Spectrum Occupancy Measurements
Loring Commerce Centre
Limestone, Maine
September 18-20, 2007

Tugba Erpek
Mark Lofquist
Ken Patton

Shared Spectrum Company
1595 Spring Hill Road, Suite 110
Vienna, VA 22182-2228
www.sharedspectrum.com

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1. Introduction

1.1 Summary

This document describes spectrum occupancy measurements performed by Shared Spectrum Company at the Loring Commerce Centre, Limestone, Maine on September 18 to 20, 2007.

1.2 Report Organization

This report is organized into five sections, as follows:

Section 1 Introduction
Section 2 Description of measurement equipment
Section 3 Site and surrounding environment where measurements were taken
Section 4 Plots showing measured spectrum occupancy for each band
Section 5 Summary

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 Loring Commerce Centre measurements was to gain a better understanding of the actual utilization of spectrum in a rural environment that is used for testing and development of aeronautical and other systems. Spectrum availability for this type of testing is a critical requirement. Occupancy was quantified as the amount of spectrum detected above a certain received low value power threshold.

2. Measurement Equipment

This section describes the spectrum occupancy measurement equipment.

2.1 Equipment Description

The equipment used for measurement in this study consisted of a spectrum analyzer, a low frequency discone antenna (Diamond D-130J), a high frequency discone antenna (AOR DA5000), a low band receiver amplifier (RFHIC RFW1G35H20-28), a high band receiver amplifier (Mini-Circuits ZHL-4240) and a laptop computer. The low frequency discone antenna was used to measure signals between 100 MHz and 1 GHz and the high frequency one to measure signals between 1 GHz and 3 GHz. An RG-8 cable was used to connect the discone antennas to amplifiers. 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 for low frequency discone antenna and amplifier and in Figure 2 for high frequency discone antenna and amplifier.

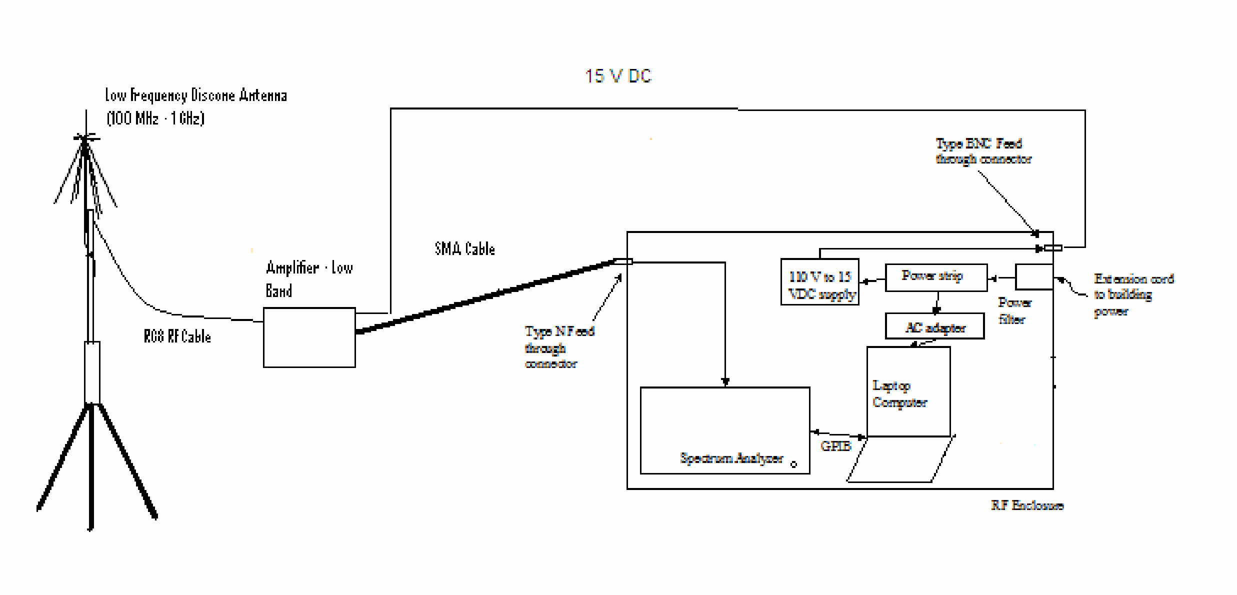

Figure 1. Spectrum Measurement Equipment Configuration for Low Frequency Bands

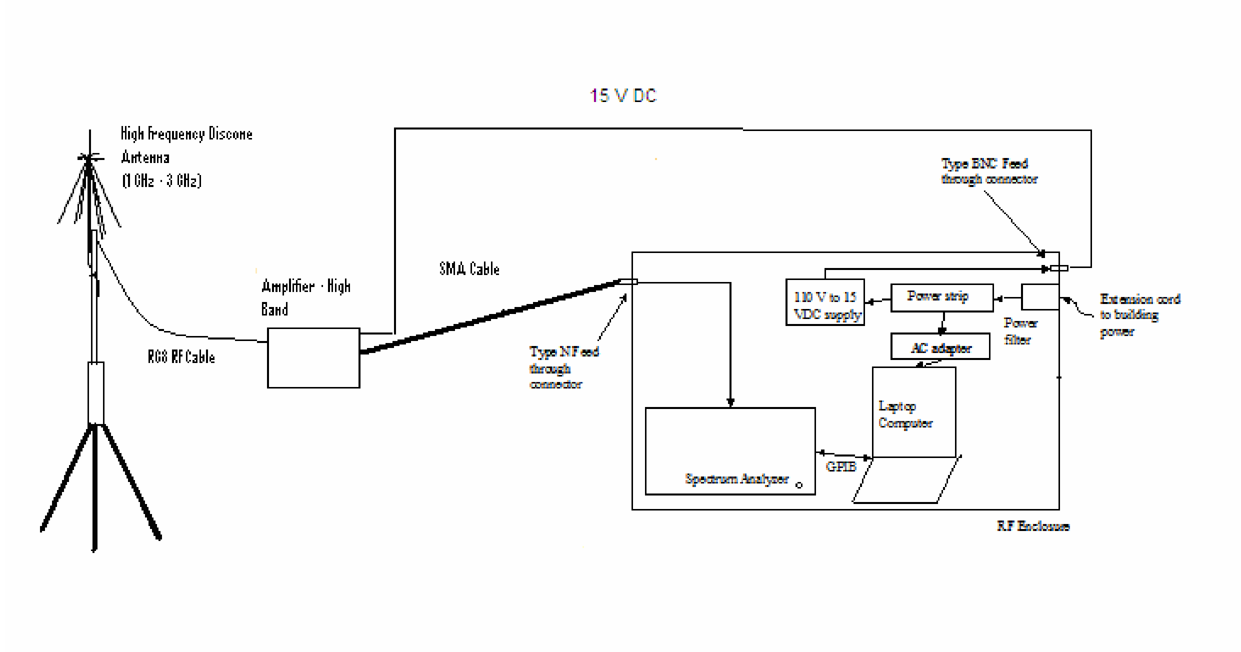

Figure 2. Spectrum Measurement Equipment Configuration for High Frequency Bands

A photograph of the discone antennas used to take measurements is given in Figure 3.

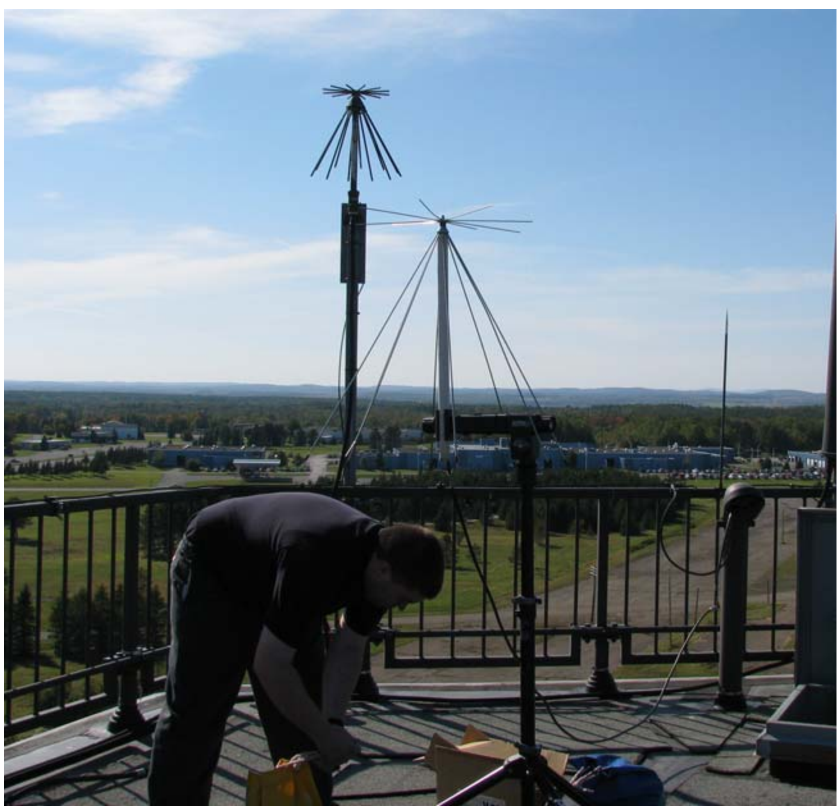

Figure 3. Discone Antennas Used to Take Measurements

The RF and other cables were routed down a building conduit to a room below the roof. The spectrum analyzer (Rhode and Schwarz EPSI-3) and laptop were located in a room just below the roof as shown in Figure 4.

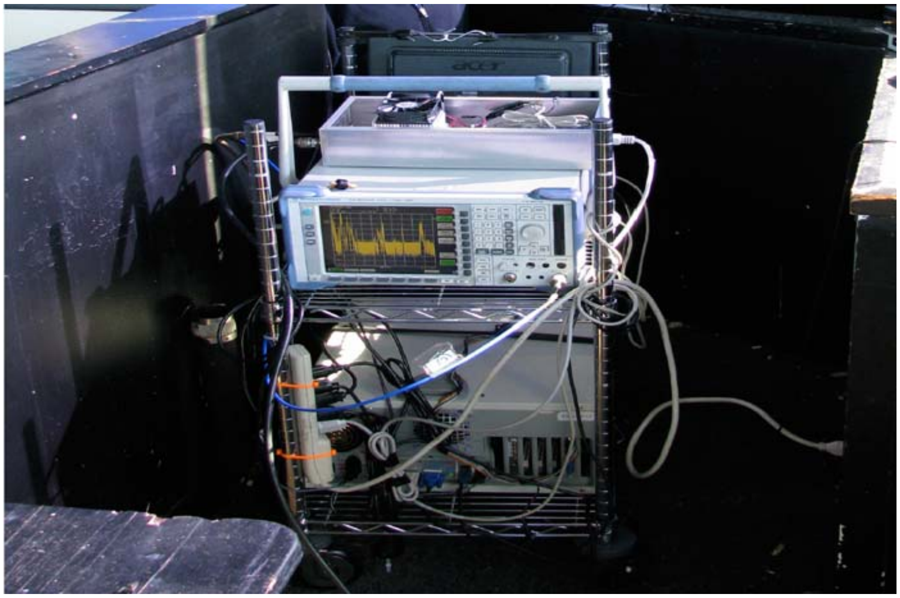

Figure 4. Spectrum Analyzer Used to Take Measurements

Before each official measurement was taken at the site, test data was collected within the frequencies designated for this experiment. The frequencies used for the test are between 335 MHz and 399 MHz. 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 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.

Long duration measurements began on September 18, 2007 and ended on September 20, 2007. Starting on September 18, 2007 at 3:39 pm, data for low frequency bands was collected for 22 hours and 30 minutes. After that, data for high frequency bands was collected for 18 hours and 39 minutes starting on September 19, 2007 at 2:27 pm.

2.2 Equipment Settings

Table 1 shows the equipment settings used for all bands. As seen in Table 1, the pre-selector of spectrum analyzer is always on; as a result, no other pre-selector is used during the experiment.

Table 1. Equipment Settings for Each Spectrum Band

Start Frequency (MHz)	Stop Frequency (MHz)	Spectrum Analyzer				
		RBW (kHz)	VBW (kHz)	Attenuation (dB)	Ref Level (dBm)	Pre-selector (on/off)
30	54	30	30	10	0	1
54	88	30	30	10	0	1
108	138	30	30	10	0	1
138	174	30	30	10	0	1
174	216	30	30	10	0	1
216	225	30	30	10	0	1
225	406	30	30	10	0	1
406	470	30	30	10	0	1
470	512	30	30	10	0	1
512	608	30	30	10	0	1
608	698	30	30	10	0	1
698	806	30	30	10	0	1
806	902	30	30	10	0	1
902	928	30	30	10	0	1
928	1000	30	30	10	0	1
1000	1240	30	30	10	0	1
1240	1300	30	30	10	0	1
1300	1400	30	30	10	0	1
1400	1525	30	30	10	0	1
1525	1710	30	30	10	0	1
1710	1850	30	30	10	0	1
1850	1990	30	30	10	0	1
1990	2110	30	30	10	0	1
2110	2200	30	30	10	0	1
2200	2300	30	30	10	0	1
2300	2360	30	30	10	0	1
2360	2390	30	30	10	0	1
2390	2500	30	30	10	0	1
2500	2686	30	30	10	0	1
2686	2900	30	30	10	0	1
2900	3000	30	30	10	0	1

2.3 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 and amplifier.
- To correct for this difference, the amplifier gain was measured using a network analyzer in each spectrum band at the conclusion of the measurements.
- The amplifier gain versus frequency data values (in dB) were 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 values in dBm at the antenna input.

