DOE/OE Transmission Reliability Program

Model Validation

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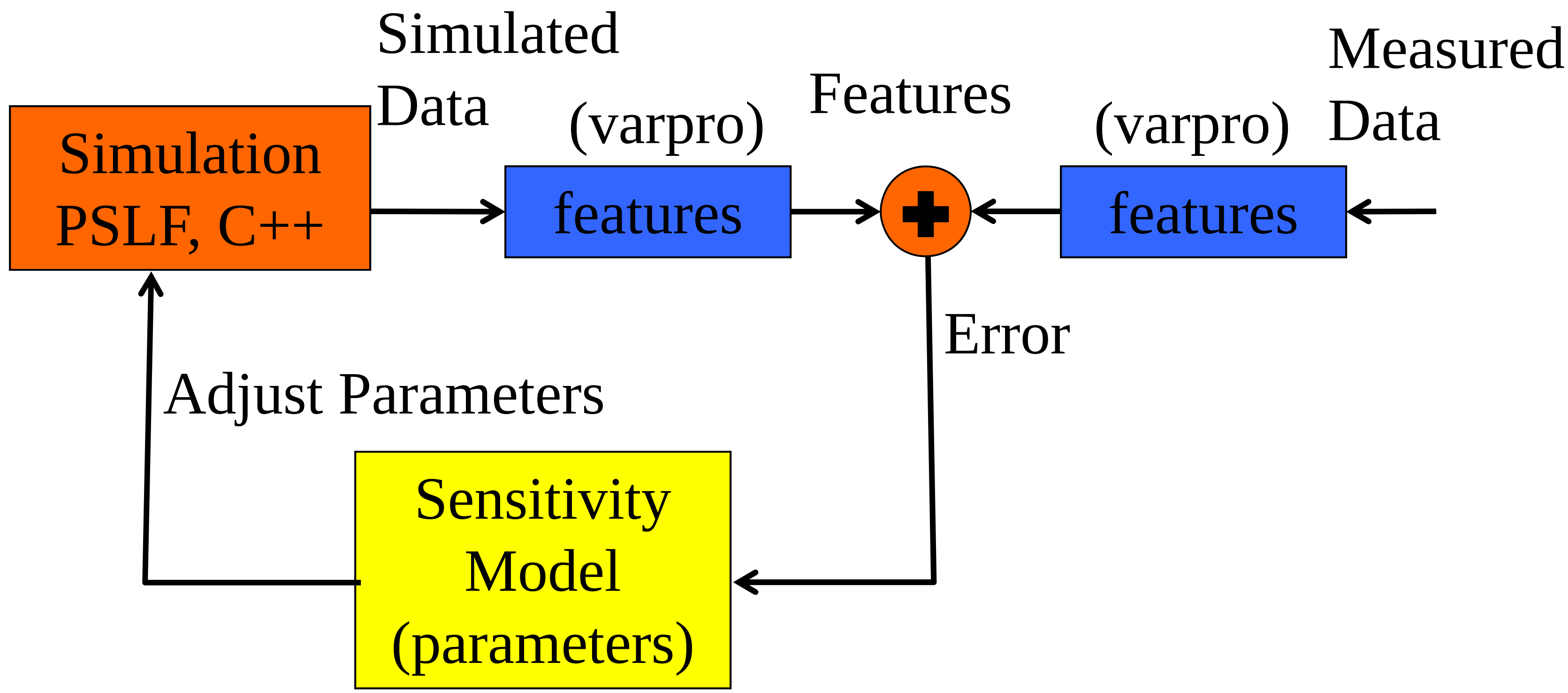
Project Objectives

To Develop techniques and tools for PMU- and feature-based power system model validation.

Background: Our prior proof-of-concept research demonstrated that feature-based sensitivity models can be used to calibrate power system dynamic models. This has been applied to FIDVR and System Disturbances. It is used for power plant validation.

Feature analysis also is informative about system fundamental characteristics.

Project Objectives



General Approach

Project Objectives

Current Research: Use PMU data to calibrate power plant models.

Current Tasks:

1. Complete Modal Ringdown Tool. (done)
2. Program Dedicated Power Plant Simulation
3. Perform Calibration Studies
4. Examine Parameter Identifiability
5. Technology Transfer
6. Oscillation Detection NEW!

