Spectrum Occupancy Measurements
Chicago, Illinois
November 16-18, 2005

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Project:
NeTS-ProWIN: Wireless Interference:
> Characterization and Impact on Network Performance
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1. Introduction

1.1 Summary

This document describes spectrum occupancy measurements performed by Shared Spectrum Company in conjunction with the Wireless Interference Lab of the Illinois Institute of Technology in Chicago, Illinois on November 16 to 18, 2005. This site was intentionally selected as an urban setting with a presumed high level of wireless activity. The research was funded by the National Science Foundation under its Computer and Information Sciences & Engineering organization and specifically its NeTS-ProWIN program.

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 Description of the Date Files Collected
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 for spectrum from both public and private sectors is increasing very rapidly, if not exponentially. Increasingly, there is recognition that most of the spectrum is actually unused and that real root of the problem is that 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 Chicago measurements was to gain a better understanding of the actual utilization of spectrum in this dense urban environment with the potential to identify spectrum bands with low occupancy. Occupancy was quantified as the amount of spectrum detected above a certain received power threshold.

1.4 NeTS-ProWIN: Wireless Interference: Characterization and Impact on Network Performance Project Goals

There has been a proliferation of wireless devices in recent years, particularly in the unlicensed bands and in emerging advanced radio technologies. This in turn has given rise to the problem of interference causing a severe degradation to the quality of data transmission and the network throughput. This situation will most certainly be aggravated as the variety of radiating devices in both licensed and unlicensed bands, and their level of use increases in the future. Thus far, this interference problem has received limited research focus.

The goals and objectives of the NeTS-ProWIN: Wireless Interference: Characterization and Impact on Network Performance Project are: to develop quantifiable characteristics of wireless receivers and both intentional and unintentional transmitting devices; to establish interference temperature as a metric to predict network performance; and to significantly enhance the interference modeling capabilities in existing network simulation tools. These will be accomplished through the development of transmitter and receiver models (using an iterative application of analysis, device simulation, and experimentation), and through network level simulation and experimentation. The research documented in this paper provides a very helpful beneficial context for the specific goals of our NSF program providing a supporting rationale for our modeling efforts and focus on interference temperature.

2. Measurement Equipment

2.1 Equipment Description

The equipment used for measurement in this study consisted of a spectrum analyzer, pre-selector, omni-directional discone antenna, a small log periodic array (LPA) for frequencies greater than 1000 MHz, and a laptop computer. A 40-foot RG-8 cable was used to connect the Pre-selector box, which is then connected to both of the antennas. Power was provided to the equipment using an extension cord plugged into a 120 volt AC outlet. A block diagram is shown in Figure 1.

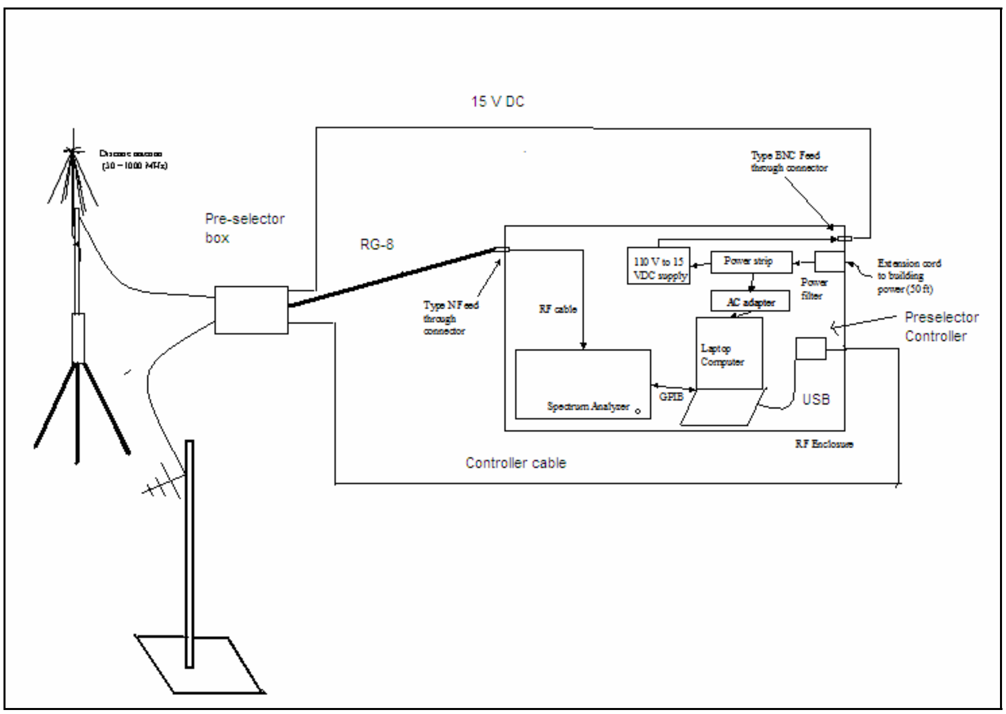

Figure 1: Spectrum Measurement Equipment Configuration

The discone was used for measuring signals below 1 GHz and LPA for measuring signals above 1 GHz as shown in Figure 2. The LPA antenna was tilted at 90^{o} to the horizontal. The Pre-selector was several meters from the antennas and sealed in a plastic bag for weather protection. The RF and other cables were routed down a building air vent to a room below the roof.

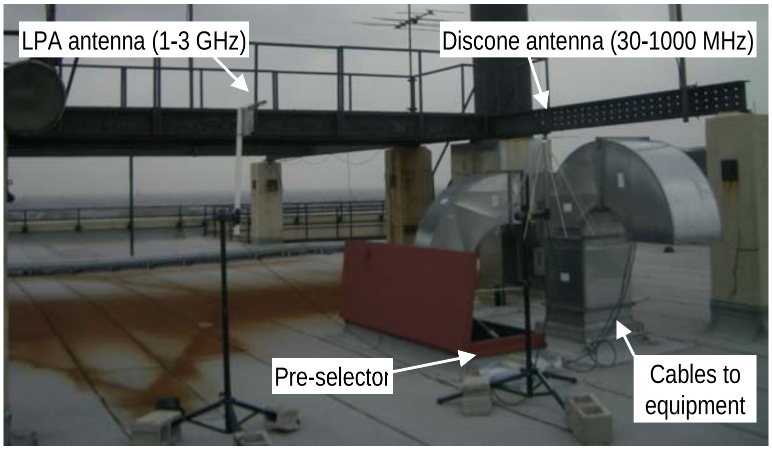

Figure 2: Antennas, Pre-selector Box, and Connections

The RF enclosure, spectrum analyzer and laptop were located in a room just below the roof as shown in Figure 3. When collecting data, all equipment was in the closed RF enclosure.

Figure 3: Shielded RF Enclosure Box Used to Reduce Emissions from Laptop and Spectrum Analyzer

Before each official measurement was taken at the site, test data was collected within the frequencies designated for this experiment. The test data was examined to ensure that all equipment was operating properly, as well as to identify strong signals that could potentially overload the pre-amplifier or the spectrum analyzer. Then the pre-selector attenuation value, the pre-selector filter choice, the spectrum analyzer reference level, the spectrum analyzer RF attenuation and the spectrum analyzer pre-selection (on or off) were varied in each band to optimize sensitivity.

After the equipment configuration was finalized, long duration collections were made using the designated frequency lists described later in this report. Separate files were created for each collection on a frequency list. The file size was dependent upon the number of frequency bands.

Official measurements began on November 16, 2005. Day 1 of the study took place over a 24-hour data-collection period from November 16 through November 17. Day 2 took place over a second 22-hour collection period from November 17 through November 18.

2.2 Pre-Selector Description

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

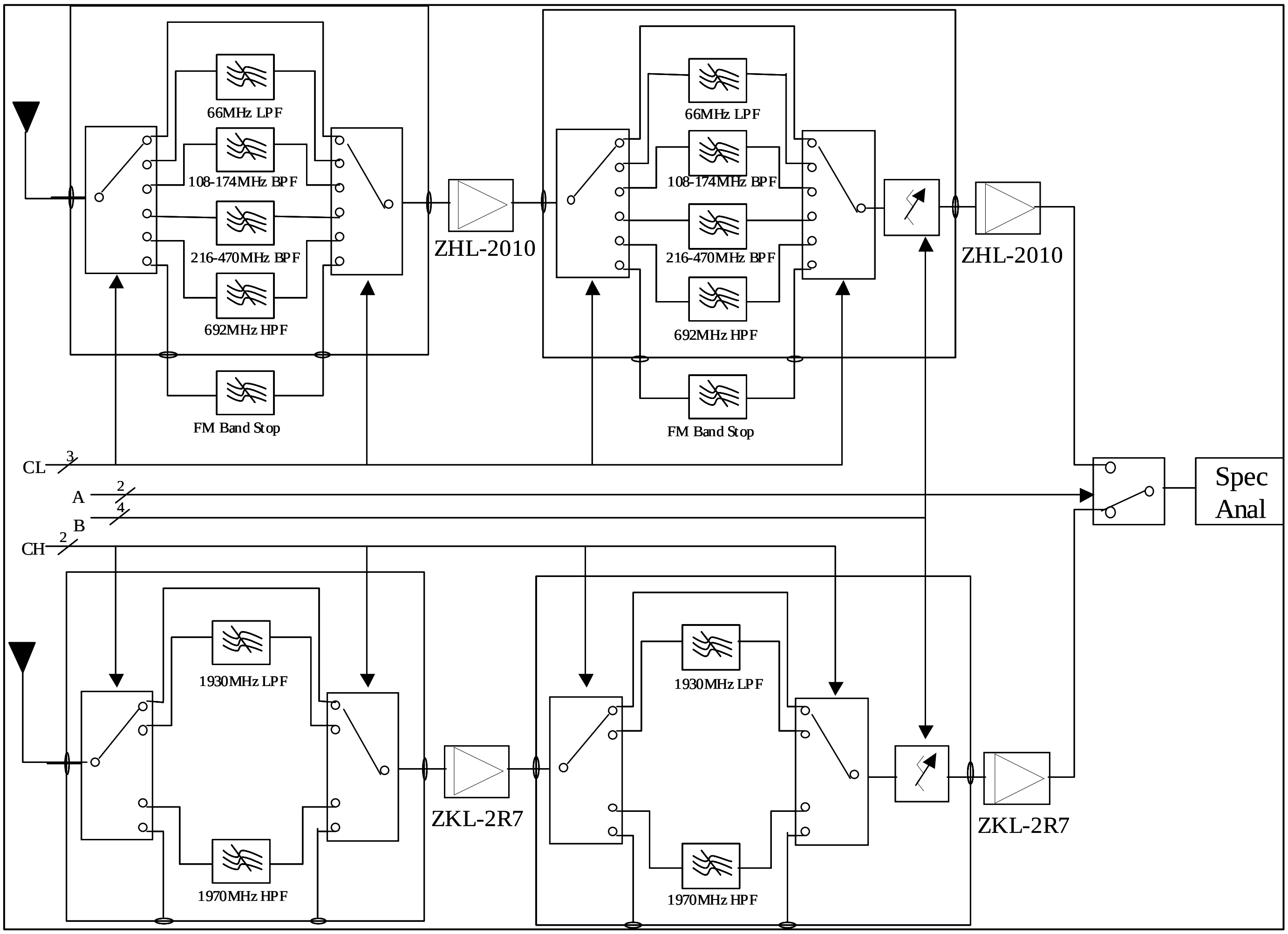

Figure 4: Pre-Selector Block Diagram

As illustrated in Figure 4, there are four ports of logic lines that control the Pre-selector. Port A (bits 0 and 1) controls the amplifier regulators and the band select filter that switches between the < 1 GHz and >1 GHz antennas. Port B (bits 0, 1, 2, and 3) control the digital attenuators for both band.

2.3 Equipment Settings

Table 1 shows the equipment settings used for all bands.

Table 1 Equipment Settings for Each Spectrum Band

Start Frequency (MHz)	Stop Frequency (MHz)	Pre-selector				Spectrum Analyzer				
		Band	Attenuation (dB)-	Filter A	Filter B	RBW (kHz)	VBW (kHz)	Attenuation (dB)	Ref Level (dBm)	Pre-selector (on/off)
30	54	1	30	0	0	10	10	20	-10	1
54	88	1	30	4	0	10	10	20	0	1
108	138	1	30	2	0	10	10	20	-10	1
138	174	1	20	2	0	10	10	20	-10	1
174	216	1	30	4	0	10	10	20	-10	1
216	225	1	10	3	0	10	10	10	-20	1
225	406	1	10	3	0	10	10	10	-20	1
406	470	1	20	3	0	10	10	10	-20	1
470	512	1	20	4	0	10	10	10	-20	1
512	608	1	20	4	0	10	10	10	-20	1
608	698	1	30	4	0	10	10	10	-20	1
698	806	1	20	5	0	10	10	10	-20	1
806	902	1	20	5	0	10	10	10	-5	1
902	928	1	20	5	0	10	10	10	-20	1
928	960	1	20	5	0	10	10	10	-20	1
960	1240	1	20	5	0	10	10	10	-20	0
1240	1300	2	0	0	0	10	10	10	-20	0
1300	1400	2	0	0	0	10	10	10	-20	0
1400	1525	2	0	0	0	10	10	10	-20	0
1525	1710	2	0	0	0	10	10	10	-20	0
1710	1850	2	0	0	0	10	10	10	-20	0
1850	1990	2	10	0	2	10	10	10	-20	0
1990	2110	2	0	0	1	10	10	10	-20	0
2110	2200	2	0	0	1	10	10	10	-20	0
2200	2300	2	0	0	1	10	10	10	-20	0
2300	2360	2	0	0	1	10	10	10	-20	0
2360	2390	2	0	0	1	10	10	10	-20	0
2390	2500	2	0	0	1	10	10	10	-20	0
2500	2686	2	0	0	1	10	10	10	-20	0
2686	2900	2	0	0	1	10	10	10	-20	0

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

The measurements were made at the Illinois Institute of Technology (IIT), Chicago, Illinois. The specific collection site was on top of the IITRI Tower building located at 10 W 35th St Chicago, IL 60616.

3.1 Location

A map of the measurement location is shown in Figure 4, below. The IIT campus is approximately three miles south of downtown Chicago.

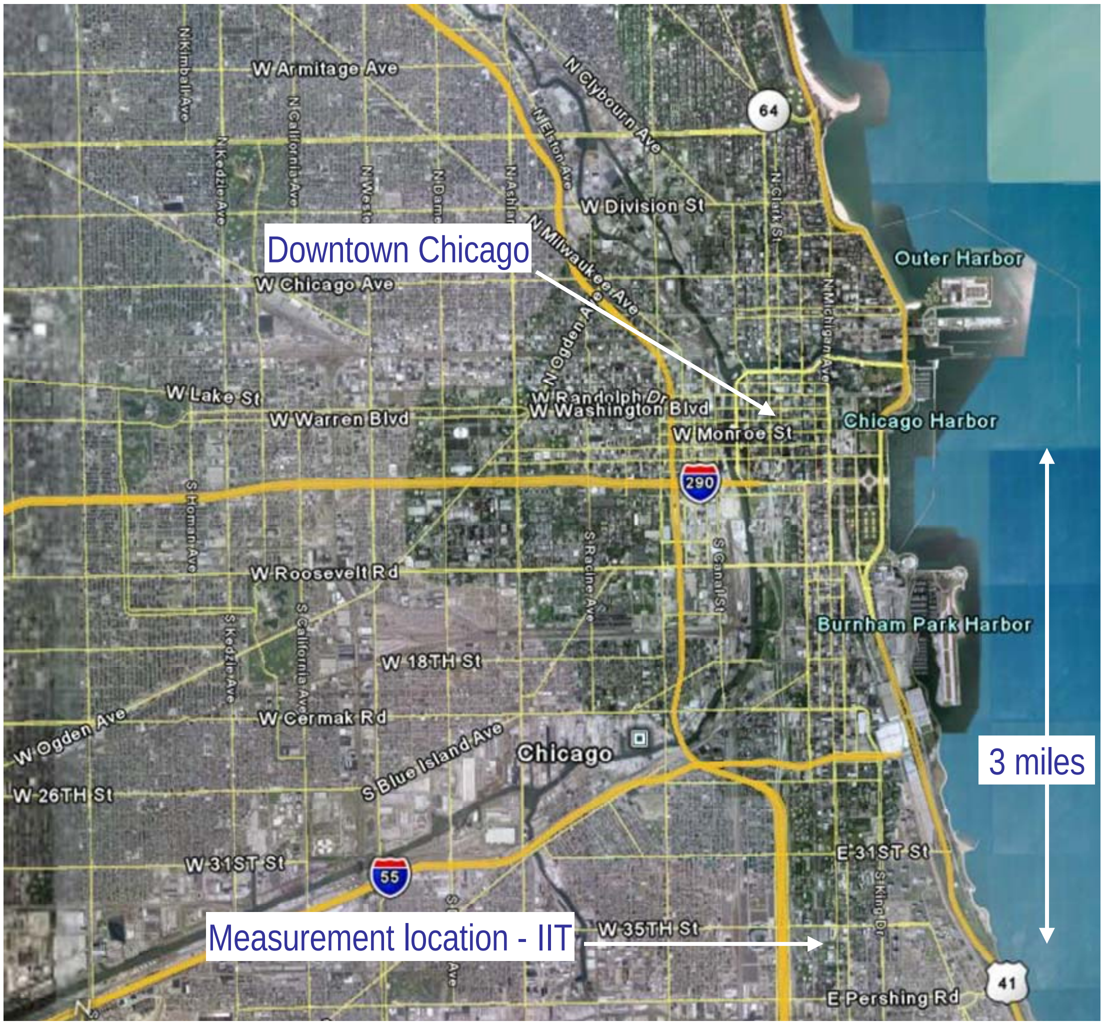

Figure 5: Map Showing Location of the Measurement Site

The IIT Tower has an unobstructed view in all directions as shown in Figure 6.

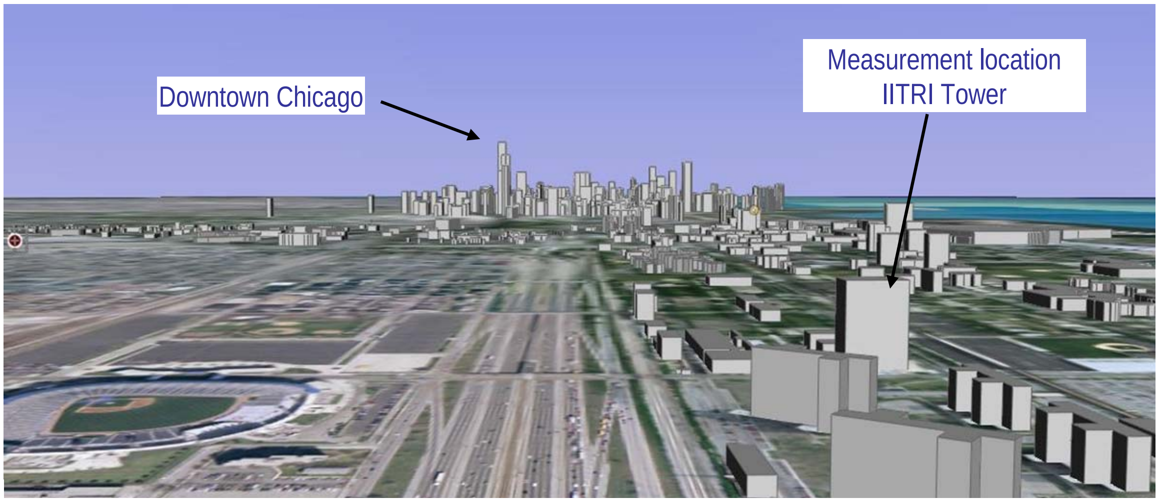

Figure 6 The IITRI Tower has direct line-of-sight to downtown Chicago and is the tallest building in the vicinity.

The measurement antennas were located on top of the building near the center at the location shown in Figure 7.

Figure 7 Top view of the IIT building showing the measurements system antenna location.

3.2 Views from Measurement Site

The subsequent figures in this section show photographs taken from the measurement antenna location, looking out in different directions.

Figure 8: View from Measurement Site to the North (Chicago).

Figure 9 View from Measurement Site to the East (Lake Michigan).

Figure 10 View from Measurement Site to the West (White Sox stadium U.S. Cellular Field).

3.3 Near-By Transmitters and Potential Noise Source

The IITRI Tower building has several transmitters on the roof. These include three Fire and Police radio channels at 153.950 MHz to 154.220, seven Fire and Police radio channels from 465.625 MHz to 468.3250, and a Cingular Wireless cell phone base station operating from 1930 MHz to 1945 MHz. The signal strength from these transmitters at our antenna was low enough to not cause significant overload to the spectrum measurement system.

The IITRI Tower has various heating and air conditioner systems on the roof that are potential broadband RF noise sources. The signals emitted by these systems are believed to be negligible. No tests were done to estimate these RF noise levels. The location of the heating and air conditioner systems relative to our tripod mounted antennas is shown in Figure 11.

Figure 11: Rooftop Equipment that was Possible Noise Sources nearby the Spectrum Measuring Equipment (antennas using tripod antennas).

4. Data Files Collected

Table 2 shows the details of the data files that were collected. Each file contained a spectrum analyzer sweep for each band in the frequency list shown in Table 1. The individual file size is 123 k.

Table 2. Spectrum Measurement Files

Filename	Start Number	End Number	Date	Start Time	End Time	Notes
ssc_Chicago_Nov_2005_X.dat	1	11	11/14/2005	3:23 pm	3:44 pm	Time zone set to Eastern time zone by mistake, file date is incorrect. Used old version of input file.
2005_1116_Chicago X.dat	12	52	11/16/2005	2:36 pm	4:36 pm	File 52 is bad. Used modified version of input file.
2005_1116_Chicago X.dat	53	970	11/16/2005-11/18/2005	5:20 pm	2:40 pm	Long-term collection file. Used final version of input file.

5. Spectrum Measurements

This section contains plots of the spectrum occupancy measurements.

5.1 Plot Format Description

The first subplot represents the maximum power value versus frequency measured during the period. The power values are the levels at the antenna port, and are corrected for cable losses, filter losses, and amplifier losses. The time shown on the plot is the measurement start time.

The second subplot is a waterfall-type of plot showing occupancy versus time and frequency. Occupancy is determined when the power level exceeds a threshold. The threshold value was intentionally selected for each run, and is shown as a dotted line on the upper subplot. Note that, in some cases, the noise level exceeds the threshold, causing inflated occupancy levels. To correct this, the threshold would have had to be hand-selected for each plot, which was not done.

The third subplot 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 that the signal was on during the entire period of measurement collection, and vice versa.

