Spectrum Occupancy Measurements Collected at the National Science Foundation Building Roof on April 16, 2004

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NSF Project: National Radio Research Testbed (NRNRT) Spectrum Occupancy Measurements and Pre-Selector Development
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Spectrum Measurements

I. Introduction

A. Summary

This document describes spectrum occupancy measurements made over multiple bands from to 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. Additional measurements were made at an RF quiet location (Riverbend Park in Northern Virginia) to establish the self-noise level of the spectrum measurement equipment.

B. Report Organization

The report is organized into four sections.

Section I is an introduction. Section II describes the measurement equipment and frequency lists used for the spectrum occupancy measurements. Section III describes the measurement location and the surrounding environment. Section IV is the main body of the report and shows the spectrum measurements. An appendix describes how the spectrum measurements were calibrated for amplifier gain, cable losses, and filter losses.

C. The National Radio Network Research Testbed (NTNRT)

These measurements are part of the National Radio Network Research Testbed (NTNRT) project. The NTNRT is a National Science Foundation project that supports research and development of new radio devices, services, and architectures, and provides a facility for the research community to test and evaluate their systems. The NRNRT consists of (1) a field deployed measurement and evaluation system for long-term radio frequency data collection and an experimental facility for testing and evaluating new radios, (2) an accurate emulation/simulation system incorporating long-term field measurement for evaluating new wireless network architectures, policies, and network protocols, and (3) experiments with innovative wireless networks that integrate analysis, emulation/simulation, and field measurements.

The NTNRT is managed by Gary Minden (785-864-4834) at the University of Kansas, Information and Telecommunication Technology Center, Center for Research, Incorporated. Request for electronic copies of this data should be addressed to Gary Minden, University of Kansas, (gminden@ittc.ku.edu) or to Mark McHenry (703-761-2818 x 103), Shared Spectrum Company, (mmchenry@sharedspectrum.com).

