NTIA Report TR-14-498

Broadband Spectrum Survey in the San Diego, California, Area

Chriss Hammerschmidt

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NOTE ON REISSUE

This was the second in a series of three reports presenting measurement data from three separate spectrum occupancy surveys carried out in 2011 and 2012 as part of ongoing research efforts. In preparing the third report for release, we discovered an incorrect display of the mean system noise and the threshold in some images. The process for generating the images was corrected and the images re-generated. In the reissue of this report, Figures 16, 17, and 18 have been replaced with correctly generated images. The measured data was not affected by the pre-publication processing and remains unchanged; only the display of the the mean system noise is changed.

DISCLAIMER

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ABBREVIATIONS/ACRONYMS

ACF	Antenna Correction Factor
ADS-B	Automatic Dependent Surveillance Broadcast
AFSCN	Air Force Satellite Control Network
ANLE	Airport Network and Location Equipment
ARSR	Air-Route Surveillance Radar
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Automated Terminal Information System
ATSC	Advanced Television Systems Committee
AWOS	Automated Weather Observation System
CDF	Cumulative Distribution Function
CCDF	Complementary Cumulative Distribution Function
CW	Continous Wave
dB	Decibel
dBi	Decibel isotropic
dBm	Decibel milliwatt
dBµV	Decibel micro-volt
DC	Direct Current
DCP	Data Collection Platform
DGPS	Differential Global-Positioning System
DIA	Denver International Airport
DME	Distance Measuring Equipment
DOI	Department of Interior

DSCS	Defense Satellite Communications Systems
DSN	Deep Space Network
DTV	Digital Television
DVA	Department of Veterans Affairs
ELT	Emergency Locating Transmitter
EPIRB	Emergency Position-Indicating Radar Beacons
EPLRS	Enhanced Position Location Reporting System
EVA	Extra-Vehicular Activity
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FFT	Fast-Fourier Transform
FS-CCDF	Field-Strength, Complementary Cumulative Distribution Function
GHz	Gigahertz
GMF	Government Master File
GOES	Geostationary Operational Environmental Satellites
GPS	Global Positioning System
IIT	Illinois Institute of Technology
INMARSAT	International Marine/Maritime Satellite
ISM	Industrial, Scientific, and Medical
ITS	Institute for Telecommunication Sciences
JTIDS	Joint Tactical Information Distribution System
kW	Kilowatt
LMR	Land Mobile Radio
LOS	Line-of-sight
LPTV	Low Power Television

LTE	Long Term Evolution
MDS	Multi-point Distribution Systems
MHz	Megahertz
MLS	Microwave Landing System
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NEXRAD	Next-Generation Radar
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NTIA	National Telecommunication and Information Administration
NTSC	National Television Systems Committee
OSM	Office of Spectrum Management
PCS	Personal Communication System
PDF	Probability Distribution Function
PGM	Precision-Guided Munitions
RBW	Resolution Bandwidth
RF	Radio Frequency
RFID	Radio Frequency Identification
RNSS	Radio Navigation Satellite Service
RSMS	Radio Spectrum Measurement Sciences
SA	Spectrum Analyzer
SAR	Synthetic Aperture Radar
SARSAT	Search and Rescue Satellite Aided Tracking
SGLS	Space-Ground Link Station

TACAN	Tactical Air Navigation
TCAS	Traffic Alert and Collision Avoidance System
TDRSS	Tracking and Data Relay Satellite System
TDwFFT	Time-Domain Acquisition with Fast-Fourier Transform Processing
TDWR	Terminal Doppler Weather Radar
TIROS	Television Infrared Operational Satellite
TTC	Telemetry, Tracking and Command
TV	Television
TVWS	Television White Space
U-NII	Unlicensed National Information Infrastructure
UPS	Uninterruptible Power Supply
VBW	Video Bandwidth
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
WAAS	Wide Area Augmentation System
WAPA	Western Area Power Administration
WGS	Wideband Gapfiller Satellite
WLAN	Wireless Local Area Network
YIG	Yttrium Iron Garnet

BROADBAND SPECTRUM SURVEY IN THE SAN DIEGO, CALIFORNIA METROPOLITAN AREA

Chriss Hammerschmidt[1]

NTIA is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the Radio Spectrum Measurement Sciences system to collect spectrum occupancy data for radio frequency assessments. This report shows measured frequency data spanning spectrum from 108 MHz to 10 GHz in the metropolitan area of San Diego, California, during the months of May and June 2012.

Keywords: land mobile radio (LMR); radar emission spectrum; radio spectrum measurements sciences (RSMS); radio frequency environment; spectrum occupancy; spectrum resource assessment; spectrum survey

1 INTRODUCTION

1.1 Background

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. Part of this responsibility is to establish policies concerning spectrum assignment, allocation, and use; and to provide the various departments and agencies with the guidance to ensure that their conduct of telecommunications activities 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 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 radio frequency spectrum utilization. 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. These measurements support agency needs such as Federal spectrum management, usage assessments, interference resolution, and propagation research support. The RSMS-4 measurement vehicle used to conduct the measurements reported here is the fourth generation mobile measurement laboratory developed by NTIA and is equipped with state-of-the-art instrumentation, measurement methods, and analysis capabilities.

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1.2 Purpose of this Survey

Under U.S. Department of Commerce Departmental Organizational Order 25-7 [2], one of the assigned functions of 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.

RSMS measurement activities are carried out as part of ongoing research projects undertaken to fulfill the statutory directive that NTIA conduct research and analysis in the general field of telecommunications sciences. They may also be carried out at the direction of the Office of Spectrum Management (OSM), either on behalf of another Federal agency that has requested assistance from OSM or in support of OSM's mission to meet the spectrum management requirements of NTIA.

This survey of spectrum occupancy in the San Diego area was conducted in 2012 as part of ongoing research efforts. This is the second in a series of new spectrum survey reports. The first report, published in August 2013, describes occupancy survey results in the Denver area [3]. The Denver measurements and the San Diego measurements were performed at locations where previous spectrum surveys were conducted [4], [5]. This enables a comparison between current and previous spectrum occupancy measurements. Two other locations were chosen, Table Mountain and the campus at the Illinois Institute of Technology (IIT) in Chicago, Illinois. Reports on those measurements are being prepared for publication. The Table Mountain location was chosen because this is our research site and we wanted to understand current signal levels. The IIT location provided the opportunity to collect measurements at a location with nearby cellular sites and different terrain than either Denver or San Diego. It also provided an opportunity to compare our methods and results with those of IIT's ongoing spectrum measurement research program.

The spectrum occupancy data presented in this report does not include identification of specific emitters. The data are provided for the spectrum management community to enable a better understanding of how telecommunication systems use the licensed and unlicensed spectrum, and to make available information on current frequency band usage.

These measurements were not intended to assess the feasibility of using alternative services or systems in a band. To generalize spectrum occupancy measurements for such analysis, further consideration must be given to the spectrum management procedures and types of missions performed in each band.

1.3 Report Layout

Section 2 begins by describing criteria used to select a spectrum survey measurement site and describes the measurement site selected for the San Diego, CA Metropolitan Area, spectrum survey. The section also gives a brief description of the measurement system along with the measurement parameters for this spectrum survey. Section 3 presents the measurement results followed by a discussion of frequency bands, the types of signals that exist in the bands and notes about the measurement graphs. Appendix A explains the calculations for the graphs shown in Section 3. Appendix B discusses the operation of radars and how to optimize radar emission measurements.

2 MEASUREMENTS IN THE SAN DIEGO METROPOLITAN AREA

2.1 General Site Selection

The area chosen for a spectrum survey will affect measured spectrum occupancy. For example, measurements taken in a metropolitan area, such as Denver, CO, [3], [4] or Los Angeles, CA, [6] may not represent activity in other metropolitan areas. Some metropolitan areas will lack strong emissions from maritime radionavigation sources or extensive military operations. On the other hand, cities such as San Diego [5] or San Francisco [7], with major naval installations, will show higher levels of usage in bands supporting those operations. We attempt to choose locations that provide the greatest opportunity to measure emissions from the following sources:

- 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), either from ground or airborne transmitters within the range of our measurement system.
- Cellular, broadband wireless, and trunked communication systems
- Broadcasting transmitters such as 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
- Unlicensed National Information Infrastructure (U-NII) systems
- Common carrier (point-to-point) microwave signals
- Satellite earth station uplink transmissions

Potential emissions not normally receivable during spectrum surveys may include:

- Satellite downlink emissions
- Galactic and solar noise
- Some types of spread spectrum signals (such as Global Positioning System codes (GPS))
- Licensed radio transmitters that are turned off
- Receive-only systems, passive sensing systems and systems used for radio astronomy observations.

Choice of measurement site within an area will also affect measured spectrum occupancy. In an area with heavy foliage, rough terrain, or widely dispersed transmitters, multiple measurement locations may be required to accurately characterize usage.

The measurement site must be carefully chosen to intercept a large majority of the signals in the area and to minimize logistical problems. To intercept a large majority of signals in the area the site should:

1. Provide line-of-sight (LOS) coverage so that the probability of intercepting weak signals, such as mobile units, is maximized

2. Limit the number of nearby transmitters to minimize intermodulation or saturation problems, even if preselection and/or filtering is used

3. Limit sources of man-made noise such as impulsive noise from automobile ignition systems and electrical machinery

Primary logistical considerations are:

1. Commercial power to decrease the probability of power interruptions and increase the probability of interruption-free measurements

2. Security for personnel, vehicle, and electronic hardware

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

Spectrum occupancy fluctuates over time for individual assignments associated with the different operations in the bands. For example, frequencies assigned to law enforcement may be used intermittently but are needed for special events. During a special event, such as an emergency, disaster, Olympic Games [8], or Presidential activities, spectrum requirements may change around that event. Regardless of usage, such dedicated channels must be available for any safety-of-life functions and are a spectrum requirement.

Spectrum measurements provide data on expected signal levels and probability of occurrences. Such information is difficult to obtain from the Federal Communications Commission (FCC) or Government Master File (GMF) frequency assignment databases, or from an understanding of spectrum management procedures.

2.2 San Diego Area Measurement Site Description

The selected measurement site reported here is in San Diego, CA. The name of this location is Point Loma and is located about 500 m northwest of the Cabrillo National Monument. The measurement location is shown in Figure 1 and the latitude and longitude are 32°40′39.2″ N and 117°14′38.2″ W. The elevation at this location is 116 meters above mean sea level (MSL). The site is located about 9.5 km west-by-southwest of downtown San Diego and is owned by the

Department of the Interior and maintained by the National Park Service and the Cabrillo National Monument.

The San Diego metropolitan area occupies a low coastal zone that is bounded by high mountains to the east, and rough but lower terrain to the north. It adjoins the city of Tijuana, Mexico, on the southern side of the U.S./Mexico border. Proiminent physical features in the area include Mission Bay, San Diego Bay, and a large peninsula named North Island that forms one side of San Diego Bay. North Island and the bays support extensive naval, commercial shipping, and aviation activities that contribute to spectrum usage. Urban development in the area is extensive.

The RSMS truck was located near one of the maintenance facilities at the Cabrillo National Monument. During the tests, the antenna masts were raised approximately 10 m to get an unobstructed view of the surrounding area. Line-of-sight coverage over the ocean extended to a radius of about 40 km from the RSMS-4 location on the Point. The only structure at the site that was higher than the RSMS-4 antennas was a mast (made of metal and approximately 0.67 m in diameter) about 15 m high and about 80 m from the RSMS-4 location.

The site was well removed from fixed RF transmitters and man-made noise sources such as constant vehicular traffic. Mobile communications originating on Point Loma were primarily associated with the Cabrillo Monument maintenance staff, the Navy Public Works Center, and security patrols. The Point Loma Wastewater Treatment Plant was located over the hill near the water and the Fort Rosecrans National Cemetery is located to the north of Point Loma. There are television transmitters within 20 km of the measurement location. There are also X-band (8 GHz to 12 GHz) transmitters, fixed point-to-point microwave links, and PCS/Cellular antennas approximately 0.6 km from the measurement location.

The former San Diego spectrum report [5], showed areas with line-of-sight coverage and those that are terrain shadowed or non-line-of-sight (see Figure 2, [5]). Some of the line-of-sight coverage will include emissions from Tijuana or other parts of Mexico, south of the border.

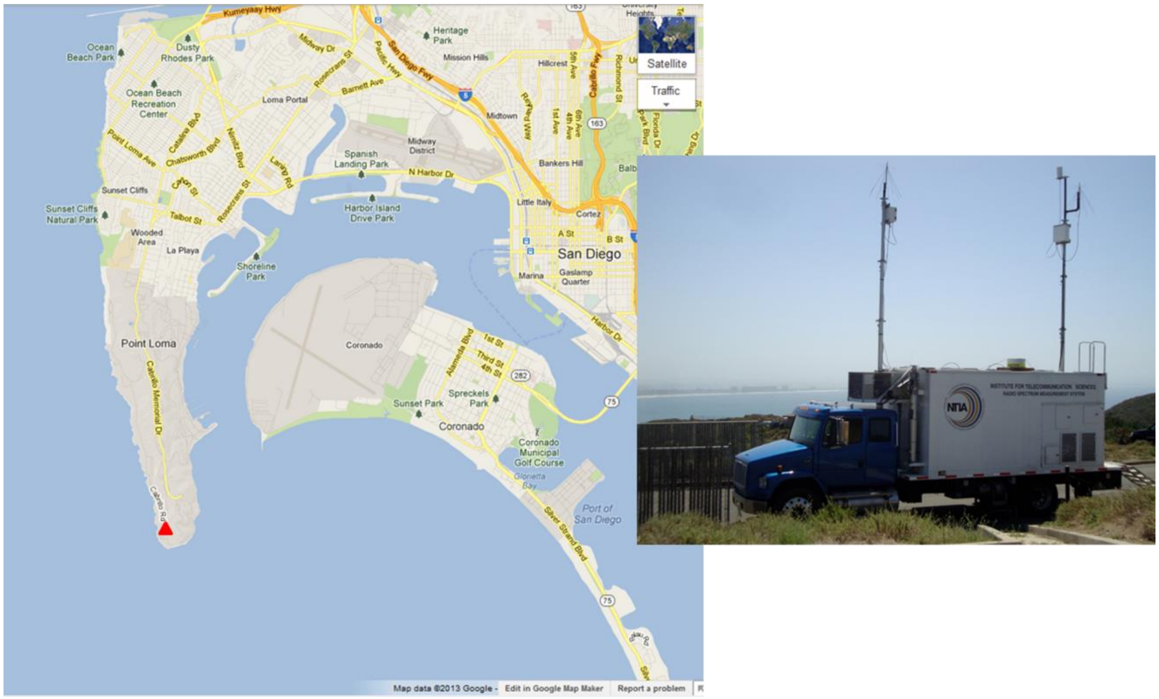

Figure 1. Google Earth® map showing the Point Loma area and the RSMS truck at the measurement location. The red triangle marks the measurement location.

2.3 Measurement System Description

The spectrum survey was conducted from May 30, 2012 to June 14, 2012. The measurement software includes a scheduler so that some bands could be measured more often than others. For example, LMR activity occurs throughout the day but is intermittent and therefore should be measured as often as possible. Television bands can show diurnal variations but are on almost all the time and so are scheduled to be measured at different times during the day and at night but may be measured less frequently than LMR bands. Radar bands are very active in the San Diego area and so are measured often. The measurement schedule was adjusted to obtain a maximal number of measurements in bands where higher signal activity is anticipated.

Each band is measured with a hardware configuration and measurement algorithms specifically designed to give the most useful information about the particular types of signal(s) expected in a frequency sub-band. The measurement hardware and system parameters considered for each signal type and frequency band include: antennas, sweep time, measurement bandwidth, detector mode, measurement repetitions, preselector filters, and preamplifier paths. Some bands contain multiple signal types, which require tailored measurement algorithms to address the specific characteristics of the different types of radio emitters and, therefore, some bands may appear more than once in the report.

The RSMS-4 measurement software is automated to control instrument operation and data capture for each frequency sub-band. The measurements are repeated according to signal intercept probability, signal variability, significance of signal-type and how often it changes, the need for data in specific bands, and efficiency of system resources.

Two separate systems were used. The schematics for both systems are shown in Figure 2. The first system, the LMR system, measures only narrowband signals below 500 Megahertz (MHz) using the following fixed filters: 108–116 MHz, 138–174 MHz, 216–225 MHz, and 406–420 MHz. A discone antenna with a frequency specification from 25 MHz to 1300 MHz was used with the LMR system. These bands are measured consecutively and as often as possible.

The second system, named the broad-frequency system, measures wideband television and LMR signals below 500 MHz and all other signal types from 500 MHz to 10,000 MHz. The broad-frequency system is a more complex system. The preselectors incorporate digitally-tuned, yttrium iron garnet (YIG) and fixed filters in the system. There are different amplifiers for each selected hardware path. A discone antenna similar to that used in the LMR system is used with the broad-frequency system for measurements below 1000 MHz and an omni-directional antenna with a frequency specification from 300 MHz to 18,000 MHz is switched into the broad-frequency system for measurements above 1000 MHz. Measurements of fixed point-to-point microwave transmitters were not conducted during this survey, which includes taking no measurements in the radar altimeter band from 4200 to 4400 MHz.

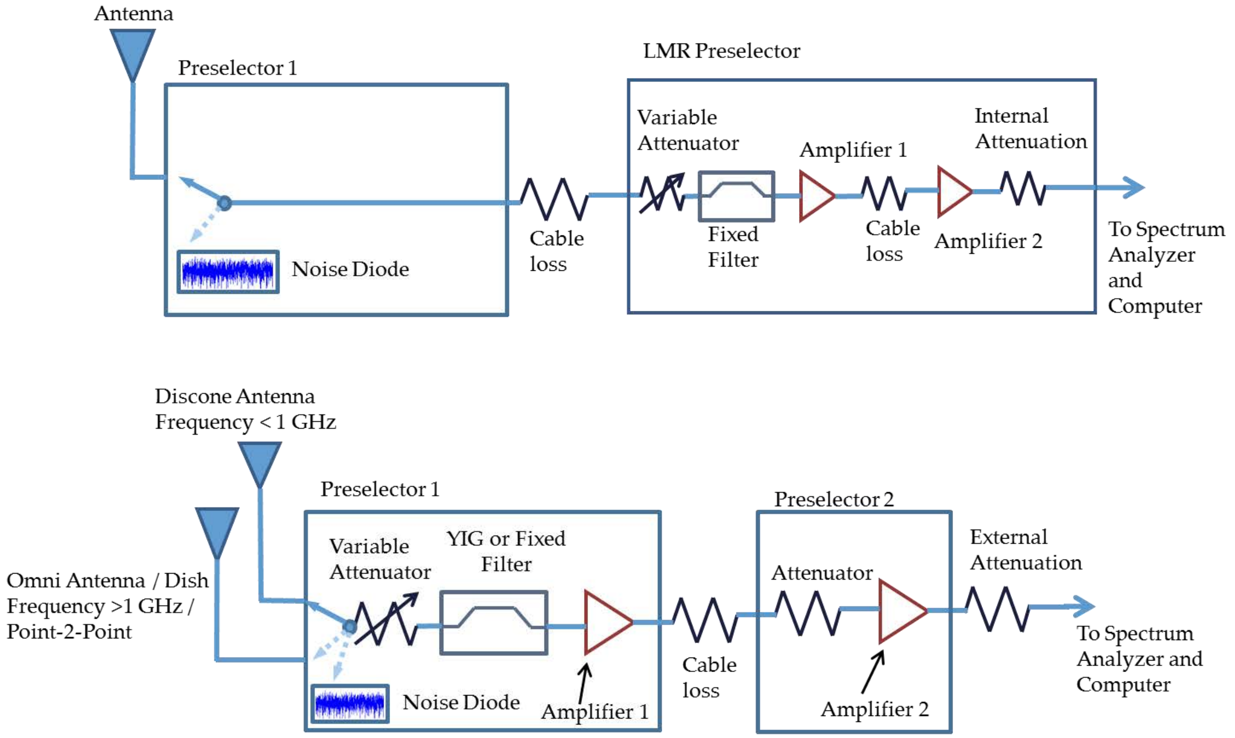

Figure 2. System schematic for the LMR system and the broad-frequency system.

The preselector/preamplifier unit, schematically depicted in Figure 2, serves to extend the dynamic range, improve measurement system sensitivity, and reduce measurement system responses to signals outside the measurement band. The variable attenuator in the first preselector is used to adjust the upper and lower bounds of the dynamic range of the measurement system. More attenuation is used in bands where strong signals may overload the measurement system, and less attenuation is used in bands with weaker signals. RF bandpass filters also help prevent system overloads by limiting the power from out-of-band emissions. The two amplifiers are a cascaded pair; they work together to reduce the measurement system noise figure and thereby improve the system's sensitivity to weak signals. The SA acquires signals and transfers information to a computer. The computer software controls instrument configurations, executes measurement routines, records the measured data, and provides real-time system logs of the measurement start and stop times and any measurement problems that may occur.

Three tailored algorithms are used for these measurements: 1) a time-domain acquisition with fast Fourier transform (FFT) processing algorithm (TDwFFT), 2) a swept-spectrum measurement algorithm (Swept), and 3) a stepped-spectrum measurement algorithm (Stepped). Measurements of frequencies below 500 MHz, independent of the system, use the time-domain acquisition with FFT processing to minimize the effects of impulsive noise. The swept-spectrum measurement algorithm is a general purpose algorithm and is used in bands with multiple signal types or where swept measurements are valid for the emission type. The stepped-spectrum measurement algorithm is used in bands where radar signals exist.

The LMR system measured two scheduled events: a calibration of the system and actual measurements. Events will be described below. Measurements were repeated on an ongoing basis for the full measurement period. These bands were measured approximately 1200 times during the entire measurement period. Calibrations were performed a minimum of every 12 hours for both the LMR system and the broad-frequency system to ensure the systems were operating correctly. Calibrations were accomplished using internal noise diodes and a Y-factor technique [5].

The broad-frequency system was set up to measure the 42 scheduled events shown in Table 1. Column 1 shows the event number. Column 2 shows the type of measurement, the frequency range(s), and the measurement algorithm used. This description is directly related to the measurement filename; for example, event 1 was a calibration in the frequency bands from 116–138 MHz, 406–420 MHz, and 420–476 MHz and was measured using the TDwFFT algorithm. Event 14 was a measurement in the frequency band from 763 to 1000 MHz (which contains signals such as cellular uplinks and downlinks, ISM bands and other miscellaneous signals) and was measured using the swept-spectrum measurement algorithm. These events are called by the scheduler, which schedules each event using the timing parameters shown in columns 3 and 4 of Table 1. Column 3 shows how often the scheduler repeated a measurement. Column 4 shows the minimum number of hours between measurements and Column 5 shows the total number of times the measurement was made during the course of the survey.

For example, measurements of TV bands were repeated ten times during the survey to show they are fixed in frequency and possibly only vary in output power during the day and at night. Radar bands were measured every 10 hours since radars in this area are prevalent in the area. This interval also ensured that we measured some radars in the evening to observe diurnal variations. Measurement events under 500 MHz were repeated as often as possible. The following frequency bands, designated by the 0 in column 4, were also measured as often as possible:

- Cellular_Misc[2]_763–1000 MHz cellular bands
- Narrowband_1000–2000 MHz
- Narrowband_2000–2700 MHz
- Narrowband_2900–4200 MHz
- Misc_4400–5000 MHz
- Misc_5000–7000 MHz
- Misc_7000–8000 MHz
- Misc_8000–9000 MHz
- Misc_9000-10000 MHz

Table 1. Scheduled events for the broad-frequency system.

Event	Description of Measurement (type; frequencies; algorithm)	How measurement is repeated	Minimum Hours Between	Total Times Measured
1	Calibration; 116–138_225–406_420–476 MHz; TDwFFT	Repeat Ongoing	54	6
2	Measurement; 116–138_225–406_420–476 MHz; TDwFFT	Repeat Ongoing	0	22
3	Calibration; TV_174–216_476–500 MHz; TDwFFT	Repeat 10x	46	7
4	Measurement; TV_174–216_476–500 MHz; TDwFFT	Repeat 10x	30	10
5	Calibration; TV_500–608_614–763 MHz; Swept	Repeat 10x	46	7
6	Measurement; TV_500–608_614–763 MHz; Swept	Repeat 10x	30	10
7	Calibration; TVWS_180–210 MHz; TDwFFT	Repeat 2x	200	2
8	Measurement; TVWS_180–210 MHz; TDwFFT	Repeat 2x	200	2
9	Calibration; TVWS_500–608_614–763 MHz; Swept	Repeat 2x	200	2
10	Measurement; TVWS_500–608_614–763 MHz; Swept	Repeat 2x	200	2
11	Calibration; Radar_420–450 MHz; Stepped	Repeat Ongoing	46	7
12	Measurement; Radar_420–450 MHz; Stepped	Repeat Ongoing	10	21
13	Calibration; Cellular_Misc_763–1000 MHz; Swept	Repeat Ongoing	46	7
14	Measurement; Cellular_Misc_763–1000 MHz; Swept	Repeat Ongoing	0	21
15	Calibration; Radar_902–928 MHz; Stepped	Repeat Ongoing	46	7
16	Measurement; Radar_902–928 MHz; Stepped	Repeat Ongoing	10	21
17	Calibration; Narrowband_1000–2000 MHz; Swept	Repeat Ongoing	46	7
18	Measurement; Narrowband_1000–2000 MHz; Swept	Repeat Ongoing	0	21
19	Calibration; Radar_1215–1400 MHz; Stepped	Repeat Ongoing	46	7
20	Measurement; Radar_1215–1400 MHz; Stepped	Repeat Ongoing	10	21
21	Calibration; Narrow_2000–2700 MHz; Swept	Repeat Ongoing	46	7
22	Measurement; Narrow_2000–2700 MHz; Swept	Repeat Ongoing	0	21

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[2] Misc refers to other miscellaneous signals that may be present in this frequency band.

Event	Description of Measurement (type; frequencies; algorithm)	How measurement is repeated	Minimum Hours Between	Total Times Measured
23	Calibration; Radar_2700–2900 MHz; Stepped	Repeat Ongoing	46	7
24	Measurement; Radar_2700–2900 MHz; Stepped	Repeat Ongoing	10	20
25	Calibration; Radar_2900–3650 MHz; Stepped	Repeat Ongoing	46	7
26	Measurement; Radar_2900–3650 MHz; Stepped	Repeat Ongoing	10	20
27	Calibration; Narrowband_2900–4200 MHz; Swept	Repeat Ongoing	46	7
28	Measurement; Narrowband_2900–4200 MHz; Swept	Repeat Ongoing	0	20
29	Calibration; Radar_5250–5925 MHz; Stepped	Repeat Ongoing	46	7
30	Measurement; Radar_5250–5925 MHz; Stepped	Repeat Ongoing	10	20
31	Calibration; Misc_4400–5000 MHz; Swept	Repeat Ongoing	46	7
32	Measurement; Misc_4400–5000 MHz; Swept	Repeat Ongoing	0	20
33	Calibration; Misc_5000–7000 MHz; Swept	Repeat Ongoing	46	7
34	Measurement; Misc_5000–7000 MHz; Swept	Repeat Ongoing	0	20
35	Calibration; Misc_7000–8000 MHz; Swept	Repeat Ongoing	46	7
36	Measurement; Misc_7000–8000 MHz; Swept	Repeat Ongoing	0	20
37	Calibration; Misc_8000–9000 MHz; Swept	Repeat Ongoing	46	14
38	Measurement; Misc_8000–9000 MHz; Swept	Repeat Ongoing	0	38
39	Calibration; Misc_9000–10000 MHz; Swept	Repeat Ongoing	46	14
40	Measurement; Misc_9000–10000 MHz; Swept	Repeat Ongoing	0	38
41	Calibration; Radar_8500–10000 MHz; Stepped	Repeat Ongoing	46	7
42	Measurement; Radar_8500–10000 MHz; Stepped	Repeat Ongoing	10	7

Each scheduled event is described by a unique set of parameters that include the instrument setup, measurement events, and data collection subroutines. Each event also contains measurement parameters such as start and stop frequency, sweep time, the number of points per trace, the resolution bandwidth (RBW), the video bandwidth (VBW), detector type, filter type, and preselector attenuation. Table 2 shows generic parameters for scheduled events for the different measurement algorithms discussed above.

The swept, and stepped algorithms have similar parameters because they used the spectrum mode of the spectrum analyzer. The time-domain parameters are different because they use the basic mode of the spectrum analyzer.

Table 2. Sample events for measurement algorithms.

Parameter	Swept	Stepped
RBW (MHz)	0.3	1.0
VBW (MHz)	0.3	1.0
Start Frequency (MHz)	4400	2900

Time-domain parameter	FFT processing
RBW (kHz)	6.25
Span (kHz)	4.1
1st Channel (MHz)	108

Parameter	Swept	Stepped
Stop Frequency (MHz)	5000	3650
Sweep Time (ms)	1000	12000
Points/Trace	2001	8192
Preselector Antenna Ports	2-1	2-1
Detector Type	Average	Positive Peak
Filter Type	Fixed	Fixed or Tunable
Preselector Attenuation (dB)	0	Auto
Sweeps/Event	100	751
Step size (MHz)		1

Time-domain parameter	FFT processing
kHz/Channel (kHz)	6.25
Channels/Band	640
Points/RBW	10
Traces/Median	5
Event Acquisition Time (min)	1.1
Time/median (sec)	0.9
Window type	Flattop
Preselector Attenuation (dB)	30
Preselector Antenna Ports	2-1
Filter Center Frequency (MHz)	110

After the survey is completed additional processing is necessary to obtain statistical descriptions of the data. These processing steps are briefly described in the following section.

3 MEASURED DATA

There are over 220 individual processed events. Where possible, we have combined events to minimize the report graphs while providing useful clarity. The graphs are generated from the measurement data using a MATLAB® script developed at ITS. This script has limitations, such as layout restrictions that may result in label truncation or displacement. The script also has advantages, such as being able to pull information from the FCC and GMF databases to show assignments directly in the report graph.

The frequency allocations, shown in the yellow strips at the top of each figure, are taken from the United States Frequency Allocation Chart [9] in which the names of primary services are printed in capital letters, and secondary services are printed in upper and lower case. The numbers shown above the allocation bar are the band-edge frequencies for the allocations. Some of the frequency allocation information is truncated in the boxes above the graphs due to the band edge labels.

There are two presentations of data in this report. Swept-spectrum and TDwFFT data are shown using three graphs and stepped-spectrum measurements are shown using two graphs.

When three graphs are shown on a page, the top graph is the statistical description of the data at each frequency: the 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 are referred to in this report as the M4 statistics plots. These were introduced in [4]–[7] as Swept/m3 or Swept/m4 measurements. The middle graph shows field strength as a function of frequency and time and is commonly referred to as a waterfall plot. These are displayed as contour plots having 20 contoured field-strength 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 field-strength on the y-axis is shown in the legend.

The threshold level, shown by the dashed black trace in the bottom plot, is used to display the data in the middle plot (field strength as a function of time and frequency). Threshold levels are either set to minimize the display of impulsive noise without excluding low-level signals, such as in frequencies below 500 MHz, or set to a field-strength level that is likely to be exceeded by the system noise less than 0.01% of the time. The thresholds set for various bands are summarized in Table 3 and are restated above the FS-CCDF plots. Typically FS-CCDFs can be used to understand signal types and are useful for displaying the probability that a signal exceeds a certain field-strength level. The spacing of the lines gives us an indication as to whether a signal is Gaussian-distributed, pulsed continuous-wave (CW), or another signal type and also is indicative of the measurement algorithm used.

Table 3. Threshold levels for measured frequency ranges.

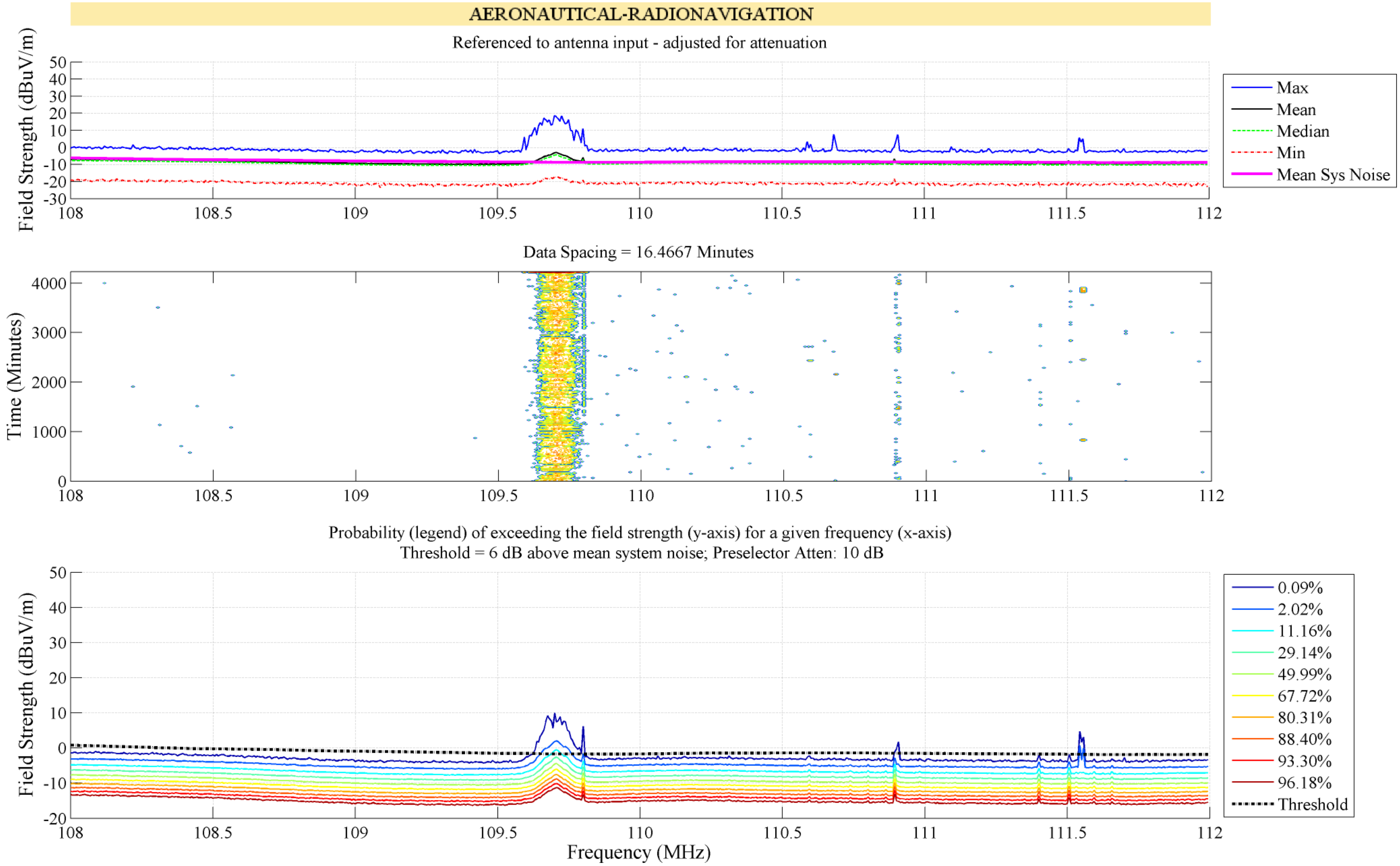
Frequency Range (MHz)	**Threshold Level (dB above mean system noise)**
108 – 116	6
116 – 149	10
149 – 174	6
174 – 216	4
216 – 225	6
225 – 406	10
406 – 420	6
420 – 500	10
500 – 4200	6
4400 – 10,000	1

Radar or stepped measurements are shown using two graphs. The top graph shows the M4 statistics and peak system noise statistics, and the bottom graph shows the individual traces so that changes in the radar characteristics, such as frequency tuning, can be differentiated.

Data presented in these graphs is affected by both the measurement parameters given in Table 2 and the post-processing algorithms. Each graph is plotted with a unique field-strength scale to see more detail in the plots. Field strength is referenced to the antenna input and calculated so that measurements from different systems can be compared. The notation "Referenced to antenna input – adjusted for attenuation" in each graph means that any losses due to the antenna or cables and attenuators between the preselector and the input of the antenna are accounted for.

The data presentation in each graph is intended to best describe the signal environment within its measured frequency band or bands. The measurement range of the receiving system is dependent on the system sensitivity in each band. Based on the measurement parameters, algorithms, and statistical analysis, we believe that these data represent a good statistical sampling of the activity in the radio spectrum in the San Diego area. Maximum and minimum activity levels measured in the spectrum are representations of actual activity levels. The mean and median levels provide an unbiased, quantitative estimate of typical received field-strength levels as a function of frequency. While the data presented here can be used to infer the density of frequency occupancy, it cannot be used to infer the statistical percentage of time that channels are occupied. Two reasons for this are: 1) the RBW is not always set equal to the channel bandwidth, and 2) some events are measured only intermittently, therefore a complete set of statistics is not available. To obtain data for the latter purpose, a dedicated time-occupancy study similar to previously reported LMR occupancy studies [8], [10] should be performed.

The following figures show results from the spectrum survey. Discussions about each graph follow after the data in Section 3.1. Only the allocation information necessary to understanding the signals represented in the figure being discussed is given in the notes column of Table 4. This allocation information is taken from the FCC Online Table of Frequency Allocations [11] and the Federal Spectrum Use Summary [12]. For a complete description of the allocations, the reader is referred to [1], [9], [11], or [12].



AERONAUTICAL-RADIONAVIGATION

Referenced to antenna input - adjusted for attenuation

Data Spacing = 16.4667 Minutes

Probability (legend) of exceeding the field strength (y-axis) for a given frequency (x-axis)
Threshold = 6 dB above mean system noise; Preselector Atten: 10 dB

Figure 3. NTIA spectrum survey results from 108 to 112 MHz in San Diego, CA, May/June 2012.

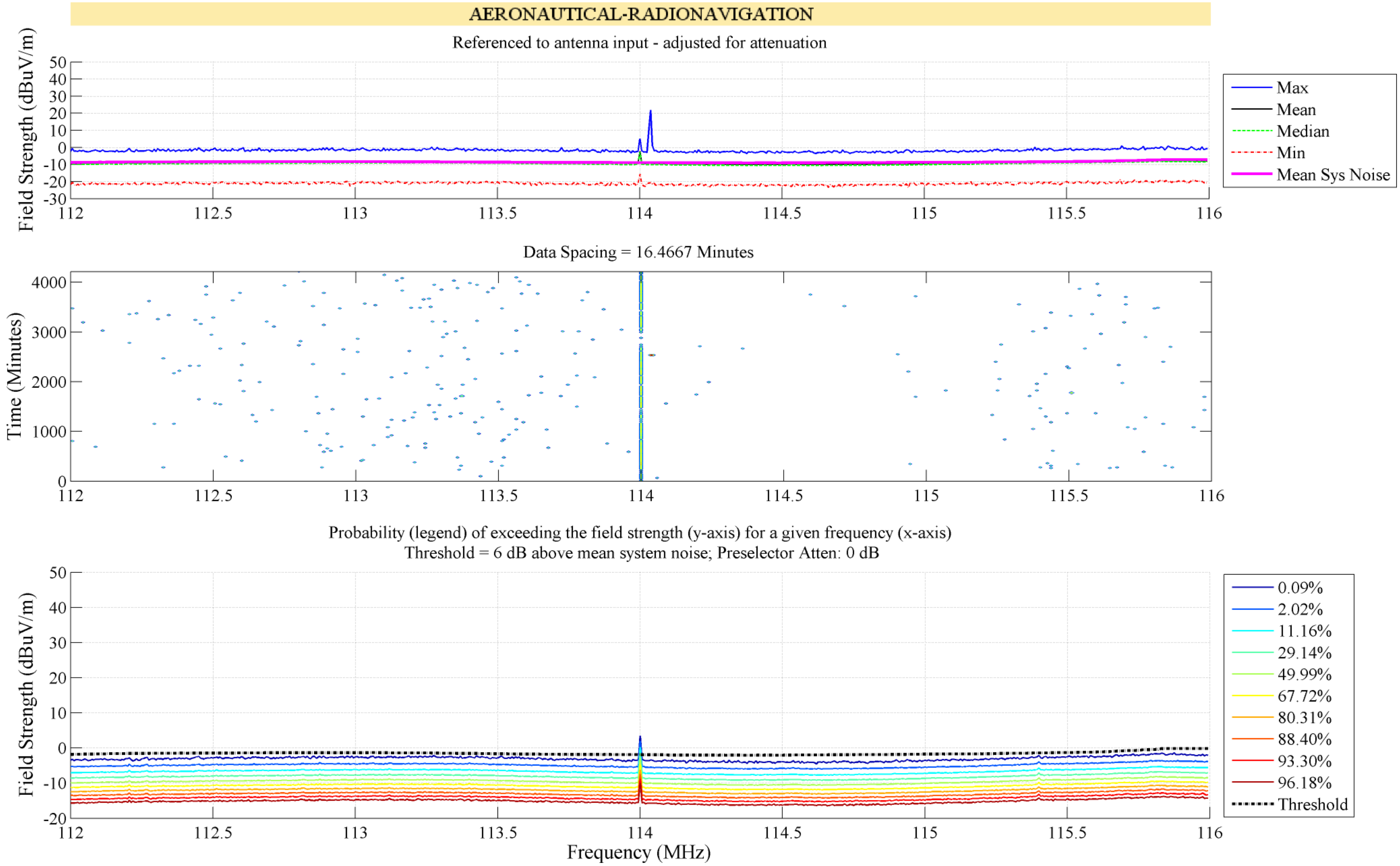


Figure 4. NTIA spectrum survey results from 112 to 116 MHz in San Diego, CA, May/June 2012.

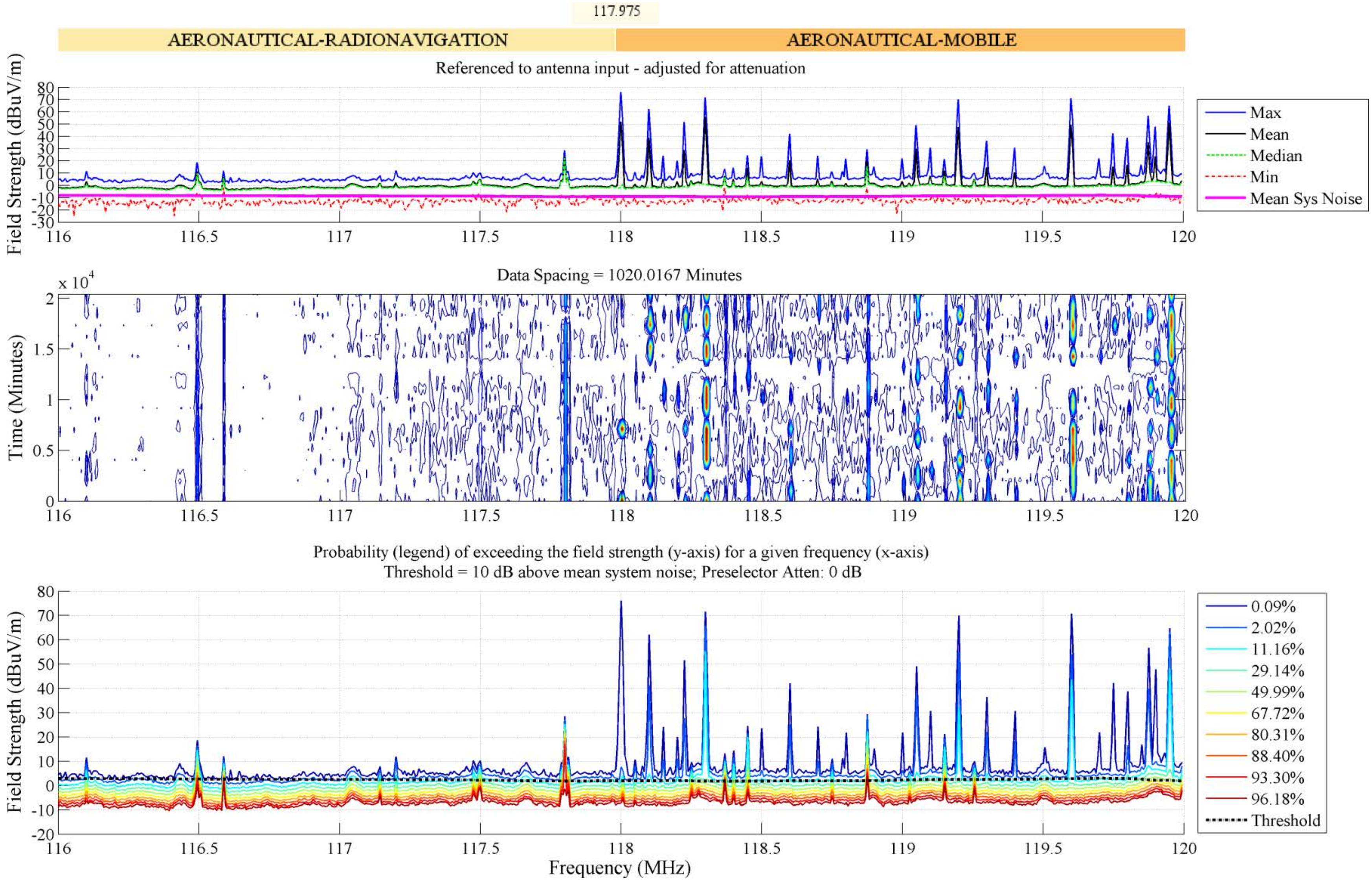


Figure 5. NTIA spectrum survey results from 116 to 120 MHz in San Diego, CA, May/June 2012.

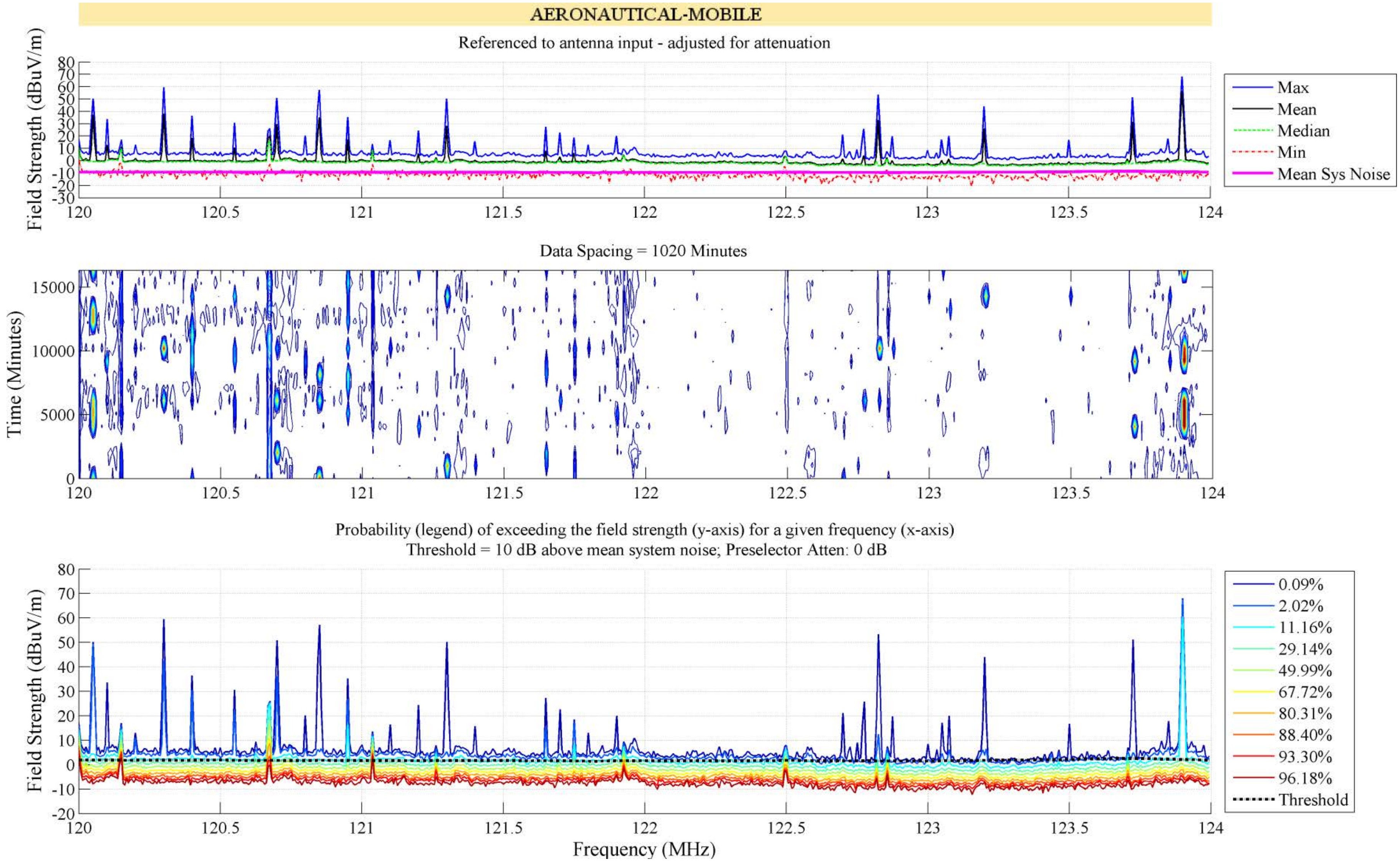


Figure 6. NTIA spectrum survey results from 120 to 124 MHz in San Diego, CA, May/June 2012.

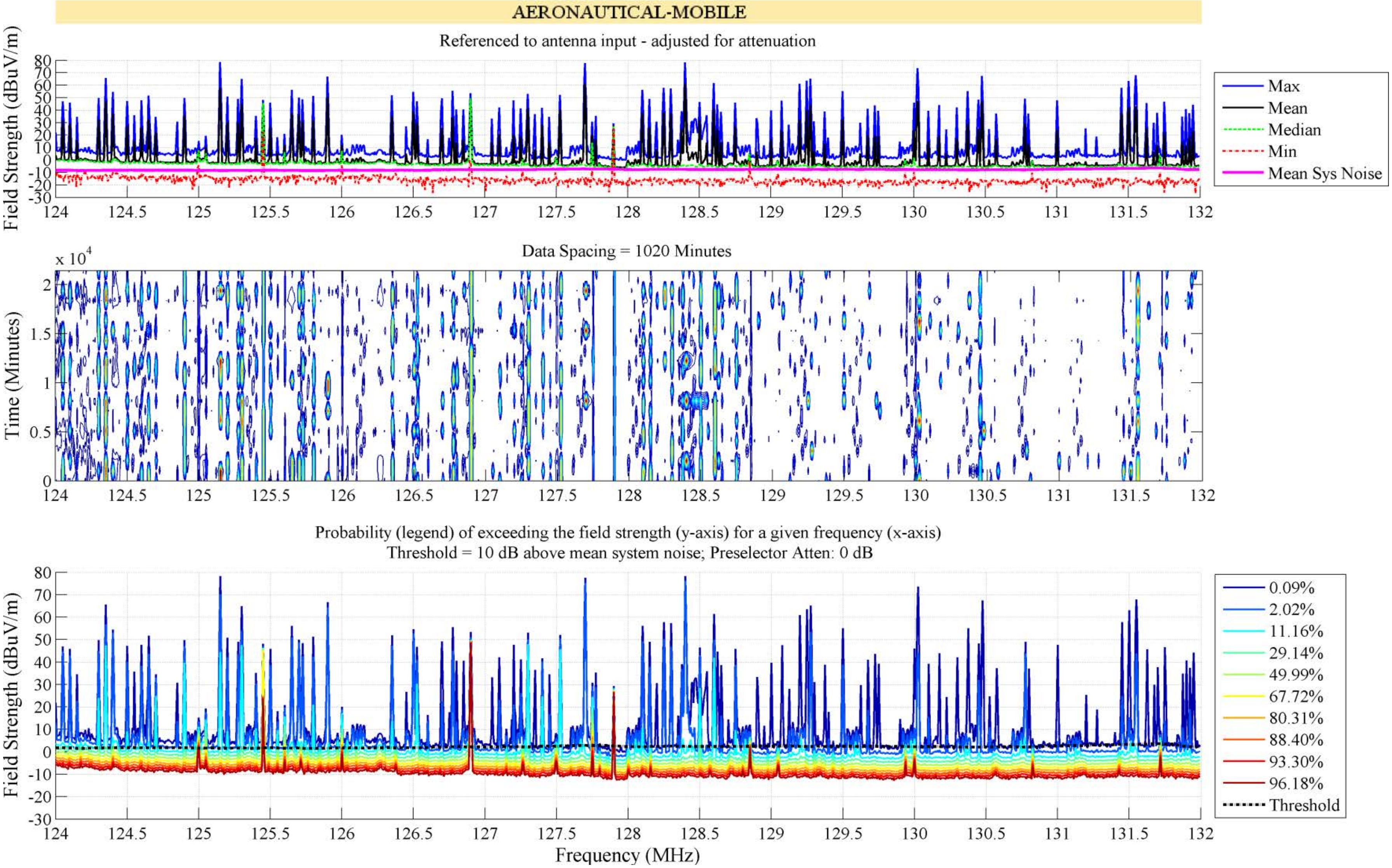


Figure 7. NTIA spectrum survey results from 124 to 132 MHz in San Diego, CA, May/June 2012.

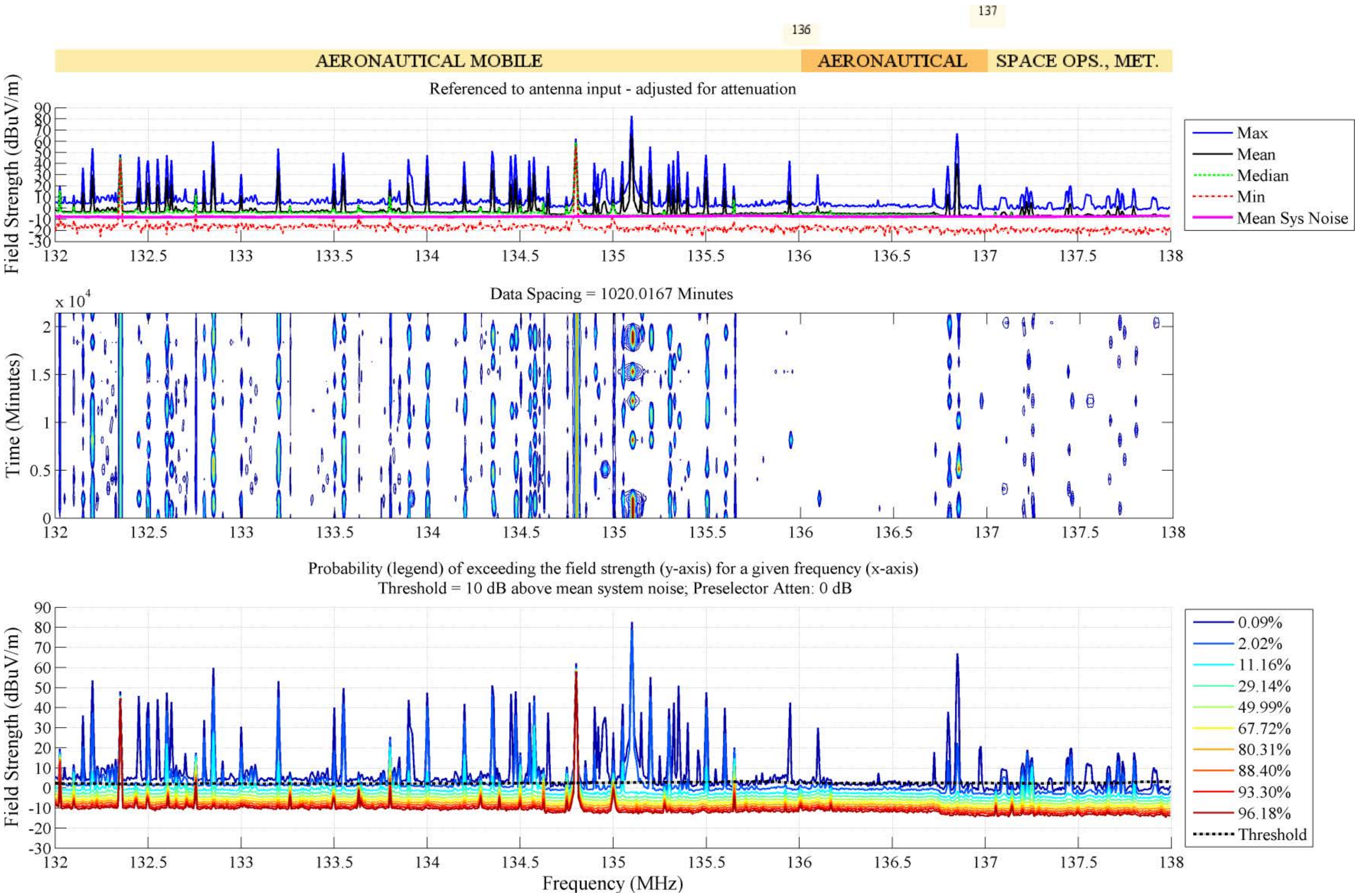


Figure 8. NTIA spectrum survey results from 132 to 138 MHz in San Diego, CA, May/June 2012.