5.2 Measurements Made Below 1,000 MHz

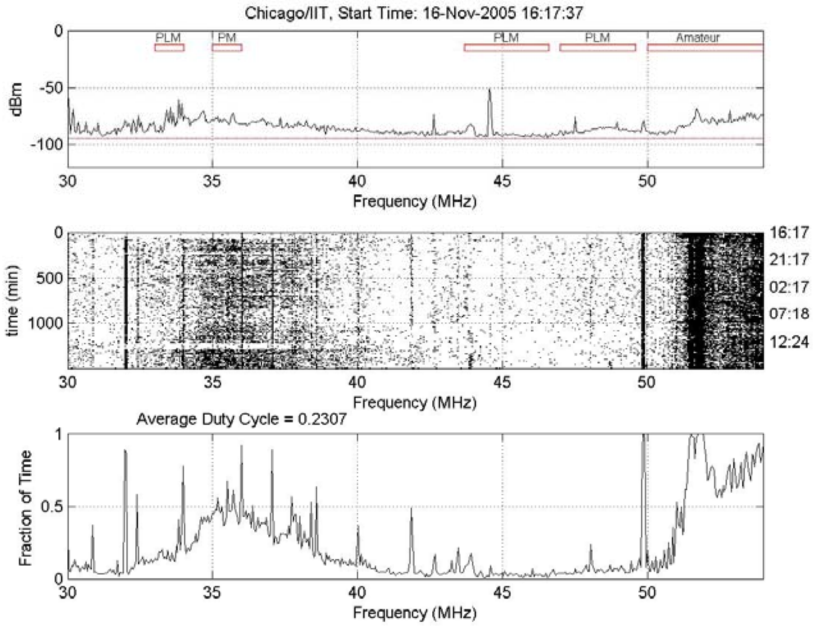

Figure 12: 30 MHz to 54 MHz, 24 hour period starting on November 16

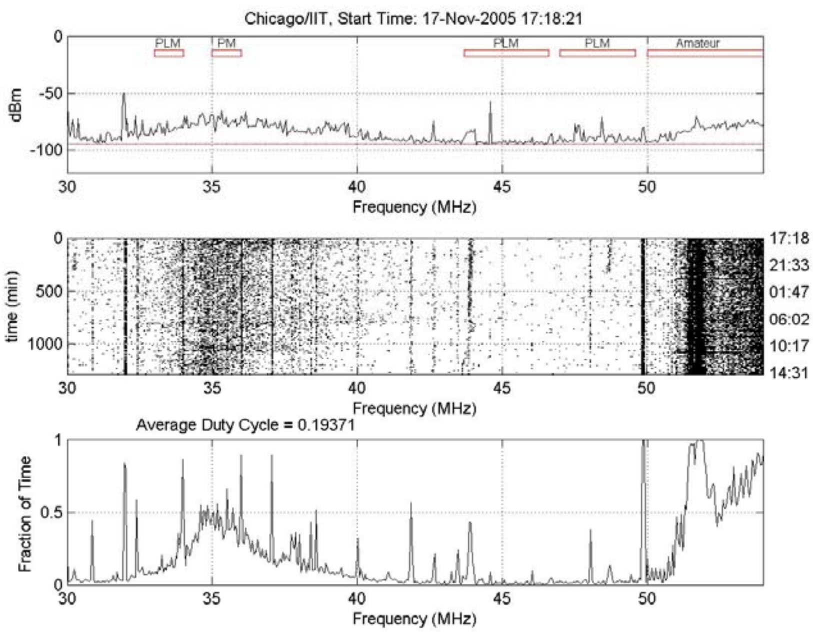

Figure 13: 30 MHz to 54 MHz, 22 hour period starting on November 17

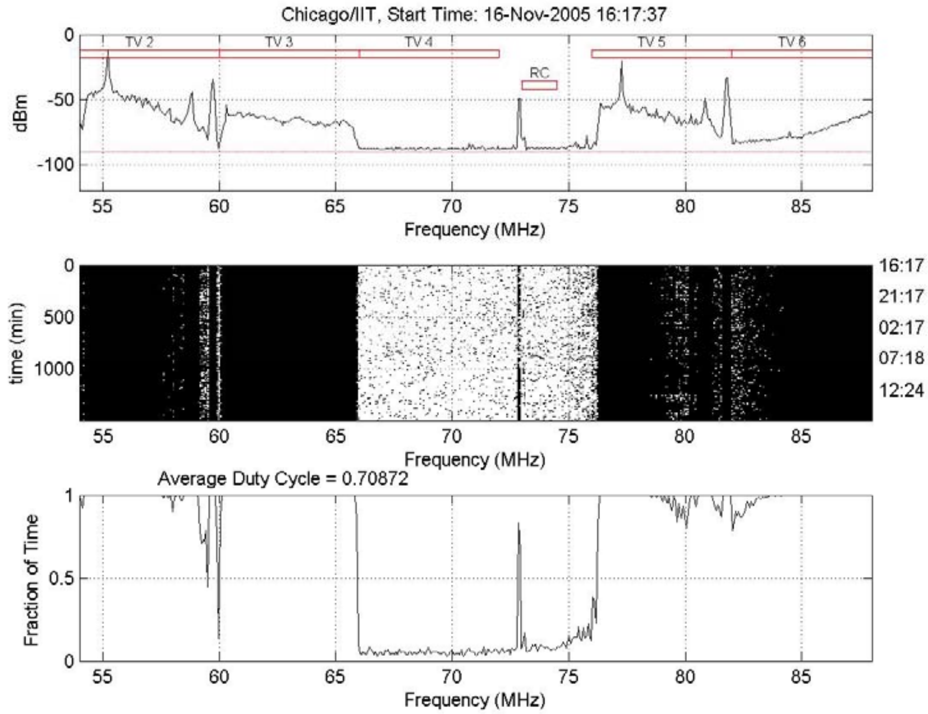

Figure 14: 54 MHz to 88 MHz, 24 hour period starting on November 16

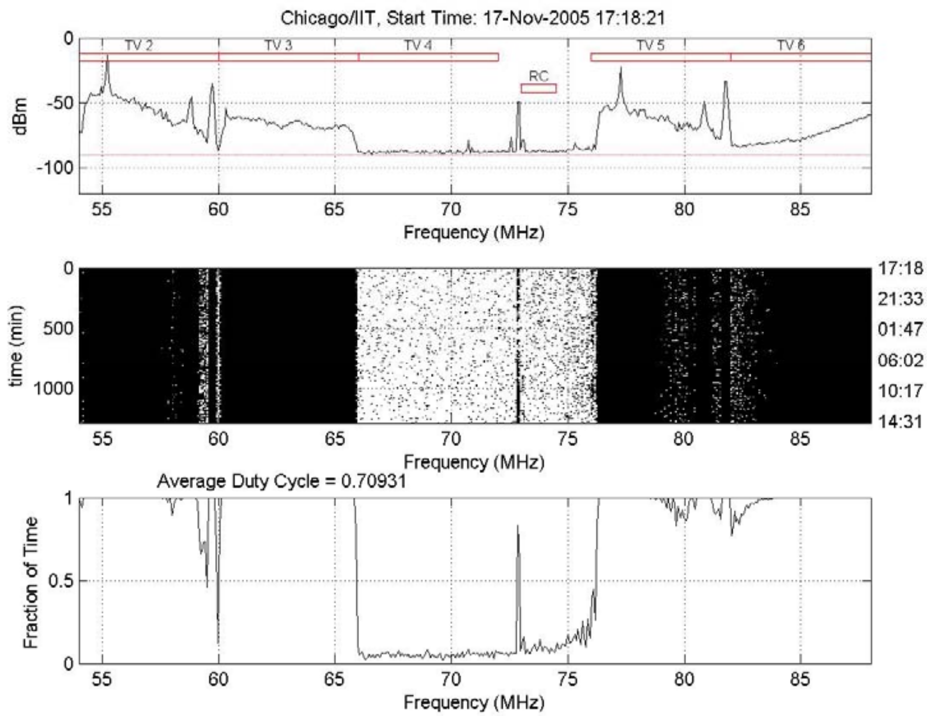

Figure 15: 54 MHz to 88 MHz, 22 hour period starting on November 17

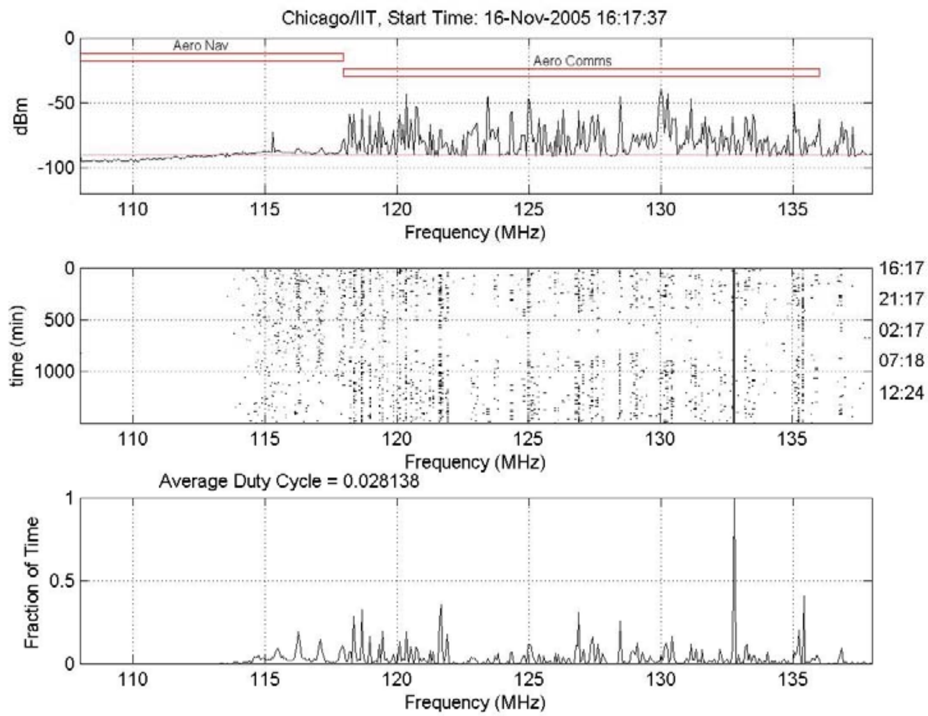

Figure 16: 108 MHz to 138 MHz, 24 hour period starting on November 16

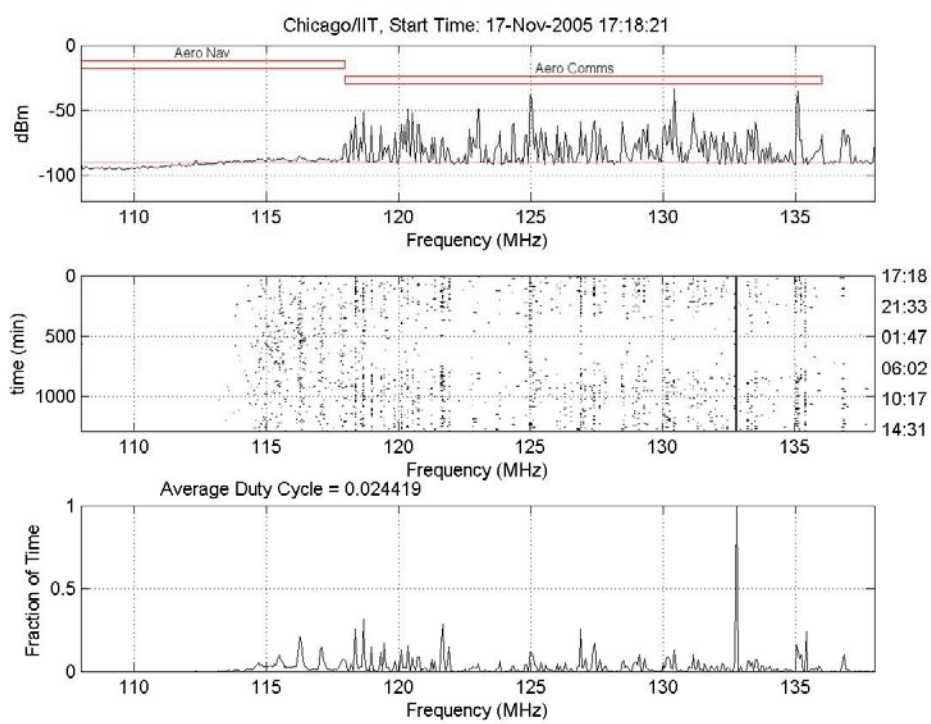

Figure 17: 108 MHz to 138 MHz, 22 hour period starting on November 17

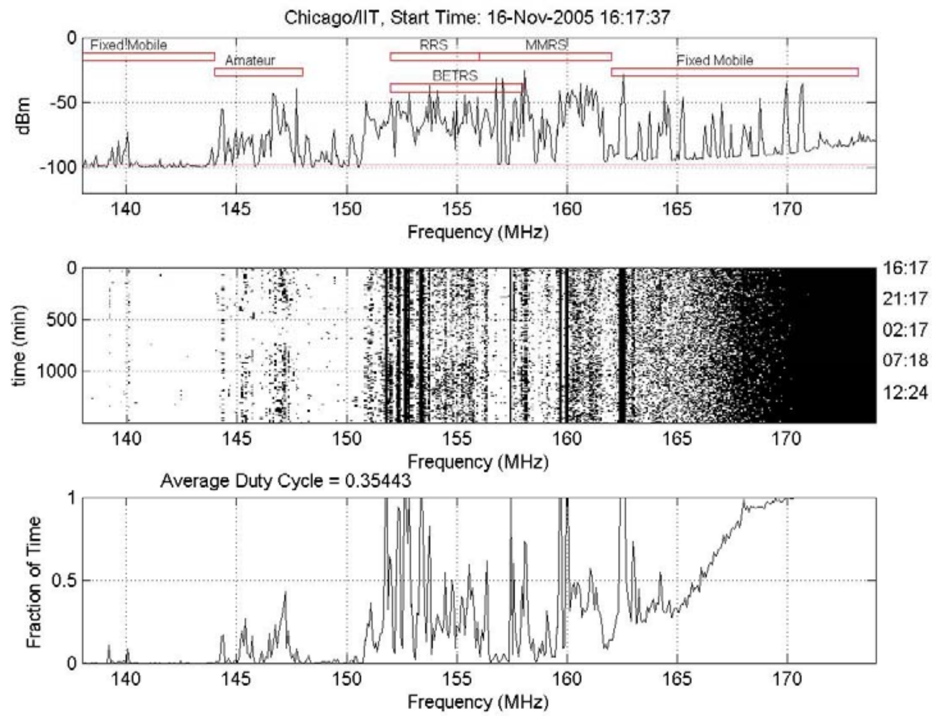

Figure 18: 138 MHz to 174 MHz, 24 hour period starting on November 16

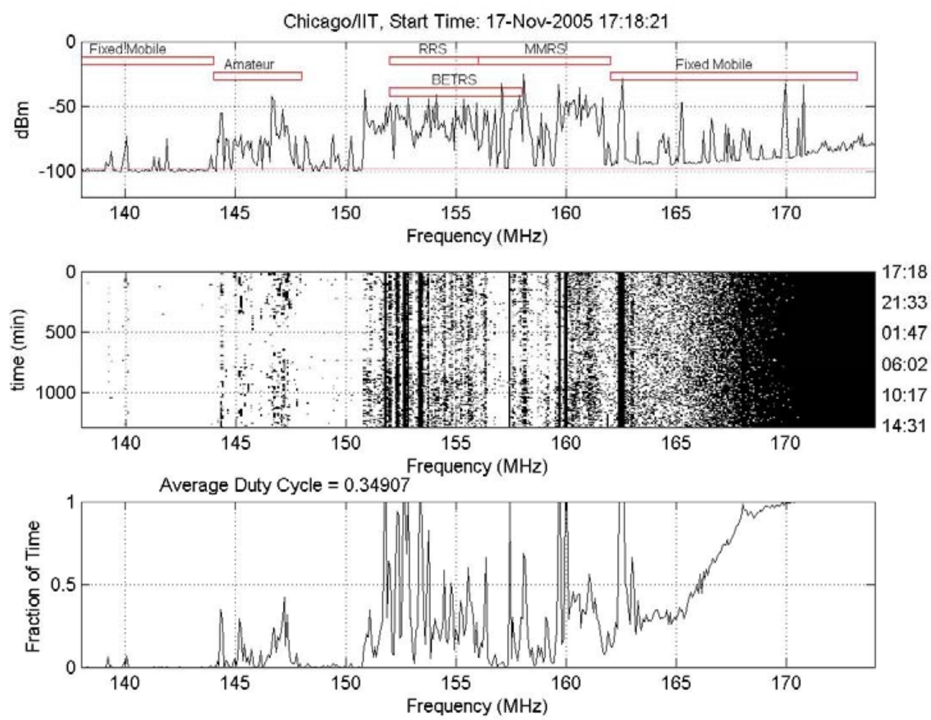

Figure 19: 138 MHz –174 MHz, 22 hour period starting on November 17

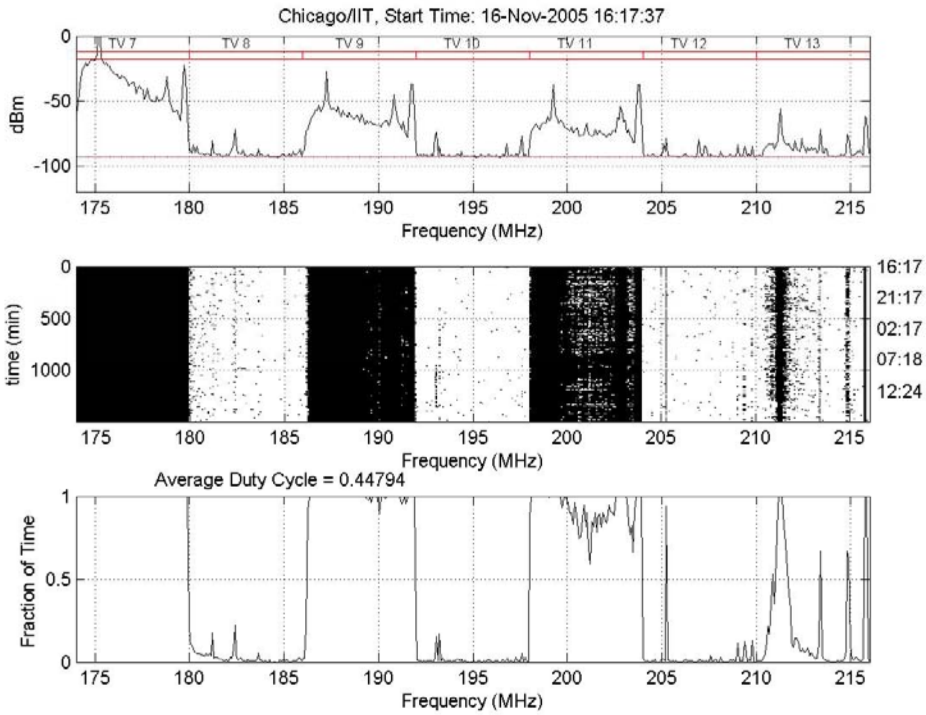

Figure 20: 174 MHz to 216 MHz, 24 hour period starting on November 16

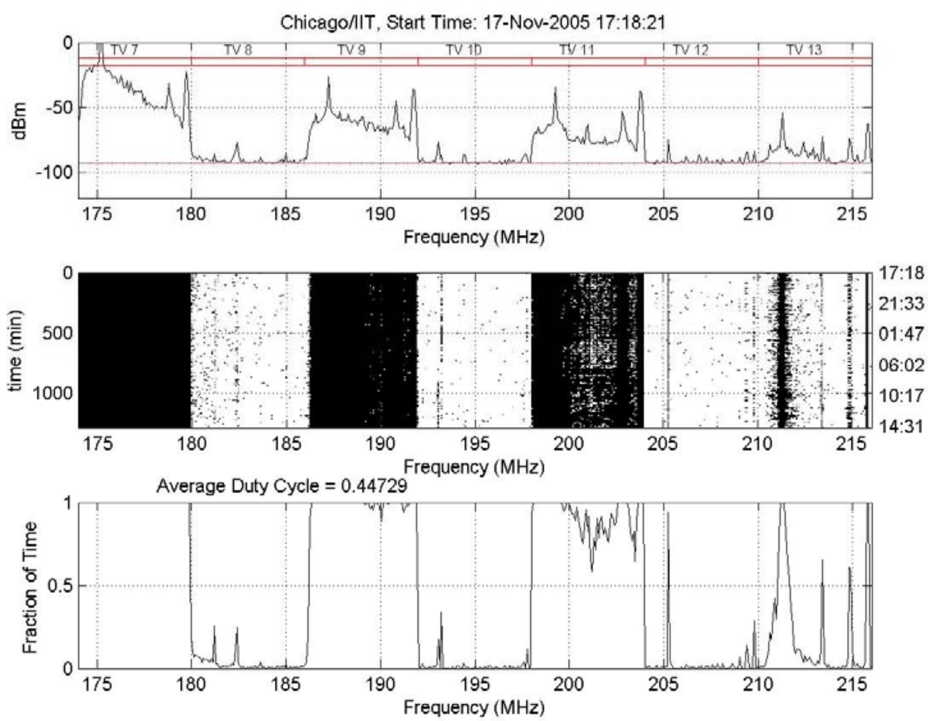

Figure 21: 174 MHz to 216 MHz, 22 hour period starting on November 17

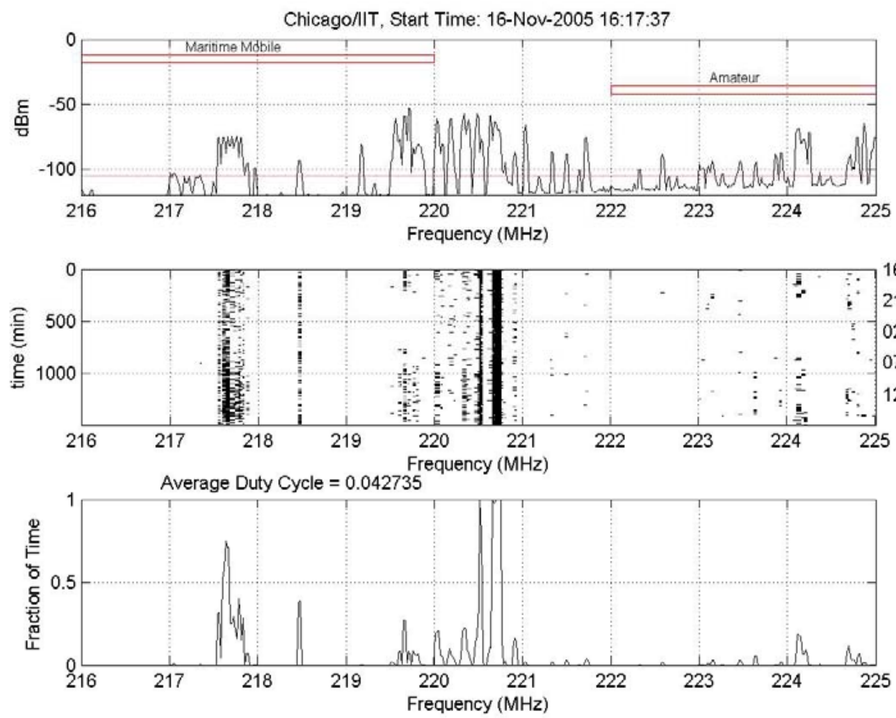

Figure 22: 216 MHz to 225 MHz, 24 hour period starting on November 16

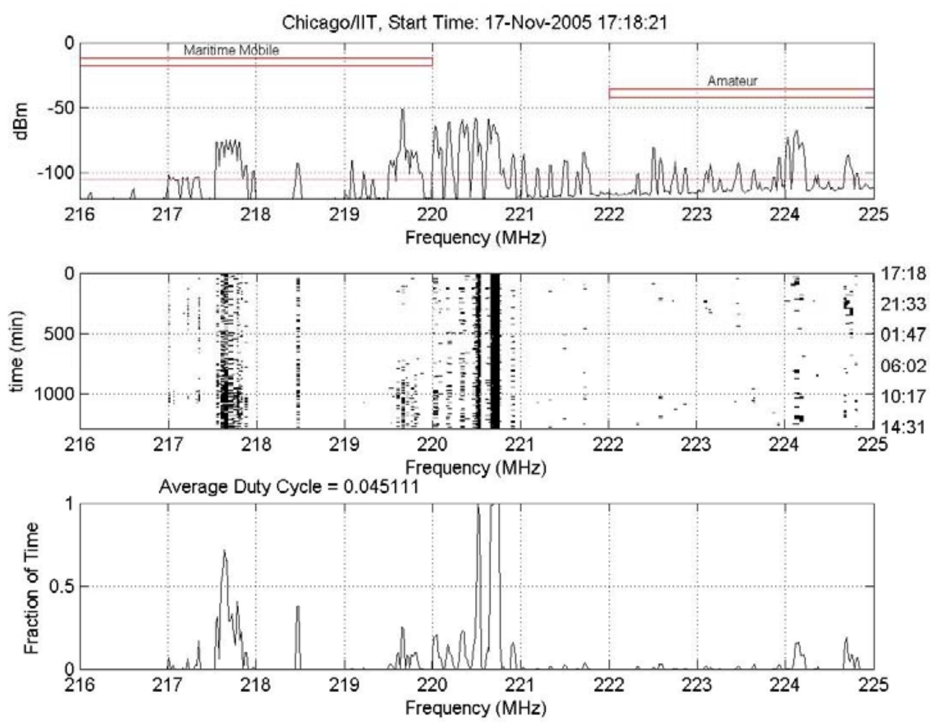

Figure 23: 216 MHz to 225 MHz, 22 hour period starting on November 17

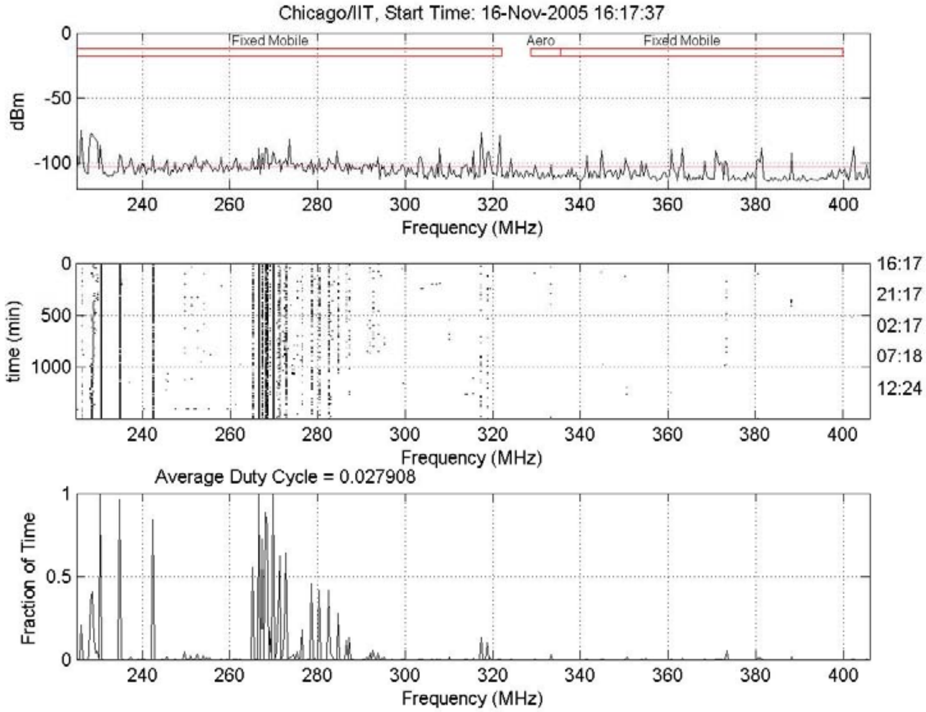

Figure 24: 225 MHz to 406 MHz, 24 hour period starting on November 16

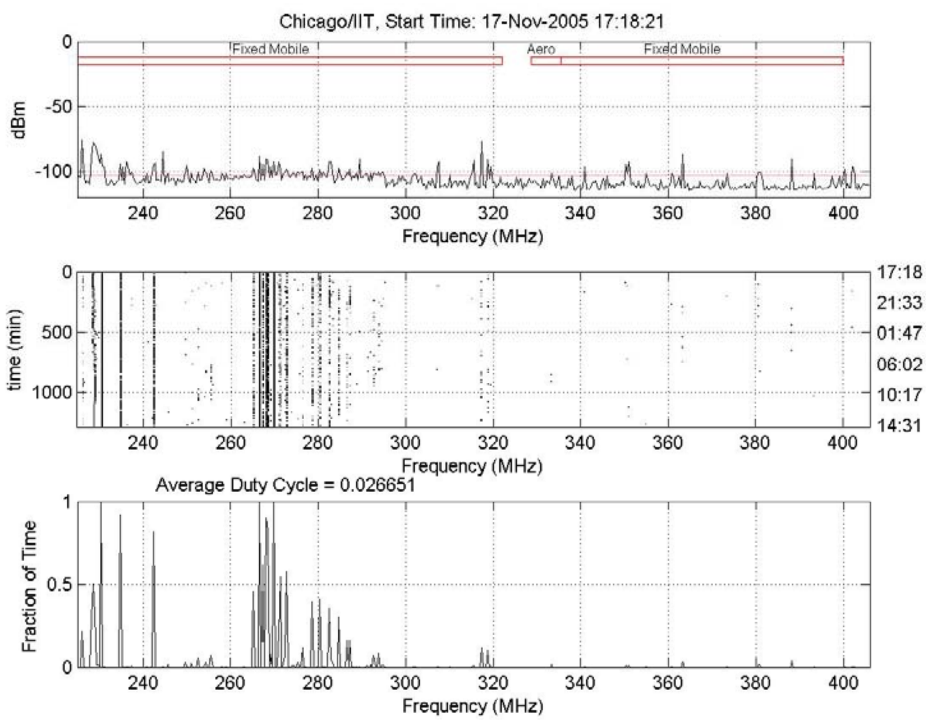

Figure 25: 225 MHz to 406 MHz, 22 hour period starting on November 17

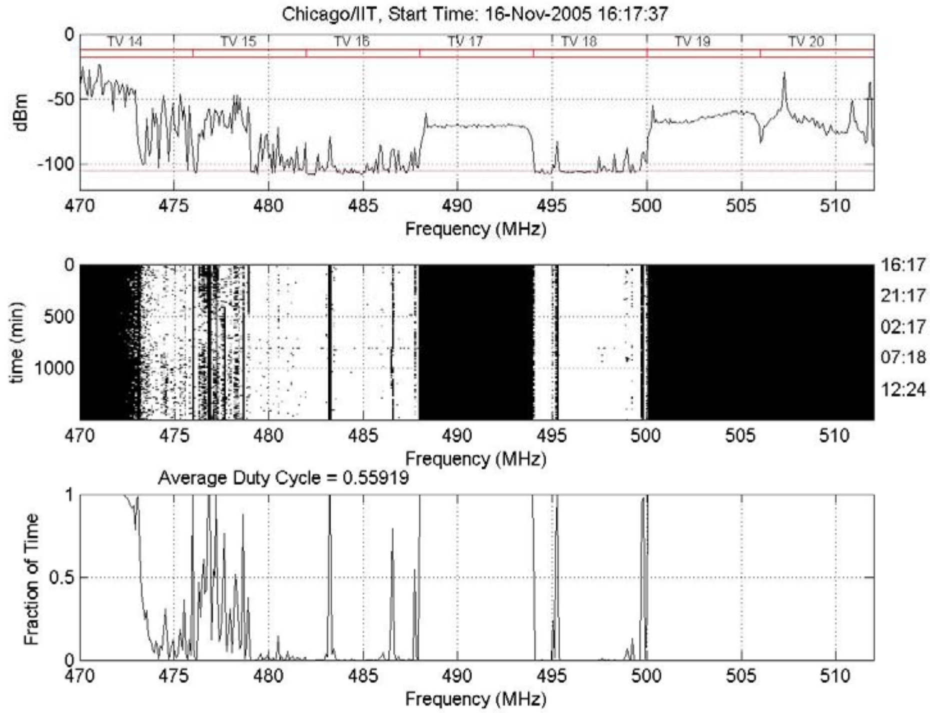

Figure 26: 406 MHz to 470 MHz, 24 hour period starting on November 16

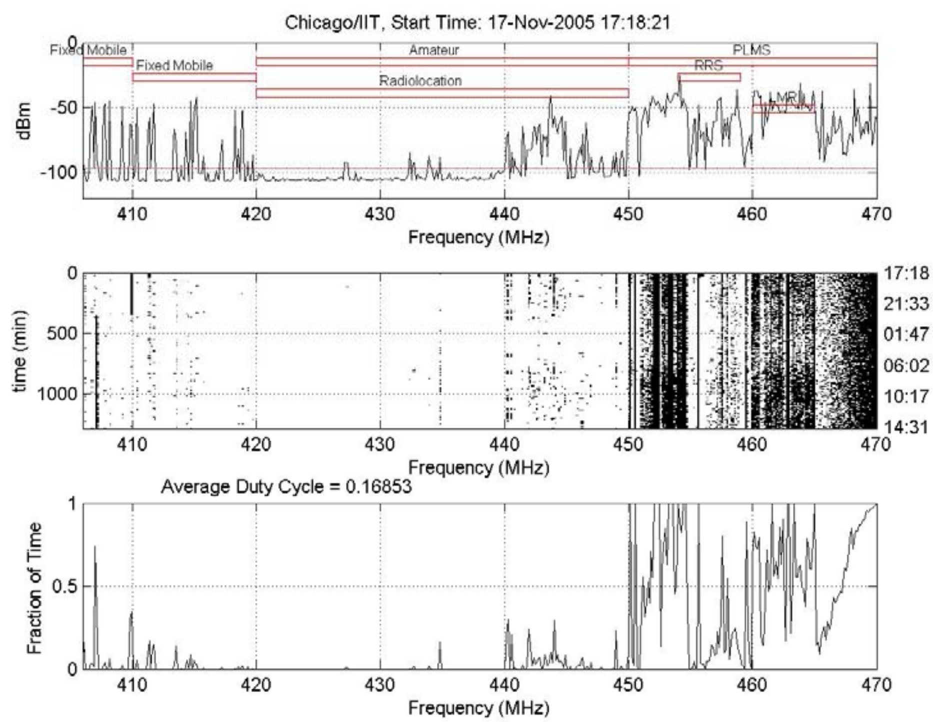

Figure 27: 406 MHz to 470 MHz, 22 hour period starting on November 17

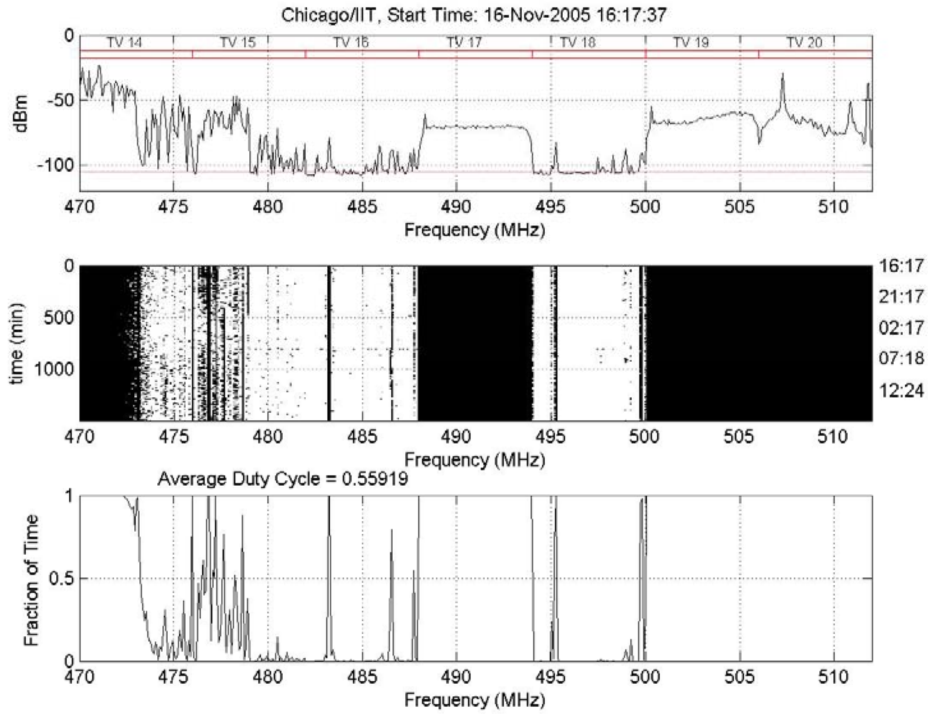

