Spectrum Occupancy Results from Several Surveys

Chriss Hammerschmidt [#1], Heather Ottke [#2]

[#] *National Telecommunications and Information Administration*

Institute for Telecommunication Sciences
325 Broadway, Boulder, CO 80305, U.S.A.

[1] chammerschmidt@its.bldrdoc.gov

[2] hottke@its.bldrdoc.gov

***Abstract*—This paper presents spectrum occupancy results from spectrum surveys conducted at three locations: Denver, CO, Table Mountain near Boulder, CO, and Point Loma, near San Diego, CA. Equipment setups are described along with the measurement algorithms used to measure various emission types. Various statistical graphs, M4 statistics plots and FS-CCDF plots, as well as time vs. frequency or waterfall plots give different representations of the data. Results are shown for a land-mobile radio band and a radar band. Five bands in total will be shown during the presentation.**

I. BACKGROUND

The National Telecommunications and Information Administration (NTIA) manages the Federal Government's use of the radio spectrum. NTIA establishes policies concerning spectrum assignment, allocation, and use; and provides guidance to the various departments and agencies to ensure that their use of spectrum dependent systems is consistent with these policies [1]. In discharging this responsibility, NTIA 1) assesses spectrum utilization, 2) identifies existing and/or potential compatibility problems among the 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 radio frequency spectrum utilization. Under U.S. Department [of Commerce] Organizational Order 25-7 [2], one of the assigned functions for the Institute for Telecommunication Sciences (ITS) is to acquire, analyze, synthesize, and disseminate data and perform research in general on the description and prediction of electromagnetic transmission, noise, and interference, and on methods for improving the use of the spectrum for telecommunication purposes. ITS conducted these surveys of spectrum occupancy in support of this mission.

The Radio Spectrum Measurement Sciences (RSMS) system was developed by NTIA to perform thorough and accurate spectrum occupancy measurements in virtually any location in a broad range of spectrum bands. The RSMS-4 mobile measurement truck (Fig. 1) is the fourth generation mobile measurement laboratory and is equipped with state-of-the-art instrumentation, measurement methods, and analysis capabilities.

The RSMS-4 is under the administrative control of the Director of the Institute for Telecommunication Sciences (ITS). RSMS measurement activities are directed by ITS in coordination with OSM. Federal agencies with spectrum management needs can request support of the RSMS through OSM or by entering into a cost reimbursable agreement with ITS. RSMS is also available for academic or industry research through cooperative research and development agreements.

Three locations were chosen for spectrum occupancy measurements so that comparisons could be made to previous occupancy measurements [3] and [4] and to obtain new information. These locations include Denver, CO, Table Mountain, Boulder, CO, and San Diego, CA. Fig. 1 shows pictures taken at the three measurement locations. Details for certain selected frequency bands are included in this paper.

Fig. 1. The RSMS-4 truck shown at three locations for spectrum occupancy measurements: Table Mountain, CO; Denver, CO; and San Diego, CA.

II. INSTRUMENTATION AND MEASUREMENT ALGORITHMS

A. Instrumentation

Two separate systems were used. The first system, the LMR system, measures only narrowband signals below 500 megahertz (MHz). A discone antenna with a frequency specification from 25 MHz to 1300 MHz was used for this system. The second system, the broad-frequency system, measures wideband television, narrowband LMR signals below 500 MHz, and all other signal types from 500 MHz to 10,000 MHz. A second discone antenna with the same specifications was used for measurements below 1000 MHz and an omnidirectional antenna with a frequency specification from 300 MHz to 18,000 MHz was used above 1000 MHz. The two system schematics are shown in Fig. 2 and a photo of the two systems located inside the RSMS-4 is shown in Fig. 3.