3. Measurement Site

The measurements were made at Loring Commerce Centre, Limestone, Maine. The specific collection site was on top of the control tower of the old Loring AFB located at 5100 Texas Road, Limestone, ME 04751.

3.1 Location

A map of the measurement location is shown in Figure 5, below.

Figure 5. Photograph Showing the Location of the Loring Development Centre Measurement Location

The measurement location (on the roof of the Air Base Control Tower) had an unobstructed view in all directions as shown in Figure 6.

Figure 6. Measurement Site Located on top of Air Base Control Tower

3.2 Views from Measurement Site

Figure 7 and Figure 8 in this section show photographs taken from the measurement antenna location, looking out in different directions. The LPA antenna seen in Figure 7 is not part of the measurement system, and did not affect the measurement results.

Figure 7. View from Measurement Site

Figure 8. View from Measurement Site

3.3 Near-By Transmitters and Potential Noise Sources

Loring is a rural environment and spectrum occupancy is low in this area. Near-by TV transmitter locations are given in Table 2 below. The closest TV transmitter (Channel 51) is 21.56 km away from the test location. The signal strength from those transmitters was low enough, so they did not cause significant overload to the spectrum measurement system.

Table 2. TV Transmitter Locations

Channel	City	State	Distance From Test Location (km)
10	Presque Isle	ME	42.97
10.1	Presque	ME	42.97
8	Presque Isle	ME	42.97
8.1	Presque Isle	ME	42.97
51	Presque Isle	ME	21.56

4. Spectrum Occupancy Measurements

This section contains plots of the spectrum occupancy measurements.

4.1 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.

