

ISART March 1, 2005

**Analysis and Comparison of Spectrum
Measurements performed in Urban and
Rural Areas to Determine the Total
Amount of Spectrum Usage**

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Outline

- Spectrum Measurement System
- Data Analysis Method
- Spectrum Usage Levels
- TV Band
- Conclusion

Spectrum Management

- How Much Spectrum is Being Used?
- Where is Spectrum Vacant?
- Can I Please Have It?

Radio Spectrum Usage Study

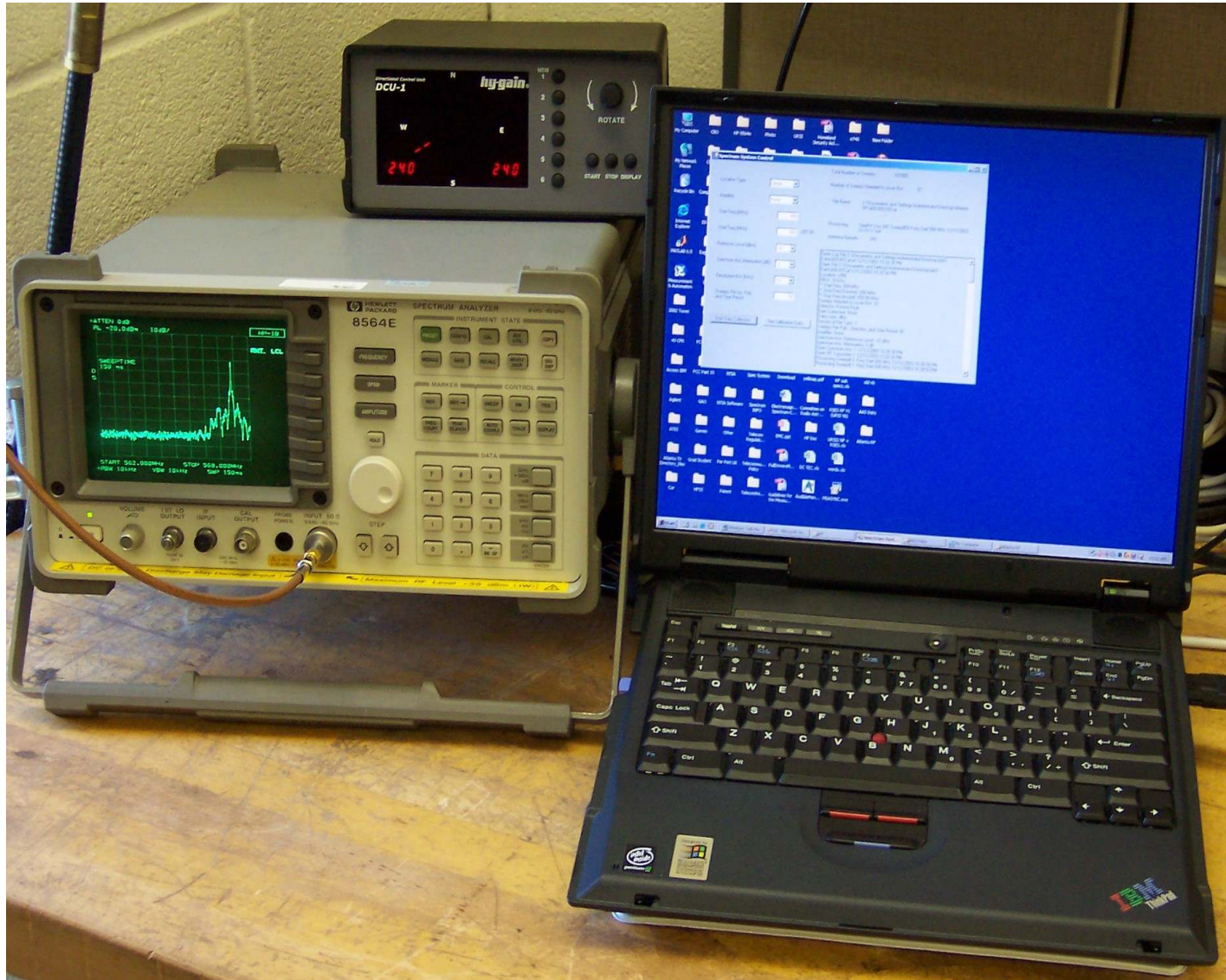
- Simulation Approach
 - Incomplete Database of Transmitters and Receivers
 - Propagation is Difficult to Predicate Accurately
- Measured Usage
 - Limited Past Spectrum Studies

