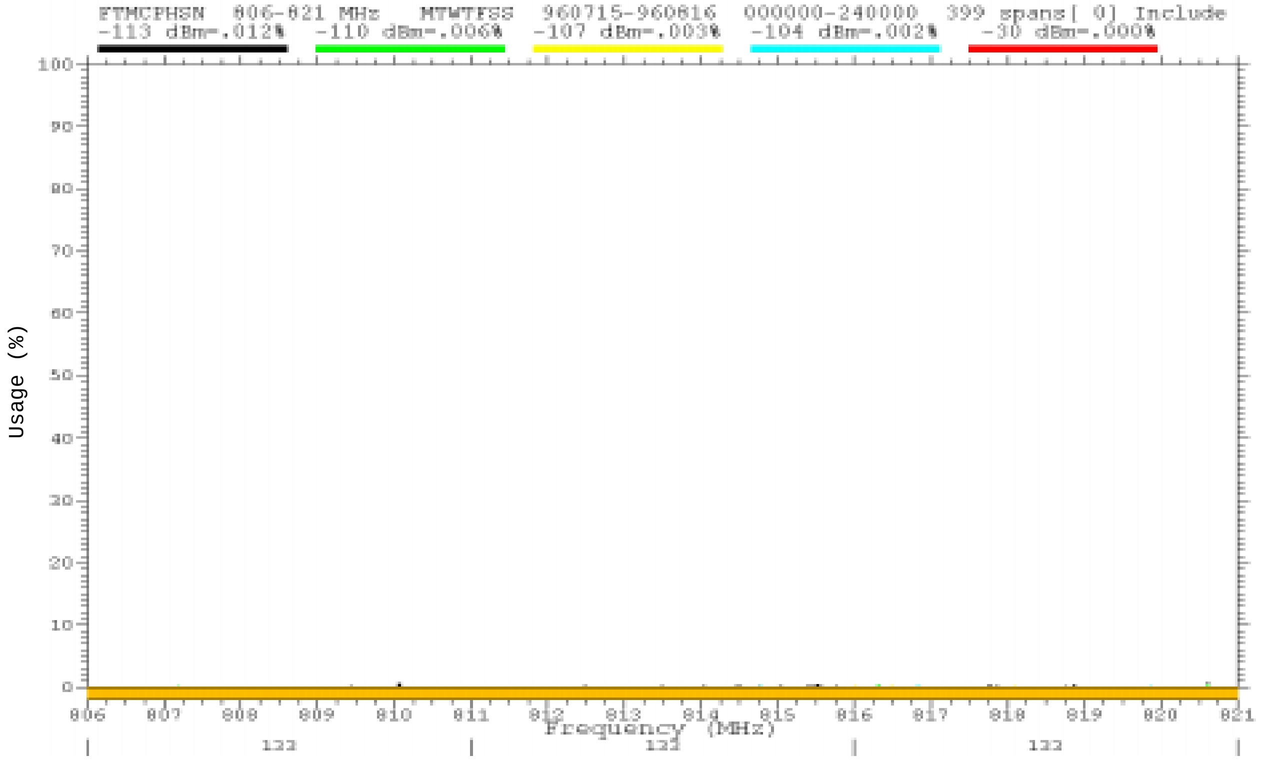

Figure 54. Usage vs. frequency plot of 806-821 MHz measurements at Fort McPherson.

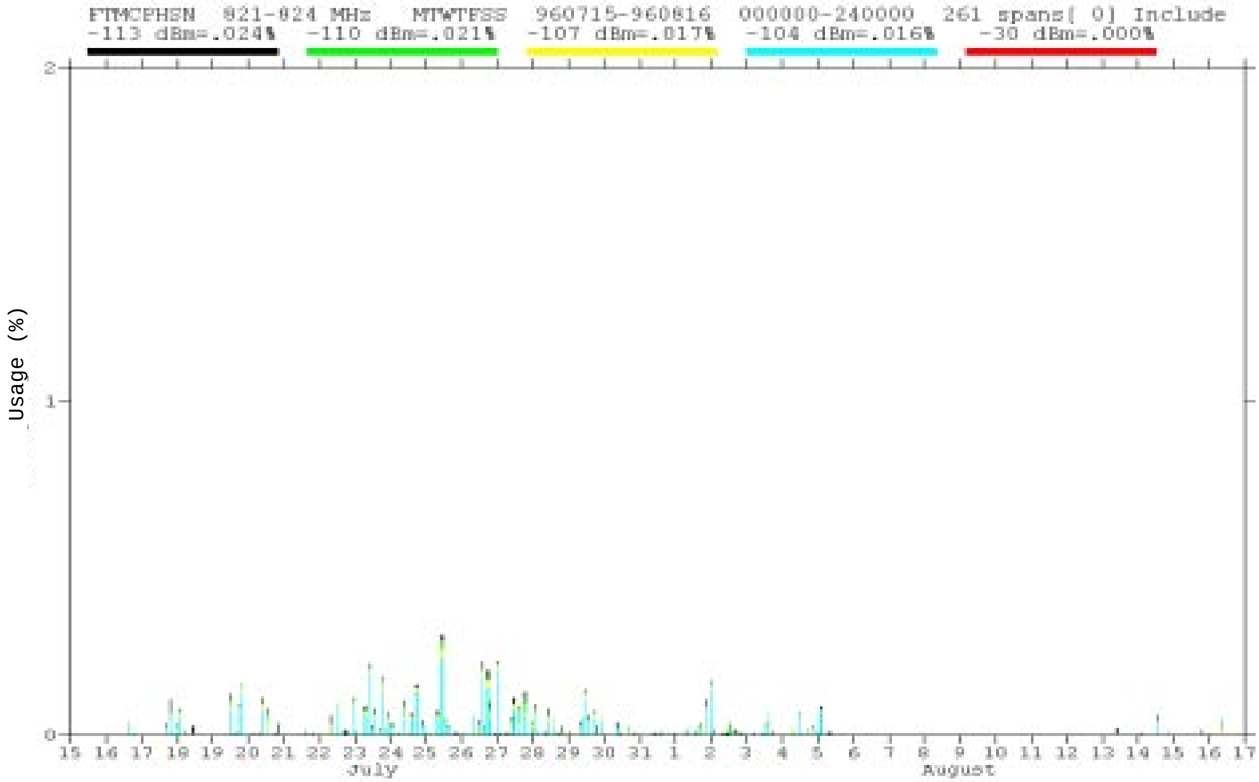

Figure 55. Usage vs. time plot of 821-824 MHz measurements at Fort McPherson.

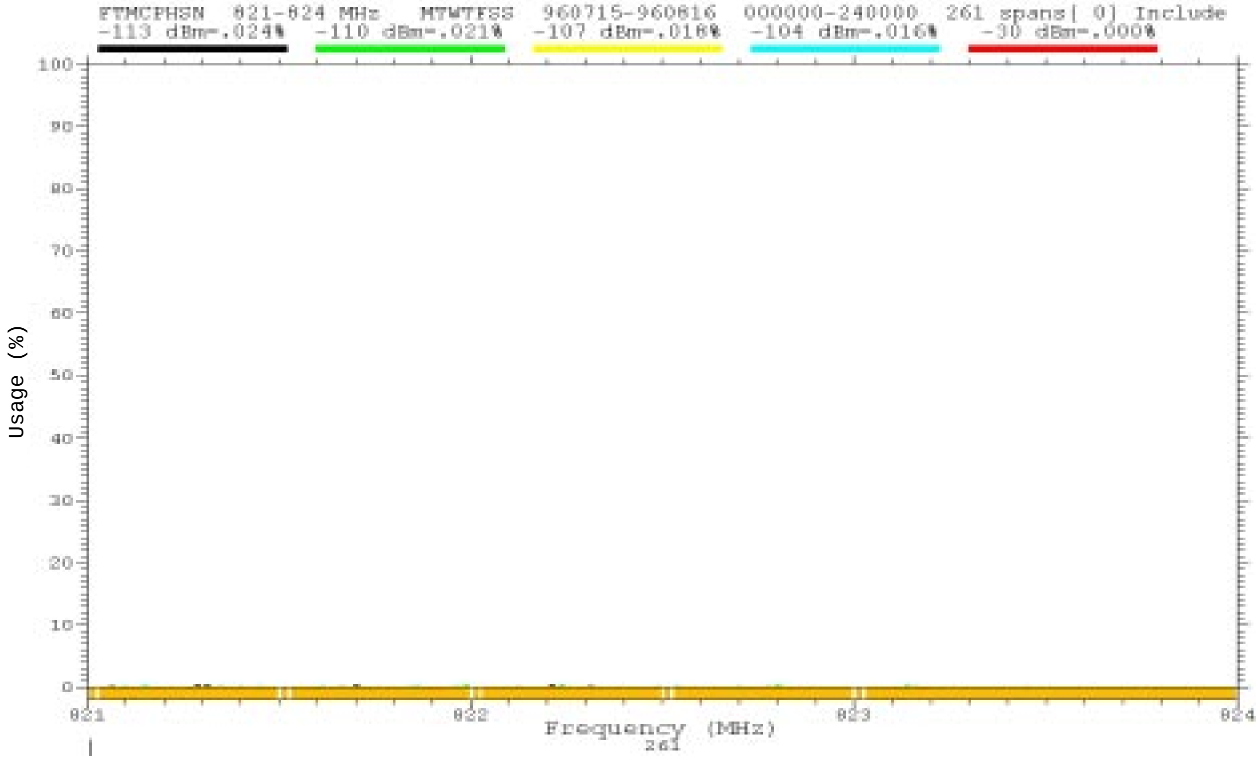

Figure 56. Usage vs. frequency plot of 821-824 MHz measurements at Fort McPherson.

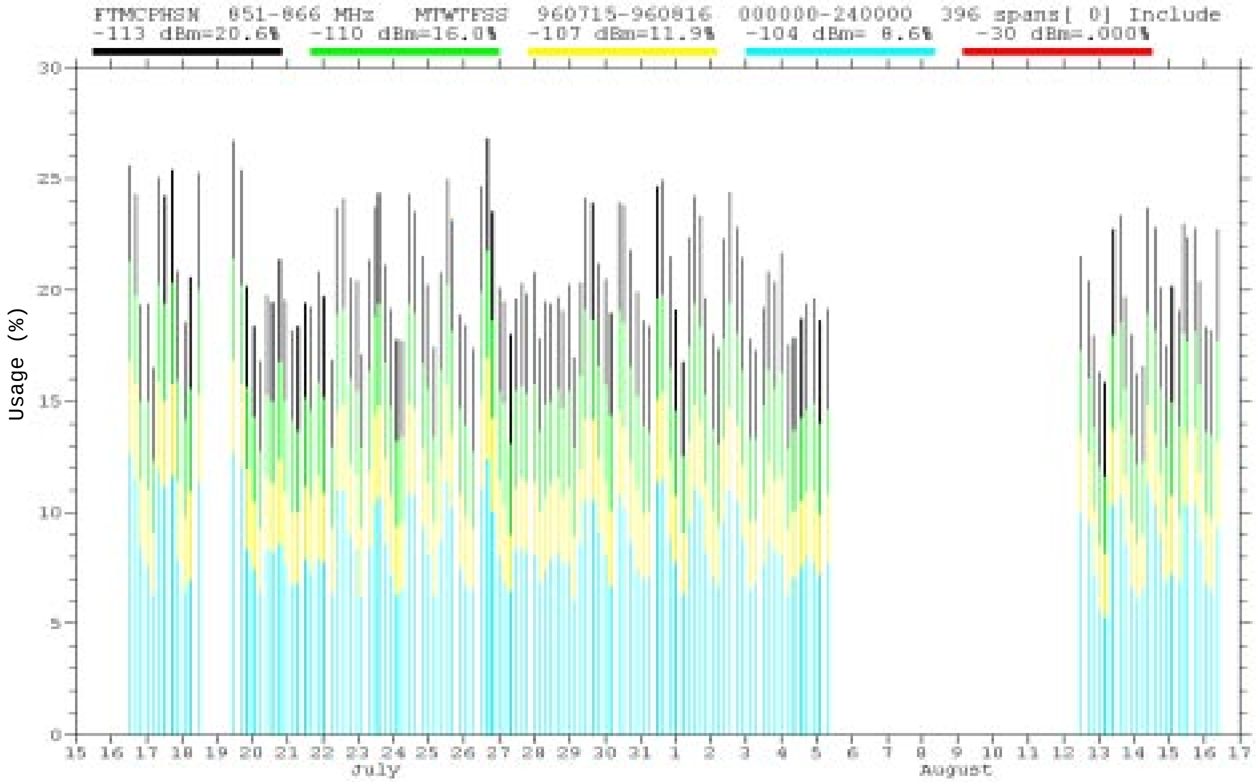

Figure 57. Usage vs. time plot of 851-866 MHz measurements at Fort McPherson.

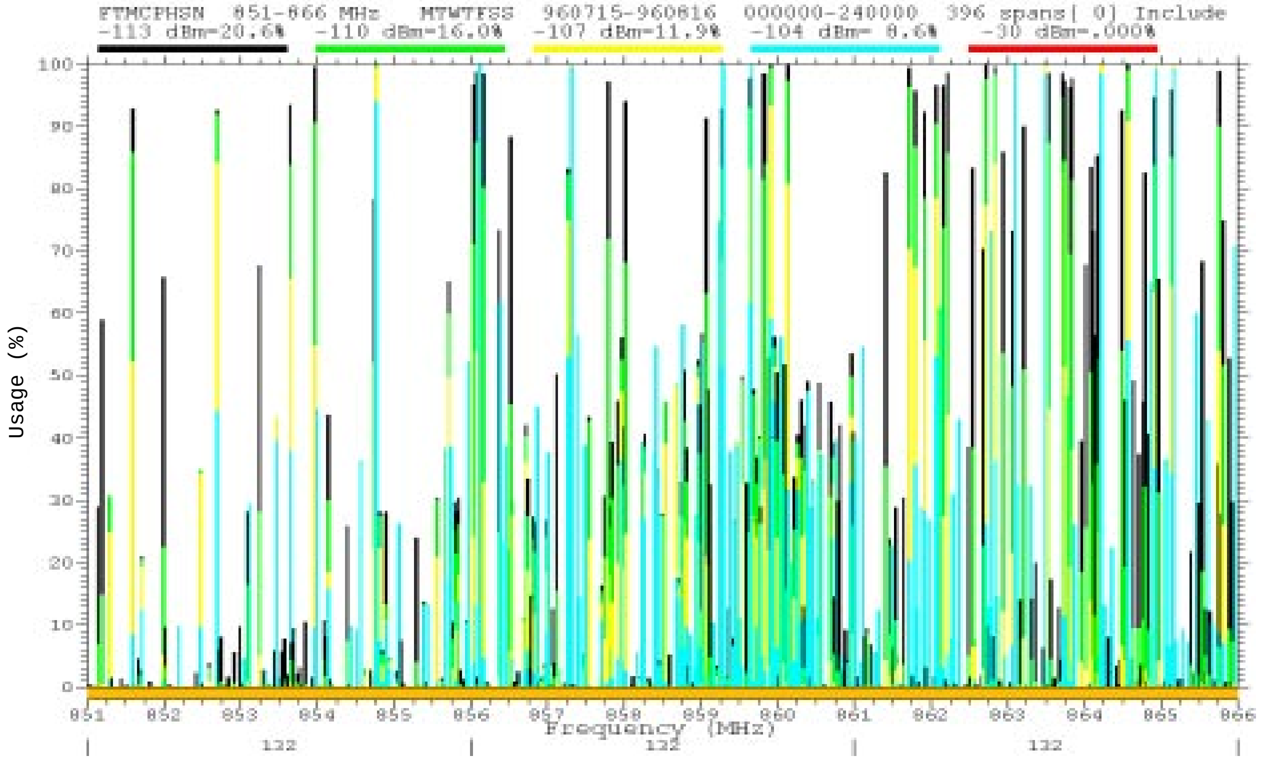

Figure 58. Usage vs. frequency plot of 851-866 MHz measurements at Fort McPherson.

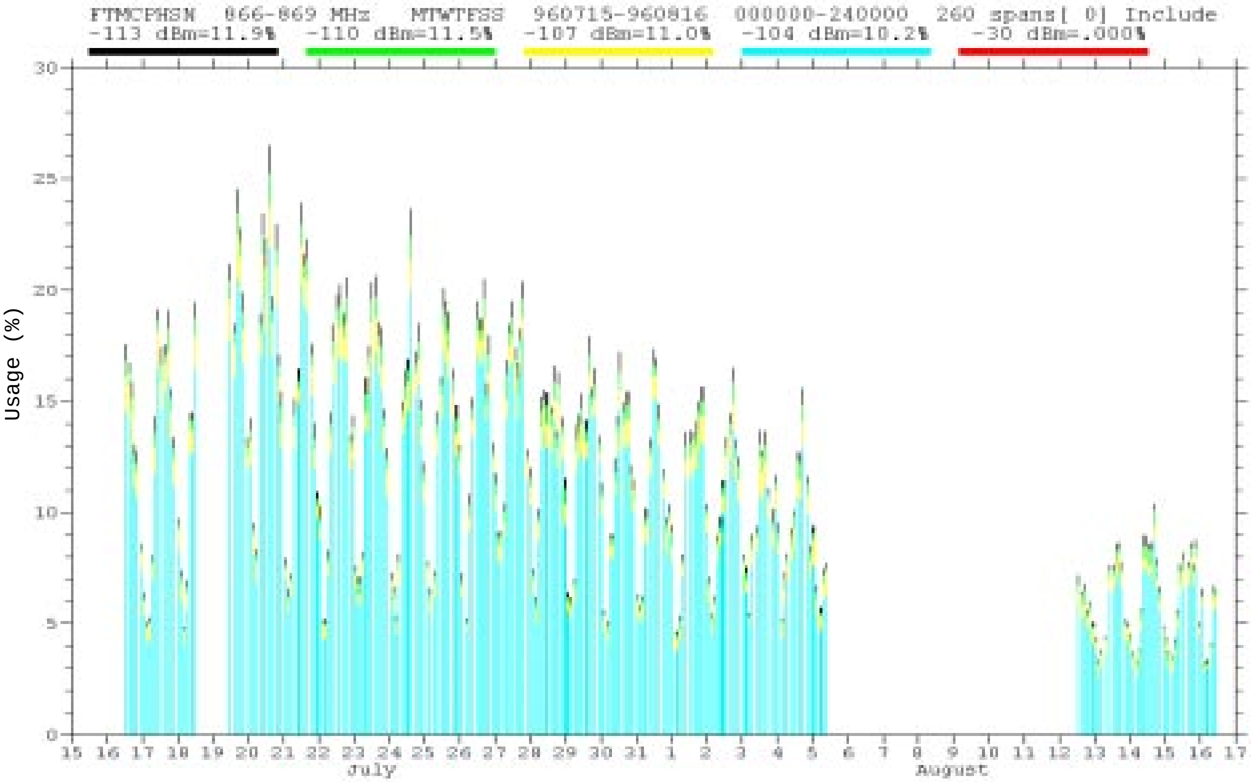

Figure 59. Usage vs. time plot of 866-869 MHz measurements at Fort McPherson.

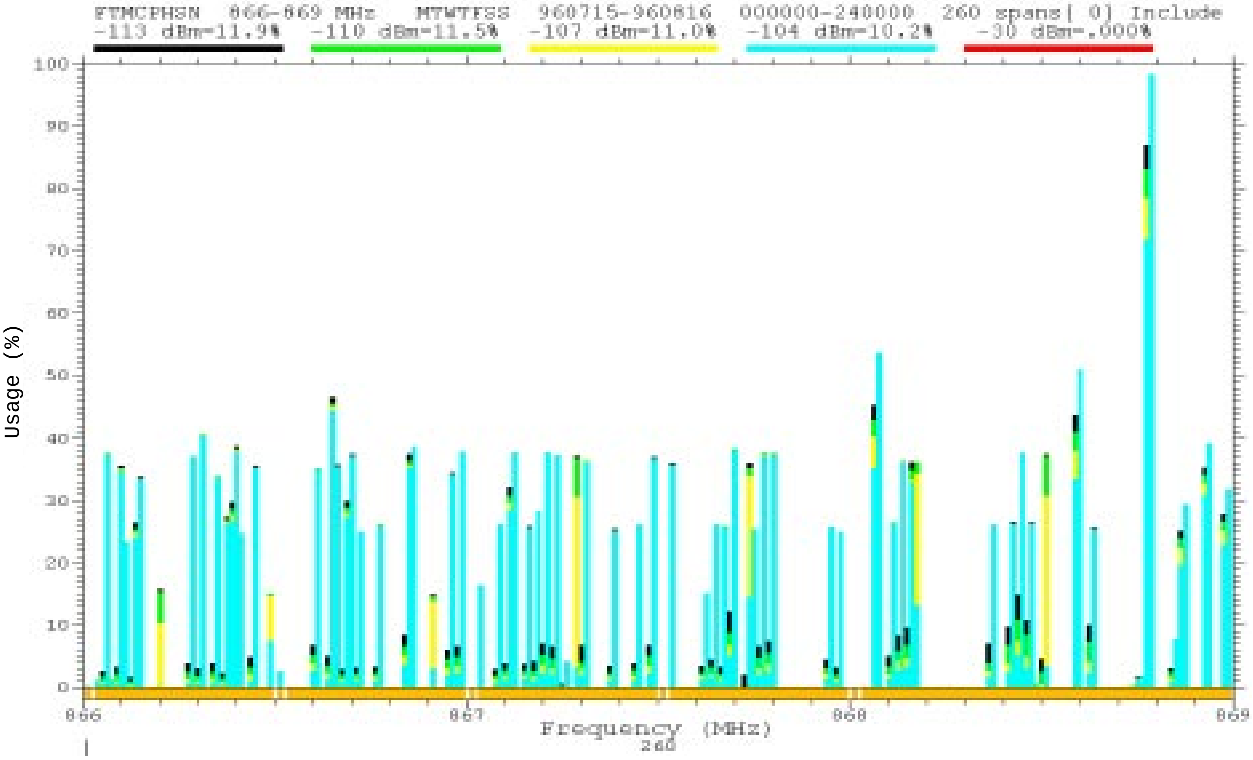

Figure 60. Usage vs. frequency plot of 866-869 MHz measurements at Fort McPherson.

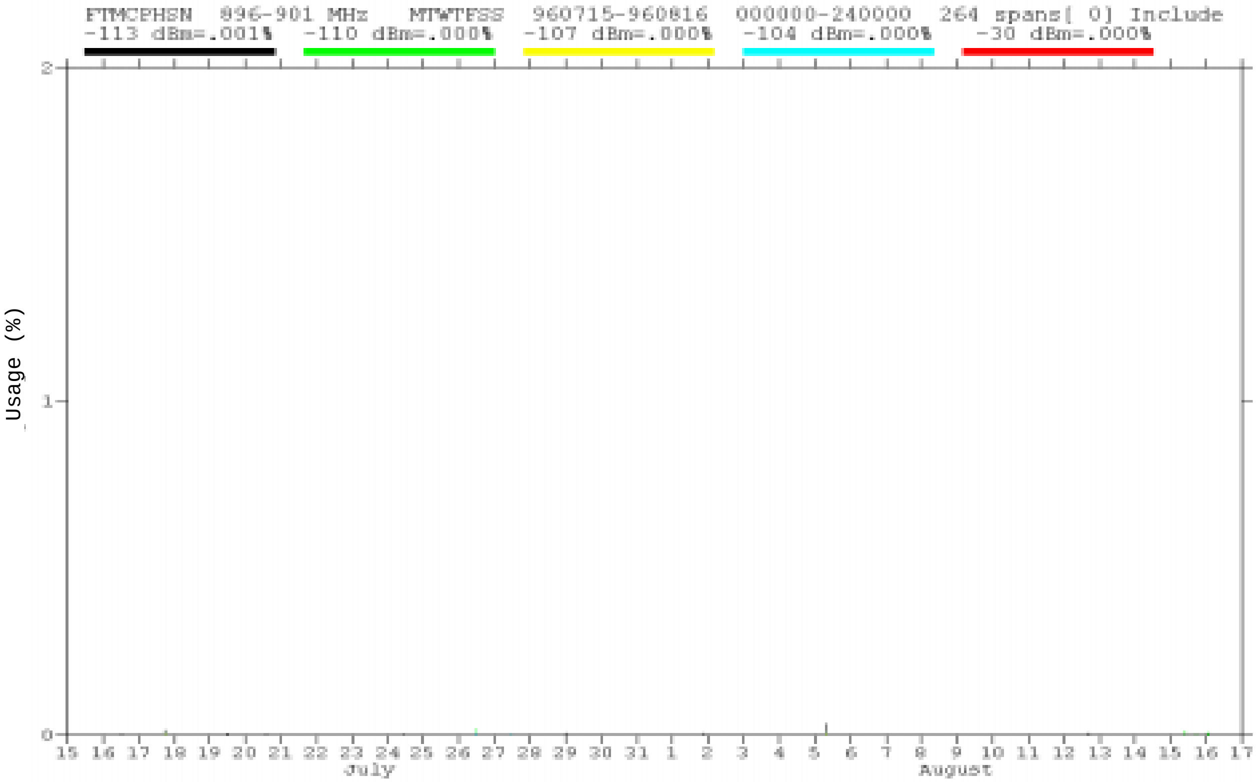

Figure 61. Usage vs. time plot of 896-901 MHz measurements at Fort McPherson.

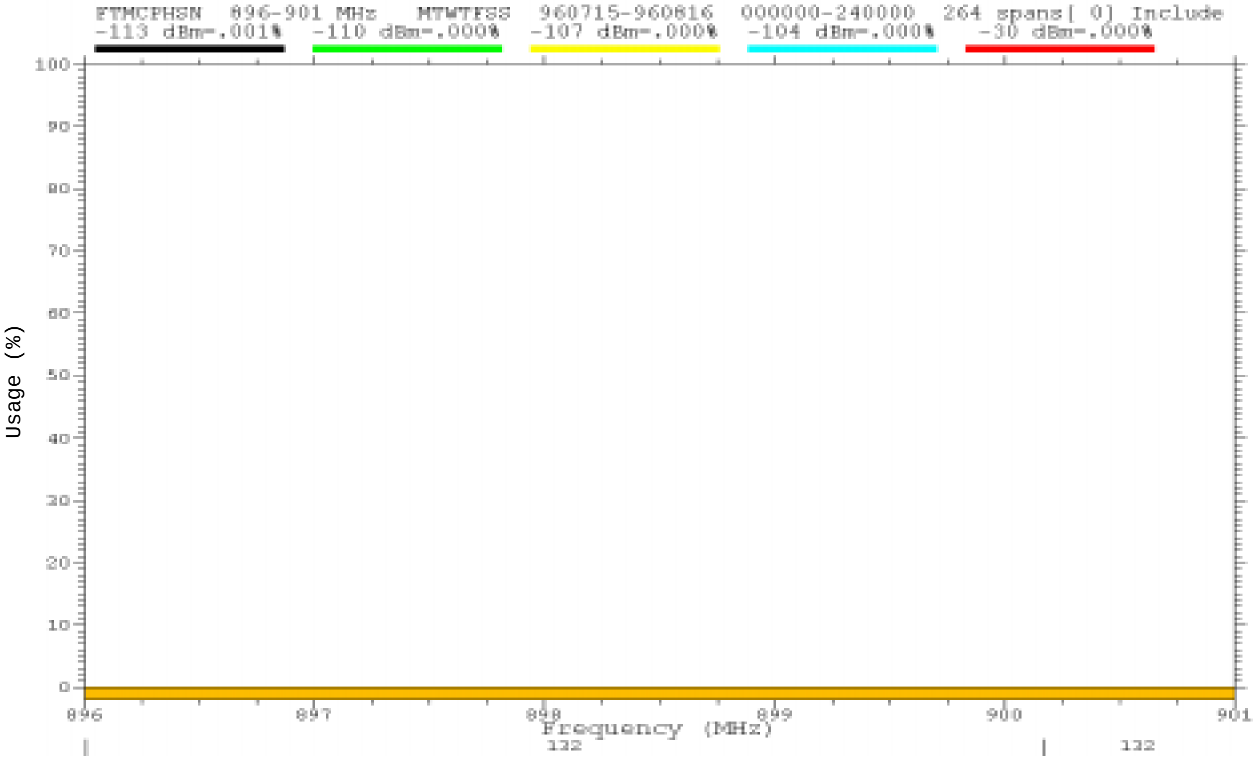

Figure 62. Usage vs. frequency plot of 896-901 MHz measurements at Fort McPherson.

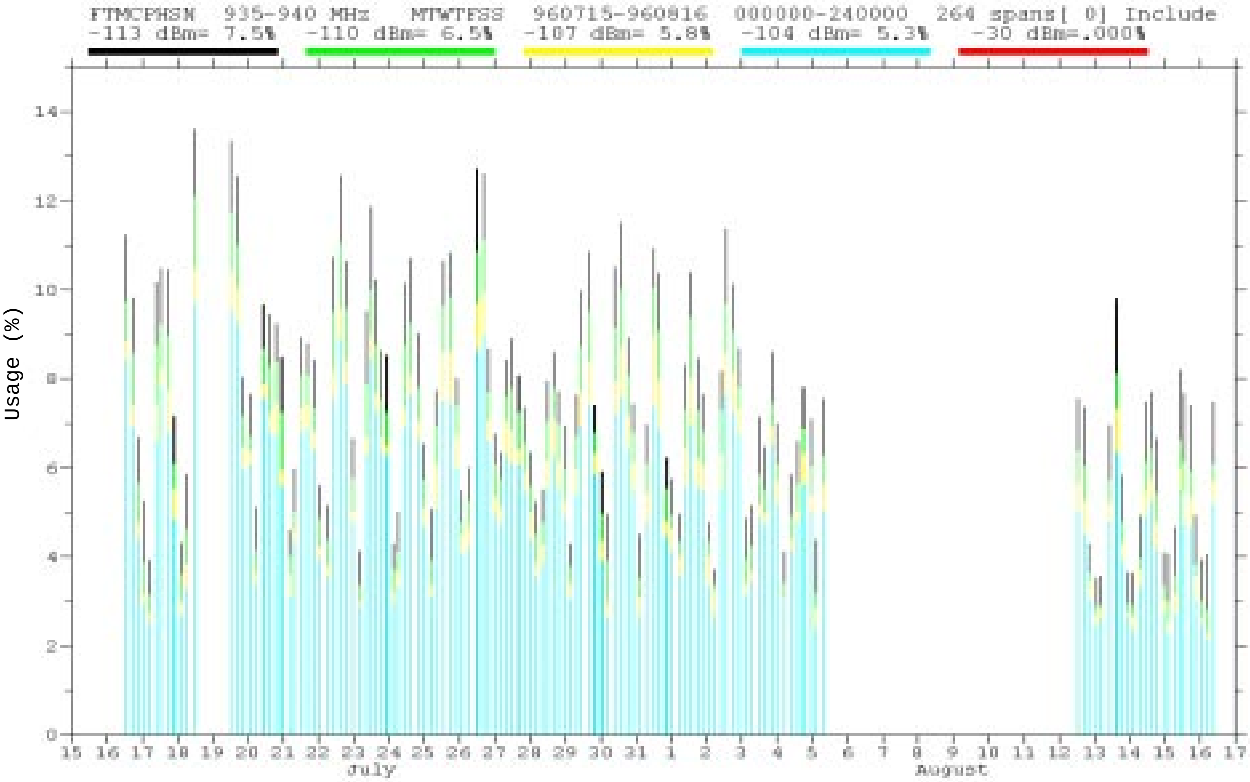

Figure 63. Usage vs. time plot of 935-940 MHz measurements at Fort McPherson.

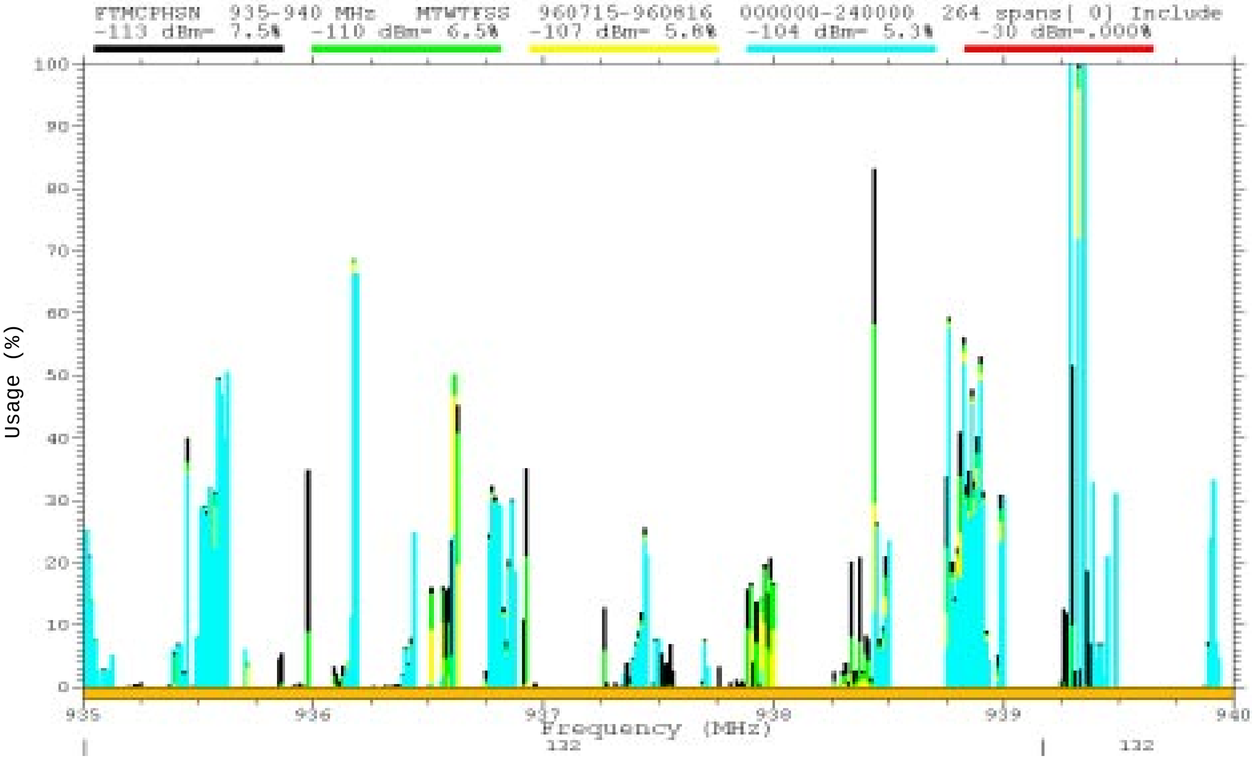

Figure 64. Usage vs. frequency plot of 935-940 MHz measurements at Fort McPherson.

3.6 Six Flags Site Channel Usage Statistics

This section presents graphs showing usage vs. time and usage vs. frequency for measurements at the Six flags site. The graphed analysis plots in this section are formatted the same as the plots previously described in Section 3.4; so, that description is not repeated here. The data are presented as two graphed analysis plots of channelized LMR data displayed on one page. The graph at the top of the page shows percentage usage as a function of time (time plot), and the bottom graph shows percentage usage as a function of frequency (frequency plot).

All of the usage graphs (both time plots and frequency plots) are color coded to show usage as a function of measured power threshold (color bars in the graph header show the analysis band thresholds). Each vertical line on the time-dependence plot (upper graph) represents the average analysis band usage (i.e., average of all scans exceeding each color-coded threshold) at the time indicated. Each vertical line on the frequency plots shows the average usage for each threshold at the indicated frequency. The orange bar at the bottom of the frequency plots indicates which frequencies were included in the analysis.

The color bars in the header represent the total usage based on each of the exceeded thresholds. When plotted, the colors are stacked because data that exceeded the higher thresholds must have also exceeded the lower thresholds.

Figures 65 through 88 are the time and frequency plots for all of the Six Flags analysis bands. Band-by-band observations on relative levels of LMR usage and comments on the extrapolation of all measured data are found in Section 3.9.

