

Multi-Band, Multi-Location Spectrum Occupancy Measurements

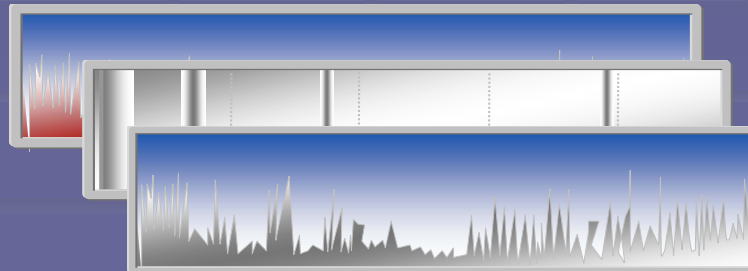
Presentation to:
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The Future of Multimedia Communications
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SSC-ISART 1

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- Introduction
 - Support development of dynamic spectrum sharing radio technology
- Measurement locations
- Measurement equipment
- Sample spectrum occupancy data
- Summary data
- Next steps
- Conclusions

- Shared Spectrum Company conducted a series of spectrum occupancy measurements
 - Initially supported by DARPA, later by NSF
 - Started 2002, latest measurements in Nov 2005
- Goals
 - Prove that there are bands with low occupancy
 - Estimate “whitespace”
 - Determine characteristics of spectrum holes (time and frequency)
- Approach
 - Fixed locations, most with excellent line-of-sight
 - Long-term (hours-days) data collections at most locations
 - Optimized for best sensitivity (vs. revisit rate)
 - ◆ Spectrum analyzer with high dynamic range, “band-by-band optimized” pre-selector



Spectrum Measurement Locations

| Location | Dates | Purpose |
|--|---------------------------------|----------------------------|
| Inside Shared Spectrum Company offices | 2/4/2004 2/9/2004 10/28/2004 | Test equipment |
| Outside in Shared Spectrum parking lot | 4/6/2004 | Urban location |
| Riverbend Park in Northern Virginia | 4/7/2004 | Rural location |
| Tysons Corner shopping center parking lot in Vienna, Virginia | 4/9/2004 | Urban location |
| National Science Foundation (NSF) building roof in Arlington, Virginia | 4/16/2004 | Elevated, urban location |
| New York City | 8/5/2004 8/30/2004 | Elevated, urban location |
| National Radio Astronomy Observatory, Green Bank, West Virginia | 10/4/2004 | Very quiet, rural location |
| Shared Spectrum office roof in Vienna, VA | 12/15/2004- 6/9/2005 | Elevated, urban location |
| IIT Building Roof in Chicago, IL | 11/2005 | Elevated, urban location |

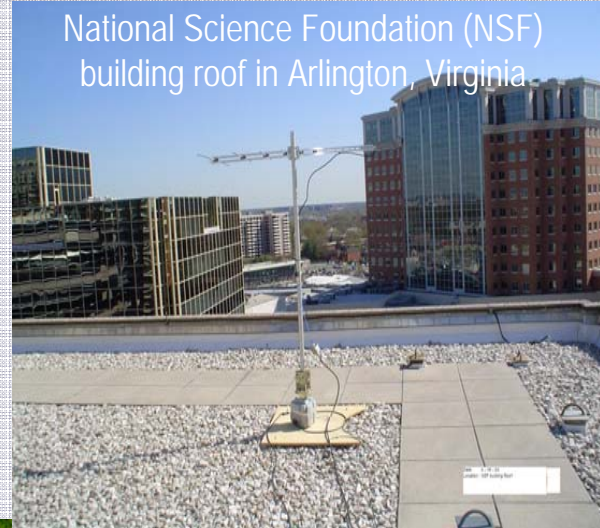
Note 1: Reports available on SSC website (except for Chicago report, which will be on website soon)

Measurement Location Photos (1 of 2)

Tysons Corner shopping center parking lot in Vienna, Virginia



National Science Foundation (NSF) building roof in Arlington, Virginia



Riverbend Park in Northern Virginia



Measurement Locations (2 of 2)

National Radio Astronomy Observatory, Green Bank,
West Virginia



Shared Spectrum office roof in Vienna, VA

IIT Building Roof in Chicago, IL



Measurement Equipment



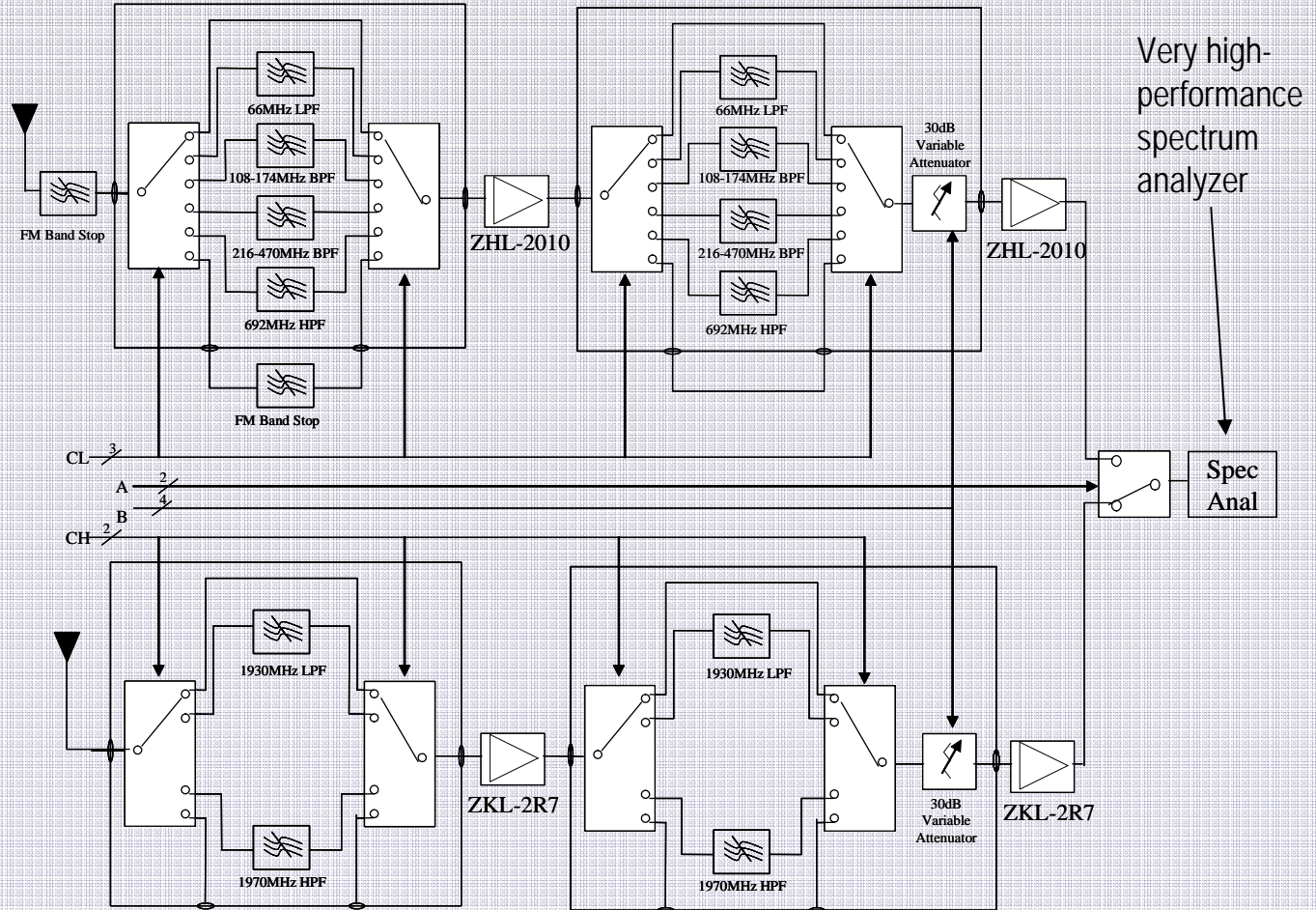
Faraday cage used to reduce undesired collection equipment RF noise



