3.5 GHz Waveform Generation for Testing and Development of ESC Detectors

Raied Caromi, John Mink, Michael Souryal

{raied.caromi, john.mink, michael.souryal}@nist.gov

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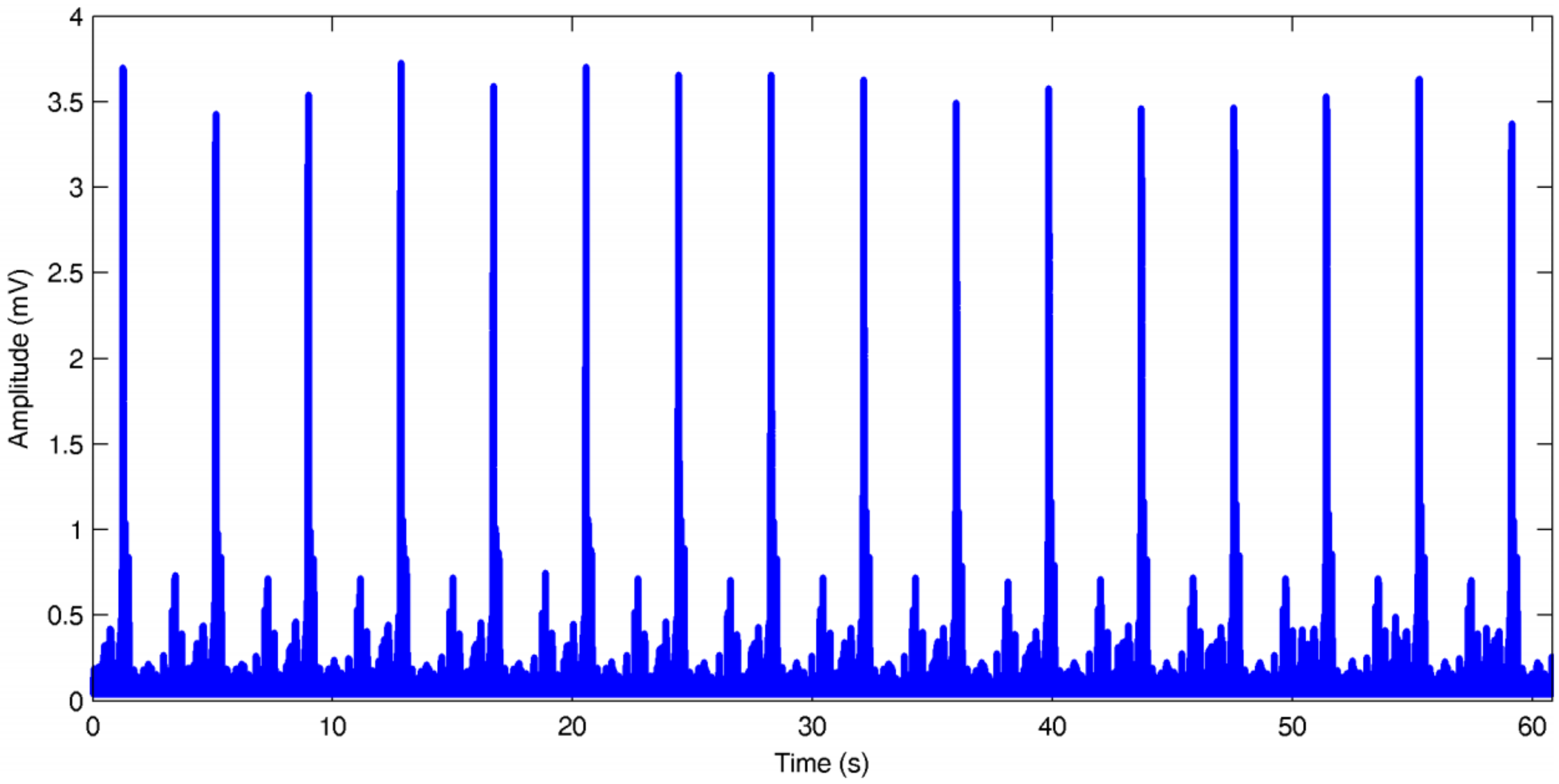
Background

- Citizens Broadband Radio Service (CBRS) allows spectrum sharing in 3550 MHz – 3700 MHz band between federal and commercial users, in accordance with FCC rules
- Environmental Sensing Capability (ESC) detects and reports the presence of federal incumbent radar signals in these bands
- ESC sensors will not have full knowledge of radar waveform parameters such as pulse repetition, pulse duration and center frequency of the incumbent radar
- Field-measured waveforms include channel propagation effects such as time-varying multipath fading and pulse dispersion
- Utilize field-measured radar waveforms and computer generated interference signals to generate waveforms similar to what an actual ESC sensor will observe
- Develop open source code for framework, signal processing blocks and GUI generation tool
- The waveforms and their parameters can be used by ESC applicants and developers for training and testing incumbent radar detection algorithms

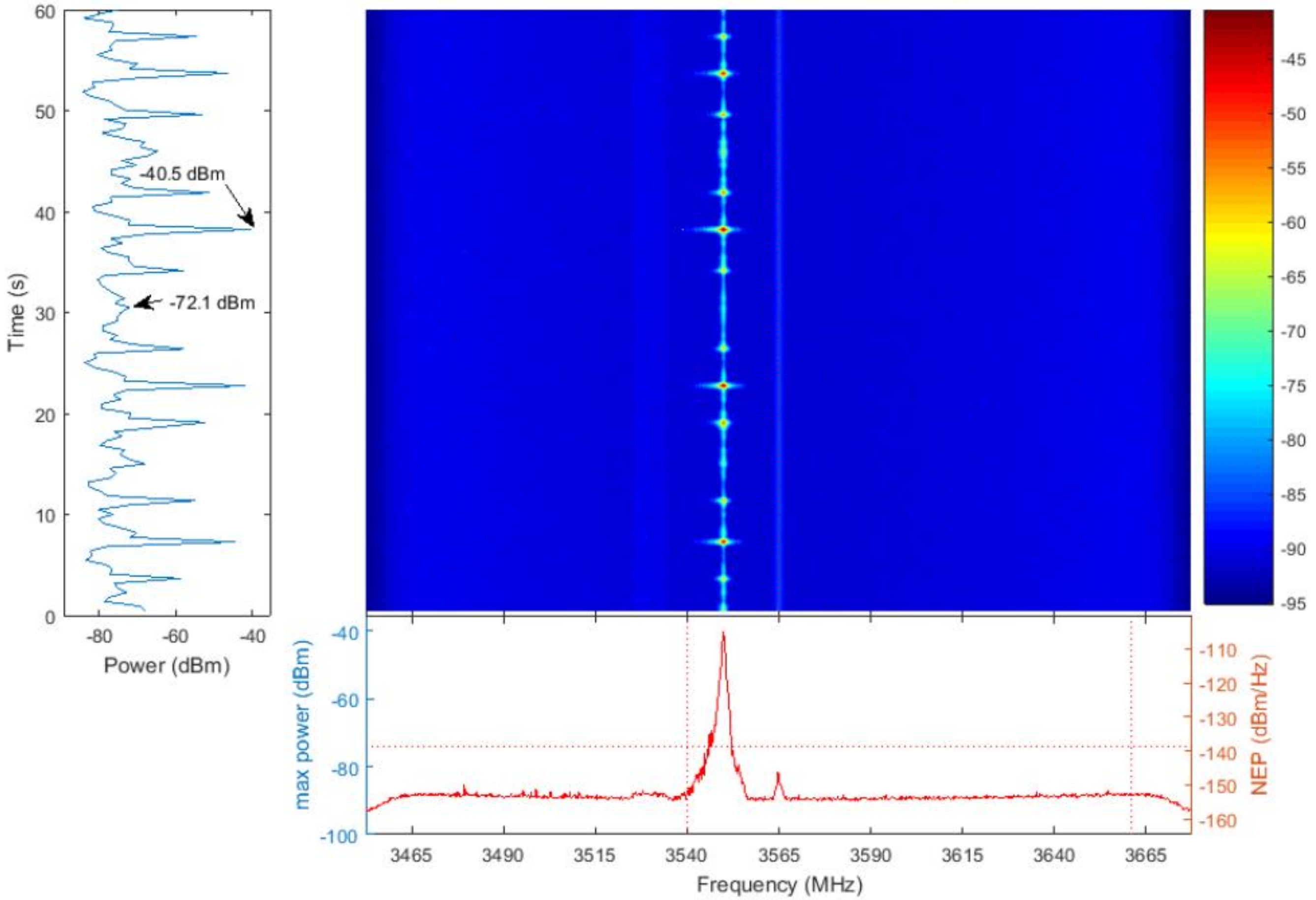
Examples of field-measured radar waveforms



Magnitude of an IQ capture of a typical 3550 MHz SPN43 radar. The full capture epoch of just over 60 s duration is shown here.