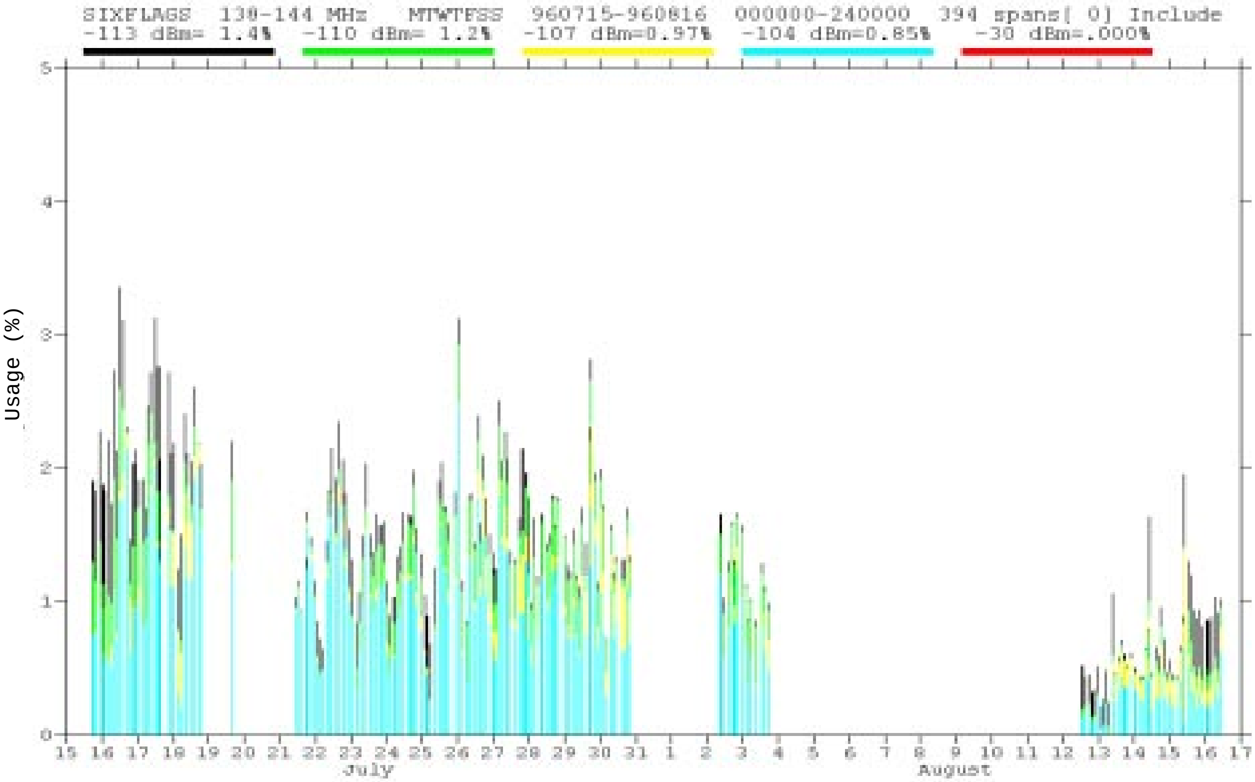

Figure 65. Usage vs. time plot of 138-144 MHz measurements at Six Flags.

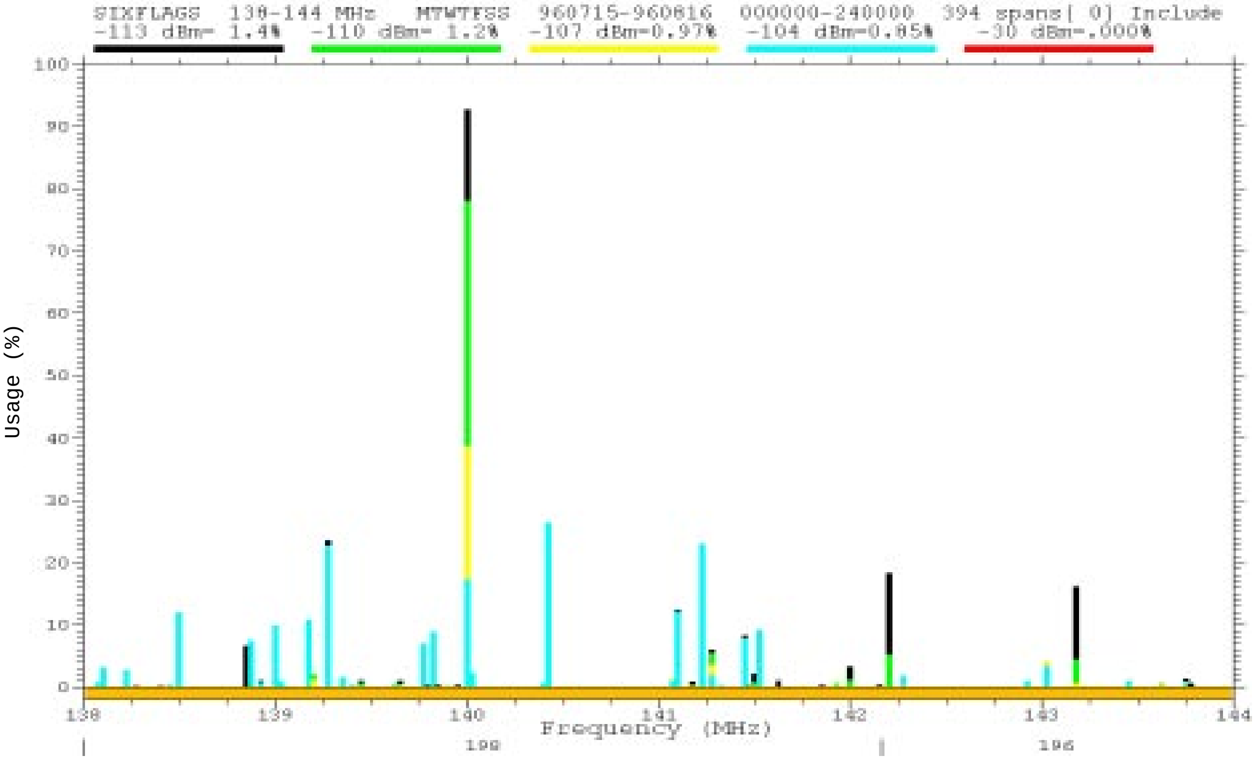

Figure 66. Usage vs. frequency plot of 138-144 MHz measurements at Six Flags.

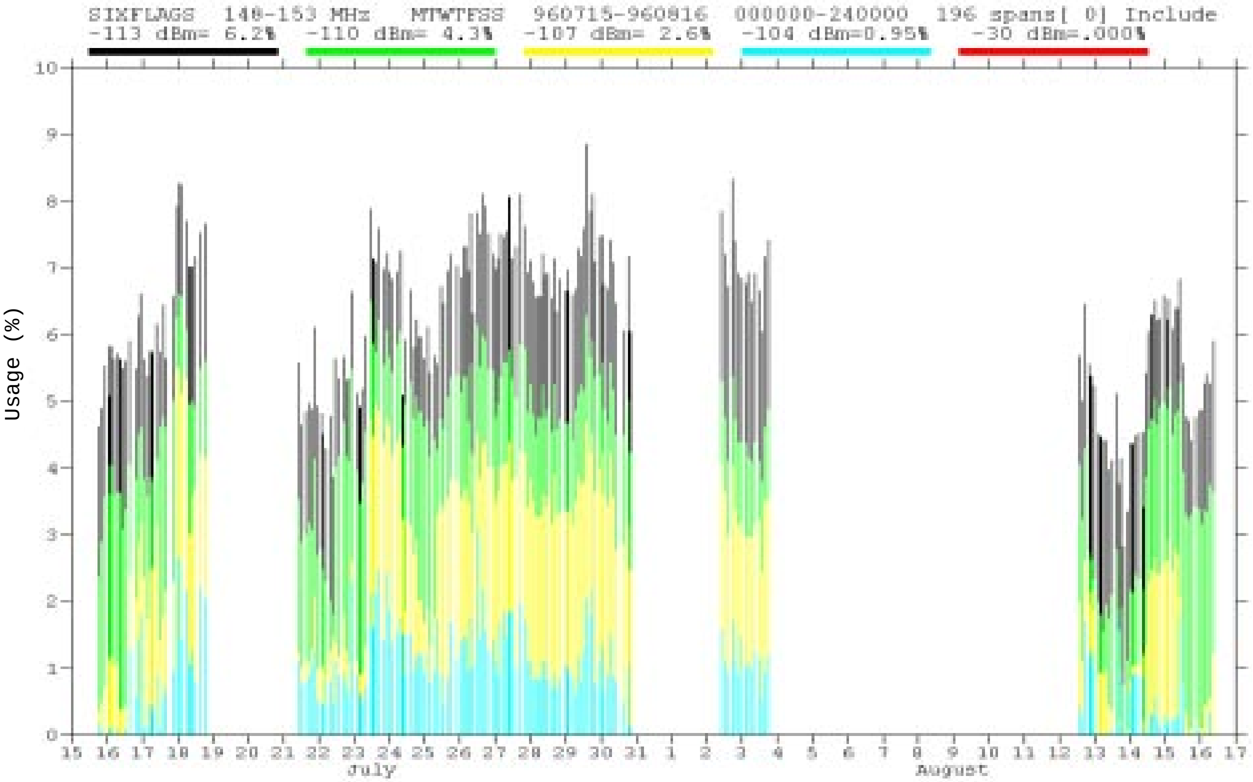

Figure 67. Usage vs. time plot of 148-151 MHz measurements at Six Flags.

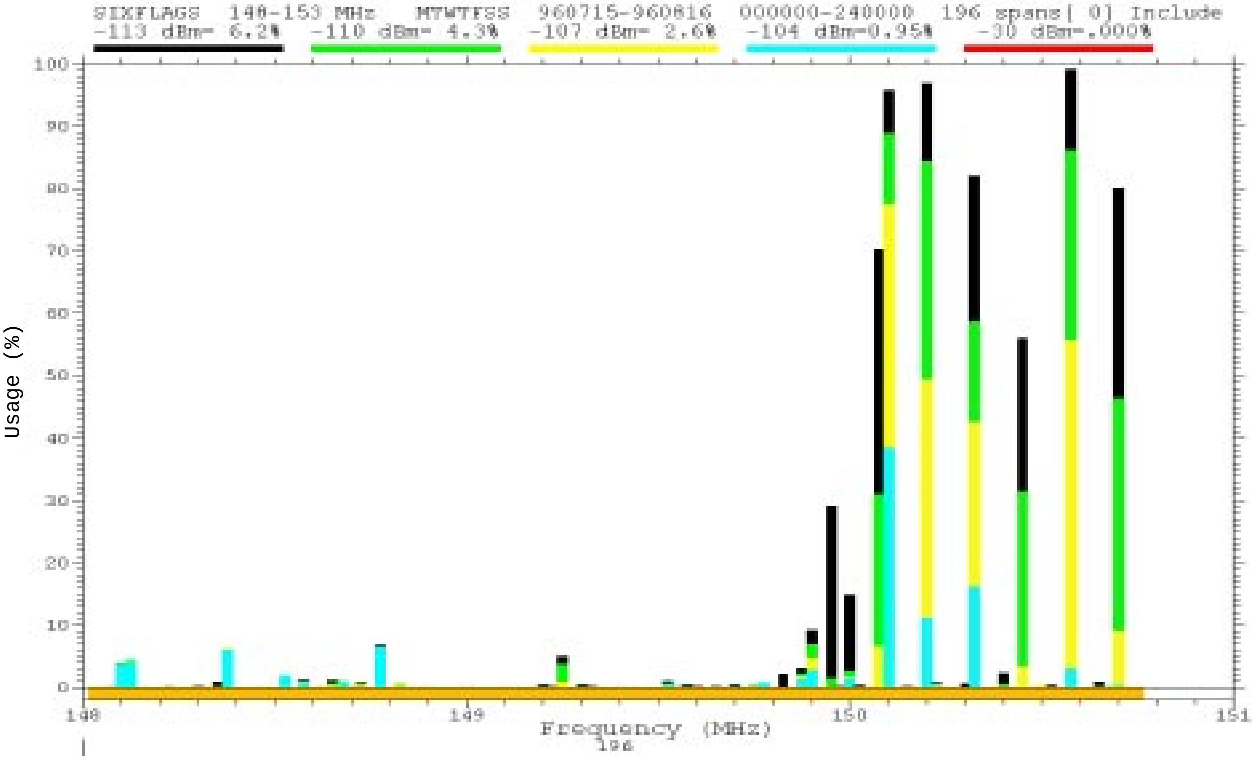

Figure 68. Usage vs. frequency plot of 148-151 MHz measurements at Six Flags.

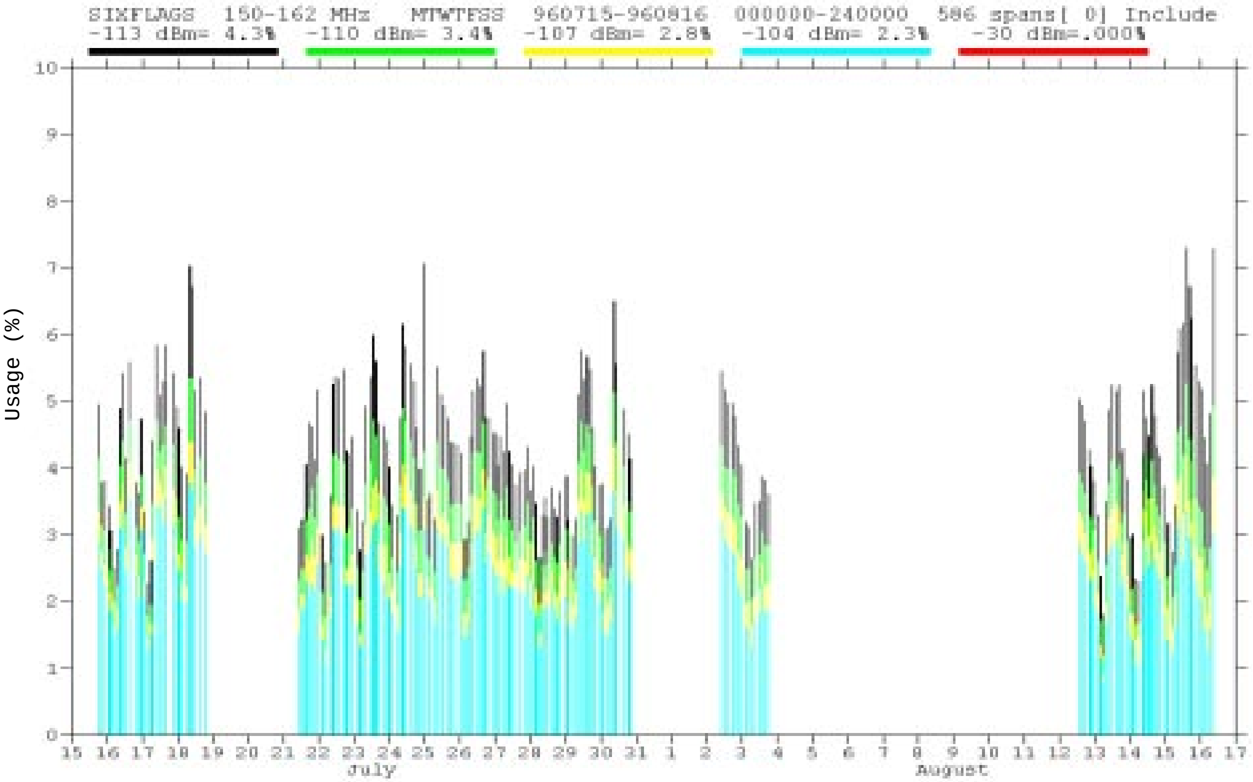

Figure 69. Usage vs. time plot of 150-162 MHz measurements at Six Flags.

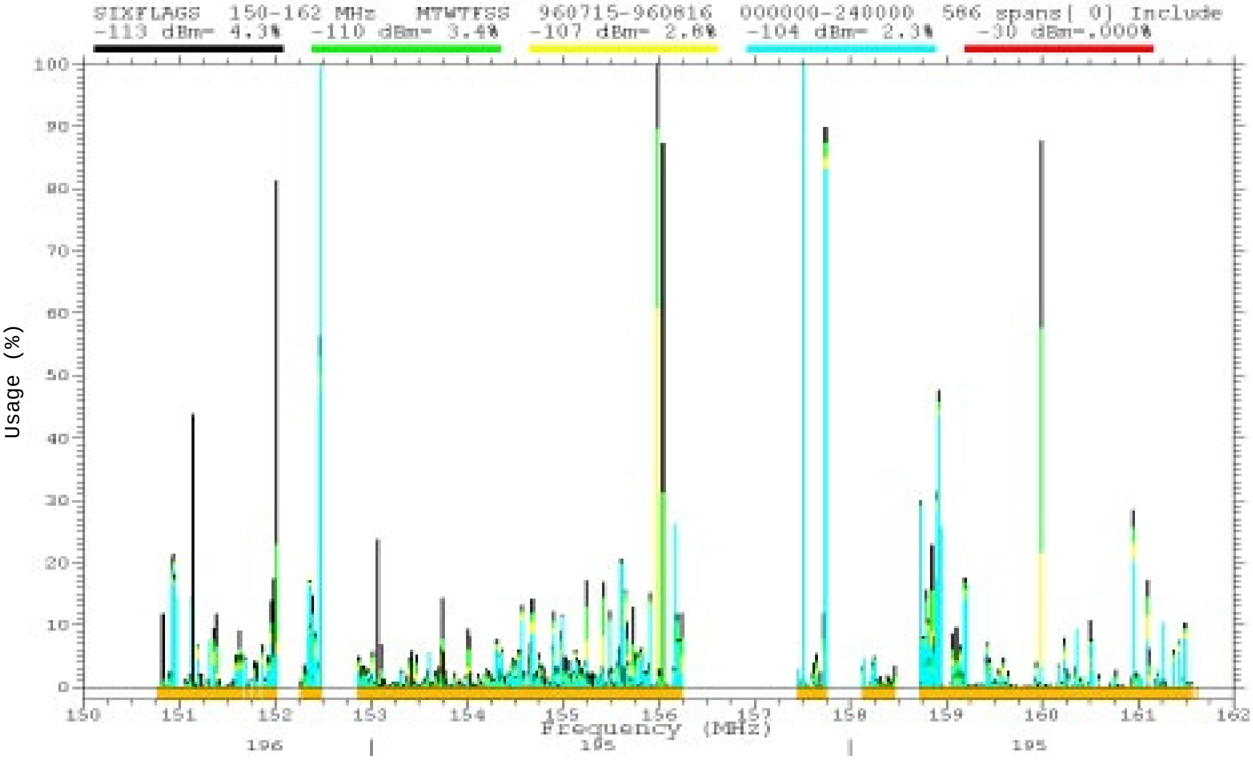

Figure 70. Usage vs. frequency plot of 150-162 MHz measurements at Six Flags.

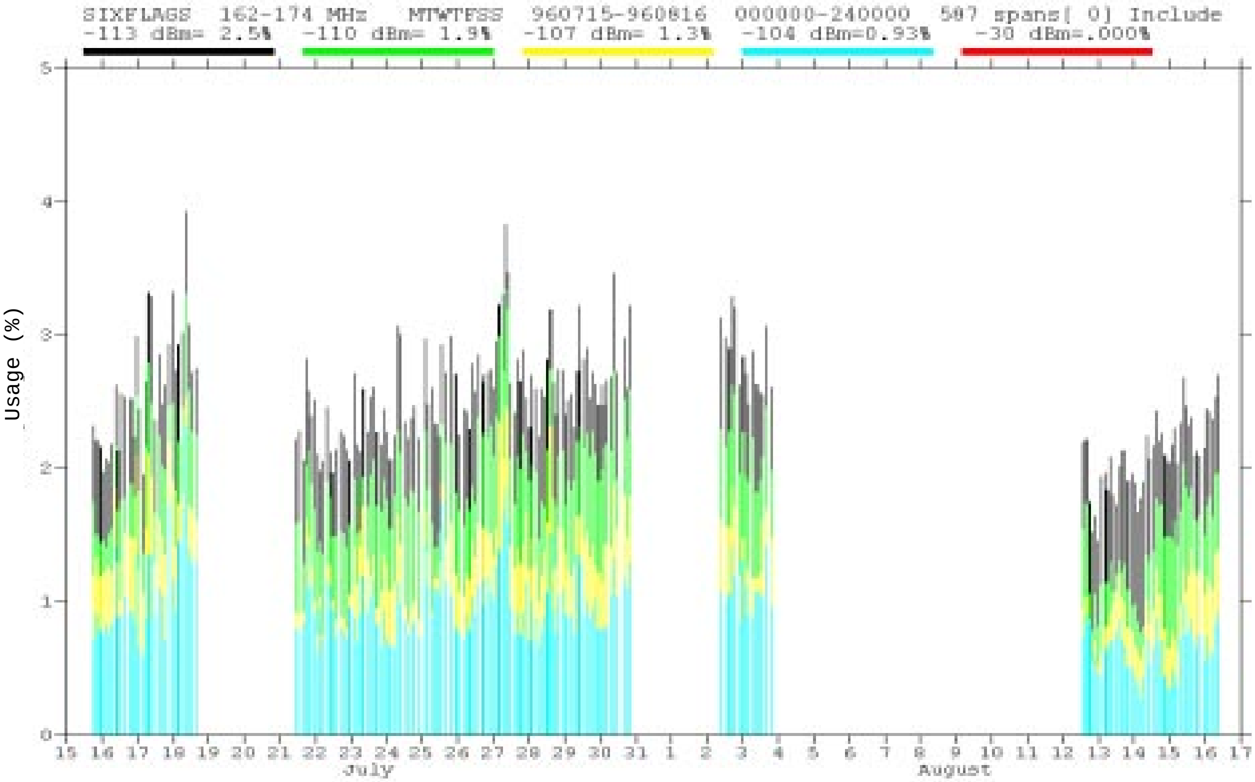

Figure 71. Usage vs. time plot of 162-174 MHz measurements at Six Flags.

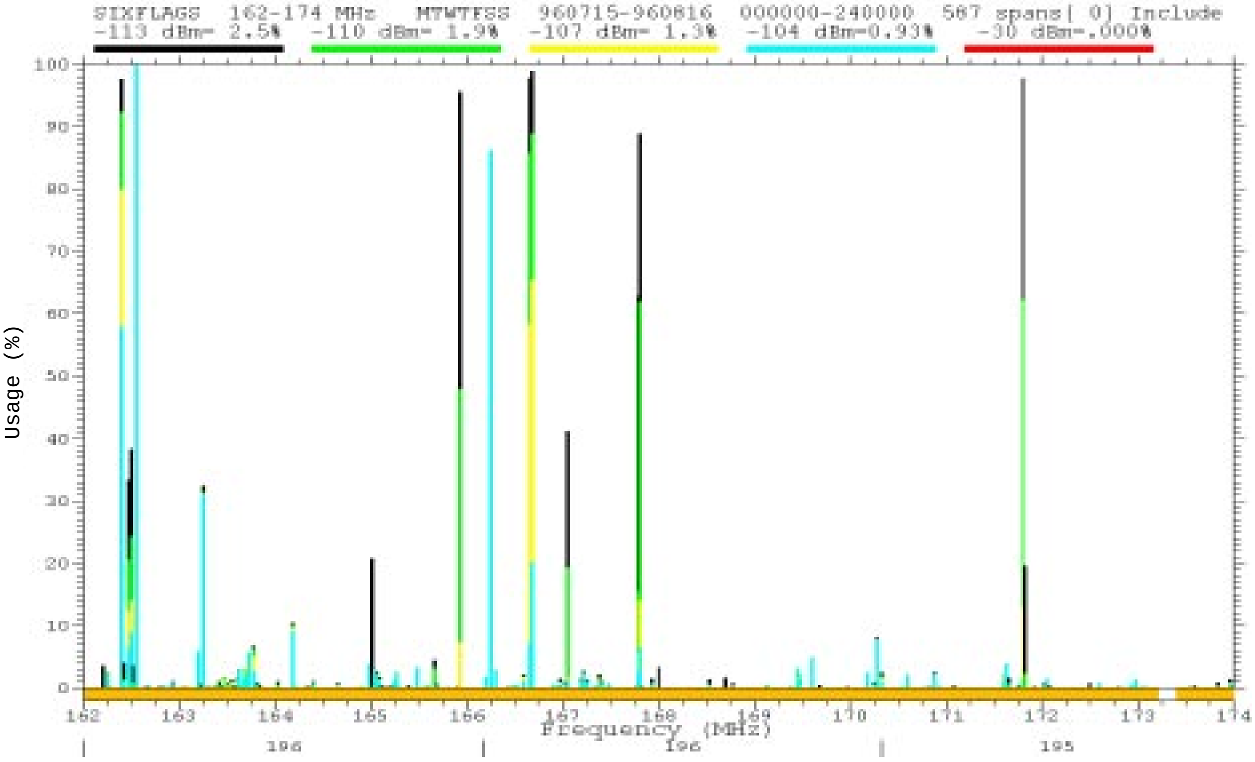

Figure 72. Usage vs. frequency plot of 162-174 MHz measurements at Six Flags.

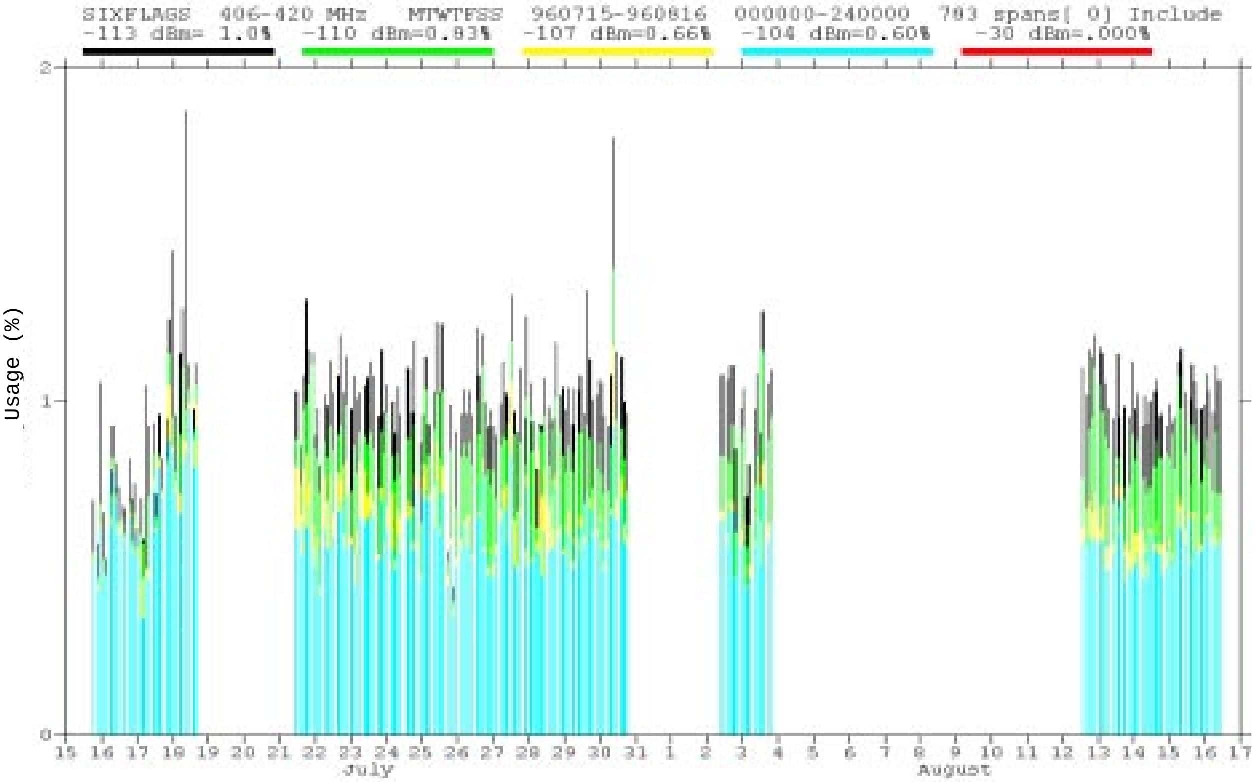

Figure 73. Usage vs. time plot of 406-420 MHz measurements at Six Flags.

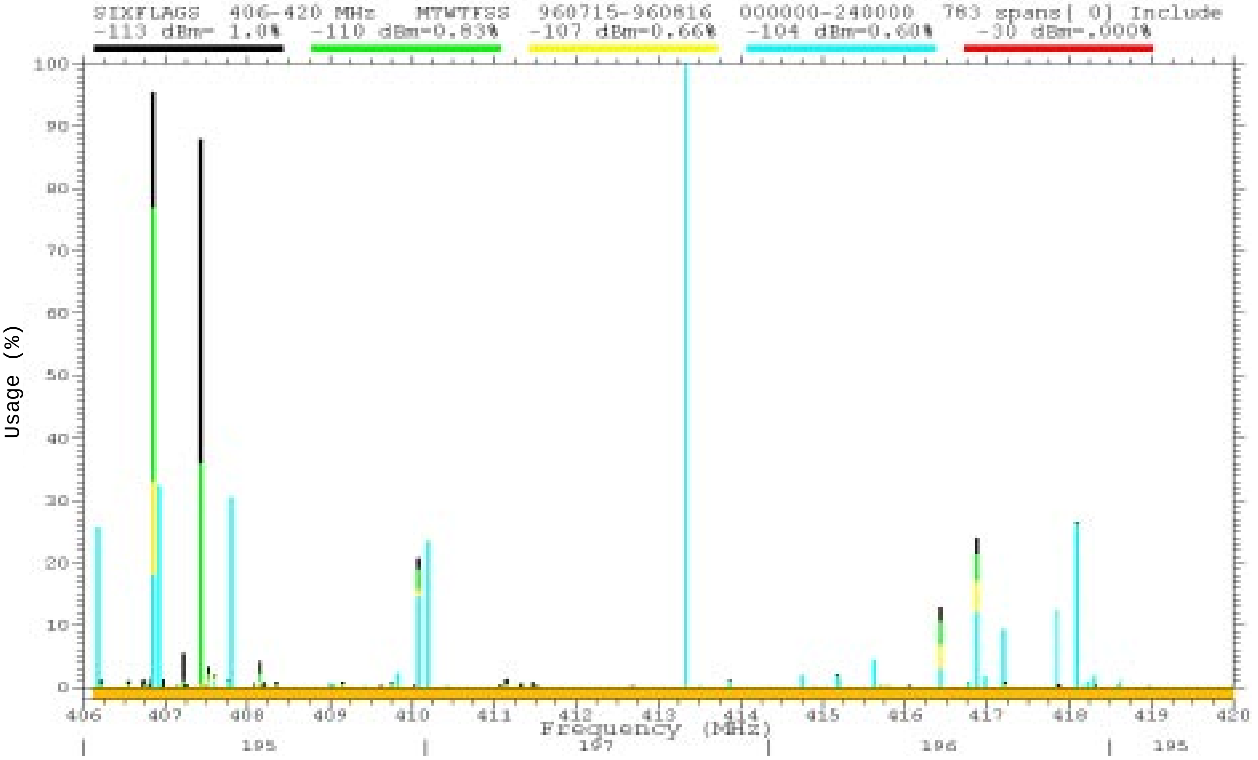

Figure 74. Usage vs. frequency plot of 406-420 MHz measurements at Six Flags.

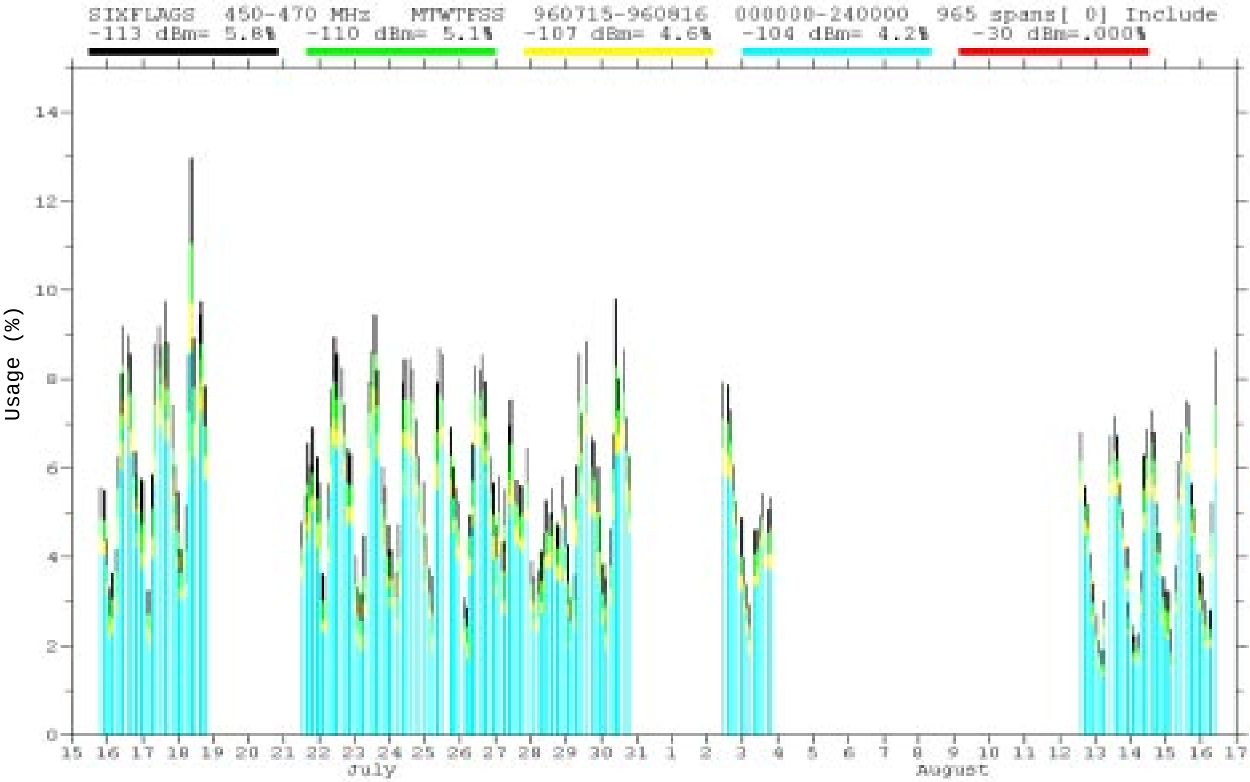

Figure 75. Usage vs. time plot of 451-470 MHz measurements at Six Flags.

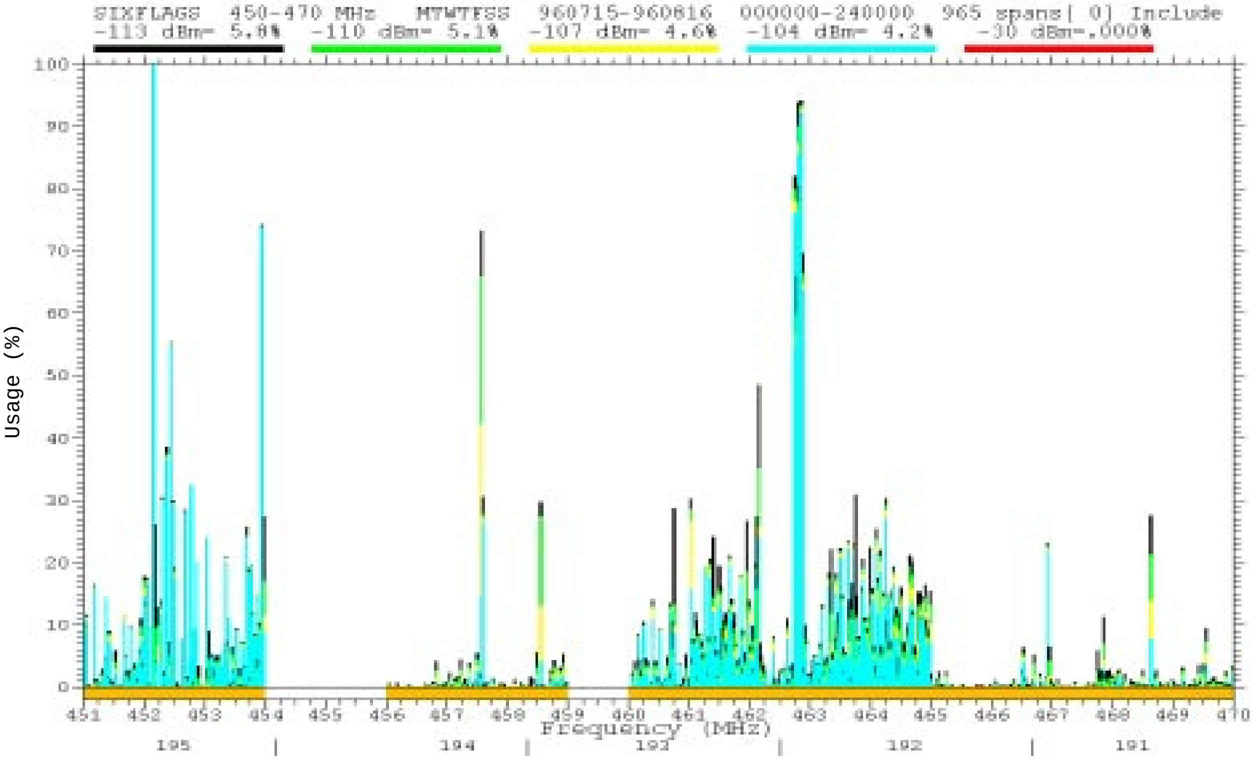

Figure 76. Usage vs. frequency plot of 451-470 MHz measurements at Six Flags.

