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Setting Thresholds for the RMS-Energy Oscillation Detector

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Jim Follum

U.S. DEPARTMENT OF ENERGY BATTELLE

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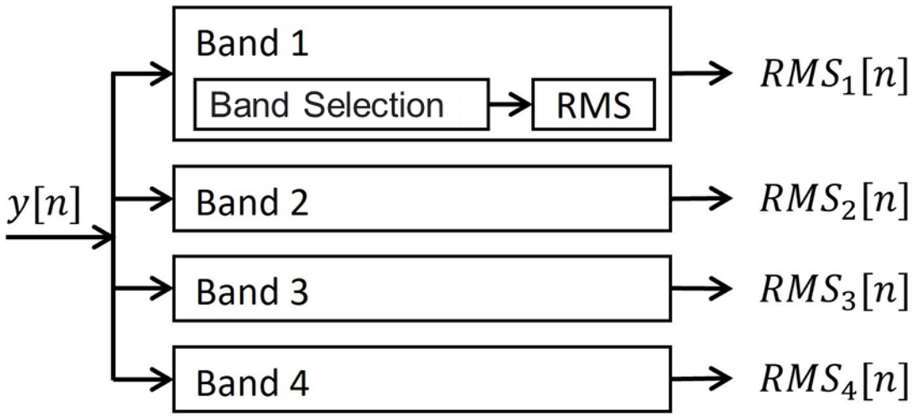
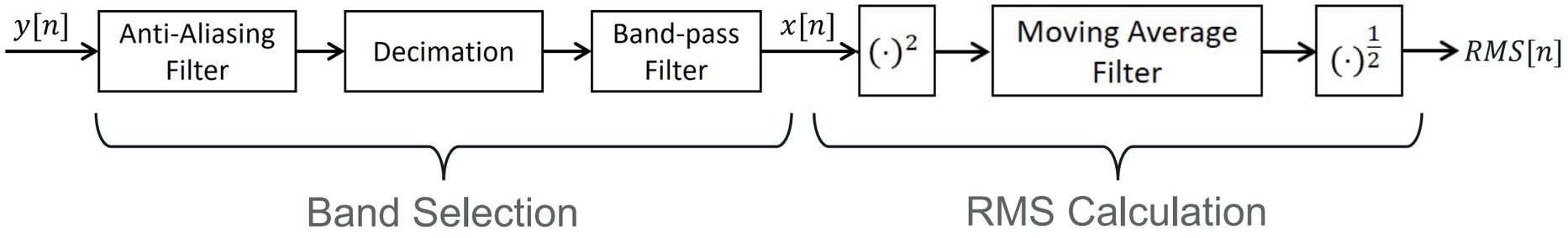
Motivation and Objective

- Good oscillation detection performance is critical for tool adoption and supports reliable system operation
- Commercial RMS-energy detectors trigger alarms when the PMU signal's RMS-energy remains above a threshold for a certain duration
- A good RMS-energy threshold:
  - Avoids false alarms
  - Avoids nuisance alarms
  - Has predictable performance for oscillations of interest
- A good thresholding method:
  - Supports automation
  - Can be implemented readily
  - Does not require excessive time, compute power, or storage

RMS-Energy Detector



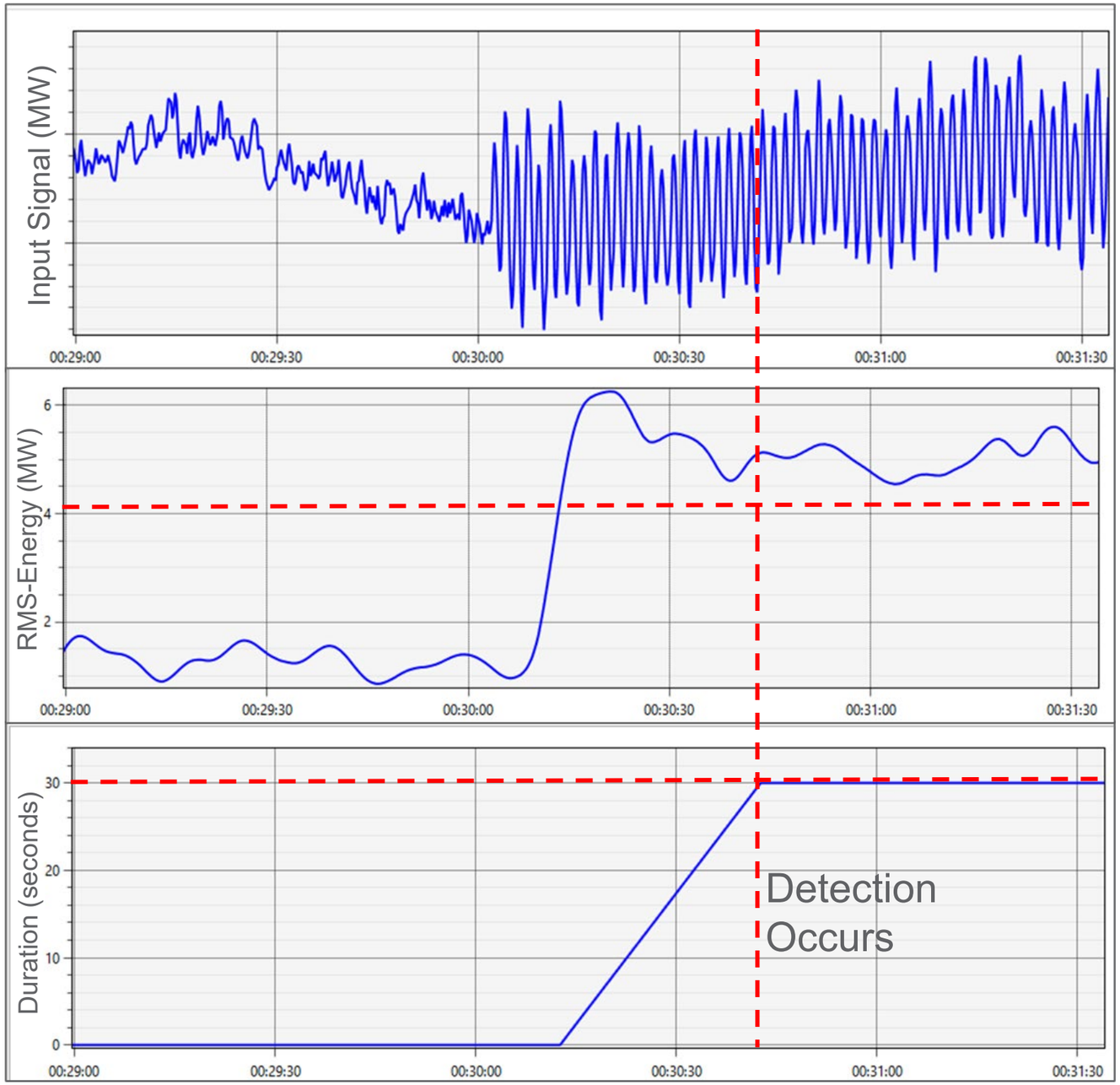
Band	Range (Hz)
1	0.01 – 0.15
2	0.15 – 1
3	1 – 5
4	5 – 15 or 30