Figure 3.1 , NASCTN Report 2, NIST Technical Note 1954, 3.5 GHz Radar Waveform Capture at Point Loma, Final Test Report, https://doi.org/10.6028/NIST.TN.1954

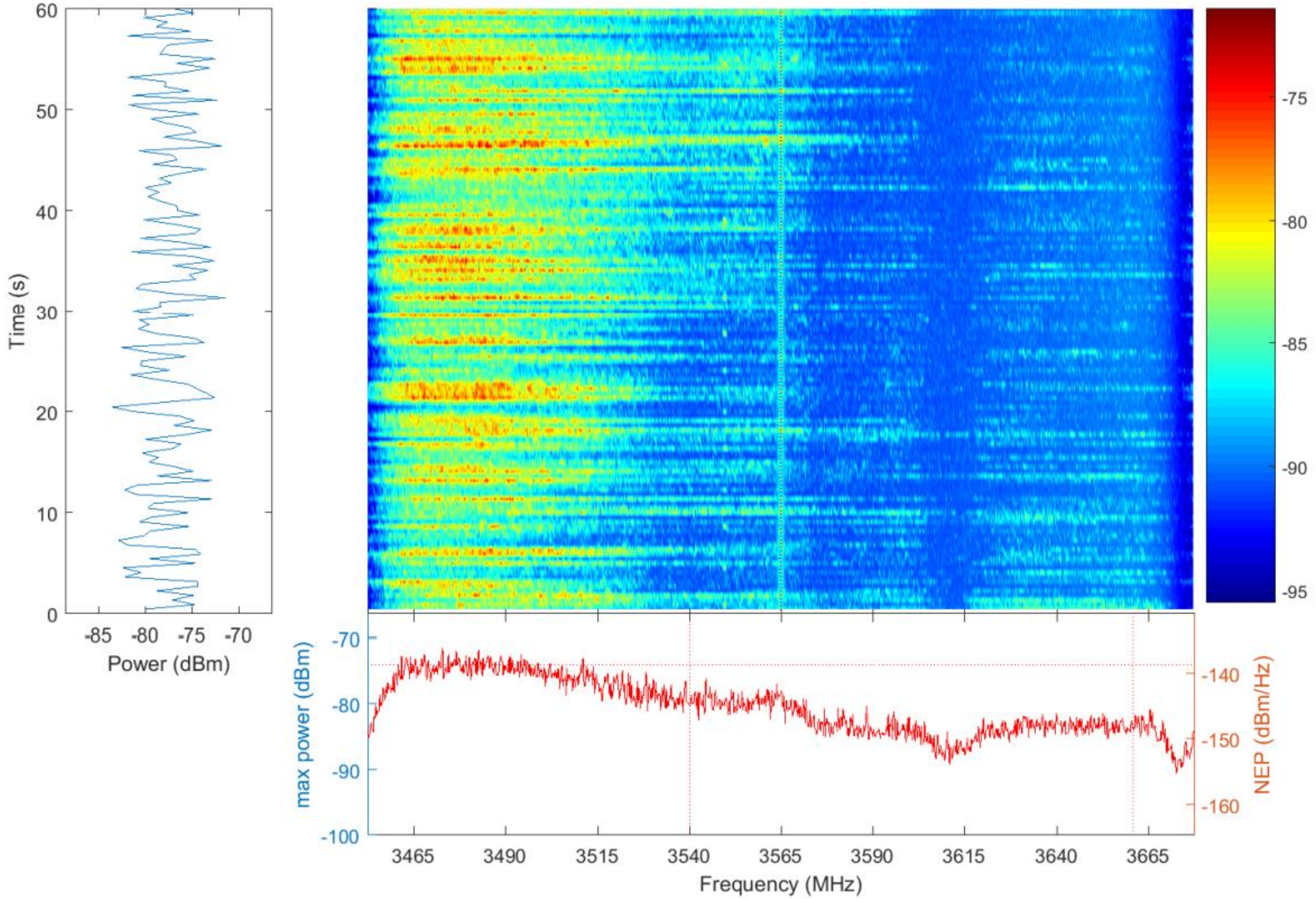
Examples of field-measured radar waveforms



Spectrogram of a SPN-43 signal with temporal fading, captured with the omni-directional antenna showing spread of peak rotation power of 31.5 dB, while the mean peak power, pooled over all rotations in this capture, is -54.6 dBm.

Figure 3.8, NASCTN Report 2, NIST Technical Note 1954, 3.5 GHz Radar Waveform Capture at Point Loma, Final Test Report, https://doi.org/10.6028/NIST.TN.1954

Examples of field-measured radar waveforms



Spectrogram showing broadband noise from Radar 3. Note that SPN-43 peaks at 3550 MHz are visible earlier than 30 s, but are hidden by interference at later times.

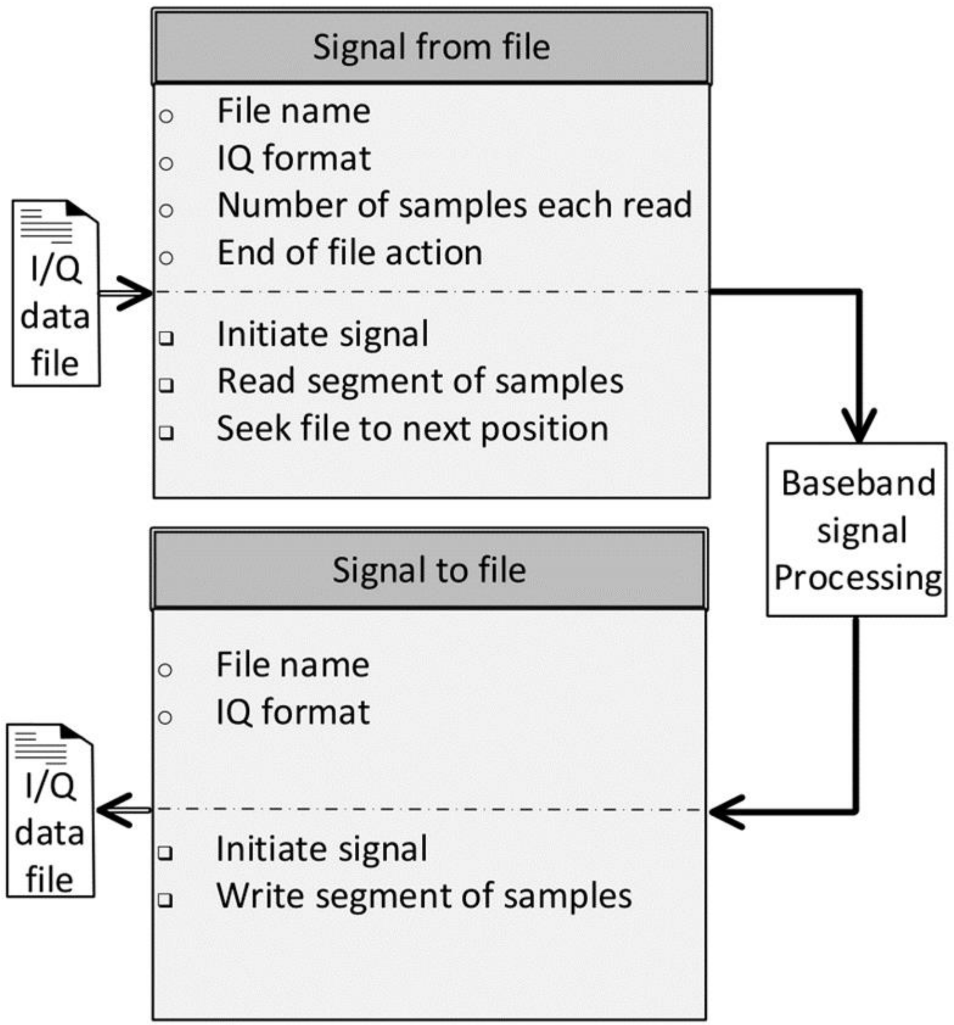
Figure 3.18 , NASCTN Report 2, NIST Technical Note 1954, 3.5 GHz Radar Waveform Capture at Point Loma, Final Test Report, https://doi.org/10.6028/NIST.TN.1954