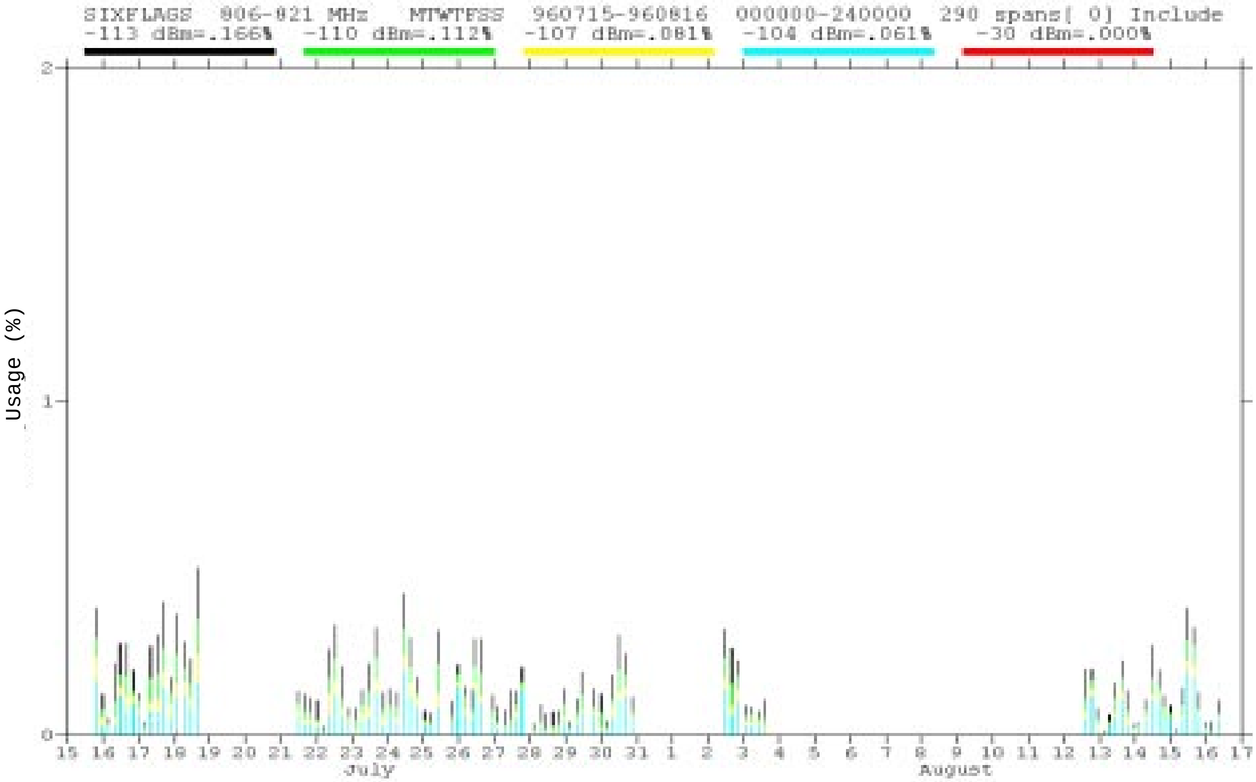

Figure 77. Usage vs. time plot of 806-821 MHz measurements at Six Flags.

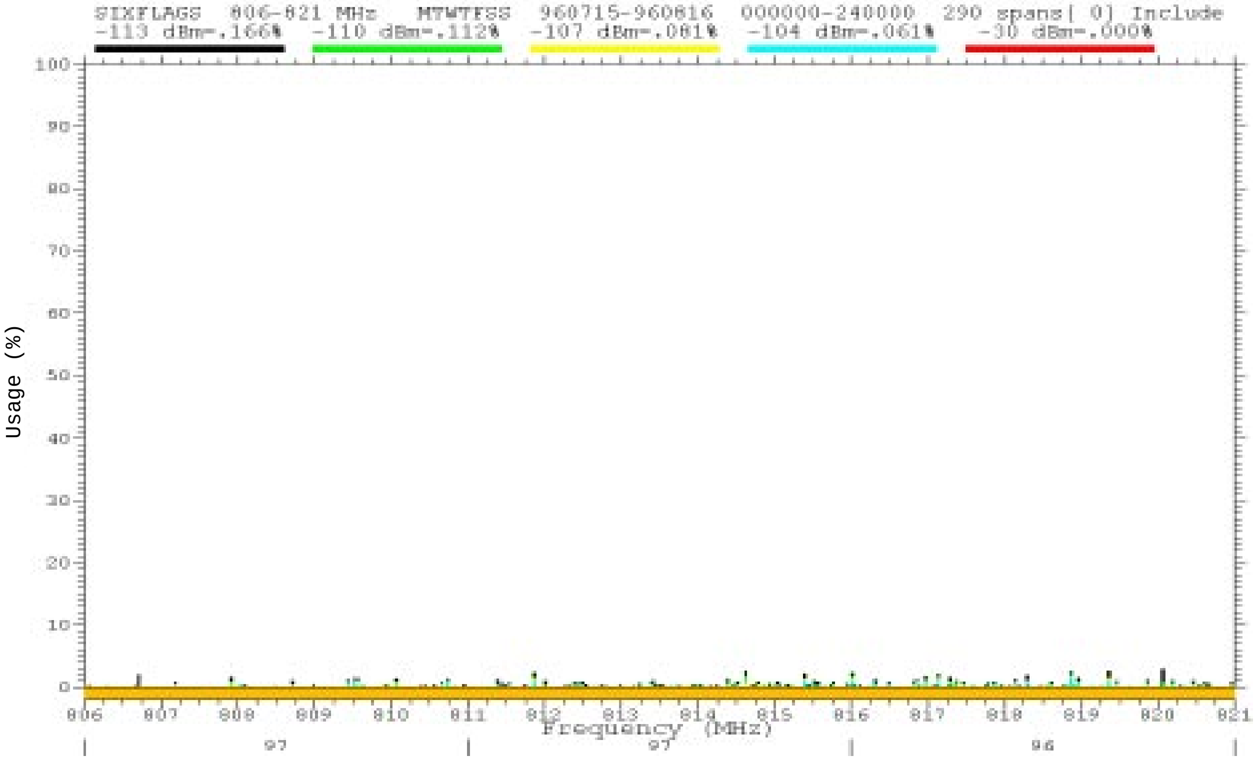

Figure 78. Usage vs. frequency plot of 806-821 MHz measurements at Six Flags.

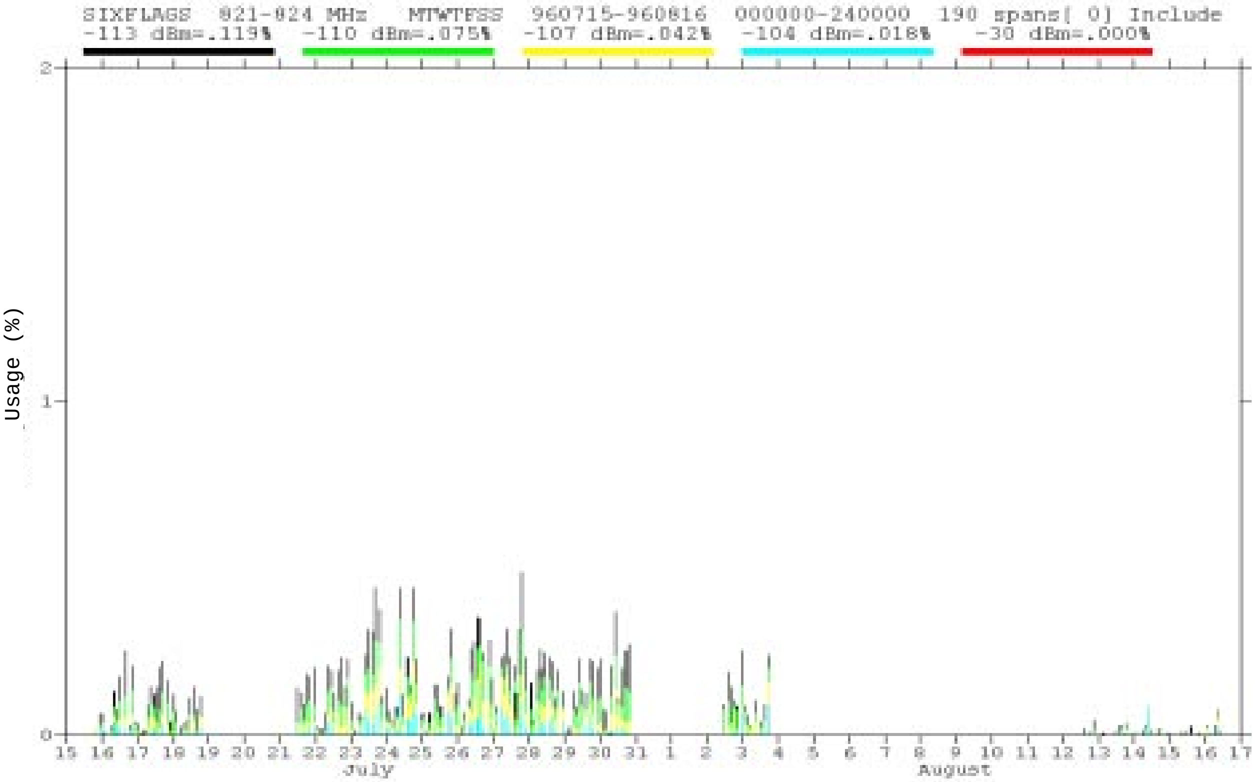

Figure 79. Usage vs. time plot of 821-824 MHz measurements at Six Flags.

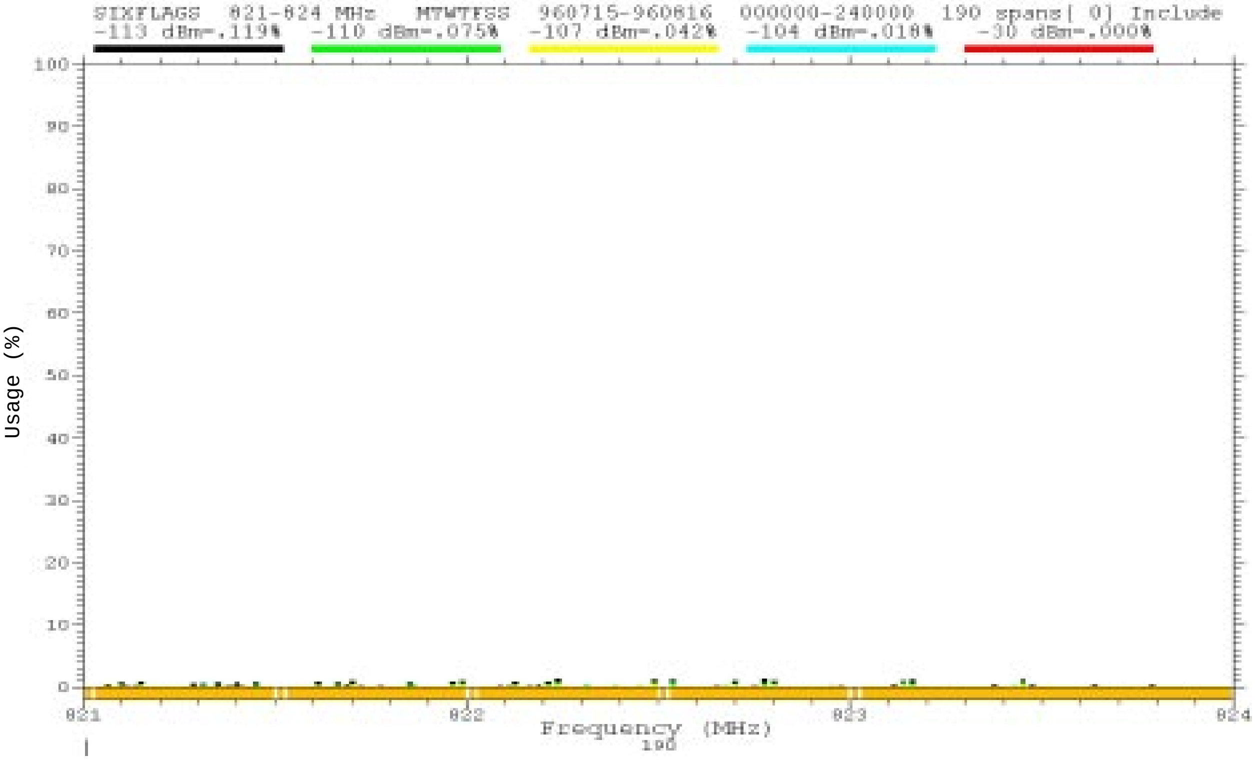

Figure 80. Usage vs. frequency plot of 821-824 MHz measurements at Six Flags.

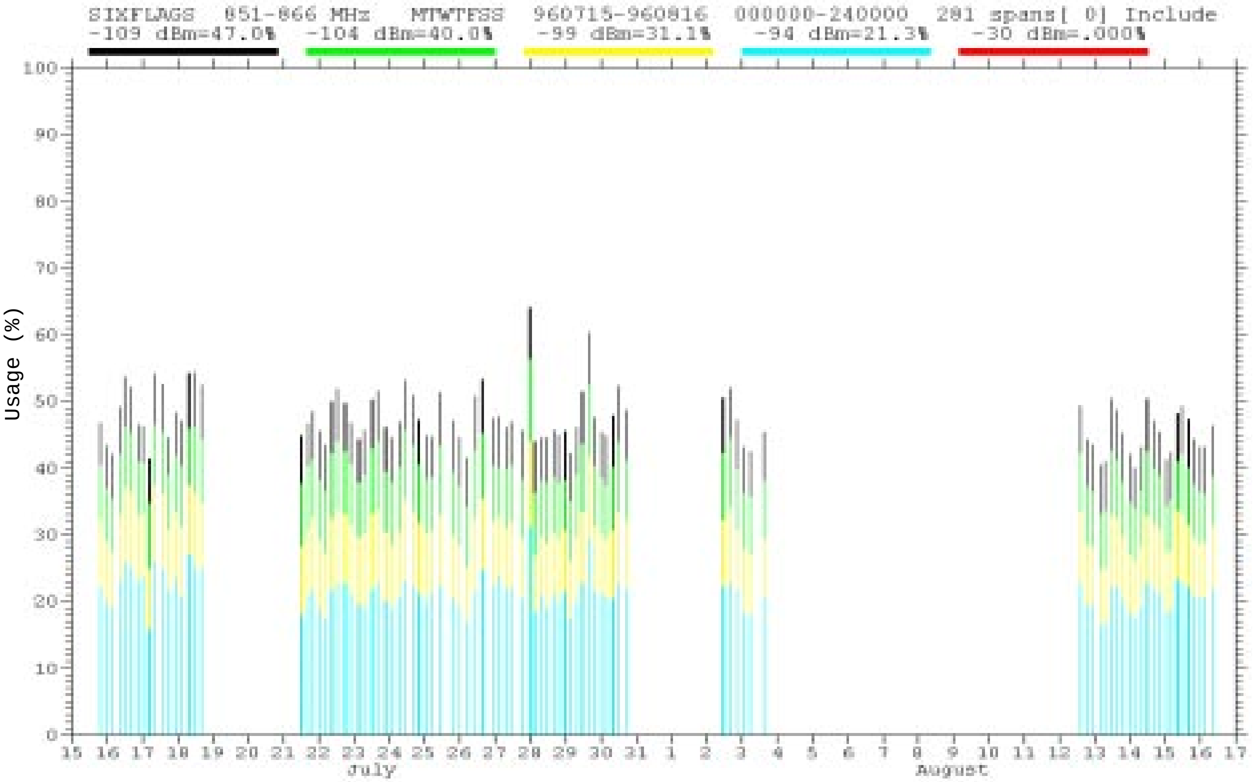

Figure 81. Usage vs. time plot of 851-866 MHz measurements at Six Flags.

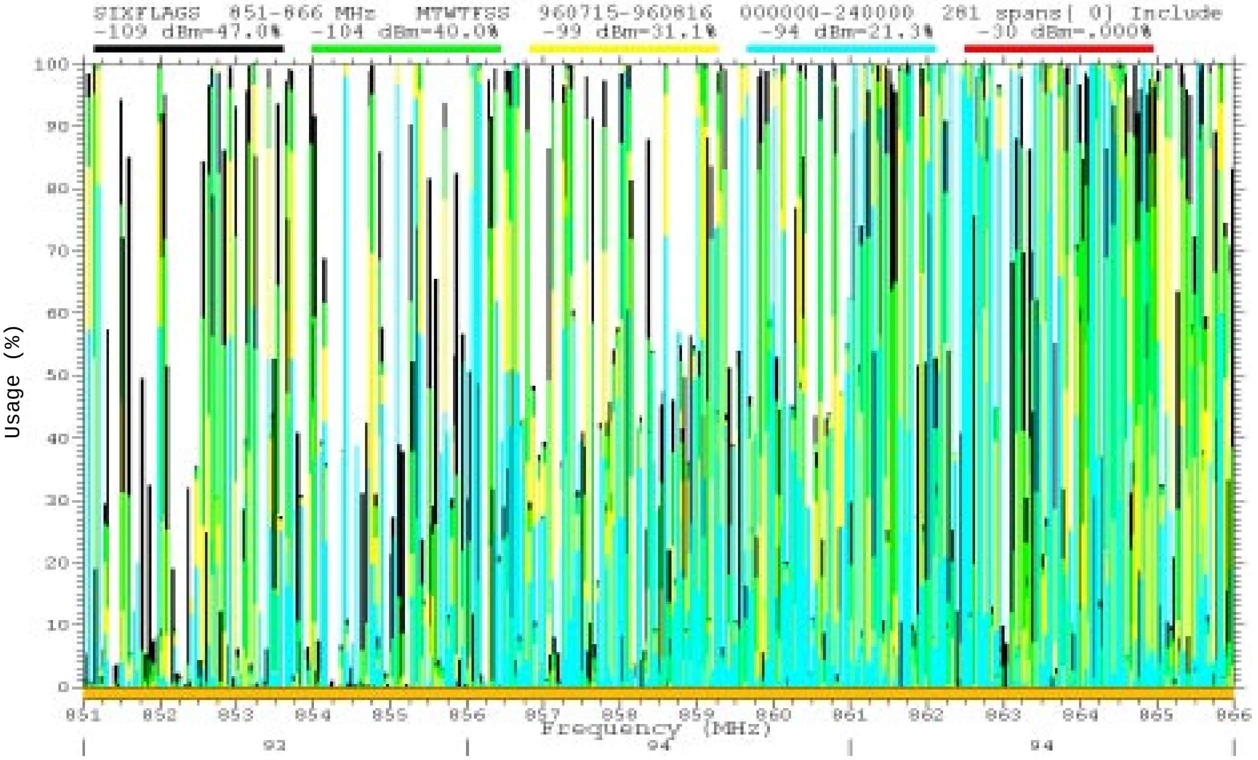

Figure 82. Usage vs. frequency plot of 851-866 MHz measurements at Six Flags.

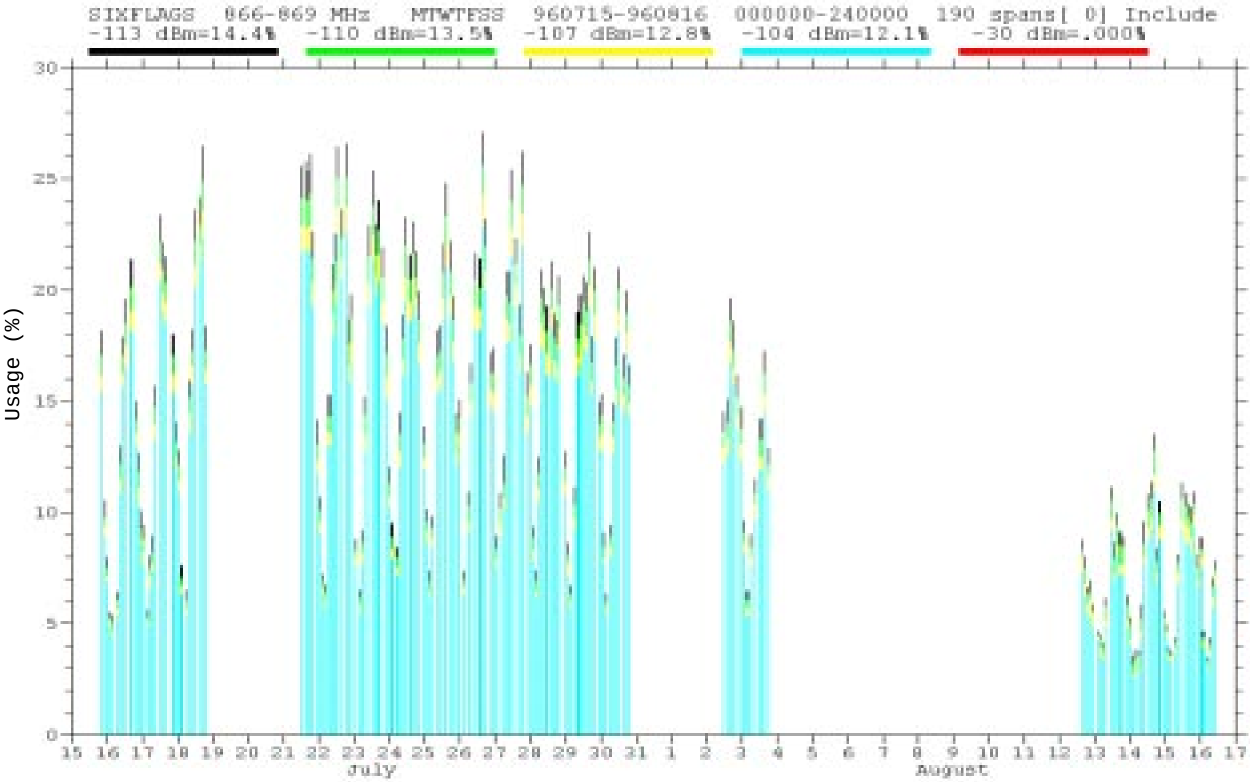

Figure 83. Usage vs. time plot of 866-869 MHz measurements at Six Flags.

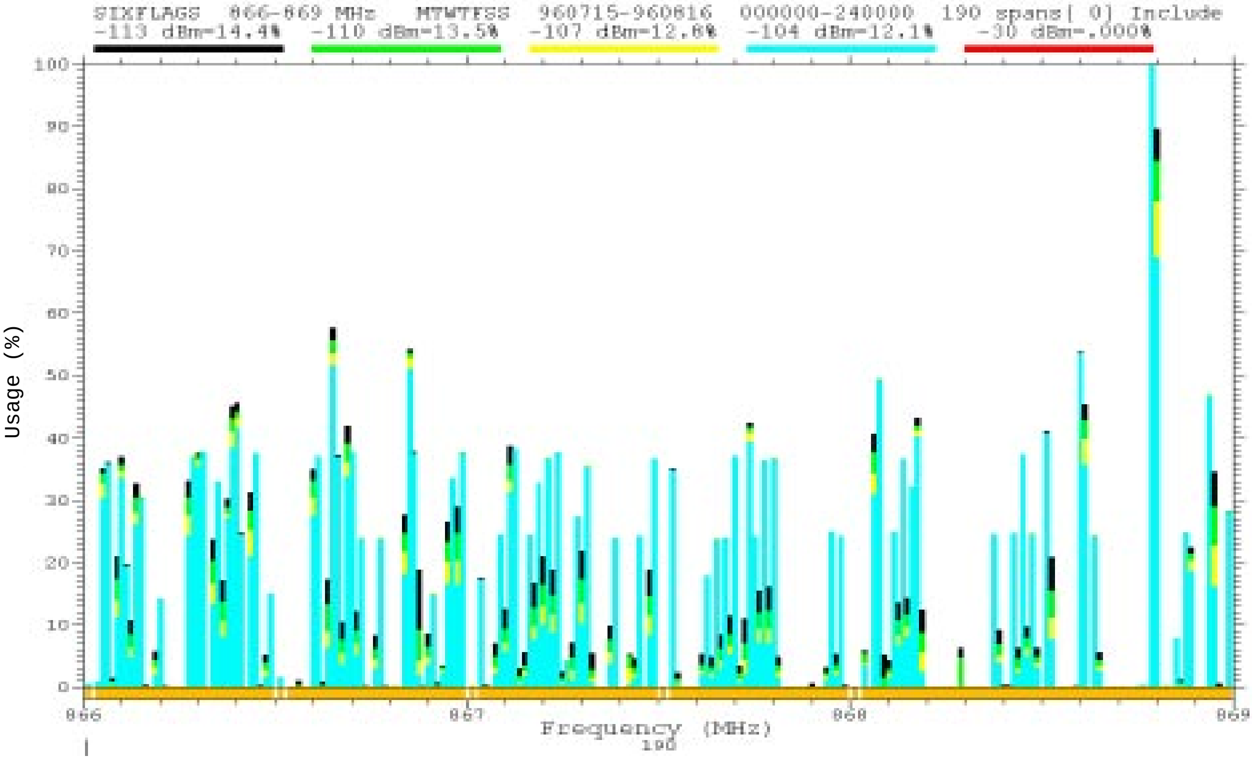

Figure 84. Usage vs. frequency plot of 866-869 MHz measurements at Six Flags.

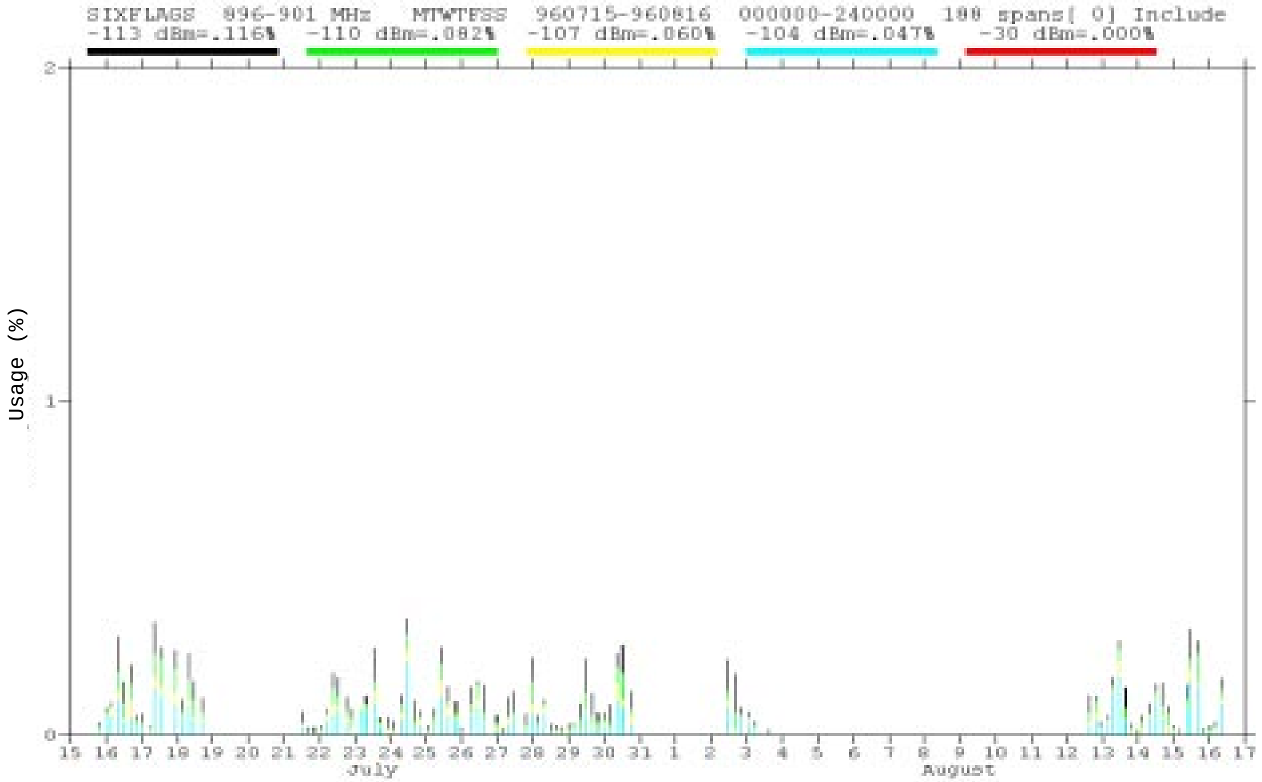

Figure 85. Usage vs. time plot of 896-901 MHz measurements at Six Flags.

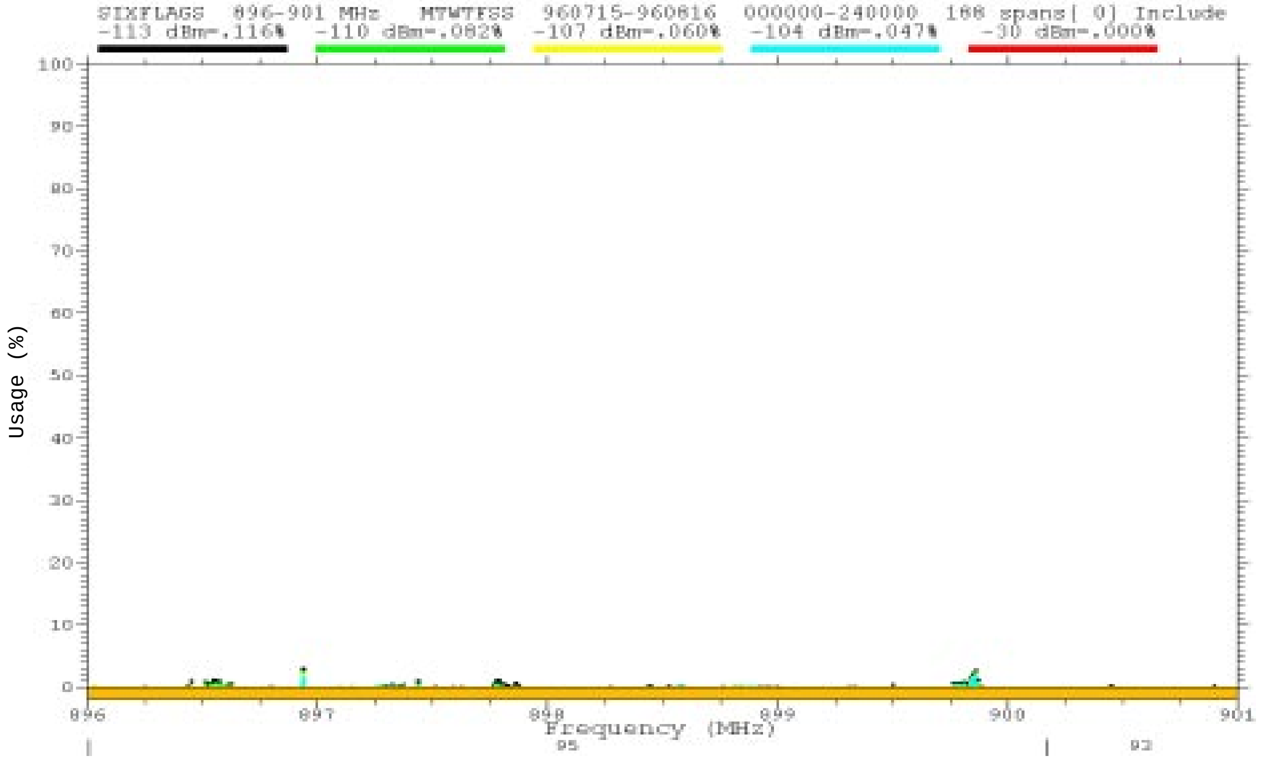

Figure 86. Usage vs. frequency plot of 896-901 MHz measurements at Six Flags.

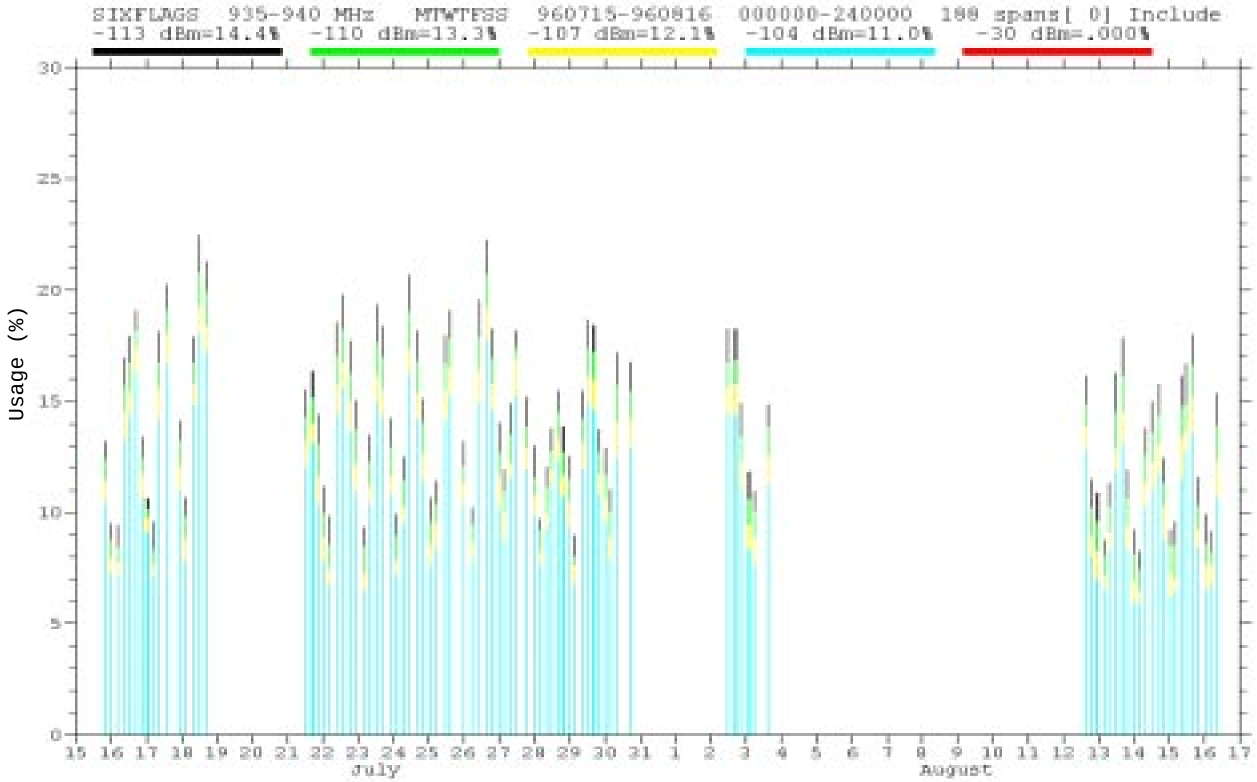

Figure 87. Usage vs. time plot of 935-940 MHz measurements at Six Flags.

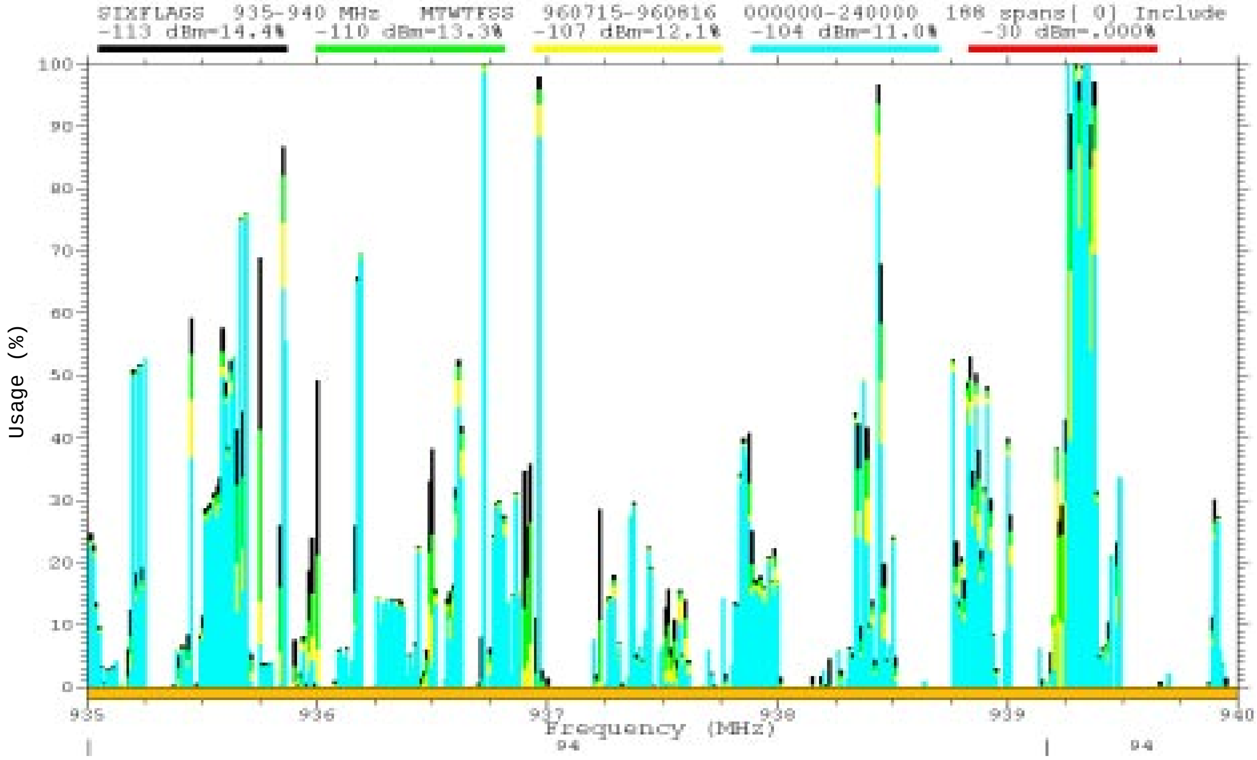

Figure 88. Usage vs. frequency plot of 935-940 MHz measurements at Six Flags.

3.7 Summary Analysis of Channel Usage Statistics

This section contains usage statistic summaries of all analysis bands for all three measurement sites. Figures 89 through 103 are summary usage plots for each analysis band. Each graph shows results for all thresholds at all three measurement sites. Data are plotted as histogram bars, with the height of each bar representing the percentage of measurement time that the band was in use. Each bar represents a combination of measurement parameters shown in the labeling below the bar. The measurement parameters are location (site), thresholds (with corresponding colors), and inclusive time and date codes. Analysis band, number of LMR channels represented, and include/exclude codes (as explained in Section 3.4) are labeled above each graph. The following labeling keys are relevant to each figure in this section.

