Spectrum Occupancy Measurements
Location 5 of 6:
National Radio Astronomy Observatory (NRAO)
Green Bank, West Virginia
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National Radio Research Testbed (NRNRT)
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1. Introduction

This document describes spectrum occupancy measurements performed by Shared Spectrum Company in October of 2004 at the National Radio Astronomy Observatory (NRAO) at Green Bank, West Virginia. The Green Bank site, located within the Allegheny Mountains in Pocahontas County, was chosen because of the National Radio Quiet Zone (NRQZ), which allowed for very low spectrum occupancy measurements to be taken at this location.

1.1 Report Organization

The 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

1.2 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 the National Radio Astronomy Observatory was to identify spectrum bands with low occupancy. Occupancy was quantified as the amount of spectrum detected above a certain received power threshold.

1.3 The National Radio Network Research Testbed (NRNRT)

Measurements described 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) a field measurement and evaluation system for long-term radio frequency data collection, and an experimental facility for testing and evaluation of new radios;

[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)

(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 used for measurements in this study included an omni-directional, discone antenna for frequencies below 1000MHz, and a small, log periodic array (LPA) for frequencies above 1000 MHz. The antennas were connected to a high-linearity Pre-Selector. Shared Spectrum Company employed a 20-foot RG8 cable, along with a Pre-Selector control cable and a Pre-Selector power cable to connect the Pre-Selector box to a shielded enclosure, or Faraday cage. The shielded enclosure contained a 3 GHz spectrum analyzer, a laptop computer and power supplies. The equipment was powered by an extension cord plugged into a standard, 120 volt AC outlet where available. Where not available, a shielded gasoline-powered generator was used to provide 120 volt AC power. The specific spectrum measurement equipment employed in this effort is depicted below in Figure 1 through 3.

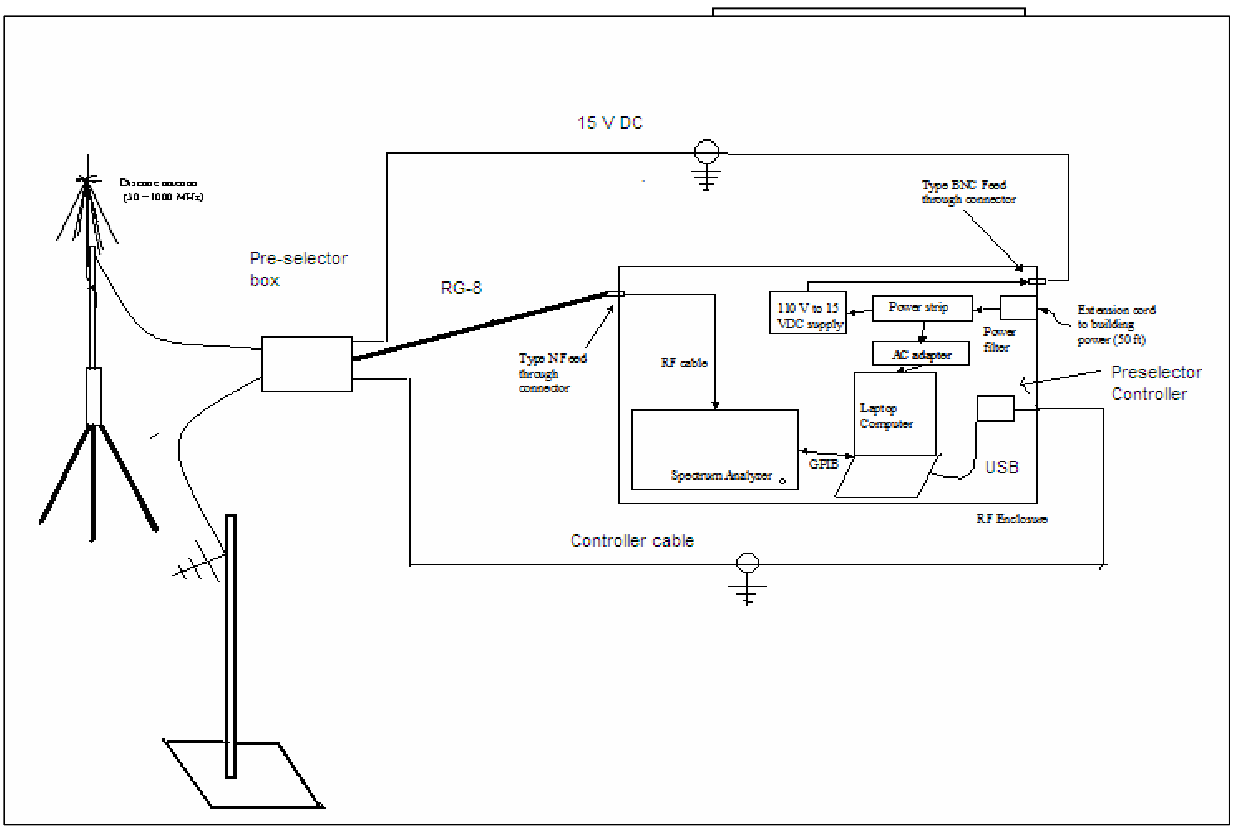


Figure 1: Spectrum Measurement Equipment Configuration

Figure 2: Discone Antenna at NRAO Site

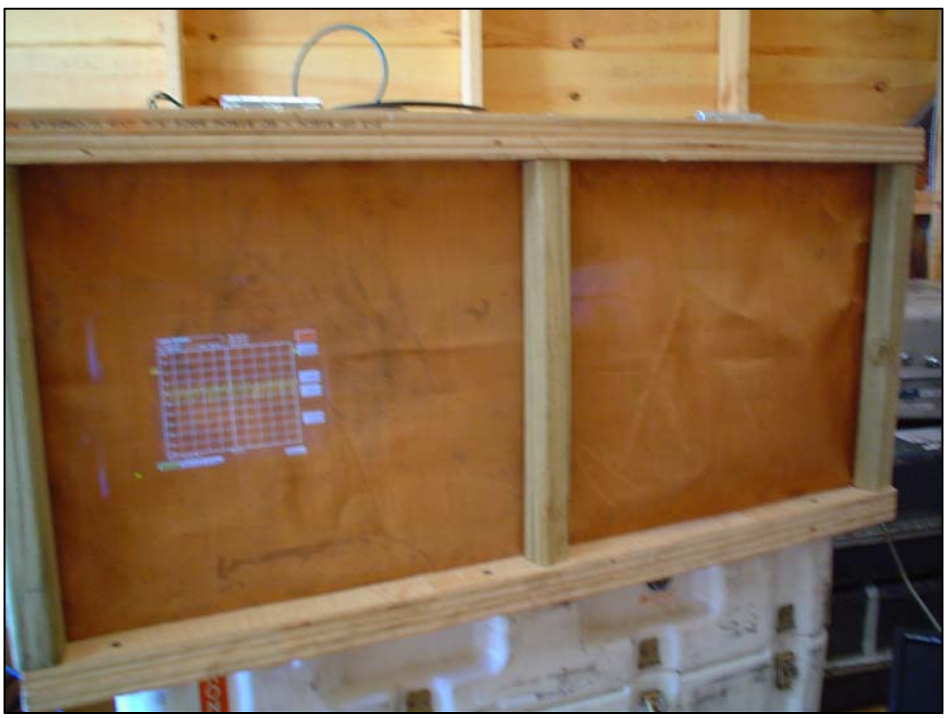


Figure 3: The RF Shield Box Containing Data Collection Equipment

As discussed earlier, the discone antenna was used for measuring signals below 1000 MHz, and the LPA was used for measuring signals above 1000 MHz. The LPA antenna was tilted at 45 degrees to the horizontal to allow for reception of both horizontally and vertically polarized signals.

At each measurement location, the antennas, cables, filters, fixed attenuators, and pre-amplifiers were set to optimize the dynamic range of the measurements.

2.2 Pre-Selector Description

The Pre-Selector configuration is illustrated in the block diagram shown in Figure 4 below.

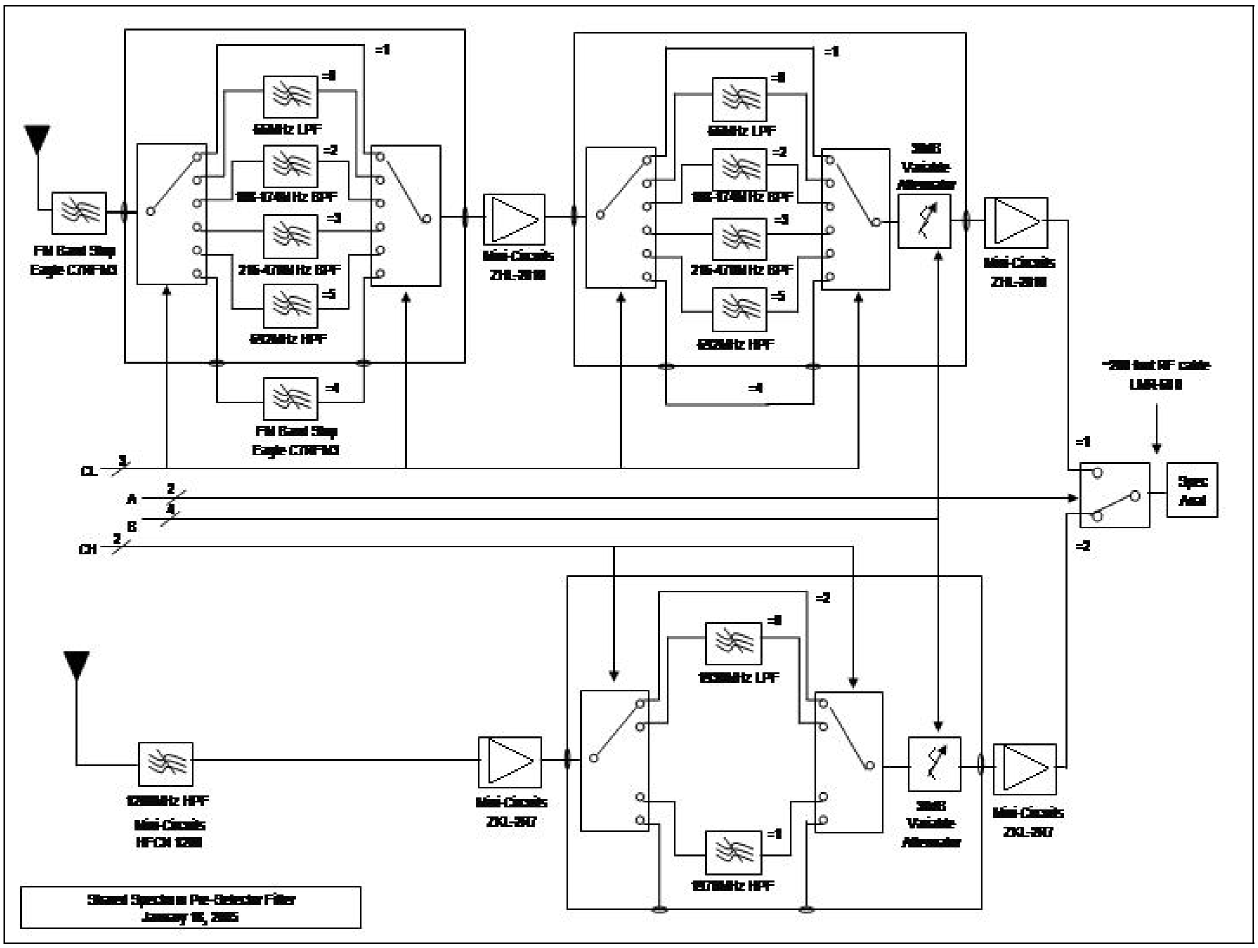


Figure 4: Block Diagram of the Pre-Selector

As illustrated in Figure 4, four sets of logic lines (ports) control the Pre-Selector, Port A (bits 0 and 1) selects either “<1 GHz” or “>1 GHz” antenna, and the appropriate amplifiers and filter bank. Port B (bits 0, 1, 2, and 3) controls the digital attenuators for both bands.

2.3 Equipment Settings

Table 1 and Table 2 show the measurement equipment settings used for Frequency List A and Frequency List B.

