NTIA 3.5 GHz Band Sharing Studies: Review to Date

For the 2015 ISART Spectrum Sharing Workshop

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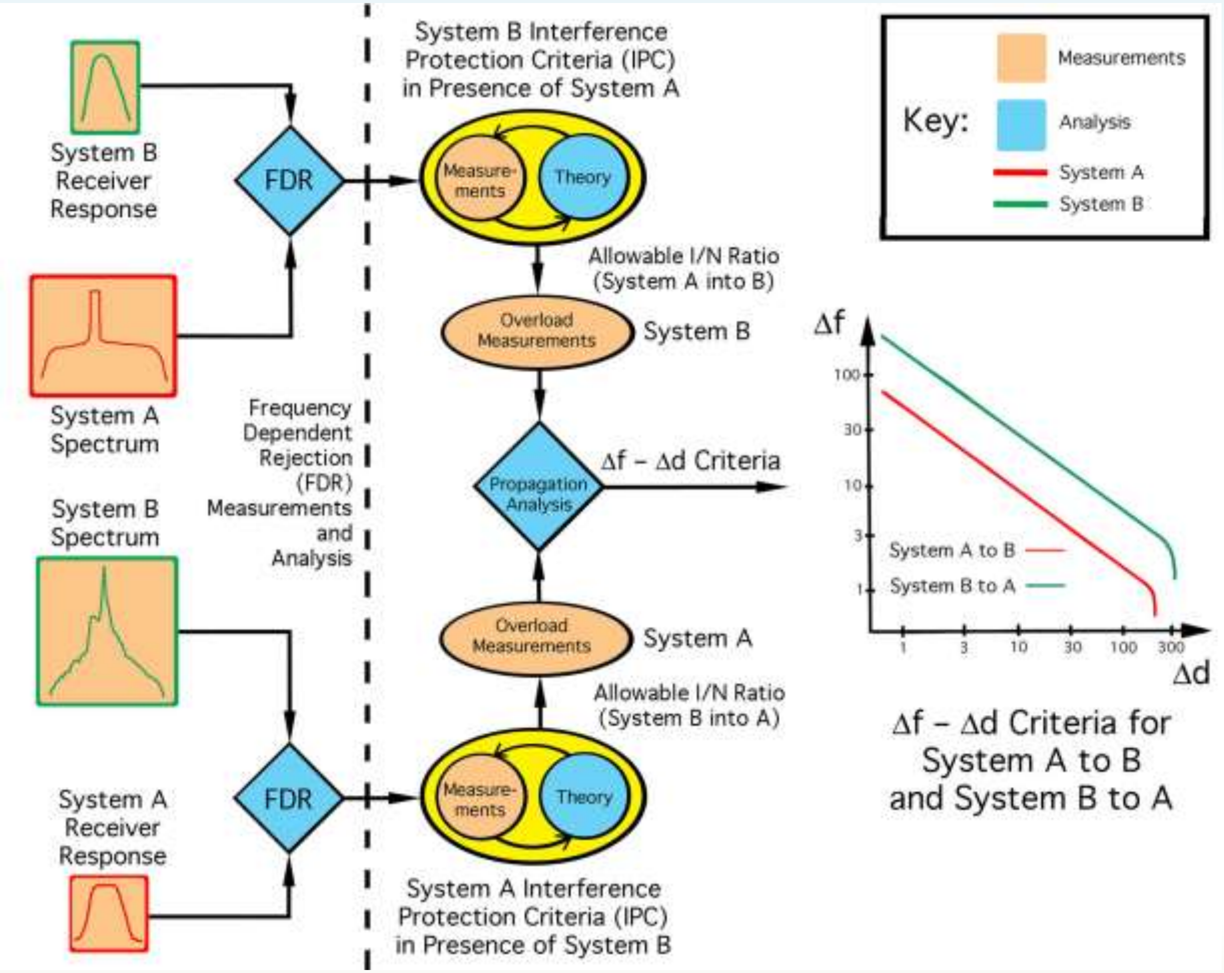
Spectrum Sharing Studies: Overall General Approach

- This is the process flow for spectrum sharing studies Best Practices
- ITS performs all of these elements for sharing studies
- IPC are critical part of spectrum-sharing EMC analyses



IPC Measurement & Simulation

- IPC used by regulatory bodies to set interference power limits for spectrum sharing
- IPC are often evaluated through field measurements
- However, field measurements are:
  - Difficult to execute because of system location / availability
  - Prone to error because of lack of access to performance metrics / subsystems
  - Can only be performed on existing systems
- Simulation addresses shortfalls of field measurement
- Measurements & simulations *complement* each other

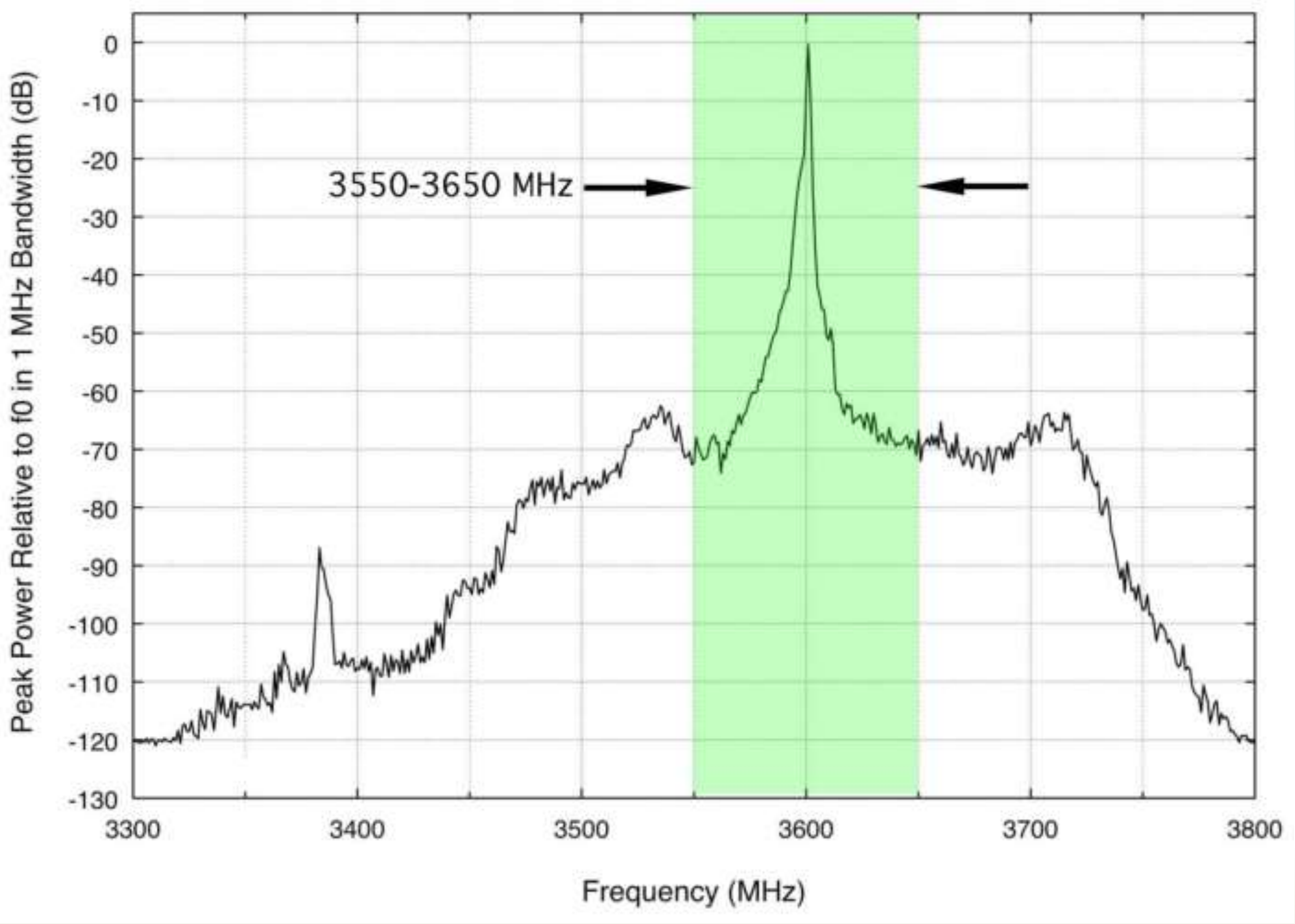
3550-3650 MHz (Radar-LTE) Band Sharing

- Most significant incumbents are Navy air traffic control radars
- Operate in littoral waters adjacent to 55% of US population
- Must be protected from new entrants (e.g., LTE systems) in 3550-3650 MHz band