Date and time-of-day codes (labels below each set of bars):

A	bar represents data from ***all*** days measured (7/15 - 8/16, 1996);
<	bar represents data measured ***before*** the Summer Olympic Games (7/15 - 7/18, 1996);
D	bar represents data measured ***during*** the Summer Olympic Games (7/19 - 8/04, 1996);
>	bar represents data measured ***after*** the Summer Olympic Games (8/12 - 8/16, 1996);
0000-2400	bars represent all data measured during the dates specified;
0900-1600	bars represent core hour data (9am - 4pm, Monday through Friday only).

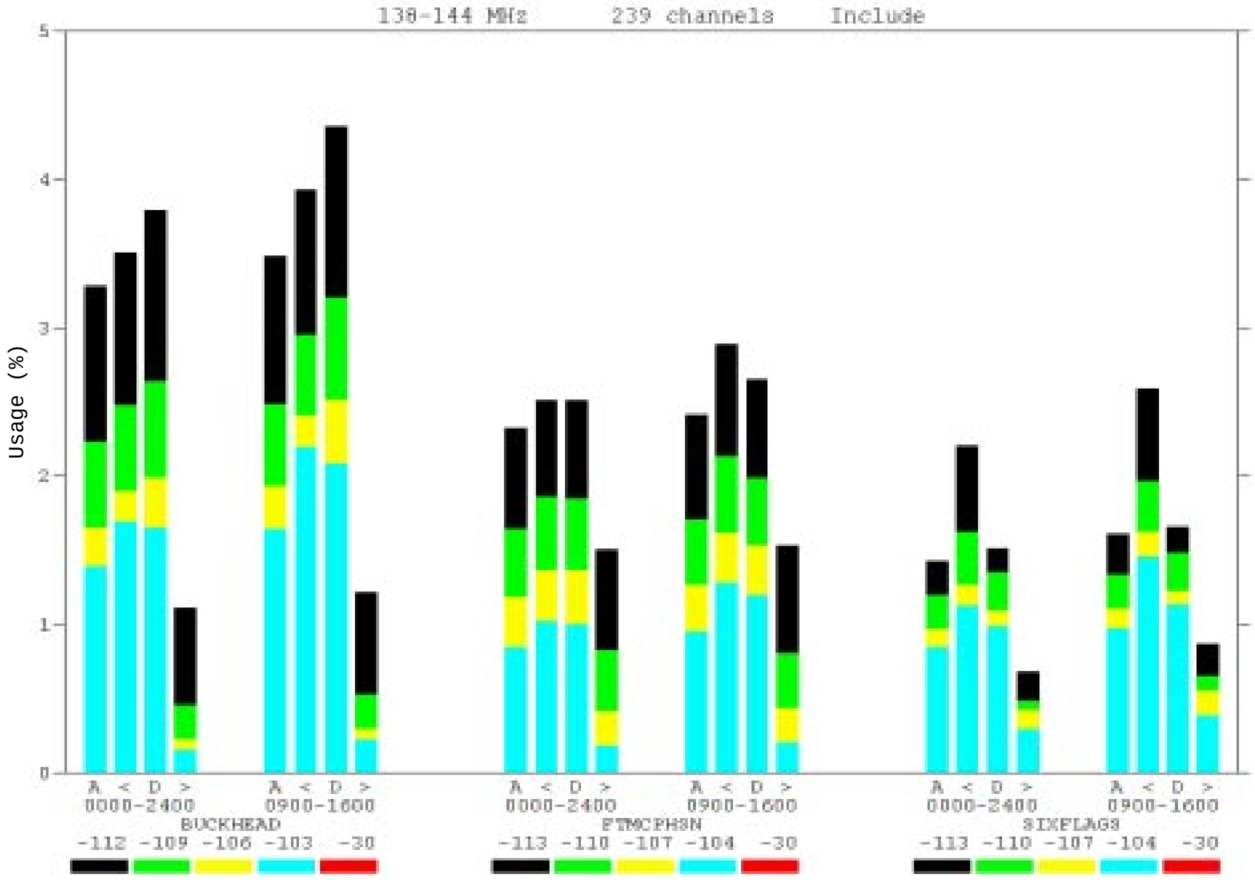

Figure 89. Summary plot of 138-144 MHz measurements at Atlanta, Georgia.

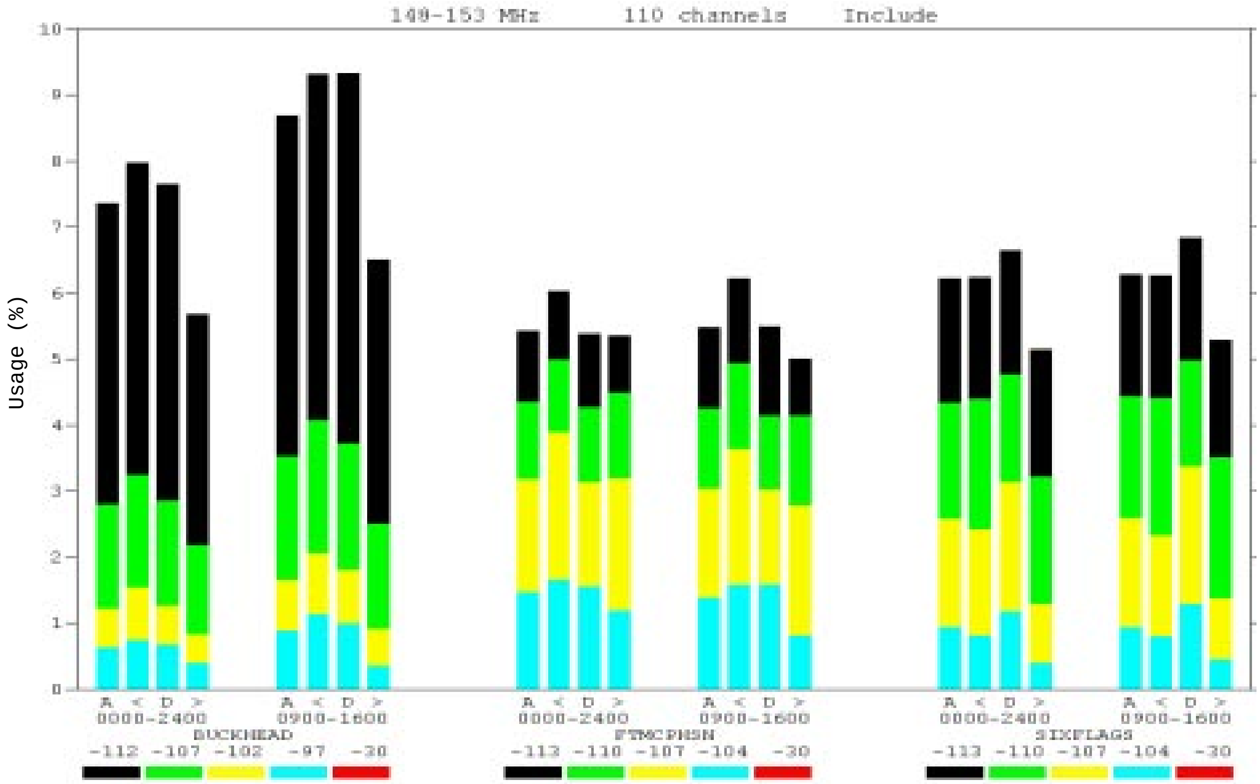

Figure 90. Summary plot of 148-153 MHz measurements at Atlanta, Georgia.

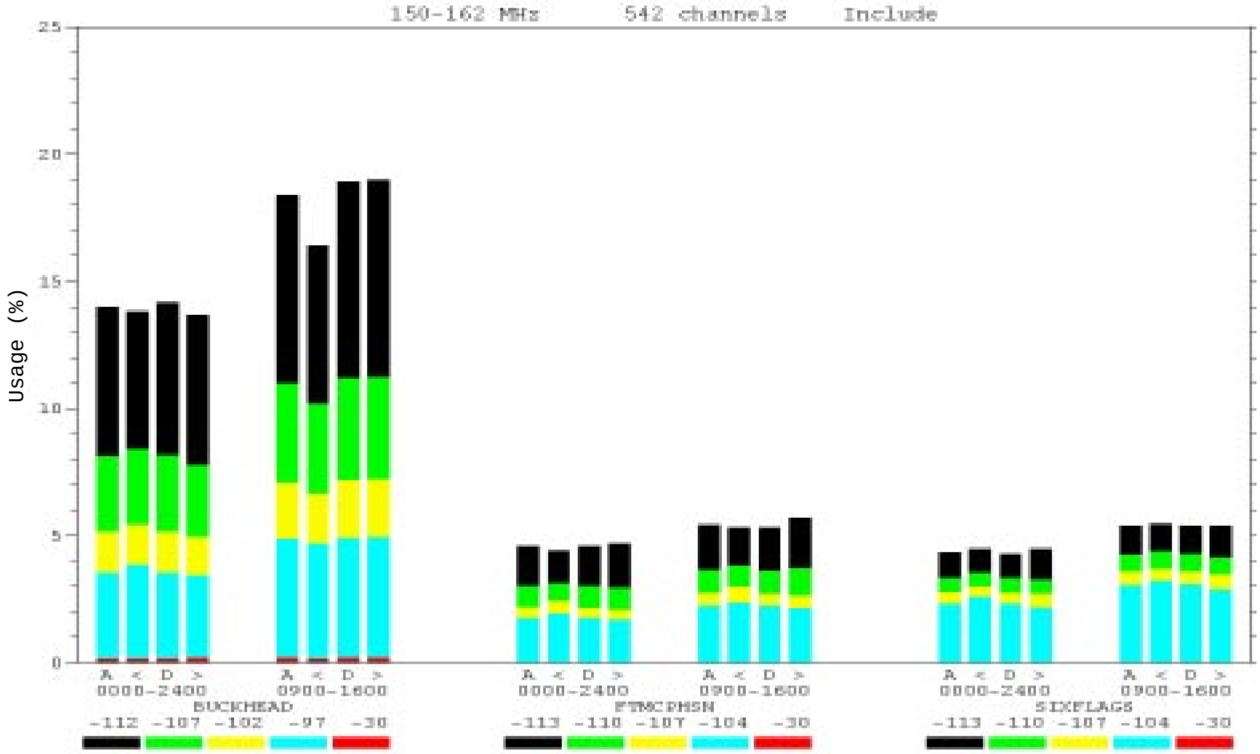

Figure 91. Summary plot of 150-162 MHz measurements at Atlanta, Georgia.

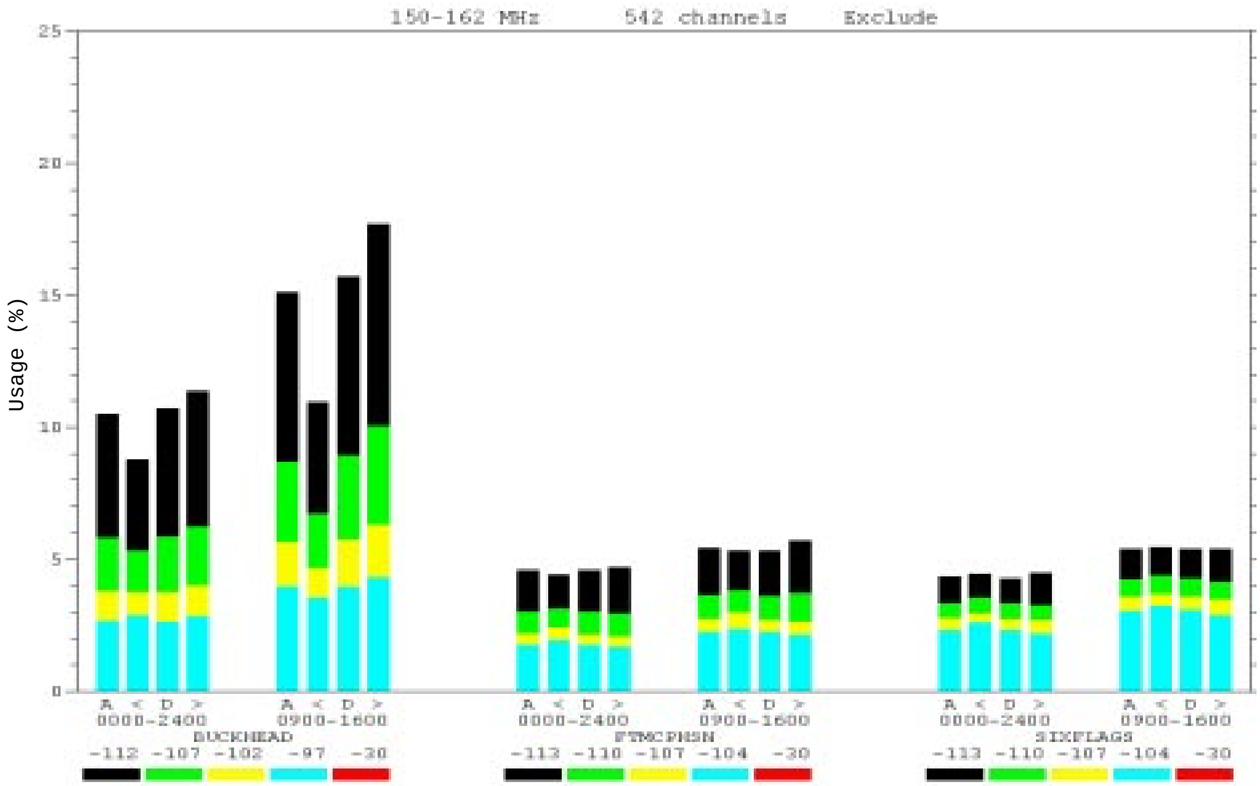

Figure 92. Summary plot of 150-162 MHz measurements at Atlanta, Georgia (exclude data).

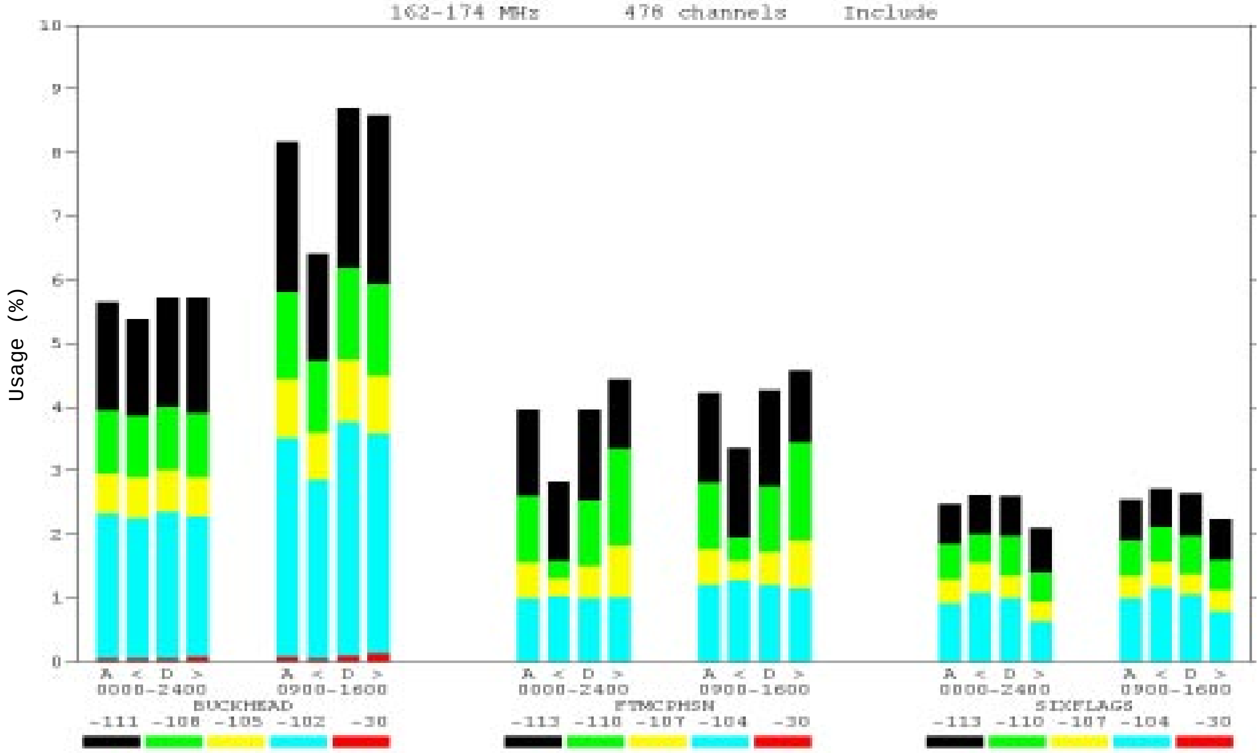

Figure 93. Summary plot of 162-174 MHz measurements at Atlanta, Georgia.

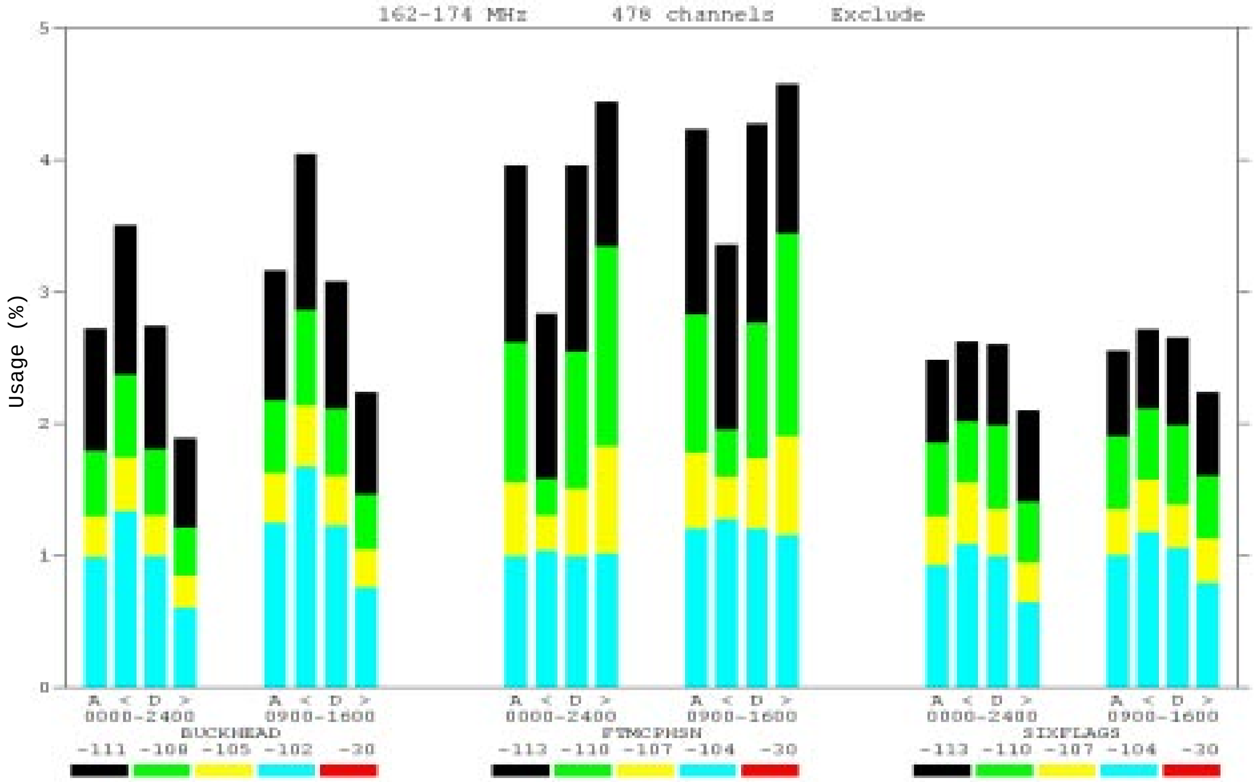

Figure 94. Summary plot of 162-174 MHz measurements at Atlanta, Georgia (exclude data).

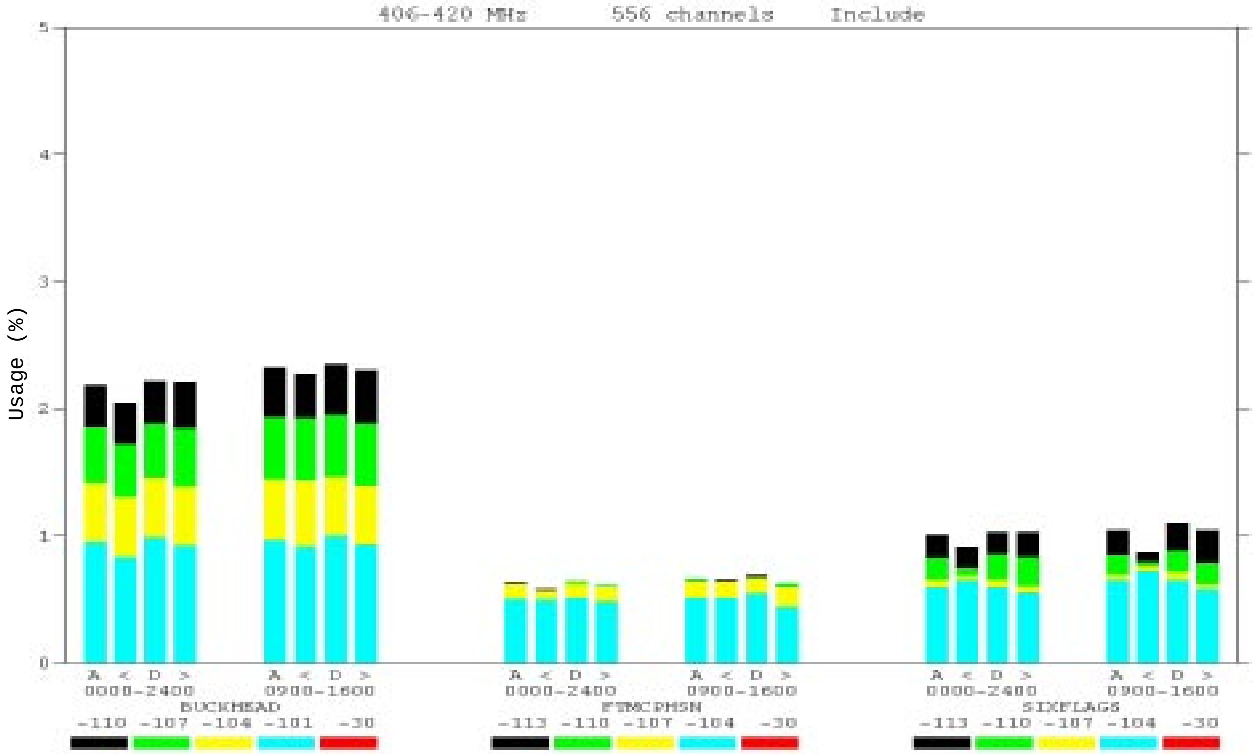

Figure 95. Summary plot of 406-420 MHz measurements at Atlanta, Georgia.

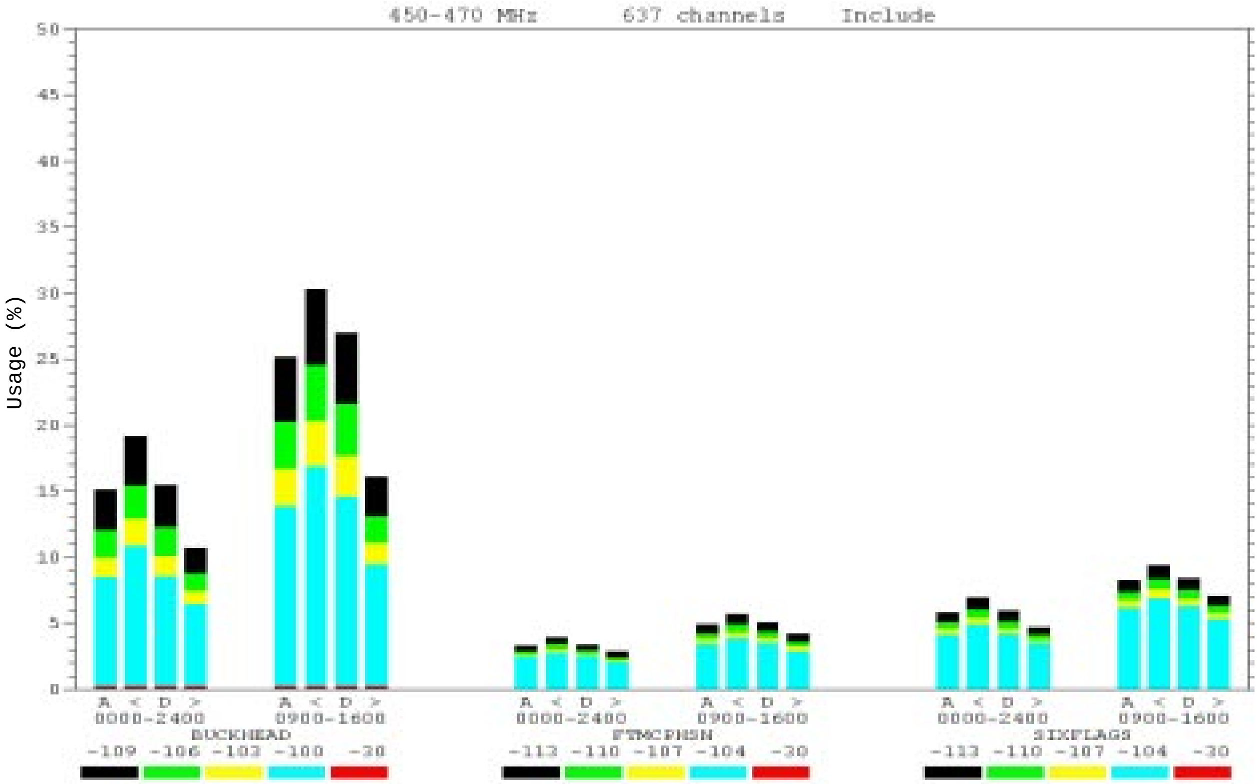

Figure 96. Summary plot of 450-470 MHz measurements at Atlanta, Georgia.

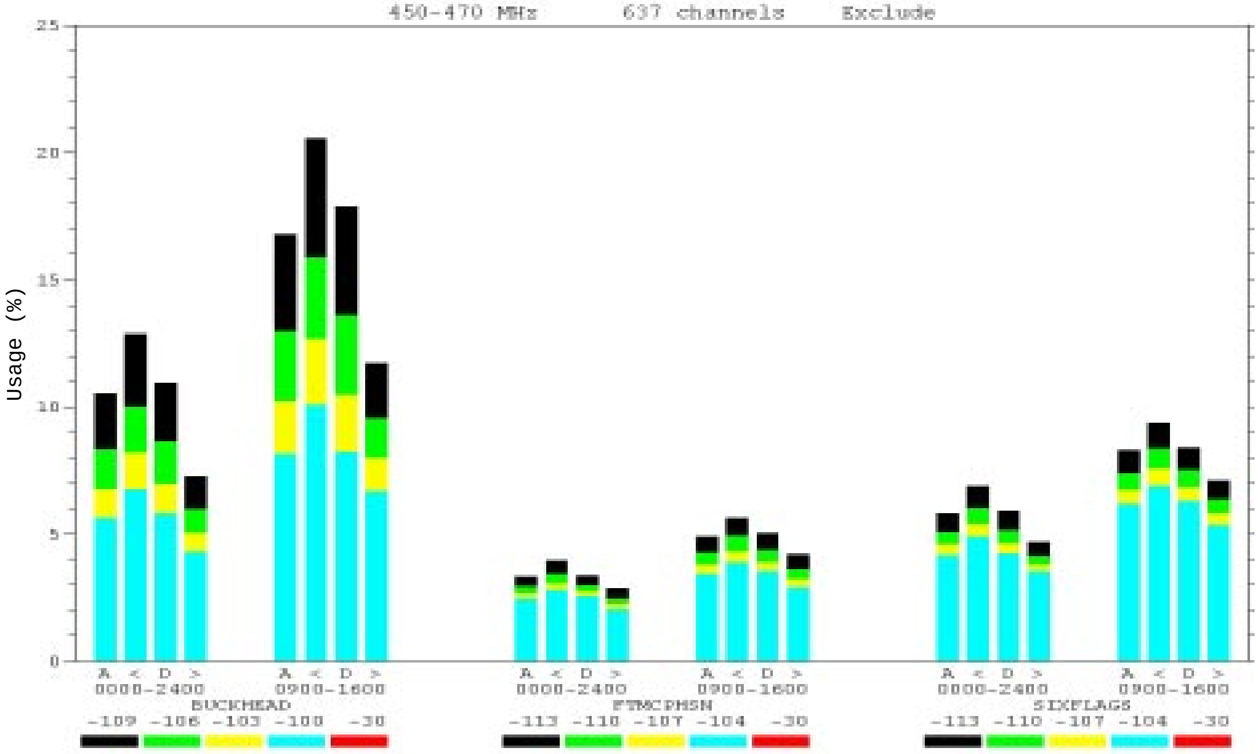

Figure 97. Summary plot of 450-470 MHz measurements at Atlanta, Georgia (exclude data).

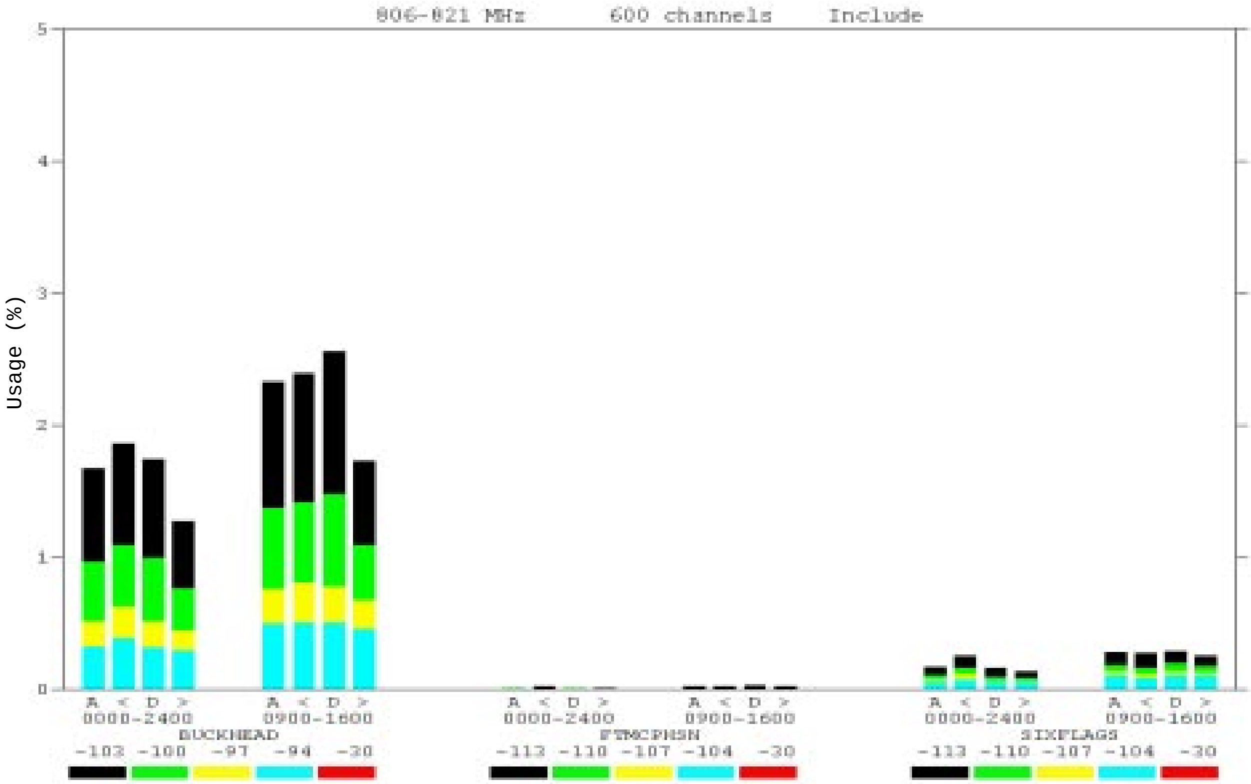

Figure 98. Summary plot of 806-821 MHz measurements at Atlanta, Georgia.

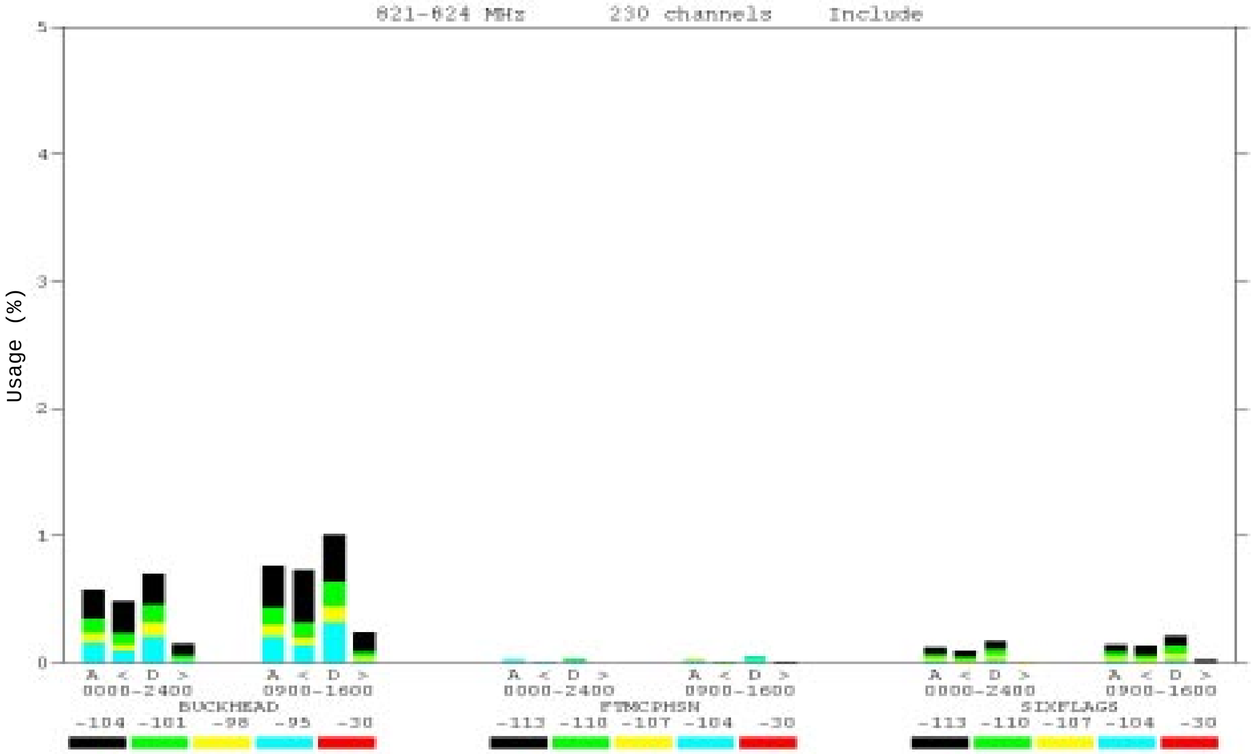

Figure 99. Summary plot of 821-824 MHz measurements at Atlanta, Georgia.

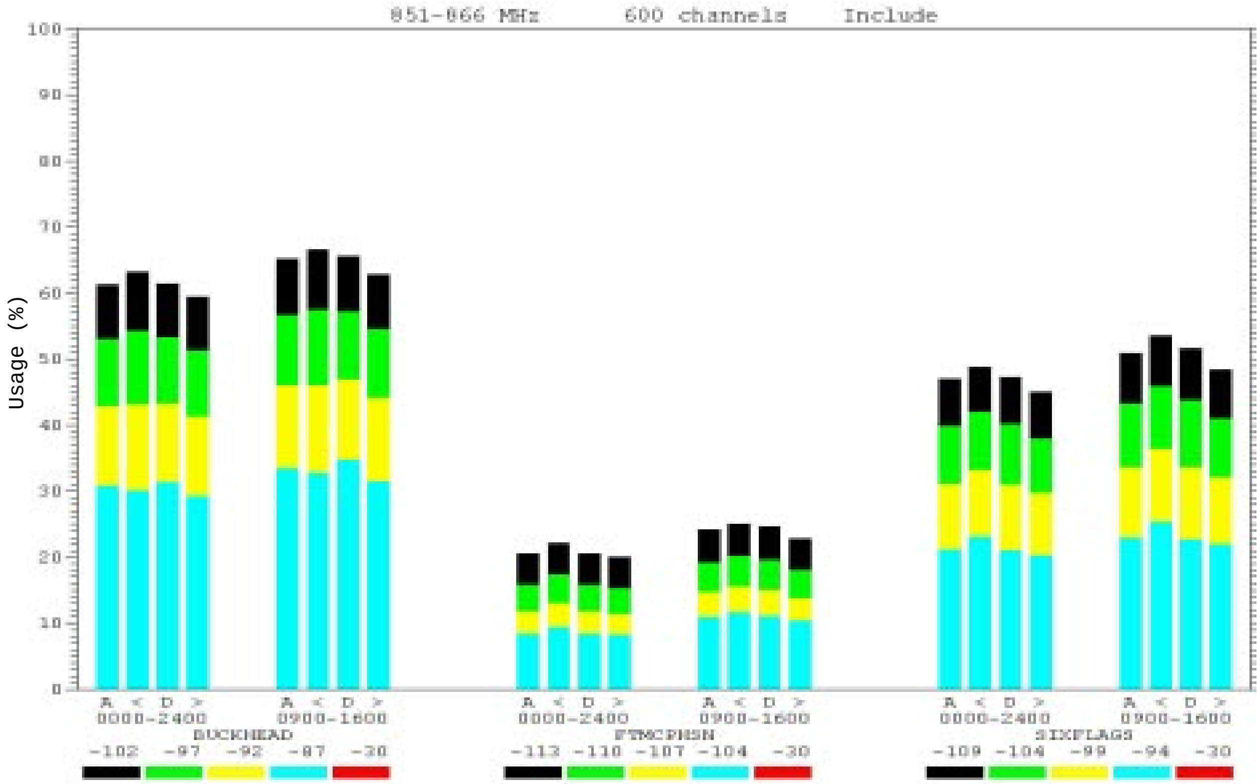

Figure 100. Summary plot of 851-866 MHz measurements at Atlanta, Georgia.