TM. Donnelly, D. Trudnowski, J. Colwell, J. Pierre and L. Dosiek, "RMS-energy filter design for real-time oscillation detection," 2015 IEEE Power & Energy Society General Meeting, Denver, CO, USA, 2015, pp. 1-5, doi: 10.1109/PESGM.2015.7286192.

RMS-Energy Detector

Detection occurs when the RMS-energy exceeds a threshold for a specified period



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Current Industry Practice

- Calculate RMS-energy for historical ambient conditions
- Establish a threshold as the energy's mean plus 3 or 4 standard deviations
- Evaluate on >3 months of data

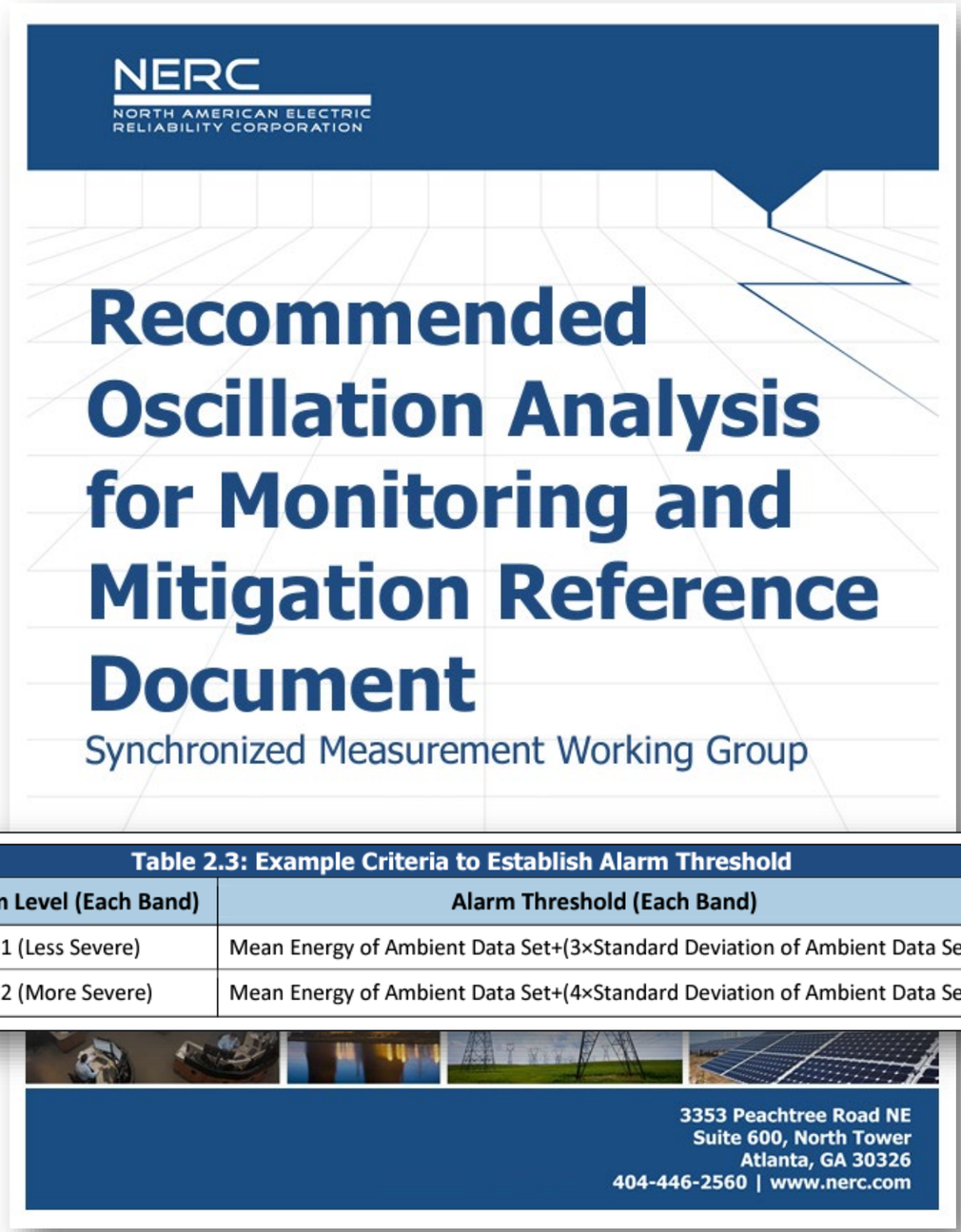


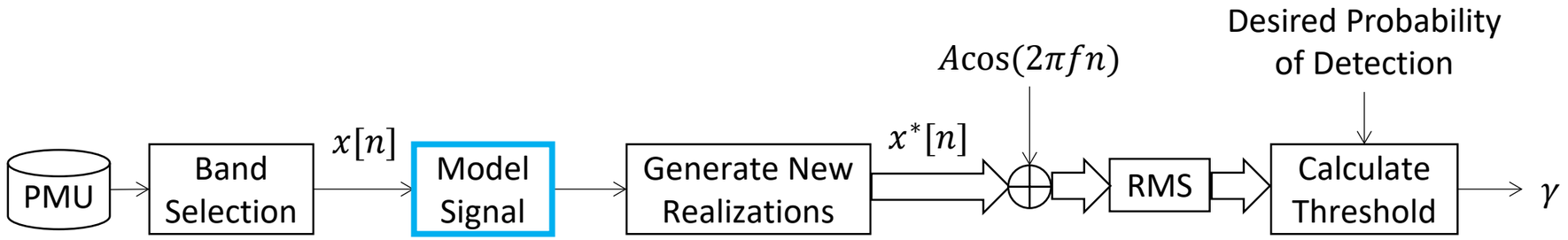
Table 2.3: Example Criteria to Establish Alarm Threshold

Alarm Level (Each Band)	Alarm Threshold (Each Band)
Level-1 (Less Severe)	Mean Energy of Ambient Data Set+(3×Standard Deviation of Ambient Data Set)
Level-2 (More Severe)	Mean Energy of Ambient Data Set+(4×Standard Deviation of Ambient Data Set)

Proposed Approach

- Build a statistical model of each signal using a limited amount of ambient data
- Bootstrapping: use the model to generate new realizations of synthetic ambient data
- Add oscillations of various sizes
- Run RMS-energy detector with the duration requirement
- Determine threshold that provides desired performance

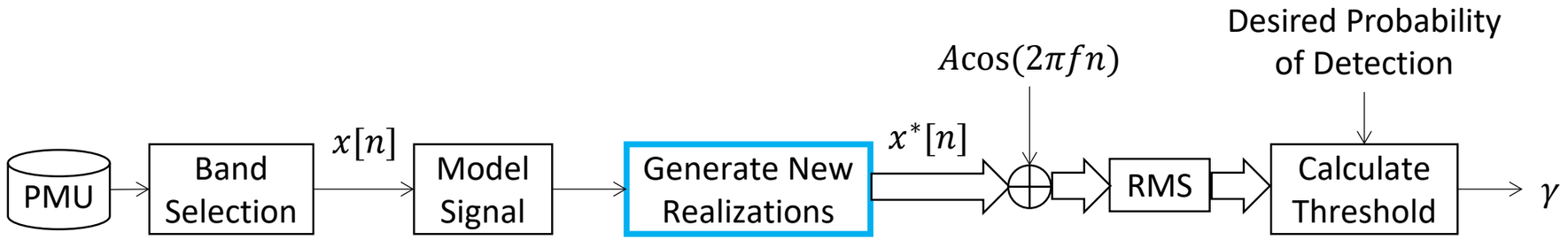
Bootstrap-Based RMS-Energy Thresholds



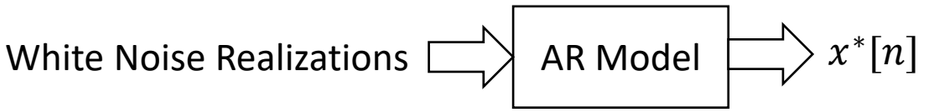
- Represent $x[n]$ as the output of an AutoRegressive (AR) model