New York City: Excellent line of sight to urban area

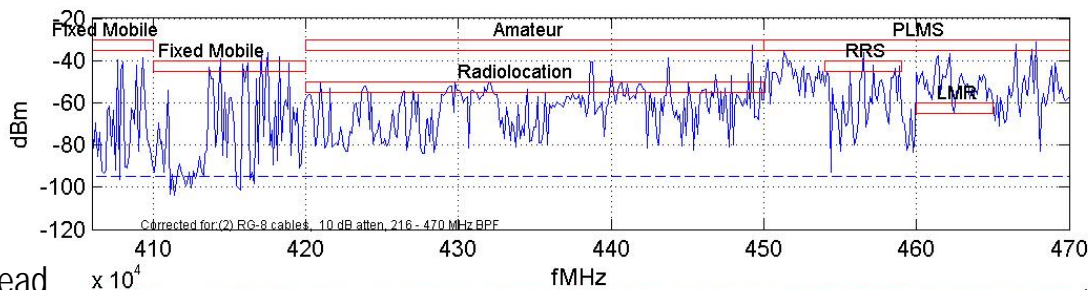
Pre-Selector Provides High Dynamic Range

- Antennas
 - Discone 30-1000 MHz
 - LPA: 1000-3000 MHz
- Filtering and gain used to reject strong signals
 - Computer controlled for each band
- NF ~ 12 dB

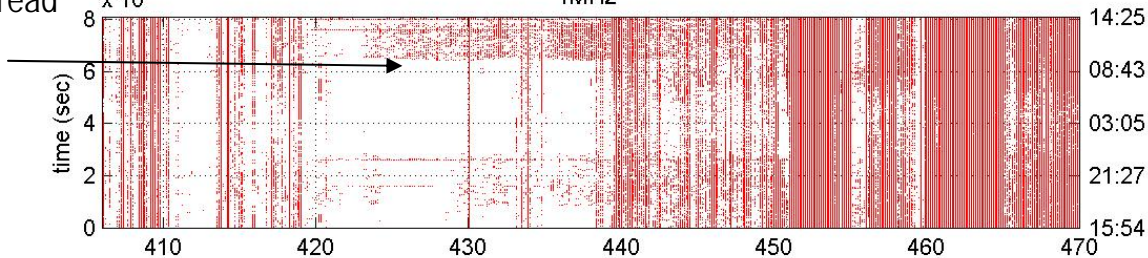


High Utilization (Public Safety Band)

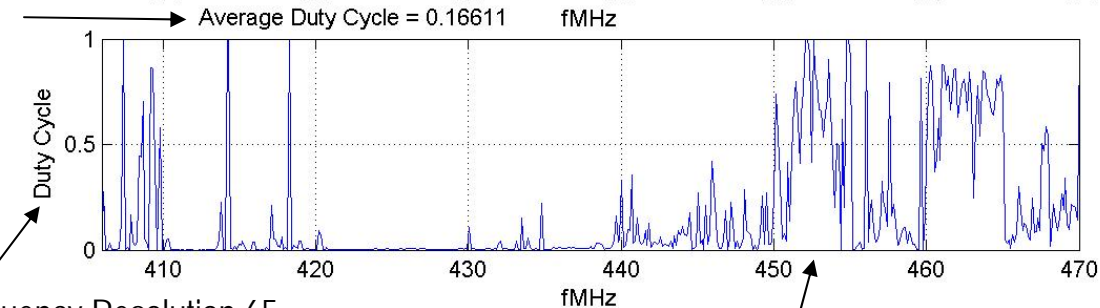
NYC Measurements 31-Aug-2004 15:54:22



High Bandwidth, Spread Spectrum Signal



17% Duty Cycle

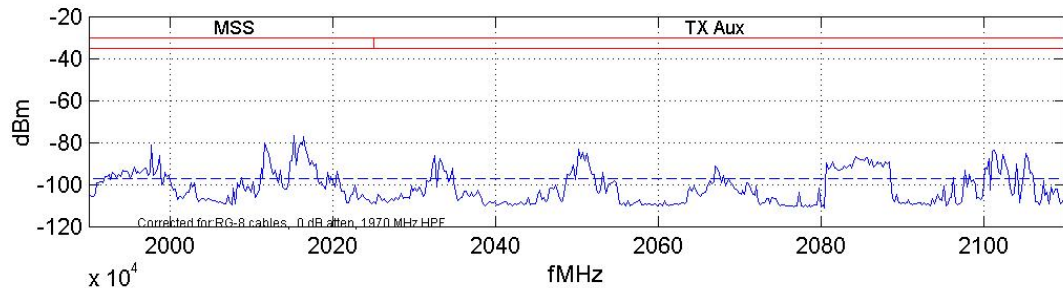


Upper Bound (Frequency Resolution 65 MHz/501=130 kHz/bin)

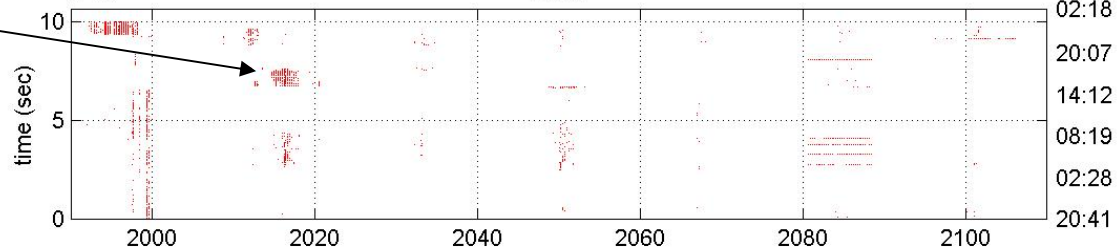
50% Duty Cycle is too High, 19% Utilization Measured Using Small Frequency Bins (450-455 MHz)

