

3.5 GHZ ESC SENSOR TEST APPARATUS USING FIELD-MEASURED WAVEFORMS

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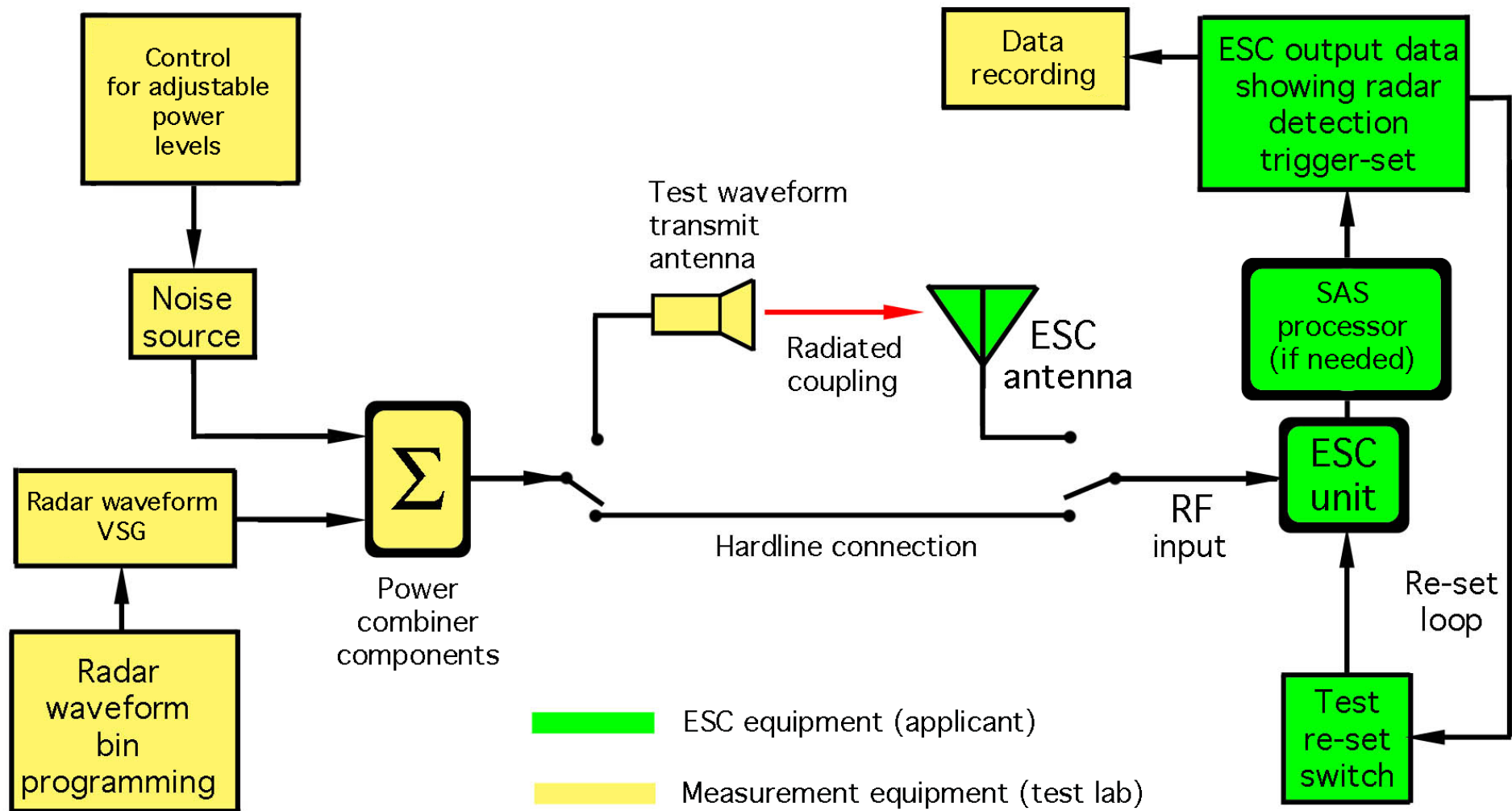
Outline

- Background
- 3.5 GHz NASCTN field-measured waveforms
- Waveform generation
- ESC test harness
- Test waveform examples
- Detection example

Evaluating the Environmental Sensing Capability

- ESC systems are required to:
 - Detect a federal incumbent signal received at -89 dBm/MHz or higher within 60 s with 99% probability
 - In the presence of interference from CBSDs and Radar 3 OOB emissions
- The material in this presentation is for research purposes and is unrelated to the ongoing certification of CBRS ESC systems.
- The technical approach presented here employing field-measured waveforms can be used to:
 - Develop detection algorithms for ESC sensors with real-world scenarios
 - Evaluate sensors designed for future bands to be shared

Laboratory Evaluation of Commercial ESC Sensors

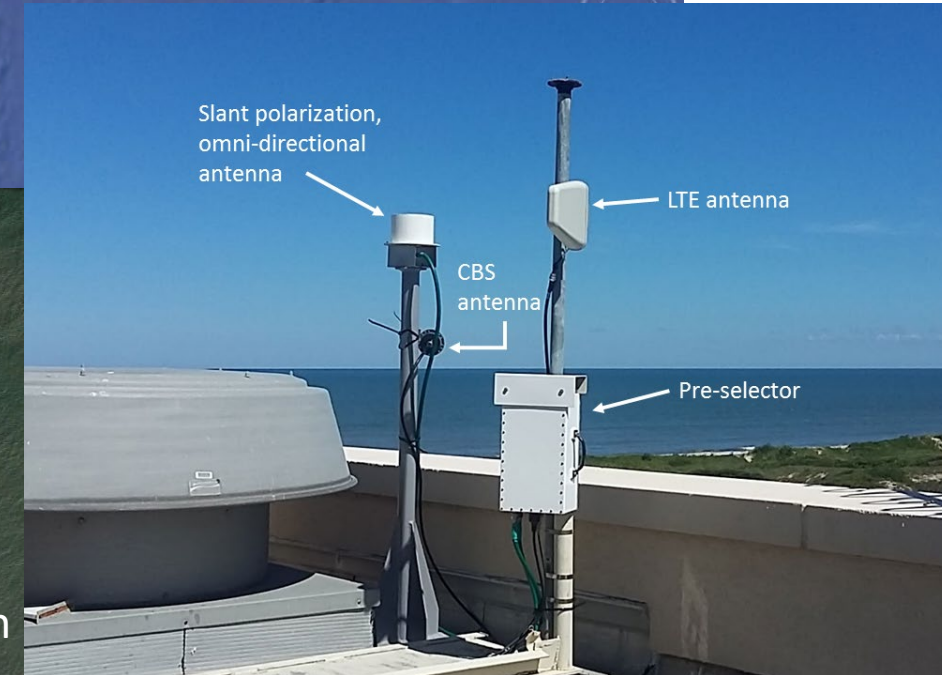


Source: NTIA Technical Memorandum 18-527, "Procedures for Laboratory Testing of Environmental Sensing Capability Sensor Devices"

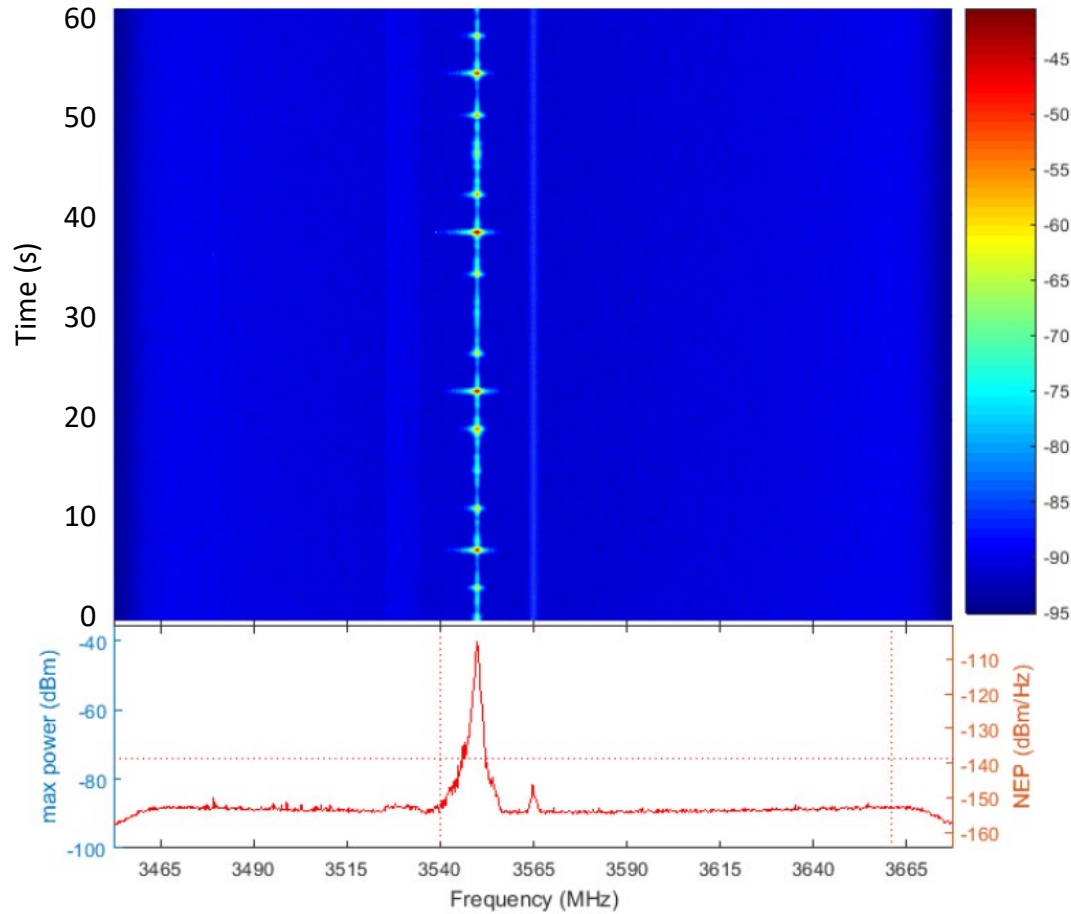
Measurement Site at Fort Story, Virginia Beach



