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

Michael Cotton
mcotton@its.blrdoc.gov, 303-497-7346
U.S. Department of Commerce
National Telecommunications and Information Administration
Institute for Telecommunication Sciences • Boulder, CO
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

Air Marshalling Radar:
- SPN-43
- Military

Maritime Navigation and Surface Search Radar

Stage IV Local Frequency Assignment

(MHz)
SPN-43 Air Marshaling Radar

- 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: $\tau = 0.9 \pm 0.15 \mu\text{sec}$
  - Pulse interval:
    - PRF = 1125 $(\pm 25)$ pps $\rightarrow$ PRI = 889 $(\pm 20)$ $\mu\text{sec}$
  - Antenna rotation rate:
    - $\frac{\partial \theta}{\partial t} = 15$ rpm $\rightarrow$ $T_{\text{Ant}} = 4$ sec

(Courtesy: Defense Video and Imagery)
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

Omnidirectional Antenna
- Gain = 2 dBi Typical on Horizon
- Polarization = Linear (Vertical)
- EL Beamwidth = 65 degrees

Laptop
- Controls DC Power to Noise Diode, RF Switch, and Spectrum Analyzer

Front End
- Noise Diode
  - ENR = 13.7 dB
- Band-pass Filter
  - Freq = 3500-3650 MHz
  - Insertion Loss = 1 dB
- Low-Noise Amplifier
  - Gain = 33 dB
  - Noise Figure = 5 dB
  - Max Output Power = 30 dBm

Spectrum Analyzer
- System
  - Gain = 28 dB
  - Noise Figure = 7.5 dB
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 $\tau$
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
  - $X(t) = 1$ if signal at $t$ is above $L_k$ and 0 otherwise
  - $U =$ Length of time a signal continuously exists above $L_k$
  - $V =$ Length of time between transmissions

- **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

- $\beta =$ Mean channel occupancy
  \[
  \beta = \frac{E[U]}{E[U] + E[V]}, \text{ where } E[\cdot] \text{ denotes expected value}
  \]
Channel Occupancy
U and V distributions

<table>
<thead>
<tr>
<th>$L$ (dBm)</th>
<th>$\alpha$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-74</td>
<td>0.059</td>
<td>0.070</td>
</tr>
<tr>
<td>-77</td>
<td>0.105</td>
<td>0.121</td>
</tr>
<tr>
<td>-80</td>
<td>0.163</td>
<td>0.186</td>
</tr>
<tr>
<td>-83</td>
<td>0.231</td>
<td>0.267</td>
</tr>
<tr>
<td>-86</td>
<td>0.293</td>
<td>0.343</td>
</tr>
</tbody>
</table>
Band Occupancy

● Setup
  ▪ $L_k =$ Threshold level
  ▪ $\Delta f =$ channel bandwidth
  ▪ $Y(f) = 1$ if signal at $f$ is above $L_k$ and 0 otherwise
  ▪ $n =$ Number of channels occupied

● Measurements
  ▪ $y_1, y_2, ..., y_N$ are represented by a sequence of 0’s and 1’s
  ▪ $N =$ Number of measurements
  ▪ $N\Delta f =$ Frequency span of measurement

● $\alpha =$ Mean Band Occupancy $= \frac{E[n]}{N}$, where $E[\cdot]$ denotes expected value
Band Occupancy Vs Threshold

Band Occupancy: 3550 =f= 3650 MHz, L= 74 dBm @ Isotropic Receive Antenna Port, α= 0.059
Band Occupancy Probability Statistics

<table>
<thead>
<tr>
<th>$L$ (dBm)</th>
<th>$\alpha$</th>
<th>$P(n/N=0)$</th>
<th>$P(n/N=1)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-74</td>
<td>0.059</td>
<td>0.66</td>
<td>0.01</td>
</tr>
<tr>
<td>-77</td>
<td>0.105</td>
<td>0.60</td>
<td>0.01</td>
</tr>
<tr>
<td>-80</td>
<td>0.163</td>
<td>0.55</td>
<td>0.03</td>
</tr>
<tr>
<td>-83</td>
<td>0.231</td>
<td>0.49</td>
<td>0.07</td>
</tr>
<tr>
<td>-86</td>
<td>0.293</td>
<td>0.45</td>
<td>0.13</td>
</tr>
</tbody>
</table>
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


3. Agilent, “Spectrum and Signal Analyzer Measurements and Noise,” Agilent Application Note,

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

Omnidirectional Antenna
Gain = 2 dBi Typical on Horizon
Polarization = Linear (Vertical)
EL Beamwidth = 65 degrees

Laptop
Controls DC Power to Noise Diode, RF Switch, and Spectrum Analyzer

Front End

Band-pass Filter
Freq = 3500-3650 MHz
Insertion Loss = 1 dB

Low-Noise Amplifier
Gain = 33 dB
Noise Figure = 5 dB
Max Output Power = 30 dBm

System
Gain = 33 dB
Noise Figure = 5 dB

Noise Diode
ENR = 13.7 dB

-2.6 dB
24.2 dB
Dry Run
2700-2900 MHz ASRs around Boulder, CO
Preliminary SD Data from RSMS

Day 2 Measurements

Frequency (MHz)
- Stepped 1
- Stepped 2
- Stepped 3
- Stepped 4
- Stepped 5

Power (dBm)
- 10
- 0
- -10
- -20
- -30
- -40
- -50
- -60
- -70

2900 3000 3100 3200 3300 3400 3500 3600 3700
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