Spectrum Study Variables

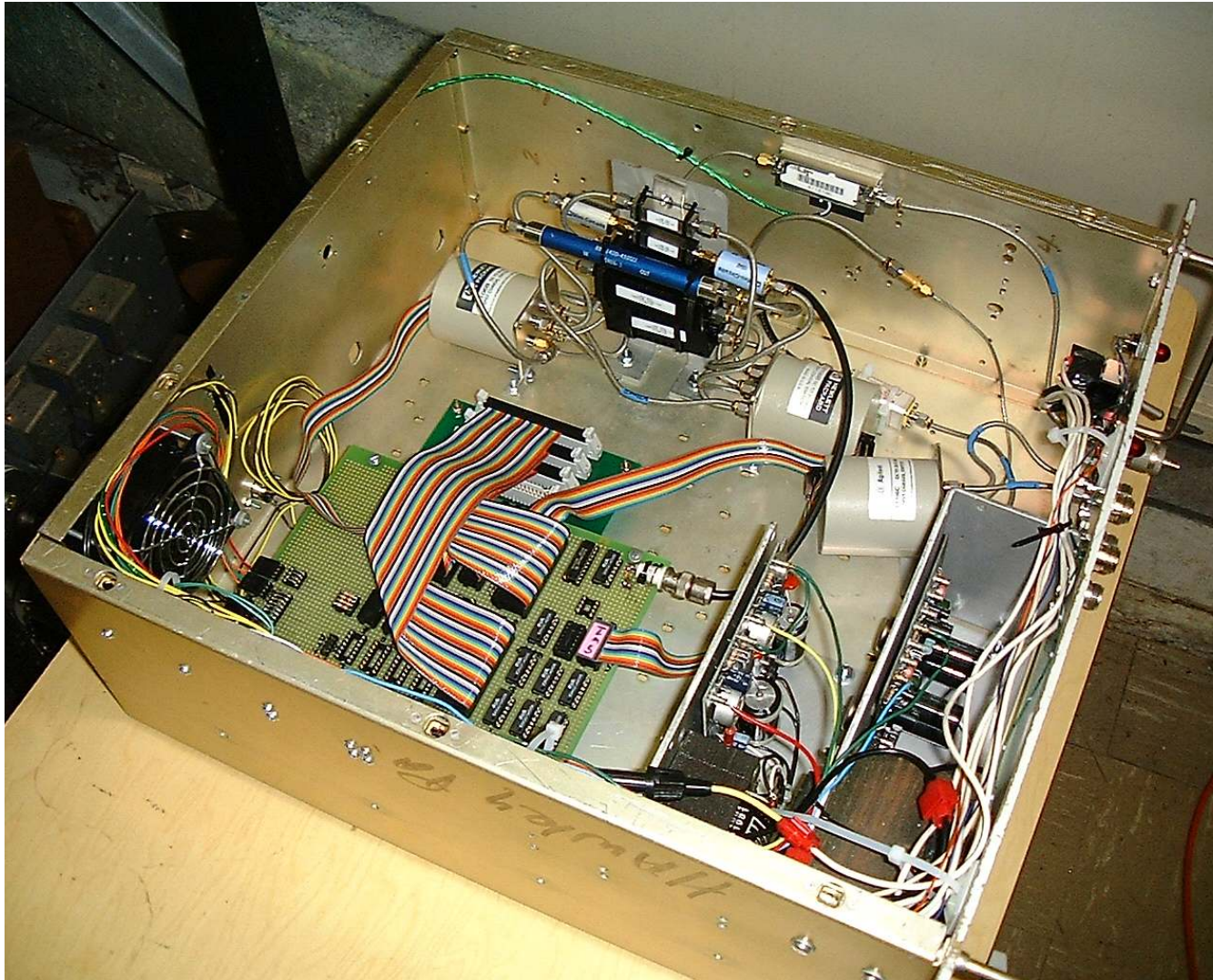
- Frequency (400 MHz – 7.2 GHz)
- Time (short term usage, minutes)
- Time Period (6 discrete time periods per day, hours)
- Polarization (Linear: Horizontal & Vertical)
- Azimuth (6 directions)
- Location Type (Urban, Suburban, Rural)

~2.5 billion data measurements per location!