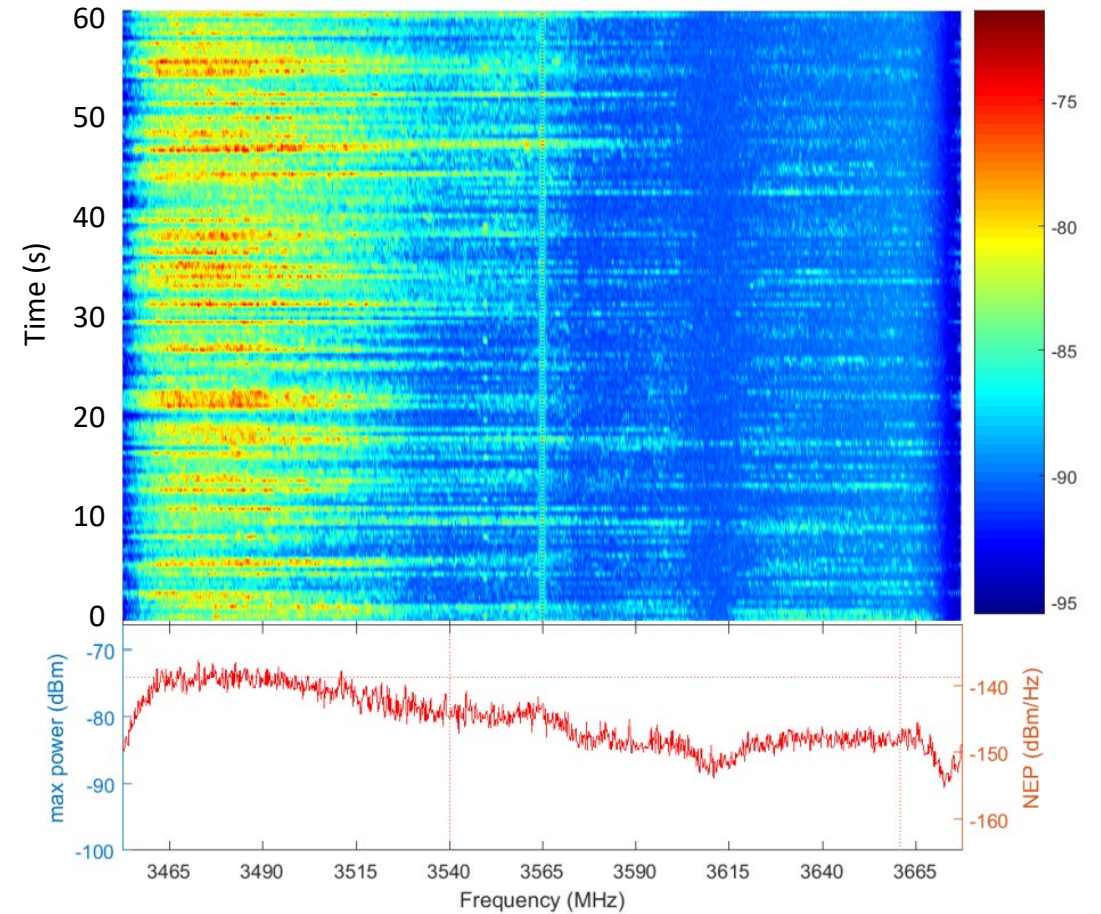
- Top of small building
- ~20 m elevation
- Trees and small buildings to the west



NASCTN 3.5 GHz Radar Waveform Measurements



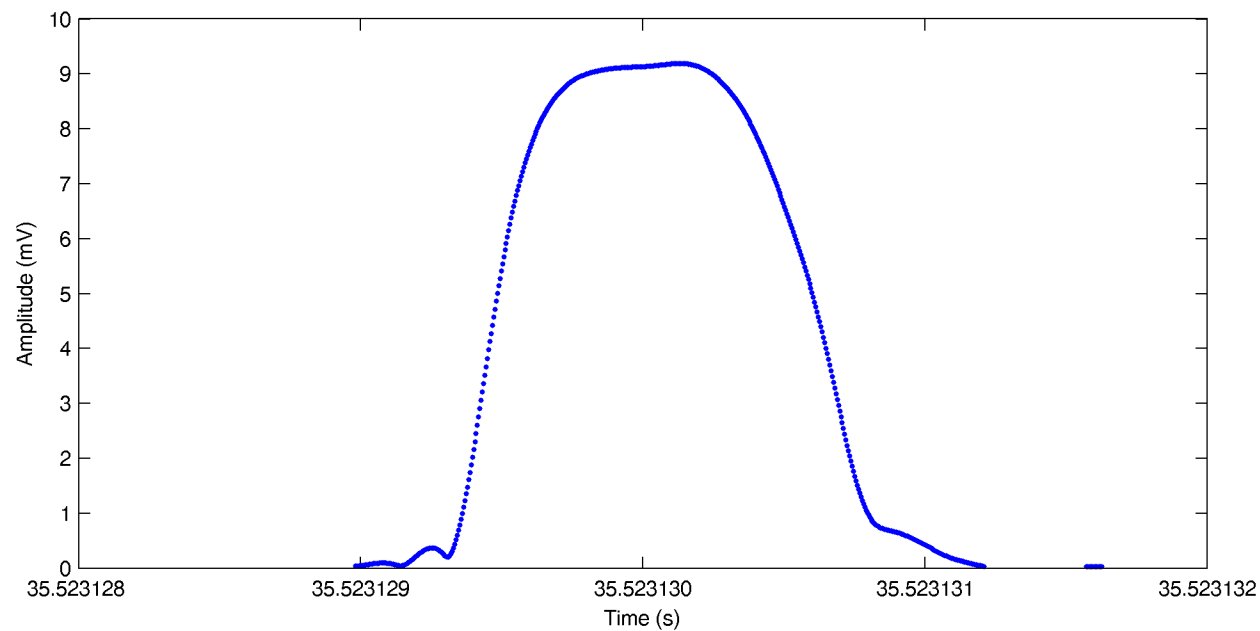
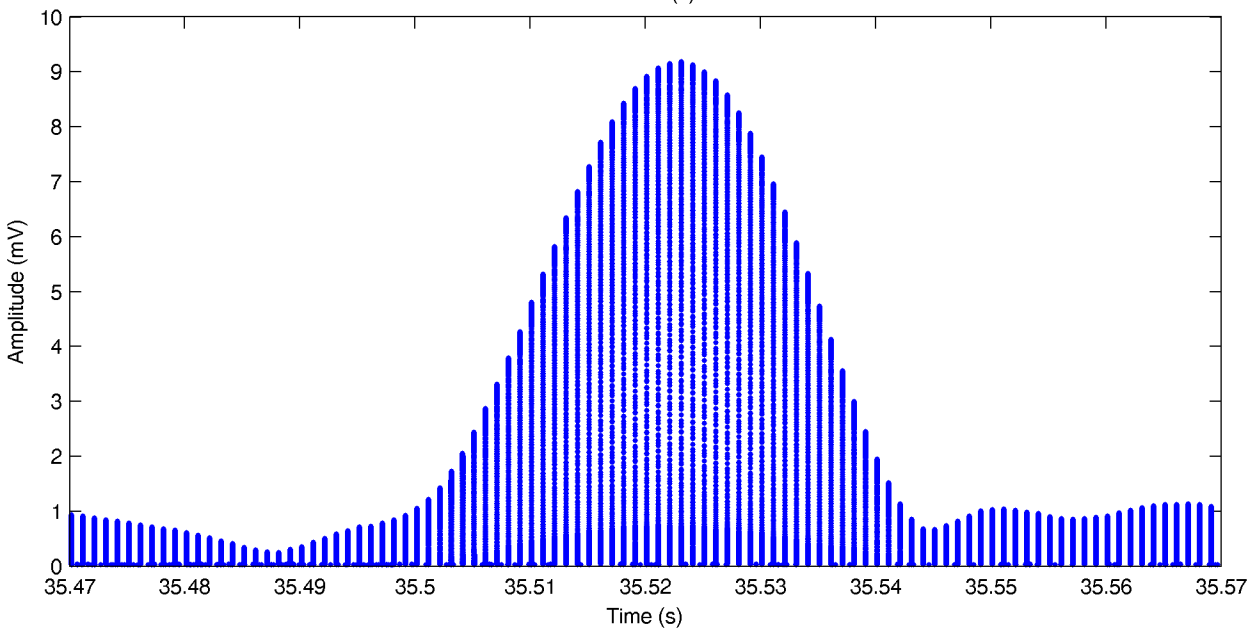
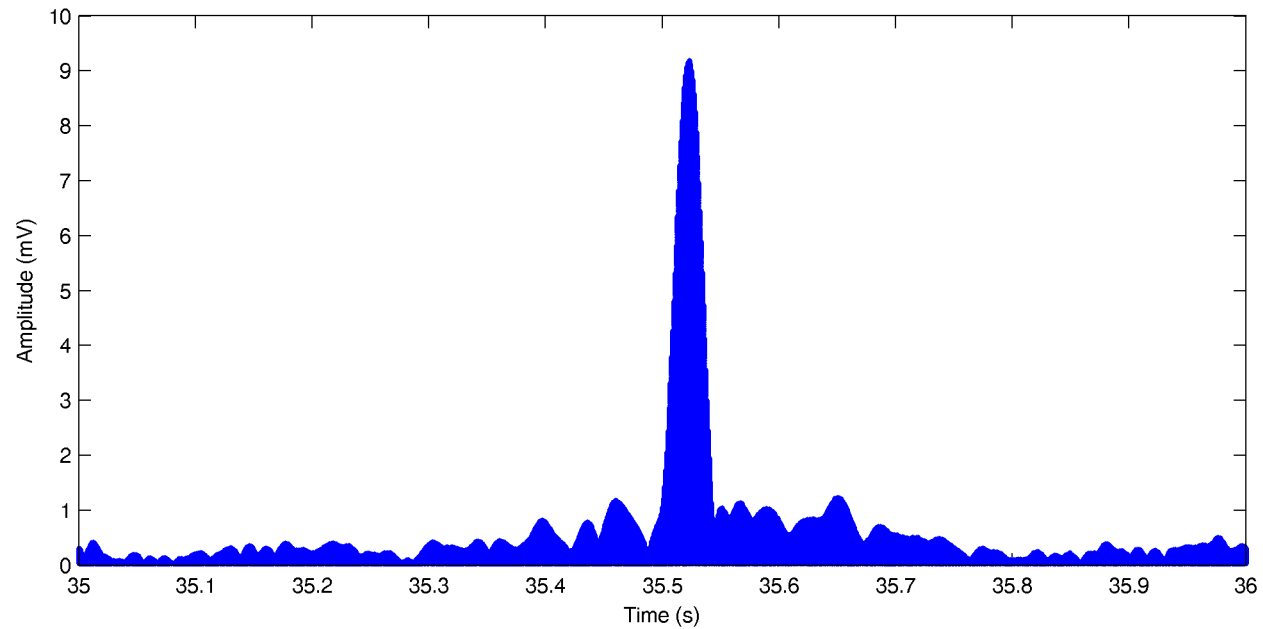
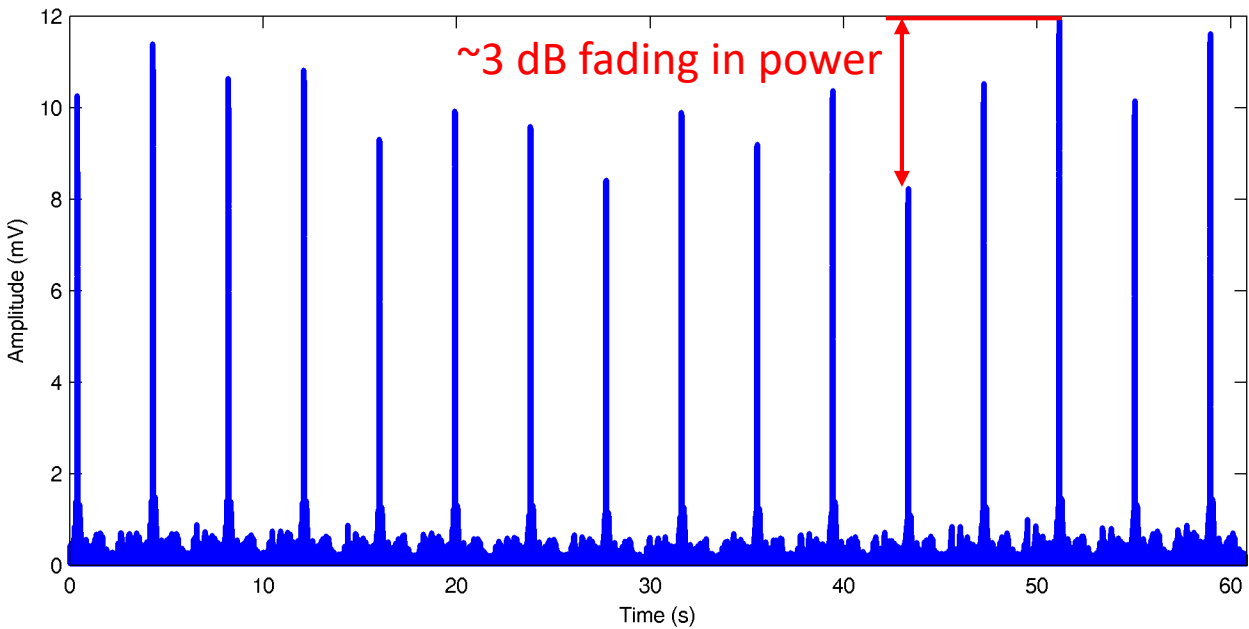
SPN-43 signal without Radar 3 OOB emissions



