Spectrum Occupancy Measurements of 3550-3650 MHz Maritime Radar Band Near San Diego, CA

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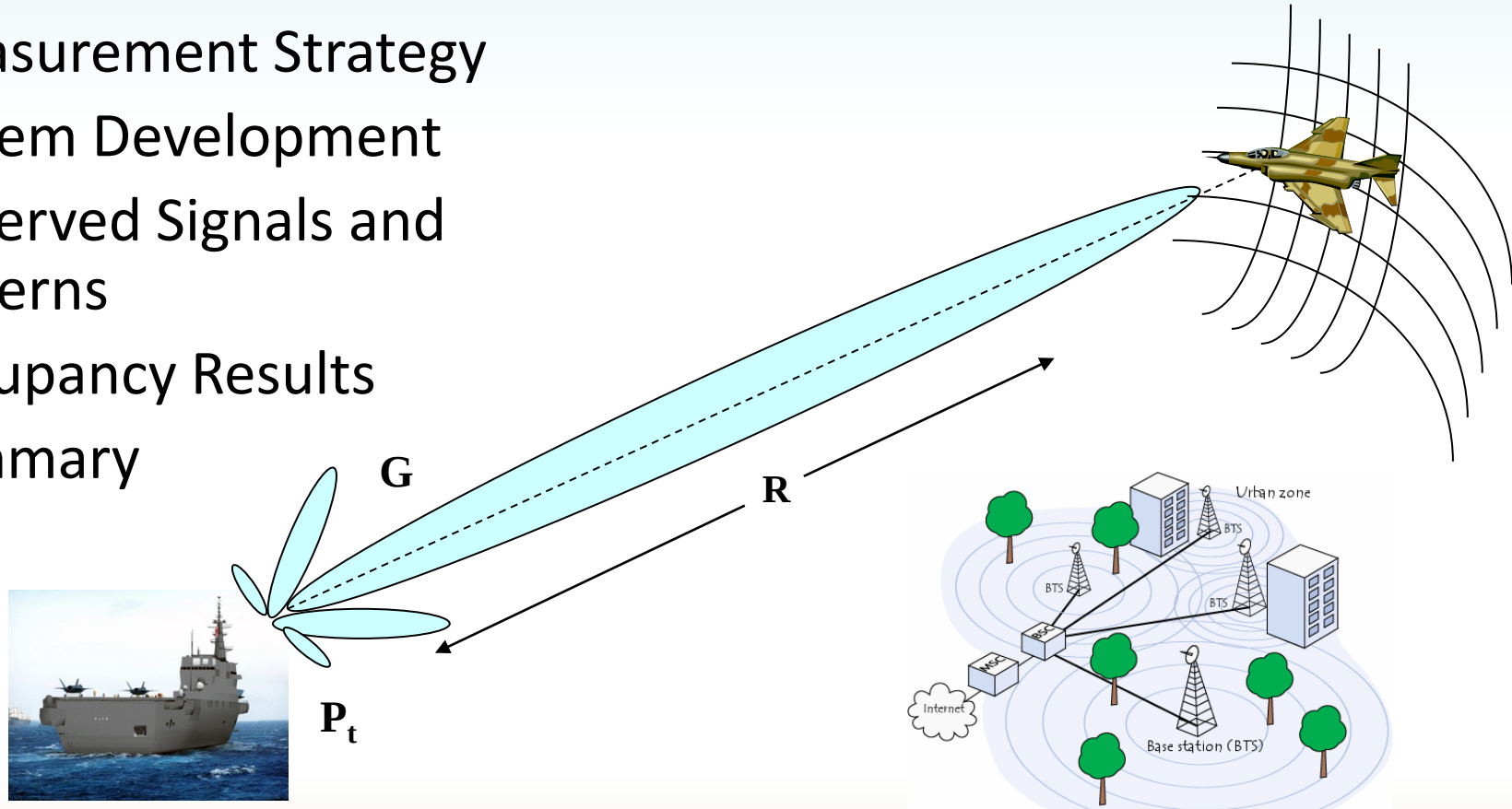
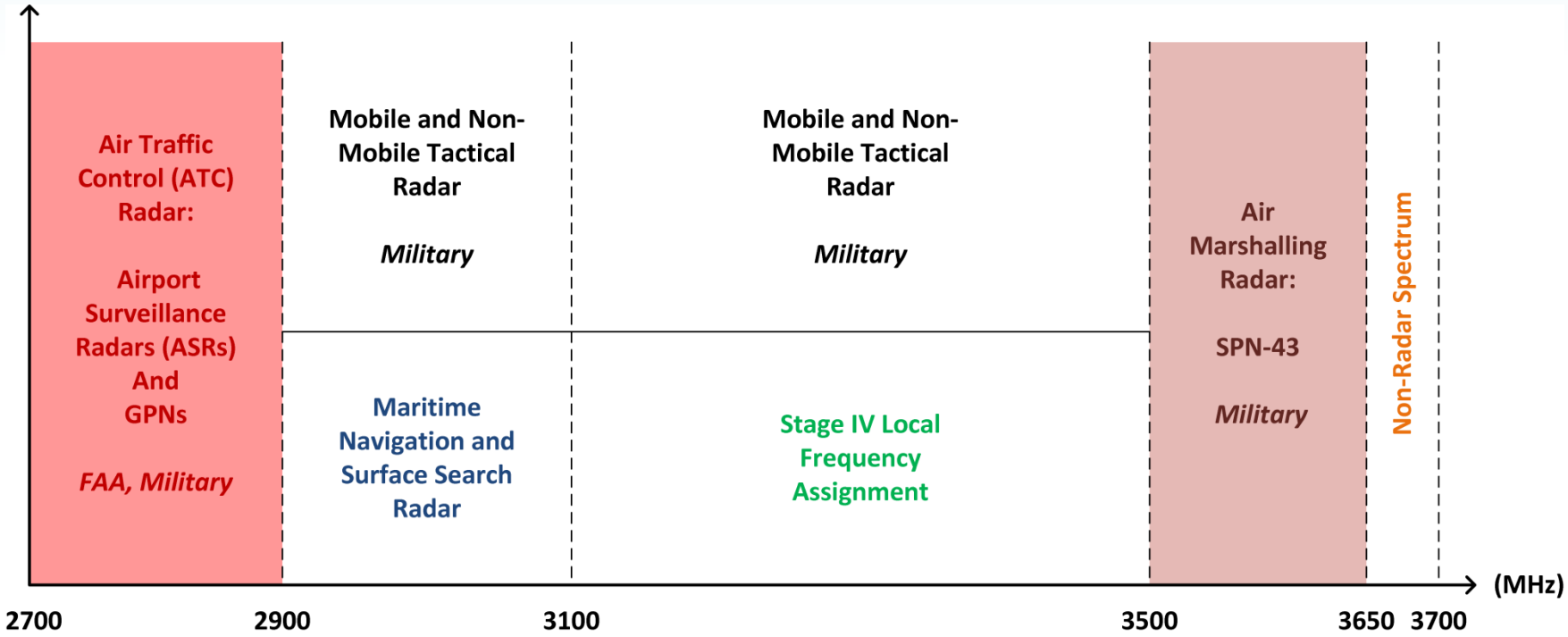
Outline

- S-Band Maritime Radar
- Measurement Strategy
- System Development
- Observed Signals and Patterns
- Occupancy Results
- Summary



S-Band Radar


Air Traffic Control (ATC) Radar:
Airport Surveillance Radars (ASRs) And GPNs
FAA, Military
Mobile and Non-Mobile Tactical Radar
Military
Mobile and Non-Mobile Tactical Radar
Military
Maritime Navigation and Surface Search Radar
Stage IV Local Frequency Assignment
Air Marshalling Radar:
SPN-43
Military
Non-Radar Spectrum
(MHz)
2700
2900
3100
3500
3650
3700

SPN-43 Air Marshaling Radar

(Courtesy: Defense Video and Imagery)