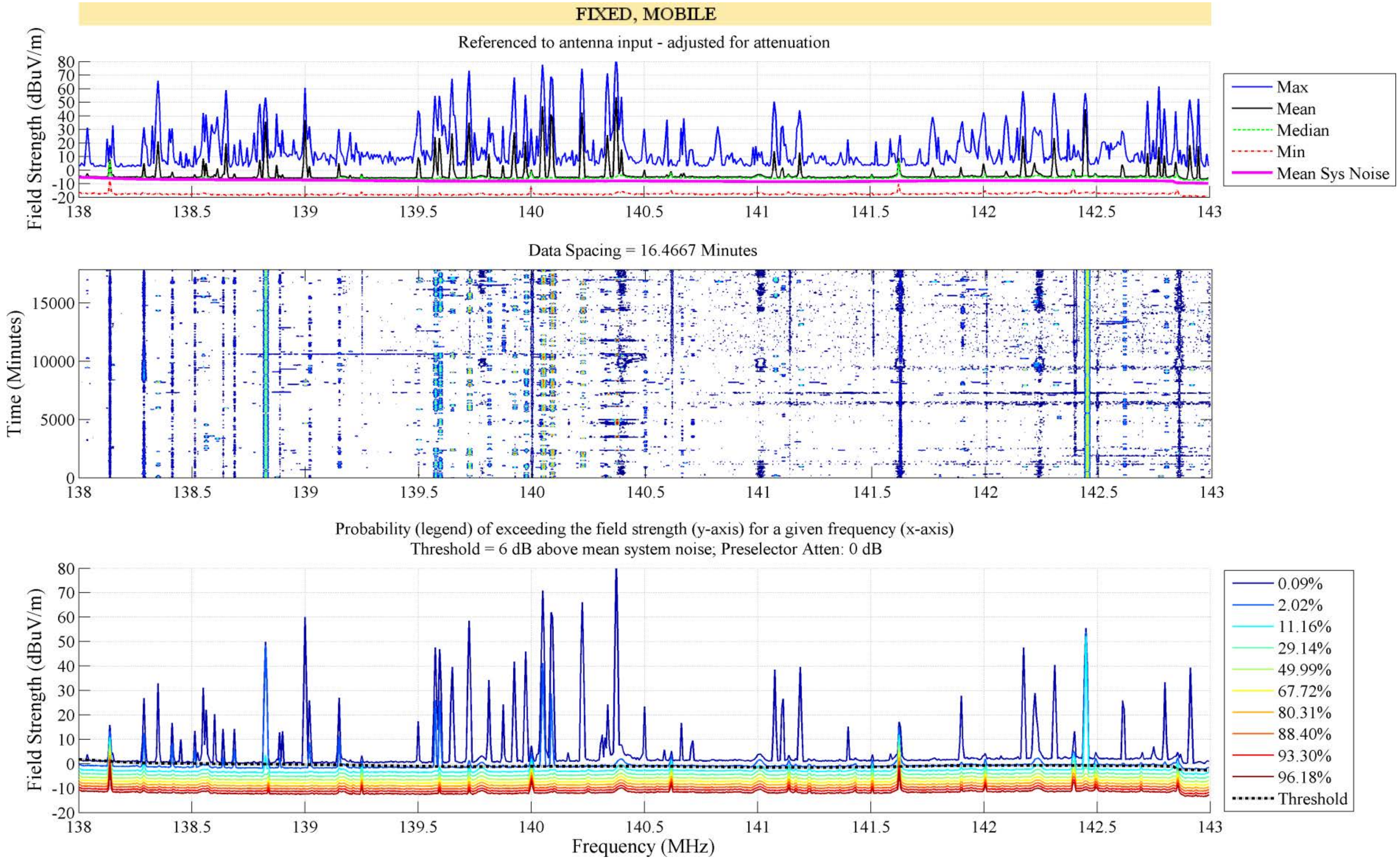


Figure 9. NTIA spectrum survey results from 138 to 143 MHz in San Diego, CA, May/June 2012.

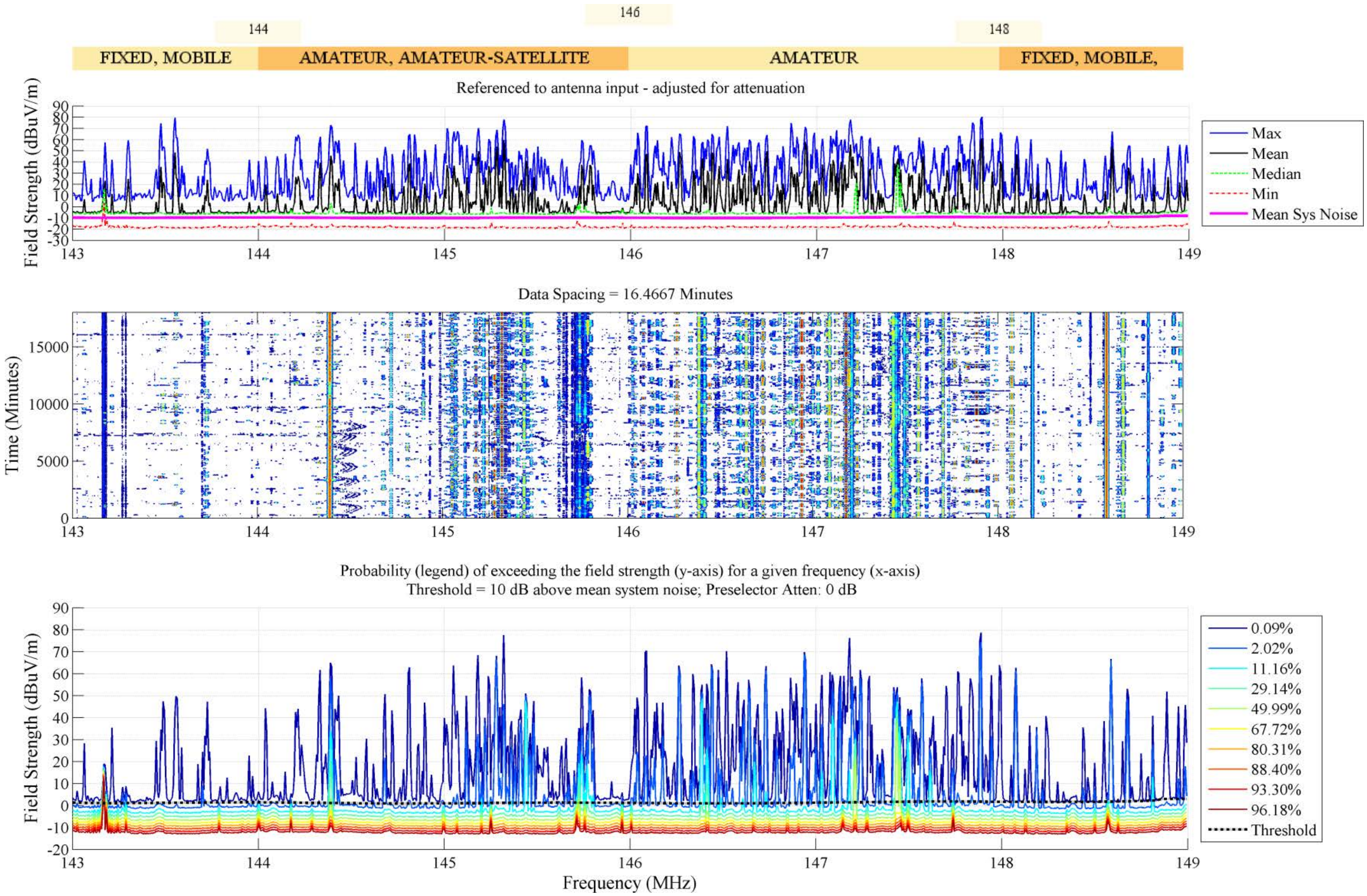
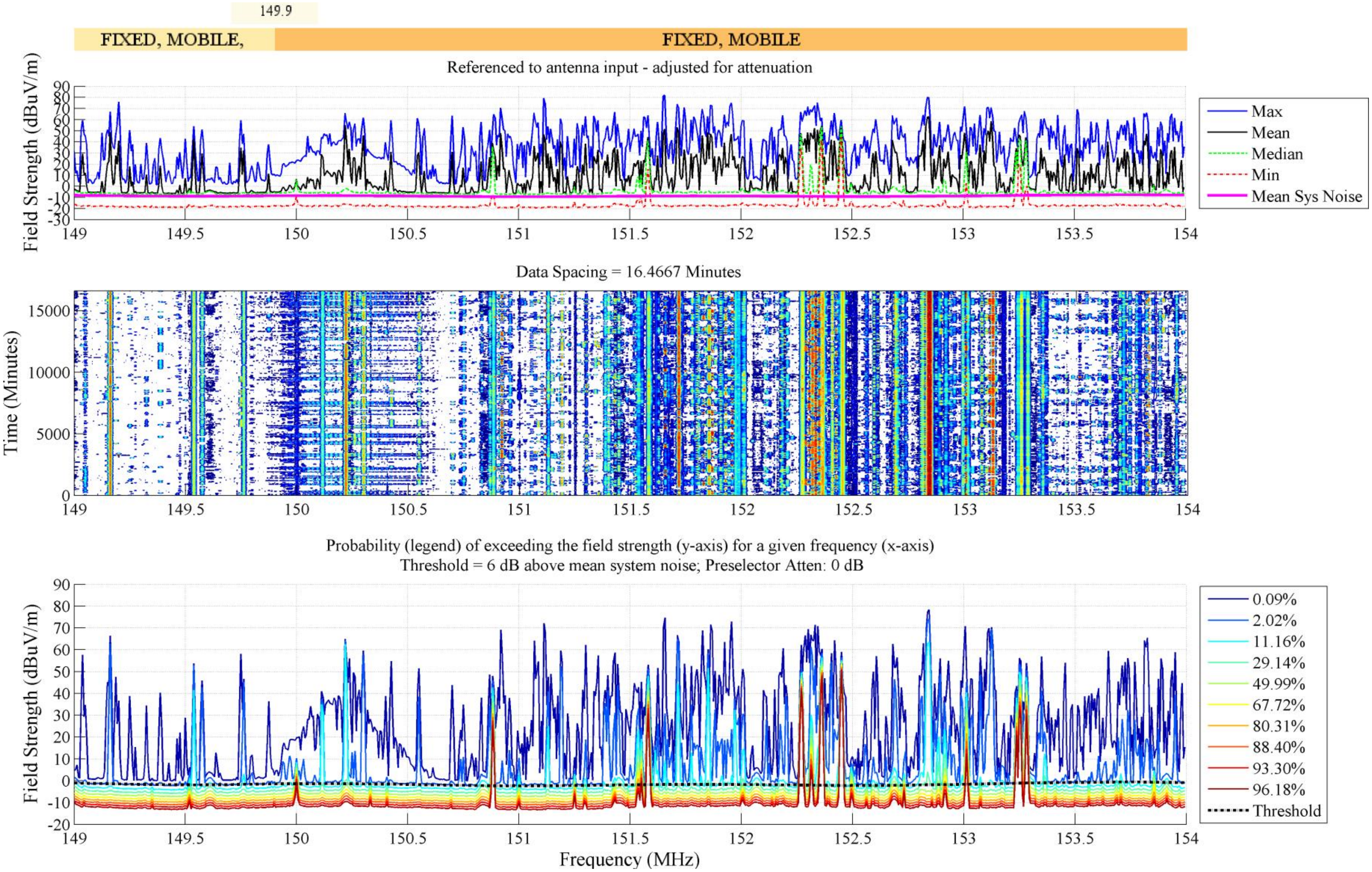


Figure 10. NTIA spectrum survey results from 143 to 149 MHz in San Diego, CA, May/June 2012.



Referenced to antenna input - adjusted for attenuation

Data Spacing = 16.4667 Minutes

Probability (legend) of exceeding the field strength (y-axis) for a given frequency (x-axis)
Threshold = 6 dB above mean system noise; Preselector Atten: 0 dB

Figure 11. NTIA spectrum survey results from 149 to 154 MHz in San Diego, CA, May/June 2012.

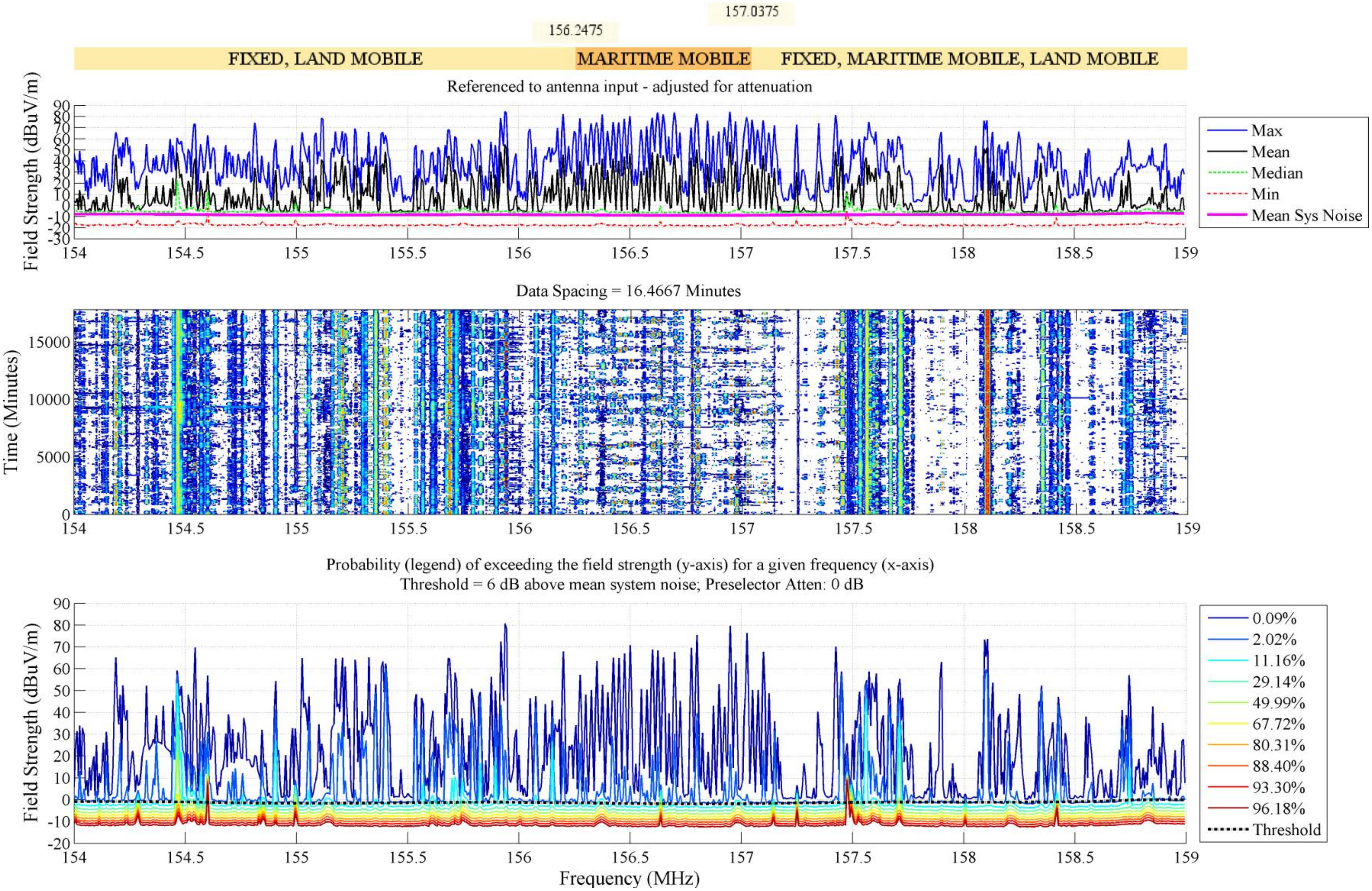


Figure 12. NTIA spectrum survey results from 154 to 159 MHz in San Diego, CA, May/June 2012.

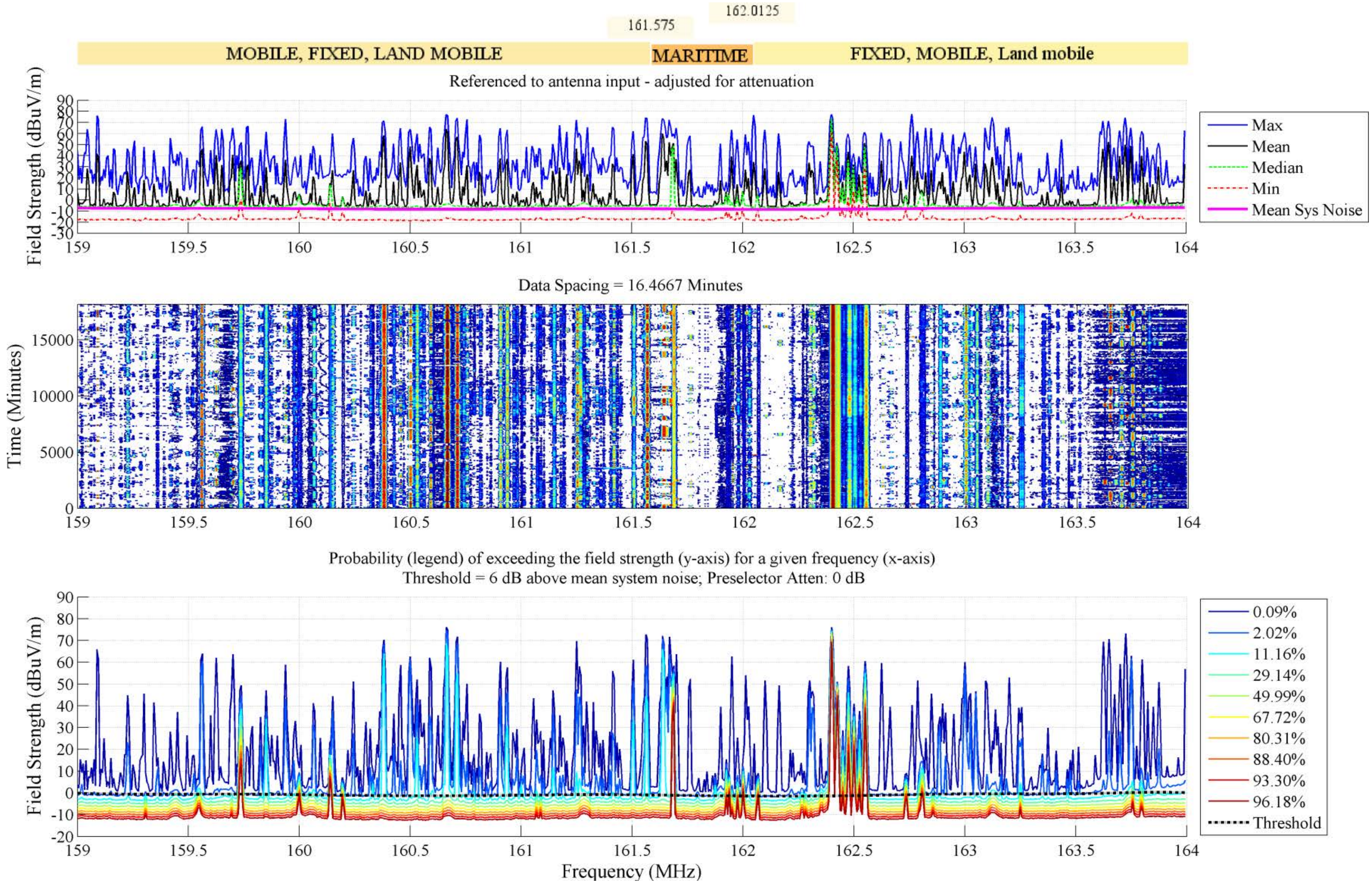


Figure 13. NTIA spectrum survey results from 159 to 164 MHz in San Diego, CA, May/June 2012.

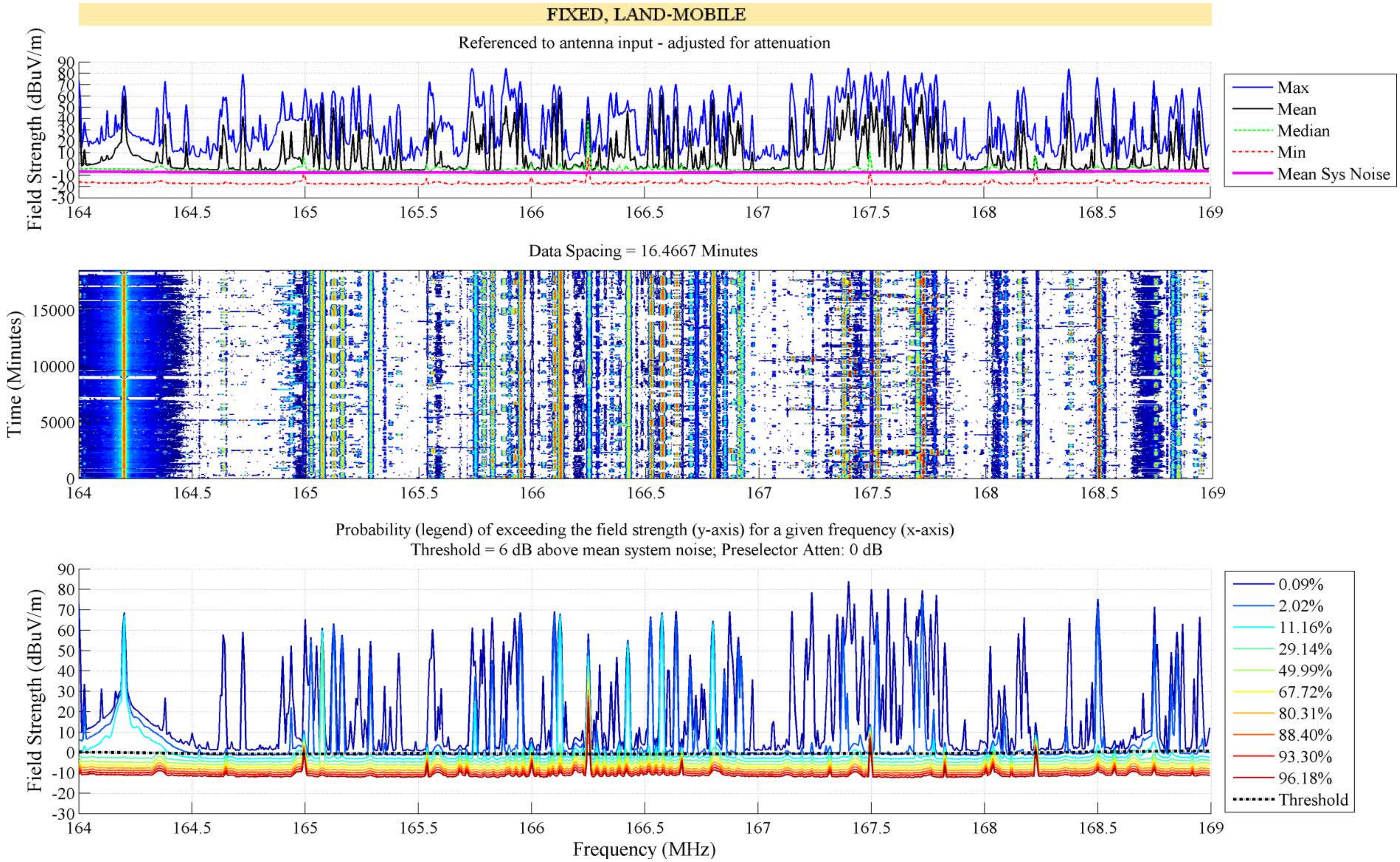


Figure 14. NTIA spectrum survey results from 164 to 169 MHz in San Diego, CA, May/June 2012.

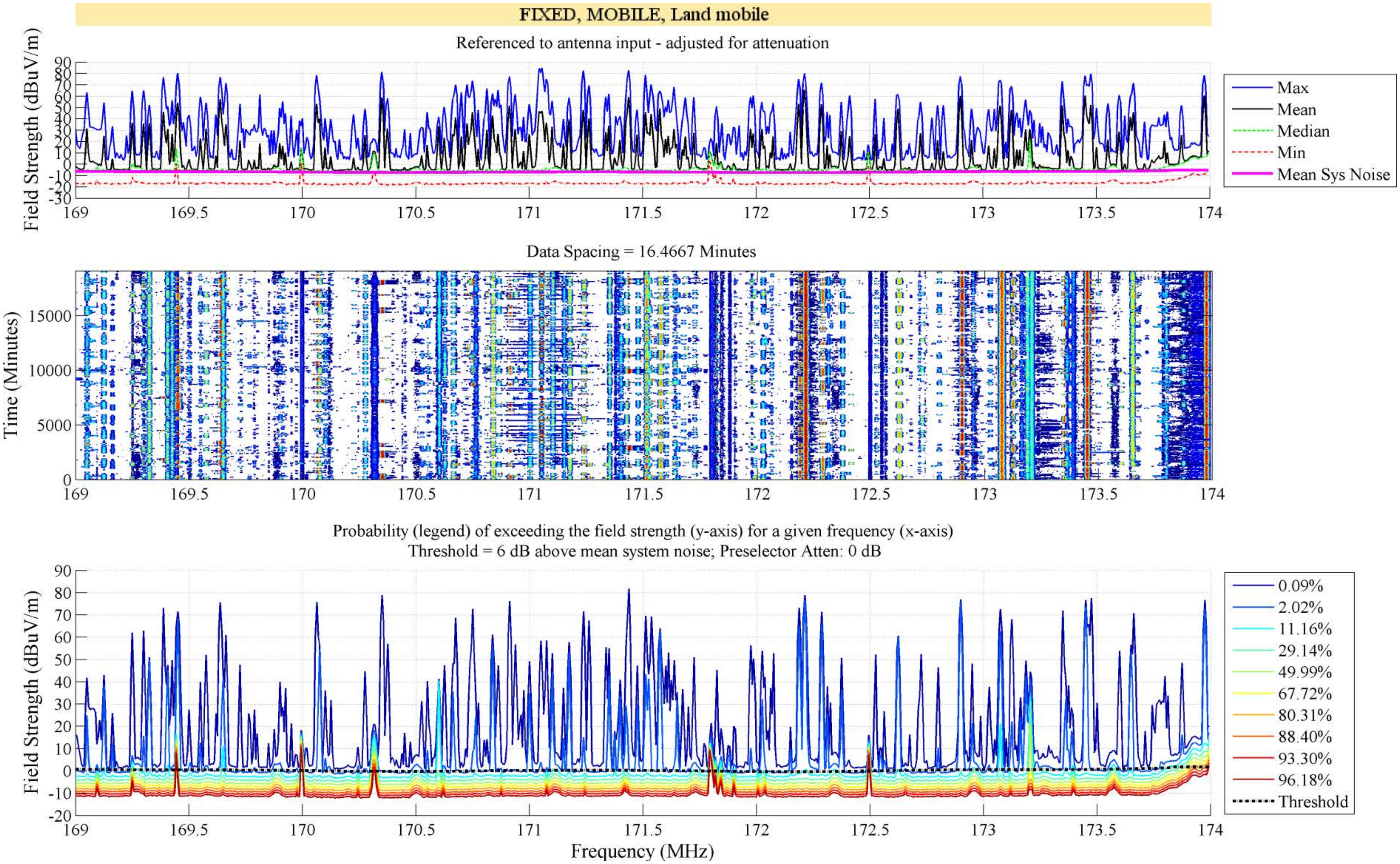


Figure 15. NTIA spectrum survey results from 169 to 174 MHz in San Diego, CA, May/June 2012.

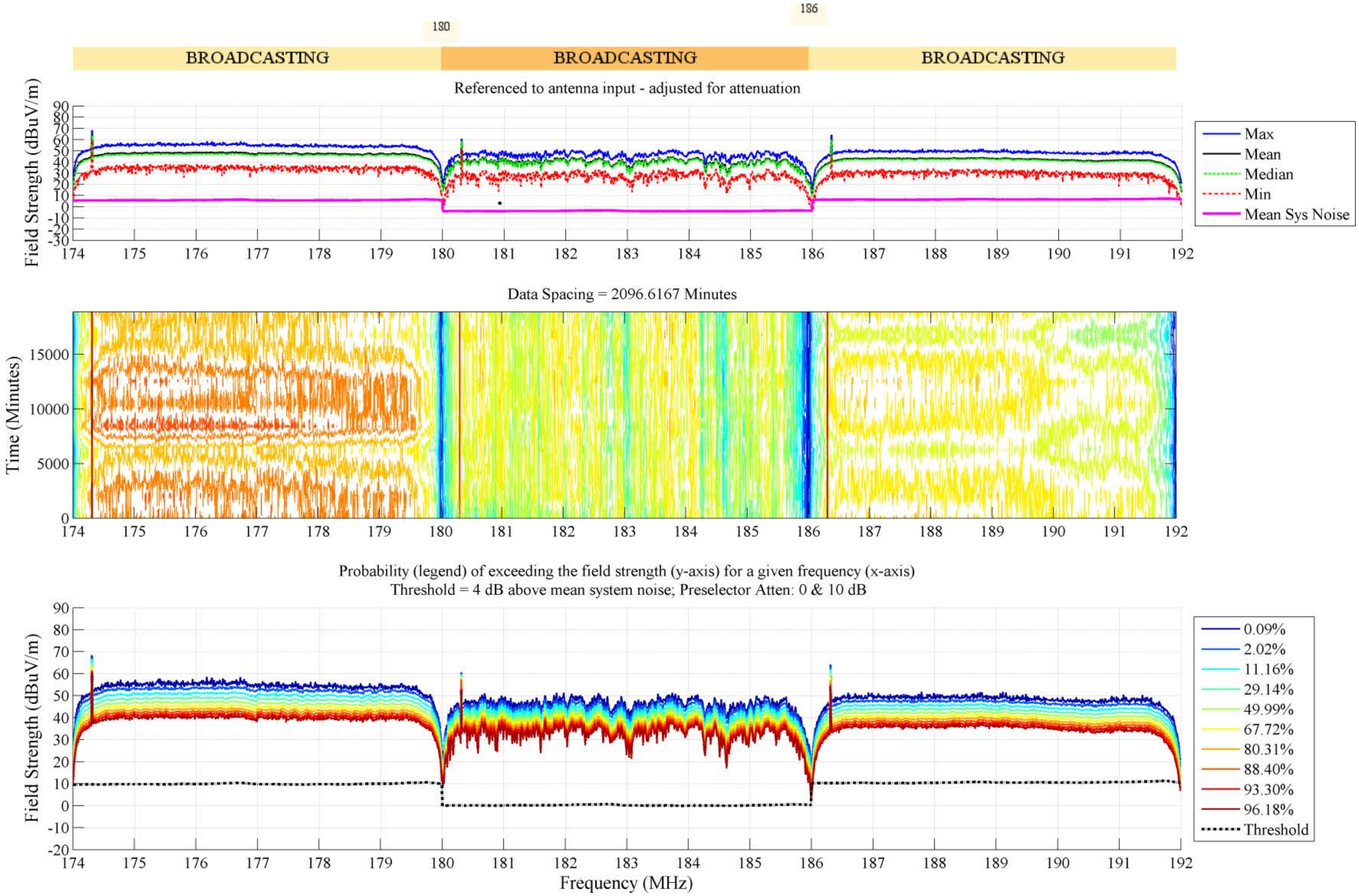


Figure 16. NTIA spectrum survey results from 174 to 192 MHz in San Diego, CA, May/June 2012.

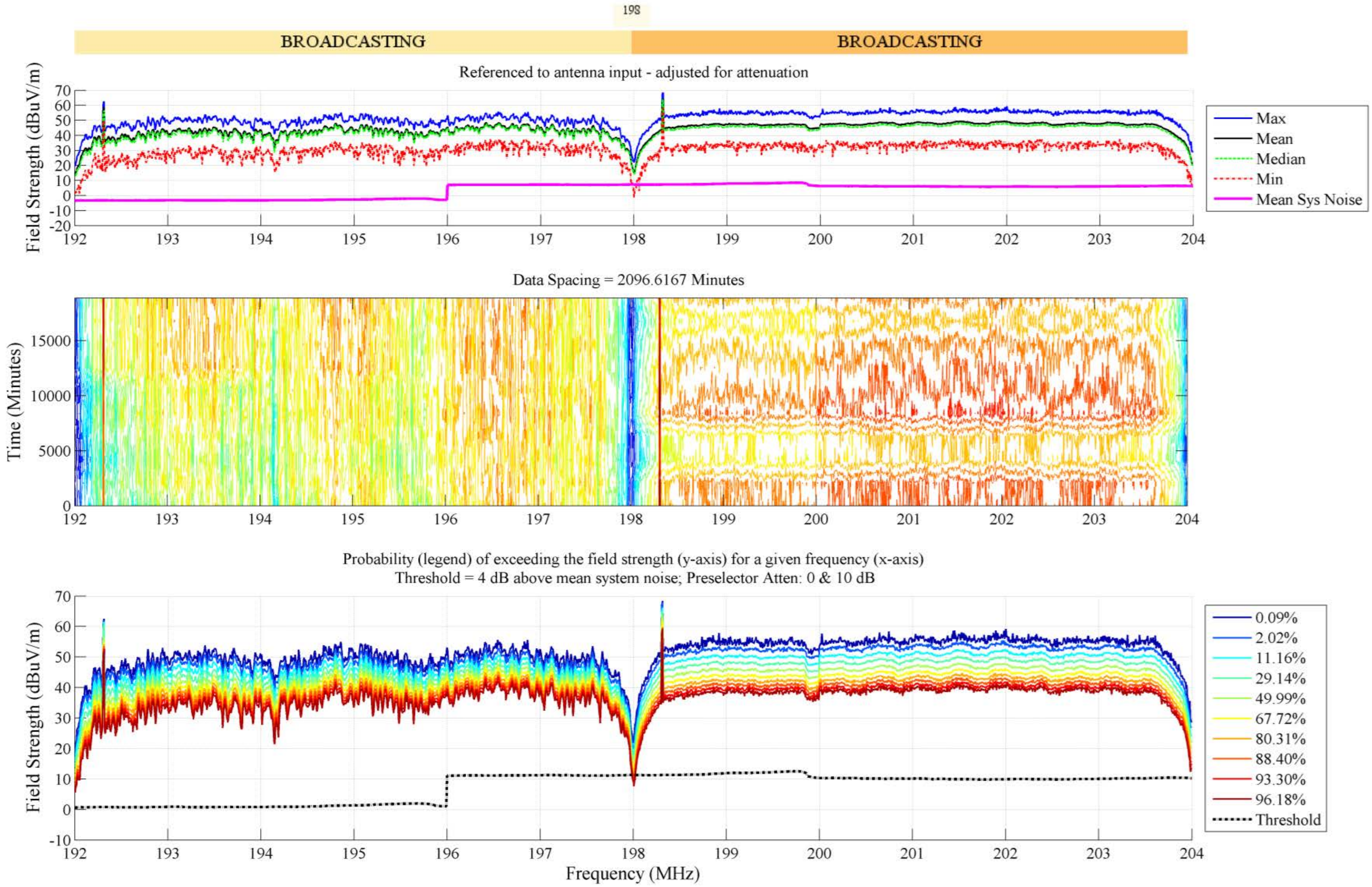


Figure 17. NTIA spectrum survey results from 192 to 204 MHz in San Diego, CA, May/June 2012.

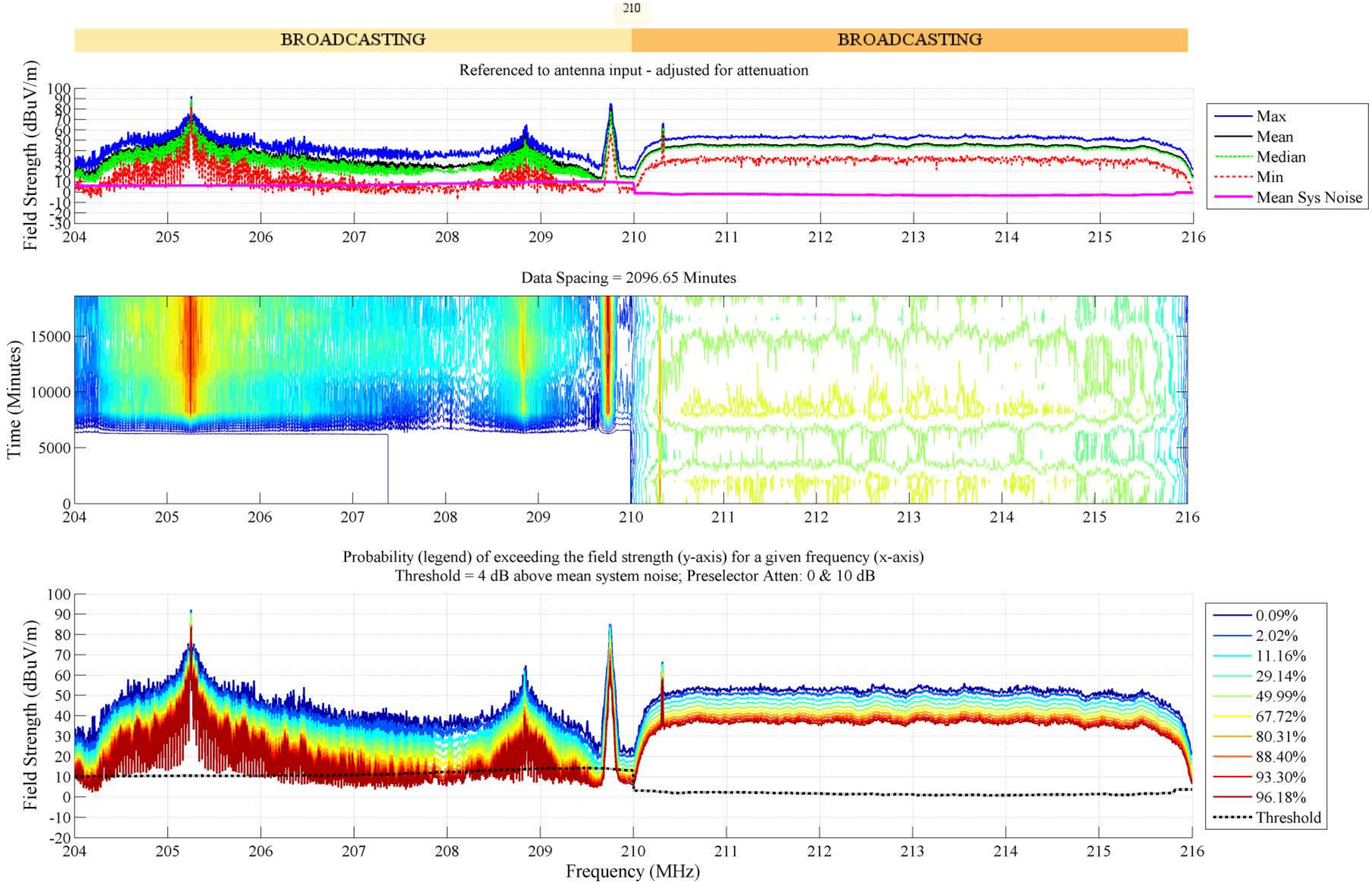


Figure 18. NTIA spectrum survey results from 204 to 216 MHz in San Diego, CA, May/June 2012.

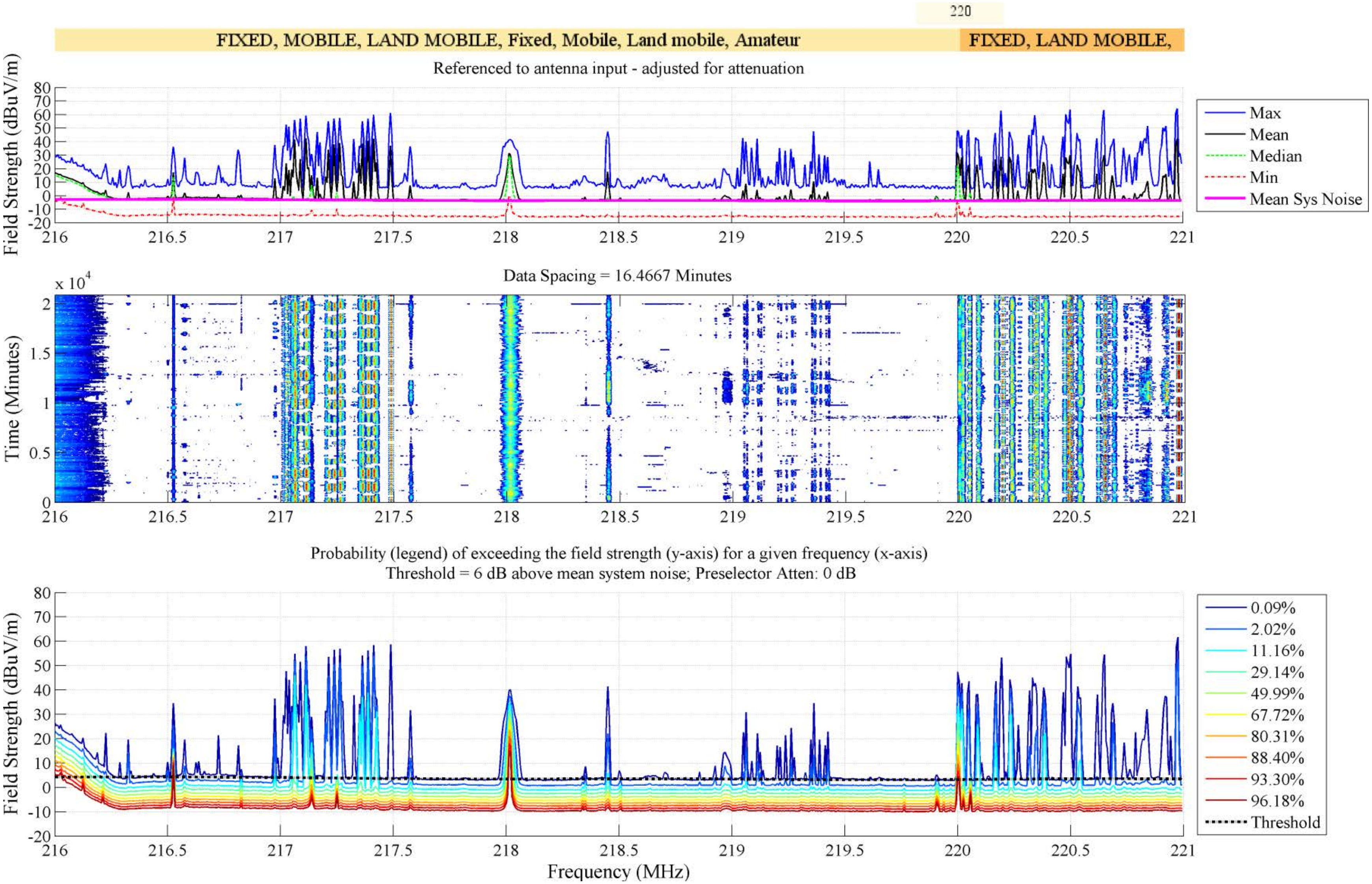


Figure 19. NTIA spectrum survey results from 216 to 221 MHz in San Diego, CA, May/June 2012.

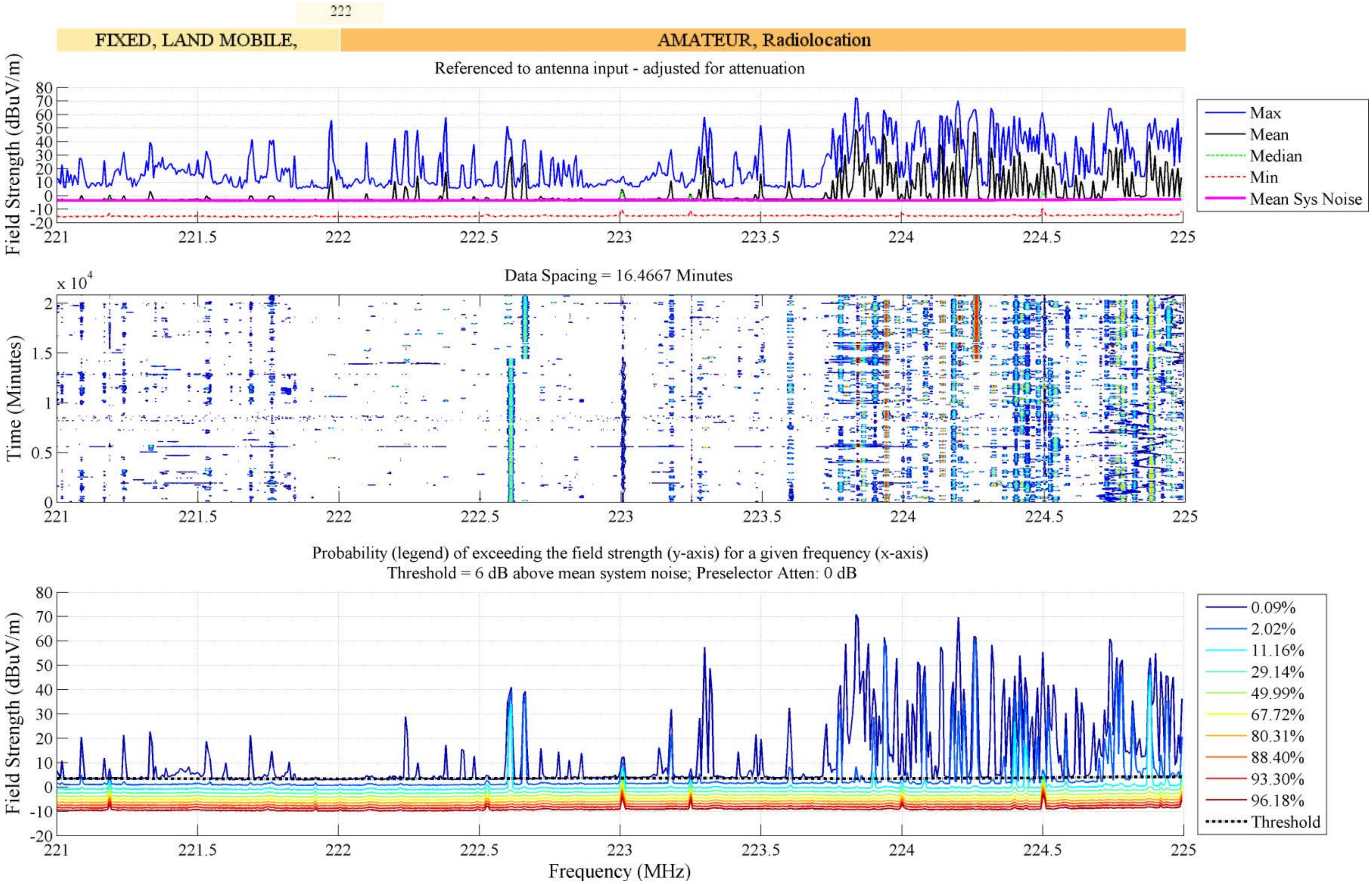


Figure 20. NTIA spectrum survey results from 221 to 225 MHz in San Diego, CA, May/June 2012.

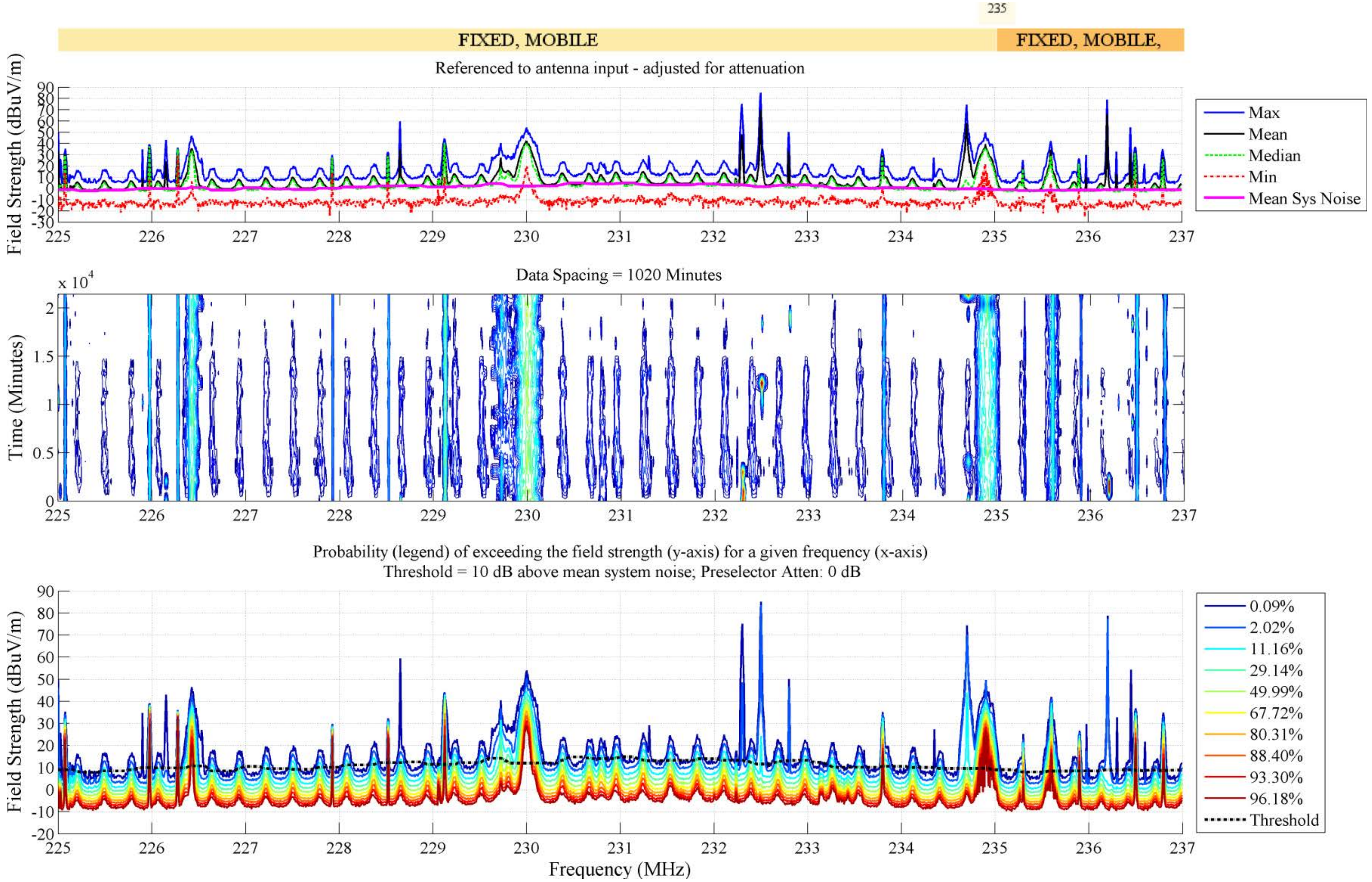


Figure 21. NTIA spectrum survey results from 225 to 237 MHz in San Diego, CA, May/June 2012.

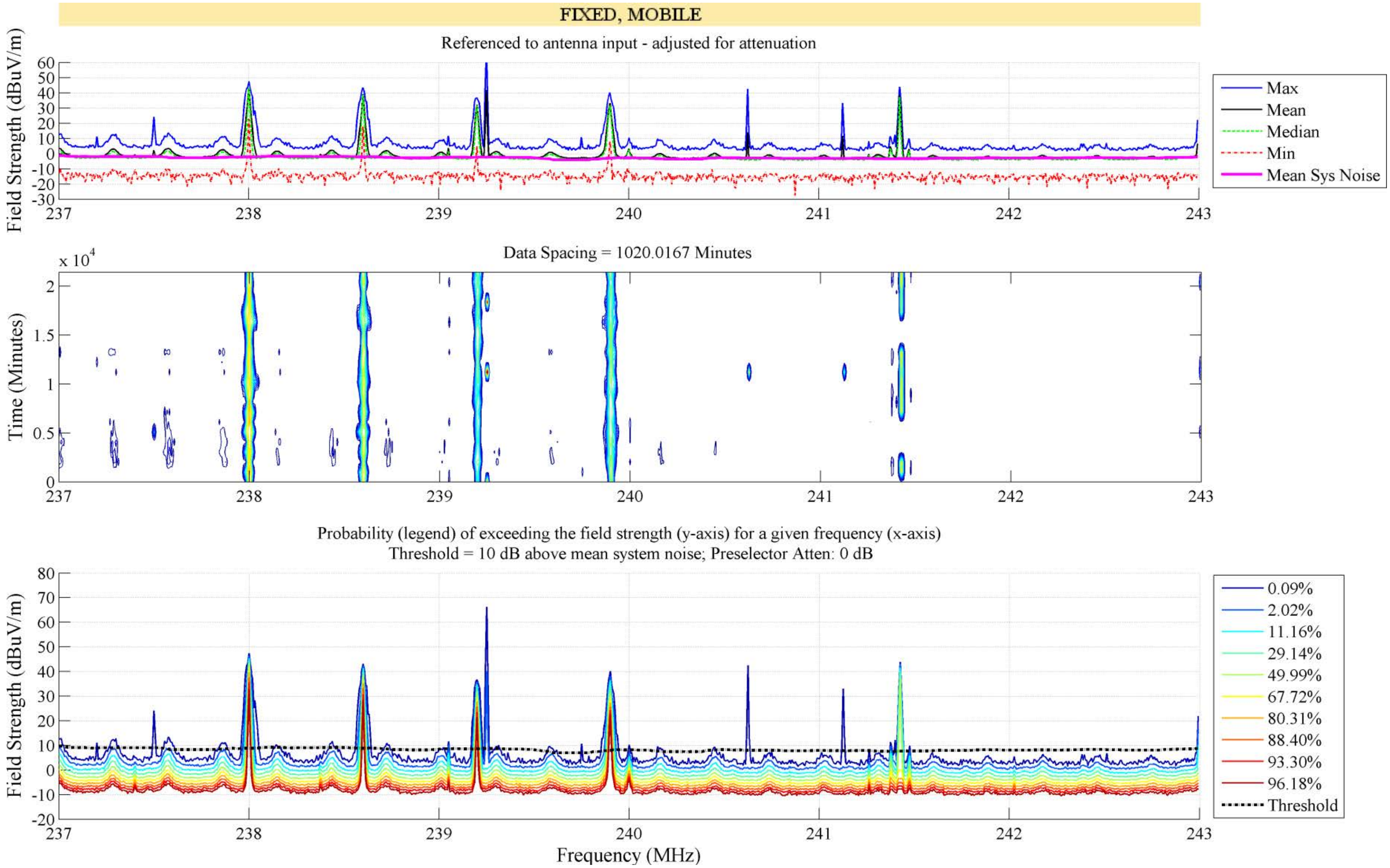


Figure 22. NTIA spectrum survey results from 237 to 243 MHz in San Diego, CA, May/June 2012.

