Spectrum Occupancy Measurements
Location 3 of 6:
National Science Foundation Building Roof
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Revision 2

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Spectrum Occupancy Measurements and Pre-Selector Development
National Radio Research Testbed (NRNRT)
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1. Introduction

1.1 Summary

This document describes spectrum occupancy measurements made over multiple bands from 30 MHz to 3,000 MHz performed by Shared Spectrum Company. The purpose was to quantify the electromagnetic noise and interference over a four-hour period at the National Science Foundation Building roof in Arlington, Virginia.

1.2 Report Organization

This report is organized into six sections, as follows:

Section 1 Introduction
Section 2 Description of measurement equipment
Section 3 Site and surrounding environment where measurements were taken
Section 4 Frequency lists used for the spectrum occupancy measurements
Section 5 Plots showing measured spectrum occupancy for each band.
Section 6 Conclusions

1.3 Measurement Goals

The need to assure access to radio spectrum is at a crossroads. More and more technological alternatives are becoming available and demand from both public and private sectors is increasing very rapidly, if not exponentially. Increasingly, there is recognition that the root of the problem is that most of the spectrum is actually unused, and the present system of spectral regulation is grossly inefficient. Current spectral regulation is based upon the premise that slices of the spectrum, representing uses within specified upper and lower frequency bounds, must be treated as exclusive domains of single entities – who are the recipients of exclusive licenses to use specific frequency bands.

The goal for the measurements taken at Riverbend Park was to identify spectrum bands with low occupancy. Occupancy was quantified as the amount of spectrum detected above a certain received power threshold.

1.4 The National Radio Network Research Testbed (NRNRT)

Measurements contained in this report are part of the National Radio Network Research Testbed (NRNRT) project.[1] The NRNRT is a National Science Foundation (NSF) project that supports research and development of new radio devices, services, and architectures, providing a valuable facility for use by the research and development community in testing and evaluating their systems.

The NRNRT consists of:

[1] Electronic copies of the data provided in this report may be requested from NRNRT by contacting Professor. Gary Minden, University of Kansas, Information and Telecommunication Technology Center, Center for Research, Inc., (email: gminden@ittc.ku.edu; tel: 785-864-4834), or Dr. Mark McHenry, Shared Spectrum Company, (email: mmchenry@sharedspectrum.com; tel: 703-761-2818 x-103)

(1) a field measurement and evaluation system for long-term radio frequency data collection, and an experimental facility for testing and evaluation of new radios;
(2) an accurate emulation/simulation system that incorporates long-term field measurement, for use in evaluating new wireless network architectures, policies, and network protocols; and
(3) innovative experimentation with wireless networks that integrate analysis, emulation/simulation, and field measurements.

2. Measurement Equipment

2.1 Equipment Description

The equipment consisted of an antenna, antenna rotator, filter, pre-amp, shielded enclosure, and a spectrum analyzer as shown in Figure 1.

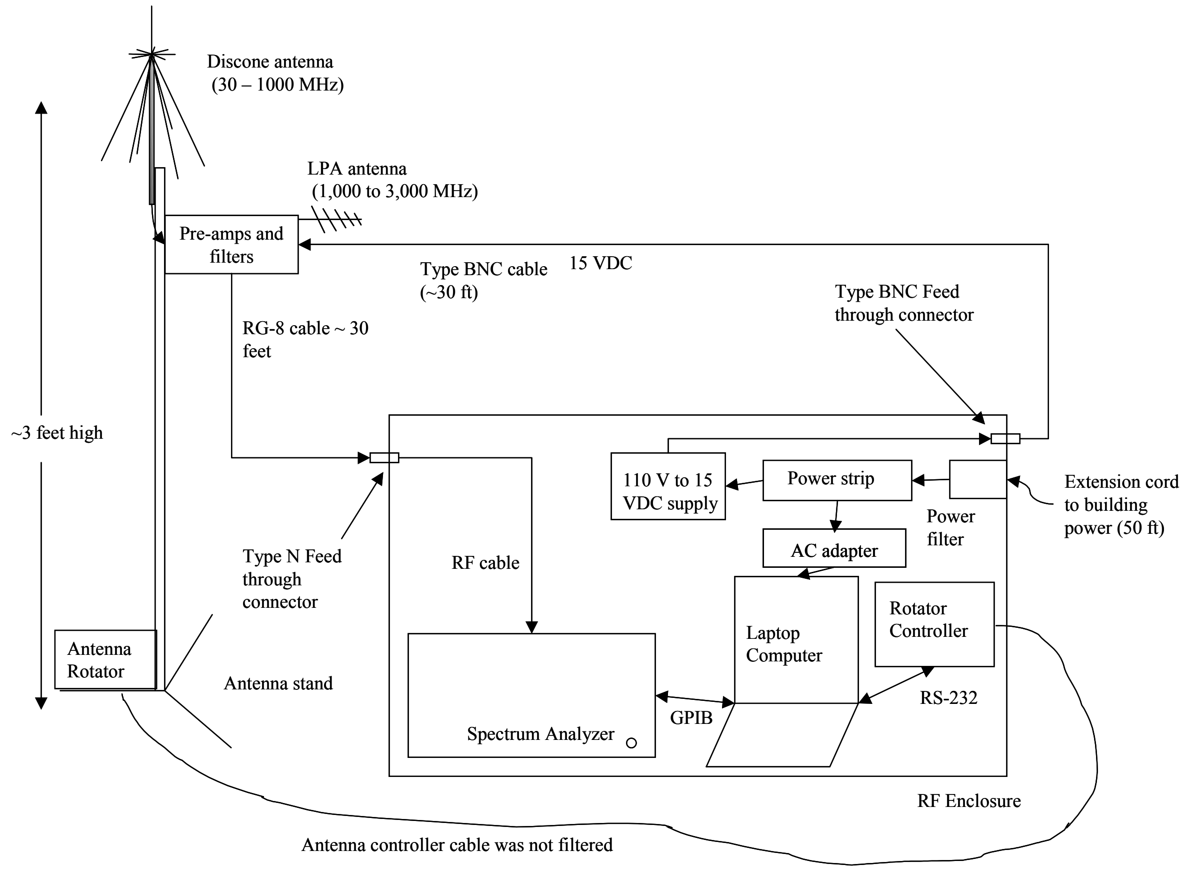

Figure 1: Spectrum occupancy measurement equipment configuration.

At the NSF location, the equipment was powered by a 50-foot long extension cord plugged into the building power.

Figure 2: RF Shielded Enclosure Used With the Spectrum Analyzer and Laptop Computer

The spectrum analyzer specifications are shown in Table 1.

Table 1. Rohde and Schwarz ESPI Spectrum Analyzer Parameters

Parameter	Value
Frequency Range	9 kHz to 3 GHz
Pre-selector	BW=15 MHz (30 MHz to 70 MHz), BW=30 MHz (70 MHz to 150 MHz), BW=60 MHz (150 MHz to 300 MHz), BW=80 MHz (300 MHz to 600 MHz), BW=100 MHz (600 MHz to 1000 MHz), BW=Tracking high pass (1000 MHz to 2000 MHz), BW=Fixed high pass (>2,000 MHz).
Noise Figure	21.5 dB
Input Third Order Intercept Point	+10 dBm (typ), +5 dBm (with pre-selector on)
Input Second Order Intercept Point	+35 dBm (typ), +5 dBm (with pre-selector on)
Phase Noise	-106 dB/Hz at 10 kHz offset
Sweep Time	320 ms sweep time for 100 MHz sweep and 10 kHz RBW, 100 ms sweep time for 10 MHz sweep and 10 kHz RBW.

2.2 RF Configuration Used Below 1,000 MHz

The configuration for signals below 1,000 MHz is shown in Figure 3. The FM band stop filter was an Eagle HLC-700, C7RFM3NFNF filter.

Two antennas were used. A Create Model CLP-5130-2N log period antenna was used in the horizontal polarization configuration. This antenna has a specified frequency range of 105 MHz to 1.3 GHz and a manufacturer's specified gain of 11 to 13 dBi. The second antenna was a vertically-polarized "scanner" discone antenna.

Two sets of measurements were conducted, one using a pre-amplifier and another not to check if the pre-amplifier or spectrum analyzer was overloaded with large signals.

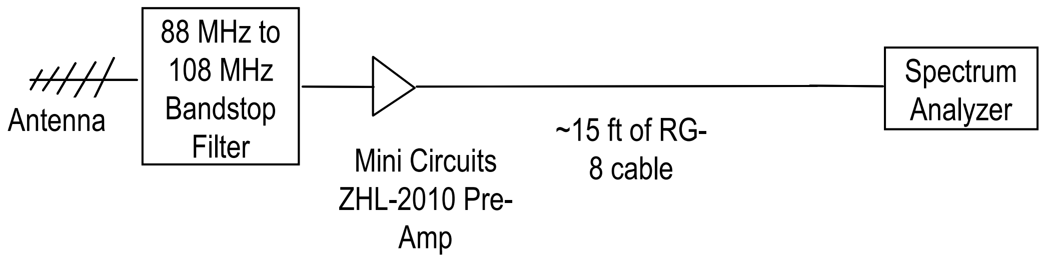

Figure 3: Equipment configuration used for signals below 1,000 MHz.

Figure 4: Omni-Directional Discone Antenna (used for frequencies above 1,000 MHz)

2.3 RF Configuration Used Above 1,000 MHz

Figure 5 shows the equipment configuration used for signals above 1,000 MHz. A highpass filter is used to remove the strong FM and broadcast TV signals. The pre-amplifier is used to improve the system noise temperature.

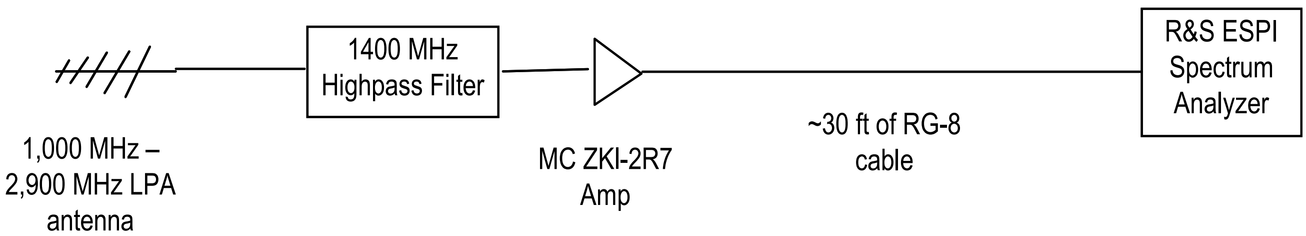

Figure 5: Equipment configuration used for signals above 1,000 MHz.

An LPA antenna was used for all measurements above 1 GHz. It was rotated to a horizontal polarization angle. The antenna was installed on the filter/pre-amplifier module as shown in Figure 6. The antenna size is shown in Figure 7.

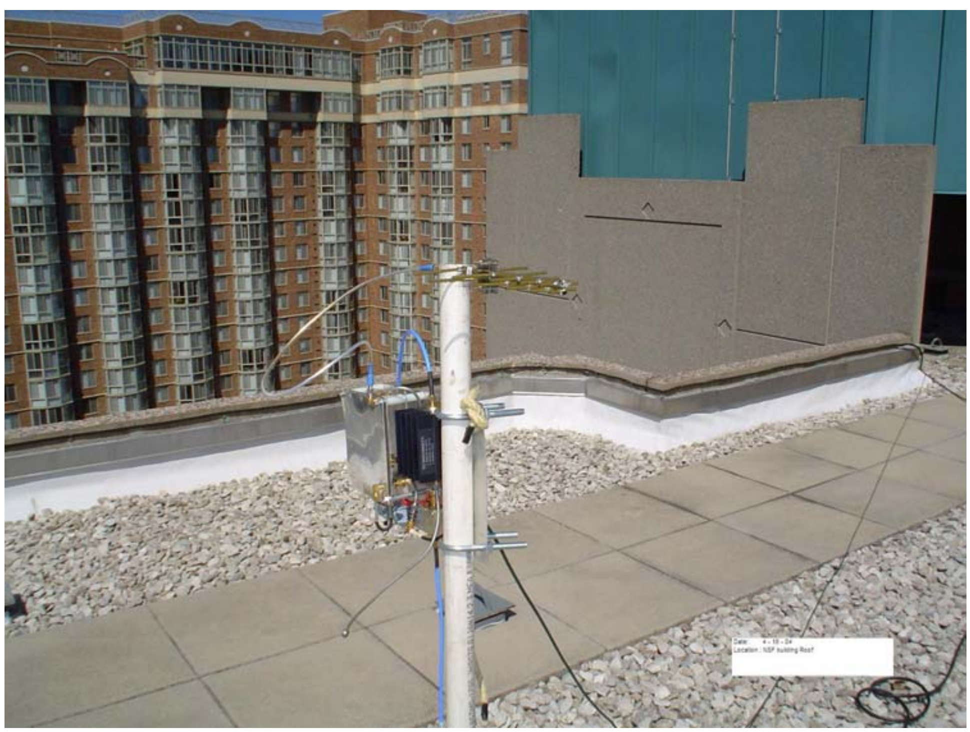

Figure 6: Small LPA Antenna and Pre-Amplifier Used for Frequencies Above 1 GHz

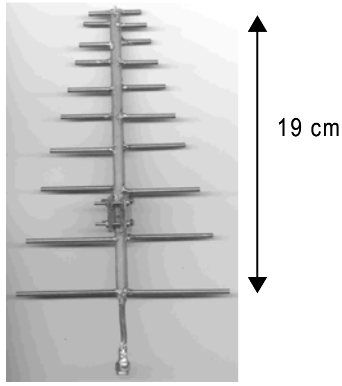

Figure 7: Log-Periodic Array (LPA), Directional Antenna Used for 1,000 MHz to 3,000 MHz.

2.4 Equipment Configurations for Each Run

Different equipment configurations were used for each run described below. The antennas, cables, filters, fixed attenuators, and pre-amplifiers were varied to optimize the dynamic range of the measurements. Table 2 provides a list of the equipment parameters and Table 3 provides the configuration used for each measurement run. Section 2.3 provides more information on the equipment. Section 2 describes the frequency lists.

Before each measurement, data using a variety of frequency lists were collected to look for strong signals that might overload the pre-amplifier and/or the spectrum analyzer. Also, the data was examined to insure the equipment was operating properly. After the equipment configuration was finalized, long duration collections were made using the frequency lists in Table 5 and Table 6.

Table 2. General Equipment Configuration Parameters

Parameter	Value
Antenna Type	=0 for no antenna (system noise), =1 for discone, =2 for large LPA, =3 for small LPA
Cable Type	=1 for (1) RG-8 cables, =2 for (2) RG-8 cables, =3 for (3) RG-8 cables, =4 for short orange cable
Attenuation	=Value of fixed attenuator in dB =0 for none, XX dB otherwise, XX > 0
Filter Type	=0 for none, =1 for 30-88 MHz bandpass, =2 for 225-450 MHz bandpass, =3 for 1400 MHz highpass, =4 for FM Bandstop (HLC-700)
Pre-Amplifier Type	=0 for none, =1 for MC ZHL-2010, =2 for (3) MC ERA-5, =3 for MC ZKL-2R7

Table 3. Description of Runs Showing the Frequency List, the Antenna Type, the Cable Type, the Attenuation Value, the Filter Type, and the Pre-Amplifier Type Used

Start Time	Location	Comment	Freq List	Start File	End File	Num Files	Duration (sec)	Antenna Type	Cable Type	Attenuation (dB)	Filter Type	Pre-Amplifier Type
9:26 am	SE corner		Table 5	1414	1527	111	3600	1	2	0	4	1
10:29 am	SE corner		Table 5	1528	1641	114	3600	1	2	0	4	0
11:35 am	SE corner	Broken filter/bad data (not plotted)	Table 6	1642	1728	87	3600	3	2	0	3	3
12:50 pm	Central location		Table 5	1730	1843	113	3600	1	2	0	4	1
3:53 pm	SE corner		Table 5	1844	1938	95	3600	2	2	0	4	0
5:05 pm	SE corner		Table 6	1939	2015	77	3600	3	2	0	3	3

Table 4. Antenna Direction and Rotation Used for Each Measurement

Start Time	Location	Comment	Rotating	Antenna Type
9:26 am	SE corner	Omni with pre-amp	N	1 - discone
10:29 am	SE corner	Omni-no pre-amp	N	1 - discone
11:35 am	SE corner	Broken filter / bad data	N	3 - small LPA
12:50 pm	Central location		N	1 - discone
3:53 pm	SE corner	Directional, rotating antenna	Y	2 - large LPA
5:05 pm	SE corner	Directional, rotating antenna	Y	3 - small LPA

Separate files were collected for each collection of a frequency list. The file size is 60 k to 65 k, depending on the number of frequency bands.

2.5 Data Calibration

The plotted spectrum data is calibrated to the power level at the antenna input using the following procedure:

- The recorded power levels measured by the spectrum analyzer are provided in dBm relative to the analyzer input.
- The difference between the power level at the analyzer input and the power level at the antenna input is due to the losses and gain of the RF cables, filters, and amplifiers associated with the Pre-selector.
- To correct for this difference, the Pre-selector loss was measured using a network analyzer in each spectrum band at the conclusion of the measurements.
- The Pre-selector loss versus frequency data values (in dB) where then added to the measured values (via an interpolation process) when plotting the spectrum data in this report.

Thus, the plotted power level values are the absolute value in dBm at the antenna input.

3. Measurement Location

3.1 NSF Measurement Site

The principle measurements were made on the roof of the National Science Foundation building, 4201 Wilson Boulevard, Arlington, Virginia. A map showing the measurement location is shown in Figure 8.