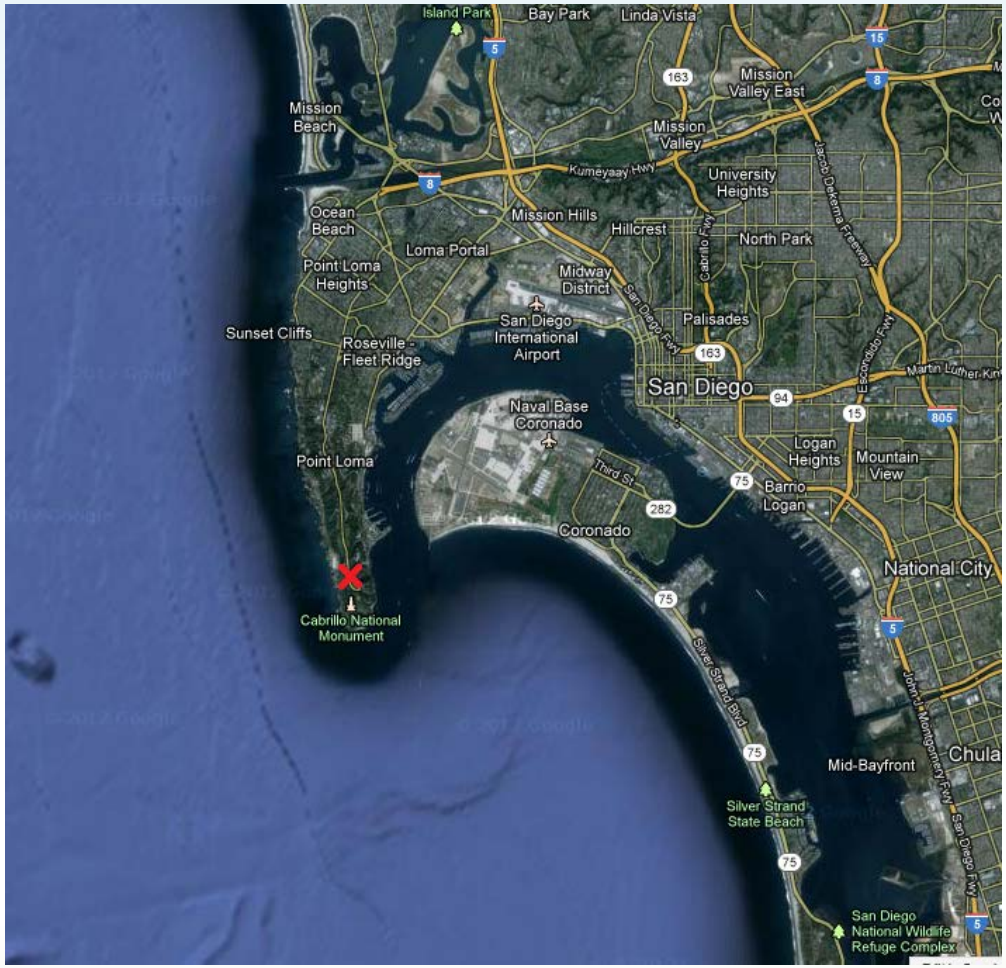
- Function: As a critical part of U.S. Navy carrier ATC systems, SPN-43 marshals in-bound aircraft before negotiating their final landings.
- Specifications [2]:
  - Frequency: 3500-3650 MHz
  - Pulse width: τ=0.9 (±0.15) µsec
  - Pulse interval:

    PRF=1125 (±25) pps → PRI=889 (±20) µsec
  - Antenna rotation rate:

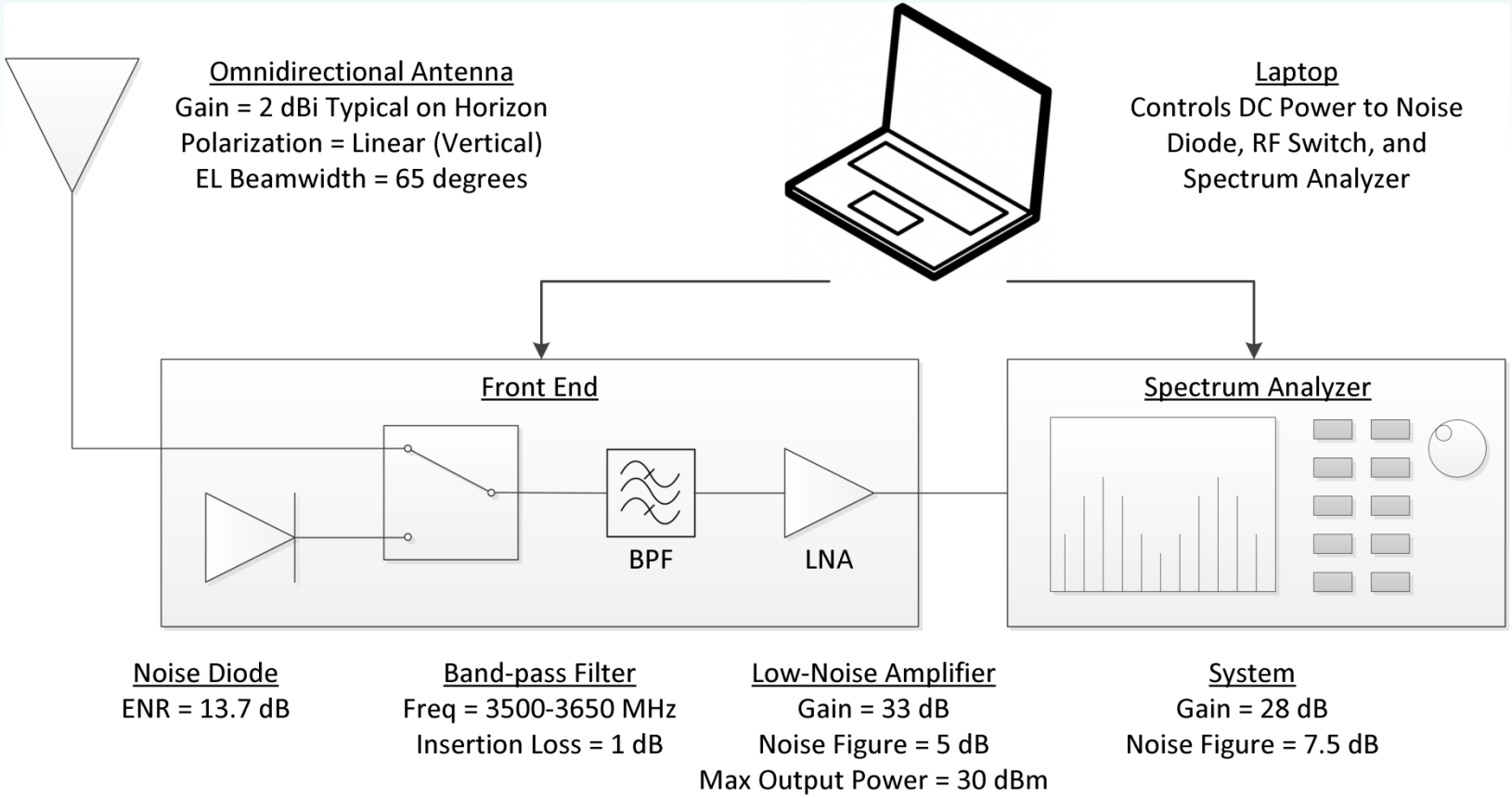
    $\partial\theta/\partial t$=15 rpm → T_{Ant}=4 sec

Measurement Strategy

- Measurement Site: Point Loma, CA on Pacific Coast Near Naval Base
- Duration: Two Weeks
- Channelization: Divide 3500-3650 MHz band into 150x1-MHz channels
- System Design
- Measurement Procedure