Table 1: Frequency List A Equipment Settings

						Preselector Settings					Spectrum Analyzer Settings				
Start Freq (MHz)	Stop Freq (MHz)	Antenna Type	Antenna Polarization Angle (0 is horizontal)	Antenna Direction (Magnetic azimuth)	Antenna to Preselector Cable Type	BS	Atten	Filter A	Filter B	Preselector to Spectrum Analyzer Cable Type	RBW (kHz)	VBW (kHz)	Atten (dB)	Ref Level (dBm)	Spectrum Analyzer
138	174	1	90	x	2	1	15	2	x	3	10	10	10	-20	ESPI
406	470	1	90	x	2	1	10	3	x	3	10	10	10	-10	ESPI

Table 2: Frequency List B Equipment Settings

						Preselector Settings					Spectrum Analyzer Settings				
Start Freq (MHz)	Stop Freq (MHz)	Antenna Type	Antenna Polarization Angle (0 is horizontal)	Antenna Direction (Magnetic azimuth)	Antenna to Preselector Cable Type	BS	Atten	Filter A	Filter B	Preselector to Spectrum Analyzer Cable Type	RBW (kHz)	VBW (kHz)	Atten (dB)	Ref Level (dBm)	Spectrum Analyzer
30	54	1	90	x	2	1	5	0	x	3	10	10	10	-10	ESPI
54	88	1	90	x	2	1	10	4	x	3	10	10	20	-10	ESPI
108	138	1	90	x	2	1	5	2	x	3	10	10	10	-10	ESPI
174	216	1	90	x	2	1	10	4	x	3	10	10	20	-10	ESPI
216	225	1	90	x	2	1	5	3	x	3	10	10	10	-10	ESPI
225	406	1	90	x	2	1	5	3	x	3	10	10	10	-10	ESPI
470	512	1	90	x	2	1	10	4	x	3	10	10	20	-10	ESPI
512	608	1	90	x	2	1	5	4	x	3	10	10	10	-10	ESPI
608	698	1	90	x	2	1	5	4	x	3	10	10	10	-10	ESPI
698	806	1	90	x	2	1	5	5	x	3	10	10	10	-10	ESPI
806	902	1	90	x	2	1	5	5	x	3	10	10	10	-10	ESPI
902	928	1	90	x	2	1	5	5	x	3	10	10	10	-10	ESPI
928	960	1	90	x	2	1	5	5	x	3	10	10	10	-10	ESPI
960	1240	2	45	0	2	2	10	x	1	3	10	10	10	-10	ESPI
1240	1300	2	45	0	2	2	5	x	1	3	10	10	10	-20	ESPI
1300	1400	2	45	0	2	2	5	x	1	3	10	10	10	-20	ESPI
1400	1525	2	45	0	2	2	5	x	1	3	10	10	10	-20	ESPI
1525	1710	2	45	0	2	2	5	x	1	3	10	10	10	-20	ESPI
1710	1850	2	45	0	2	2	10	x	1	3	10	10	10	-20	ESPI
1850	1990	2	45	0	2	2	10	x	1	3	10	10	10	-20	ESPI
1990	2110	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2110	2200	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2200	2300	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2300	2360	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2360	2390	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2390	2500	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2500	2686	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2686	2900	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI

2.4 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 Site

All spectrum occupancy measurements were made at the National Radio Astronomy Observatory (NRAO), at Green Bank, West Virginia. It is situated in a sheltered, valley location within the Allegheny Mountains in Pocahontas County, nestled at the center of the National Radio Quiet Zone (NRQZ). The NRQZ is a 13,000 square-mile area that is protected from radio frequency interference broadcasts by Federal regulation.

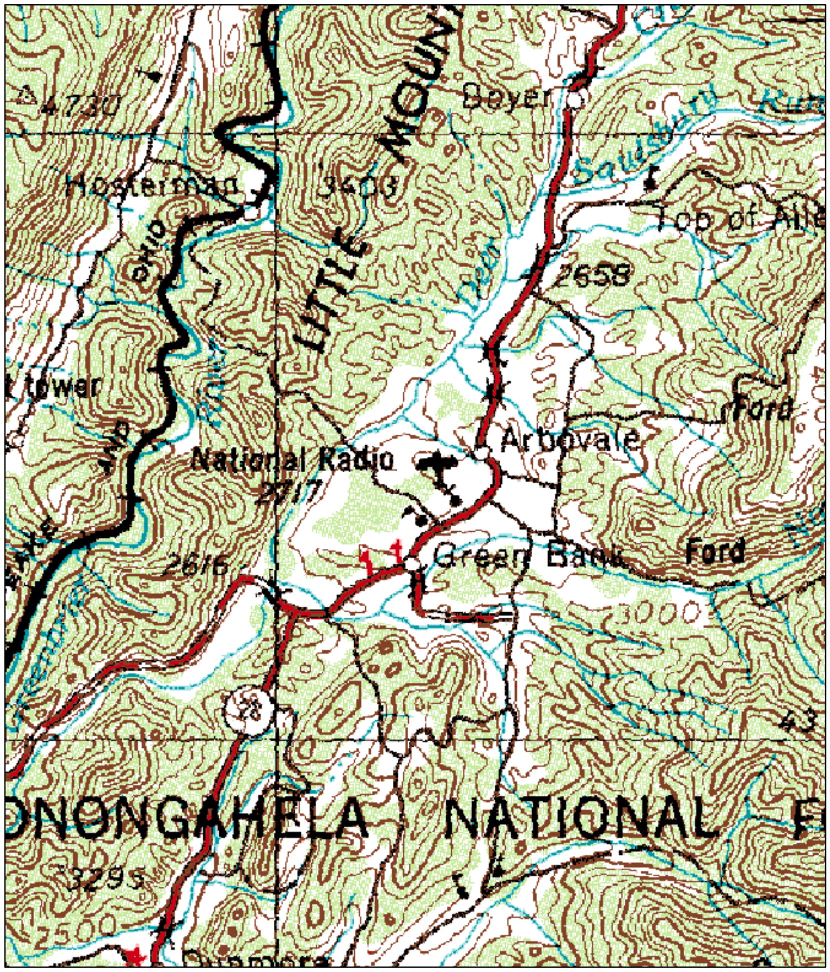
This section further describes the location, surrounding environment and other characteristics of interest at the Green Bank site.

3.1 Location Characteristics

The NRAO measurement site is located in the Allegheny Mountains in Pocahontas County at the red star in the map in Figure 5.

Figure 5: Map Showing the Location of the Measurement Site

Figure 6 further depicts the surrounding terrain elevations.



topozone
Copyright 1999-2003 Maps a la carte, Inc.

Figure 6: Topographic Map of Green Bank, West Virginia

3.2 Views from Measurement Site

The photographs in Figure 7 through 10 below provide a series of different views looking out from the measurement antenna location. As is seen here, the location provided a clear line of sight in most directions.

Figure 7: View Towards the North

Figure 8: View Towards the East

Figure 9: View Towards the South

Figure 10: View Towards the Southwest

4. Frequency Collection Lists and Data Files

4.1 Frequency Lists

Two difference frequency collection lists – List A and List B -- were used for spectrum occupancy measurements. Table 3 details the Public Safety Bands in Collection List A. Table 4 details other band usage in Collection List B.

Table 3: Collection List A – Public Safety Bands

						Preselector Settings					Spectrum Analyzer Settings				
Start Freq (MHz)	Stop Freq (MHz)	Antenna Type	Antenna Polarization Angle (0 is horizontal)	Antenna Direction (Magnetic azimuth)	Antenna to Preselector Cable Type	BS	Atten	Filter A	Filter B	Preselector to Spectrum Analyzer Cable Type	RBW (kHz)	VBW (kHz)	Atten (dB)	Ref Level (dBm)	Spectrum Analyzer
138	174	1	90	x	2	1	15	2	x	3	10	10	10	-20	ESPI
406	470	1	90	x	2	1	10	3	x	3	10	10	10	-10	ESPI

Table 4: Collection List B – Other Bands from 30 MHz – 3 GHz

Start Freq (MHz)	Stop Freq (MHz)	Antenna Type	Antenna Polarization Angle (0 is horizontal)	Antenna Direction (Magnetic azimuth)	Antenna to Preselector Cable Type	BS	Atten	Filter A	Filter B	Preselector to Spectrum Analyzer Cable Type	RBW (kHz)	VBW (kHz)	Atten (dB)	Ref Level (dBm)	Spectrum Analyzer
30	54	1	90	x	2	1	5	0	x	3	10	10	10	-10	ESPI
54	88	1	90	x	2	1	10	4	x	3	10	10	20	-10	ESPI
108	138	1	90	x	2	1	5	2	x	3	10	10	10	-10	ESPI
174	216	1	90	x	2	1	10	4	x	3	10	10	20	-10	ESPI
216	225	1	90	x	2	1	5	3	x	3	10	10	10	-10	ESPI
225	406	1	90	x	2	1	5	3	x	3	10	10	10	-10	ESPI
470	512	1	90	x	2	1	10	4	x	3	10	10	20	-10	ESPI
512	608	1	90	x	2	1	5	4	x	3	10	10	10	-10	ESPI
608	698	1	90	x	2	1	5	4	x	3	10	10	10	-10	ESPI
698	806	1	90	x	2	1	5	5	x	3	10	10	10	-10	ESPI
806	902	1	90	x	2	1	5	5	x	3	10	10	10	-10	ESPI
902	928	1	90	x	2	1	5	5	x	3	10	10	10	-10	ESPI
928	960	1	90	x	2	1	5	5	x	3	10	10	10	-10	ESPI
960	1240	2	45	0	2	2	10	x	1	3	10	10	10	-10	ESPI
1240	1300	2	45	0	2	2	5	x	1	3	10	10	10	-20	ESPI
1300	1400	2	45	0	2	2	5	x	1	3	10	10	10	-20	ESPI
1400	1525	2	45	0	2	2	5	x	1	3	10	10	10	-20	ESPI
1525	1710	2	45	0	2	2	5	x	1	3	10	10	10	-20	ESPI
1710	1850	2	45	0	2	2	10	x	1	3	10	10	10	-20	ESPI
1850	1990	2	45	0	2	2	10	x	1	3	10	10	10	-20	ESPI
1990	2110	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2110	2200	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2200	2300	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2300	2360	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2360	2390	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2390	2500	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2500	2686	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI
2686	2900	2	45	0	2	2	0	x	2	3	10	10	10	-20	ESPI

4.2 Measurement Operation

Before each official measurement was taken at a site, Shared Spectrum Company collected test data using the frequencies indicated above in List A and List B, then analyzed the data to ensure proper operation of the equipment, as well as to identify the presence of any strong signals that could overload either the pre-amplifier or the spectrum analyzer. Based on the analysis, the equipment was reconfigured as necessary. Long duration collections were then made using the frequencies shown above.

List A (Public Safety) and List B (Other Usage) were operated in a "ping-pong mode" over a several hour period as shown below in Table 5. This operating mode provided improved resolution within the Public Safety bands.

Table 5: "Ping-Pong" Mode Used

Frequency List	List Measurement Time (sec)	Repetitions	Duration (sec)	Experiment Duration (hours)	Experiment Duration (sec)	Number of Measurements
A	5	1	5			308
B	100	1	100			308
Total	105	2	105	9	43200	308

4.3 Data Files

Table 6 provides the data file information for each measurement.

Table 6: Equipment Configuration during Measurement

Start Time	Location	Comment	Freq List	Start File	End File	Num Files	Duration (sec)	Antenna Type
10/4/04 11:35 pm	NRAO		List A	15681	15921	241	32400	1
10/4/04 4:00 pm	NRAO		List B	391	631	241	32400	3

Separate files were created for each collection on a frequency list. The file size is 9k or 110k, depending on the number of frequency bands.

5. Spectrum Measurements

5.1 Plot Format Description

For each of the following spectrum measurement figures have three sub-plots.

The upper sub-plot is the maximum power value, versus frequency measured during the period. The power values are corrected for cable losses, filters, and attenuators, thereby calibrating the measurements to 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 declared 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 manually selected for each plot. This manual selection was not done.

The last sub-plot, "Duty-Cycle" indicates how often the signal was seen on each frequency during a sample period. A value of '1' means the signal was seen for all measurements made during the sample period.