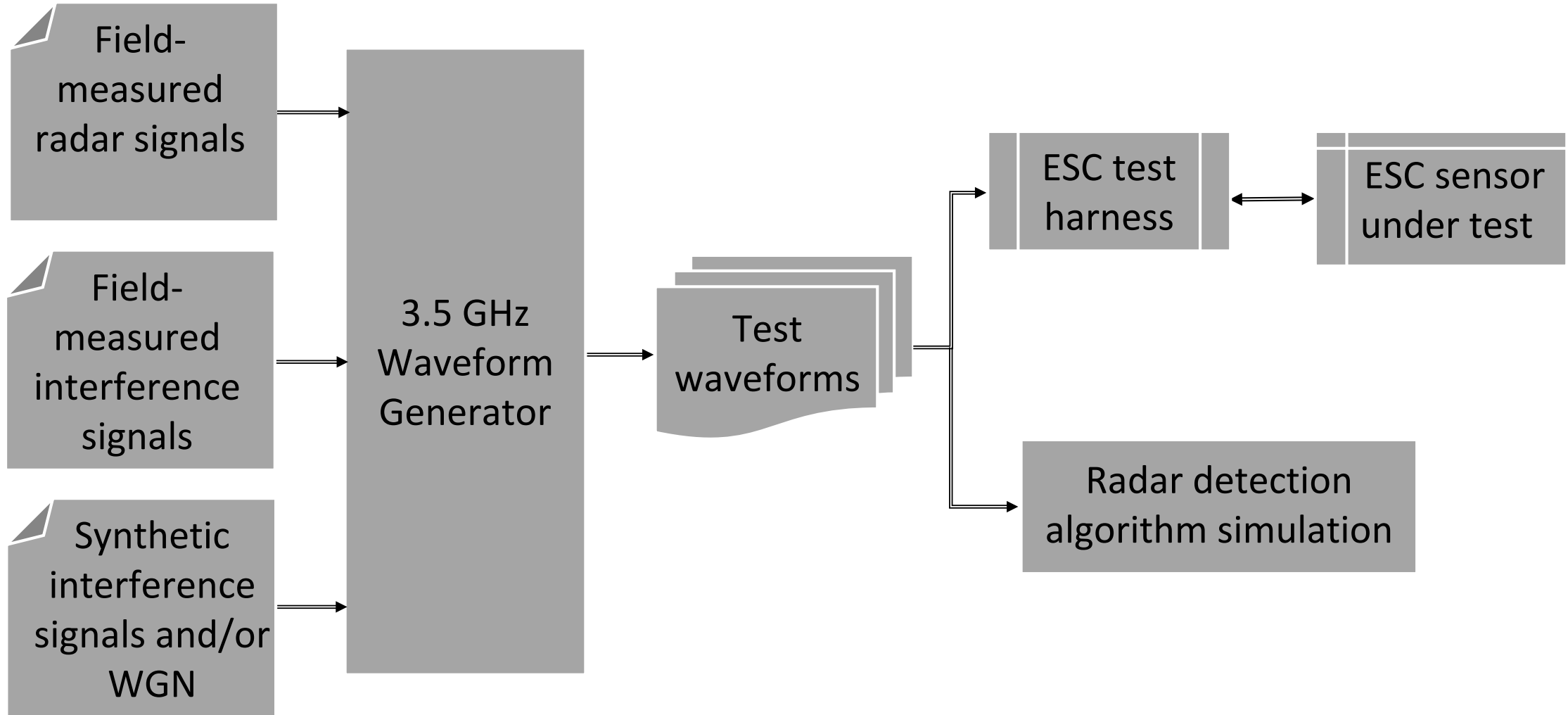
SPN-43 signal embedded in Radar 3 OOB emissions

Source: NASCTN Report 2, NIST Technical Note 1954, "3.5 GHz Radar Waveform Capture at Point Loma: Final Test Report"