Waveform generation framework

- Define basic objects to handle signal input/output from/to files
- Read signals in terms of segments of samples
- Perform signal processing procedures on the segment of samples
- Track signal timing, end of file action, IQ format and scaling
- Signal processing procedures are built on top of the basic framework
- GUI to visualize the resulting waveforms and to automate the process of generating the waveforms
- The GUI utilizes the framework and the waveform signal processing blocks to mix up to two radar, one adjacent band interference (ABI), and two LTE signals
- The GUI simplifies the selection of certain parameters such as signal power levels, and randomizes other parameters such as start time, and frequency
- The software automates the generation of multiple waveform files

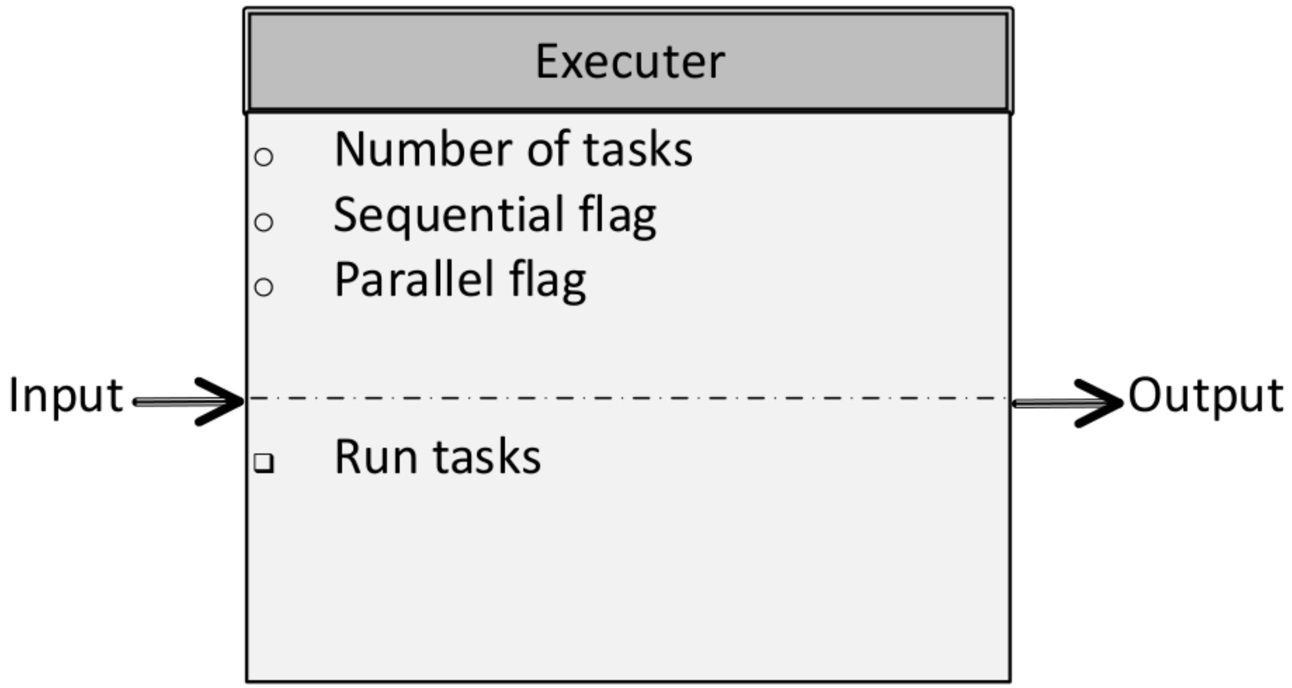
Read and write complex baseband signals

- All signals are saved as integer 16-bit interleaved I/Q data file to minimize disk storage size
- Signal from file: read a segment of samples from a signal file and prepare it for baseband processing
- Signal to file: write a segment of samples to a file
- A waveform object can have one or more (signal from file)/(signal to file) objects



Multi-task execution

- Organize multi-task execution
- Manage the type of the execution, i.e., sequential or parallel.



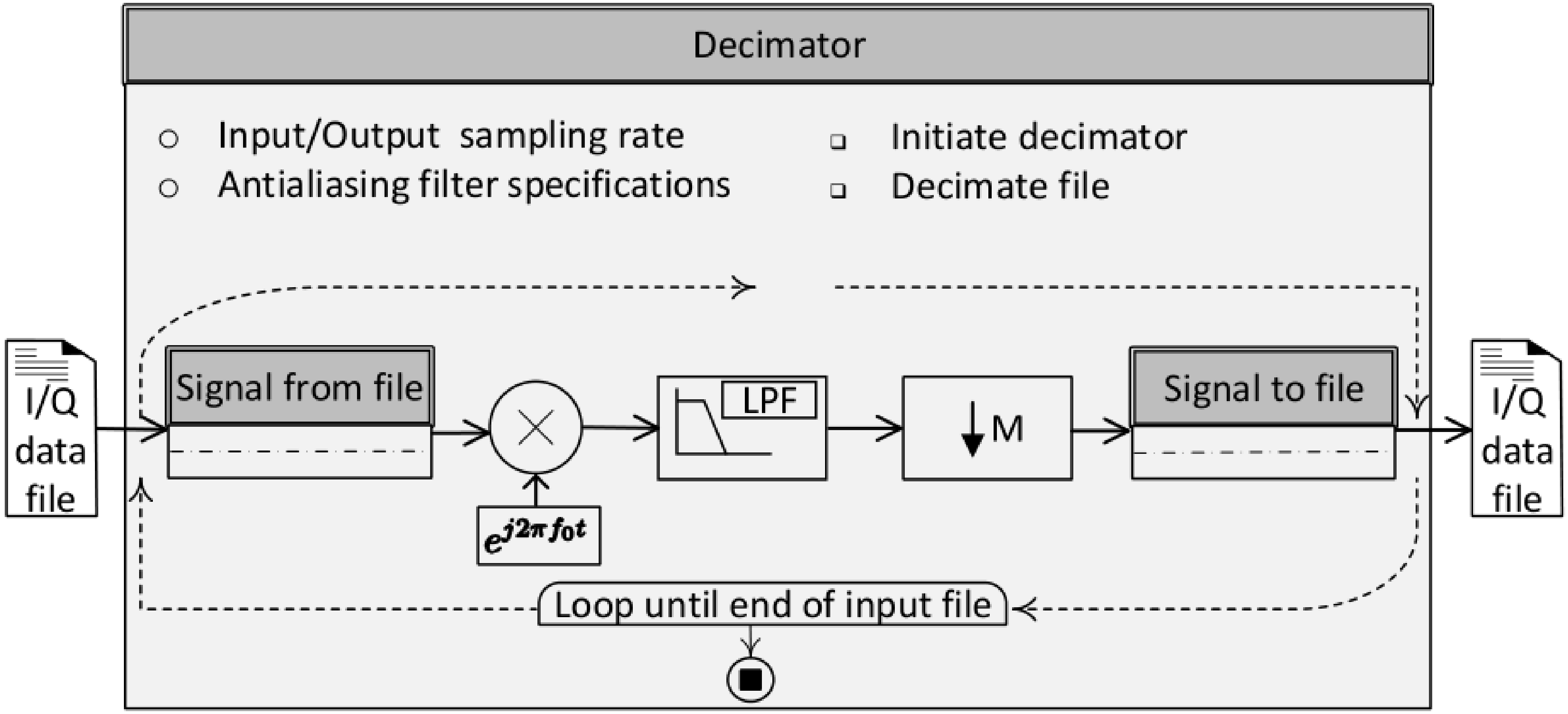
Signal preprocessing and measurement preparations

Certain tasks are performed before waveform generation

- Decimation is performed on the original radar waveforms to extract clean radar signals centered at zero Hz baseband
- Instantaneous signal to interference ratio (SIR) calculation during the generation process requires estimation of radar peaks and their times at every sweep
- LTE TDD signals are simulated and up-sampled to the final waveform sampling rate beforehand
- Real captured LTE TDD signals can also be used instead of the synthetically generated LTE signals