5.2 Measurements Made Below 1,000 MHz

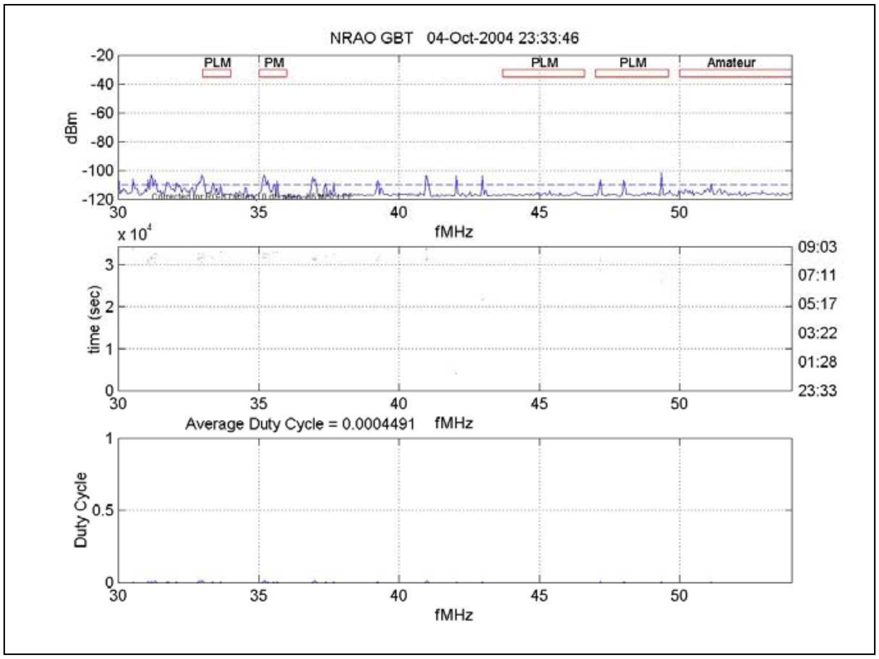


Figure 11: 30 MHz – 54 MHz

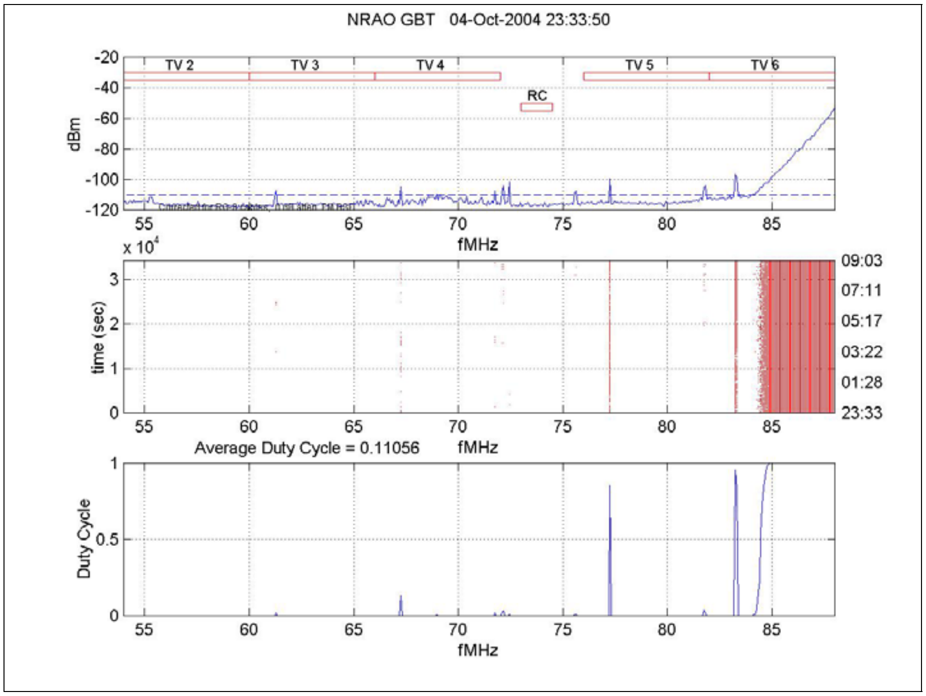


Figure 12: 54 MHz – 88 MHz

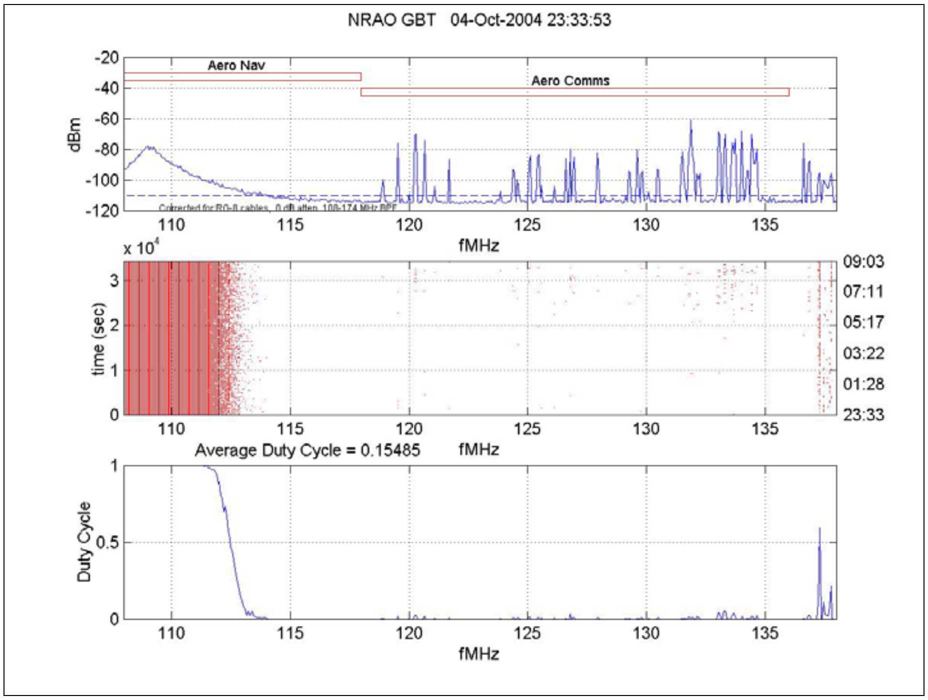


Figure 13: 108 MHz – 138 MHz

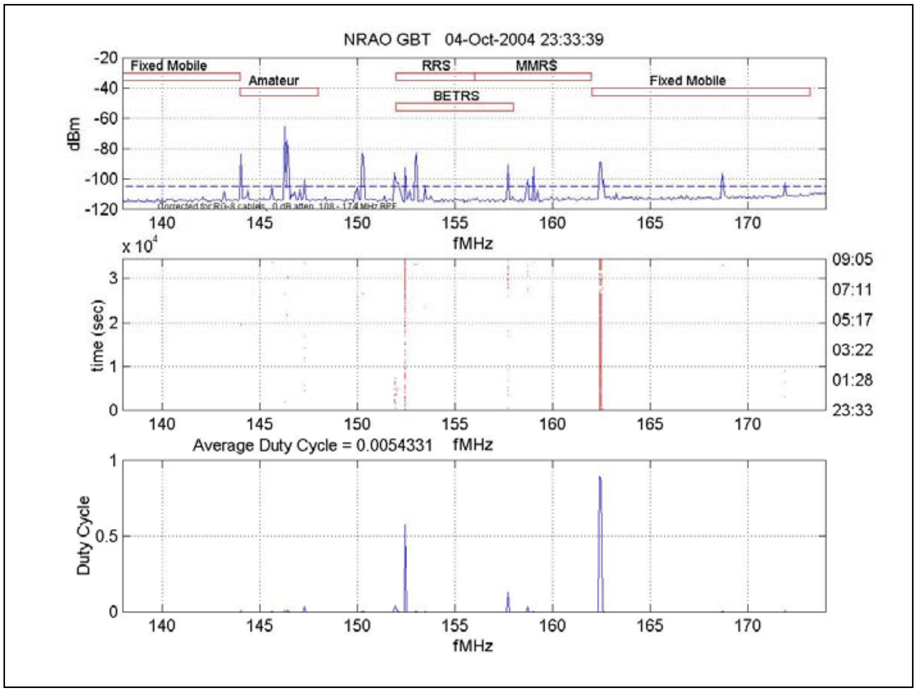


Figure 14: 138 MHz – 174 MHz

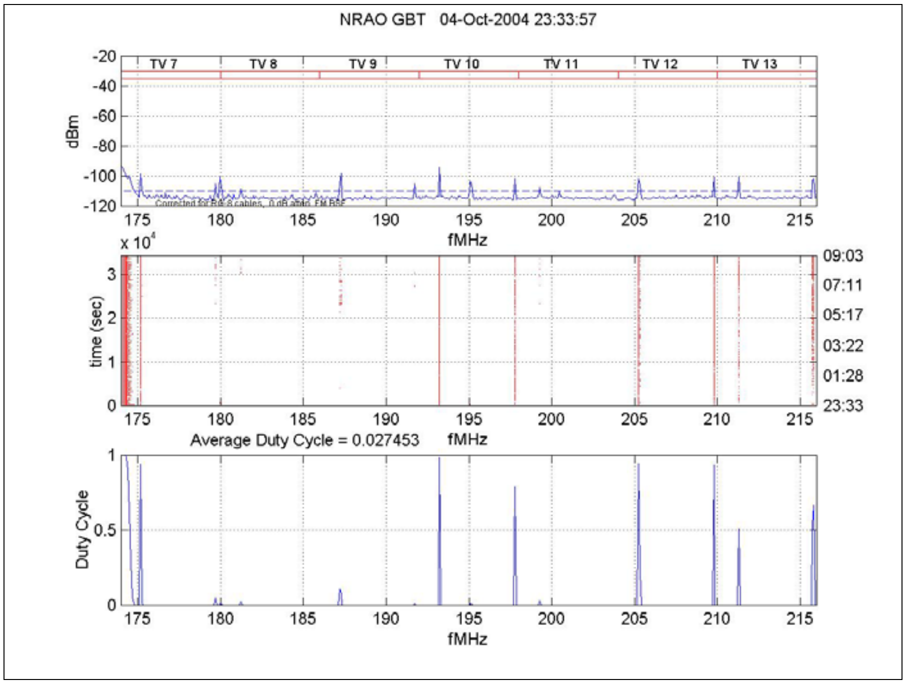


Figure 15: 174 MHz – 216 MHz

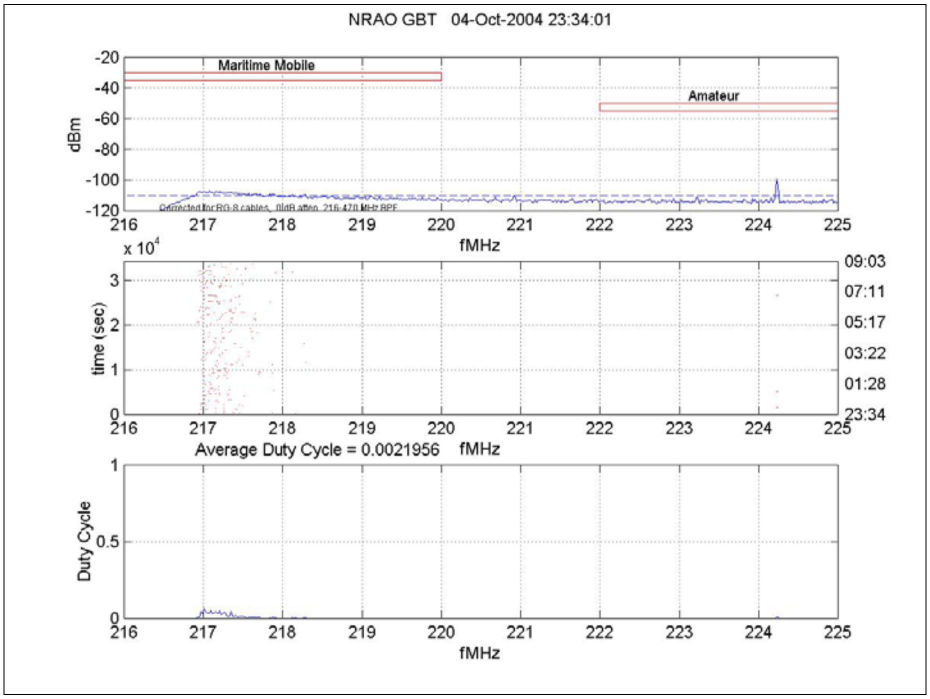


Figure 16: 216 MHz – 225 MHz

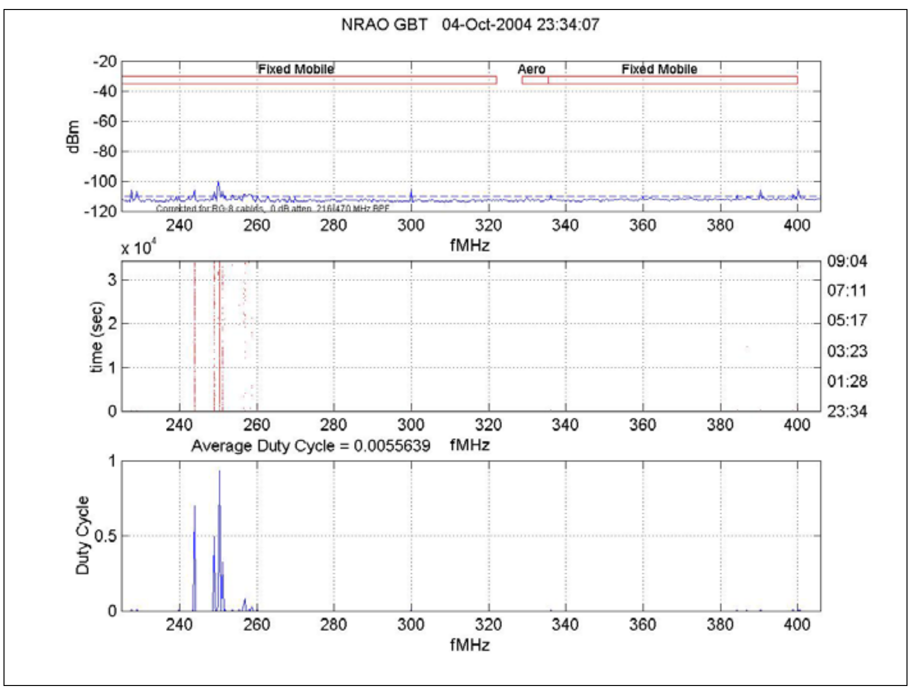


Figure 17: 225 MHz – 406 MHz

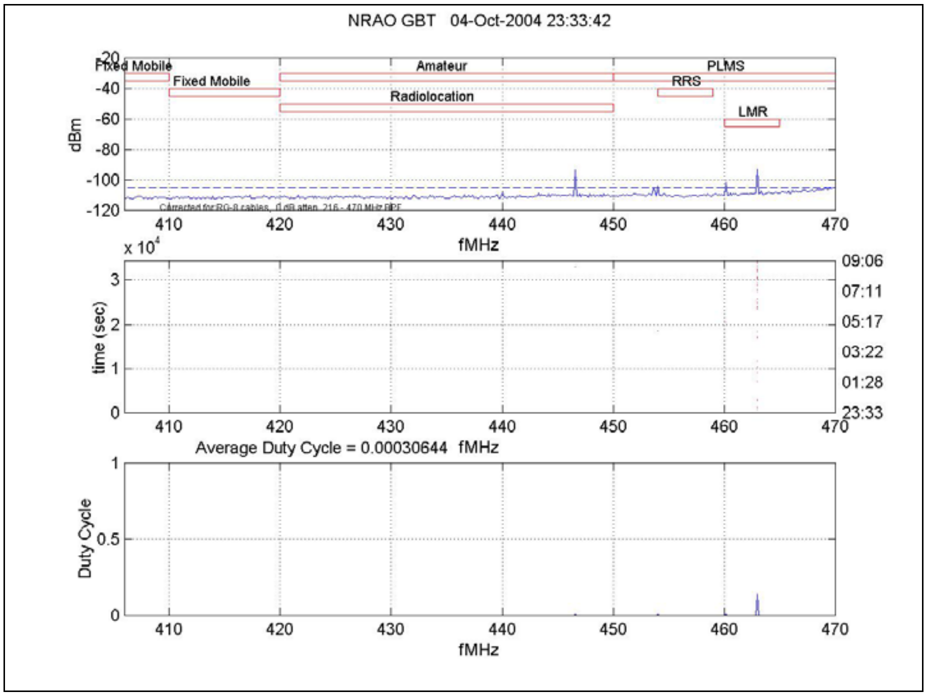


Figure 18: 406 MHz – 470 MHz

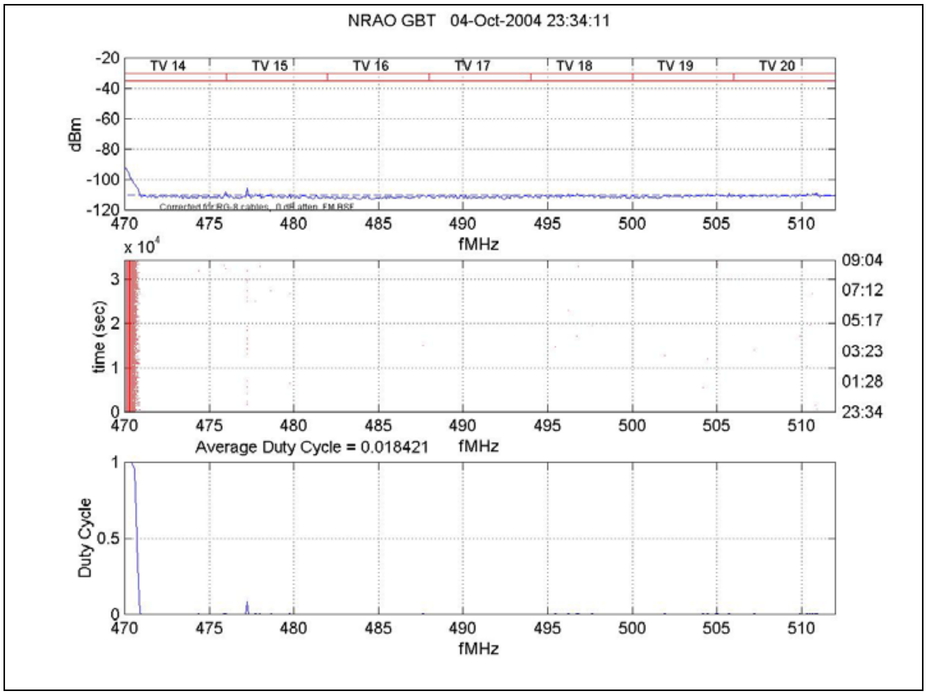


Figure 19: 470 MHz – 512 MHz

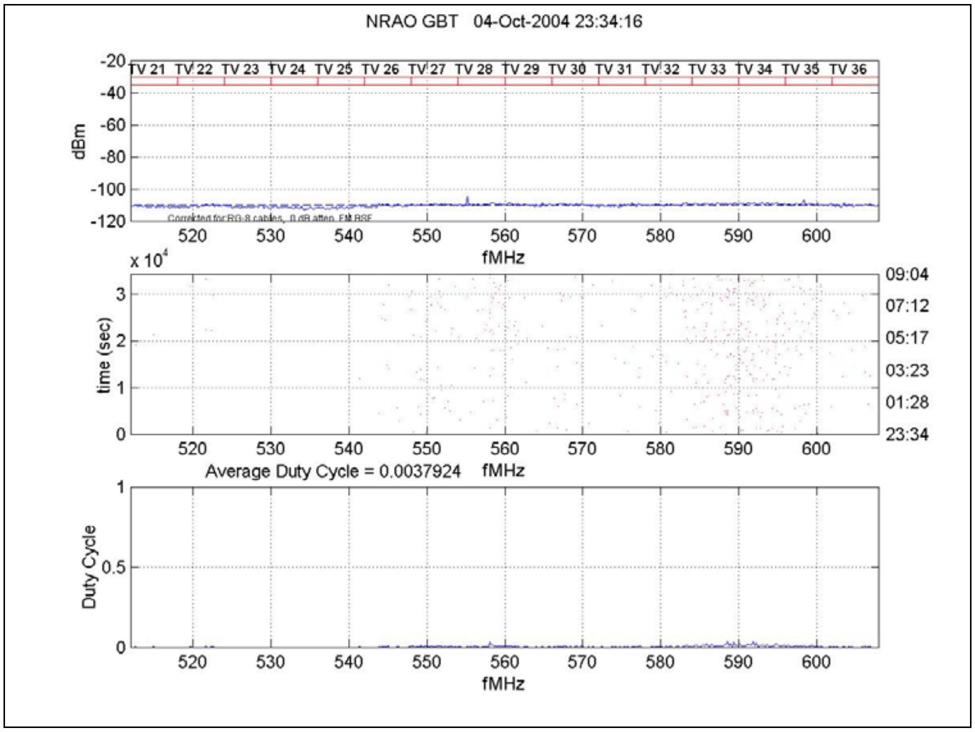


Figure 20: 470 MHz – 512 MHz

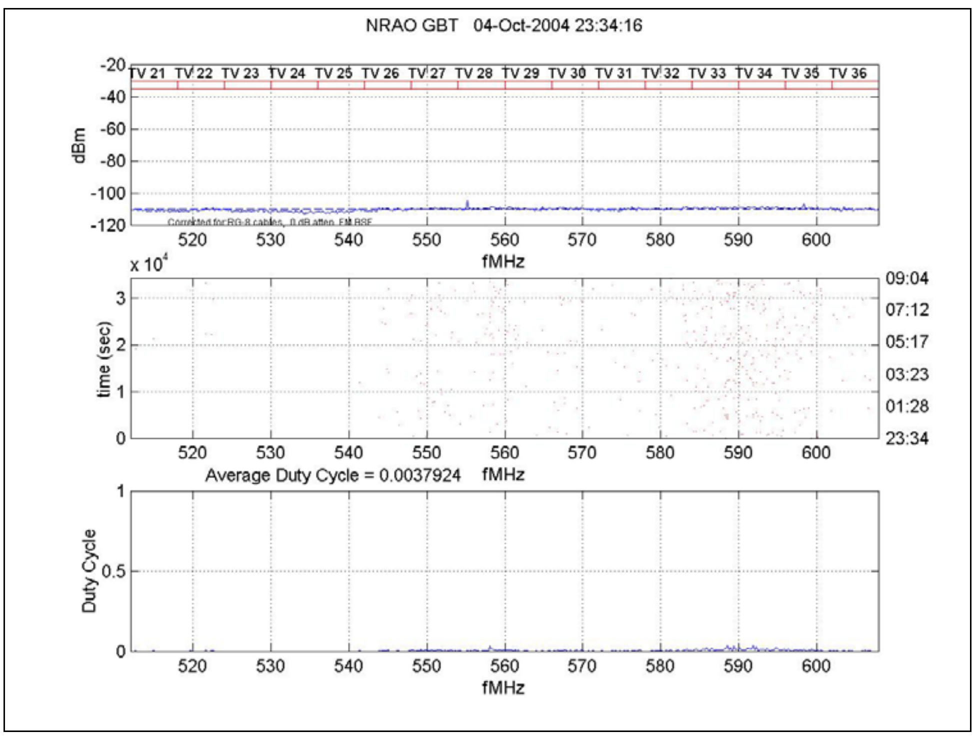


Figure 21: 512 MHz – 608 MHz