Time Domain Envelopes – Four Timescales

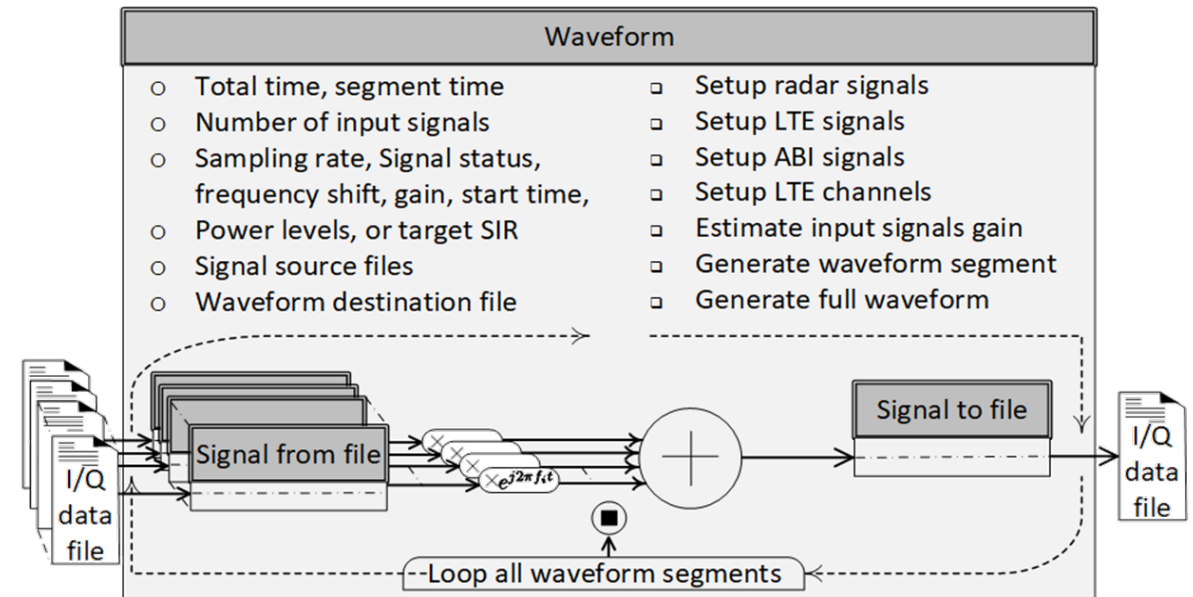


3.5 GHz Waveform Generation and Playback: System Overview



3.5 GHz Waveform Generator

- Preprocessing:
 - The field-measured radar waveforms (60 s in duration sampled @ 225 MHz) are decimated to 25 MHz
 - Generate 90-second LTE TDD waveforms
- Generation:
 - Select desired waveform parameters (waveform files, frequency, signal timing, power levels, etc.)
 - GUI to simplify the selection of the parameters
 - Automate the generation process for multiple waveform files



Source: <https://github.com/usnistgov/ESCWaveformGenerator>

Preview Panel of the Waveform Generator GUI

The screenshot displays the ESC Waveform Generator V 1.00 GUI. The interface is divided into several sections for configuring signal sources and previewing the waveform.

Signal Sources:

- Radar #1:** Frequency Offset MHz: 0, Gain: 0.01271
- Radar #2:** Frequency Offset MHz: 0, Gain: 0.01130
- Adjacent Band Interference (ABI):** Frequency Offset MHz: 0, Gain: 1.00000
- LTE #1:** Frequency Offset MHz: -5, Gain: 1.573180e-05, Channel Type: EPA5Hz
- LTE #2:** Frequency Offset MHz: 5, Gain: 2.694738e-05, Channel Type: EVA5Hz

Signal Timing (sec):

- Total preview: 4
- Segment preview: 0.001311

Forward Preview Signals (sec):

- Radar #1: 3.5
- Radar #2: 2
- ABI: 40
- LTE #1: 0

Other Parameters:

- Gain Method: Power Levels
- Estimate Gain Parameters (button)
- Target SIR dB: 30
- Signal power reference dBm: Radar Peak Power (-89), LTE Power (-109)

Spectrum Analyzer (Overlay):

- Y-axis: dBm / Hz (range: -240 to -160)
- X-axis: Frequency (MHz) (range: -10 to 10)
- Time History (ms): 0 to 25
- Color scale: dBm / Hz (range: -230 to -170)
- RBW=18.31 kHz, Sample rate=25 MHz, Time res.=250 us, Offset=49.5398 s, T=49.5374

Buttons at the bottom: Load Preview>>Generation Parameters, Reset Spectrum Analyzer and Time Scope

GUI: Waveform Generation Panel

- Load all the preview parameters in one place
- Provide capability to edit/modify parameters in one place
- Generate single or multiple files
- Parallel processing to speed up the generation process

ESC Waveform Generator V 1.00

Signal Sources | Waveform Preview | Waveform Generation | Waveform Player

Fixed Parameters (Time:sec, Frequency:Hz, SIR:dB)

| | Radar1 | Radar2 | ABI | LTE1 | LTE2 |
|------------------|-------------------------------------|--------------------------|--------------------------|-------------------------------------|-------------------------------------|
| Status | <input checked="" type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |
| Frequency Offset | 0 | 10000000 | 0 | -5000000 | 5000000 |
| Gain | 1 | 1 | 1 | 0.001 | 0.001 |
| Start Time | 4 | 6 | 0 | 0 | 0 |

Multiple File Generation

Parallel Process Available Number of Workers=20 Set Number of Workers 20

| | Method | Lower Bound | Upper Bound | Step Value |
|-------------------|--------|-------------|-------------|------------|
| Radar1 Start Time | Random | 4 | 30 | 1 |
| Radar2 Start Time | Random | 4 | 30 | 1 |
| ABI Start Time | Fix | 4 | 30 | 1 |
| Radar1 Frequency | Vary | -100000 | 100000 | 10000 |
| Radar2 Frequency | Vary | 9900000 | 10100000 | 10000 |
| ABI Frequency | Fix | -5000000 | 5000000 | 10000 |
| Target SIR | Fix | 0 | 50 | 2 |
| LTE Channel Type | Fix | | | |

Gain Method

Target SIR

Power Levels

Power dBm

| | |
|------------|------|
| Radar Peak | -89 |
| LTE | -109 |
| ABI | 30 |
| AWGN PSD | -165 |

Single File Generation

Save Waveform As []

Generate This Waveform

Ready

Multiple File Generation

Waveform File Prefix: testRadarWaveform Number of Files: 120

Save Waveform Dir: D:\MixedWaveformsTest Generate Waveforms

File Sources: (Change in signal sources tab)

Radar Signals Dir: D:\Spectrum-Share_Public\Shared-Data for Group Users\Radarsynth

Radar Meta File:

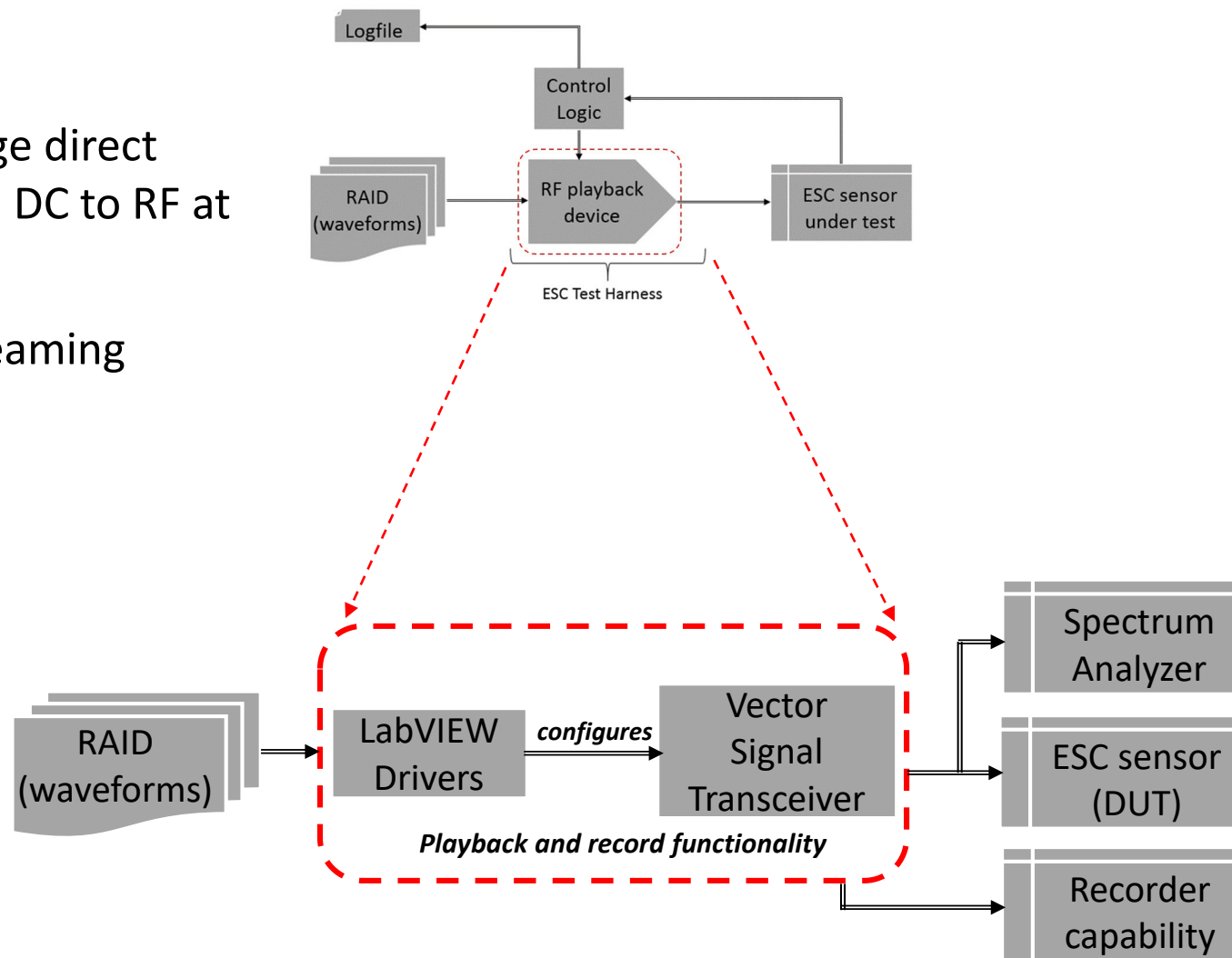
LTE Signals Dir: D:\Spectrum-Share_Public\LTESignals