4.2 Measurements Made Below 1,000 MHz

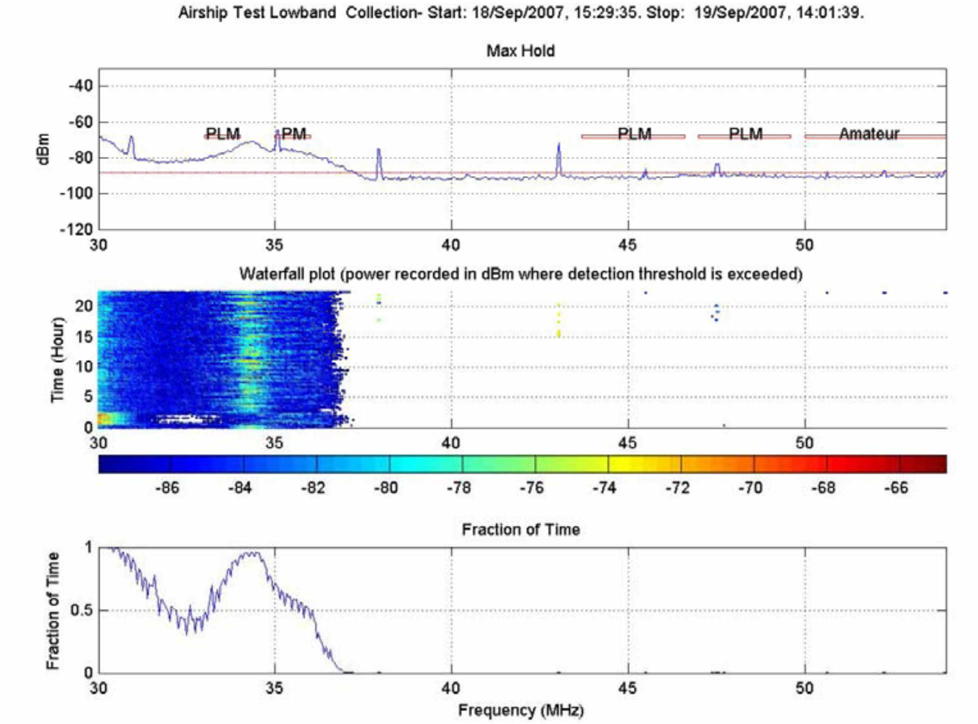

Figure 9. 30 MHz to 54 MHz

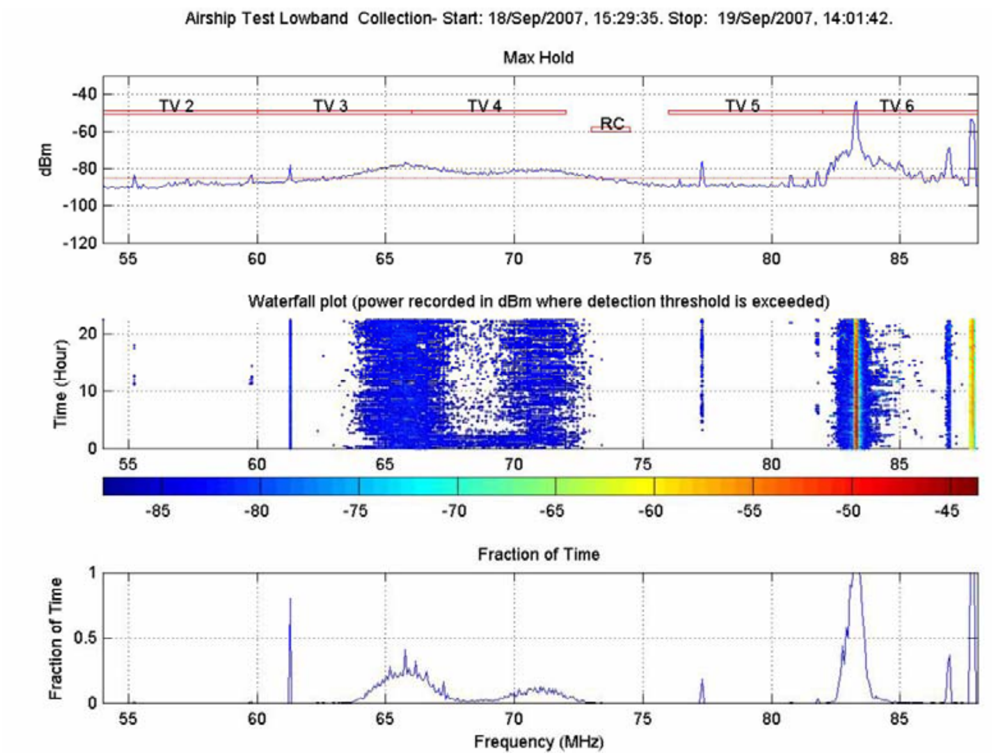

Figure 10. 54 MHz to 88 MHz

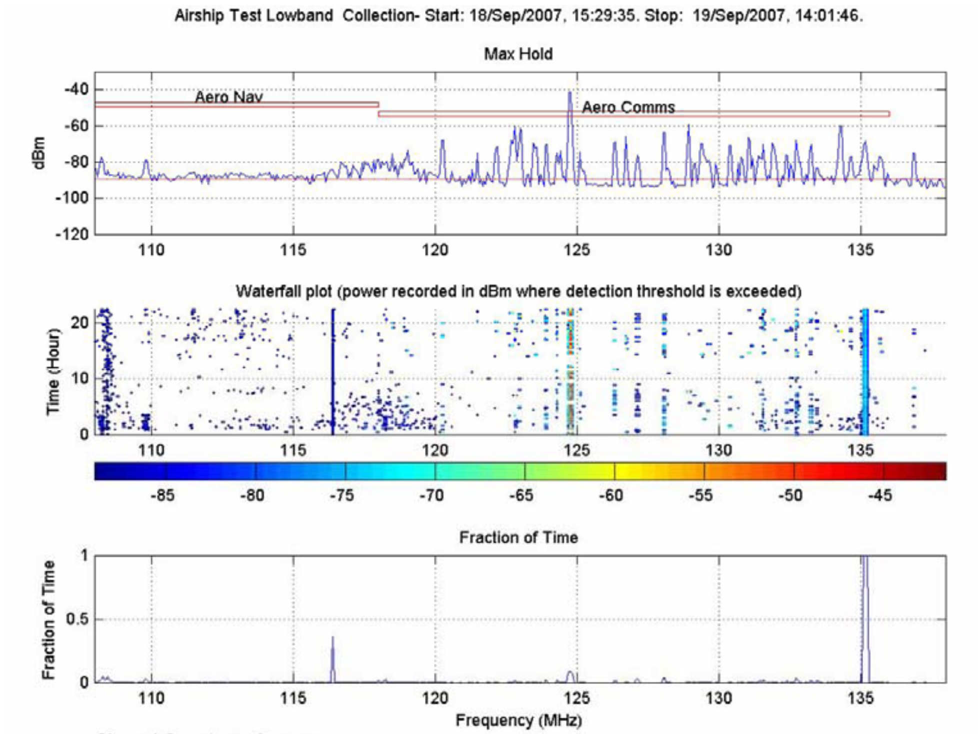

Figure 11. 108 MHz to 138 MHz

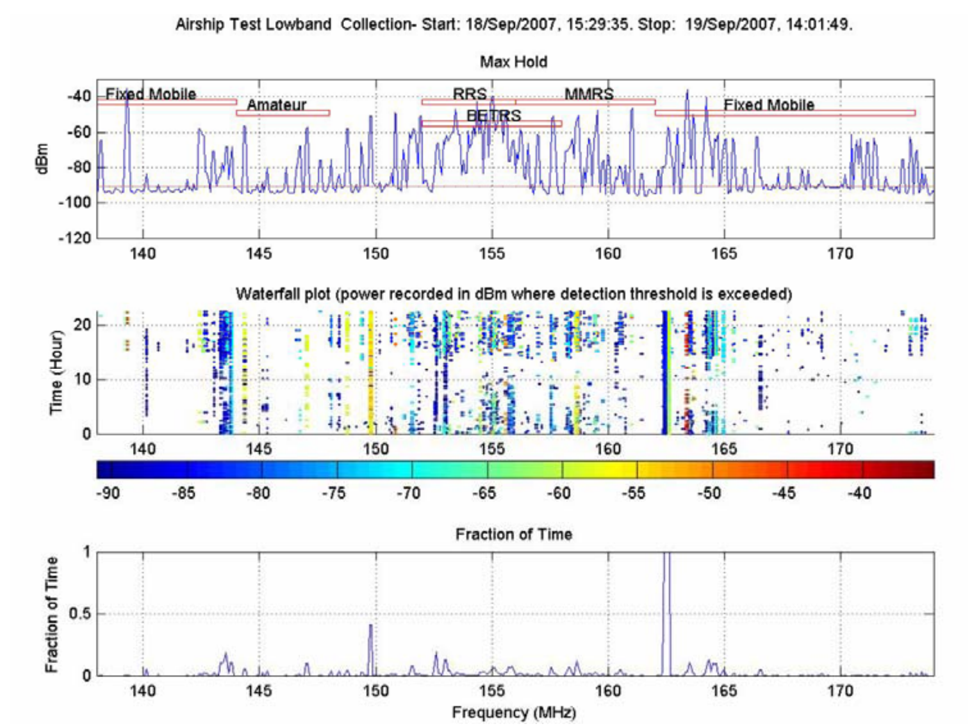

Figure 12. 138 MHz to 174 MHz

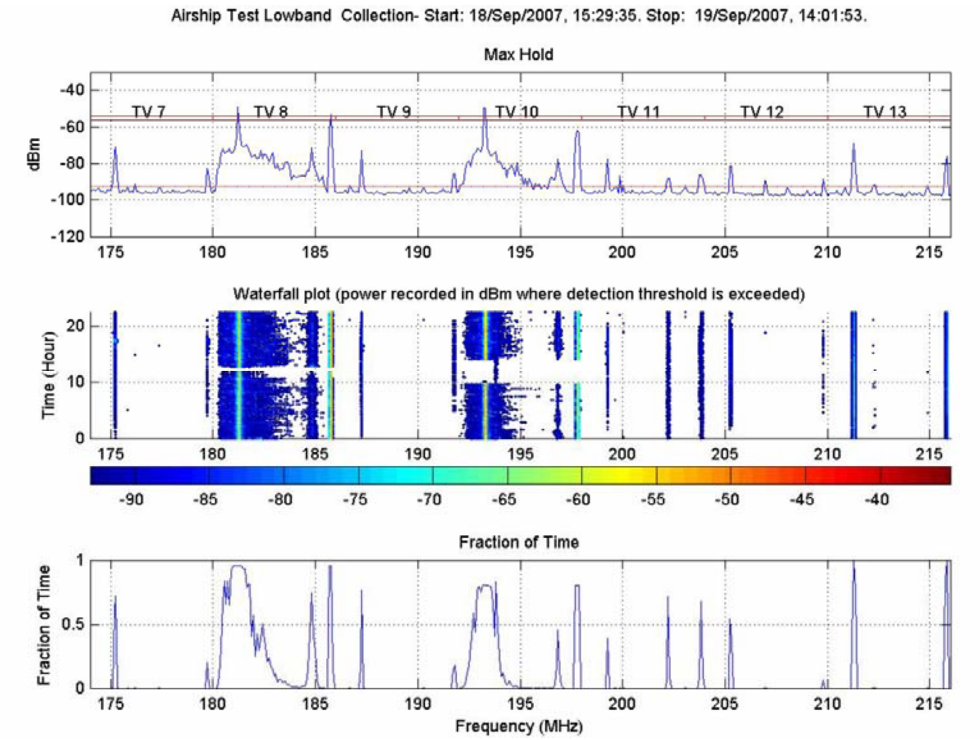

Figure 13. 174 MHz to 216 MHz

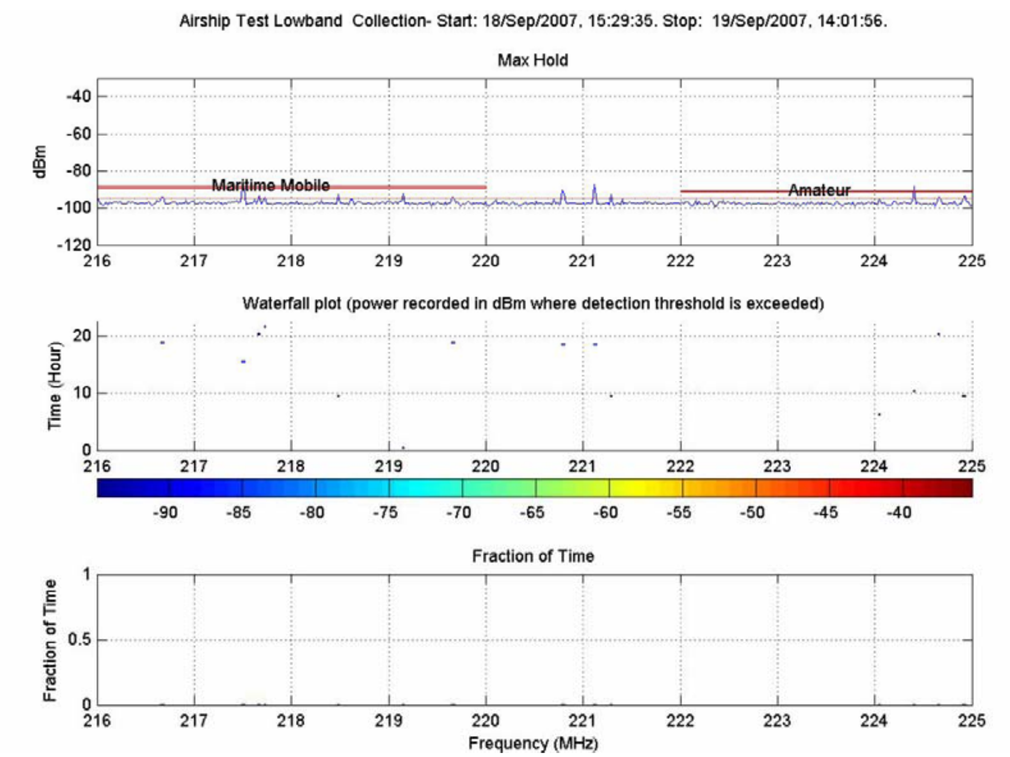

Figure 14. 216 MHz to 225 MHz

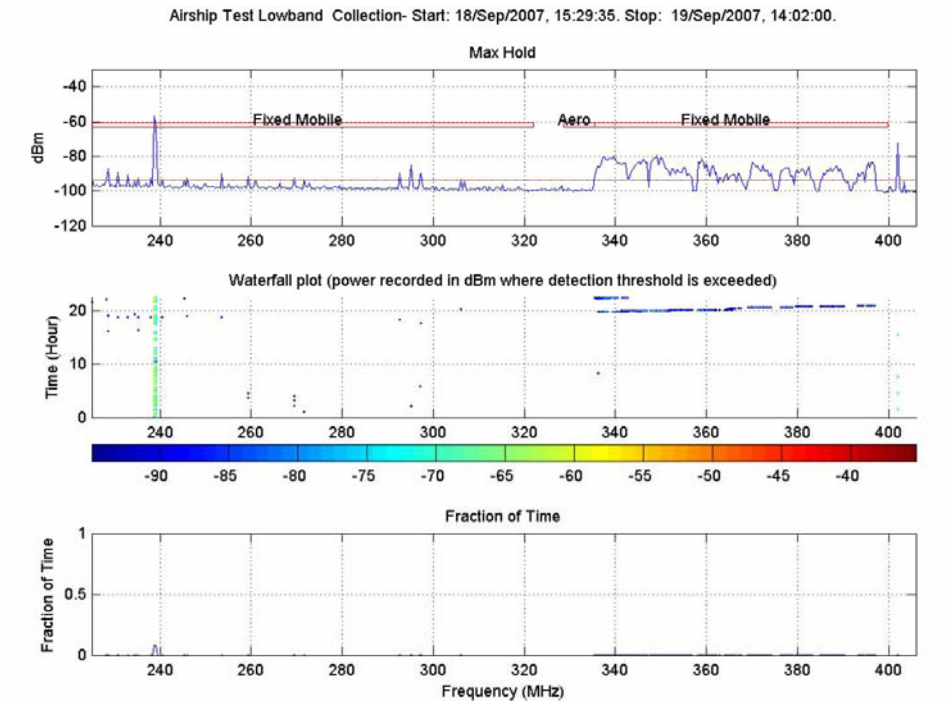

Figure 15. 225 MHz to 406 MHz

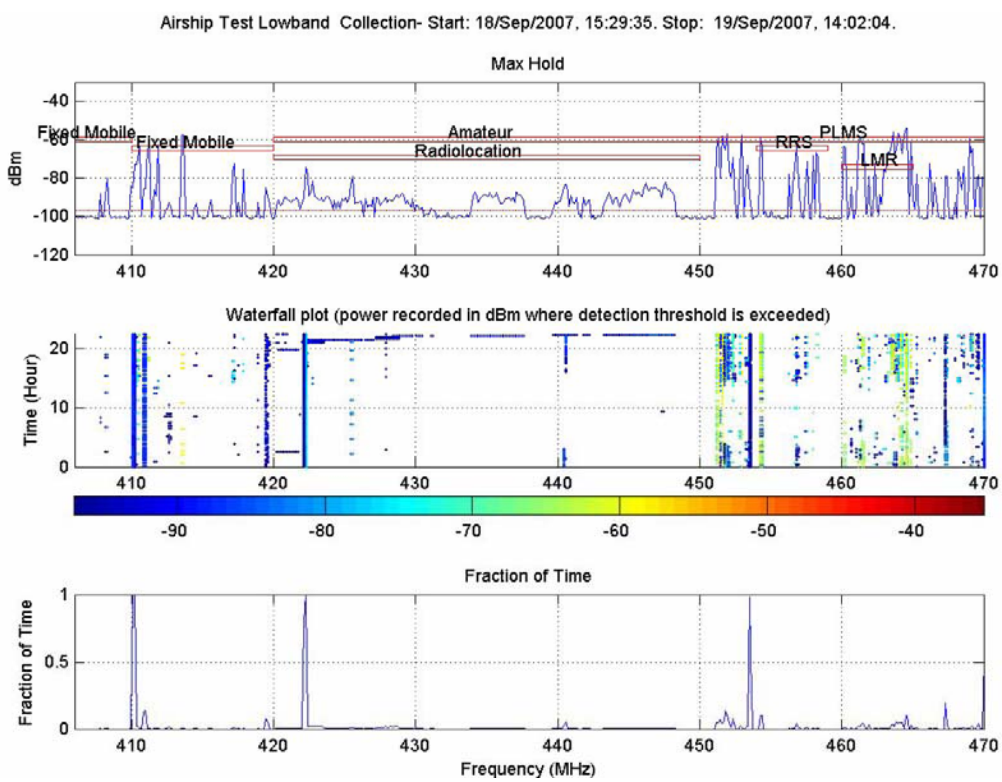

Figure 16. 406 MHz to 470 MHz

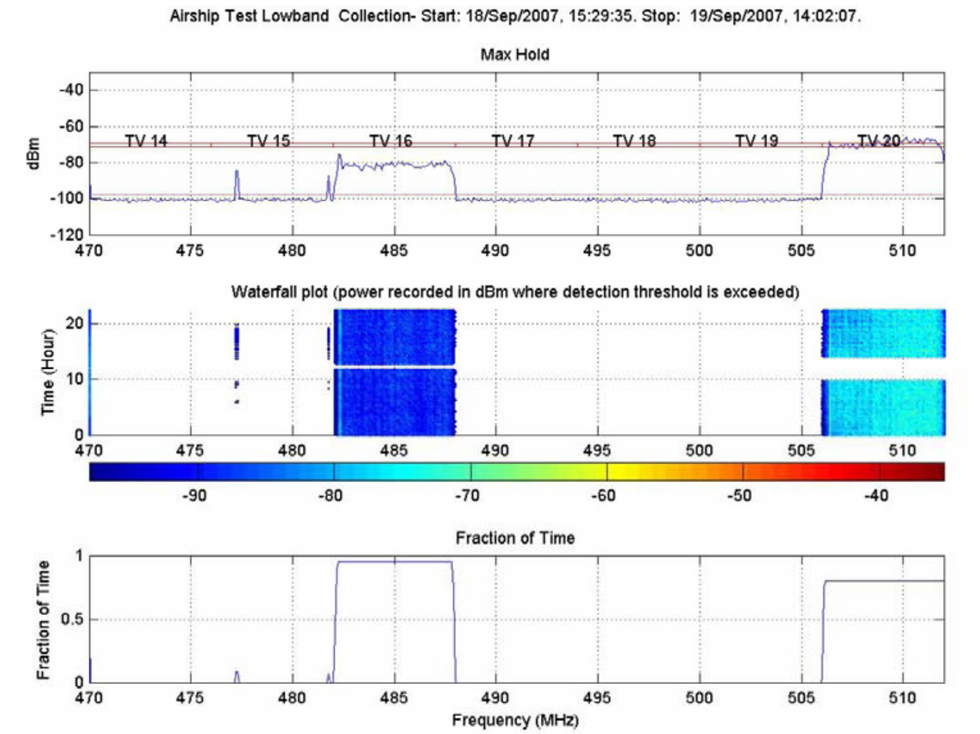

Figure 17. 470 MHz to 512 MHz

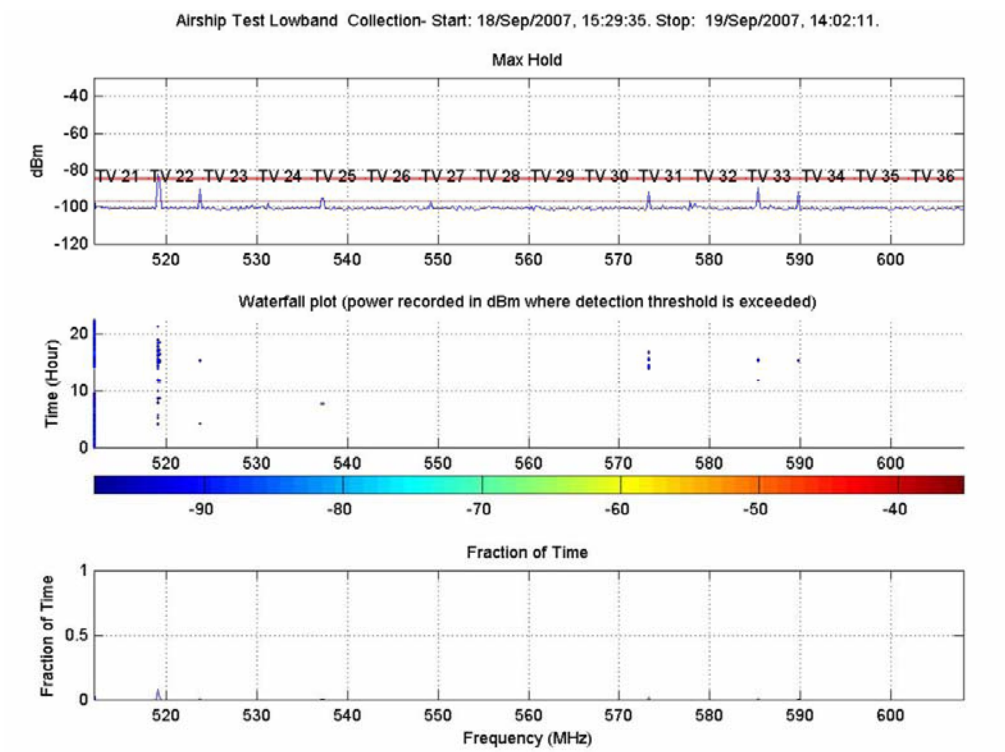

Figure 18. 512 MHz to 608 MHz

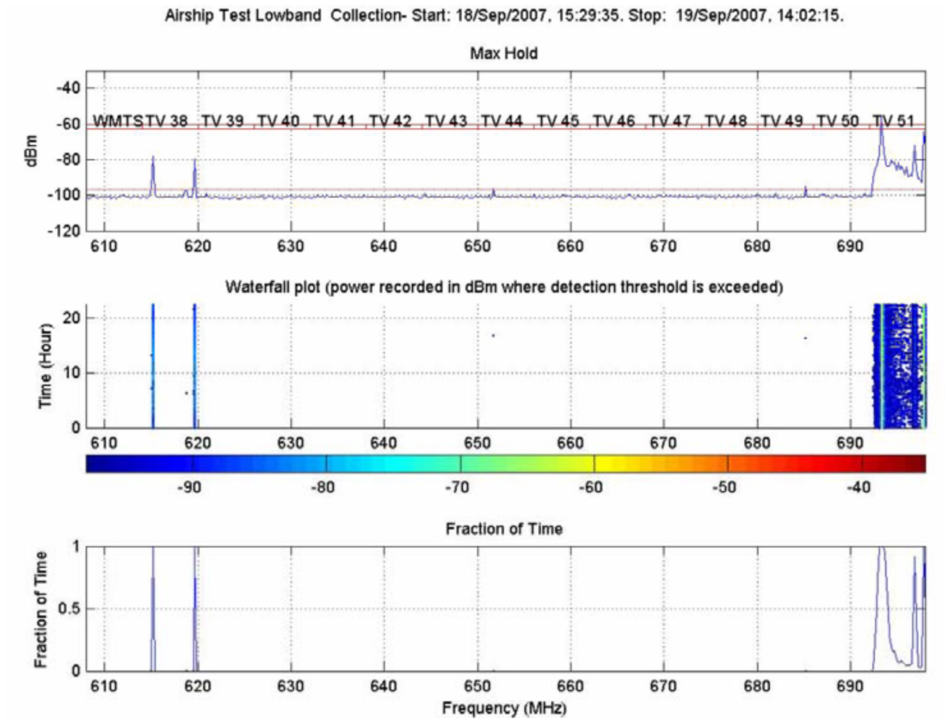

Figure 19. 608 MHz to 698 MHz

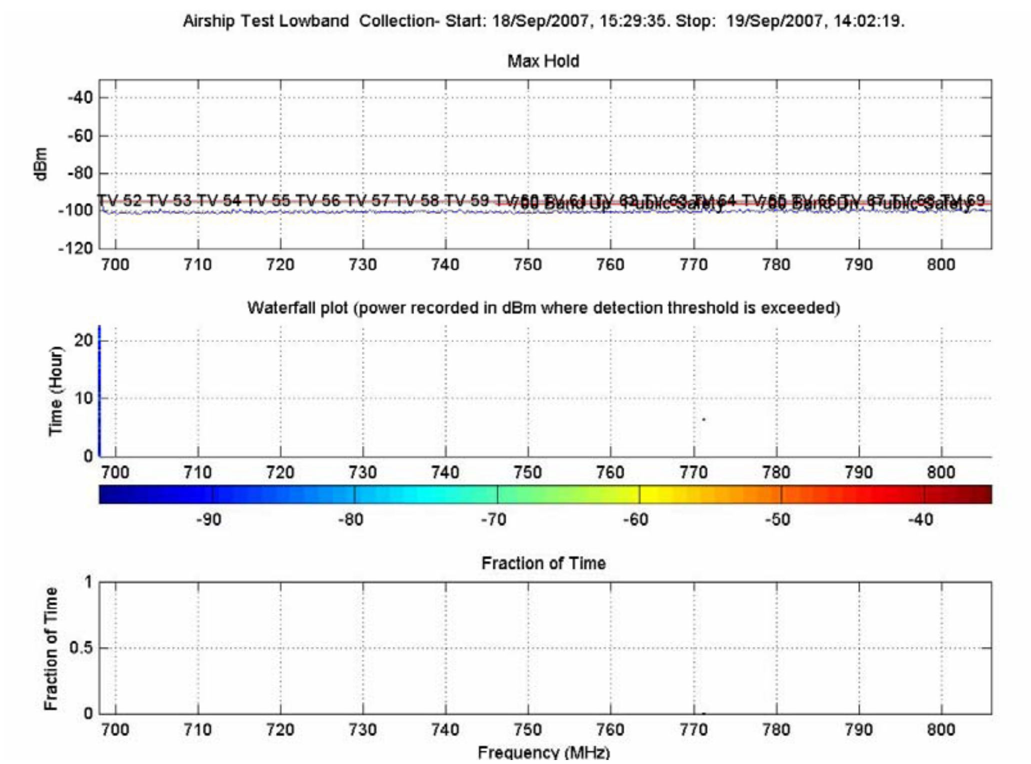

Figure 20. 698 MHz to 806 MHz

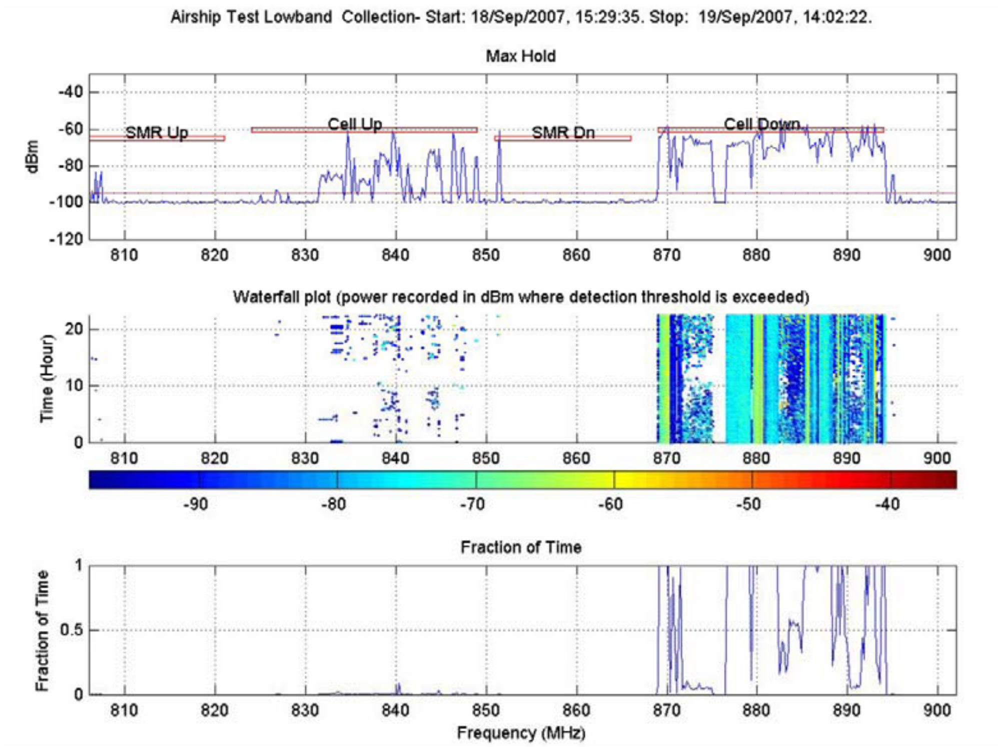

Figure 21. 806 MHz to 902 MHz

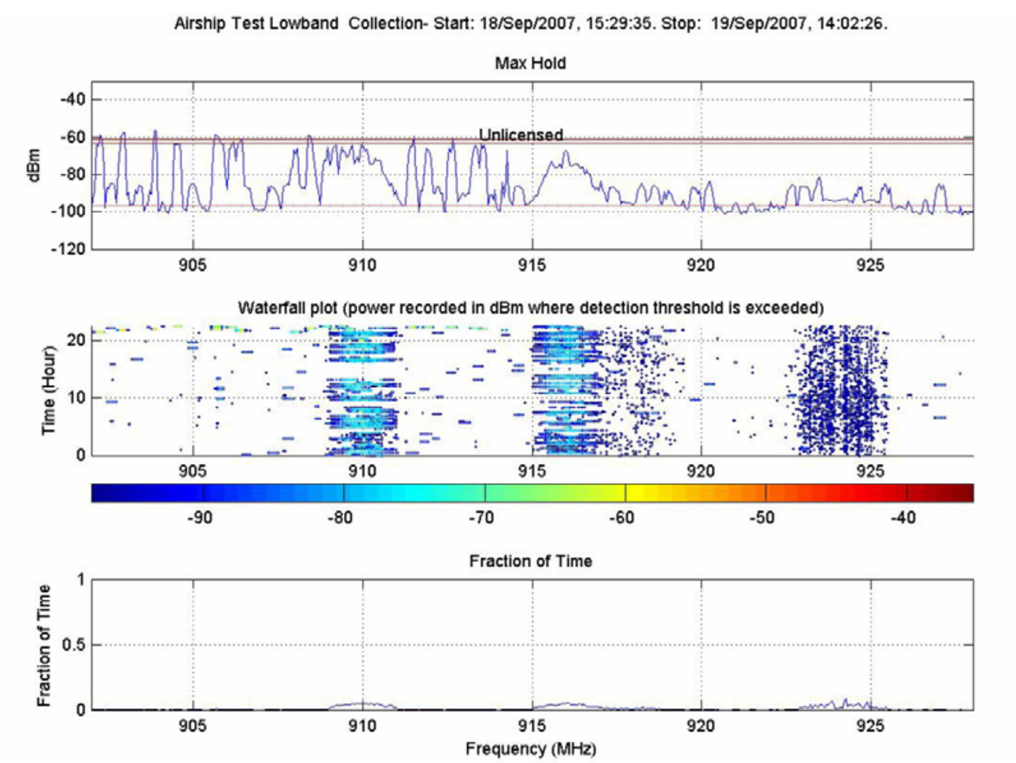

Figure 22. 902 MHz to 928 MHz

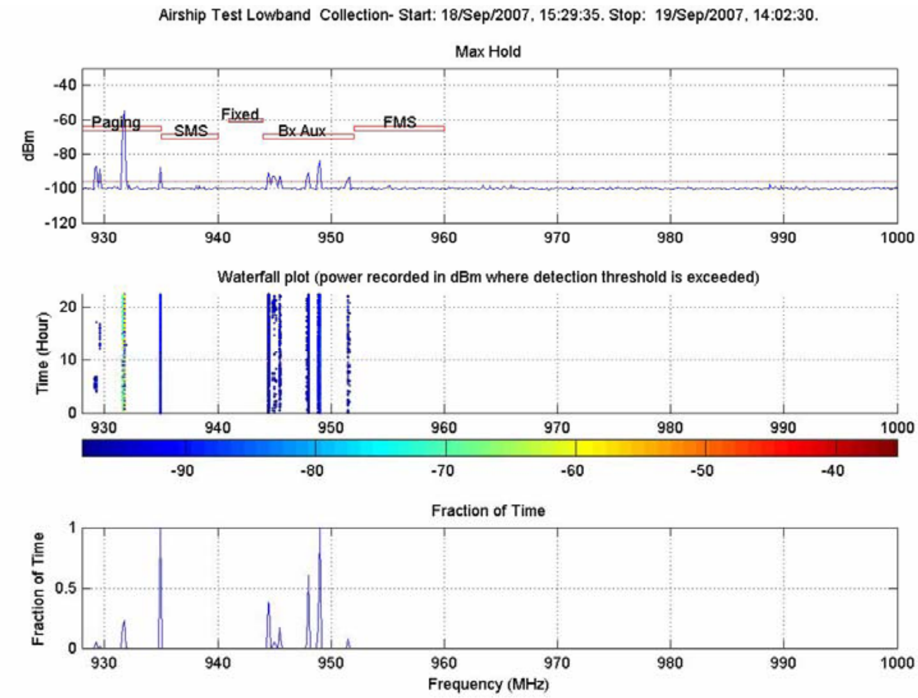