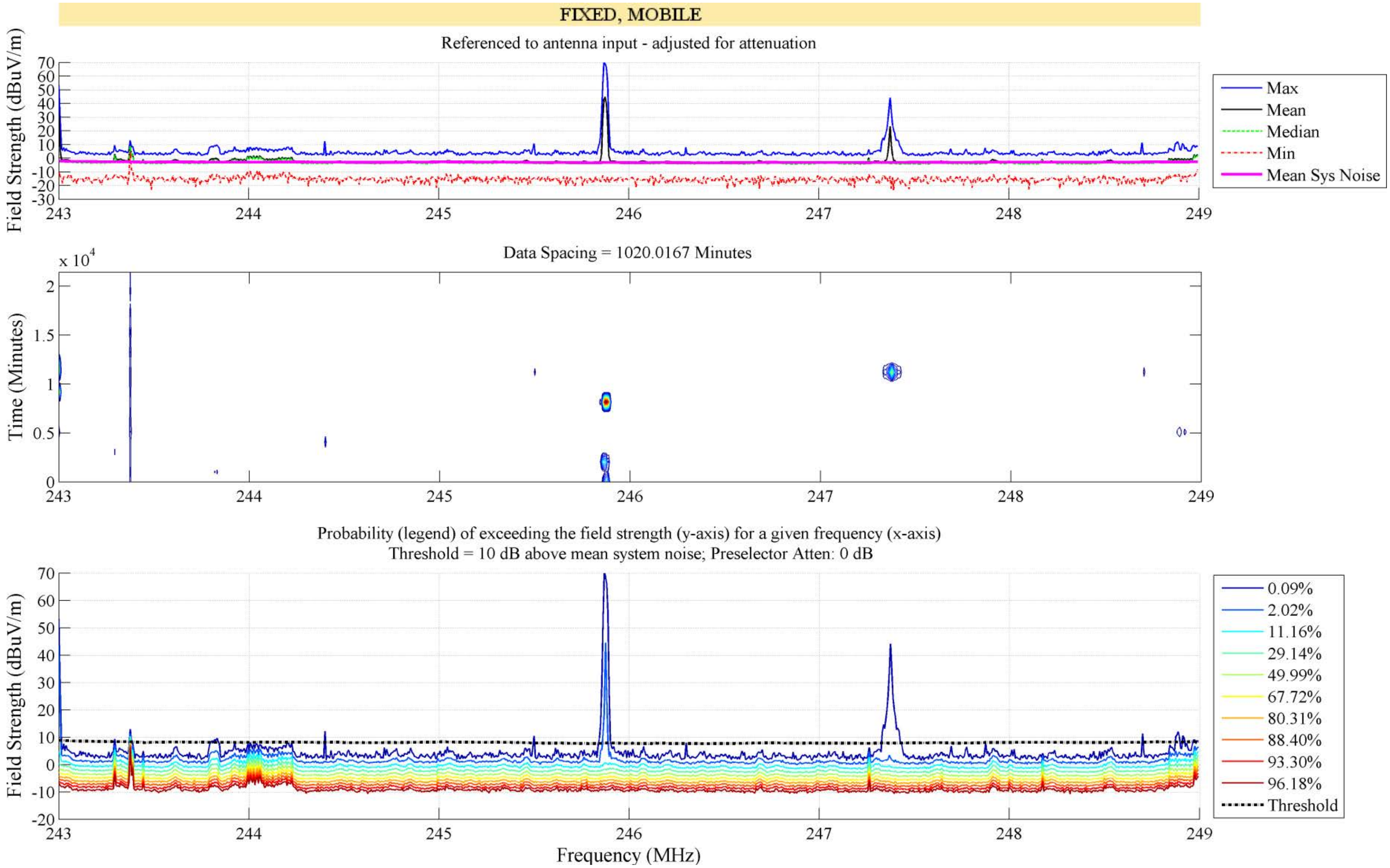


Figure 23. NTIA spectrum survey results from 243 to 249 MHz in San Diego, CA, May/June 2012.

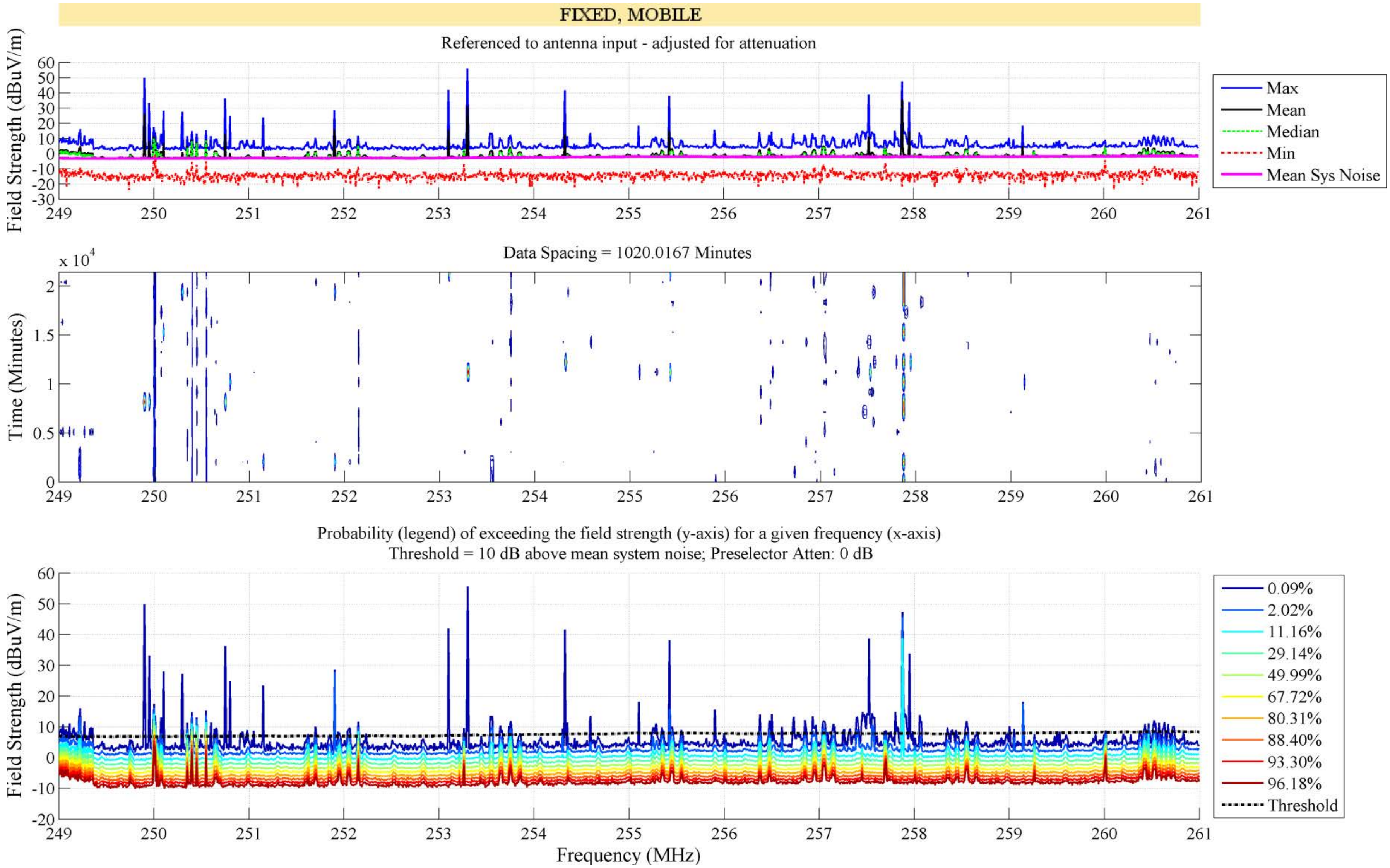


Figure 24. NTIA spectrum survey results from 249 to 261 MHz in San Diego, CA, May/June 2012.

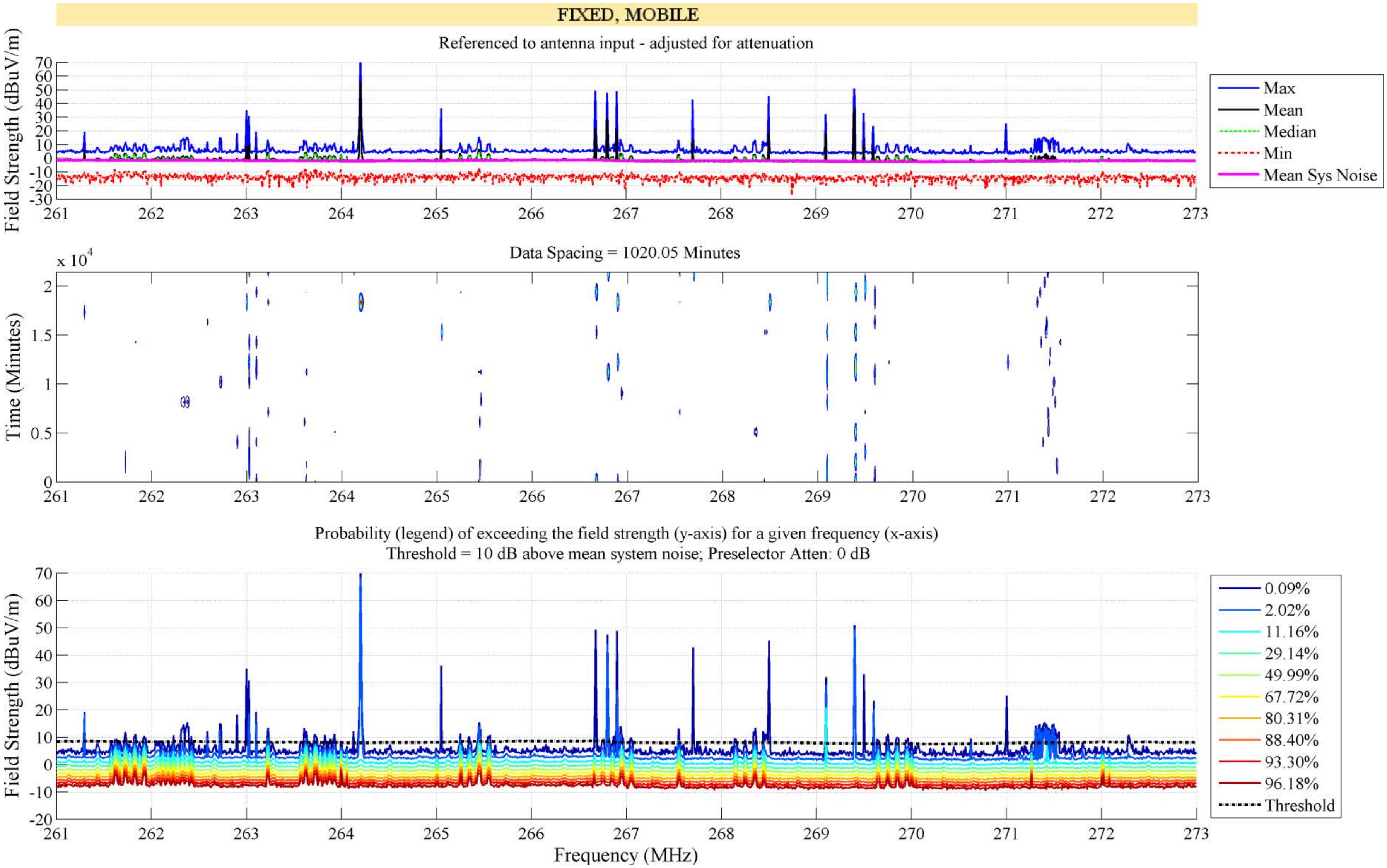


Figure 25. NTIA spectrum survey results from 261 to 273 MHz in San Diego, CA, May/June 2012.

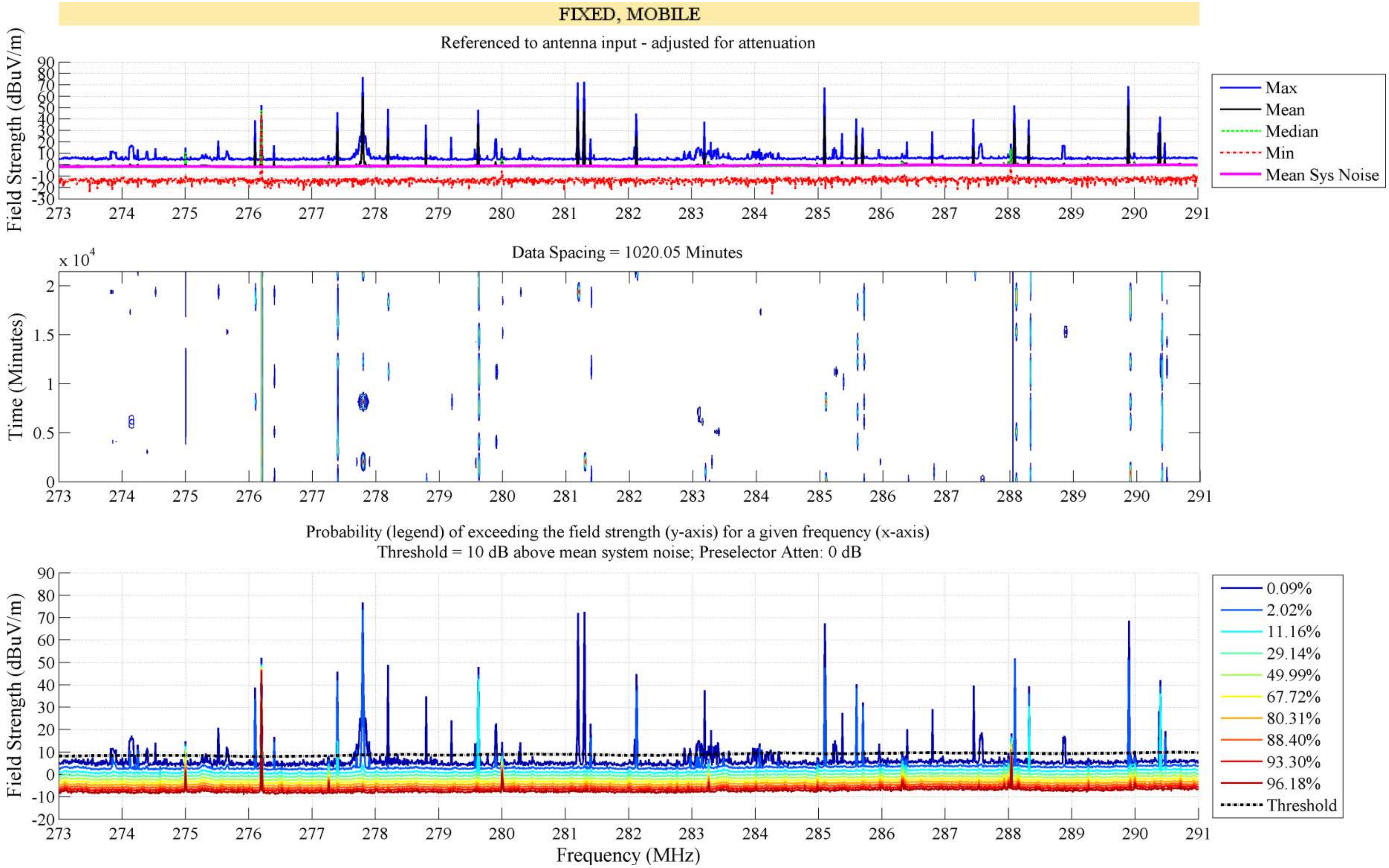


Figure 26. NTIA spectrum survey results from 273 to 291 MHz in San Diego, CA, May/June 2012.

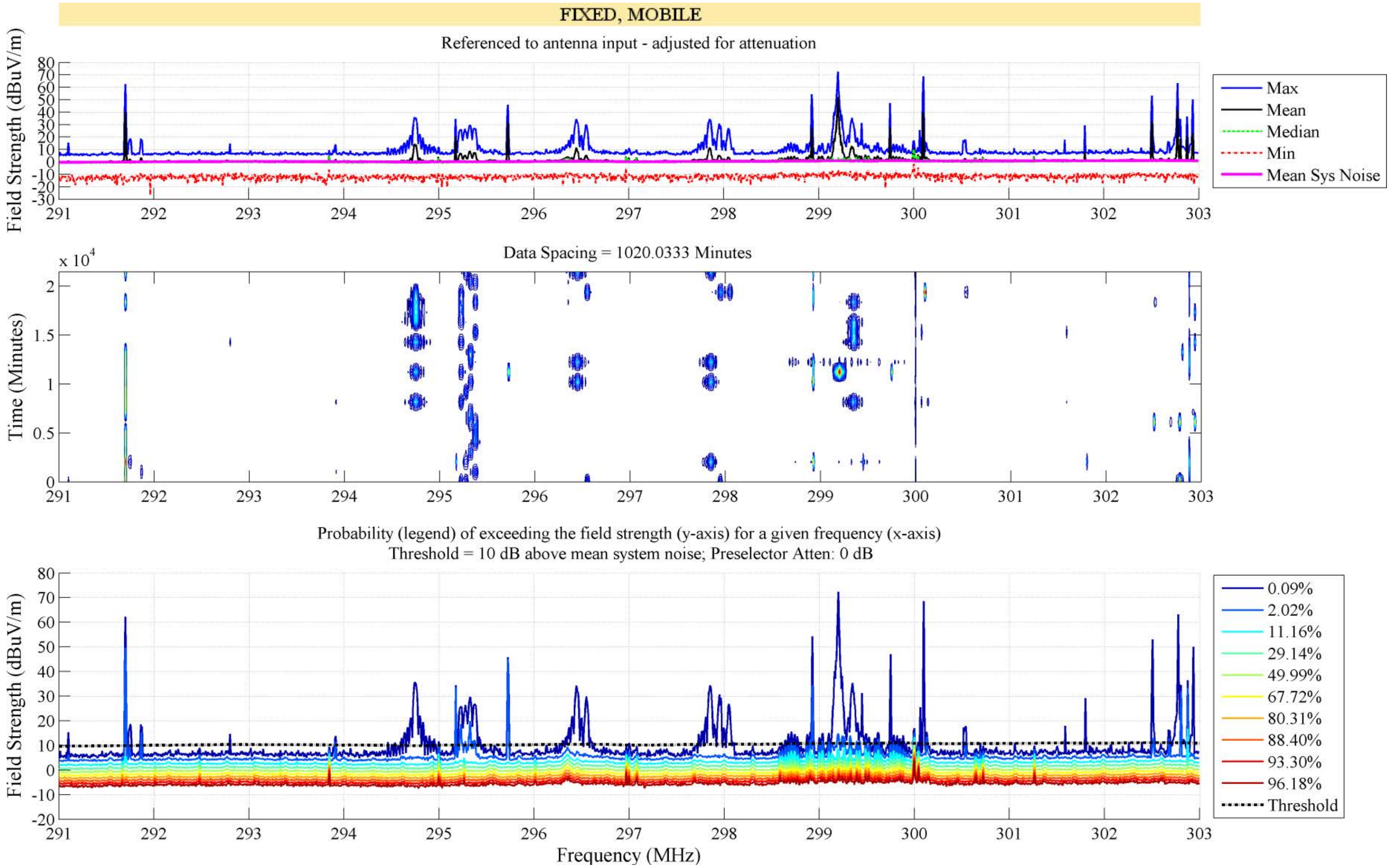


Figure 27. NTIA spectrum survey results from 291 to 303 MHz in San Diego, CA, May/June 2012.

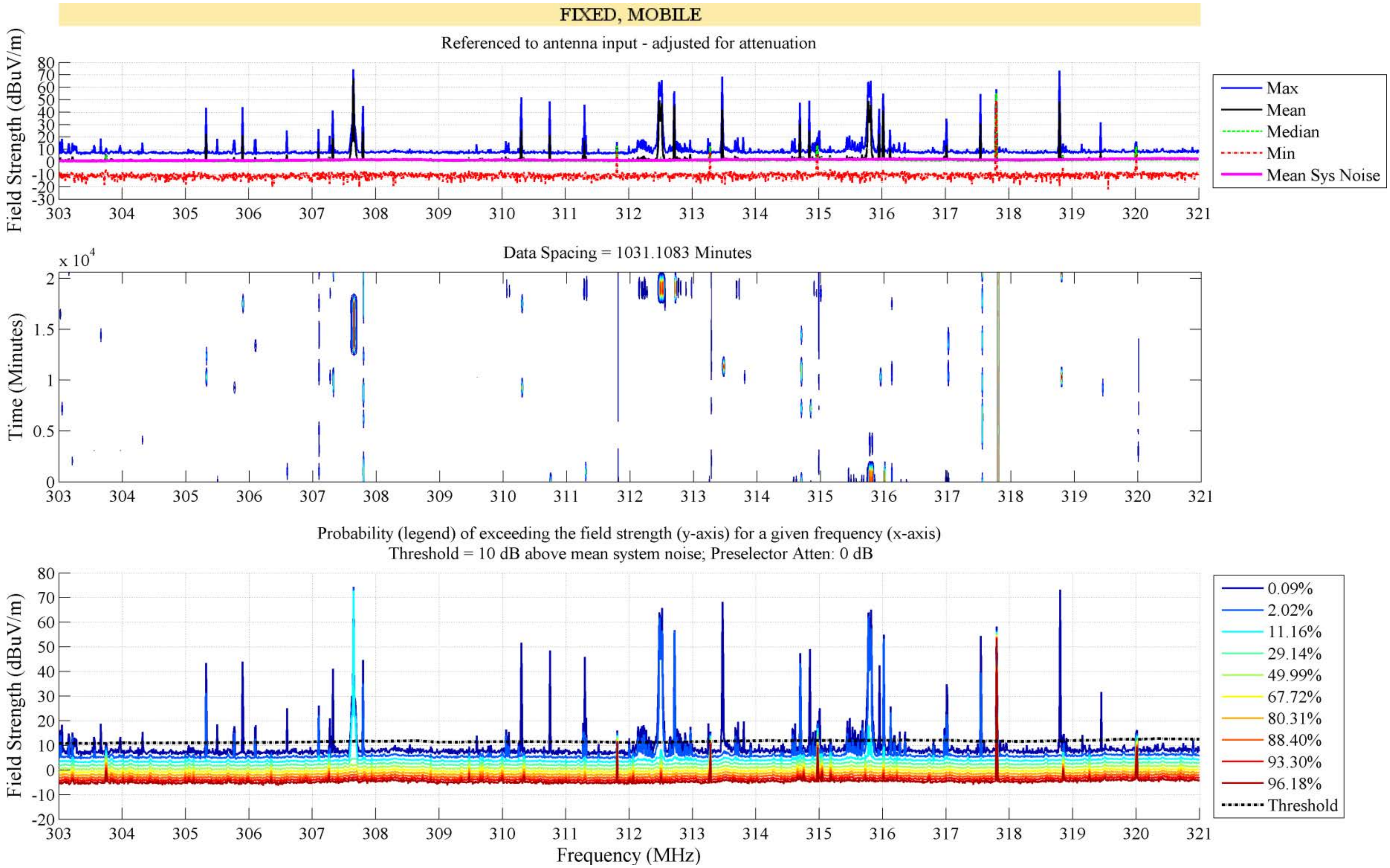


Figure 28. NTIA spectrum survey results from 303 to 321 MHz in San Diego, CA, May/June 2012.

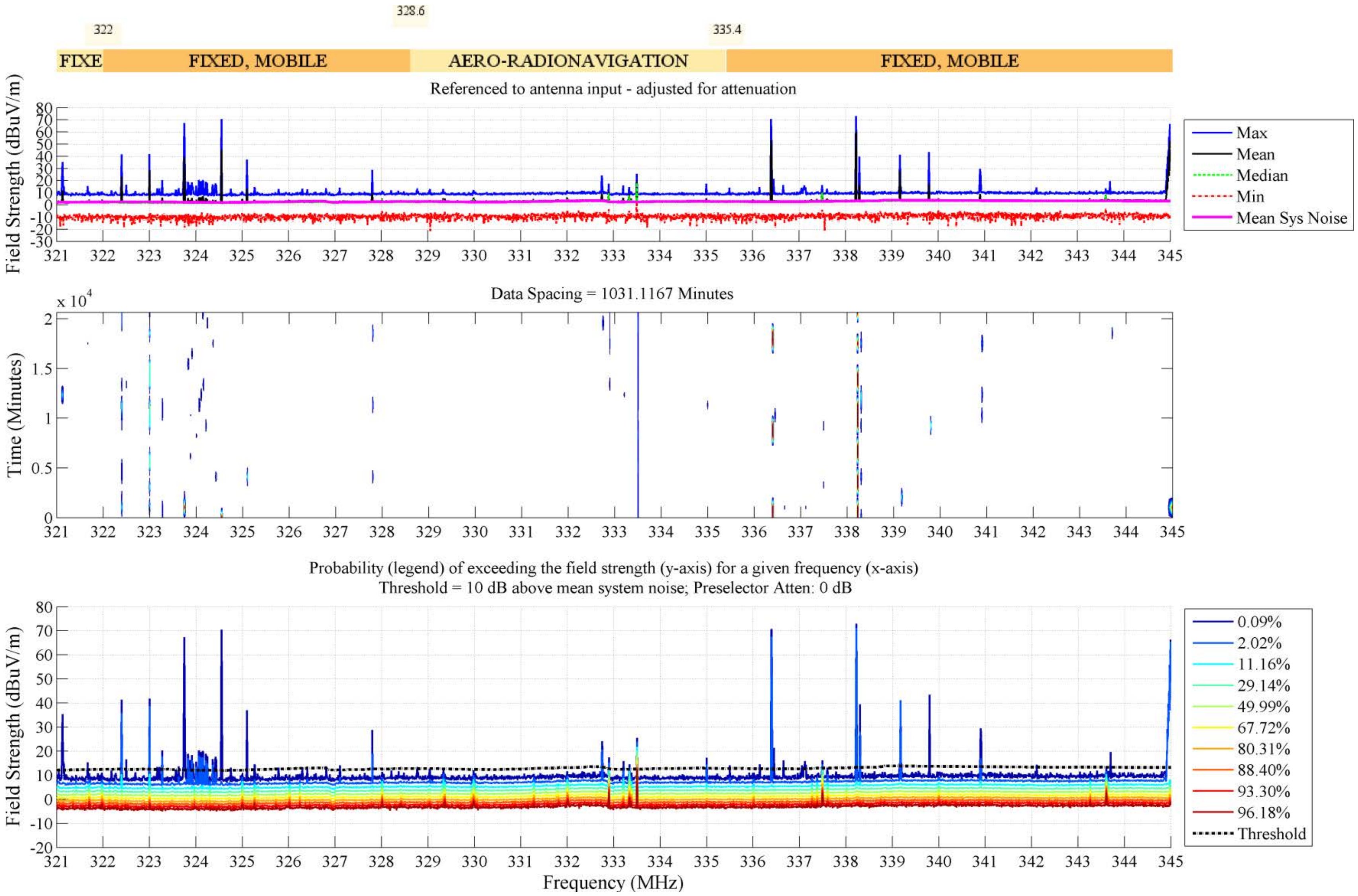


Figure 29. NTIA spectrum survey results from 321 to 345 MHz in San Diego, CA, May/June 2012.

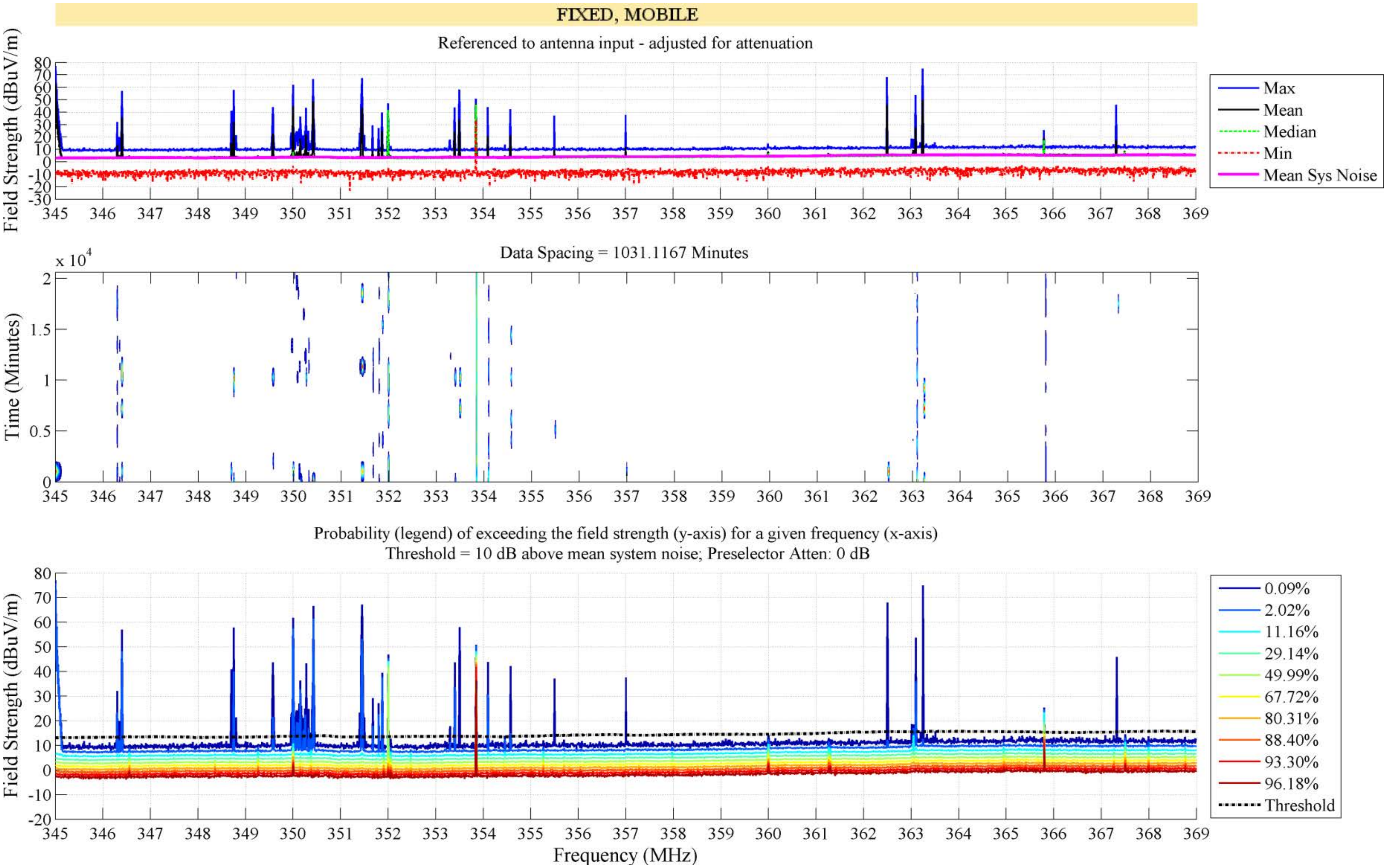


Figure 30. NTIA spectrum survey results from 345 to 369 MHz in San Diego, CA, May/June 2012.

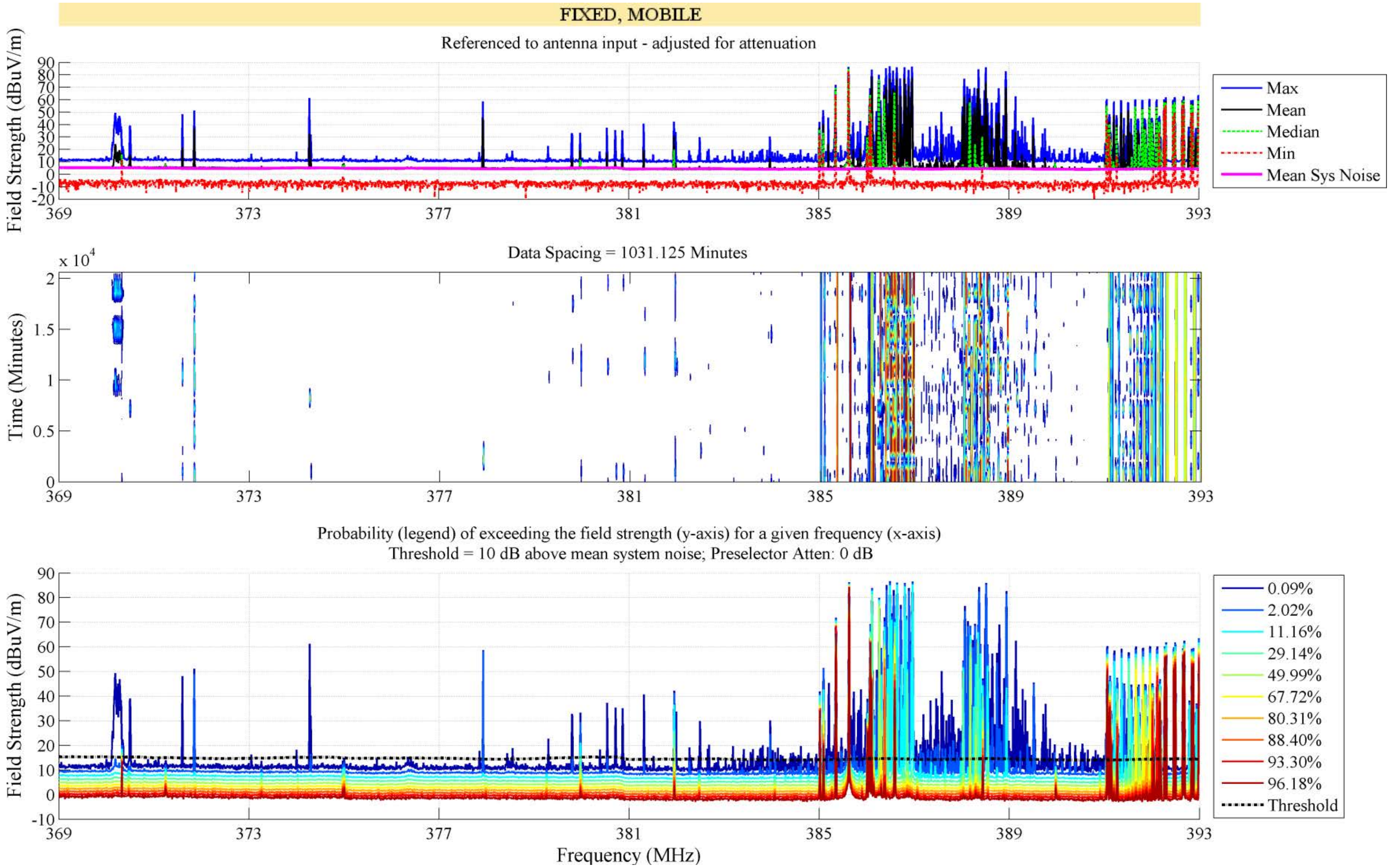


Figure 31. NTIA spectrum survey results from 369 to 393 MHz in San Diego, CA, May/June 2012.

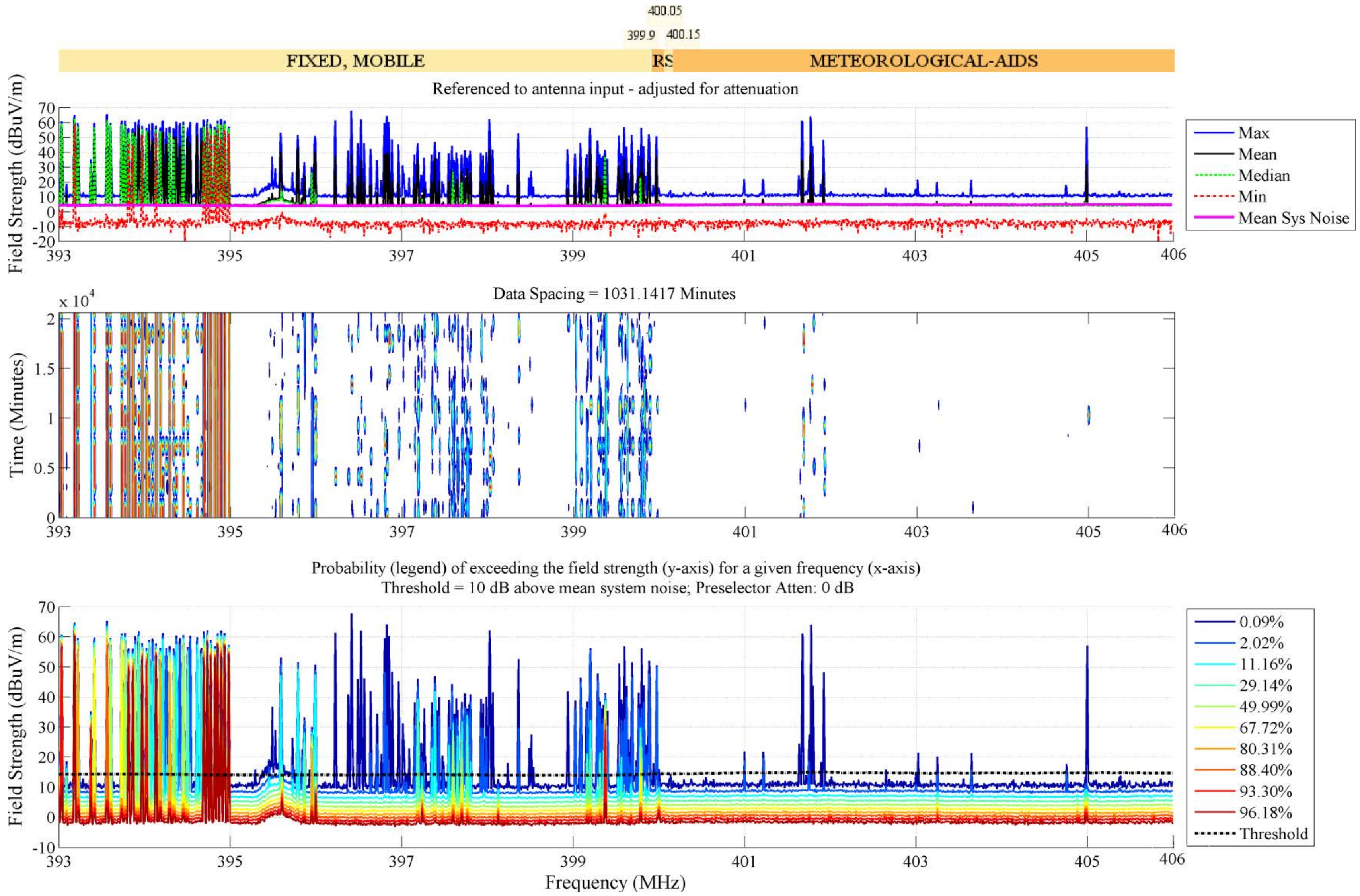


Figure 32. NTIA spectrum survey results from 393 to 406 MHz in San Diego, CA, May/June 2012.

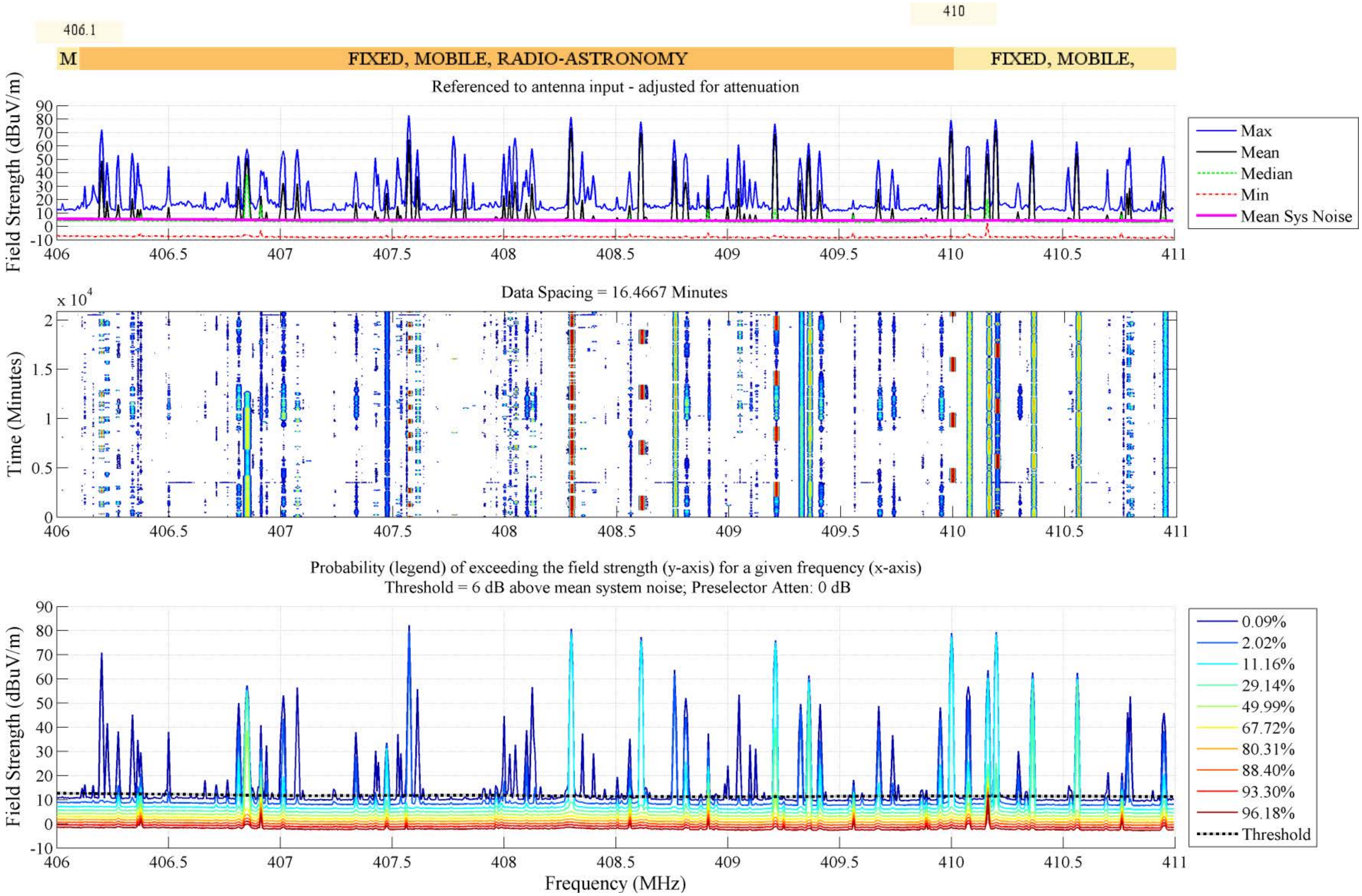


Figure 33. NTIA spectrum survey results from 406 to 411 MHz in San Diego, CA, May/June 2012.

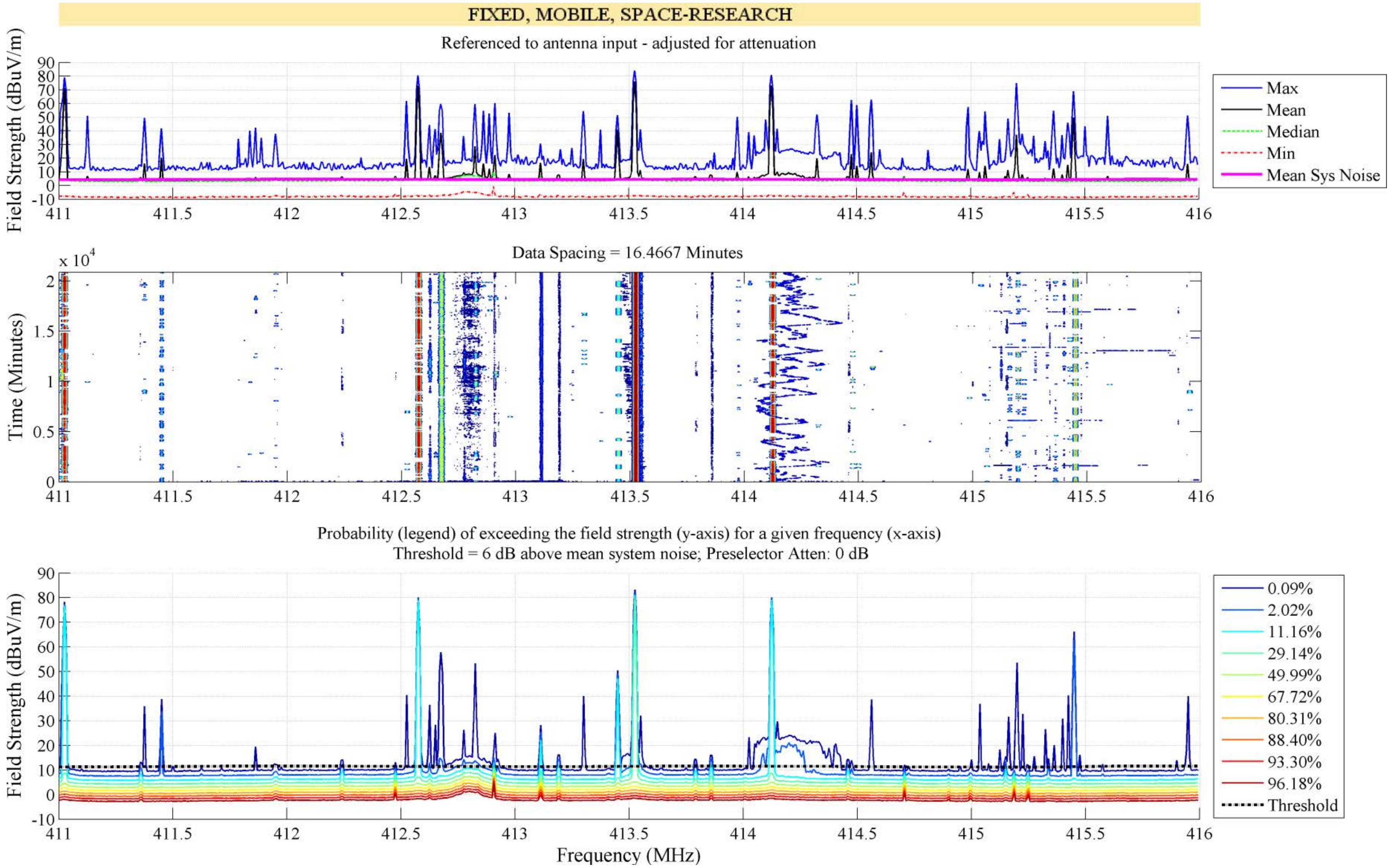


Figure 34. NTIA spectrum survey results from 411 to 416 MHz in San Diego, CA, May/June 2012.

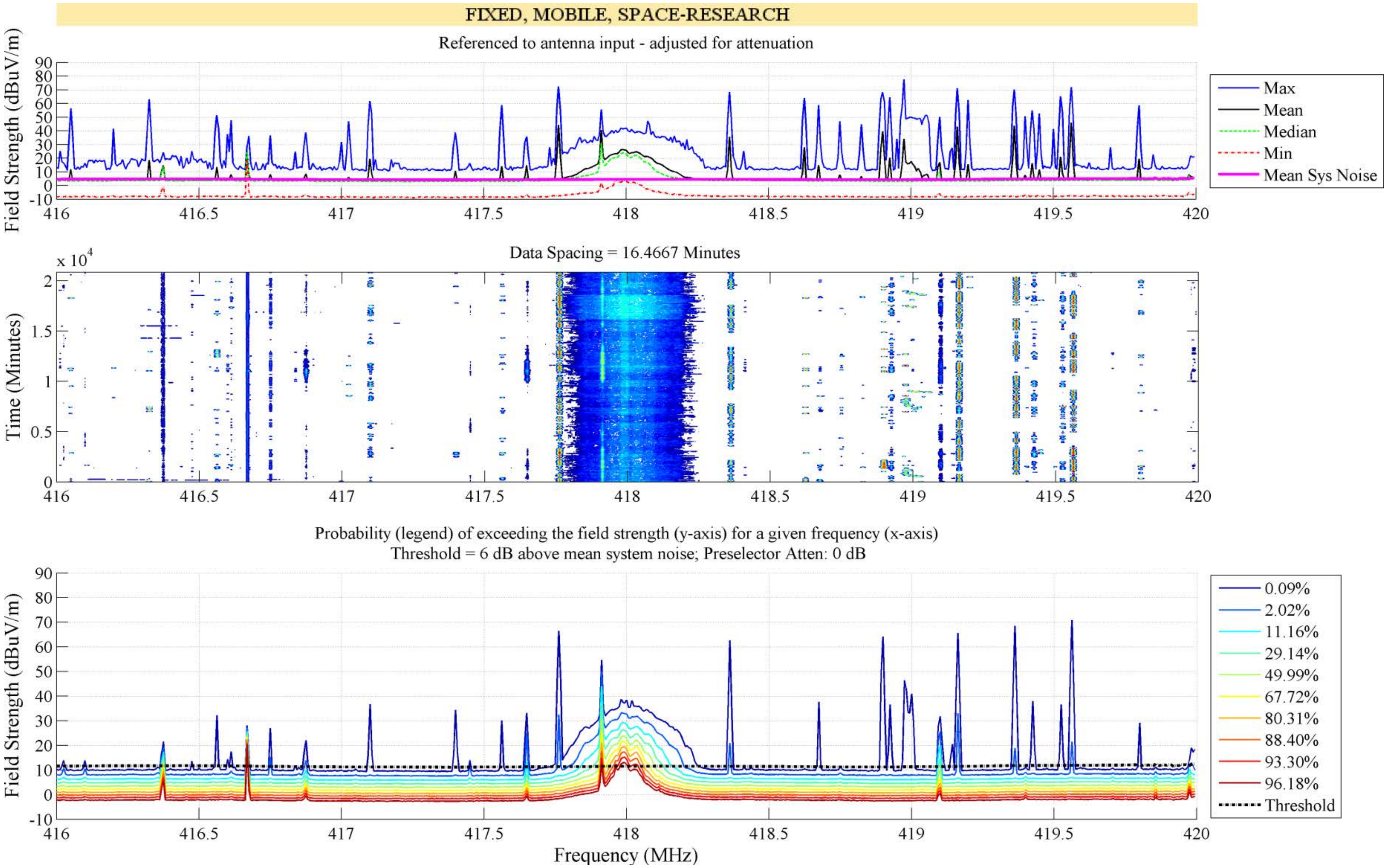


Figure 35. NTIA spectrum survey results from 416 to 420 MHz in San Diego, CA, May/June 2012.

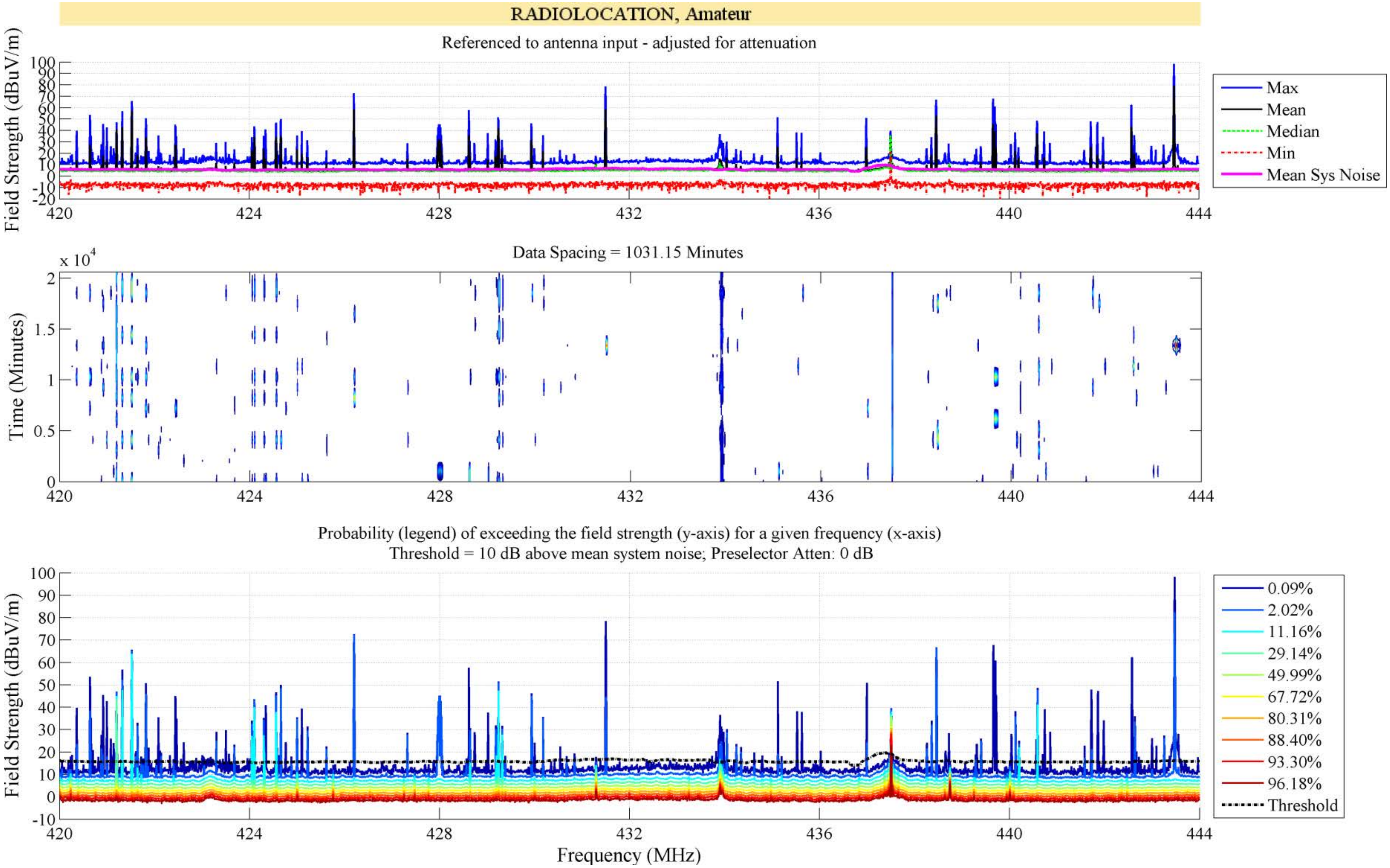


Figure 36. NTIA spectrum survey results from 420 to 444 MHz in San Diego, CA, May/June 2012.