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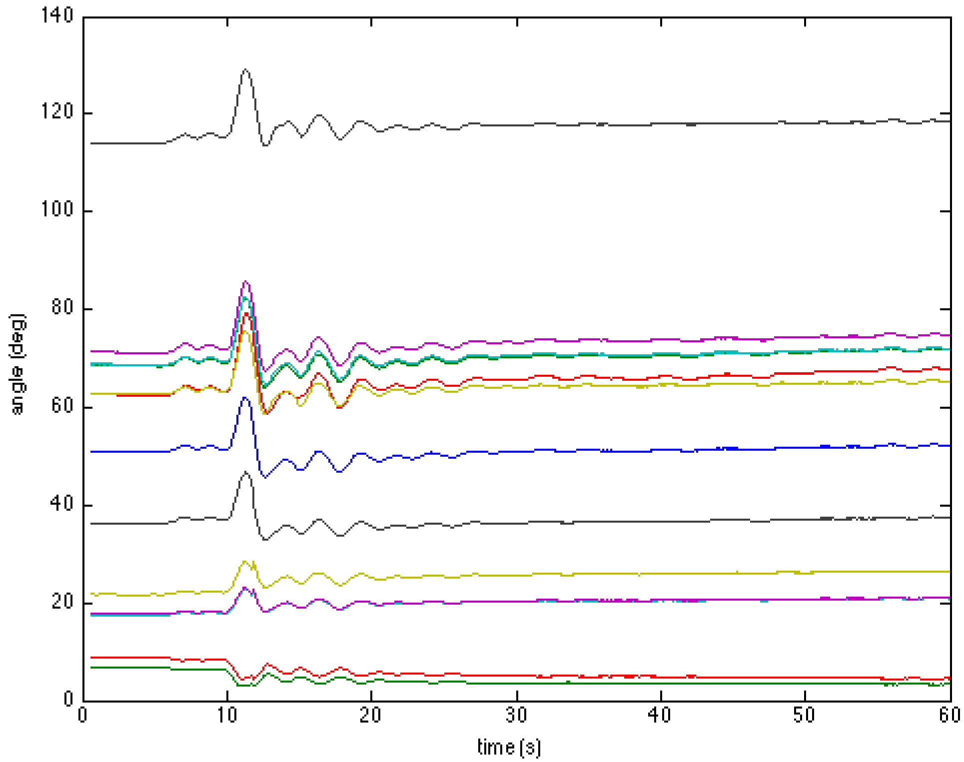
Major Accomplishments

- Completed Ringdown Analysis Tool
  - VAPRO-based Algorithm
  - Successful Tech Transfer:
    - BPA uses CERTS Matlab tool
    - Implemented in PowerWorld (expected public release in Version 18)
    - Under development at EPG
  - Additional Visibility
    - Prize Papers, 2012 and 2013 North American Power Symposium.
    - Paper accepted for publication in IEEE Transactions.
    - Technique used and taught at the University of Wisconsin and University of Illinois

Accomplishments

- Model Validation Coding
  - Power plant simulation coded in Matlab (slow)
  - Parameter sensitivity studies
  - Power plant simulation coded in C++ (fast)
  - Model validation studies
- Oscillation Detection
  - Preliminary investigation of matched filter approach, suggests further research and probable application

Ringdown Analysis Tool



Modes

- Frequency $\omega_i \left[\frac{rad}{sec}\right]$
- Damping $\sigma_i \left[\frac{rad}{sec}\right]$

Mode Shapes

- Amplitude A_i
- Phase ϕ_i $[rad]$

$$x(t) \approx \sum_{i=1} b_i e^{\lambda_i t} = \sum_{i=1} A_i e^{\sigma_i t} \cos(\omega_i t + \phi_i$$

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Nonlinear Method: VARPRO

$\alpha = [\alpha_1 , \ldots , \alpha_p]$ *Optimization variables (damping & frequencies)*

$\Phi(\alpha) = [\phi_1(\alpha) , \ldots , \phi_n(\alpha)]$ *Basis functions (sinusoids & exponentials)*

$\hat{y}(\alpha) = \Phi(\alpha)\, b$ $\quad r(\alpha) = y - \hat{y}(\alpha)$ $\Longrightarrow$ $b = \Phi(\alpha)^{\dagger} y$

$$\min_{\alpha} \tfrac{1}{2} \| r(\alpha) \|_2^2 = \min_{\alpha} \tfrac{1}{2} \| (I - \Phi(\alpha)\Phi(\alpha)^{\dagger})\, y \|_2^2$$