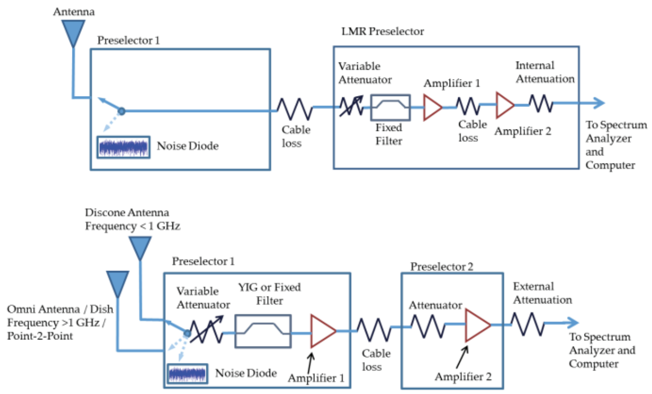

Fig. 2. System schematics for spectrum survey measurements.

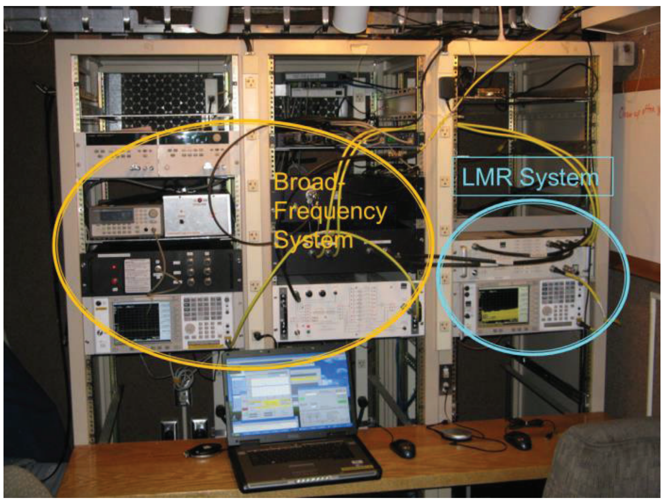

Fig. 3. LMR and broadband systems inside the RSMS.

B. *Measurement Algorithms*

There are four measurement algorithms used in a spectrum survey. We refer to them as:

- Swept-Spectrum Algorithm
- Stepped-Spectrum Algorithm
- Fast-Fourier Transform (FFT) Algorithm
- Azimuthal-Scanning Algorithm

Most measurements below 500 MHz are obtained using a time-domain acquisition with fast Fourier transform (FFT) processing to minimize the effects of impulsive noise. Measurements at other frequencies employ swept-spectrum or stepped-spectrum algorithms using a spectrum analyzer. The azimuthal-scanning algorithm is used to measure fixed microwave links and is not presented in this paper. These tailored algorithms are used to address specific characteristics of the radio emitters in each frequency band. Emissions from the following sources are routinely observed during an RSMS spectrum survey:

- Land-mobile, marine-mobile, and air-mobile communications radios
- Terrestrial, marine, and airborne radars, and airborne radio transmitters
- Radionavigation emitters, such as Tactical Air Navigation (TACAN) and VHF Omnidirectional Range (VOR)
- Cellular and trunked communication systems
- Broadcasting transmitters such as very-high frequency (VHF) and ultra-high frequency (UHF) analog television, digital television (DTV), and multi-point distribution systems (MDS, wireless cable television (TV))
- Industrial, scientific, and medical (ISM) sources, including vehicular tracking systems, welders, and microwave ovens
- Common carrier (point-to-point) microwave signals

C. *Data Presentation*

The following types of graphs are used to represent measured data,

- Maximum, median, mean, and minimum (M4) statistics plots
- Time vs. frequency or waterfall plots
- Field-strength complementary cumulative distribution (FS-CCDF) plots

In this report, swept-spectrum and FFT data are shown using all three graphs mentioned above. These graphs are stacked into one figure. The top graph is the M4 statistical description of the data at each frequency: the peak or maximum value (blue trace), the mean value (black trace), the median value (green trace), the minimum value (red trace), and the mean system noise (magenta trace). These graphs were first introduced in [3] and [4] as Swept/M3 or Swept/M4 measurements. The middle graph shows field strength as a function of frequency and time. These are displayed as contour plots having 20 contoured power levels. Red values indicate relative maximum field strength levels, and blue values indicate relative minimum field strength levels. The bottom graph shows the complementary cumulative distribution functions of the electric field strength (FS-CCDFs) as a function of frequency. The probability that a measured signal exceeds the specified field-strength is shown in the legend. The threshold level (black trace) used to display the time-varying information above the threshold is indicated on the graph as a dashed line. Typically, FS-CCDFs can be used to understand signal types and are useful for displaying the probability that a signal exceeds a certain power or field strength value. The spacing of the lines gives us an indication as to whether a signal is Gaussian-distributed, continuous wave (CW), or another signal type.