- Uses a classic approach based on least-squares curve fitting

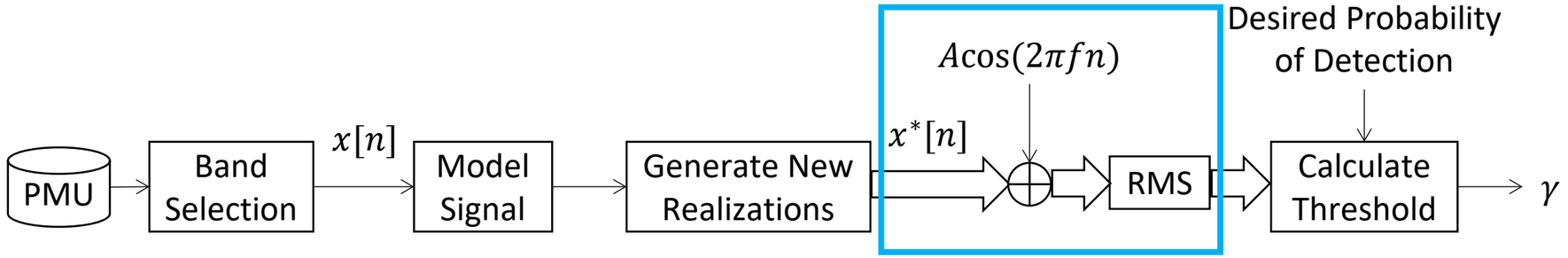
Bootstrap-Based RMS-Energy Thresholds



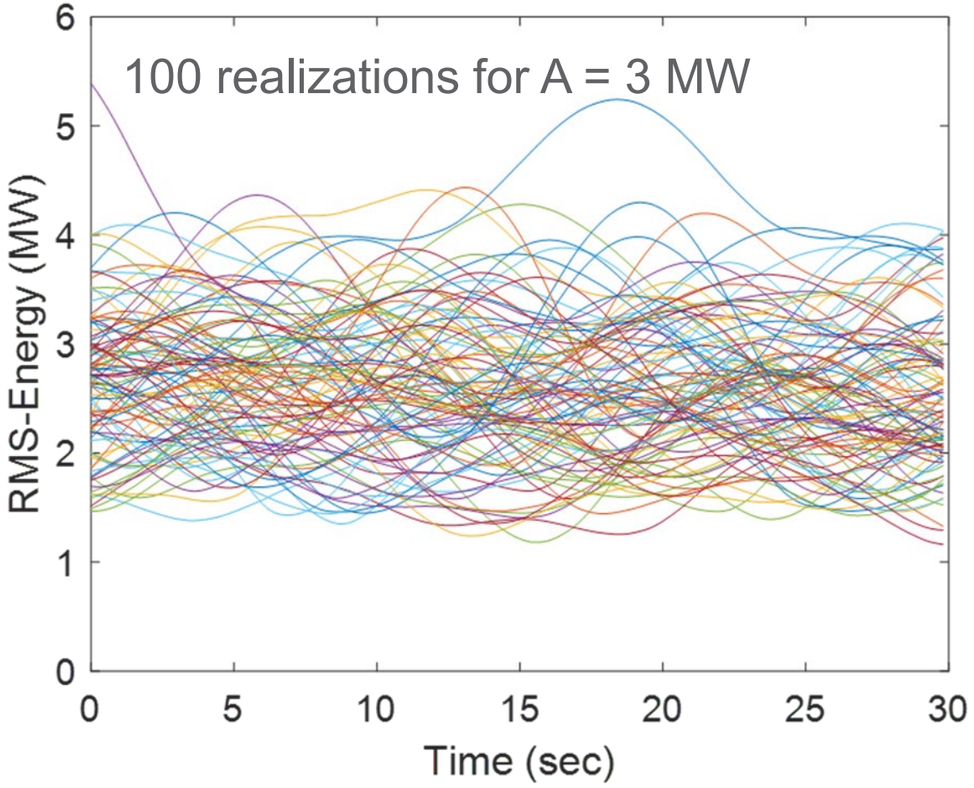
- Bootstrapping uses information from a statistical sample to generate new realizations
- For each signal model, 100 realizations of $x^*[n]$ are generated



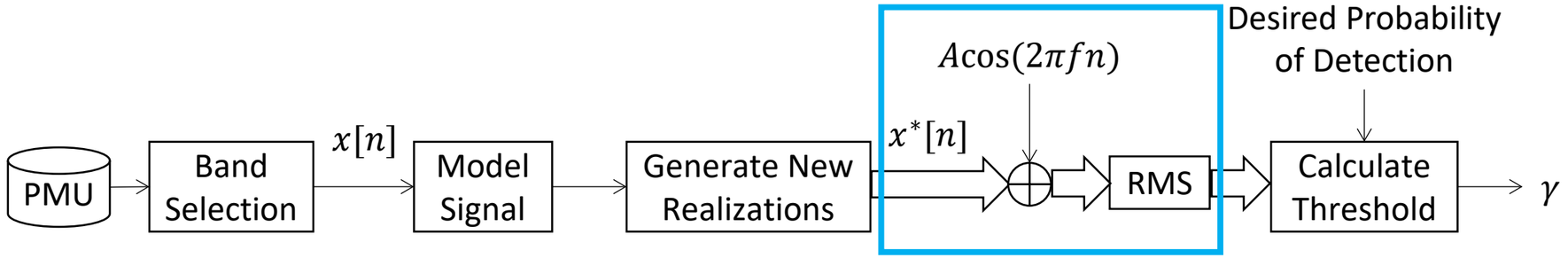
Bootstrap-Based RMS-Energy Thresholds



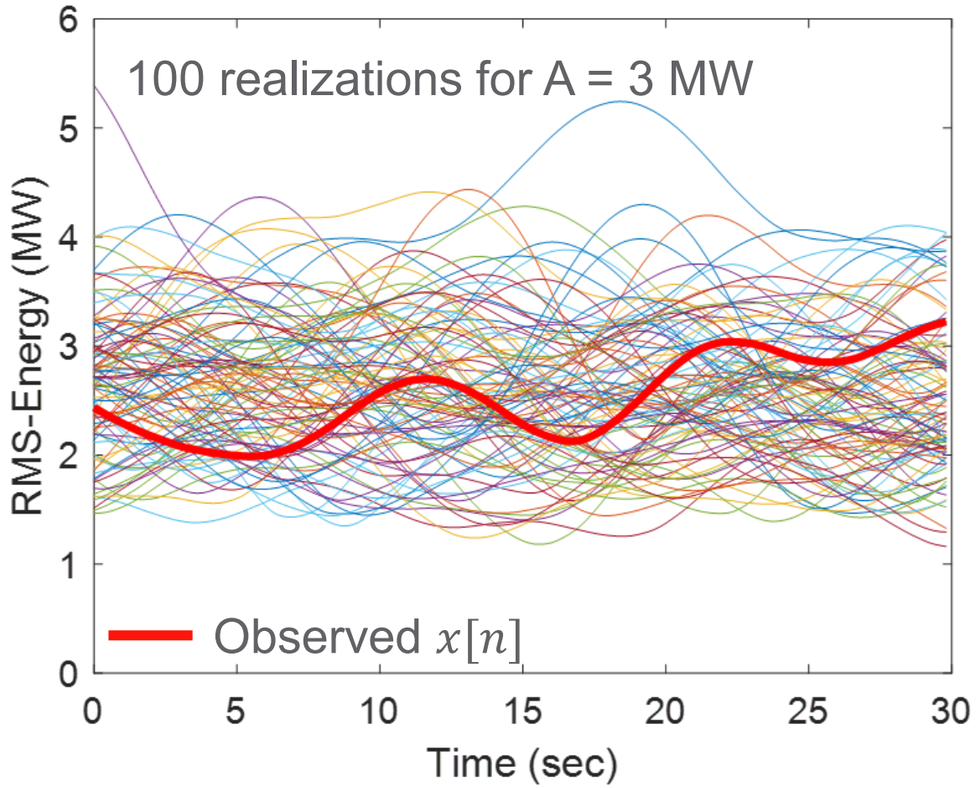
- Add oscillations of various amplitudes
- Calculate the RMS-energy