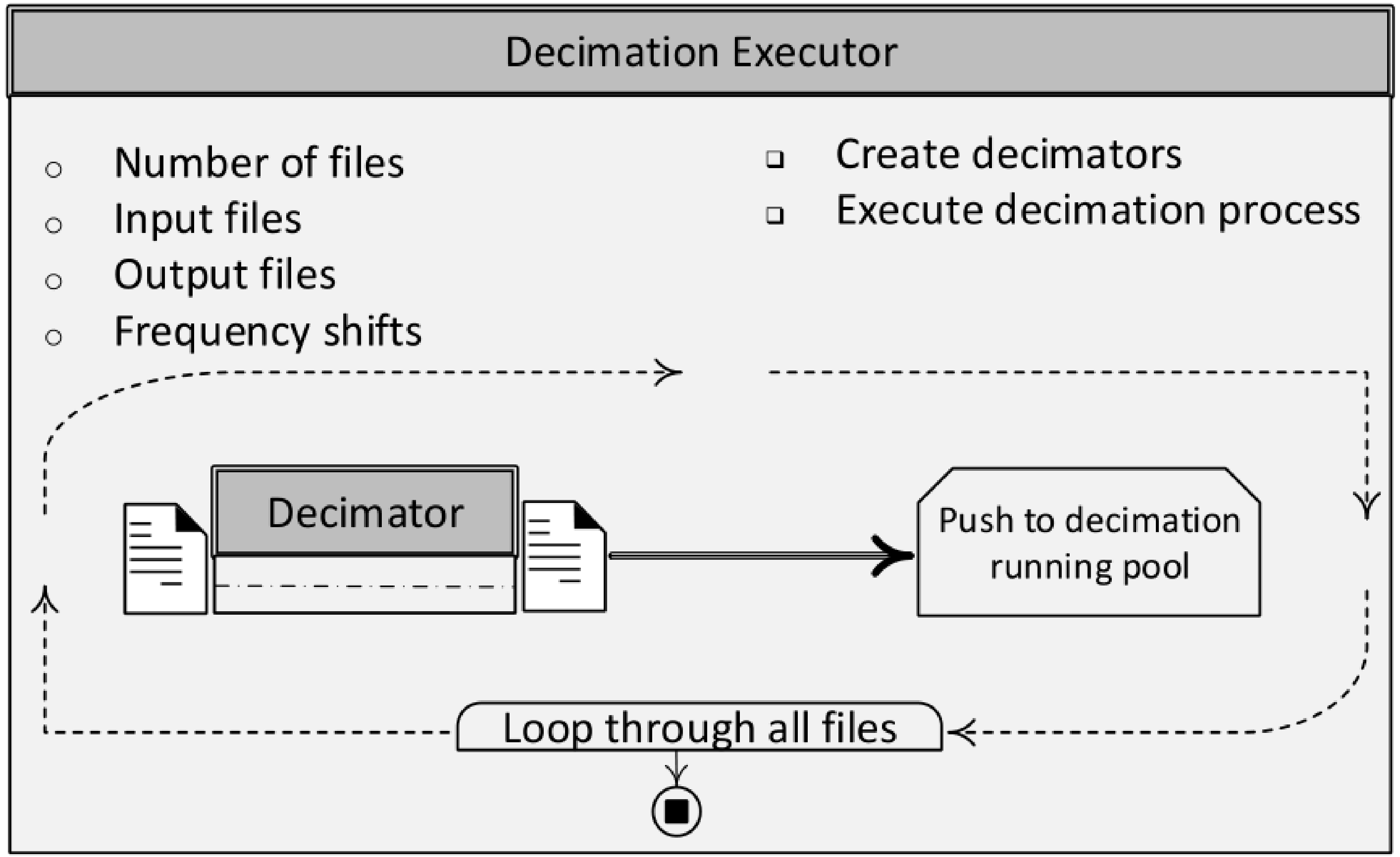
Decimation process

- The field-measured radar waveforms are sampled at 225 MHz and are about 60 seconds long
- Each waveform is shifted with an offset frequency so that the radar is set at zero baseband center frequency
- An antialiasing low-pass filter is applied
- The signal is then down-sampled to 25 MHz and saved to a file
- The waveform is processed in segments due to large size of the file



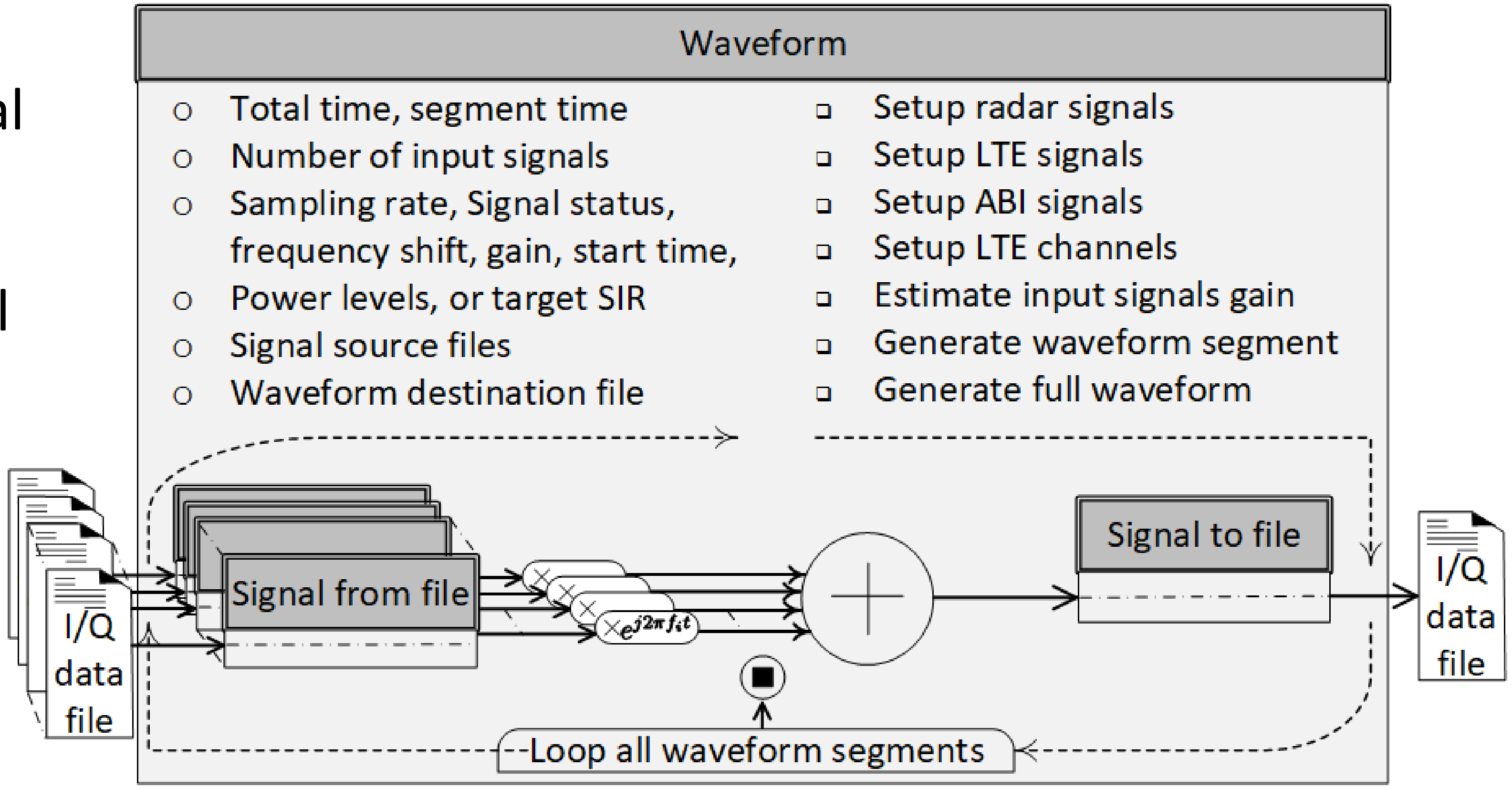
Decimation execution

- The decimation executor handles the task of processing multiple files
- To reduce the run time, the waveform files are processed in parallel



Waveform signal processing

- Creates an object with multiple signals (signal from file) and output signal (signal to file)
- Three types of signal files (radar, ABI, LTE with channel effect)
- Number of each signal type
- Parameters of each signal
- Generate a waveform segment for preview
- Generate full waveform up to total time and save to a file and measure the instantaneous SIR



Waveform object example

An example of a waveform object used by the waveform generator with certain waveform parameters:

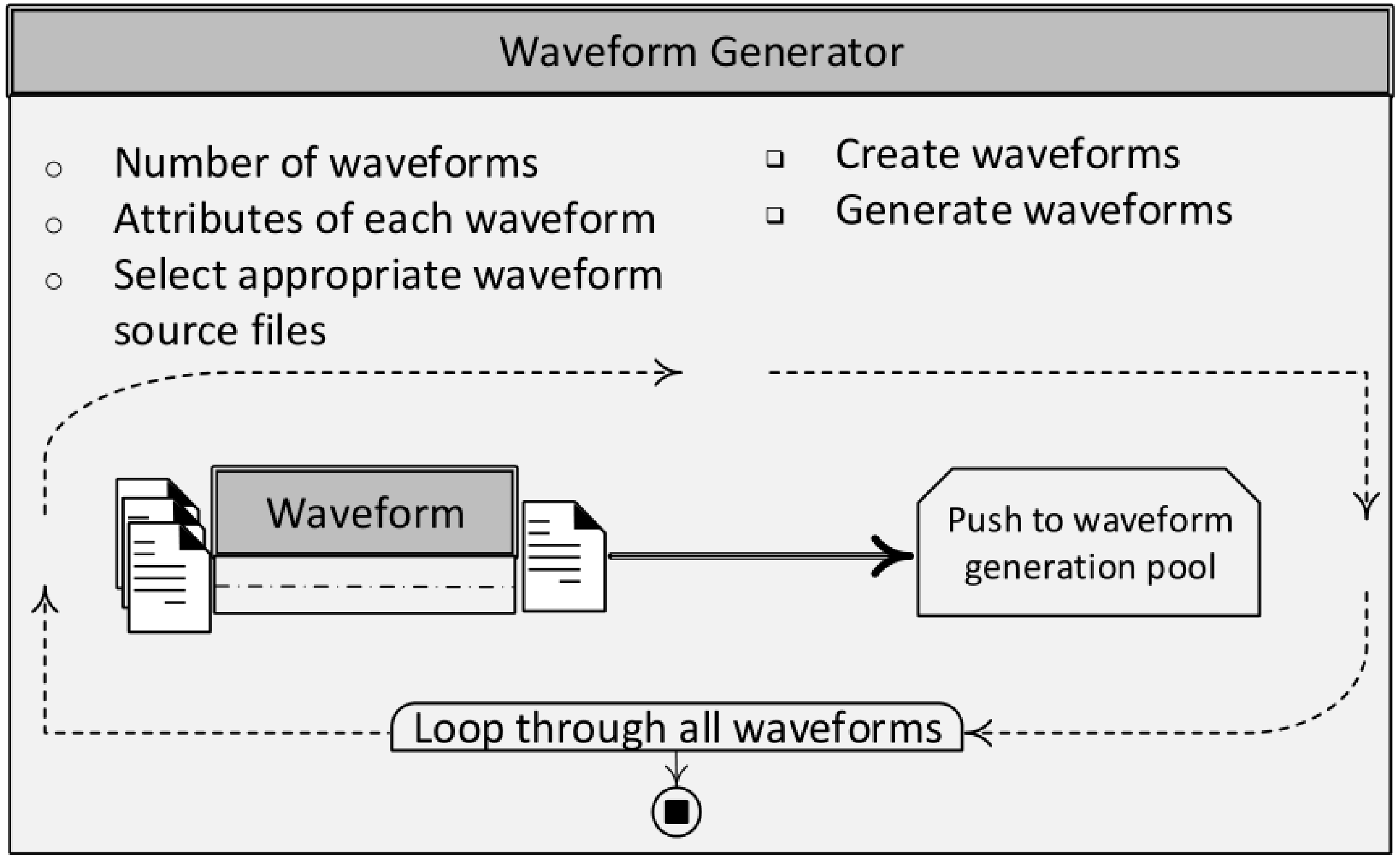
- 90-second waveform with two radars starting at 5 seconds and 11 seconds
- Gains are set according to desired power levels
- After the generation process all the object parameters, instantaneous SIR values, and signal sources are saved in JSON format for easy access

```
waveform with properties:

                   Fs: 25000000
    samplesPerSegment: 2500000
            totalTime: 90
      numRadarSignals: 2
          radarStatus: [1 1]
       radarStartTime: [5 12]
          radarSignal: [1×2 radarSignalFromFile]
            radarGain: [0.000425696016324576 0.000304713328878698]
       radarFreqOffset: [0 10000000]
        numLTESignals: 2
            LTEStatus: [1 1]
         LTEStartTime: [0 0]
            LTESignal: [1×2 signalFromFile]
              LTEGain: [1.65507398254251e-06 1.57317975332633e-06]
         LTEFreqOffset: [-5000000 5000000]
           LTEChState: 0
            LTEChType: {'EPA5Hz'  'EVA5Hz'}
           LTEChannel: [1×1 threeGPPChannel]
        numABISignals: 1
            ABIStatus: 0
         ABIStartTime: 0
            ABISignal: [1×1 radarSignalFromFile]
              ABIGain: 0.0316227766016838
         ABIFreqOffset: 0
           AWGNStatus: 0
              AWGNVar: 0
      writeScaleFactor: 1218500000
       waveformToFile: [1×1 signalToFile]
              success: []
    gainEstimateMethod: 'Power Levels'
       PowerLevels_dBm: [1×1 struct]
            targetSIR: 25
        measParameters: [1×1 struct]
             SIRdBmin: []
             SIRdBmax: []
            SIRdBmean: []
              SIRData: [1×2 struct]
            signalOut: []
            errorColl: []
```

Waveform generation

- Handles multiple waveform generation process sequentially or in parallel
- Tracks waveform parameters
- Tracks signals sources and output files



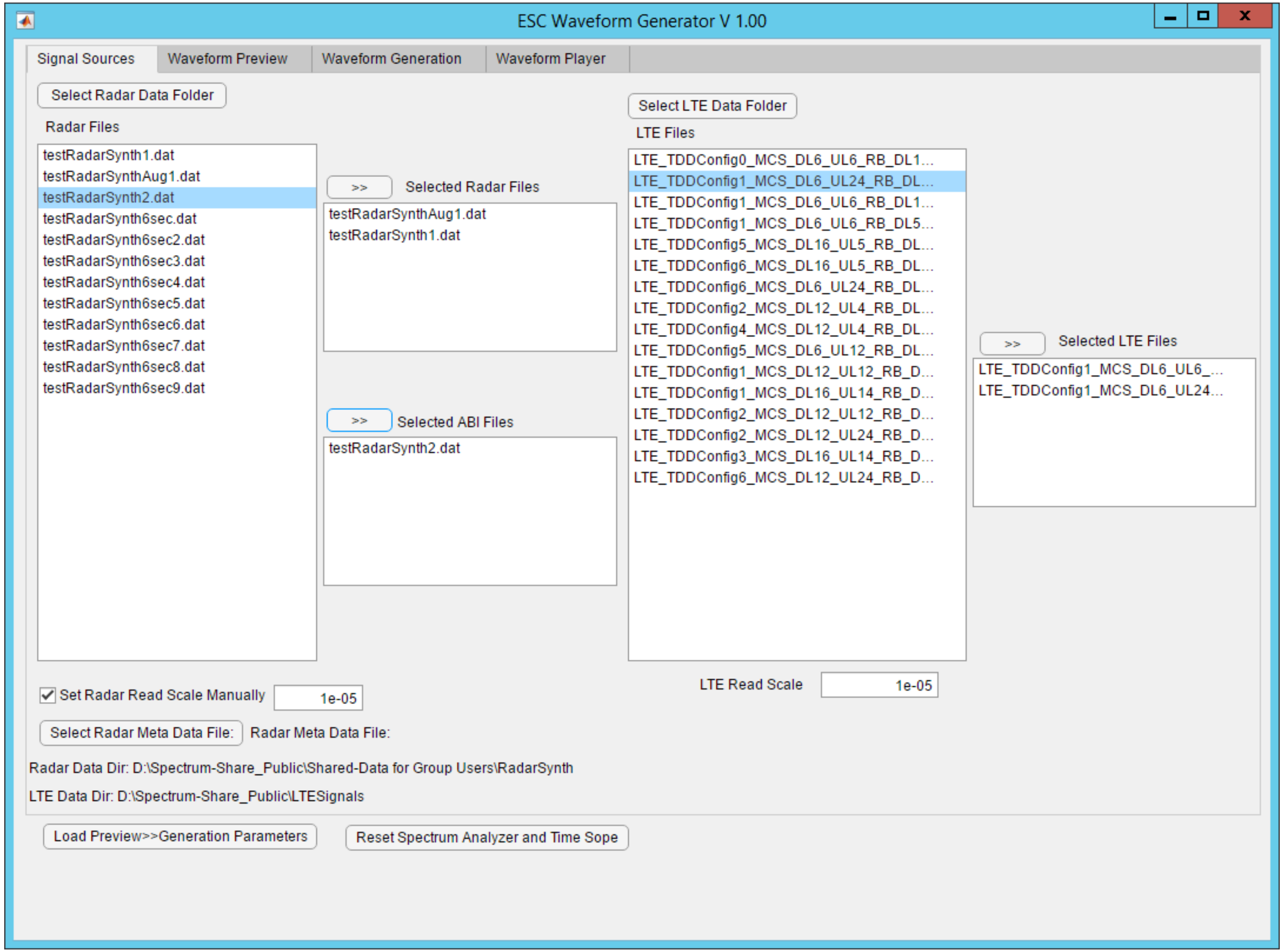
GUI waveform generation

The GUI provides a convenient way to access all the generation parameters

- Select signal sources
- Change frequencies, gains, turn ON/OFF signals
- Instantaneous preview of the waveform
- Set specific power levels, or desired SIR
- Generate parameters by randomization or with predefined intervals
- Generate multiple waveform files