Stepped-spectrum measurements are shown using two graphs. The top graph shows the M4 statistics of all individual measurements and the bottom graph shows the individual measurements.

The FS-CCDFs are calculated from the measured probability density function (PDF) at each frequency. A PDF at 116 MHz is shown in Fig. 4. We then calculate the CCDF (Fig. 5) from the PDF and choose equally spaced points along the x-axis, shown by the red x's.

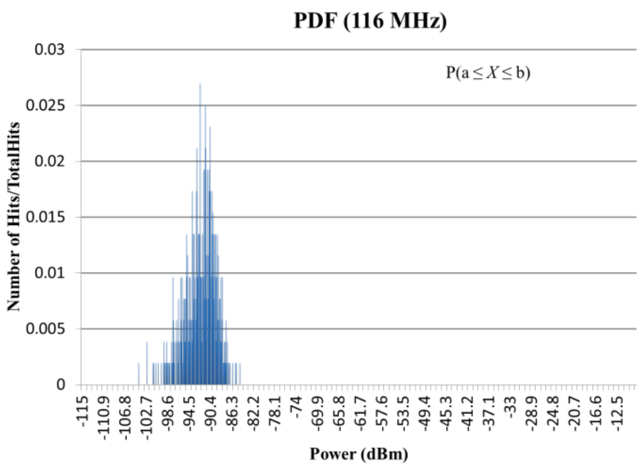

Fig. 4. PDF at 116 MHz from measured data.

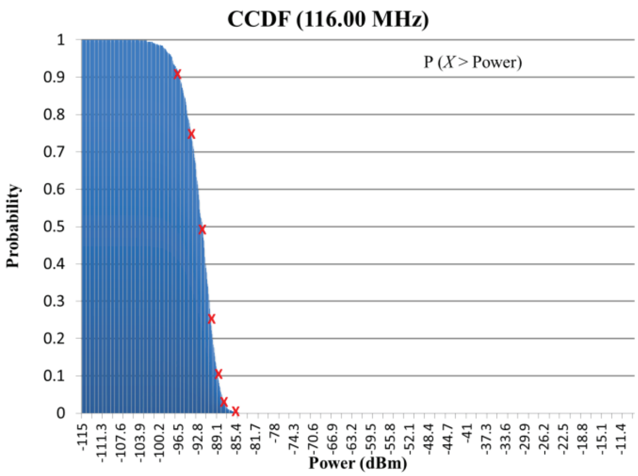

Fig. 5. CCDF at 116 MHz calculated from measured data.

The x- and y-axis are then inverted and these points are plotted on a linear scale to show the difference between different signals types. Fig. 6 and Fig. 7 show measured data plotted on a linearized x-scale, re-labeled with the "percent probability of exceeding ordinate" versus the "power". The various signals are plotted with the system noise where both have been measured using sample detection. Fig. 6 shows measured system noise versus several CW signals at different power levels and Fig. 7 shows measured system noise versus intermittent signals at various power levels. We see in Fig. 7 that if we have a strong CW signal then all probabilities would converge into one point at that frequency. For a strong intermittent signal, the upper points would be separated by a larger spacing than for the lower points.

III. Measurement Results

During the presentation, we will show results for five different frequency bands. The first band is a land-mobile radio (LMR) band, 143 to 149 MHz, which was measured using the FFT algorithm. The second band is a television band, 572–596 MHz, measured using the swept-spectrum algorithm. An ISM band, 902–928 MHz, was measured using the swept-spectrum measurement algorithm. A cellular band from 1900 to 2000 MHz was measured with a swept-spectrum algorithm, and a radar band from 2700 to 2900 MHz was measured using the stepped-spectrum algorithm.