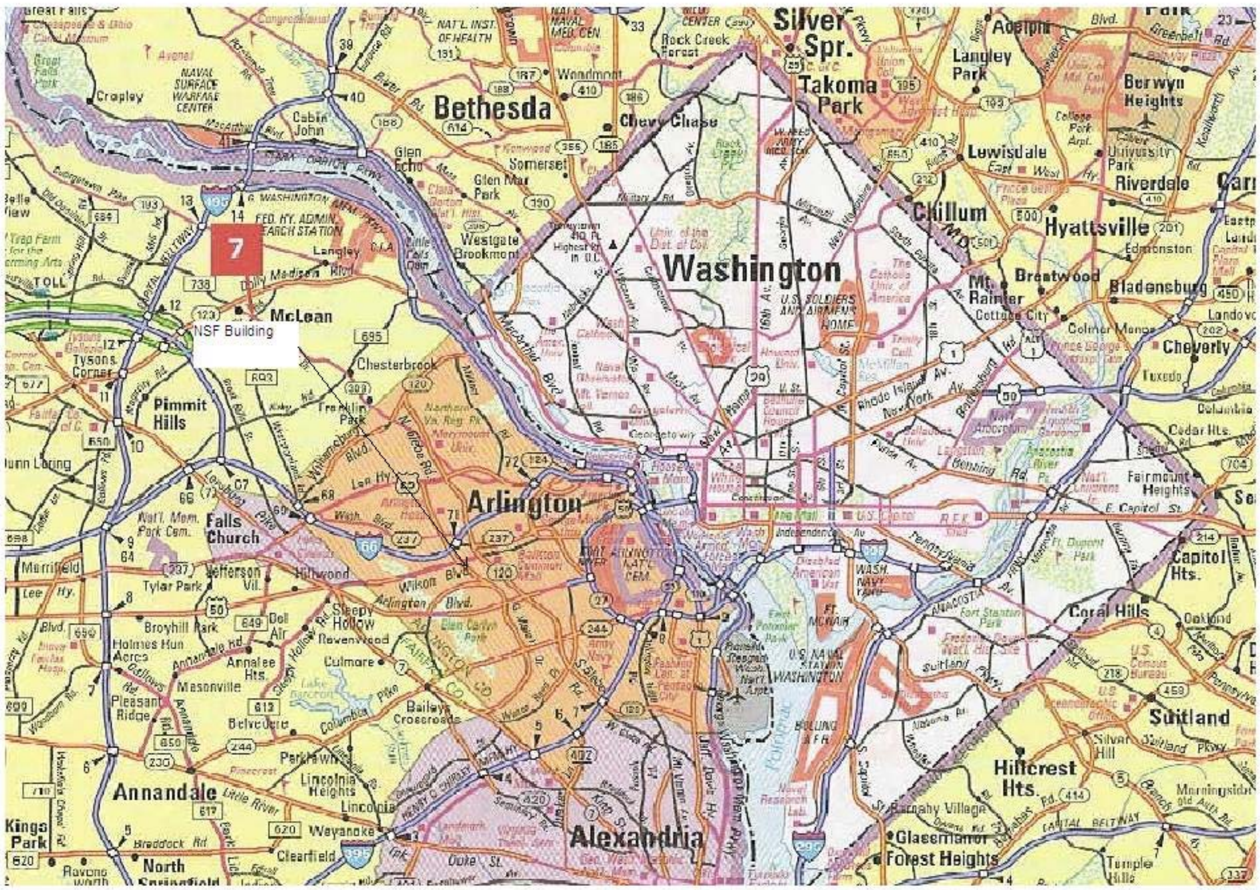

Figure 8: Map Showing NSF Measurement Location

3.2 Views from Measurement Site

The measurement location had good line sight except in the North direction due to blockage. Figure 9 and Figure 10 show the view from the measurement antenna location looking in different directions.

Figure 9: View From the NSF Measurement Site Towards the East

Figure 10: View From the NSF Measurement Site Towards the West

3.3 Near-By Transmitters and Potential Noise Sources

There were several near-by antennas located other-side of the NSF building. One was a TV reception antenna, another was a satellite dish-type antenna (frequency unknown), and a directional antenna that we believe operates at 2.4 GHz. These are shown in Figure 12. If these antennas were transmitting, they used a low power and did not over drive the spectrum measurement equipment.

Figure 11: Nearby, potentially transmitting antennas (> 50 feet away and blocked by building structure from collection antenna) at the NSF location.

At each site there were potential noise sources in close proximity to the spectrum measurement equipment. At the NSF location, there were several pieces of equipment within 20 feet of the collection antenna. Photographs of each of them are shown in Figure 12, Figure 13, and Figure 14. Tests were not done to estimate any potential RF noise emitted by these items.

Figure 12: HVAC equipment located approximately 20 feet from the collection antenna at the NSF location.

Figure 13: HVAC equipment located approximately 20 feet from the collection antenna at the NSF location.

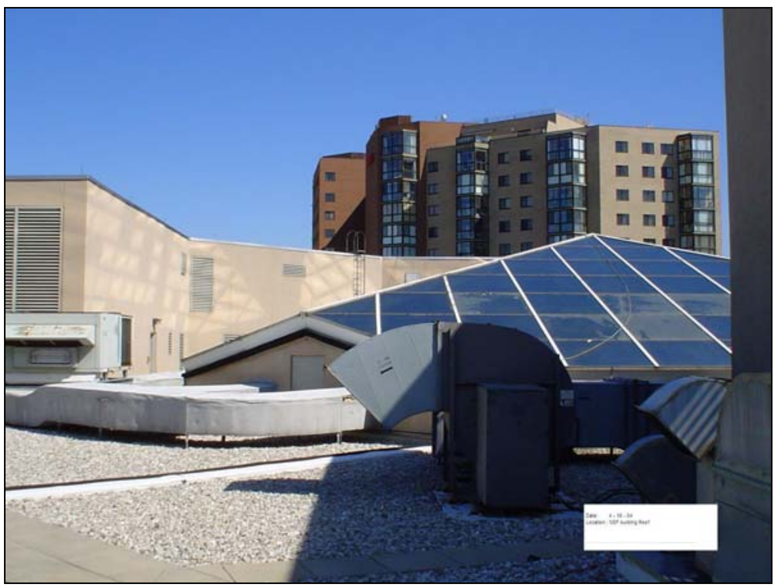

Figure 14: Building exhaust fan located approximately 20 feet from the collection antenna at the NSF location.

4. Frequency Lists

4.1 Frequency Collection List Used Below 1,000 MHz

Table 5 shows the frequency list used from 30 MHz to 960 MHz. In addition to the band start and stop frequencies, several spectrum analyzer settings are shown such as the reference level, the number of dB per division, the resolution bandwidth, the video bandwidth, the amount of RF attenuation, and the sweep time.

Table 5. Frequency List Used to Collect Data Below 1,000 MHz

Start Freq (MHz)	Stop Freq (MHz)	Ref Level (dBm)	dB/div	Res_BW (Hz)	Vid_BW (Hz)	Attenuatio n (dB)	Sweep Time (sec)
30	54	-10	10	1.00E+04	1.00E+04	10	0.3
54	88	-10	10	1.00E+04	1.00E+04	10	0.425
88	108	-10	10	1.00E+04	1.00E+04	10	0.25
108	138	-10	10	1.00E+04	1.00E+04	10	0.375
138	174	-10	10	1.00E+04	1.00E+04	10	0.45
174	216	-10	10	1.00E+04	1.00E+04	10	0.525
216	225	-10	10	1.00E+04	1.00E+04	10	0.1125
225	406	-10	10	1.00E+04	1.00E+04	10	2.2625
406	470	-10	10	1.00E+04	1.00E+04	10	0.8
470	512	-10	10	1.00E+04	1.00E+04	10	0.525
512	608	-10	10	1.00E+04	1.00E+04	10	1.2
608	698	-10	10	1.00E+04	1.00E+04	10	1.125
698	806	-10	10	1.00E+04	1.00E+04	10	1.35
806	902	-10	10	1.00E+04	1.00E+04	10	1.2
902	928	-10	10	1.00E+04	1.00E+04	10	0.325
928	960	-10	10	1.00E+04	1.00E+04	10	0.4

4.2 Frequency Collection List Used Above 1,000 MHz

Table 6 shows the frequency list used from 1,240 MHz to 2,900 MHz.

Table 6. Frequency List Used to Collect Data Above 1,000 MHz

Start Freq (MHz)	Stop Freq (MHz)	Ref Level (dBm)	dB/div	Res_BW (Hz)	Vid_BW (Hz)	Attenuation (dB)	Sweep Time (sec)
1240	1300	-10	10	1.00E+04	1.00E+04	0	.6
1300	1400	-10	10	1.00E+04	1.00E+04	0	1.00
1400	1525	-10	10	1.00E+04	1.00E+04	0	1.5625
1525	1710	-10	10	1.00E+04	1.00E+04	0	2.3125
1710	1850	-10	10	1.00E+04	1.00E+04	0	1.75
1850	1990	-10	10	1.00E+04	1.00E+04	0	1.75
1990	2110	-10	10	1.00E+04	1.00E+04	0	1.5
2110	2200	-10	10	1.00E+04	1.00E+04	0	1.125
2200	2300	-10	10	1.00E+04	1.00E+04	0	1.25
2300	2360	-10	10	1.00E+04	1.00E+04	0	0.75
2360	2390	-10	10	1.00E+04	1.00E+04	0	0.375
2390	2500	-10	10	1.00E+04	1.00E+04	0	1.375
2500	2686	-10	10	1.00E+04	1.00E+04	0	2.325
2686	2900	-10	10	1.00E+04	1.00E+04	0	2.675

4.3 Data Files

For each spectrum band, multiple, one-hour long runs were made with different equipment configurations. A description of each run and information for the data files collected are shown in Table 7.

Table 7. Data Files

Date	Frequency Range	Antenna	Frequency List	Start Time	End time	File Prefix	Calibration File Name	Start File Number	End File Number	Number of Files	Duration (sec)	Duration (hr)
20040416	30-960MHz	Omni with pre-amp	List_B2	9:25	10:26	nsf	No_pre-selector_calibration_v4.xls	1414	1527	114	3660	1.0
20040416	30-960MHz	Omni-no pre-amp	List_B2	10:29	11:29	nsf	No_pre-selector_calibration_v4.xls	1528	1641	114	3600	1.0
20040416	1240-2900MHz	Broken filter / bad data	List_C2	11:37	12:38	nsf	No_pre-selector_calibration_v4.xls	1642	1728	87	3660	1.0
20040416	30-960MHz		List_B2	12:51	13:52	nsf	No_pre-selector_calibration_v4.xls	1731	1843	113	3660	1.0
20040416	30-960MHz	Directional, rotating antenna	List_C2	15:54	16:53	nsf	No_pre-selector_calibration_v4.xls	1844	1938	95	3540	1.0
20040416	1240-2900MHz	Directional, rotating antenna	List_C2	17:08	18:07	nsf	No_pre-selector_calibration_v4.xls	1939	2015	77	3540	1.0

5. Spectrum Measurements

This section contains plots of the spectrum occupancy measurements.

5.1 Plot Format Description

In each figure, there are two plots for each spectrum band. The upper sub-plot is the maximum power value versus frequency measured during the period. The power values are corrected for cable losses, filter losses, and amplifier losses to the power level at the antenna. The time shown on the plot is the measurement start time.

The middle sub-plot is a waterfall-type plot with occupancy plotted versus time and frequency. Occupancy is determined when the power level exceeds a threshold. The threshold value was "hand-selected" for each run, and is shown as a dotted line on the upper plot. In some cases, the noise level exceeds the threshold, causing inflated occupancy levels. To correct this, the threshold would have to be hand-selected for each plot, which was not done. Figure 15 is annotated to illustrate the above description.

The last sub-plot is the fraction of time the signal is on versus the frequency measured during the period. If the fraction of time is '1' it means the signal was on for all the measurement time and vice versa.

The lower plot is a three-dimensional mesh plot with X and Y axes as frequency and time respectively and 'Z' axis is received signal level in dBm.

5.2 Measurements Made Below 1,000 MHz

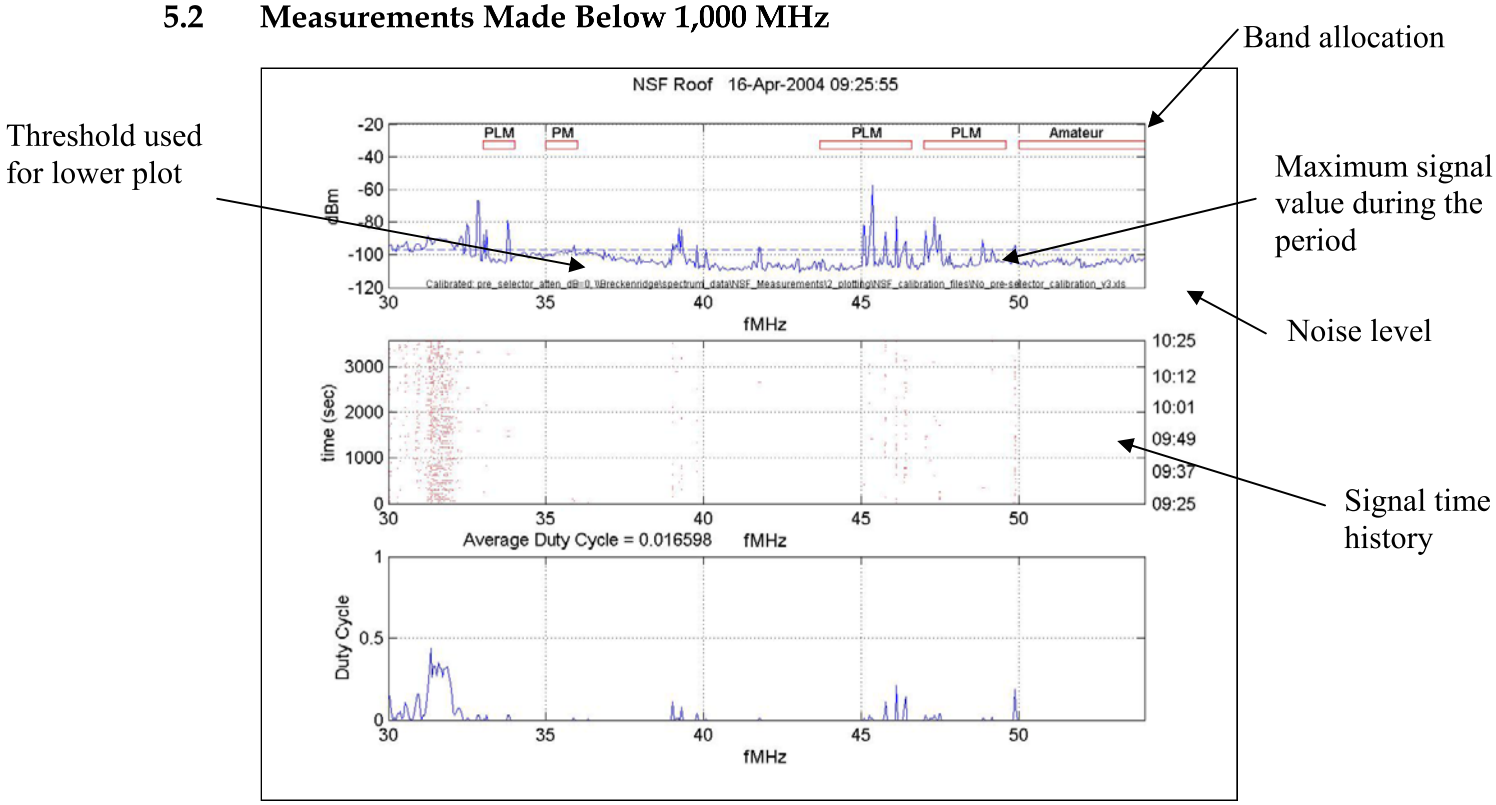

Figure 15: 30 MHz – 54 MHz (Antenna Stationary).

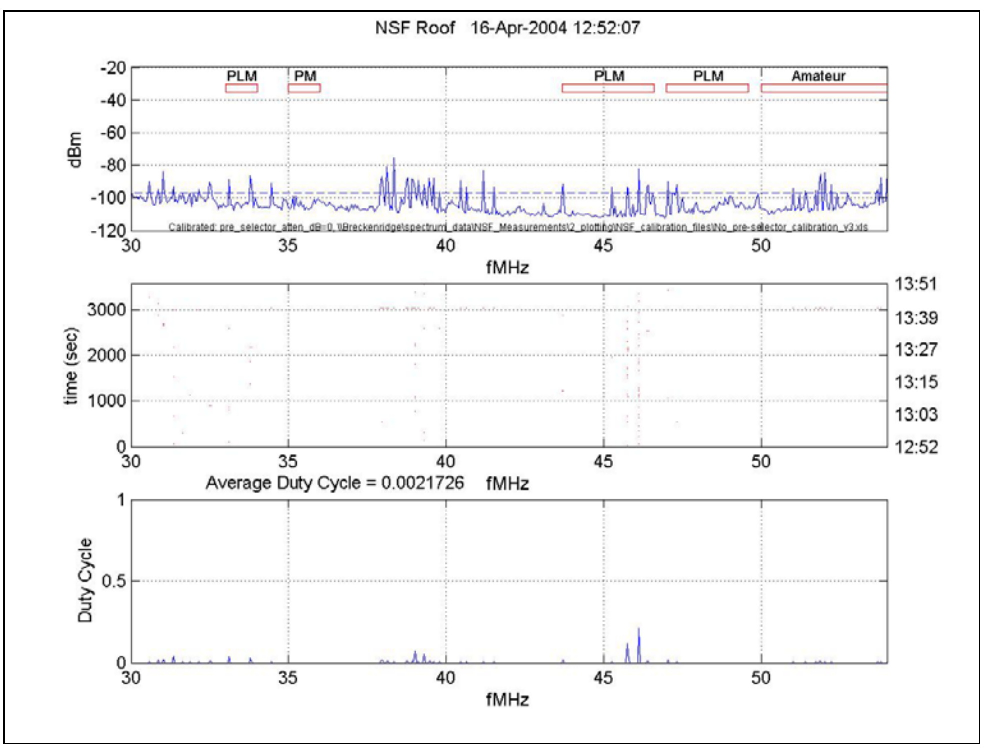

Figure 16: 30 MHz – 54 MHz (Antenna Rotating)