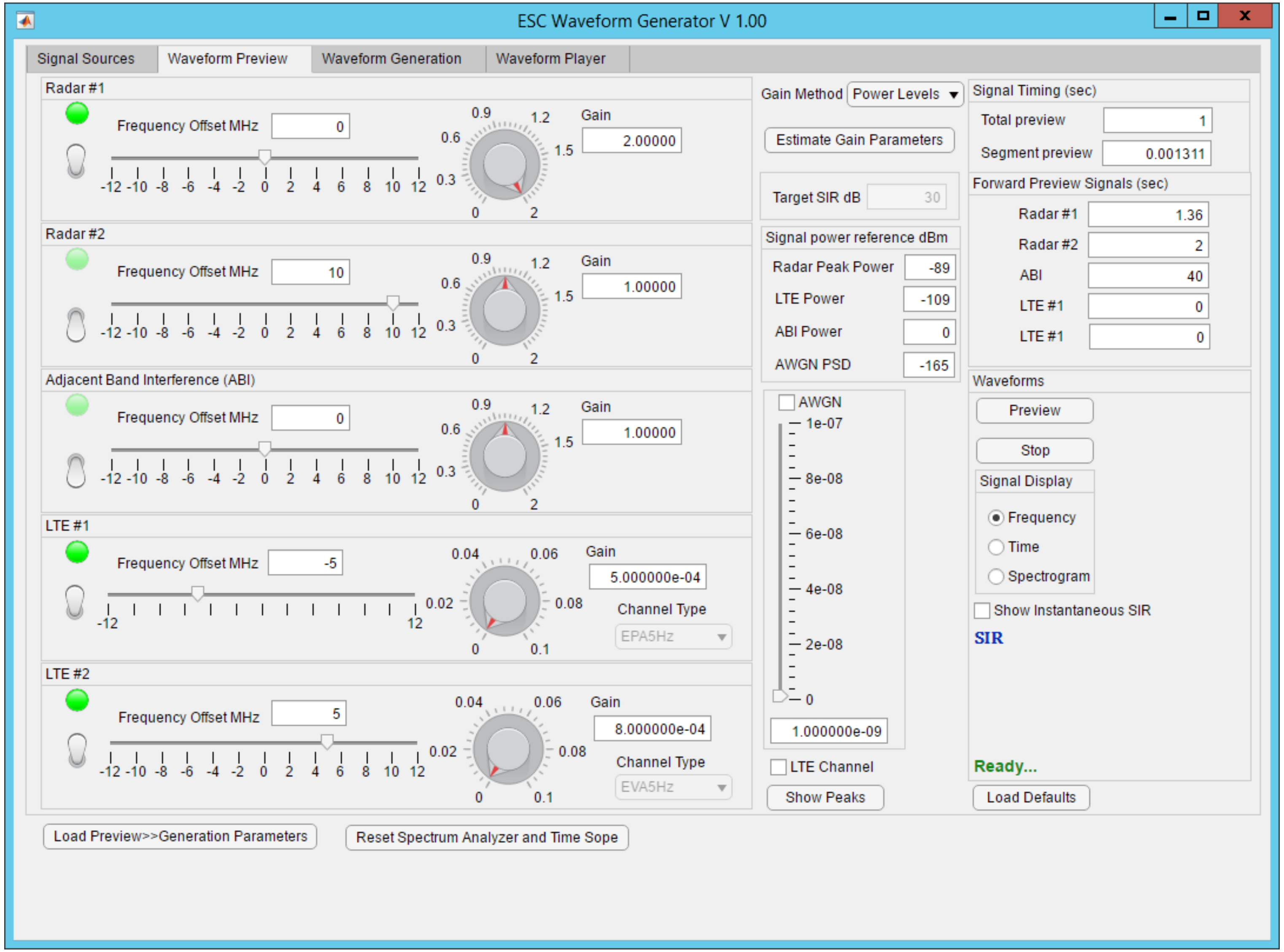
Signal Sources Panel

- Select signal source paths
- Add desired files to the selection boxes
- Selected files will be used for waveform preview and single file generation



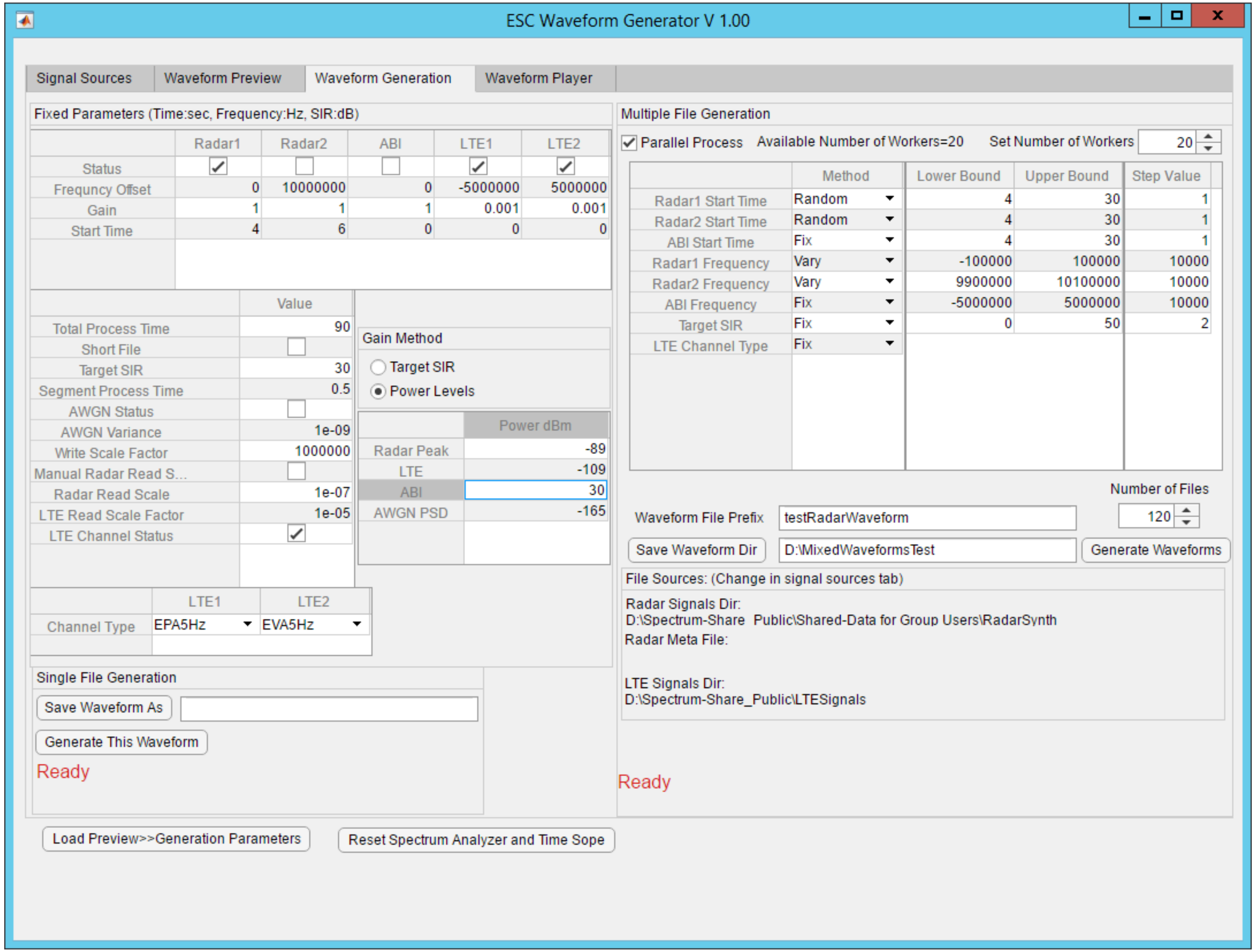
Waveform Preview Panel

- The GUI mixes two radar signals, one ABI signal, two LTE signals with different channel settings, and an optional AWGN signal
- Preview panel provide access to all signal parameters (Status, Gain, Frequency)
- Demonstrates the waveform before the generation process
- Estimate gains based on the desired power levels or target SIR
- Access to spectrum analyzer/ spectrogram and time scope during preview