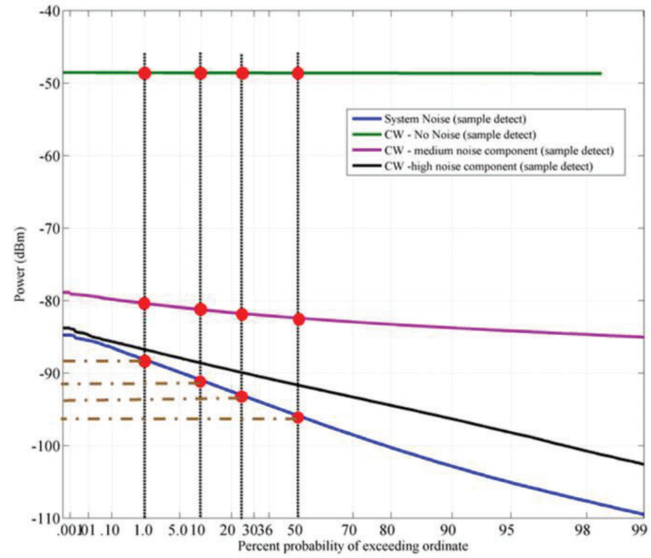

Fig. 6. System noise and CW signals at various power levels plotted on a power complementary cumulative distribution plot.

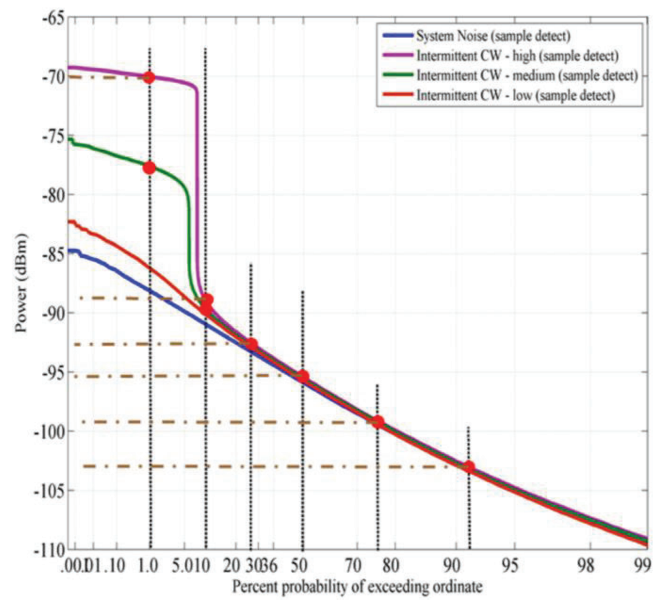

Fig. 7. System noise and intermittent signals at various power levels plotted on power complementary cumulative distribution plot.

In this paper, we limit the discussions to two frequency bands: the LMR band from 143 to 149 MHz and the radar band from 2700 to 2900 MHz. For the first frequency band we show results for each location in the following order: Denver, Table Mountain, and San Diego. For the radar band, we show only results for the Denver location.

A. Land-Mobile Radio Band (143–149 MHz)

Fig. 8, Fig. 9 and Fig. 10 show results for the LMR band from 143 to 149 MHz for the locations of Denver, CO (Fig. 8); Table Mountain, CO (Fig. 9); and San Diego, CA (Fig. 10). These three figures show the difference between measurements made in these locations. In Fig. 8, Fig. 9, and Fig. 10 the maximum field-strengths are about 70 dBμV/m, 90 dBμV/m, and 90 dBμV/m, respectively. These values are valid only at these locations and may change if measured at another location. The waterfall plots seem to indicate more spectrum activity at the Table Mountain location. The FS-CCDF plots capture activity using a probability scale that runs from 0.09% to 96.18%. To understand these plots, we will begin by looking at the probability traces associated with a frequency of 144 MHz. For these values, we look at the bottom trace, which is the probability that a measured power level converted to field strength and referenced to the input of the antenna was exceeded 96.18% of the time. In Fig. 8, a field strength of -2 dBμV/m was exceeded with a probability of 96.18%; in Fig. 9, a field strength of approximately -1 dBμV/m was exceeded with a probability of 96.18%; and in Fig. 10, a field strength of approximately -10 dBμV/m was exceeded with a probability of 96.18%. On the other end of the probability scale, a field strength of approximately 70 dBμV/m was exceeded 0.09% of the time at a frequency of approximately 148.8 MHz as shown in Fig. 8.