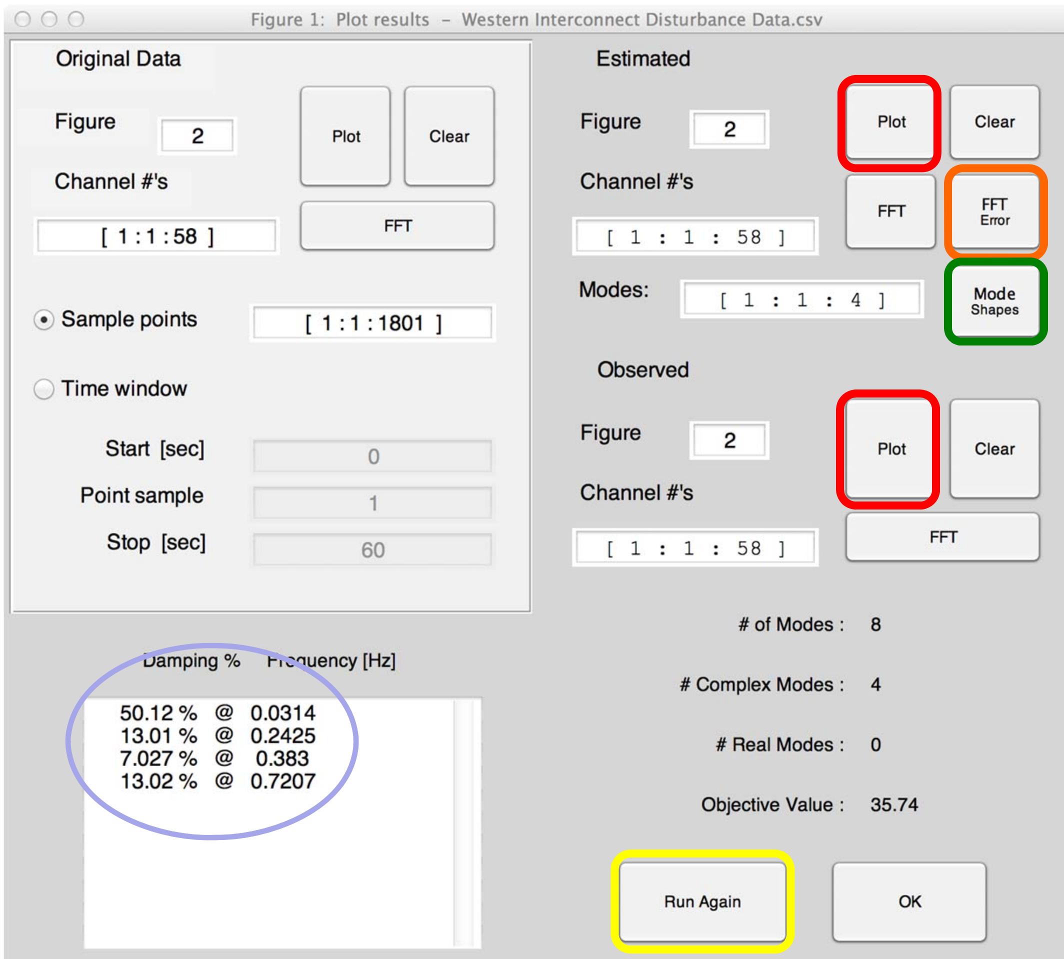
- Variable Projection Method
  - *"The Differentiation of Pseudo-Inverses and Nonlinear Least Squares Problems Whose Variables Separate,"* Golub and Pereyra (1973)

Gradient: $\nabla \tfrac{1}{2} \| r(\alpha) \|_2^2 = J^T r(\alpha)$ $\quad J = \left[\frac{\partial r(\alpha)}{\partial \alpha_1} \ \cdots \ \frac{\partial r(\alpha)}{\partial \alpha_p} \right]$

$$\frac{\partial r(\alpha)}{\partial \alpha_j} = -\left[\left(P^{\perp} \frac{\partial \Phi(\alpha)}{\partial \alpha_j} \Phi(\alpha)^{-} \right) + \left(P^{\perp} \frac{\partial \Phi(\alpha)}{\partial \alpha_j} \Phi(\alpha)^{-} \right)^{\mathrm{T}} \right] y \qquad P^{\perp} = I - \Phi(\alpha)\, \Phi^{\dagger}(\alpha)$$