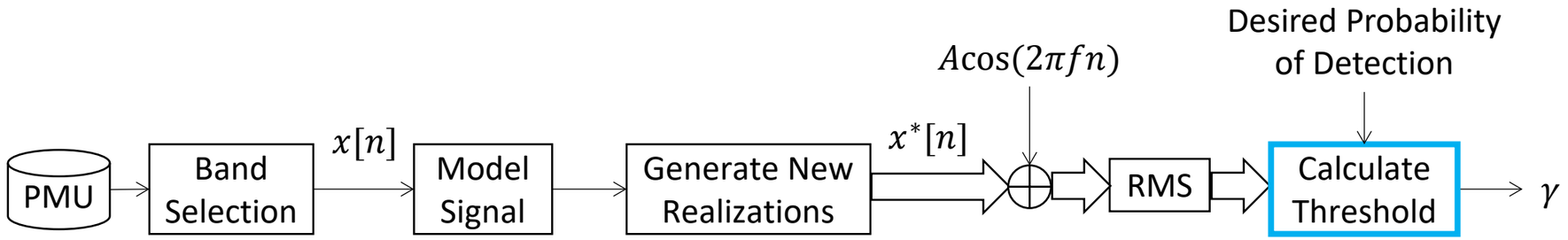
Bootstrap-Based RMS-Energy Thresholds



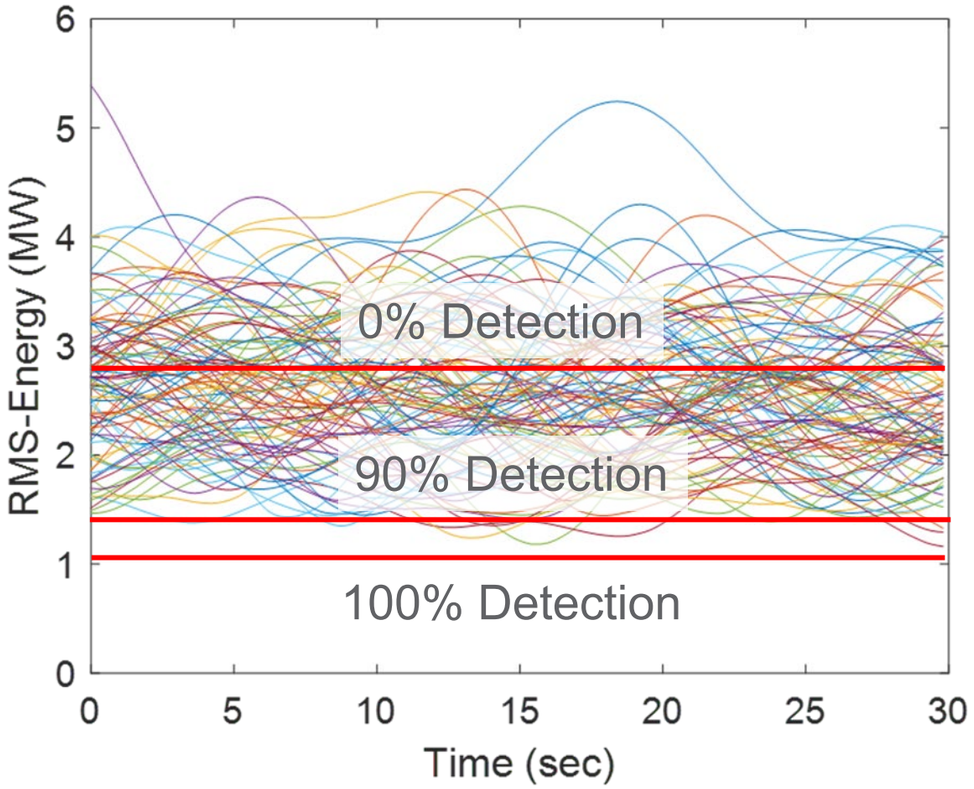
- Add oscillations of various amplitudes
- Calculate the RMS-energy
  - Due to the use of a statistical model, the RMS-energy of the $x^*[n]$ realizations can be more extreme than the RMS-energy of the observed $x[n]$