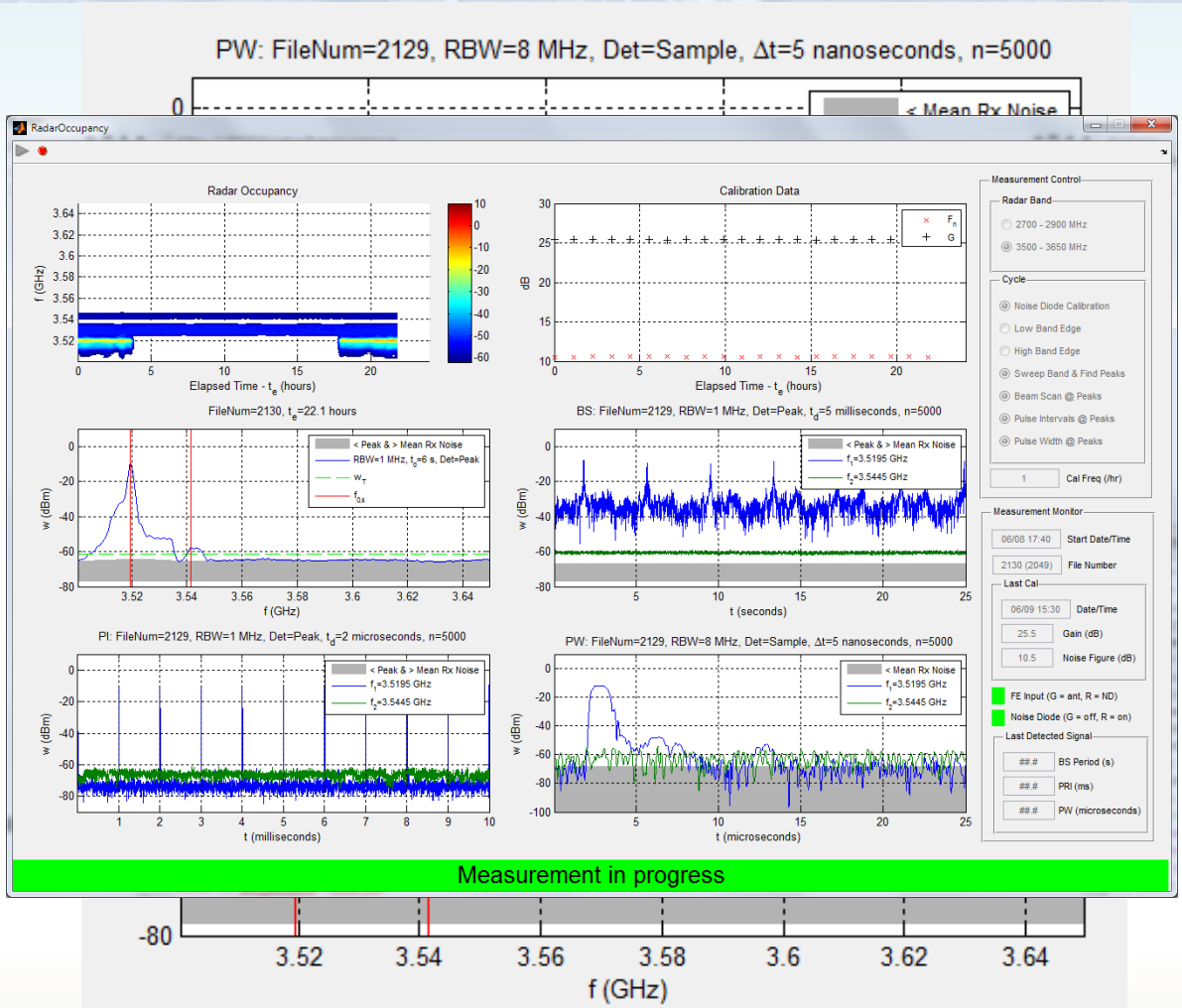


System Design



Measurement Procedure

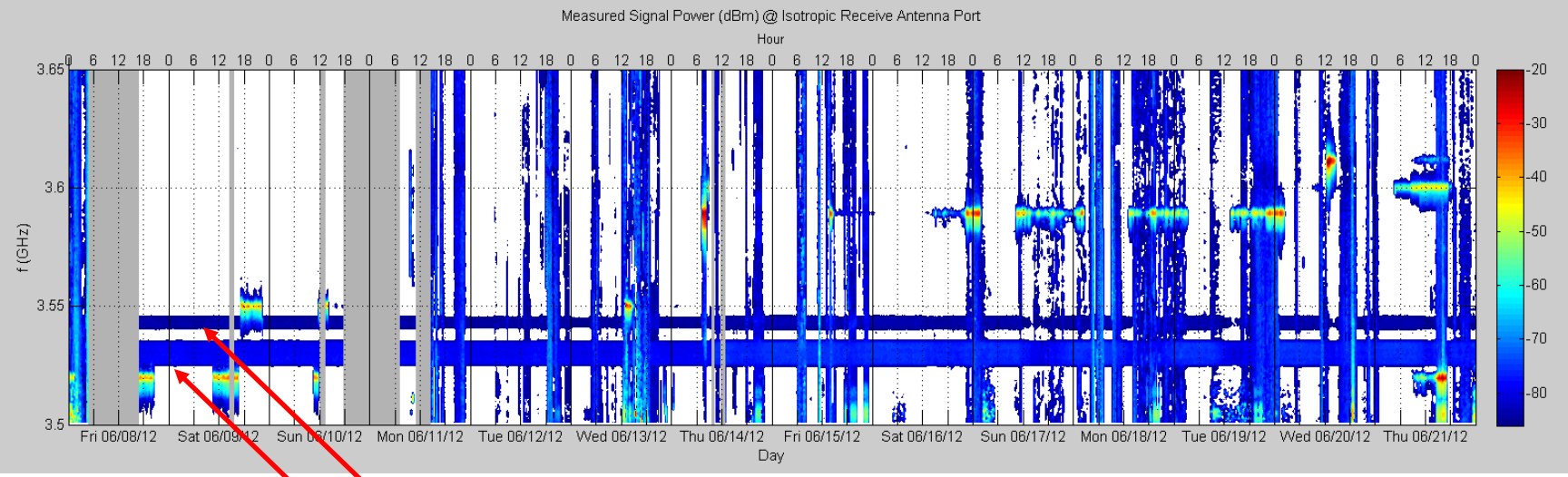
- Calibration
  - Conducted once per hour
  - Y-factor: measure noise figure and gain
- Determine Thresholds
- Frequency Sweep Measurements
  - 100 x 1-MHz channels
  - Peak-detected with $t_{dwell}=1.5T_{Ant}$
- Determine frequencies at max signal levels ($f_{0,k}$)
- Time-Domain Measurements at $f_{0,k}$ to measure T_{Ant}, PRI, and τ

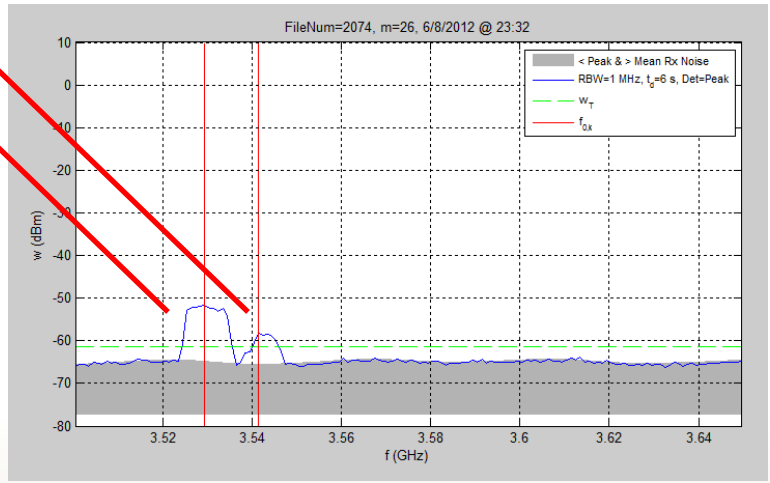


Observed Signals and Patterns

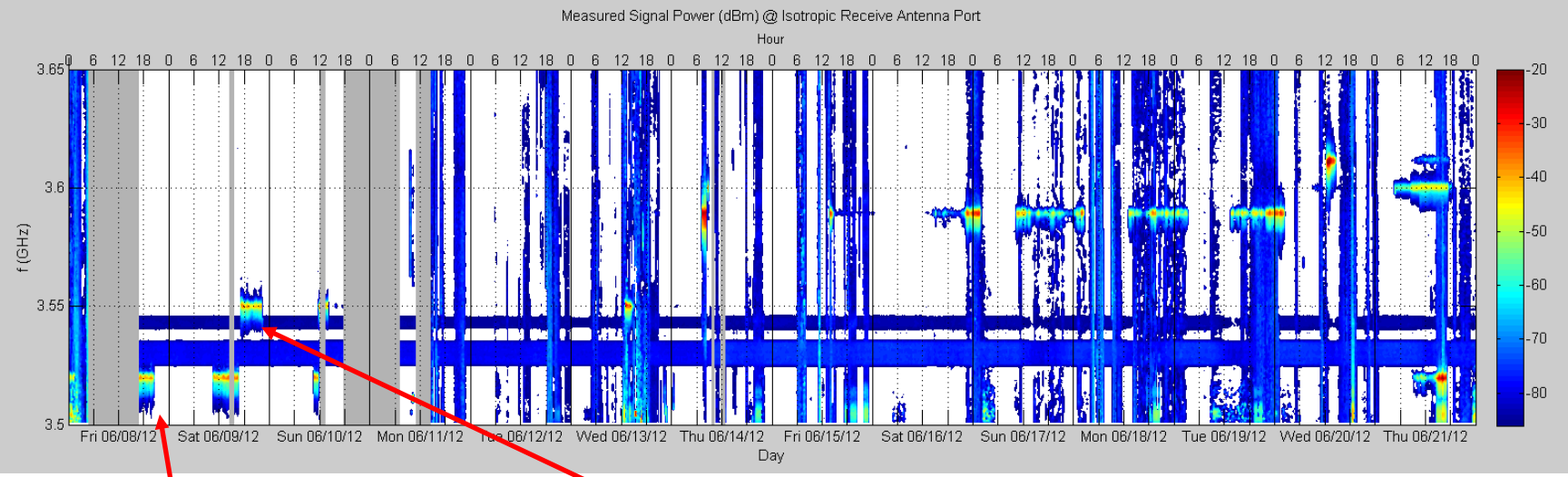
- WiMAX (testing for export) at 3530 MHz and comm at 3542 MHz
- SPN-43
  - At 3520 and 3530 MHz
  - Multiple systems operating simultaneously in 3550-3650 MHz range
  - Spectral spreading
- Adjacent-band radar signals
- Systems are intermittently turned on/off