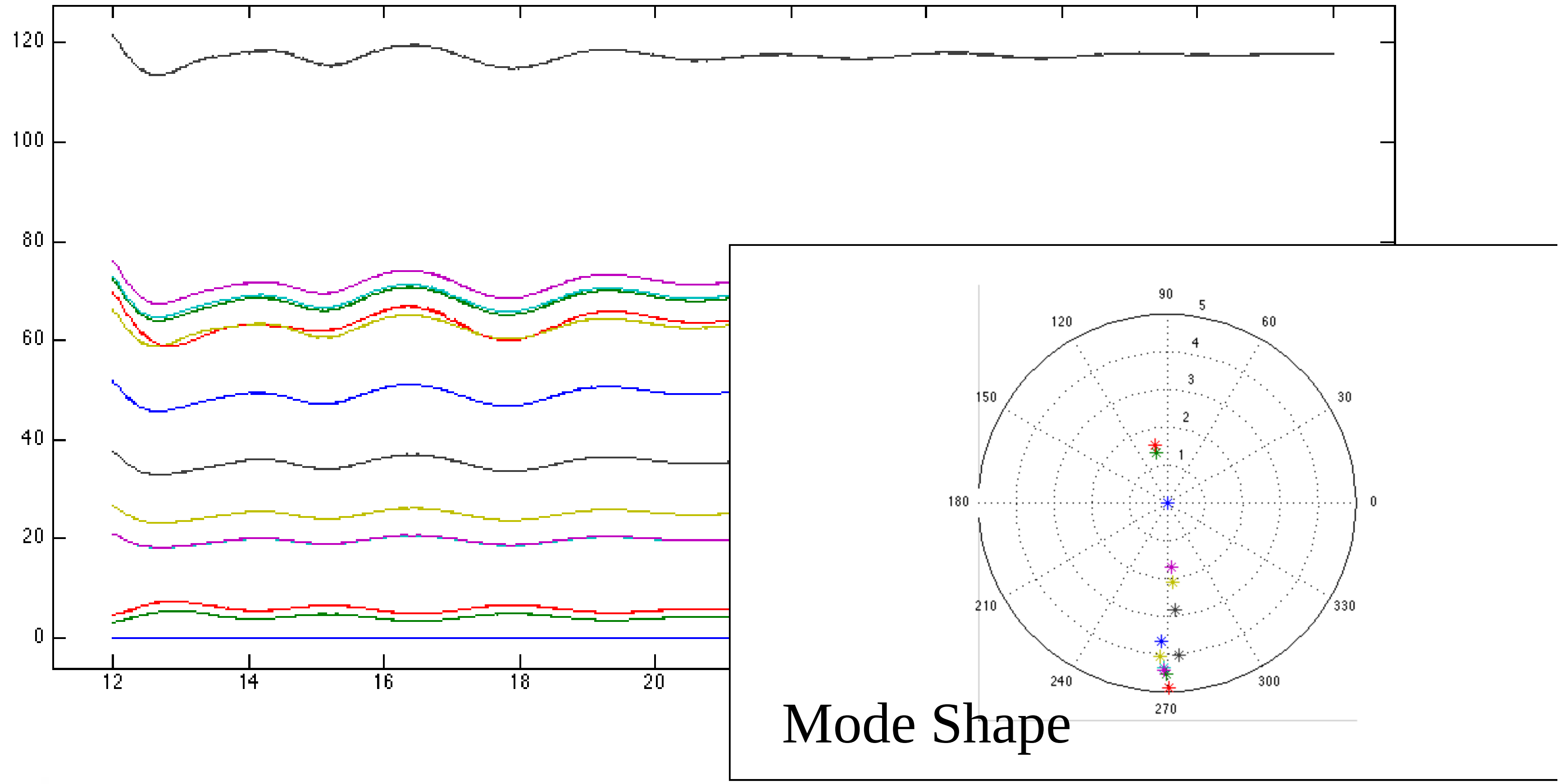
VARPRO GUI

Results, Analysis page



Sample Results

Compare data and Ringdown Tool fit.