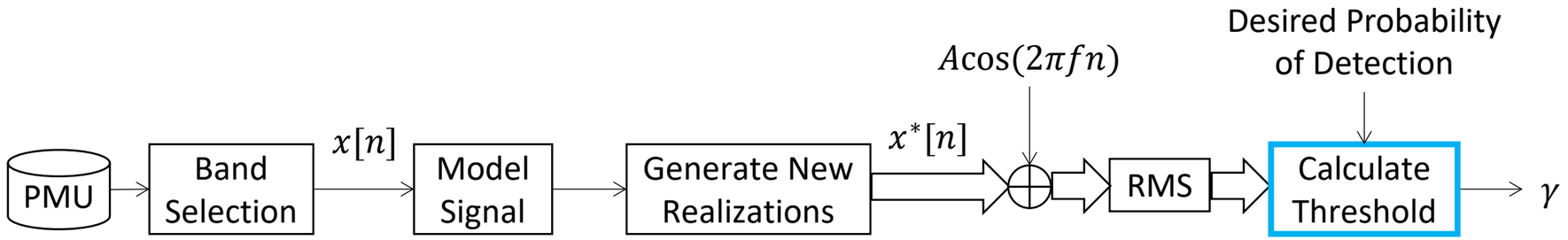
Bootstrap-Based RMS-Energy Thresholds



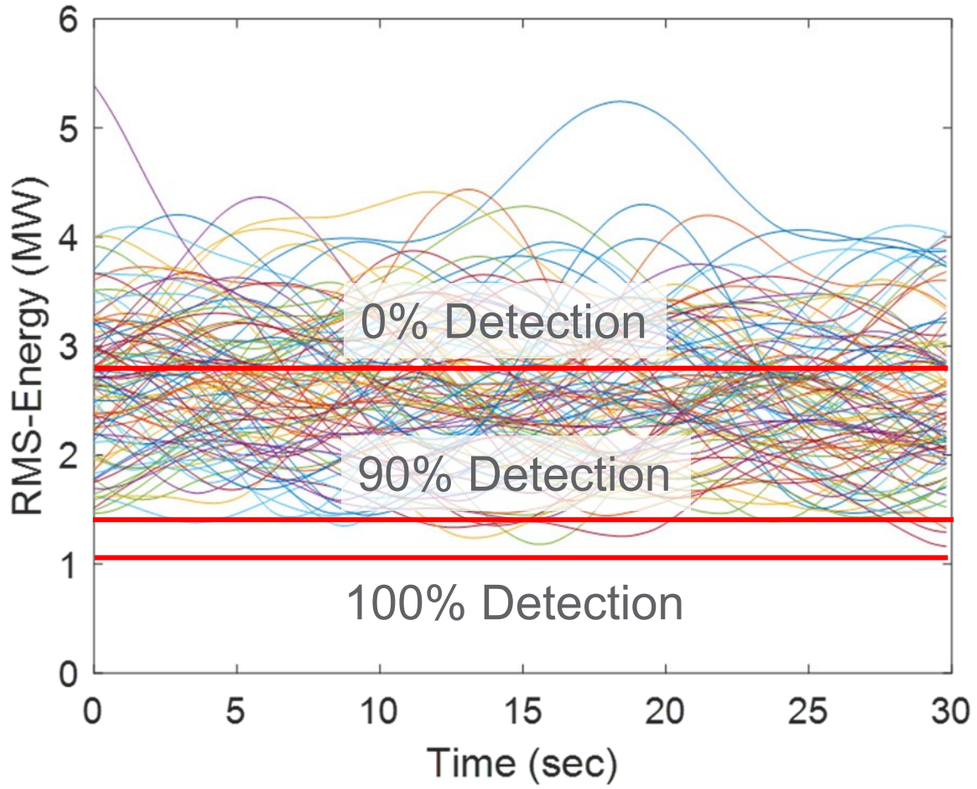
- Determine the threshold by considering the probability of detecting oscillations of various amplitudes
- In practice, this is done for realizations from several different AR models capturing various operating conditions



Bootstrap-Based RMS-Energy Thresholds



- User input:
  - Nuisance amplitude, e.g., 3 MW
  - Max probability of detection, e.g., 0.1%
- Algorithm output:
  - Threshold that limits nuisance alarms
  - Summary of oscillations expected to be detected with various probabilities, e.g., 50%, 90%, 99.9%



BPA/DOE Archive Walker

Archive Walker Projects

Please Select Results Storage Directory

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Add Project

- FO Task Force Demo
- Analysis
- NASPI
  - Design Thresholds
  - Design Thresholds 2

Coordinates | Settings | Results | Signal Inspection

Available Results: 01/01/2010 00:00:00 - 01/02/2010 23:59:00

Forced Oscillations | Out of Range Events | Ringdowns | Wind Ramps | Mode Meter | FRM | VRM | Voltage Schedule | RMS Thresholding

Search Start Time: 01/02/2010 00:00:00 Search End Time: 01/02/2010 23:59:59

Detector: Detector 2

Save Path: C:\Users\foll154\OneDrive - PNNL\Documents\DTSA\SOCO\ConfiguringThresholds\Tir