II. Measurement Equipment

A. Equipment Summary

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

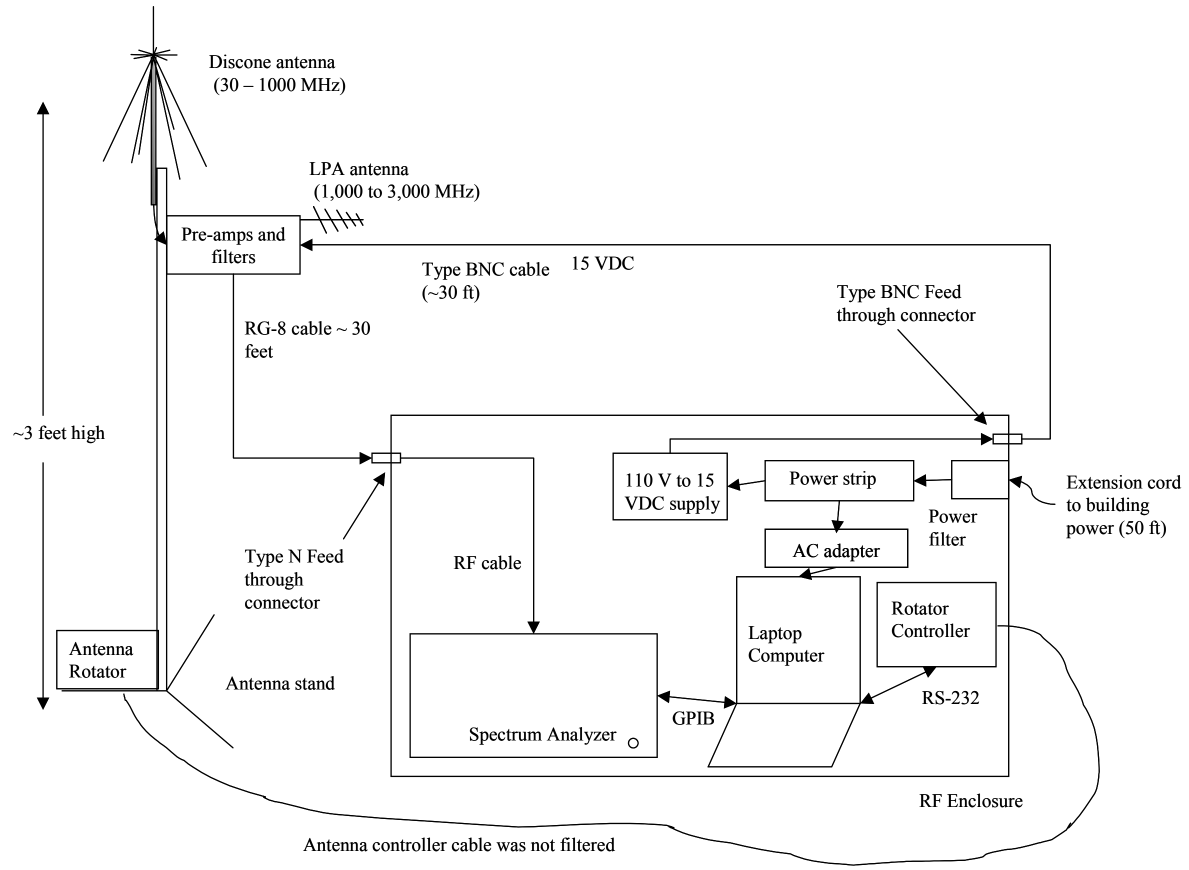

Figure 1: Spectrum occupancy measurement equipment configuration.

At the NSF location, the equipment was powered by a 50-foot long extension cord plugged into the building power. At the Riverbend Park location, the equipment was powered by a 50-foot long extension cord plugged into a gasoline power AC generator. The generator is believed to have added significant noise in the 30 MHz to 54 MHz band (especially at 45 MHz).

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.

B. Equipment Configurations for Each Run

Different equipment configurations were used for each run that are 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. Sections II.D and II.F provide information on the equipment.

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
Att (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 preamp	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.

C. 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)	Attenuation (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

D. RF Configuration Used Below 1,000 MHz

The configuration for signals below 1,000 MHz is shown in Figure 3. The FM bandstop 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.

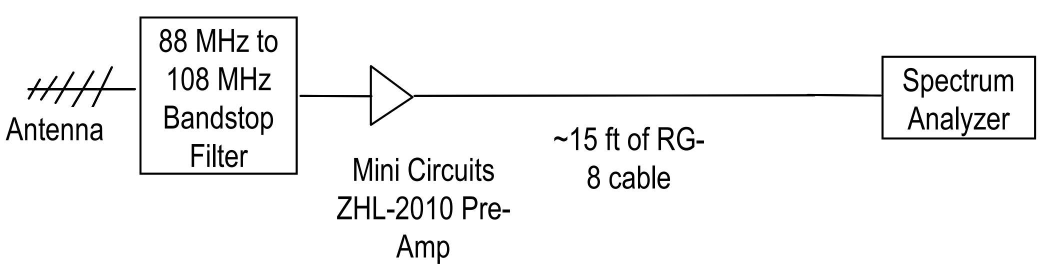

Figure 3: Equipment configuration used for signals below 1,000 MHz.

Figure 4: Omni-directional discone antenna (used for frequencies above 1,000 MHz).

E. 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

F. 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.

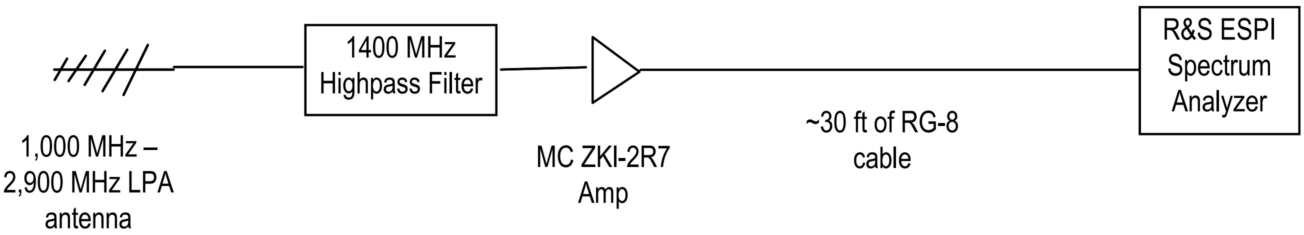

Figure 5: Equipment configuration used for signals above 1,000 MHz.