Ready

Load Preview>>Generation Parameters Reset Spectrum Analyzer and Time Scope

RF Playback System Overview

- VST RF Signal Generator consists of single stage direct conversion I/Q upconverter; upconverts from DC to RF at configured LO frequency (e.g., 3.6 GHz)
- VST configured as an AWG for continuous streaming
- Read 9 GB IQ file in segments
- Configure parameters:
 - Sampling rate 25 MSa/s
 - Center Frequency 3.6 GHz
 - Digital gain
 - RF power level

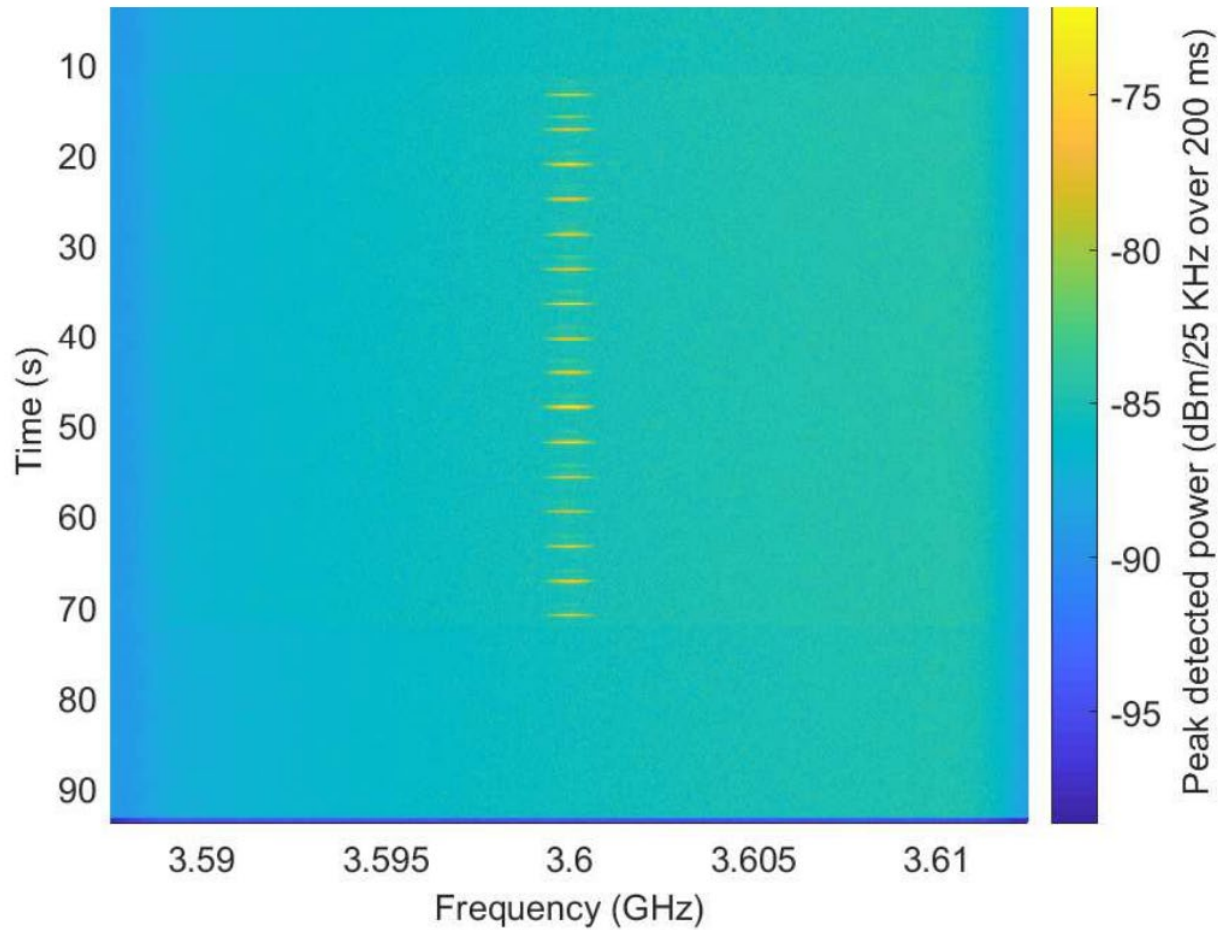


RF Waveform Recorder

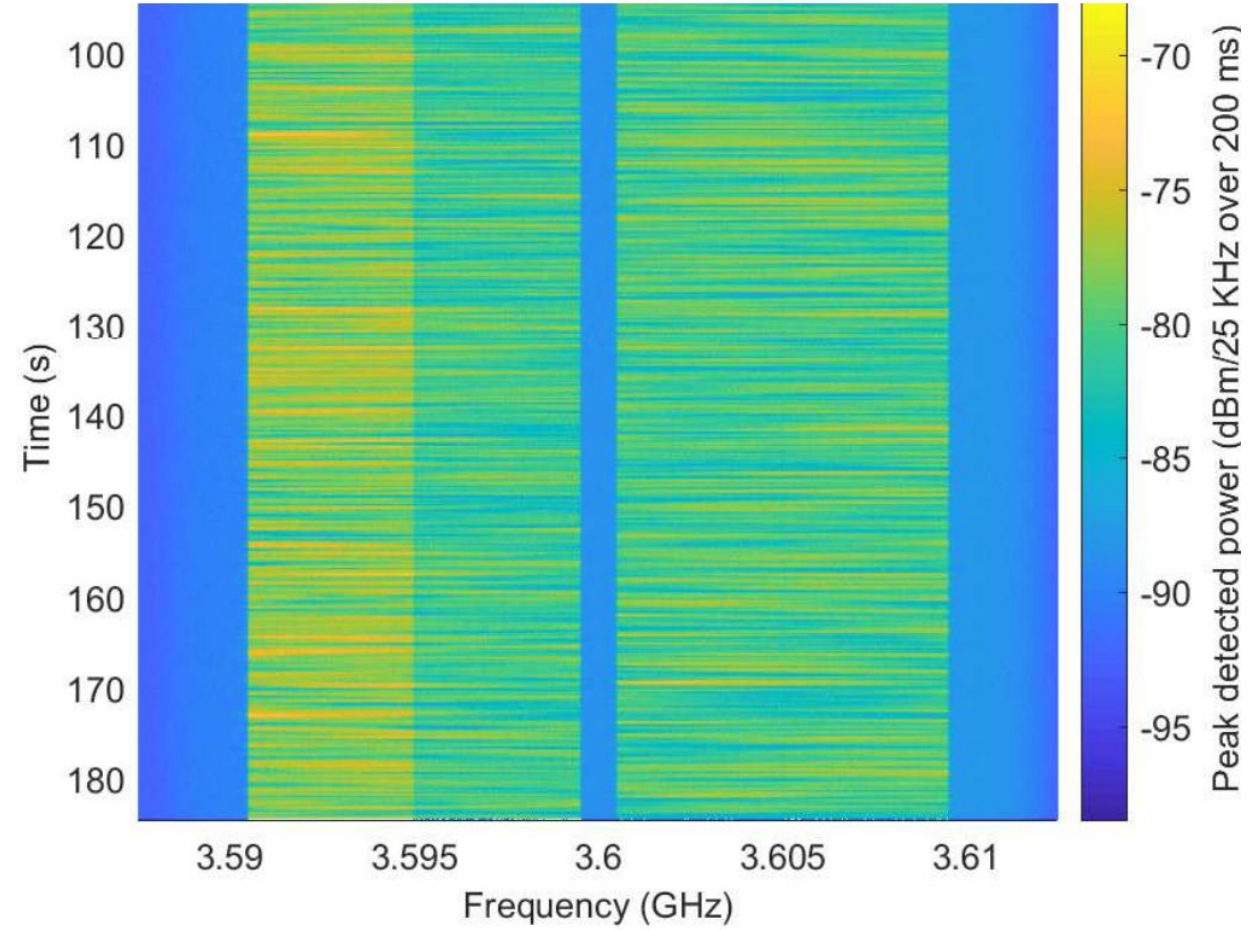
The screenshot displays the RF Waveform Recorder software interface, which is divided into several functional areas:

- 5668Rs:** A vertical stack of four dropdown menus, with the top one set to 'VSA'.
- Base Folders:** A folder selection area with a dropdown menu showing 'D:\FOUO' and three folder icons below it.
- IQ Rate:** A numeric input field set to '25M S/s'.
- Center Frequency:** A numeric input field set to '3.6G Hz'.
- Reference Level:** A numeric input field set to '-30 dBm'.
- IF Filter Bandwidth:** A numeric input field set to '320 MHz'.
- Digitizer Dither:** A dropdown menu set to 'Disabled'.
- Overflow Status:** A row of four green indicator lights.
- Time String In:** An empty text input field.
- Acquisition Name:** A text field containing 'Record_test_File-FOUO-6-28-2018'.
- Maximum File Size:** A text field set to '16384 MB'.
- Max Async Writes:** A numeric input field set to '4'.
- Write Block Size:** A text field set to '12582912 5'.
- Host DMA Buffer Depth:** A numeric input field set to '16 Blocks'.
- RBW:** A numeric input field set to '20k Hz'.
- Record/Quit Buttons:** A red 'Record' button and a red 'X' 'Quit' button.
- Acquisition Preview:** A tabbed interface with 'Acquisition Preview' and 'Status' tabs. The 'Acquisition Preview' tab is active, showing a 'Waveform Spectrum Display' graph. The graph plots Power (dBm) on the y-axis (ranging from -150.49 to -70) against Frequency (Hz) on the x-axis (ranging from -14M to 14M). The plot shows a noisy signal centered around 0 Hz. A 'wvfm' icon and a blue envelope icon are in the top right of the graph area.
- File Progress:** Four horizontal progress bars labeled 'File Progress 0', 'File Progress 1', 'File Progress 2', and 'File Progress 3', all showing 0% completion.
- Gain to scale waveform data:** A text field set to '1.22389E-6'.
- Offset:** A text field set to '0'.