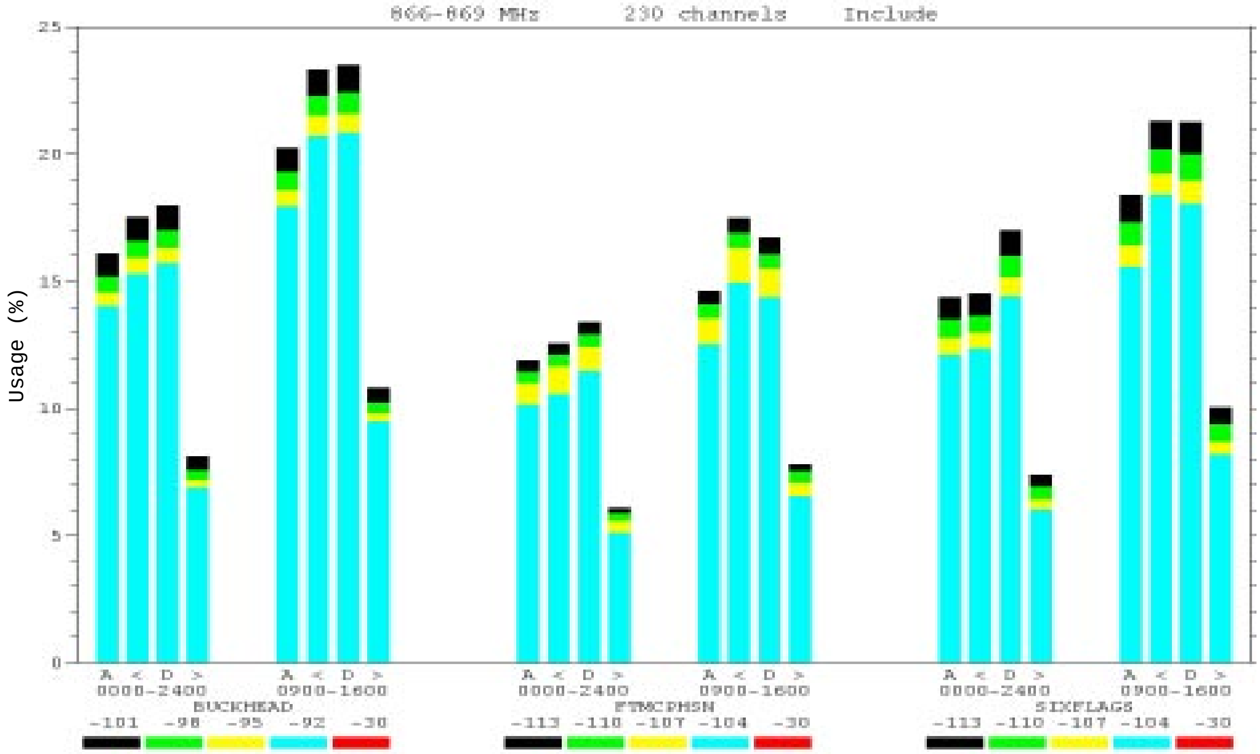

Figure 101. Summary plot of 866-869 MHz measurements at Atlanta, Georgia.

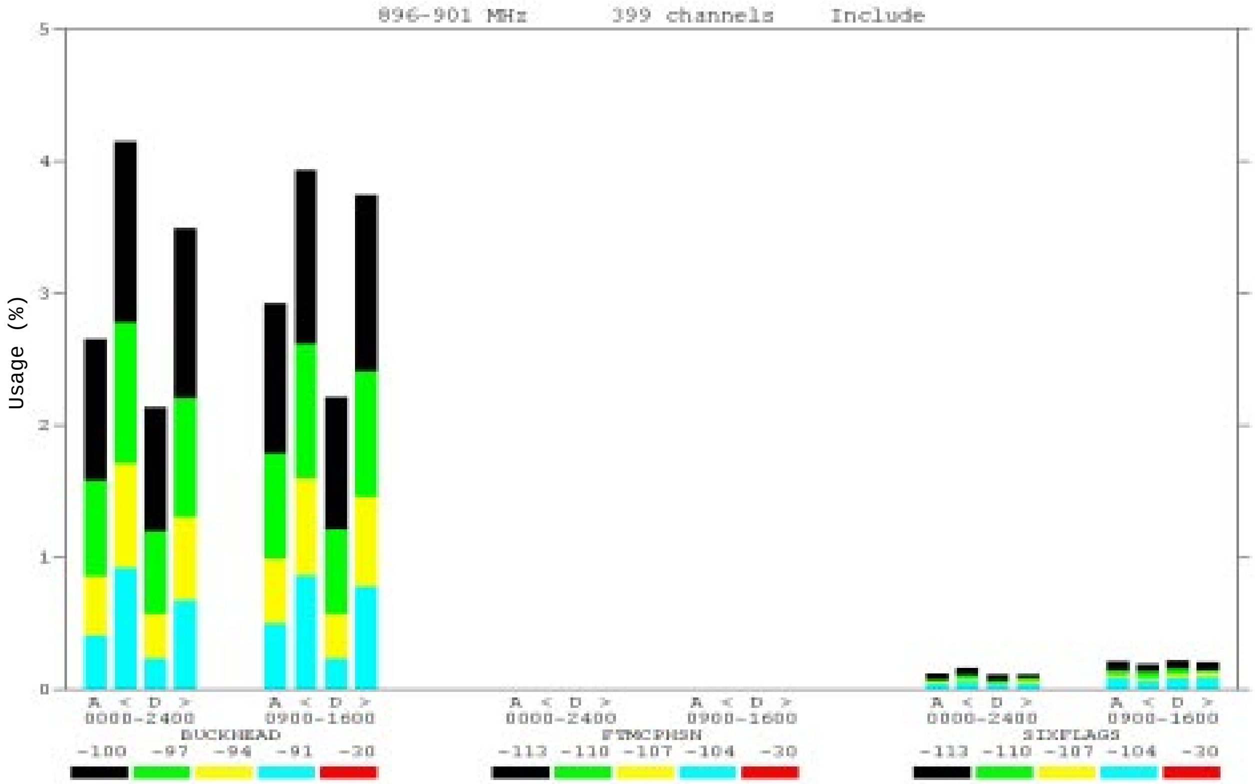

Figure 102. Summary plot of 896-901 MHz measurements at Atlanta, Georgia.

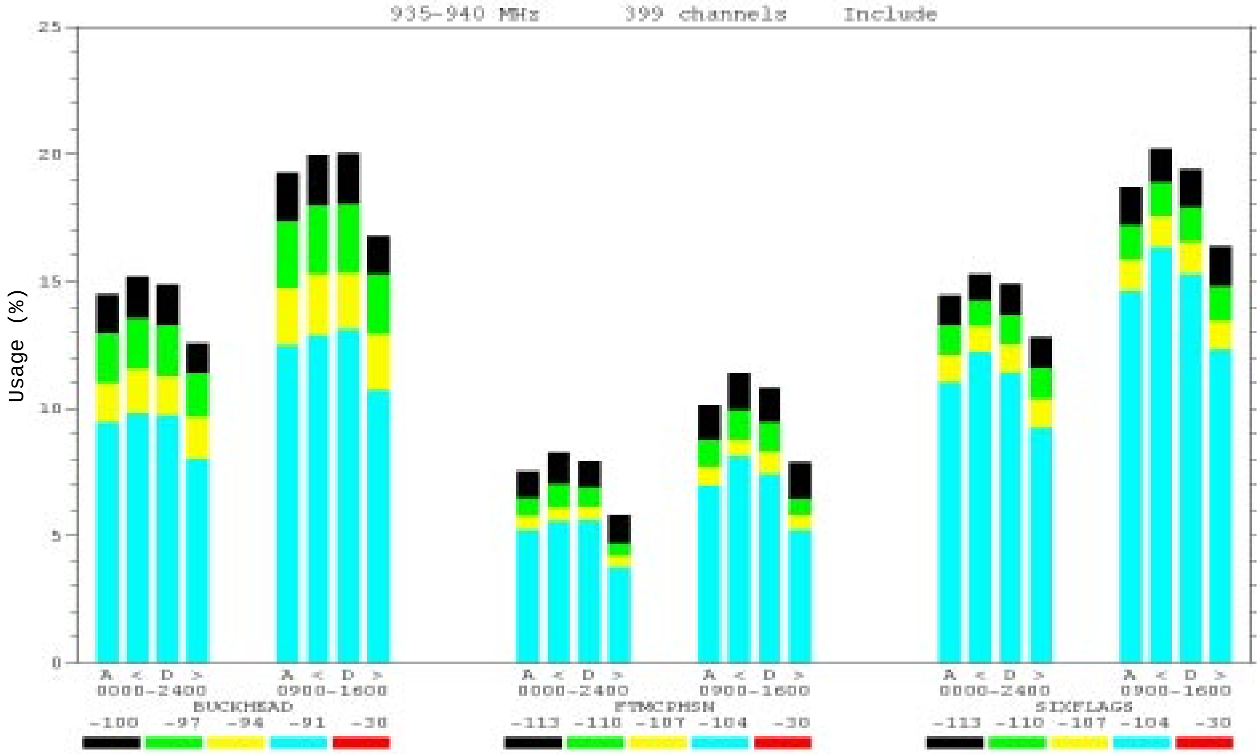

Figure 103. Summary plot of 935-940 MHz measurements at Atlanta, Georgia.

3.8 Public Safety Channel Usage Statistics and Summary Analysis

Additional wireless communication requirements for public safety services (such as, emergency response teams and law enforcement) at the 1996 Summer Olympics were expected to show a measurable impact on usage in public safety LMR channels. Therefore, the Atlanta data were analyzed not only for general (all-channel) usage, but also for public safety channel usage statistics. Channels included in this analysis are those listed as Public Safety Services in 47 CFR [2, part 90.555]. These services and their two-letter designators are: Fire (PF), Highway Maintenance (PH), Local Government (PL), Emergency Medical (PM), Forestry-Conservation (PO), Police (PP), and Special Emergency (PS).

This section contains usage statistic summaries for frequency bands that are partially allocated for public safety assignments. Table 3 describes the public safety channels individually analyzed in this section and the analysis results are shown in Figures 104 through 119.

Table 3. Public Safety LMR Channels Analyzed from Atlanta Measurement Data

LMR Band (MHz)	**Frequencies (MHz)**	**Public Safety Services**	**Comments**
150-162	150.775, 150.790	PS	2 channels, 15 kHz/channel
"	150.995-151.490	PH, PO (shared with IB)*	34 channels, 15 kHz/channel
"	153.740-154.445	PF, PL	48 channels, 15 kHz/channel
"	154.650-154.950	PP	21 channels, 15 kHz/channel
"	154.965-156.240	PH, PL, PP	86 channels, 15 kHz/channel
"	158.730-159.225	PH, PL, PO, PP	34 channels, 15 kHz/channel
"	159.240-159.465	PO (shared with IS)*	16 channels, 15 kHz/channel
450-470	453.025-453.975	PF, PH, PL, PO, PP, PM	39 channels, 25 kHz/channel
"	458.025-458.975	PF, PH, PL, PO, PP, PM	39 channels, 25 kHz/channel
"	460.025-460.625	PP, PF, PM	25 channels, 25 kHz/channel
"	462.950-463.175	PM	10 channels, 25 kHz/channel
"	465.025-465.265	PP, PF, PM	25 channels, 25 kHz/channel
"	467.950-468.175	PM	10 channels, 25 kHz/channel
806-821 851-866	809-816 854-861	All Services	70 channel pairs (paired bands),** 25 KHz/channel

[*] Industrial Services Business (IB) and Industrial Services Special (IS) share some frequencies with public safety.

[**] These channels are assigned as follows: Each mobile channel in the 809-816 MHz band is paired with a base channel 45 MHz above it in the 854-861 MHz band. Channels are 25 kHz wide, allocated as shown in Figures 112 through 119. In the 806-821 MHz and 851-866 MHz bands, Federal agencies coordinate use with non-Federal agencies on a state-by-state basis.

The 162-174, 406-420, 821-824, and 866-869 MHz LMR analysis bands are allocated exclusively for public safety assignments, and analysis results for these bands are presented with the overall (all-channel) band usage statistics in Sections 3.4 through 3.7.

For each of the four subbands that were analyzed for public safety channel usage statistics (150-160, 453-469, 809-816, and 854-861 MHz), four plots are presented. Three of the four are usage vs. frequency plots. These plots are in the same format as the plots in Sections 3.4-3.6; one each for the Buckhead, Fort McPherson, and Six Flags measurement sites. They differ from the plots in Sections 3.4-3.6 in that they include only the public safety channels described in Table 3. Section 3.4 describes in detail the interpretation of data for this type of plot.

The fourth graph in each group of four is a statistical usage summary plot of the public safety channels at the three measurement locations. Each of these graphs show results for all thresholds for all public safety channels at all three measurement sites. The graph header shows the measurement subband frequency range, number of public safety channels represented and the include/exclude code (as explained in Section 3.4).[5] Data are plotted as histogram bars, with the height of each bar representing the percentage of measurement time that the band was in use. Additionally, each bar represents a combination of measurement parameters shown in the labelling below each set of bars. The measurement parameters are location (in computer processing code; BUCKHEAD, FTMCPHSN, and SIXFLAGS), thresholds (with associated color bands), and inclusive time and date codes defined as follows.

Coded labels below bar groups:

A	bar represents data from ***all*** days measured (7/15 - 8/16, 1996);
<	bar represents data measured ***before*** the Summer Olympic Games (7/15 - 7/18, 1996);
D	bar represents data measured ***during*** the Summer Olympic Games (7/19 - 8/04, 1996);
>	bar represents data measured ***after*** the Summer Olympic Games (8/12 - 8/16, 1996);
0000-2400	bars represent all data measured during the dates specified;
0900-1600	bars represent core hour data (9am - 4pm, Monday through Friday only).

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[5] There were no overload (i.e., ***exclude***) occurrences in any of the four subbands that were analyzed for public safety channel usage statistics.

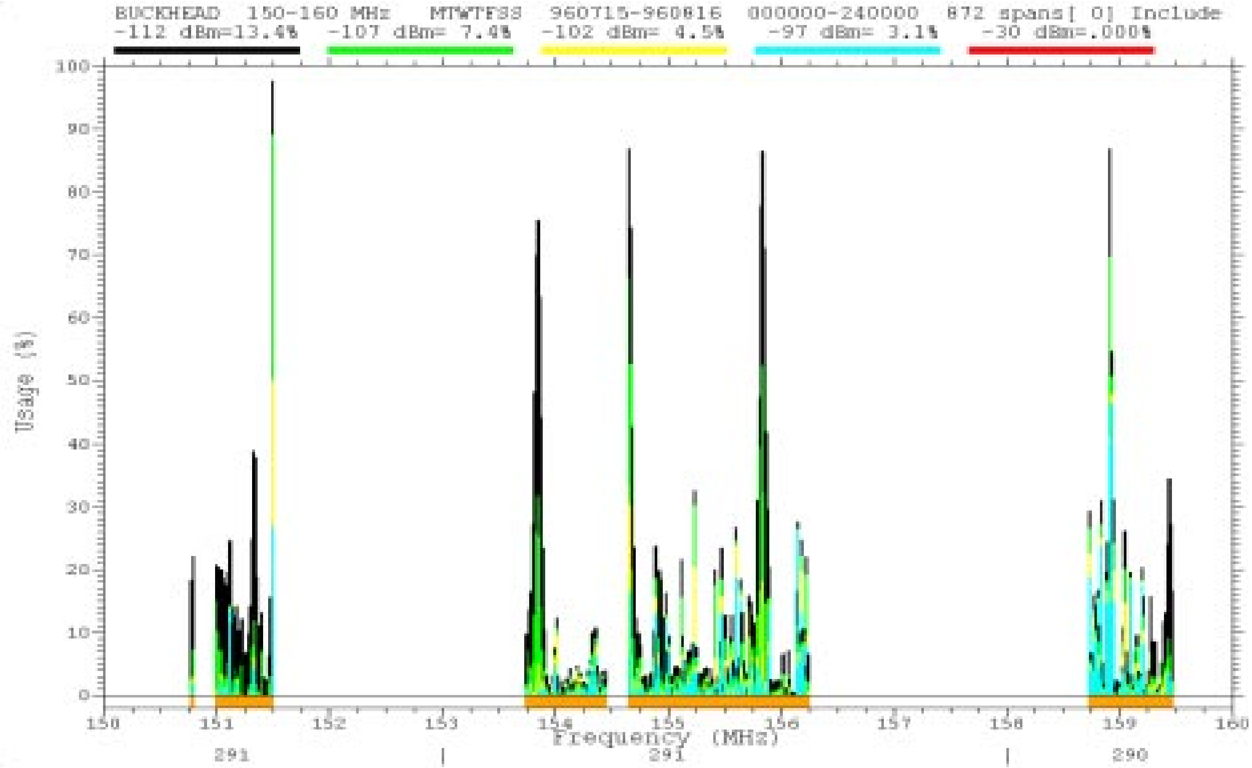

Figure 104. Plot of 150-160 MHz public safety channels measured at the Buckhead site.

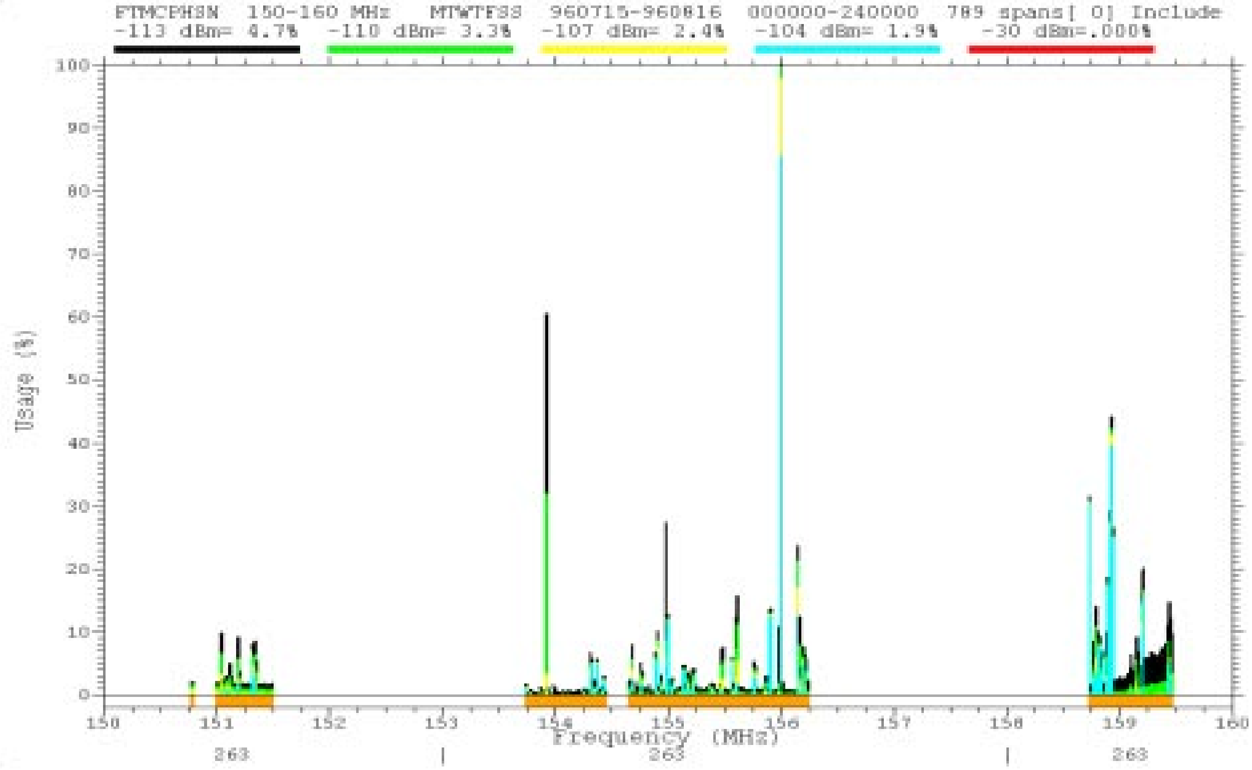

Figure 105. Plot of 150-160 MHz public safety channels measured at the Fort McPherson site.

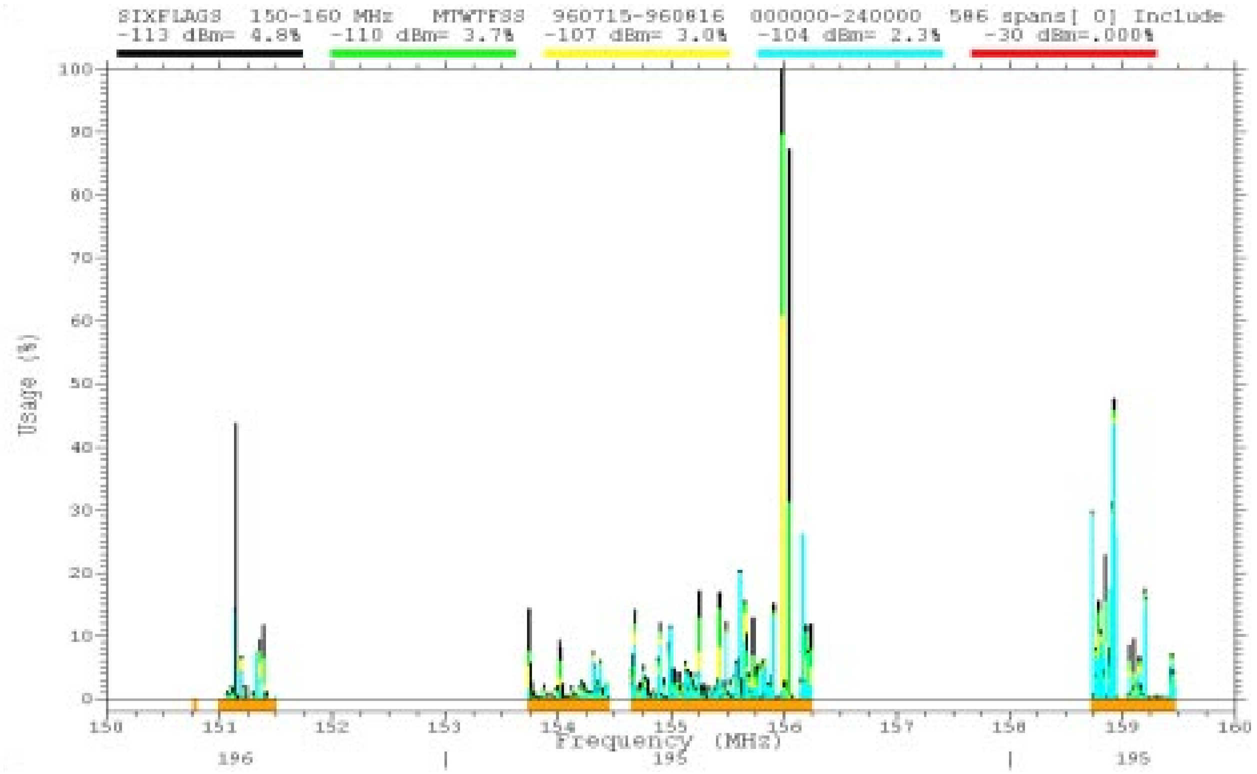

Figure 106. Plot of 150-160 MHz public safety channels measured at the Six Flags site.

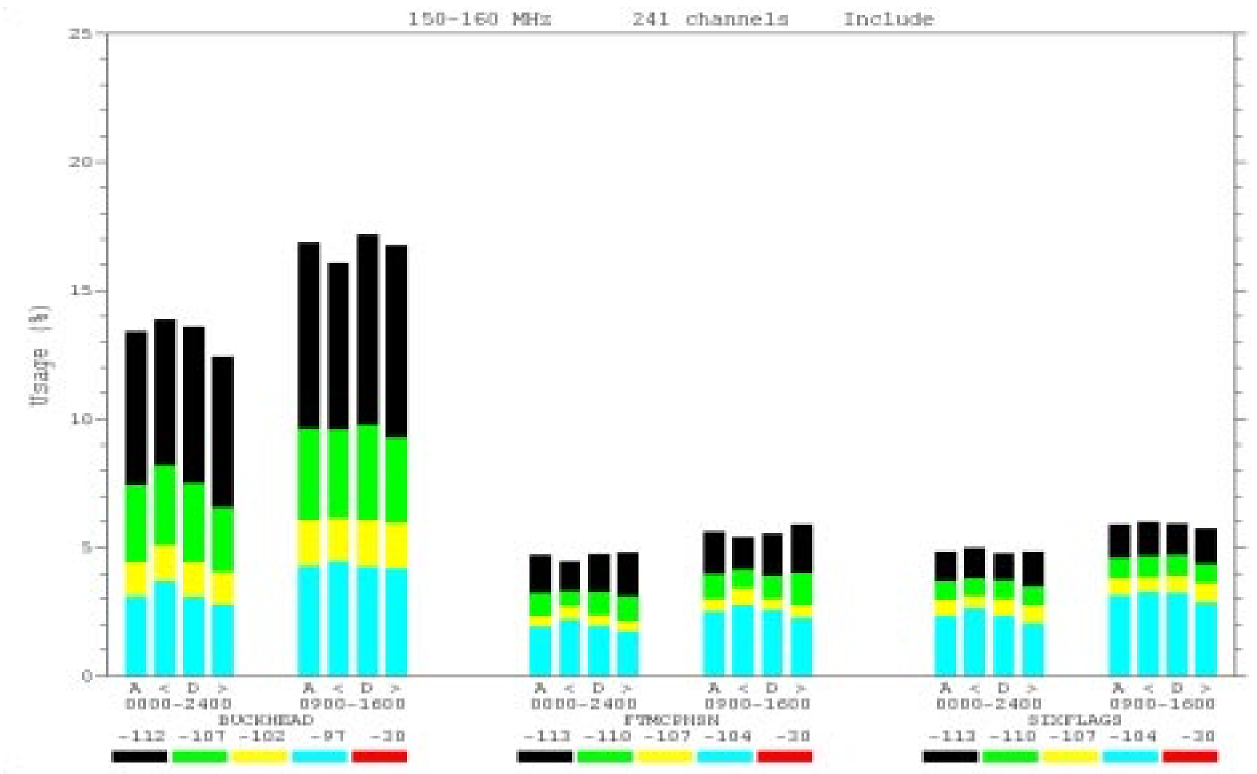

Figure 107. Summary plot of the 150-160 MHz public safety channel measurements.

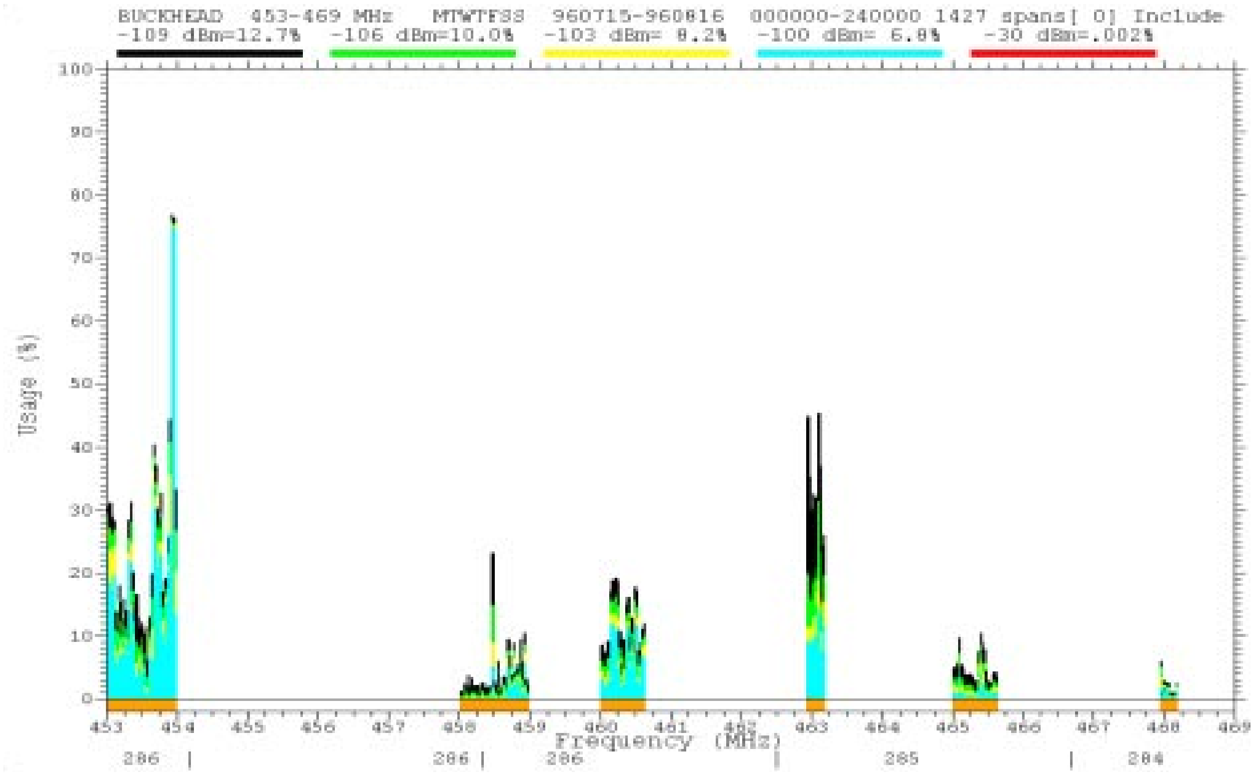

Figure 108. Plot of 453-469 MHz public safety channels measured at the Buckhead site.

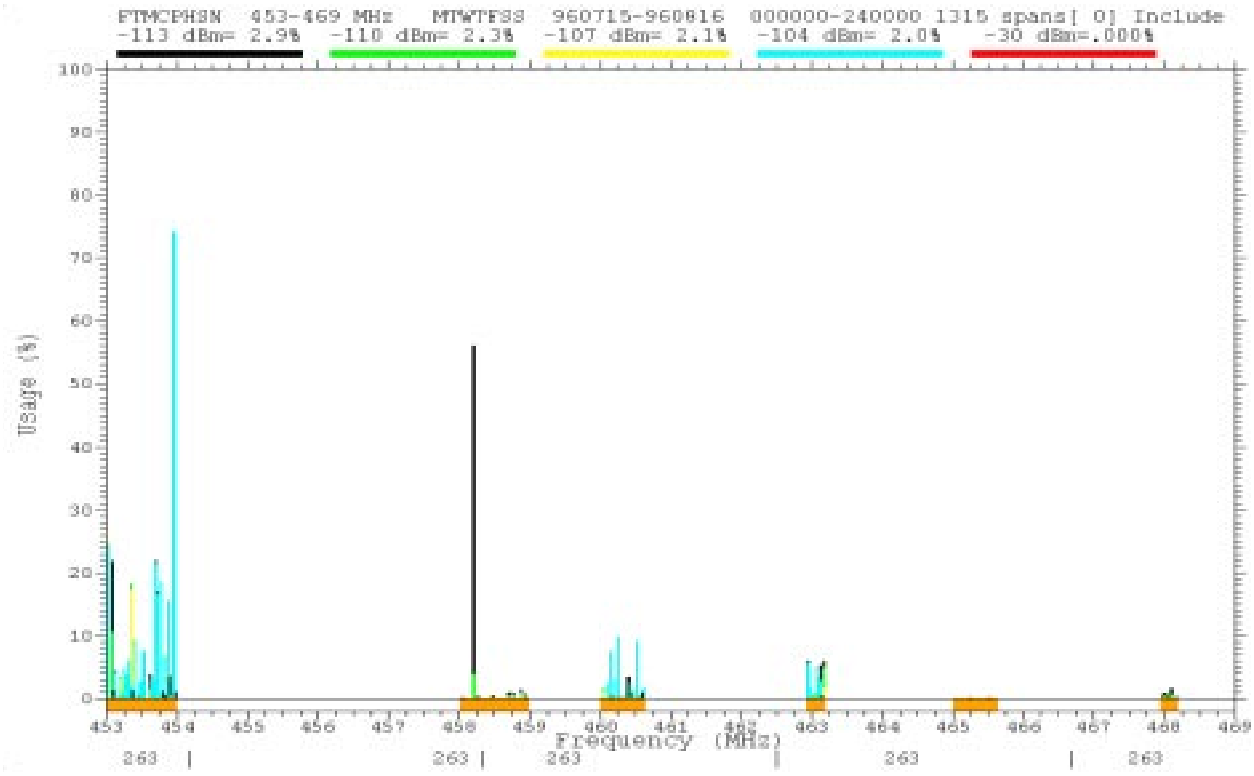

Figure 109. Plot of 453-469 MHz public safety channels measured at the Fort McPherson site.

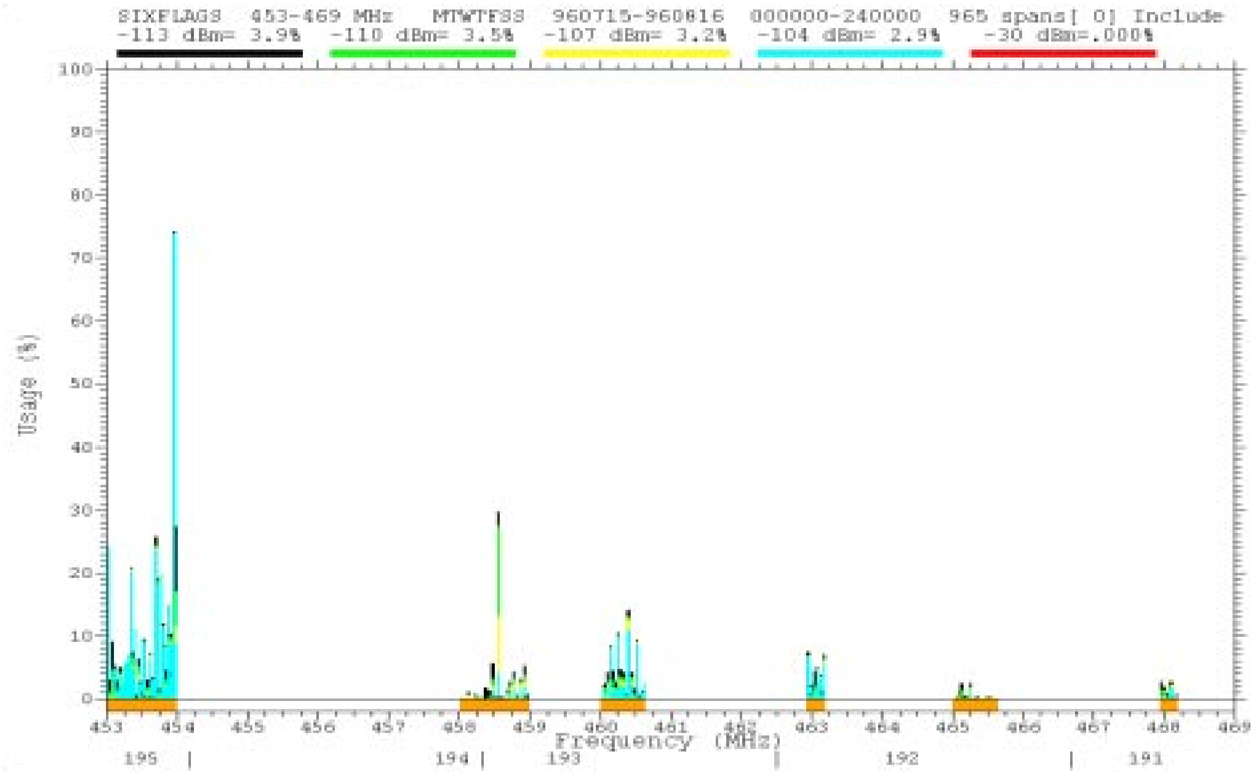

Figure 110. Plot of 453-469 MHz public safety channels measured at the Six Flags site.