File Name: ThreshB2 .mat

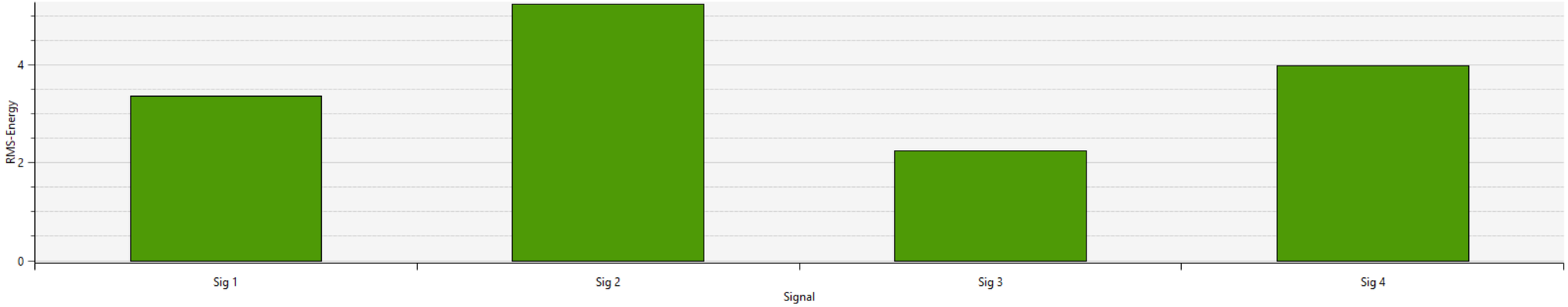
Nuisance Amplitude: 3 Probability of Detection: 0.001

Probabilities of Detection for Evaluation: 0.5,0.9,0.999 (separate entries with a comma)