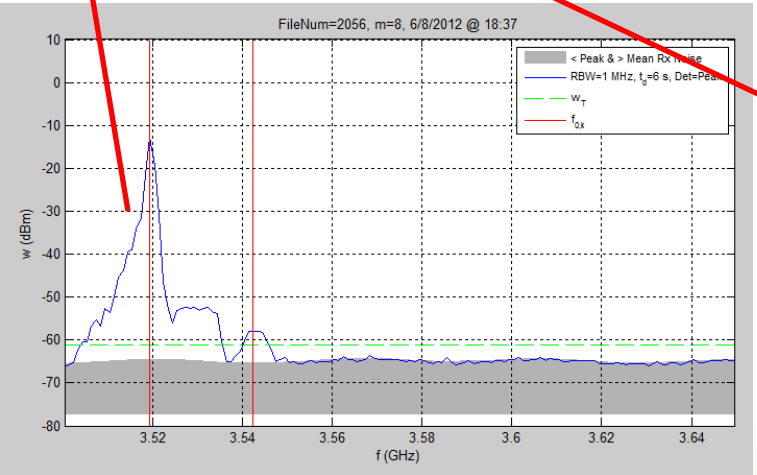
WiMAX/comm at 3530 MHz and 3542 MHz

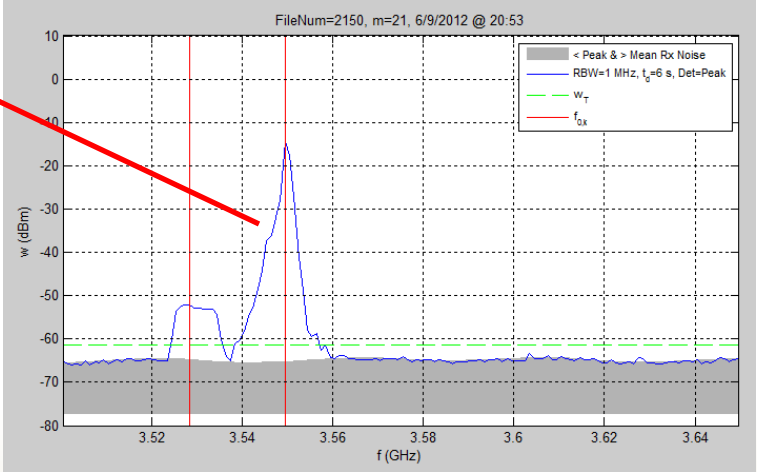




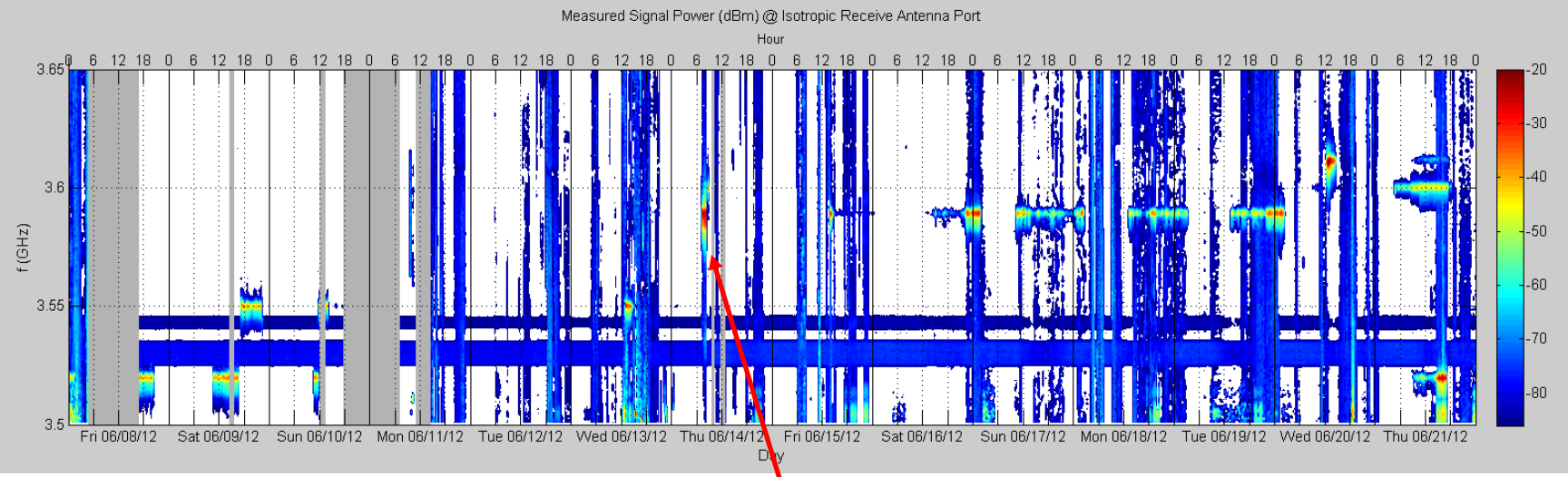
SPN-43 at 3520 MHz and 3530 MHz (Interference?)