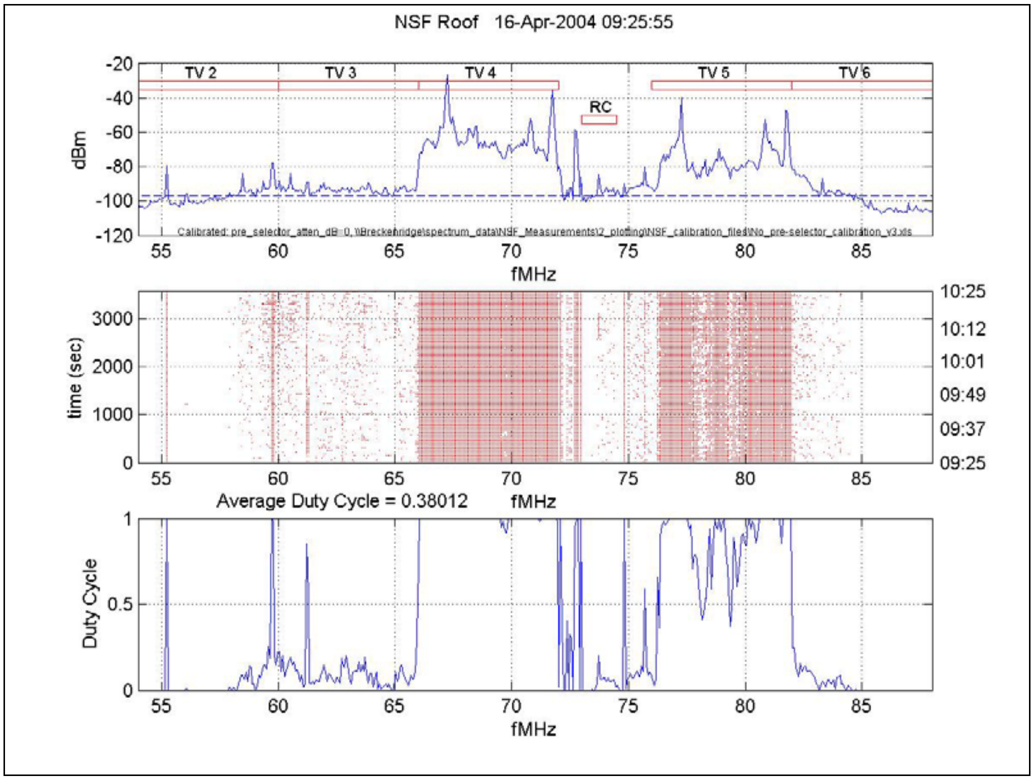

Figure 17: 54 MHz – 88 MHz (Antenna Not- Rotating)

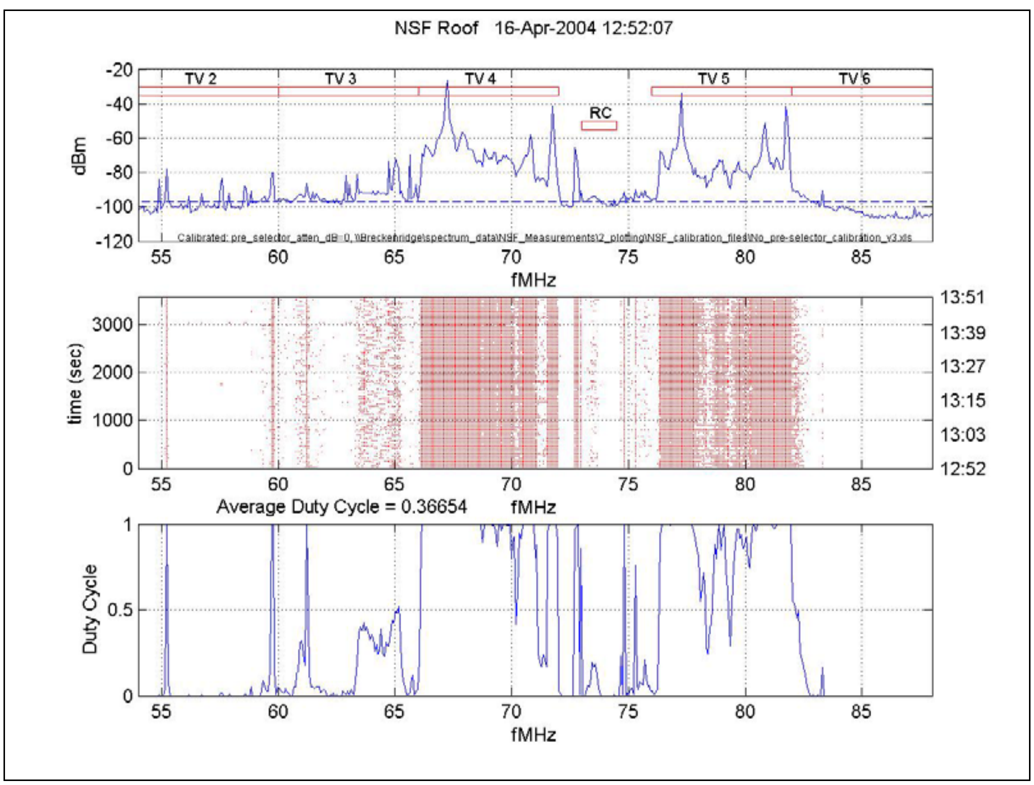

Figure 18: 54 MHz – 88 MHz (Antenna Rotating)

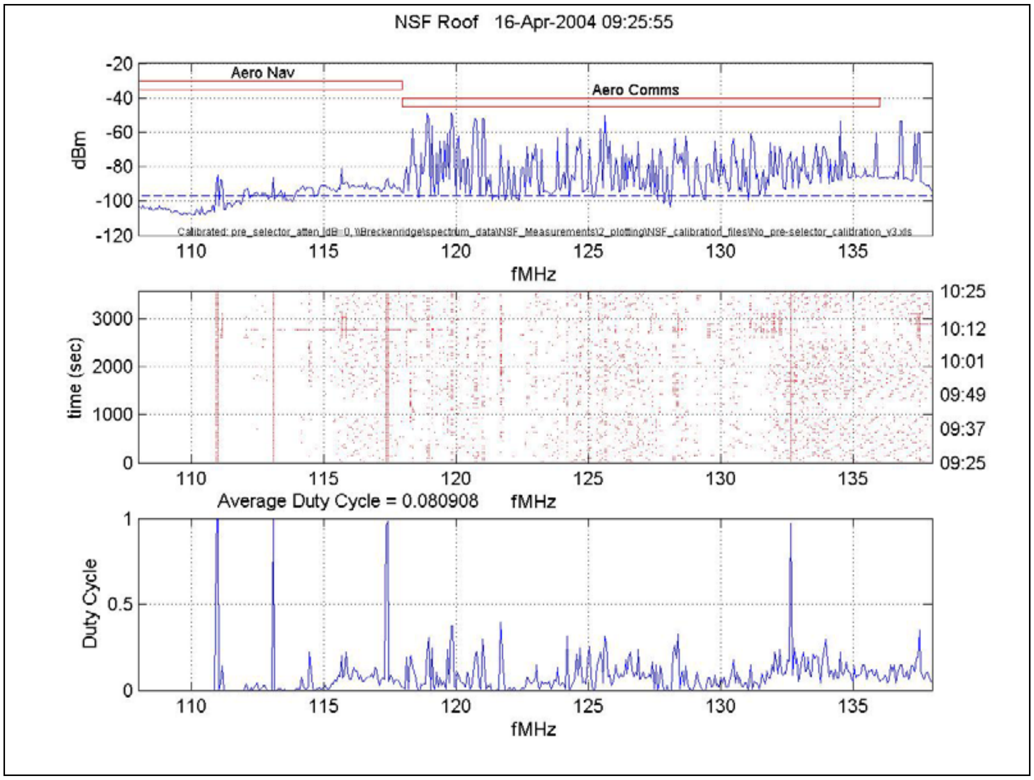

Figure 19: 108 MHz – 138 MHz (Antenna Stationary).

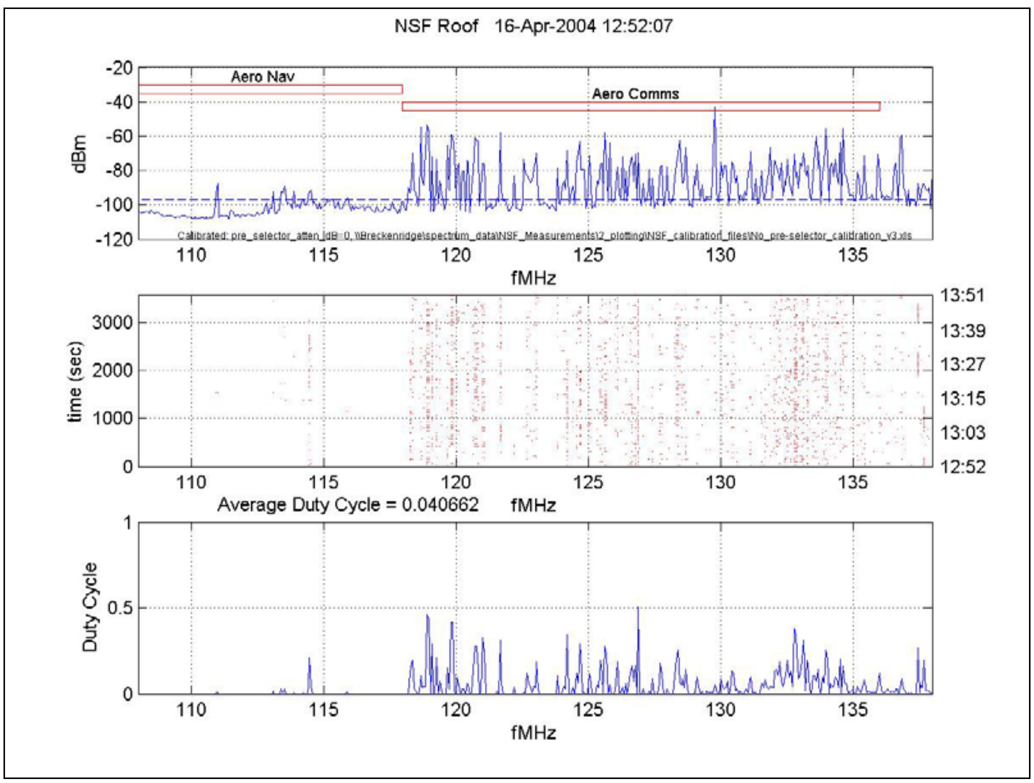

Figure 20: 108 MHz – 138 MHz (Antenna Rotating).

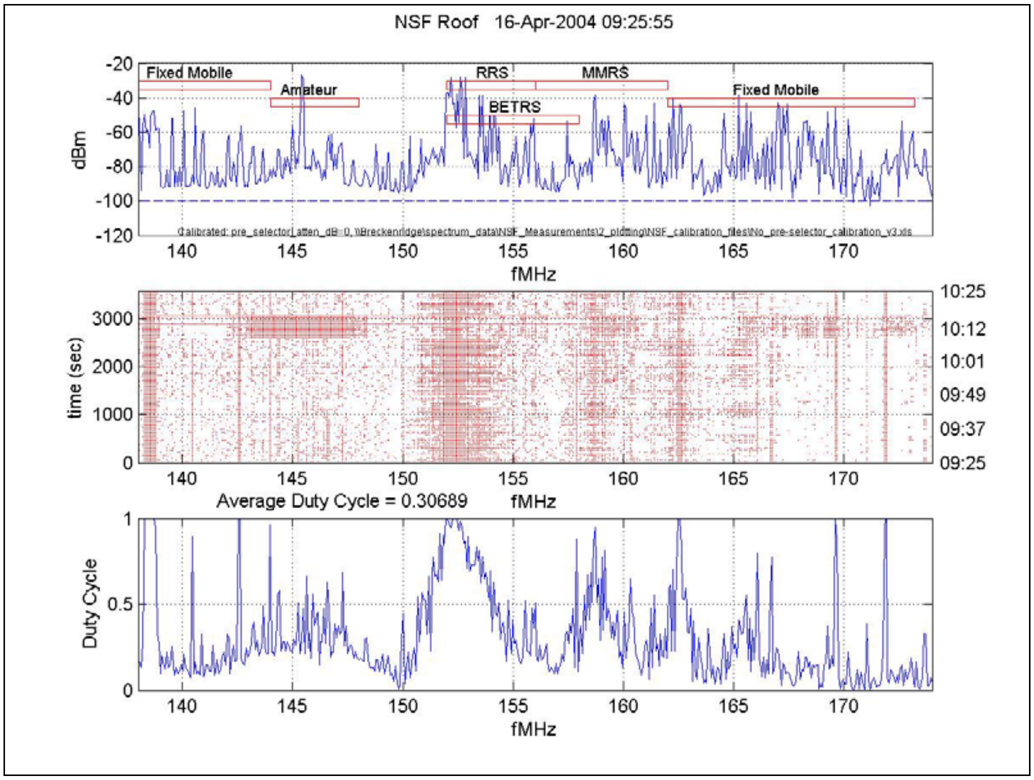

Figure 21: 138 MHz – 174 MHz (Antenna Stationary).

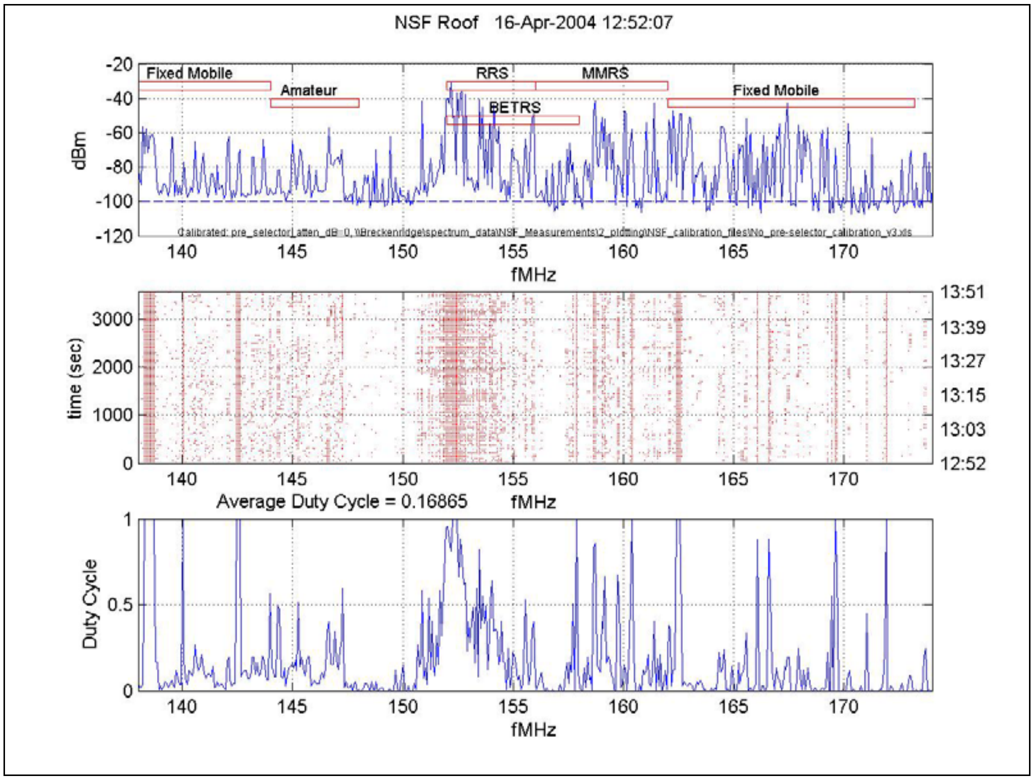

Figure 22: 138 MHz – 174 MHz (Antenna Rotating).

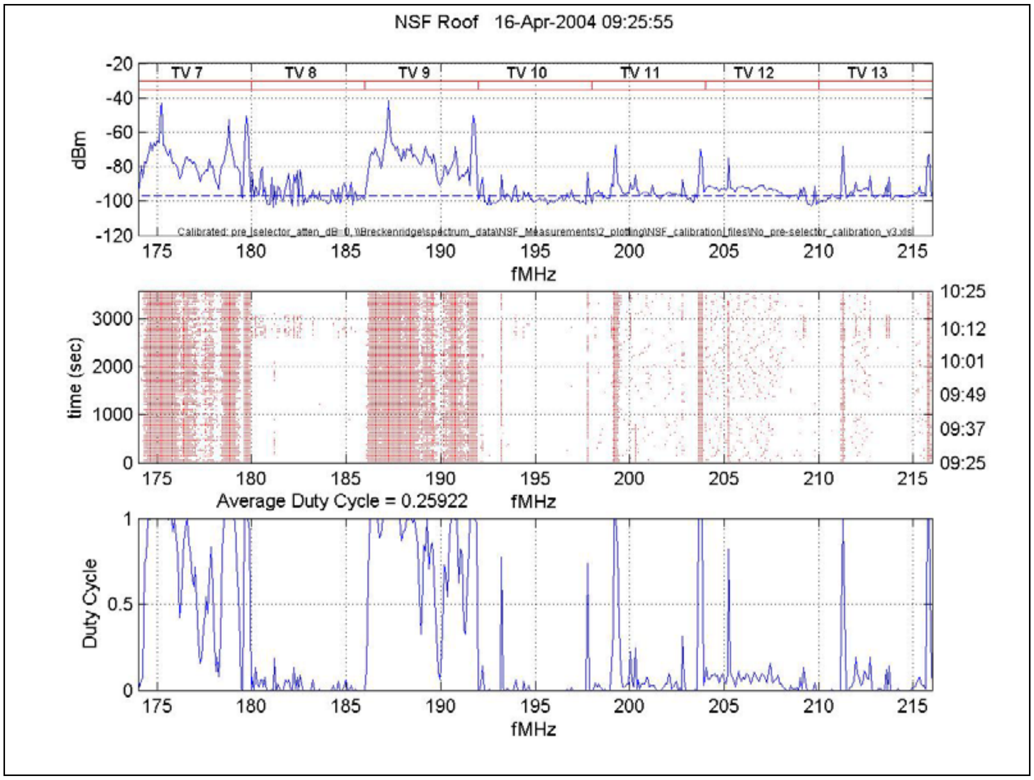

Figure 23: 174 MHz – 216 MHz (Antenna Stationary).

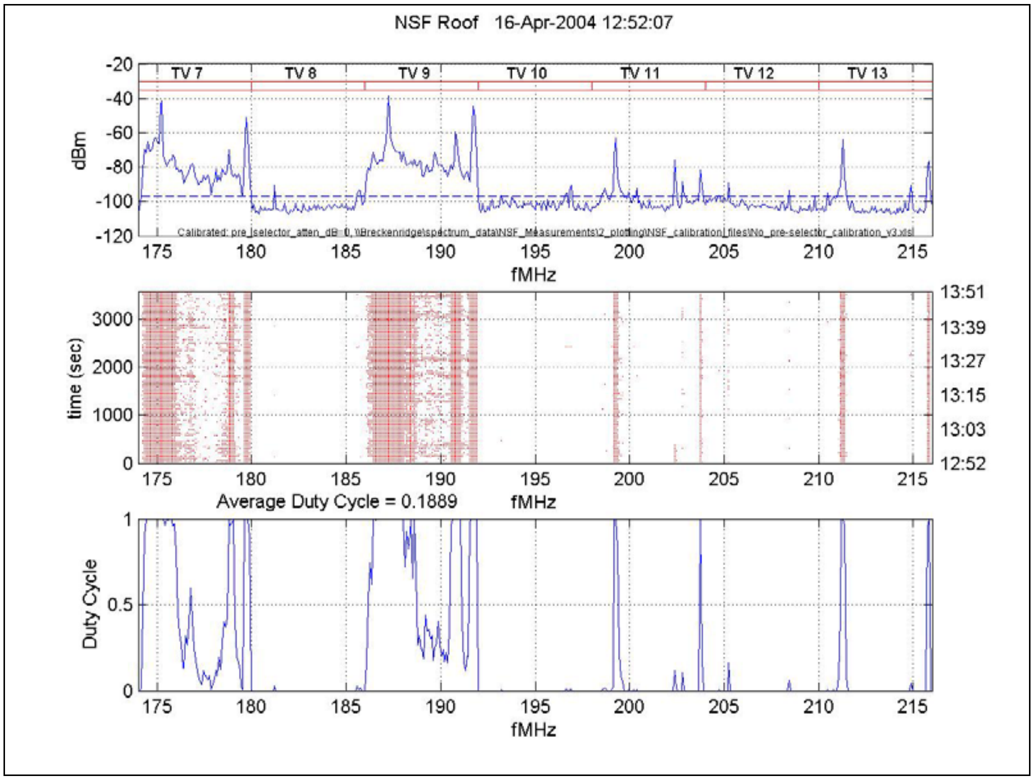

Figure 24: 174 MHz – 216 MHz (Antenna Rotating).