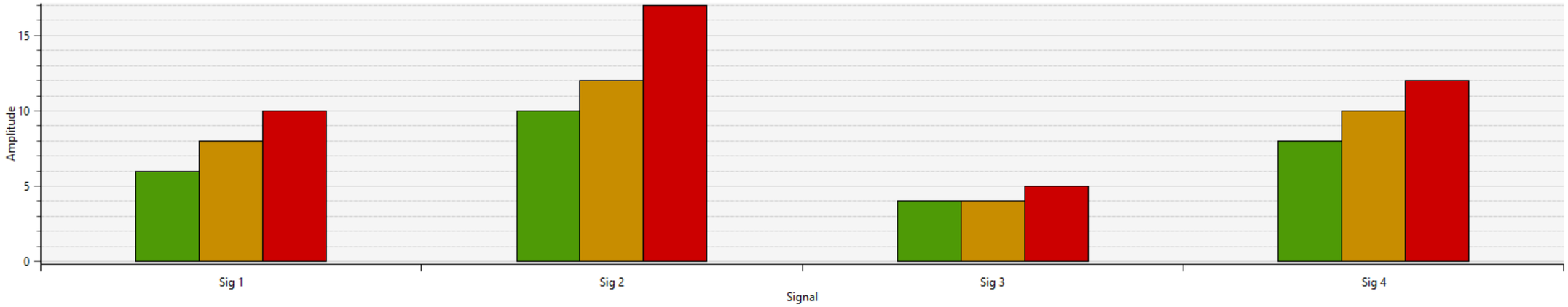
Generate Thresholds

Demo

Thresholds



Detection Performance



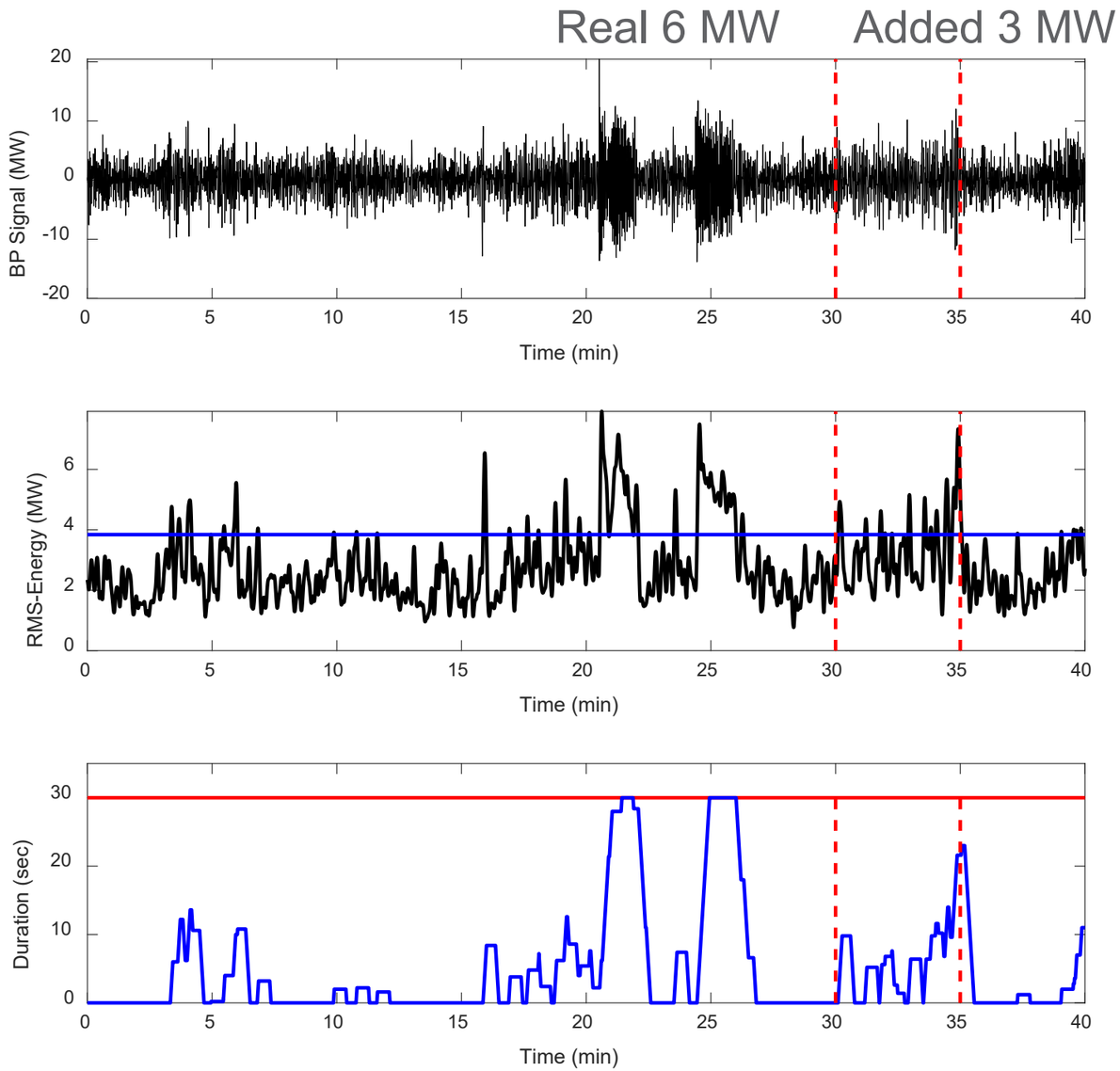
Utility Example

- Setup
  - 130 MW signals, 130 MVAR signals
  - 14400 realizations per frequency band
    - 48 hours of data from December 2023
    - AR model for every 20-minute window
    - 100 trials per model
  - 4 frequency bands
- Processing
  - PMU analysis (bootstrapping): 3 hours
    - Storage: 1 GB