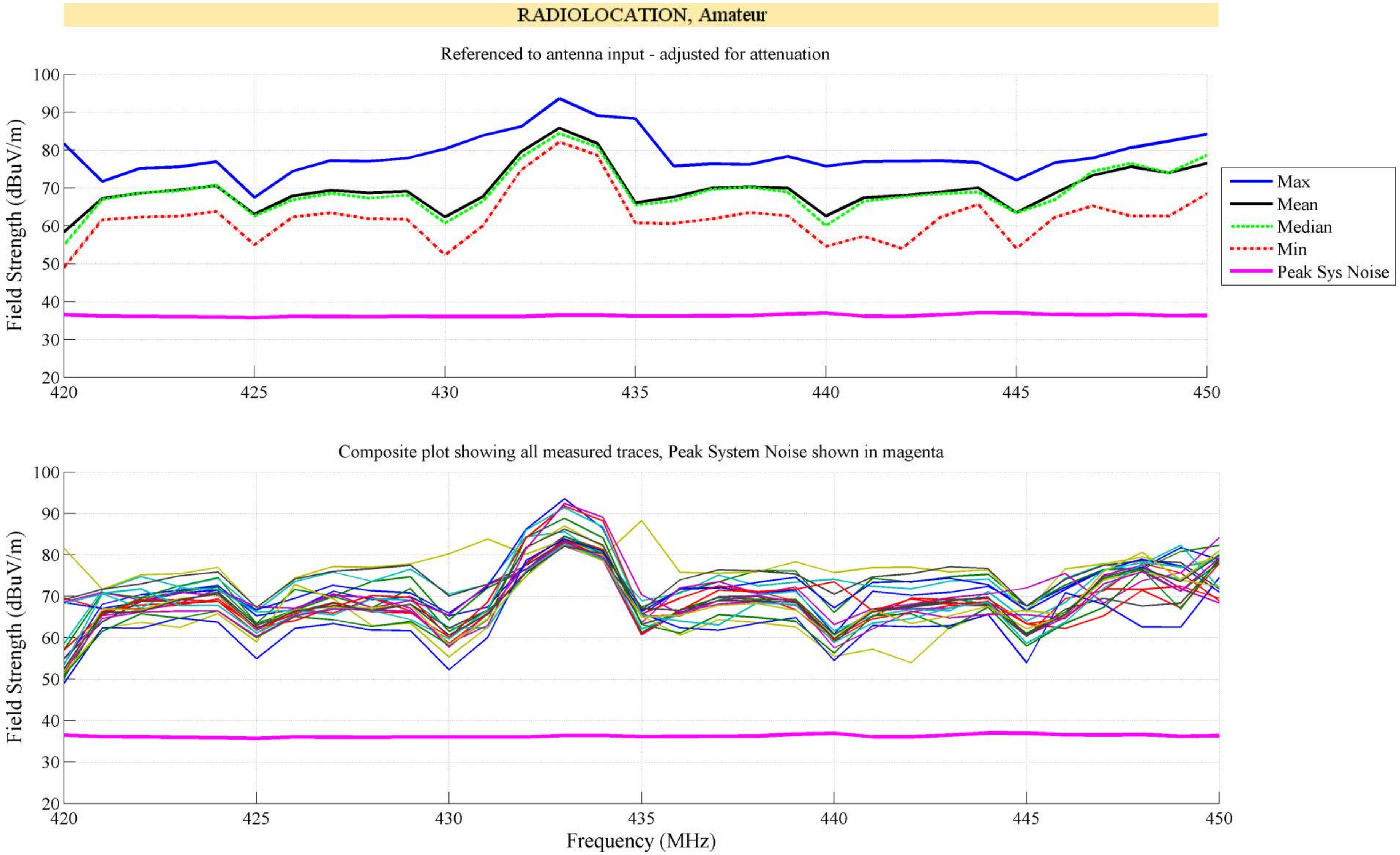


Figure 37. NTIA spectrum survey results from 420 to 450 MHz in San Diego, CA, May/June 2012. This measurement was taken using the stepped-spectrum measurement algorithm.

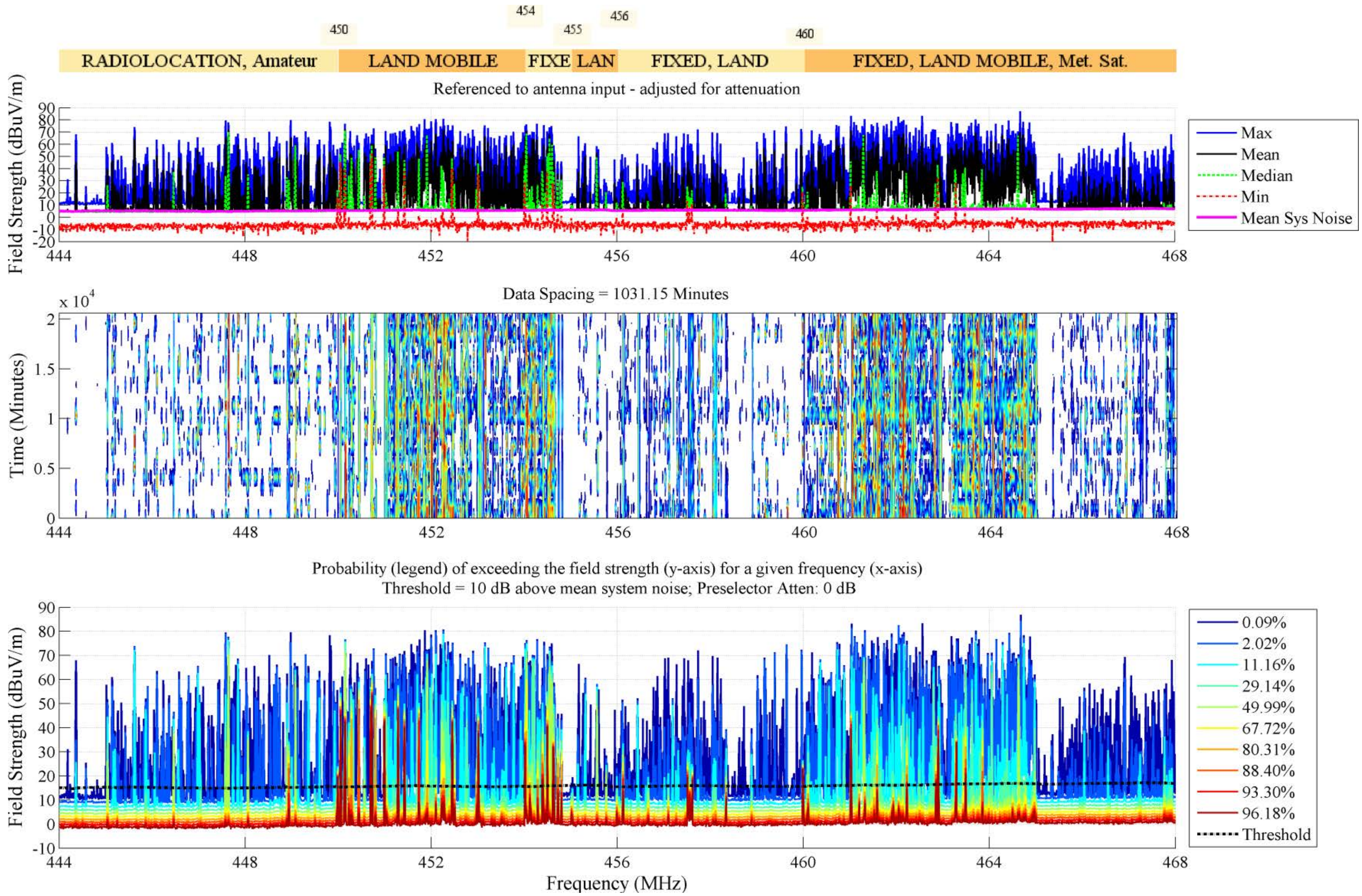


Figure 38. NTIA spectrum survey results from 444 to 468 MHz in San Diego, CA, May/June 2012.

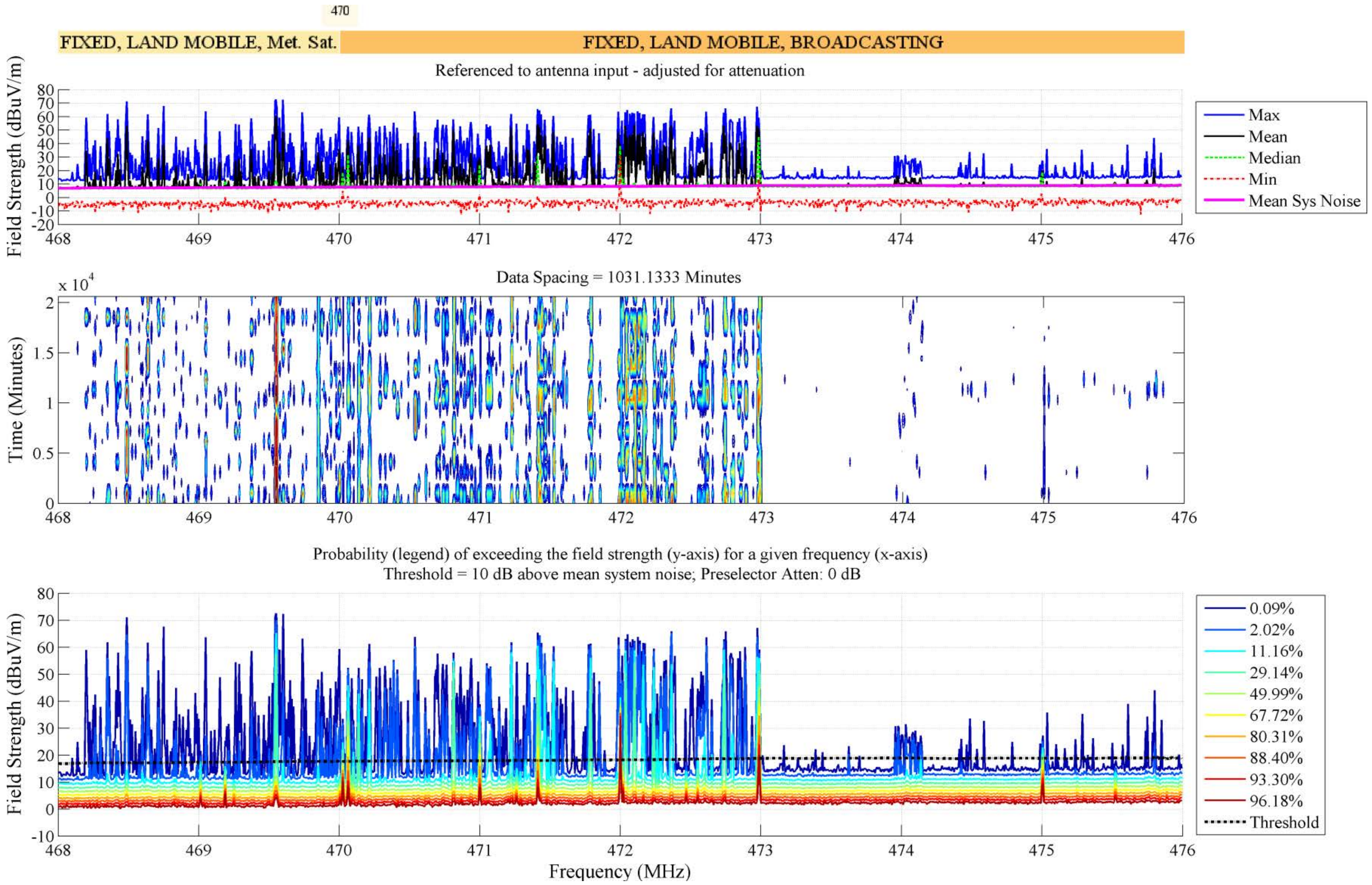


Figure 39. NTIA spectrum survey results from 468 to 476 MHz in San Diego, CA, May/June 2012.

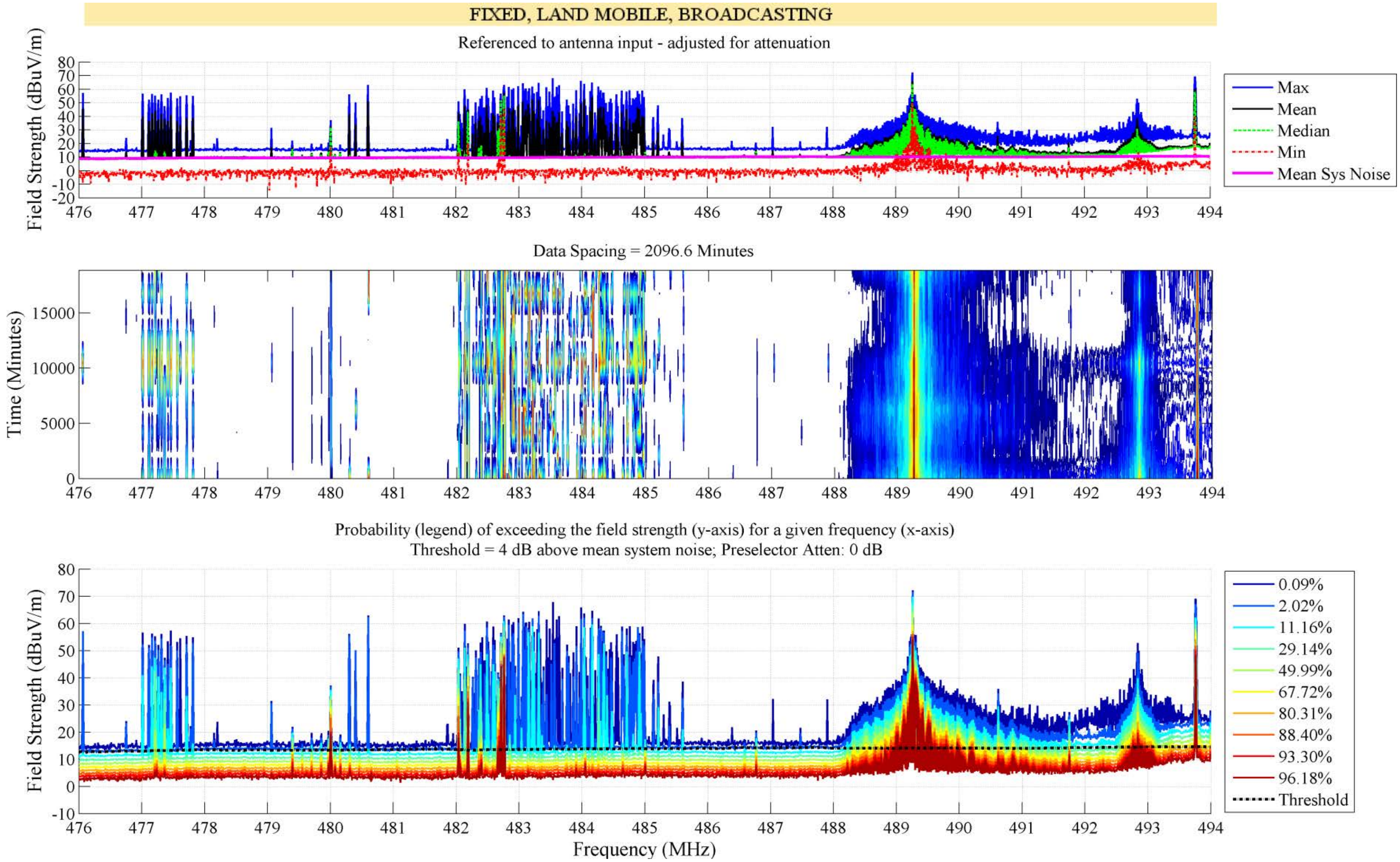


Figure 40. NTIA spectrum survey results from 476 to 494 MHz in San Diego, CA, May/June 2012.

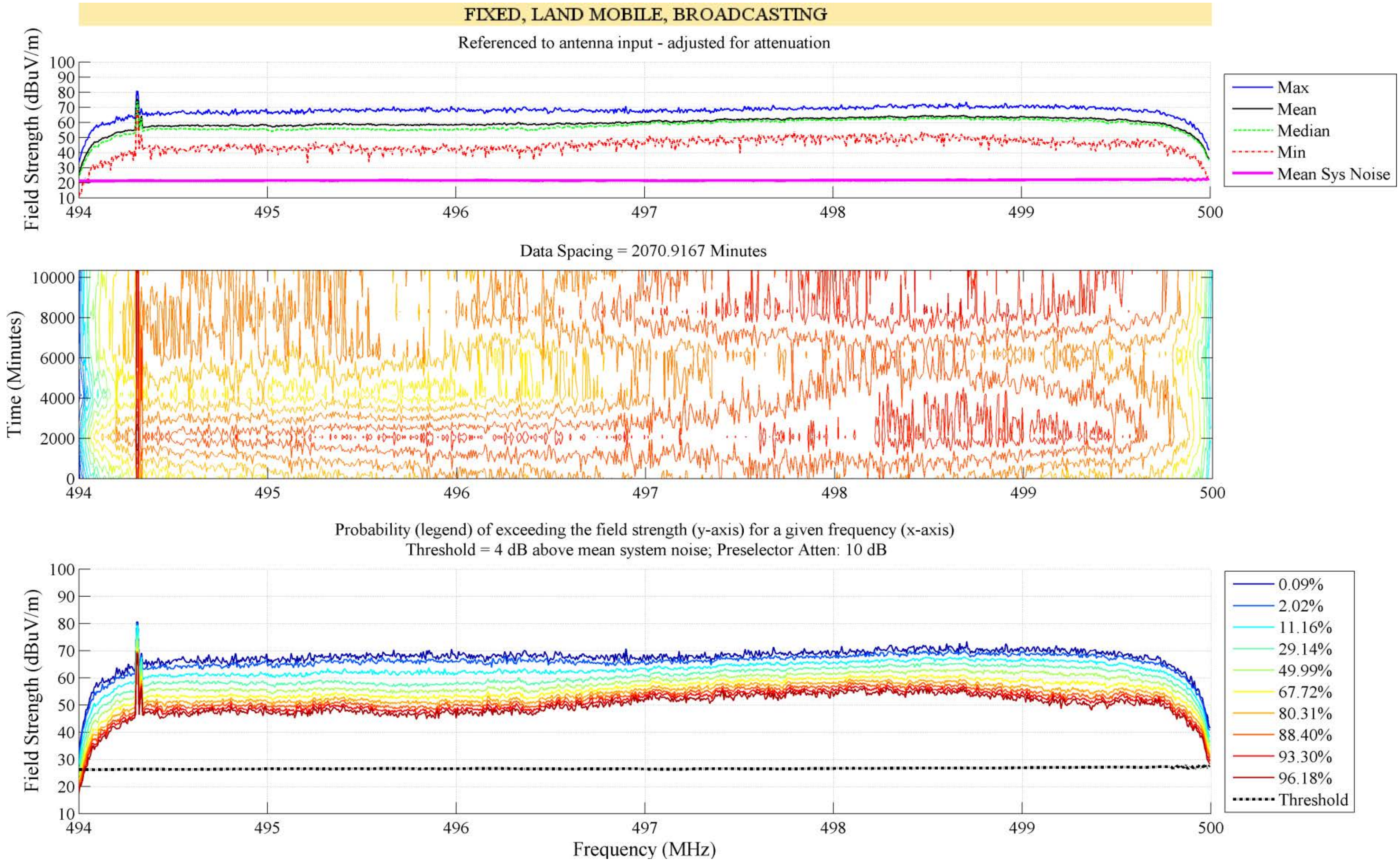


Figure 41. NTIA spectrum survey results from 494 to 500 MHz in San Diego, CA, May/June 2012.

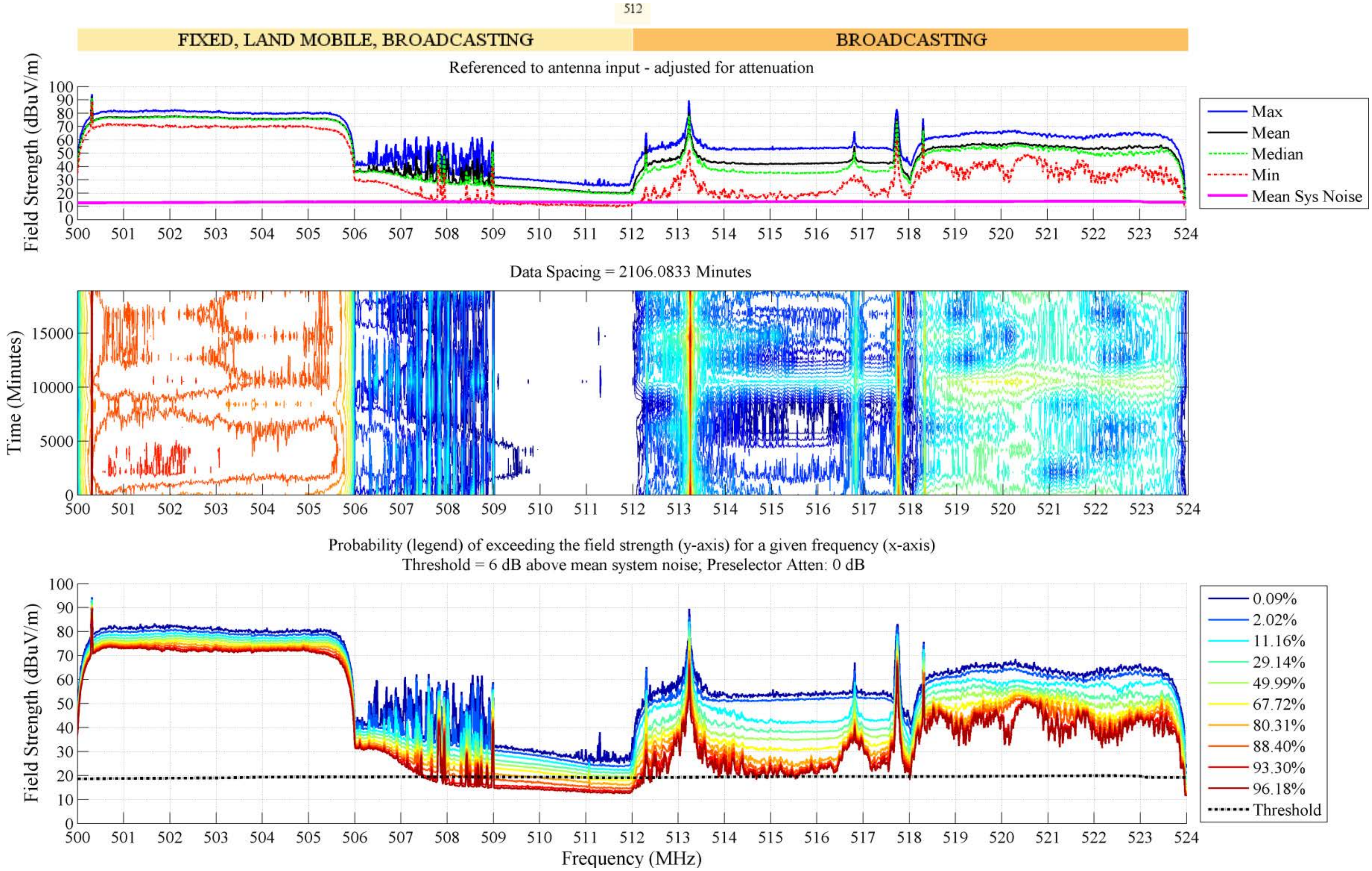
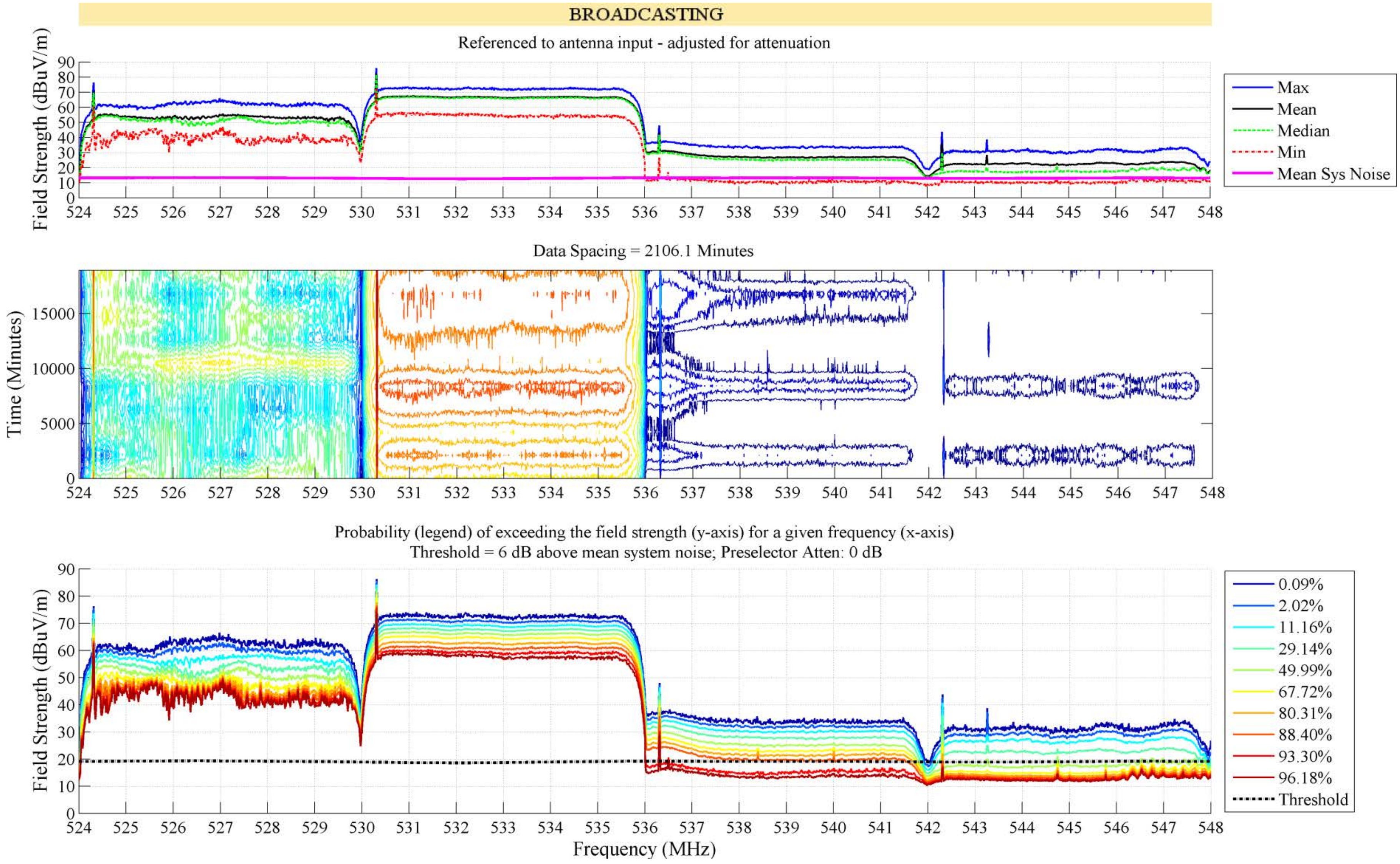


Figure 42. NTIA spectrum survey results from 500 to 524 MHz in San Diego, CA, May/June 2012.



BROADCASTING

Referenced to antenna input - adjusted for attenuation

Data Spacing = 2106.1 Minutes

Probability (legend) of exceeding the field strength (y-axis) for a given frequency (x-axis)
Threshold = 6 dB above mean system noise; Preselector Atten: 0 dB

Figure 43. NTIA spectrum survey results from 524 to 548 MHz in San Diego, CA, May/June 2012.

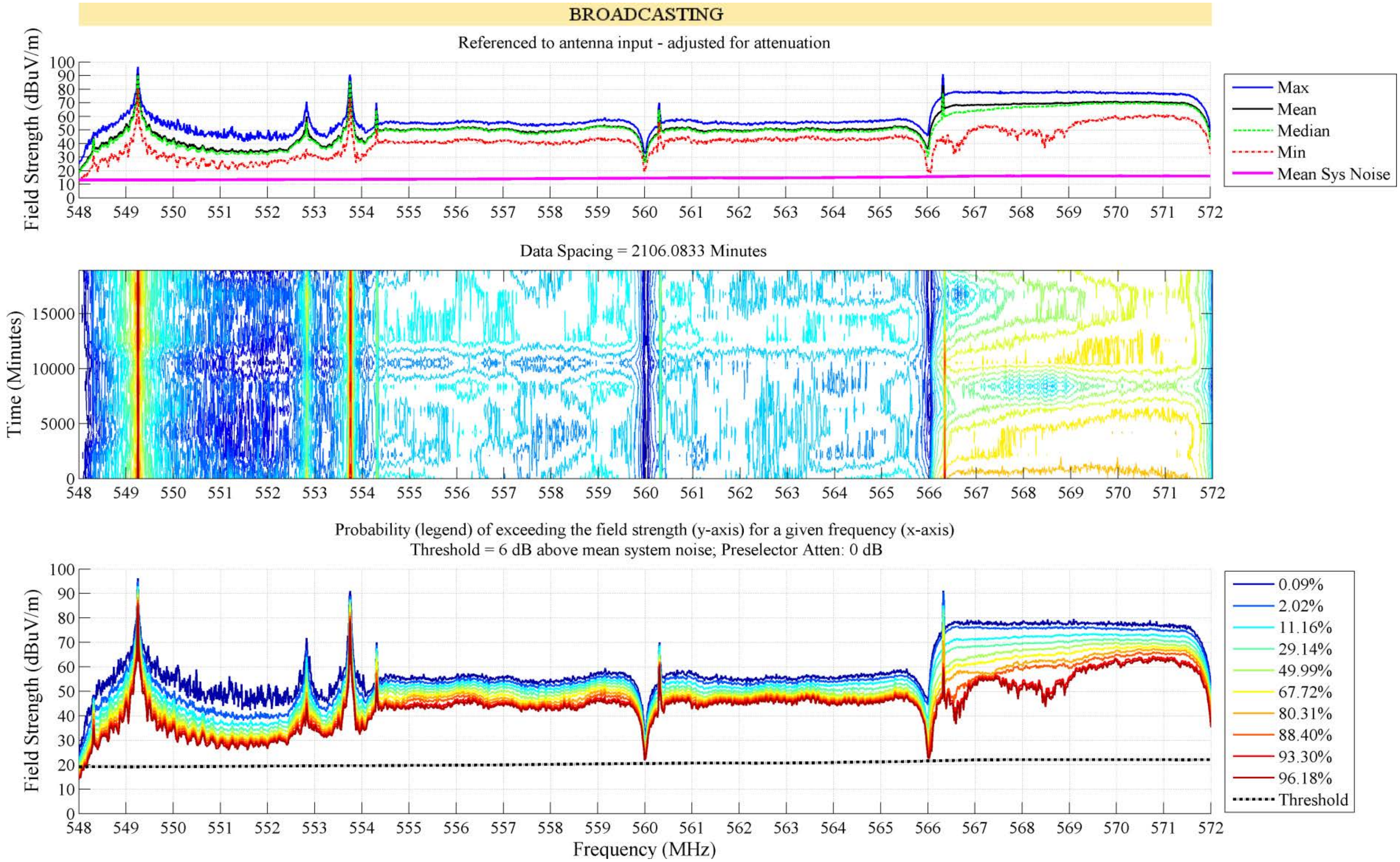


Figure 44. NTIA spectrum survey results from 548 to 572 MHz in San Diego, CA, May/June 2012.

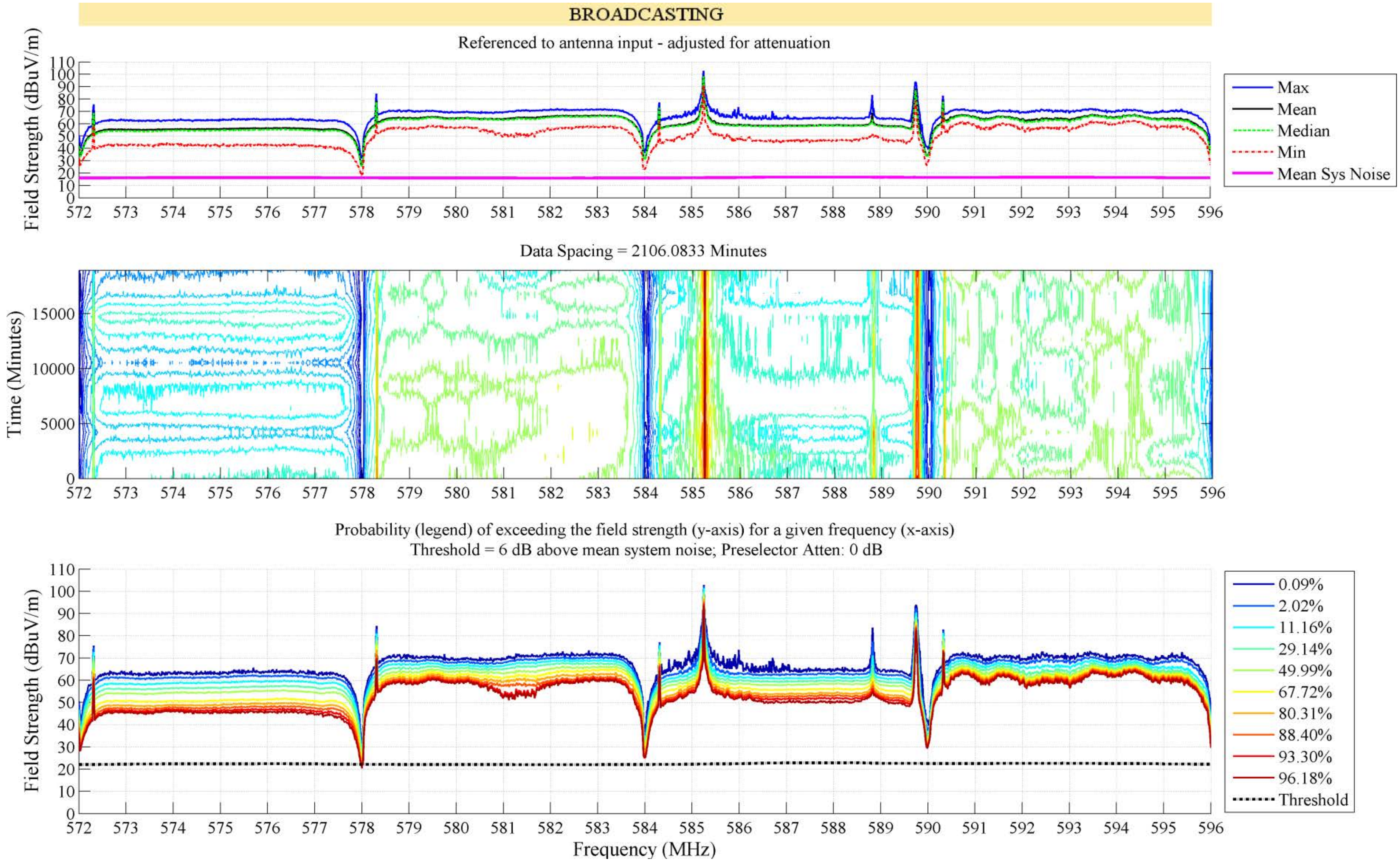


Figure 45. NTIA spectrum survey results from 572 to 596 MHz in San Diego, CA, May/June 2012.

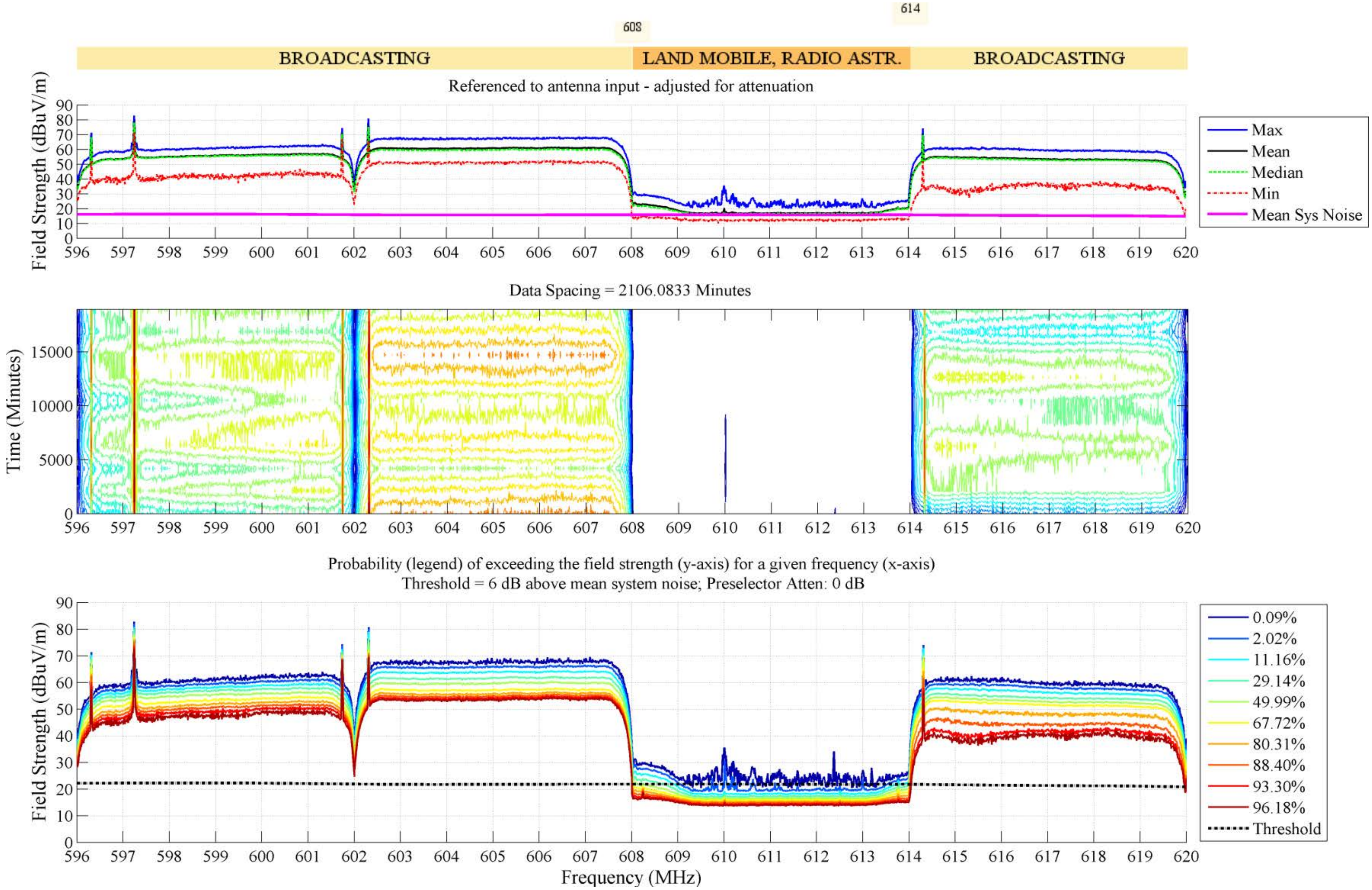


Figure 46. NTIA spectrum survey results from 596 to 620 MHz in San Diego, CA, May/June 2012.

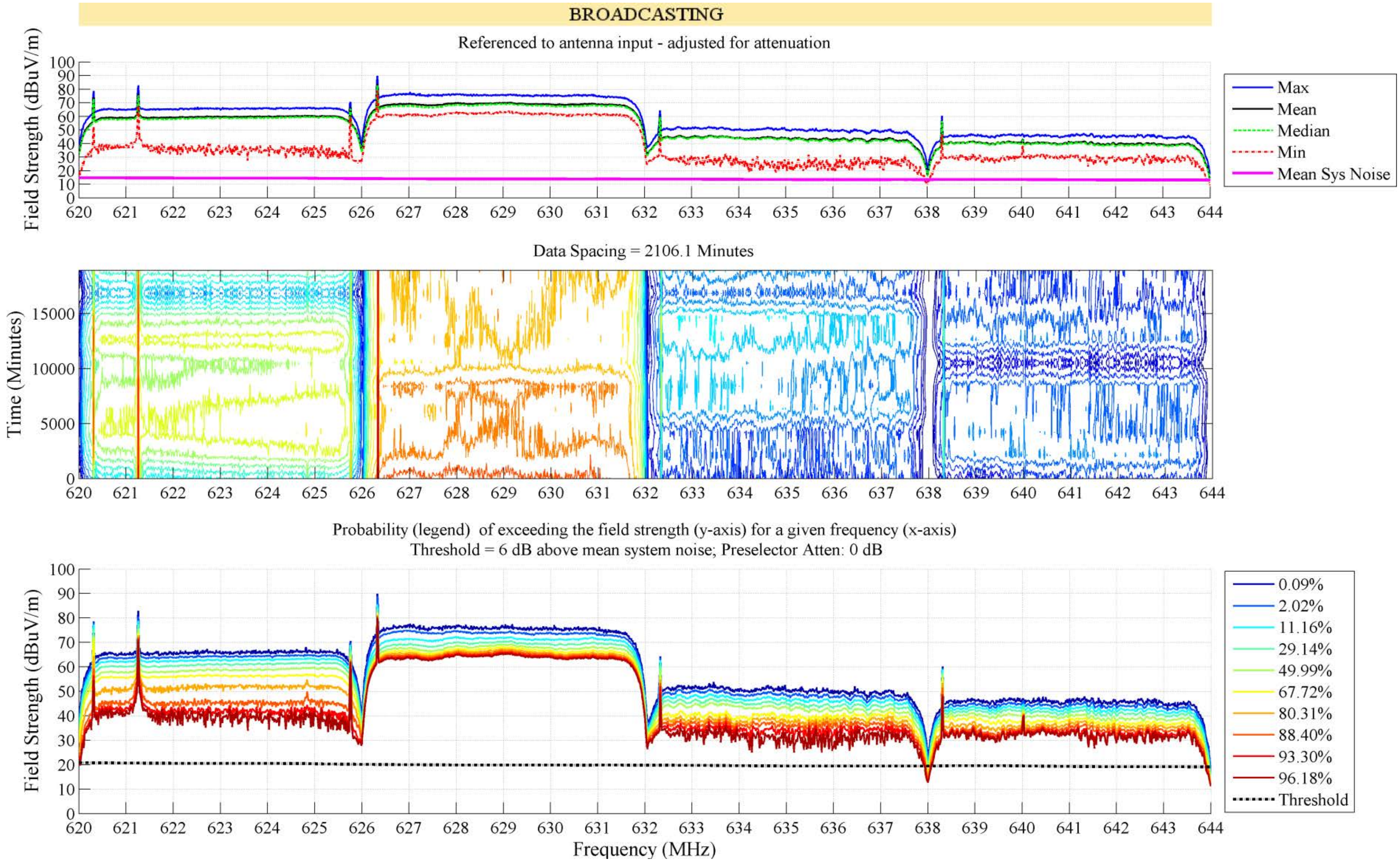


Figure 47. NTIA spectrum survey results from 620 to 644 MHz in San Diego, CA, May/June 2012.

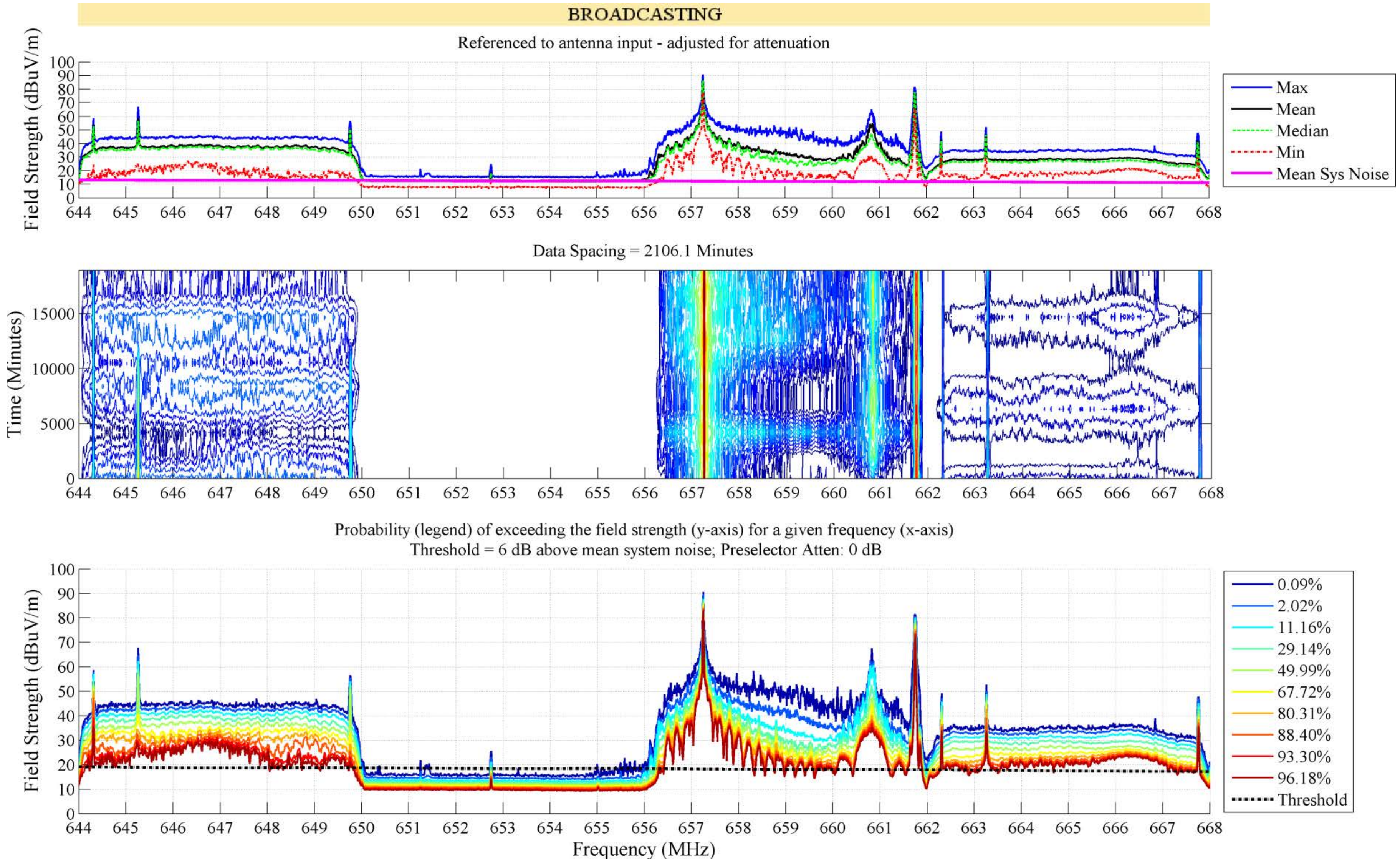


Figure 48. NTIA spectrum survey results from 644 to 668 MHz in San Diego, CA, May/June 2012.

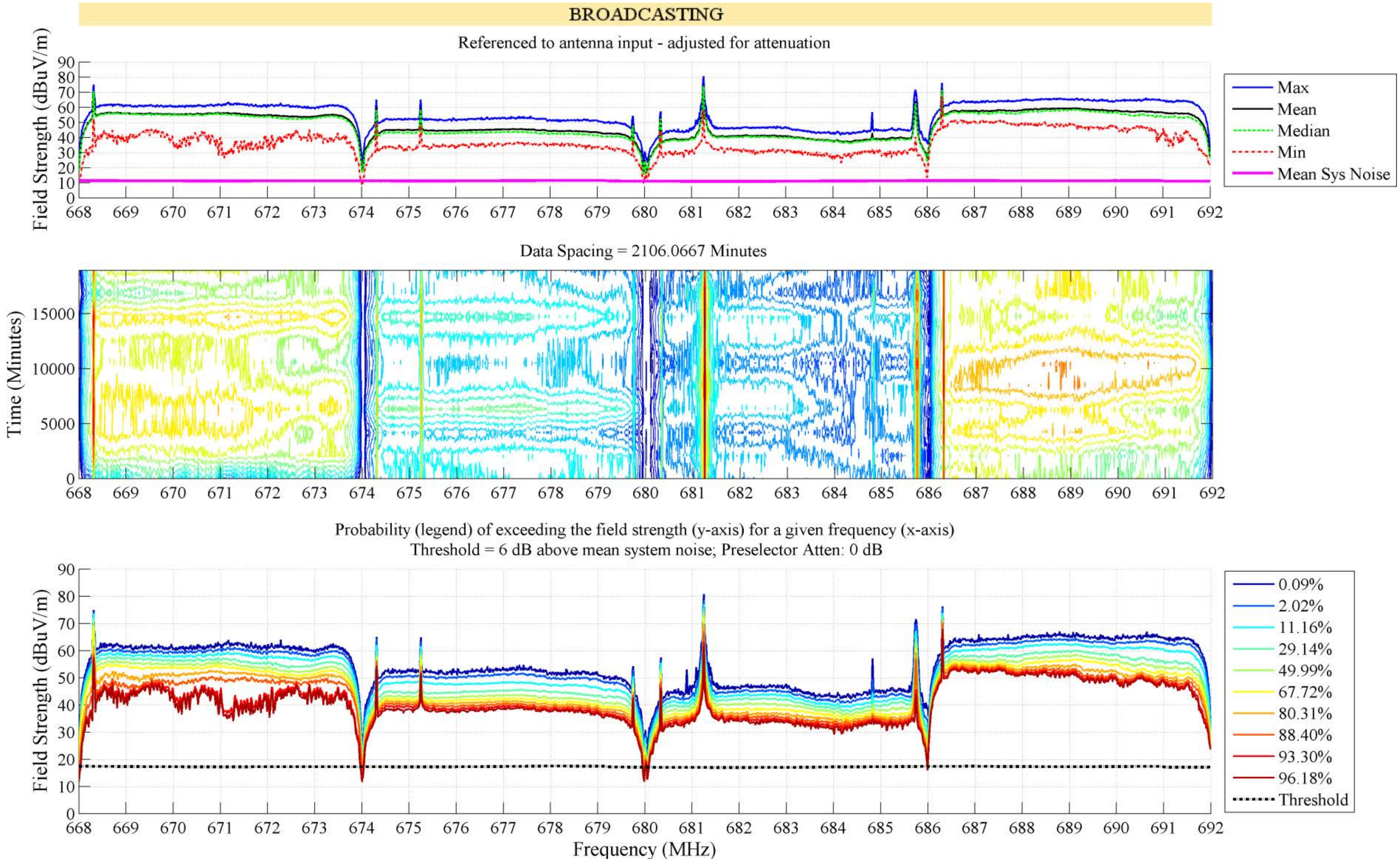


Figure 49. NTIA spectrum survey results from 668 to 692 MHz in San Diego, CA, May/June 2012.

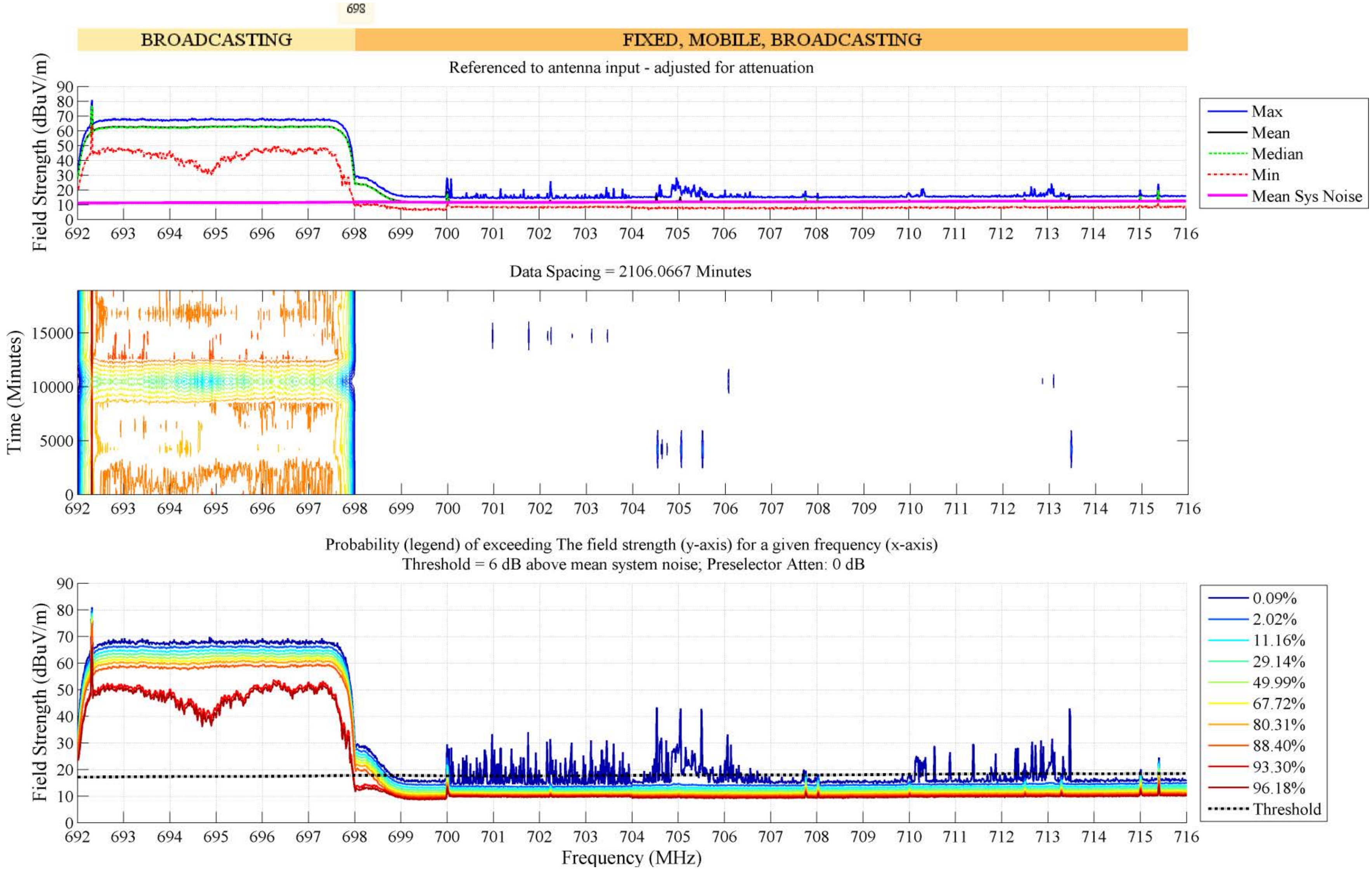


Figure 50. NTIA spectrum survey results from 692 to 716 MHz in San Diego, CA, May/June 2012.

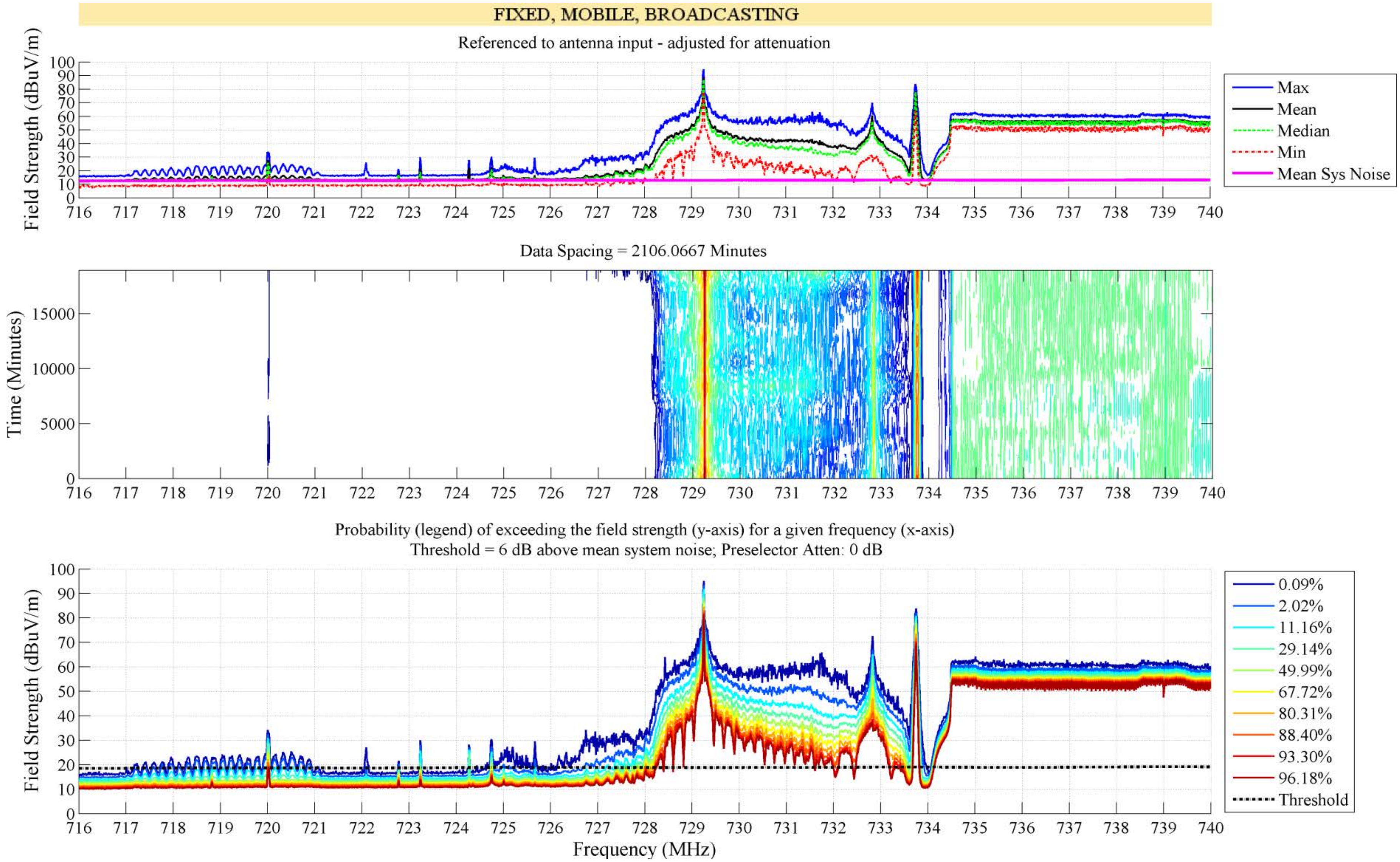


Figure 51. NTIA spectrum survey results from 716 to 740 MHz in San Diego, CA, May/June 2012.