Test Waveform Examples

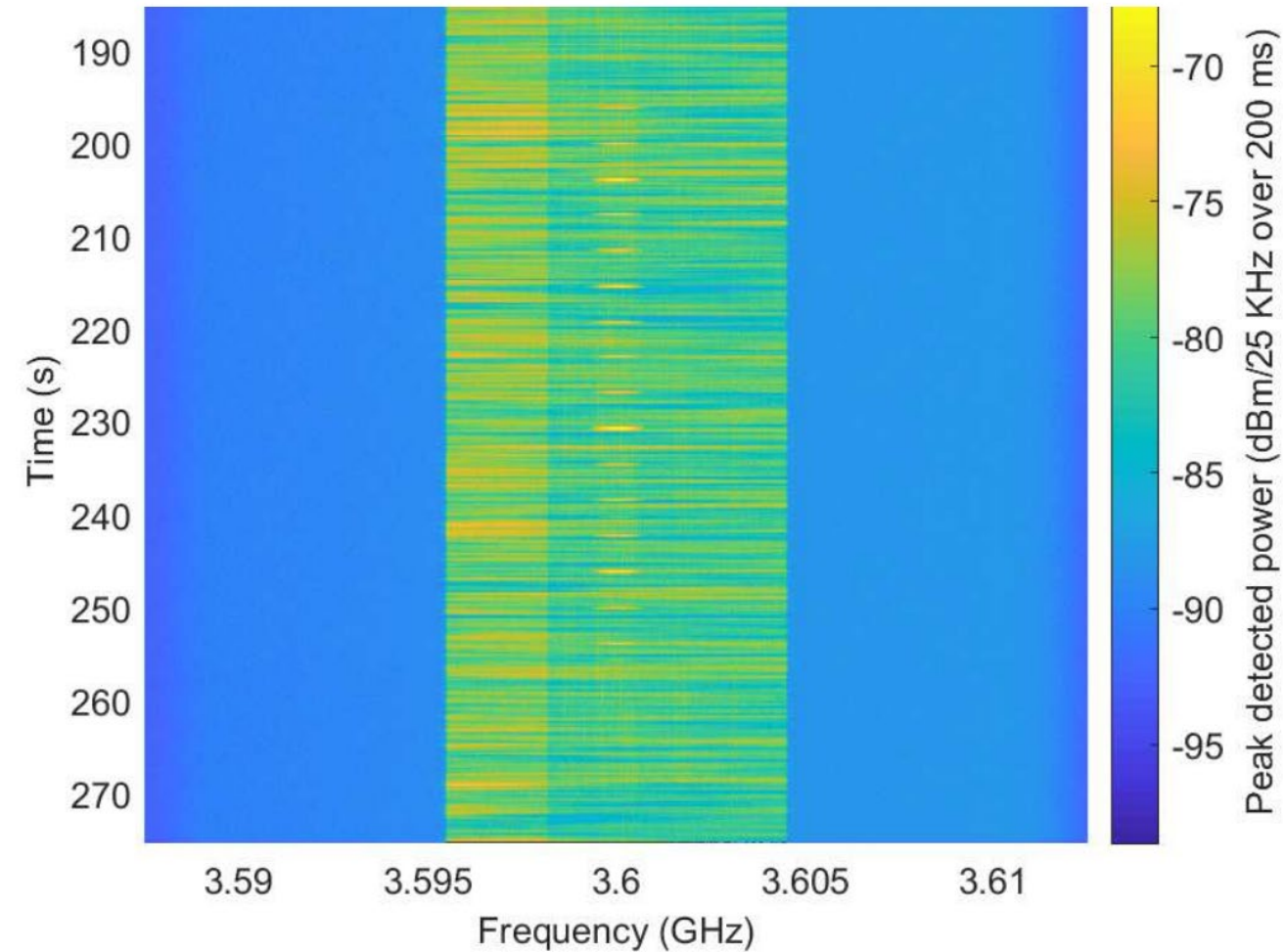


Spectrogram of in-band radar signal

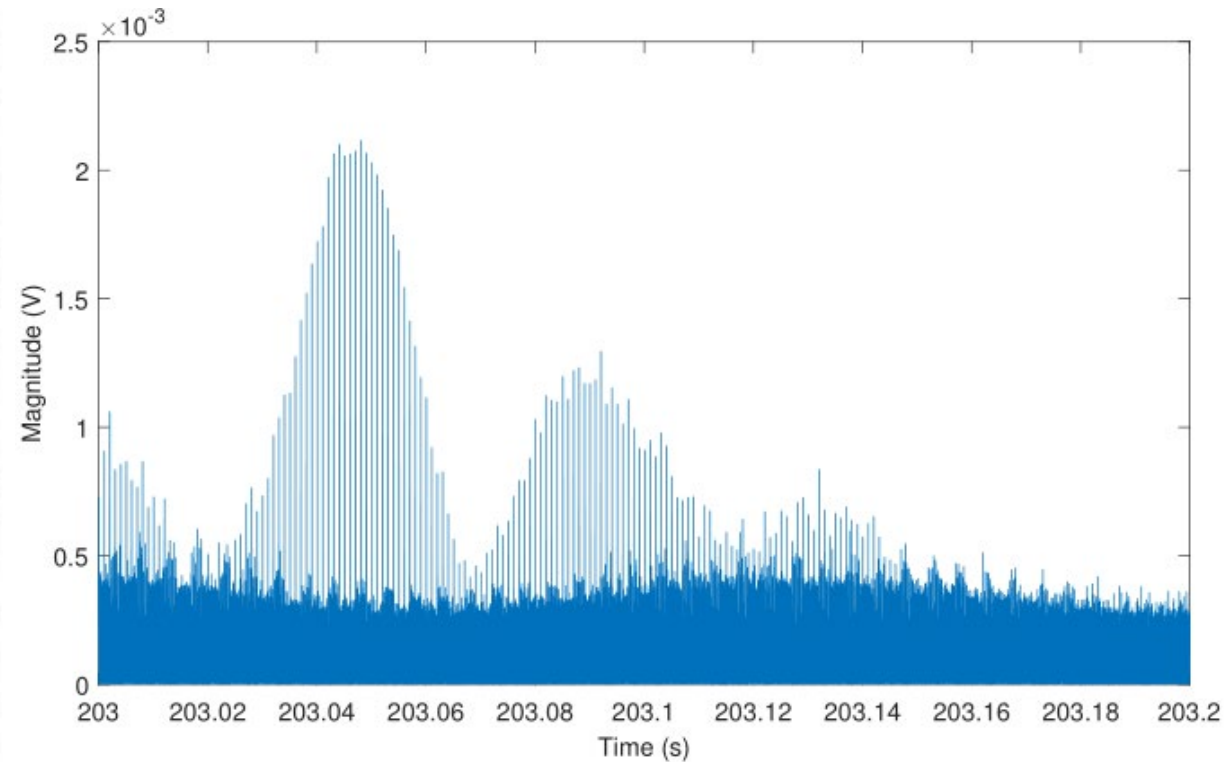


Spectrogram of two LTE signals with fading

Test Waveform Examples