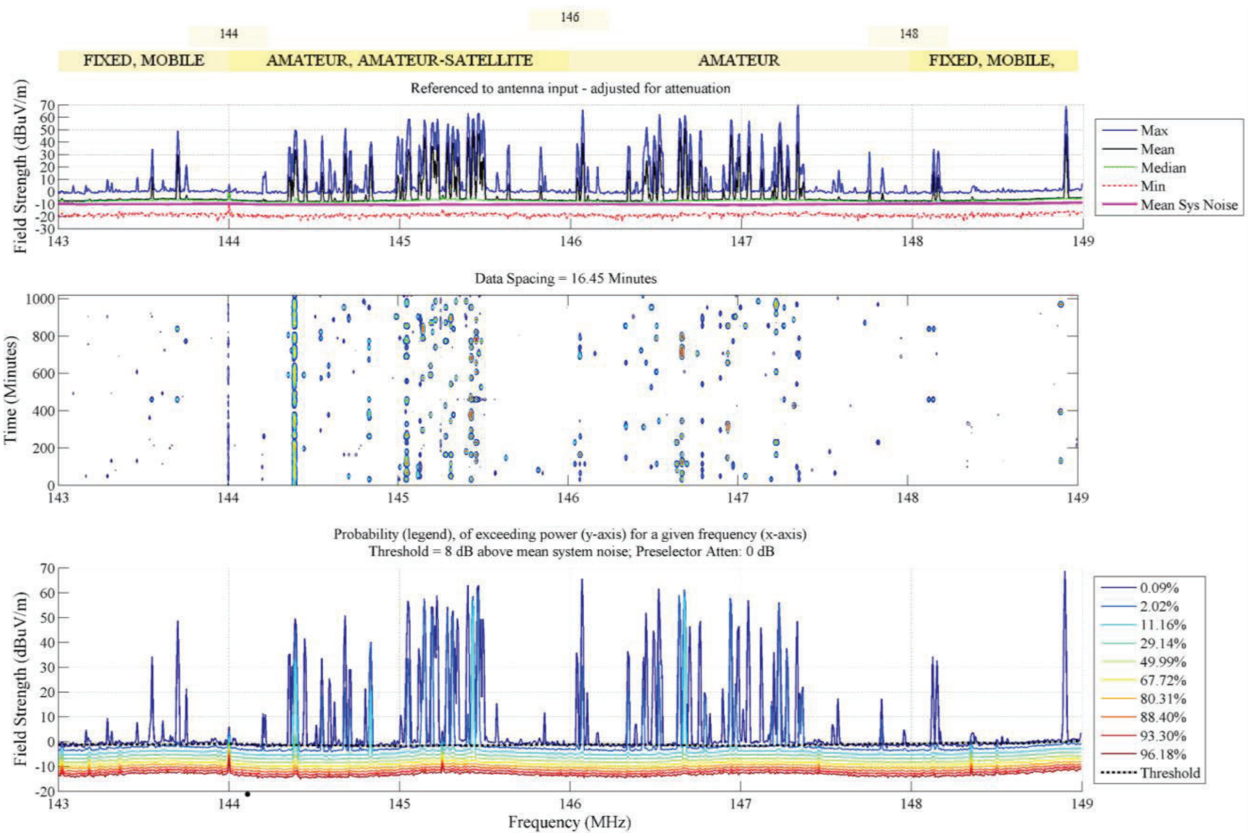

Fig. 8. Spectrum occupancy results for the LMR band in Denver from 143 to 149 MHz.