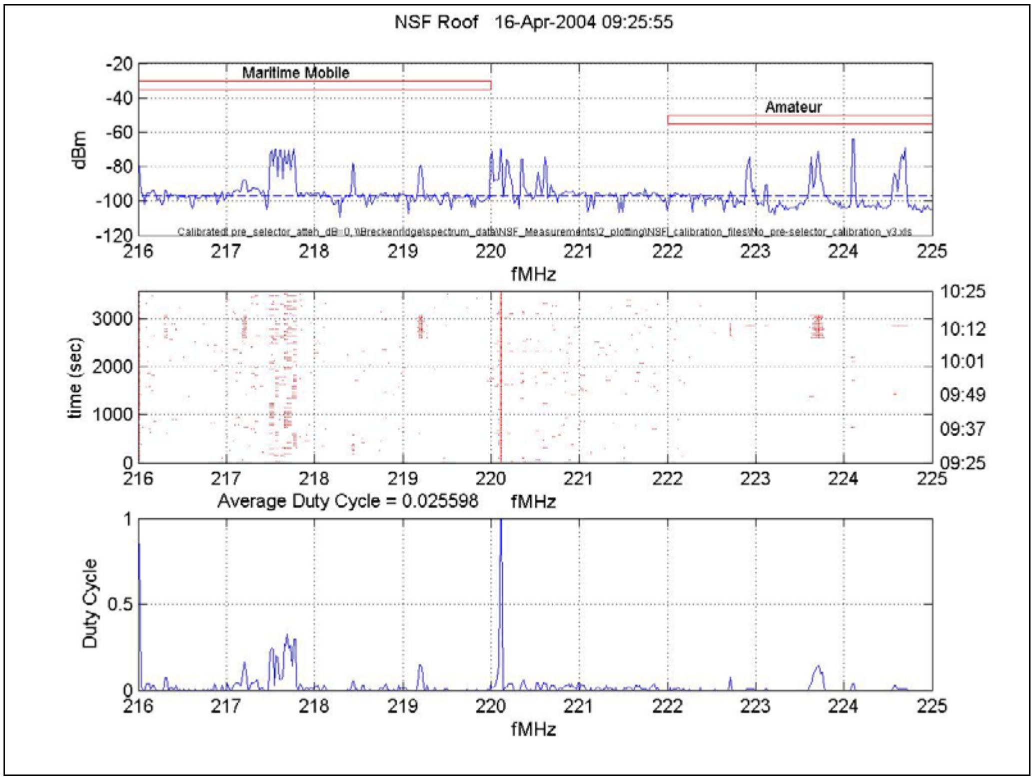

Figure 25: 216 MHz – 225 MHz (Antenna Stationary).

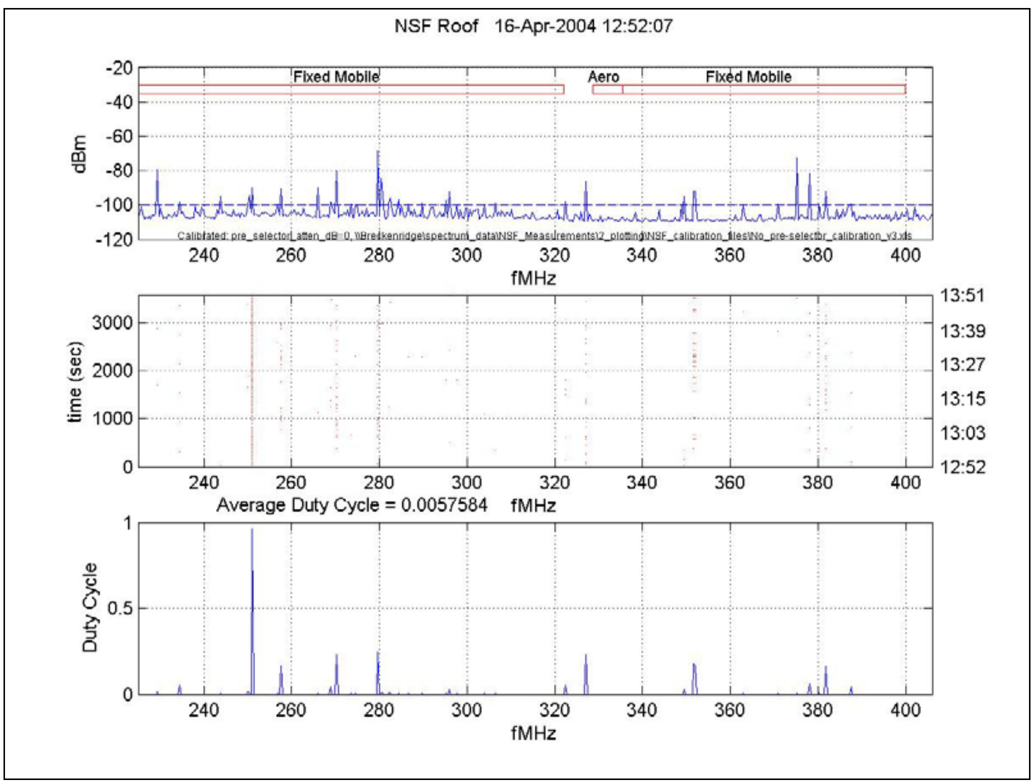

Figure 26: 216 MHz – 225 MHz (Antenna Rotating).

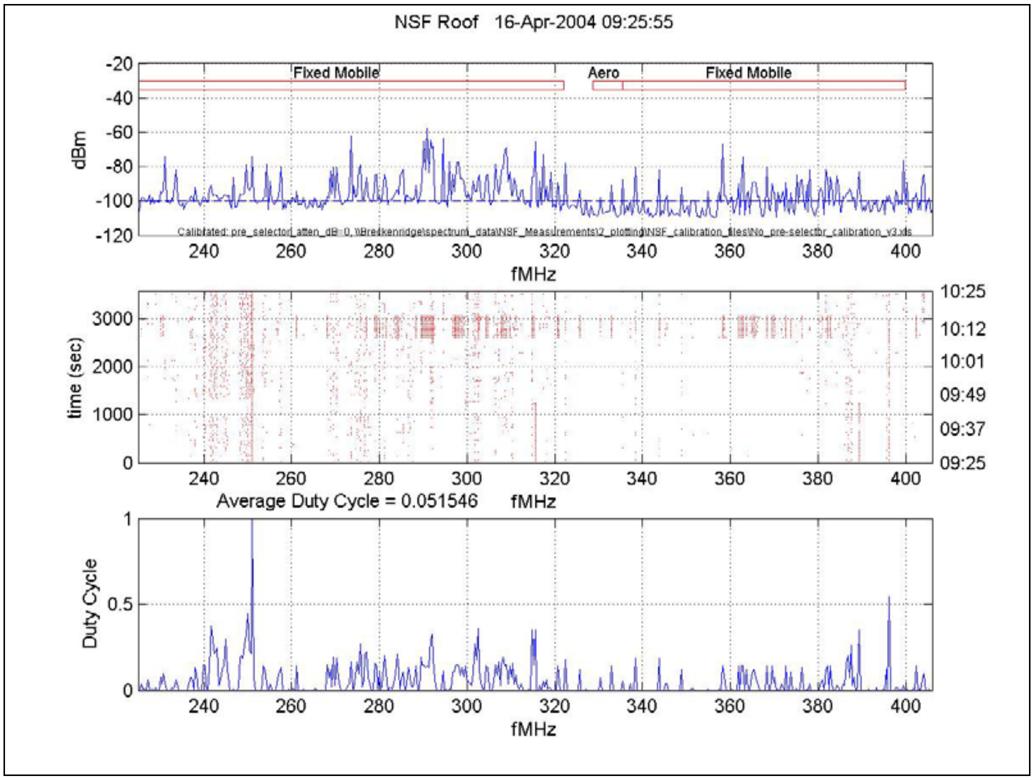

Figure 27: 225 MHz – 406 MHz (Antenna Stationary).

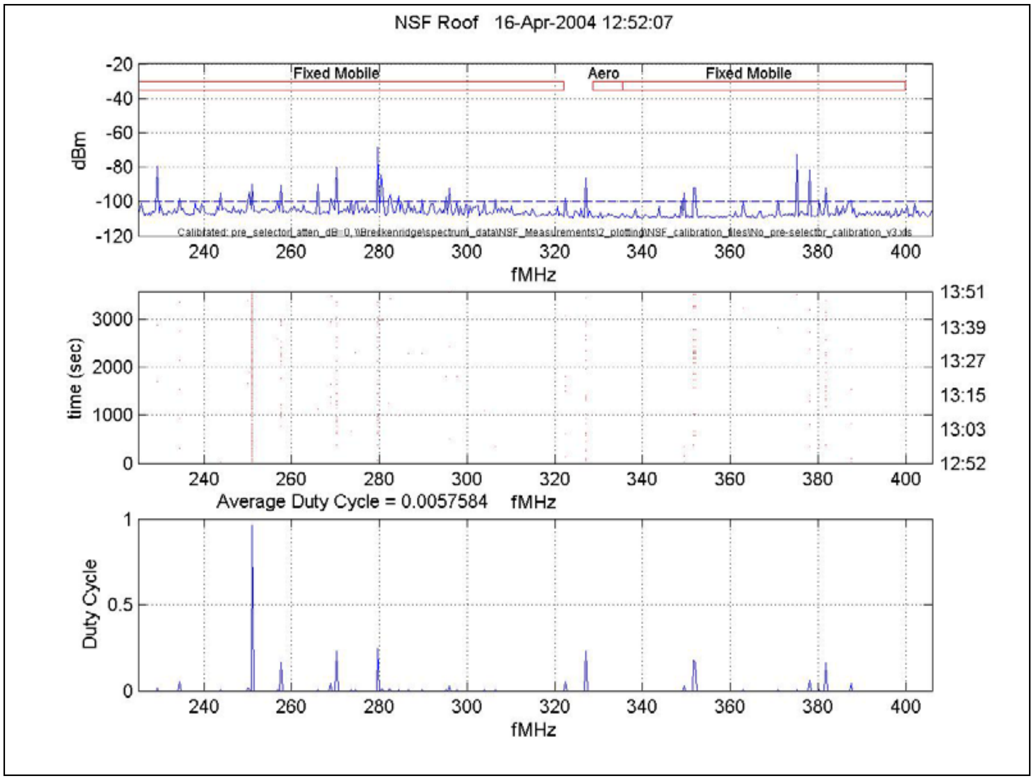

Figure 28: 225 MHz – 406 MHz (Antenna Rotating).

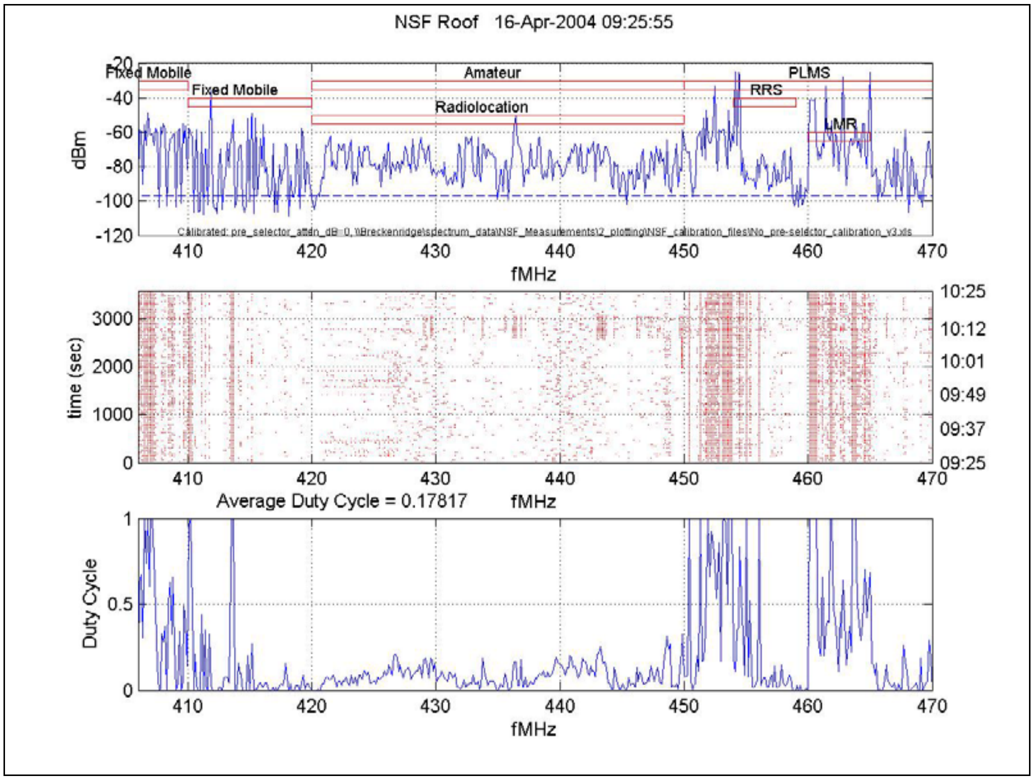

Figure 29: 406 MHz – 470 MHz (Antenna Stationary).

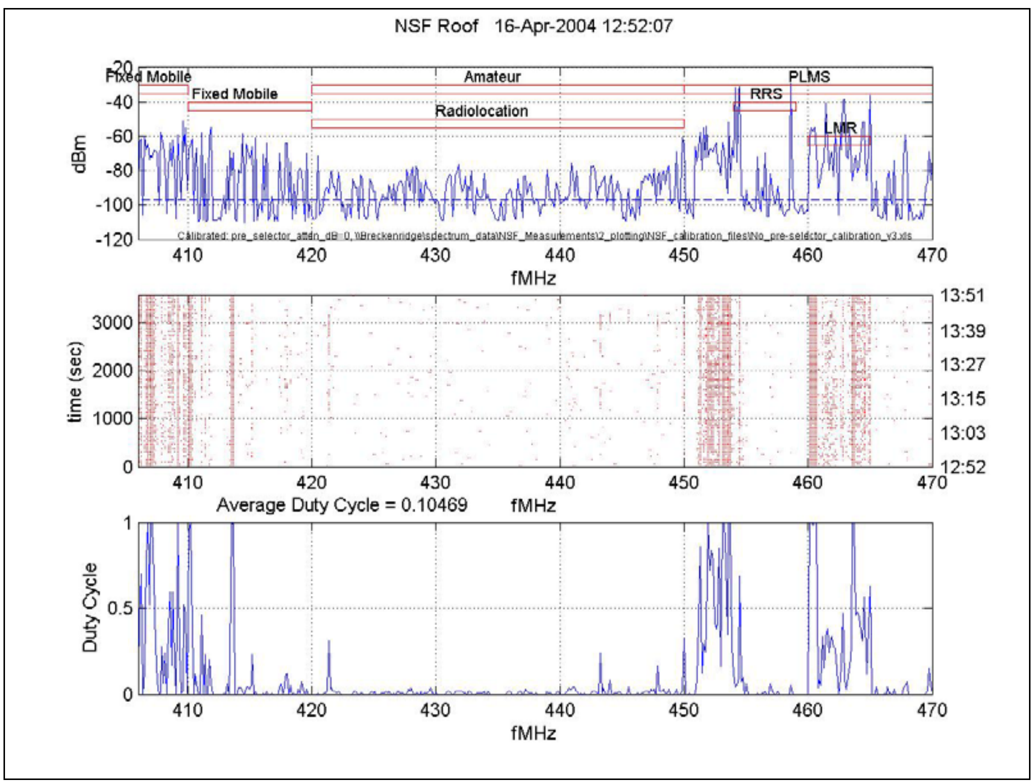

Figure 30: 406 MHz – 470 MHz (Antenna Rotating).

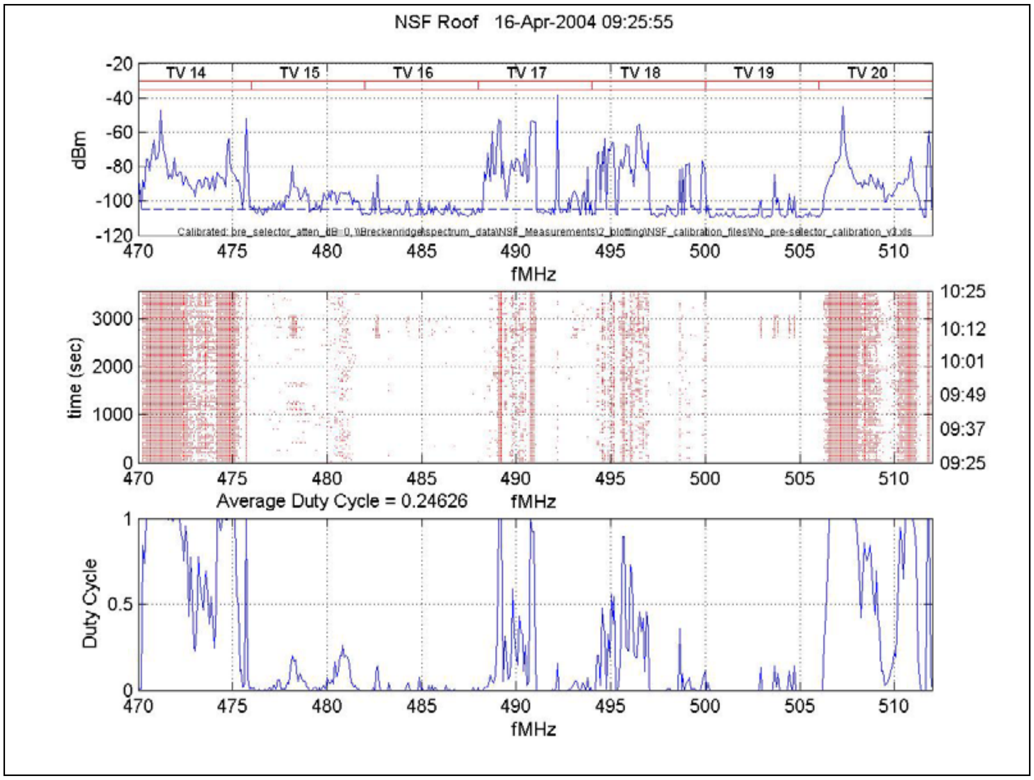

Figure 31: 470 MHz – 512 MHz (Antenna Stationary).