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 small LPA antenna is shown in Figure 7.

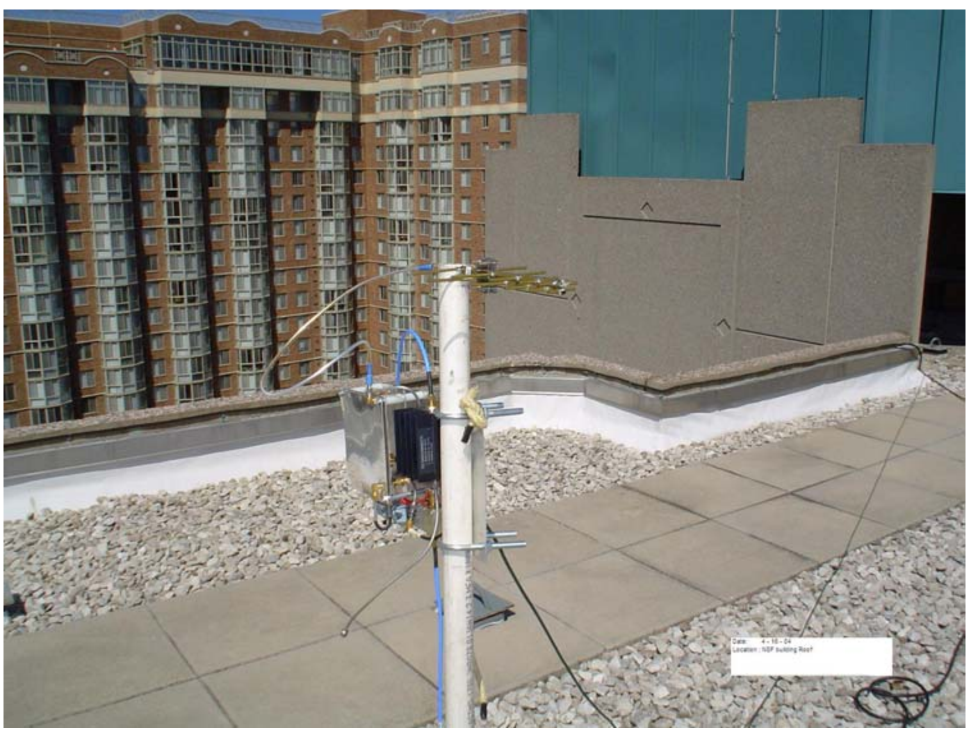

Figure 6: Small LPA antenna and pre-amplifier used for frequencies above 1 GHz.

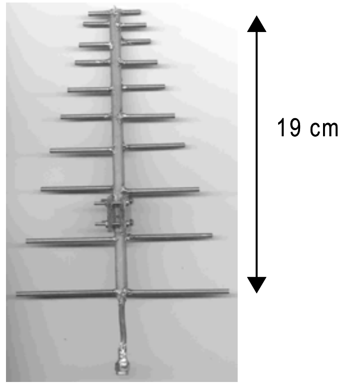

Figure 7: Directional antenna used for 1,000 MHz to 3,000 MHz, 19 cm long Log-Periodic Array (LPA).