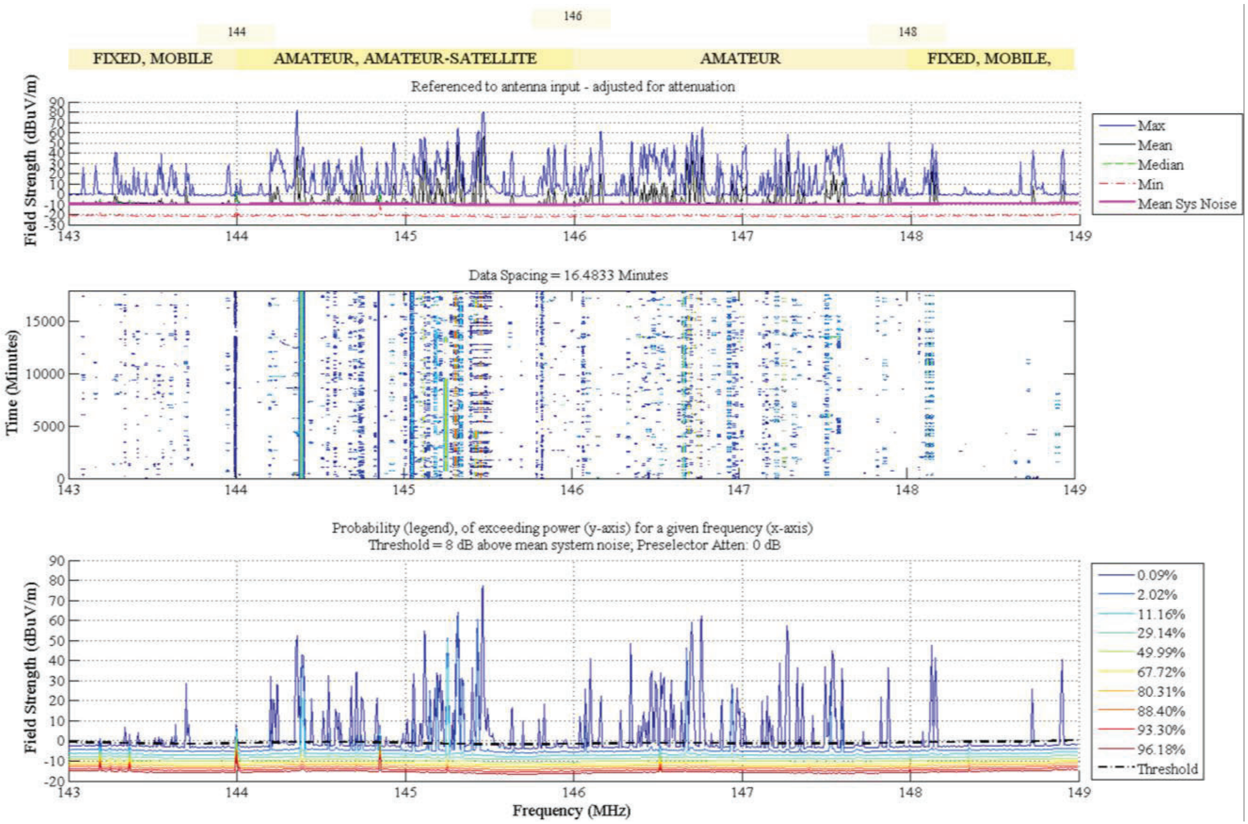

Fig. 9. Spectrum occupancy results for the LMR Band at Table Mountain from 143 to 149 MHz.