Related Publications

- Borden, A.R., Lesieutre, B.C.; Gronquist, J.; "Power System Modal Analysis Tool Developed for Industry Use," *45th Annual North American Power Symposium (NAPS), 2013*, 22-24 Sept. 2013 **(2cd Prize, Student Paper Contest)**

- Borden, A.R., Lesieutre, B.C.; "Determining Power System Modal Content of Data Motivated by Normal Forms," *44th Annual North American Power Symposium (NAPS), 2012*, 9-11 Sept. 2012 **(1st Prize, Student Paper Contest)**

- Borden, A.R., Lesieutre, B.C.; "Variable Projection Method for Power System Modal Identification," to appear in the *IEEE Transactions on Power Systems.*

Schedule and Deliverables

Task: Ringdown Tool: complete.

Task: Programming power plant model: Initial Matlab and C++ programs running for *generator*, *pss2a*, and *exst4b*. A few more models are needed, and further user-friendly development needed.

Task: Calibration study. One in progress, set out to complete two this FY.

Task: Identifiability. Sensitivity Analysis on-going. Next step to map modes with models.

Task: Technology Transfer. Goal: to promote feature-based approach.

FY 2015 Ideas

- Continue and complete power plant modeling tasks: programming, identifiability, and model calibration and validation.
- Modal Analysis: work with BPA and others to maintain Matlab implementation of ringdown tool.
- Modal Analysis: Apply “matched filter” approach to oscillation detection.