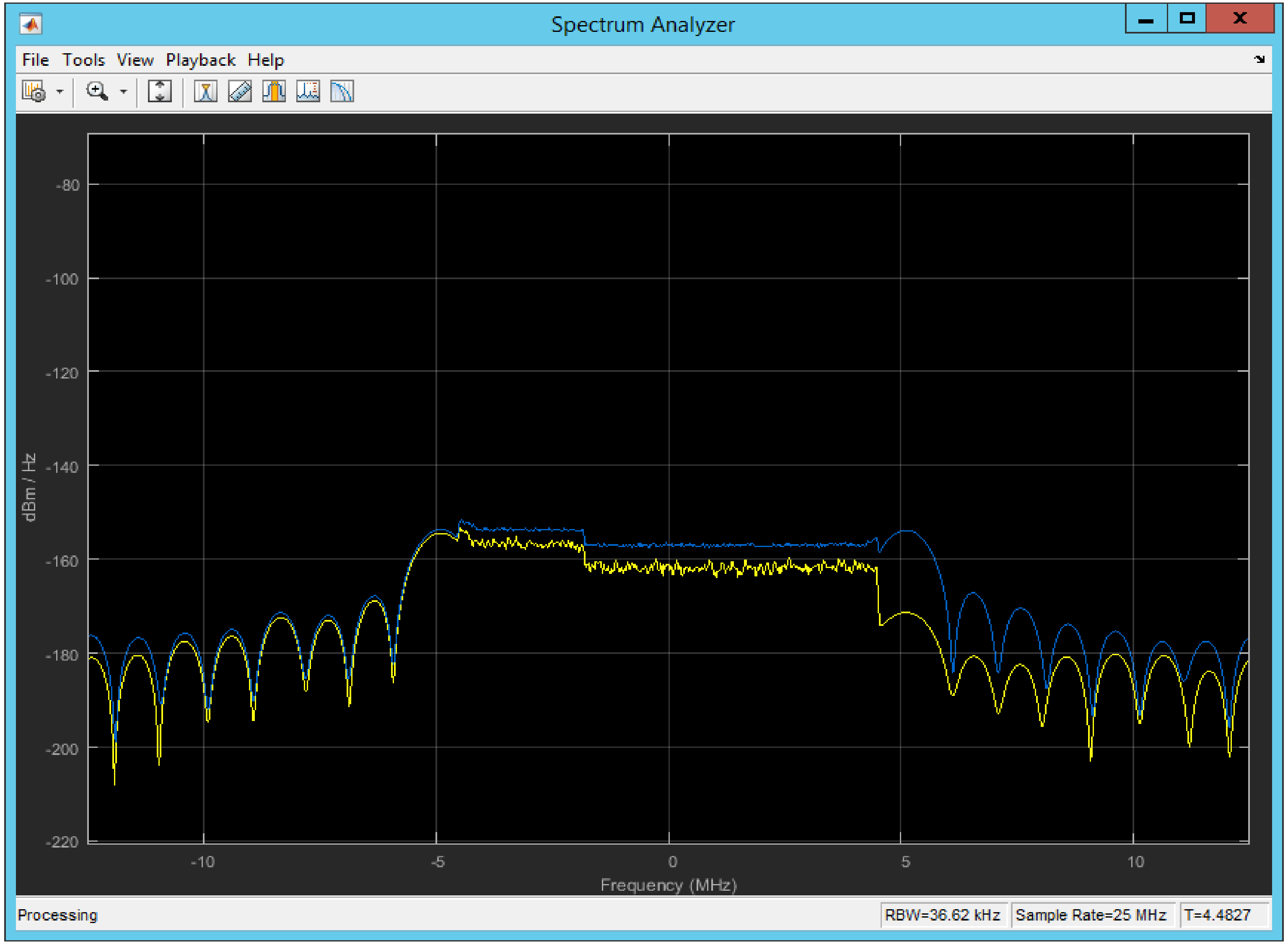
Waveform Generation Panel

- Load all the preview parameters in one place
- Provide capability to edit/modify parameters in one place
- Generate single or multiple files
- Turn On/Off parallel processing



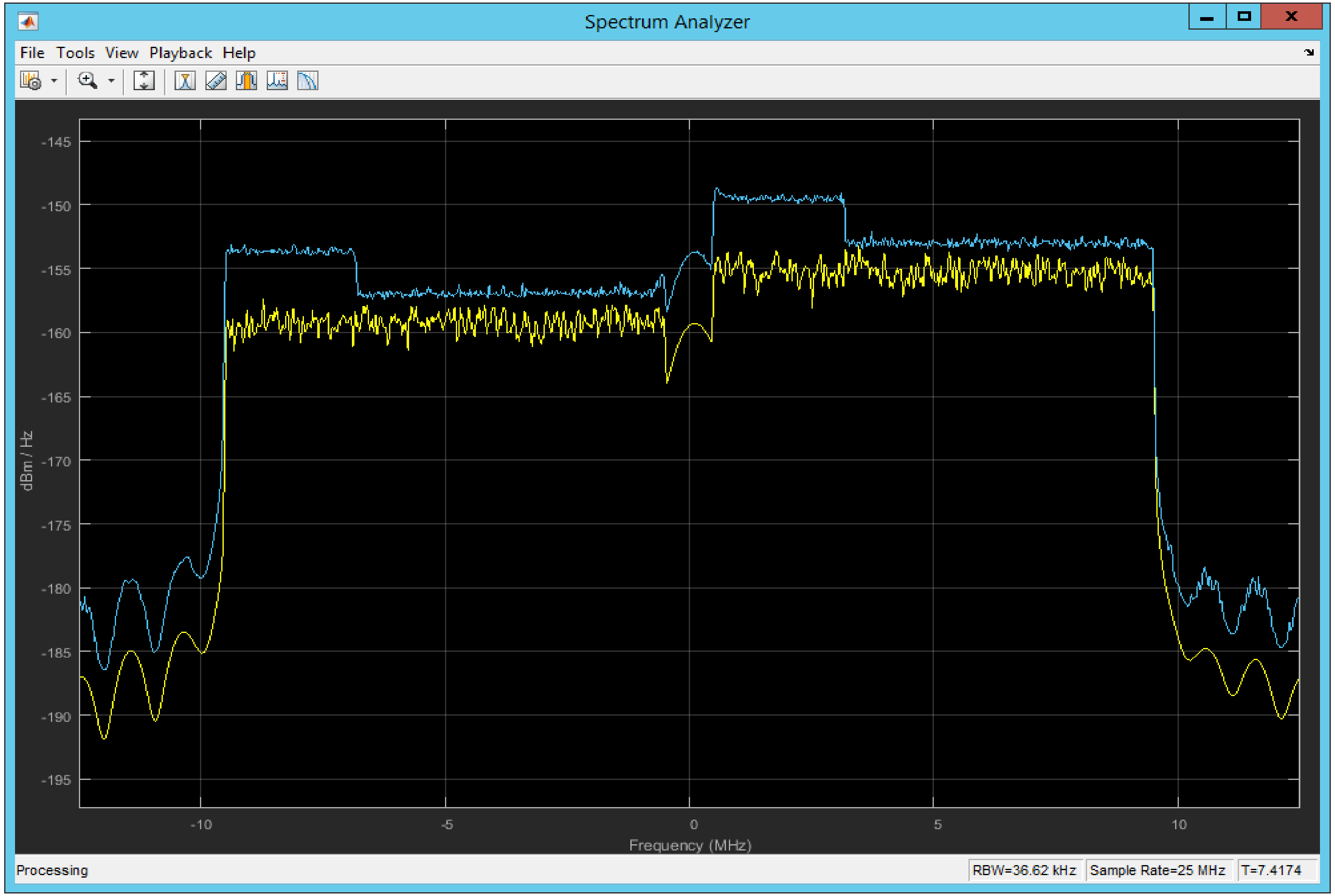
Waveform Preview Demonstrations

- For the purpose of this demonstration, we use a synthetically generated radar signal
- Two radar signals at -5 MHz and +5 MHz and One LTE TDD centered at 0 Hz