Mid-Level Utilization – TX Aux Band

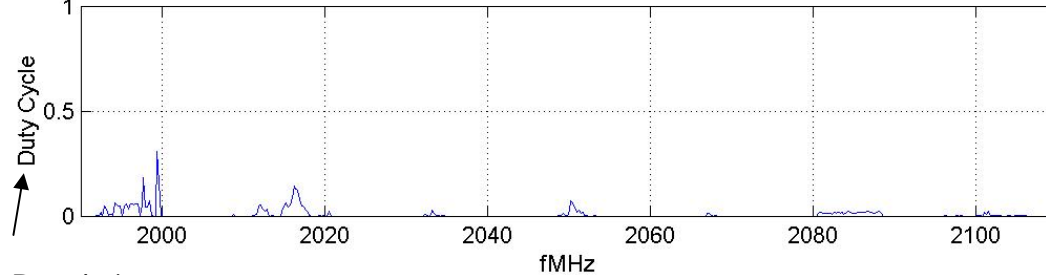
NYC Measurements 01-Sep-2004 20:41:01



Mobile Video Links

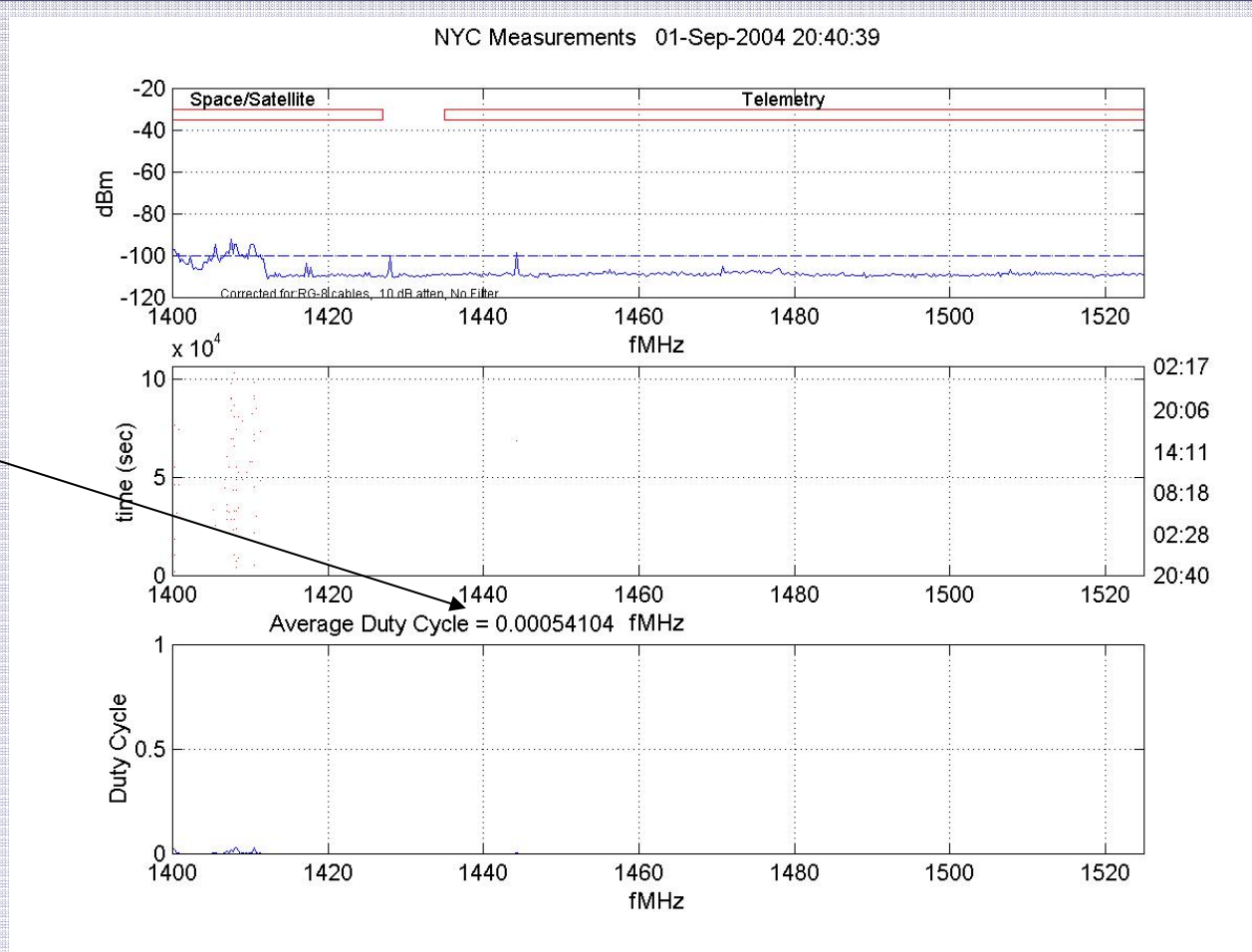


Average Duty Cycle = 0.0082253 fMHz



Upper Bound (Frequency Resolution)
120 MHz/501=240 kHz/bin

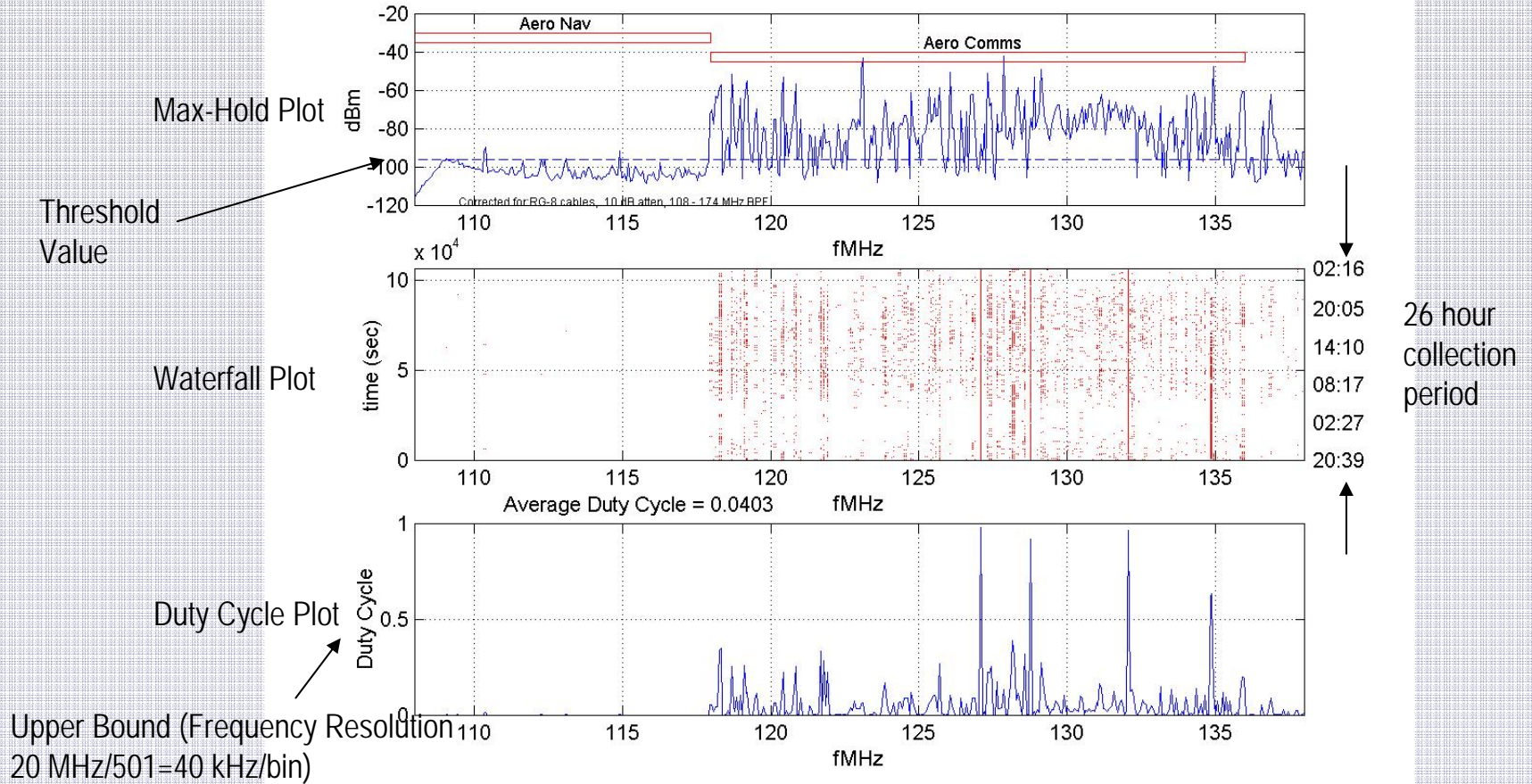
Low Utilization Band



Less Than 1%
Apparent Duty
Cycle

Aviation Band

NYC Measurements 01-Sep-2004 20:39:32

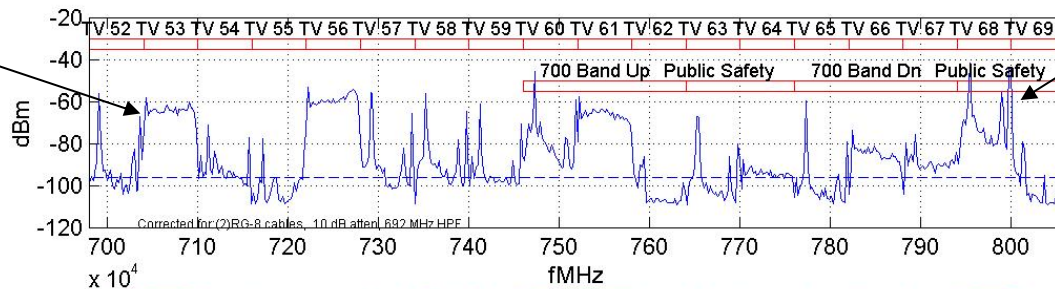


UHF TV Band

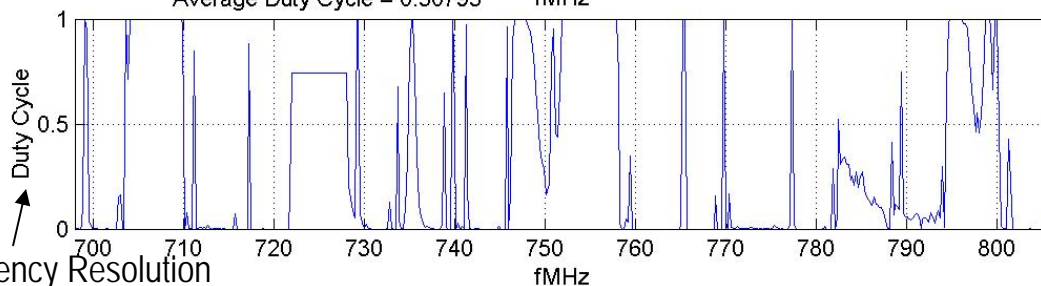