Questions

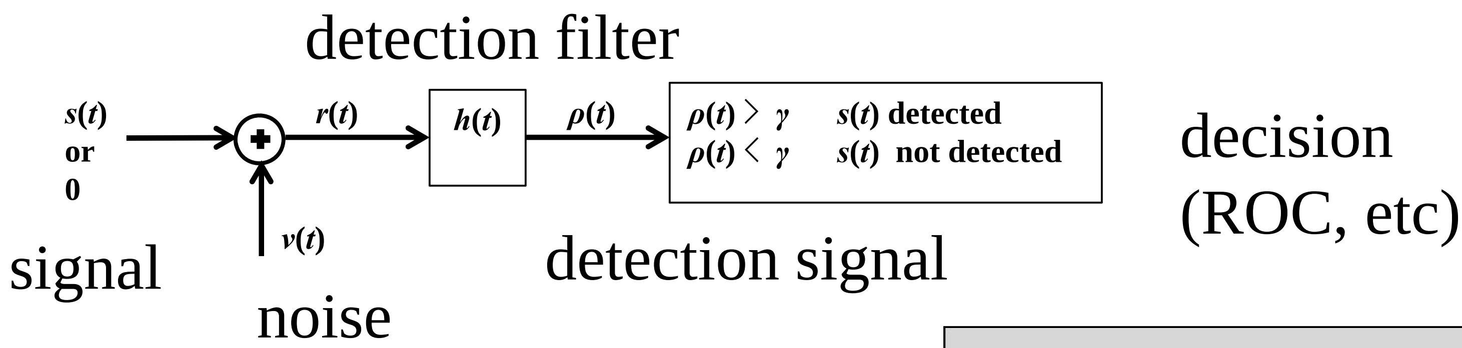
Oscillation Detection

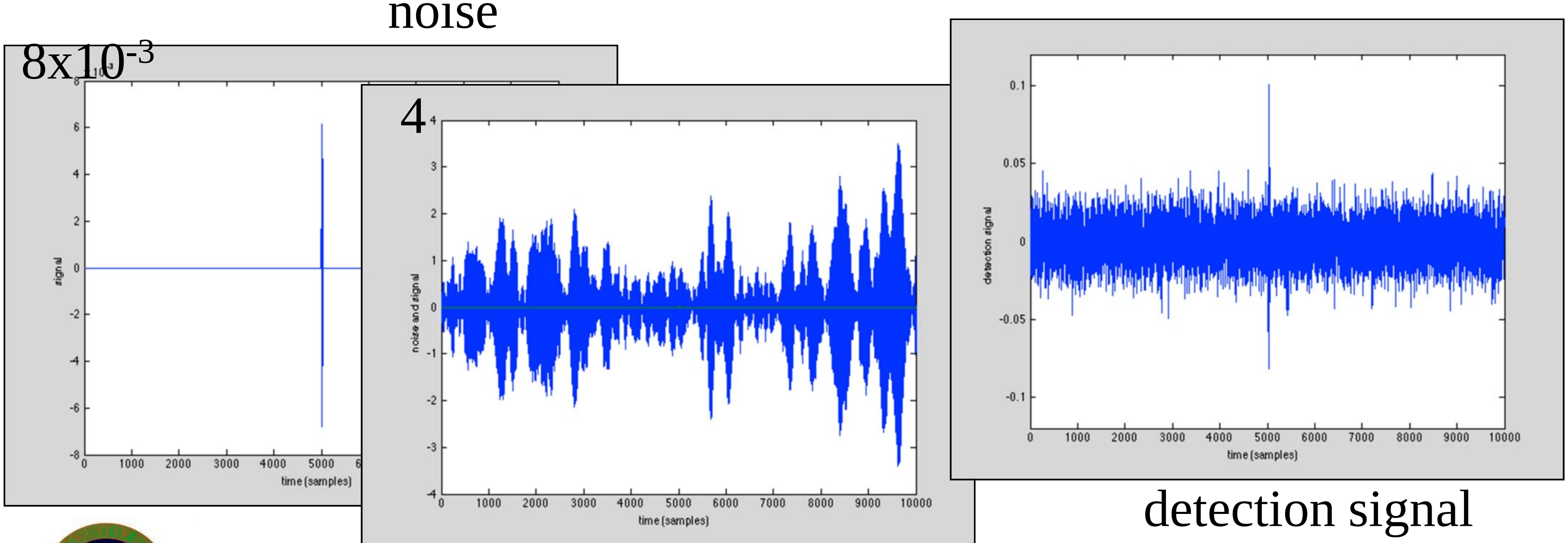
We want to detect oscillations **quickly**.

We could use FFTs for detection … but then we are beholden to the lowest frequency of interest, which slows detection of higher frequencies.

Furthermore, *if* we know *a priori* the frequencies of interest, we can focus on detecting those. This leads to matched filters.