Figure 23. 928 MHz to 1000 MHz

4.3 Measurements Made Above 1,000 MHz

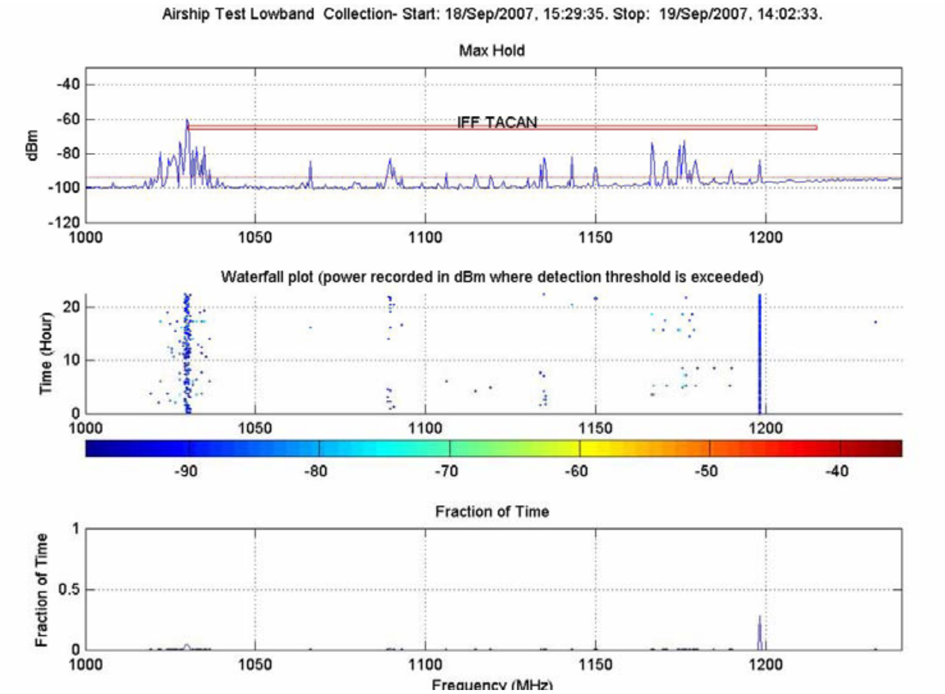

Figure 24. 1000 MHz to 1240 MHz

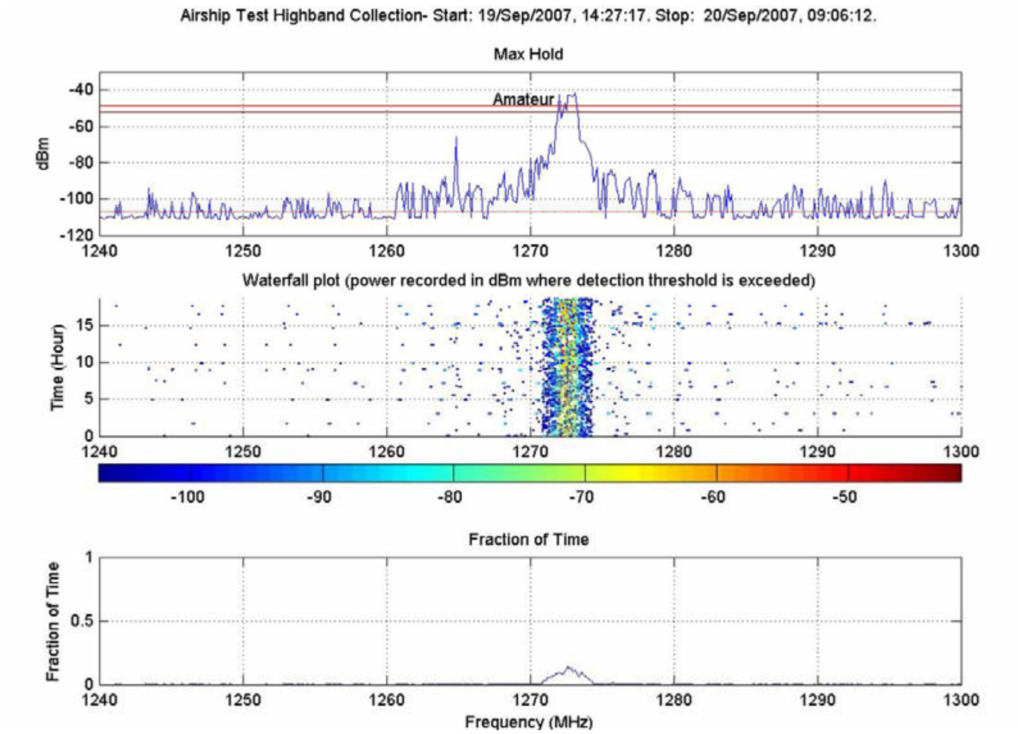

Figure 25. 1240 MHz to 1300 MHz

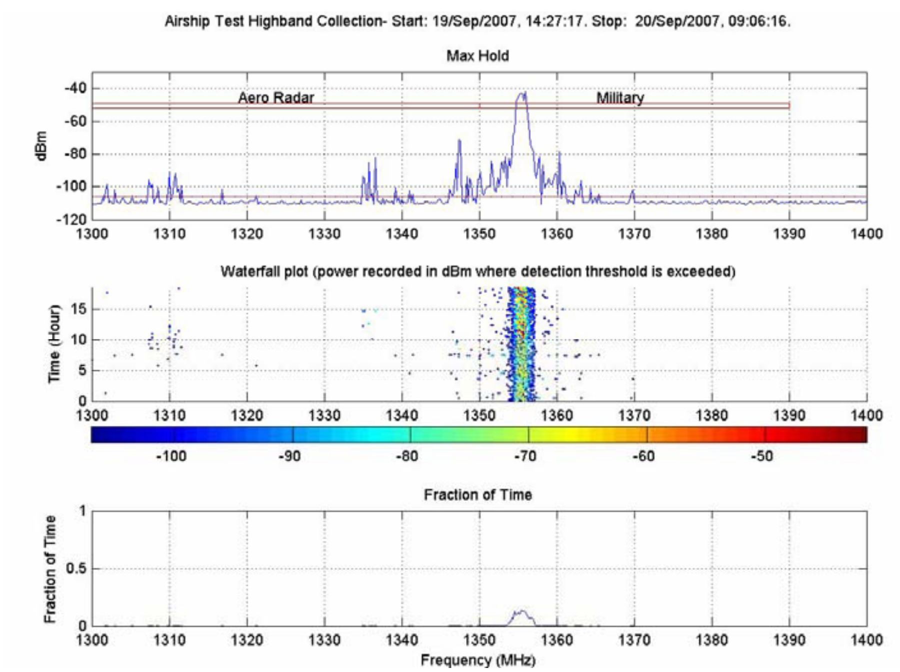

Figure 26. 1300 MHz to 1400 MHz

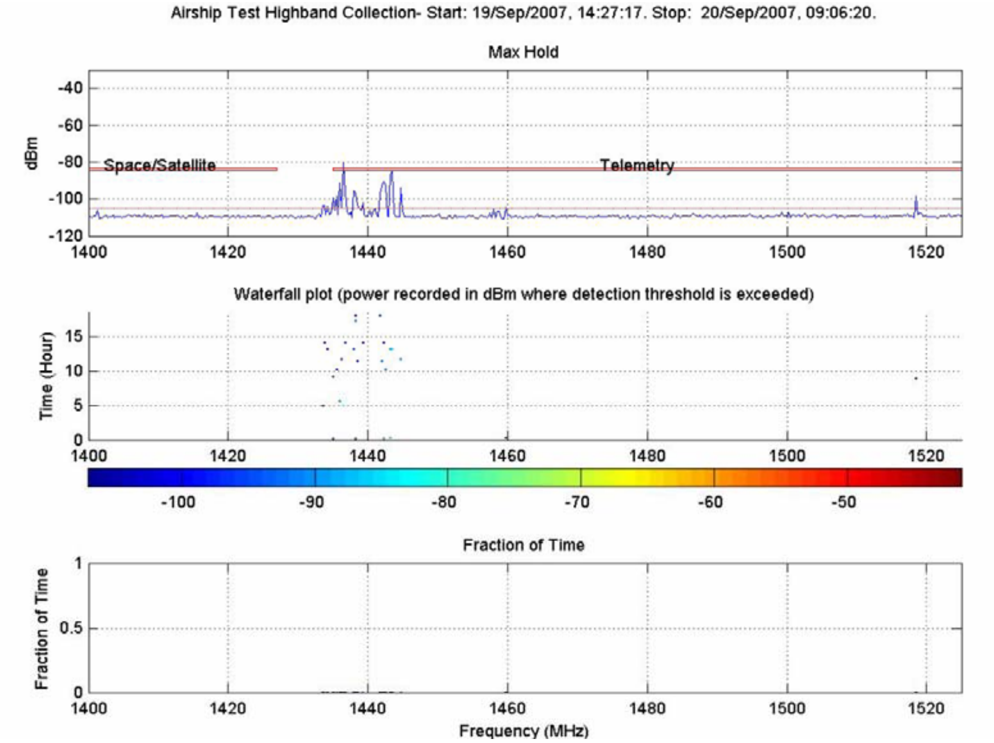

Figure 27. 1400 MHz to 1525 MHz

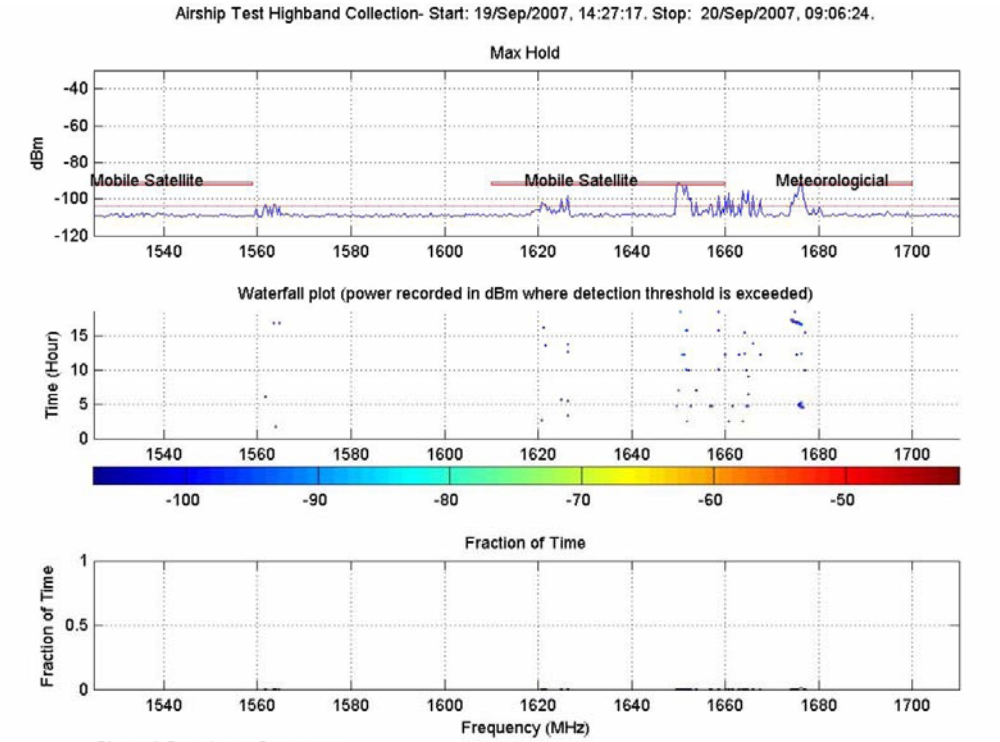

Figure 28. 1525 MHz to 1710 MHz

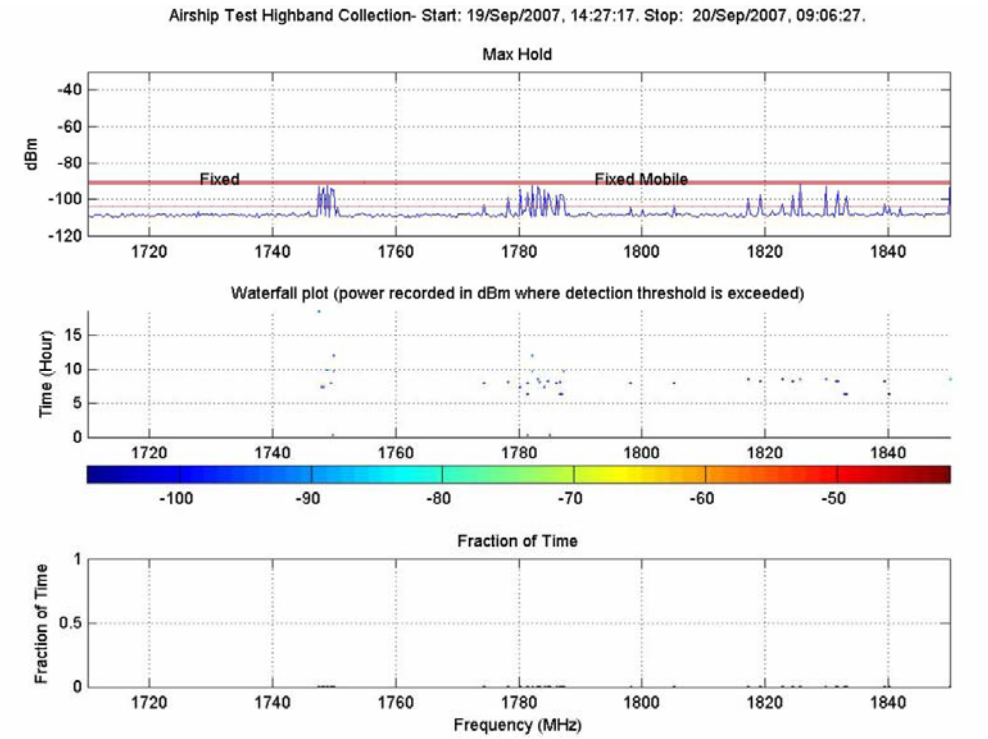

Figure 29. 1710 MHz to 1850 MHz

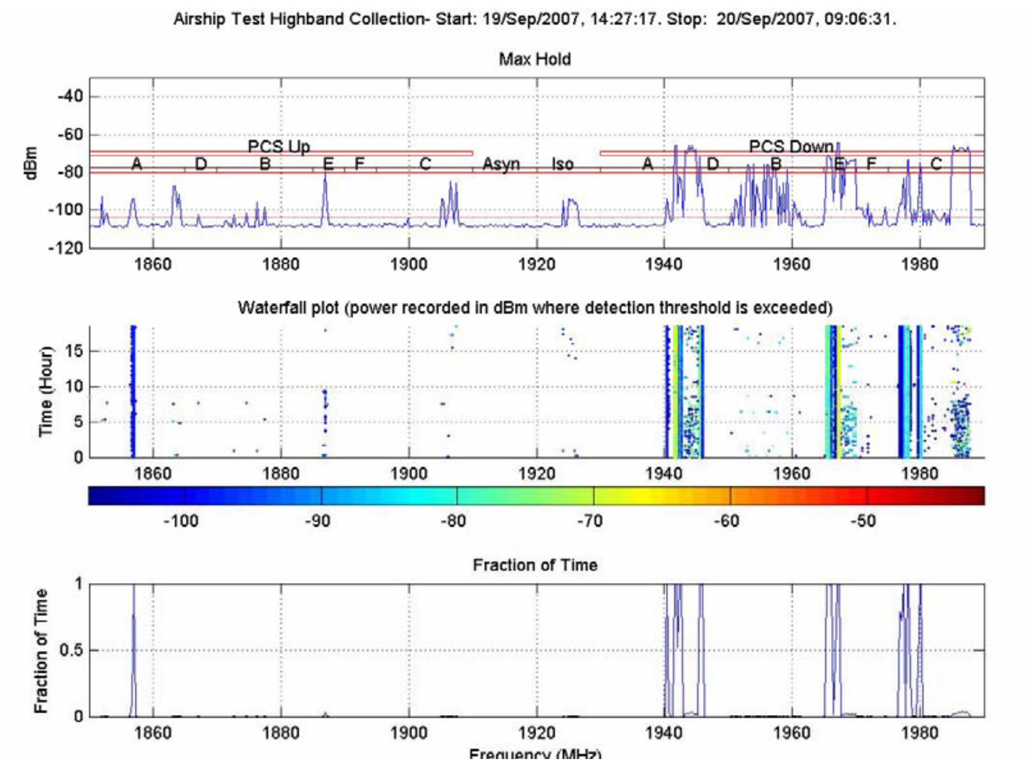

Figure 30. 1850 MHz to 1990 MHz

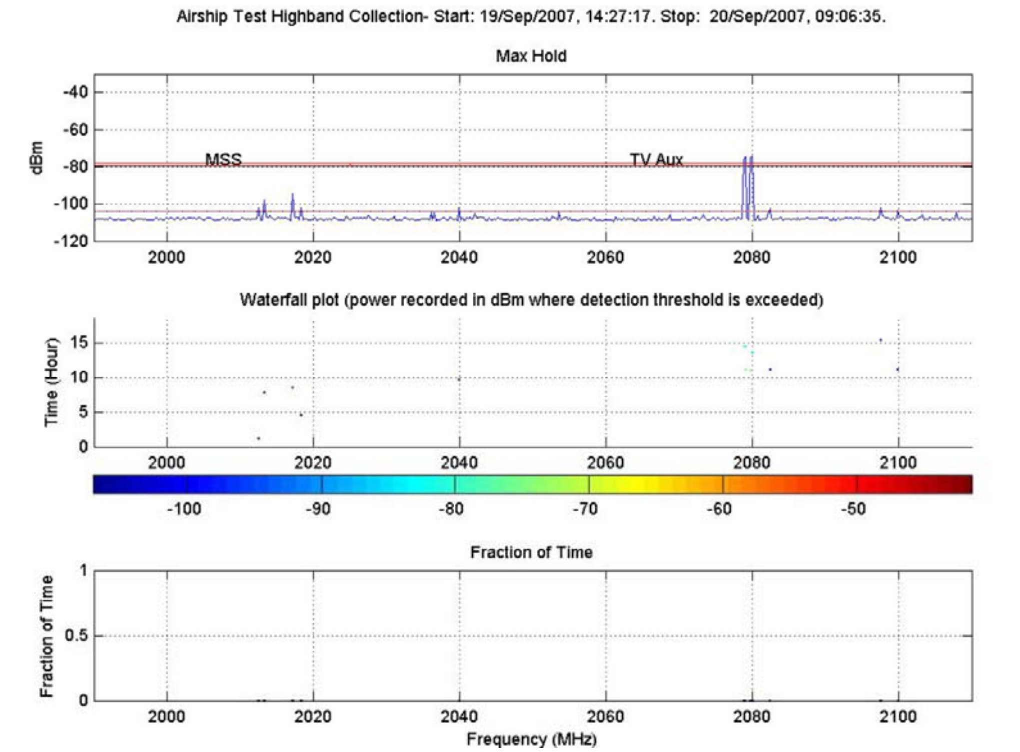

Figure 31. 1990 MHz to 2110 MHz

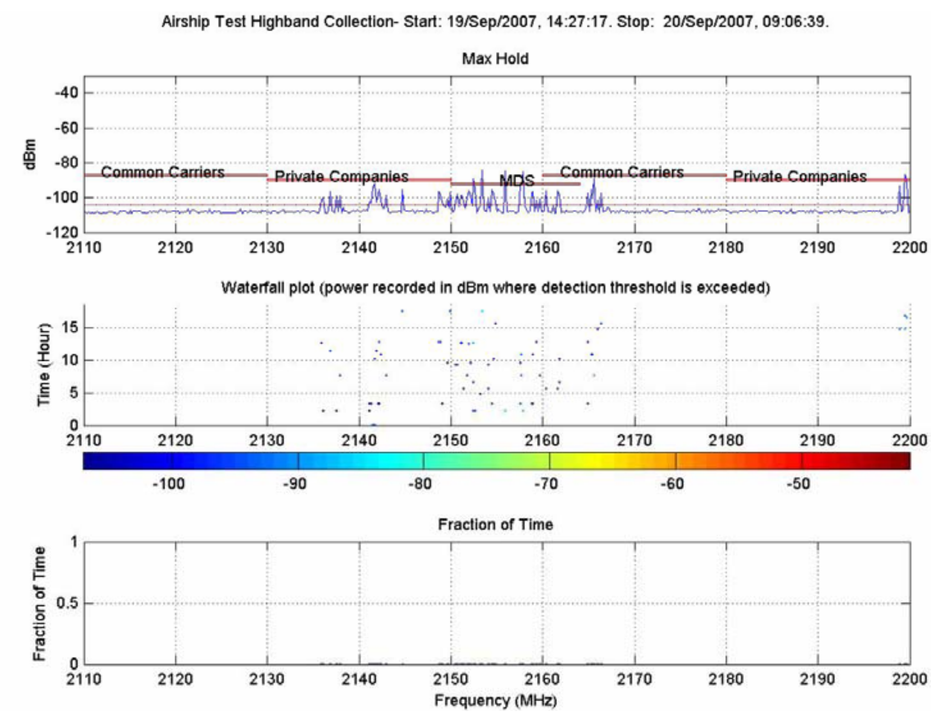

Figure 32. 2110 MHz to 2200 MHz

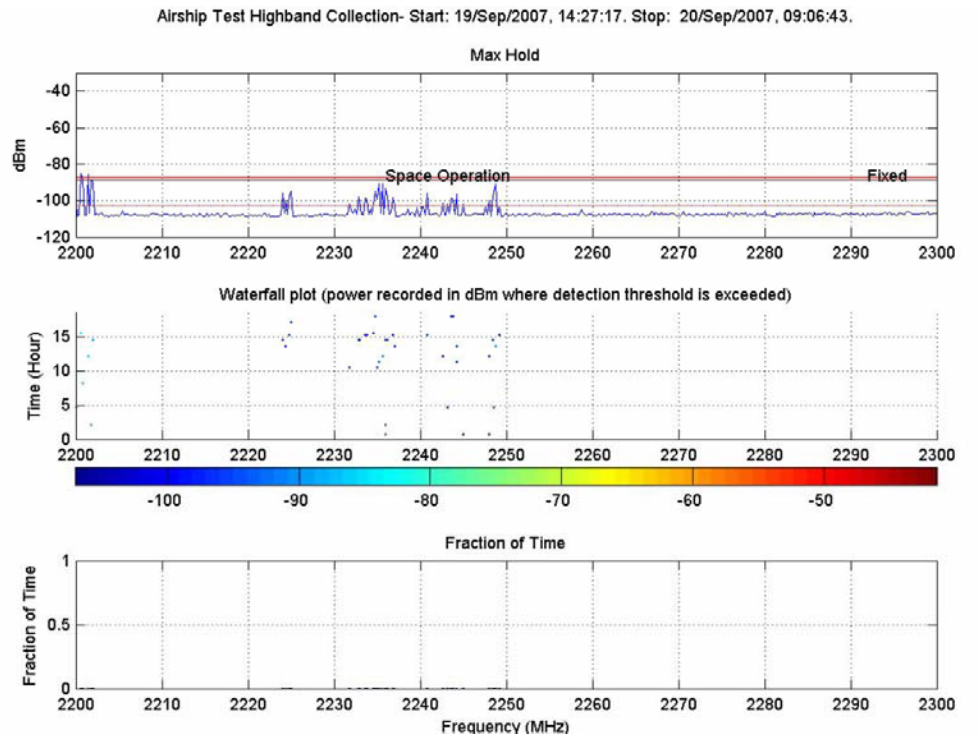

Figure 33. 2200 MHz to 2300 MHz

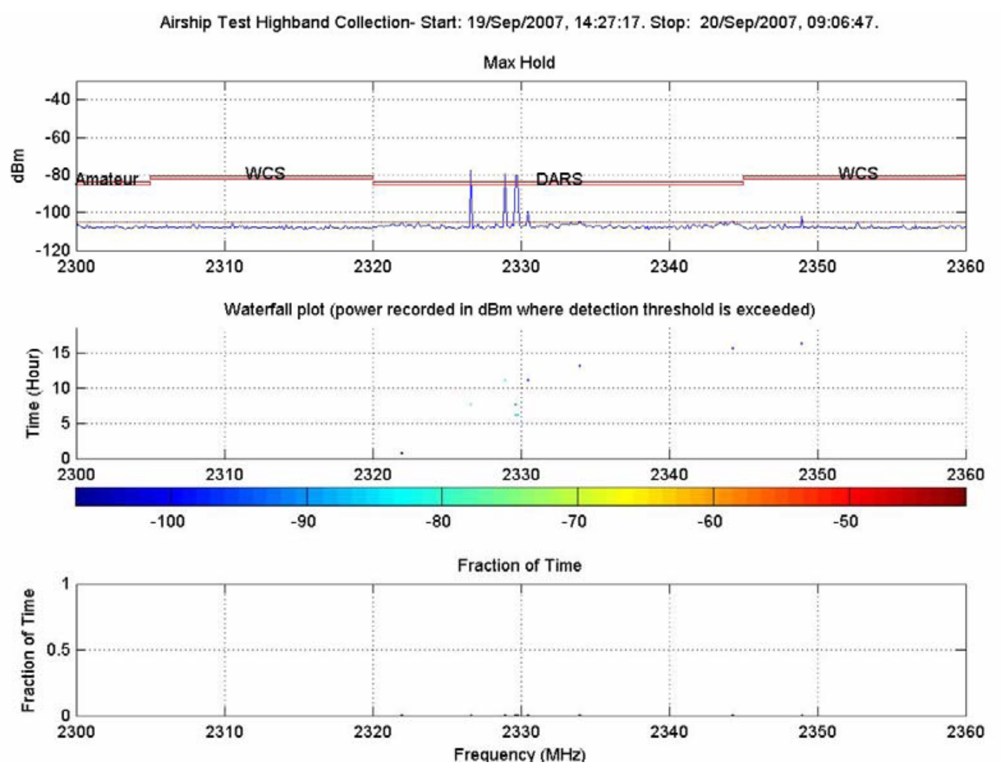

Figure 34. 2300 MHz to 2360 MHz

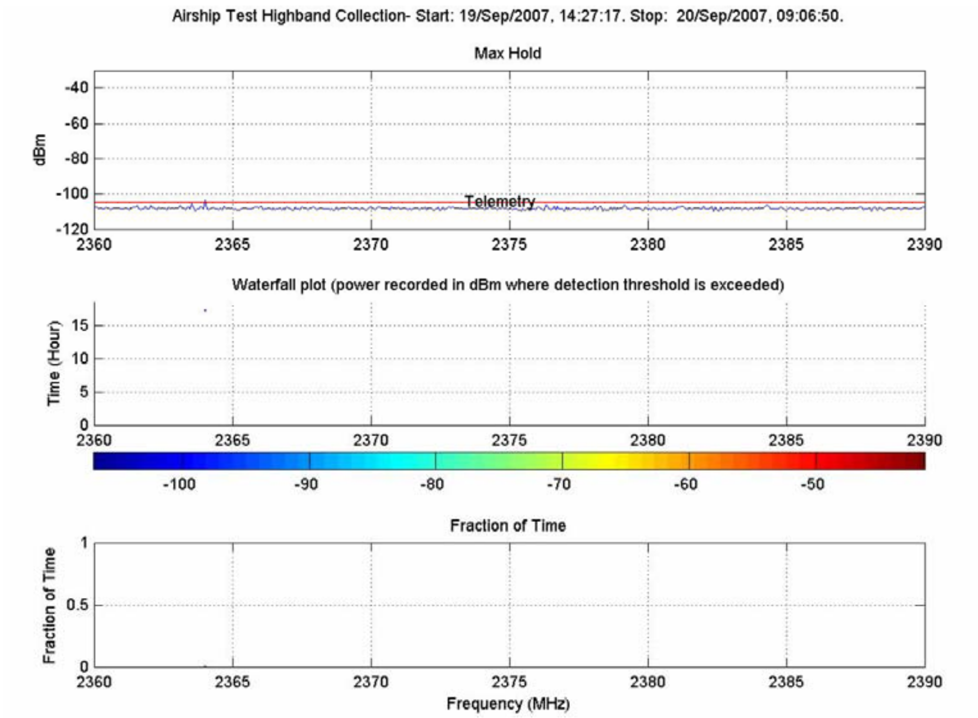

Figure 35. 2360 MHz to 2390 MHz

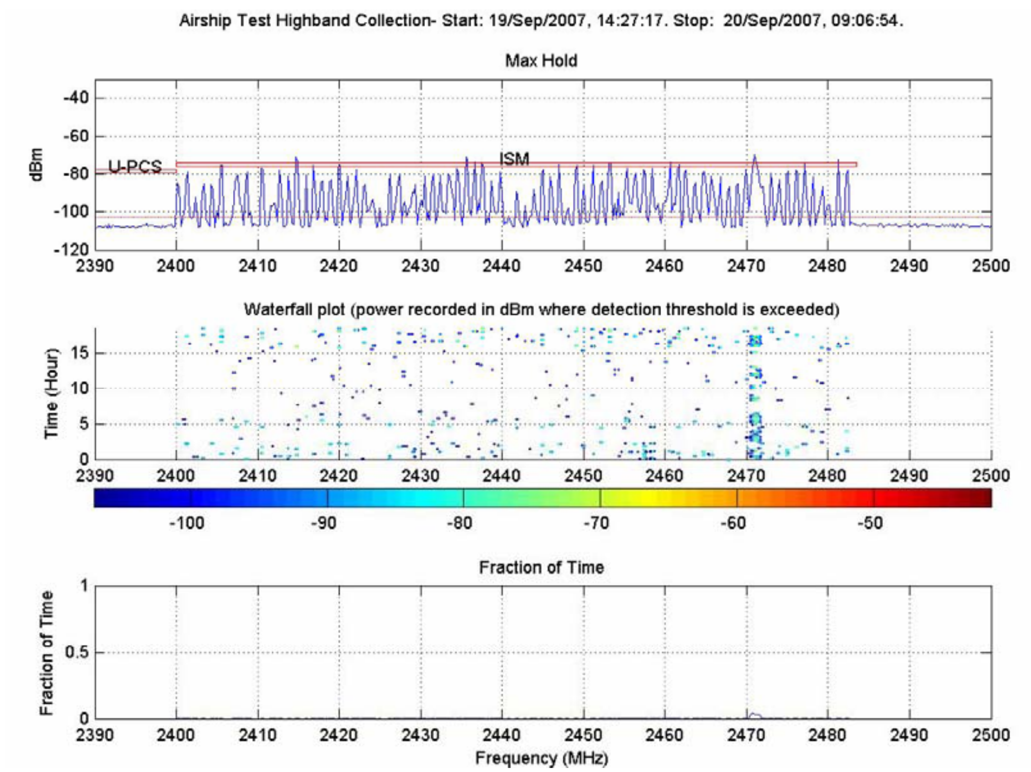

Figure 36. 2390 MHz to 2500 MHz

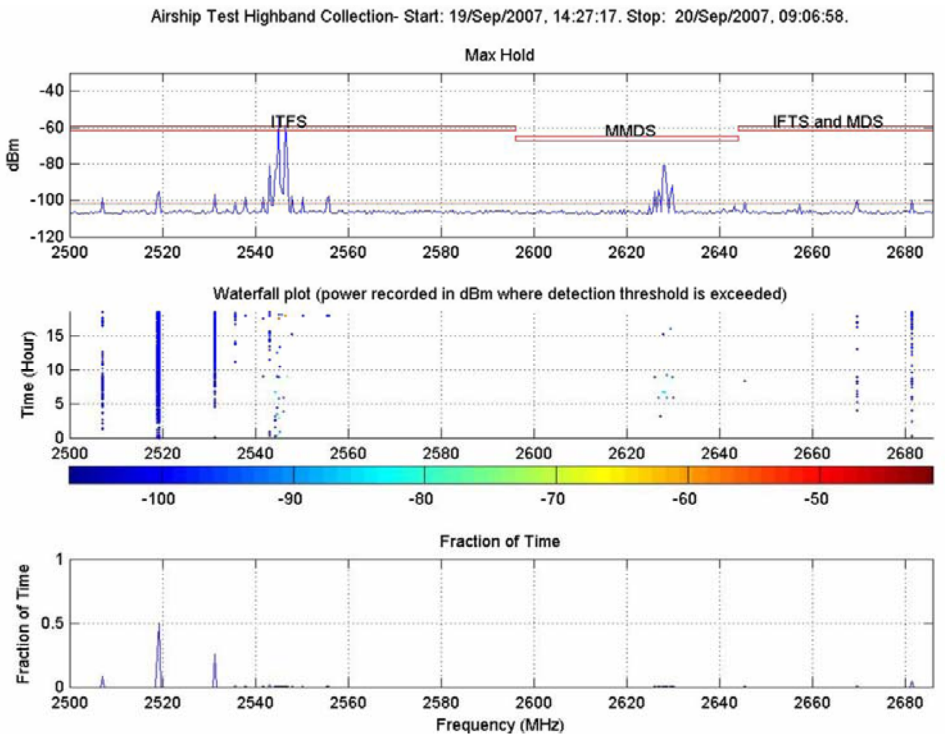

Figure 37. 2500 MHz to 2686 MHz