III. Measurement Sites

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

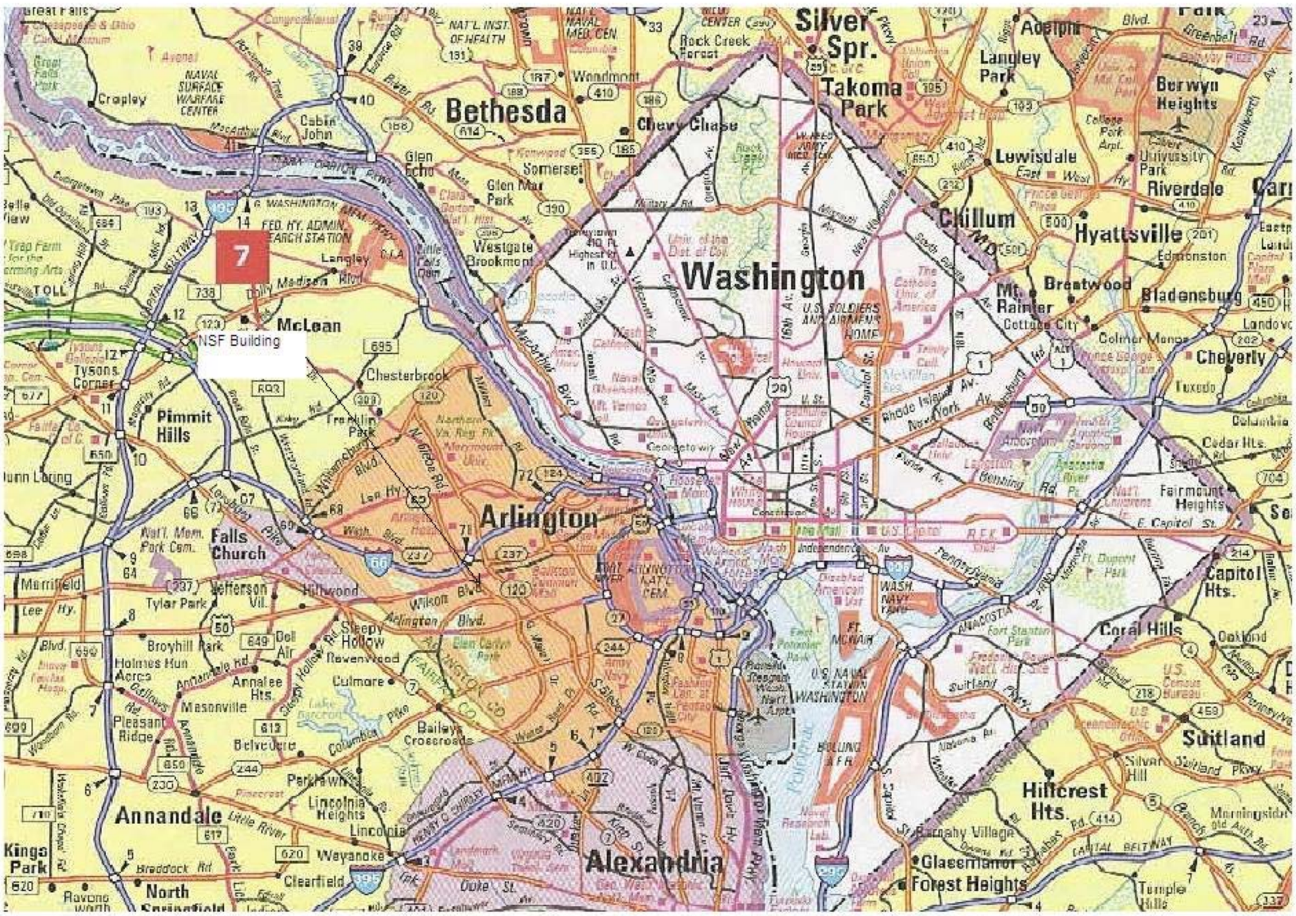

Figure 8: Map showing NSF measurement location.

Figure 9: View from the NSF measurement site looking towards the east.

Figure 10: View from the NSF measurement site looking towards the west.

B. Riverbend Park Measurement Site

To provide a baseline of the spectrum measurement equipment self-generated noise, measurements were made at an RF quiet area (Riverbend Park in Northern Virginia). This location is shown in Figure 11. Figure 12 and Figure 13 are photographs of the park area.