Signal Detection





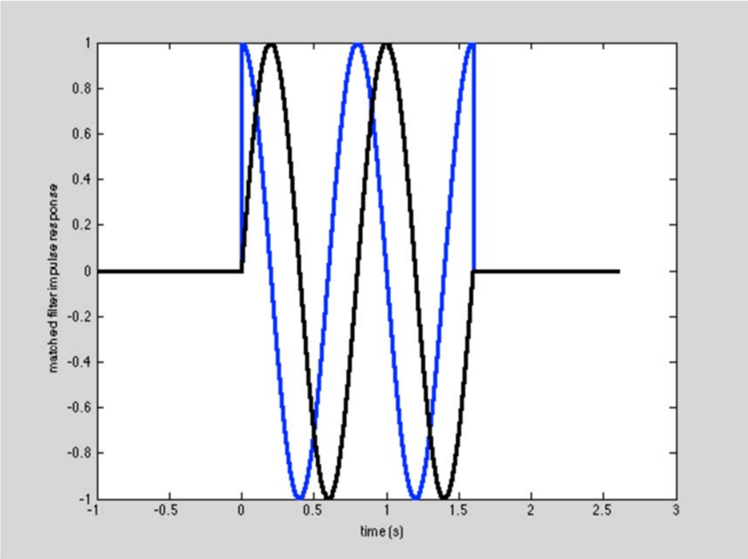
signal

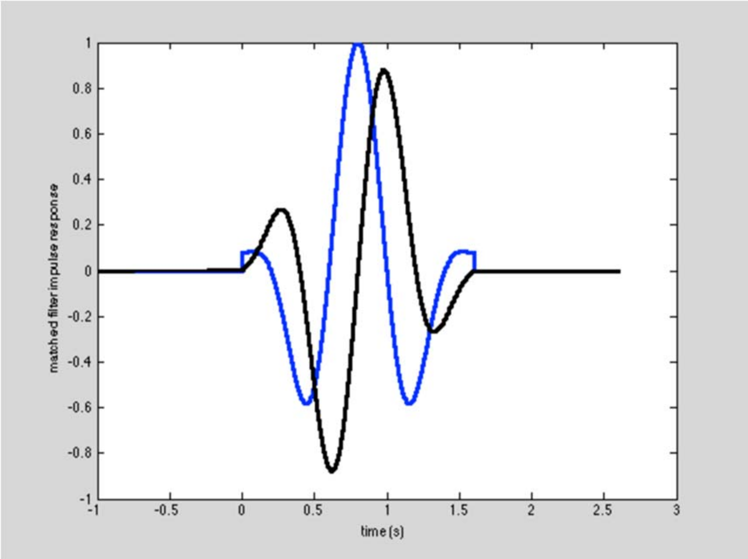
noise and signal

detection signal

Oscillation Detection

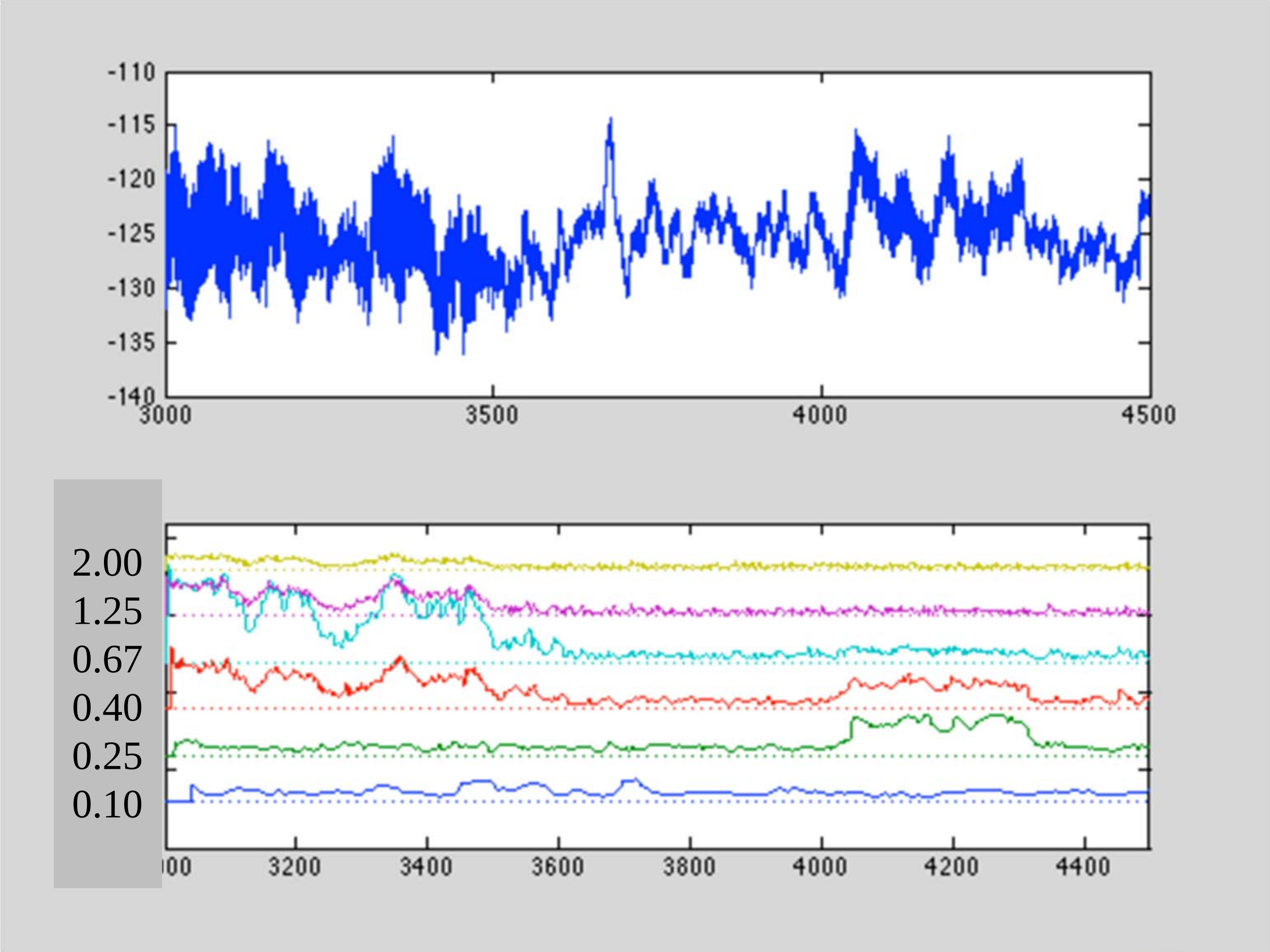
Candidate "matched" Filters for detecting 1.25 Hz. It matches two cycles of a sinusoidal waveform… and with hamming window