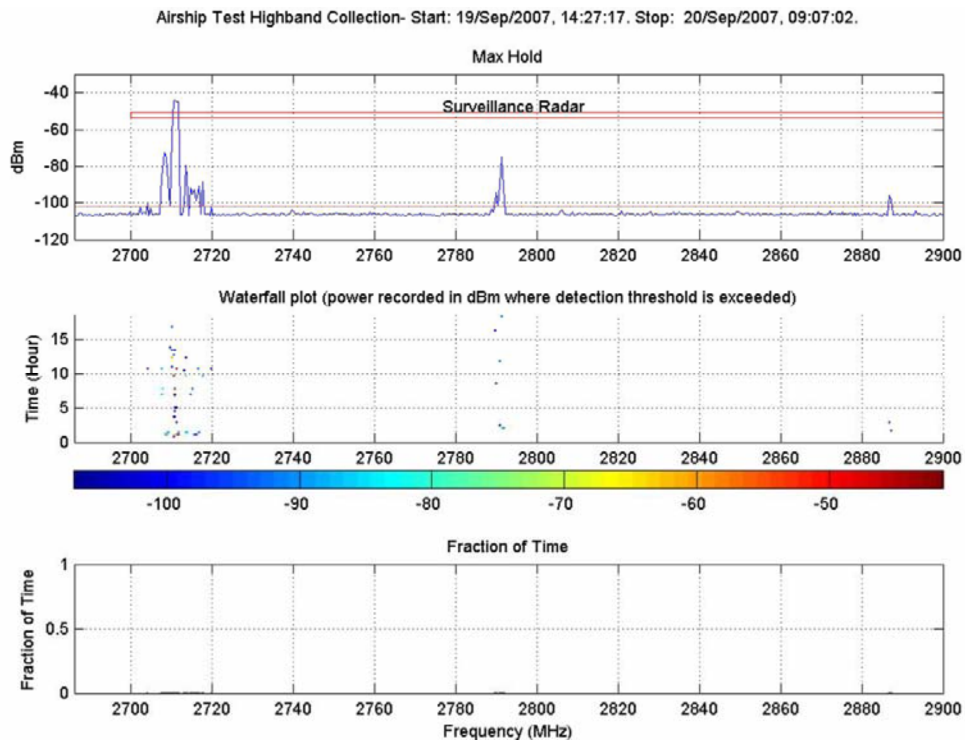

Figure 38. 2686 MHz to 2900 MHz

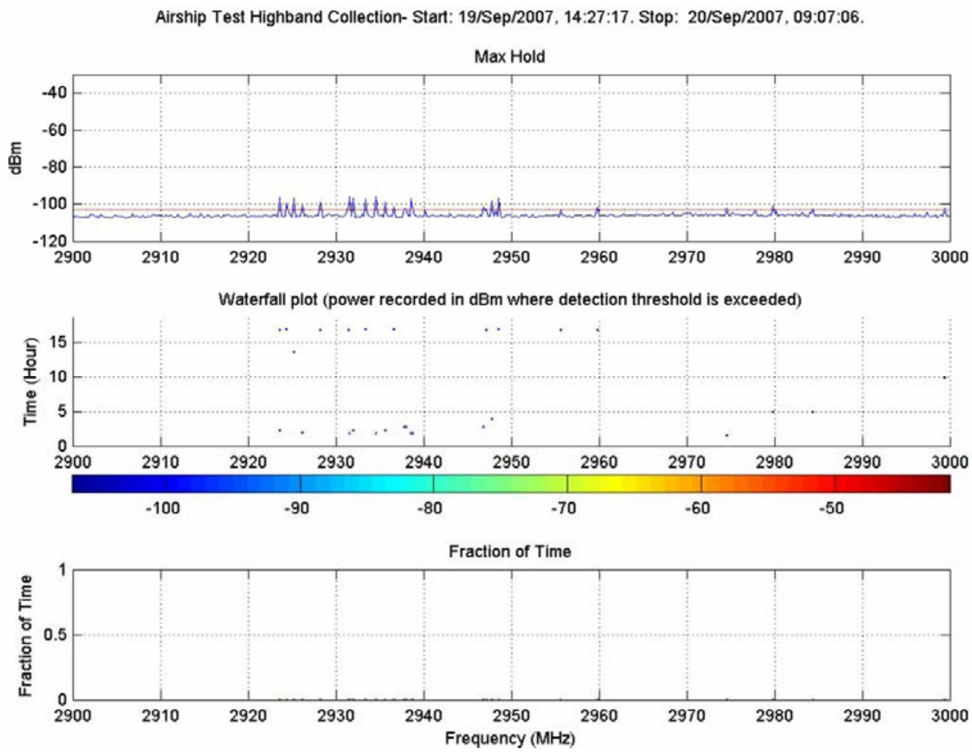

Figure 39. 2900 MHz to 3000 MHz

5. Conclusions

5.1 Introduction

This report documents extensive spectrum occupancy measurements made by Shared Spectrum Company at the Loring Commerce Centre, Limestone, Maine. Measurements were made in all bands in the 30 MHz to 3000 MHz range. The measurements were made during a normal work week (Tuesday through Thursday) and are believed to be a high usage period.

5.2 Spectrum Occupancy Upper Bounds

Based on the results of the study, we conclude that the average spectrum usage during the measurement period was 1.7%. Occupancy[1] varied from less than 1% to 24.65% (470 MHz – 512 MHz) in the measurement area as shown in Table 3. The Loring Commerce Centre spectrum occupancy is very low.

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

Table 3. Spectrum Occupancy in Each Band

Start Frequency (MHz)	Stop Frequency (MHz)	Span (MHz)	Spectrum Band Allocation	Loring Spectrum Fraction Used	Loring Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others: 30-54 MHz	0.18357	4.406	18.4%