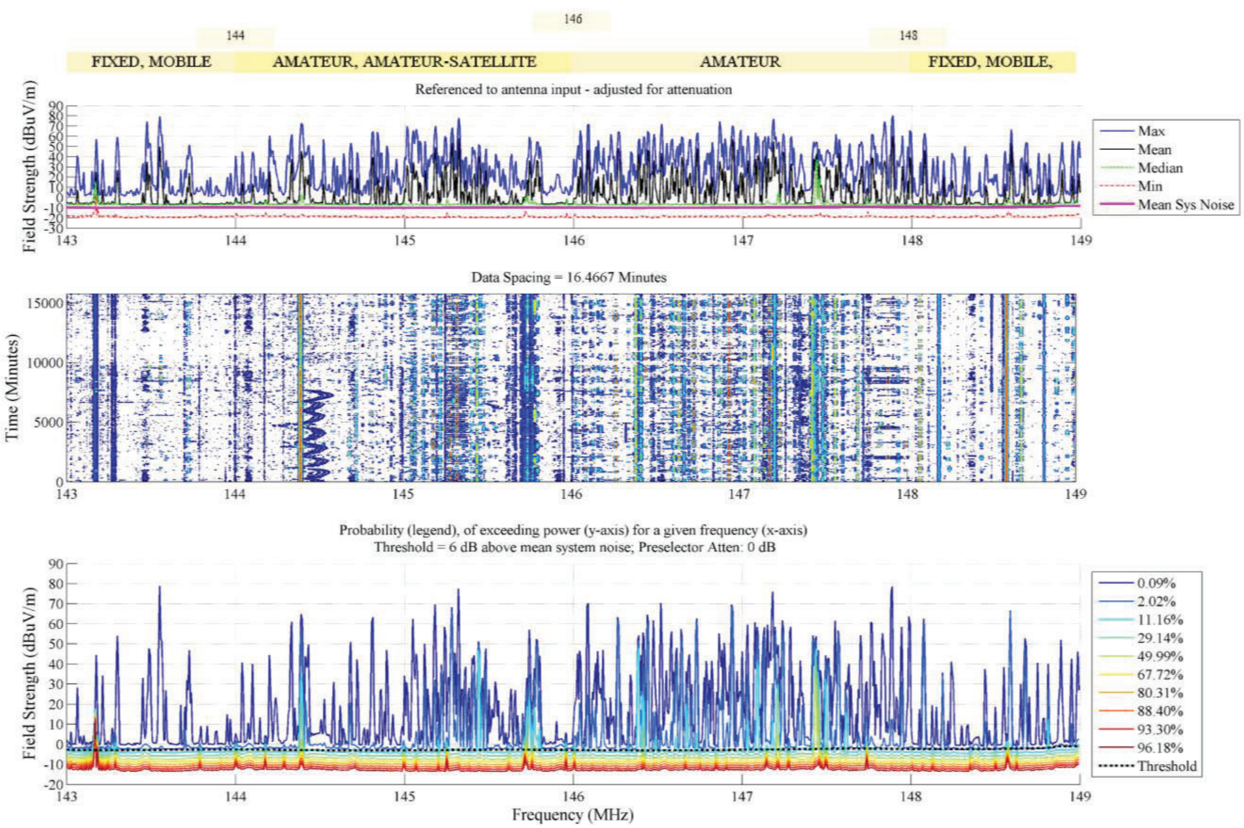

Fig. 10. Spectrum occupancy results for the LMR Band in San Diego from 143 to 149 MHz.

B. Radar Band (2700–2900 MHz)

This section shows results for a radar band from 2700–2900 MHz measured at Denver (Fig. 11), Table Mountain (Fig. 12), and San Diego (Fig. 13). In Fig. 11, the M4 statistics plot shows peak values at approximately 2719 MHz, 2760 MHz, 2782 MHz, 2822 MHz, and 2888 MHz. The bottom graph contains traces for each individual measurement and shows that the radar signal at 2888 MHz was present during all but one sweep, the radar at approximately 2822 MHz was measured three times, and the other signals were measured more than four times. Fewer measurements were performed at Table Mountain, but the same radars were visible there as for Denver because it is just north of Boulder and has a good view of the Denver area. The maximum peak value for the Denver measurements was approximately 140 dBμV/m at 2822 MHz. For Table Mountain the maximum peak value was approximately 130 dBμV/m at 2822 MHz, and in San Diego, the maximum peak value was approximately 150 dBμV/m at 2822 MHz. There was more activity in this radar band in San Diego than at either the Denver or the Table Mountain location.

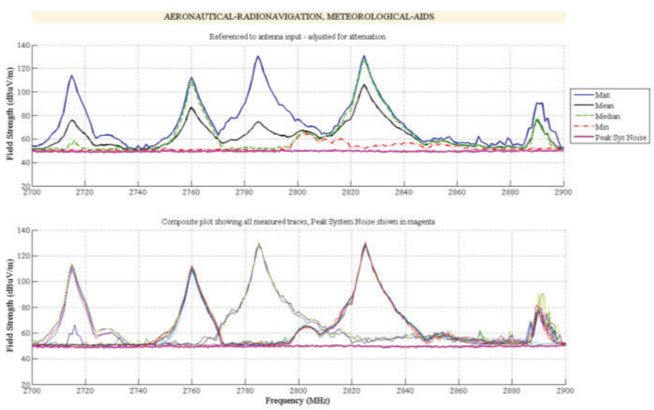

Fig. 11. Spectrum occupancy results for a radar band in Denver from 2700 to 2900 MHz.