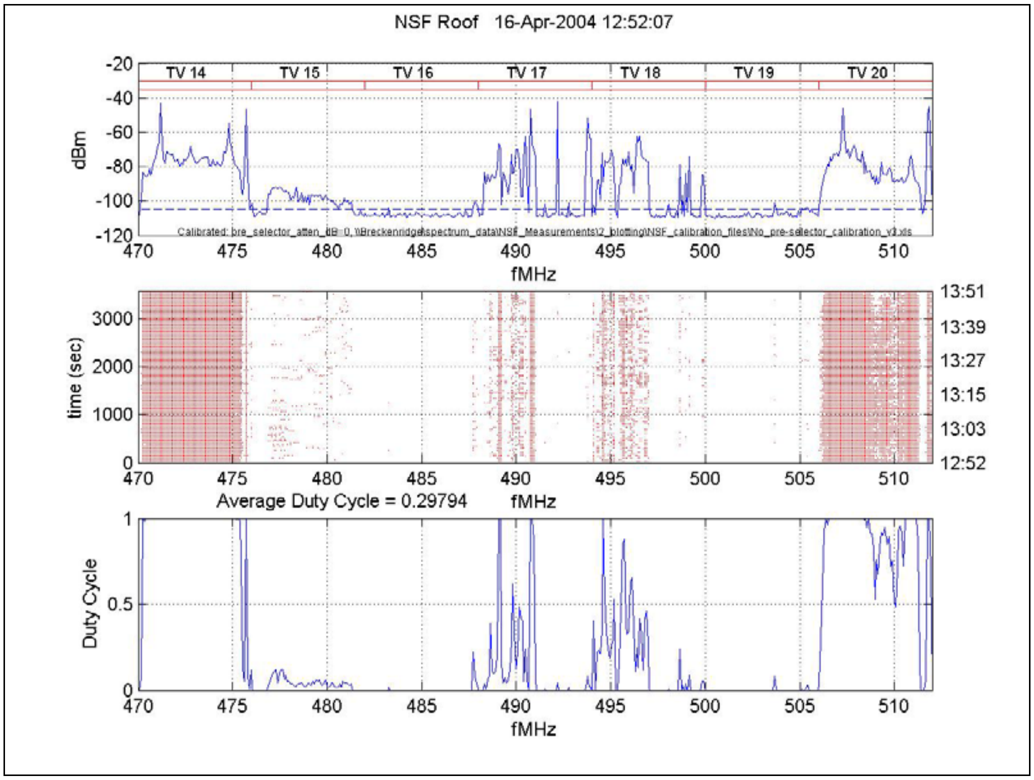

Figure 32: 470 MHz – 512 MHz (Antenna Rotating).

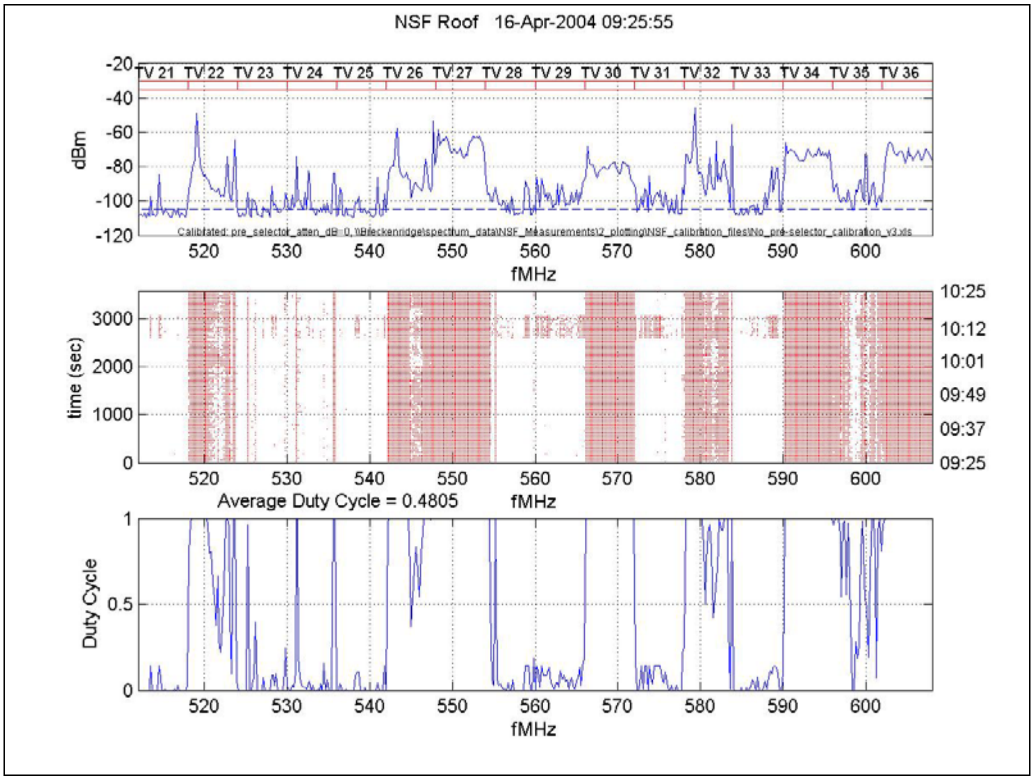

Figure 33: 512 MHz – 608 MHz (Antenna Stationary).

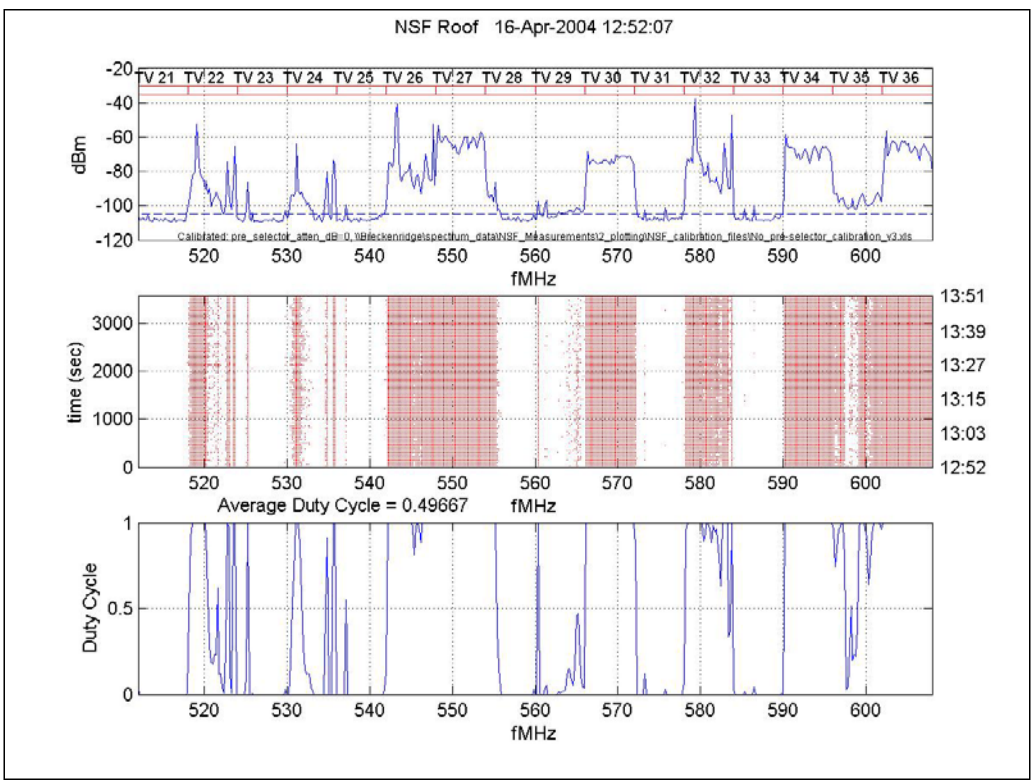

Figure 34: 512 MHz – 608 MHz (Antenna Rotating).

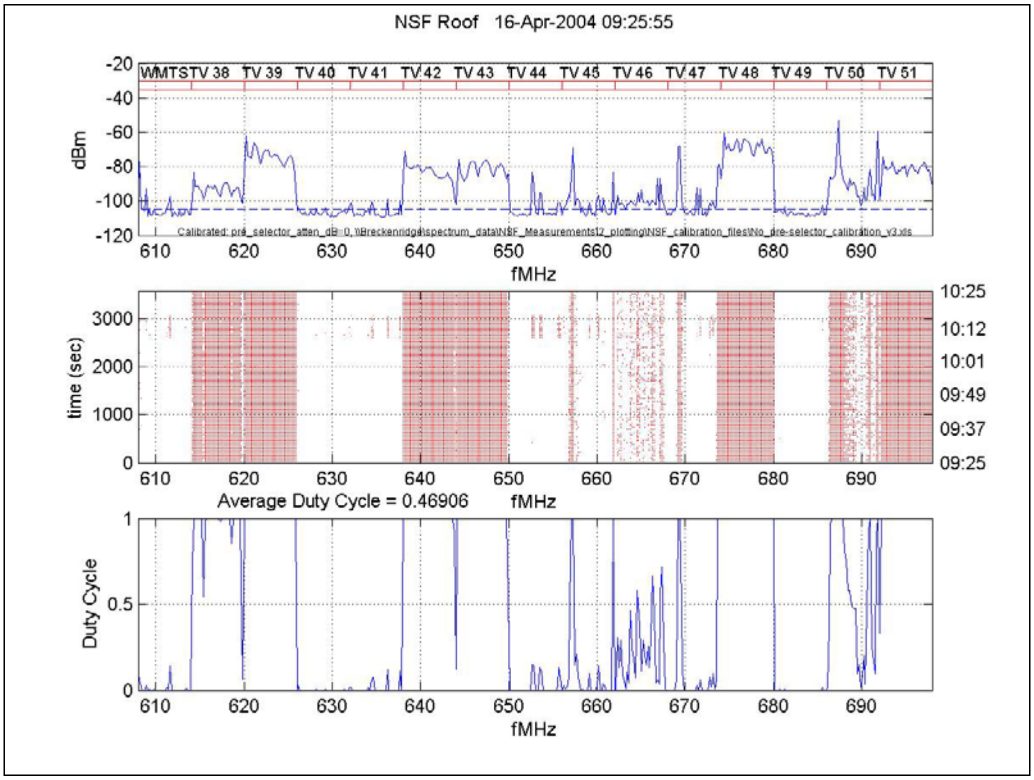

Figure 35: 608 MHz – 698 MHz (Antenna Stationary).

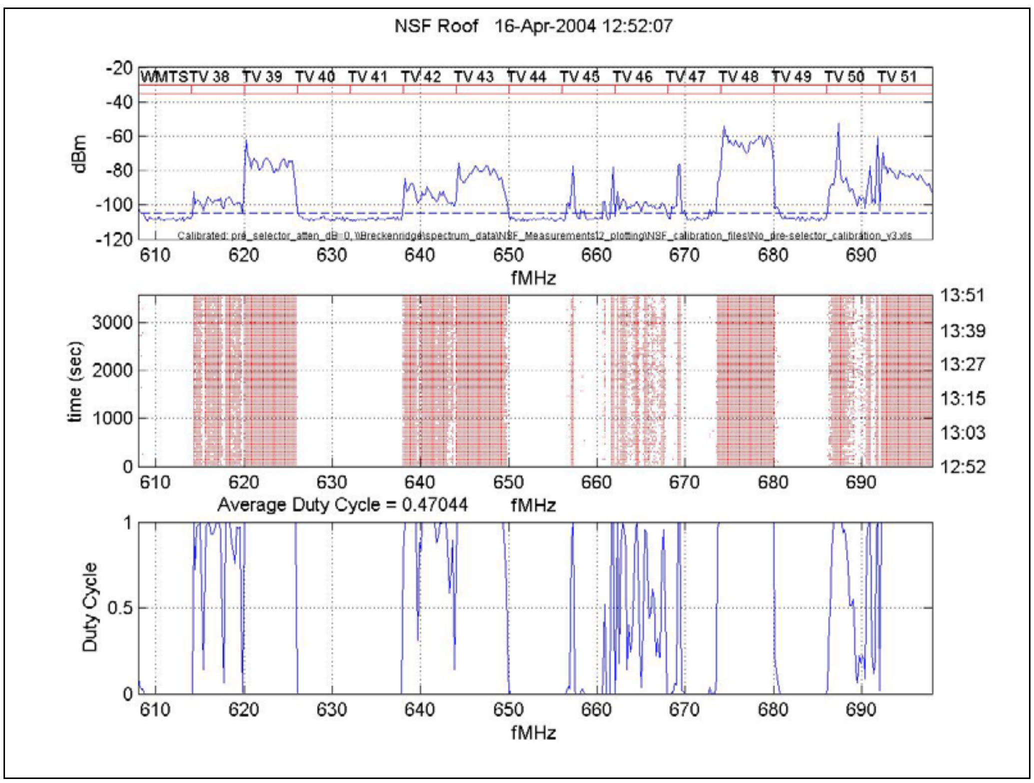

Figure 36: 608 MHz – 698 MHz (Antenna Rotating).

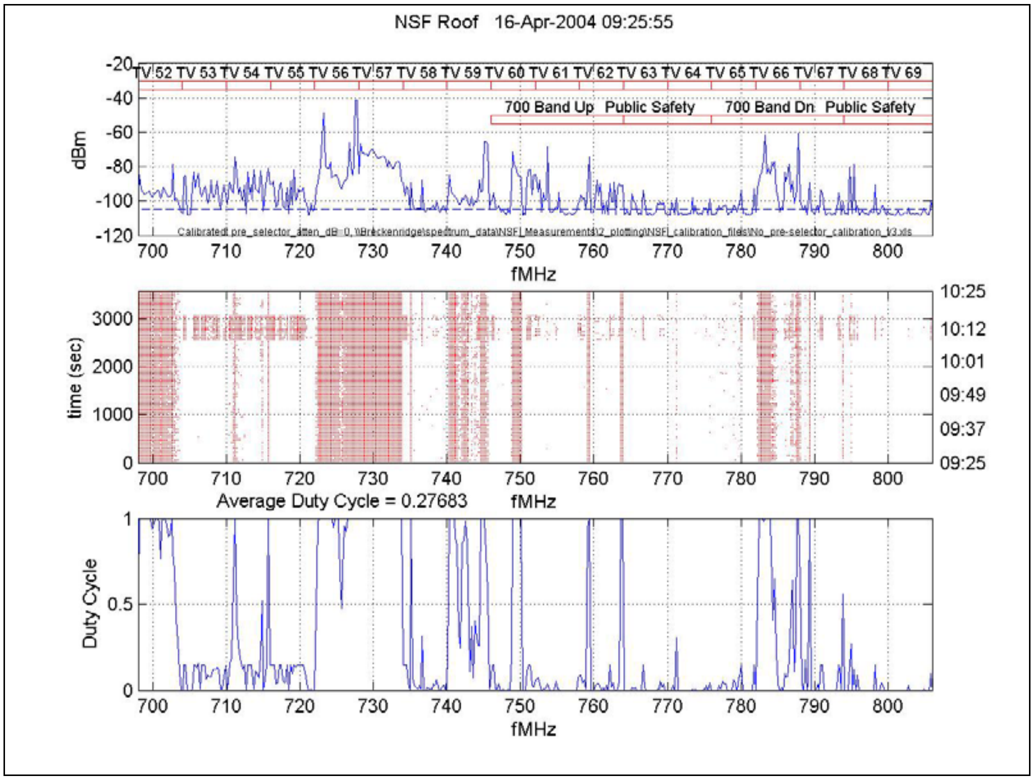

Figure 37: 698 MHz – 806 MHz (Antenna Stationary).

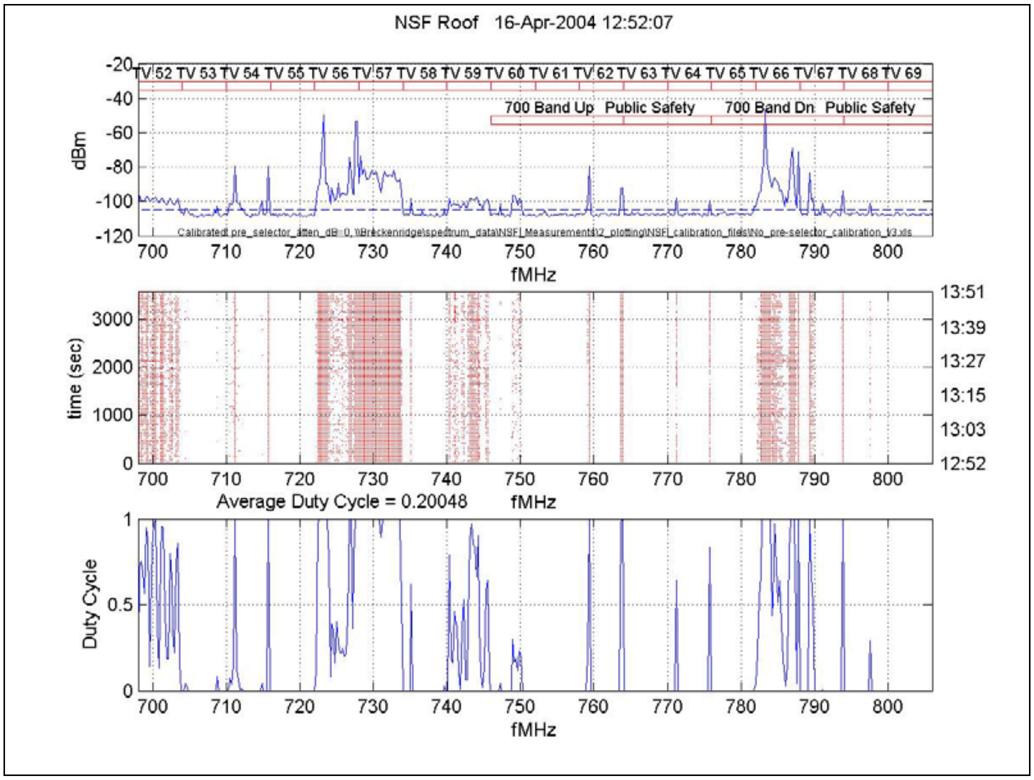

Figure 38: 698 MHz – 806 MHz (Antenna Rotating).