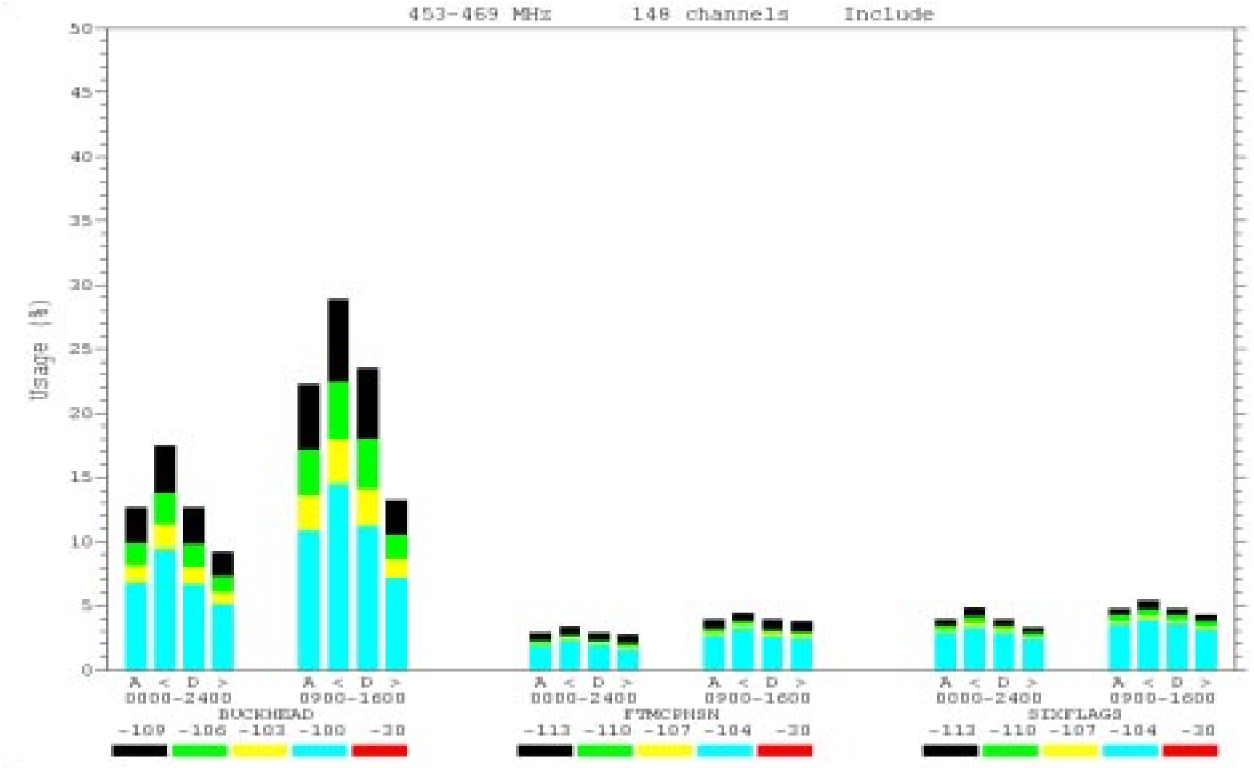

Figure 111. Summary plot of the 453-469 MHz public safety channel measurements.

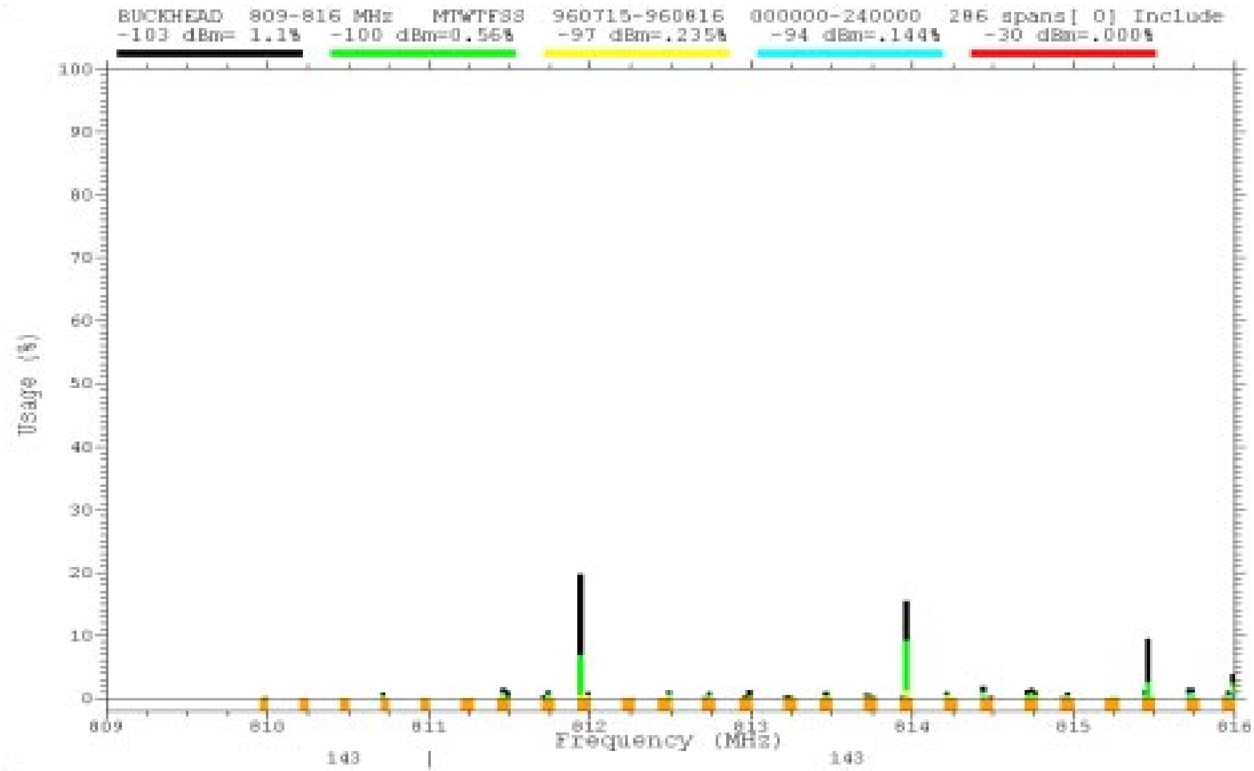

Figure 112. Plot of 809-816 MHz public safety channels measured at the Buckhead site.

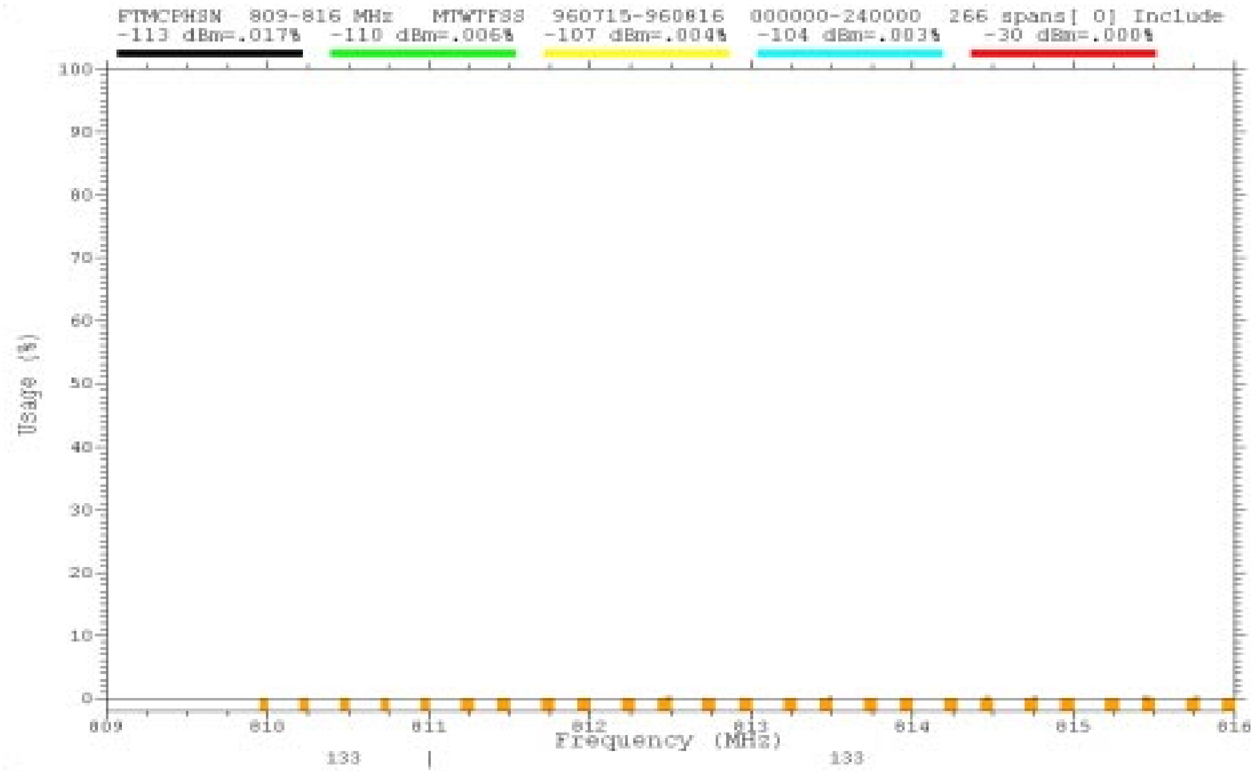

Figure 113. Plot of 809-816 MHz public safety channels measured at the Fort McPherson site.

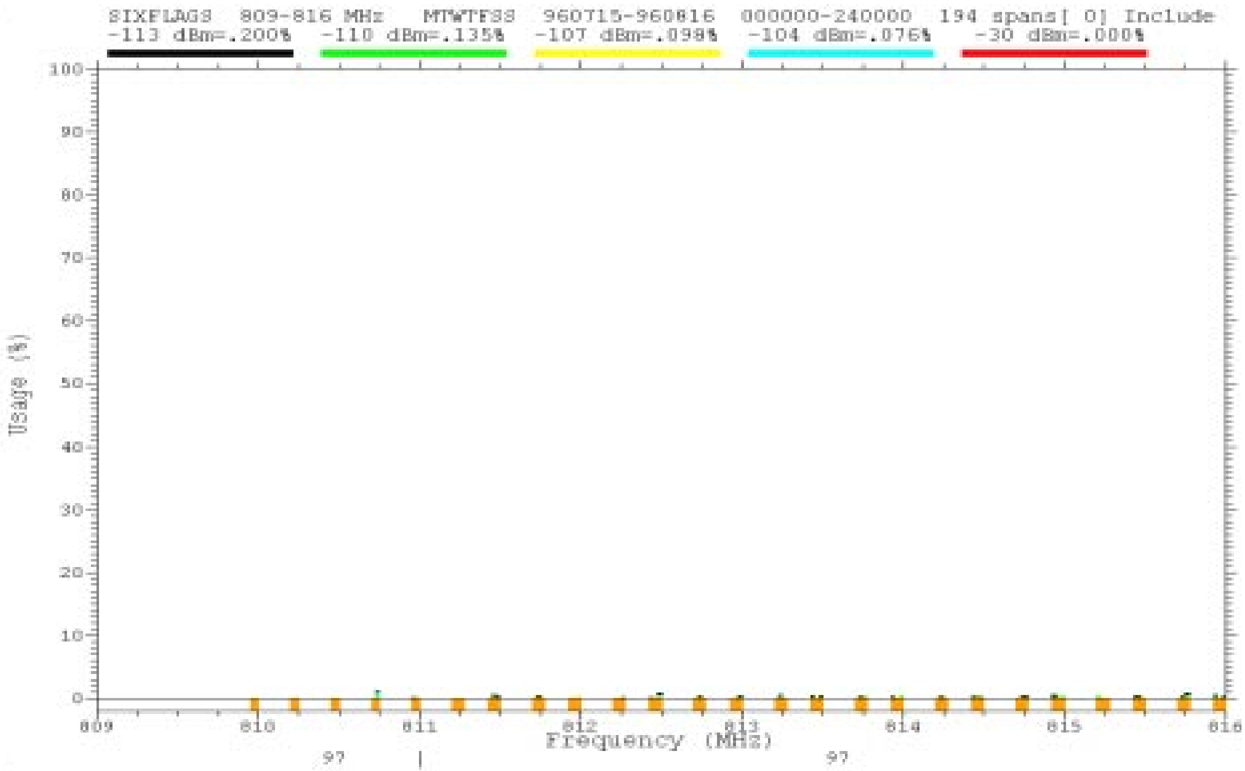

Figure 114. Plot of 809-816 MHz public safety channels measured at the Six Flags site.

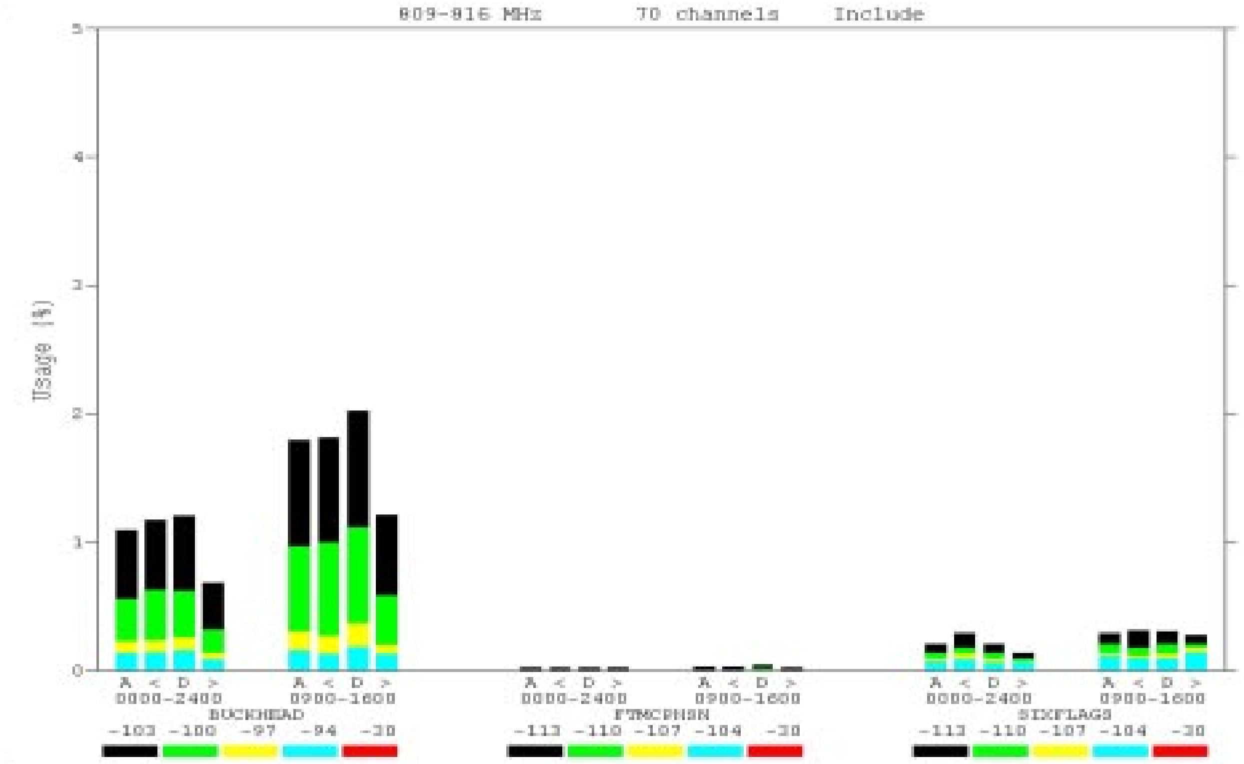

Figure 115. Summary plot of the 809-816 MHz public safety channel measurements.

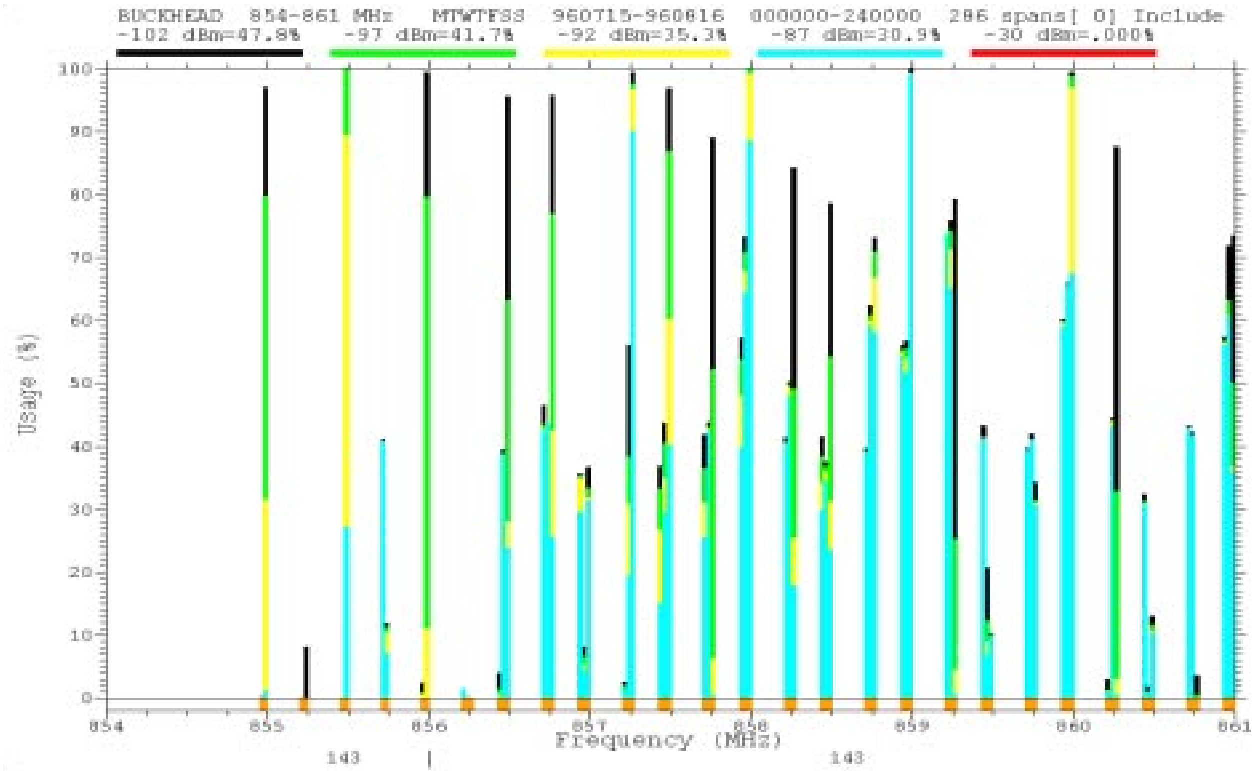

Figure 116. Plot of 854-861 MHz public safety channels measured at the Buckhead site.

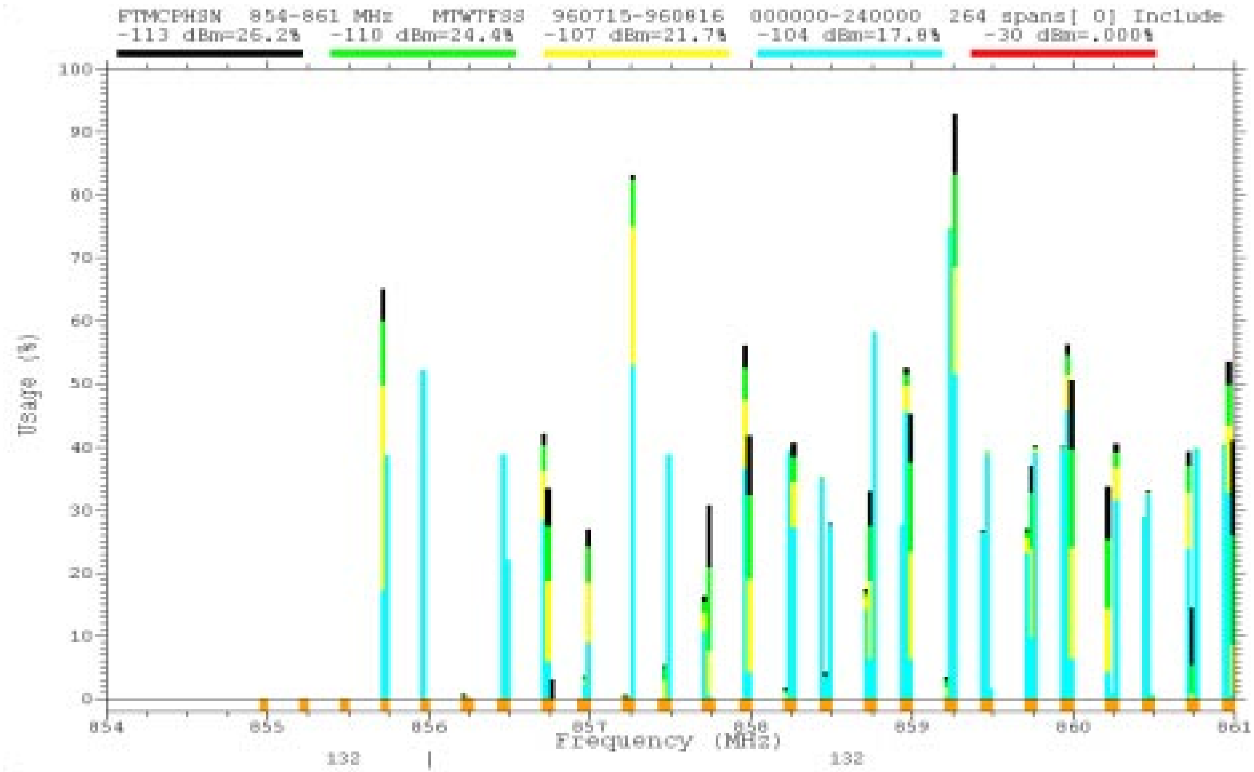

Figure 117. Plot of 854-861 MHz public safety channels measured at the Fort McPherson site.

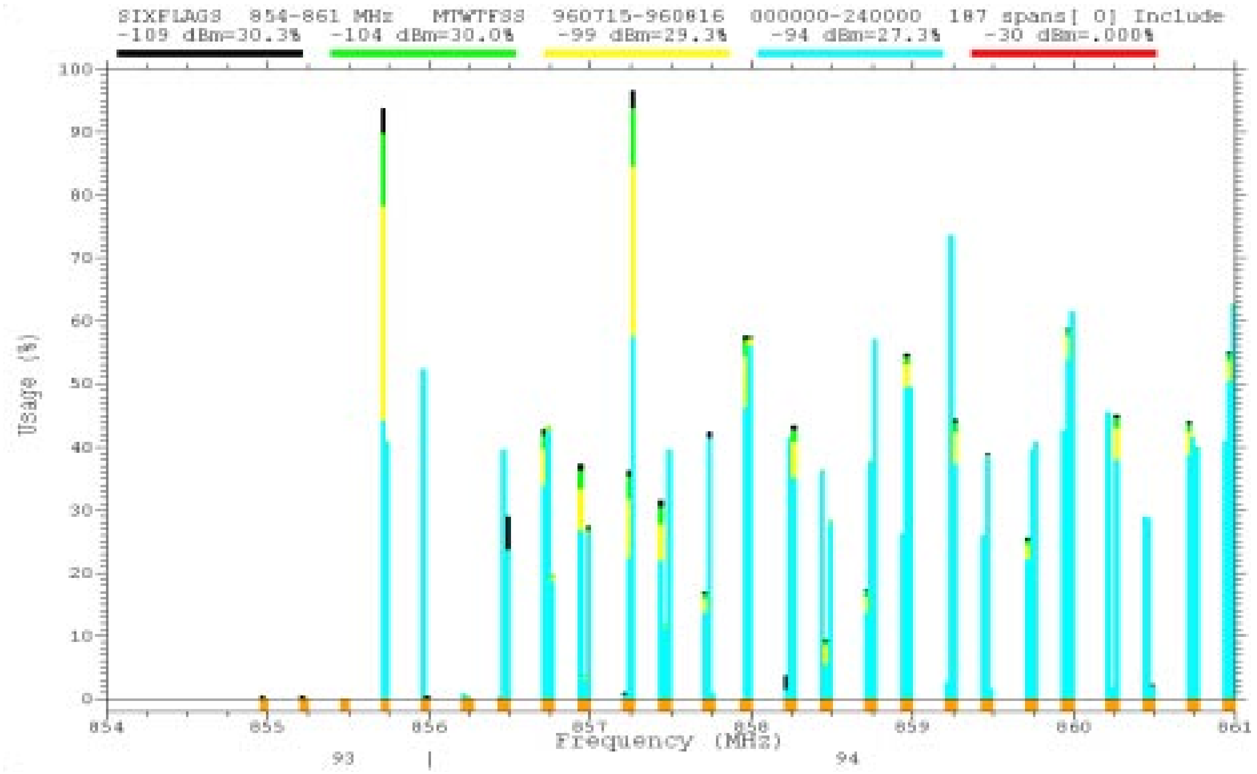

Figure 118. Plot of 854-861 MHz public safety channels measured at the Six Flags site.

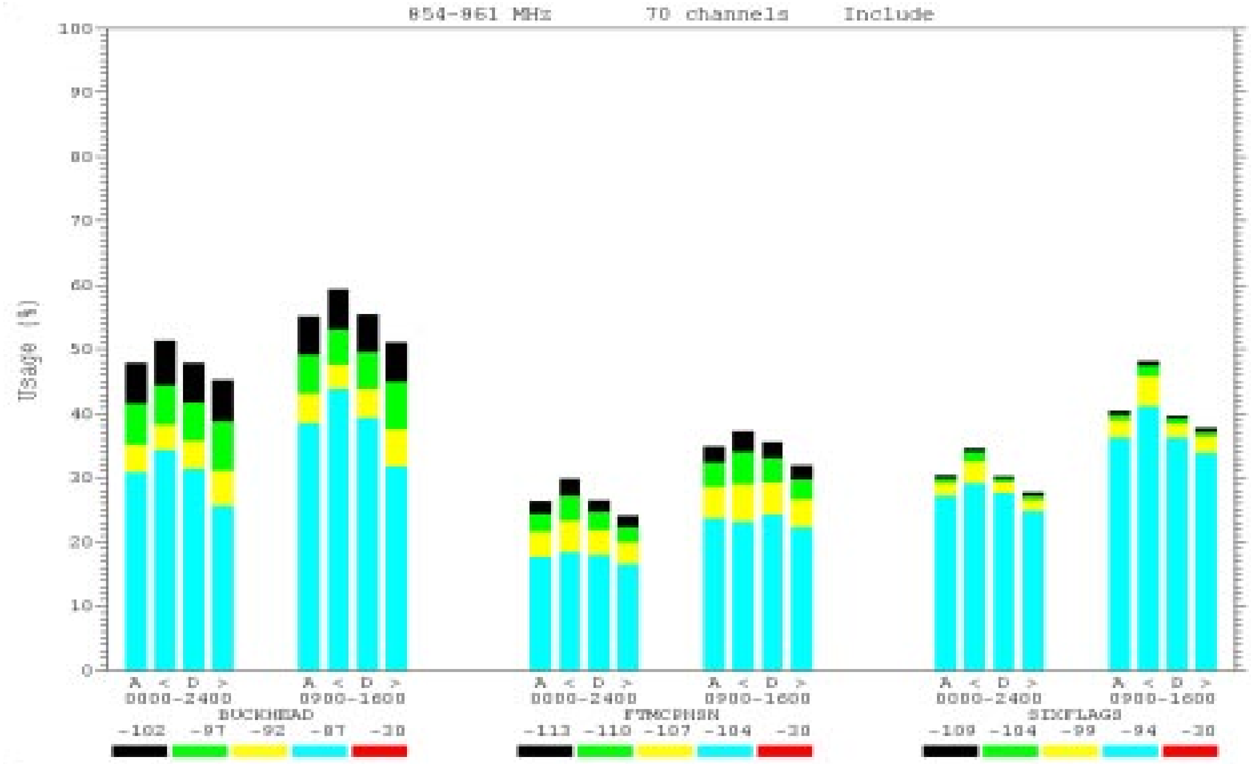

Figure 119. Summary plot of the 854-861 MHz public safety channel measurements.

3.9 Band-by-Band Evaluation of LMR Usage Before, During, And After the 1996 Summer Olympic Games

It is important to understand what aspects of spectrum use can be extrapolated from the measured usage 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 three locations in the Atlanta metropolitan area during the 1-month period of July 16-August 16, 1996, with a one-week break between August 6-12, 1996. In the measured LMR bands, the data presented in this report show the percentage of time that channels were occupied during the measurement periods at each measurement location. In these bands, the cumulative measurement time during the survey was typically several hours, spread uniformly over the diurnal cycle.

Based on the measurement and sampling techniques used, these data represent a valid statistical sampling of the activity in the LMR bands in the Atlanta metropolitan area, for purposes of comparing relative band activity levels before, during, and after the 1996 Summer Olympic Games (often referred to hereafter as: the 1996 Games or the Games). The measured data show the percentage of measurement time that channel usage exceeded measurement thresholds at each of the three measurement locations. Statistical analysis of these data do not show absolute usage levels in the LMR bands for the entire metropolitan area; however, they do show the relative impact of the channel usage during the 1996 Games, as compared to usage before and after the Games. The purpose of these data is to indicate the relative impact on channel usage of a major spectrum loading event, rather than absolute levels.

Table 4 contains a band-by-band evaluation of relative levels of LMR usage in the Atlanta area before, during, and after the 1996 Games. Observations and comments are based on examination and evaluation of usage data collected during the spectrum survey; diurnal variation and day-to-day variation in usage statistics are also considered. Where applicable, the comments also include information on unique systems or capabilities that were brought to Atlanta by the Federal Government for use during the Games. For bands containing a mixture of public safety channel assignments and other assignments (as noted in Table 3 and Figures 104-119), the comments are broken down into two parts: observations on overall channel usage and on public safety channel usage.

Early on Saturday morning, July 27, 1996, at about 0120 local time a pipe bomb exploded in Centennial Olympic Park, downtown Atlanta, Georgia, instigating a major law-enforcement and emergency-services response. If the olympics are to be considered a major spectrum-usage loading event, then the Centennial Olympic Park bombing represented a crisis within the larger, spectrum loading background stress. Thus, it would be expected that some LMR bands might show a measurable impact on usage levels just after the bombing event. The analyzed data do, in fact, show some impact from the bomb event in some bands.

According to published accounts, the Centennial Park bombing occurred at approximately 0120 local time, and was preceded by a telephoned threat to the authorities on the same date at approximately 0100 local time. Thus, the impact of the bombing on spectrum usage should have become visible in the data soon after 0100 local time on that date. In Table 4, each LMR band is also examined in terms of its measured usage response, if any, to the Centennial Park bombing event on July 27, 1996.

Table 4. Comments on Atlanta Spectrum Usage Measurement Results

LMR Band (MHz)	Figures	Comments
138-144	All channels: 11, 12, 41, 42, 65, 66, and 89. Public Safety channels: None.	**Federal Government systems brought to Atlanta for the 1996 Games:** Although channels for Public Safety (see Table 3) are not allocated in this band, availability of this band for use by Federal emergency response organizations is critical. In this band during the Games, the Army, acting for the whole of the Department of Defense, set up numerous LMR stations in the Atlanta area, including repeaters and cross-links. Hundreds of frequencies were used by these systems. Secure communications were made available in this band for all state and Federal command posts, including the Georgia Emergency Operations Center (EOC), the Federal Bureau of Investigation (FBI), the Federal Emergency Management Agency (FEMA), and the Department of Health and Human Services (HHS). HHS used the frequencies to ensure the availability of hundreds of physicians who were on standby for fast response to catastrophic emergencies. FEMA maintained 5 repeater channels and 5 simplex channels for command and control of the Federal Response Plan (FRP). Although events at the Games never required FRP implementation, the channels in this band were used between various agencies at the Federal command posts in the Atlanta area. Systems in this band were also used to coordinate Air Force acrobatic team flyovers at olympic events. **Usage trends observed before, during, and after the 1996 Games:** At all three measurement sites, the band usage after the Games was substantially lower (by a factor of three or more) than the levels before and during the Games. This implies, in turn, that there was a usage impact in this LMR band. Twenty-four-hour usage statistics were only slightly lower than 0900-1600 usage statistics at the three sites, implying that the usage levels were roughly the same during normal business hours (8:00 am - 5:00 pm) and all other hours of the day. This may be because much of the usage is connected with public safety activities that operate in shifts, around the clock. Diurnal variation did occur, but the drop in activity at night and during weekend periods still left off-peak usage levels (as at midnight) at 75-80% of the peak levels measured (as at midday) on weekdays. Usage levels measured at the Buckhead site were about three times higher before and during the Games than they were after the Games. At Fort McPherson, usage levels after the Games dropped by almost half, and at the Six Flags site, usage was highest before the Games, dropping by a factor of one third to one half during the Games, then dropping by another factor of two after the Games had ended. Thus, although the patterns were not identical at the three measurement sites, the measured data show a substantial increase in the usage levels in this band at locations across the metropolitan area. *Continued on next page.*

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	Figures	Comments
138-144 (Continued)	All channels: 11, 12, 41, 42, 65, 66, and 89. Public Safety channels: None.	At least half the channels in this band did not show usage above the lowest processing threshold at any time at any of the three measurement locations. This does not mean that the unused channels at the measurement locations were not used anywhere in the metropolitan area during the measurement period; indeed, channels that are unoccupied at one location often show usage at another measurement location, implying a high probability that all channels in this band were used at one location or another, somewhere in the Atlanta area, during the measurement period. But, it also means that, at any given location, many channels were available for an entire 2-week period, and that if communication system architectures could take advantage of such channels between multiple points in the area (identifying channels that were simultaneously available at both ends of the desired communication path), then additional communications could theoretically be handled, even during high-use, emergency-event periods such as the 1996 Games. Although the Games clearly had an impact on the usage levels in this band, the data do not show a sizable impact due to the Centennial Park bombing. This is probably because the bombing, although newsworthy, was not an emergency that warranted the activation of the FRP or other major responses that systems in this band were intended to support. The Buckhead and Fort McPherson sites show slight increases in activity at about 0130, and the Six Flags site shows a slight increase somewhat later in the morning. But the increase in usage levels is not as large as observed in some other bands, such as the 162-174 MHz band at Buckhead and Six Flags (see 162-174 MHz LMR band comments). Again, this is probably because the park bombing did not require implementation of the major response that the systems in the 138-144 MHz band were intended to facilitate.
148-153	All channels: 13, 14, 43, 44, 67, 68, and 90. Public Safety channels: None.	**Federal Government systems brought to Atlanta for the 1996 Games:** Few, if any, Federal systems were deployed in this band to support the communications requirements at the Games. Thus, this band served as a control for the other bands; i.e., activity in this band was not expected to show a large variance attributable to the 1996 Summer Olympic Games. **Usage trends observed before, during, and after the 1996 Games:** At all three measurement sites, the band usage was not significantly affected by the Games. At two sites, almost no change occurred, and at the Buckhead site, only a 25% drop occurred after the Games ended. Twenty-four-hour usage statistics were almost identical to the 0900-1600 usage statistics at the three sites, implying that the usage levels were roughly the same during business and non-business hours. Diurnal variation did occur at the Buckhead site, but very little diurnal variation occurred at the other two sites. However, note the comments on measurements in this band at the Six Flags and Fort McPherson sites. *Continued on next page.*

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	**Figures**	**Comments**
148-153 (Continued)	All channels: 13, 14, 43, 44, 67, 68, and 90. Public Safety channels: None.	Usage levels measured at the Buckhead site were only about 25% higher before and during the Olympics than they were after the Olympics. At the Fort McPherson site, usage levels after the Olympics dropped very slightly, and at the Six Flags site, usage after the Games dropped by only 20%. Although the patterns were not identical at the three measurement sites, the Olympics clearly caused very little impact on usage in this band. About 25% of the channels in this band did not show usage above the lowest processing threshold at any time at the Buckhead measurement site. Also, three wideband channels (about 100 kHz bandwidth) caused disproportionate weighting of the statistics; usage on other channels was lower than the overall statistics imply. At the Fort McPherson site, a broadband, low-level noise source generated approximately 2% usage on all channels across the band, but usage by communication signals appeared on only about 10 channels during the entire measurement period. At the Six Flags site, usage occurred on about half the channels in the band, but the statistics were dominated by only six channels; the rest of the channels that showed any usage at all were mostly below 5% usage. This does not mean that the unused channels at the measurement locations were not used anywhere in the metropolitan area; indeed, channels that are unoccupied at one location sometimes show usage at another measurement location, implying a probability that many channels in this band were used at one location or another, somewhere in the Atlanta area, during the measurement period. But, it also means that, at any given location, most channels were available for an entire 2-week period, and if communication system architectures could take advantage of such channels between multiple points in the area (by identifying channels that are simultaneously available at both ends of a desired communication path), then additional communications could theoretically be handled, even during emergencies or high-demand events such as the Olympic Games. In fact, the statistics at the measurement locations were dominated by a relatively small number of high-usage channels, implying that considerably more communications throughput might be possible with such architectures. These data do not show a noticeable impact due to the Centennial Park bombing. This is consistent with the minimal overall observed impact due to the 1996 Games, and also is consistent with the fact that few, if any Federal systems were deployed in this band to support communication requirements for the Games. The three sites show impacts that range from zero to possibly even slight decreases in activity at about 0130. This contrasts with increased usage levels observed in some other bands, such as 162-174 MHz at the Buckhead and Six Flags sites (see 162-174 MHz comments).