54	88	34	TV 2-6, RC: 54-88 MHz	0.057212	1.945	5.7%
108	138	30	Air traffic Control, Aero Nav: 108-138 MHz	0.0099482	0.298	1.0%
138	174	36	Fixed Mobile, Amateur, others:138-174 MHz	0.021382	0.770	2.1%
174	216	42	TV 7-13: 174-216 MHz	0.099688	4.187	10.0%
216	225	9	Maritime Mobile, Amateur, others: 216-225 MHz	3.04E-05	0.000	0.0%
225	406	181	Fixed Mobile, Aero, others: 225-406 MHz	0.00074778	0.135	0.1%
406	470	64	Amateur, Fixed, Mobile, Radiolocation, 406-470 MHz	0.018239	1.167	1.8%
470	512	42	TV 14-20: 470-512 MHz	0.24653	10.354	24.7%
512	608	96	TV 21-36: 512-608 MHz	0.00049611	0.048	0.0%
608	698	90	TV 37-51: 608-698 MHz	0.026363	2.373	2.6%
698	806	108	TV 52-69: 698-806 MHz	2.89E-06	0.000	0.0%
806	902	96	Cell phone and SMR: 806-902 MHz	0.15632	15.007	15.6%
902	928	26	Unlicensed: 902-928 MHz	0.0097356	0.253	1.0%
928	1000	72	Paging, SMS, Fixed, BX Aux, and FMS: 928-906 MHz	0.0089632	0.645	0.9%
1000	1240	240	IFF, TACAN, GPS, others: 960-1240 MHz	0.00096329	0.231	0.1%
1240	1300	60	Amateur: 1240-1300 MHz	0.0052258	0.314	0.5%