Control and Data Acquisition



RF Subsystem



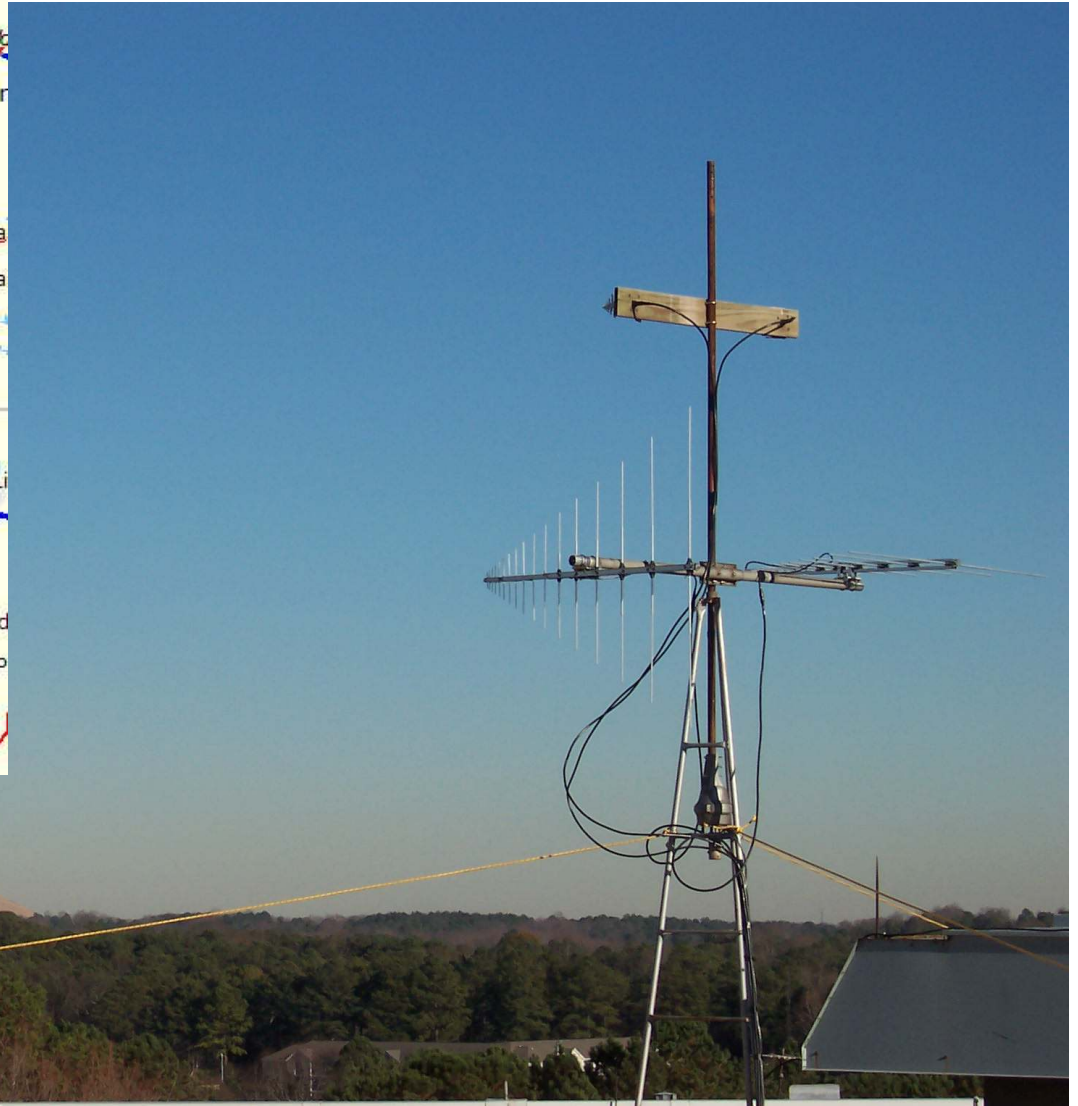