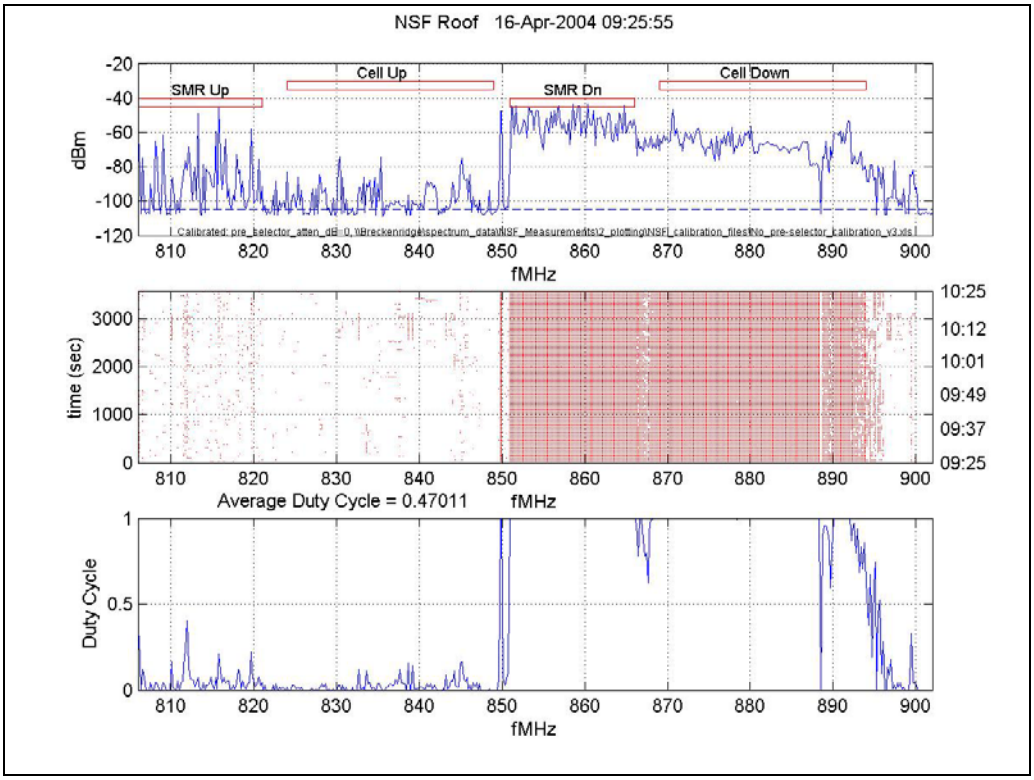

Figure 39: 806 MHz – 902 MHz (Antenna Stationary).

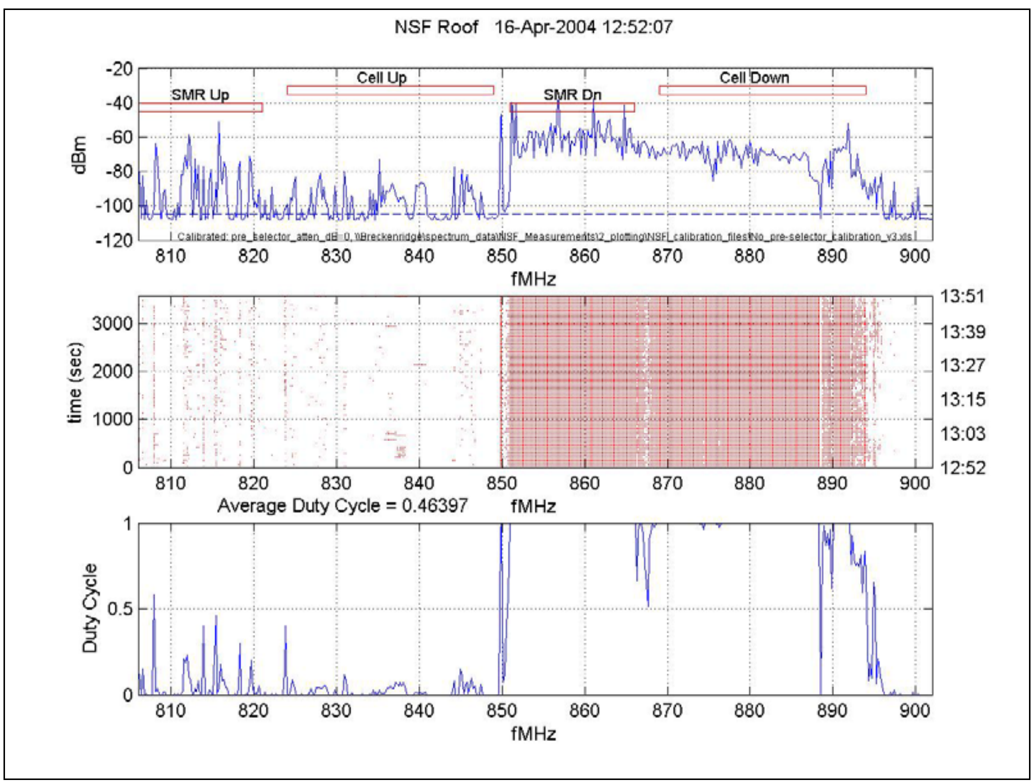

Figure 40: 806 MHz – 902 MHz (Antenna Rotating).

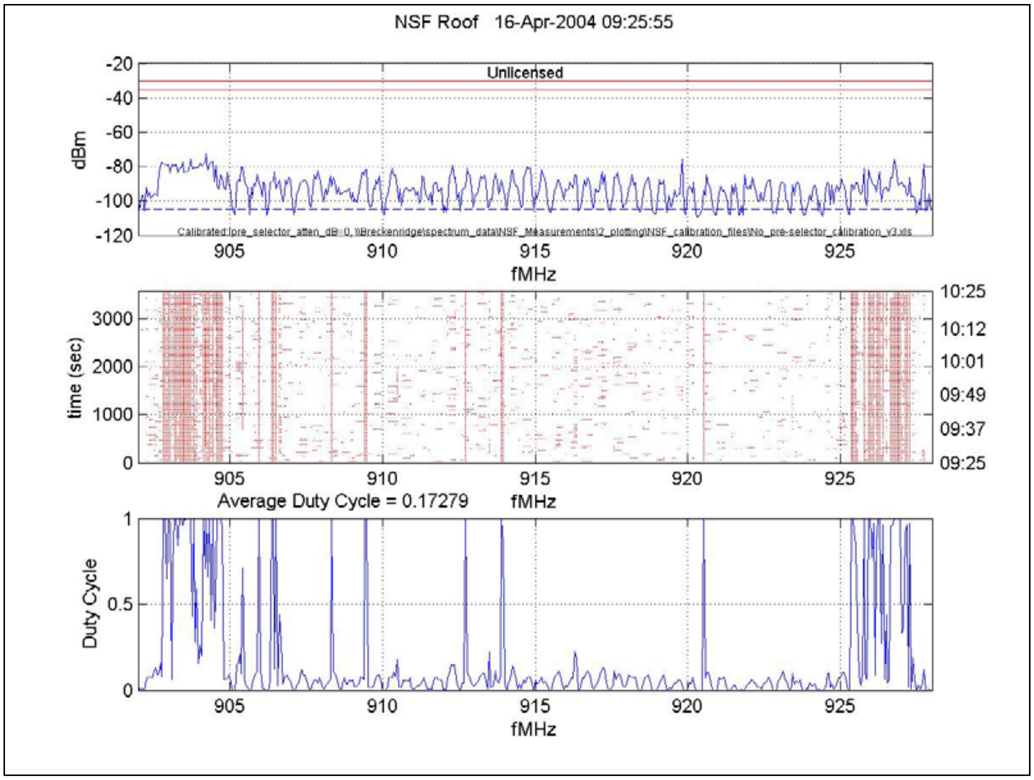

Figure 41: 902 MHz – 928 MHz (Antenna Stationary).

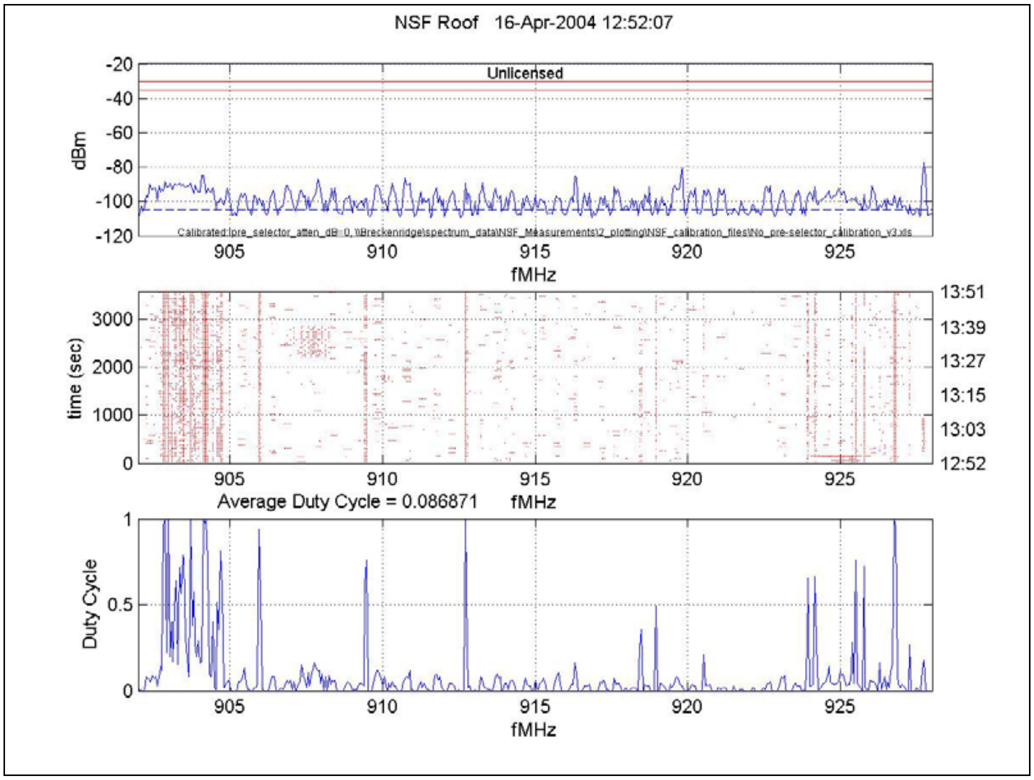

Figure 42: 902 MHz – 928 MHz (Antenna Rotating).

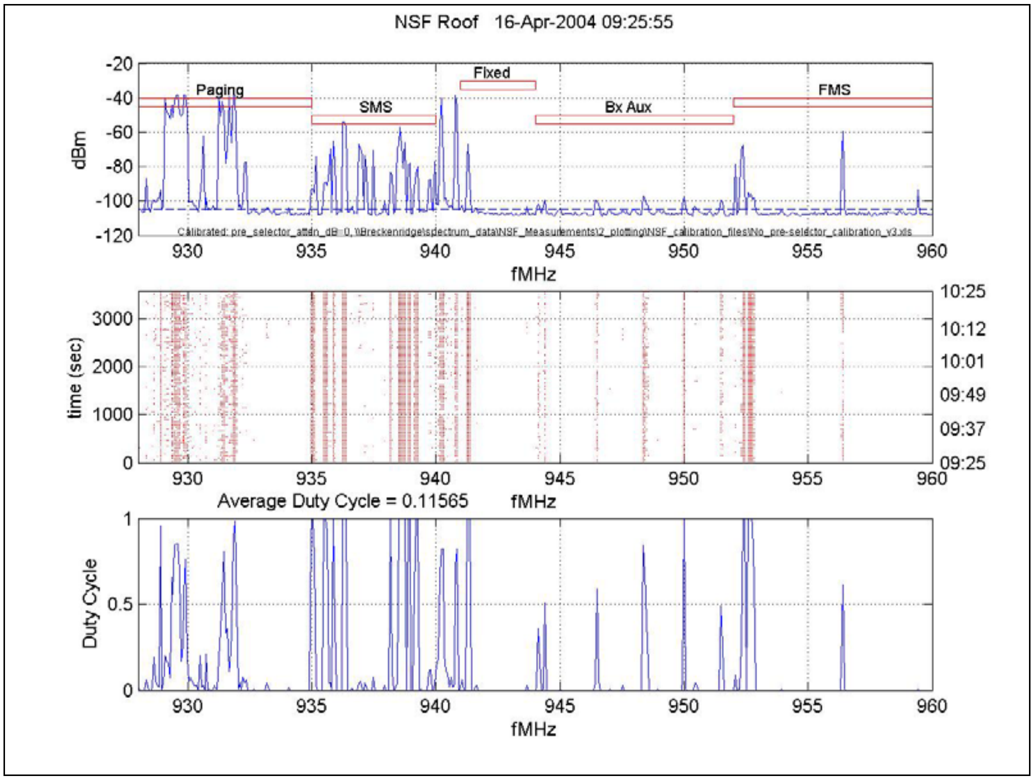

Figure 43: 928 MHz – 960 MHz (Antenna Stationary).

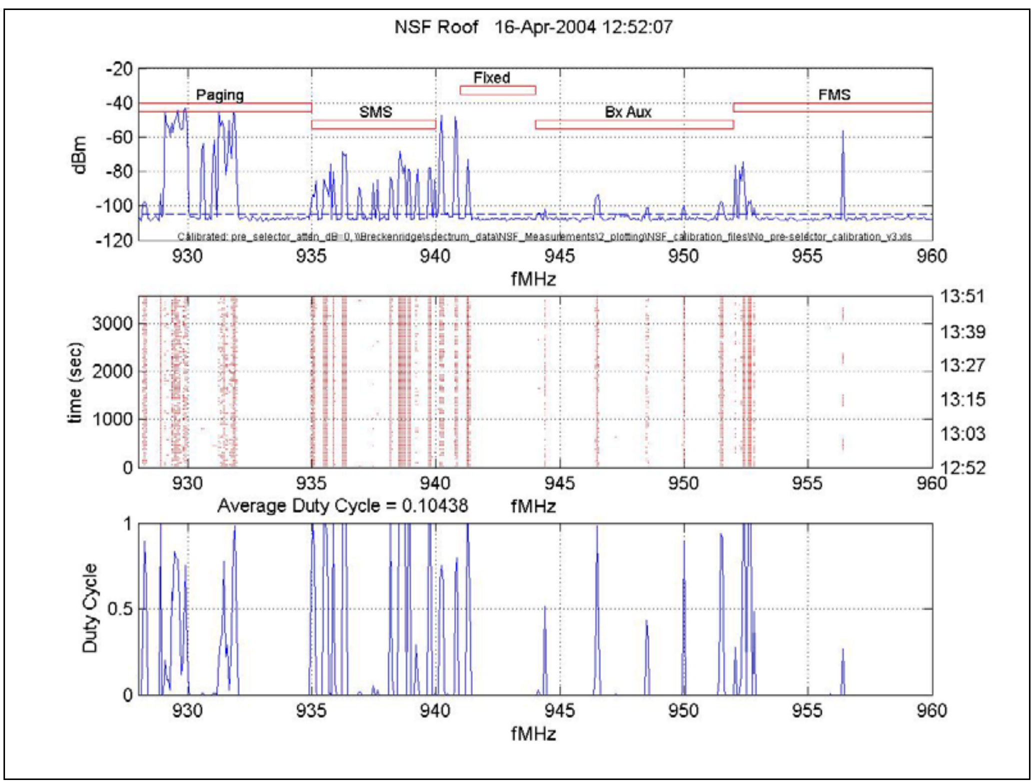

Figure 44: 928 MHz – 960 MHz (Antenna Rotating).

5.3 Measurements Made Above 1,000 MHz

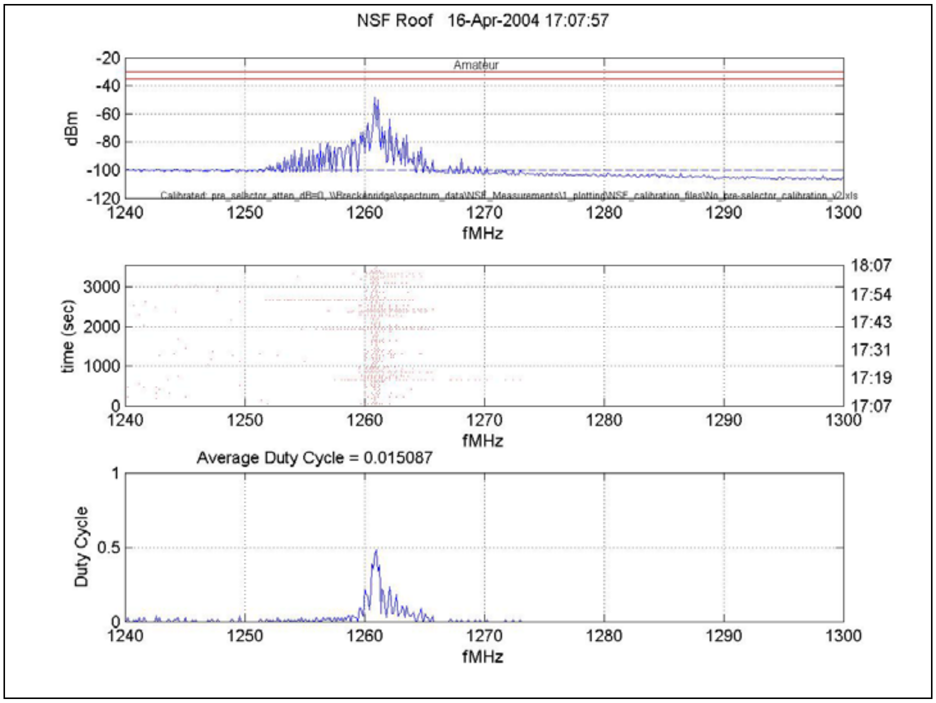

Figure 45: 1.24 GHz – 1.3 GHz (Antenna Rotating).