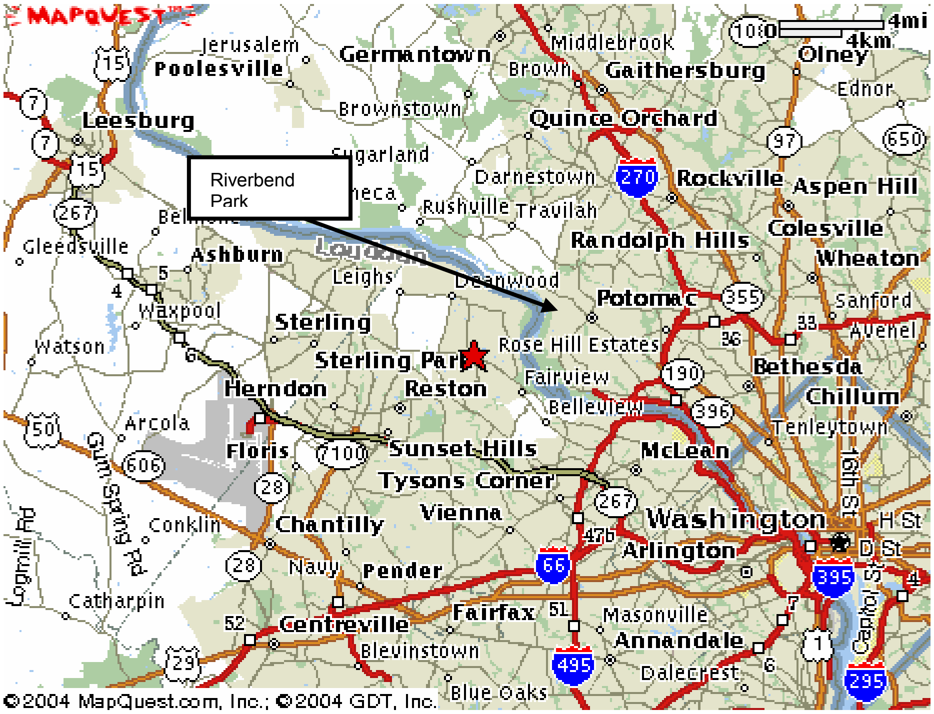

Figure 11: Map showing the Riverbend Park measurement location.

Figure 12: View from the measurement site looking towards NE.

Figure 13: View from Measurement site looking towards East

C. Near-By Transmitters and Potential Noise Sources

1. Transmitters

There were several near-by antennas not related to our experiment located on 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 (Figure 14). If these antennas were transmitting, they used a low power setting, and they did not over drive our spectrum measurement equipment.

Figure 14: Nearby, potentially transmitting antennas (> 50 feet away and blocked by building structure from collection antenna) at the NSF location.

2. Potential Noise Sources

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 heating/air conditioning equipment within 20 feet of the collection antenna. Photographs of each of them are shown in Figure 15, Figure 16, and Figure 17. Tests were not done to estimate any potential RF noise emitted by these items.

Figure 15: HVAC equipment located approximately 20 feet from the collection antenna at the NSF location.

Figure 16: HVAC equipment located approximately 20 feet from the collection antenna at the NSF location.

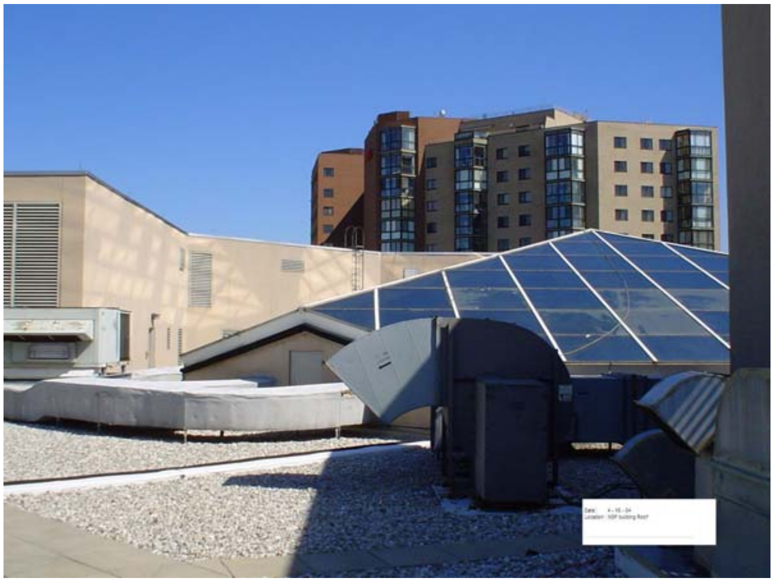

Figure 17: Building exhaust fan located approximately 20 feet from the collection antenna at the NSF location.

At the Riverbend Park location, there were nearby (~10 meters away) cars (shown in Figure 18) that were potential noise sources.

Figure 18: Noise sources (cars) in close proximity to the spectrum measuring equipment at the Riverbend Park location.