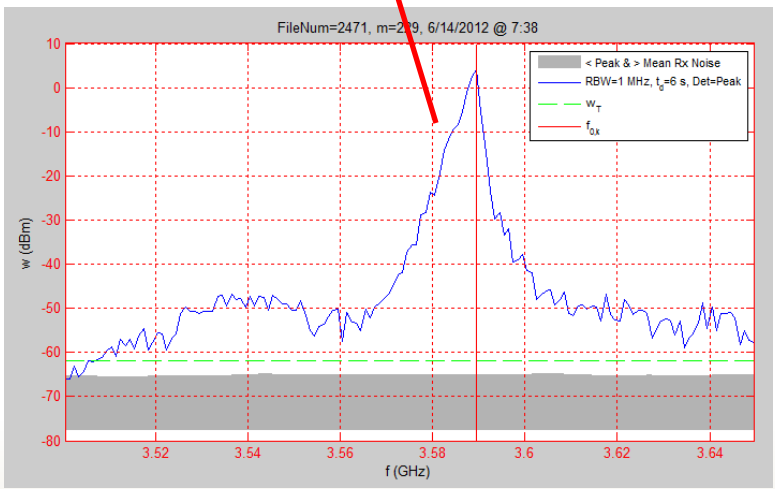




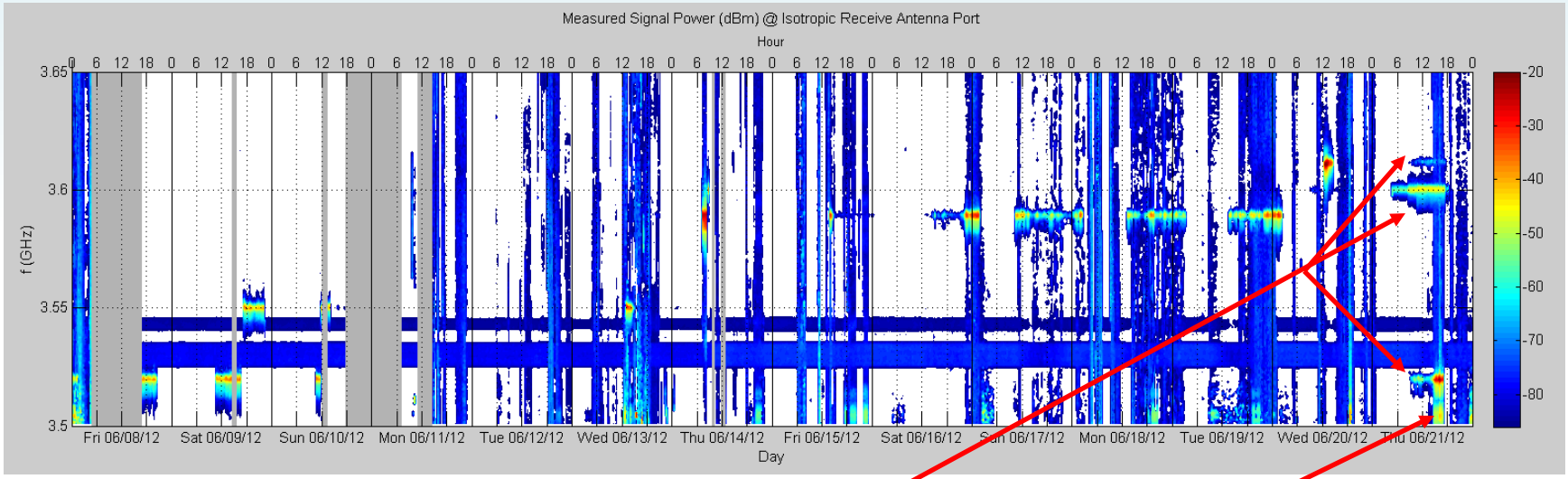


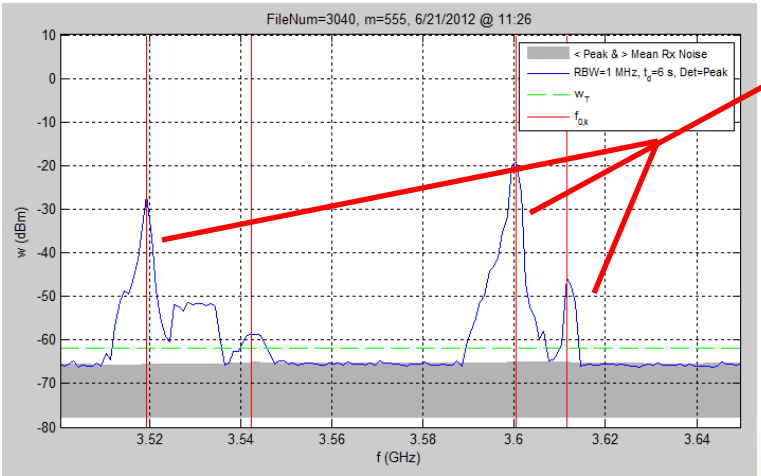
SPN-43 Spectral Spreading

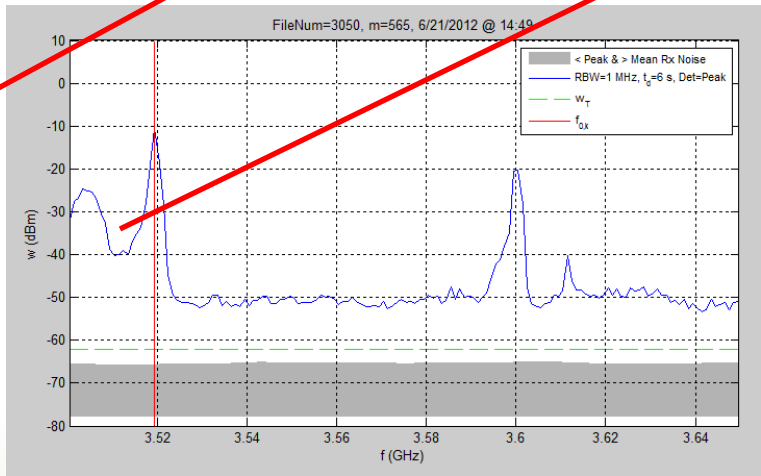




Multiple Systems Operating Simultaneously and Adjacent-Band Radar Turning On/Off Intermittently







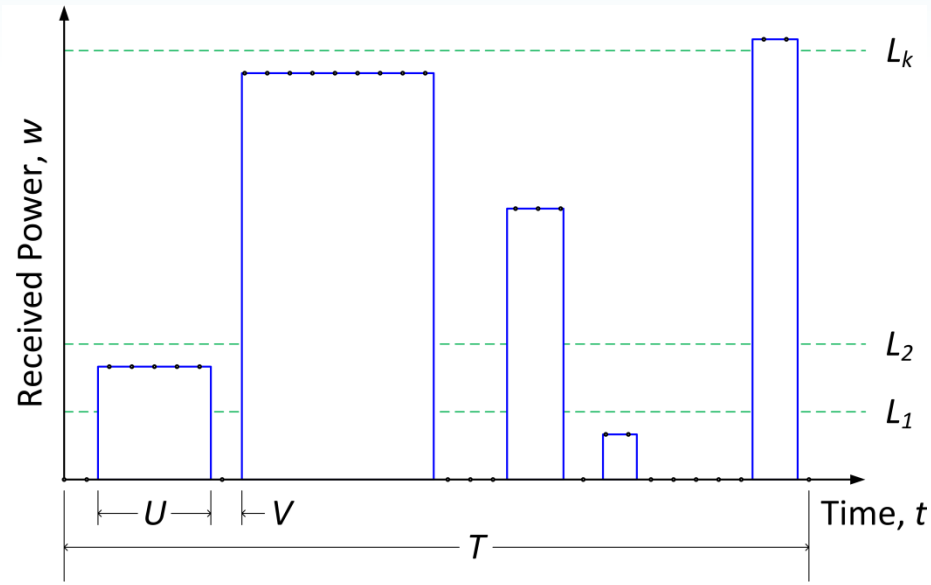
Occupancy Results

- Channel Occupancy to Quantify Duration that Channel (at a Given Frequency) is Occupied or Unoccupied
- Band Occupancy to Quantify Fraction of Band Occupied at a Given Time

Channel Occupancy

- Setup
  - L_k = Threshold level
  - $\boldsymbol{X}(t)$ = 1 if signal at t is above L_k and 0 otherwise
  - $\boldsymbol{U}$ = Length of time a signal continuously exists above L_k
  - $\boldsymbol{V}$ = Length of time between transmissions

(At frequency f)



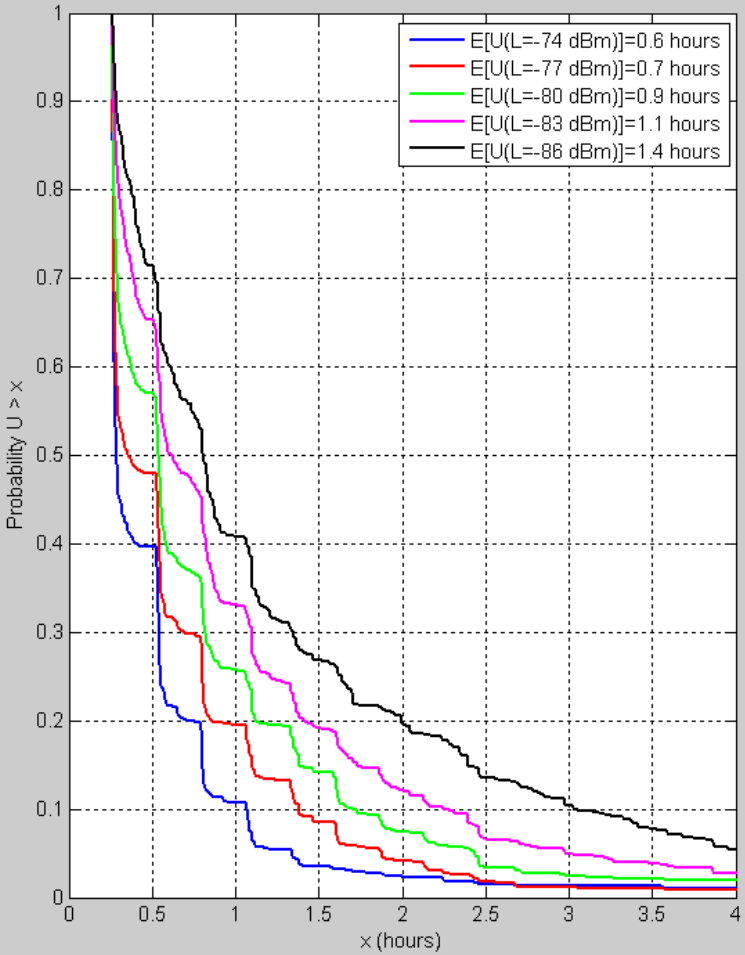
- Measurements
  - $x_1, x_2, \ldots, x_J$ are represented by a sequence of 0's and 1's
  - J = Number of measurements
  - T = Measurement duration