1300	1400	100	Aero Radar, Military: 1300-1400 MHz	0.0033726	0.337	0.3%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry: 1400-1525 MHz	4.65E-05	0.006	0.0%
1525	1710	185	Mobile Satellite, GPS, Meteorologicial: 1525-1710 MHz	0.00017895	0.033	0.0%
1710	1850	140	Fixed, Fixed Mobile: 1710-1850 MHz	7.05E-05	0.010	0.0%
1850	1990	140	PCS, Asyn, Iso: 1850-1990 MHz	0.047792	6.691	4.8%
1990	2110	120	TV Aux: 1990-2110 MHz	2.58E-05	0.003	0.0%
2110	2200	90	Common Carriers, Private, MDS: 2110-2200 MHz	0.00011701	0.011	0.0%
2200	2300	100	Space Operation, Fixed: 2200-2300 MHz	6.88E-05	0.007	0.0%
2300	2360	60	Amateur, WCS, DARS: 2300-2360 MHz	1.72E-05	0.001	0.0%
2360	2390	30	Telemetry: 2360-2390 MHz	1.72E-06	0.000	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed): 2390-2500 MHz	0.001466	0.161	0.1%
2500	2686	186	ITFS, MMDS: 2500-2686 MHz	0.0024726	0.460	0.2%
2686	2900	214	Surveillance Radar: 2686-2900 MHz	8.95E-05	0.019	0.0%
2900	3000	100	Microwave: 2900-3000 MHz	4.89E-05	0.005	0.0%
		2950			49.877	

Total Available Spectrum	2950.000
Average Spectrum Use (%)	1.7%

Figure 40 shows the percentage occupancy across all frequency bands graphically.