Figure 28: 470 MHz to 512 MHz, 24 hour period starting on November 16

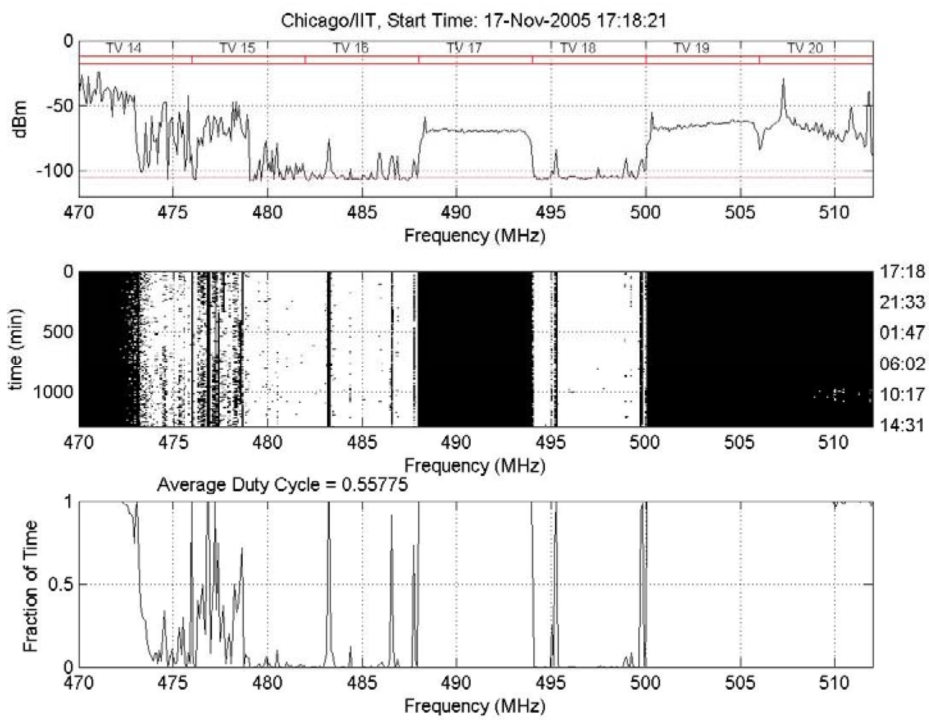

Figure 29: 470 MHz to 512 MHz, 22 hour period starting on November 17

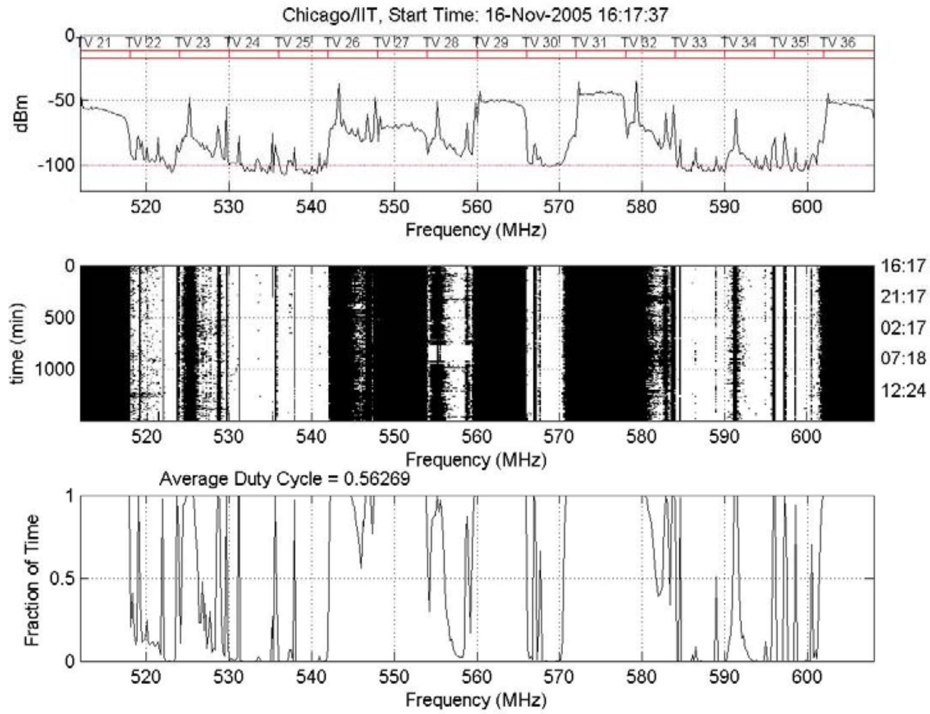

Figure 30: 512 MHz to 608 MHz, 24 hour period starting on November 16

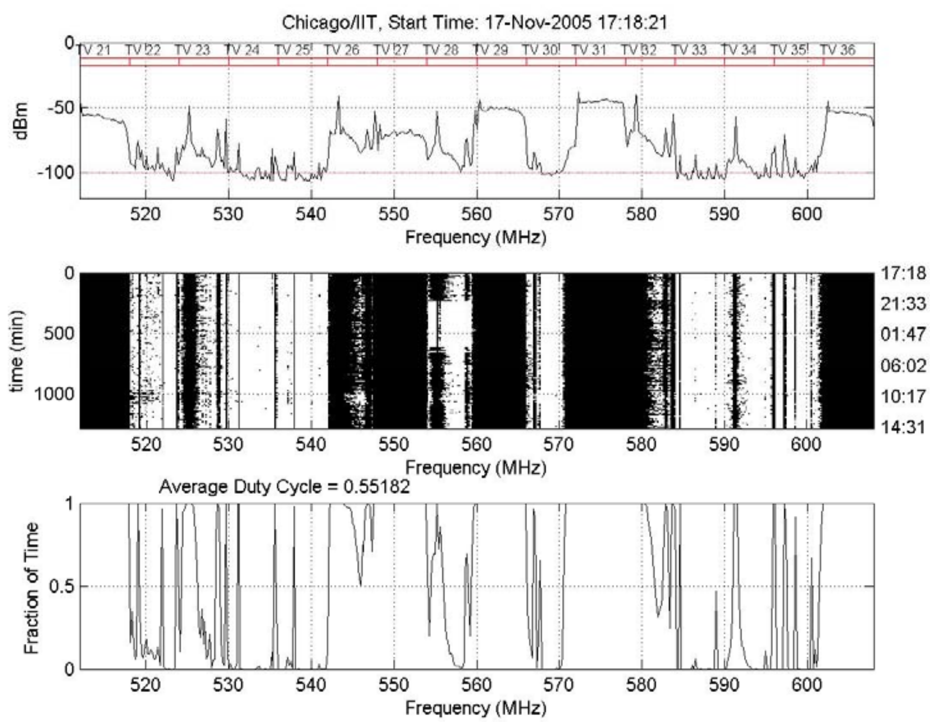

Figure 31: 512 MHz to 608 MHz, 22 hour period starting on November 17

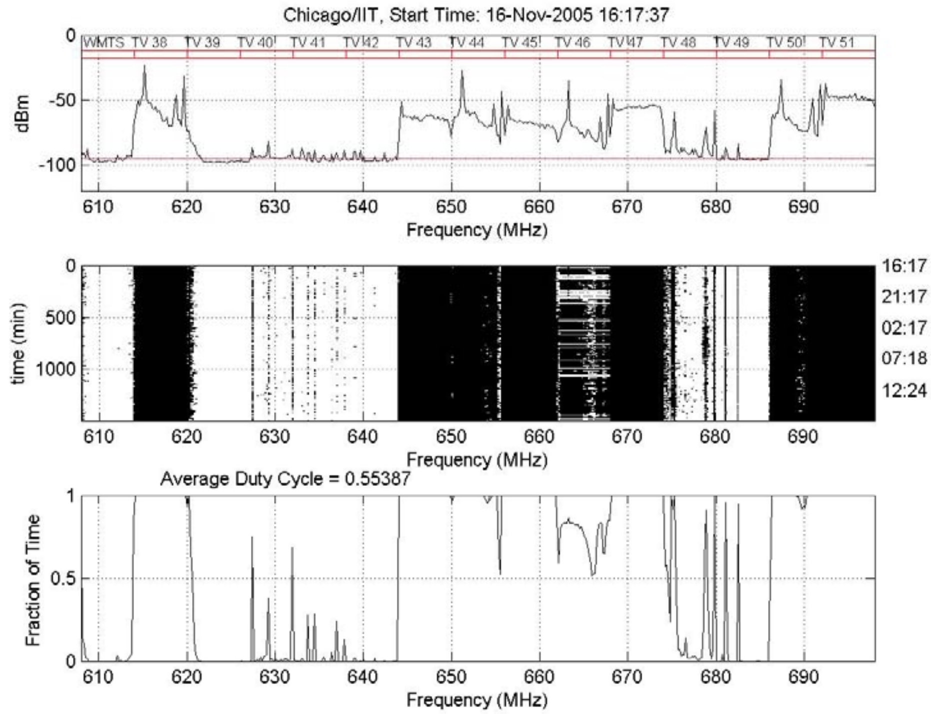

Figure 32: 608 MHz to 698 MHz, 24 hour period starting on November 16

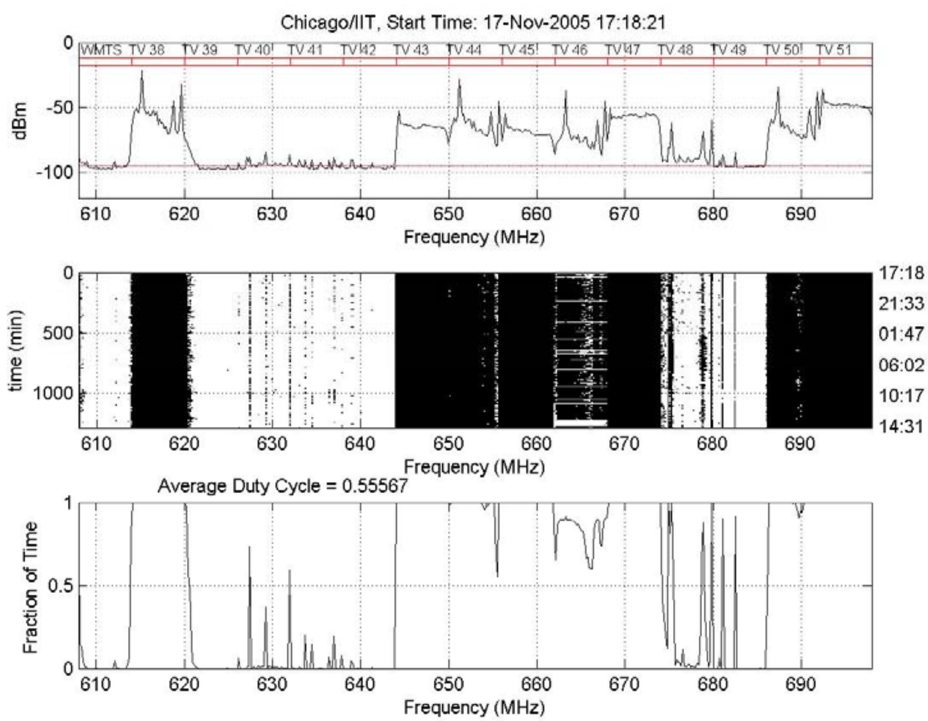

Figure 33: 608 MHz to 698 MHz, 22 hour period starting on November 17

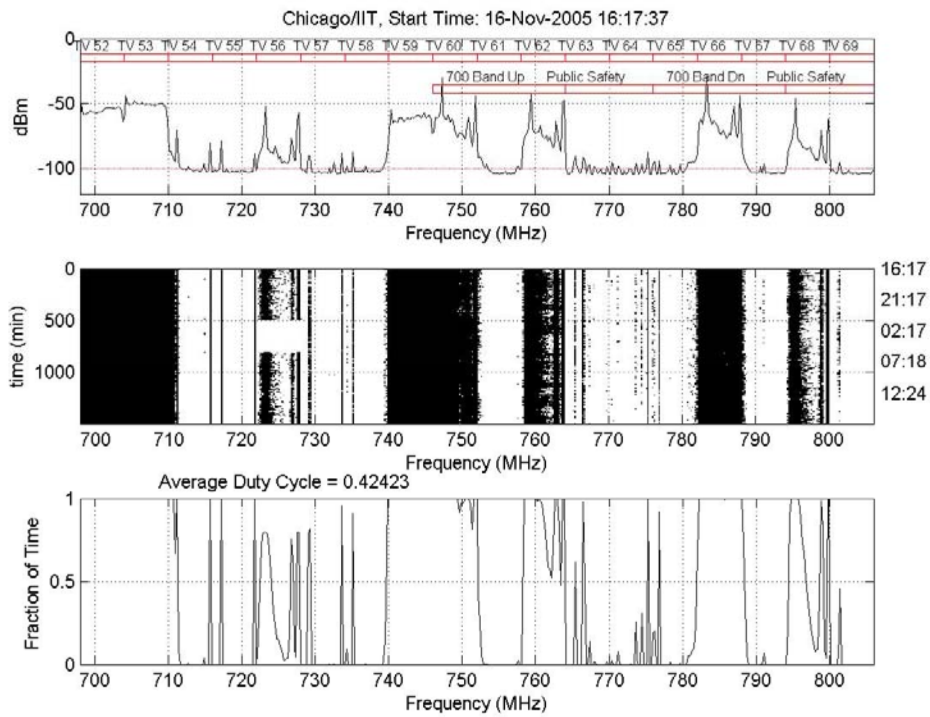

Figure 34: 698 MHz to 806 MHz, 24 hour period starting on November 16

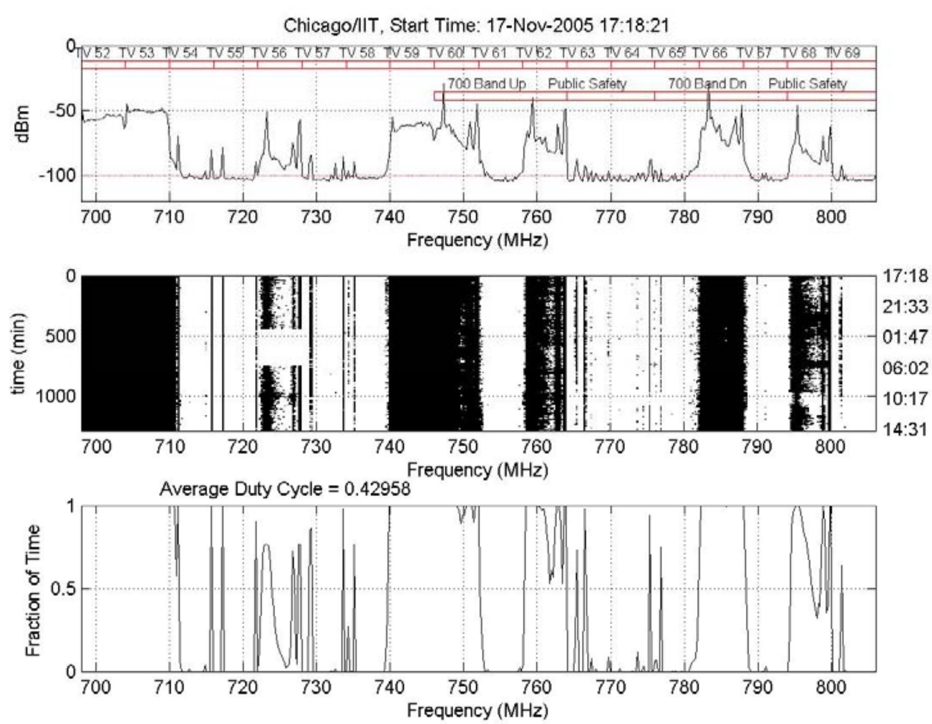

Figure 35: 698 MHz to 806 MHz, 22 hour period starting on November 17

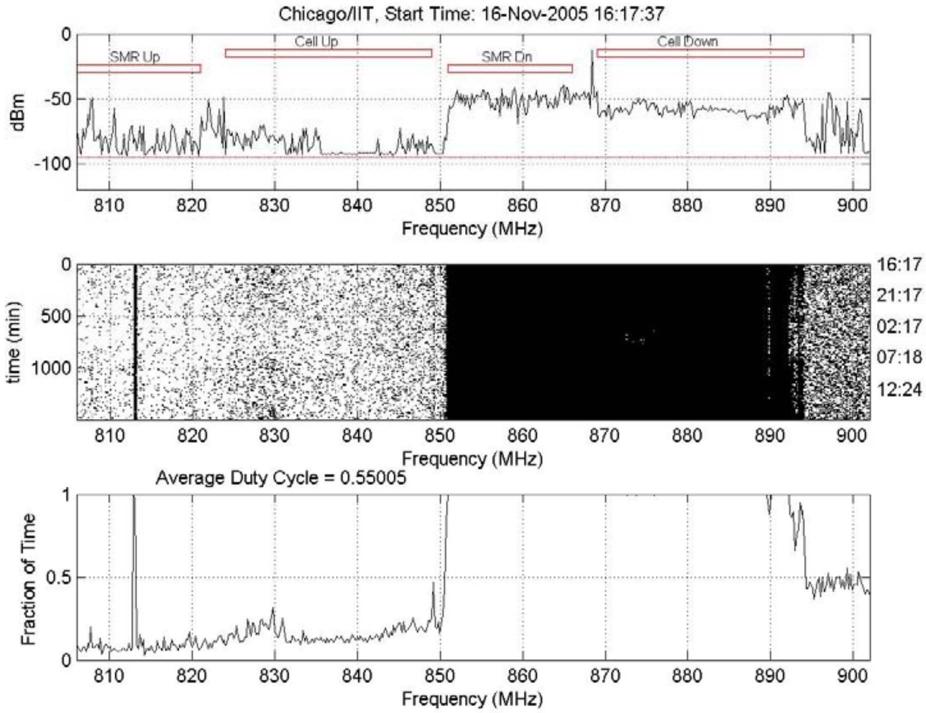

Figure 36: 806 MHz to 902 MHz, 24 hour period starting on November 16

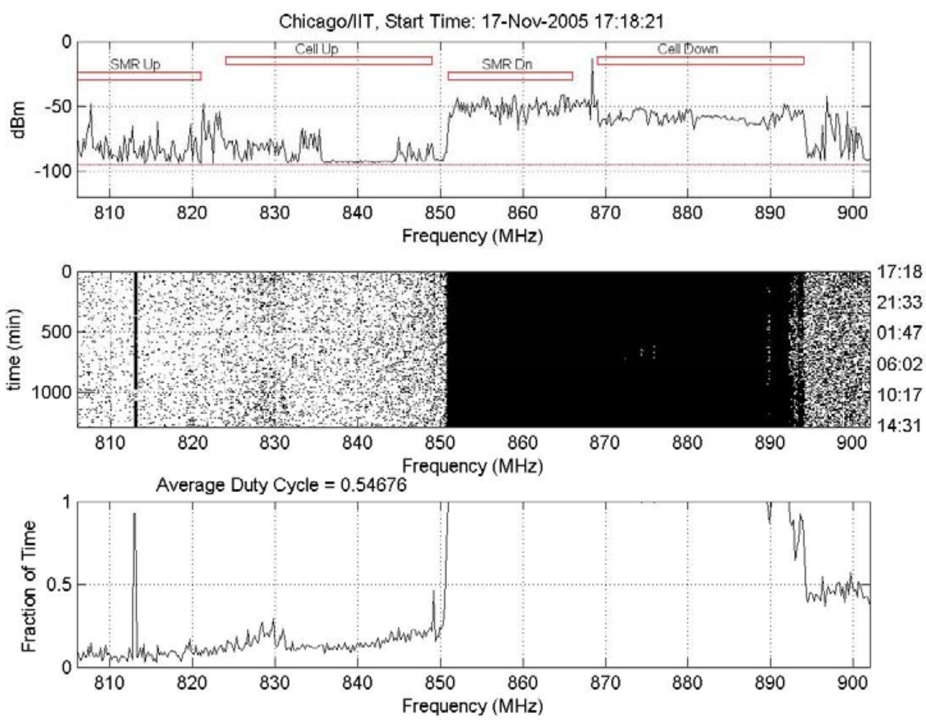

Figure 37: 806 MHz to 902 MHz, 22 hour period starting on November 17

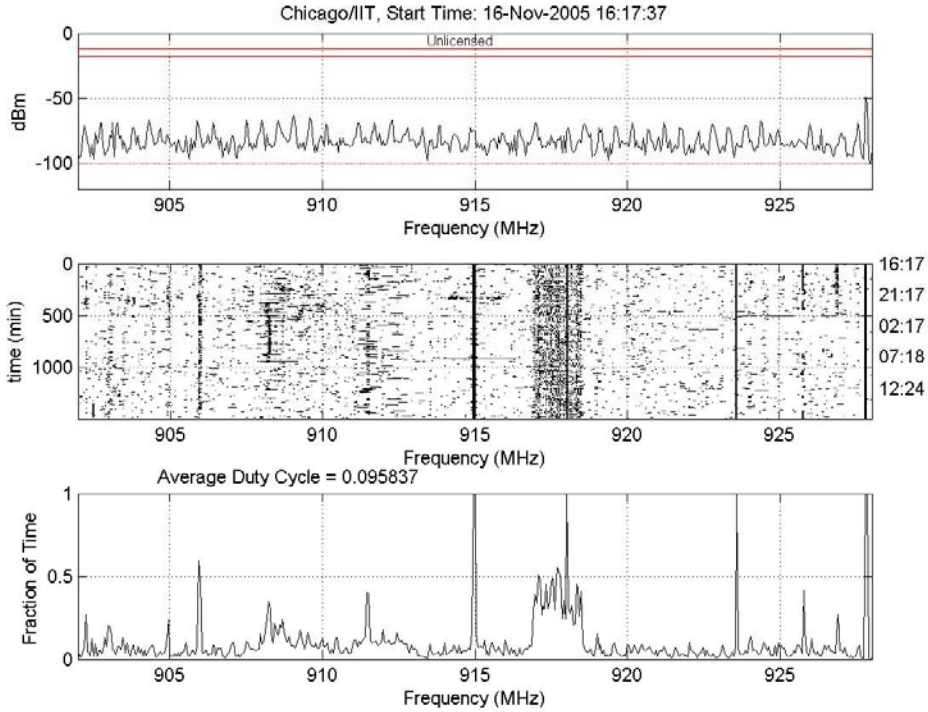

Figure 38: 902 MHz to 928 MHz, 24 hour period starting on November 16

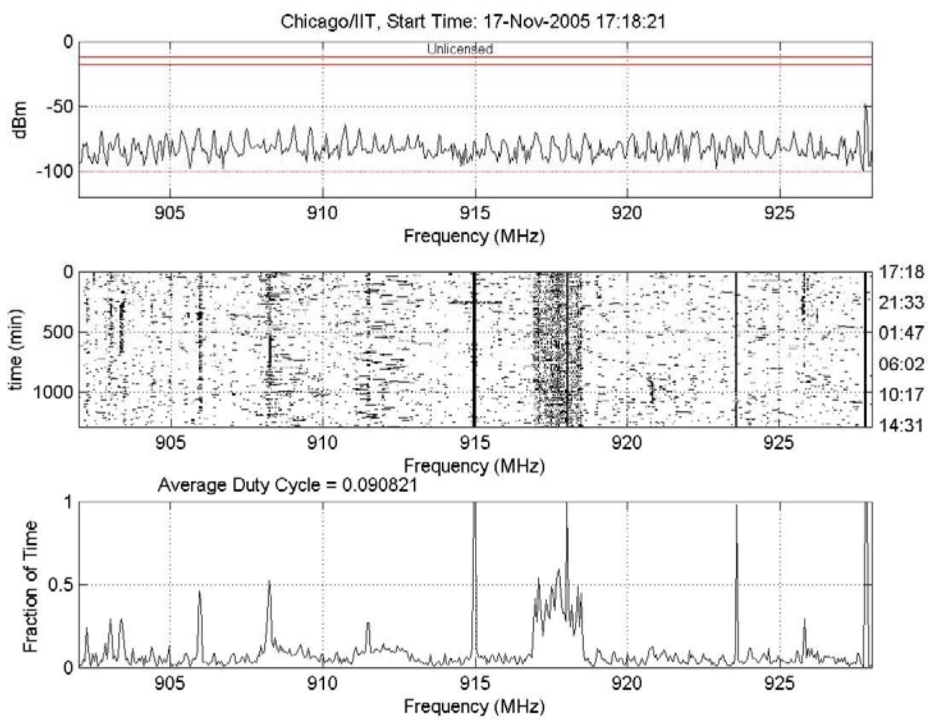

Figure 39: 902 MHz to 928 MHz, 22 hour period starting on November 17

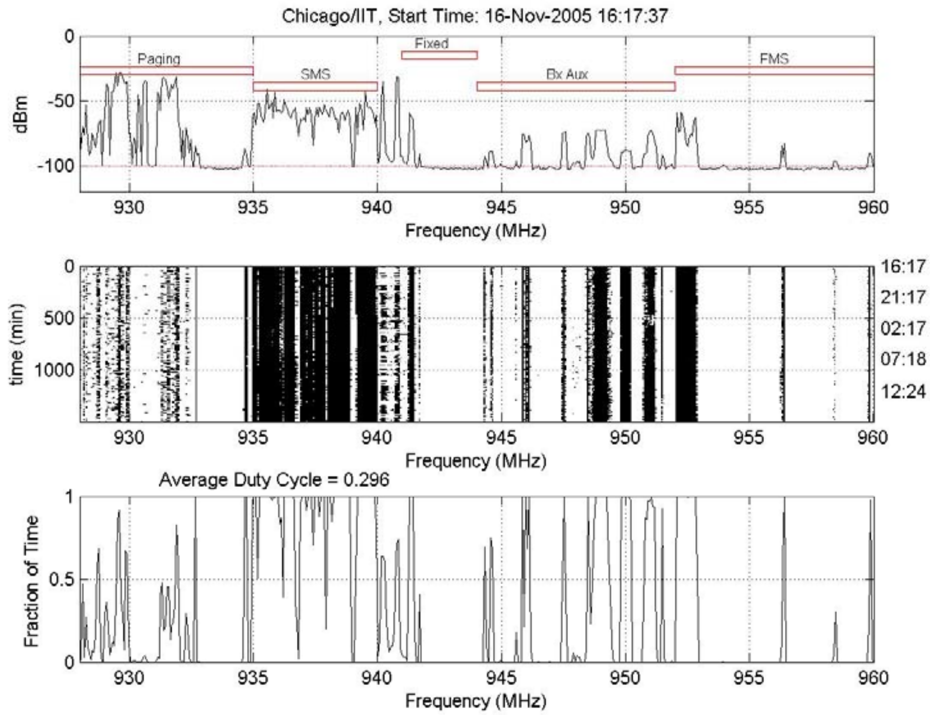

Figure 40: 928 MHz to 960 MHz, 24 hour period starting on November 16

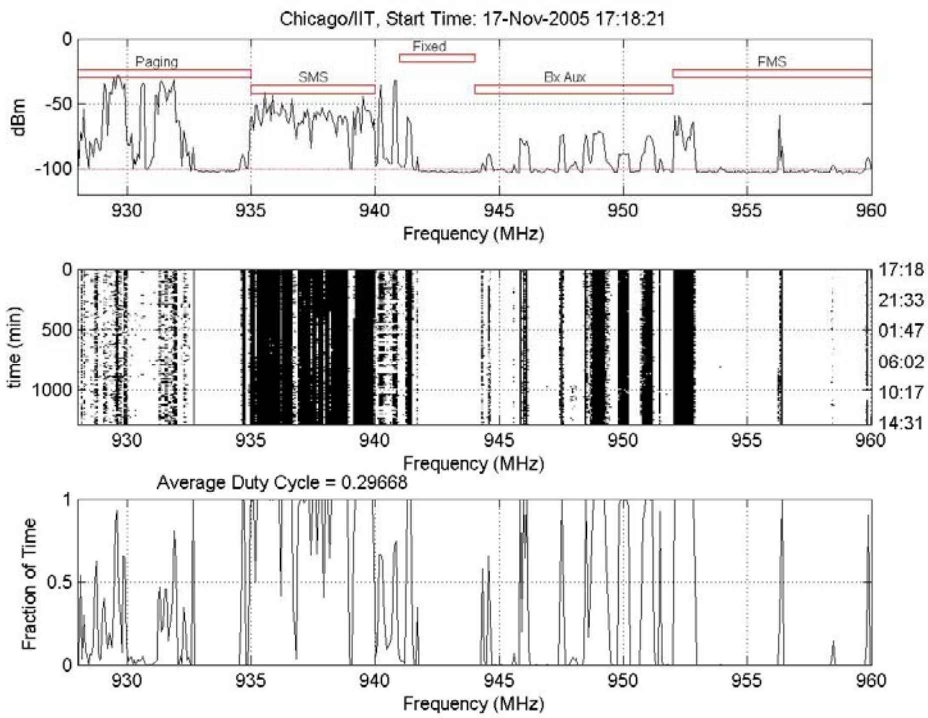

Figure 41: 928 MHz to 960 MHz, 22 hour period starting on November 17

5.3 Measurements Made Above 1,000 MHz

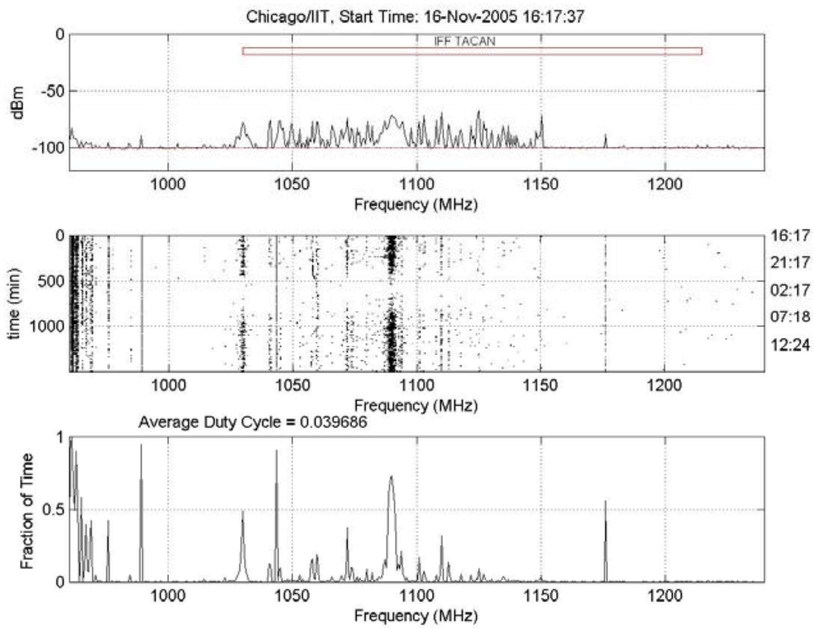

Figure 42: 960 MHz to 1240 MHz, 24 hour period starting on November 16

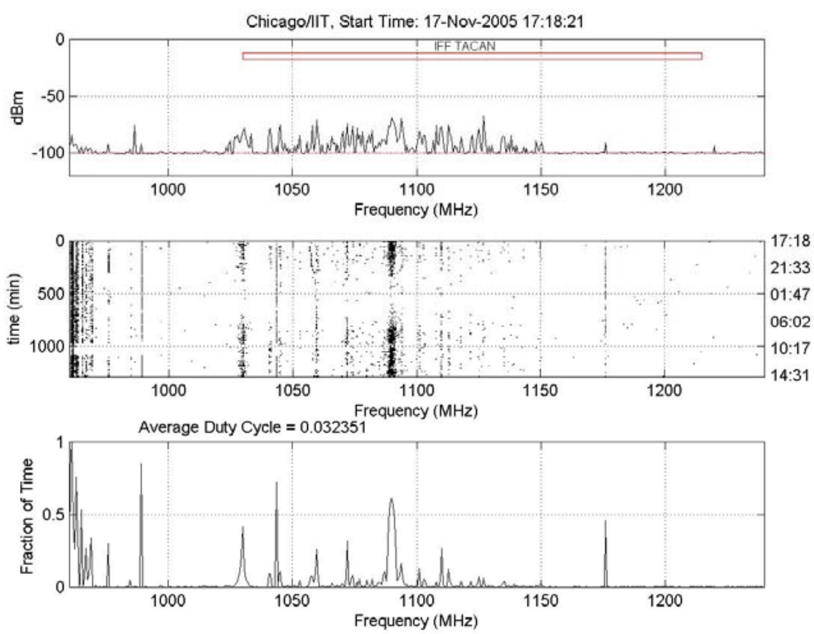

Figure 43: 960 MHz to 1240 MHz, 22 hour period starting on November 17

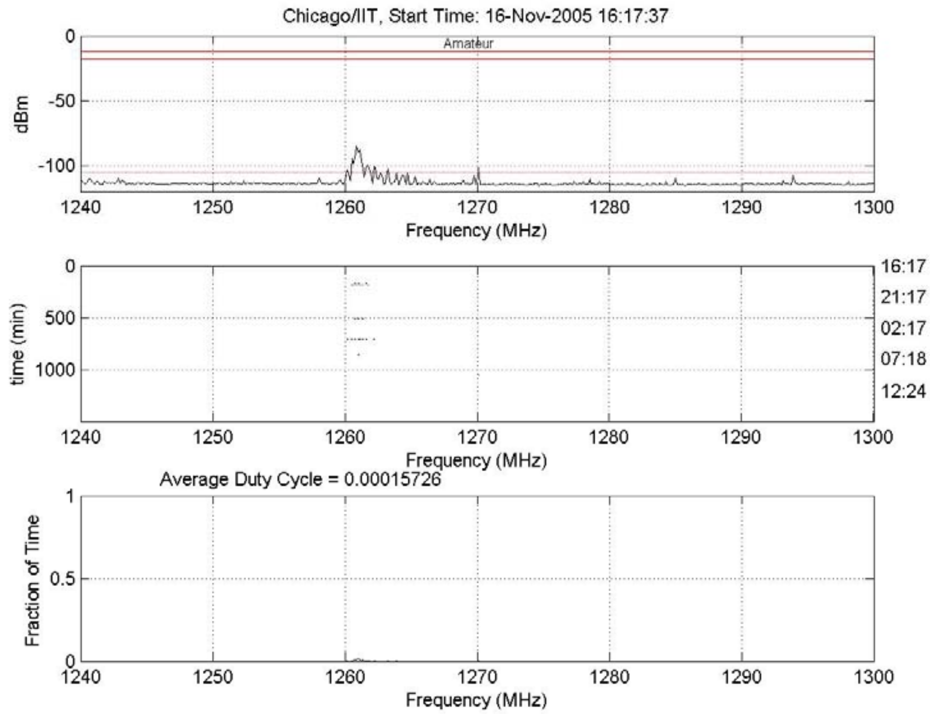

Figure 44: 1240 MHz to 1300 MHz, 24 hour period starting on November 16