- New entrants will be broadband terrestrial communication systems (e.g., LTE systems)
- Biggest markets in U.S. coastal areas
- Must be protected from radar interference
- ***QUESTION: What's the longest technical pole in this spectrum-sharing tent??***

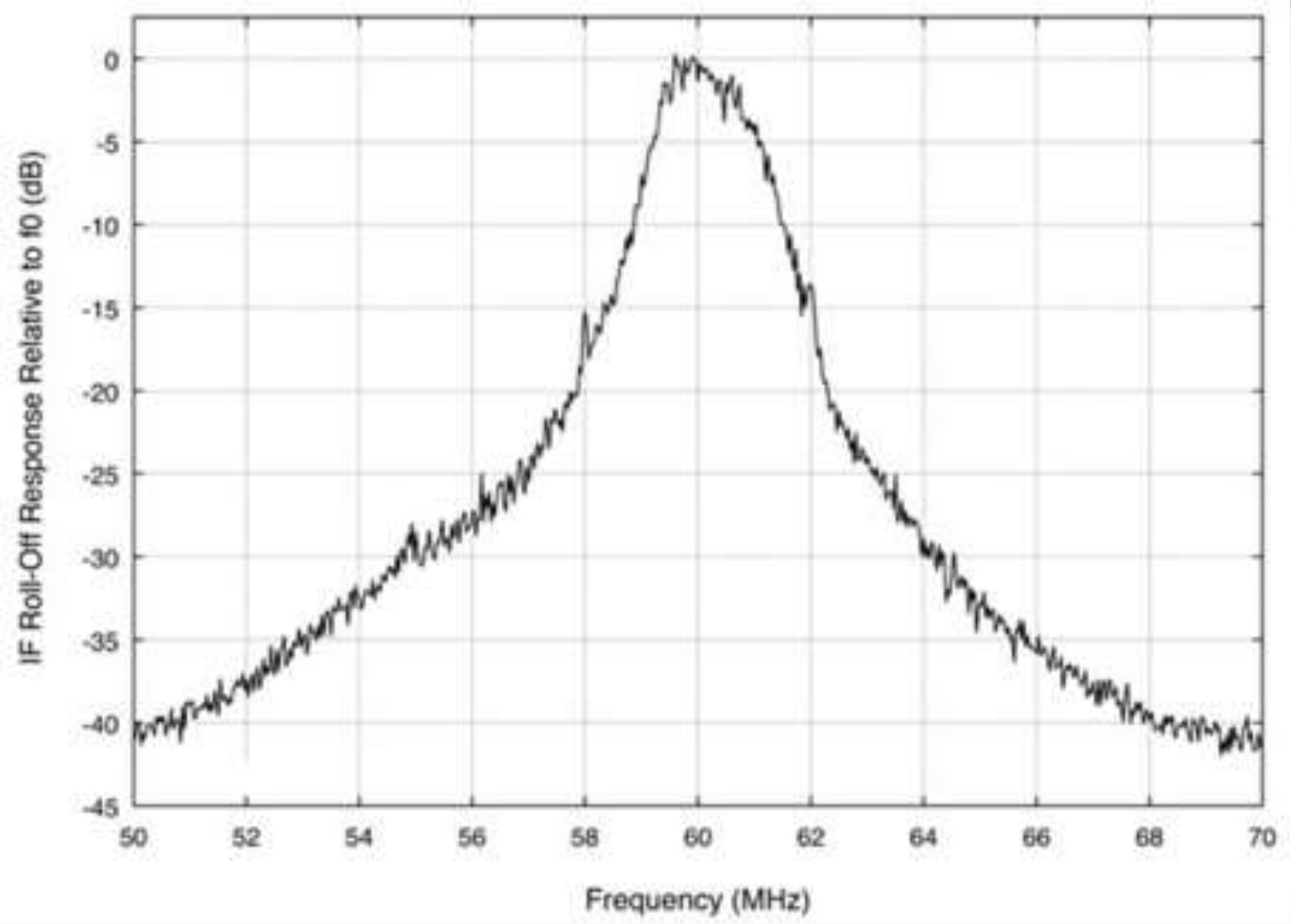
Fast Track Report Radar 1 Emission Spectrum

- Emission spectrum needs to be measured to -100 dBc or better
- Theoretical predictions only good to about -40 dBc
- Measurement Best Practices defined in NTIA TR-05-420



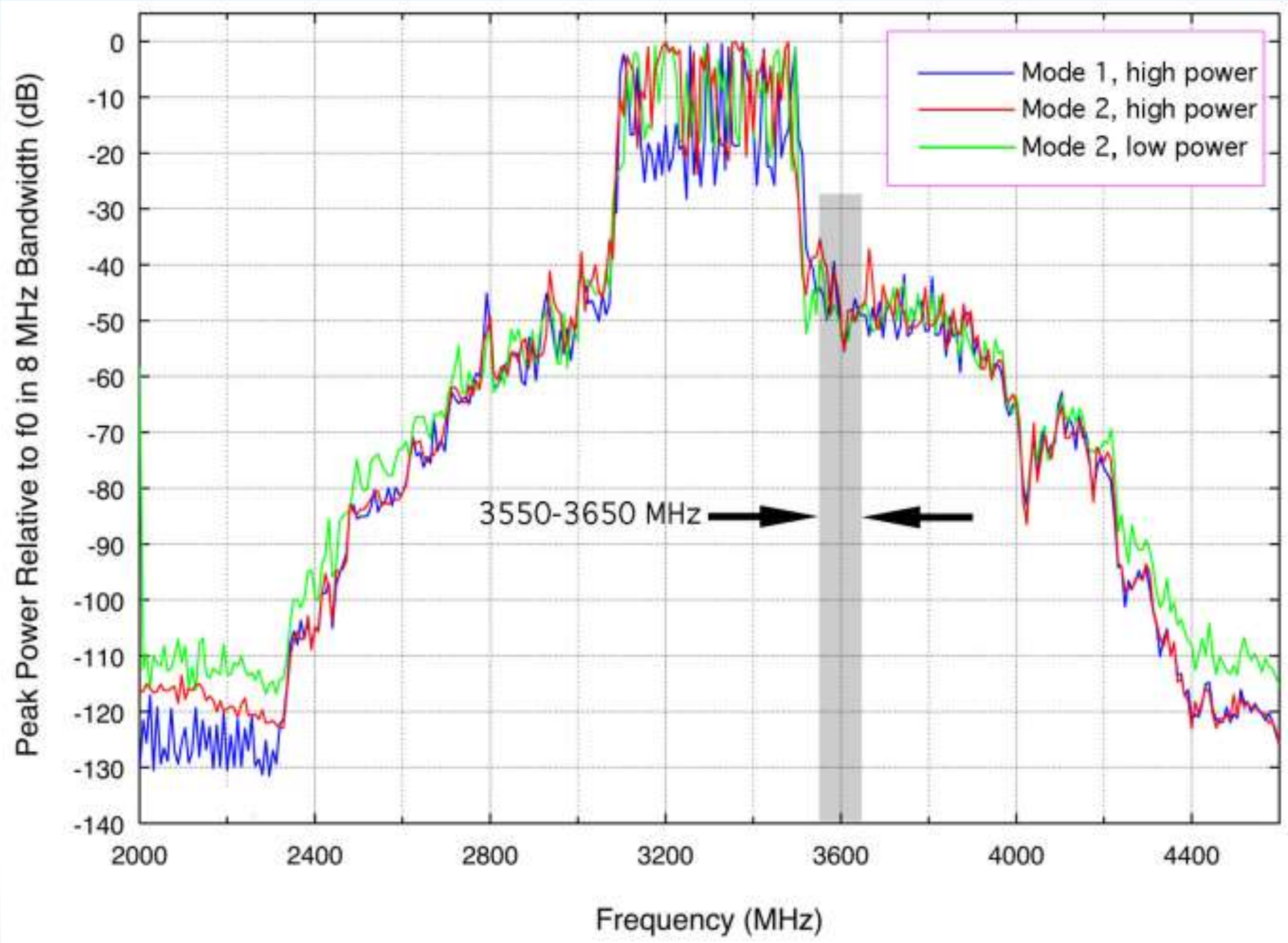
Fast Track Radar 1 IF Response Curve

- Receiver IF response curve, measured
- Needed for FDR analyses (see EMC studies Best Practices flow diagram)
- Measured with procedure described in NTIA TR-05-420