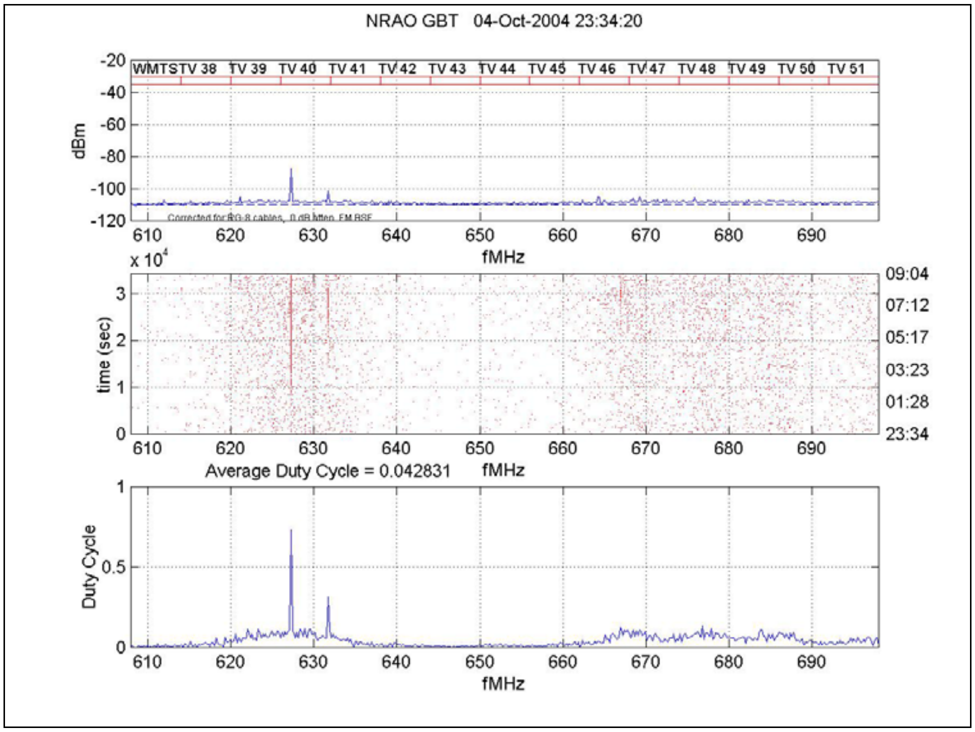


Figure 22: 608 MHz – 698 MHz

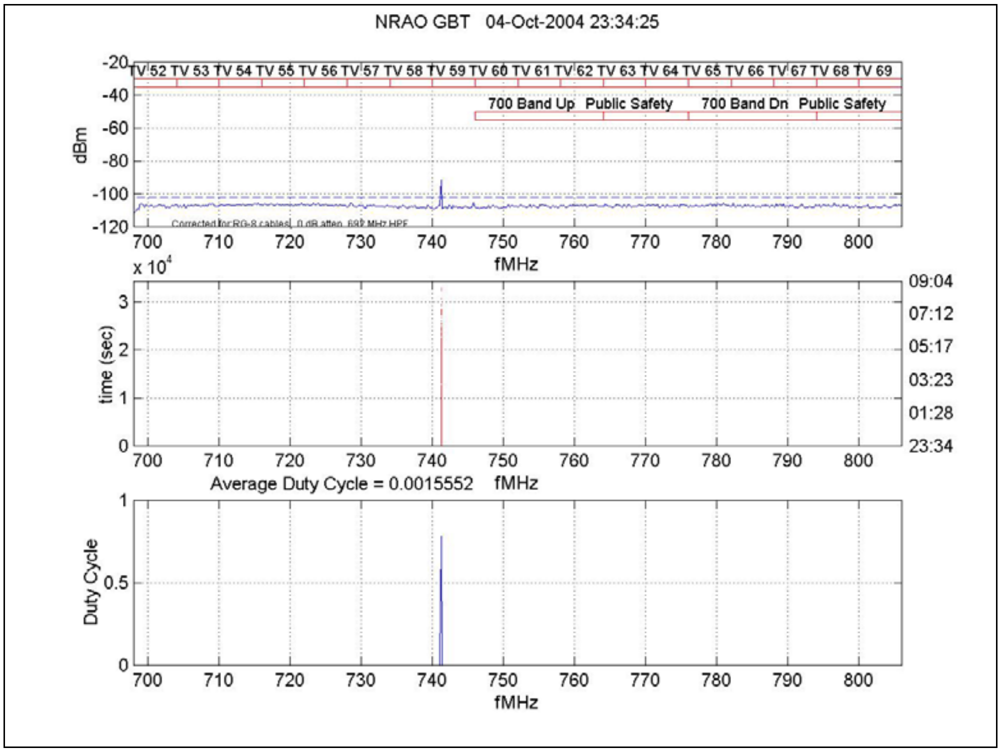


Figure 23: 698 MHz – 806 MHz

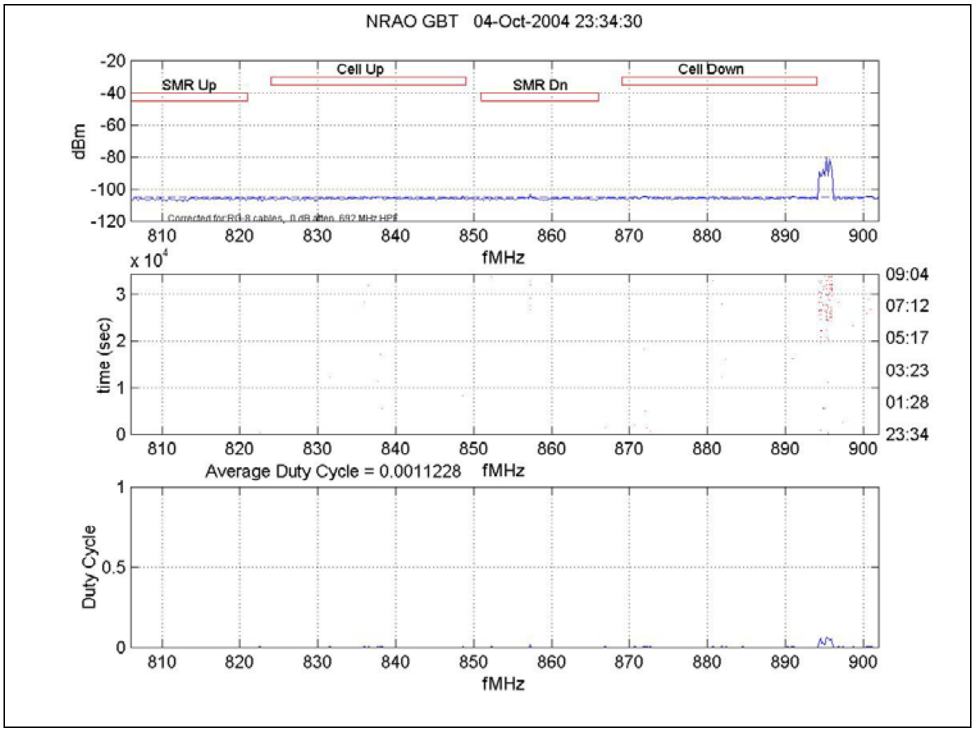


Figure 24: 806 MHz – 902 MHz

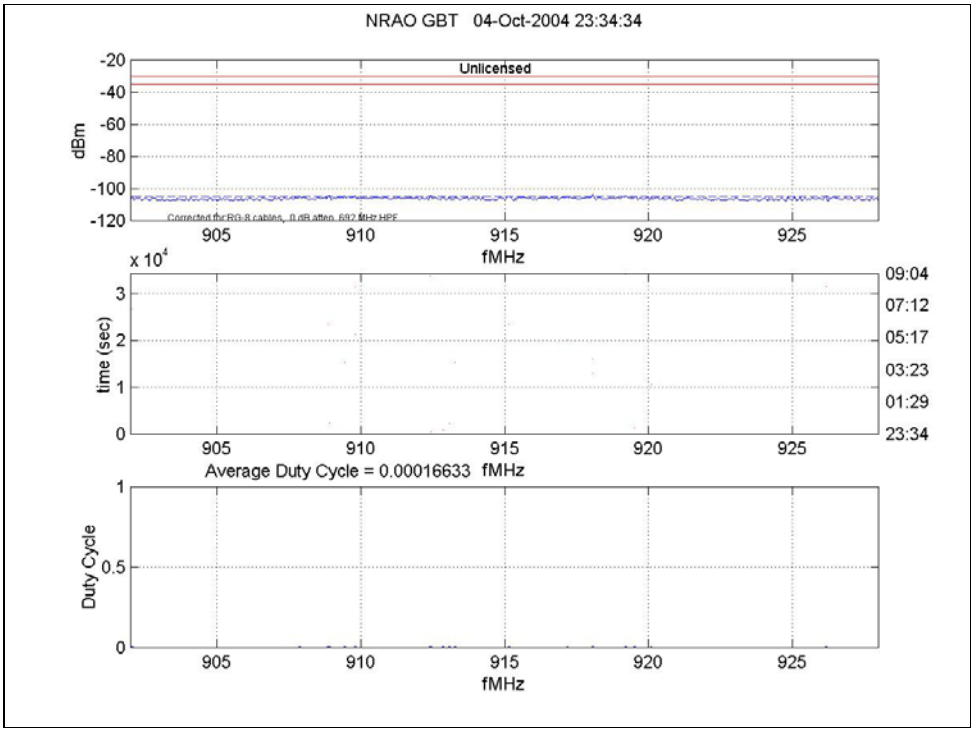


Figure 25: 902 MHz – 928 MHz

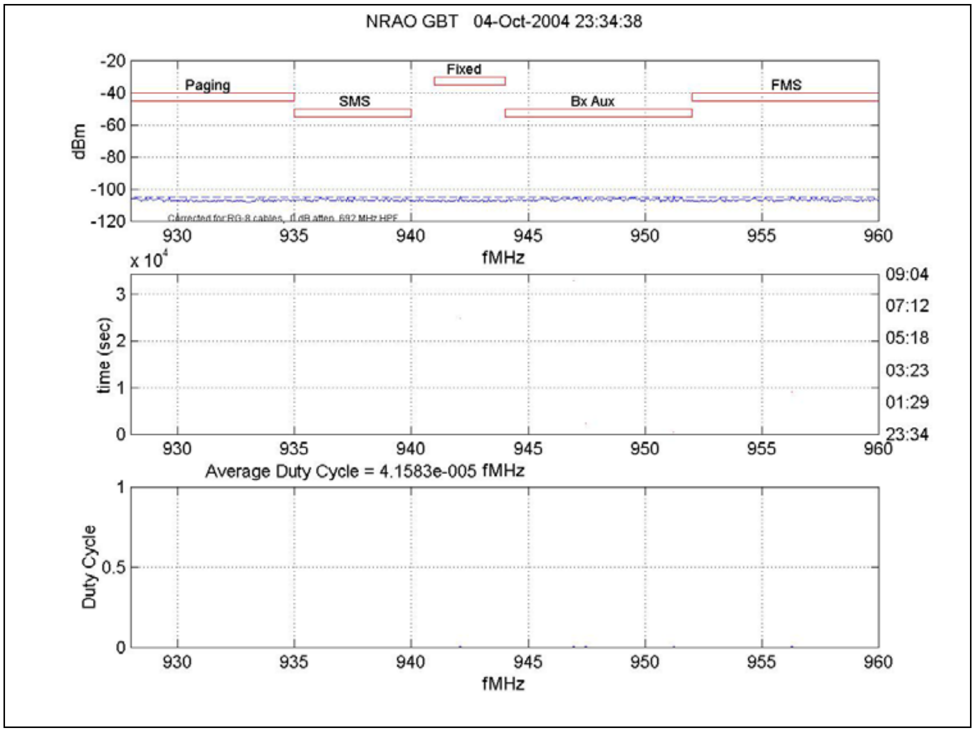


Figure 26: 928 MHz – 960 MHz

5.3 Measurements Made Above 1,000 MHz

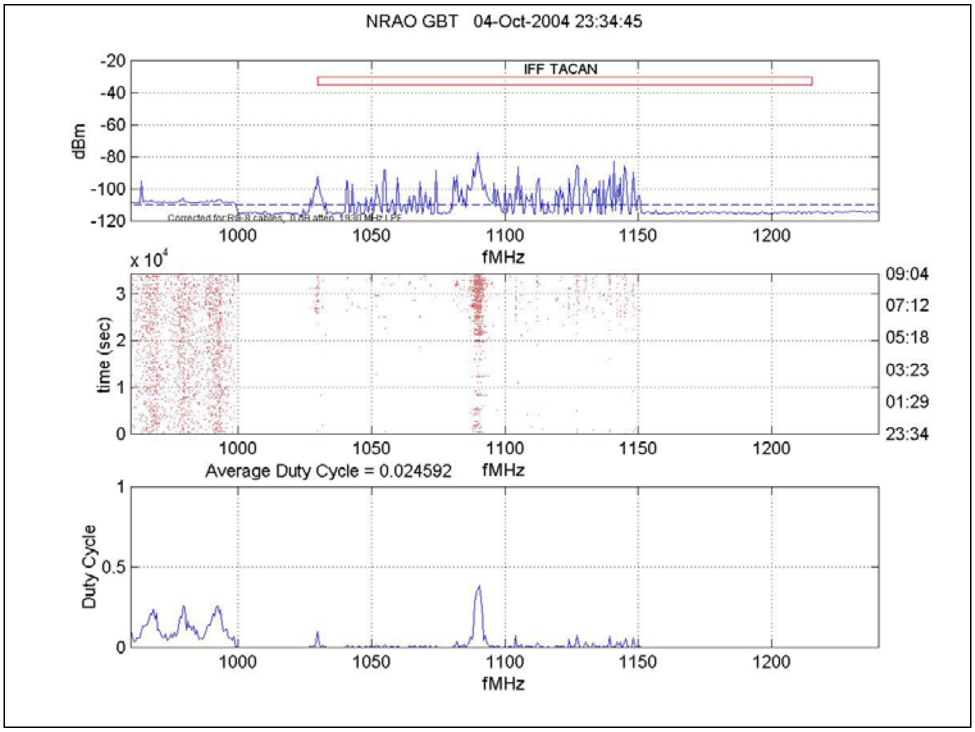


Figure 27: 960 MHz – 1240 MHz

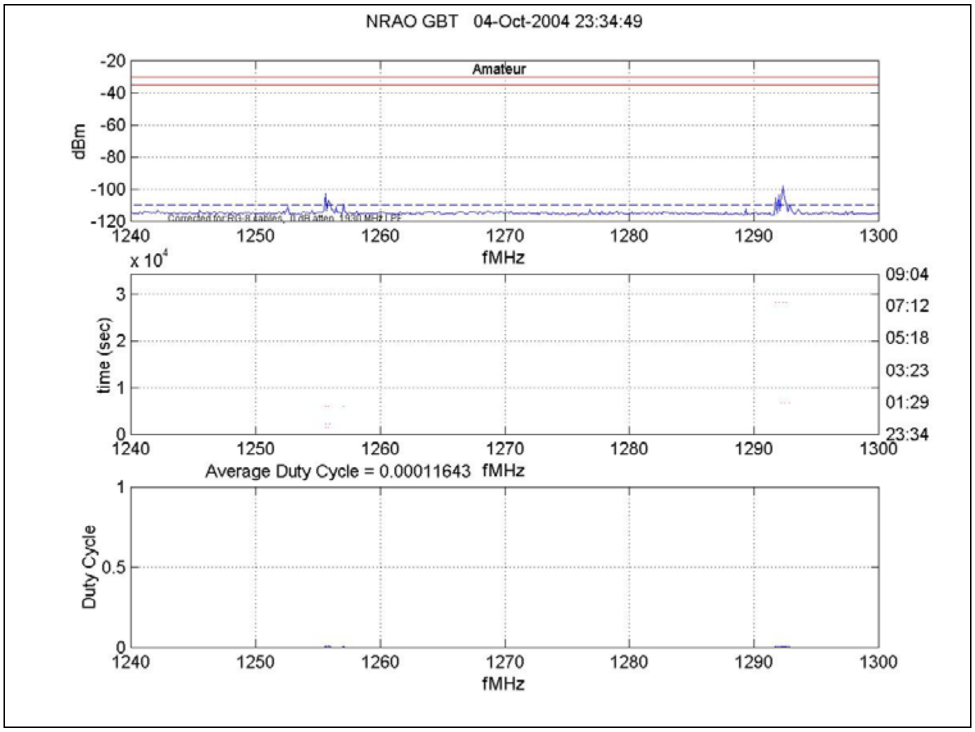


Figure 28: 1240 MHz – 1300 MHz

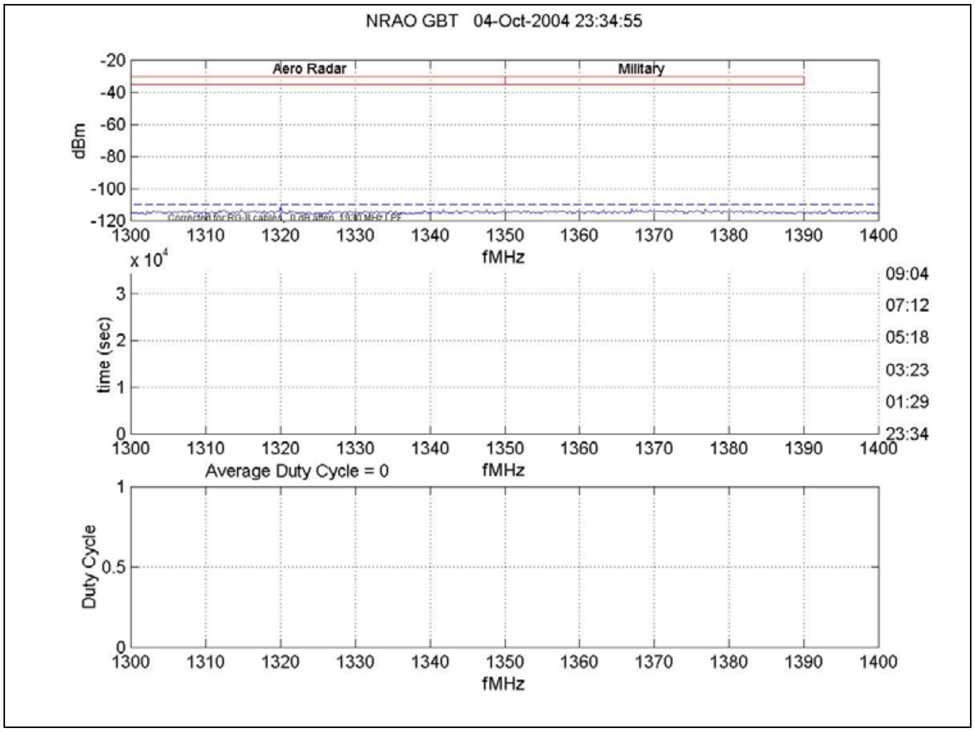


Figure 29: 1300 MHz – 1400 MHz

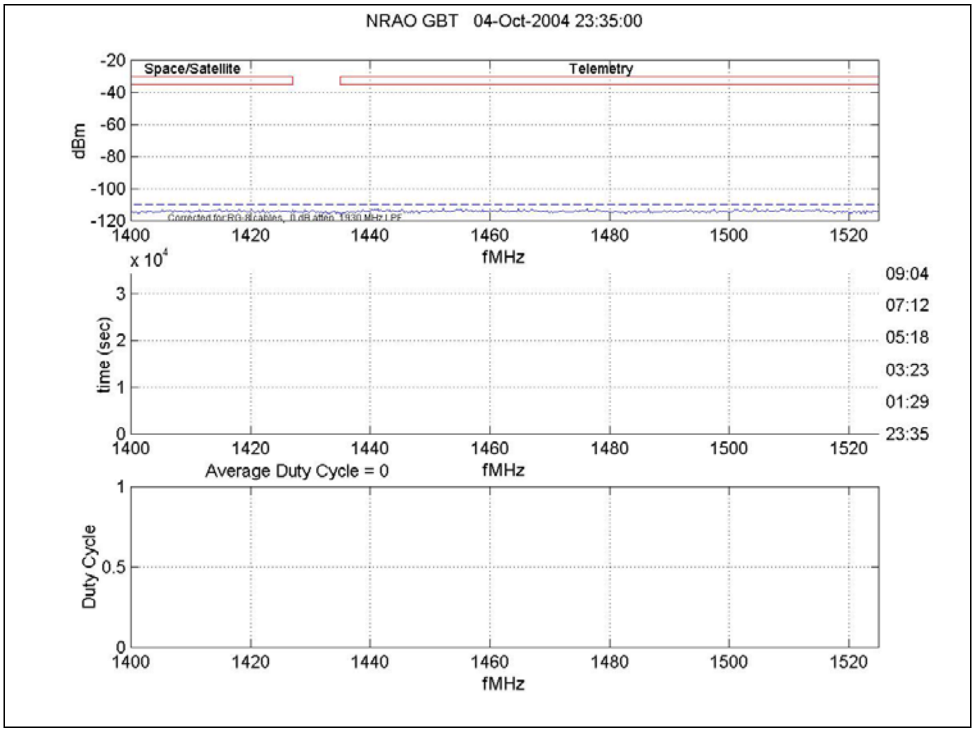


Figure 30: 1400 MHz – 1525 MHz

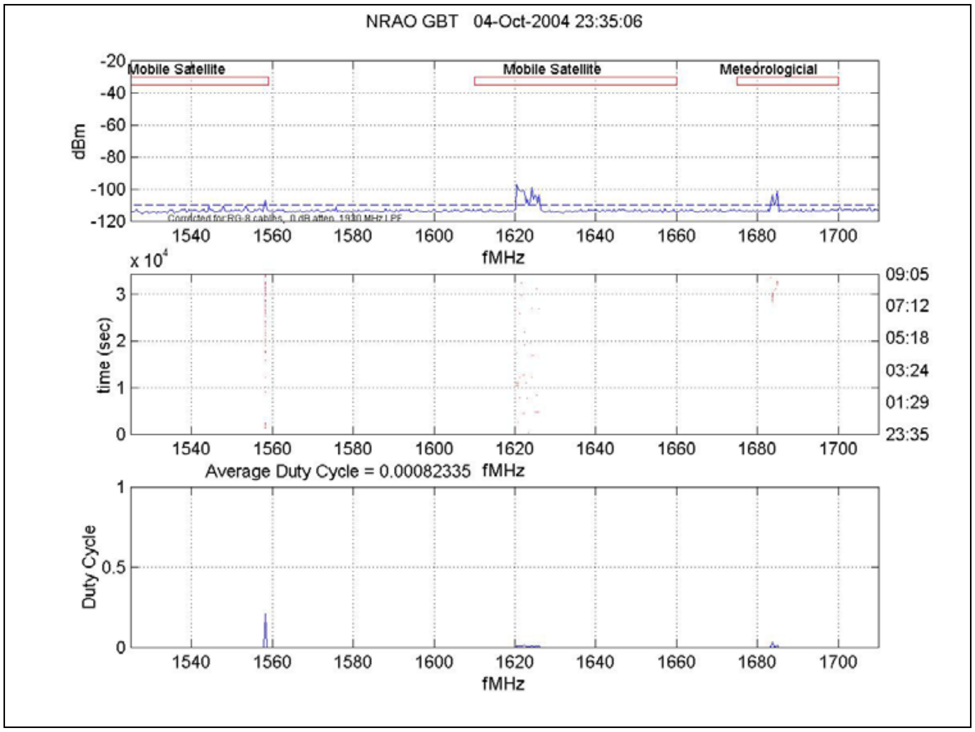


Figure 31: 1525 MHz – 1710 MHz

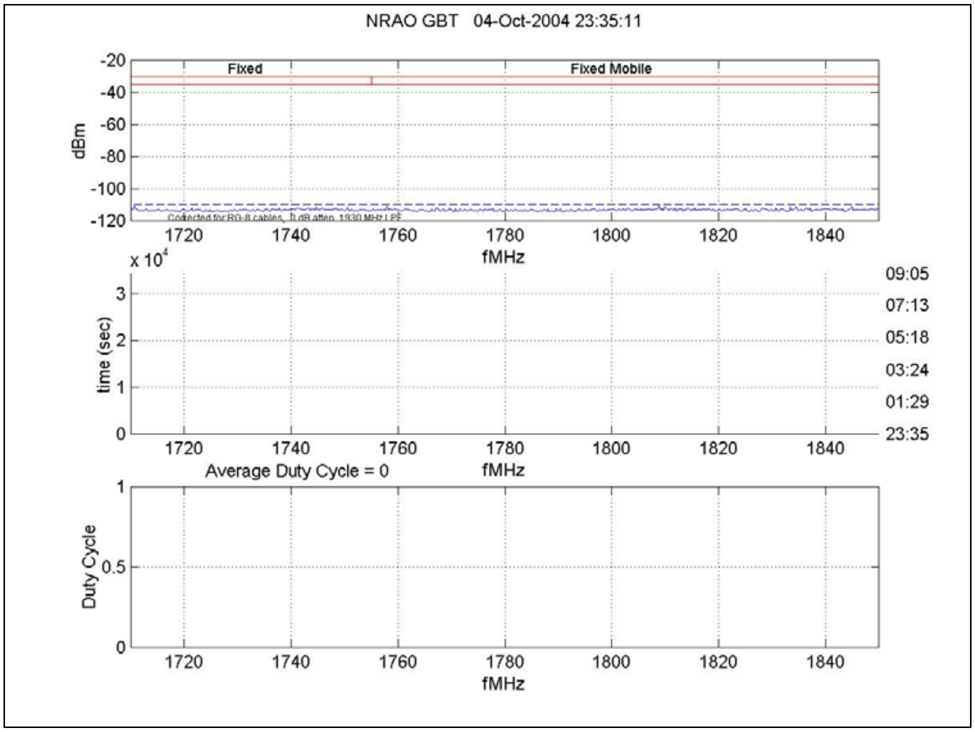