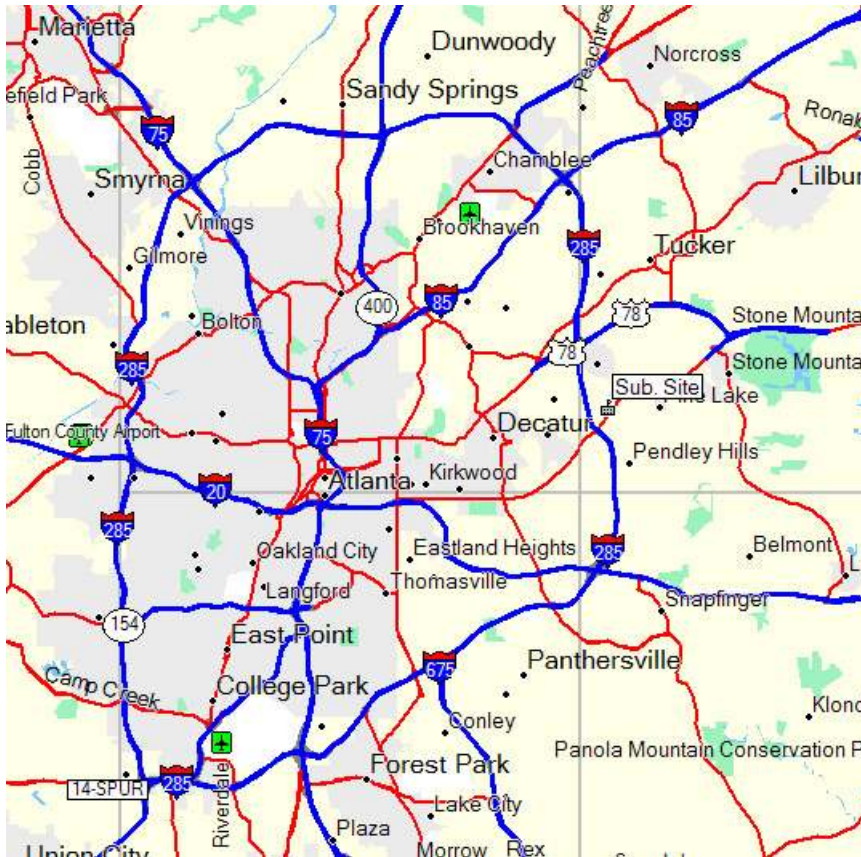
Spectrum Study Locations