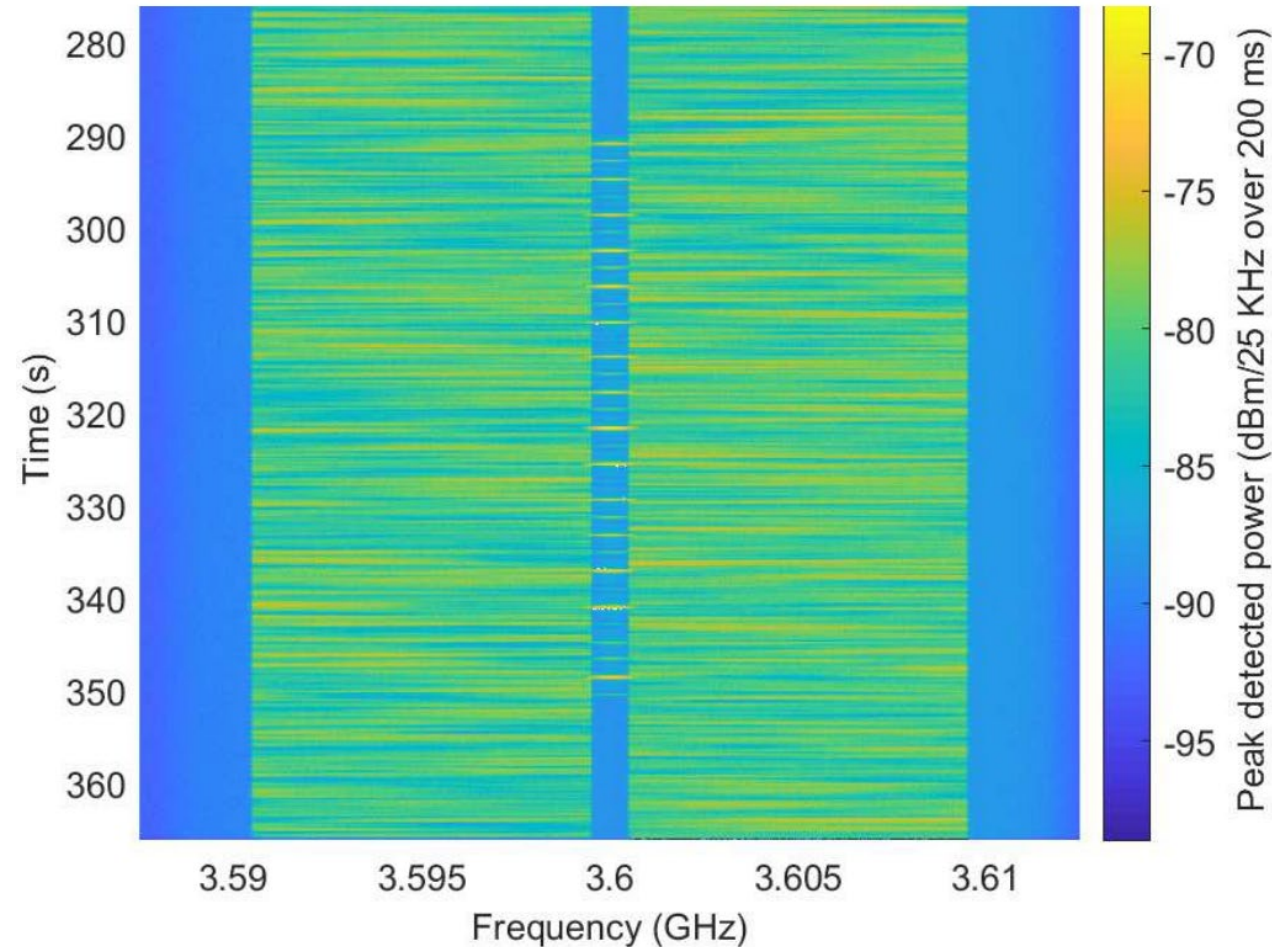


Spectrogram of in-band radar signal with co-channel LTE

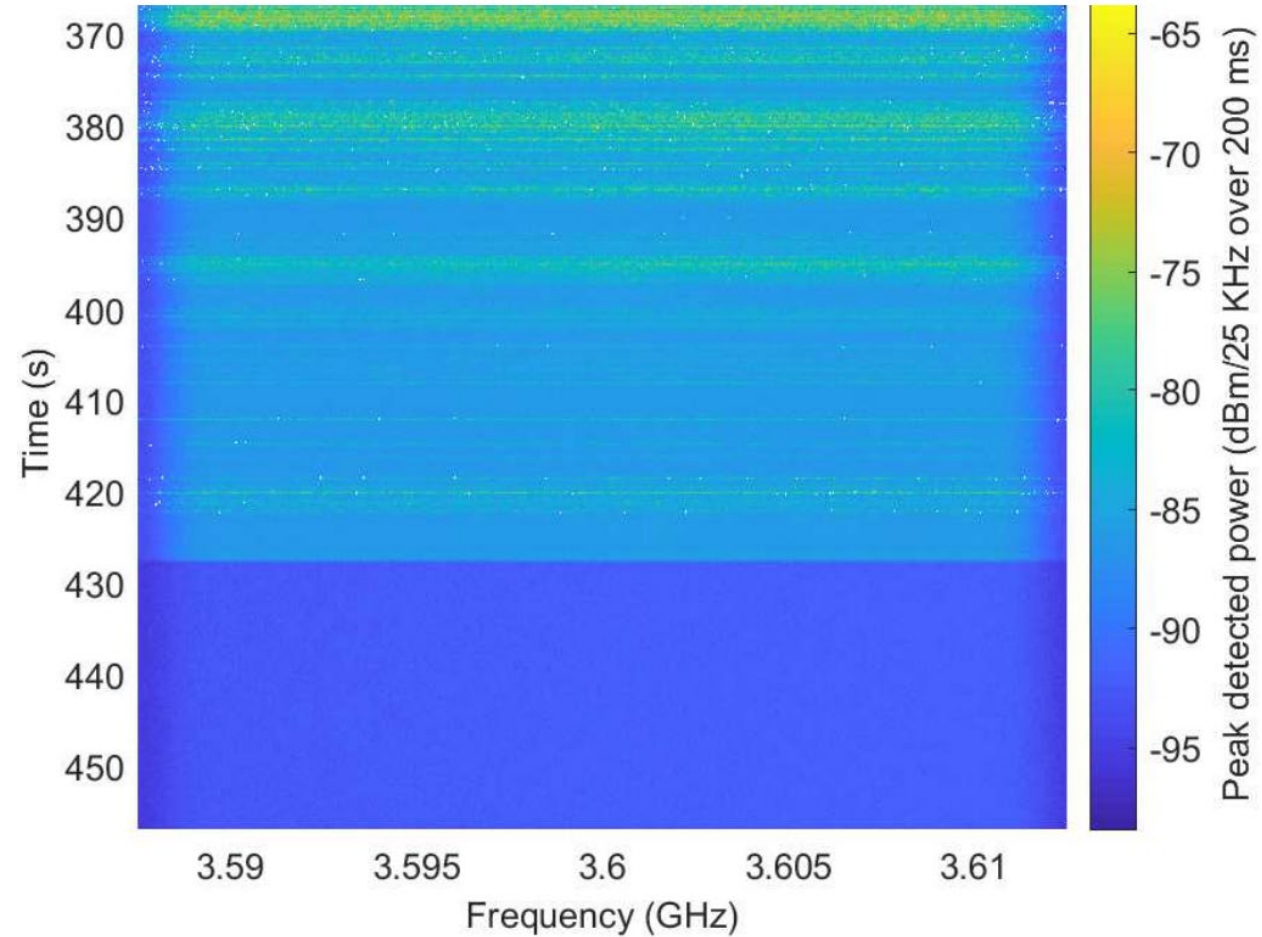


Time-domain plot of a 0.2s portion of the in-band radar signal with co-channel LTE (at the 203s mark of the test)