Figure 32: 1710 MHz – 1850 MHz

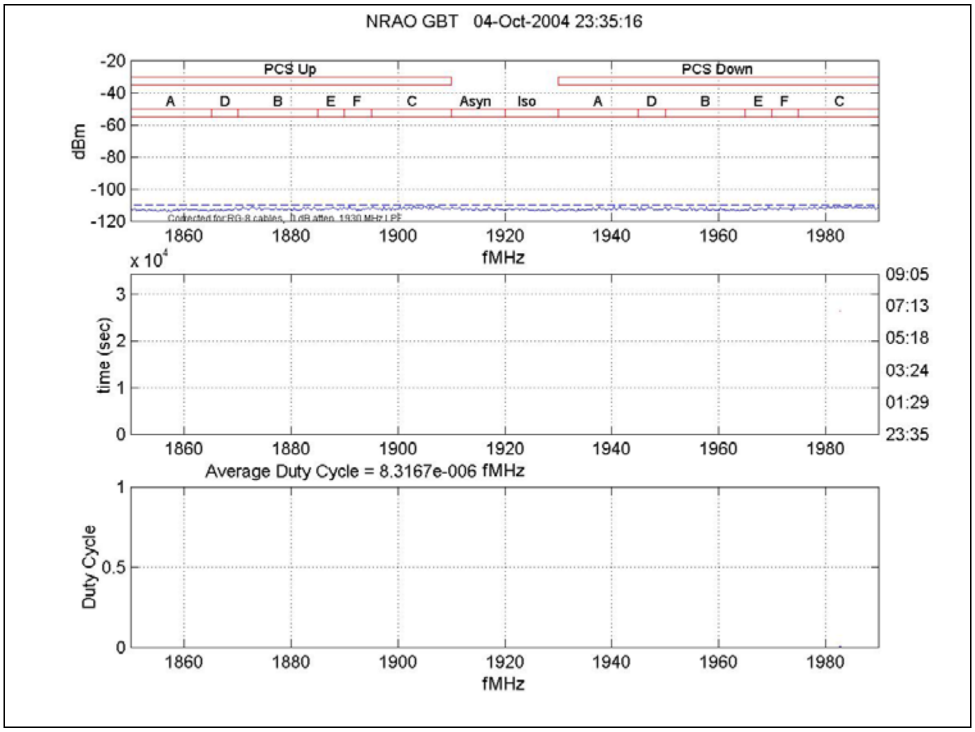


Figure 33: 1850 MHz – 1990 MHz

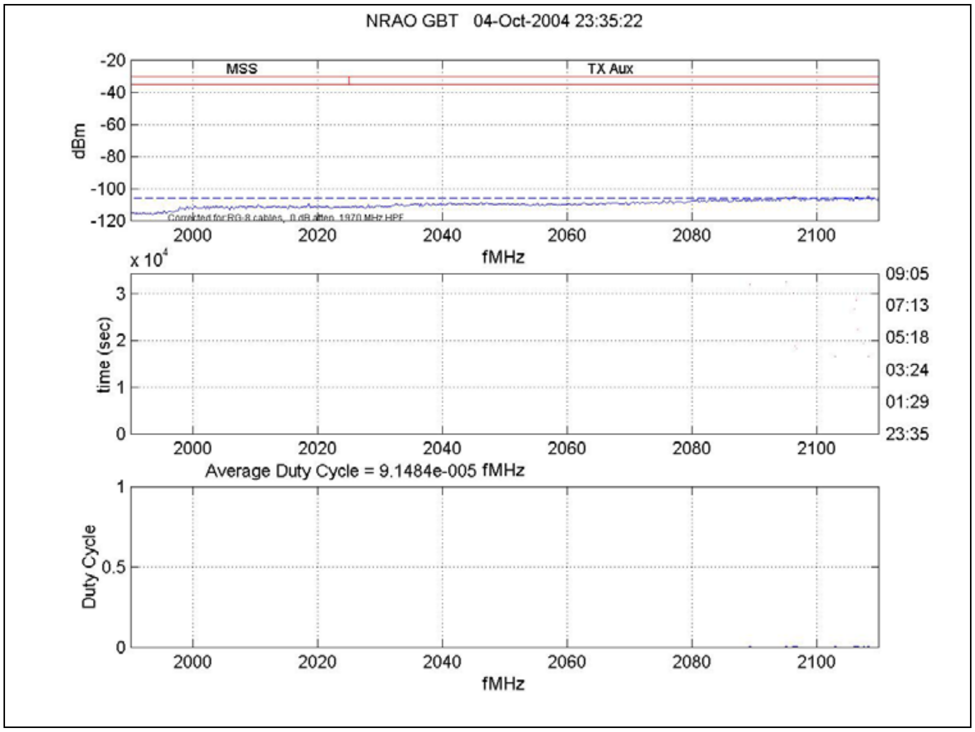


Figure 34: 1990 MHz – 2110 MHz

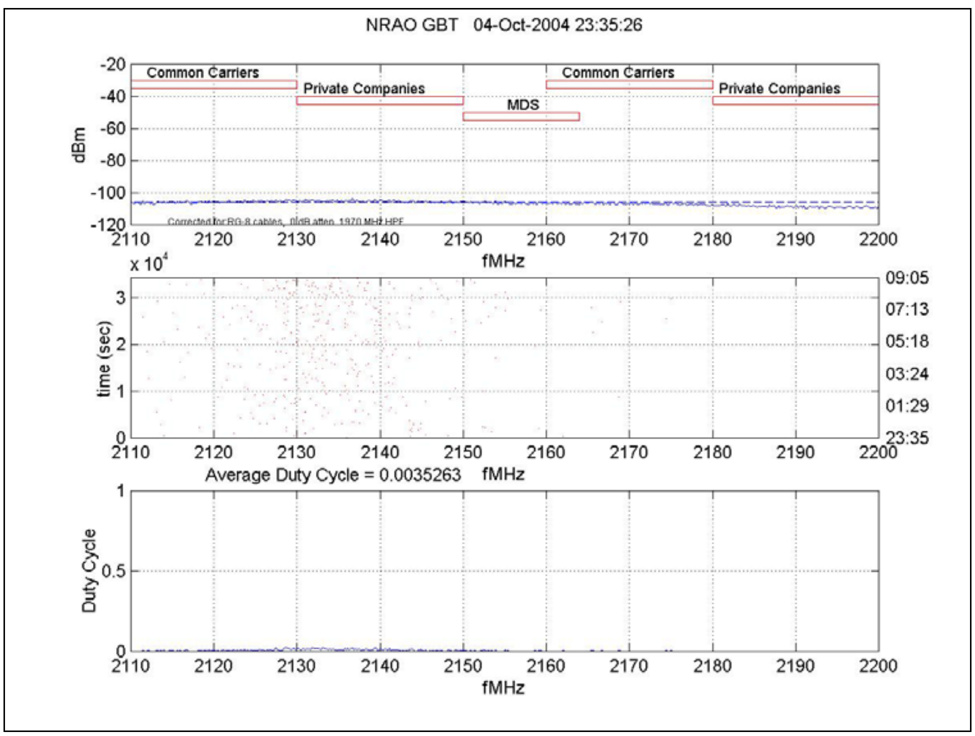


Figure 35: 2110 MHz – 2200 MHz

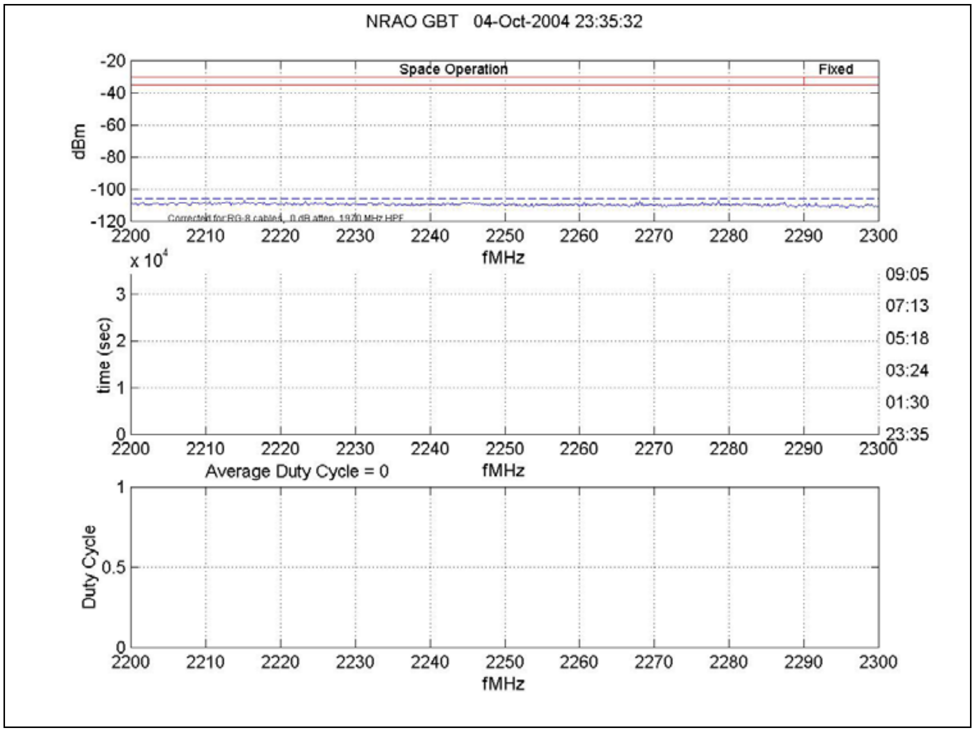


Figure 36: 2200 MHz – 2300 MHz

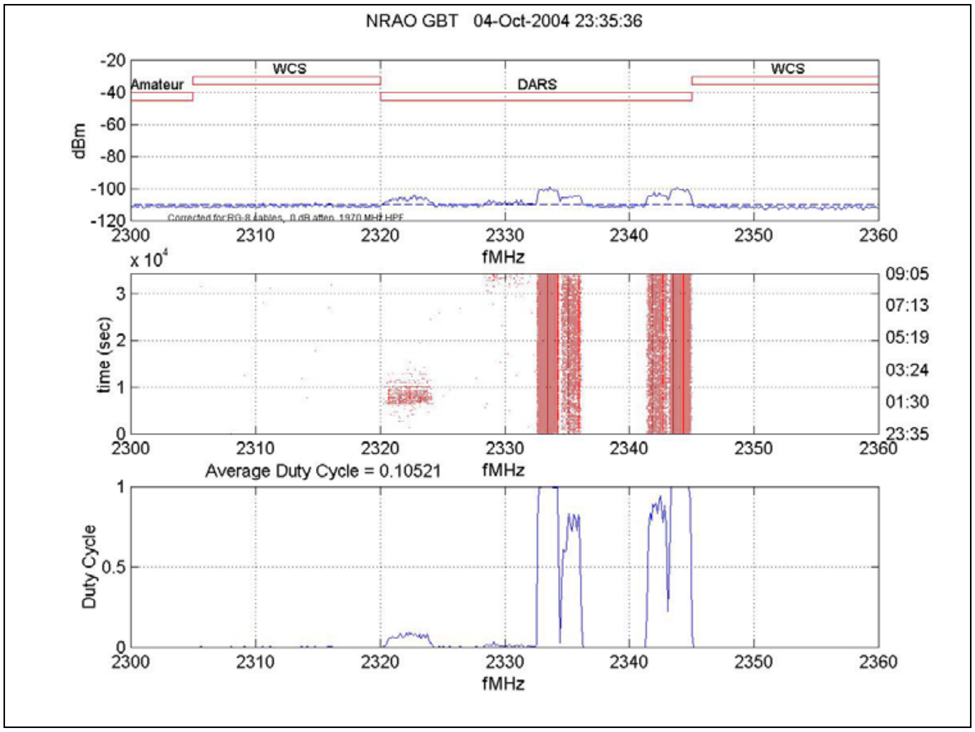


Figure 37: 2300 MHz – 2360 MHz

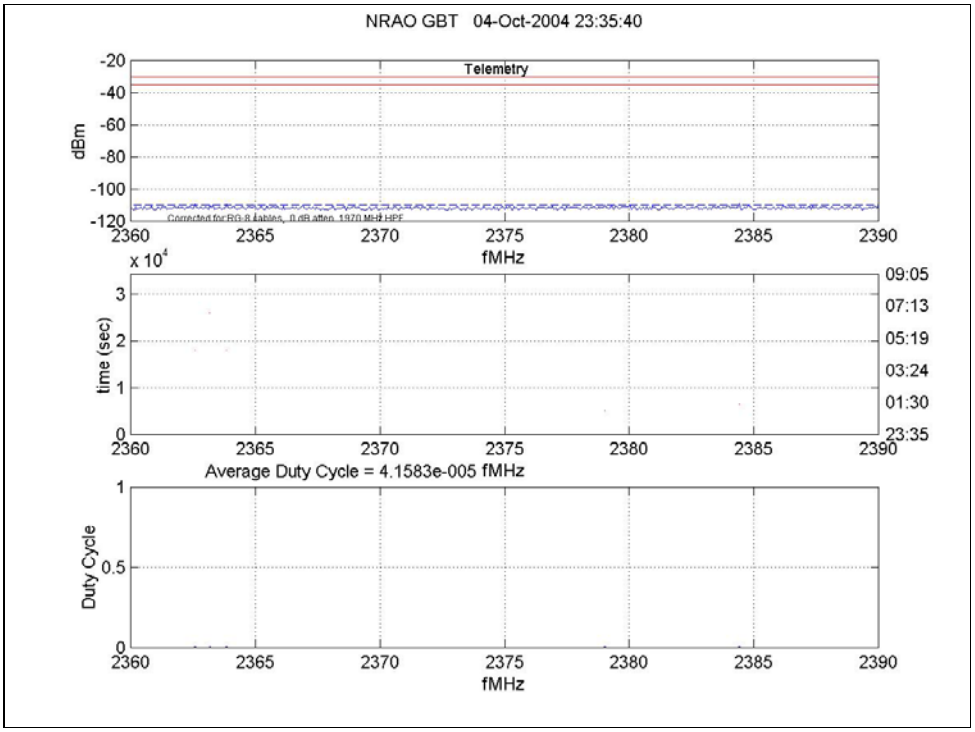


Figure 38: 2360 MHz – 2390 MHz

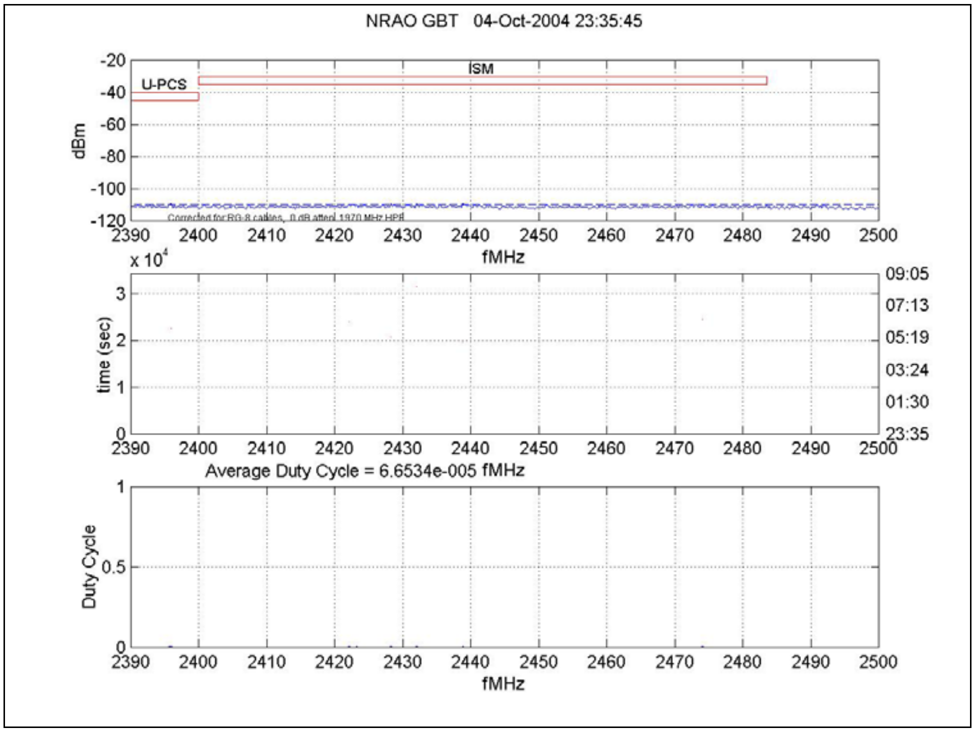


Figure 39: 2390 MHz – 2500 MHz

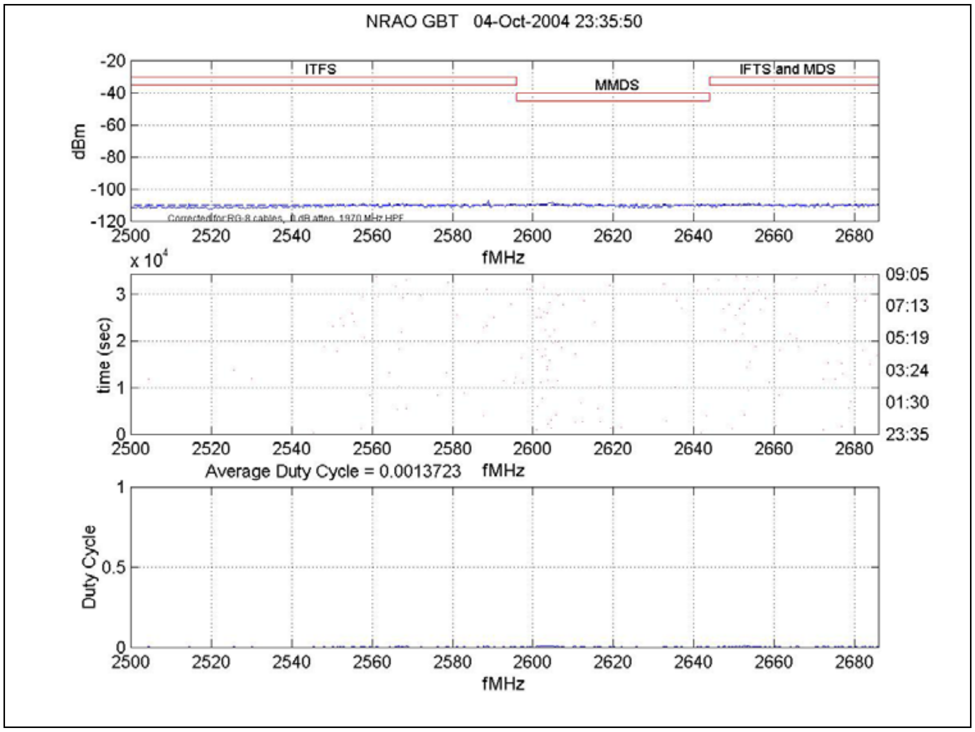


Figure 40: 2500 MHz – 2686 MHz

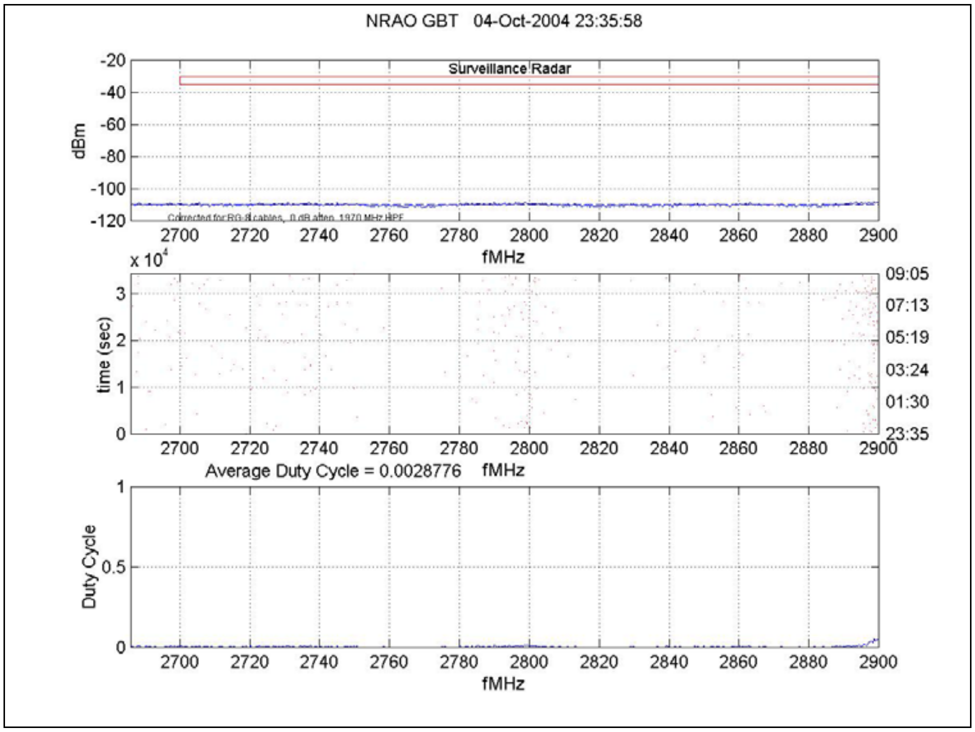


Figure 41: 2686 MHz – 2900 MHz

6. Conclusions

6.1 Introduction