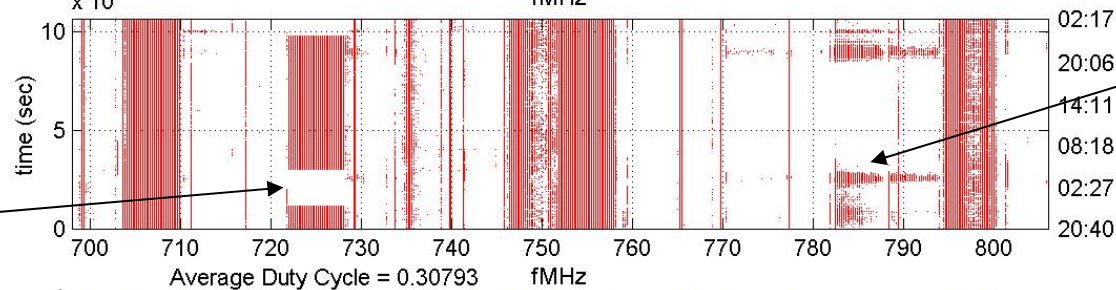
NYC Measurements 01-Sep-2004 20:40:05

Digital TV

Analog TV



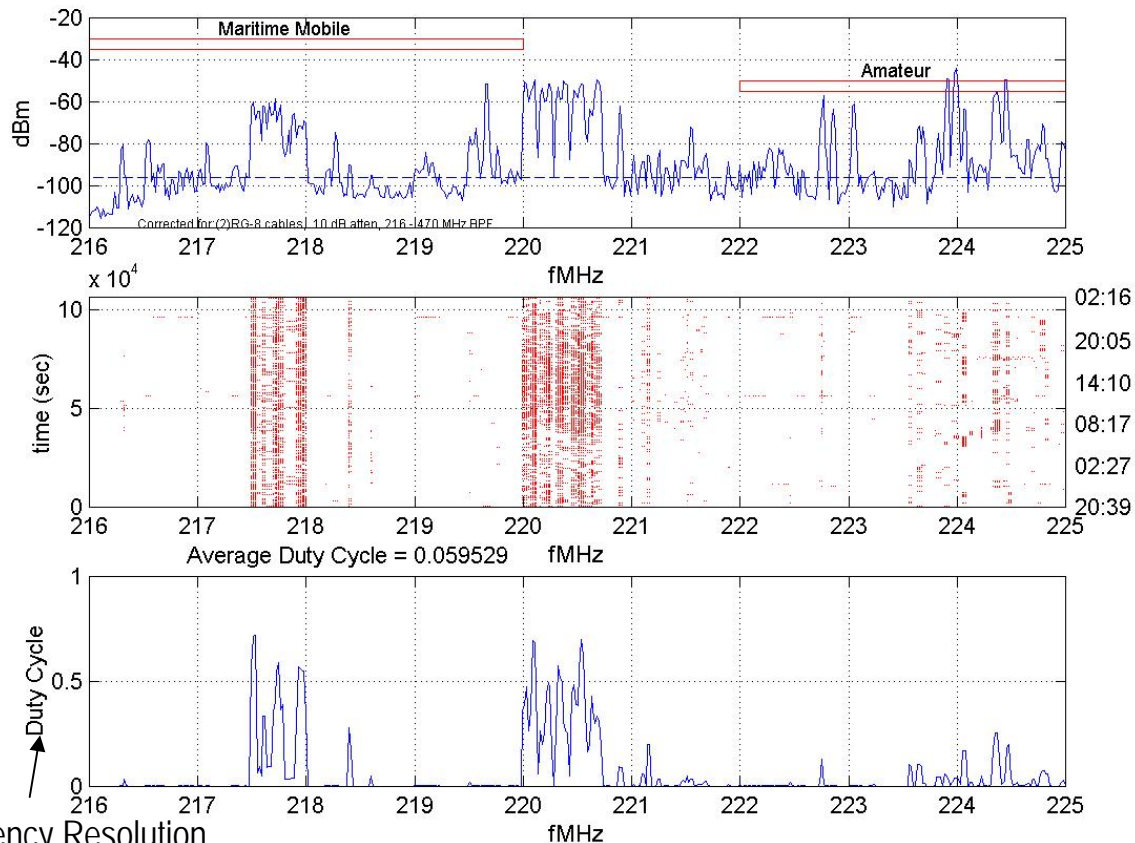
Transmitter Turned Off At Night



Upper Bound (Frequency Resolution
108 MHz/501=216 kHz/bin)

Maritime Mobile and Amateur Band

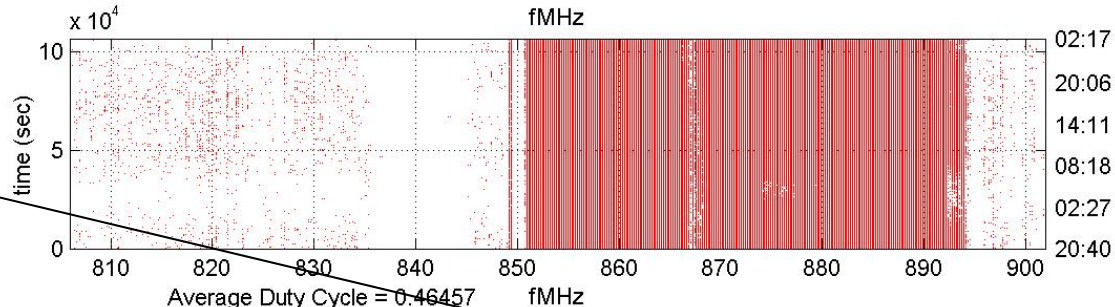
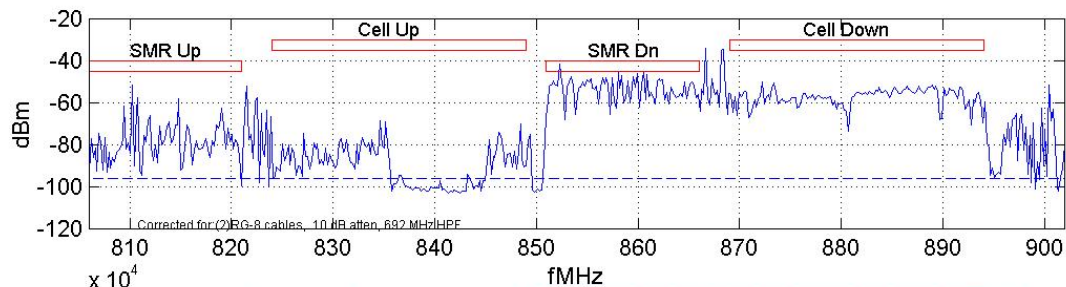
NYC Measurements 01-Sep-2004 20:39:40



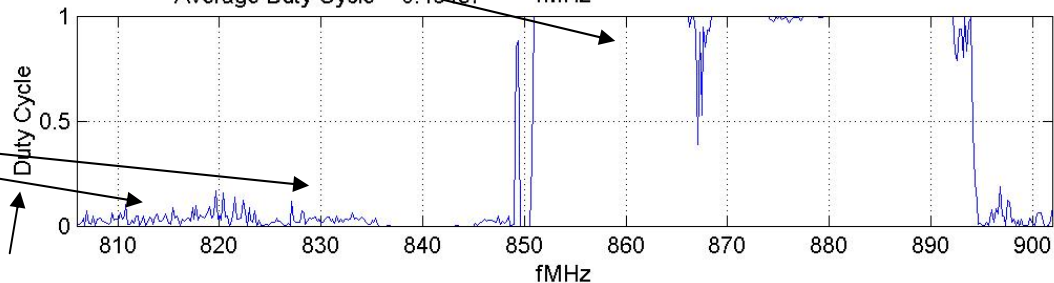
Upper Bound (Frequency Resolution
20 MHz/501=40 kHz/bin)