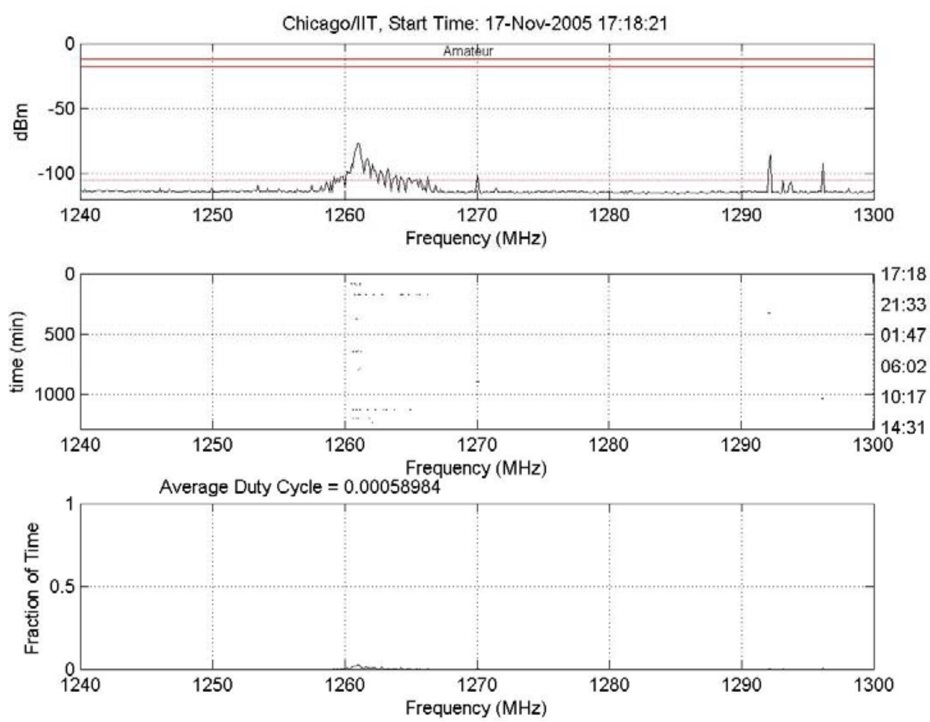

Figure 45: 1240 MHz to 1300 MHz, 22 hour period starting on November 17

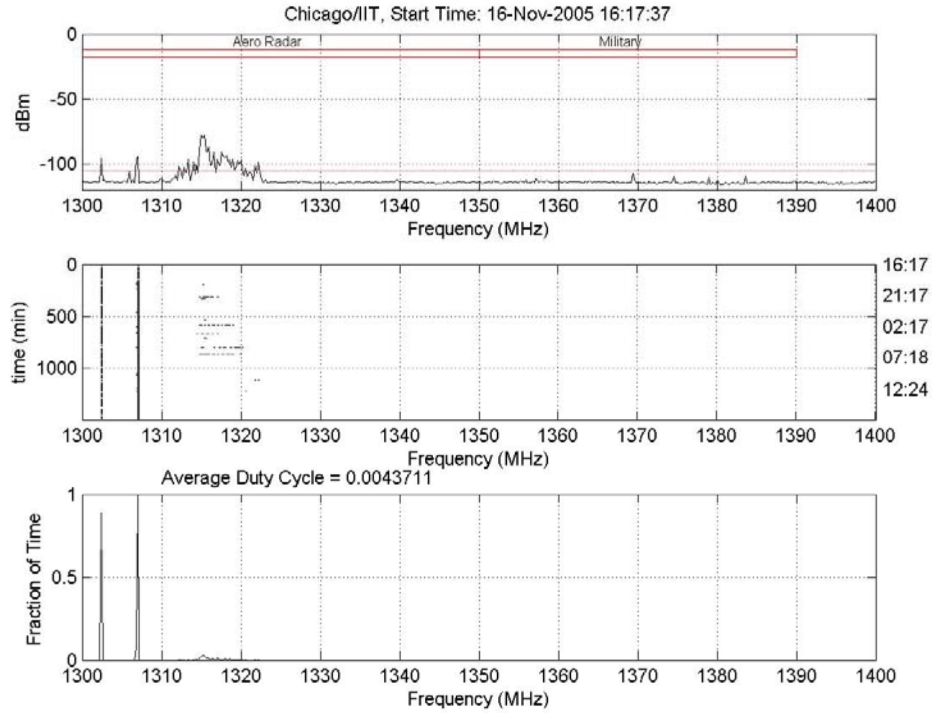

Figure 46: 1300 MHz to 1400 MHz, 24 hour period starting on November 16

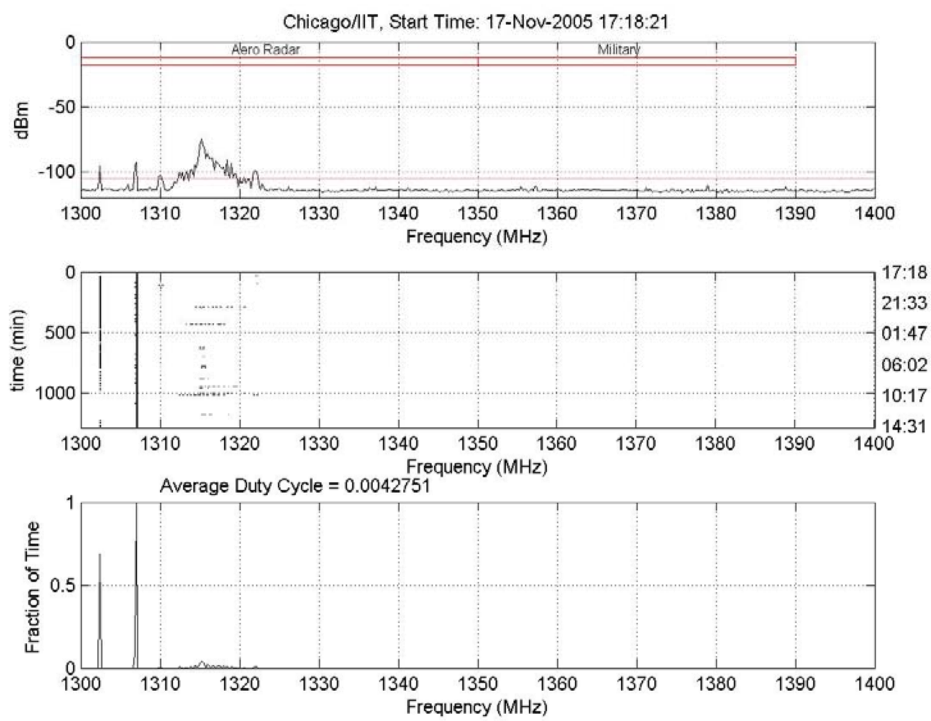

Figure 47: 1300 MHz to 1400 MHz, 22 hour period starting on November 17

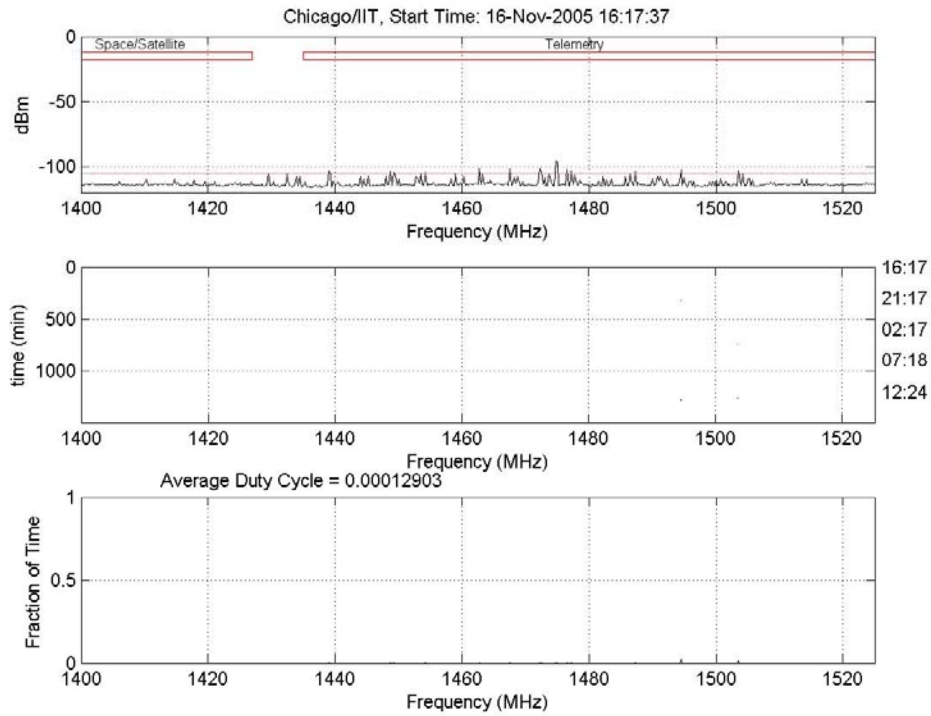

Figure 48: 1400 MHz to 1525 MHz, 24 hour period starting on November 16

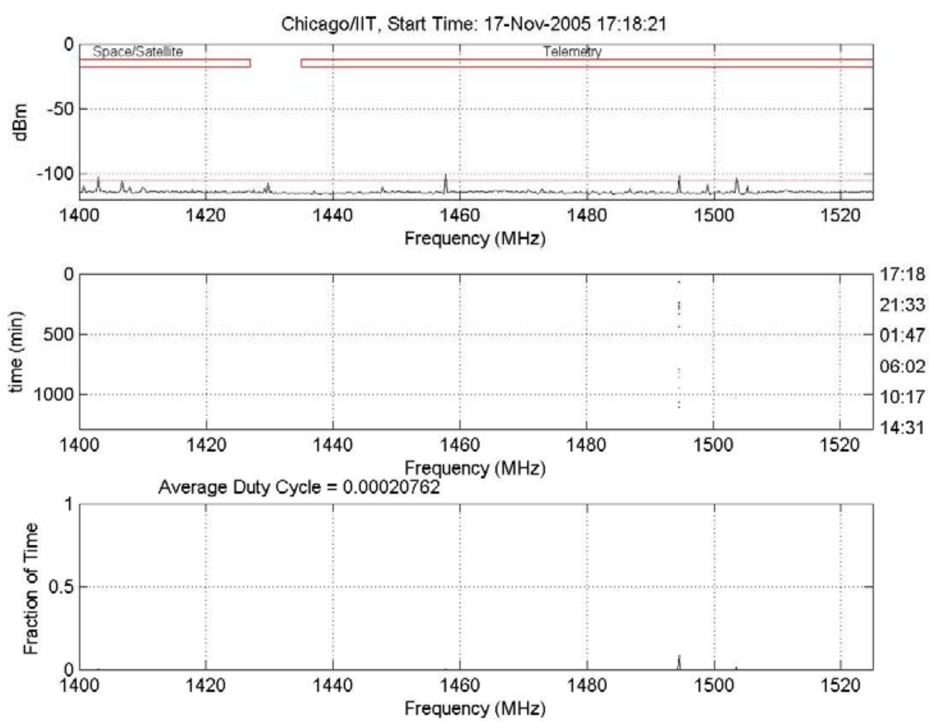

Figure 49: 1400 MHz to 1525 MHz, 22 hour period starting on November 17

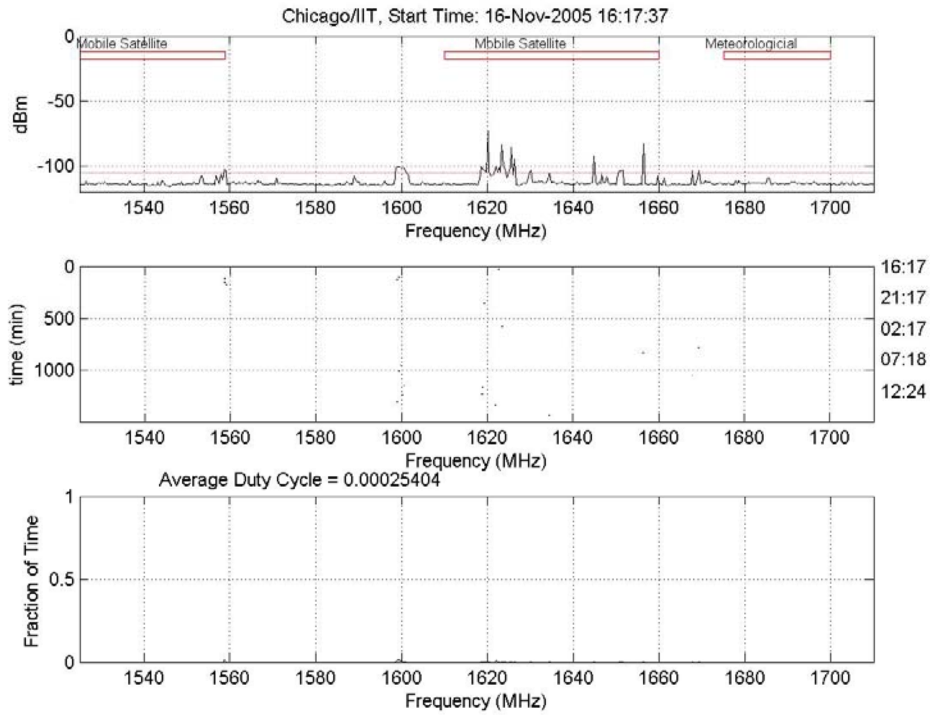

Figure 50: 1525 MHz to 1710 MHz, 24 hour period starting on November 16

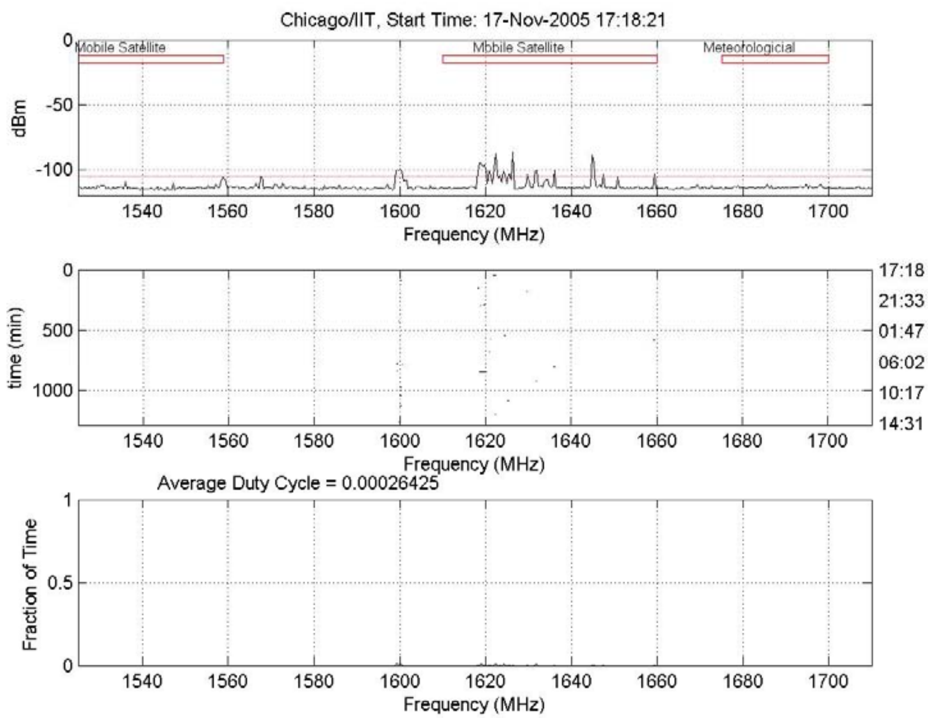

Figure 51: 1525 MHz to 1710 MHz, 22 hour period starting on November 17

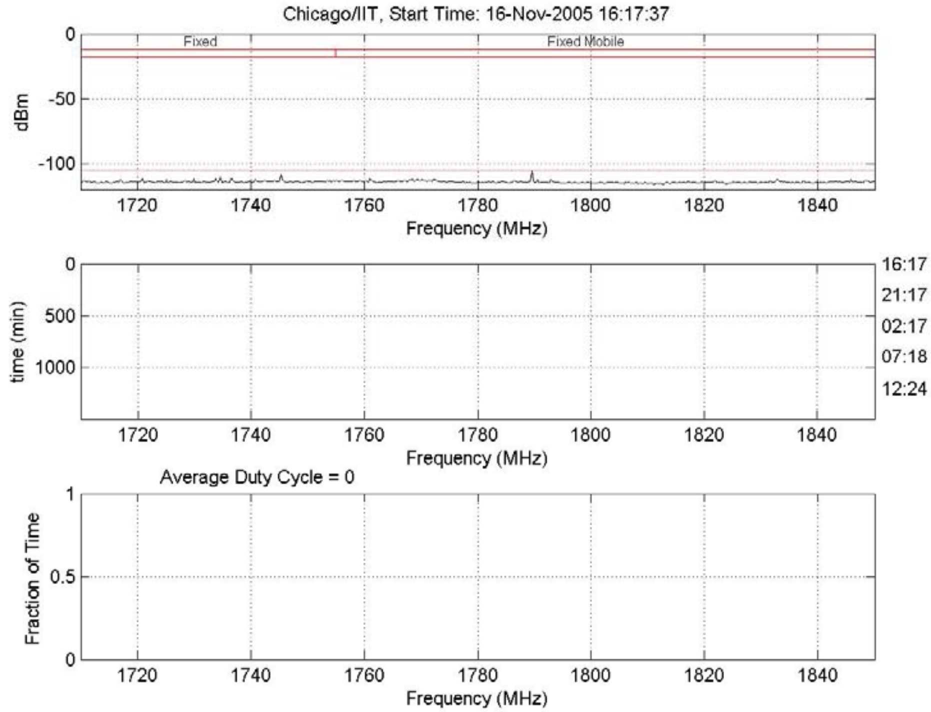

Figure 52: 1710 MHz to 1850 MHz, 24 hour period starting on November 16

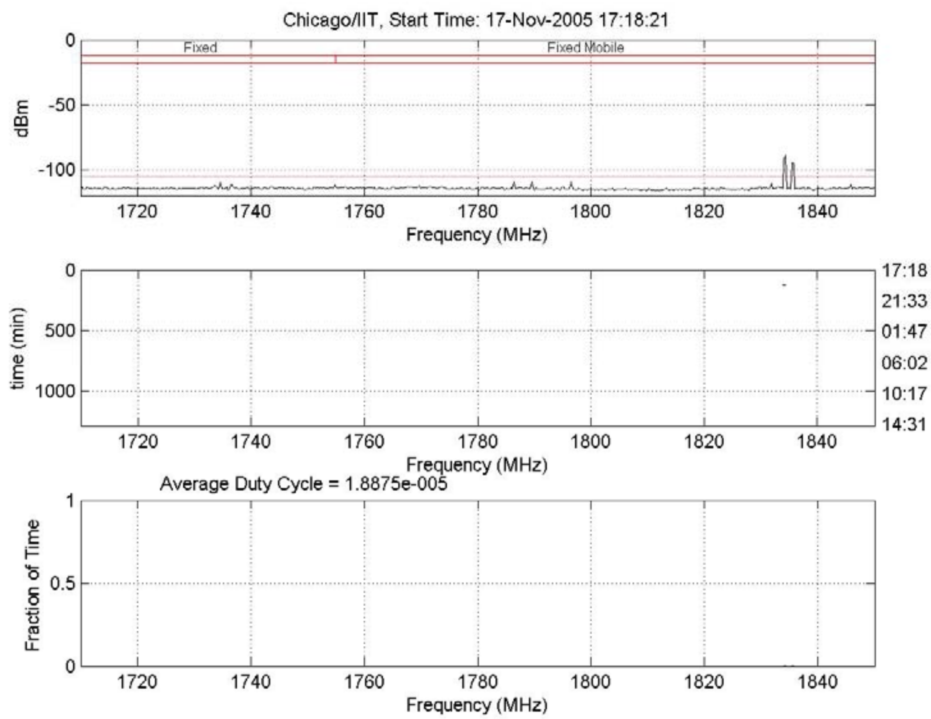

Figure 53: 1710 MHz to 1850 MHz, 22 hour period starting on November 17

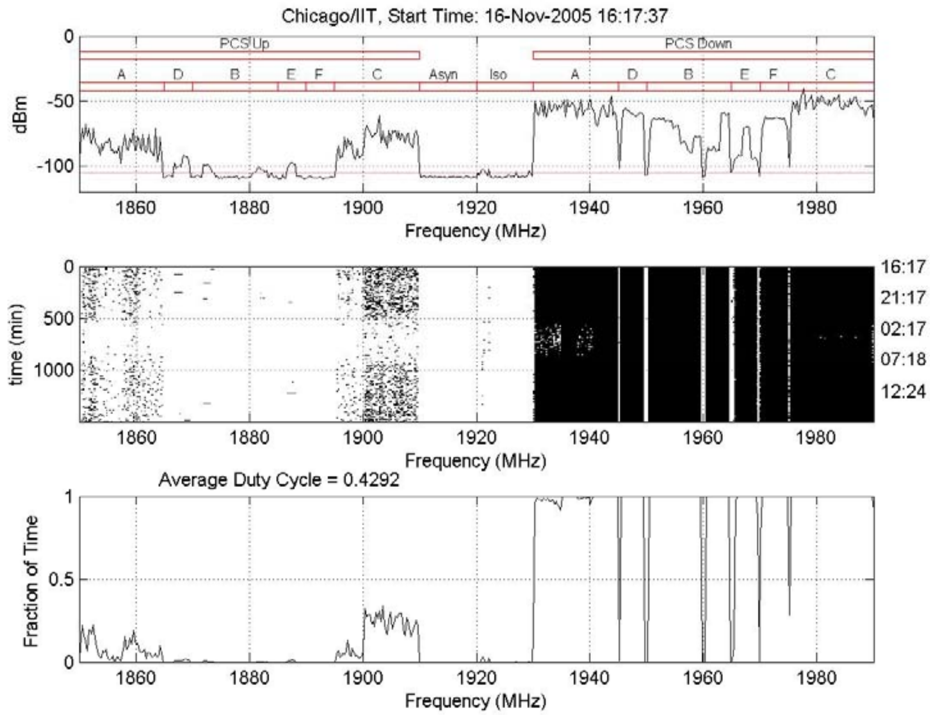

Figure 54: 1850 MHz to 1990 MHz, 24 hour period starting on November 16

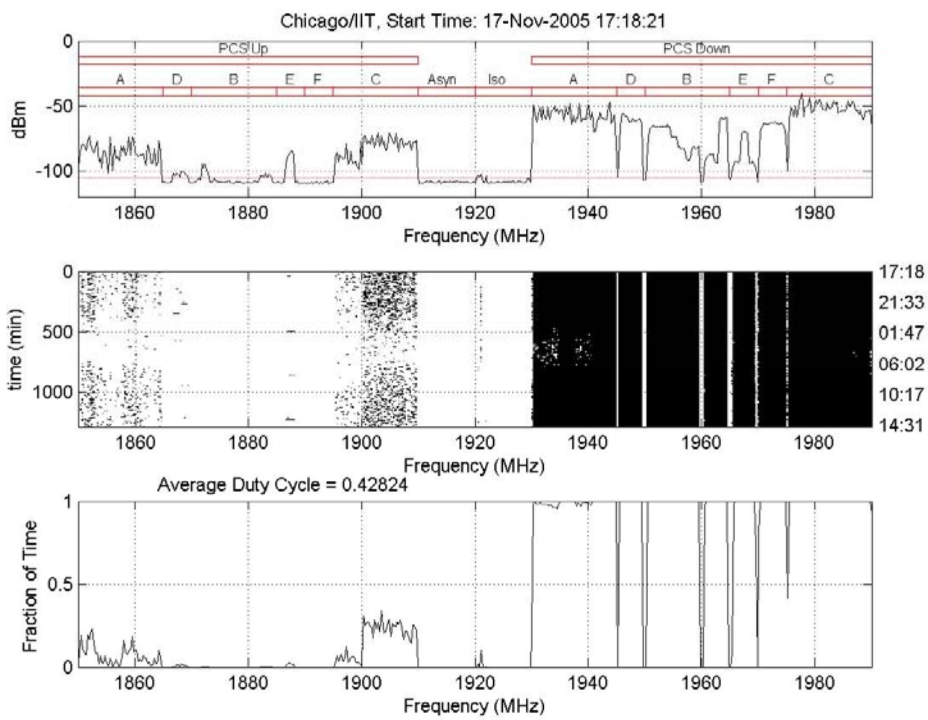

Figure 55: 1850 MHz to 1990 MHz, 22 hour period starting on November 17

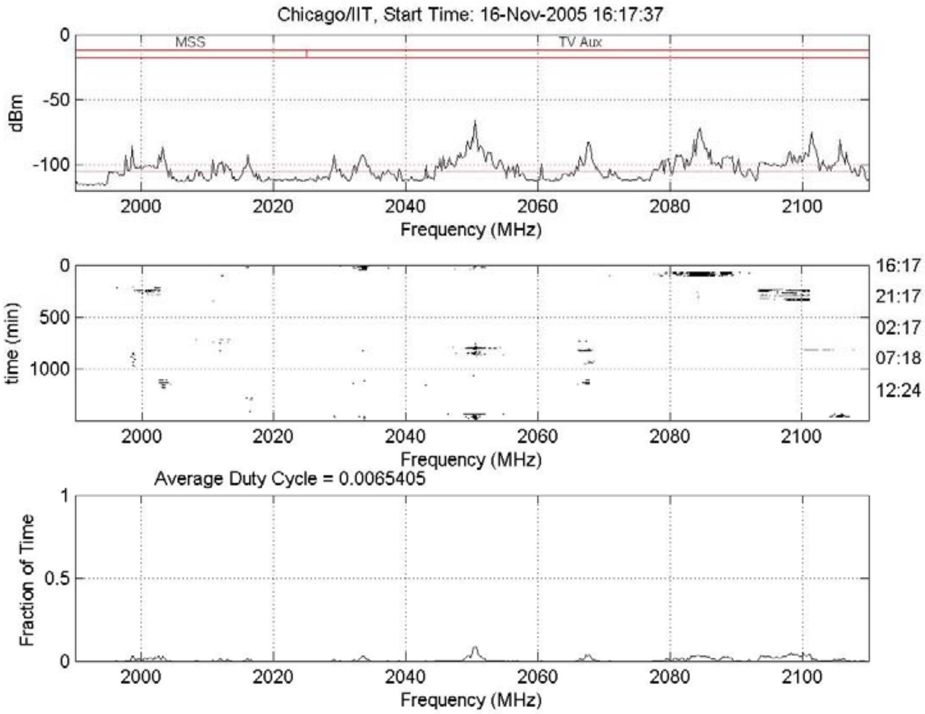

Figure 56: 1990 MHz to 2110 MHz, 24 hour period starting on November 16

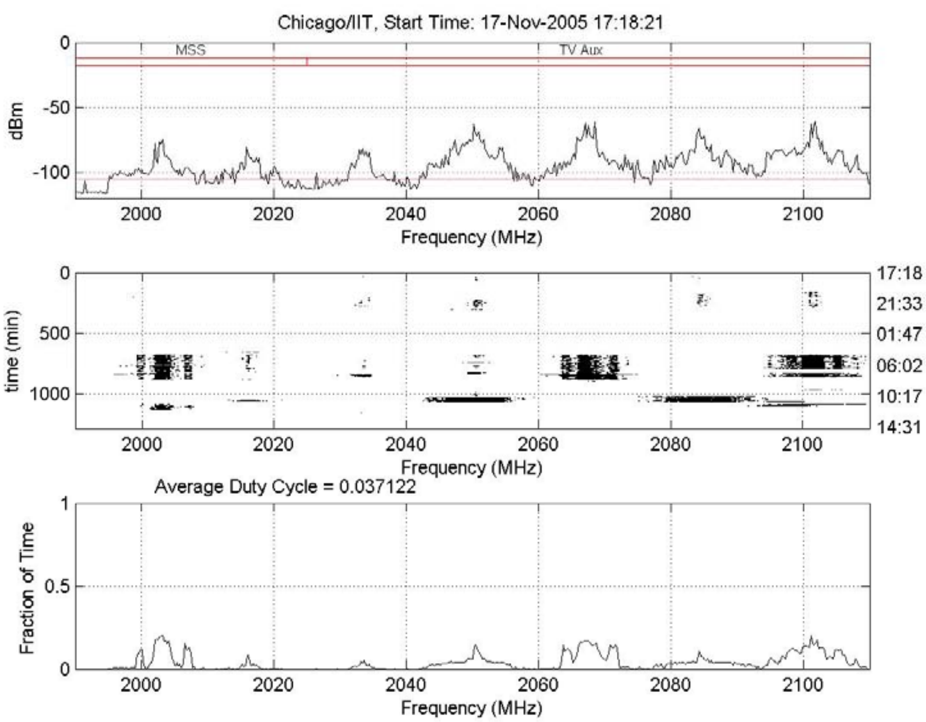

Figure 57: 1990 MHz to 2110 MHz, 22 hour period starting on November 17

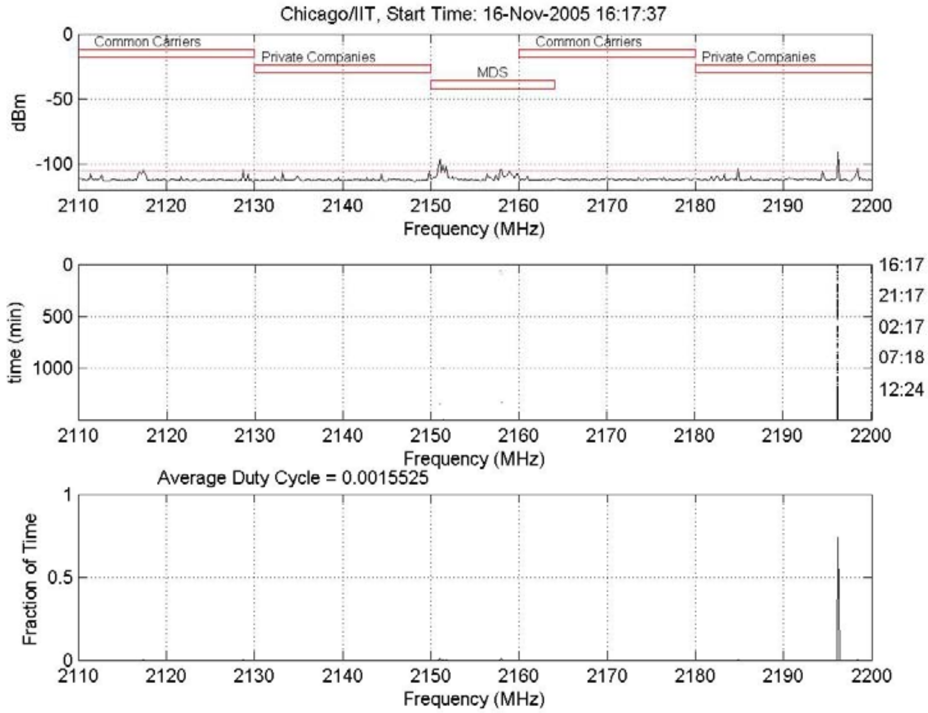

Figure 58: 2110 MHz to 2200 MHz, 24 hour period starting on November 16

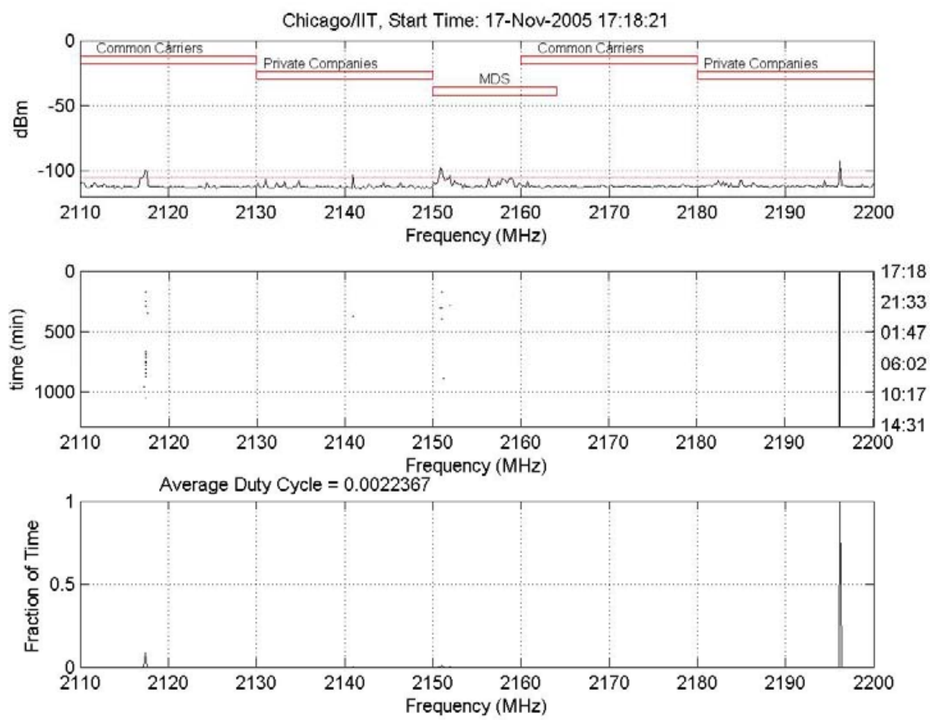

Figure 59: 2110 MHz to 2200 MHz, 22 hour period starting on November 17

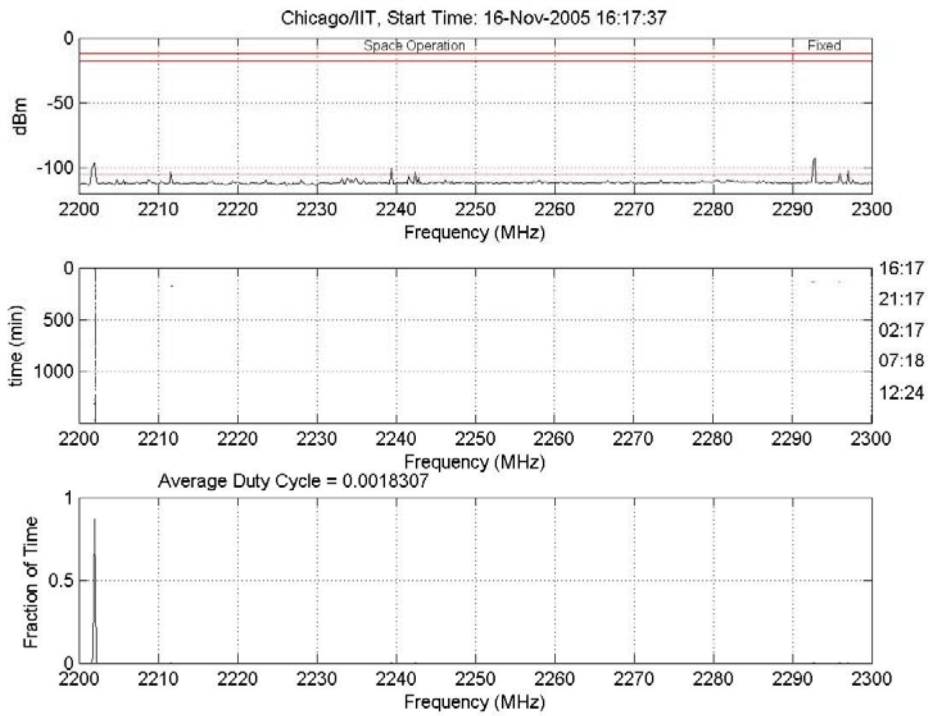

Figure 60: 2200 MHz to 2300 MHz, 24 hour period starting on November 16

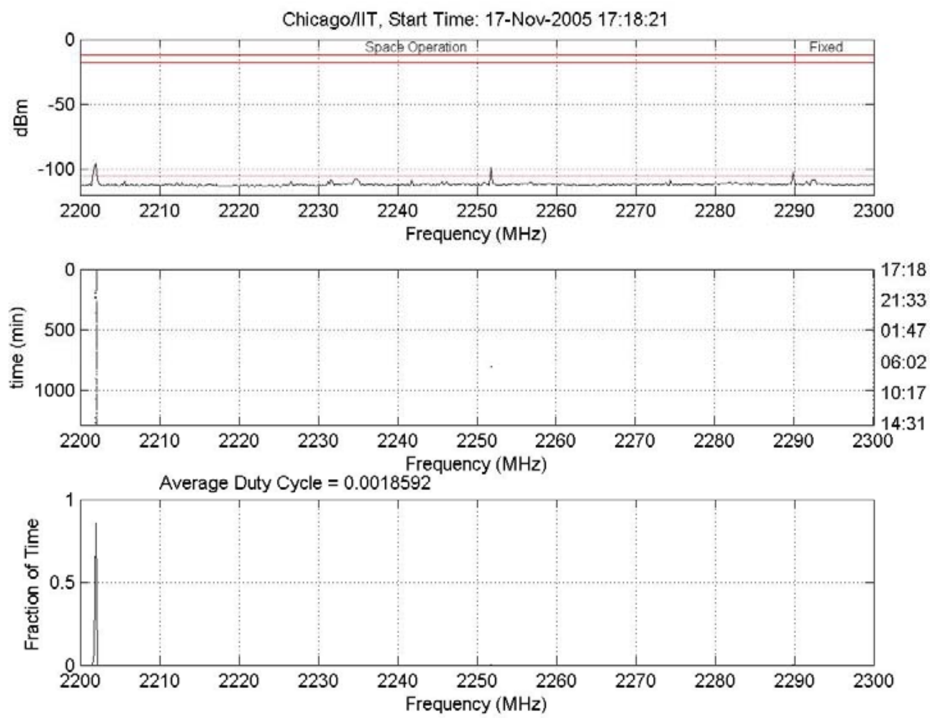