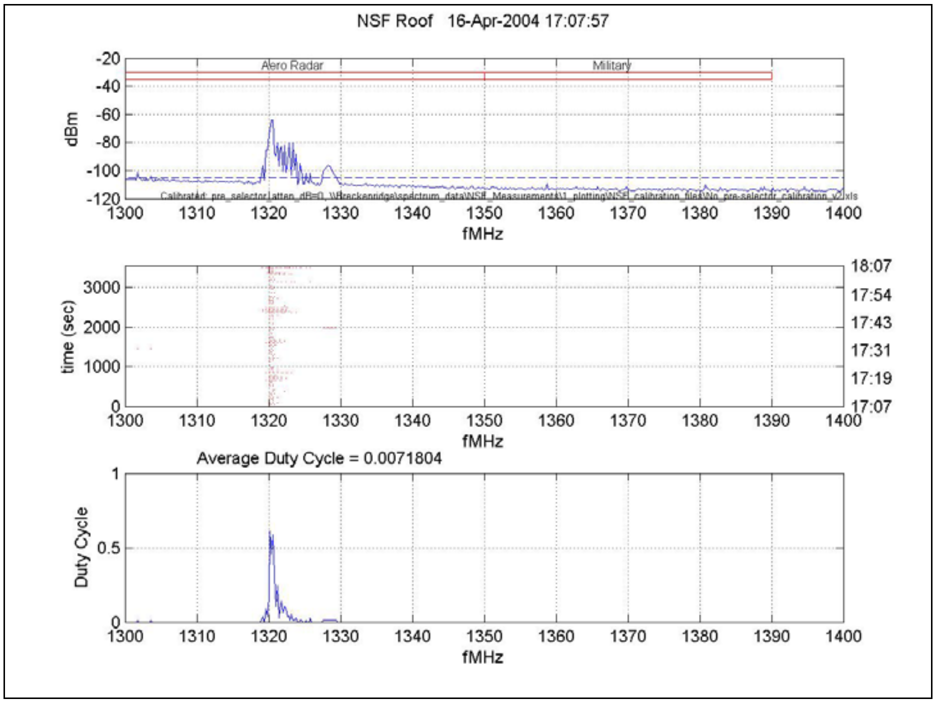

Figure 46: 1.3 GHz – 1.4 GHz (Antenna Rotating).

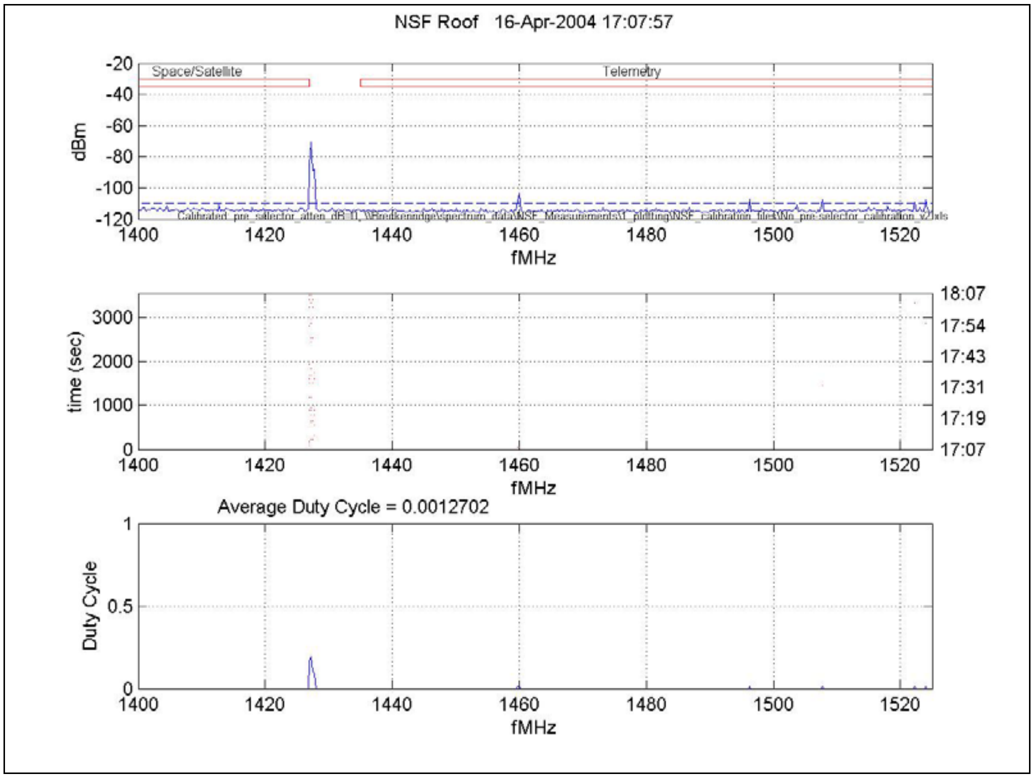

Figure 47: 1.4 GHz – 1.525 GHz (Antenna Rotating).

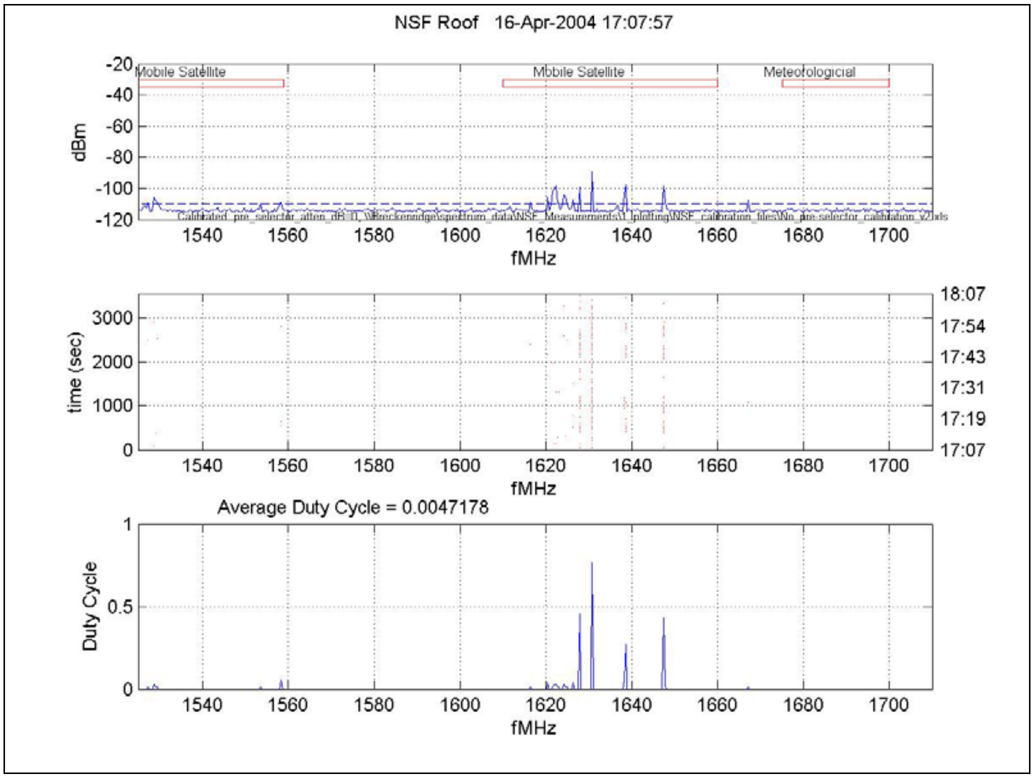

Figure 48: 1.525 GHz – 1.71 GHz (Antenna Rotating).

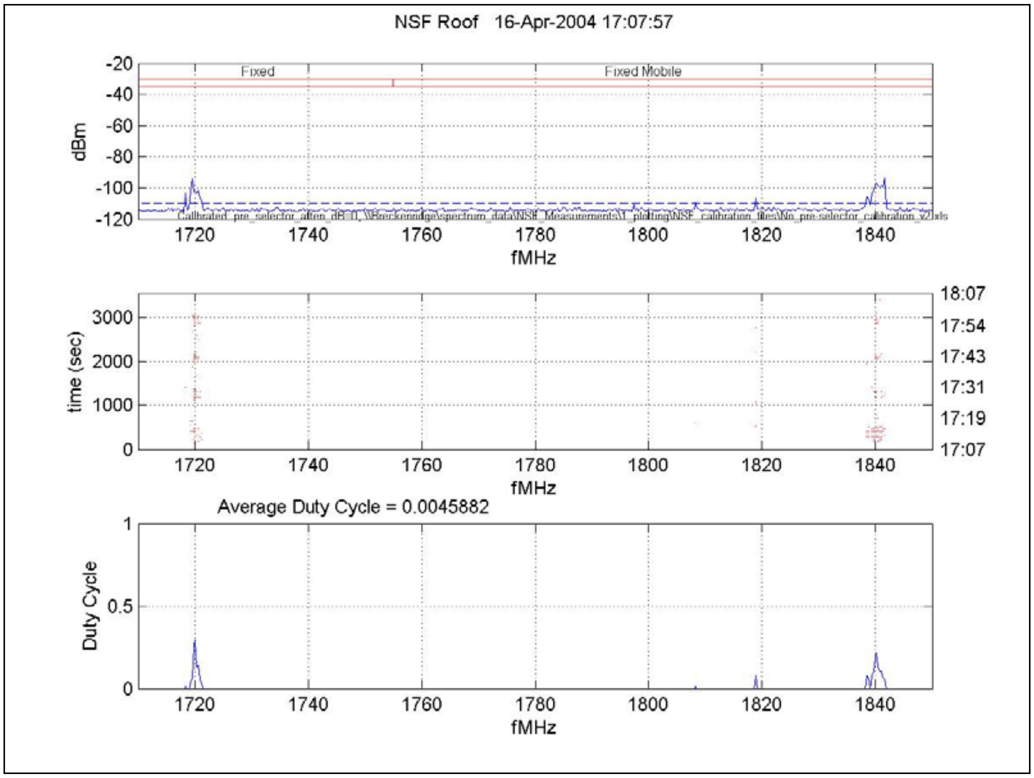

Figure 49: 1.71 GHz – 1.85 GHz (Antenna Rotating).

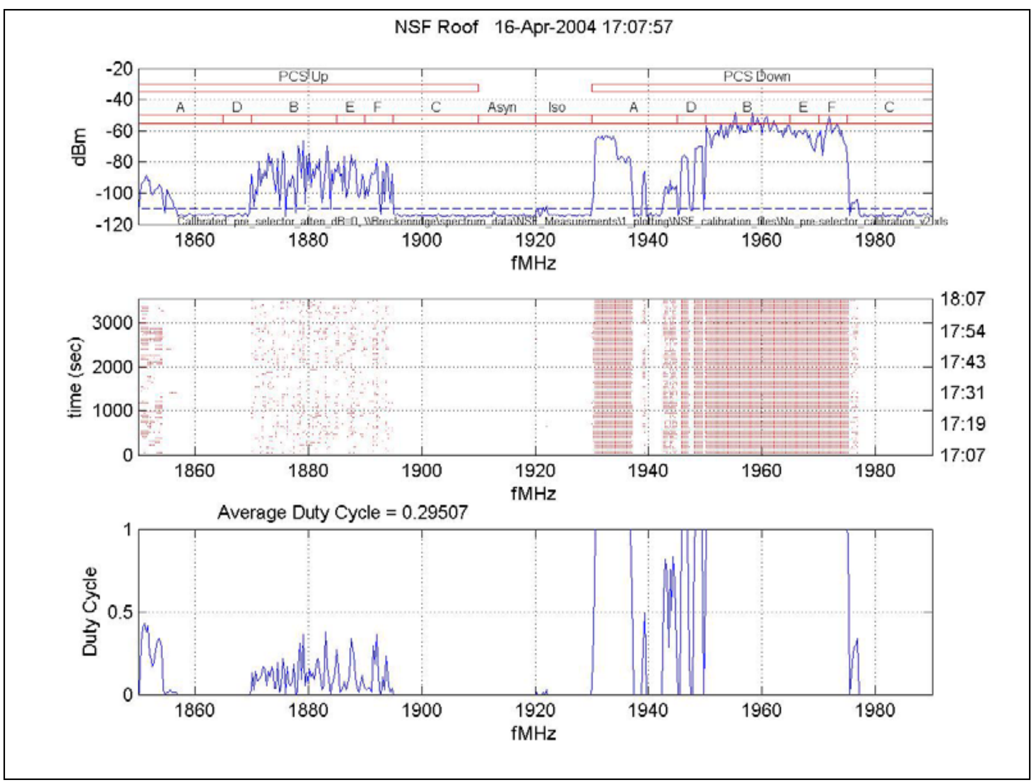

Figure 50: 1.85 GHz – 1.99 GHz (Antenna Rotating).

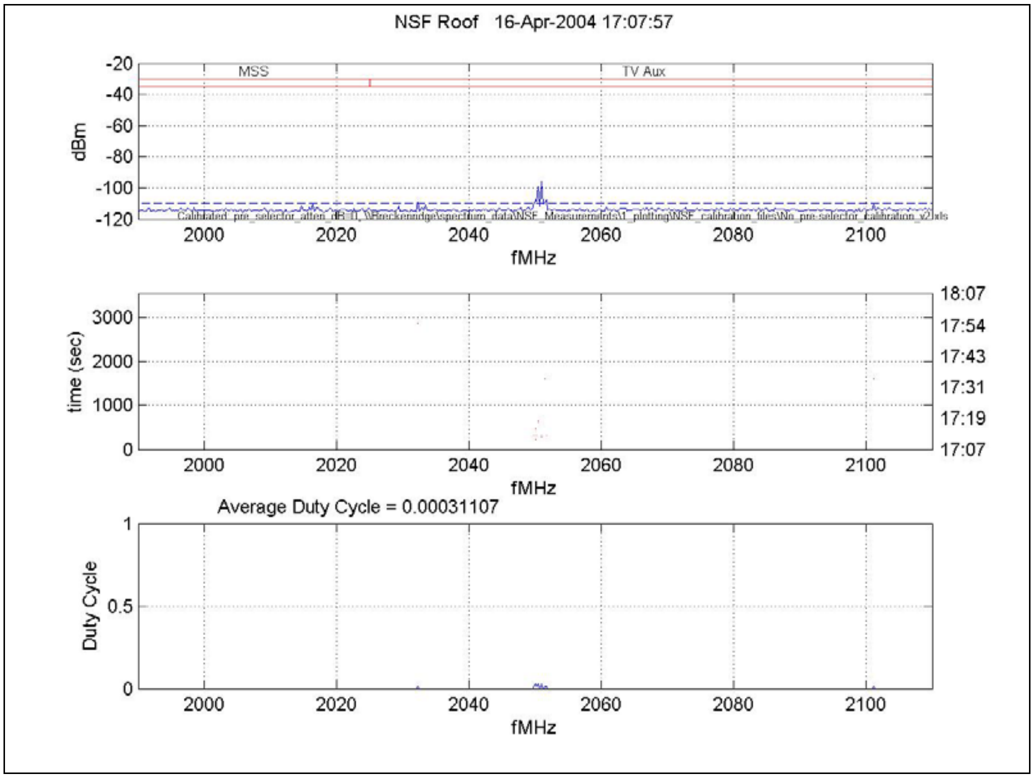

Figure 51: 1.99 GHz – 2.11 GHz (Antenna Rotating).

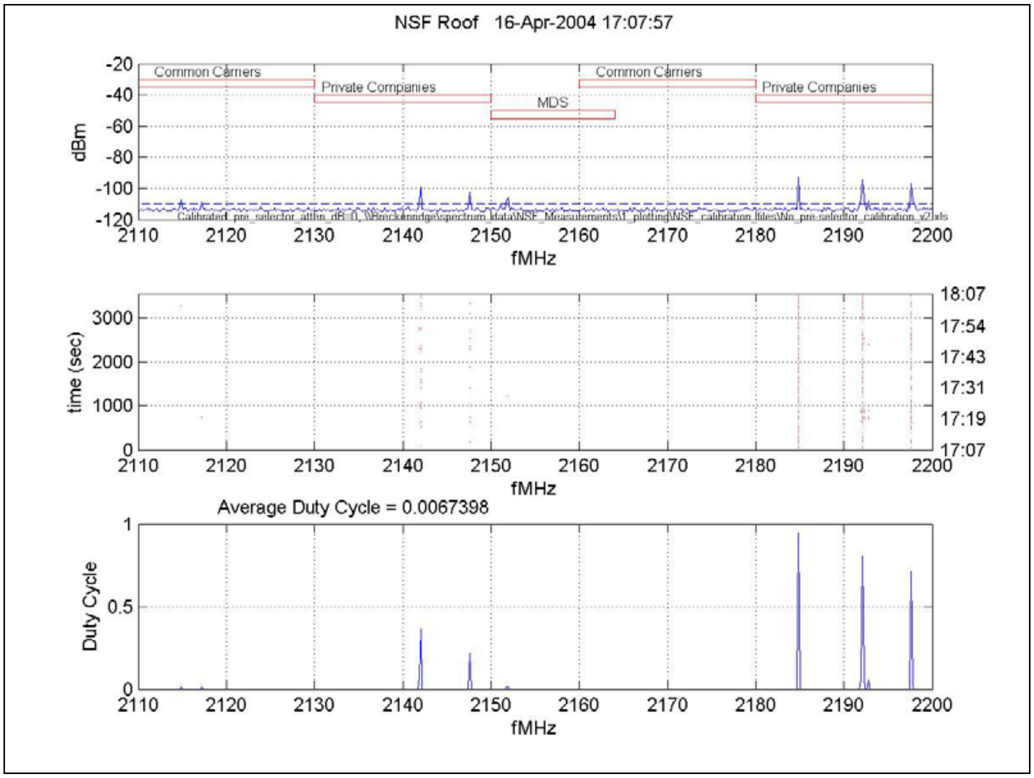

Figure 52: 2.11 GHz – 2.2 GHz (Antenna Rotating).