  - Generating thresholds: 15 seconds
- Thresholds validated using oscillation events gathered throughout 2024

Example 1

Expected Performance:

Amplitude (MW)	Detection (%)
3	< 0.1
7	≈ 50
9	≈ 90
12	≈ 99.9



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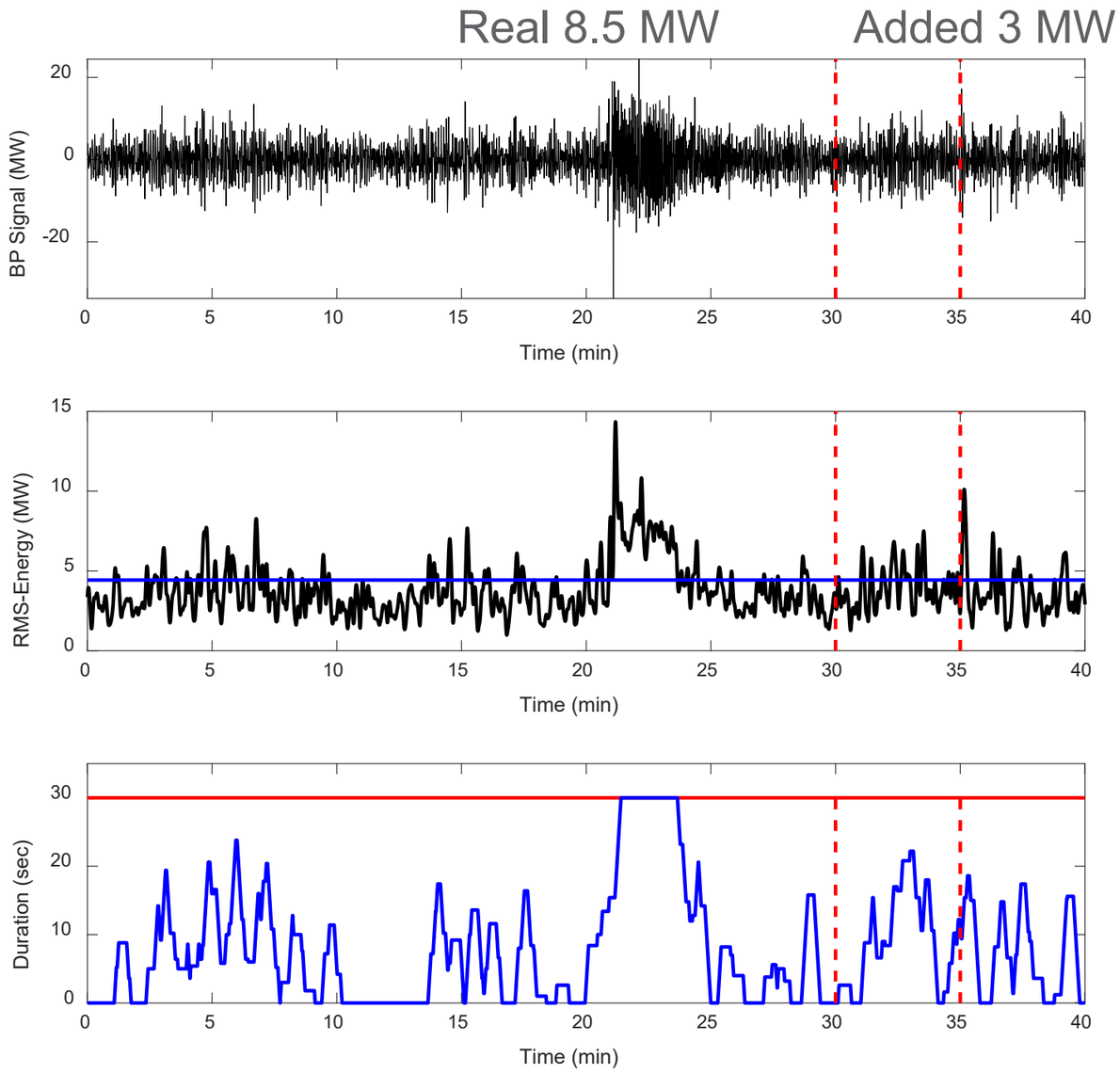
Example 2

Expected Performance:

Amplitude (MW)	Detection (%)
3	< 0.1
9	≈ 50
11	≈ 90
15	≈ 99.9



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Thank you