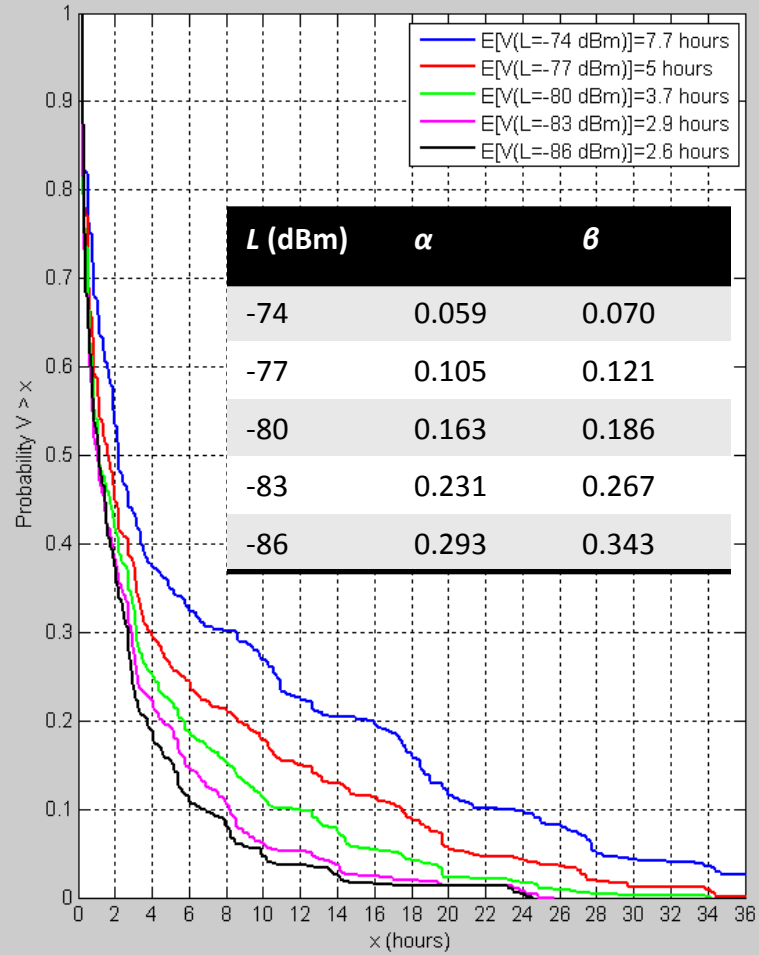
- β = Mean channel occupancy

$$= \frac{E[\boldsymbol{U}]}{E[\boldsymbol{U}] + E[\boldsymbol{V}]}$$, where $E[\cdot]$ denotes expected value

Channel Occupancy

U and V distributions



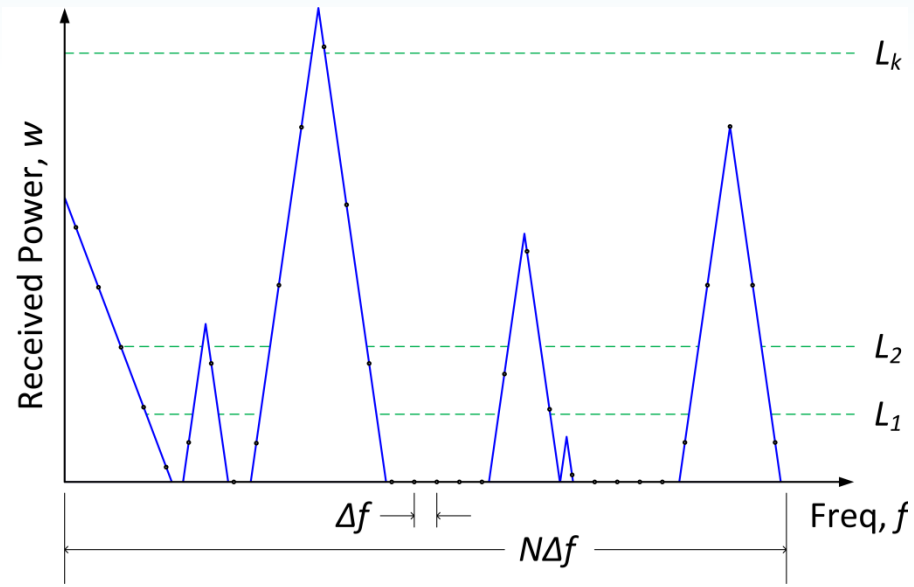


L (dBm)	*α*	*β*
-74	0.059	0.070
-77	0.105	0.121
-80	0.163	0.186
-83	0.231	0.267
-86	0.293	0.343

Band Occupancy

- Setup
  - L_k = Threshold level
  - Δf = channel bandwidth
  - $\boldsymbol{Y}(f)$ = 1 if signal at f is above L_k and 0 otherwise
  - $\boldsymbol{n}$ = Number of channels occupied

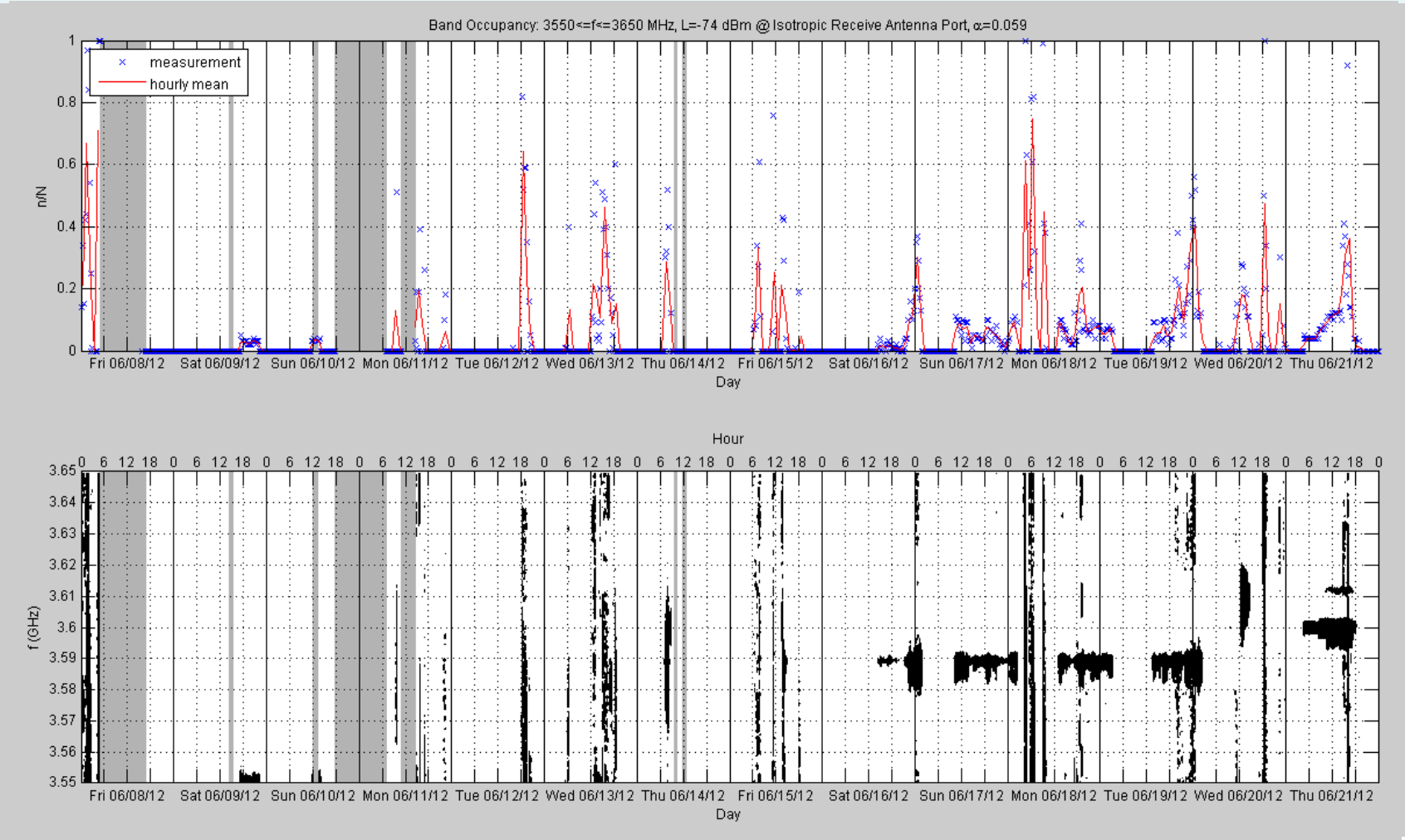
(At time t)