- Urban
 - Atlanta (complete)
- Suburban
 - Atlanta Area (expected completion 1Q05)
- Rural
 - North Carolina, PARI (complete)
- >6 Billion Measurements Taken

Atlanta Measurement Site



Suburban Atlanta Measurement Site



Rural North Carolina Measurement Site



PARI

Pisgah Astronomical Research Institute



- Radio and Optical Astronomy
- Frequencies: 8 KHz to 22 GHz
- Rural:
 - Pisgah National Forest
 - 53 km from Asheville, NC
 - 58 km from Greenville, SC
 - 127 km from Knoxville, TN

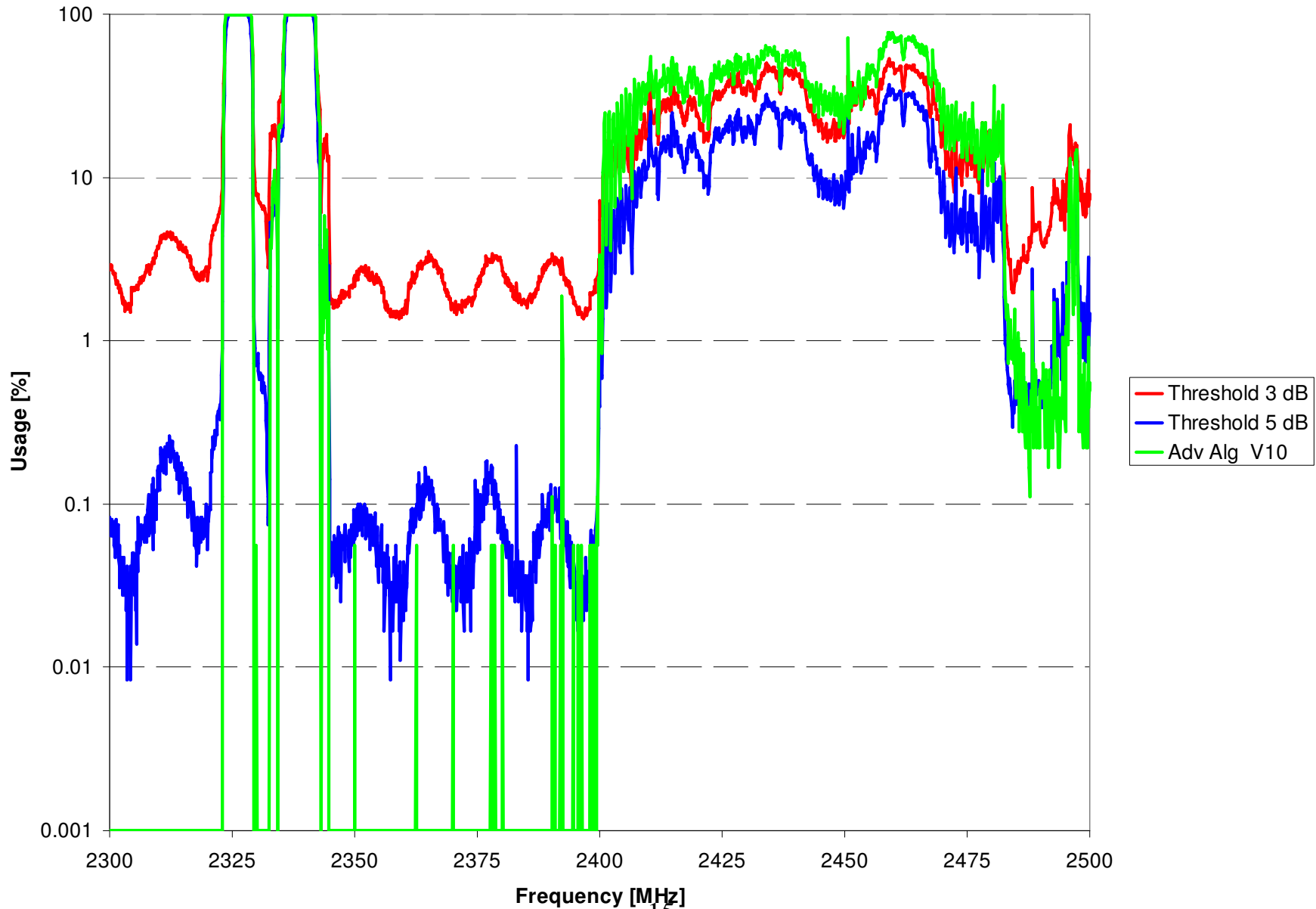
Spectrum Measurement System Detection Ability

- Terrestrial Communication
 - Broadcast
 - Intermittent
 - Narrow Band (10 KHz RBW)
 - Spread Spectrum
- Terrestrial Radar
- Satellite
 - LEO
 - GEO
 - HEO

Advanced Usage Detection Algorithm

- Derived from Mining Spectrum Studies
- Identify Spectral Usage by the Use of
 - Profile of Spectral Emitters
 - Effects of the Propagation Environment
- No A Priori on Emitters or Frequency Plan
- No Time Averaging
 - Able to Detect Intermittent Signals

Usage Detection: 2300 – 2500 MHz



Detection Methods Comparison with Real Data

- 3 dB Threshold
 - False Alarm Rate of ~ 0.04
 - False Alarm every 25 Seconds*
- 5 dB Threshold
 - False Alarm Rate of ~ 0.002
 - False Alarm every 8 Minutes*
- Advanced Detection (Generic V10)
 - False Alarm Rate of $<10^{-6}$
 - False Alarm every Month*
 - Probability of Detection Comparable to 3 dB Threshold

* = Detection Once a Second

Radio Spectrum Usage Results Disclaimer

- We Cannot Detect
 - Signals Below or Marginally Above our Sensitivity Level
 - GPS Satellite Downlinks
 - C-Band Satellite Downlinks
 - CDMA Handsets (occasionally)
 - Passive Spectrum Users
 - Remote Sensing
 - Radio Astronomy

Radio Spectrum Usage Results Disclaimer

- Results May Show Overuse
 - Positive Peak Detection is Used
 - Pulsed Signals (RADAR)
- **Results Have Not Been Cherry Picked**
 - Immense Effort was Made to Find All Usage
 - Spectrum Measurement System
 - Detection Method