Cell Phone Band

NYC Measurements 01-Sep-2004 20:40:09



Average Duty Cycle = 0.46457



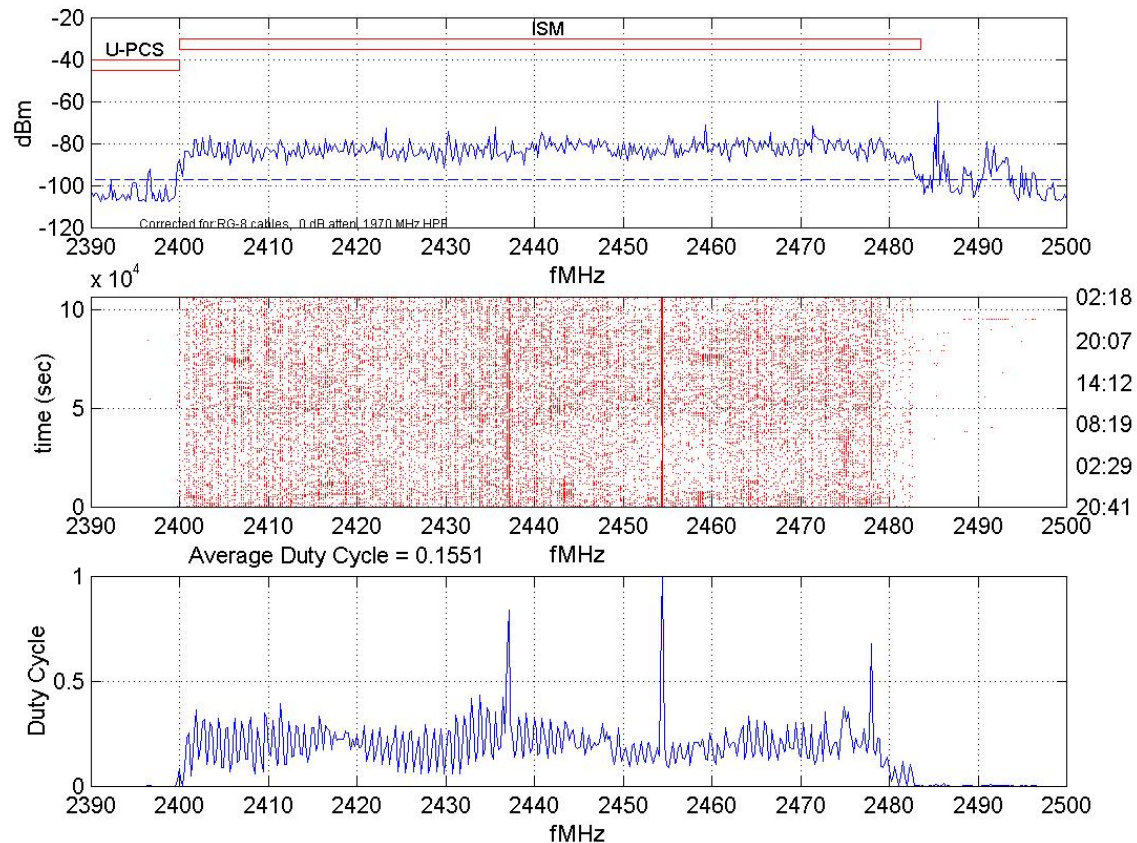
Base Stations
Easy to Detect
and Have High
Apparent Duty
Cycle

SMR Provide
Has Higher
Usage Than
Cell Provider

Upper Bound (Frequency Resolution
 $96 \text{ MHz}/501 = 192 \text{ kHz/bin}$)

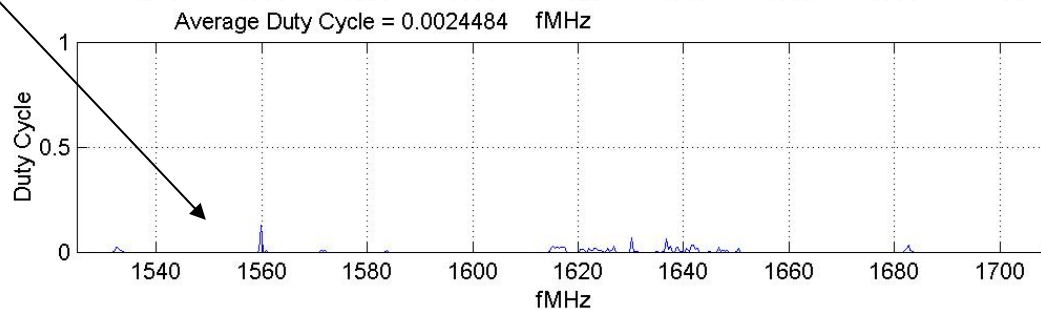
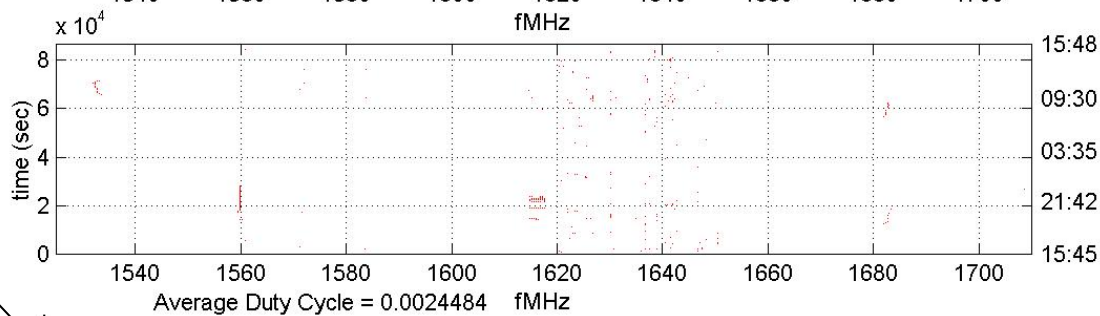
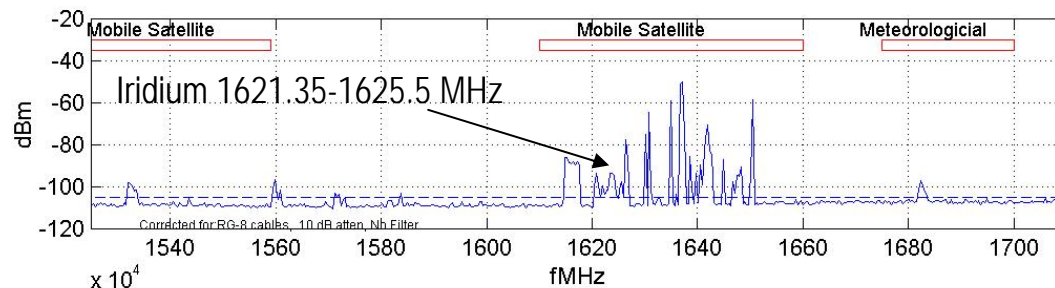
Unlicensed Band