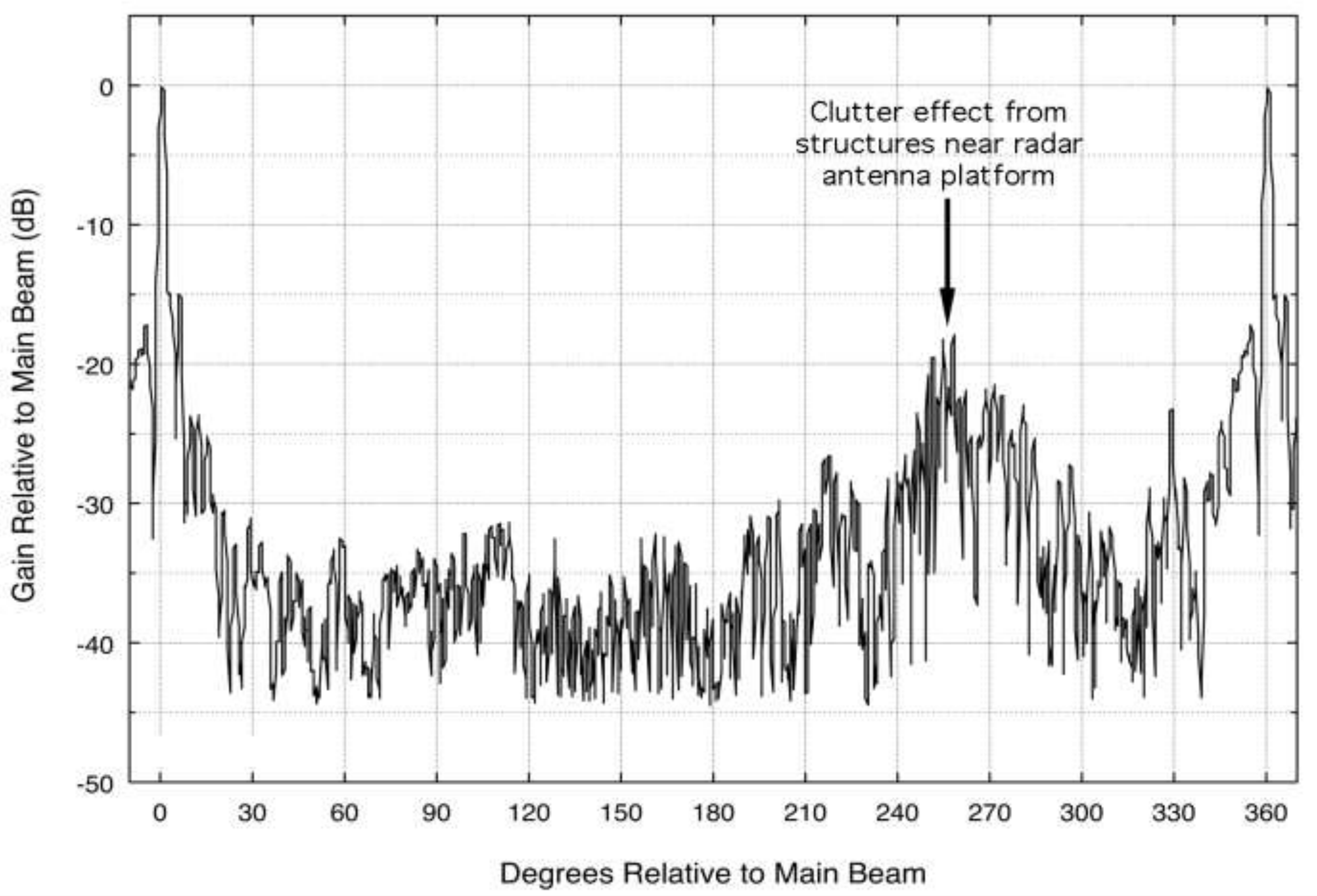
Fast Track Report Radar 3 Spectrum

- This radar operates just below the proposed band-sharing lower edge



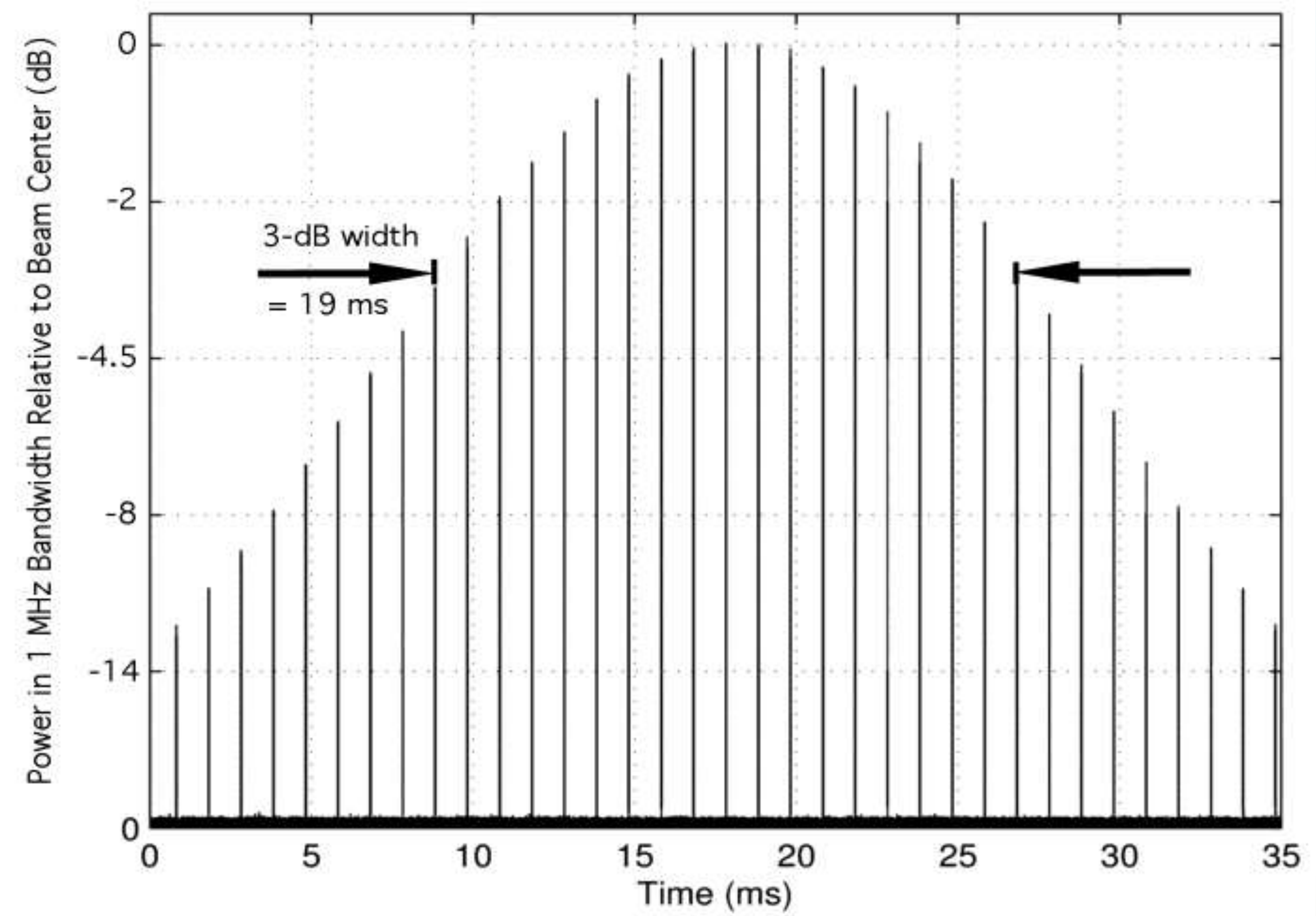
Radar 1 Antenna Pattern

- This radar antenna scans 360 degrees every 4 seconds



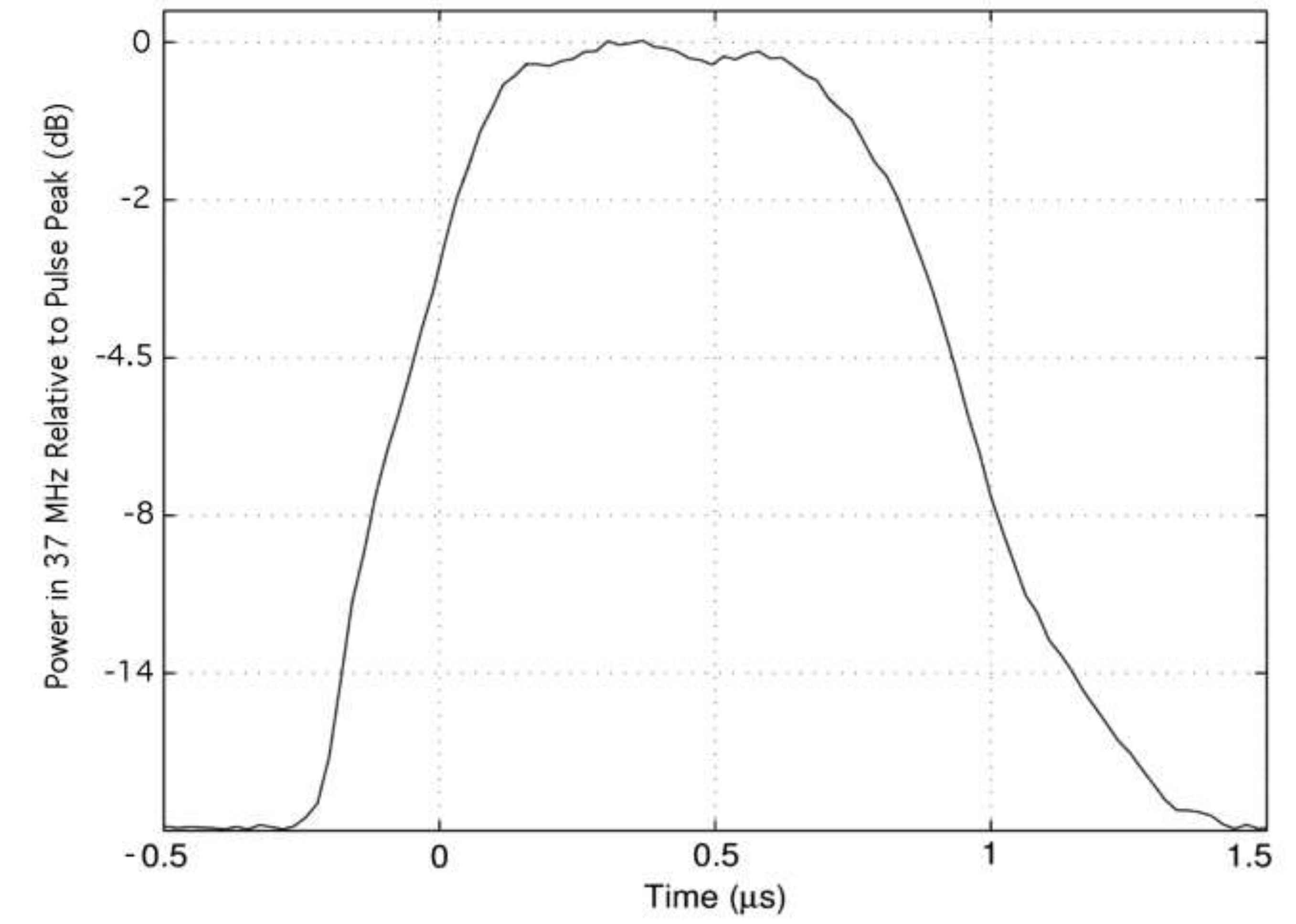