Usage Results: 400 MHz to 7.2 GHz

- Urban
 - Usage in Time and Space: **6.5 %**
 - Spectrum Vacant: **77.6 %**
 - Amount of “White Space”: **5.3 GHz**
- Rural
 - Usage in Time and Space: **0.8 %**
 - Spectrum Vacant: **96.8 %**
 - Amount of “White Space”: **6.6 GHz**

All “White Space” Cannot be Reused

- Sharing Impediments
 - Incumbent System’s Receiver Vulnerably
- Spectrum May be Undesirable
 - Dispersed
 - Adjacent to High Power Signals
 - Intermodulation Issues

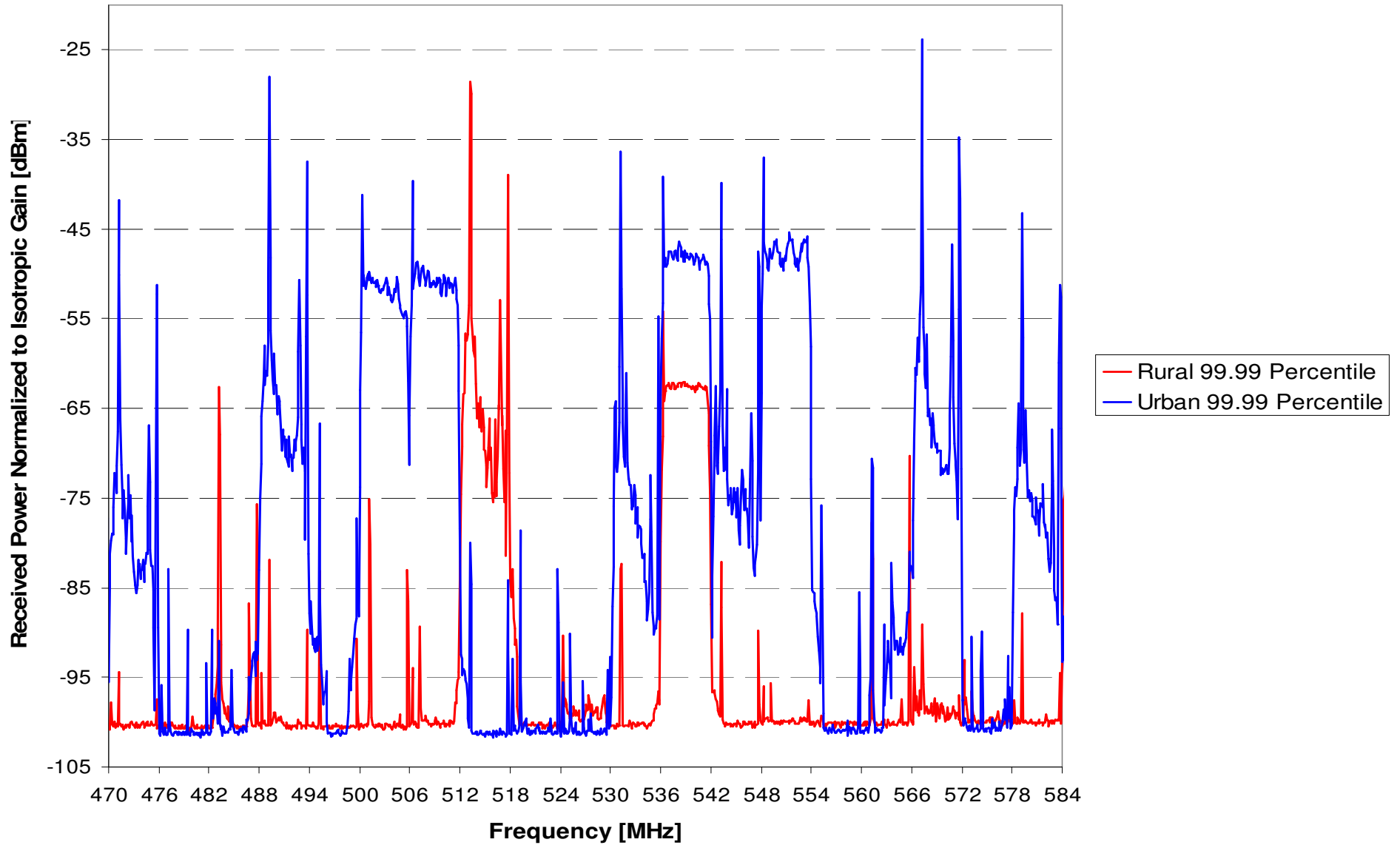
UHF TV Bands

- FCC Has Proposed Sharing
 - May 2004 NPRM FCC 04-113
- ATSC and NTSC Transmitted
 - Channels 14 to 69
 - 470 to 806 MHz
- Will be Reduced to
 - Channels 14 to 52
 - 470 to 698 MHz