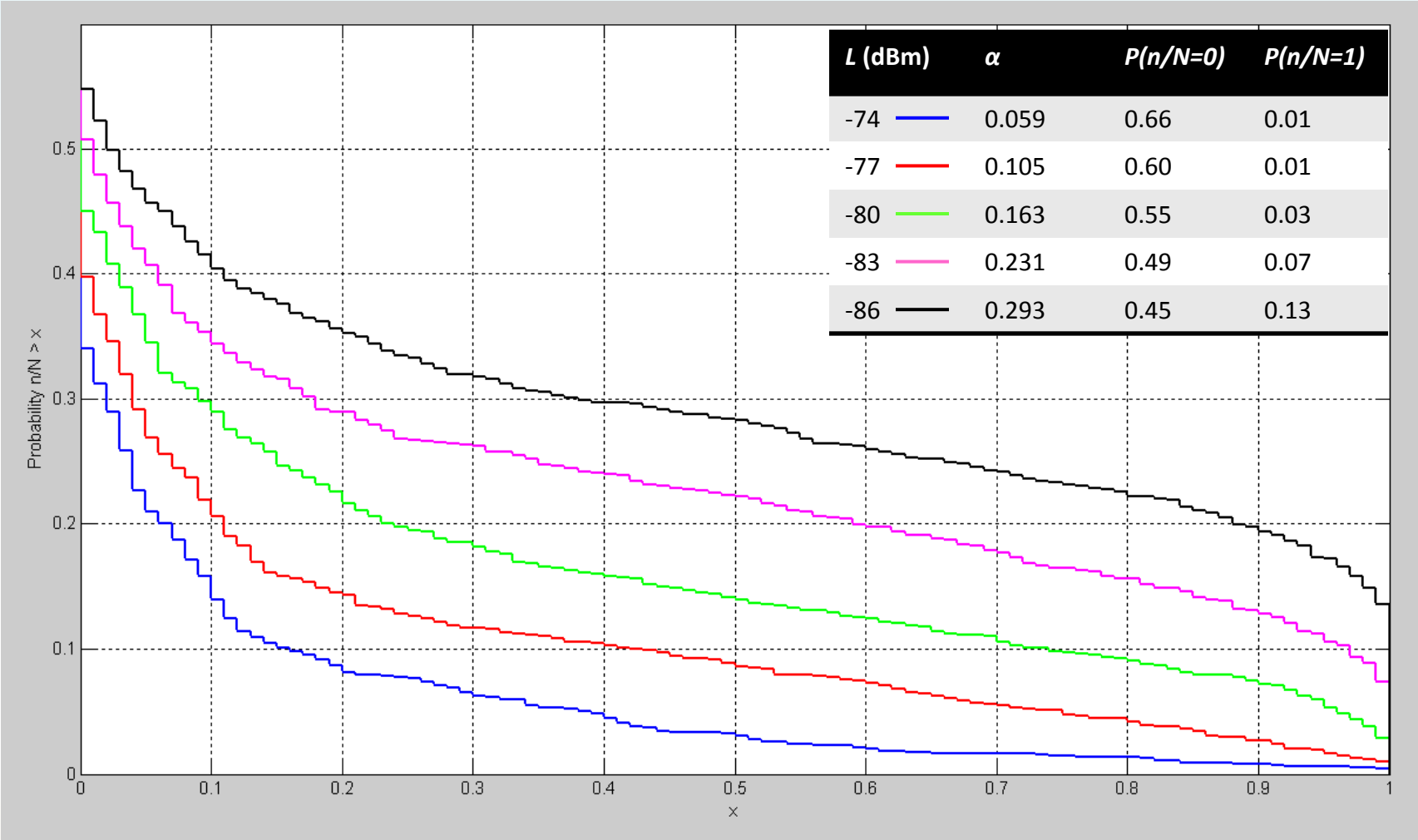
- Measurements
  - $y_1, y_2, \ldots, y_N$ are represented by a sequence of 0's and 1's
  - N = Number of measurements
  - $N\Delta f$ = Frequency span of measurement

- α = Mean Band Occupancy $= \dfrac{E[\boldsymbol{n}]}{N}$, where $E[\cdot]$ denotes expected value

Band Occupancy
Vs Threshold



Band Occupancy
Probability Statistics



L (dBm)	*α*	*P(n/N=0)*	*P(n/N=1)*
-74	0.059	0.66	0.01
-77	0.105	0.60	0.01
-80	0.163	0.55	0.03
-83	0.231	0.49	0.07
-86	0.293	0.45	0.13

Summary

- There is Whitespace Available in the 3550-3650 MHz band at the High-Usage San Diego Site. Depending on threshold:
  - Mean Band Occupancy: 6 – 30%
  - Probability Band was Empty: 45 – 66%
  - Probability Band was Full: 1 – 13%
  - Mean Time Channel was Continuously Occupied: 0.6 – 1.4 hrs
  - Means Time Channel was Continuously Vacant: 2.6 – 7.7 hrs
- Suggestions for Future Work
  - Measure Other Sites – E.g., Sites with Lower Usage
  - Integrate Front-End into Antenna
  - Reduce Entire System into Remote Unit for Monitoring
  - Deploy Monitoring Units and Accumulate Data in Dashboard
  - Evaluate Interference Thresholds and Propagation Effects
  - Integrate Spectrum Sharing Database into Monitoring System

References

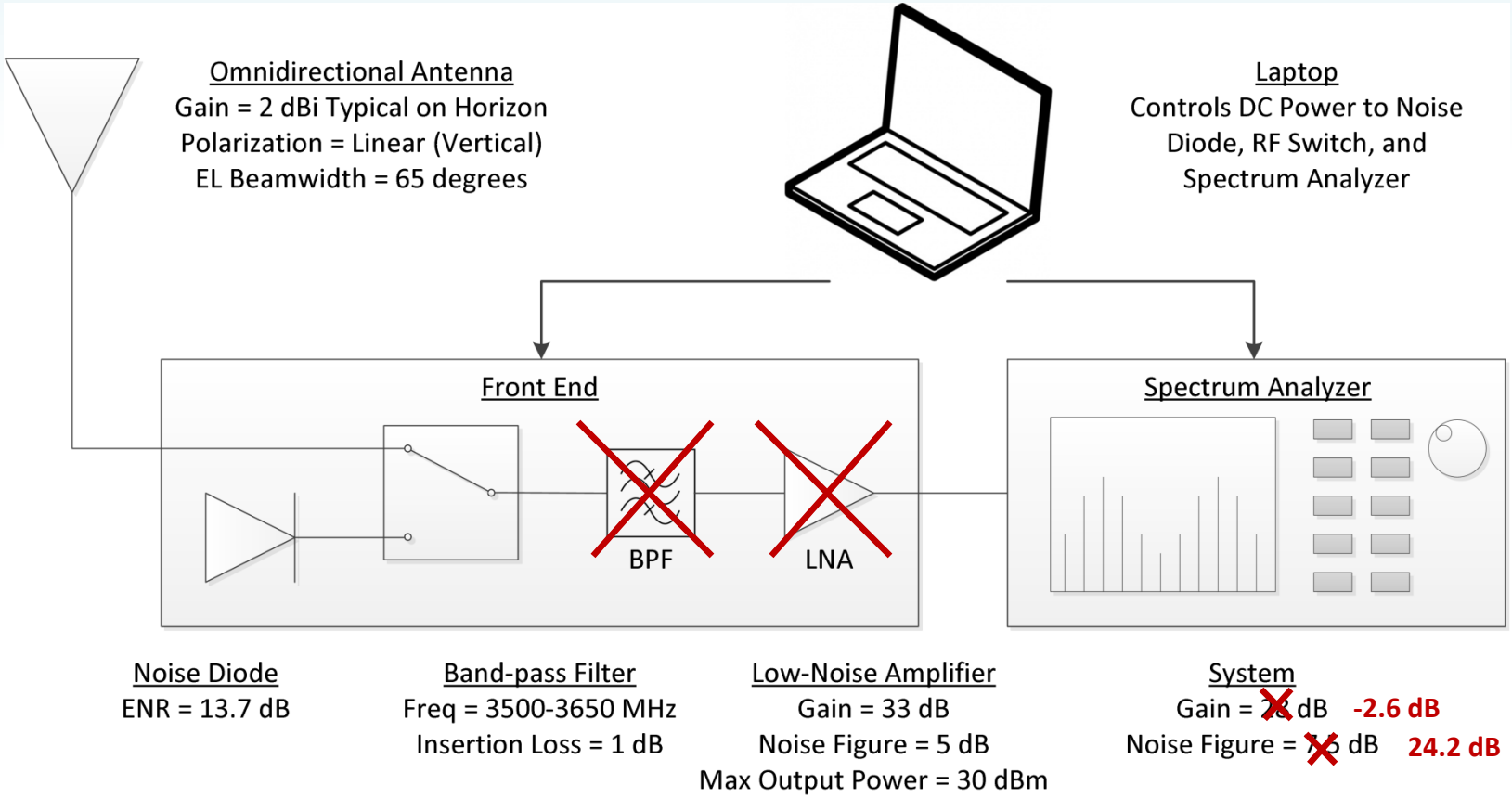
1. M.G. Cotton, et al, "ISART 2011 Proceedings – Developing Forward Thinking Rules and Processes to Fully Exploit Spectrum Resources: An Evaluation of Radar Spectrum Use and Management," *NTIA SP-12-485*, Boulder, CO, Jul. 27-30, 2011.
2. Military Standardization Handbook, *MIL-HDBK-162B*, Dec. 1973.
3. Agilent, "Spectrum and Signal Analyzer Measurements and Noise," Agilent Application Note,
4. A.D. Spaulding and H. Hagn, "On the Definition and Estimation of Spectrum Occupancy," *IEEE Transactions on EMC*, Vol. EMC-19, No. 3, Aug. 1977.