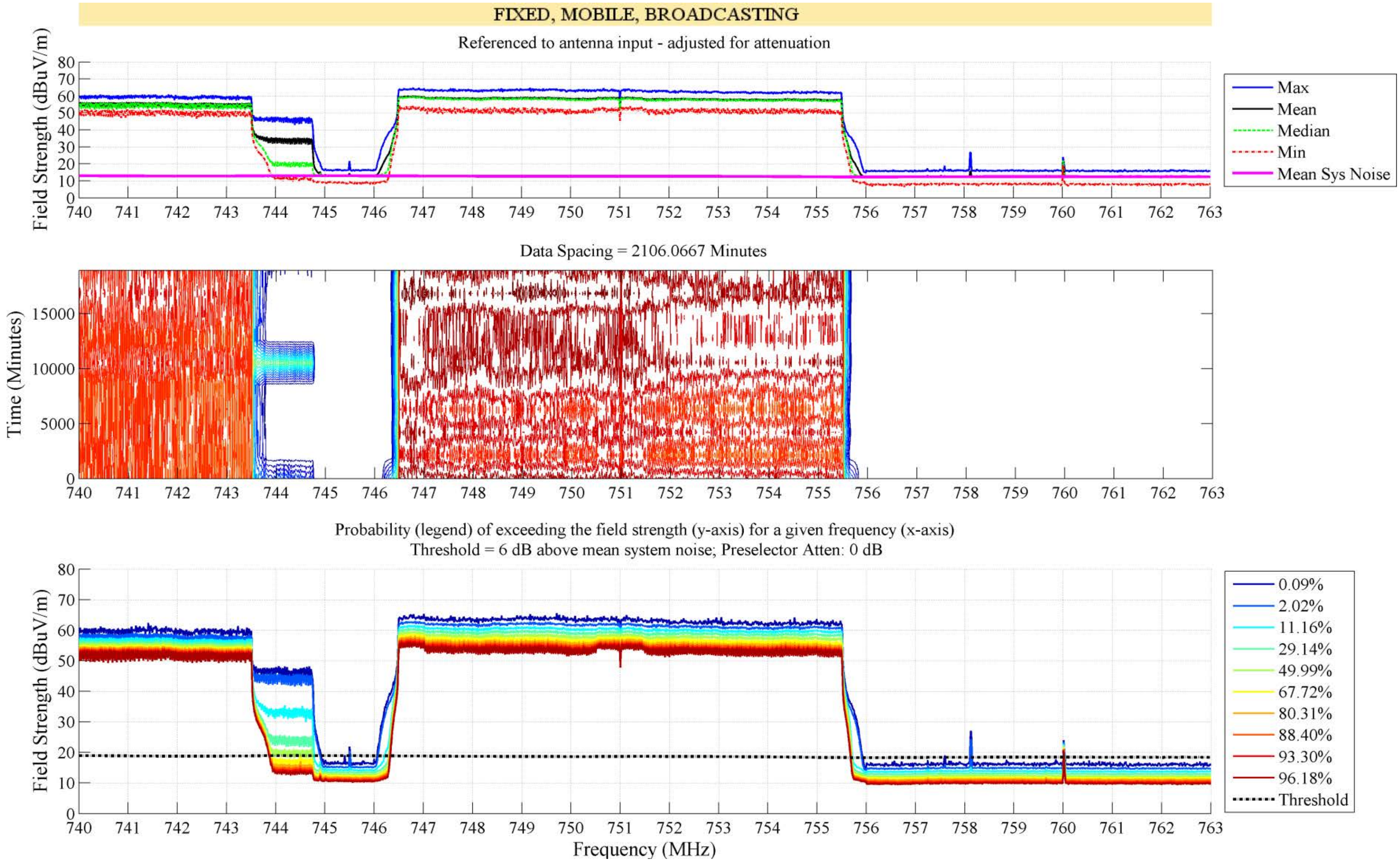


Figure 52. NTIA spectrum survey results from 740 to 763 MHz in San Diego, CA, May/June 2012.

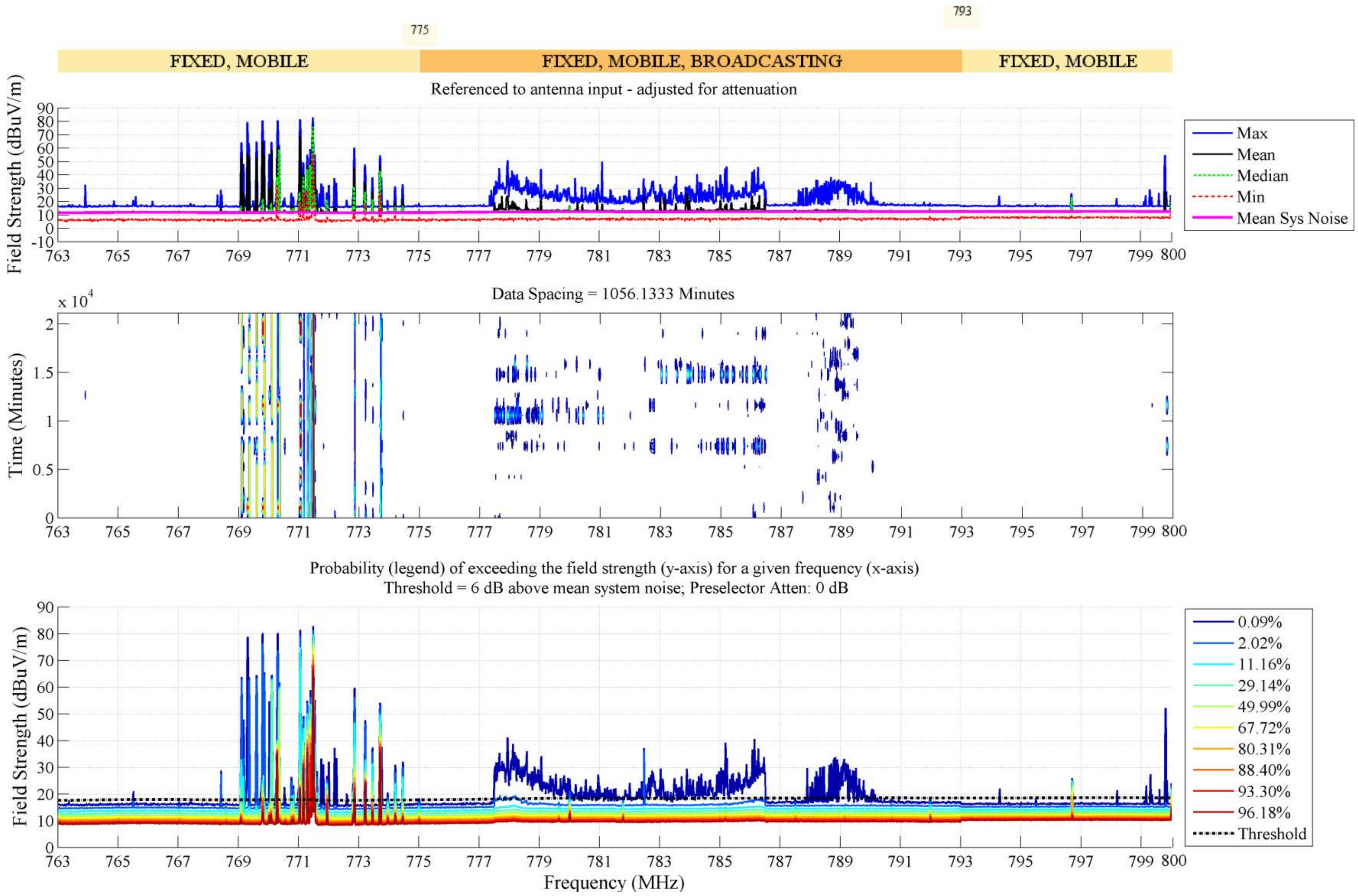


Figure 53. NTIA spectrum survey results from 763 to 800 MHz in San Diego, CA, May/June 2012.

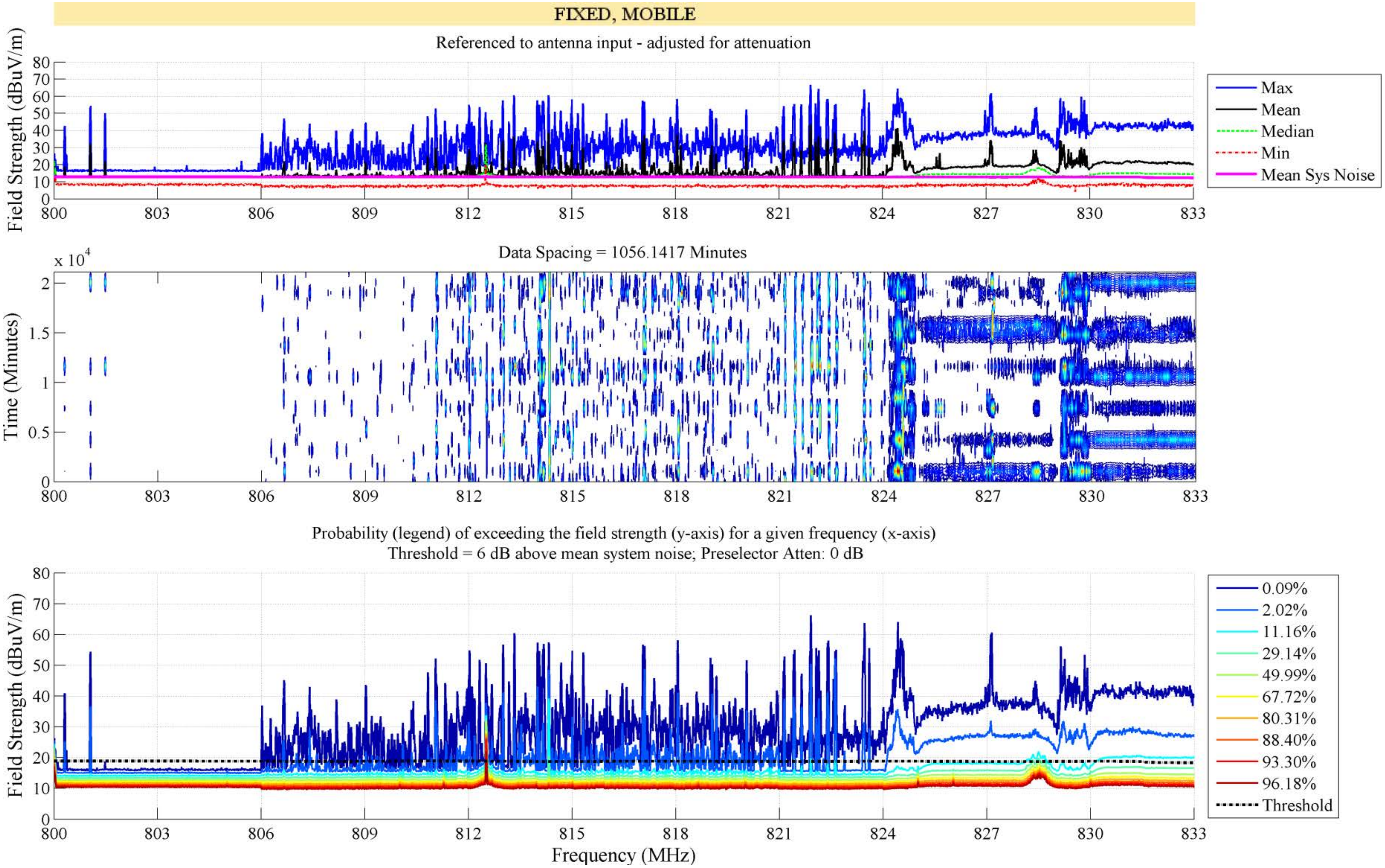


Figure 54. NTIA spectrum survey results from 800 to 833 MHz in San Diego, CA, May/June 2012.

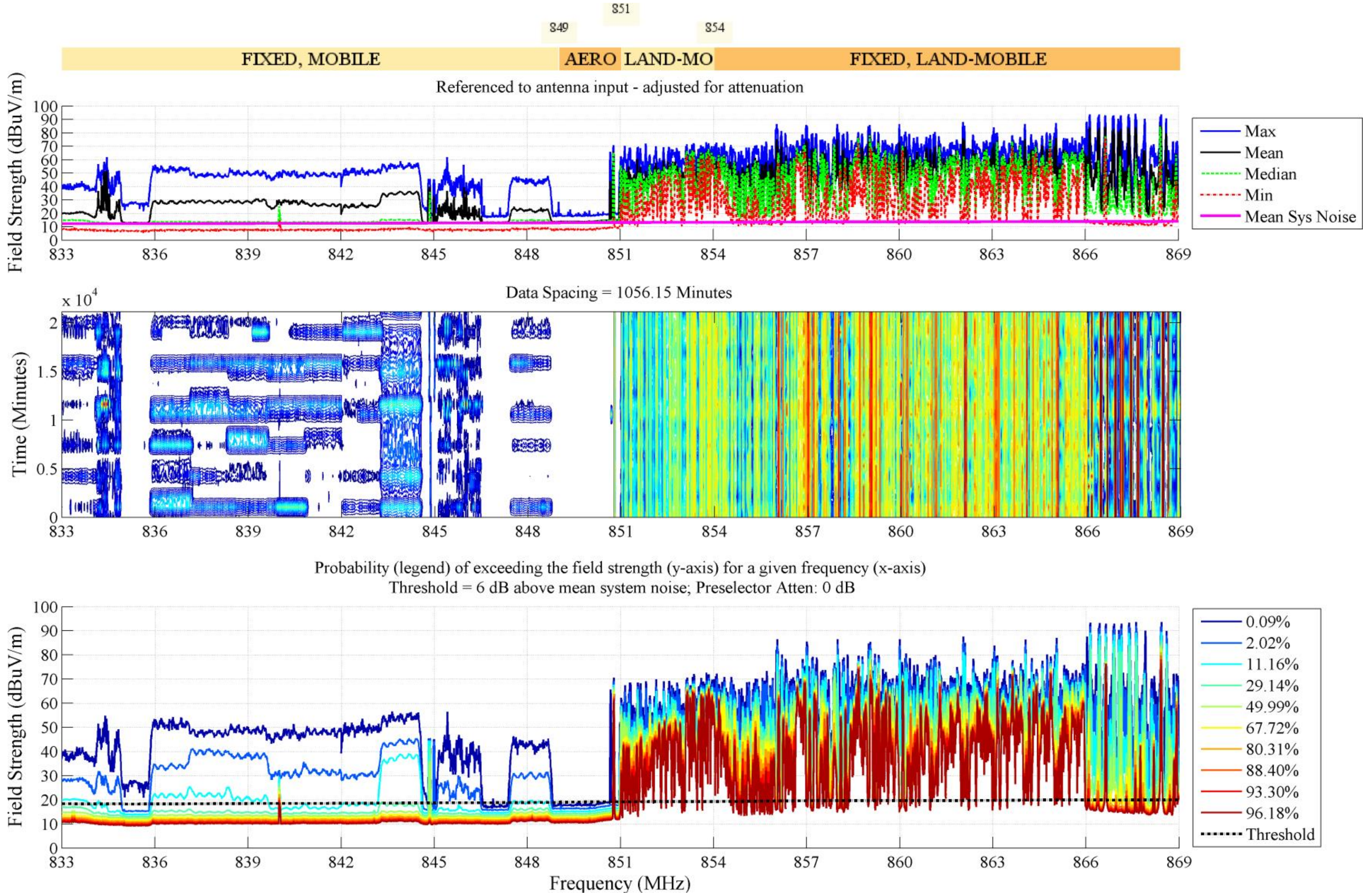


Figure 55. NTIA spectrum survey results from 833 to 869 MHz in San Diego, CA, May/June 2012.

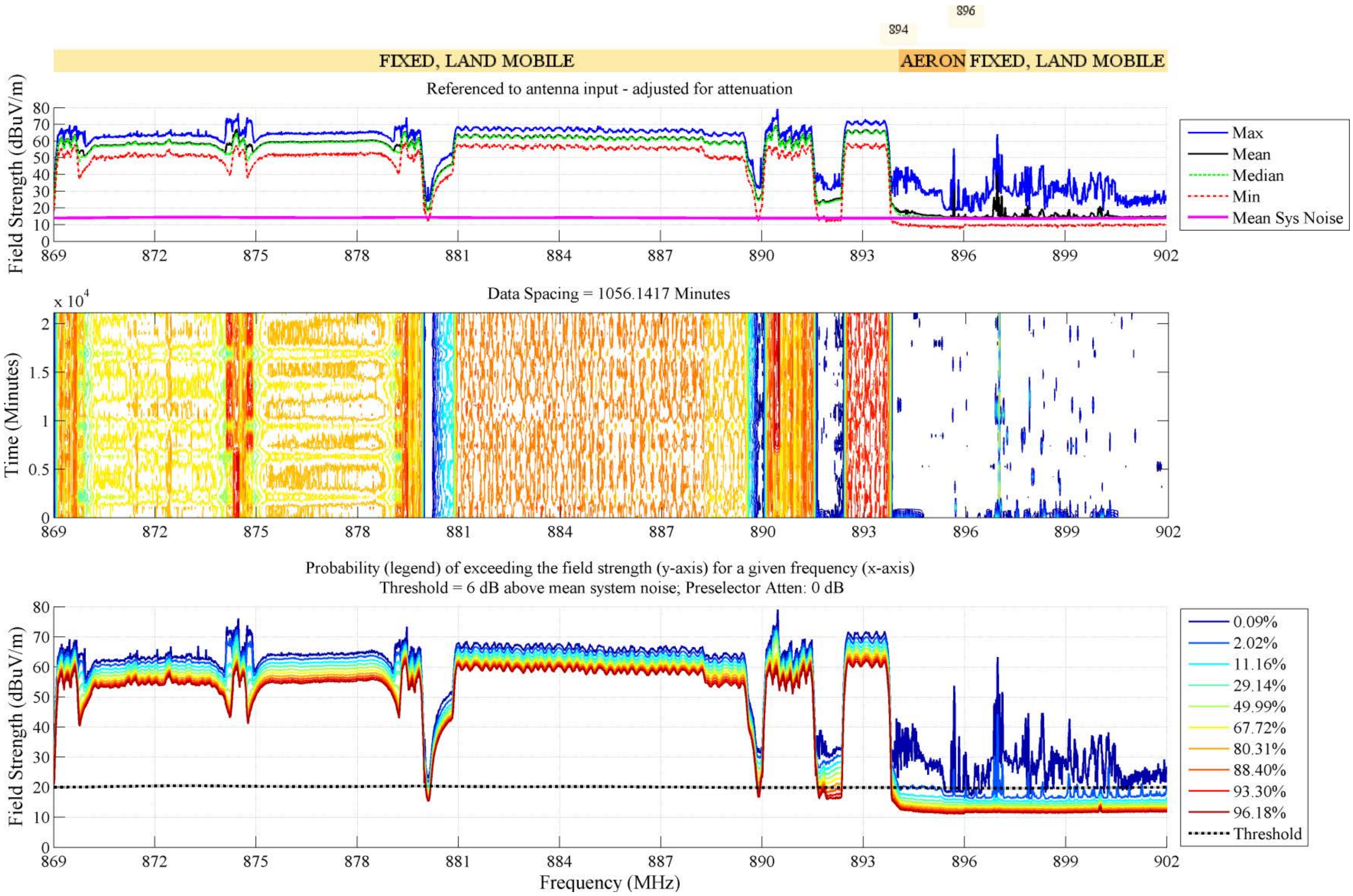


Figure 56. NTIA spectrum survey results from 869 to 902 MHz in San Diego, CA, May/June 2012.

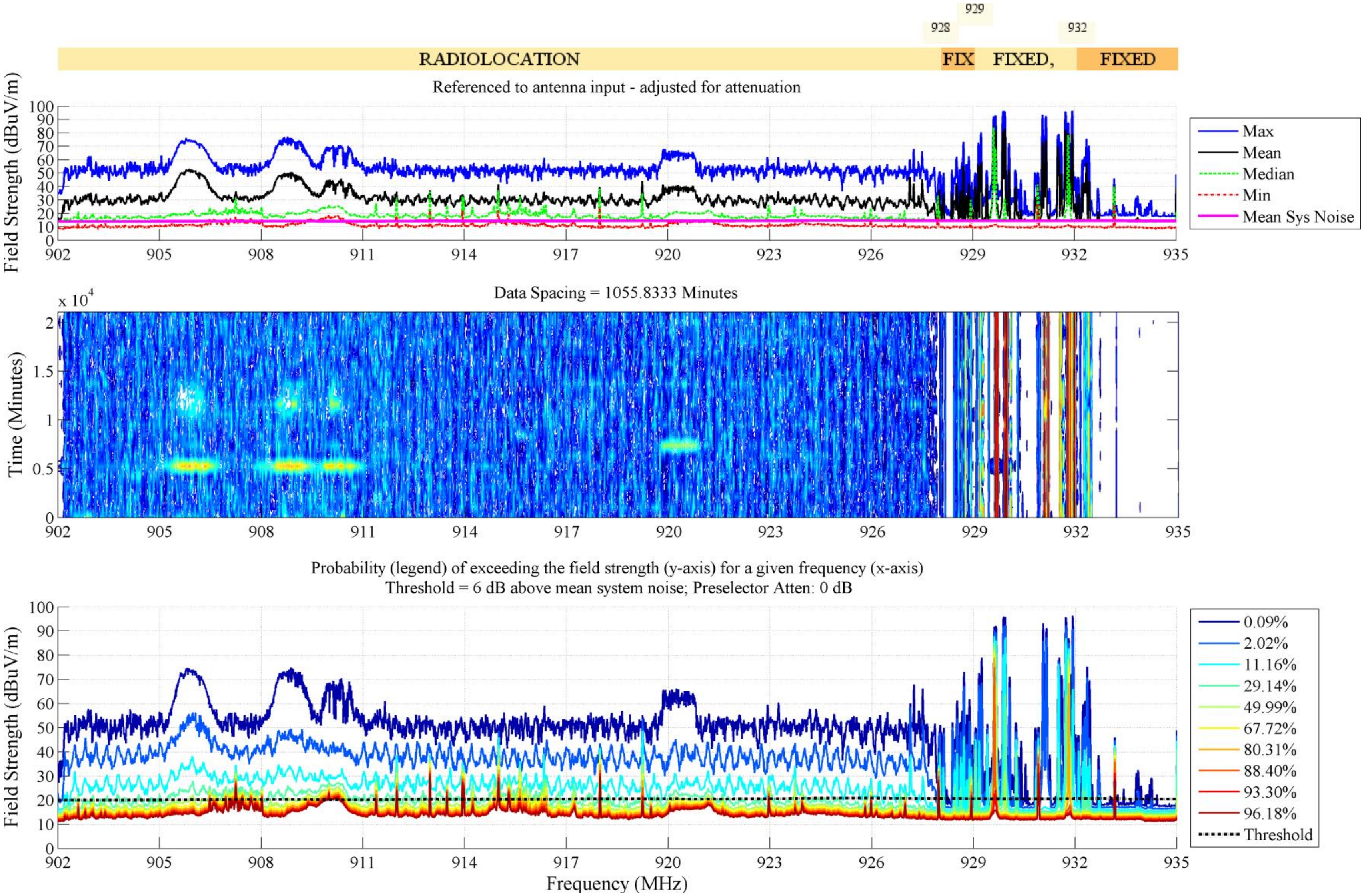


Figure 57. NTIA spectrum survey results from 902 to 935 MHz in San Diego, CA, May/June 2012.

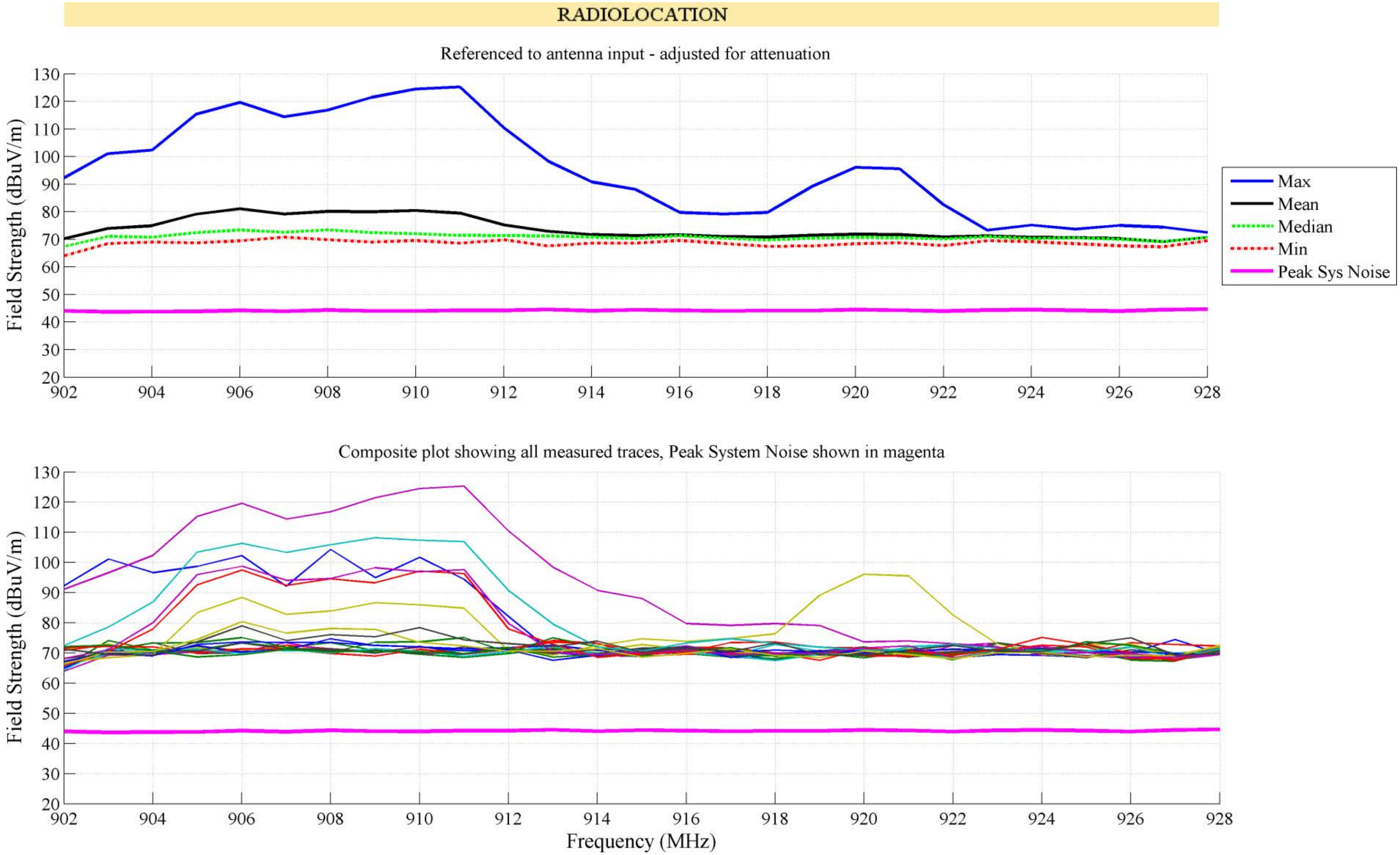


Figure 58. NTIA spectrum survey results from 902 to 928 MHz in San Diego, CA, May/June 2012. This measurement was taken using the stepped-spectrum measurement algorithm.

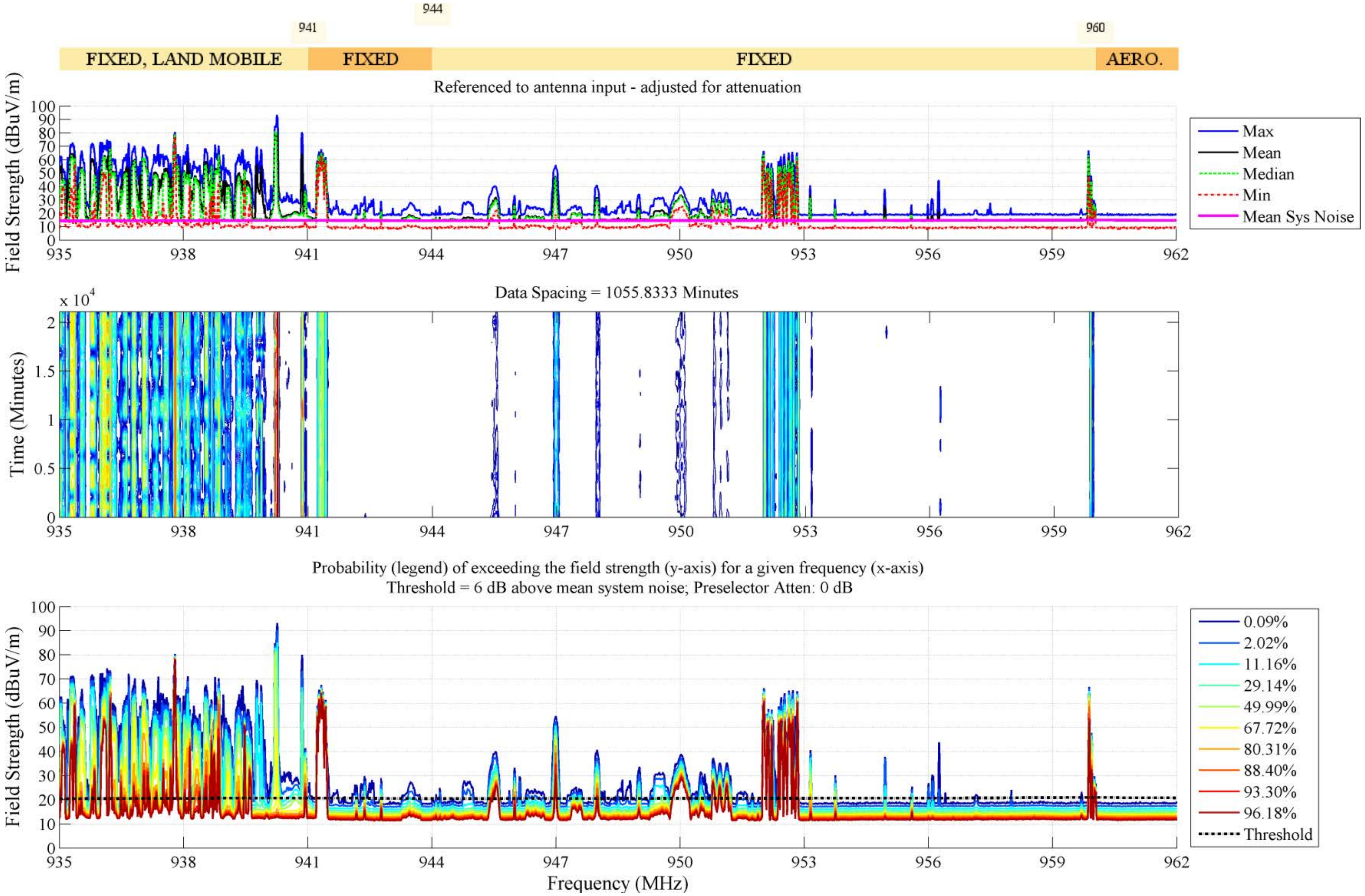


Figure 59. NTIA spectrum survey results from 935 to 962 MHz in San Diego, CA, May/June 2012.

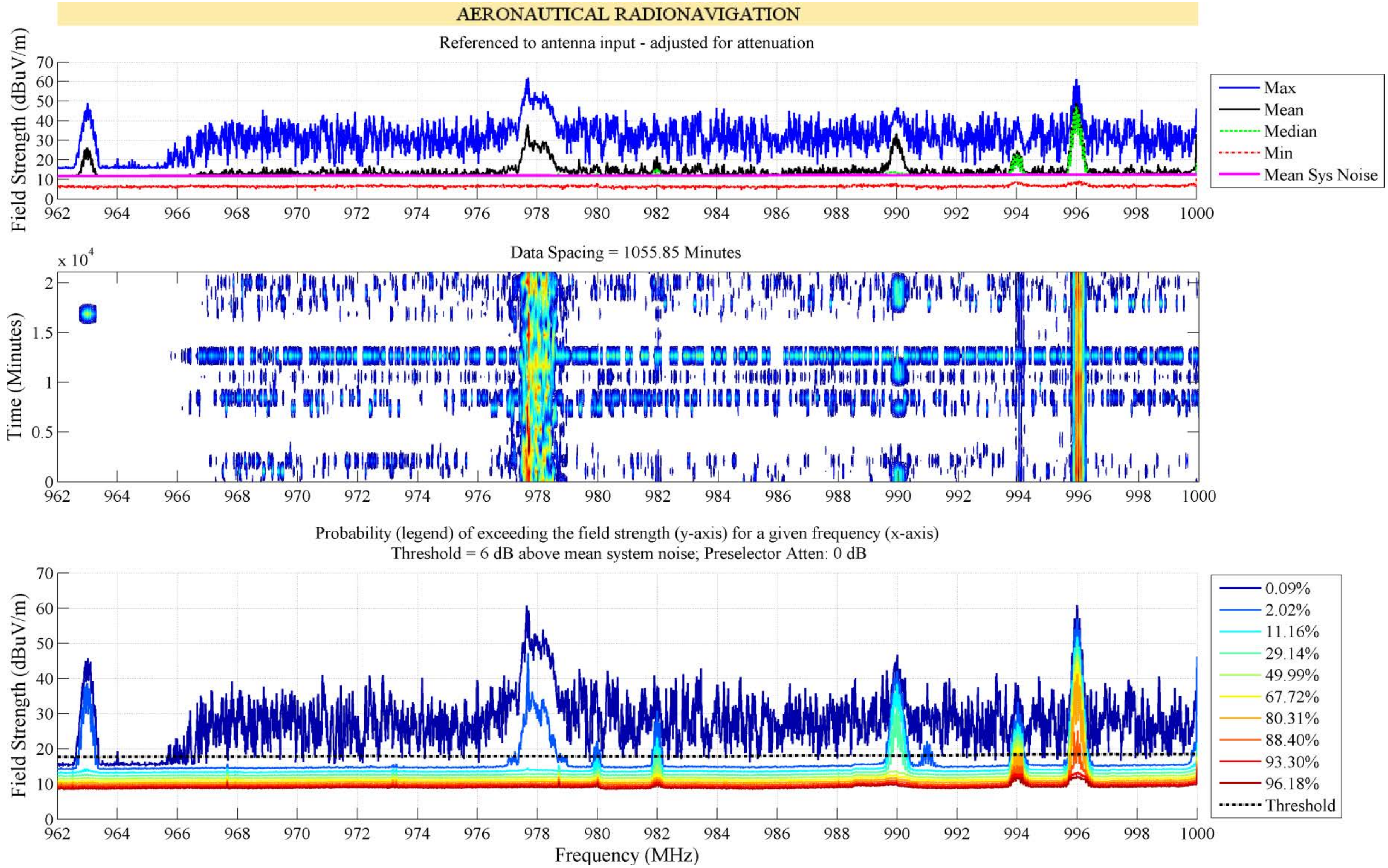


Figure 60. NTIA spectrum survey results from 962 to 1000 MHz in San Diego, CA, May/June 2012.

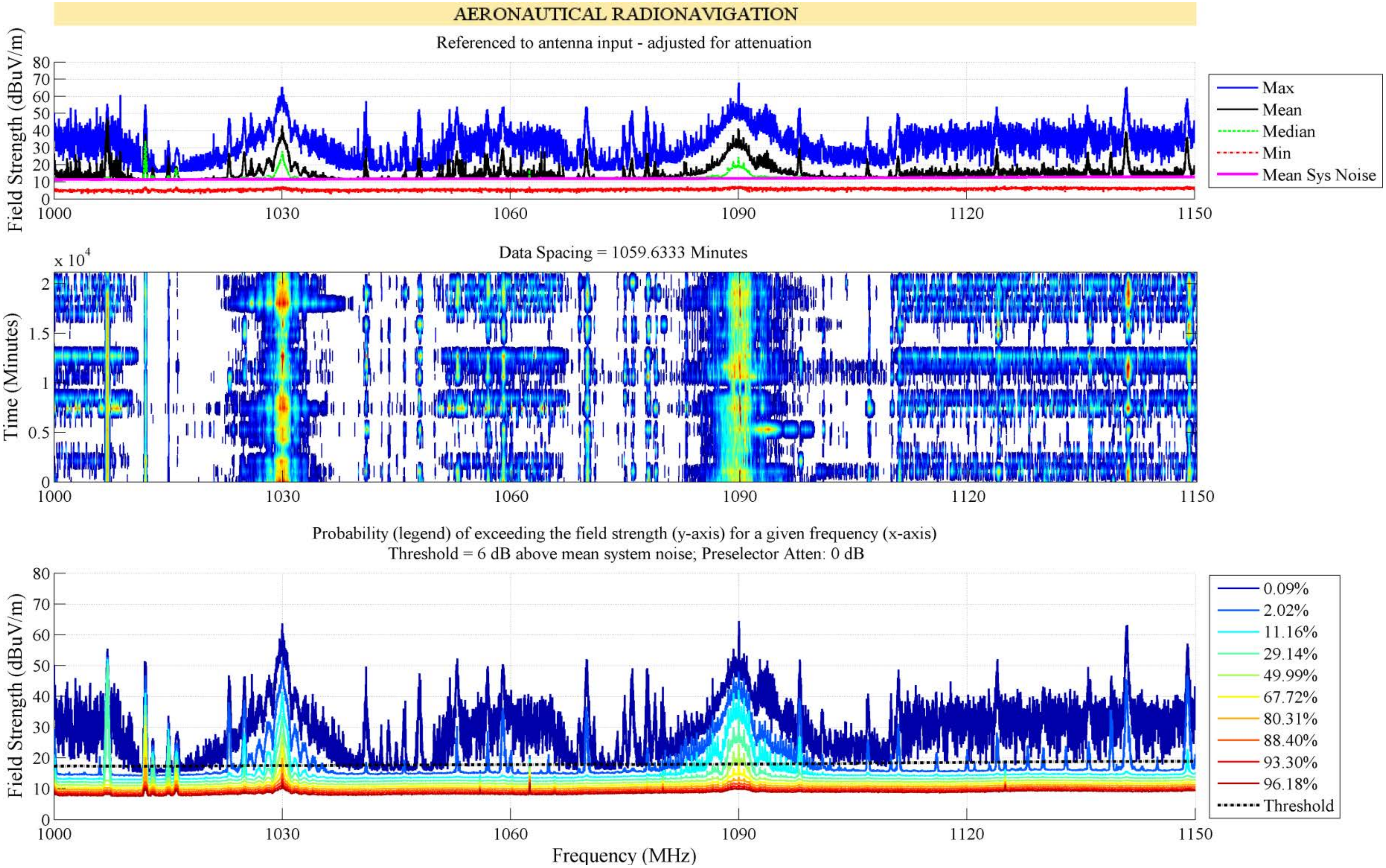


Figure 61. NTIA spectrum survey results from 1000 to 1150 MHz in San Diego, CA, May/June 2012.

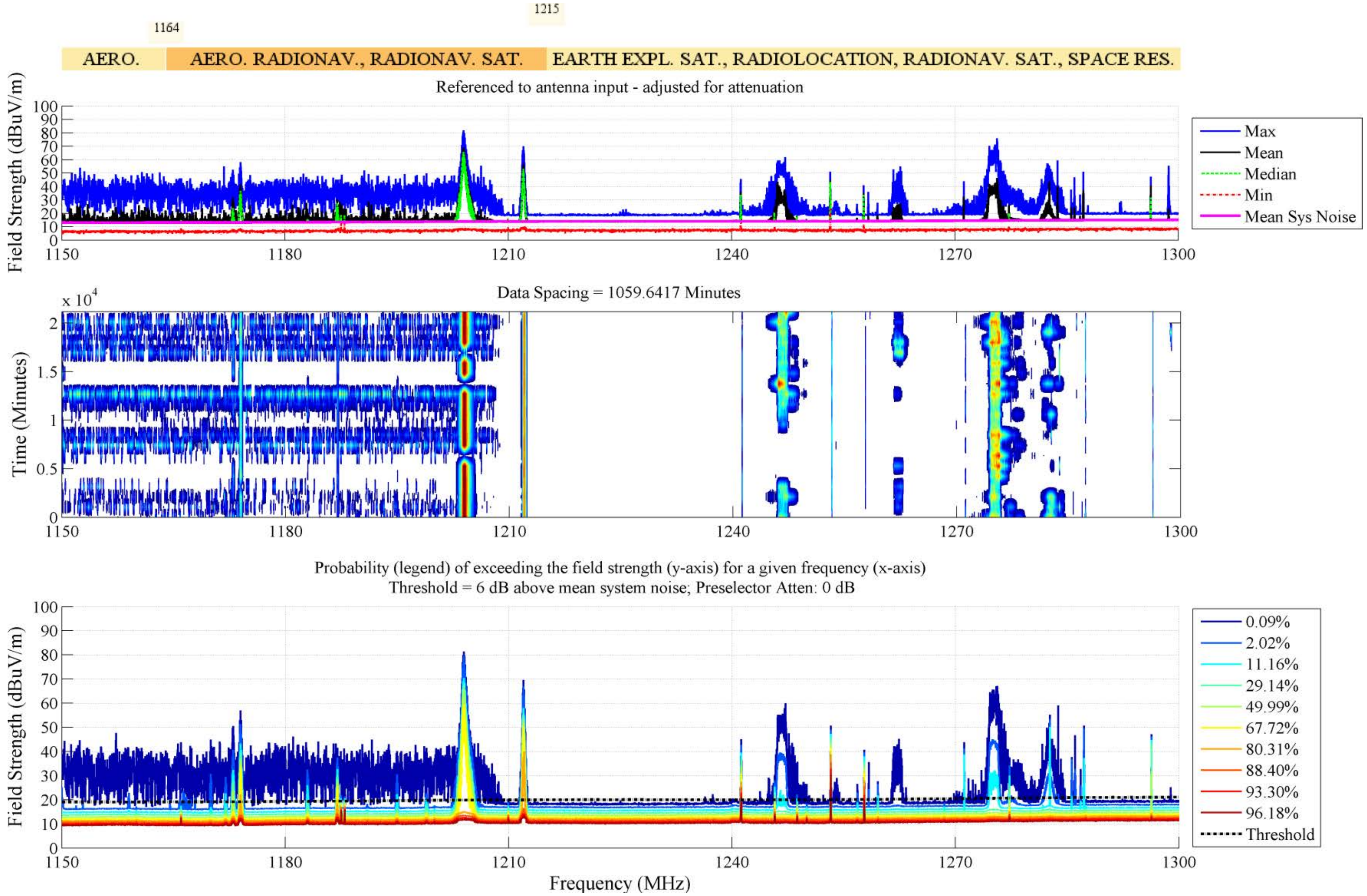


Figure 62. NTIA spectrum survey results from 1150 to 1300 MHz in San Diego, CA, May/June 2012.

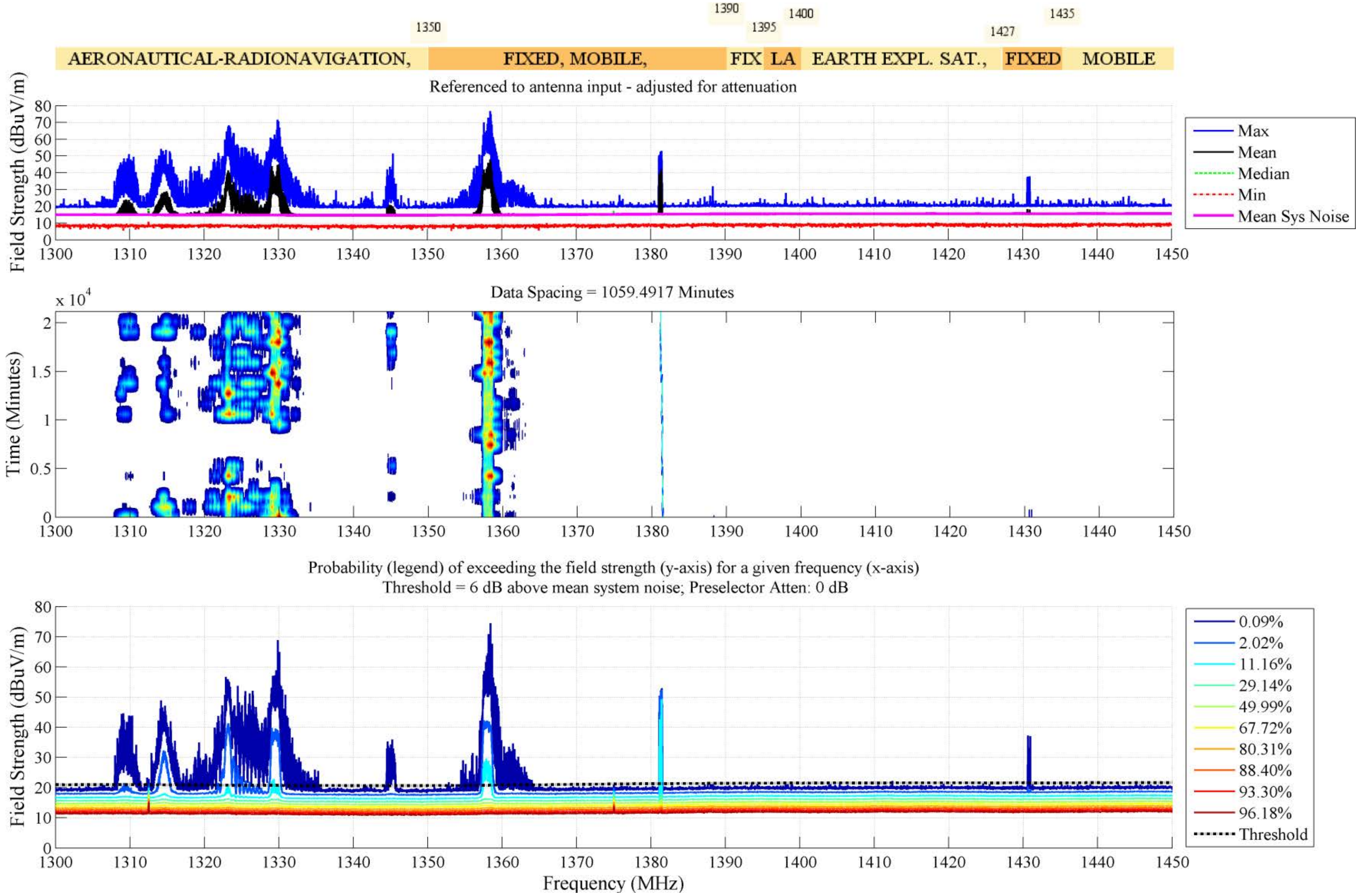


Figure 63. NTIA spectrum survey results from 1300 to 1450 MHz in San Diego, CA, May/June 2012.

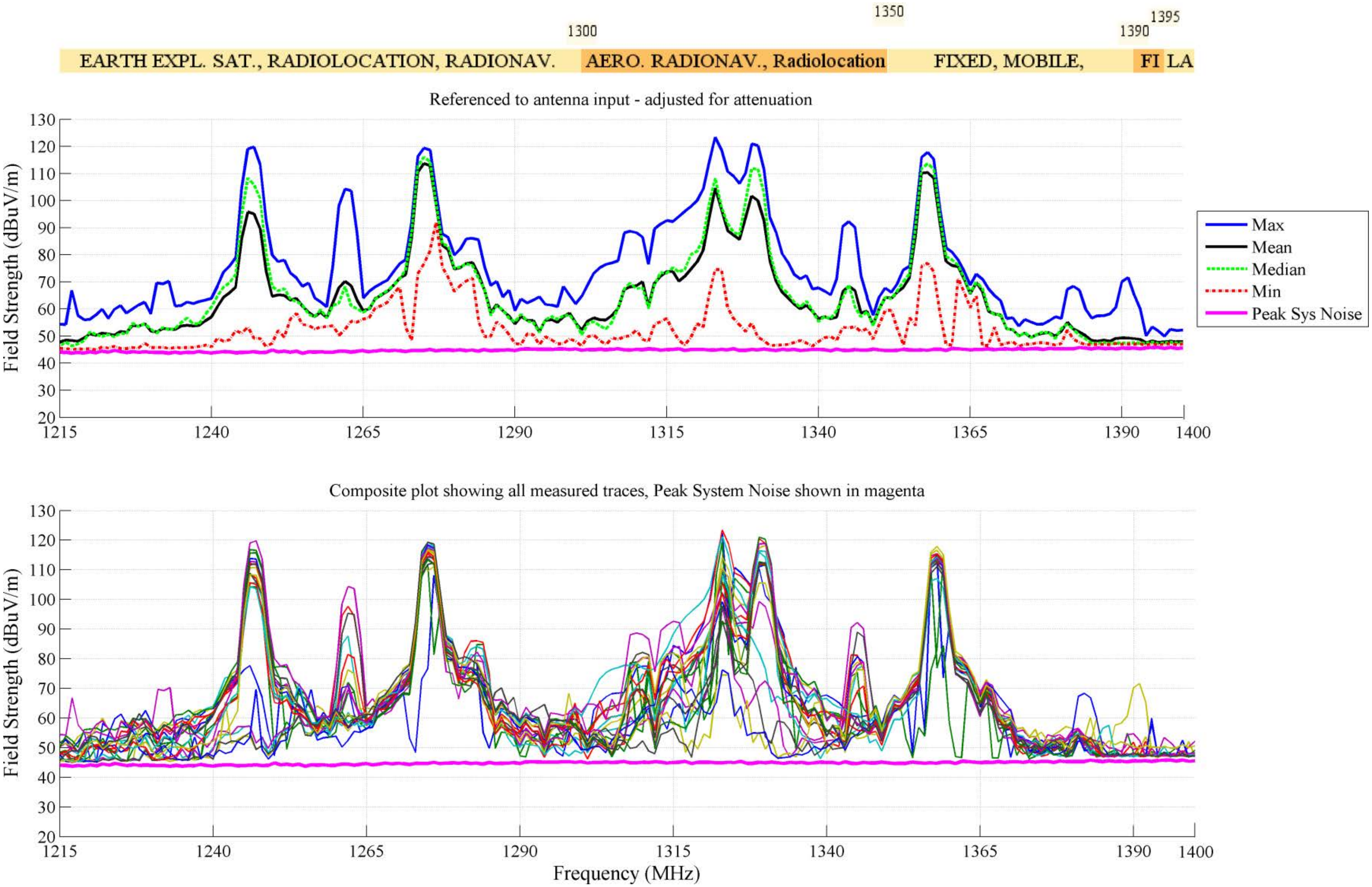


Figure 64. NTIA spectrum survey results from 1215 to 1400 MHz in San Diego, CA, May/June 2012. This measurement was taken using the stepped-spectrum measurement algorithm.

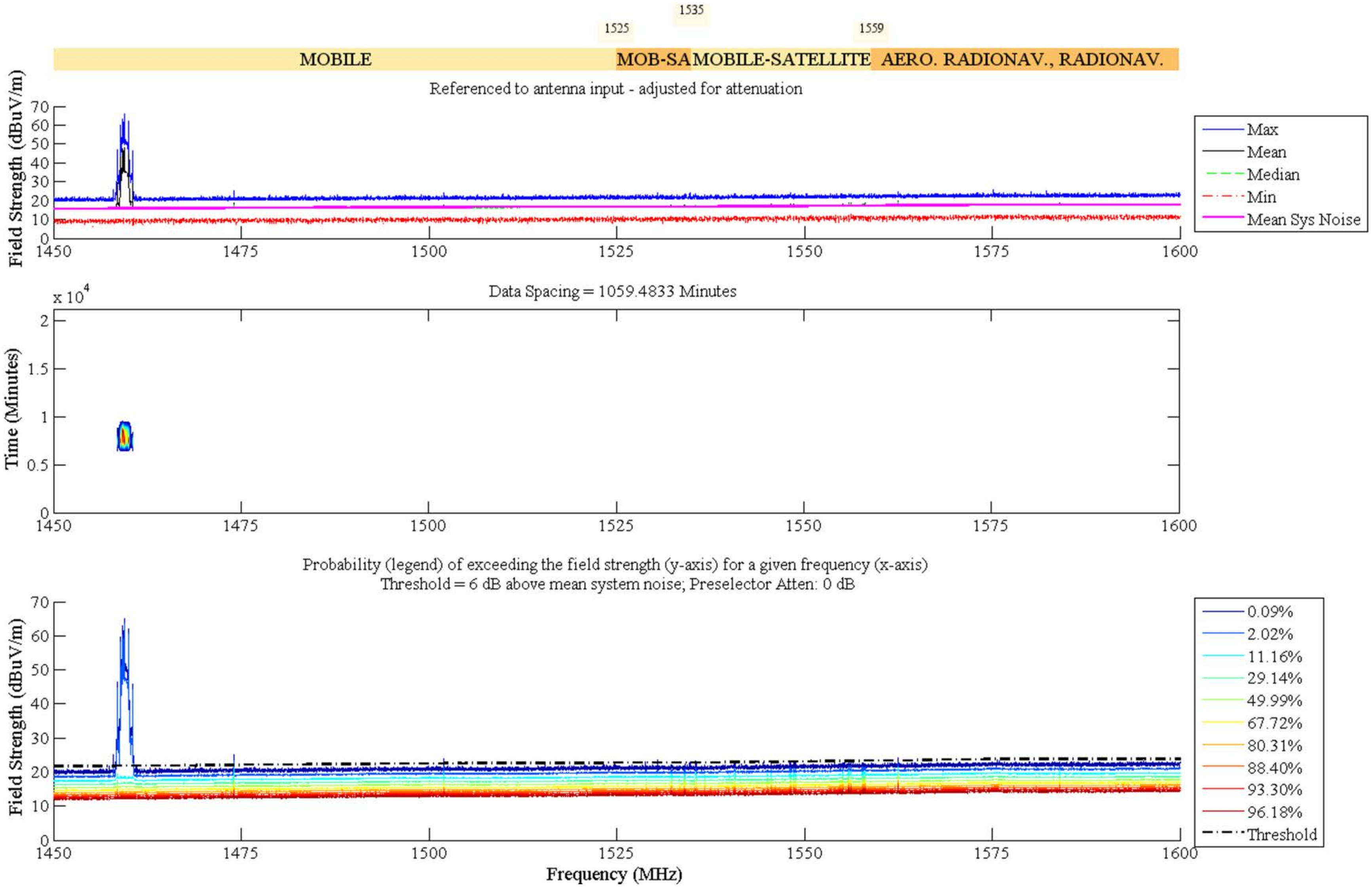


Figure 65. NTIA spectrum survey results from 1450 to 1600 MHz in San Diego, CA, May/June 2012.