Figure 61: 2200 MHz to 2300 MHz, 22 hour period starting on November 17

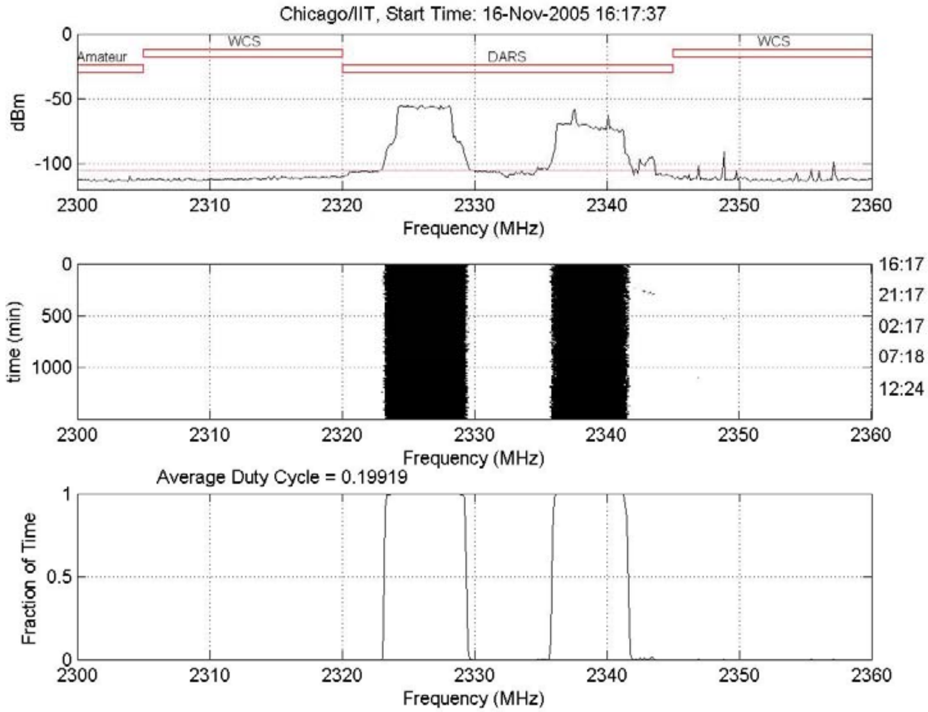

Figure 62: 2300 MHz to 2360 MHz, 24 hour period starting on November 16

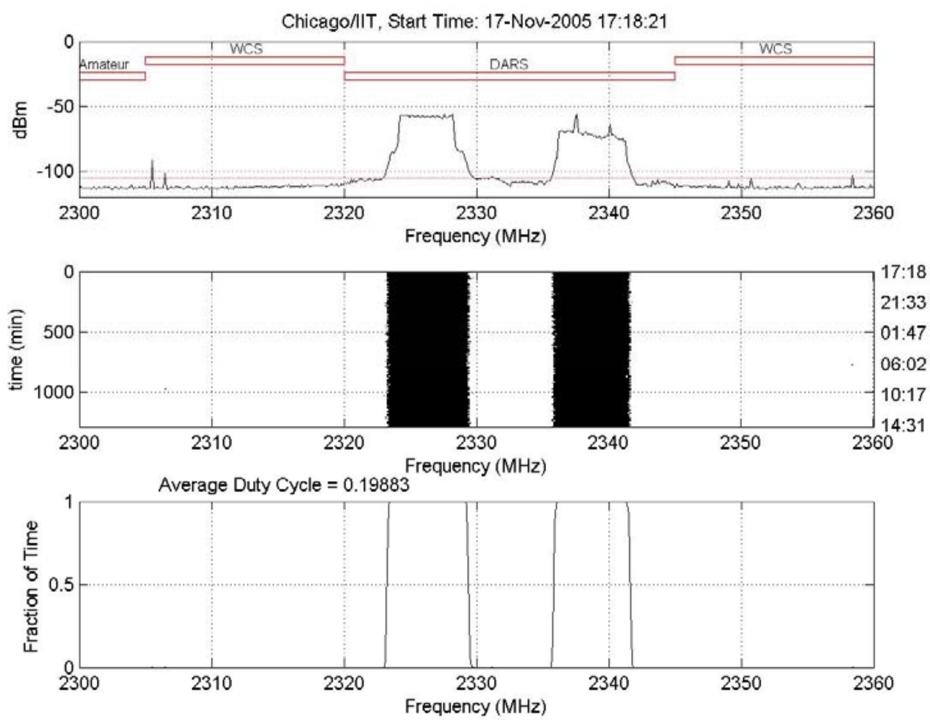

Figure 63: 2300 MHz to 2360 MHz, 22 hour period starting on November 17

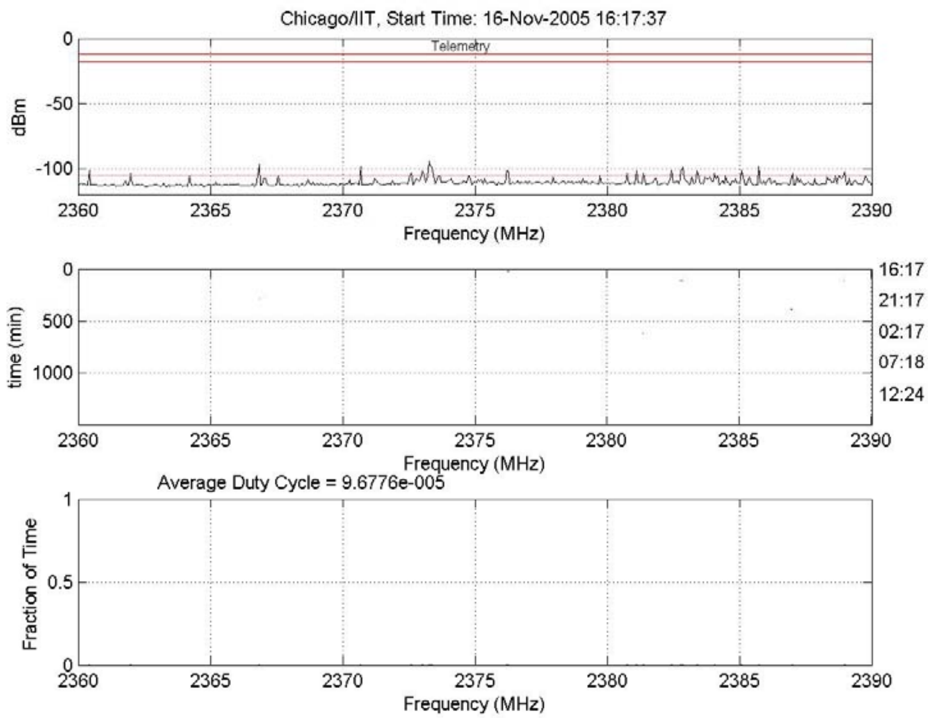

Figure 64: 2360 MHz to 2390 MHz, 24 hour period starting on November 16

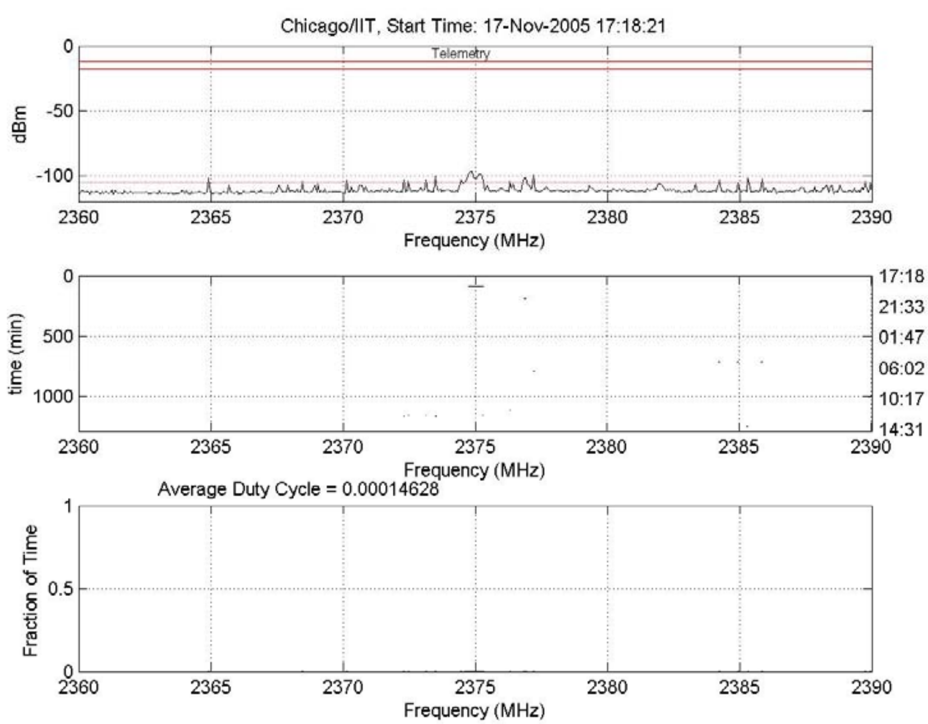

Figure 65: 2360 MHz to 2390 MHz, 22 hour period starting on November 17

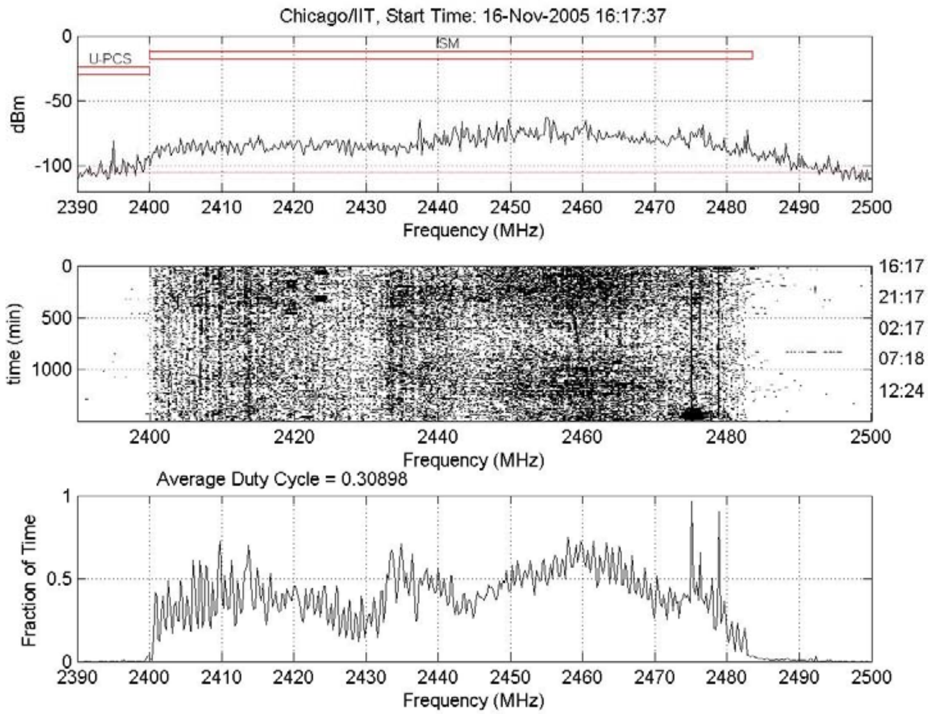

Figure 66: 2390 MHz to 2500 MHz, 24 hour period starting on November 16

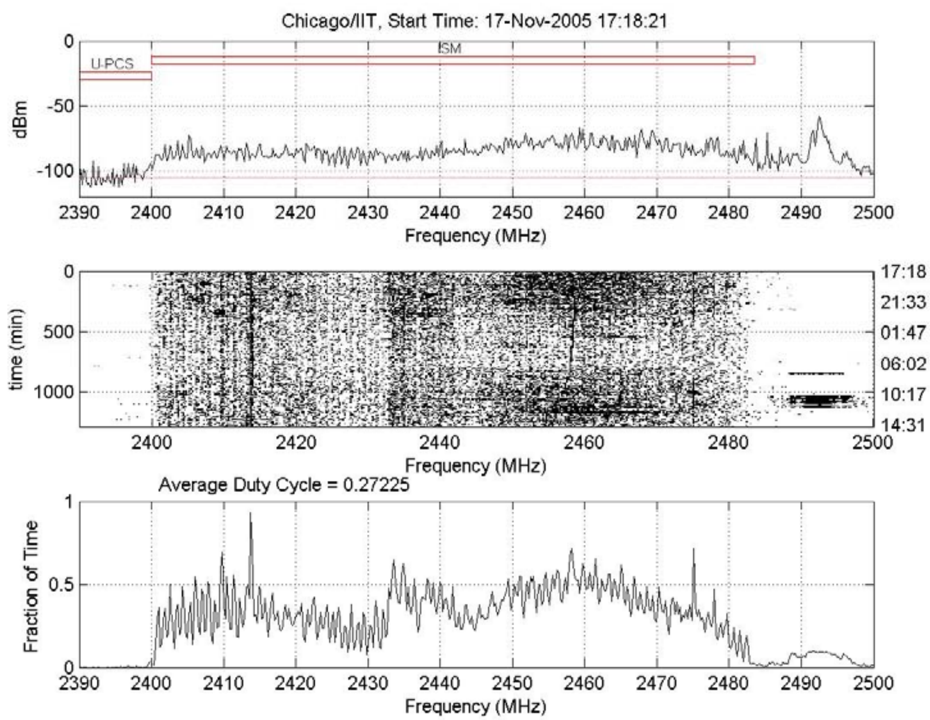

Figure 67. 2390 MHz to 2500 MHz, 22 hour period starting on November 17

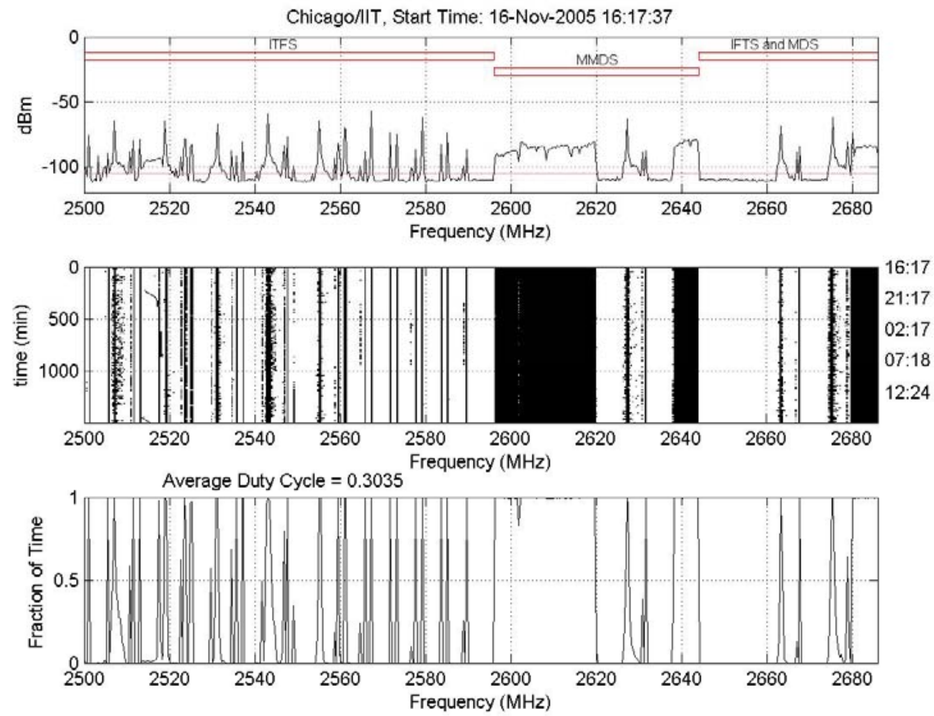

Figure 68. 2500 MHz to 2680 MHz, 24 hour period starting on November 16

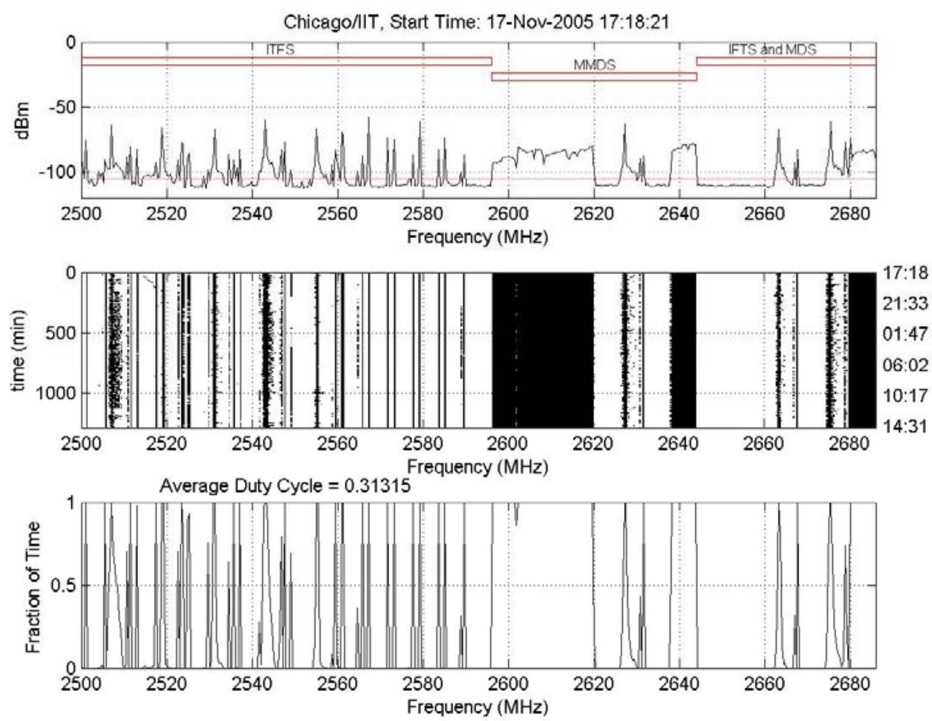

Figure 69: 2500 MHz to 2680 MHz, 22 hour period starting on November 17

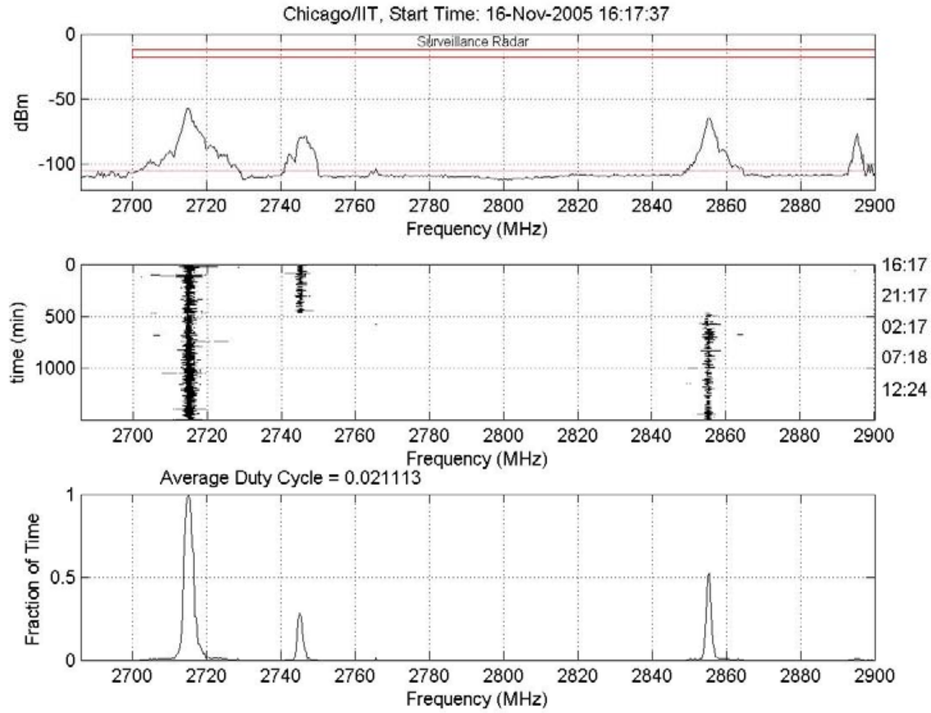

Figure 70. 2686 MHz to 2900 MHz, 24 hour period starting on November 16

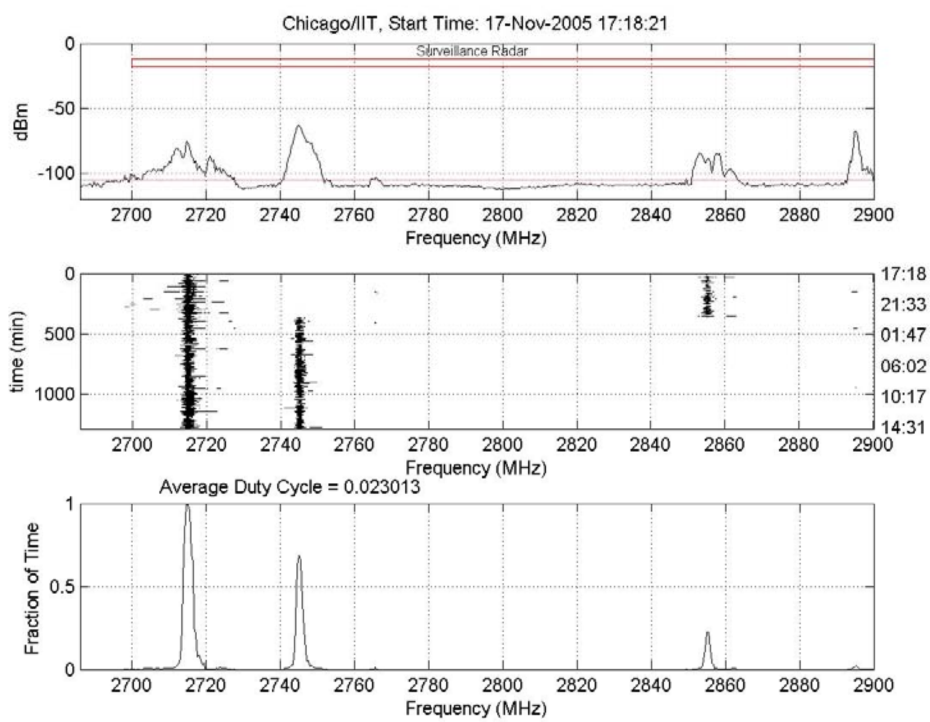

Figure 71. 2686 MHz to 2900 MHz, 22 hour period starting on November 17

5.4 Data Issues and Comments

5.4.1 30 MHz to 55 MHz

The existence of wide band noise at 35 and 55 MHz was measured at the Chicago location. This was most likely due to man-made noise.

5.4.2 88 MHz to 108 MHz

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

5.4.3 108 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 use of an FM band stop filter.

6. Conclusions

6.1 Introduction

This report documents extensive spectrum occupancy measurements made by Shared Spectrum Company and the Illinois Institute of Technology in Chicago, Illinois – one of the most densely populated areas in the United States. The IIT location had excellent visibility to Chicago's Loop and was specifically selected for study of spectrum occupancy. Measurements were made in all bands in the 30 MHz to 3000 MHz range. The measurements were made during a normal work week (Wednesday through Friday) and are believed to be a high usage period.