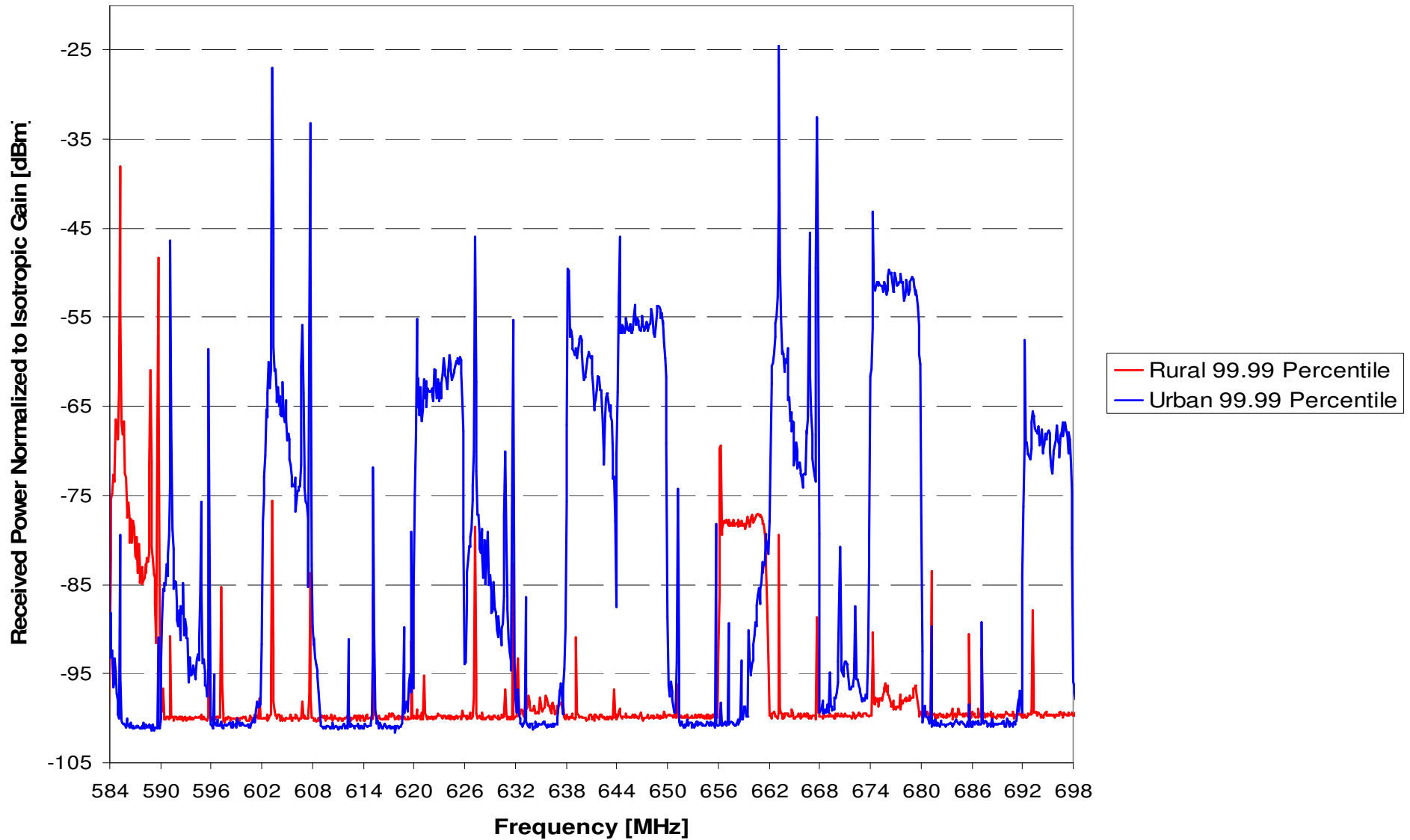
UHF TV Usage, 470 – 806 MHz

- Urban
 - Amount of “White Space”: **167 MHz**
- Rural
 - Amount of “White Space”: **265 MHz**