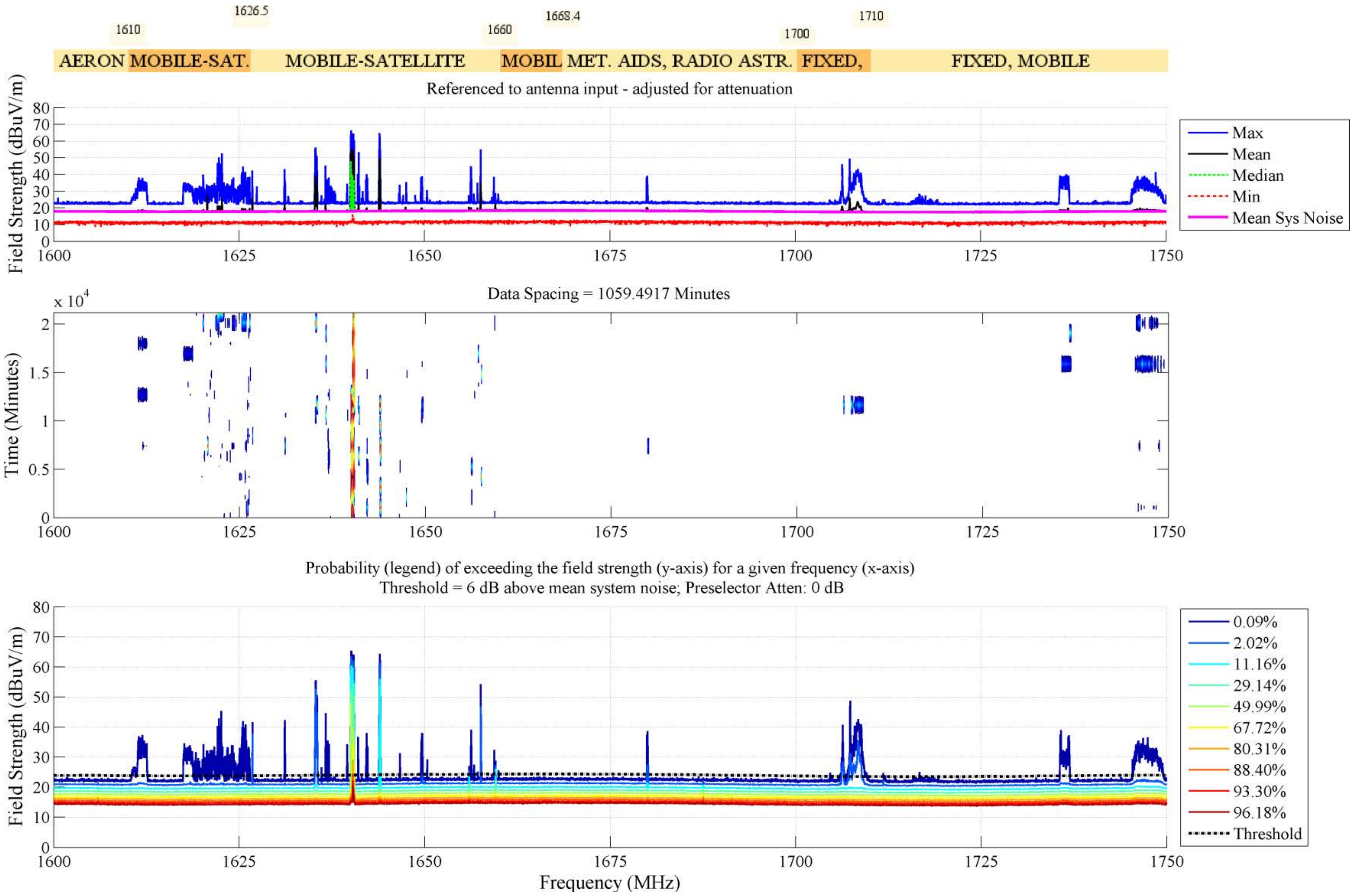


Figure 66. NTIA spectrum survey results from 1600 to 1750 MHz in San Diego, CA, May/June 2012.

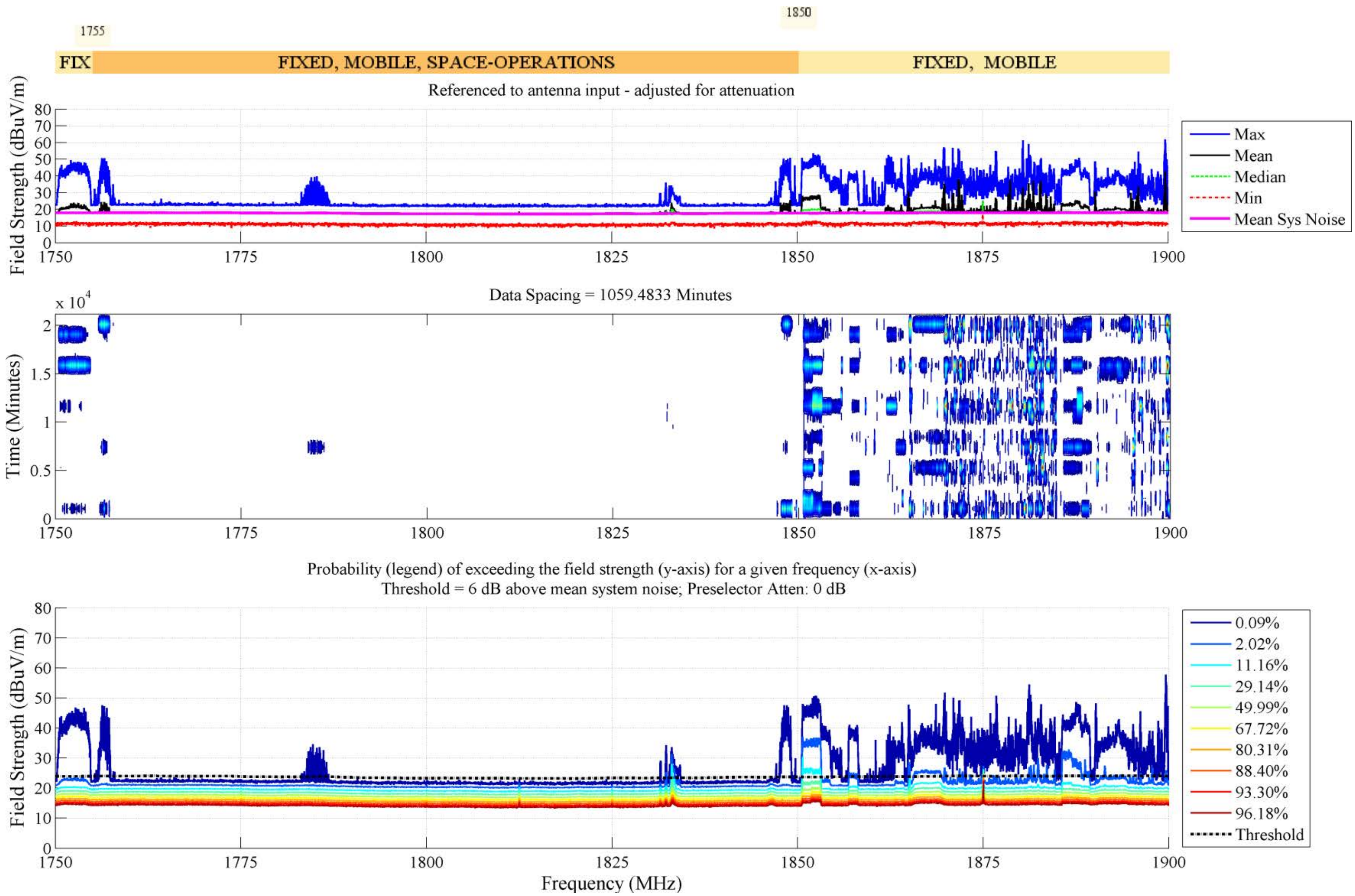


Figure 67. NTIA spectrum survey results from 1750 to 1900 MHz in San Diego, CA, May/June 2012.

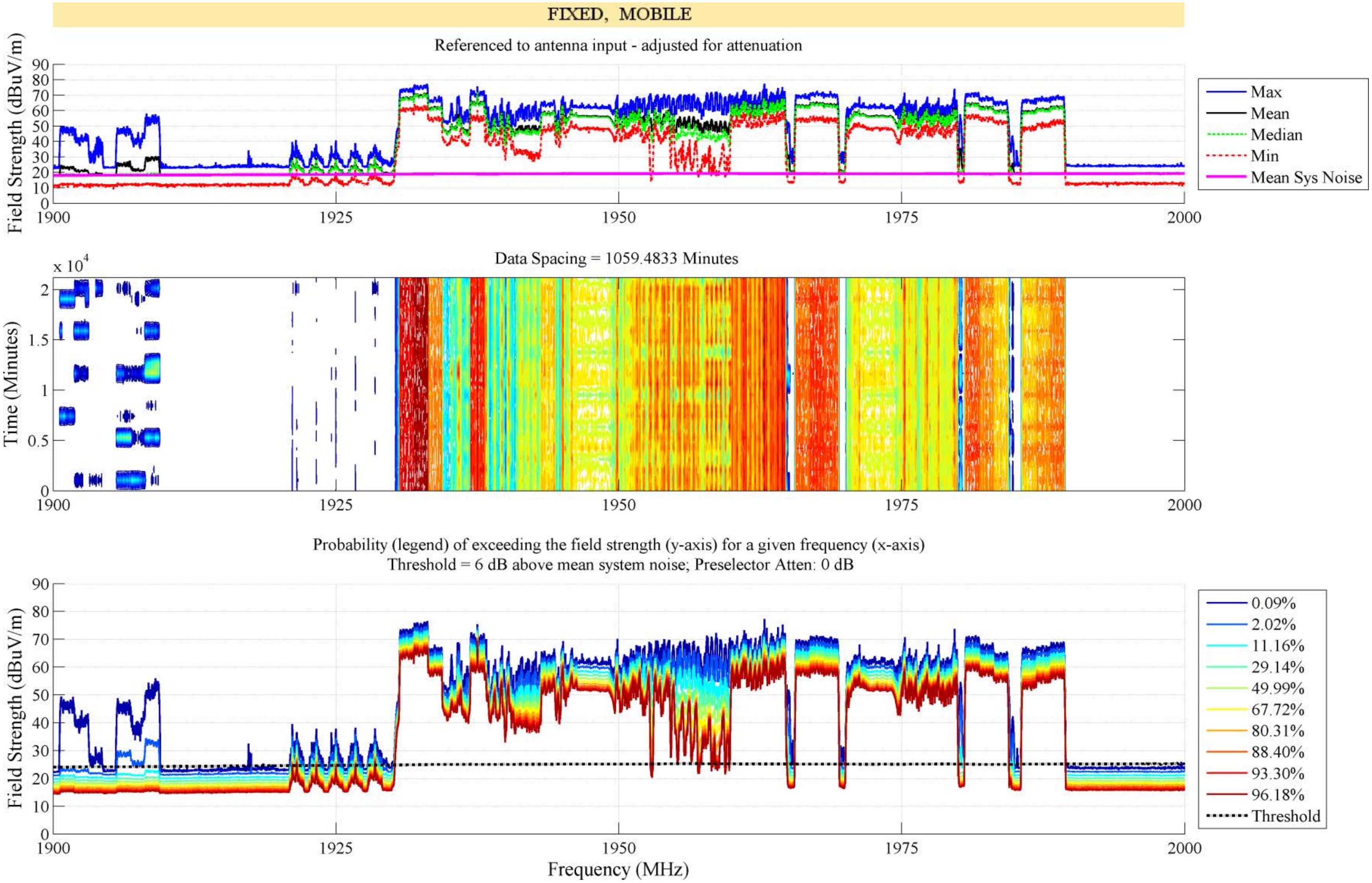


Figure 68. NTIA spectrum survey results from 1900 to 2000 MHz in San Diego, CA, May/June 2012.

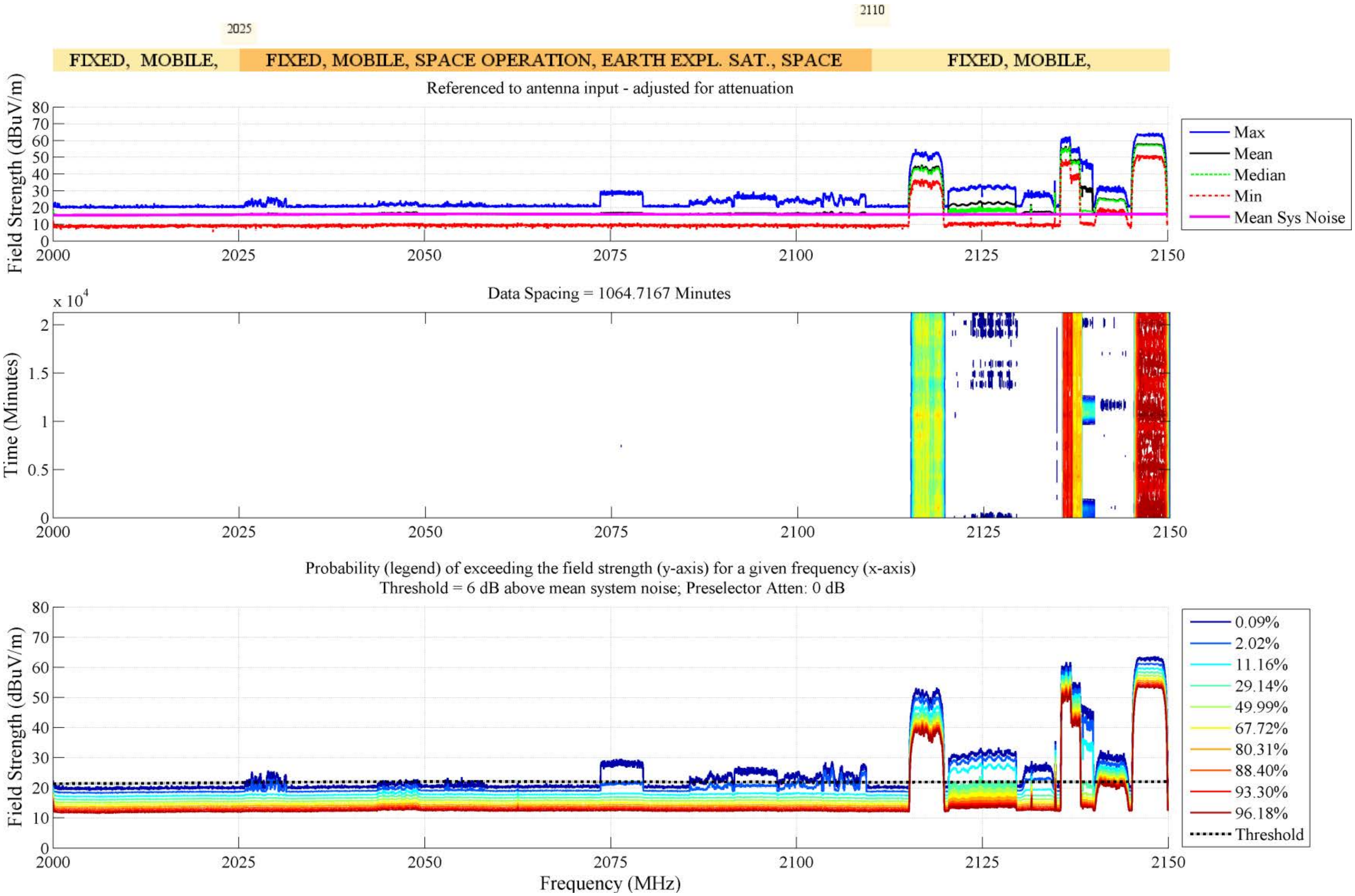


Figure 69. NTIA spectrum survey results from 2000 to 2150 MHz in San Diego, CA, May/June 2012.

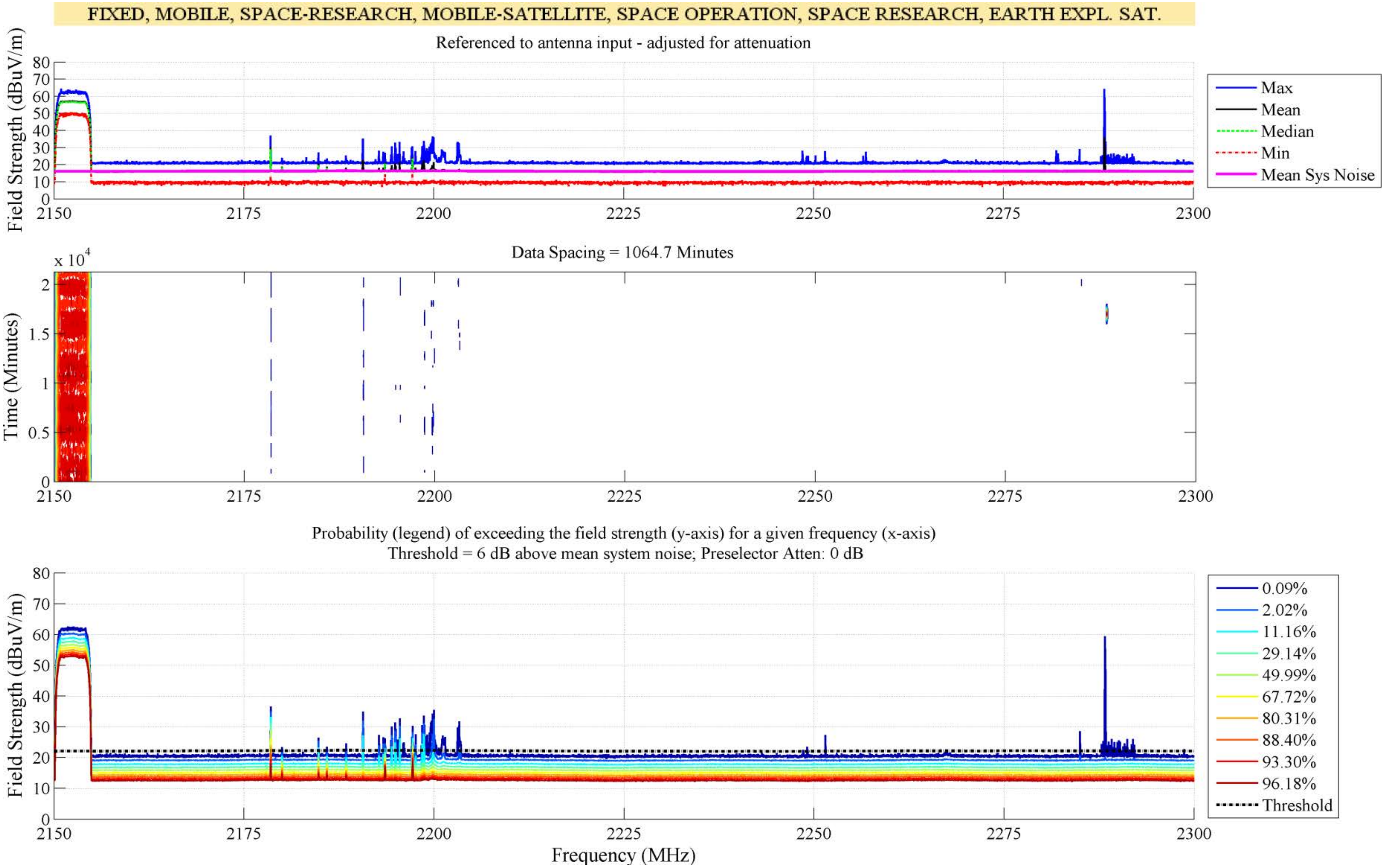


Figure 70. NTIA spectrum survey results from 2150 to 2300 MHz in San Diego, CA, May/June 2012.

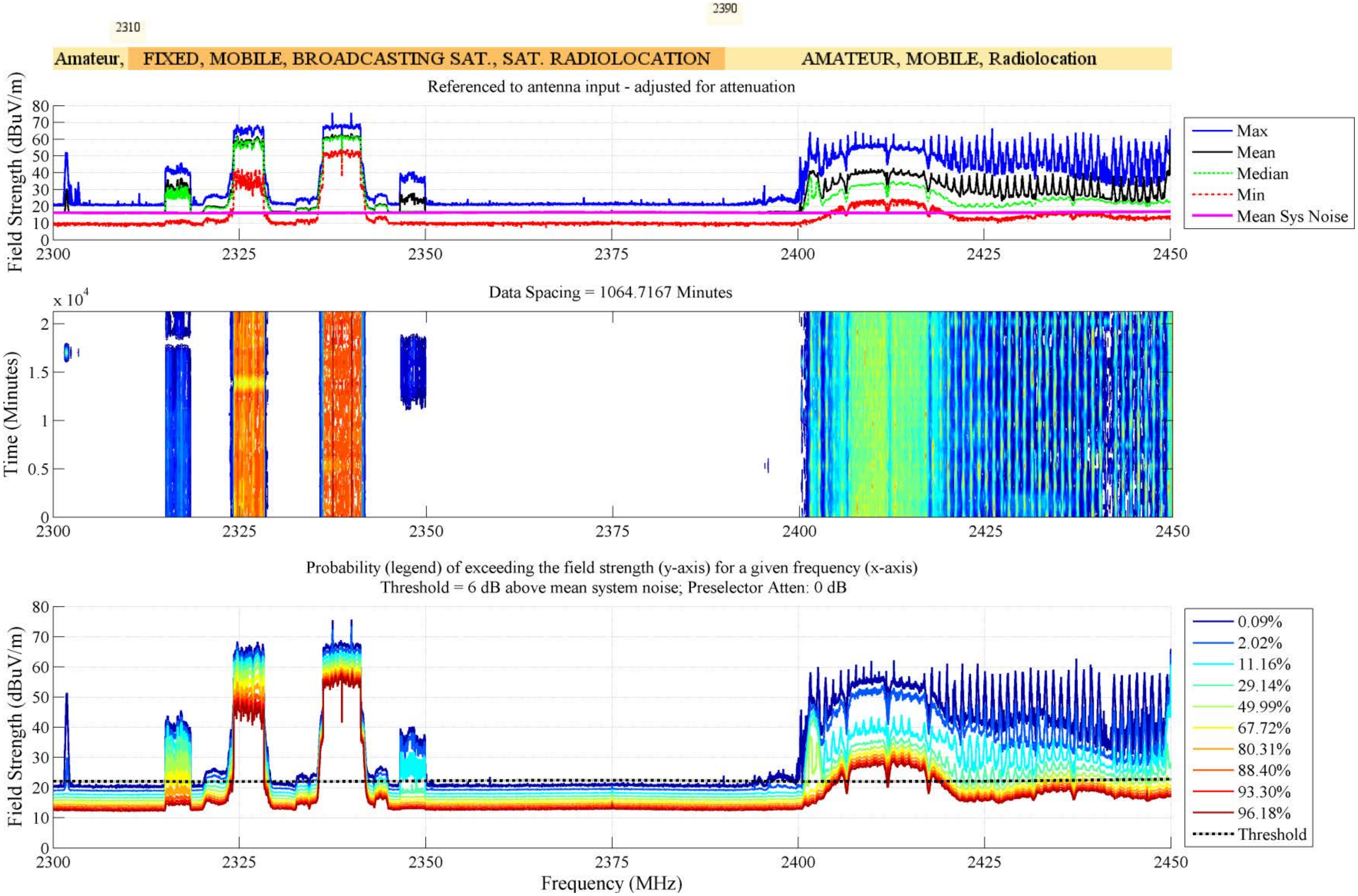


Figure 71. NTIA spectrum survey results from 2300 to 2450 MHz in San Diego, CA, May/June 2012.

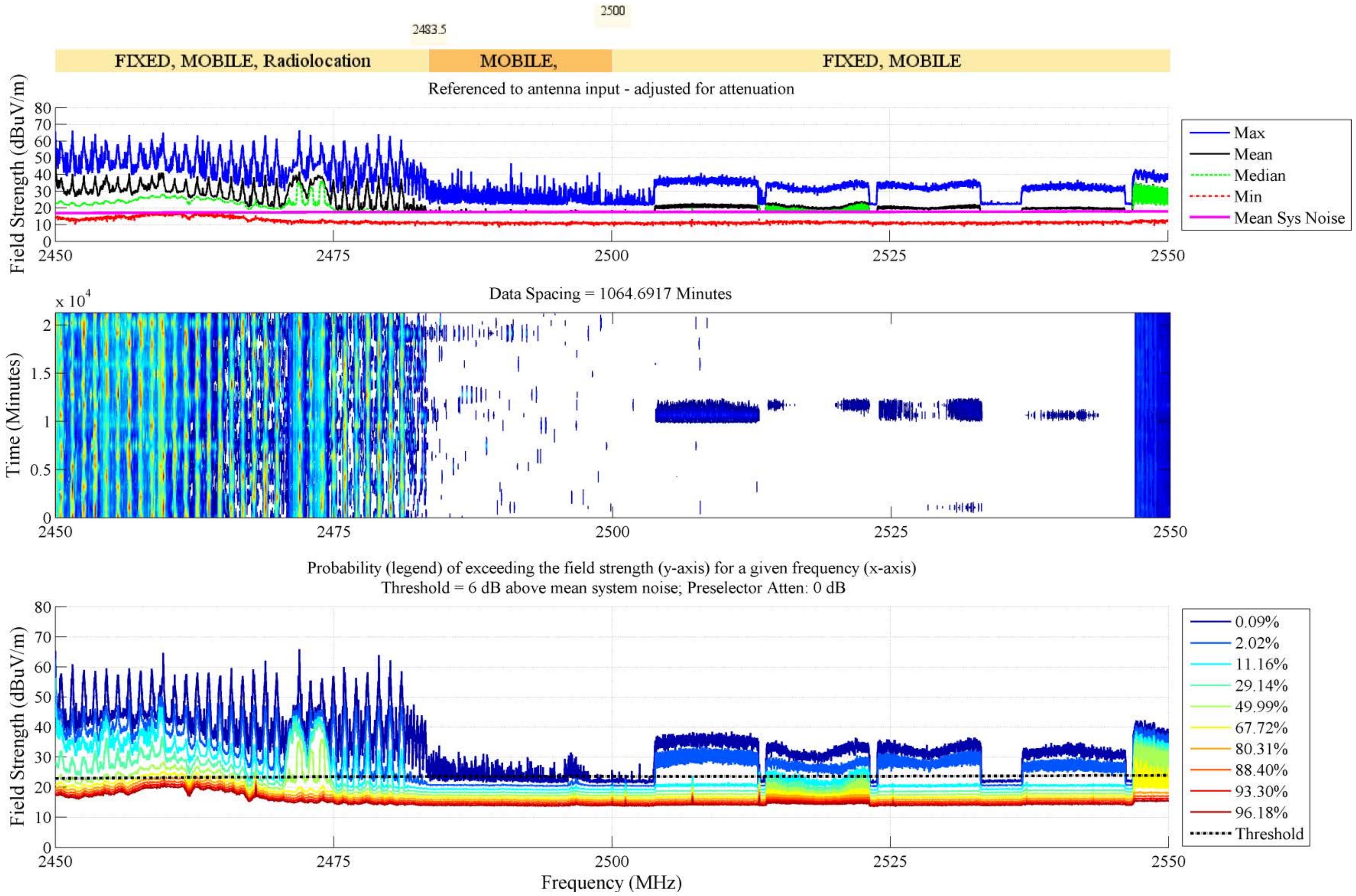
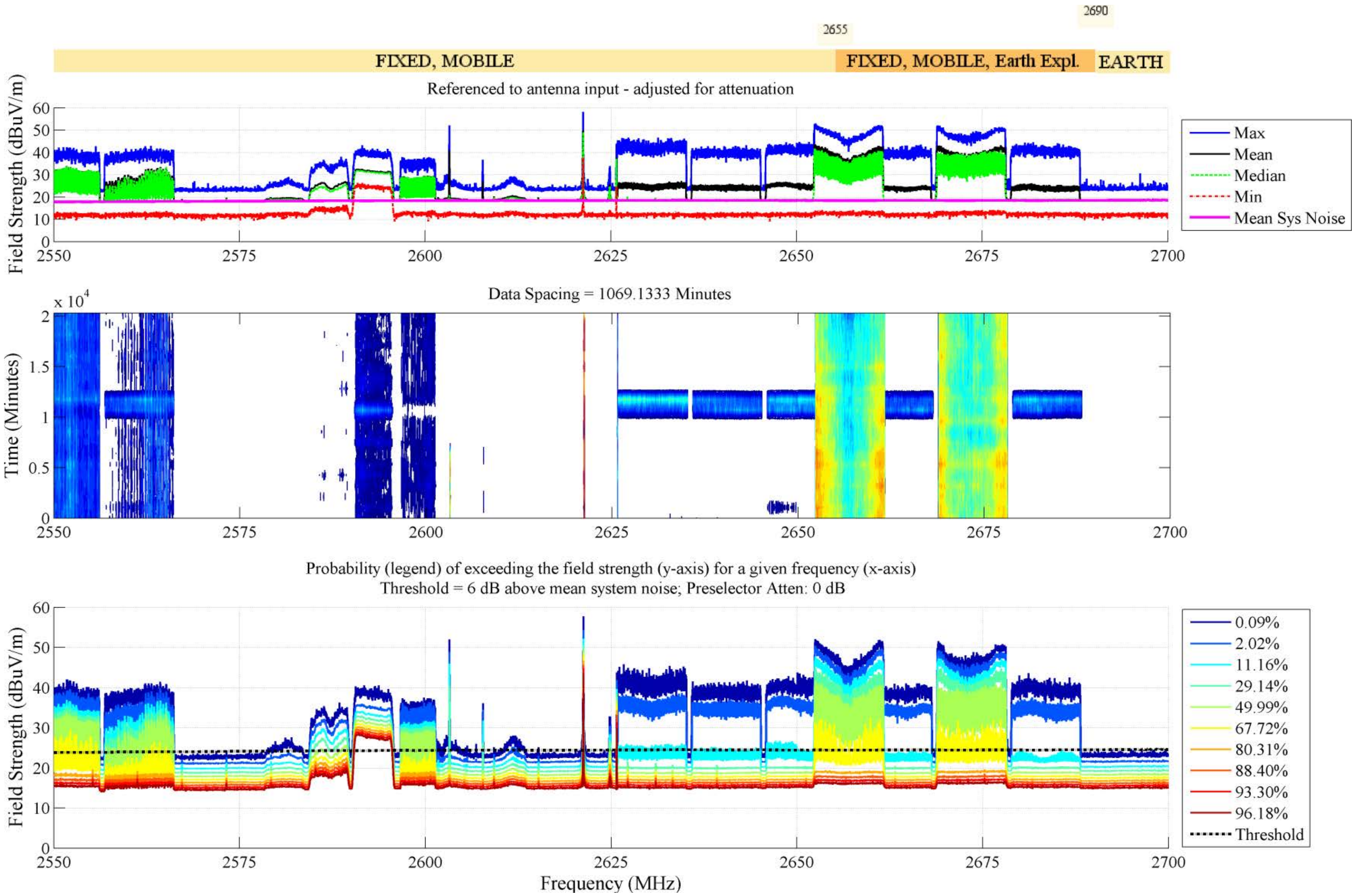


Figure 72. NTIA spectrum survey results from 2450 to 2550 MHz in San Diego, CA, May/June 2012.


Referenced to antenna input - adjusted for attenuation

Data Spacing = 1069.1333 Minutes

Probability (legend) of exceeding the field strength (y-axis) for a given frequency (x-axis)
Threshold = 6 dB above mean system noise; Preselector Atten: 0 dB

Figure 73. NTIA spectrum survey results from 2550 to 2700 MHz in San Diego, CA, May/June 2012.

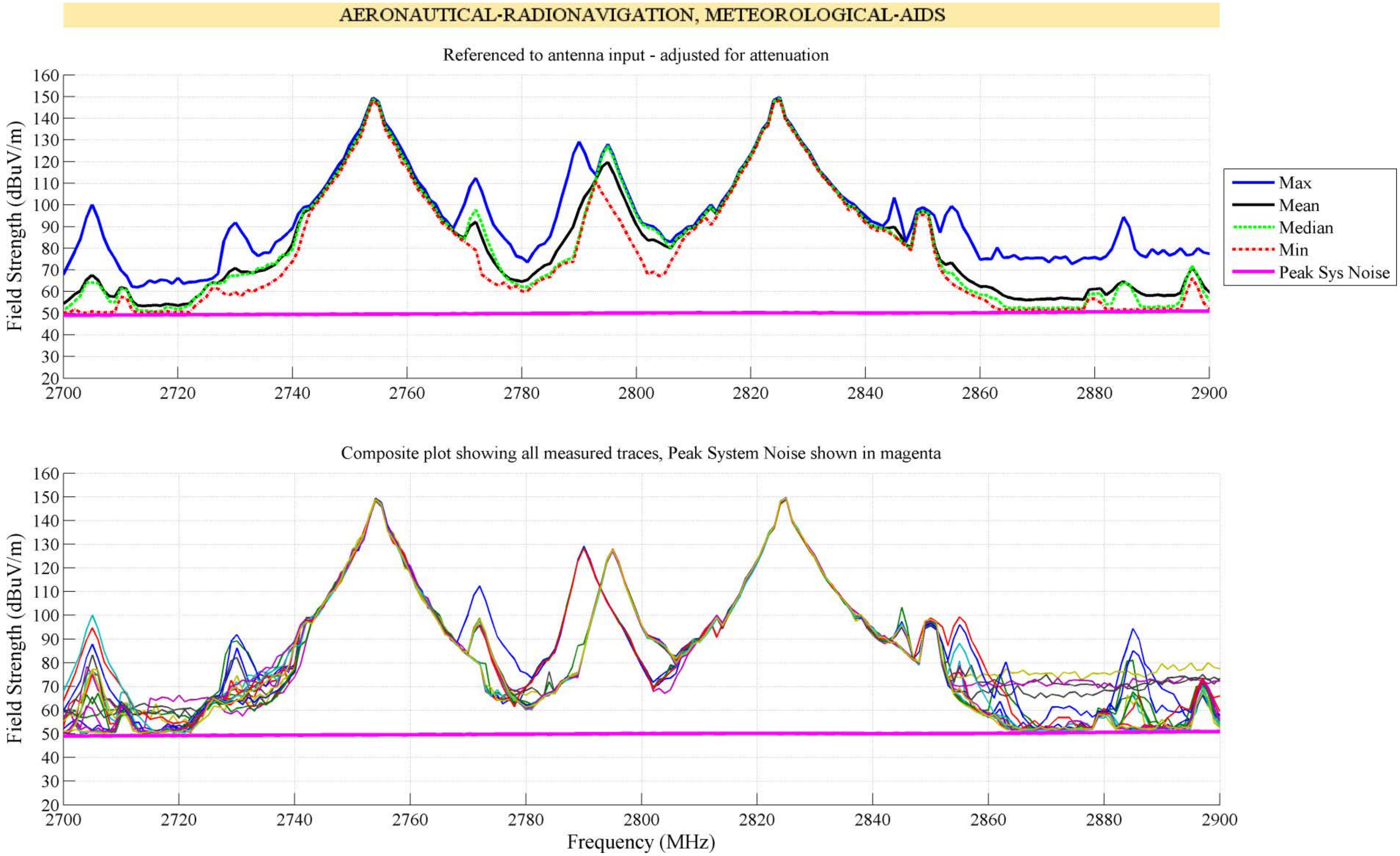


Figure 74. NTIA spectrum survey results from 2700 to 2900 MHz in San Diego, CA, May/June 2012. This measurement was taken using the stepped-spectrum measurement algorithm.

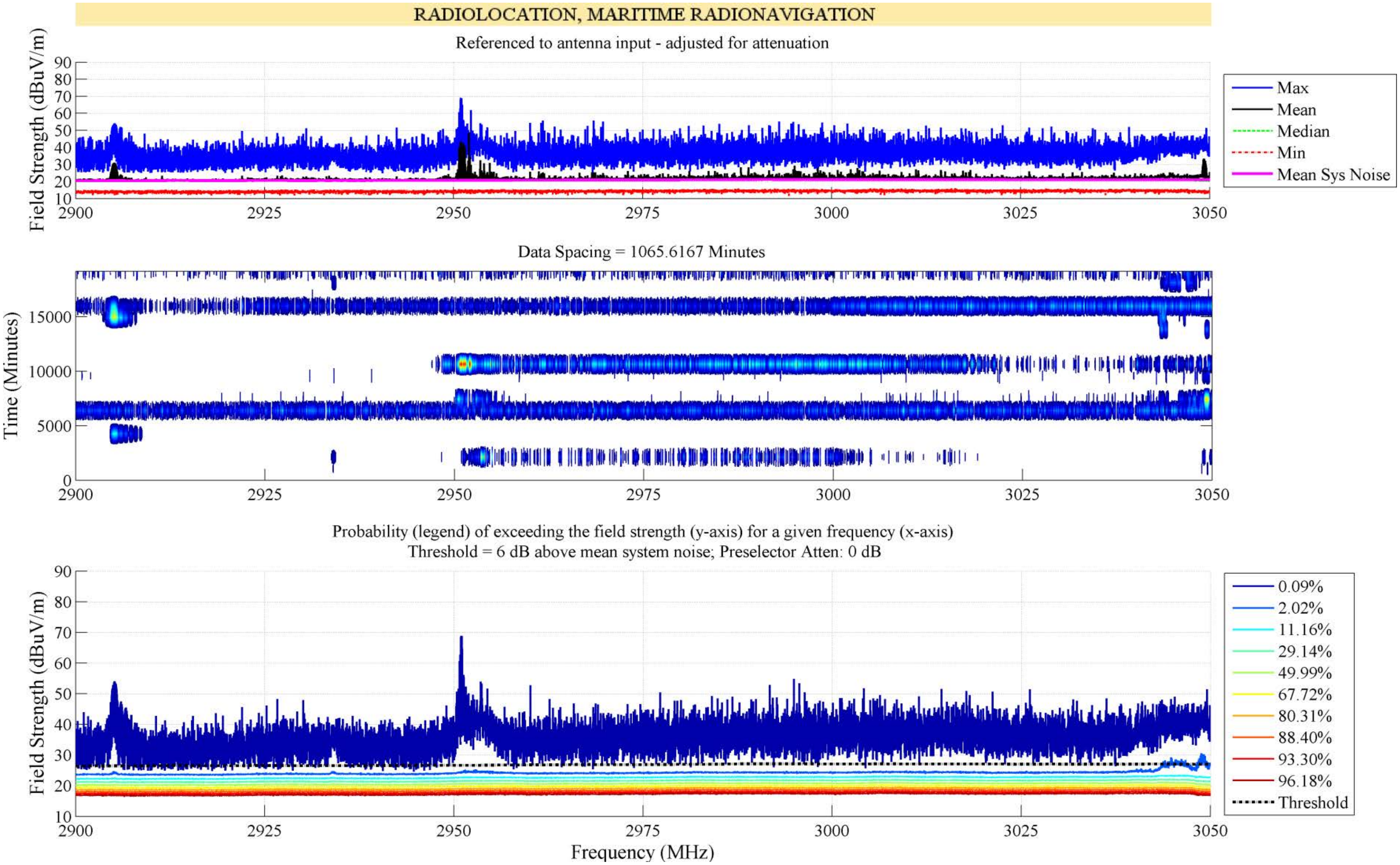


Figure 75. NTIA spectrum survey results from 2900 to 3050 MHz in San Diego, CA, May/June 2012.

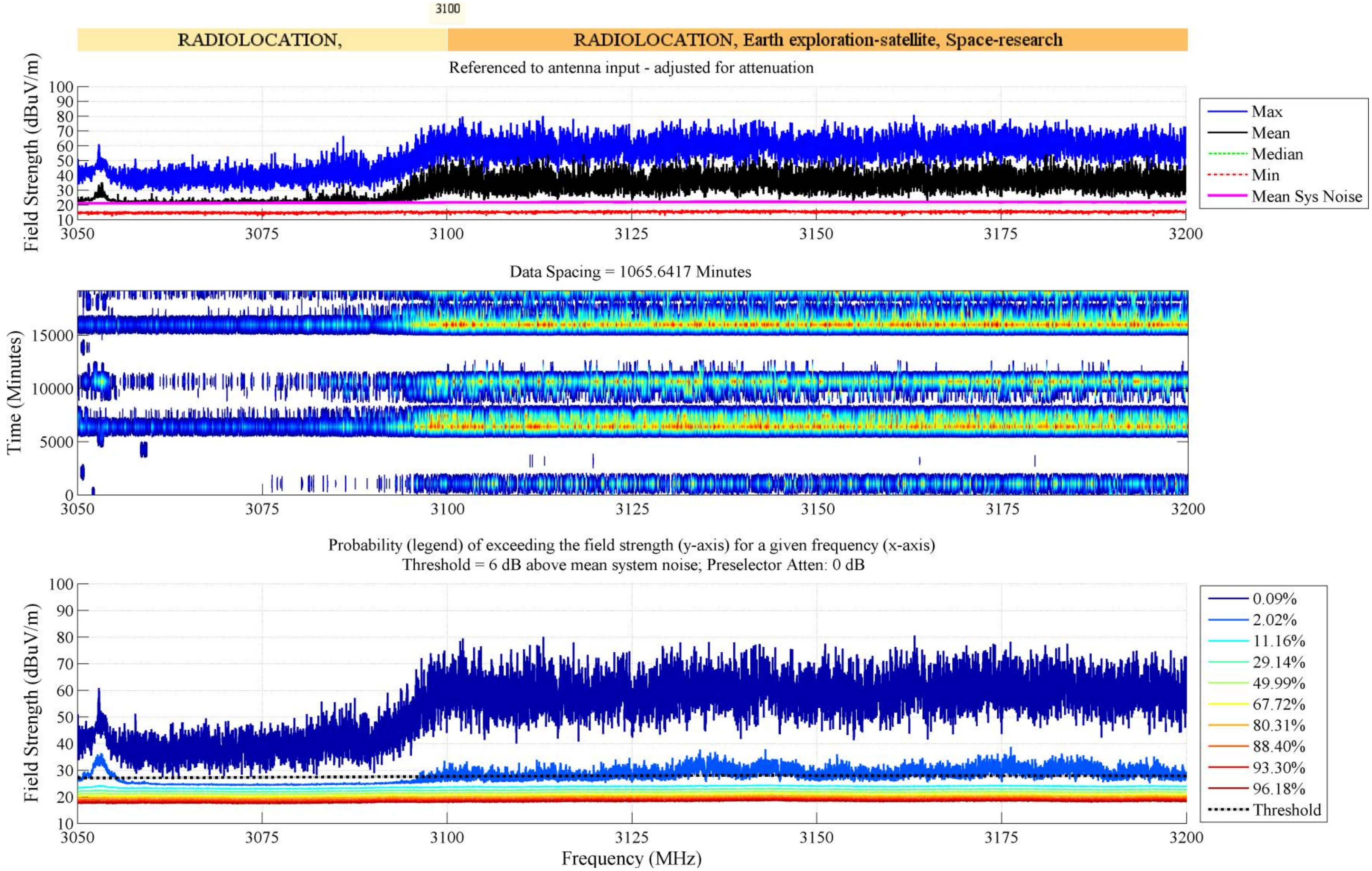


Figure 76. NTIA spectrum survey results from 3050 to 3200 MHz in San Diego, CA, May/June 2012.

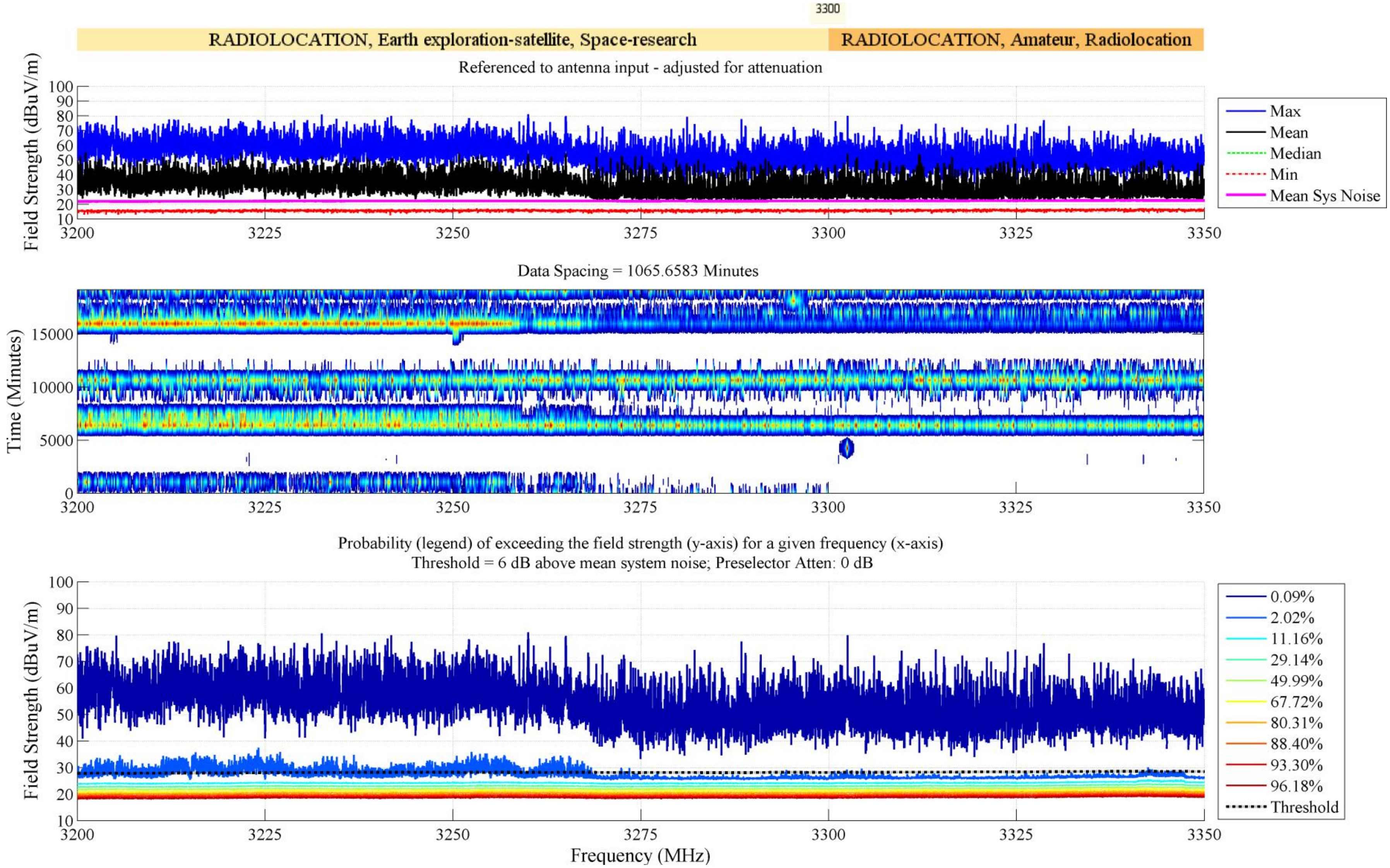


Figure 77. NTIA spectrum survey results from 3200 to 3350 MHz in San Diego, CA, May/June 2012.

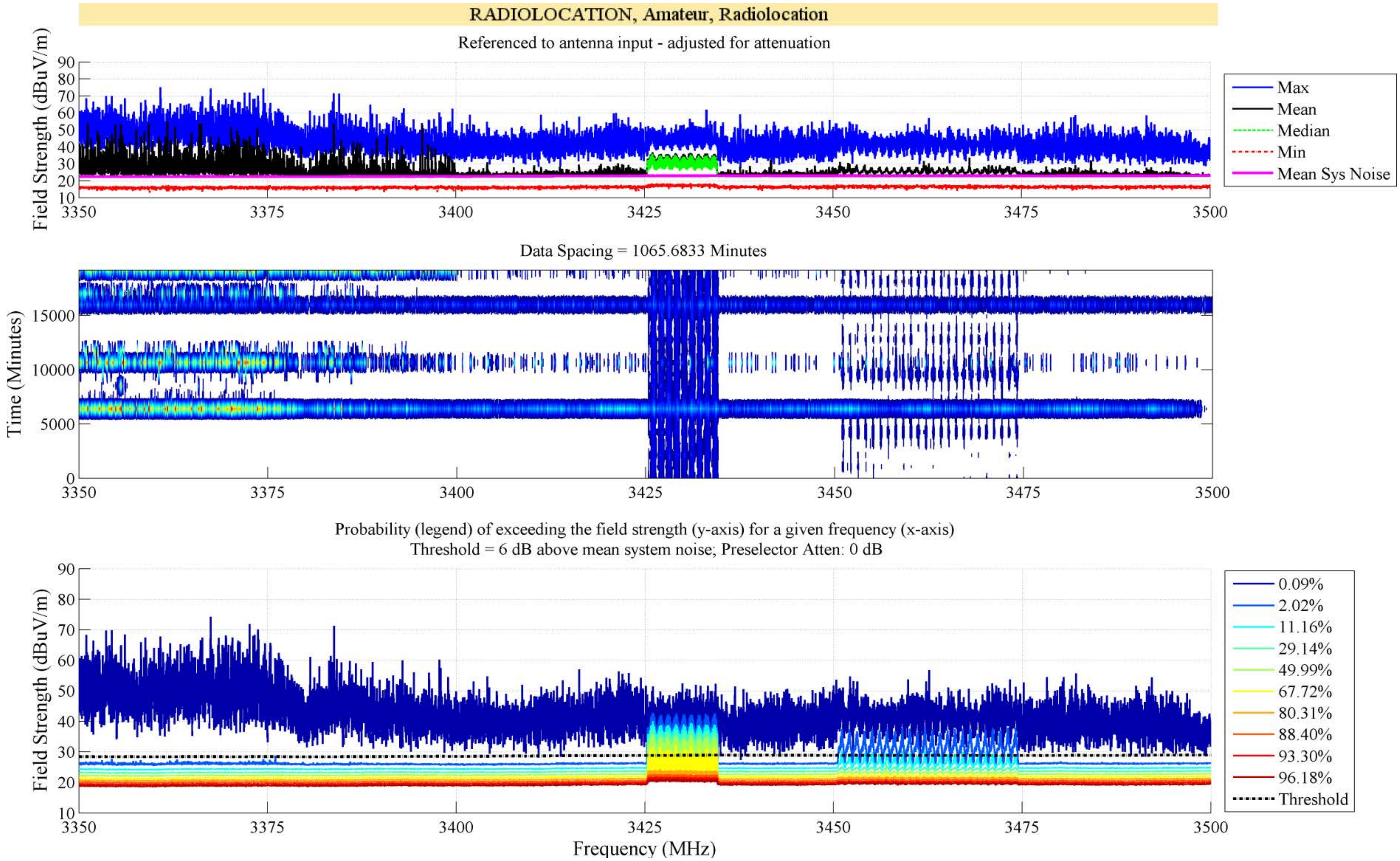


Figure 78. NTIA spectrum survey results from 3350 to 3500 MHz in San Diego, CA, May/June 2012.

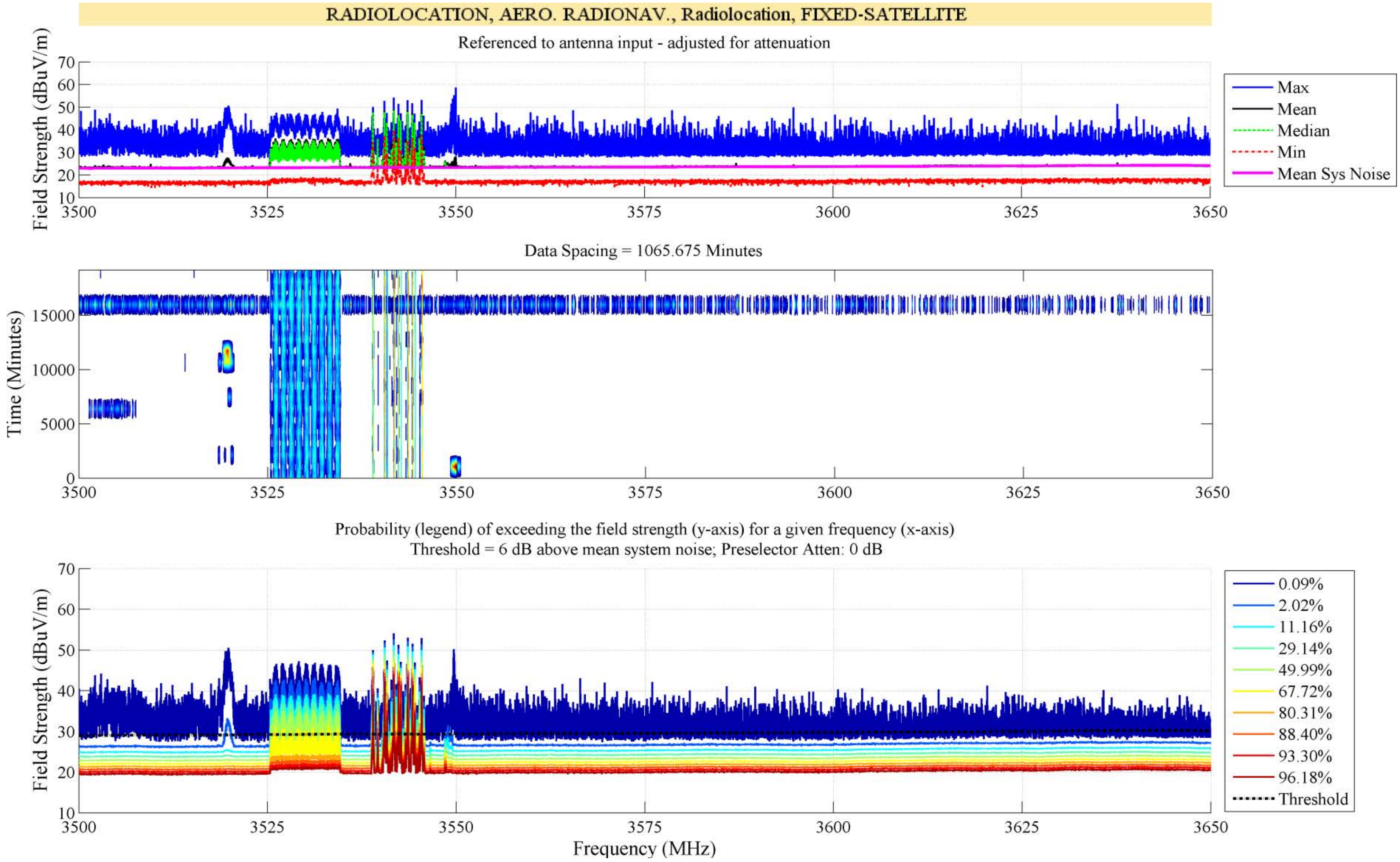


Figure 79. NTIA spectrum survey results from 3500 to 3650 MHz in San Diego, CA, May/June 2012.