Shared Spectrum Company concludes that less than 1% of the spectrum opportunities, both in frequency and time, were utilized at the Tyson's Square Center site on April 9, 2004. Analyses regarding these spectrum occupancy conclusions are provided in Table 7 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 7. The average duty cycle (in frequency and time) of each band is noted on the related spectrum plots shown in Section 0. The 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 (1%) is shown in the bottom row of Table 7. The total available spectrum (2850 MHz) is the sum of all of the bands measured. The overall occupied spectrum (26.14 MHz) is the sum from each band. The overall occupancy is the occupied spectrum divided by the total available spectrum.

Table 7: Summary of Spectrum Occupancy in Each Band

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	NRAO Spectrum Fraction Used	NRAO Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.00045	0.01	0.0%
54	88	34	TV 2 -6, RC	0.11056	3.76	11.1%
108	138	30	Air traffic Control, Aero Nav	0.15485	4.65	15.5%
138	174	36	Fixed Mobile, amateur, others	0.02745	0.99	2.7%
174	216	42	TV 7-13	0.00220	0.09	0.2%
216	225	9	Maritime Mobile, Amateur, others	0.00556	0.05	0.6%
225	406	181	Fixed Mobile, Aero, others	0.01842	3.33	1.8%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.00379	0.24	0.4%
470	512	42	TV 14-20	0.00379	0.16	0.4%
512	608	96	TV 21-36	0.04283	4.11	4.3%
608	698	90	TV 37-51	0.00156	0.14	0.2%
698	806	108	TV 52-69	0.00113	0.12	0.1%
806	902	96	Cell phone and SMR	0.00017	0.02	0.0%
902	928	26	Unlicensed	0.00004	0.00	0.0%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.02459	0.79	2.5%
960	1240	280	IFF, TACAN, GPS, others	0.00000	0.00	0.0%
1240	1300	60	Amateur	0.00012	0.01	0.0%
1300	1400	100	Aero Radar, military	0.00000	0.00	0.0%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00000	0.00	0.0%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorologicial	0.00082	0.15	0.1%
1710	1850	140	Fixed, Fixed Mobile	0.00000	0.00	0.0%
1850	1990	140	PCS, Asyn, Iso	0.00001	0.00	0.0%
1990	2110	120	TV Aux	0.00009	0.01	0.0%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00353	0.32	0.4%
2200	2300	100	Space Operation, Fixed	0.00000	0.00	0.0%
2300	2360	60	Amateur, WCS, DARS	0.10521	6.31	10.5%
2360	2390	30	Telemetry	0.00004	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.00007	0.01	0.0%
2500	2686	186	ITFS, MMDS	0.00137	0.26	0.1%
2686	2900	214	Surveillance Radar	0.00288	0.62	0.3%
Total		2850			26.14	
Total Available Spectrum					2570	
Average Spectrum Use (%)					1.0%	