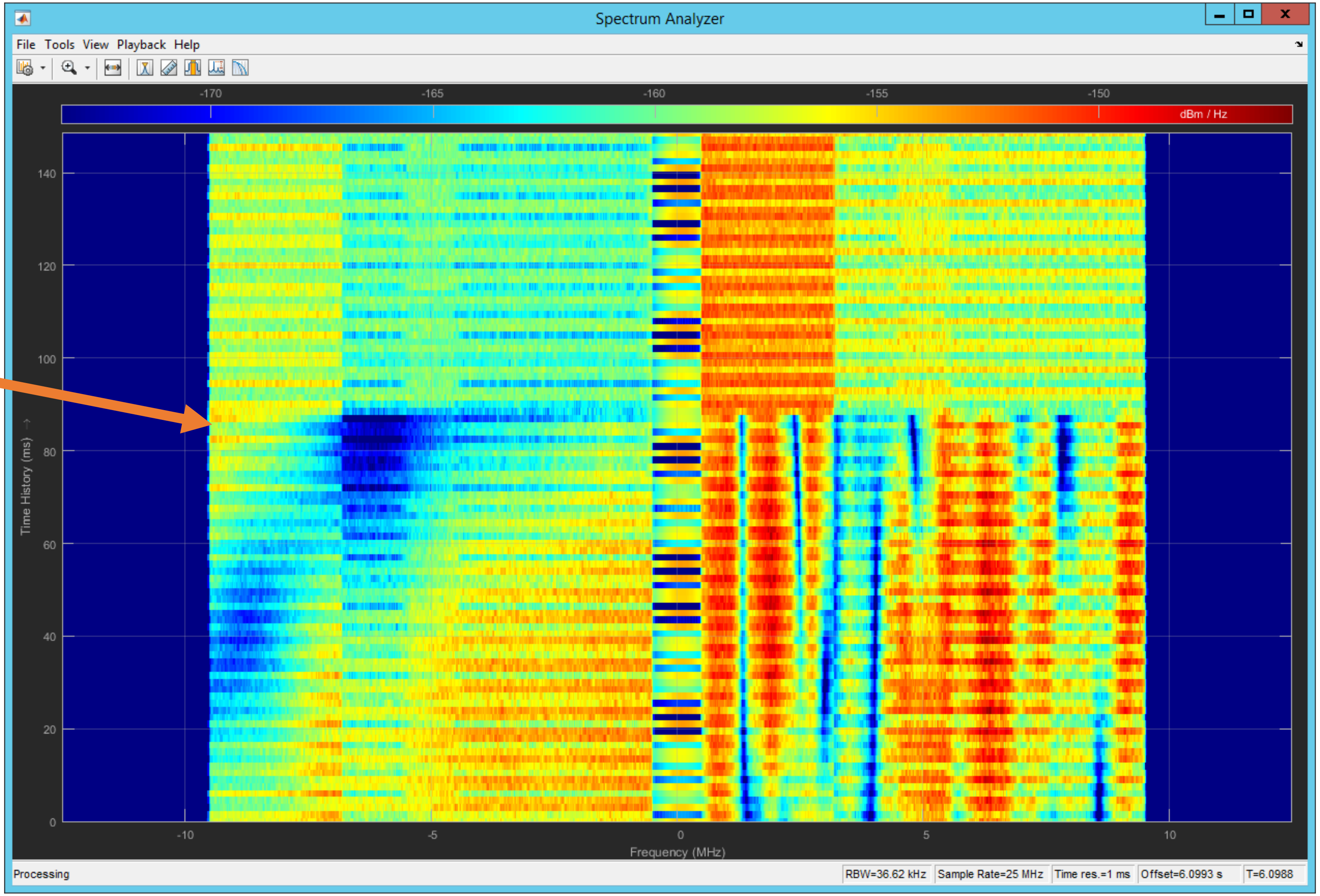
Waveform Preview Demonstrations

- Spectrum of two LTE TDD signals with one radar signal at the center
- Spectrum/ Spectrogram/ and time scope panels keeps previewing the waveform while the engine keeps sampling and mixing the signals until the end of the preview time



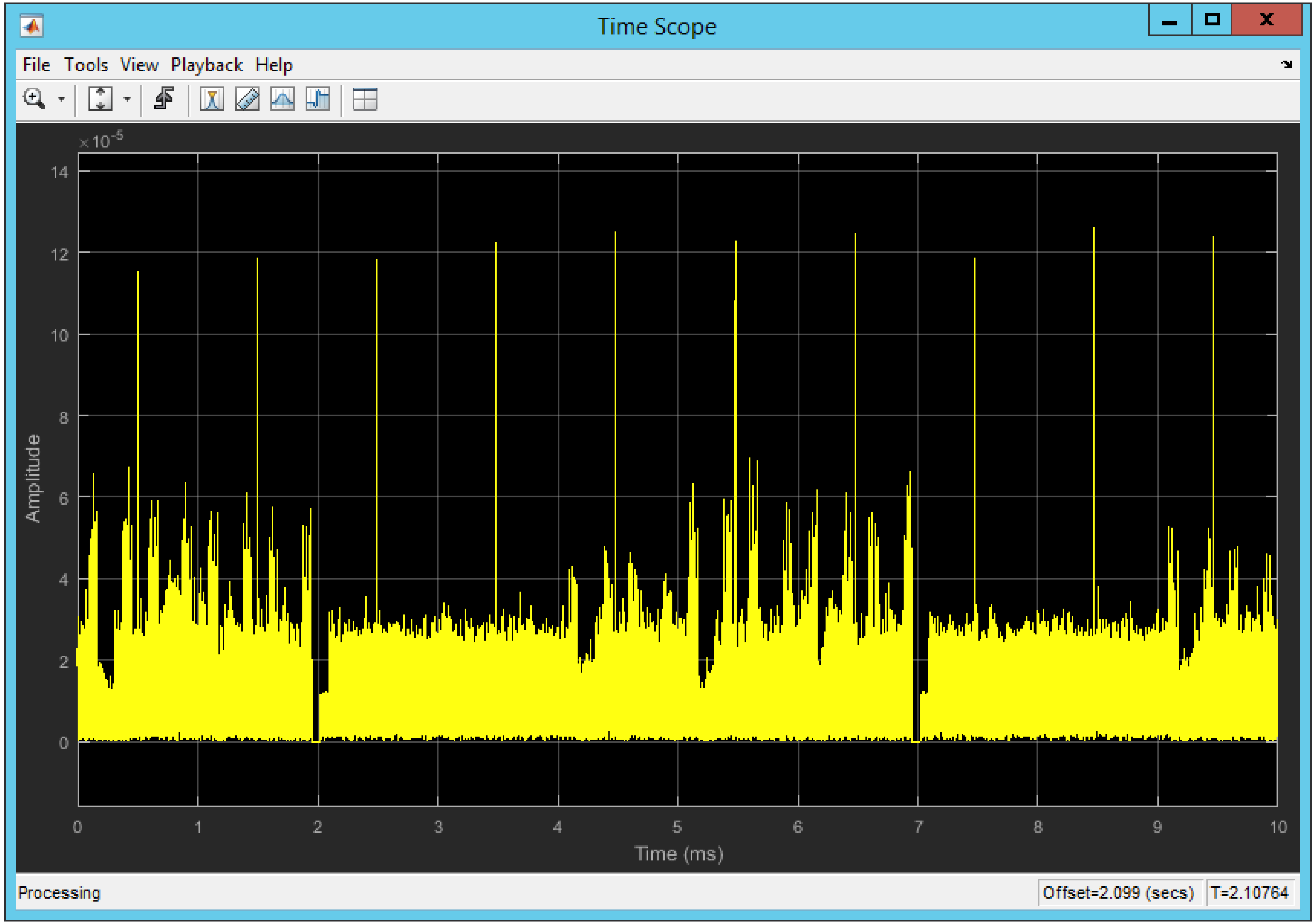
Waveform Preview Demonstrations

- Spectrogram of the waveform
- Radar at zero center frequency
- The LTE channel was turned ON in the middle of the preview process



Waveform Preview Demonstrations

- Time scope showing the LTE TDD signals and the radar signal pulses



Concluding Remarks

- CBRS spectrum sharing requires ESC sensor deployment to detect and report the presence of federal incumbent radar
- Some characteristics of the actual incumbent radar signals are difficult to generate
- Utilize field-measured radar waveforms
- Waveform generation with certain power levels or SIR values for testing and development of incumbent radar detection algorithms
- Framework and signal processing block to handle signal mixing and generation process
- GUI to demonstrate the waveform and automate the generation process
- The GUI tool is deployable and can run without licensed software

Questions?

Source Code: https://github.com/usnistgov/ESCWaveformGenerator.git

Contacts: Raied Caromi, raied.caromi@nist.gov

John Mink, john.mink@nist.gov

Michael Souryal, michael.souryal@nist.gov