6.2 Spectrum Occupancy Upper Bounds

Based on results of the study, we conclude that the overall average spectrum usage during the measurement period was 17.4% or less. Occupancy[1] varied from less than 1% in the 1240-1300 MHz Amateur Band, to 70.9% in the 54 MHz – 88 MHz, TV Channel 2-6 Band.

Table 3 shows a summary of each average duty cycle for each spectrum band. The average duty cycle of each band is noted on each of the spectrum plots. The average for November 16 through November 17 (Day 1) and the average for November 17 through November 18 (Day 2) are averaged to find the overall Average Duty Cycle. The amount of spectrum occupied is then calculated. The total spectrum occupied divided by the total spectrum in the bands is used to find the overall occupancy value of 17.4%. Thus, no more than 17.4% of the spectrum opportunities (in frequency and in time) were utilized in Chicago during a high use period when measured from an elevated location.

[1] Occupancy is defined as the average duty cycle based on the time-frequency product.

Table 3. Summary of Spectrum Occupancy in Each Band

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	Chicago Day 1 Spectrum Fraction Used	Chicago Day 2 Spectrum Fraction Used	Chicago Avg Spectrum Fraction Used	Chicago Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.23070	0.19371	0.21221	5.09	21.2%
54	88	34	TV 2 -6, RC	0.70872	0.70931	0.70902	24.11	70.9%
108	138	30	Air traffic Control, Aero Nav	0.02814	0.02442	0.02628	0.79	2.6%
138	174	36	Fixed Mobile, amateur, others	0.35443	0.34908	0.35175	12.66	35.2%
174	216	42	TV 7-13	0.44794	0.44730	0.44762	18.80	44.8%