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	Figures	Comments
150-162	All channels: 15, 16, 17, 18, 45, 46, 69, 70, 91, and 92. Public Safety channels: 104, 105, 106, and 107.	**Federal Government systems brought to Atlanta for the 1996 Games:** Available assignment lists do not show any dedicated Federal LMR systems brought to Atlanta for the Games. However, there are dedicated public safety channels that were utilized during the Games, and those channels were analyzed separately from the all-channel usage statistics. See Section 3.8 and particularly Table 3 for a description of the public safety channel allocations in this band. **Usage trends observed before, during, and after the 1996 Games:** In this band, an overload signal occurred at the Buckhead site (see red threshold-exceeded marks in Figures 17 and 18). The presence of this signal may have caused apparent usage on channels where none actually occurred. Thus, the Buckhead site data were analyzed twice, once with the overload signal included (called INCLUDE data; see Figures 15, 16, and 91), and again with scans containing overload data excluded (called EXCLUDE data; see Figures 17, 18, and 92). The INCLUDE data show usage levels that are as high or higher than actual levels; the EXCLUDE data show usage levels that represent the lowest usage statistics, possibly even lower than the levels really were. Actual all-channel usage levels may fall between these two analyzed data sets. At two measurement sites, Fort McPherson and Six Flags, all-channel usage was unaffected by the Games. At the Buckhead site, overall usage either was unaffected (INCLUDE data) or possibly even increased slightly (EXCLUDE data, which should be considered more reliable) after the Olympics. In short, the Games appear to have had a negligible effect on overall usage in this band. **Usage trends observed in public safety channels before, during, and after the 1996 Games:** Figures 104 through 107 present the results of analysis of the public safety channels in this band, as described in Section 3.8. Comparison of Figures 104 through 106 with the corresponding all-channel usage Figures 16, 46, and 70 indicates that a large percentage of the communications occurring in this band were in fact for public safety assignments. However, Figure 107 indicates that, just as all-channel usage in this band was not much affected by the Games, neither was the public safety channel usage significantly affected by the Games. Statistical data before, during, and after the Games were nearly identical. **Observations applicable to both public safety and all-channel usage:** Most channels in this band show some usage (usually 10% or less) above the lowest processing threshold at least once during the measurement period at each of the measurement locations. However, the all-channel usage statistics appear to be dominated at each measurement location by a small number of very high-usage channels. In other words, most channels in this band were used less than the overall band statistics would imply. Analyzed data do not show a measurable impact due to the Centennial Park bombing incident. In fact, all three sites show a steady decrease in usage levels from midnight to midday on July 27, 1996.

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	Figures	Comments
162-174	All channels: 19, 20, 21, 22, 47, 48, 71, 72, 93, and 94. Public Safety channels: None.	**Federal Government systems brought to Atlanta for the 1996 Games:** Although channels for Public Safety (see Table 3) are not allocated in this band, availability of this band for use by Federal law enforcement and emergency response organizations is critical. This band is, in fact, heavily used by Federal law enforcement organizations, and in Atlanta some new assignments were made in this band for such organizations. For the duration of the 1996 Games, assignments were maintained for "special case" purposes involving law enforcement at the tactical level. The Department of Health and Human Services (HHS) also brought some portable communications into the Atlanta area for use during the Games. **Usage trends observed before, during, and after the 1996 Games:** An overload signal occurred at the Buckhead site (note red threshold-exceeded marks in Figures 19 and 20). This signal's presence may have caused apparent usage on channels where none actually occurred. Thus, Buckhead site data were analyzed twice, once with the overload signal included (called INCLUDE data; see Figures 19, 20, and 93), and again with scans containing overload data excluded (called EXCLUDE data; see Figures 21, 22, and 94). INCLUDE data show usage levels that are as high or higher than actual levels; EXCLUDE data show usage levels that are the lowest possible. Actual usage levels may fall between these two analyzed data sets. Patterns of overall usage in this band were complex. At the Buckhead site, the INCLUDE data imply that peak usage levels were unaffected, while the EXCLUDE data (which should be considered more reliable) show some decrease in usage after the Games. At the Fort McPherson site, usage levels increased somewhat after the Games (implying that some activities in this band near this location may have been suspended during the Games), while a slight decrease in usage occurred at the Six Flags site. It is also significant that, while overall usage levels in this band were not significantly changed during the Games, dips in diurnal cycles became markedly lower after the Games. This implies that usage remained high during nighttime periods that under other circumstances would probably have been lower; i.e., usage was sustained at higher overall levels during 24-hr periods when the Games were in progress. Although overall band statistics were not heavily affected by the Games, the highest usage levels measured at the Buckhead and Six Flags sites did occur just prior to and during the Games, and some overall decrease in the usage statistics did occur in the Buckhead EXCLUDE data after the Games had ended. At the Fort McPherson site, the highest usage occurred after the Games. But, at Fort McPherson, diurnal variations were more pronounced after the Games than before and during the Games. As noted above, this implies a higher sustained level of activity during the Olympics in each 24-hr period, even though peak usage levels were not affected very much. *Continued on next page.*

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	**Figures**	**Comments**
162-174 (Continued)	All channels: 19, 20, 21, 22, 47, 48, 71, 72, 93, and 94. Public Safety channels: None.	About two-thirds of the channels in the EXCLUDE data set from the Buckhead site show usage above the lowest processing threshold at sometime during the measurement period. At the Fort McPherson and Six Flags sites, fewer than half the channels showed any activity above the lowest processing threshold at any time during the measurement period. (Data from Fort McPherson shows a broadband noise signature across the band, which should not be confused with the actual signal usage that was measured above the noise.) However, most of the occupied channels show 10% usage or less. Thus, the overall channel usage statistics tend to be dominated at each measurement location by a small number of very high-usage channels. This does not mean that the unused channels at the measurement locations were not used anywhere in the area during the measurement period; indeed, channels that are unoccupied at one location sometimes show usage at another location, implying that many channels in this band were used at one location or another, somewhere in the area, during the measurement period. But, it also means that, at any given location, most channels were available for an entire 2-week period, and communication system architectures that could take advantage of such channels (by identifying channels that are simultaneously available at both ends of a desired communication path), could theoretically be handled, even during emergencies or spectrum demanding periods such as olympic games. Data from all three measurement sites show large increases in usage after midnight on July 27, 1996, indicating a noticeable impact due to the Centennial Park bombing. This implies that much of the LMR response activity occurred in this band, and indicates that this band needs the capacity to handle large increases in emergency communications.
406-420	All channels: 23, 24, 49, 50, 73, 74, and 95. Public Safety channels: None.	**Federal Government systems brought to Atlanta for the 1996 Games:** Although channels for Public Safety (see Table 3) are not allocated in this band, availability of this band for use by Federal law enforcement and emergency response organizations is critical. Furthermore, nearly every Federal Government assignment listed in the Government Master File (GMF) for the Atlanta area, is part of a trunked system, and this band is considered optimal for such systems due to good propagation characteristics for communication. This band is, in fact, heavily used by Federal law enforcement organizations, and for the 1996 Games in Atlanta, some new assignments were provided for such organizations. For example, communication systems were available that would allow law enforcement authorities to maintain negotiations with terrorists who might have seized hostages. This band was also used during the Olympics for security operations at facilities utilized by law-enforcement authorities, e.g., an assignment was found in the GMF for a new 5-channel trunked system that was procured by GSA and used by other agencies during the Games. *Continued on next page.*

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	Figures	Comments
406-420 (Continued)	All channels: 23, 24, 49, 50, 73, 74, and 95. Public Safety channels: None.	**Trends observed in usage before, during, and after the 1996 Games:** At all three measurement sites, the band usage did not appear to be significantly affected by the Games. At two sites, Fort McPherson and Six Flags, almost no change occurred, and at the Buckhead site, only a peak on July 19, the opening day of the 1996 Summer Olympics, indicated any effect on this band by the Games. Twenty-four-hour usage statistics were essentially identical to the 0900-1600 usage statistics at the three sites, implying that the usage levels were roughly the same during 8:00 am - 5:00 pm business hours and all other periods. Diurnal variation did not seem to occur at the Fort McPherson site, and only slight diurnal variation occurred at the other two sites. Usage levels measured at the Buckhead site were only slightly higher on the day of the Opening Ceremonies than they were during and after the Games. At Fort McPherson, usage levels were unaffected; and at the Six Flags site, usage levels showed somewhat more variation from day to day, but overall statistics were not distinguishable between the periods of before, during, and after the Games. Although the patterns were not identical at the three measurement sites, the 1996 Games caused very little impact on usage in this band. More than half of the channels in this band did not show usage above the lowest processing threshold at any time at the Buckhead site. Also at the Buckhead site, a small number of high-usage channels caused disproportionate weighting of the statistics; usage on other channels was lower than the overall statistics imply. At Fort McPherson, usage by communication signals appeared on only about 10-15 channels during the entire measurement period. At the Six Flags site, usage occurred on many of the channels in the band. This does not mean that the unused channels at the measurement locations were not used anywhere in the metropolitan area during the measurement period; indeed, channels that are unoccupied at one location sometimes show usage at another measurement location, implying that there is a probability that many channels in this band were used at one location or another, somewhere in the Atlanta area. But, it also means that, at any given location, most channels were available for an entire 2-week period. The trunked systems that were in extensive use in Atlanta in this band were presumably better adapted to dynamically assign users to such available channels than could conventional LMR systems. Thus, substantial levels of additional communications could theoretically be handled, even during emergencies and high-use periods such as olympic games. The data do not show a noticeable impact due to the Centennial Park bombing. This is consistent with the fact that Federal emergency-response communication systems were already in place that would have been used in conjunction with such an incident.

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	Figures	Comments
450-470	All channels: 25, 26, 27, 28, 51, 52, 75, 76, 96, and 97. Public Safety channels: 108, 109, 110, and 111.	**Federal Government systems brought to Atlanta for the 1996 Games:** Available assignment lists do not show any dedicated Federal LMR systems that were brought to Atlanta specifically for the 1996 Summer Olympics. However, there are dedicated public safety channels that were utilized during the Games, and those channels were analyzed separately from the all-channel usage statistics. See Section 3.8 and particularly Table 3 for a description of the public safety channel allocations in this band. **Usage trends observed before, during, and after the 1996 Games:** In this band, an overload signal occurred at the Buckhead site (see red threshold-exceeded marks in Figures 25 and 26). The presence of this signal could have caused apparent usage on channels where none actually occurred. Thus, Buckhead site data were analyzed twice, once with the overload signal included (called INCLUDE data, see Figures 25, 26, and 96); and again, with scans containing overload data excluded (called EXCLUDE data, see Figures 27, 28, and 97). The INCLUDE data show usage levels that are as high or higher than actual levels; the EXCLUDE data show usage levels representing the lowest usage statistics, possibly even lower than the levels really were. Actual all-channel usage levels probably fall between these two analyzed data sets. At two measurement sites, Fort McPherson and Six Flags, all-channel usage was only slightly affected by the Olympics. At the Buckhead site, usage was affected significantly more than at the other two sites, as indicated in both the INCLUDE and the EXCLUDE data. Based on the Buckhead site results, the Games appear to have had a measurable effect on usage in at least some parts of the area. Most channels in this band showed usage above the lowest processing threshold at each measurement site at least once during the measurements. However, most of the channels show 15% usage or less, and the all-channel usage statistics tend to show domination at each measurement location by a small number (usually ten or fewer) of high-usage channels. In other words, most channels in this band were used less than the band analysis would imply. **Usage trends observed in public safety channels before, during, and after the 1996 Games:** Figures 108 through 111 show analysis results for the public safety channels in this band, as described in Section 3.8. Comparison of Figures 108 through 110 with the corresponding all-channel usage Figures 26, 28, 52, and 76 indicates that a large percentage of the communications occurring in this band were, in fact, public safety channels. Moreover, comparison of Figures 96, 97, and 111 indicates that overall usage in this band, including public safety usage, was significantly affected by the Games, especially as measured at the Buckhead site. Statistics for before, during, and after the Games at that location show that public safety channel usage was twice as high immediately prior to the Games than after the Games (30% before vs. 15% after), and the public safety channel usage levels during the Games also were substantially higher than after the Games (25% during vs. 15% after). *Continued on next page.*

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	Figures	Comments
450-470 (Continued)	All channels: 25, 26, 27, 28, 51, 52, 75, 76, 96, and 97. Public Safety channels: 108, 109, 110, and 111.	**Observations applicable to both public safety and all-channel usage:** Most channels in this band showed usage above the lowest processing threshold at all of the three measurement locations at least once during the measurement period. Most of the public safety channels show relatively high usage, with levels ranging between 5% and 80% usage. Thus, overall usage levels were substantially affected by the Games, and public safety channel usage, which contributed heavily to overall usage, was also significantly affected by the Games. Although the 1996 Games clearly had an impact on the overall usage levels in this band, the data do not show any measurable impact on usage due specifically to the Centennial Park bombing, as inferred by examination of data taken during the day of the bombing. In fact, all three sites show July 27, 1996 as one of the lowest-usage days of the measurement period. This observation is consistent with the determination that public safety communications in this band were not specifically tailored for response to this sort of event.
806-821 paired with: 851-866.	All channels: 29, 30, 53, 54, 77, 78, and 98. Public Safety channels: 112, 113, 114, and 115.	The 809-816 MHz portion of the 806-821 MHz LMR band (mobile stations) is allocated for public safety channels and is paired with the 854-861 MHz portion of the 851-866 MHz LMR band (base stations). **Federal Government systems brought to Atlanta for the 1996 Games:** Available assignment lists do not show any dedicated Federal LMR systems that were brought to Atlanta to operate in this band during the Olympics. Federal use of this band is conducted through sharing agreements with local law enforcement agencies on a state-by-state basis. In Georgia, specifically Atlanta, the only GMF entries for Federal sharing that existed during 1996 were U.S. Postal Service assignments. However, assignment lists show dedicated public safety channels that could have been utilized by law enforcement agencies during the Games, and those channels were analyzed separately from the all-channel usage statistics. See Section 3.8 and particularly Table 3 for a description of the public safety channel allocations in this band. **Usage trends observed before, during, and after the 1996 Games:** Mobile-band usage dropped about 25% after the Games ended, although fixed-band usage statistics were hardly affected (possibly due to the presence of control channels in the fixed-station spectrum). Mobile-usage measurements at the Buckhead site show that most channels exceeded the lowest threshold at least once during the measurement period, and that ten channels reached usage levels of 20-30 percent during the same period. *Continued on next page.*

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	**Figures**	**Comments**
806-821 (Continued) paired with: 851-866.	All channels: 29, 30, 53, 54, 77, 78, and 98. Public Safety channels: 112, 113, 114, and 115.	**Usage trends observed in public safety channels before, during, and after the 1996 Games:** Figures 112 through 115 show analysis results for the public safety channels in this band, as described in Section 3.8. Comparison of Figures 112 through 115 with the corresponding all-channel usage Figures 29 and 30 for mobile spectrum at the Buckhead site (the only location where the mobile spectrum shows measurable usage) indicates that about 20 channels in this spectrum may have been used for public safety, although only three of those channels were clearly distinguishable above the measurement system noise floor. Base-station statistics are substantially higher, and show between 21 and 24 channels in use in the public safety spectrum. It is not known to what extent these statistics were affected by control-channel operations. The mobile-spectrum statistics show an approximate 30% drop in usage after the Games, comparable to the 25% drop that occurred in the overall mobile band after the Games. Base-station public safety spectrum statistics were not substantially affected by the Games, indicating that control-channel operations may tend to mask actual usage statistics for base stations. Overall, the Games appear to have increased usage of mobile public safety channels in this band by about 30%, an impact comparable to the overall band impact. **Observations applicable to both public safety and all-channel usage:** Mobile channel spectrum statistics dropped by 25% to 30% in both the overall and public safety portions of this band. Base-station channel spectrum statistics were only slightly affected for both cases, possibly the result of control-channel activity that would mask changes in actual usage. The data for this band show no measurable impact as a result of the Centennial Park bombing.
821-824 paired with: 866-869.	All channels: 31, 32, 55, 56, 79, 80, and 99. Public Safety channels: None.	This band is used for mobile-station transceivers, and the paired band (866-869 MHz) is used by base-stations. **Federal Government systems brought to Atlanta for the 1996 Games:** No public safety channels are allocated in this band (see Section 3.8). Available channel assignment lists do not indicate that any dedicated Federal LMR systems were brought to Atlanta to operate in this band during the 1996 Summer Games. **Usage Trends observed before, during, and after the 1996 Games:** At all three measurement sites, base-station transmissions were present at consistently higher percentages than the mobile signals (as shown by comparing the 821-824 MHz band measurement data with the corresponding 866-869 MHz band data), but the patterns of usage were the same for the base and mobile stations (compare Figures 99 and 101). *Continued on next page.*

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	Figures	Comments
821-824 (Continued) paired with: 866-869	All channels: 31, 32, 55, 56, 79, 80, and 99. Public Safety channels: None.	At all three sites, measured usage levels before and during the Games were about twice as high as the levels after the Games. A 50% drop after the Games ended was observed in both the 24-hour usage statistics and the 0900-1600 usage statistics. Diurnal variation is very distinct in this band, especially at the Buckhead site, indicating a preponderance of activity during daytime periods in this band. Although base-station channels typically show high usage, about half the mobile channels did not show usage above the lowest processing threshold at any time at any of the measurement locations. This does not mean that the unused channels at these locations were not used anywhere in the metropolitan area during the measurement period; indeed, channels that were unoccupied at any given location were probably used at other locations. But it also means that, at any given location, many channels in the band could have been available for an entire two-week period. And, of the mobile channels that showed usage, most were measured at levels of 3% to 5%. Corresponding base-station channels typically show usage levels of 20% to 50%, although half of the base-station channels did not show any usage during the measurement period. The offset between mobile channel and base-station channel statistics probably represents the higher probability of intercept for base stations as compared to mobile stations. The overall results are interesting, because they indicate that while usage in this band was doubled for the Games, this trunked-system spectrum was still not saturated during the Games. This may be a result of the relative efficiency of trunked-channel system architecture, which dynamically allocates channels to users on an as-needed basis. No measurable change occurred in the usage statistics for this band as a result of the Centennial Park bombing.
851-866 paired with: 806-821.	All channels: 33, 34, 57, 58, 81, 82, and 100. Public Safety channels: 116, 117, 118, and 119.	See remarks for paired band 806-821 MHz. No measurable change occurred in the usage statistics for this band as a result of the Centennial Park bombing.

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	Figures	Comments
866-869 paired with: 821-824.	All channels: 35, 36, 59, 60, 83, 84, and 101. Public Safety channels: None.	See remarks for paired band 821-824 MHz. No measurable change occurred in the usage statistics for this band as a result of the Centennial Park bombing.
896-901 paired with: 935-940.	All channels: 37, 38, 61, 62, 85, 86, and 102. Public Safety channels: None.	The 896-901 MHz band is used by mobile transmitters and is paired with the 935-940 MHz band used by base stations. **Federal Government systems brought to Atlanta for the 1996 Games:** No public safety channels are allocated in this band (see Section 3.8). Available channel assignment lists do not indicate that any dedicated Federal LMR systems were brought to Atlanta to operate in this band during the 1996 Games. **Usage Trends observed before, during, and after the 1996 Games:** At all three measurement sites, the base station signals were present at consistently higher percentages than the mobile signals, but the patterns of usage were the same for both the base station band and the mobile band. Base-station channel statistics at the three measurement locations dropped somewhat after the Games ended. However, the relative percentage decrease was small, only about 10% to 20%, implying that the Games had only a moderate impact on usage activity in the paired 935-940 MHz band. Usage patterns in mobile channels varied considerably between the three measurement locations. At the Buckhead site, usage levels substantially decreased during the Games, implying that the mobile-channel users in this band were actually staying away from the area, or at least were avoiding the use of the radio during this period. (Note, too, that the Buckhead site mobile-channel users were active on only five wideband channels; this is an instance where a change in usage by a small number of users could have a large effect on overall band statistics.) At the Fort McPherson site, mobile-channel signals were never observed above the lowest processing threshold. At the Six Flags site, mobile-channel signals were measured, but at such low usage levels that the resulting statistics were unusable for discerning usage trends. *Continued on next page.*

Table 4. Comments on Atlanta Spectrum Usage Measurement Results (Continued)

LMR Band (MHz)	**Figures**	**Comments**
896-901 (Continued) paired with: 935-940.	All channels: 37, 38, 61, 62, 85, 86, and 102. Public Safety channels: None.	Given the difficulties in interpreting the mobile-radio usage data for this band, the base-station usage statistics appear to be the best indicator of usage during the measurement period. The implication, derived from the base-station data at all three sites, is that the Games influenced a 10% to 20% increase in usage. This change, while measurable, was small compared to changes in some other bands, such as 138-144 MHz. Most mobile-station channels were unoccupied at each site during the measurement period, and about 20% of the base-station channels show no measurable usage during the measurement period. Given this observation, and considering these bands' trunked architecture, it appears likely that these frequency bands did not approach saturation during the Games, and that considerably more communications traffic could have been accommodated by the systems utilizing these bands. No measurable change occurred in the usage statistics for this band as a result of the Centennial Park bombing.
935-940 paired with: 896-901.	All channels: 39, 40, 63, 64, 87, 88, and 103. Public Safety channels: None.	See comments for the paired band 896-901 MHz. No measurable change occurred in the usage statistics for this band as a result of the Centennial Park bombing.

4. CONCLUSIONS

Although it was widely believed, prior to the 1996 Summer Olympic Games in Atlanta, Georgia, that the event would produce a spectrum loading crisis; the data collected at three measurement sites before, during, and after the 1996 Games indicate that the impact was much less dramatic, although quite measurable. Table 5 summarizes the spectrum loading impact of the 1996 Games on the LMR bands that were measured.

Table 5. Measured Impact of the 1996 Summer Olympic Games on LMR Band Usage

LMR Band (MHz)	**Impact on All channels**	**Impact on Public Safety Channels**	**Impact Due to the Centennial Park Bombing**
138-144	Usage 200-300% higher during the Games than afterward	No Public Safety allocations, but high usage by Federal emergency response activities; see comments in Section 3.9 and Table 4.	No
148-153	Usage 25% higher during the Games than afterward	Small impact	No
150-162	No measurable impact	Small impact	No
162-174	Small impact	Small impact	Yes
406-420	No measurable impact	No measurable impact	No
450-470	Usage twice as high just prior to the Games, compared to the period after the Games	Usage twice as high immediately prior to the Games, compared to the period after the Games	No
806-821 paired with: 851-866	Usage 25% higher during the Games than afterward	Usage 25%-30% higher during the Games than afterward	No
821-824 paired with: 866-869	Usage 50% higher during the Games than afterward	Usage 50% higher during the Games than afterward; entire band is allocated for Public Safety	No
896-901 paired with: 935-940	50% drop in mobile usage during the Games, base station activity dropped slightly after the Games	No Public Safety allocations	No

As shown in Table 5, some bands, such as 138-144 MHz, show an approximate increase of two to three times higher usage before and during the Games than afterward, while some other bands show essentially no change during the entire measurement period, and most bands show only intermediate increases in usage due to activities associated with the Games. Even the Centennial Park bombing, a crisis within a crisis, produced no measurable impact in any band except 162-174 MHz. As explained below, these results were commensurate with the types of systems that were installed in these bands for the Olympic Games.

Before accepting a conclusion that many land-mobile radio bands in Atlanta, Georgia, did not, for the most part, experience substantial impacts in channel usage due to the 1996 Summer Olympic Games, alternative explanations for the measurement results should first be examined.

Is it possible that a surge in overall spectrum usage occurred during the measurement period, and was somehow missed? This explanation might seem plausible if the measurements had been performed at only one location (thus introducing a possible bias due to some fluke of conditions at a single location), or if the measurements had been directed toward the goal of determining absolute, rather than relative, spectrum usage levels (since, for reasons presented earlier in this report, absolute usage levels are difficult or impossible to obtain directly from measurements). But, the twin facts that the measured usage trends tend to be repeated at every measurement location, and that the measured usage levels were relative in nature (comparing usage at each location under conditions that were controlled for all variables except the presence of the Games) tends to support the validity of the data. Furthermore, a large increase was measured in the 138-144 MHz band, implying that the measurement systems were fully capable of registering surges in spectrum usage when they occurred.

Is it possible that a surge in usage occurred in many bands, but that the majority of those communications were conducted with low-power handheld units that were not observable by the deployed measurement systems? For example, handie-talkie radio communications within a stadium would not normally be receivable outside the confines of the stadium. Thus, although many handie-talkies might flood the city, their impact on spectrum usage would be highly localized, only reaching a few blocks radius for each unit, and overall spectrum impact would be contained within relatively isolated areas. This possibility is highly plausible, although it could only be proven or disproven by deploying measurement systems in such locations as stadiums. However, if this scenario is true, the fact remains that such impact would be localized, and overall spectrum congestion across the metropolitan area would be minimal.

Is it possible that, with attention focussed on the 1996 Games, many routine activities that ordinarily generate spectrum usage may have been overridden by higher-priority communications for the main event, the effect being that increased usage levels due to the Games were offset by decreased usage levels for routine activities? For example, routine law enforcement activities and their concomitant communications requirements may have been largely suspended during the Games, while the enforcement personnel were detailed to other, higher-priority tasks. They would still have used their radios, but usage of their radios would have been a substitute for, rather than an increase of, routine daily communications. This possibility is quite plausible, and can be neither proven nor disproven from the measurement data. However, if the plausible is actually true, then the implication is that spectrum loading levels would not be increased by emergency situations, since any emergency situation is likely to cause the same focus on crisis events at the expense of routine activities.

Is it possible that, for all the anticipation of a communications crisis in Atlanta during the 1996 Summer Olympic Games, the usage statistics for the area might ordinarily be so low that, even with the loading due to the Games, the overall usage levels did not climb significantly higher than would be measured in larger metropolitan areas on average days? That is to say, perhaps Atlanta, Georgia, in the midst of a mobile communications crisis might look like Los Angeles, California, on a regular weekday. This possibility seems unlikely, because a major spectrum-loading crisis in an area that ordinarily has relatively low spectrum usage levels should result in an even larger increase in measured usage statistics than would be observed in an area that has routinely higher usage levels. In other words, the 1996 Summer Olympic Games should have made an even larger impact on relative spectrum usage levels in Atlanta, Georgia, than they would have made in Los Angeles, California, assuming the same number of visitors, same security procedures, etc., in both locations. The fact that usage statistics did not substantially increase in most bands in Atlanta implies that even smaller percentage increases would be measured in areas that have routinely higher-level spectrum usage statistics.

Is it possible that the advance preparations for radio communications at the 1996 Summer Olympic Games had the effect of preventing spectrum usage levels from significantly increasing? This seems unlikely, as advance preparations should not have reduced the volume of usage, but rather should have facilitated high levels of usage. As a corollary to this question, is it possible that most of the preparation for radio communications in Atlanta was designed to accommodate crisis contingencies much larger than the Centennial Park bombing, and that the occurrence of such a crisis would have substantially increased the measured spectrum usage levels? This is a more likely possibility, and may have contributed to the relatively small increase in spectrum usage levels, and apparently low levels of congestion, that are indicated by the measurement data.

In the final analysis, the data lead to the conclusion that the 1996 Summer Olympic Games in Atlanta, Georgia, did not (in most land mobile radio bands) produce substantially higher overall spectrum usage levels in mobile-communication bands across the metropolitan area, and that public safety channels were likewise not generally congested by the occurrence of the 1996 Games. Furthermore, a large proportion of mobile-radio channels were available for use during a large percentage of time at any given location in the metropolitan area during the Games. Public safety bands and band assignments do not show usage patterns that are substantially different from those of other channel assignments, and in general do not exhibit large relative increases in usage levels.

Taken as a whole, these results indicate that a significant reserve spectrum capacity was available in Atlanta during the Games. This is consistent with the fact that, as summarized in Table 4, the bands that showed little or no impact during the Games were required for the operation of a large number of public safety communication systems that were installed for use in the event of a major disaster. In effect, the presence of these systems meant that a large amount of reserve capacity had to be available, to accommodate the possibility that the systems would have been operated.

This conclusion is supported by the increase in channel usage that was observed in the 138-144 MHz band. Of all the mobile bands, this was the one that was used most extensively for purposes of crowd control and other, related tactical public safety communications. The channel usage increase of two to three times the background level in this band is probably indicative of the reserve spectrum capacity that would have been required if the emergency communication systems in the other mobile bands had been needed. Since no emergencies requiring the use of these systems occurred, these systems were not used, and they never generated measurable spectrum usage. However, their spectrum requirements were probably similar in magnitude to that of the 138-144 MHz band, regardless of whether they were used operationally.

To the extent to which the 1996 Summer Olympic Games represent a model crisis event for mobile radio operations, the measurement results have implications for mobile-radio spectrum loading in the midst of other sorts of crisis events, such as natural disasters or terrorist attacks.

The lesson of the Atlanta Olympic Games appears to be that, in the event of a crisis in a metropolitan area, land mobile radio bands required for emergency responses should have a reserve capacity for communication traffic that will allow channel usage levels that are approximately two to three times higher than normal, non-emergency channel usage levels. Such accommodation may depend critically upon substantial advance spectrum planning, including coordination of plans between agencies at the local, state, and federal levels, and improvements to metropolitan area radio communication infrastructure. It is not known how well the spectrum needs in Atlanta might have been accommodated if advance planning had not been performed, but it is reasonable to assume that spectrum loading problems would have been significantly worse if substantial advance planning and communications infrastructure improvements had not been accomplished. The fact that the 138-144 MHz band was able to accommodate an increase of two to three times the background level, and that a similar reserve capacity was apparently available in the other mobile radio bands, which were to be used in the event that a significant disaster had occurred, indicates that this type of planning and coordination did contribute to the success of the land mobile radio communications in Atlanta. To the extent that communication planning and infrastructure improvements for the 1996 Summer Olympic Games helped to prevent overloading in any given mobile bands during the event, then similar planning needs to be performed prior to the occurrence of events of similar magnitude in other U.S. metropolitan areas.

To further test these hypotheses, additional measurements should be performed, to which the Atlanta results can be compared. Likely measurement locations would be Los Angeles, California, San Diego, California, and New York, New York, where spectrum loading on any given day may be significantly higher than occurs in Atlanta, Georgia. San Diego, California, and Los Angeles, California, have shown routinely high levels of loading in the mobile radio bands during previous RSMS broadband spectrum surveys [3],[4]. Such measurements would help verify the Atlanta results, and would indicate the locations where future spectrum crisis loading events should be measured.

5. REFERENCES

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

[2] *Title 47 Code of Federal Regulations, Telecommunication*, Part 90.555 revised Oct. 1994, (U.S. Government Printing Office, Superintendent of Documents, Mailstop: SSOP, Washington, DC 20402-9328).

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

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

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APPENDIX A: INTERPRETATION OF SPECTRUM SURVEY DATA

A.1 INTRODUCTION

Institute for Telecommunication Sciences (ITS) radio spectrum measurement system (RSMS) and compact radio spectrum measurement system (CRSMS) spectrum survey measurements are performed with a variety of receiver algorithms (see Section C.2 of Appendix C). 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 a spectrum survey. Measurement algorithms are assigned on an individual basis to optimally measure spectrum use in a spectrum survey frequency 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/CRSMS data are to be used accurately. This appendix describes the algorithms currently used for RSMS/CRSMS spectrum 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.

A.2 SIGNAL PROBABILITY OF INTERCEPT FACTORS

RSMS/CRSMS 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 s 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-MW peak power from a radar vs. perhaps a fraction of a watt from a personal cellular telephone);

- the signal amplitude 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 hrs/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 A.8). For bands in which signals are expected to originate primarily from a single quadrant as seen from the RSMS/CRSMS 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/CRSMS uses omnidirectional antennas.

Slant (antenna) polarization is used for all RSMS/CRSMS 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 omnidirectional 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/CRSMS 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/CRSMS 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/CRSMS site survey. Inevitably, some signals will be missed; however, the standard RSMS/CRSMS 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.

A.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 are used to perform swept-frequency measurements.

The HP-8566B spectrum analyzers used in the RSMS/CRSMS sweep across the spectrum in individual segments that are 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 and storing a reading in each of the 1001 bins. For example, a 20-ms sweep time divided by 1001 measurement bins per sweep yields a 20-µs measurement time in each frequency bin. Within each bin measurement interval (in this example, 20 µs), 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 the spectrum analyzer detector mode that has been selected. The detector modes available in the RSMS/CRSMS 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 A.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 µs) 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 noise source (such as thermal electron noise in a circuit or a noise diode) is being measured, then an average value of the noise will be displayed, irrespective of the detector mode that has been selected. This feature is used in channel usage measurements (where the video bandwidth is set to 100 Hz) to discriminate against noise-like emissions in favor of channel traffic.

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).

A.3.1 Description of the Swept/m3 and Swept/m3/apd Measurement Algorithms

The swept/m3 algorithm 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 control computer, but the data traces are not individually recorded. Instead, for each of the 1001 frequency bins that the analyzer returns in each sweep, the computer 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 (i.e., the 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. This real-time cumulating (cuming) process compresses data volume by several orders of magnitude, but the compression causes loss of the original data sweeps, and thus precludes the possibility of processing the original data sweeps with different algorithms during postmeasurement analysis.

The swept/m3/apd algorithm is the same as the swept/m3 algorithm, except that amplitude-probability distribution (apd) data are added for percentage channel usage information that is stored with each data scan. The apd information is acquired by counting the number of times that preconfigured amplitude thresholds are exceeded at each measured frequency during the course of the measurement. The number of threshold crossings at each frequency are stored, along with the swept/m3 maximum, minimum and average curves.

Figure A-1 shows how the swept/m3 and swept/m3/apd cumulative processes are integrated with the normal RSMS/CRSMS processing path. All band events measured more than once during the same survey are cumulatively processed (cumed) during postmeasurement analysis. In the figure, all measured data identified as "RSMS data output for lab analysis" are considered to be postmeasurement data. For spectrum surveys, swept/m3 and swept/m3/apd postmeasurement (m3) data are cumed again for a maximum of maximums, mean of means, and minimum of minimums.

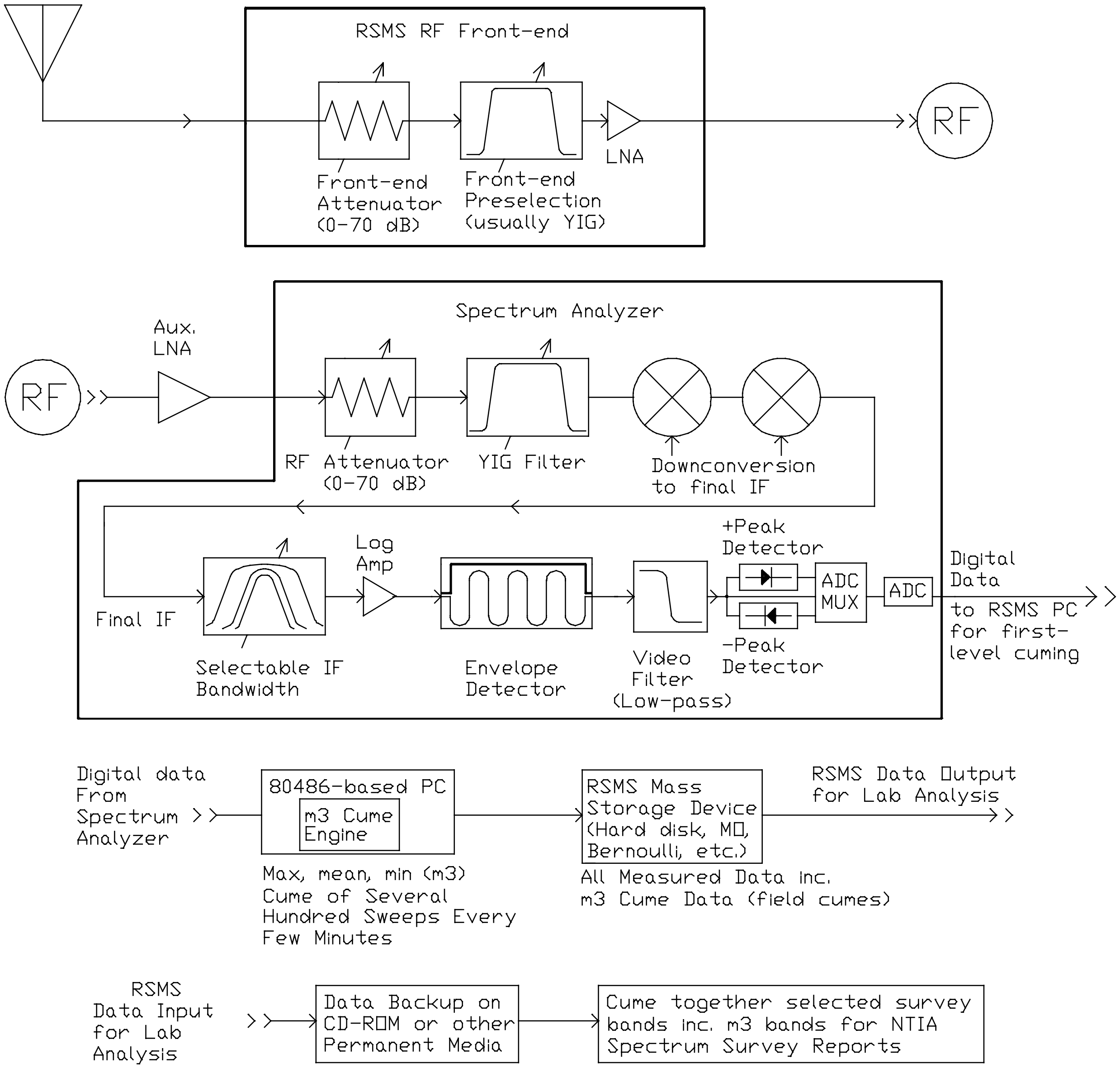

Figure A-1. Diagram of the RSMS/CRSMS signal-processing path for measured data.