Radar 1 Pulse Sequence

- About 19-20 pulses occur in main beam once every 4 seconds



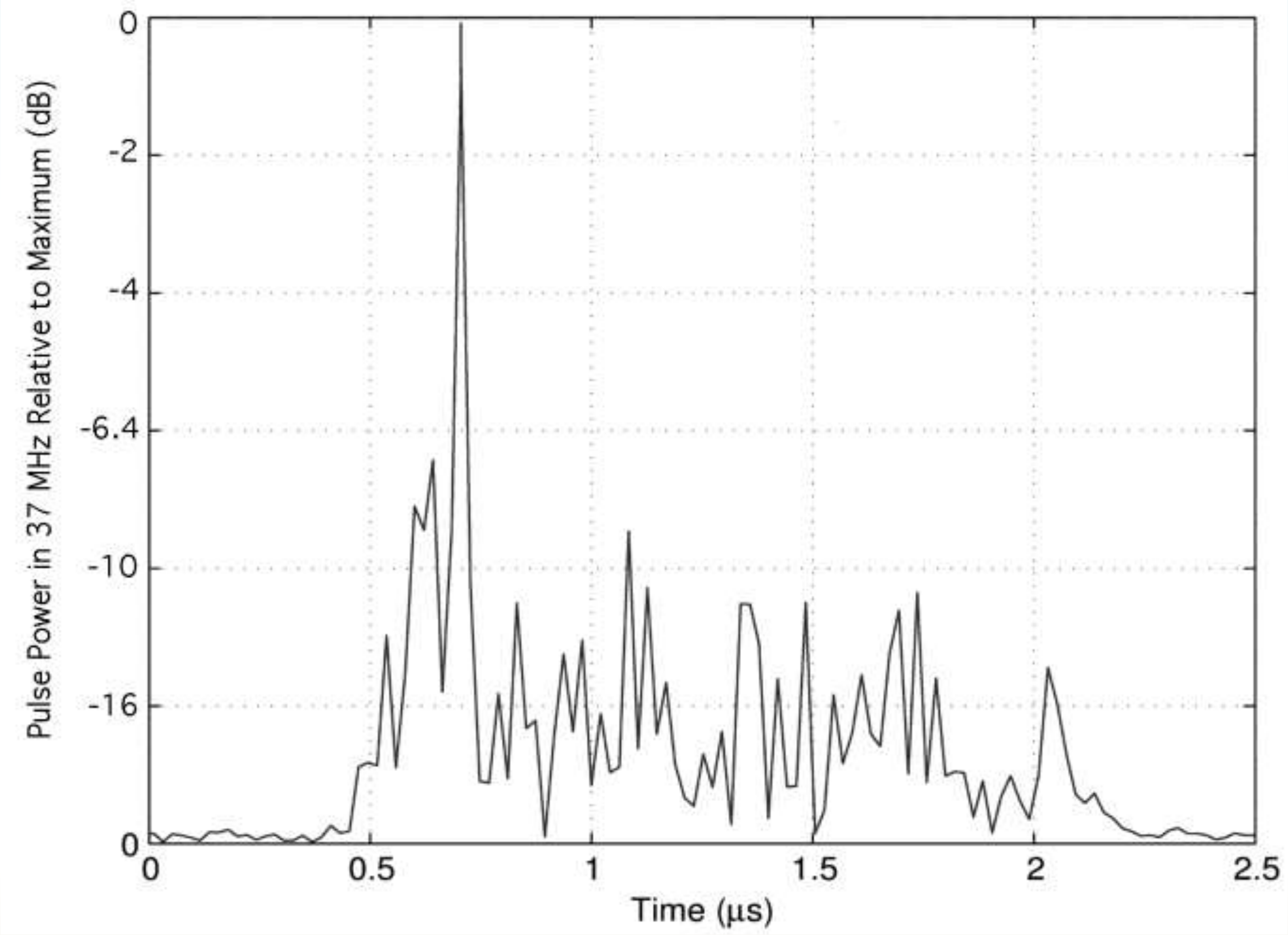
Radar 1 Pulse Envelope: On-Tuned

- Envelope of an on-tuned radar pulse at 3600 MHz



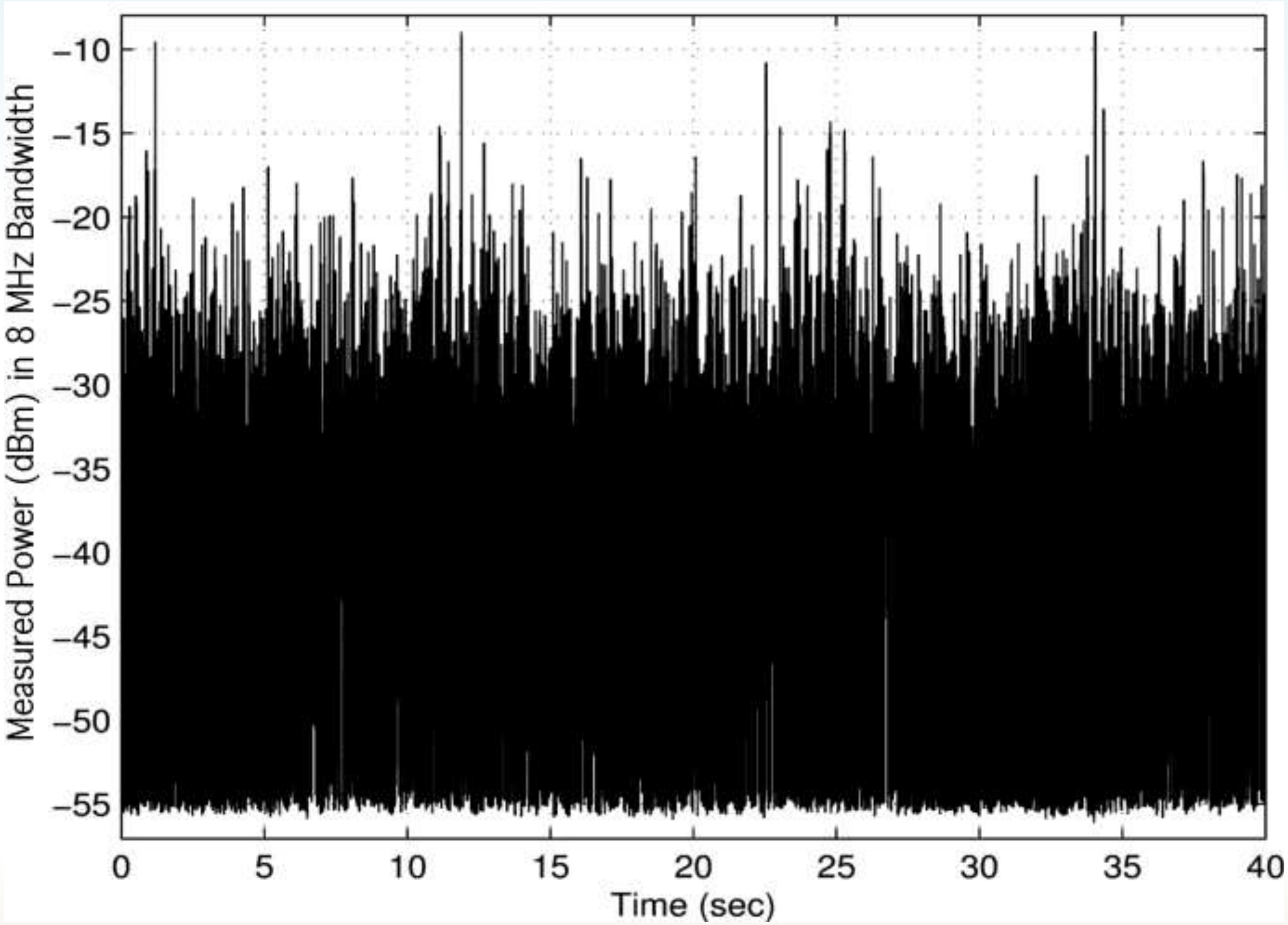
Radar 1 Pulse Envelope: Off-Tuned