216	225	9	Maritime Mobile, Amateur, others	0.04274	0.04511	0.04392	0.40	4.4%
225	406	181	Fixed Mobile, Aero, others	0.02791	0.02665	0.02728	4.94	2.7%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.17462	0.16853	0.17158	10.98	17.2%
470	512	42	TV 14-20	0.55919	0.55775	0.55847	23.46	55.8%
512	608	96	TV 21-36	0.56269	0.55182	0.55726	53.50	55.7%
608	698	90	TV 37-51	0.55387	0.55567	0.55477	49.93	55.5%
698	806	108	TV 52-69	0.42423	0.42958	0.42691	46.11	42.7%
806	902	96	Cell phone and SMR	0.55005	0.54676	0.54841	52.65	54.8%
902	928	26	Unlicensed	0.09584	0.09082	0.09333	2.43	9.3%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.29600	0.29668	0.29634	9.48	29.6%
960	1240	280	IFF, TACAN, GPS, others	0.03969	0.03235	0.03602	10.09	3.6%
1240	1300	60	Amateur	0.00016	0.00059	0.00037	0.02	0.0%
1300	1400	100	Aero Radar, military	0.00437	0.00428	0.00432	0.43	0.4%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00013	0.00021	0.00017	0.02	0.0%
1525	1710	185	Mobile Satellite, GPS, Meteorologicial	0.00025	0.00026	0.00026	0.05	0.0%
1710	1850	140	Fixed, Fixed Mobile	0.00000	0.00002	0.00001	0.00	0.0%
1850	1990	140	PCS, Asyn, Iso	0.42920	0.42824	0.42872	60.02	42.9%
1990	2110	120	TV Aux	0.00654	0.03712	0.02183	2.62	2.2%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00155	0.00224	0.00189	0.17	0.2%
2200	2300	100	Space Operation, Fixed	0.00183	0.00186	0.00185	0.18	0.2%
2300	2360	60	Amateur, WCS, DARS	0.19919	0.19883	0.19901	11.94	19.9%
2360	2390	30	Telemetry	0.00010	0.00015	0.00012	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.30898	0.27225	0.29061	31.97	29.1%
2500	2686	186	ITFS, MMDS	0.30350	0.31315	0.30833	57.35	30.8%
2686	2900	214	Surveillance Radar	0.02111	0.02301	0.02206	4.72	2.2%
Total		2850		0.0000	0.0000	0.0000	494.90	
							0.00	
Total Available Spectrum							2850.00	
Average Spectrum Use (%)							17.4%	

Figure 72 shows the percentage occupancy in each band graphically.