System Development

- Code Development and Dry-Run: 2700-2900 MHz Airport Surveillance Radar (ASR) Band around Boulder, CO
- Preliminary Data from RSMS SD Measurements
- First Days at Point Loma, CA Site

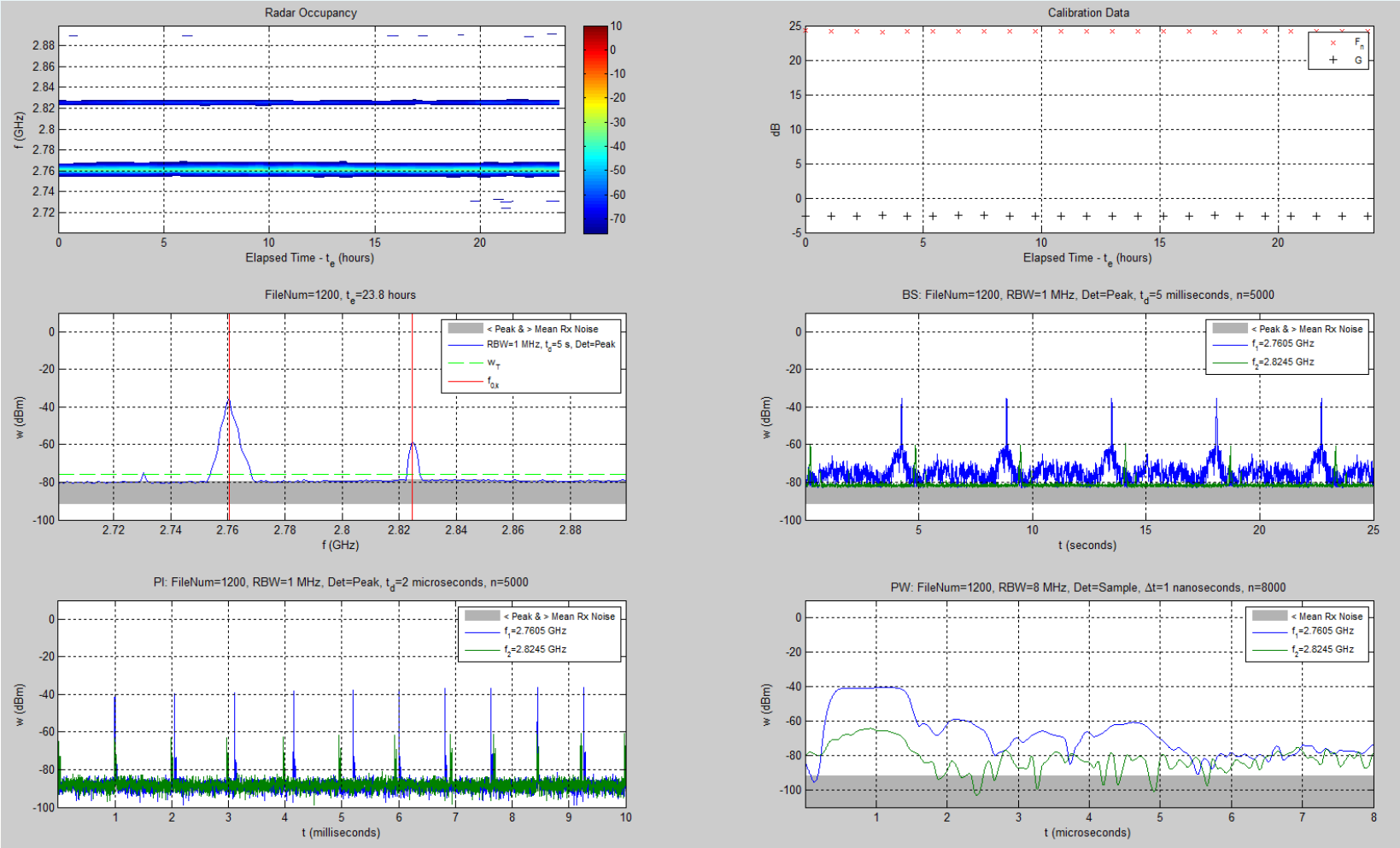
Code Development

2700-2900 MHz ASRs around Boulder, CO

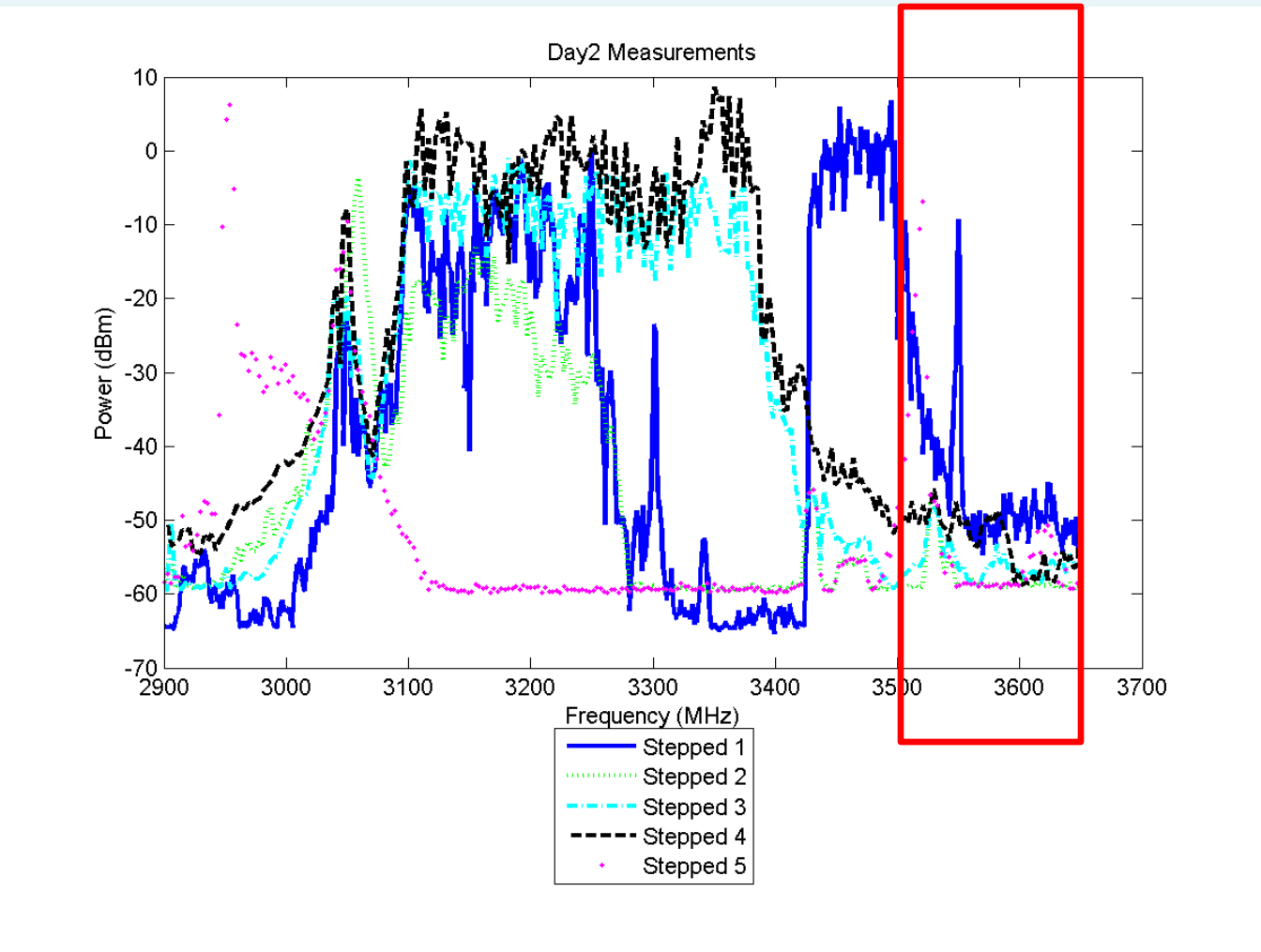


Dry Run

2700-2900 MHz ASRs around Boulder, CO



Preliminary SD Data from RSMS



First Days at Point Loma Site

- What is the cause of the strong measured signals saturating the entire band?
  - Spectrum analyzer overload?
  - Amplifier compression?
  - Actual signal?
- Evaluation
  - Checked individual components
  - Added attenuation to check linearity
  - Changed code to track spectrum analyzer overload
  - Swapped in high-power amplifier to ensure analyzer overloads first
  - Measured signals with only spectrum analyzer