- Envelope of an off-tuned radar pulse at 3600 MHz.
- Classic example of the rabbit ears effect (see NTIA Technical Report on this topic)
- This phenomenon could complicate dynamic band-sensing schemes



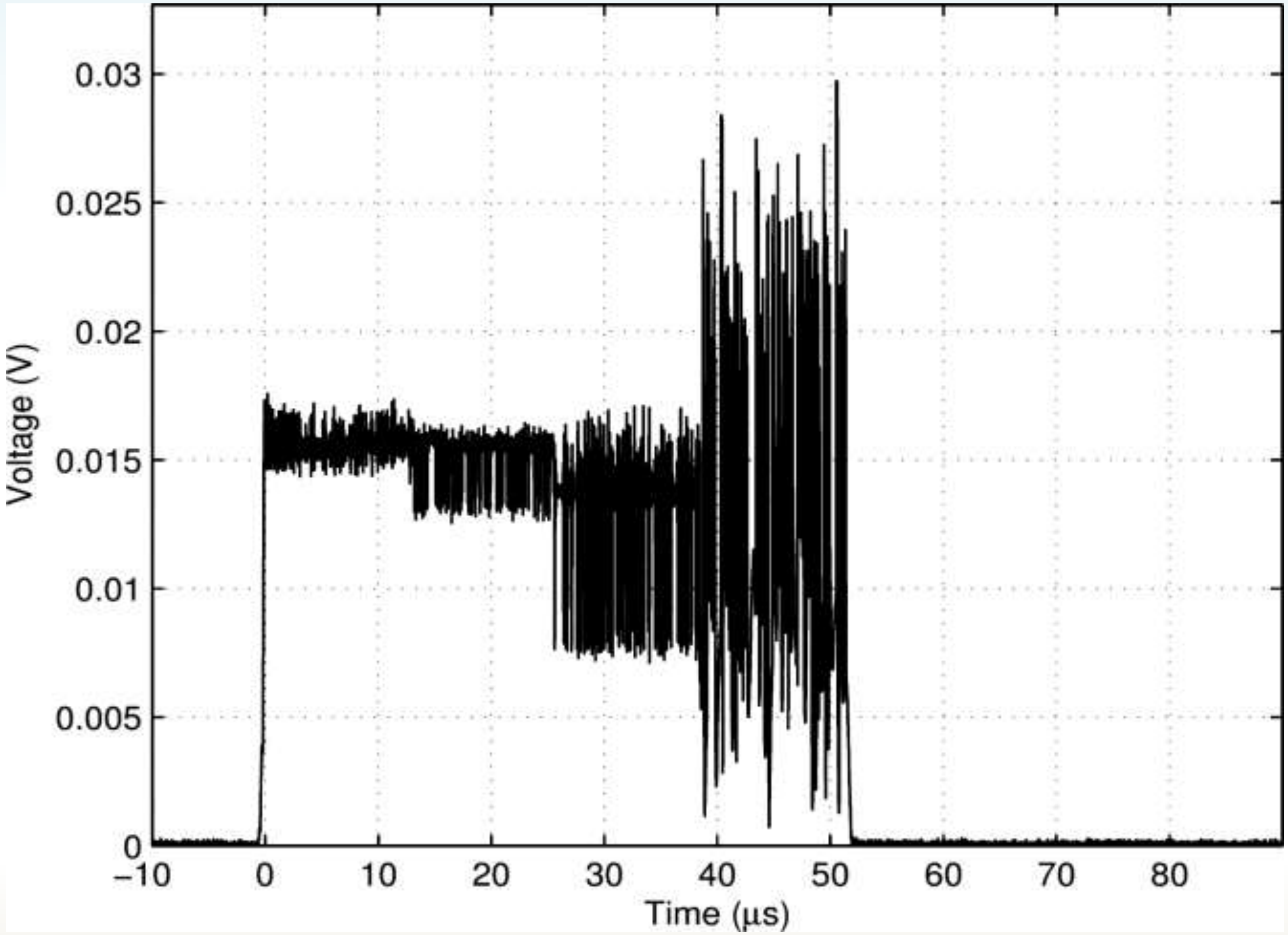
Example Radar 3 Pulse Sequence

- 40 seconds' worth of pulses from Radar 3.