NYC Measurements 01-Sep-2004 20:41:24



Satellite Band

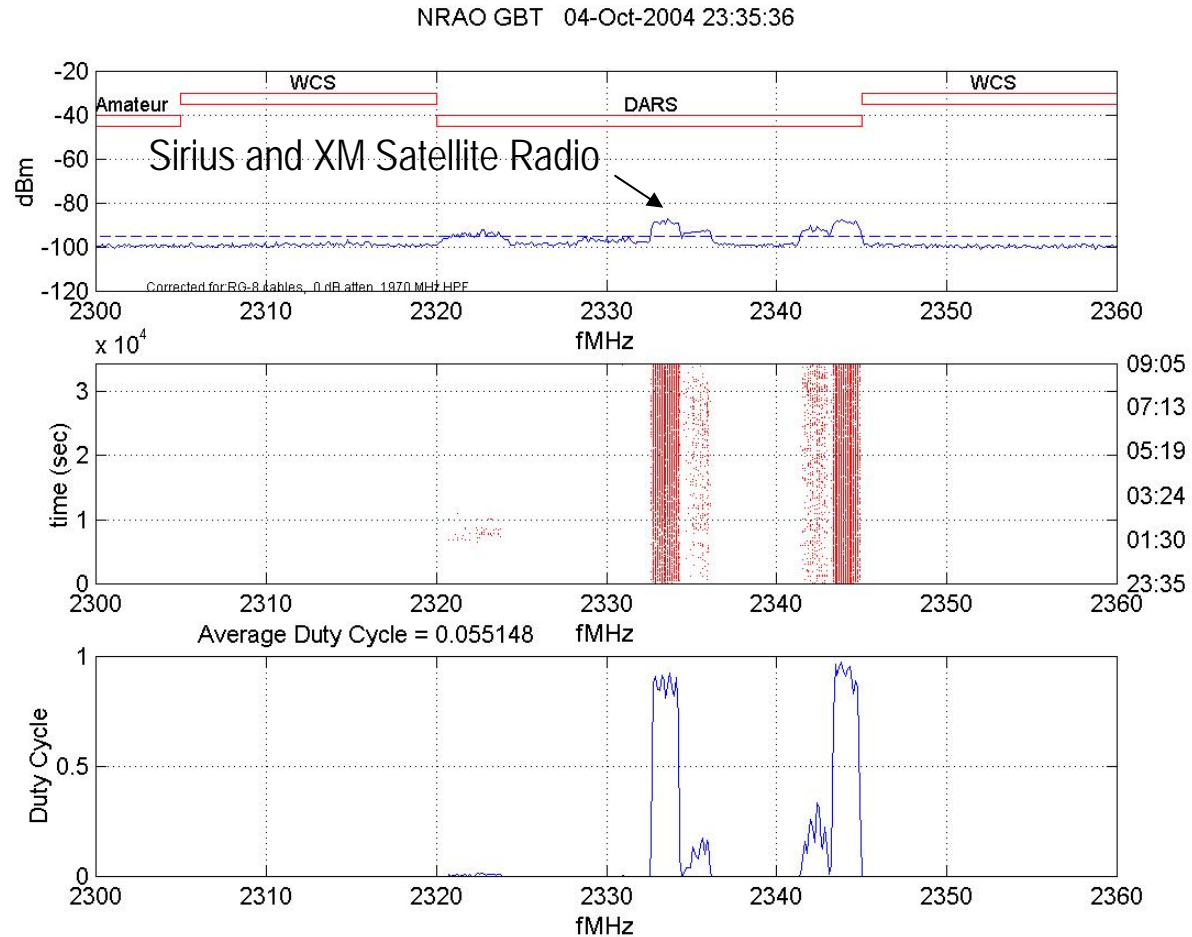
NYC Measurements 31-Aug-2004 15:45:30



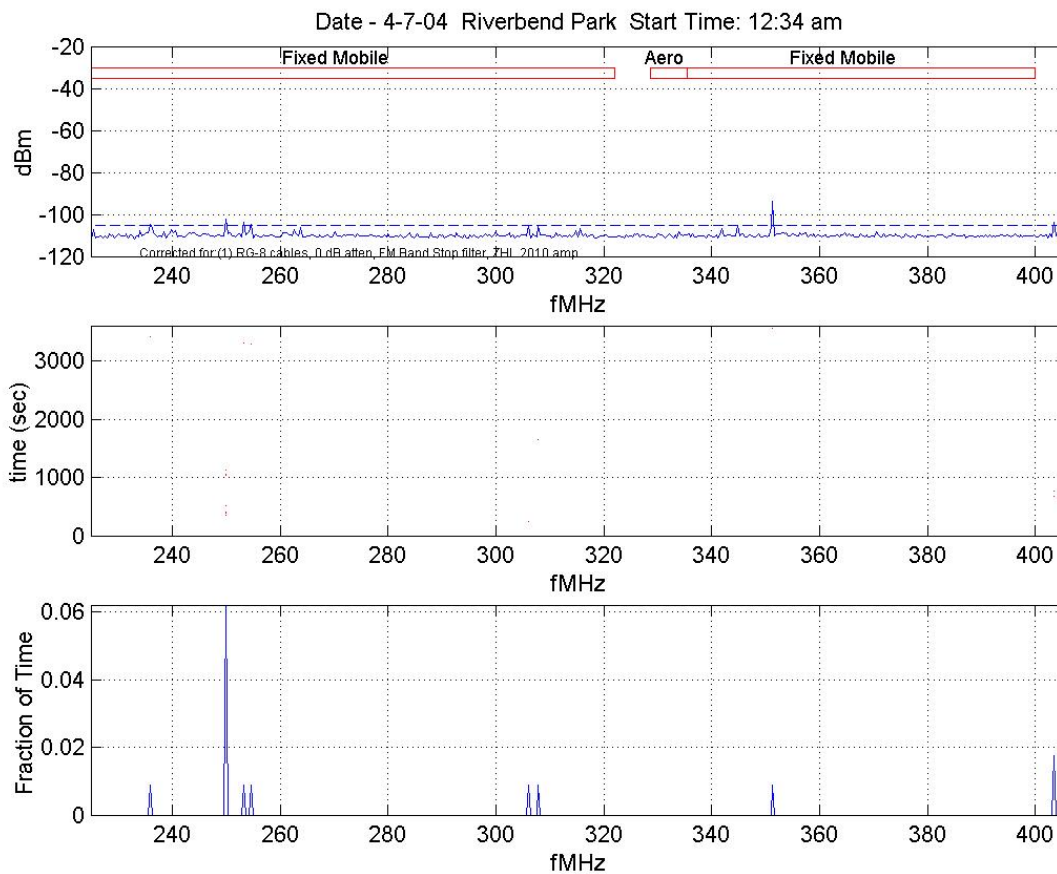
Signals are not detected because

- Not there, or
- Too weak

Signals At Radio Quiet Zone

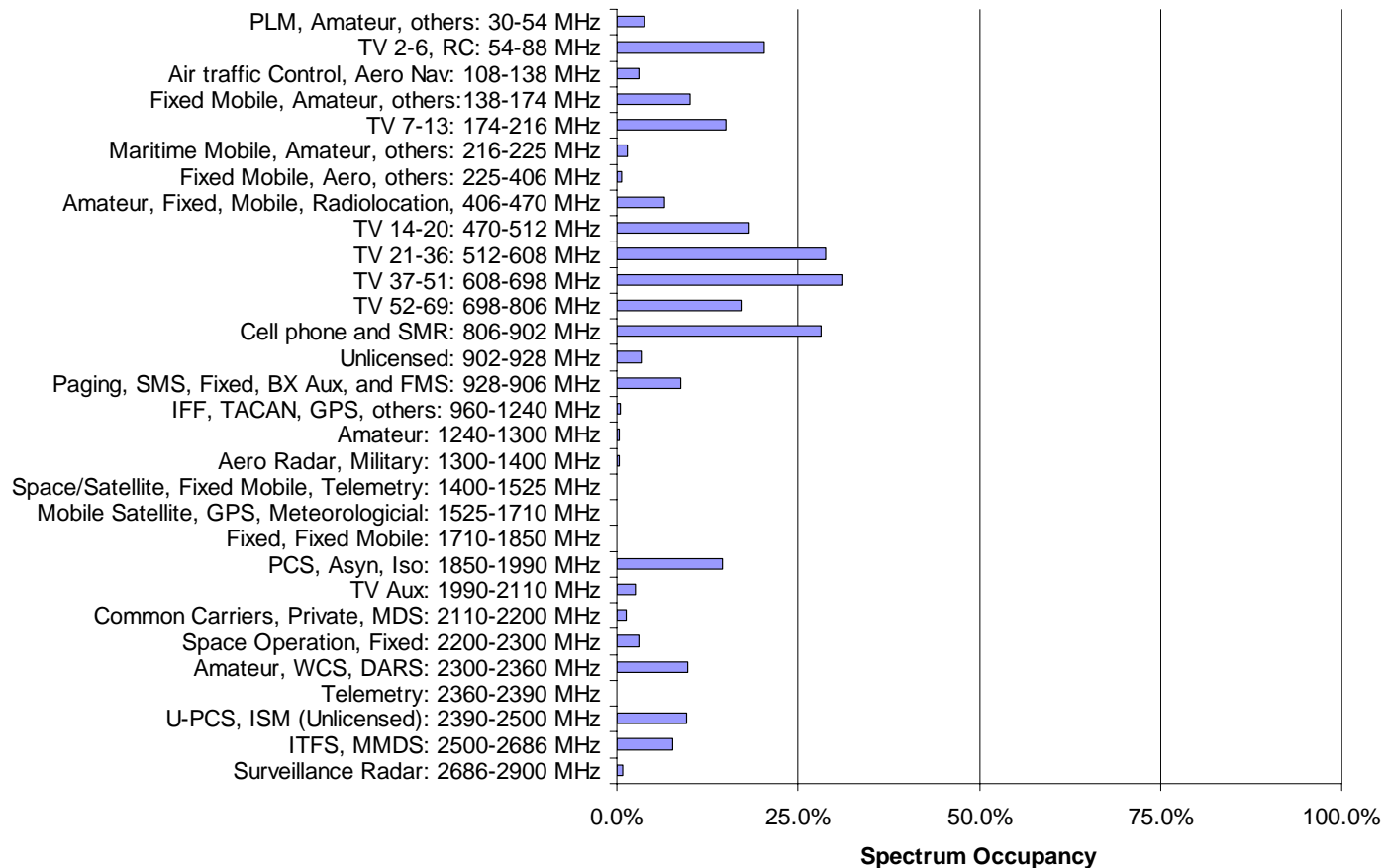