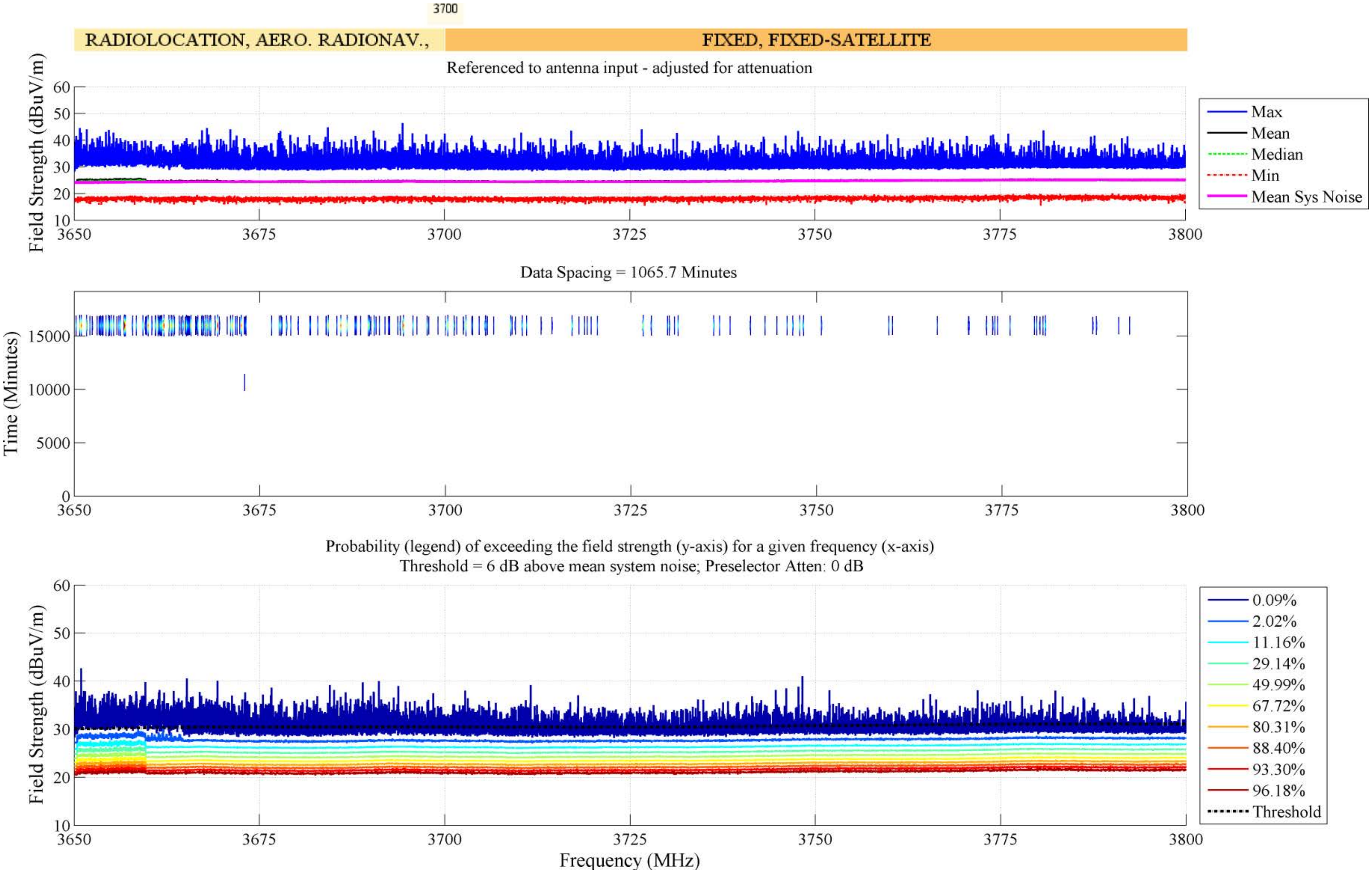


Figure 80. NTIA spectrum survey results from 3650 to 3800 MHz in San Diego, CA, May/June 2012.

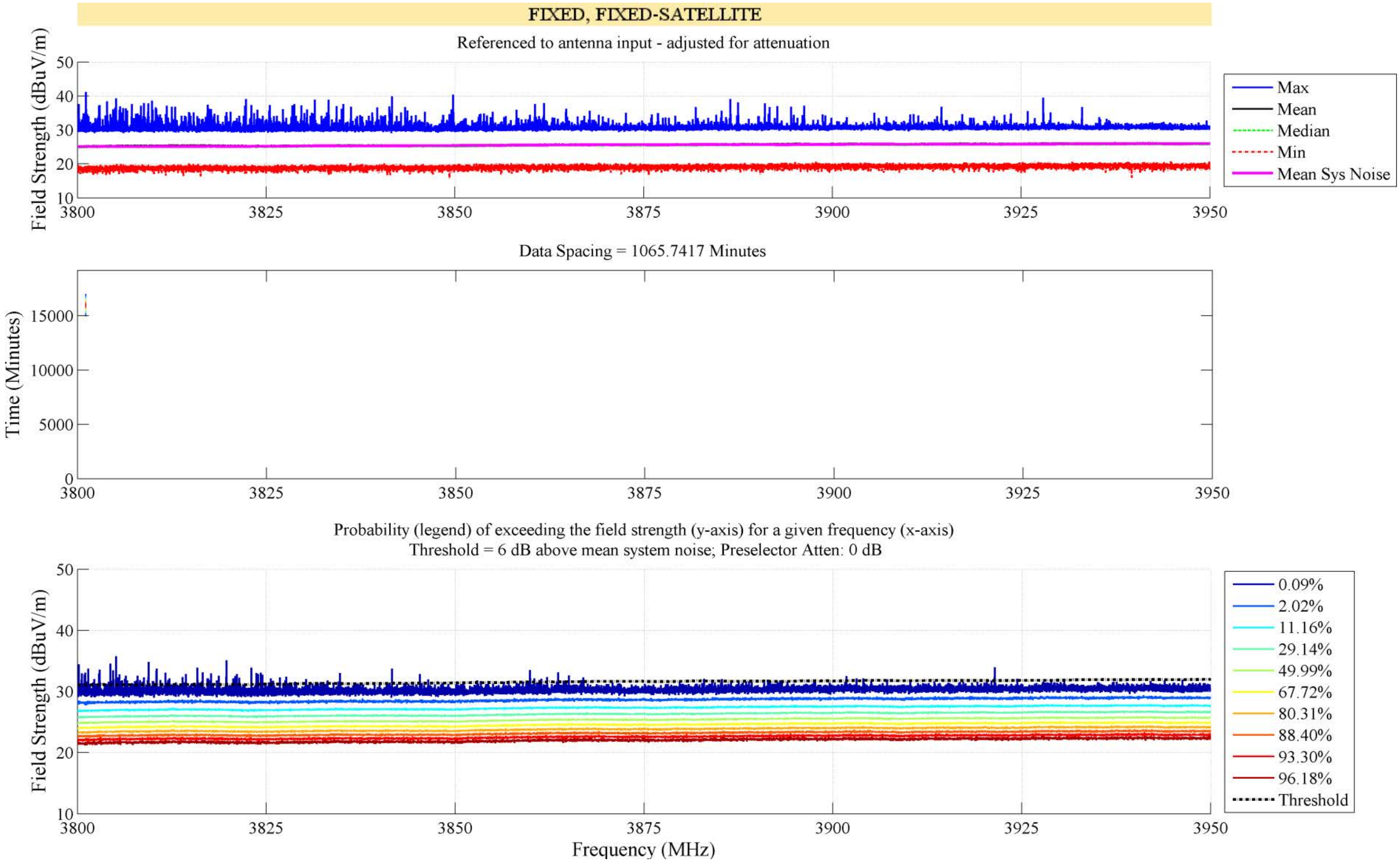


Figure 81. NTIA spectrum survey results from 3800 to 3950 MHz in San Diego, CA, May/June 2012.

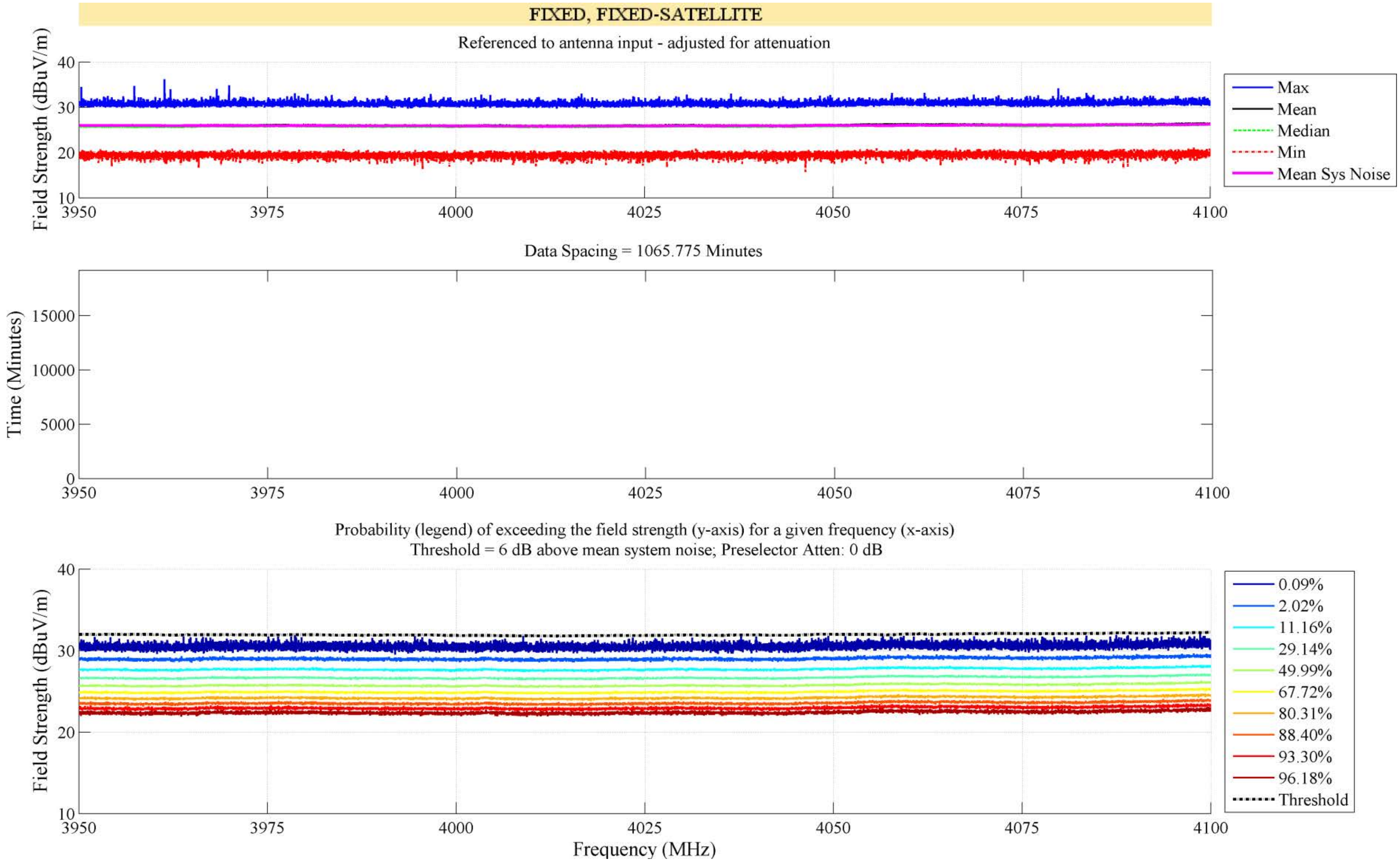


Figure 82. NTIA spectrum survey results from 3950 to 4100 MHz in San Diego, CA, May/June 2012.

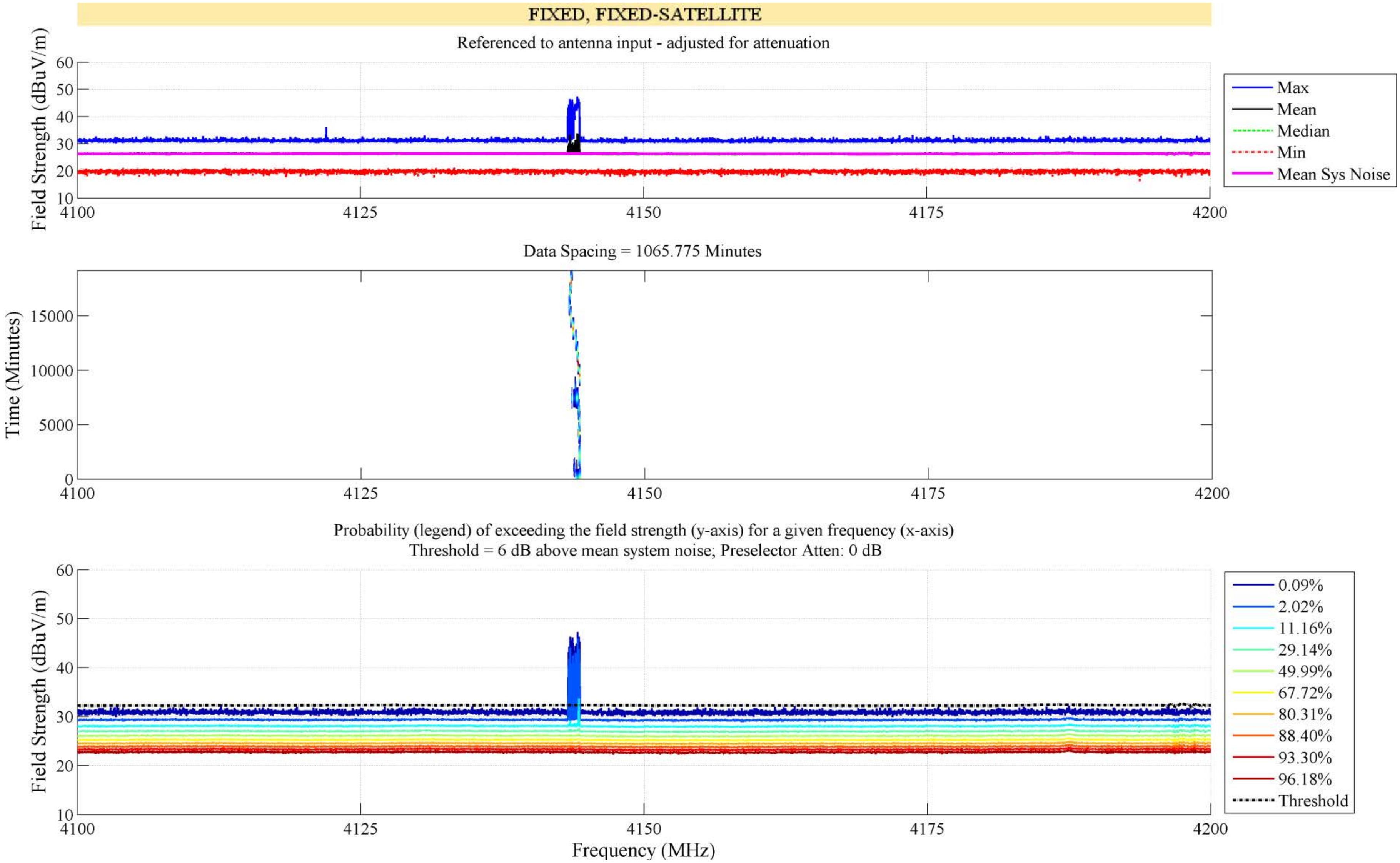


Figure 83. NTIA spectrum survey results from 4100 to 4200 MHz in San Diego, CA, May/June 2012.

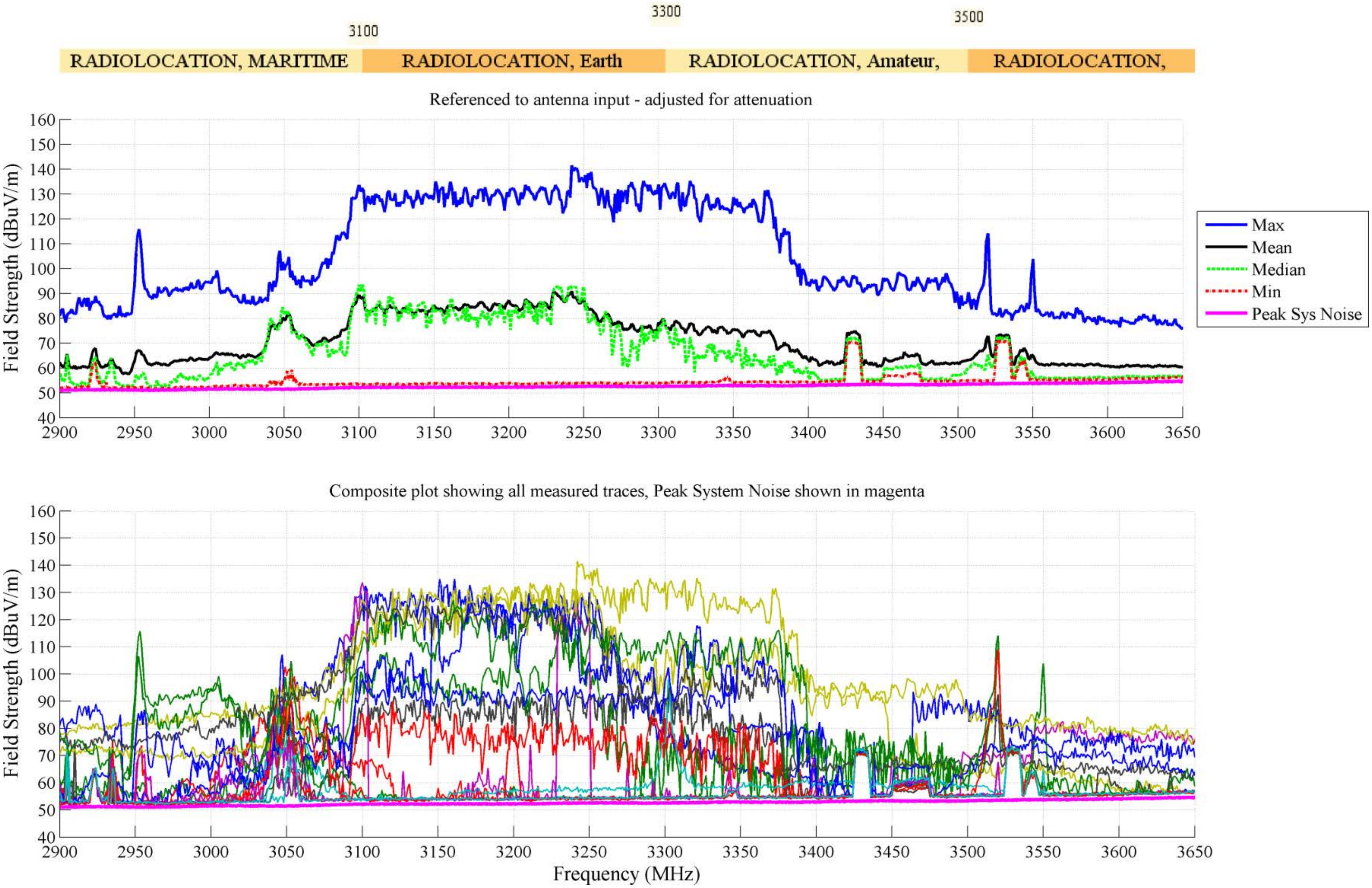


Figure 84. NTIA spectrum survey results from 2900 to 3650 MHz in San Diego, CA, May/June 2012. This measurement was taken using the stepped-spectrum measurement algorithm.

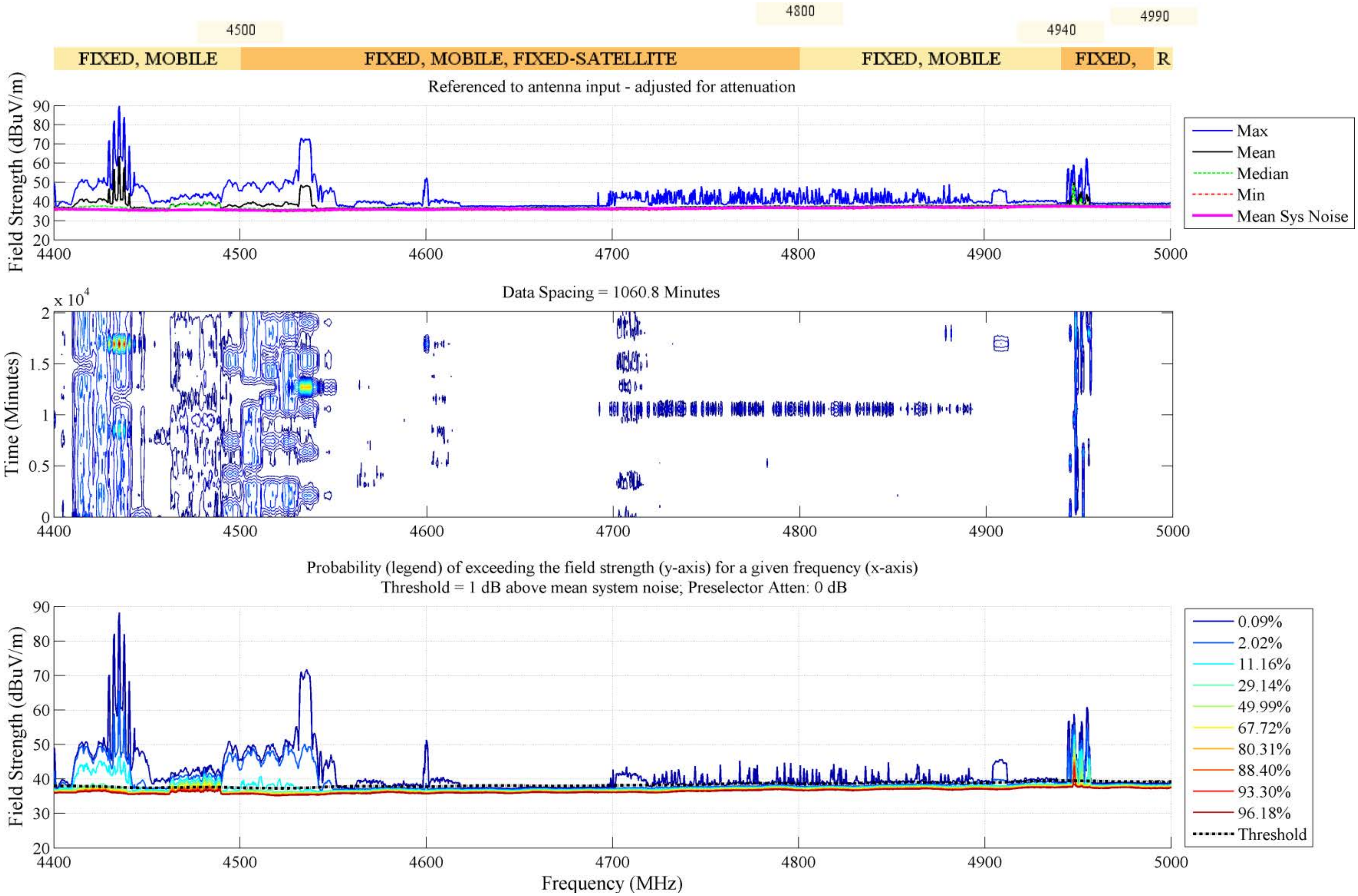


Figure 85. NTIA spectrum survey results from 4400 to 5000 MHz in San Diego, CA, May/June 2012. This measurement was taken using the swept-spectrum measurement algorithm.

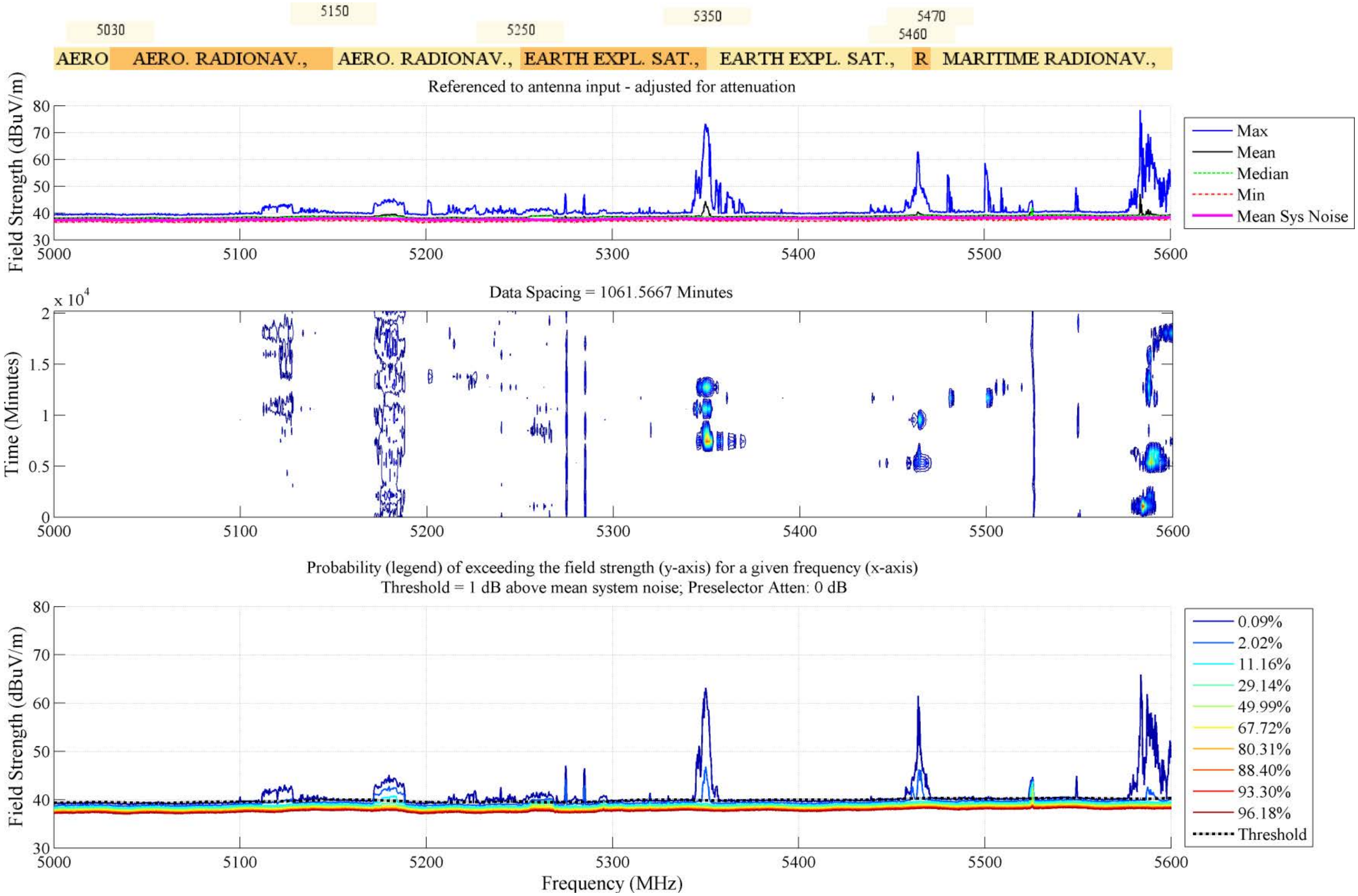


Figure 86. NTIA spectrum survey results from 5000 to 5600 MHz in San Diego, CA, May/June 2012. This measurement was taken using the swept-spectrum measurement algorithm.

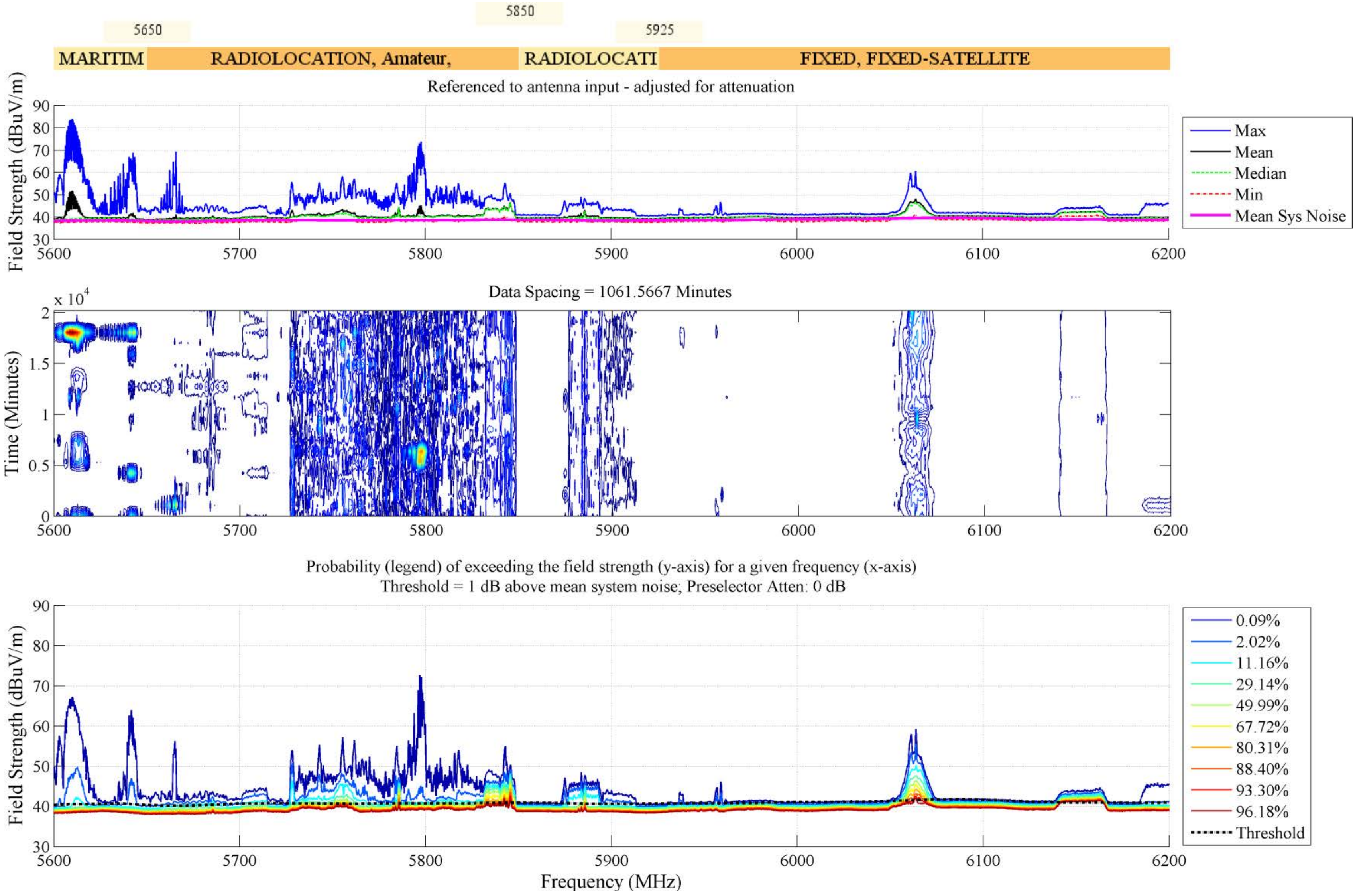


Figure 87. NTIA spectrum survey results from 5600 to 6200 MHz in San Diego, CA, May/June 2012. This measurement was taken using the swept-spectrum measurement algorithm.

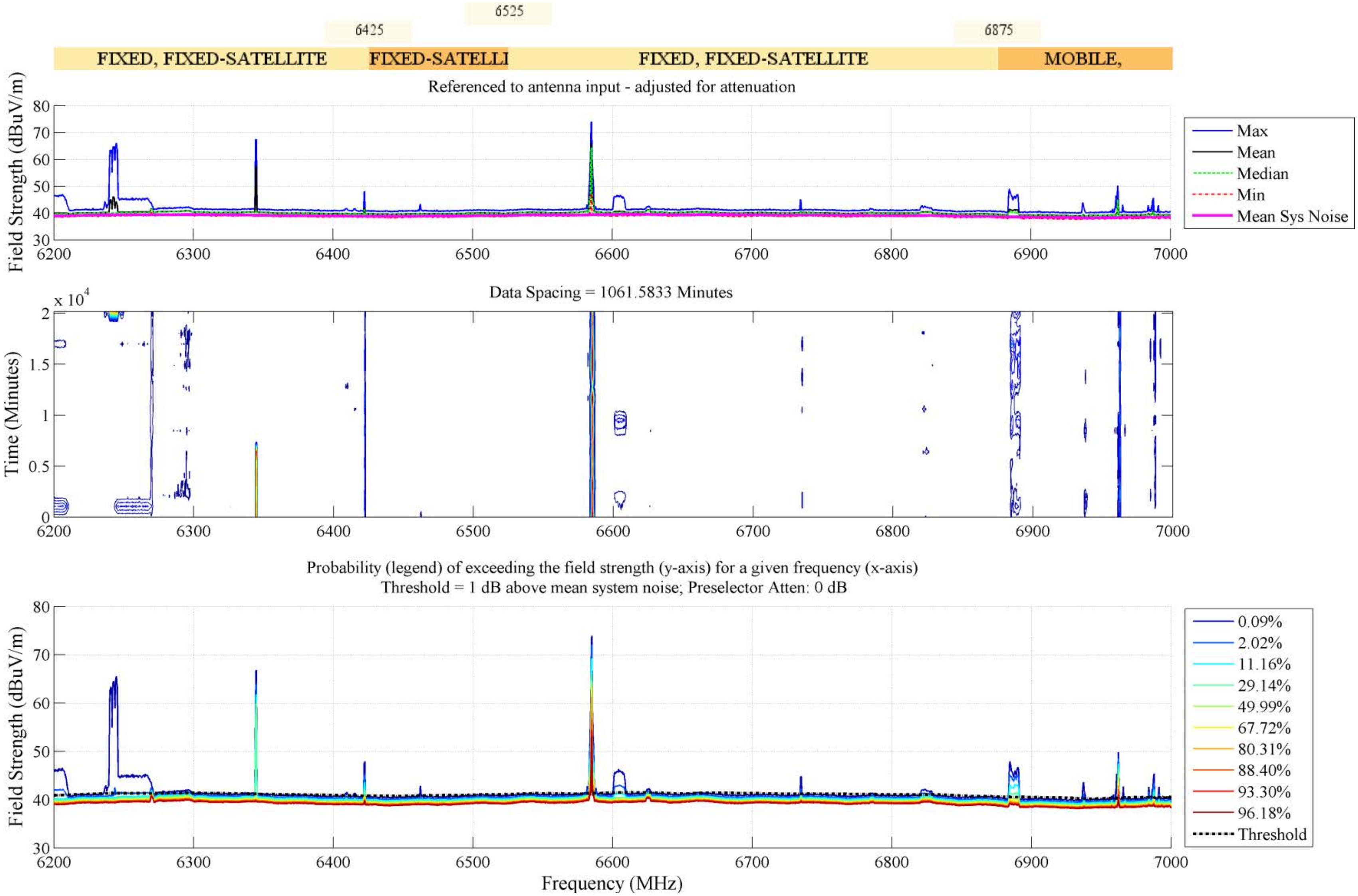


Figure 88. NTIA spectrum survey results from 6200 to 7000 MHz in San Diego, CA, May/June 2012. This measurement was taken using the swept-spectrum measurement algorithm.

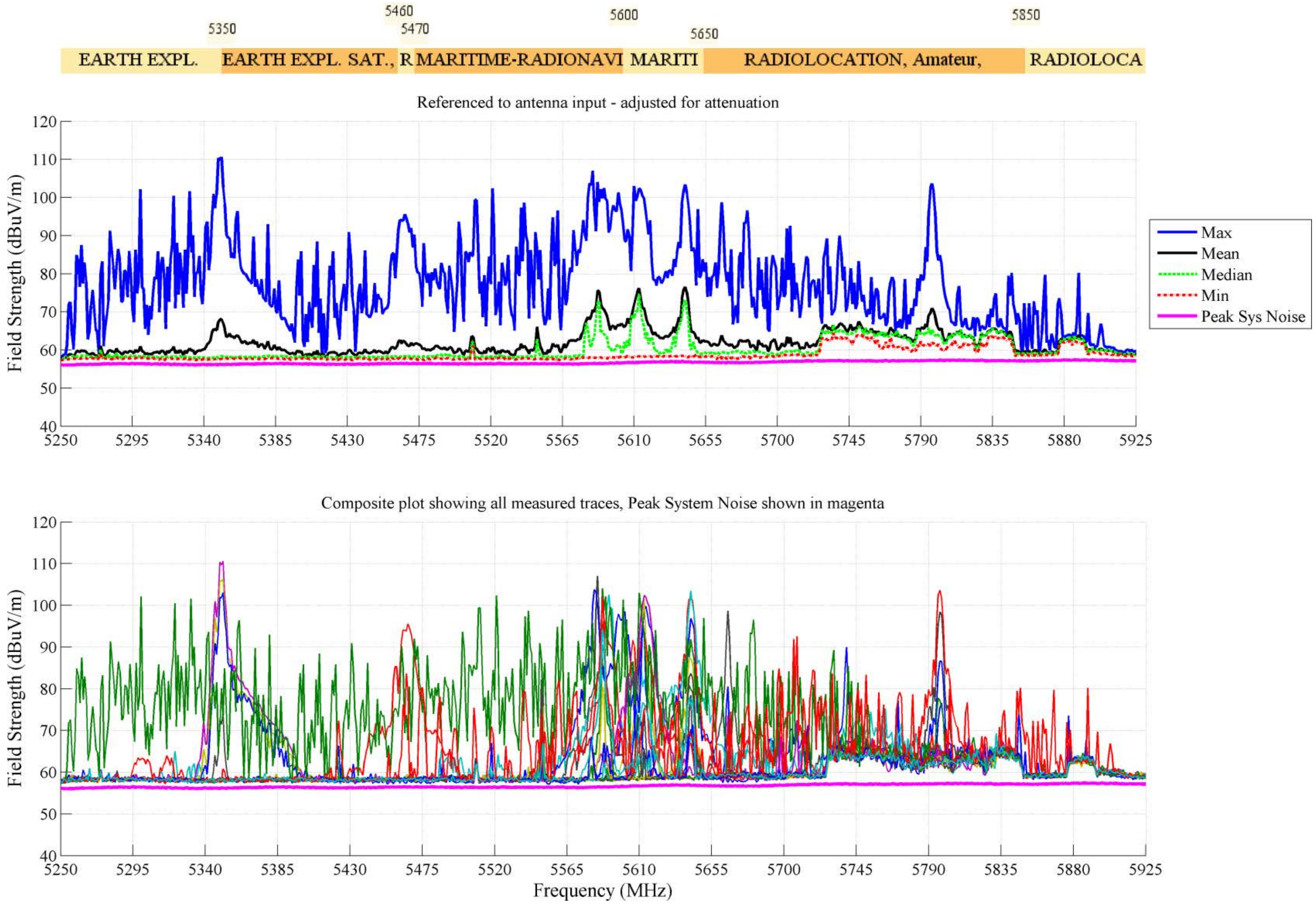


Figure 89. NTIA spectrum survey results from 5250 to 5925 MHz in San Diego, CA, May/June 2012. This measurement was taken using the stepped-spectrum measurement algorithm.

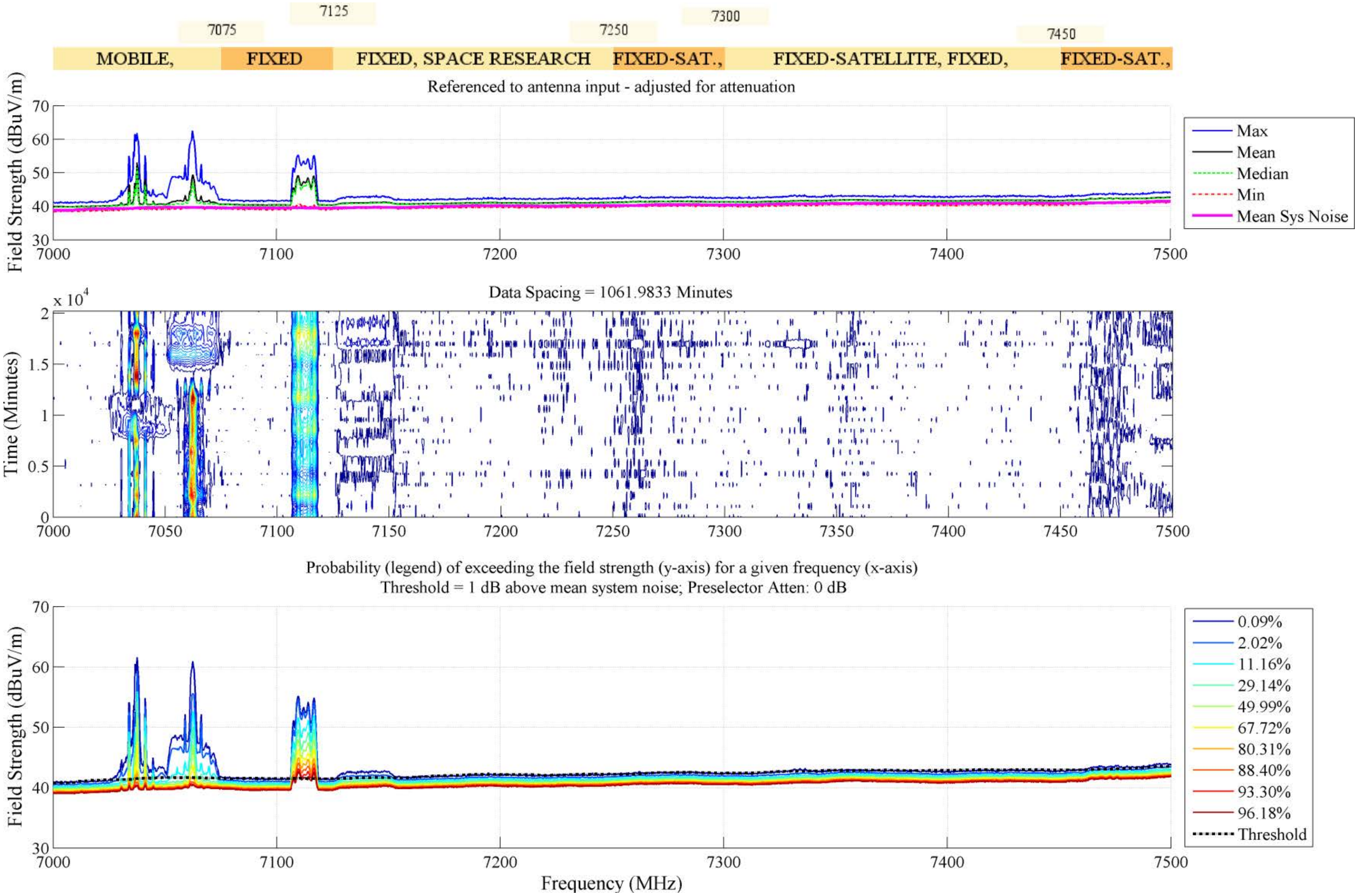


Figure 90. NTIA spectrum survey results from 7000 to 7500 MHz in San Diego, CA, May/June 2012. This measurement was taken using the swept-spectrum measurement algorithm.

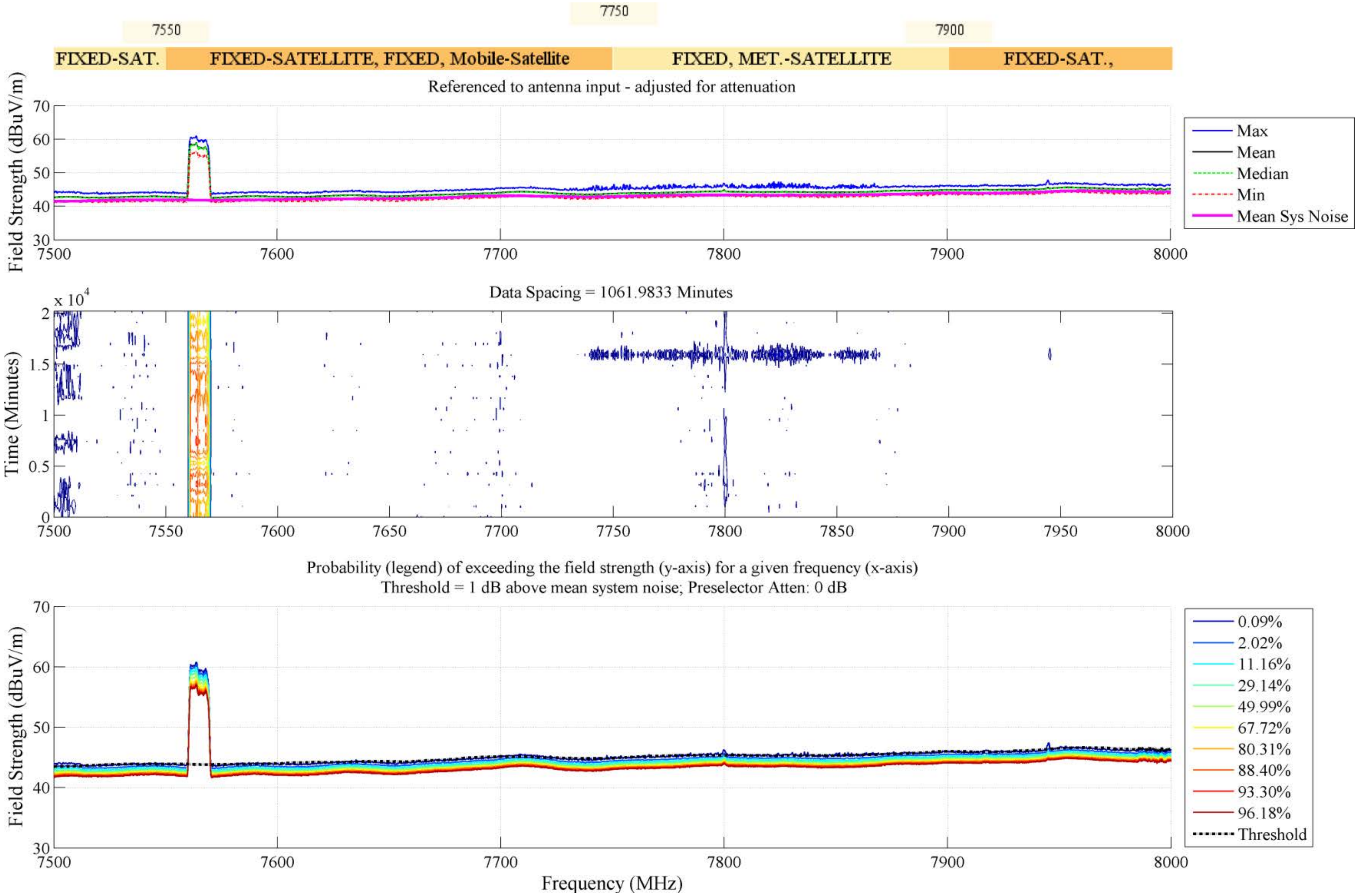


Figure 91. NTIA spectrum survey results from 7500 to 8000 MHz in San Diego, CA, May/June 2012. This measurement was taken using the swept-spectrum measurement algorithm.

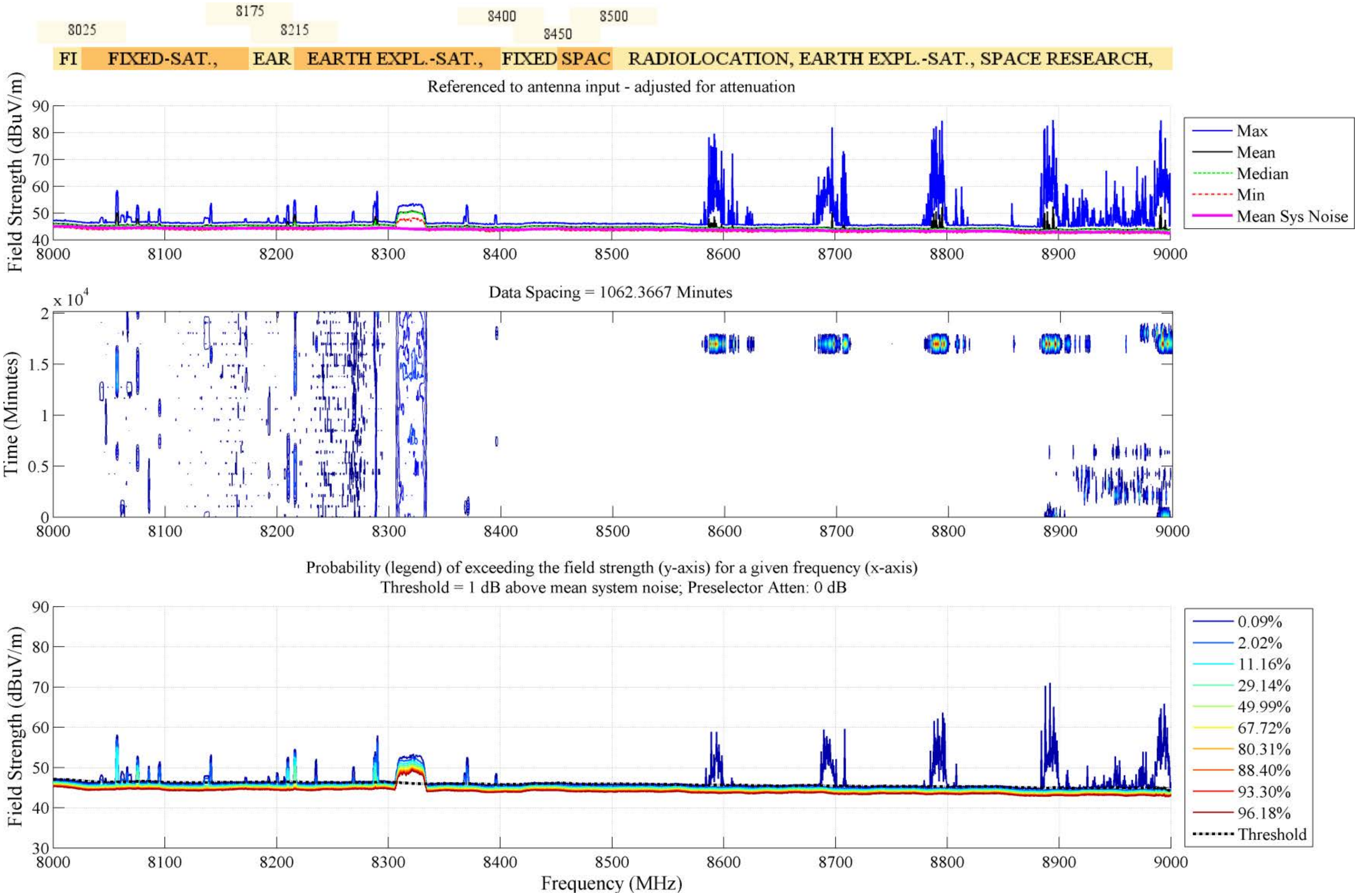


Figure 92. NTIA spectrum survey results from 8000 to 9000 MHz in San Diego, CA, May/June 2012. This measurement was taken using the swept-spectrum measurement algorithm.

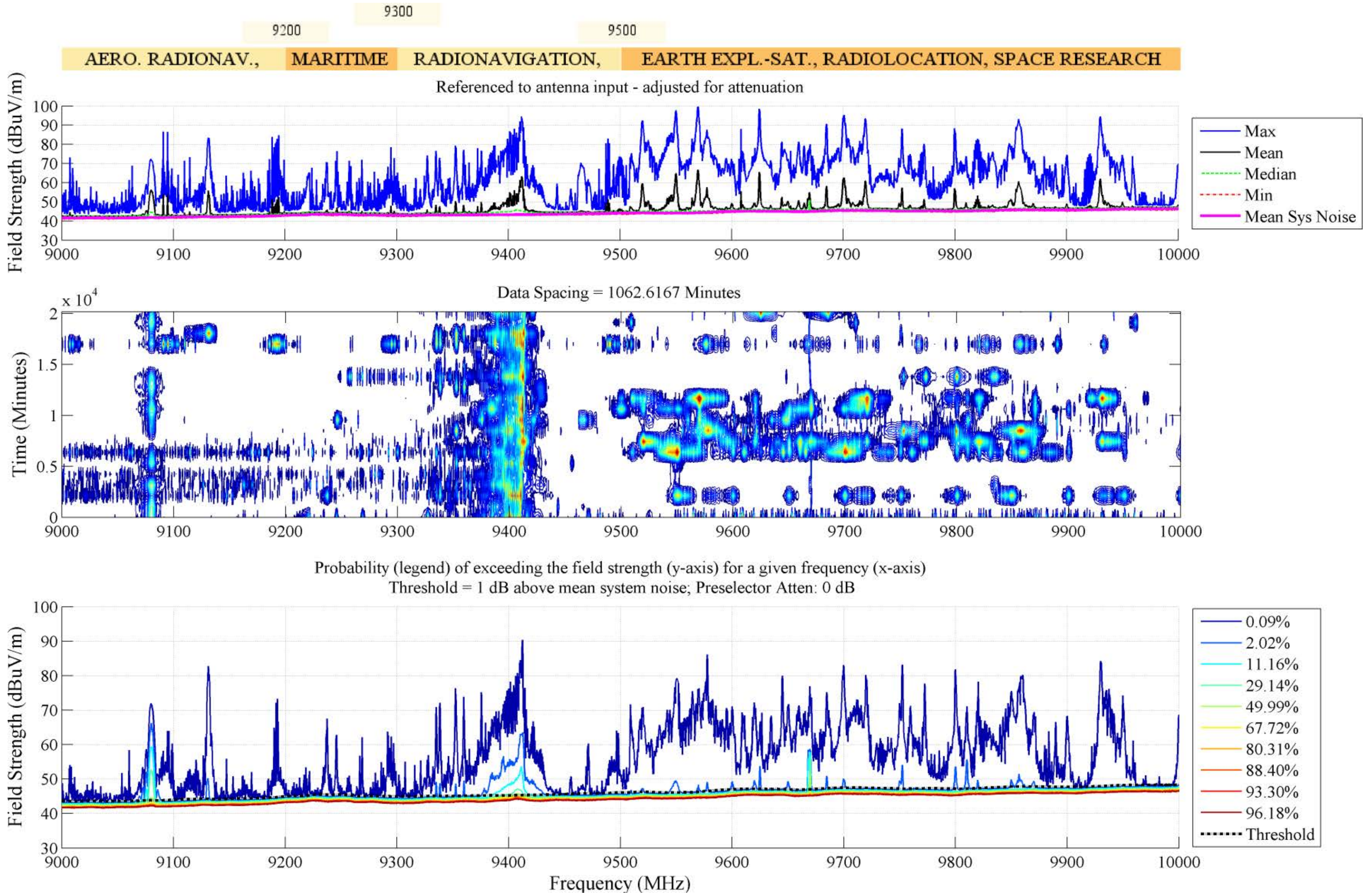


Figure 93. NTIA spectrum survey results from 9000 to 10000 MHz in San Diego, CA, May/June 2012. This measurement was taken using the swept-spectrum measurement algorithm.

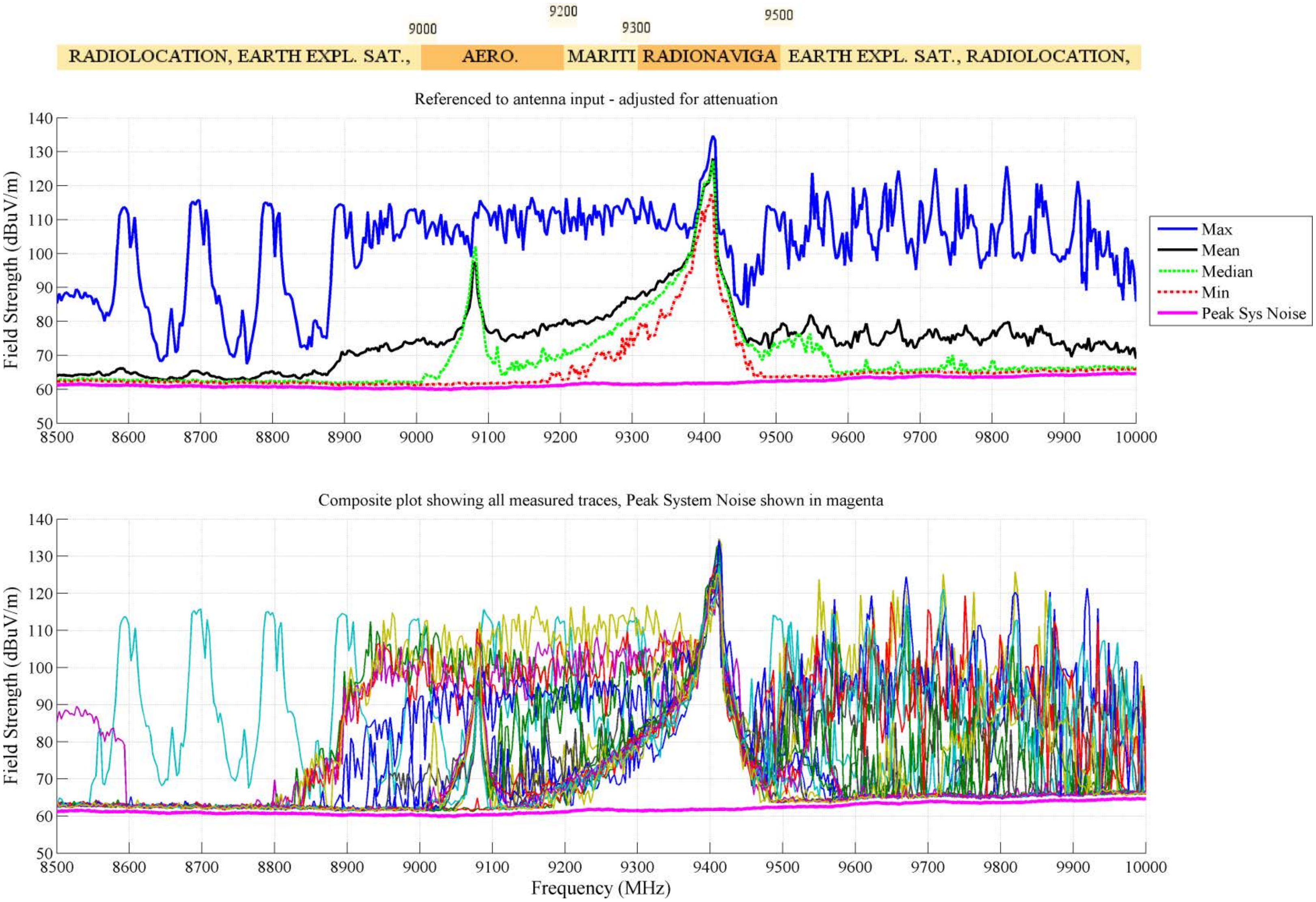


Figure 94. NTIA spectrum survey results from 8500 to 10000 MHz in San Diego, CA, May/June 2012. This measurement was taken using the stepped-spectrum measurement algorithm.