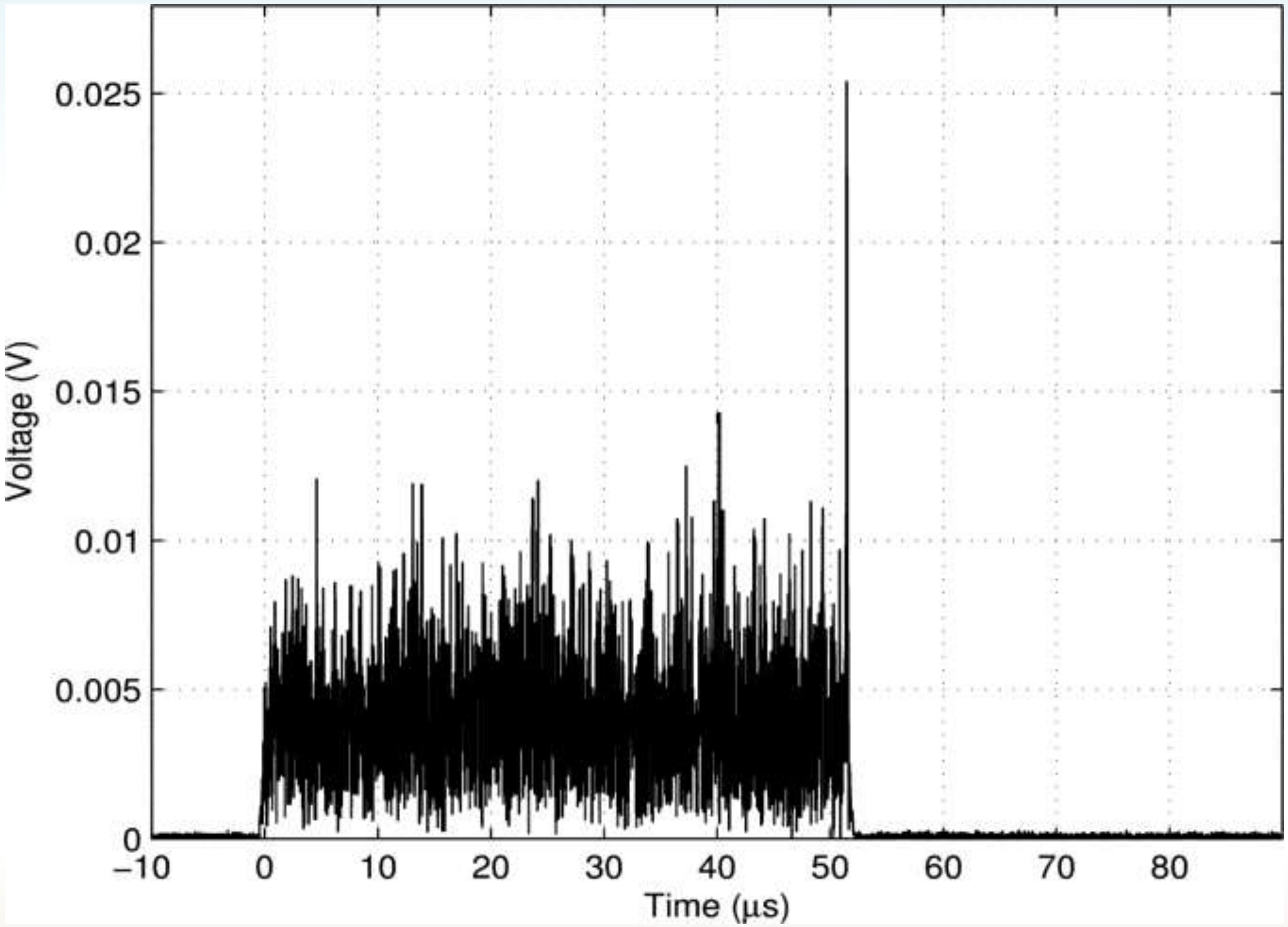
Example Radar 3 Single Pulse: Partly On-Tuned

- Single Radar 3 pulse
- Starts on-tuned and then moves off-tuned relative to the detection system's frequency
- An interesting example of the rabbit ears effect



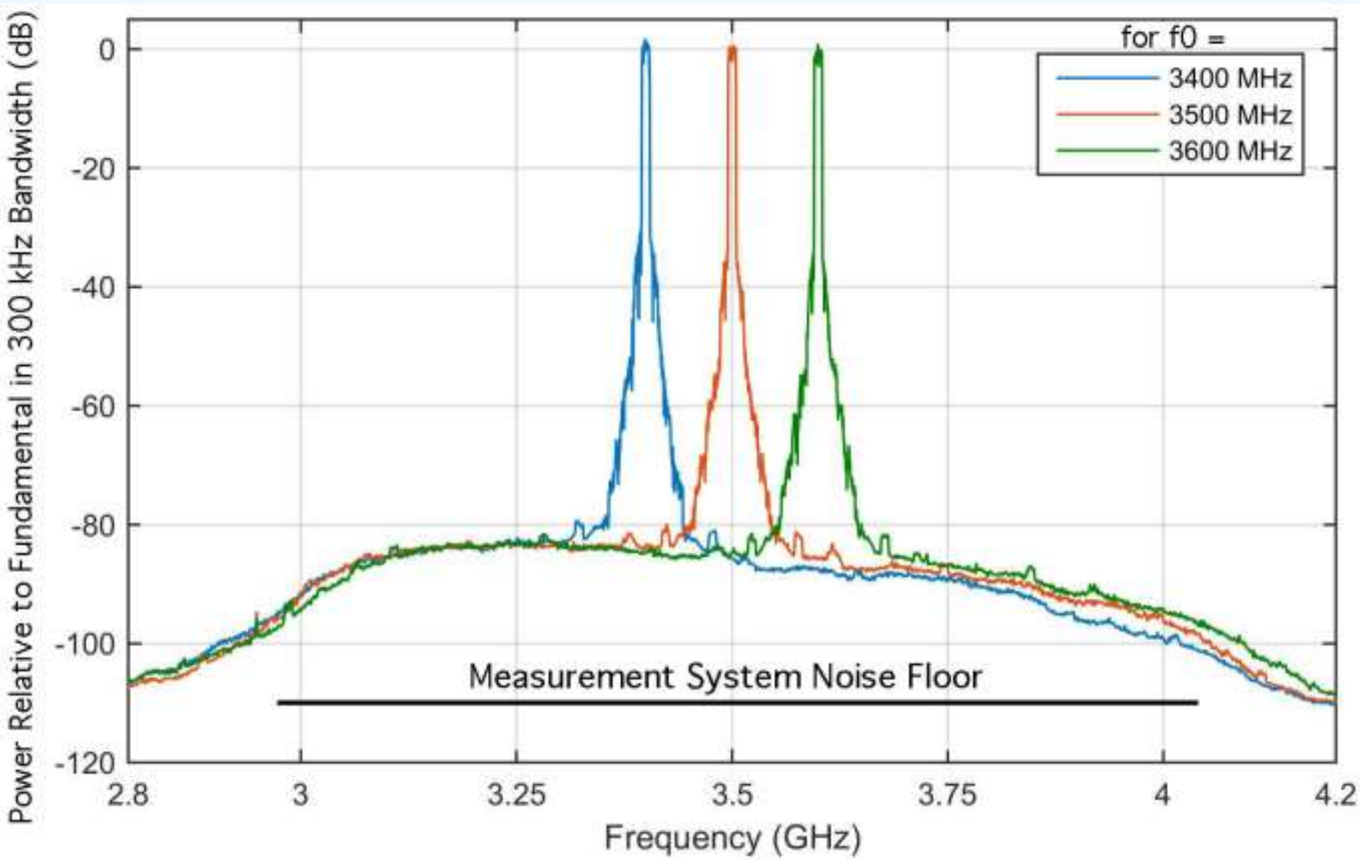
Example Radar 3 Single Pulse: Completely Off-Tuned

- Single Radar 3 pulse completely off-tuned from the detection system
- Another interesting example of the rabbit ears effect