Low Utilization in a Rural Environment



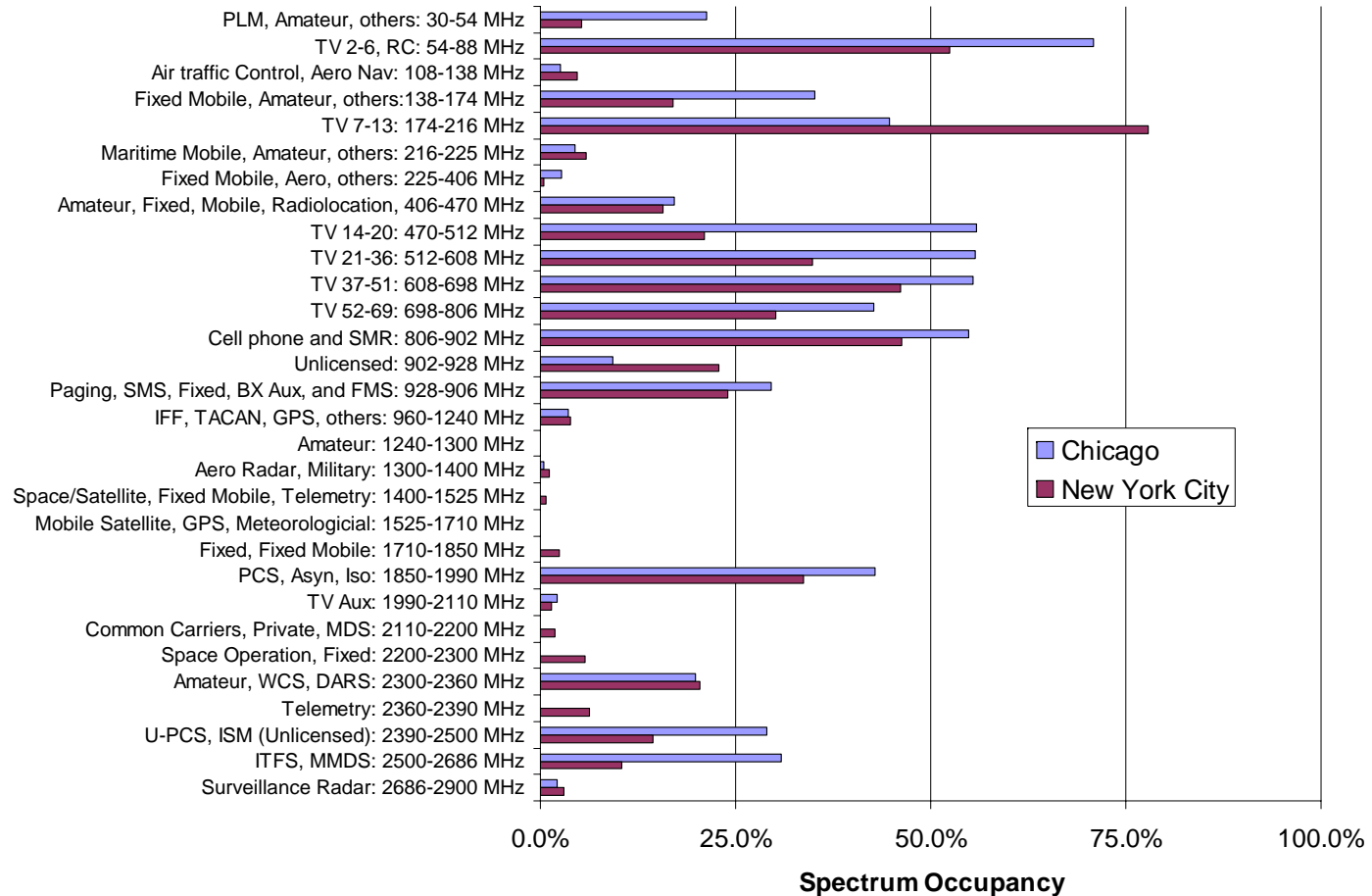
Average Occupancy In Each Band

Measured Spectrum Occupancy Averaged over Seven Locations



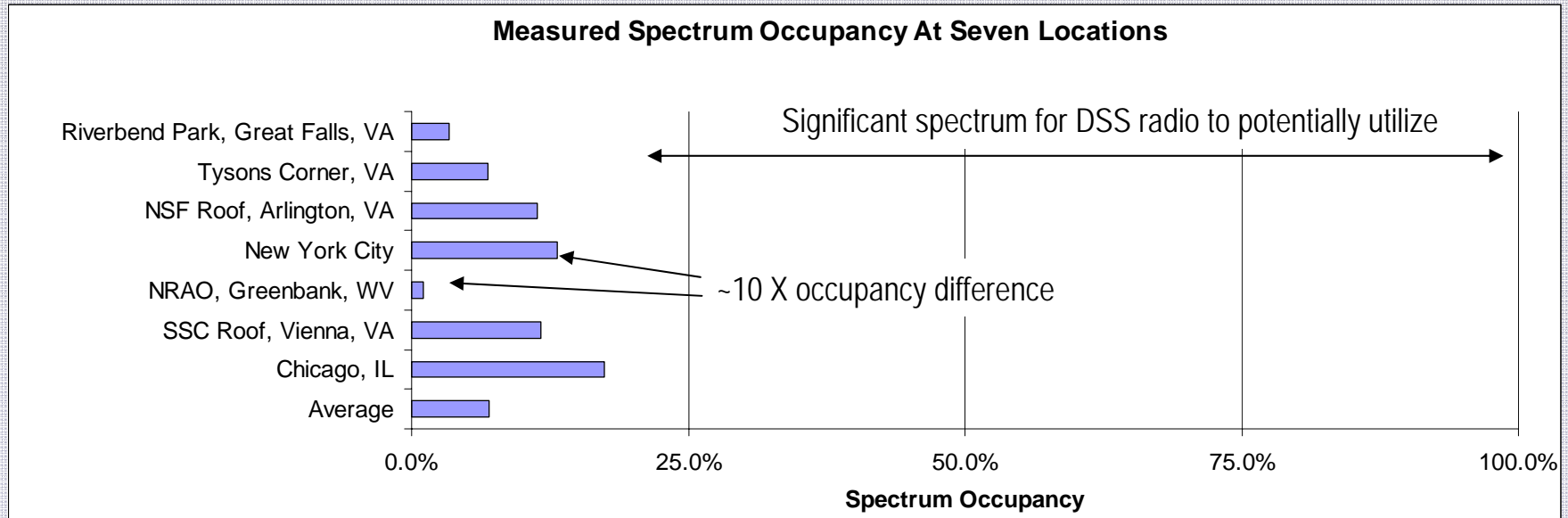
Significant Occupancy Differences Between Similar Locations