3.1 Discussion of Measured Data

A discussion of Figures 5, 10, 19, 93, and 94 is provided to give the reader an understanding of how to interpret the data contained in the graphs. After this brief introduction, Table 4 provides notes about specific measurement results presented in the figures. For a more complete understanding of the frequency allocations in each measured band, the reader is directed to references [1], [9], [11] and [12].

Figure 5 shows signals from 116 to 120 MHz. In the FS-CCDF graph (bottom), there is a signal at approximately 116.5 MHz that exceeds a field strength level of approximately 0 dBμV/m with a probability of 96.18% and exceeds a field strength level of 19 dBμV/m with a probability of 0.09%. The time-varying plot (middle) shows this signal is on continuously. Time data was decimated and plotted approximately every 1020 minutes.

There is another signal at approximately 118 MHz that exceeds a field strength level of approximately −7 dBμV/m with a probability of 96.18% and a field strength level of 77 dBμV/m with a probability of 0.09%. This signal is on intermittently for the entire time that data was taken; however, it appears with higher field strength at the beginning of the measurements (Time = 0 minutes) and again at approximately Time = 0.75×10^4 minutes. This particular signal corresponds to an assignment in the GMF database for local ground control.

There is another signal at approximately 119.2 MHz that shows elevated signal levels of 70 dBμV/m with a probability of 0.09%, 55 dBμV/m with a probability of 2.02%, and 32 dBμV/m with a probability of 11.16% as shown in the bottom graph. None of the other probability levels are elevated. The mean system noise level, shown in the top graph, is at approximately −9 dBμV/m and the threshold used to plot the time-information is 10 dB above the mean system noise level. Only signals above the threshold are displayed in the middle graph. The mean and median signal levels are elevated above the mean system noise in this band which usually indicates that external noise sources such as impulsive noise or broadband emissions have contributed to elevating the noise floor of the measurement system.

Figure 10 shows data from 143 to 149 MHz. There is a signal at approximately 144.5 MHz which exceeds a field strength level of approximately 22 dBμV/m with a probability of 0.09%. When we look at this signal in the time-varying plot we notice that the signal varies with frequency from 0 minutes to approximately 8000 minutes, and then turns off and we do not see it again during the survey period.

If we look at the line spacing of the probabilities in the quiet areas of the spectrum (see Figure 19 between 217.5 and 218 MHz), we notice the lines are spaced approximately one dB apart based on a median-of-five probability distribution function. This is because the measurement uses the TDwFFT algorithm which takes five measurements and computes the median at each frequency. The separation of these lines indicates Gaussian-distributed system noise.

Figures 93 and 94 show measurement results for both a swept-spectrum measurement and a stepped-spectrum measurement. The stepped-spectrum measurement is an algorithm optimized for measuring radars. There is a radar signal at 9400 MHz that shows up in both spectrum plots. In Figure 93, the swept-spectrum measurement is set up to run with RMS average detection, an

RBW of 300 kHz, and a sweep time of 1000 ms. This results in a dwell time of approximately 0.3 ms/point. In Figure 94, the stepped-spectrum measurement is set up with peak detection, an RBW of 3 MHz, and a sweep-time of 4000 ms, in a zero-span mode. The swept-spectrum measurement is not an optimal algorithm for detecting radars, which gives a reduced field-strength level and a smaller, occupied bandwidth. A comparison between a swept-spectrum radar measurement vs. a stepped-spectrum radar measurement is given in Appendix B.

Table 4. Notes on Figures 3–94.

Figure(s)	Frequency Range (MHz)	Notes
3-5	108.0–117.975	The aeronautical radionavigation signals in this band, which include aviation, VOR, and Differential Global-Positioning System (DGPS), are generally low-level signals. This band is adjacent to the 88–108 MHz FM radio band. These signals can raise the noise floor in the 108–112 MHz frequency band. To suppress FM signals above 108 MHz, we inserted 10 dB of preselector attenuation into the system and a high-pass filter, which may affect the ability of our system to detect the low-level aeronautical radionavigation signals.
5-8	117.975–136.0	The aeronautical mobile signals in this band originate from air traffic control (ATC), private aircraft, and search and rescue. These signals are characterized by their small bandwidth. The duration of the signals in this band vary as shown in Figures 5–8.
8	136.0–137.0 137.0–138.0	The signals in these bands originate from aeronautical mobile, space operations and research (space-to-earth) transmissions. The FAA uses this band for ATC via the Automated Weather Observation System (AWOS) and the Automated Terminal Information System (ATIS). The National Aeronautics and Space Administration (NASA) uses this band for tracking and telemetry and the National Oceanic and Atmospheric Administration (NOAA) uses the band to collect meteorological data from the Geosynchronous Operational Environment Satellite (GOES). The San Diego area survey show only eight signals from 136–137 MHz, and low-level transmissions from 137–138 MHz.
9, 10	138.0–144.0	This band is generally used for non-tactical, trunked military land mobile communications and civil air patrol. There are several strong signals in this band, some of which are on intermittently and others which are on continuously.
10	144.0–148.0	The signals in this band are from amateur radio and amateur satellite. There are no Federal uses between 144.0–146.0 MHz. There is a signal at approximately 144.4 MHz that varies with frequency and is on continuously from 0 minutes to approximately 10,000 minutes and then turns off and is not seen again during the course of the survey. This band also shows a lot of usage during this survey.
10-13	148.0–162.0	These frequency bands are used by NASA for satellite uplinks and infrastructure functions. Other fixed or mobile signals for Civil Air Patrol, military non-tactical mobile, fixed communications, transit-satellite downlinks, land transportation, public safety, industrial, Earth telecommand, VHF distress systems communication, and industrial are found in this band. Maritime-mobile signals are found between 156.2475–157.1875 MHz and 161.575–162.0125 MHz. This band was heavily used during the spectrum survey
13-15	162.0–174.0	Fixed and mobile transmitters such as LMR and weather radio, used by public safety and industry, are found throughout this band. The signal at 162.55 MHz is a public broadcast weather information channel. There is a wideband signal at approximately 164.2 MHz and most other signals in this band are narrowband signals.

Figure(s)	Frequency Range (MHz)	Notes
16-18	174.0–216.0	This part of the spectrum is used for broadcasting television. Channels 7, 8, 9, 10, 11, and 13 are occupied with Advanced Television Systems Committee (ATSC) transmissions. Channel 12 is occupied with a National Television Systems Committee (NTSC) transmission. There are no white spaces between these channels. There was no data collected from 204-210 MHz for the first four measurements due to system overload. We then added 10 dB of preselector attenuation and collected data to the end of the measurement. There are no Federal uses in this band.
19	216.0–220.0	The signals in this band are from fixed, mobile, radiolocation and amateur transmitters. The users in this band are automated maritime telecommunications systems, radiolocation, and non-Government telemetry, tracking and command (TTC). There are several experimental research allocations in this range. There is some activity in this band from approximately 216.5–217.9 MHz, intermittent activity from 218.0–219.9 MHz.
19, 20	220.0–225.0	Fixed and land mobile signals are found from 220.0 to 222.0 MHz and amateur signals from 222.0 to 225.0 MHz. The general uses in these bands are trunked and conventional LMR systems and amateur (1.25m band) radio. The signal at approximately 222.6 MHz is on continuously at one frequency until 15,000 minutes and then appears to change frequencies and is on continuously at that frequency until the end of the spectrum survey.
21-29	225.0–328.6	This band is used for military tactical and training communications including ATC, space operations from 267 to 273 MHz, space-to-earth and earth-to-space communications, and mobile-satellite from 312 to 315 MHz. The National Science Foundation (NSF) uses this band for radio astronomy research from 322 to 328.6 MHz. There are no FCC assignments in these bands. There appears to be a strong interfering signal that appears as a periodic signal from 225.0 to 243.0 MHz.
29	328.6–335.4	The only allocated signals in this band are for aeronautical radionavigation transmissions. Instrument landing systems are used by the Federal Aviation Administration (FAA) and DGPS and microwave scanning beam landing systems are used by NASA. Some of these assignments are paired with frequencies from 108 to 117 MHz and frequencies from 960 to 1215 MHz for VORs and TACANs. We see both intermittent signals and signals that are on continuously. We do not see a lot of spectrum use in this band.
29-32	335.4–399.9	This band is used by the military, North American Treaty Organization (NATO), U.S. Coast Guard, FAA and NASA for radio and airborne communications; the military uses frequencies from 380 to 399.9 MHz for trunked LMR. Frequencies from approximately 385–399.9 MHz are heavily used, whereas frequencies from 335.4 to 385 MHz are not heavily used. We see both intermittent signals and signals that are on continuously.

Figure(s)	Frequency Range (MHz)	Notes
32	399.9–400.05 400.05–400.15 400.15–406.0	In this figure, it is not possible to read the primary allocation for two narrow bandwidths, 399.9–400.05 MHz and 400.05–400.15 MHz. The allocation for 399.9–400.05 MHz is "RADIONAVIGATION-SATELLITE, MOBILE-SATELLITE." We do see signals in this band in San Diego. We saw an intermittent signal at approximately 400 MHz. The allocation for 400.05–400.15 MHz is the "STANDARD FREQUENCY AND TIME SIGNAL-SATELLITE" at 400.1 MHz ± 25 kHz. We saw no signals in this band during the San Diego spectrum survey. Meteorological aids occupy the band 400.15–406.0 MHz and include National Oceanic and Atmospheric Administration (NOAA) and Department of Interior (DOI) radiosonde systems and satellite transmitter uplinks called data collection platforms (DCP). The military also uses this band for radio communication and MedRadio. We saw a number of signals that were on intermittently.
33-35	406–406.1 406.1–420.0	The primary allocation in the 406–406.1 band is "MOBILE-SATELLITE," which cannot be read from the graph. This band is used by Emergency Position-Indicating Radio Beacon (EPIRB), the Emergency Locator Transmitter (ELT) systems and for distress alert and locations using Search and Rescue Satellite Aided Tracking (SARSAT) to public safety rescue authorities. We saw one signal in this band that was on for a very short time. The signals in the 406.1–420.0 band are from fixed, land-mobile, radio astronomy, and space research signals. Federal agencies use these bands for trunked LMR and transmission of hydrologic and meteorological data. The NSF uses this for radio astronomy and NASA used this for remote operation of cranes and extra-vehicular activity (EVA) communications. There are LMR control channels from 406.1 to 411 MHz. There are strong signals in this band that are on both continuously and intermittently. There is a signal between 414.0 MHz and 414.5 MHz that appears to vary with frequency and there is a wideband signal at approximately 418.0 MHz.
36-38	420.0–450.0	The signals in this band originate from radiolocation and amateur radio. General uses in this band include private land mobile and amateur radio. Certain military and Federal agencies also use this band for long-range surveillance radars, enhanced position location reporting systems (EPLRS), space telecommand (449–451 MHz), wind-profiler weather radars (449 MHz), and synthetic aperture radars (SARs) (432-438 MHz). This frequency range was measured using a stepped-spectrum measurement algorithm (Figure 37) to detect radar signals and a swept-spectrum measurement algorithm (Figures 36 and 38) to detect all other signals. The signal at approximately 434 MHz in Figure 36 is also seen in Figure 37.
38, 39	450.0–470.0	Most of the signals in this band originate from land-mobile and fixed communications by non-Federal users. The secondary allocation from 460 to 470 MHz is for Federal meteorological satellite users. General uses in these bands are remote pickup, low power auxiliary, private land mobile, and maritime. Federal agencies use this for LMR shared systems and mutual aid responses with public safety agencies, and testing and evaluation of programs. There are medical telemetry transmissions occupying this band and NASA uses some of these frequencies to support balloon experiments. There are also space-to-earth and personal radio communications. This part of the spectrum is heavily used as indicated by the number of signals that have 96.18% exceedance levels in the FS-CCDF plot in Figure 39.

Figure(s)	Frequency Range (MHz)	Notes
39-42	470.0–512.0	These bands are used by fixed, land-mobile and broadcasting services. Uses in this band include public mobile, broadcast radio (Channels 14–19), low power television (LPTV), TV translator/booster, low power auxiliary, private and land mobile services. Federal agencies use this band for shared LMR systems and mutual aid responses with the public sector. During the measurement, Channel 17 (488.0 to 494.0 MHz) appears to be an NTSC broadcast. ATSC broadcast signals occupy channels 18 and 19.
42-53	512.0–793.0	Broadcasting, land-mobile, radio astronomy, and mobile signals are assigned in this band. The radio astronomy allocation and land-mobile is found from 608 to 614 MHz. Broadcast radio Channels 21–36 occupy frequencies from 512 to 608 MHz. We see that Channels 27, 45 and 57 are still in the old National Television Systems Committee (NTSC) transmission format. We received signals from both ATSC and NTSC transmitters in Channels 21, 33, 35, 39, 43, 46, and 49. Channels 38 to 51 occupy the spectrum from 614 to 698 MHz. The other utilizations in these bands include LPTV, TV translator/booster, low power auxiliary, personal radio, and Federal agencies,who use this band for experimental testing and evaluation of programs. Radio astronomy research for observing pulsars, the sun, the planet Jupiter, the Milky Way galaxy, and observations of spectral lines are present. The Department of Veterans Affairs (DVA) uses this band for medical telemetry devices. From 734.0 to 744.0 MHz and from 746.0 to 756.0 MHz we see digitally-modulated signals which appear to be related to Long Term Evolution (LTE).
53-56	793.0–902.0	Most of the signals in these frequencies originate from fixed, mobile, aeronautical-mobile and land mobile transmissions with a small primary allocation for broadcasting from 805.0 to 806.0 MHz. These bands are used by Federal agencies for experimental research and systems shared by public safety and military agencies. Military agencies operate some radar systems in the 854.0–902.0 MHz frequency band. There are public safety mobile and control channels from 806 to 824 MHz, commercial cellular mobile channels from 824 to 849 MHz, public safety base station transmit frequencies from 851 to 869 MHz, and commercial cellular base station transmit frequencies from 869 to 894 MHz. These figures show heavy usage during our survey.
57, 58	902.0–928.0	Signal allocations in this band are primarily for radiolocation and secondarily for amateur radio. The general utilizations for this band are Navy Air & Search, surveillance radars on ships and carriers, tracking radars for aeronautical flight testing monitor positions of missiles, drones, manned aircraft, security for intruder detection, NOAA wind profiler system and this is also one of the ISM bands. This frequency range was measured using a stepped-spectrum measurement algorithm (Figure 58) to detect radar signals and a swept-spectrum measurement algorithm (Figure 57) to detect all other signals. The waterfall plot shows constant usage during this spectrum survey. Several strong signals show up around 906 MHz, 909 MHz, 910 MHz, and 921 MHz.
57, 59	928.0–960.0	Signals in this band are from fixed, land mobile, and broadcasting services. General uses in this band include public mobile, aural broadcast auxiliary, fixed microwave, low power auxiliary, public safety shared systems, low-capacity (voice) systems for Federal agencies, and personal communication systems (PCS). Military agencies operate some radars in the 935.0–941.0 MHz frequency band. These bands show heavy usage during our survey.

Figure(s)	Frequency Range (MHz)	Notes
59-62	960.0–1215.0	These bands are allocated for aeronautical radionavigation and radionavigation satellite services and are used by TACAN, Distance Measuring Equipment (DME), Air Traffic Control Radar Beacon System (ATCRBS) & Mode-S at 1030 MHz and 1090 MHz, microwave landing systems (MLS), Traffic Alert and Collision Avoidance System (TCAS), Automatic Dependent Surveillance Broadcast (ADS-B) at 978 MHz, and Joint Tactical Information Distribution System (JTIDS). The GPS-L5 operates in this band at a frequency of 1176.45 MHz ± 12 MHz. There are space-to-earth and earth-to-space communications in this band as well. Some of these frequencies are paired with those in the 108.0–117.0 MHz band and the 328.0–335.4 MHz band. Signal levels in the GPS L5 band (1164–1188 MHz) are as expected, although there does appear to be a wideband noise source from 966 to 1010 MHz and from 1105 to 1210 MHz that appears at specific times during the survey.
62-64	1215.0–1400.0	These bands contain assignments for earth exploration satellites, radiolocation, radionavigation satellites, space research, aeronautical radionavigation, fixed, mobile, and land-mobile services. There is also a secondary allocation for radiolocation services from 1300.0 to 1350.0 MHz. The general utilizations in these bands are GPS-L2, which operates at 1227.6 MHz ± 12 MHz, Wide Area Augmentation System (WAAS), High-power long-range surveillance radars, FAA operates air-route surveillance radars (ARSR), balloons for drug interdiction, SARs, shipborne radars, radio astronomy research, remote sensing, fixed-mobile communication links, and GPS at 1381.05 MHz. Personal radio exists in the upper part of this band as well as medical telemetry devices, wireless communications and earth-to-space fixed satellite. This frequency range was measured using a stepped-spectrum measurement algorithm (Figure 64) to detect radar signals and a swept-spectrum measurement algorithm (Figures 62 and 63) to detect all other signals. We see radar emissions between 1240 and 1390 MHz in Figure 64. Radar emissions at approximately 1242 MHz, 1260 MHz, 1280 MHz, 1320 MHz, 1330 MHz, 1345 MHz, and 1360 MHz shown in Figures 62 and 63 in the swept-spectrum measurements are also picked up in the stepped-spectrum measurements shown in Figure 64. Notice that the actual peak power of the radar is not captured in the swept-spectrum measurement.
63, 65	1400.0–1427.0 1427.0–1535.0	The allocation from 1400.0 to 1427.0 is for earth exploration satellites, radio astronomy, space research applications. This band is a passive band which means that it is a receive-only band. We did not see activity in this band during the spectrum survey. Services in the frequency range 1427.0–1535.0 MHz include fixed, land-mobile, mobile, and mobile satellite services. This band is used for medical telemetry and telecommand, fixed telemetry, private land mobile, personal radio, wireless communication, aeronautical telemetry, flight testing of manned/unmanned aircraft missiles and space vehicles, range safety, aircraft chases, and weather data. Frequencies from 1525 to 1535 MHz contain mobile-satellite signals. We saw only two strong signals at approximately 1431 MHz and 1460 MHz during the spectrum survey.

Figure(s)	Frequency Range (MHz)	Notes
65, 66	1535.0–1710.0	The allocations in this band are for radionavigation, satellite, radio astronomy, space research, meteorological aids and fixed and mobile services. The general utilizations are space-to-earth, satellite communications, maritime, aviation, GPS-L1 (1575.42 MHz ±12 MHz) International Marine/Maritime Satellite (INMARSAT) (1626.5–1645.5 MHz), SARSAT, EPIRB and ELT for public safety rescue, WAAS, passive remote sensing and passive space research, Deep Space Network (DSN), earth-to-space communications, radiosondes, GOES, and TIROS-N. There are some signals from 1610 to 1660 MHz that are on intermittently. There are two signals at approximately 1680 and 1710 MHz that appeared only once during the spectrum survey.
66, 67	1710.0–1850.0	This frequency range is allocated for fixed, mobile, and space operations. This band is used exclusively by Federal agencies to operate point-to-point microwave, tactical radio relay communications systems, mobile subscriber equipment, precision-guided munitions (PGM), the Air Force Satellite Control Network (AFSCN) & Space-Ground Link System (SGLS), telemetry, and telecommand. We saw five signals that were on intermittently within the 1755.0 to 1850.0 MHz band during our survey.
67-69	1850.0–2025.0	The main allocation for these bands is fixed and mobile services, however, there is a small bandwidth from 2000 to 2020 MHz carved out for mobile satellite services; we measured small signal levels at four frequencies. The entire frequency band allocation is non-Federal and some of the general uses are Radio Frequency (RF) devices, personal communications, fixed microwave, and earth-to-space satellite communications. Cellular frequencies occupy the band from 1850 to 1910 MHz and from 1930 to 1990 MHz and show heavy usage.
69, 70	2025.0–2300.0	Federal agencies use this frequency range for space operations, earth exploration satellites, fixed and mobile services, and space research. The non-Federal allocations in the frequency range are fixed and mobile services, mobile-satellite, and space research. General uses include TV auxiliary broadcasting, cable TV relay, and local TV transmissions. There are research and weather satellite systems in this band such as the Deep Space Network (DSN) and the Tracking and Data Relay Satellite System (TDRSS). The Western Area Power Administration (WAPA) also has assignments in this band. Non-Federal allocations include public mobile, wireless communications, and fixed point-to-point microwave links. There appear to be digital signal transmissions from 2075 MHz to 2155 MHz. All other band usage is minimal.
71, 72	2300.0–2500.0	Signals from radiolocation, fixed and mobile services, broadcasting satellites, satellite radiolocation, amateur, mobile satellites, and radiodetermination satellites occupy this frequency range. General uses in this band are amateur radio, high-power long range surveillance radar, air-traffic control radars, telemetry, WAPA, research and developmental testing, ISM equipment (such as microwaves), downlinks, and the Arecibo radar (which operates from 2370 to 2390 MHz). There are wireless communications in this band, military tactical communications, TV auxiliary broadcasting, private land mobile, fixed microwave, scientific balloon-borne payloads, Radio Frequency Identification (RFID), and U.S. Coast Guard crew communications. In the graph we see digital signals from 2315.0 to 2350.0 MHz and various signal types from 2400.0 to 2483.5 MHz which include microwave oven emissions.

Figure(s)	Frequency Range (MHz)	Notes
72, 73	2500.0–2700.0	These bands are allocated for fixed and mobile services, broadcasting, earth exploration, fixed and mobile satellites, radio astronomy applications, and space-research. The general utilizations in these bands are wireless communications, military tactical communications NASA-research on global environmental changes and downlinks, earth exploration satellite, passive space research, radio astronomy. Most of these signals appear to be digitally modulated. There are digital signals from 2625 MHz to 2690 MHz that only appeared from approximately 10000 minutes to 12000 minutes during the spectrum survey.
74	2700.0–2900.0	The only allocations in this frequency range are for aeronautical radionavigation services and meteorological aids. Airport Surveillance Radars (ASRs) and Next-Generation Radar (NEXRAD) weather radars operate in this band and there is some radio astronomy research in this band. These signals were measured using the stepped-spectrum algorithm developed to detect radars. There are several distinct frequencies that show activity in this band in the San Diego metropolitan area. They are at 2705 MHz, 2750 MHz, 2775 MHz, 2790 MHz, 2795 MHz, 2830 MHz, and 2885 MHz.
75-80, 84	2900.0–3700.0	Radiolocation, maritime and aeronautical radionavigation, and fixed services and fixed satellite services are assigned to this band. There are secondary allocations from 3100.0 to 3300.0 MHz for earth exploration satellites and space research. The general utilizations are maritime radars, military high-power radars, long-range surveillance radars, private land mobile, SARS, amateur radio, and satellite communications. Swept measurements (Figures 75-80) were made from 2900.0 to 3700.0 MHz and stepped-spectrum measurements (Figure 84) were made from 2900.0 to 3650.0 MHz (a radar band). The swept measurements show a noise source which appear as horizontal bands in the time-varying plots from 2900 to 3800 MHz. There is a signal at 3430 MHz in Figure 78 and another from 3450 to 3475 MHz. There is activity from 3520 to 3550 MHz in Figure 79. When we look at the stepped-spectrum measurements in Figure 84, we see there was a constant source of high-level signals from 2900 to 3650 MHz. This activity correlates to the noise source as indicated by the horizontal bands mentioned above. There is a high-power radar that operates in this frequency band in the San Diego area.
80-83	3700.0–4200.0	The allocations in this frequency range include fixed, fixed-satellite, and mobile. Satellite communications, fixed microwave and reception of downlinks are the general utilizations for this band. The downlink signals are paired with transmission of uplink signals from 5925 to 6425 MHz. We measured little activity in these bands.
--	4200.0–4400.0	The only allocation in this band is for aeronautical radionavigation services. CW and pulsed radar altimeters are used in this band. We did not measure this band during the San Diego survey due to time constraints.
85	4400.0–5000.0	The allocations in this frequency range are for fixed, mobile, and fixed satellite services, radio astronomy, and space research. There is a 10 MHz allocation from 4990 to 5000 MHz for "RADIO ASTRONOMY" for passive space research. The general uses are tactical systems for point-to-point, line-of-sight and troposcatter communications, unmanned aerial video downlinks, space-to-earth communications, public safety land mobile, drug interdiction, radio astronomy, passive environmental change observations and measurements, radio astronomy, and very long baseline interferometry. There are several signals in this band that occur either intermittently or continuously.

Figure(s)	Frequency Range (MHz)	Notes
86	5000.0–5250.0	The allocations for this frequency range are aeronautical radionavigation and mobile services, radionavigation and fixed satellite services, and mobile communications. The general uses in this band are aviation, satellite communications. The FAA and the military use this band for the MLS and the Airport Network and Location Equipment (ANLE) system. The ANLE is a high-integrity, high data-rate wireless local area network (WLAN). RF devices also have assignments in this band. We measured a distinct continuous-use signal at approximately 5190 MHz and several other low-level signals.
86, 87, 89	5250.0–5925.0	This frequency range is allocated for earth exploration and fixed satellite services, radiolocation, space research, aeronautical and maritime radionavigation, meteorological aids, and mobile services. The secondary allocations from 5650.0 to 5925.0 MHz are for amateur and amateur satellite services. The general utilizations in this band are for RF devices, private land mobile, military radars, space-based observations, SARs, active radio astronomy research, aviation, ground-based meteorological radars, maritime communications, Terminal Doppler Weather Radar (TDWR) systems, ISM equipment, amateur radio, and personal radio. This area of the spectrum was also measured using the stepped-spectrum algorithm as shown in Figure 89. The signals at approximately 5340, 5470, 5590, 5610, 5630, 5790, 5845 and 5890 MHz shown in the swept-spectrum measurements of Figures 86 and 87 show up in the stepped-spectrum measurements of Figure 89 as well. The wideband set of signals from approximately 5720 to 5840 MHz show up in both the swept-spectrum plot of Figure 87 and the stepped-spectrum measurement of Figure 89.
87, 88, 90	5925.0–7250.0	The allocations across this frequency range are for fixed, fixed satellite, and mobile services. The general utilizations in this band are earth-to-space satellite communications, fixed point-to-point microwave, Federal civilian and military satellite communication uplinks (paired with 3700–4200 MHz), TV broadcast auxiliary, cable TV relay, remote sensing (6425–7250 MHz), radio astronomy (6668.518 MHz). Federal agencies use the band from 7125 to 7250 MHz for point-to-point microwave communications, weather, vessel traffic, hydroelectric and space research (7190–7235 MHz). The time-varying plot showing signals from 7000 MHz to 7125 MHz has some interesting characteristics. This frequency range was not heavily used during the spectrum survey.
90-92	7250.0–8500.0	Most of the allocations across these frequency bands are for Federal assignments and include fixed, mobile, earth exploration and meteorological satellites, and space research. The secondary allocations are for fixed services and mobile satellite services. Non-federal allocations are for space research. The general utilizations for these bands are space-to-earth communications, Defense Satellite Communications Systems (DSCS), fixed point-to-point microwave systems, weather, vessel traffic, hydroelectric and space research, Wideband Gapfiller Satellite (WGS), GOES, TTC data downlinks from non-geostationary satellites, long-range radars, deep-space probes communications. There were several low-level signals recorded in this frequency range and only a few that were on continuously during the spectrum survey.

Figure(s)	Frequency Range (MHz)	Notes
92-94	8500.0–10000.0	In this final measured frequency range, the allocations are for radiolocation, aeronautical and maritime radionavigation, and radionavigation services. Secondary allocations are for radiolocation and meteorological aids. The general utilizations are military and non-military radar systems, private land mobile, earth-exploration satellites from 8550 to 8650 MHz, search and rescue, law enforcement, navigation, surveillance, avian detectors, airport surface detection, maritime harbor and coastal traffic, meteorological radars, airborne radars to research convective storm and mesoscale phenomena, and SARs. Measurements in these bands were taken using the swept-spectrum techniques (Figures 92 and 93), and stepped-spectrum methods (Figure 94), The signal at 9400 MHz was measured using both swept- and stepped-spectrum methods. There is a lot of activity recorded from 8500 to 10000 MHz (Figure 94) in the San Diego area.

4 ACKNOWLEDGEMENTS

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APPENDIX A: EXPLANATION OF MEASUREMENT GRAPHS

There are many ways to process and present the data acquired during spectrum surveys. In this section, two methods used for the San Diego spectrum survey will be discussed.

A.1 Maximum-Mean-Median-Minimum (M4) plots

The M4 plots (top graph of Figure 3 in Section 3) show the maximum, mean[3], median, and minimum values at each frequency, and are calculated using internal MATLAB® scripts. The measured data are expressed in field strength (dBµV/m), referenced to the input of a 0 dBi antenna versus frequency. The measured data is corrected using the system gain and the antenna correction factor (ACF). The system gain and noise figure are obtained by performing calibrations periodically throughout the measurement series. The mean system noise (magenta line) is produced using the noise figure of calibrations.

A.2 Time vs. Frequency Plots

Time vs. frequency (waterfall) plots are displayed using a contour plot as shown by the middle plot of Figure 3. The generation of waterfall plots is time and memory intensive due to the large array sizes. This array is decimated by determining the median measurement time between each scheduled measurement and retaining the maximum power trace for that time interval. The time axis displays the total measurement time for all traces in minutes. The maximum value of this axis will vary depending on the number of times the event was measured. The data spacing stated at the top of the graph refers to the median number of minutes between measured events. For the data shown in Figure 3, the median time is 16.4 minutes, which means the data was measured approximately every 16.4 minutes. The threshold, shown in the bottom plot, determines the lowest field strength level in decibel-microvolts per meter (dBµV/m) at which data will be displayed in the time-varying plot. If the measured field strength does not exceed the threshold, the data point will not be displayed (it will be rendered as a white point). If the data exceeds the threshold, the color of the data point represents the amplitude of the field strength — blue represents the lowest field strength and red represents highest field strength. The time scale creates a linear time vector using the median time spacing for the time interval mentioned above.

The threshold is determined by one of two methods. One method requires a statistical analysis of the system noise. With this technique the threshold is set to a field strength level at which the system noise is likely to exceed the threshold 0.01% of the time. The second method is determined by first processing the data into M4 plots and examining the maximum value of the trace at frequencies that appear to be free of signals. The threshold level is then set to this maximum level.

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[3] The mean is taken by converting power values to linear form. The mean of these linear values is determined and then converted back to power and then into field strength in dBµV/m.

A.3 Field-Strength, Complementary Cumulative Distribution Function (FS-CCDF) Plots

When measurement system components (amplifiers, switches, filters, SAs) perform consistently the same over the course of a measurement, the statistical characteristics of the system noise remain stationary with regard to the mean, variance, and power distribution. Though noise is a random process, its consistent statistical characteristics provide a useful way to differentiate system noise from signals, especially when the signal power is very close to the mean power of the system noise. Signals will have statistical characteristics that are different from those of noise.

In this report, we plot the FS-CCDFs as shown by the bottom graph in Figure 3. These plots are useful for differentiating between intentionally-radiated signals and impulsive or Gaussian noise, quickly characterizing signals, and identifying low-level signals—something that is not generally possible with other processing methods.[4] For these types of graphs, we begin by constructing the probability density function (PDF) of the measured data. The measured data for the current software is binned into 0.1 dB power bins. From the PDF, we compute the cumulative distribution function (CDF) and the complementary cumulative distribution function (CCDF) vs. power in dBm[5]. From the CCDF shown in Figure A-1, we choose equally spaced values along the x-axis to obtain values of power or field strength at the input to the antenna on the y-axis. We also choose the spacing so that we will get probabilities close to 0.1%, 2%, 50%, and 95%. By choosing equally-spaced x-values, it is possible to scale the y-axis so that sample-detected, Gaussian system noise is displayed as a straight line. The chosen values are converted to a percent probability. Finally, at each frequency, we display the probability that the power (dBm) or field strength (dBμV) on the y-axis is exceeded as shown in Figure A-2 or the figures in the report. Because this is a cumulative distribution at each frequency, the probability value can also give us an indication of the percentage of time that the signal appeared above certain power levels during the measurement. For other signal types, the spacing of the power or field strength values will be indicative of the signal type or the type of detector used to measure the signal. For example, median-of-five processed Gaussian noise (Figure 34, 411.2–411.3 MHz) will show a probability-level spacing of approximately one dB (Figure A-3). RMS-detected Gaussian noise (Figure 50, 714.0–714.8 MHz) will show the lower-probability levels (0.09% to 2.02%) more widely spaced than higher probability levels (93.30% to 96.18%) (Figure A-4).

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[5] CCDF's are calculated using powers which are then converted to field strength in dBμV/m for the final plots.

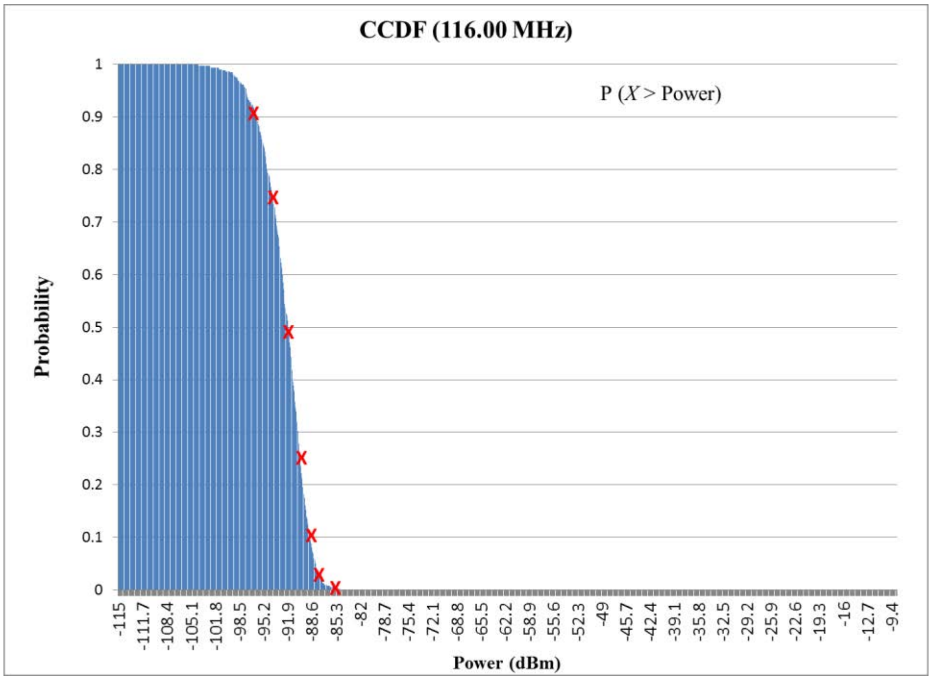

Figure A-1. Complementary cumulative distribution function (CCDF) at 116.00 MHz.

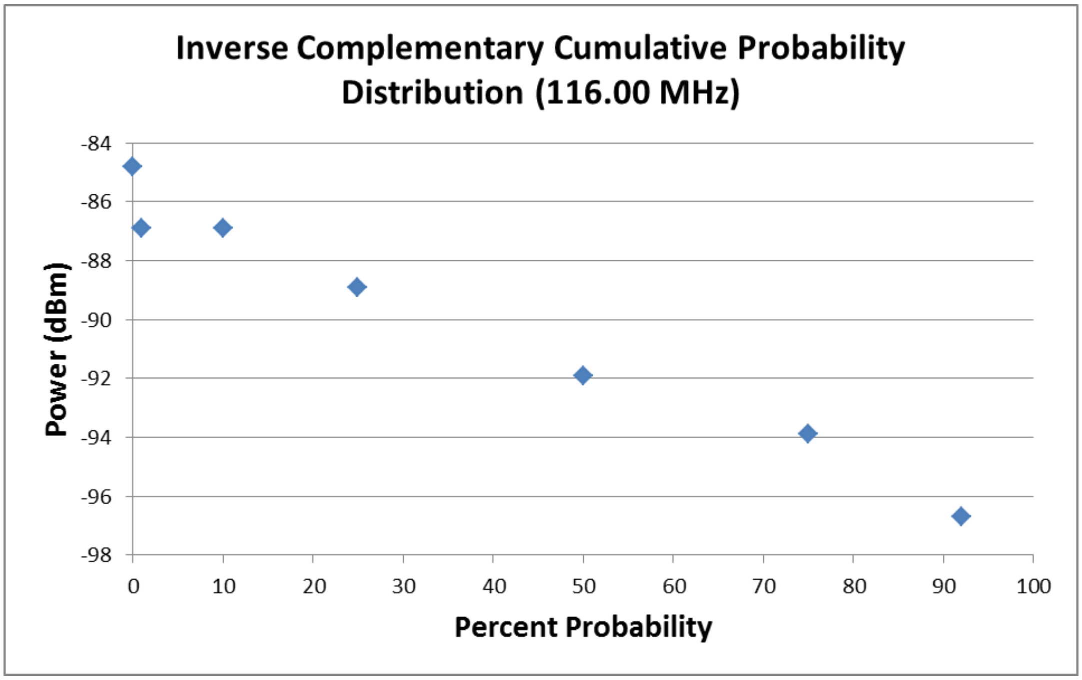

Figure A-2. Inverse complementary cumulative distribution function. The percent probability is shown along the x-axis and the power is shown along the y-axis.

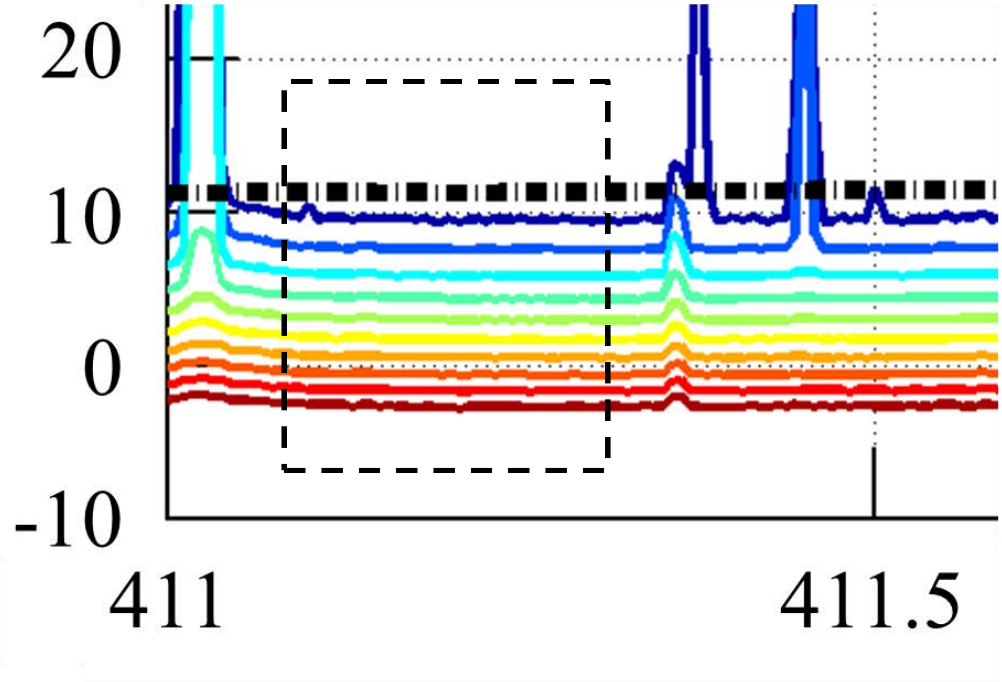

Figure A-3. Close-in view of one-dB probability spacing for median-of-five processed Gaussian noise shown inside the dotted rectangle for the frequency range from 411.2 to 411.4 MHz.

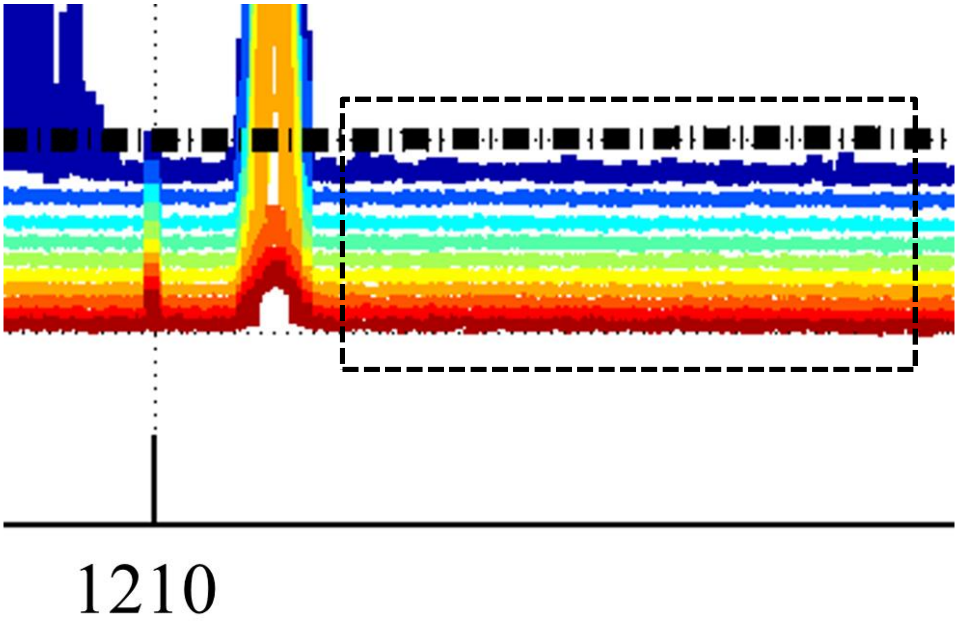

Figure A-4. Close-in view of variable probability spacing for RMS-detected Gaussian noise shown inside the dotted rectangle for the frequency range from 1210 to 1230 MHz.

APPENDIX B: OPTIMIZING RADAR MEASUREMENTS

B.1 Radar Operations

Radar spectrum occupancy measurements quantify only the very strong signal transmitted by the radar transmitter. However, there are challenges to accurately portraying the spectrum used by radar signals:

- Pulsed radars have low-duty cycles
- Radar transmitting antennas typically have narrow beamwidths

Pulsed radar signals (or very narrow, pulsed signals) are optimally measured using the stepped-spectrum algorithm developed by ITS. Measurement of high-power signals require dynamic adjustment of the sensitivity of the system. Radar signals are also usually present for only short time periods in the direction of the receive antenna, not only because of the short pulse period and low duty cycle, but also because most pulsed signals are transmitted with a narrow-beam antenna dynamically pointed in different solid angles of physical space. An example is given in the following paragraphs.

Consider a radar transmitting using a high-gain directional antenna (2º beamwidth) pointed at the horizon and making one complete azimuthal rotation every 5–12 seconds. An overhead viewpoint is shown in Figure B-1.

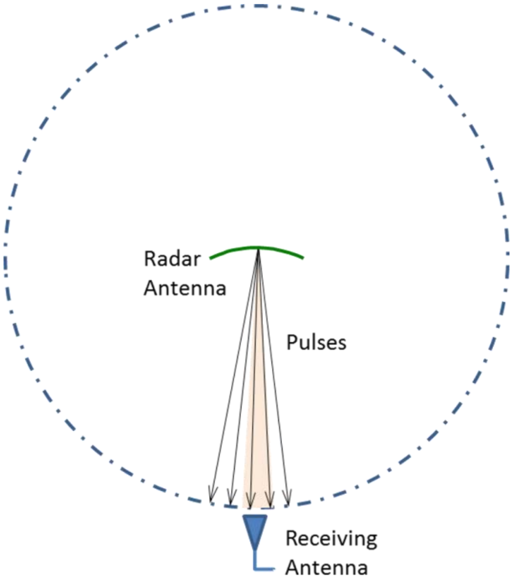

Figure B-1. Radar beam scanning past receiving antenna.

If the rotation rate of the radar is 10 s, then the beam scans past our receiving antenna in 5.6 ms or 0.56% of the rotation time. If the pulse width while the beam is transmitting is 1 μs and there are 300 pulses per second, then we see 1.68 pulses intersect our measurement antenna during the radar's "on" time. If the spectrum analyzer is set to a sweep time of 1 second then we may pick up one or two direct pulses from the radar every 10 sweeps. Therefore, we have a very small chance of intercepting the main beam and measuring the correct power levels. It will take a very long time to measure the radar's true spectrum using this method. This demonstrates that the radar spectrum is occupied continuously during each duty cycle by very weak echoes of the transmitted radar pulse returning to the radar receiver; sometimes we catch the main beam and sometimes we catch a side lobe.

Also, many types of radar are quite powerful and can overload sensitive measurement systems located even considerable distances from the transmitter. Radar signals, by their very nature, can produce low-level, unwanted emissions at several hundred MHz on each side of the center frequency. Therefore, there are potentially strong emissions at the center frequency, and at the same time, there are low emission levels throughout the band adjacent to the center frequency. For most measurement systems, the range in power levels may exceed the system instantaneous dynamic range. For this reason, it is sometimes necessary to add and remove front-end attenuation as the measurement system experiences the varying emission levels across the frequency band. It is also necessary to use tunable filters that can track the measurement center frequency, thus attenuating the strong emissions while measuring the adjacent weaker signals.

B.2 Measurement Algorithms

B.2.1 Stepped-Spectrum Measurement Algorithm

A stepped-spectrum measurement algorithm consists of one scheduled event, as discussed in Section 2.3. Because radar beams rotate or scan through space, and we want to ensure our receiving antenna intercepts the main beam of the radar once at every frequency, the important parameters set in this algorithm are the start and stop frequencies, the RBW, the sweep time, the detector type, and the filter type.

The RBW is set to the reciprocal of the typical pulse width of radars in the band. The number of frequency steps is equal to the frequency span of the measurement divided by the RBW, ensuring that there are no frequency gaps in measured power. A peak detector will give the greatest signal detectability when the RBW is equal to the inverse of the pulse width of the radar signal. The sweep time is set to the longest expected rotation rate of the radars in the band. The algorithm works by first setting the center frequency of the spectrum analyzer at the low end of the radar band, disabling the swept oscillator function by setting the span to 0 Hz (a.k.a. "zero span"), and recording the peak value measured during the sweep. The spectrum analyzer center frequency is then increased by an amount equal to the RBW and the sweep repeated. This sequence continues multiple times, until the measurement has stepped across the entire frequency band. To prevent overload at, or near, the peak signal power, front-end attenuation is automatically inserted as the total power received by the spectrum analyzer starts to approach the 1 dB compression point. It is also necessary to use a tunable filter, such as a YIG bandpass tunable filter, to prevent the power of the center lobe from overloading the system when the spectrum analyzer frequency is tuned to the lower-power components of the radar spectrum. (a YIG filter was used for all of the measurements—swept or stepped—described in this section.).

B.2.2 Swept-Spectrum Measurement Algorithm

The swept-spectrum measurement algorithm consists of sweeping the specified bands of the spectrum using a spectrum analyzer. The swept-spectrum algorithm typically uses more than one event to select an appropriate RBW based on the transmission characteristics of the emitter in each band. The user can also set other parameters such as the start and stop frequency, the measurement span, the sweep time, the number of sweeps stored in a data file during each measurement, the attenuation in the first preselector, and either a tunable filter or a fixed filter. After each sweep, overload errors are checked and noted in an error log file. Attenuation can only be inserted for the entire event and not at individual frequencies.

B.3 Comparison between a Swept-Spectrum Measurement and a Stepped-Spectrum Measurement

We will now show a comparison between a radar measured using the swept-spectrum algorithm and the stepped-spectrum algorithm.

Figures B-2 and B-3 show measurements of an air-surveillance radar (ASR). Figure B-2 shows the results for a swept-spectrum measurement and Figure B-3 shows the results for a stepped-spectrum measurement, both using peak detection.

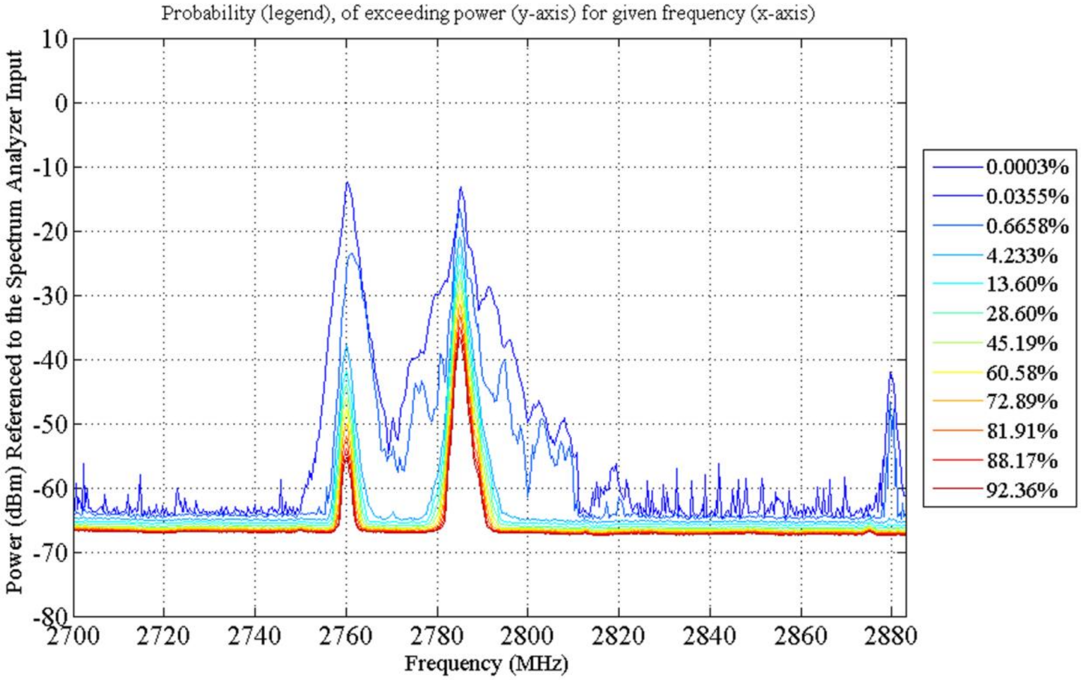

Figure B-2. Radar measurement using swept-spectrum measurement algorithm with peak detection.

The swept-spectrum measurement shown in Figure B-2 was acquired for the same amount of time as the stepped-spectrum measurement shown in Figure B–3. One can see that for the radar centered at 2784 MHz, the stepped measurement shows the received power is approximately 20 dB higher than the 0.0003% threshold line shown in Figure B-2. On the other hand, the power levels for the radar centered at 2760 MHz do not show this 20 dB received power difference. The spectrum analyzer provides an overload error message when the received power, at the SA RF input, approaches -10 dBm, and in the stepped-spectrum measurement, the software will automatically insert attenuation to increase the system sensitivity. The peak power of the radar at 2760 MHz occasionally approached this -10-dBm power level and therefore rarely caused an overload, even when the main beam of the radar intersected with the receiving antenna. The actual peak power of the radar at 2784 MHz, however, approached +10 dBm and therefore caused an overload when the spectrum analyzer was sweeping near 2784 MHz at the precise moment that the radar main beam intersected the receiving antenna.

Notice that, in Figure B-2, the top probability curve (0.0003%) never exceeds -10 dBm—the point above which an overload would occur. This is because no attenuation was inserted for the swept-spectrum measurements, and this also explains why swept-spectrum measurements can be vulnerable to overloads and may not accurately represent the spectral components of a radar. The swept-spectrum measurement algorithm could have been modified to avoid signal overloads by manually adding 20 dB of attenuation in the preselector. This would have given the correct peak amplitude but would have decreased the system sensitivity by increasing the system noise floor. The low-power signals seen from 2700 to 2740 MHz and from 2815 to 2875 MHz would not have been detected in this case.

One can also see from Figure B-2 for the radar at 2760 MHz that 50% of the traces are likely to show a center-frequency power that is approximately 35 dB below the true received power, and 96% of the traces are likely to show a center-frequency power that is approximately 15 dB below the true received power when measurements are made with the swept-spectrum algorithm. This further substantiates the argument that a single trace (or a few traces) in radar bands is highly unlikely to portray an accurate image of the spectral components. For further discussion about proper measurement techniques for radar emissions refer to [13].

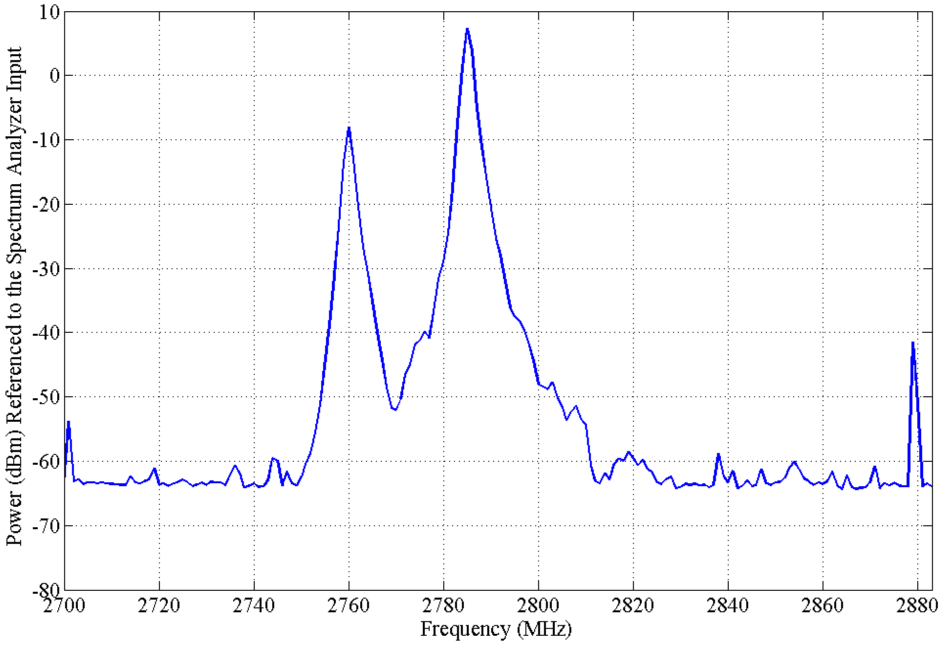

Figure B-3. Radar measurement using stepped–spectrum measurement algorithm with peak detection.

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NTIA is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the Radio Spectrum Measurement Sciences system to collect spectrum occupancy data for radio frequency assessments. This report shows measured frequency data spanning spectrum from 108 MHz to 10 GHz in the metropolitan area of San Diego, California, during the months of May and June 2012.

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