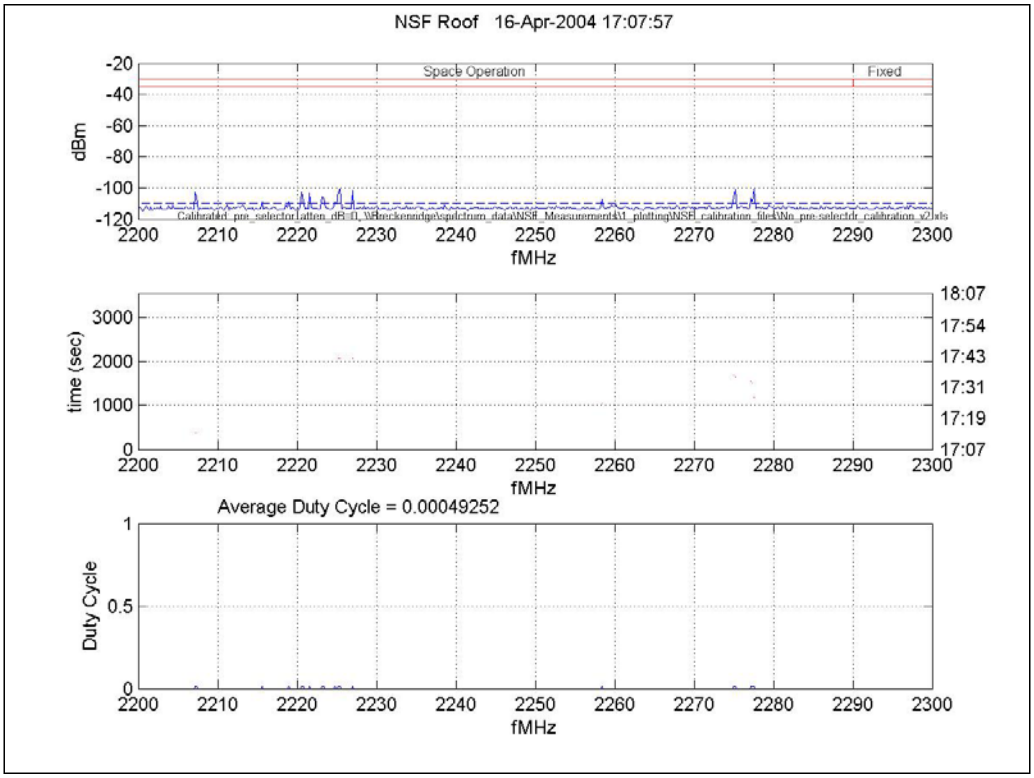

Figure 53: 2.2 GHz – 2.3 GHz (Antenna Rotating).

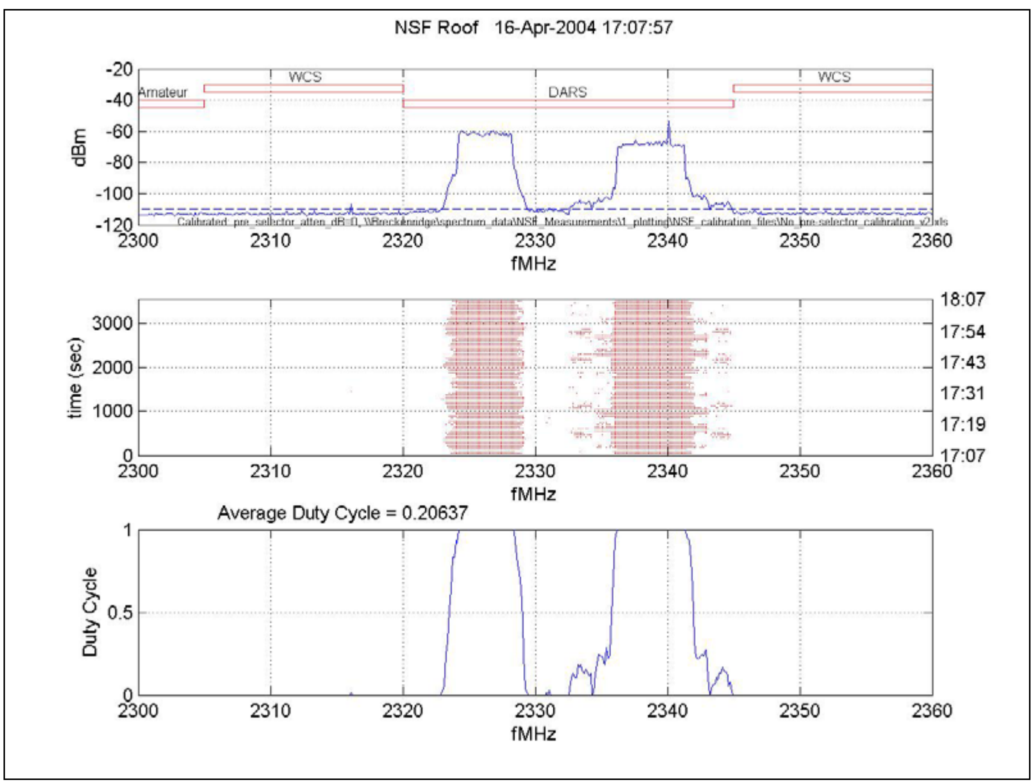

Figure 54: 2.3 GHz – 2.36 GHz (Antenna Rotating).

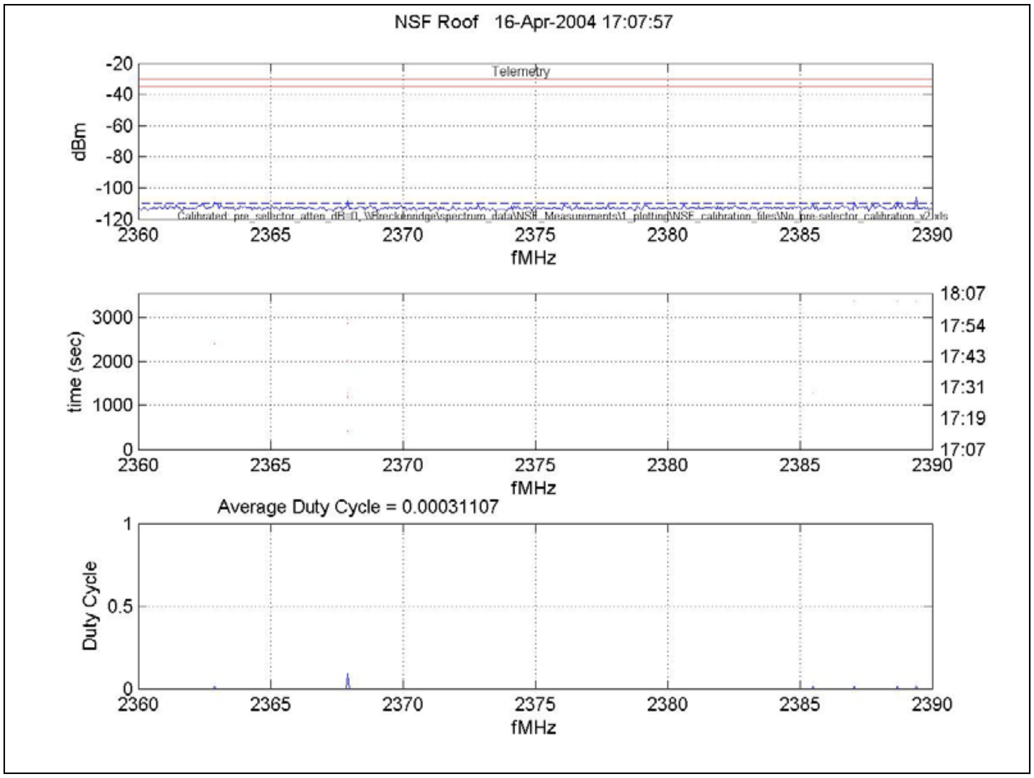

Figure 55: 2.36 GHz – 2.39 GHz (Antenna Rotating).

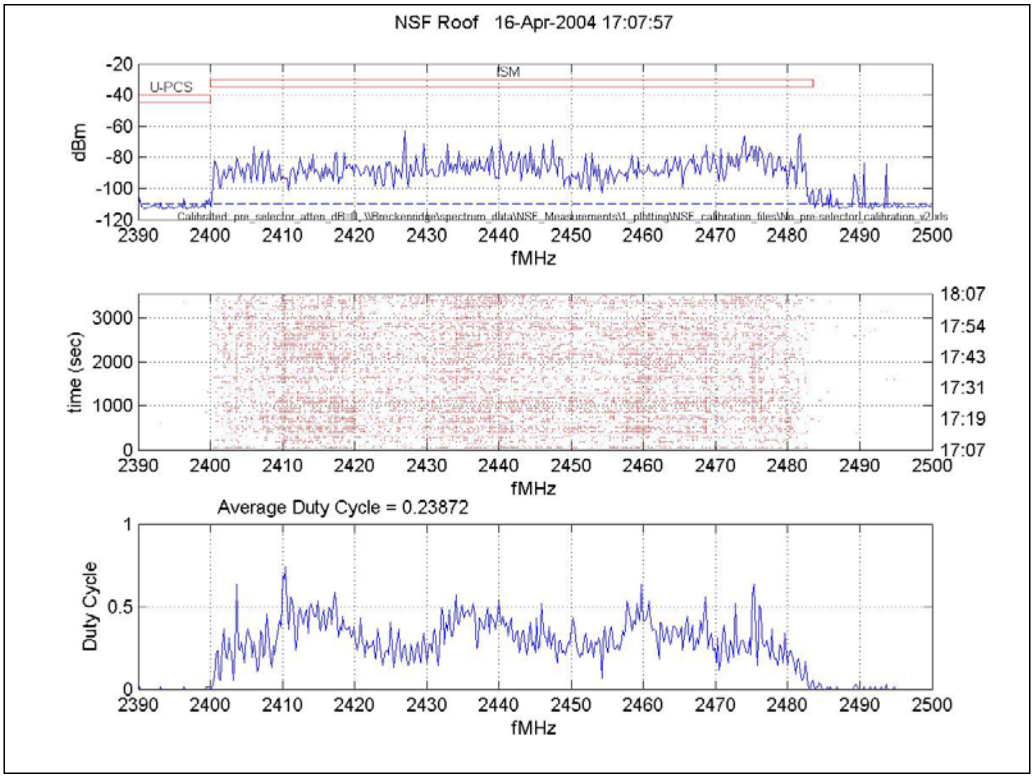

Figure 56: 2.39 GHz – 2.5 GHz (Antenna Rotating).

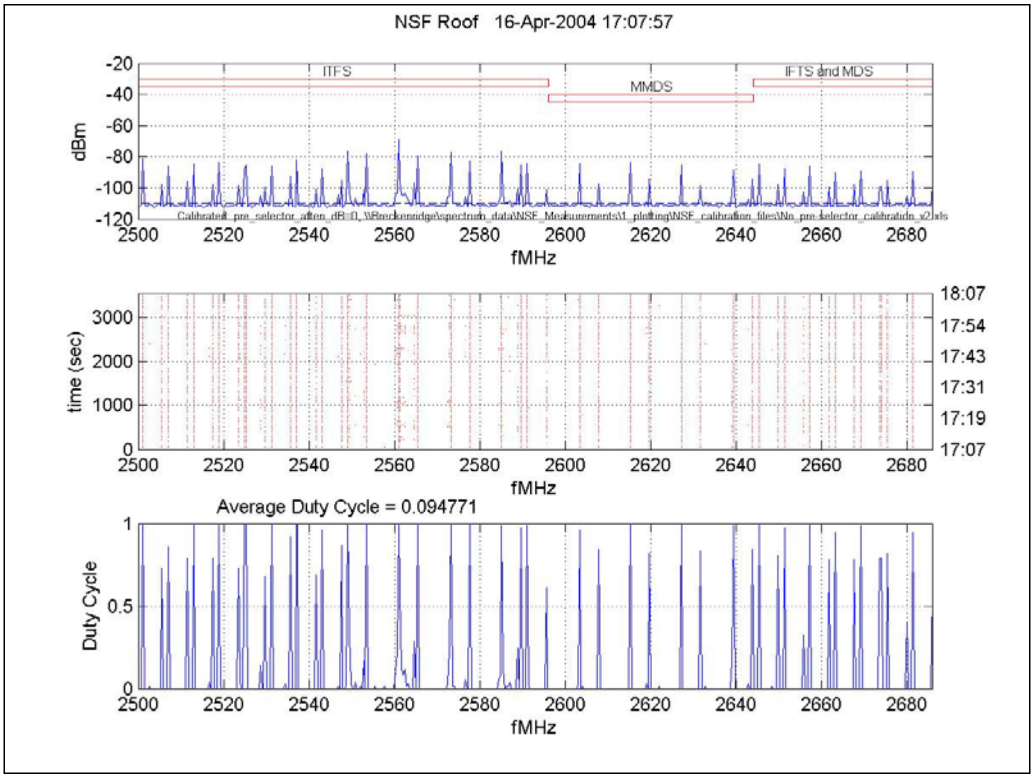

Figure 57: 2.5 GHz – 2.686 GHz (Antenna Rotating).

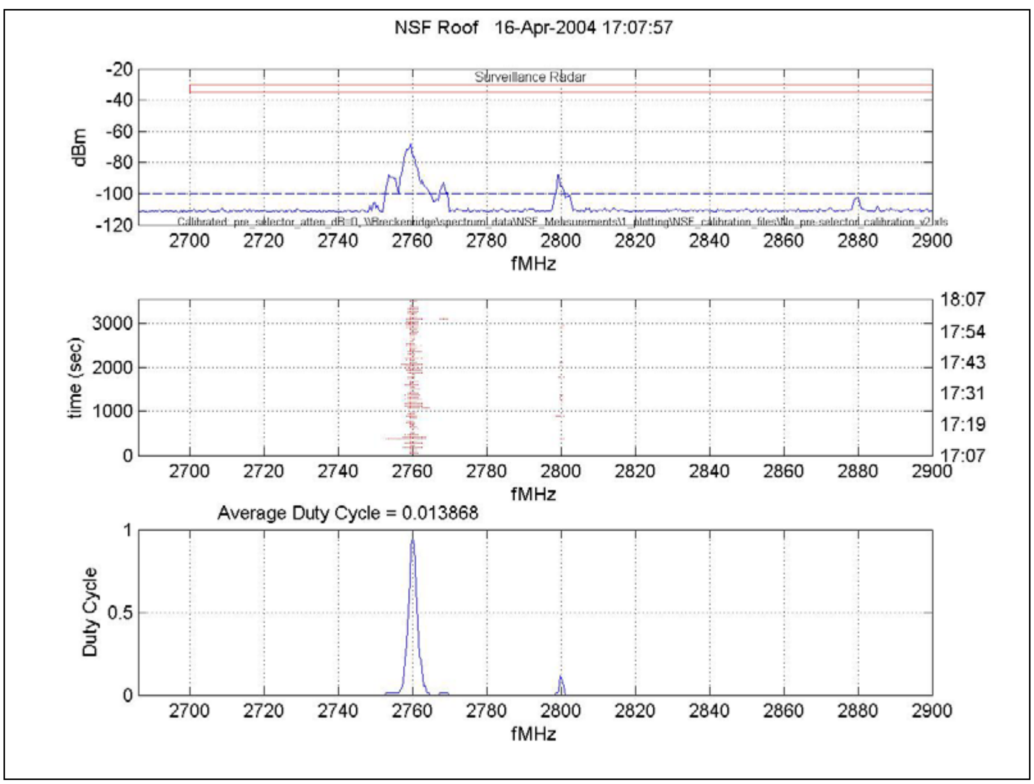

Figure 58: 2.686 GHz – 2.9 GHz (Antenna Rotating).

5.4 Data Issues/Comments

5.4.1 88 MHz to 108 MHz

The high noise level in this band is an artifact of the calibration process. An FM bandstop filter was used, which increased the RF loss and caused the system noise to artificially be increased post-calibration.

5.4.2 108 MHz to 138 MHz

The increase in the background noise level is clearly seen in the 108 MHz to 118 MHz portion of the band because of the lack of signals.

5.4.3 Intermittent Broad Bandwidth Noise

Broad bandwidth, intermittent noise was observed from 2700 seconds until 3000 seconds from the start of the NSF observation at frequencies from 512 MHz to 806 MHz. This is shown in Figure 21, Figure 23, and Figure 25. The building's HVAC equipment was intermittently operating and may have been the cause.

6. Conclusion

6.1 Introduction

Shared Spectrum Company concludes that less than 11.4% of the spectrum opportunities, both in frequency and time, were utilized at the National Science Building roof site on April 16, 2004. Analyses regarding these spectrum occupancy conclusions are provided in Table 8 for each band for the fixed antenna measurements.

6.2 Occupancy in Each Band

The percentage occupancy for each band is shown in the right column in Table 8. The average duty cycle (in frequency and time) of each band is noted on the related spectrum plots shown in Section 4The amount of spectrum occupied is then calculated by multiplying the bandwidth and the corresponding average duty cycle together. Bands with high occupancy include the TV bands, the cell phone/SM band, and the PCS band. Many bands have effectively 0% occupancy.

6.3 Overall Occupancy

The overall occupancy at this location (6.9%) is shown in the bottom row of Table 8. The total available spectrum (2570 MHz) is the sum of all of the bands measured (the 960 MHz to 1240 MHz band was not measured at this location). The overall occupied spectrum (292.57 MHz) is the sum from each band. The overall occupancy is the occupied spectrum divided by the total available spectrum.

Table 8. Summary of Spectrum Occupancy in Each Band

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	NSF Roof Spectrum Fraction Used	NSF Roof Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.00217	0.05	0.2%
54	88	34	TV 2 -6, RC	0.36654	12.46	36.7%
108	138	30	Air traffic Control, Aero Nav	0.04066	1.22	4.1%
138	174	36	Fixed Mobile, amateur, others	0.16865	6.07	16.9%
174	216	42	TV 7-13	0.18890	7.93	18.9%
216	225	9	Maritime Mobile, Amateur, others	0.01129	0.10	1.1%
225	406	181	Fixed Mobile, Aero, others	0.00576	1.04	0.6%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.10469	6.70	10.5%
470	512	42	TV 14-20	0.29794	12.51	29.8%
512	608	96	TV 21-36	0.49667	47.68	49.7%
608	698	90	TV 37-51	0.47044	42.34	47.0%
698	806	108	TV 52-69	0.20048	21.65	20.0%
806	902	96	Cell phone and SMR	0.46398	44.54	46.4%
902	928	26	Unlicensed	0.08687	2.26	8.7%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.10438	3.34	10.4%
960	1240	280	IFF, TACAN, GPS, others			
1240	1300	60	Amateur	0.01509	0.91	1.5%
1300	1400	100	Aero Radar, military	0.00718	0.72	0.7%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00083	0.10	0.1%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorologicial	0.00220	0.41	0.2%
1710	1850	140	Fixed, Fixed Mobile	0.00137	0.19	0.1%
1850	1990	140	PCS, Asyn, Iso	0.27102	37.94	27.1%
1990	2110	120	TV Aux	0.00005	0.01	0.0%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00397	0.36	0.4%
2200	2300	100	Space Operation, Fixed	0.00021	0.02	0.0%
2300	2360	60	Amateur, WCS, DARS	0.17754	10.65	17.8%
2360	2390	30	Telemetry	0.00000	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.12461	13.71	12.5%
2500	2686	186	ITFS, MMDS	0.07046	13.10	7.0%
2686	2900	214	Surveillance Radar	0.02123	4.54	2.1%
Total		2850			292.57	
Total Available Spectrum					2570	
Average Spectrum Use (%)					11.4%	