Measured Spectrum Occupancy in Chicago and New York City



Average Occupancy at Different Locations

- ~ 10 X higher occupancy difference



Needed Follow-on Work

- Establish a general and comprehensive estimate of spectrum occupancy
 - 10 urban locations
 - 10 suburban locations
 - 3 international urban locations
- Determine the size of spectrum holes
 - Simultaneous fixed and nomadic measurements
 - Synchronized spectrum analyzer trace triggering
- Determine the cause of low spectrum occupancy
 - Research the FCC/NTIA regulations and assignment databases
 - Who are the “owners”? Why they are not using the bands?
- Obtain long-term trends of spectrum usage and background noise levels
 - Collect data over a continuous, two year period
 - Determine seasonality variations
 - Long-term peak-to average occupancy ratios
- Determine the operating characteristics of the legacy users in bands with low occupancy
 - Enable dynamic spectrum sharing systems to be better designed
 - Signal parameters (transmission gaps statistics, transmitter mobility, number of transmitters, the signal bandwidths, and other parameters)

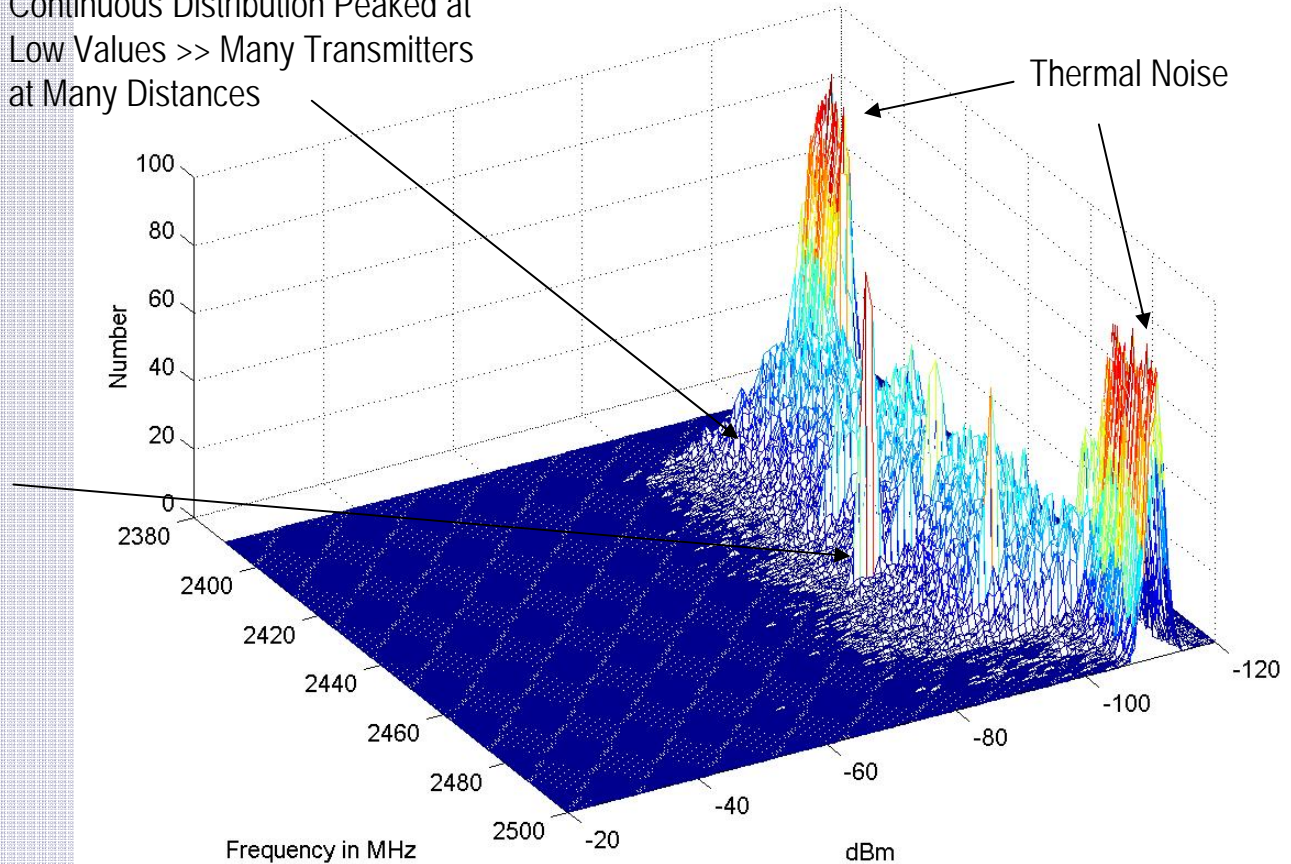
Amplitude Histogram of 2.4 GHz Band

NYC Measurements 01-Sep-2004 20:41:24

Continuous Distribution Peaked at Low Values >> Many Transmitters at Many Distances

Thermal Noise

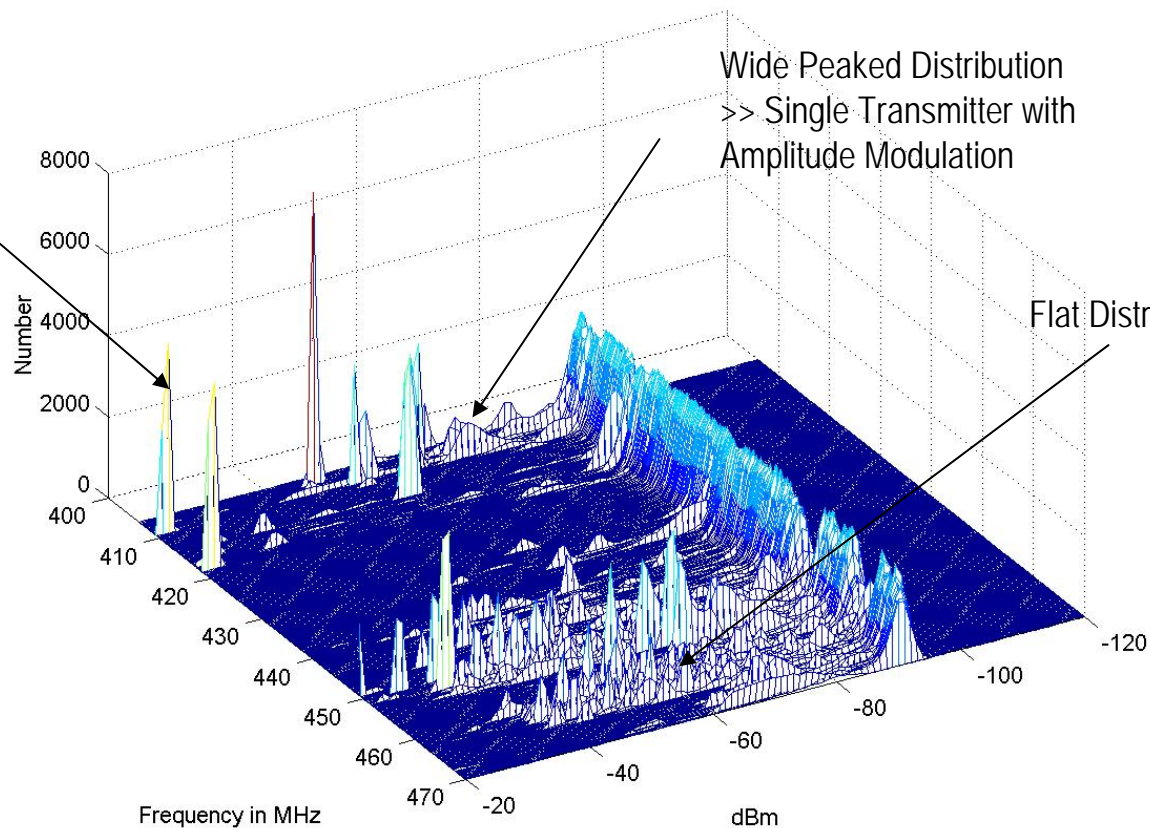
Large Amplitude Concentration >> Single Fixed Transmitter



Amplitude Histogram of Public Safety Band

NYC Measurements 31-Aug-2004 15:54:22

Large Amplitude Concentration >> Single Fixed Transmitter



Wide Peaked Distribution >> Single Transmitter with Amplitude Modulation

Flat Distribution >> ?

Conclusions

- Measurements show there is significant spectrum “whitespace”
 - 13% in NYC – peak period
 - Many bands have minimal use
 - A low agility, contiguous waveform DSS radio provides high utility
- Large occupancy differences with location
- Significant band-to-band variations in “similar” locations
 - NYC vs Chicago
- Summarized needed follow-on work