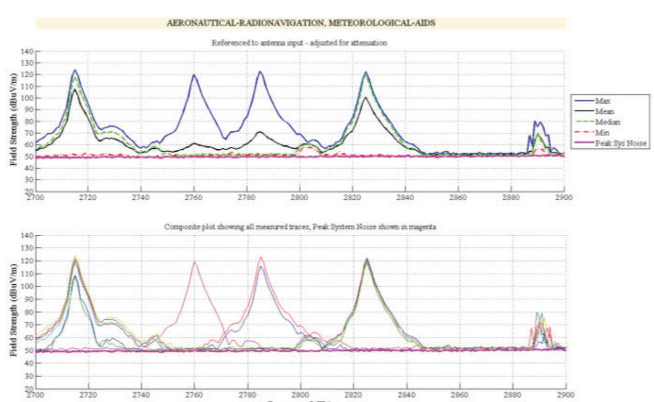

Fig. 12. Spectrum occupancy results for a radar band at Table Mountain from 2700 to 2900 MHz.

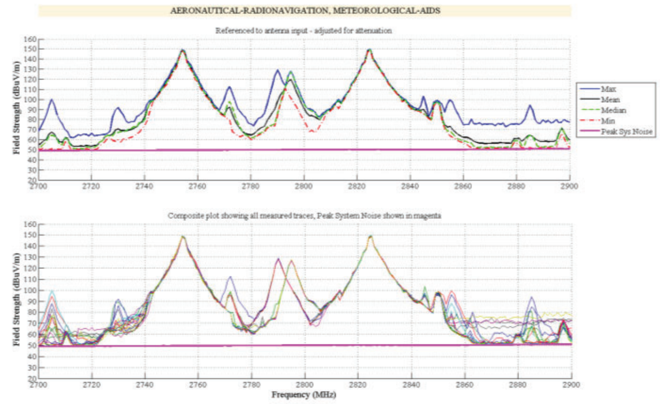

Fig. 13. Spectrum occupancy results for a radar band in San Diego from 2700 to 2900 MHz.

IV. CONCLUSION

We have presented results from three spectrum surveys in Denver, CO; Table Mountain, Boulder, CO; and San Diego, CA. The equipment setup is discussed and we briefly discuss the different measurement algorithms used to measure different emission types. These algorithms are referred to as: swept-spectrum algorithms, stepped-spectrum algorithms, FFT algorithms, and azimuthal-scanning algorithms. This paper focuses on results measured using the FFT algorithm and the stepped-spectrum algorithm, although the conference presentation will look at five frequency bands measured using three of the four algorithms. The results are displayed using various representations of the data: M4 statistics plots, time vs. frequency plots, and FS-CCDF statistical plots.

REFERENCES

[1] NTIA, Manual of Regulations and Procedures for Federal Radio Frequency Management, Chapter 2, U.S. Department of Commerce, National Telecommunications and Information Administration, Washington, D.C., revised May 2011. http://www.ntia.doc.gov/page/2011/manual-regulations-and-procedures-federal-radio-frequency-management-redbook

[2] NTIA, Department Organization Order 25-7, United States Department of Commerce, http://www.osec.doc.gov/opog/dmp/doos/doo25_7.html

[3] Frank Sanders Vincent Lawrence, and Robert Hinkle, “Broadband Spectrum Survey at Denver, Colorado,” NTIA Report 95-321, September 1995, http://www.its.bldrdoc.gov/publications/2353.aspx

[4] F.S. Sanders, B. Ramsey, and V. Lawrence, “Broadband spectrum survey at San Diego, California,” NTIA Report 97-334, December 1996. http://www.its.bldrdoc.gov/publications/2366.aspx