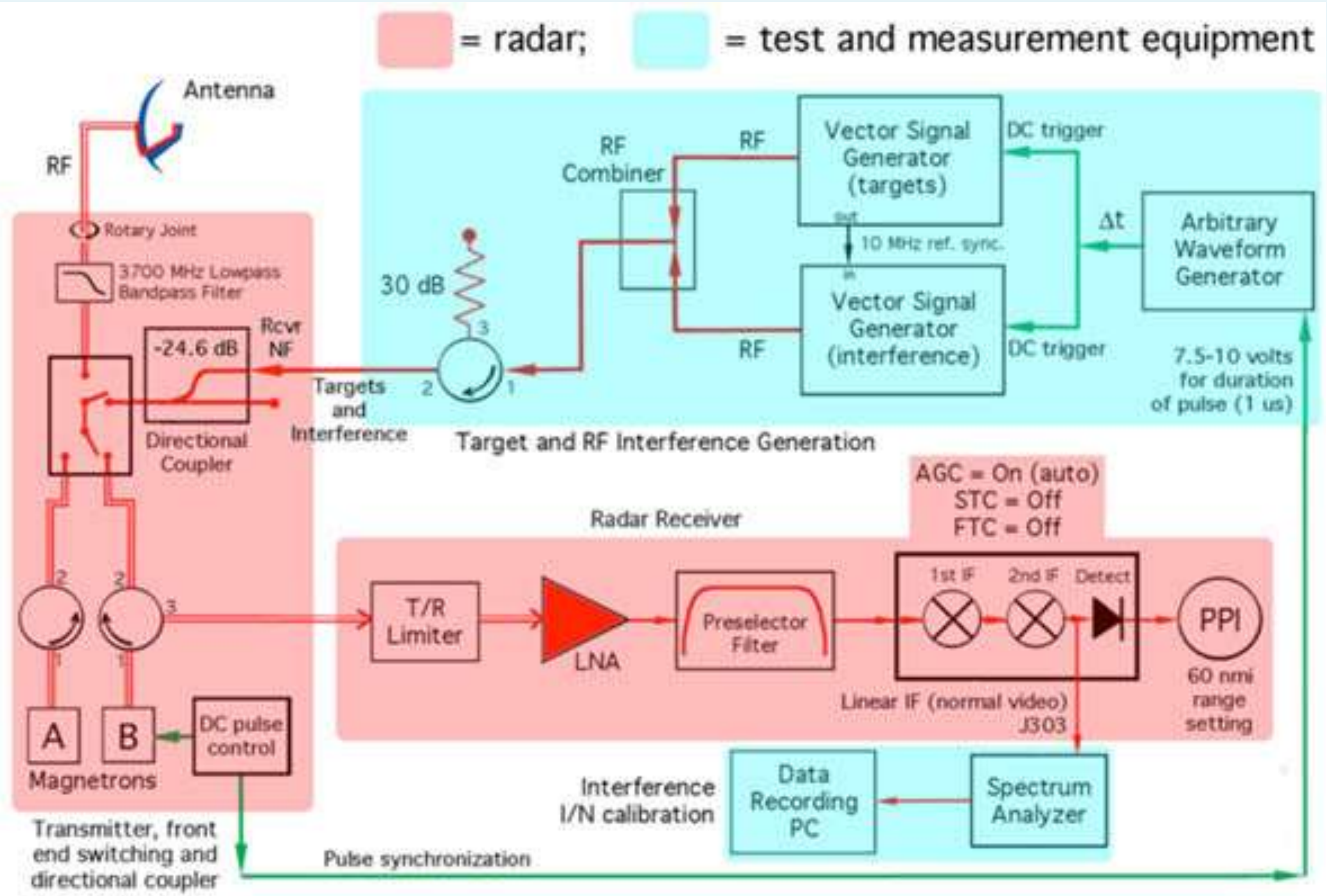
Example LTE Emission Spectrum

- This is one of many LTE transmitters measured by ITS
- Emission spectrum needs to be measured to -100 dBc or better
- Theoretical predictions only good to about -40 dBc
- Measurement Best Practices based on NTIA TR-05-420

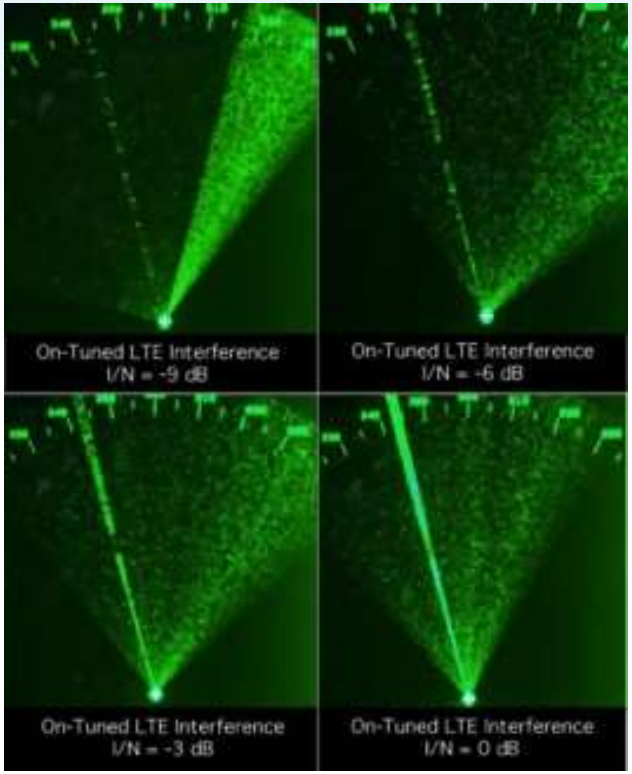


Interference Injection into Navy Radars

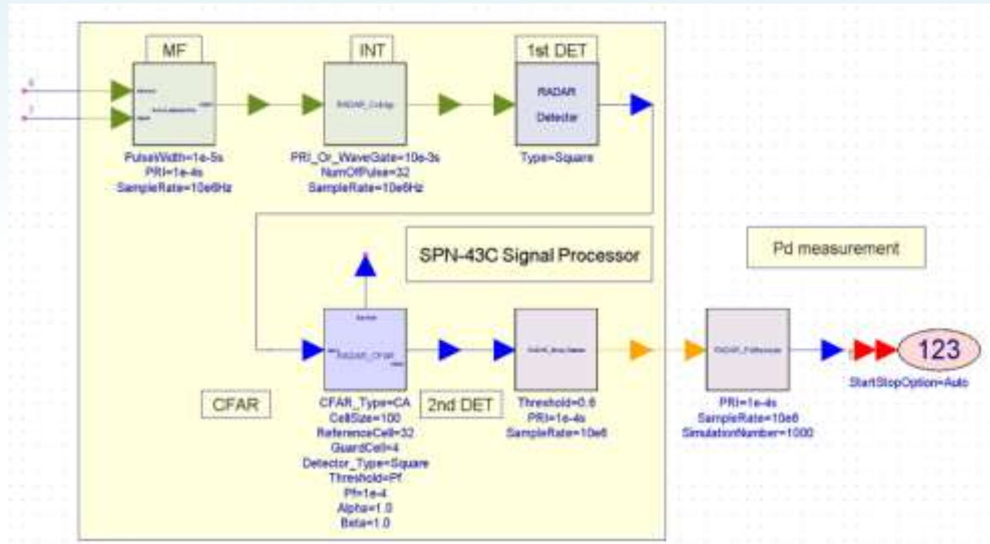
- ITS capability for injecting interference into receivers, including radar receivers, is state-of-the-art
- For radars, target generation and interference generation and injection are individually tailored to each type of radar



LTE Interference into Navy Radars, Measured and Simulated Results



- LTE , GN & CW interference injected into Navy radar receiver along with controlled, desired targets
- IPC threshold measured at I/N = -6 dB