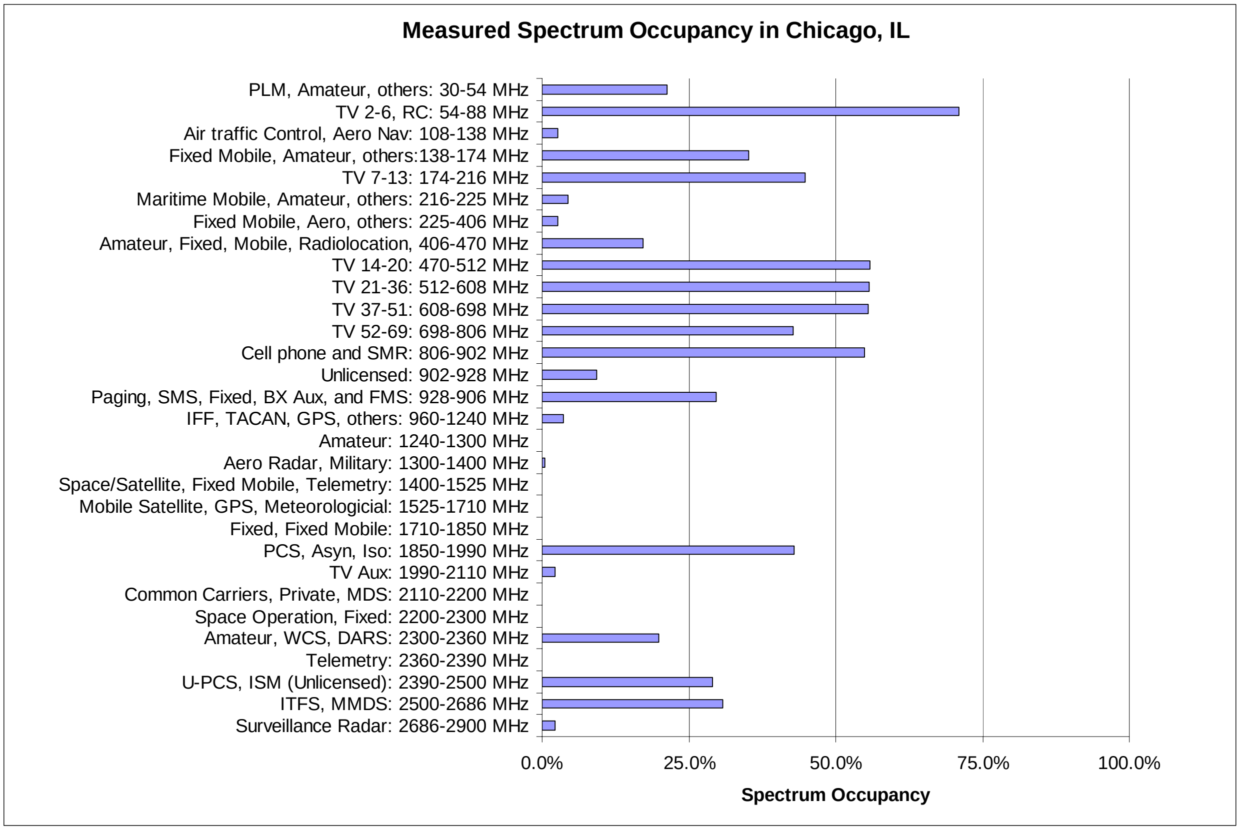

Figure 72 Spectrum occupancy in each band measured in Chicago

6.3 Difference Between Occupancy Upper Bound and Actual Value

The NYC spectrum occupancy measurements suggest that the large spectrum bin size (> 200 kHz) used in wide span (> 100 MHz) measurements significantly over estimates the actual occupancy when the signals of interest have small (~25 kHz) bandwidths.[2] This is due to the frequency bin size being larger than the signal bandwidth of interest and the spectrum analyzer's detection algorithm that uses the maximum power level in the bin to be reported as the value for the entire bin.

In the NYC experiment, measurements were made in a few bands (450 to 455 MHz for example) with both small spectrum analyzer spans (5 MHz) and large spans (approximately 100 MHz, as were used in this report). The measured spectrum occupancy with the smaller span was significantly less than that measured with the larger span, as expected.

For the above reasons, we believe that the spectrum occupancy found in these Chicago measurements are also an upper bound of the actual spectrum occupancy in many bands.

[2] "Spectrum Occupancy Measurements, Location 4 of 6: Republican National Convention, New York City, New York, August 30, 2004 - September 3, 2004, Revision 2", Mark A. McHenry, Dan McCloskey, George Lane-Roberts, Shared Spectrum Company Report, August, 2005 (www.sharedspectrum.com).

Smaller spectrum analyzer spans were not used in the Chicago measurements because of the greatly increased measurement time required.

6.4 Comparison of Chicago and New York City Spectrum Occupancy

In this section we compare the Chicago spectrum occupancy described in this report to similar measurements made in New York City.[3] These measurements used similar collection equipment (the same Pre-selector design but a different unit). The background signal levels were also different; hence, the Pre-selector and spectrum analyzer settings used to maximize the sensitivity were different. This lead to a several dB difference in the noise levels, which changed the occupancy values (which are based on a threshold value several dB about the noise level). We believe that these equipment changes had a small influence on the relative spectrum occupancy values. The measurements where made over the same frequency bands with the same resolution bandwidths.

Table 4 shows a summary of the Spectrum Occupancy in each band in New York City and Chicago measurements. Overall Chicago has higher spectrum occupancy (17.4%) than New York City (13.1%). In general, the band occupancy in each location is similar. Differences occur in the TV band where Chicago has high occupancy in TV 2-6 and 14-69, while New York has a higher occupancy in TV 7-13. Chicago had significantly higher occupancy in the 2390-2500 MHz (primarily unlicensed) band and in the 2500-2686 MHz (ITFS, MMDS) band. The reasons for this are unknown. Chicago had higher occupancy in the 1850-1990 MHz (PCS) band in part because the PCS Band "C" was occupied in Chicago and not in New York City.

3 "Spectrum Occupancy Measurements, Location 4 of 6: Republican National Convention, New York City, New York, August 30, 2004 - September 3, 2004, Revision 2", Mark A. McHenry, Dan McCloskey, George Lane-Roberts, Shared Spectrum Company Report, August, 2005 (www.sharedspectrum.com).

Table 4 Summary of Spectrum Occupancy in Each Band in New York City and Chicago

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	NYC Day 1 Spectrum Fraction Used	NYC Day 2 Spectrum Fraction Used	NYC Avg Spectrum Fraction Used	NYC Occupied Spectrum (MHz)	NYC Average Percent Occupied	Chicago Day 1 Spectrum Fraction Used	Chicago Day 2 Spectrum Fraction Used	Chicago Avg Spectrum Fraction Used	Chicago Occupied Spectrum (MHz)	Chicago Average Percent Occupied
30	54	24	PLM, Amateur, others	0.04300	0.06250	0.05275	1.27	5.3%	0.2307	0.1937	0.21221	5.09	21.2%
54	88	34	TV 2 -6, RC	0.52830	0.52080	0.52455	17.83	52.5%	0.7087	0.7093	0.70902	24.11	70.9%
108	138	30	Air traffic Control, Aero Nav	0.05270	0.04030	0.04650	1.40	4.7%	0.0281	0.0244	0.02628	0.79	2.6%
138	174	36	Fixed Mobile, amateur, others	0.17080	0.16980	0.17030	6.13	17.0%	0.3544	0.3491	0.35175	12.66	35.2%
174	216	42	TV 7-13	0.77730	0.77950	0.77840	32.69	77.8%	0.4479	0.4473	0.44762	18.80	44.8%
216	225	9	Maritime Mobile, Amateur, others	0.05860	0.05950	0.05905	0.53	5.9%	0.0427	0.0451	0.04392	0.40	4.4%
225	406	181	Fixed Mobile, Aero, others	0.00530	0.00370	0.00450	0.81	0.5%	0.0279	0.0267	0.02728	4.94	2.7%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.16610	0.14750	0.15680	10.04	15.7%	0.1746	0.1685	0.17158	10.98	17.2%
470	512	42	TV 14-20	0.21140	0.21000	0.21070	8.85	21.1%	0.5592	0.5578	0.55847	23.46	55.8%
512	608	96	TV 21-36	0.35520	0.34270	0.34895	33.50	34.9%	0.5627	0.5518	0.55726	53.50	55.7%
608	698	90	TV 37-51	0.46160	0.46090	0.46125	41.51	46.1%	0.5539	0.5557	0.55477	49.93	55.5%
698	806	108	TV 52-69	0.29580	0.30790	0.30185	32.60	30.2%	0.4242	0.4296	0.42691	46.11	42.7%
806	902	96	Cell phone and SMR	0.46190	0.46450	0.46320	44.47	46.3%	0.5501	0.5468	0.54841	52.65	54.8%
902	928	26	Unlicensed	0.22270	0.23460	0.22865	5.94	22.9%	0.0958	0.0908	0.09333	2.43	9.3%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.23640	0.24370	0.24005	7.68	24.0%	0.2960	0.2967	0.29634	9.48	29.6%
960	1240	280	IFF, TACAN, GPS, others	0.03560	0.04080	0.03820	10.70	3.8%	0.0397	0.0324	0.03602	10.09	3.6%
1240	1300	60	Amateur	0.00030	0.00010	0.00020	0.01	0.0%	0.0002	0.0006	0.00037	0.02	0.0%
1300	1400	100	Aero Radar, military	0.02160	0.00130	0.01145	1.15	1.1%	0.0044	0.0043	0.00432	0.43	0.4%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.01520	0.00050	0.00785	0.98	0.8%	0.0001	0.0002	0.00017	0.02	0.0%
1525	1710	185	Mobile Satellite, GPS, Meteorologicial	0.00240	0.00130	0.00185	0.34	0.2%	0.0003	0.0003	0.00026	0.05	0.0%
1710	1850	140	Fixed, Fixed Mobile	0.02350	0.02540	0.02445	3.42	2.4%	0.0000	0.0000	0.00001	0.00	0.0%
1850	1990	140	PCS, Asyn, Iso	0.33090	0.34430	0.33760	47.26	33.8%	0.4292	0.4282	0.42872	60.02	42.9%
1990	2110	120	TV Aux	0.01910	0.00820	0.01365	1.64	1.4%	0.0065	0.0371	0.02183	2.62	2.2%
2110	2200	90	Common Carriers, Private Companies, MDS	0.01820	0.01900	0.01860	1.67	1.9%	0.0016	0.0022	0.00189	0.17	0.2%
2200	2300	100	Space Operation, Fixed	0.05270	0.06180	0.05725	5.73	5.7%	0.0018	0.0019	0.00185	0.18	0.2%
2300	2360	60	Amateur, WCS, DARS	0.20220	0.20530	0.20375	12.23	20.4%	0.1992	0.1988	0.19901	11.94	19.9%
2360	2390	30	Telemetry	0.06200	0.06420	0.06310	1.89	6.3%	0.0001	0.0001	0.00012	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.13470	0.15510	0.14490	15.94	14.5%	0.3090	0.2722	0.29061	31.97	29.1%
2500	2686	186	ITFS, MMDS	0.10430	0.10420	0.10425	19.39	10.4%	0.3035	0.3132	0.30833	57.35	30.8%
2686	2900	214	Surveillance Radar	0.02860	0.03090	0.02975	6.37	3.0%	0.0211	0.0230	0.02206	4.72	2.2%
Total		2850					373.97					494.90	
							0					0	
Total Available Spectrum							2850					2850	
Average Spectrum Use (%)							13.1%					17.4%	

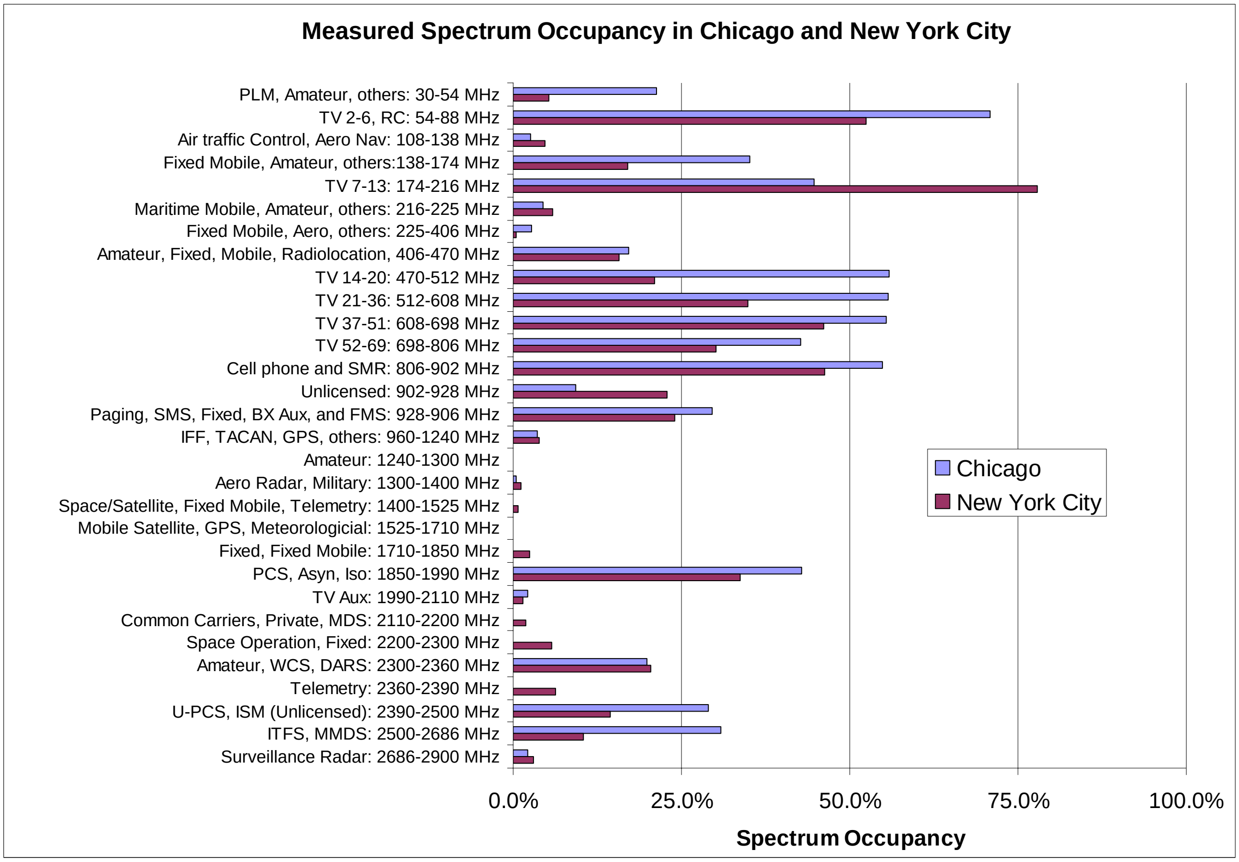

Figure 73 Bar graph of the Spectrum Occupancy in Each Band in New York City and Chicago

6.5 Comparison of Chicago and Other Location's Spectrum Occupancy

This section compares the Chicago spectrum occupancy to other measurement locations. Table 5 shows the locations of spectrum measurement made by Shared Spectrum Company utilizing techniques similar to those applied in the Chicago measurements. The locations include outdoor urban and rural locations, and an indoor location. Most of the locations were highly elevated and had excellent line-of-sight to the surround area (thus, maximizing the detection probability). The obvious bottom-line summary of these results is that by adding time and space considerations into the equation, there is indeed considerable spectrum available for exploitation.

These measurements further reinforce the desirability of additional measurements in more locations, over even broader frequency ranges, and over longer periods of time to better characterize the nation's current and future spectrum occupancy. Through these studies, the discrete opportunities for improved spectrum utilization should become very visible enhancing the focus for our wireless technology research and development activities, and providing a greatly improved knowledge base for the development of regulatory decisions in both the FCC and the NTIA.

Table 5 Measurement Locations

Location	Symbol	Dates	Purpose
Inside Shared Spectrum offices	ssc_office	10/28/2004, 2/4/2004, 2/9/2004	Test equipment
Outside in Shared Spectrum parking lot	ssc_parking	4/6/2004	Urban location
Riverbend Park	Riverbend Park	4/7/2005	Rural location
Tysons Corner shopping center parking lot	tysons_parking	4/9/2004	Urban location
National Science Foundation (NSF) building roof	NSF_building_roof	4/16/2004	Elevated, urban location
New York City	NYC	8/5/2004	Elevated, urban location
New York City	NYC_convention	8/30/2004, 4/9/2004	Elevated, urban location
National Radio Astronomy Observatory, Green Bank, West Virginia	NRAO	10/4/2004	Very quiet, rural location
Shared Spectrum office roof	ssc_roof	Multiple 12/15/2004-6/9/2005	Elevated, urban location using a wide variety of frequency lists

Figure 74 shows the overall average spectrum occupancy of seven locations that include Chicago. The chart illustrates that the current dominant spectrum use is for broadcast TV. At the same time, many of the bands have an insignificant spectrum occupancy value.

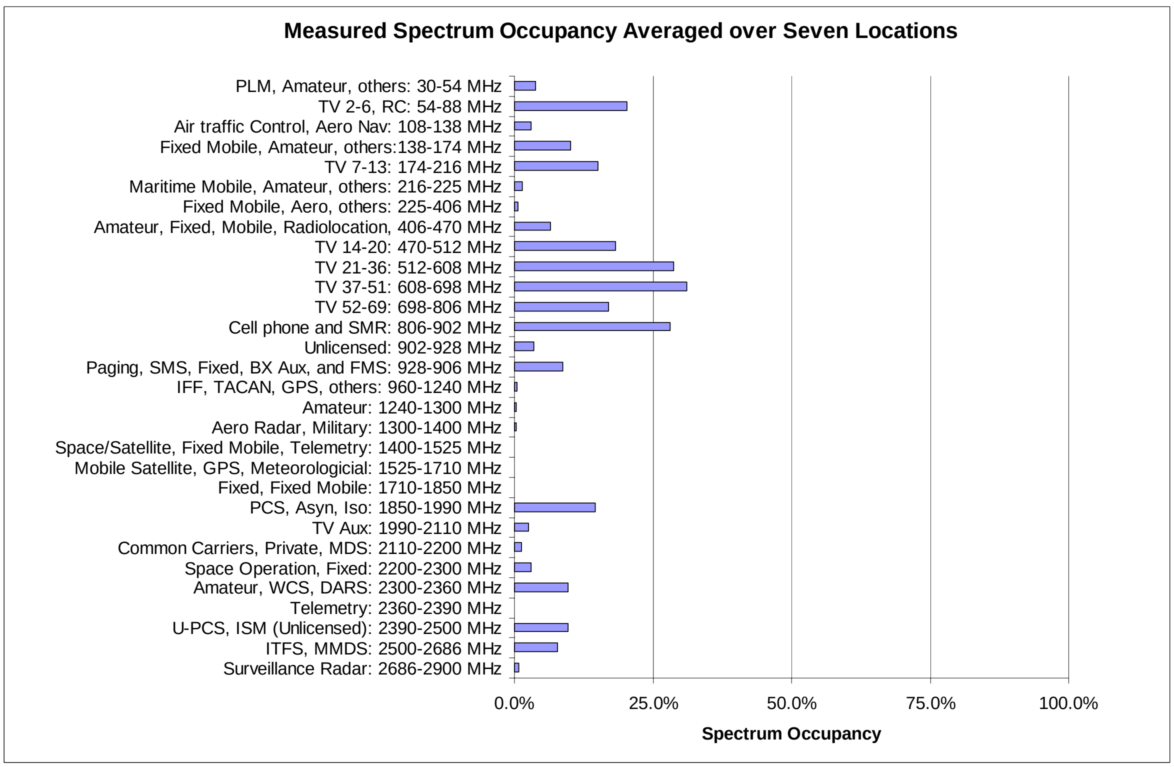

Figure 74 Bar graph of the Spectrum Occupancy Averaged over Seven Locations (including Chicago)

Figure 75 shows the overall measured at each of the seven locations. As expected, the lowest occupancy was at Green Bank, WV (1%). The highest occupancy to date is in Chicago (17.4%), which is also the most recently measured site.

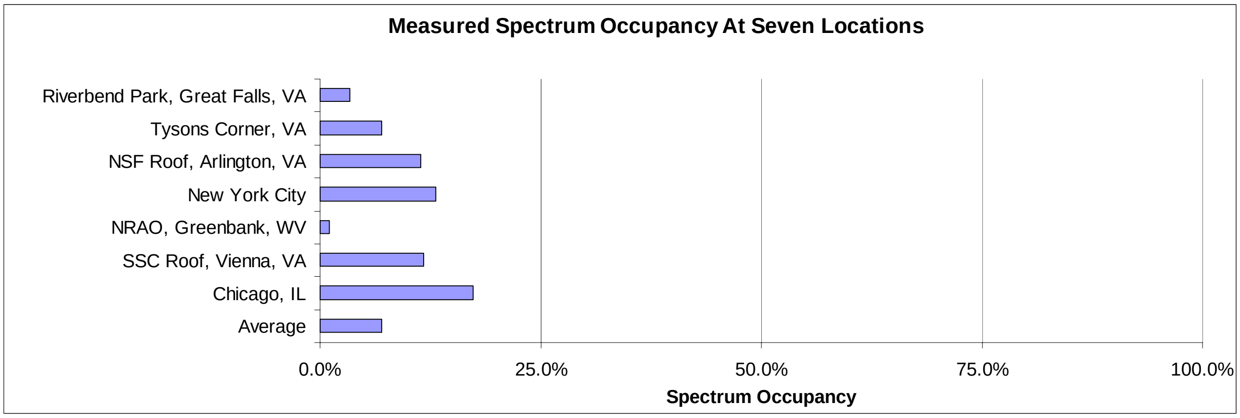

Figure 75 Overall Spectrum Occupancy Measured at Seven Locations