Test Waveform Examples

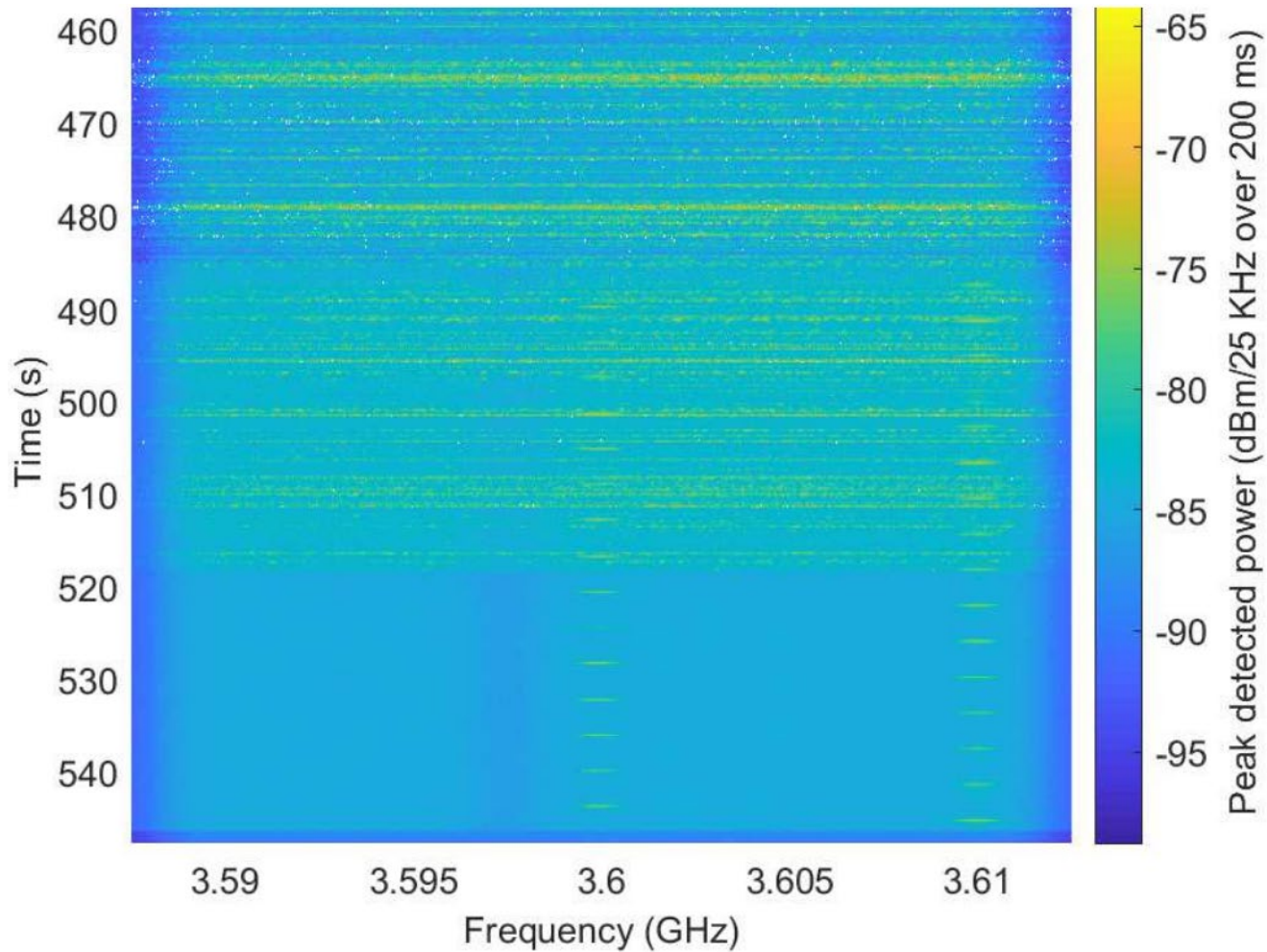


Spectrogram of in-band radar signal between two fading LTE signals

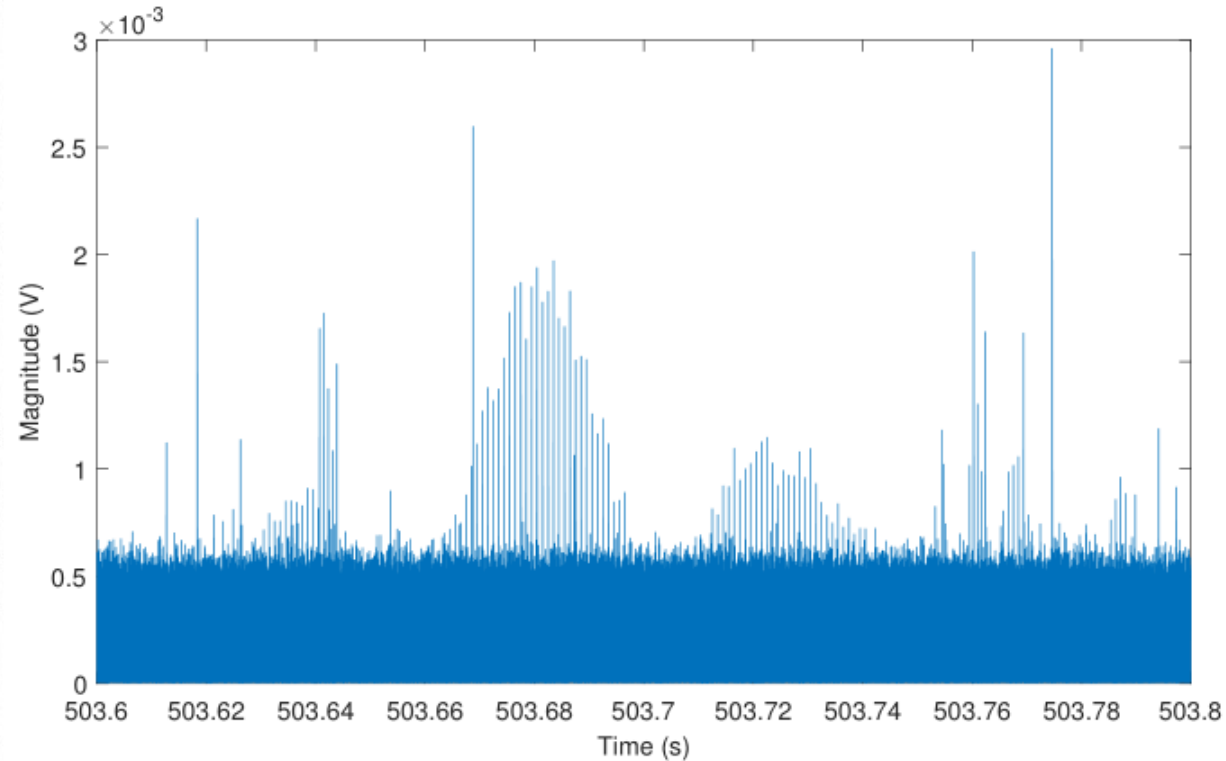


Spectrogram of adjacent-band interference

Test Waveform Examples

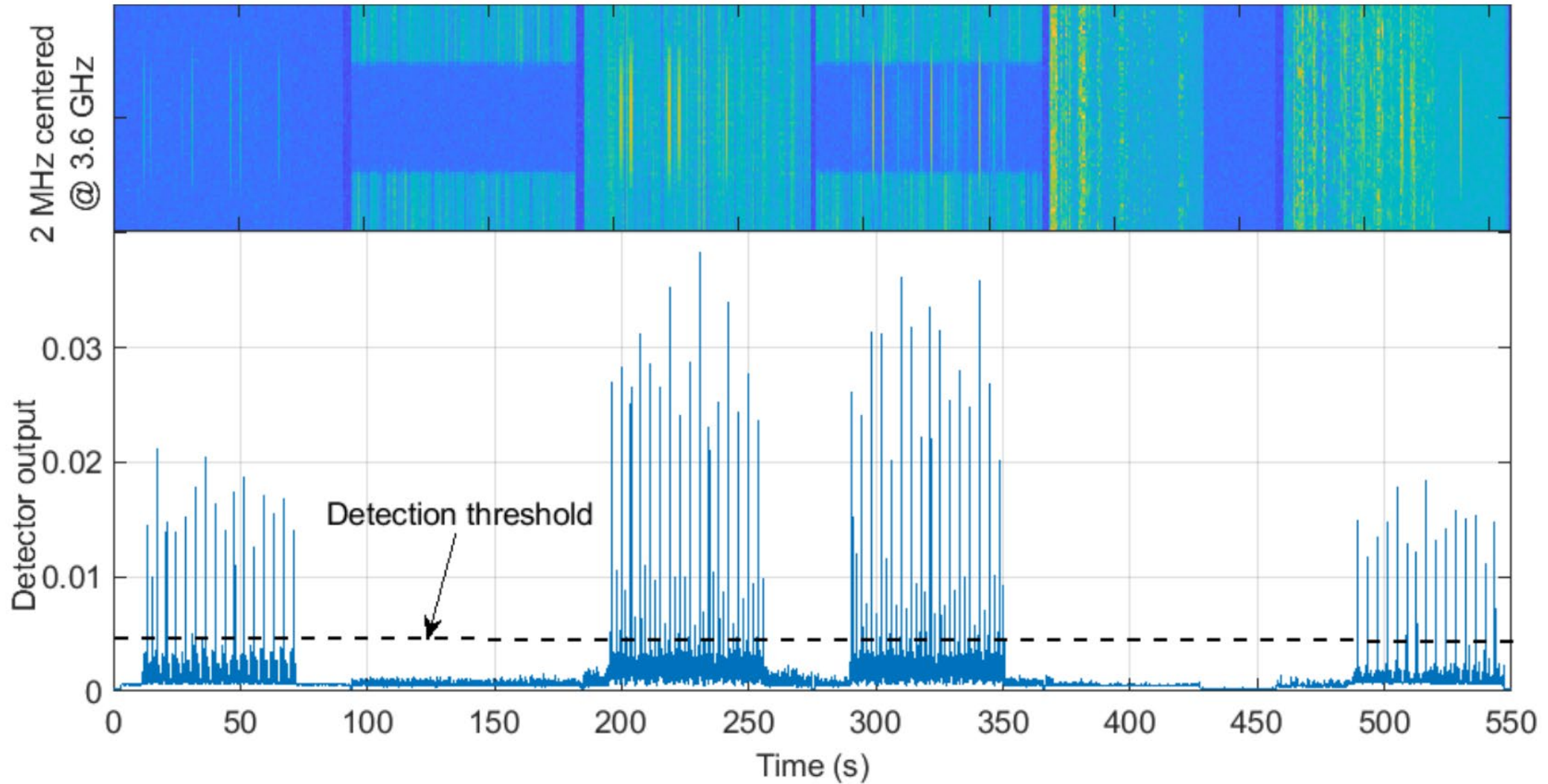


Spectrogram of two in-band radar signals with adjacent-band interference



Time-domain plot of a 0.2s portion of the two in-band radar signals with adjacent-band interference (at the 503.6s mark of the test)

Detection Example: Tested on VSA Recorded Waveform



Response of in-band radar matched filter to the recorded test waveform

Summary

- An approach and apparatus for quantitatively assessing the performance of a 3.5 GHz ESC sensor using field-measured and synthetically generated waveforms.
- Waveforms are generated prior to evaluation for a variety of commercial-federal signal scenarios in which the relative amplitudes and frequency offsets of all signal components can be varied.
- Software-controlled instrumentation automates the process by generating a script of RF waveforms and logging sensor detections. It can also record the waveforms as they are seen by the sensor under test for auditing purposes.
- Output logs can be processed to generate sensor performance metrics such as detection and false alarm rates.
- Example scenarios generated by the apparatus illustrate its flexibility and expected uses.

Thank you!

Questions?

- 3.5 GHz waveform generator, source: <https://github.com/usnistgov/ESCWaveformGenerator>
- RF Sensor Test Harness, source: https://github.com/usnistgov/RF_Sensor_Test_Harness
- Detection: Raied Caromi, Michael Souryal, and Wen-Bin Yang, “Detection of incumbent radar in the 3.5 GHz CBRS band,” in *Proc. IEEE GlobalSIP*, Nov. 2018, to appear.

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The material in this presentation is for research purposes and is unrelated to the current, ongoing certification of CBRS ESC systems.

Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.