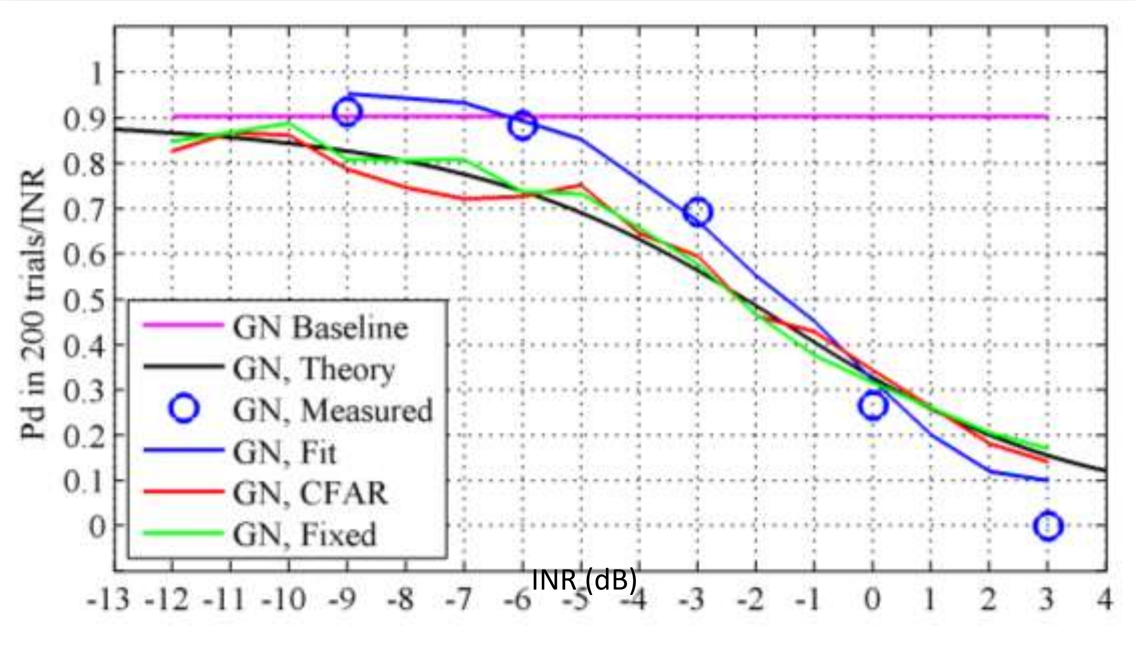
Navy radar signal processing simulation block diagram with:

- Matched filter, Integrator, 1-st detector
- CFAR, 2-nd detector

The last two blocks compute and save probability of detection.

LTE Interference into Navy Radars, Measured and Simulated

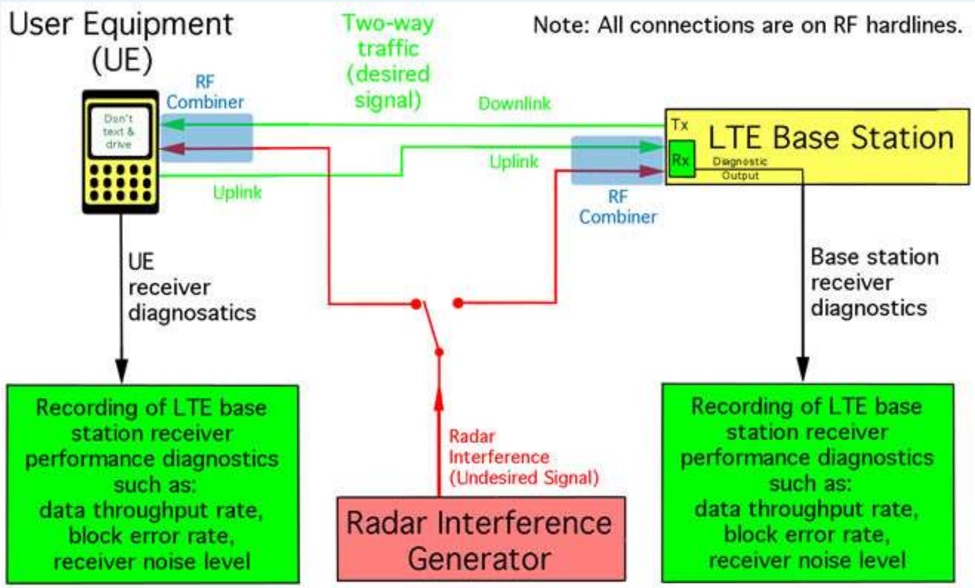
Measured/Simulated/ Theoretical comparison for GN interferer

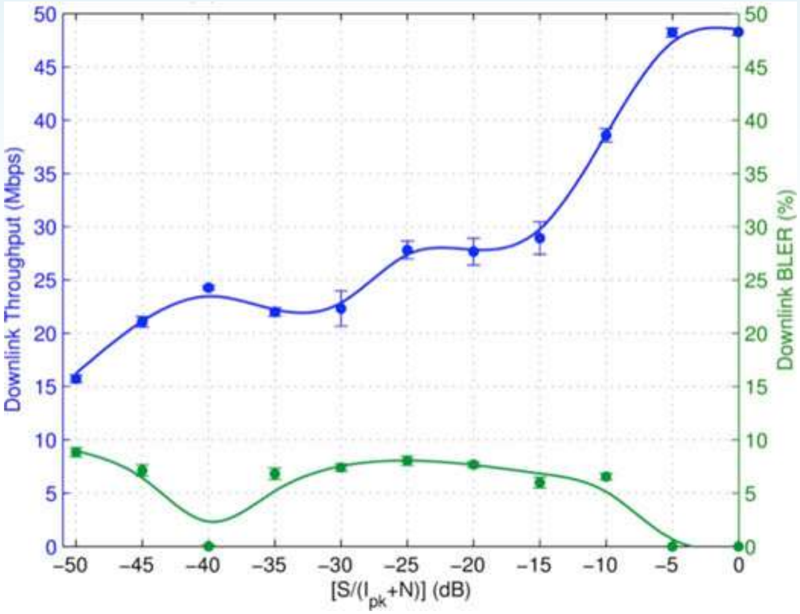


Measured: Blue
Simulated: Red and Green
Theoretical: Black

Simulated closer to Theoretical than Measured

Radar Interference into LTE Receivers, Measured and Simulated Results





- 26 types of radar pulsed interference injected into LTE(TDD) and LTE(FDD) uplinks and downlinks at multiple private-sector lab facilities
- LTE performance in the presence of radar interference found to be highly variable, ranging from highly robust to somewhat vulnerable, depending on interfering radar modulations and power levels
- Measured results checked against theory, and some simulation work undertaken

3550-3650 MHz Sharing: Conclusions

- Propagation studies at 3.5 GHz (needed to complete the spectrum EMC Best Practices flow process in the first slide and determine delta-f/delta-d curves) are still ongoing between government and private sector.
- -6 dB *I/N* IPC for Navy radar receivers is likely to be determining factor for overall spectrum sharing in 3.5 GHz band.
- I.e., radar receivers are likely going to be the long pole in the spectrum sharing tent at 3.5 GHz.
- ITS/OSM has published, and will publish, all work done in this area, for full access by other agencies and the private sector, and transparency in the technical measurements-and-simulation process

3550-3650 MHz Sharing: Publications

- Sanders, F. H., R. L. Sole, B. L. Bedford, D. Franc and T. Pawlowitz, "Effects of RF Interference on Radar Receivers", NTIA Technical Report TR-06-444, U.S. Dept. of Commerce, Feb. 2006. http://www.its.bldrdoc.gov/publications/2481.aspx

- Sanders, G. A., J. E. Carroll, F. H. Sanders, R. L. Sole and R. J. Achatz, "Emission Spectrum Measurements of a 3.5 GHz LTE Hotspot," NTIA Technical Report TR-15-512, U.S. Dept. of Commerce, Feb. 2015. http://www.its.bldrdoc.gov/publications/2790.aspx

- Sanders, F. H., J. E. Carroll, G. A. Sanders and L. S. Cohen, "Measurements of Selected Naval Radar Emissions for Electromagnetic Compatibility Analyses," NTIA Technical Report TR-15-510, U.S. Dept. of Commerce, Oct. 2014. http://www.its.bldrdoc.gov/publications/2781.aspx

- Sanders, F. H., J. E. Carroll, G. A. Sanders, R. L. Sole, R. J. Achatz and L. S. Cohen, "EMC Measurements for Spectrum Sharing Between LTE Signals and Radar Receivers", NTIA Technical Report TR-14-507, U.S. Dept. of Commerce, Jul. 2014. http://www.its.bldrdoc.gov/publications/2760.aspx

- Sanders, G. A., J. E. Carroll, F. H. Sanders and R. L. Sole, "Effects of Radar Interference on LTE (FDD) eNodeB and UE Receiver Performance in the 3.5 GHz Band", NTIA Technical Report TR-14-506, U.S. Dept. of Commerce, Jul. 2014. http://www.its.bldrdoc.gov/publications/2759.aspx

- Sanders, F. H., J. E. Carroll, G. A. Sanders and R. L. Sole, "Effects of Radar Interference on LTE Base Station Receiver Performance," NTIA Technical Report TR-14-499, U.S. Dept. of Commerce, Dec. 2013. http://www.its.bldrdoc.gov/publications/2742.aspx