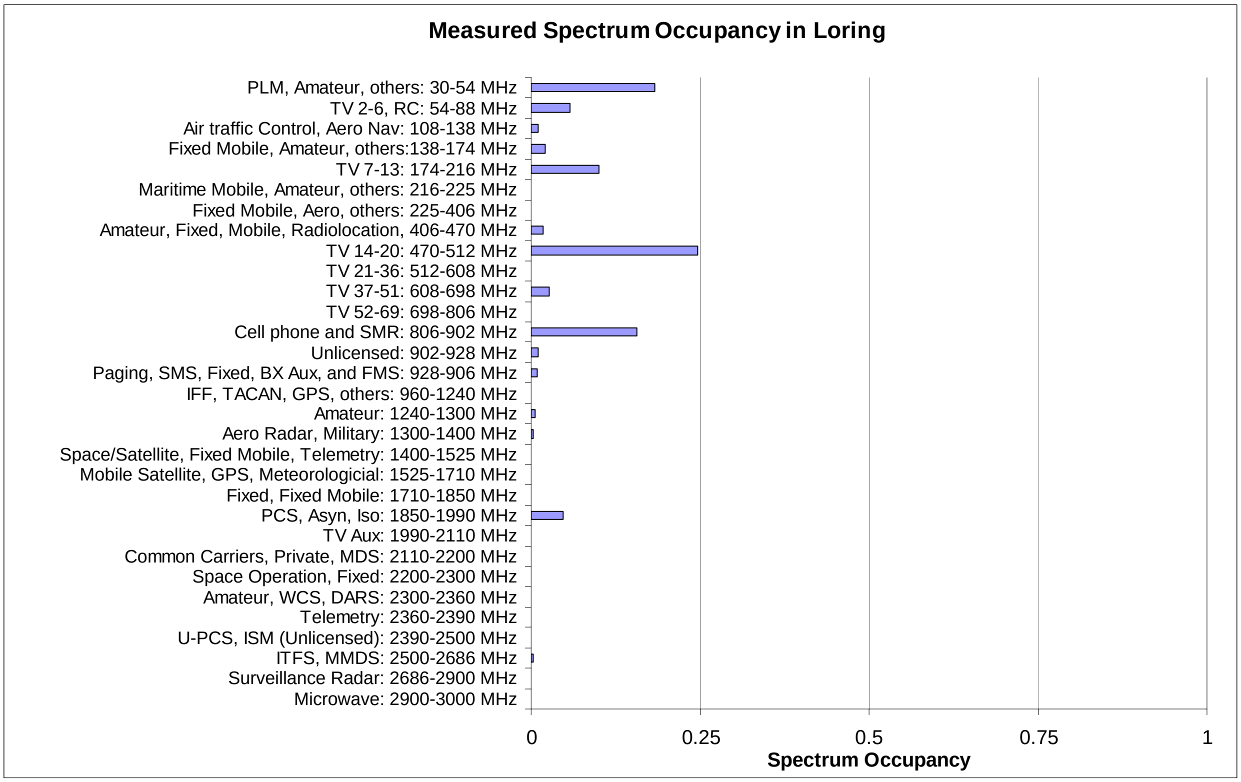

Figure 40. Spectrum Occupancy Measured in Each Band at Loring Commerce Centre, Limestone, Maine

5.3 Comparison to Other Locations

The spectrum occupancy at Loring Commerce Centre is low compared to other locations that Shared Spectrum Company has measured. The Loring Commerce Centre spectrum occupancy is comparable to the occupancy measured at the National Radio Astronomy Observatory (NRAO), West Virginia (shown in Figure 41)[2]. The NRAO spectrum occupancy is probably the lowest in the continental United States because of the significant FCC transmitter limitations in this area.

- [2] "Spectrum Occupancy Measurements, Location 5 of 6: National Radio Astronomy Observatory (NRAO), Green Bank, West Virginia, October 10 - 11, 2004, Revision 3" Mark A. McHenry Karl Steadman, Shared Spectrum Company Report, August, 2005, (www.sharedspectrum.com).

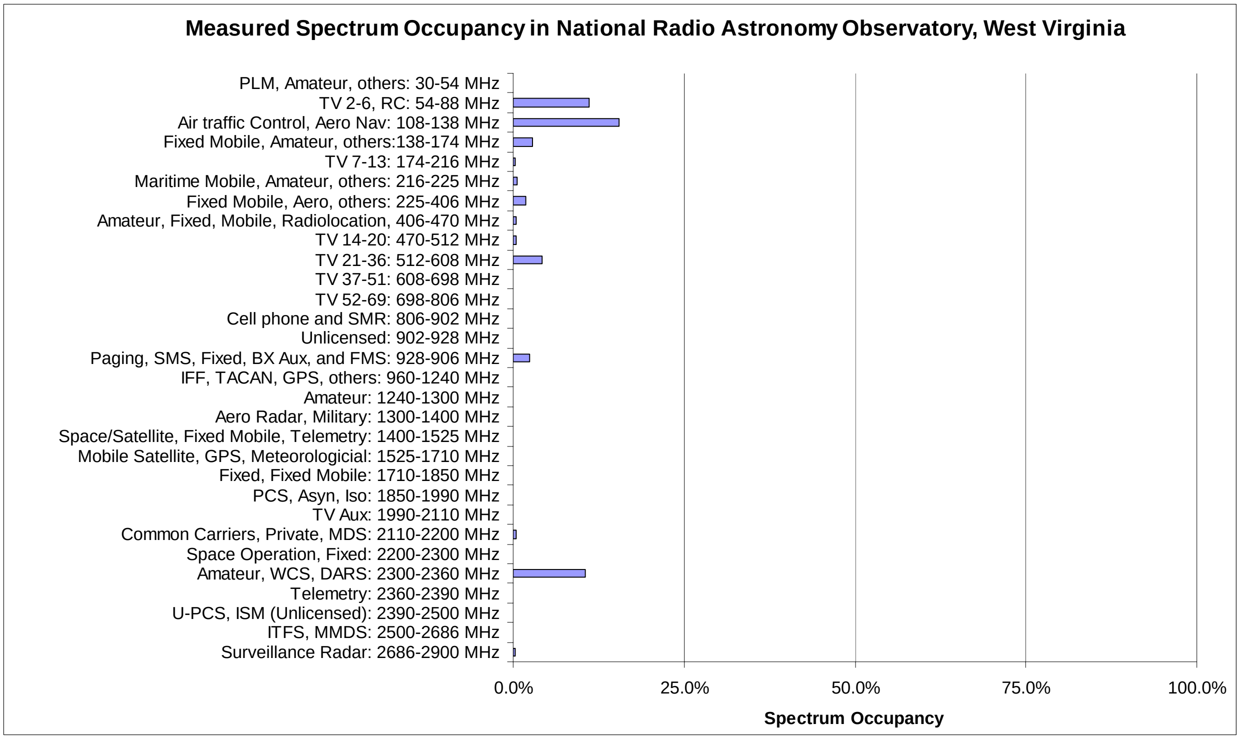

Figure 41. Bar Graphs of the Spectrum Occupancy in Each Band at the National Radio Observatory, West Virginia (very quiet location)

In contrast, Figure 42 shows the spectrum occupancy with the measurements taken in New York City[3] and Chicago[4], locations with high spectrum occupancy. The spectrum occupancy in these urban areas far exceeds the Loring occupancy.

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[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).

[4] "Spectrum Occupancy Measurements, Chicago, Illinois, November 16-18, 2005", Mark A. McHenry, Dan McCloskey, Dennis Roberson and John T. MacDonald, (www.sharedspectrum.com).

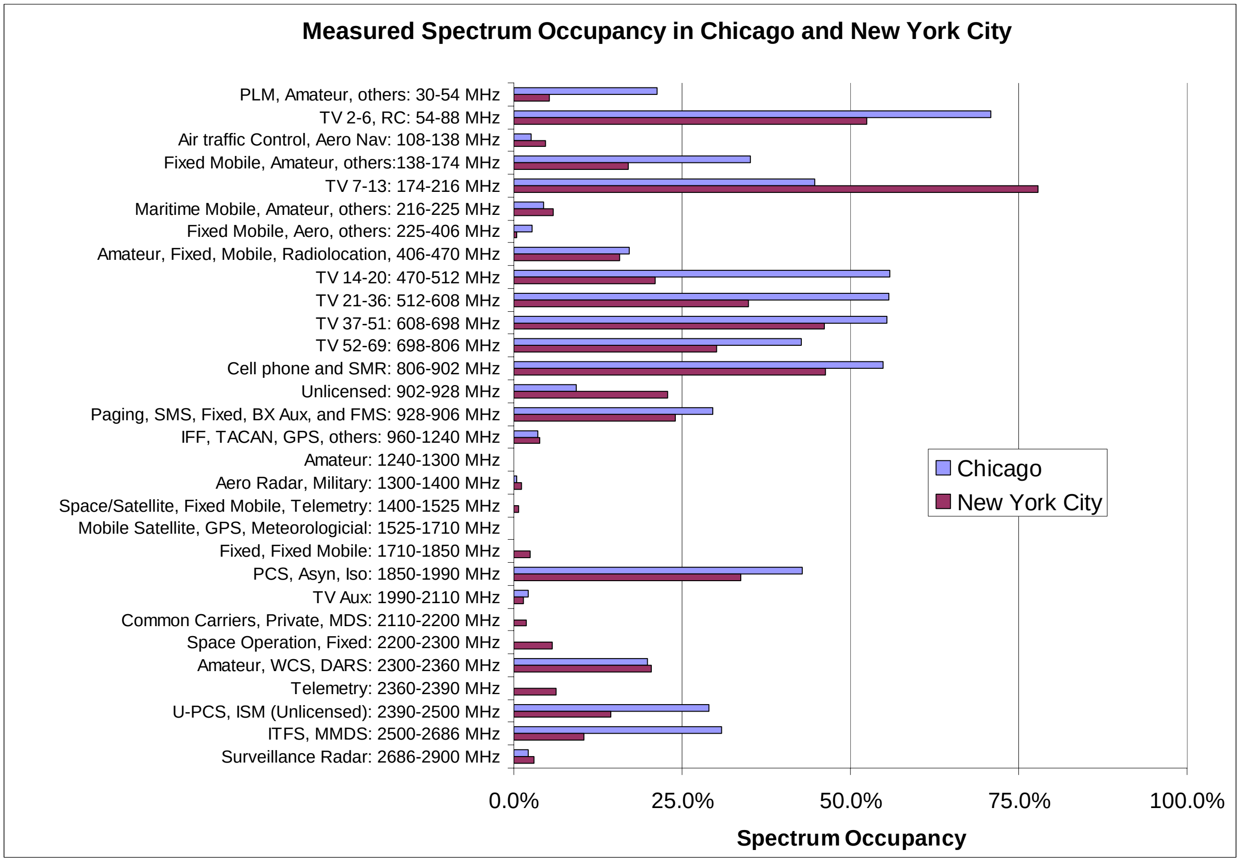

Figure 42. Bar Graph of the Spectrum Occupancy in Each Band in New York City, and Chicago (high spectrum usage)

5.4 Summary

The spectrum occupancy at the Loring Commerce Centre is very low. The average occupancy is less than 1.7%. The occupancy levels are close to the lowest location that Shared Spectrum Company has measured (the National Radio Astronomy Observatory, West Virginia). There are no strong emitters in the nearby area. These features make Loring Commerce Centre an ideal location for testing of wireless systems or for testing other systems that use wireless communications for telemetry or for command and control.