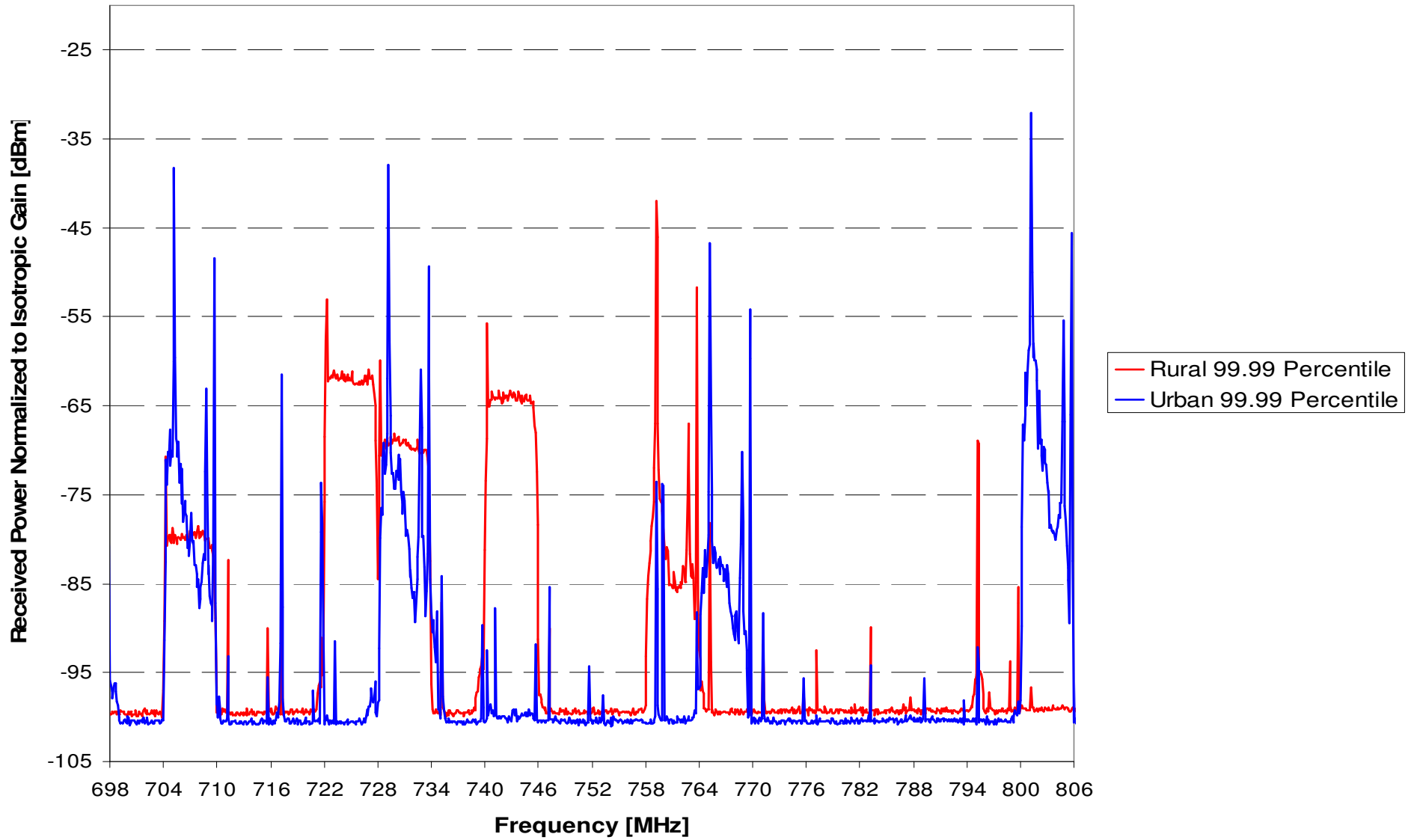
UHF TV Usage, 470 – 584 MHz



UHF TV Usage, 584 – 698 MHz



UHF TV Usage, 698 – 806 MHz



Conclusion

- Most Spectrum is Not Being Used
- The Detection Method Developed has Application in Spectrum Monitoring and Cognitive Radio
- Allen Petrin is Leaving GA Tech with a PhD in Summer 05
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Supported by the National Science Foundation, AST-0309469