A.4 DESCRIPTION OF SWEPT/M3/SAMPLE DATA COLLECTION

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

A.4.1 Noise Responses in Swept/m3/Sample and Swept/m3/apd/Sample Data

The noise level displayed by a measurement system using the sample detector will be equal to [kTB + (measurement system noise figure)].[1] 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.

If the video bandwidth (that is, the postenvelope 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/CRSMS. A 100-Hz video bandwidth is used to suppress system response to noise-like emissions when land mobile radio (LMR) channel usage measurements are being performed with the swept/m3/apd algorithm.

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

A.4.2 Signal Responses in Swept/m3/Sample and Swept/m3/apd/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 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 1/1000 (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/CRSMS project.

For swept/m3/sample and swept/m3/apd/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

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[1] 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. For B = 1 Hz, at room temperature: kTB = -174 dBm. In a 1-MHz IF bandwidth, kTB = $-174 + 10\log(10^6) = -114$ dBm.

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 and swept/m3/apd/sample data shows the power average (average 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 must have been 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 that are continuously present during the spectrum survey.

A.5 DESCRIPTION OF SWEPT/M3/+PEAK DATA COLLECTION

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

A.5.1 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 postenvelope detector, low-pass filtering bandwidth) is equal to or greater than the IF bandwidth (which is the case for RSMS/CRSMS 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 ±10-dB value for maximum and minimum levels of +peak noise is the same as the ±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 ±10-dB difference between the maximum, mean, and minimum levels 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.

A.5.2 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/CRSMS 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.

A.6 DESCRIPTION OF SWEPT/MAX-HOLD DATA COLLECTION

If a frequency-sweeping algorithm is performed using the +peak detector (see Section A.3 for a description of the +peak detector in the RSMS/CRSMS spectrum analyzers) while the spectrum analyzer display is being operated in the Maximum-Hold mode,[2] then the data are referred to as "swept/max-hold"

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 ±3 dB on noise, instead of the ±10 dB difference which usually characterizes swept/m3 data.

A.6.1 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 (at room temperature) + 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(10^6 Hz) + 10-dB noise figure + 10-dB peak detector offset + 10 dB = -84 dBm.

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[2] 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.

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.

A.6.2 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.

A.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-s rotation time, then the dwell time at each measured frequency might be set to 12 s. Thus, the emitter's rotating main beam would certainly be aimed in the direction of the measurement system at some moment during the 12-s 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 0-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 µs 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.

A.7.1 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 (at room temperature) + 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(10^6 Hz) + 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 ±2 dB relative to the mean curve.

A.7.2 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.

A.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/CRSMS. 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/CRSMS 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°/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°, 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/CRSMS 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 that use 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/CRSMS site survey measurements, this measurement is only performed once at each survey location and no cuming is performed on these data. Activity in these bands does not vary much with time and little information is gained by measuring these bands repetitively.

A.8.1 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/CRSMS.

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APPENDIX B: RADIO SPECTRUM MEASUREMENT SYSTEM AND COMPACT RADIO SPECTRUM MEASUREMENT SYSTEM

B.1 INTRODUCTION

The NTIA/ITS radio spectrum measurement system (RSMS) and compact radio spectrum measurement system (CRSMS) are transportable, self-contained computer-controlled radio receiving systems capable of many measurement scenarios over a frequency range of 30 MHz to 22 GHz. This appendix contains particulars on the vehicle (RSMS only), instrumentation, and operation of the RSMS/CRSMS when they are deployed for broadband spectrum survey measurements and land mobile radio (LMR) channel usage measurements.

B.2 RSMS VEHICLE

For maximum effectiveness, a spectrum measurement system must be readily transported to field locations that may lack sheltering structures or commercial power. In such cases, the measurement system must be deployed with its own shelter and its own power source. The RSMS is designed to meet this need. The RSMS, which includes antennas and support hardware, is carried in a shielded, insulated, climate-controlled shell mounted on a Chevrolet truck cab and chassis. 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. Figure B-1 shows the RSMS with telescoping masts in the raised position and antennas mounted for a comprehensive spectrum survey.

Figure B-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 tightly-shielded, windowless measurement compartment provides good radio frequency (RF) isolation between the measurement system and the outside environment. This shields equipment and personnel from high-level fields, as well as preventing internal computer noise from

Figure B-1. NTIA/ITS radio spectrum measurement system with telescoping masts raised and antennas mounted for a comprehensive spectrum survey.

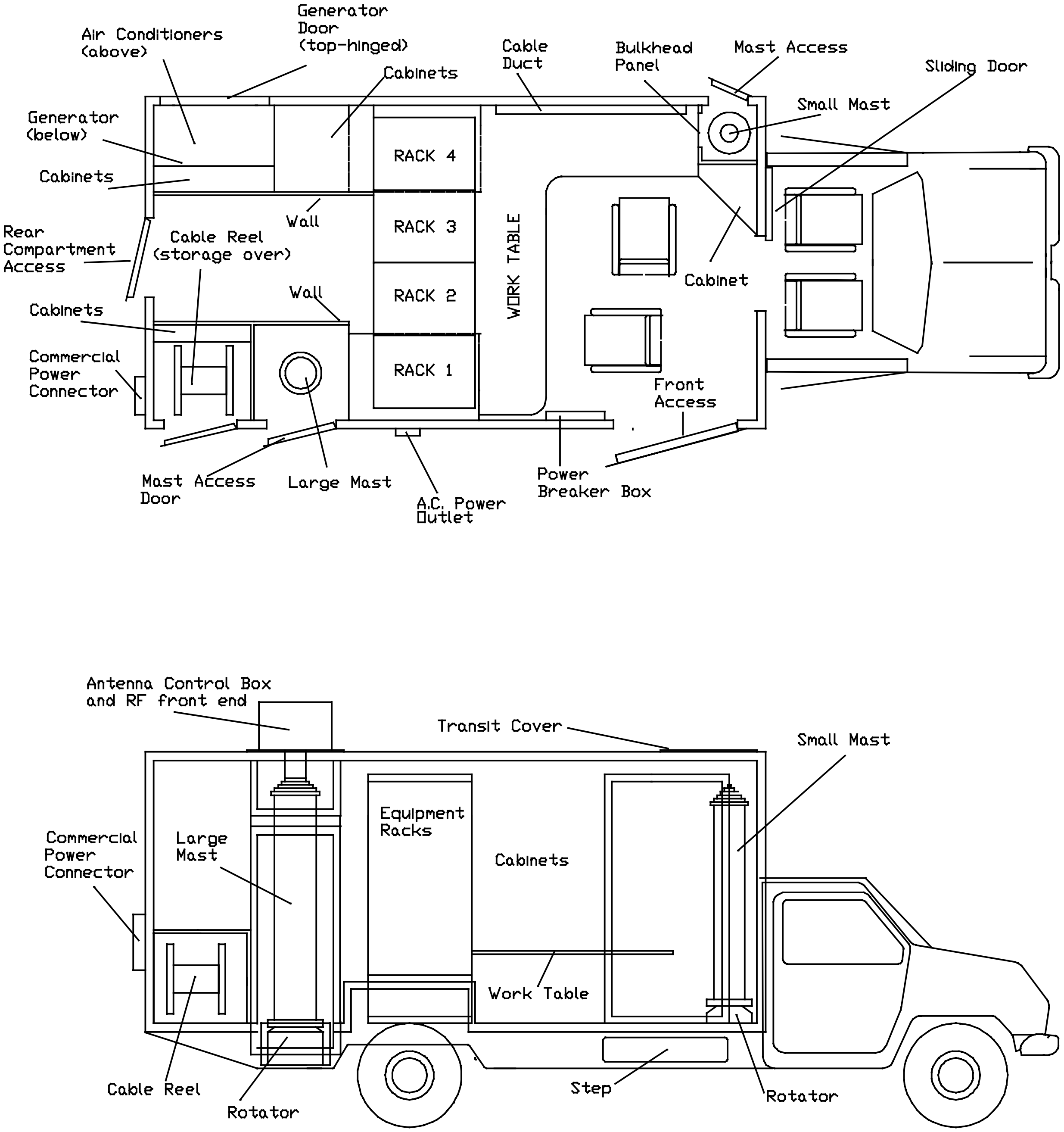

Figure B-2. Top and side view drawings of the ITS radio spectrum measurement system.

contaminating the measurements. 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 m above ground.

B.3 RSMS/CRSMS INSTRUMENTATION

The RSMS 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. A CRSMS deployment usually is comprised of one system or the other; LMR channel usage surveys are performed with a system-1 CRSMS. Figure B-3 is a fish-eye front panel view of the rack mounted instrumentation inside the RSMS main compartment. Measurement and control instruments for System-1 are in the two racks on the right of center and System-2 instruments are in the two racks on the left of center.

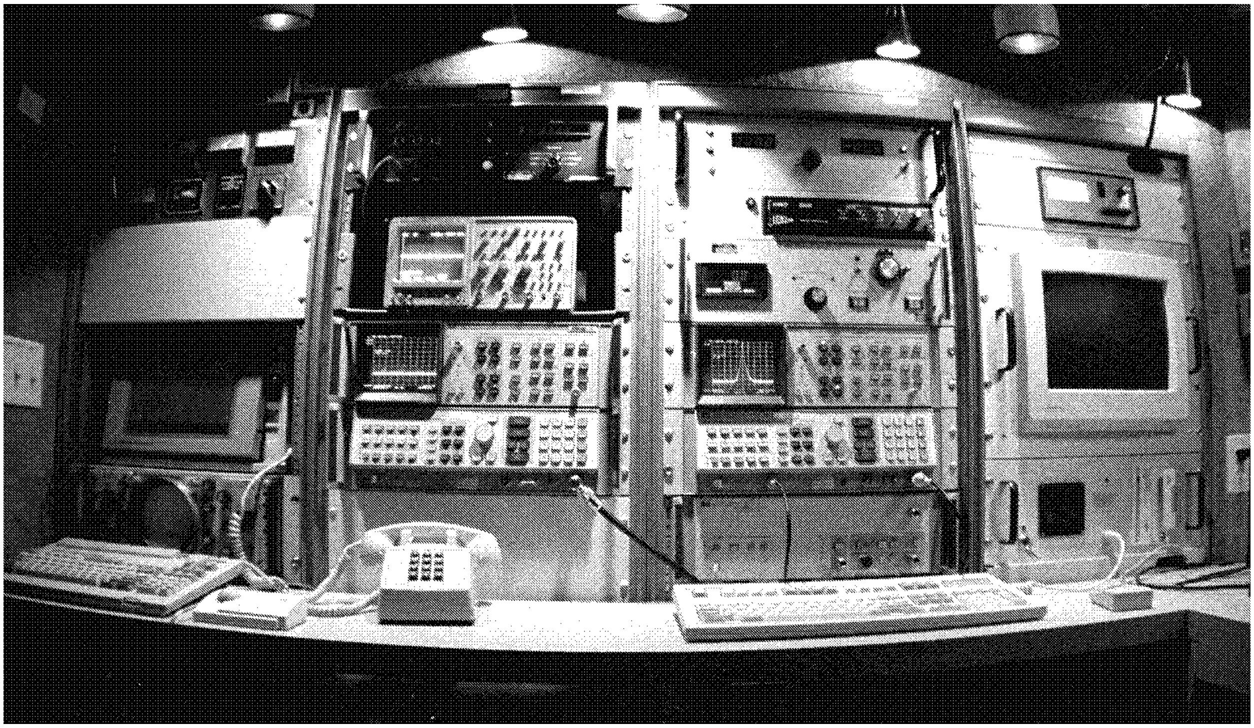

Figure B-3. Front panel of the ITS radio spectrum measurement system instrument racks.

For broadband spectrum occupancy surveys and LMR channel usage 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 1-19.7 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 RSMS receiver is depicted as a block diagram in Figure B-4. As the diagram shows, both the high and low frequency systems

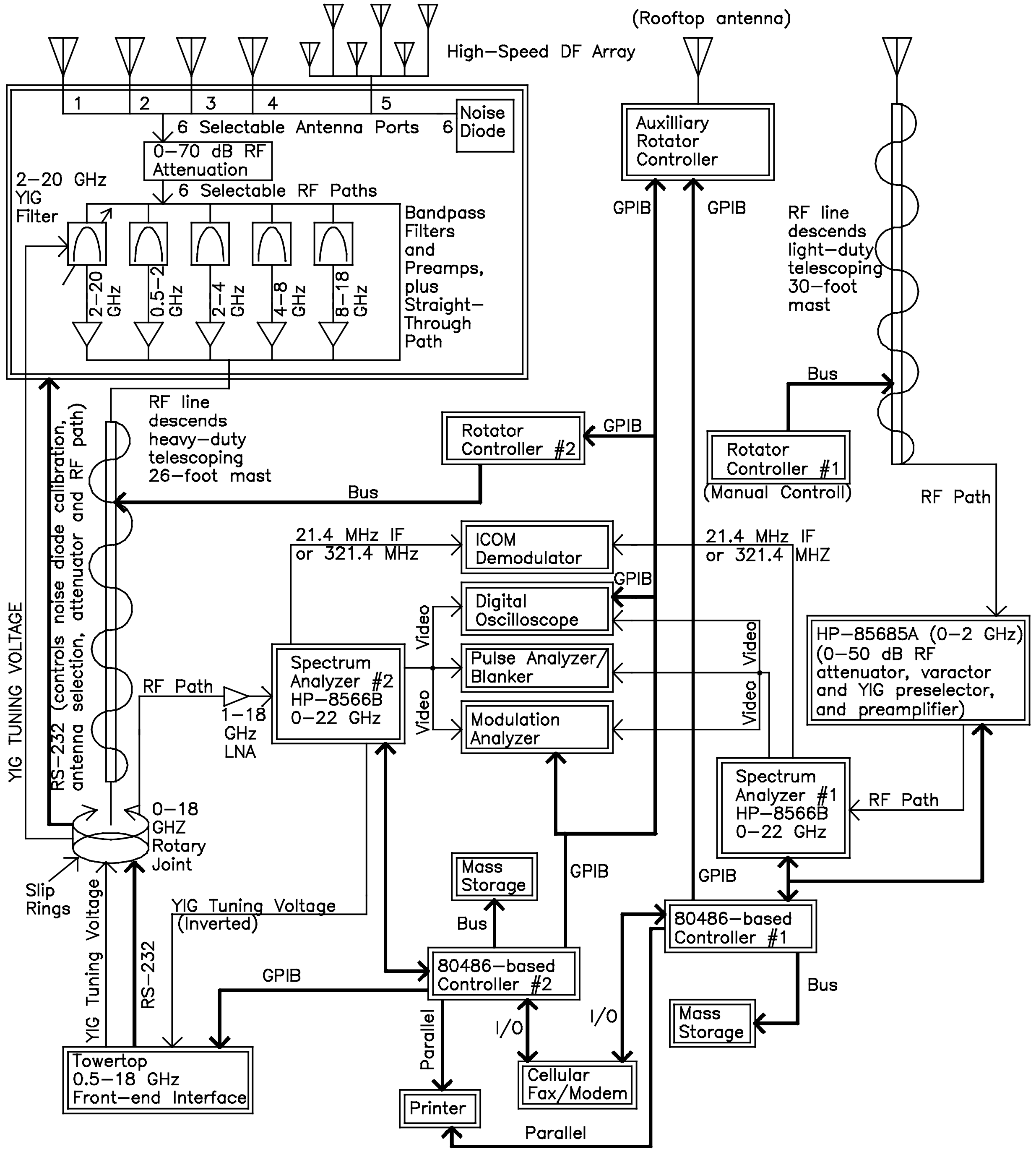

Figure B-4. Block diagram of the ITS radio spectrum measurement system receiver.

are designed around a 0-22 GHz range Hewlett-Packard 8566B spectrum analyzer, although the RSMS software will control other spectrum analyzers, such as the HP-70000 series. 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.

A CRSMS is functionally the same as an RSMS System-1 or System-2. The difference is that the CRSMS requires shelter and power provisions at the measurement site. For example, a typical CRSMS LMR channel usage survey deployment would include a set of instruments, equivalent to the RSMS System-1, assembled at a measurement site. Typically, the CRSMS measurement site is a room on the highest floor or in the attic of a tall building, or a building located on a hill or any high point in an area, with an RF cable connecting the instruments to an antenna array on the building rooftop.

RSMS/CRSMS measurements can be controlled in fully automatic, semiautomatic, and fully manual modes. In fully automatic operation, each measurement system is controlled by ITS-written software (named DA, for Data Acquisition) that runs on 80486-based and Pentium-type computers. Broadband spectrum occupancy surveys [1,2,3] are normally conducted in the fully automatic mode. LMR channel usage measurements ***must*** be made in the fully automatic mode. RSMS operators are able to interrupt automatic measurements to perform specialized measurements in semi-automatic and manual modes. These modes allow special measurements with varying degrees of automated assistance.

The two RSMS subsystems use independent antennas, RF front-ends, masts, spectrum analyzers and computers, but they share the use of auxiliary equipments for special measurements, analysis, and troubleshooting. Support equipment units 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. CRSMS deployments include some or all of these auxiliary units, as necessary for completion of the measurement effort.

The RF operational characteristics of the two RSMS subsystems are shown as a function of frequency in the signal-processing-path Table. (a CRSMS equipment set may be equivalent to either RSMS sub-system). 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 from 500 Mhz to 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 500 MHz to 22 GHz range, with YIG preselection from 2-20 GHz. This system incorporates 0-70 dB of dynamically selectable RF attenuation in the front-end, and uses low noise preamplifiers to achieve a typical noise figure of 10-15 dB up to about 10 GHz, and a noise figure that increases from 15-25 dB at frequencies from 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 preamplifiers.

Available RSMS/CRSMS RF Signal-processing Paths

Frequency Range	**RSMS/ CRSMS 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 noise diode (+25-dB excess noise ratio) and variant Y-factor calibration 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/CRSMS spectrum survey, but may be used for normal survey bands if no high-amplitude signals are anticipated in the measured frequency range.

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

B.4 ANTENNAS

The RSMS normally carries a complement of broadband antennas that cover a 0.1-20 GHz frequency range. CRSMS deployments are performed with whatever antennas are necessary and sufficient to complete the required measurements. Omnidirectional, slant-polarized biconical antennas are most frequently used for broadband occupancy and LMR channel usage surveys. These antennas provide a good response to circular, vertical, and horizontal signal polarizations. At frequencies from 0.1-1 GHz, a slant-polarized log periodic antenna (LPA) may be used if (as in the Denver, San Diego and Los Angeles surveys [1,2,3]) most of the radiowave activity is confined to an area subtending 180° or less relative to the measurement site. Omnidirectional antennas are otherwise normally used below 1 GHz. In addition to the 0.1 to 1-GHz LPA, the following omnidirectional slant-polarized biconical antennas are also available for the RSMS/CRSMS: 0.5-18 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 in the RSMS and are available for the CRSMS. These have antenna patterns that are most useful for direction-finding using differential methods at relative observation angles of 60° or 90°. 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.

A 1-meter parabolic dish antenna with a linear cross-polarized feed of 2-18 GHz is normally carried with the RSMS and can be deployed with the CRSMS. 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/CRSMS that are not calibrated in the field. Because most RSMS/CRSMS measurements are performed to acquire relative emission levels, rather than absolute incident field strength values, the main requirement for RSMS/CRSMS 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 referenced from manufacturer-generated curves, and the RSMS/CRSMS measurements are corrected in a post-acquisition analysis phase.

B.5 ATTENUATORS, PRESELECTORS, AND PREAMPLIFIERS

All RSMS/CRSMS measurements are made using the RF front-ends depicted in Figure B-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 and 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/CRSMS 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 preselection insertion loss to about 1 dB; fixed bandpass filters in an approximately octave progression are available in the ITS front-end (see Figure B-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 at least 41 dB of signal loss (6 dB of insertion loss, 10 dB of RF line loss, and at least 25 dB of spectrum analyzer noise figure). Thus, to achieve an overall noise figure of 10 dB, a single LNA would have to have a noise figure of about 8 dB, and a gain of at least33 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 YIG insertion 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).

B.6 CALIBRATION

RSMS/CRSMS calibrations are performed prior to and during every RSMS measurement scenario, such as an LMR channel usage survey. As measurements are performed, gain corrections are added automatically to every sampled data point. Gain and noise figure curves are used by RSMS operators to determine the relative health of the measurement system, and to pinpoint locations in the measurement system RF path that are operating suboptimally.

Excluding the receiving antenna, the entire signal path within the RSMS is calibrated with a noise diode source connected at the point where the RF line attaches to the receiving 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 at 128 points across the desired frequency range with the noise diode turned on (ON) and turned off (OFF). The RSMS control computer stores all of the ON vs. OFF noise diode values then uses the measured difference between ON and OFF at each of the 128 calibration points to solve calibration equations for gain and noise figure. The gain values are inverted in sign to become correction values. The resulting set of 128 noise figure and gain correction values are stored as a function of system frequency in look-up tables on the computer disk. Calibration curves, as in Figure B-5, showing system noise figure and gain corrections as a function of frequency across a selected range are generated. The frequency-dependent gain-correction curve is used to automatically correct the measured amplitudes of all received signals in subsequent measurements.

RSMS calibrations are implemented as a variant of the Y-factor calibration method [4]. The Y-factor method of amplitude calibration provides for a simple, yet accurate characterization of the amplitude response and noise figure of an RF receiver system. At frequencies below 12 GHz,

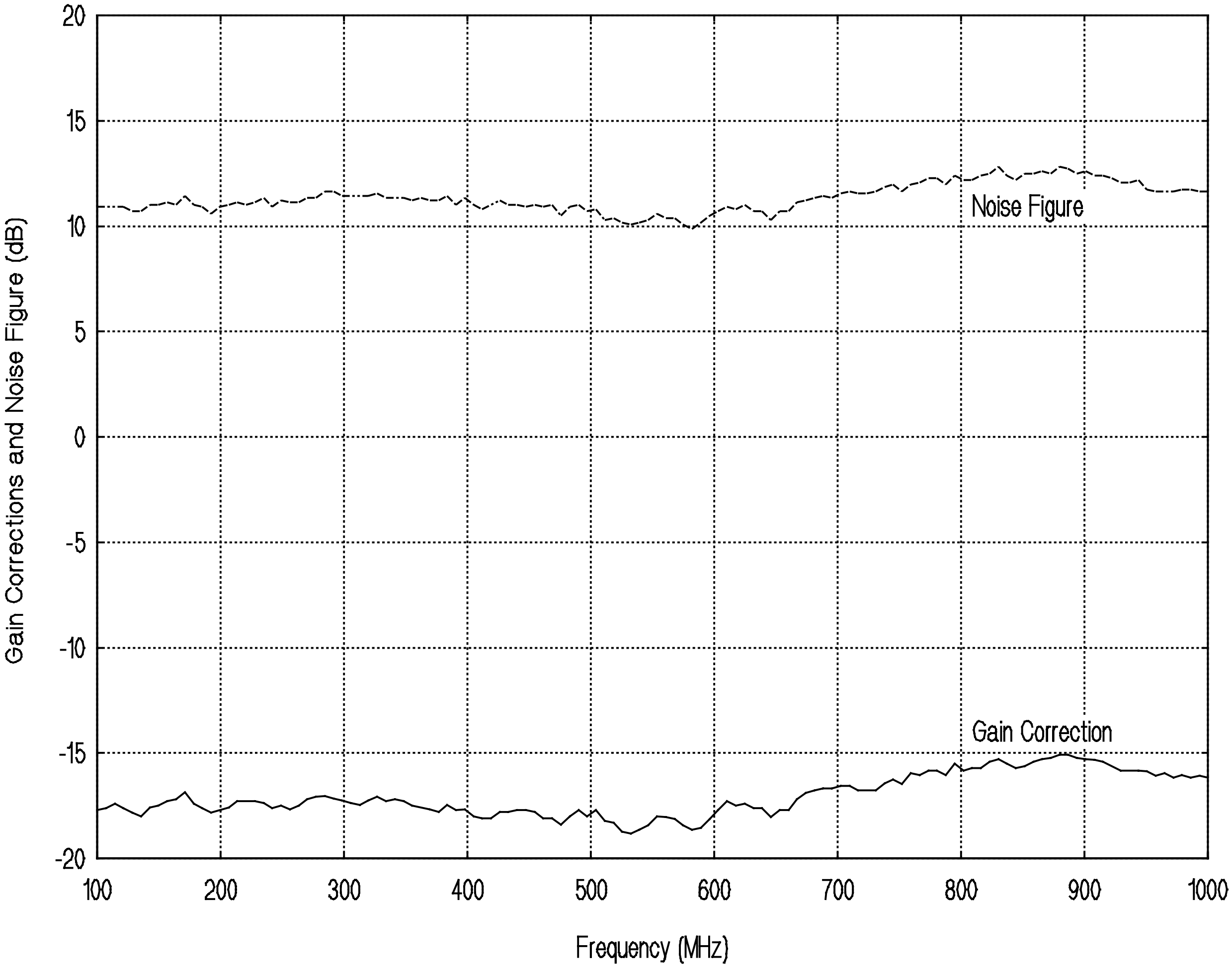

Figure B-5. Example RSMS/CRSMS calibration graph showing noise figure (upper, dashed curve) and gain correction values (lower, solid curve) as a function of frequency.

accuracy of noise diode calibration with spectrum analyzers installed in the RSMS is good to within a decibel. At frequencies from 12-18 GHz, accuracy falls to about ±2.5 dB due to a higher system noise figure. For noise diodes producing an excess noise ratio of about +25 dB, as are used for RSMS measurements, gain and noise figure calibrations cannot be performed in a practical sense if the system noise figure is more than about 30 dB or is less than about 1 dB. This is because the difference between P_{on} and P_{off} becomes too small to measure reliably in the first case, and too near the rated excess noise ratio of the noise diode to measure reliably in the second case. Noise diode calibrations will not provide information on phase shift as a function of frequency; if a measurement system must be calibrated for phase shift, then alternative calibration methods must be used. Appendix E of the Los Angeles spectrum survey report [3] provides a detailed description of RSMS noise diode calibration theory.

The RSMS calibration technique has proven very successful for field-deployed radio spectrum measurement systems. It is a fast way to determine sensitivity and gain-correction values for a measurement system, and it also is very useful for isolating the gains and losses through individual components of the measurement system, such as RF lines and amplifiers. Moreover, the relatively low cost and small size, weight, and power requirements of noise diodes make it possible to locate several of them at various places in the measurement system to diagnose where system losses are occurring; and to carry spares in the event that one fails. Noise diodes can themselves be calibrated by such entities as the National Institute of Standards and Technology.

B.7 RSMS/CRSMS MEASUREMENT CAPABILITIES

The RSMS/CRSMS is equipped to perform a variety of measurements. Following are brief descriptions of measurement capabilities currently available with these systems.

LMR Channel Usage Surveys: RSMS/CRSMS deployments may be used to measure the percentage of time that LMR channels are occupied at selected measurement locations. For these measurements, the RSMS/CRSMS is equipped with special IF filters for the elimination of off-channel signal energy from the statistical measurements. Mobile radio bands between 30 MHz and 1 GHz may be selected for measurement. These measurements are useful in determining the relative usage in LMR bands, and also in determining the variation in channel usage within bands as a function of time.

Broadband Spectrum Occupancy Surveys: RSMS/CRSMS deployments are frequently used to perform measurements of general spectrum occupancy between 30 MHz and 20 GHz. These surveys differ from the LMR channel usage measurements in that they do not indicate percentage channel usage, but rather indicate maximum, minimum, and average levels of spectrum occupancy during the survey period. These surveys are not restricted to only the LMR bands; they cover all spectrum between the start and stop frequencies. A variety of measurement algorithms are implemented on a band-by-band basis, to optimize the measurements for the types of emitters that occupy each band. Outputs from these surveys have been documented in NTIA Reports [1,2,3].

Extended Emission Spectra: Measurements of radiated and in-guide emission spectra of individual radio transmitters, particularly radars, are a major strength of the RSMS/CRSMS program. A combination of high sensitivity and interactive front-end RF attenuation make it possible to routinely measure the emission spectra of radio emitters across several gigahertz of spectrum. Specialized RSMS/CRSMS 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/CRSMS 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 (nonline-of-sight) routes. The RSMS/CRSMS dish antenna is rotated through 360° on the horizon while recording received signal strength. This results in data showing the receivability of signals at all azimuths, and reveals nonline-of-sight propagation routes, if any exist. Azimuth scanning is often used to support spectrum surveys. Examples may be found in NTIA Reports [1,2,3].

Transmitter Equipment Characteristics: RSMS/CRSMS deployments are 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 intrapulse modulation. Although the RSMS/CRSMS can observe the presence of phase coding in pulsed signals, no phase measurement capability is explicitly included in RSMS/CRSMS capabilities.

B.8 REFERENCES

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

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

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

[4] S. Adam, *Microwave Theory and Applications*, Englewood Cliffs, NJ: Prentice-Hall, Inc., 1969, pp. 490-502.

APPENDIX C: DATA ACQUISITION SOFTWARE

C.1 INTRODUCTION

The ITS radio spectrum measurement system (RSMS) and compact radio spectrum system (CRSMS) are designed to identify and characterize spectrum 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/CRSMS receivers detect almost every signal type encountered. As shown in Appendix B, the RSMS/CRSMS 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/CRSMS 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/CRSMS 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.

C.2 RECEIVER ALGORITHM SUBROUTINE

The DA receiver algorithm subroutine provides software management for up to 32 measurement algorithms (called band events for RSMS/CRSMS 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 a spectrum 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 1001 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 1001 frequencies measured on each individual spectrum analyzer sweep, the maximum, minimum, and (log) 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 A.3.1 of Appendix A) in the analysis phase of a site survey to yield long-term swept/m3 curves. RSMS/CRSMS broadband occupancy surveys use swept/m3 measurements for mobile radio bands. Swept/m3 measurements do ***not*** yield statistical usage information on mobile radio channels; the swept/m3/apd algorithm (below) is required to collect those data.
>
> **Swept/m3/apd**: This measurement, which is utilized mainly for LMR channel usage surveys, incorporates all the features and outputs of the swept/m3 algorithm (above), and acquires channel usage statistical information as well. As for swept/m3 measurements, a frequency range within an LMR band is selected for measurement, a band event is set up to measure that frequency range, and the range is then repeatedly swept by the RSMS/CRSMS under computer control. At each of the 1001 frequencies measured on each individual spectrum analyzer sweep, the maximum, minimum, and (log) mean received signal levels are measured, just as for swept/m3 data. But in addition, the 1001 data points taken during each sweep are compared to preconfigured amplitude thresholds. A set of 1001 counters is maintained in the computer, one for each of the 1001 measured frequencies. If a threshold is exceeded during a sweep, then the corresponding counter is incremented by one count. Repeated

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[1] For 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.

sweeps are made across the spectrum of interest, and for each of the measurement points returned from each sweep, the measured amplitudes are compared to the preconfigured thresholds, and the counters are incremented accordingly. This process continues until it is halted programmatically. At the end of this measurement process, the set of 1001 counters contains the number of times that each threshold was exceeded at each of the corresponding 1001 measured frequencies. This set of counts as a function of amplitude threshold is an amplitude-probability distribution (apd), from which the name of this algorithm is derived.

Dividing the counter values for each threshold by the total number of sweeps that were performed yields the percentage of time that the corresponding frequencies were occupied ("used") at the measurement location, during the measurement period. The DA program stores both the counter values and the total number of sweeps in the data files; division of these numbers to yield percentage usage is performed during the postmeasurement analysis phase of the survey.

The DA program permits the operator to specify six apd thresholds against which the measured amplitudes are compared. Five of the apd thresholds are selected at amplitudes of about 0 dB, 3 dB, 6 dB, 9 dB, and 12 dB above the system noise floor. (For example, if the system noise floor is at -105 dBm in 50 ohms, then the first five apd thresholds would be set at -105, -102, -99, -96, and -93 dBm.) The sixth threshold is set at -30 dBm in 50 ohms; this is five decibels below the overload amplitude of the HP-85685A preselector. The lowest threshold is used to verify that the apd algorithm is working; it should show 100% "usage" for every measured frequency. The highest threshold, at -30 dBm, is used to detect the presence of incipient measurement system front-end overload; i.e., if any of the measurement-bin counts acquired during a swept/m3/apd shows this threshold as exceeded, then that entire swept/m3/apd (representing typically, 10 to 20 minutes of measurement time) is excluded from the postmeasurement analysis. This ensures that measured data containing possible "usage" artifacts resulting from overload do not contaminate the final survey results.

The IF bandwidth used for the measurements is of special concern because the IF-bandwidth filtering available in commercially manufactured spectrum analyzers typically has a gaussian shape. While that shape is adequate for general-purpose spectrum measurements, and particularly for measurements of pulsed emitters, it is inadequate for measuring channel usage statistics. This is because the gaussian filter, when tuned to the center frequency of a mobile radio channel, and with its bandwidth[2] set equal to the nominal channel width, will convolve not only the energy present in the tuned channel, but also substantial amounts of energy from the adjacent channels just above and below the tuned channel frequency. The result is that usage activity

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[2] Filter bandwidths in spectrum analyzers are usually specified at the 3-dB points, and sometimes at the 6-dB points; in either case, the gaussian filter shapes convolve substantial amounts of energy in the spectrum outside the specified filter bandwidth.

in channels adjacent to the tuned channel can (and will) be measured as though it were occurring in the tuned channel; erroneous usage statistics will result.

To avoid this problem, channel usage must be measured with an IF filter shape that rolls off substantially faster than the gaussian shape. In the RSMS/CRSMS systems, this roll-off is implemented by inserting a rectangular 15 kHz-wide IF filter into the spectrum analyzer signal-processing path after the spectrum analyzer's own (gaussian) IF filter section. The spectrum analyzer IF bandwidth is set to a value greater than 15 kHz (30 kHz is the normal selection), so that the rectangular 15-kHz filter becomes the effective IF filter for the measurement system.

In closed-system tests conducted at the ITS laboratory, this system was tested for adjacent-channel usage rejection by tuning the measurement system to an unoccupied LMR frequency while generating signals on adjacent channels. With the rectangular, 15 kHz-wide IF channel filter in place, no usage was measured on the empty channel even when the adjacent channel was saturating the measurement system RF front-end.

Although the 15 kHz-wide channel filter provides a much sharper roll-off than a gaussian filter, the channel filter still occupies a few kilohertz of spectrum within its roll-off. This means that, if the spectrum analyzer sweeps were set to record one LMR channel for each of the 1001 spectrum analyzer bins, adjacent channel activity could still contaminate the channel usage statistics. To avoid this problem and further protect the measurement results from adjacent-channel contamination, the spectrum analyzer frequency sweep range is therefore adjusted in the band event parameter table so that each LMR channel is represented by five or seven spectrum analyzer measurement bins. That is, the 1001 bins measured during each sweep represent measurements on (1001/7) = -143 whole channels, or (1001/5) = 200 channels plus a fraction of a channel that is thrown away in the data processing phase. In both cases, the channel usage statistics are derived from the middle bin on each channel, with the remaining two or three bins on each side being used to provide for IF filter roll-off.

Finally, it is imperitive, with channel usage measurements, to ensure that measured activity represents usage by intentional LMR traffic, and not noise from such sources as automotive ignitions. This problem is minimized by selecting sample detection (see Appendix A, Section A.4) and a relatively narrow video (postdetected, baseband low-pass filtering) of 100 Hz. Both of these selections have the effect of minimizing the measurement of noise emissions, which tend to be broadband in nature.

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/CRSMS at some time during that interval. The RSMS/CRSMS, 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/CRSMS then tunes to the next frequency (one step), and repeats the process until the entire specified spectrum has been measured.

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/CRSMS 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.

C.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 table of Section 2.3.1. For example, [algorithm] in the table shows which of the above described subroutines 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 [scans (# 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.

Sweeps [sweeps (# 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.

C.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. The software protects against out-of-range and nonfunctional configurations but the operator can control the analyzer manually for unusual situations.

C.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 table in 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/CRSMS front-end attenuators are available and if so will set them to the selected value. Spectrum analyzer attenuation is set to zero when RSMS/CRSMS attenuation is active; if however, RSMS/CRSMS 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 [detector type]: Normal, positive peak, negative peak, sample, maximum hold, and video average modes are available. See Appendix A 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 (#swps)]: Number of analyzer-processed sweeps per scan. This parameter is only used with maximum hold or video-averaged detection.

Sweep Time [swp/stp (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.

C.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/CRSMS 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;
- gain relative to an isotropic antenna;
- front to back gain ratio; and
- side lobe gain levels.

C.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/CRSMS calibrations are performed with noise diodes as described in Section B.6 of Appendix B.