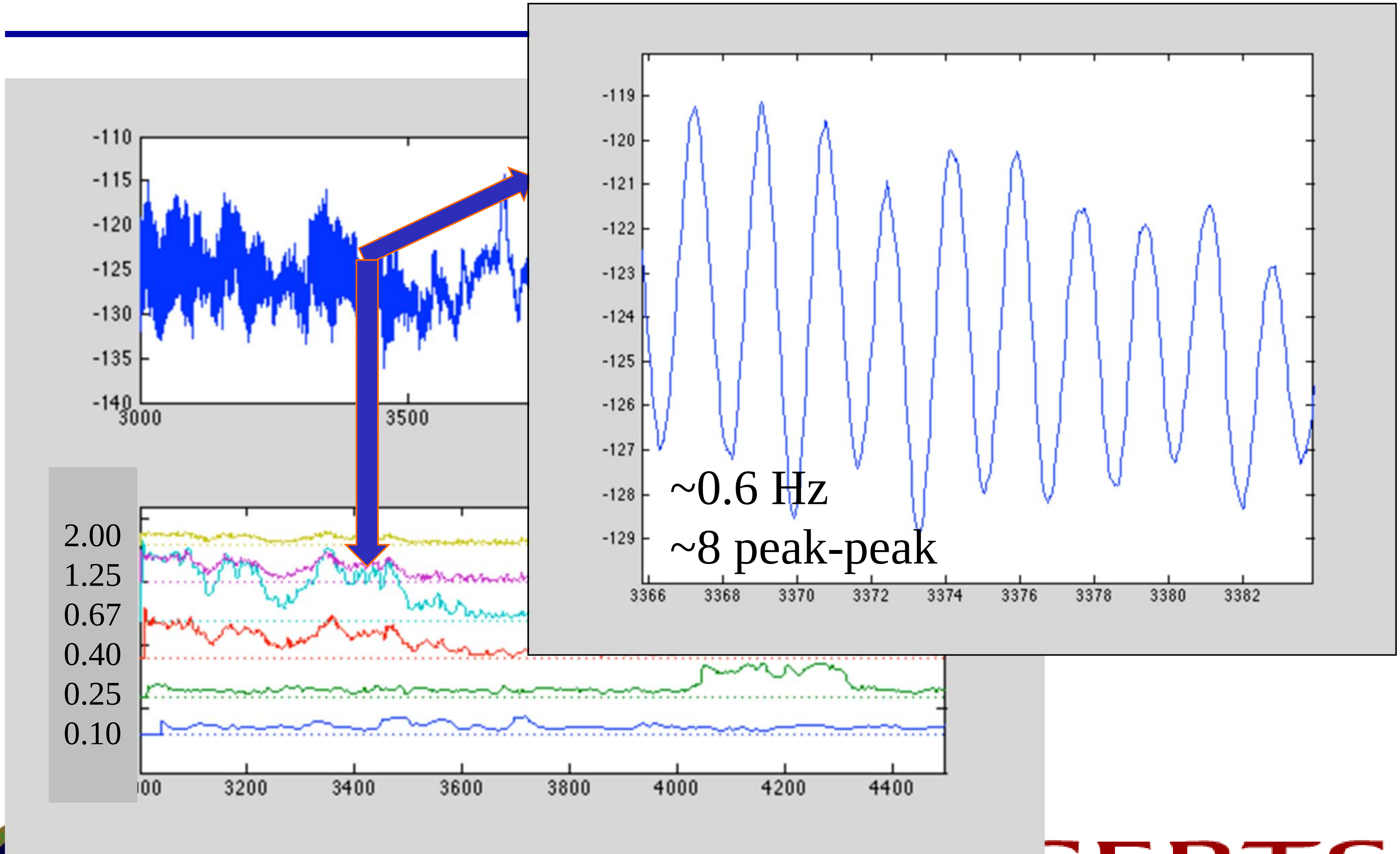


Initial Approach: form a set of filters centered on certain frequencies. For illustration here, use 0.10, 0.25, 0.40, 0.67, 1.25, and 2.00 Hz.

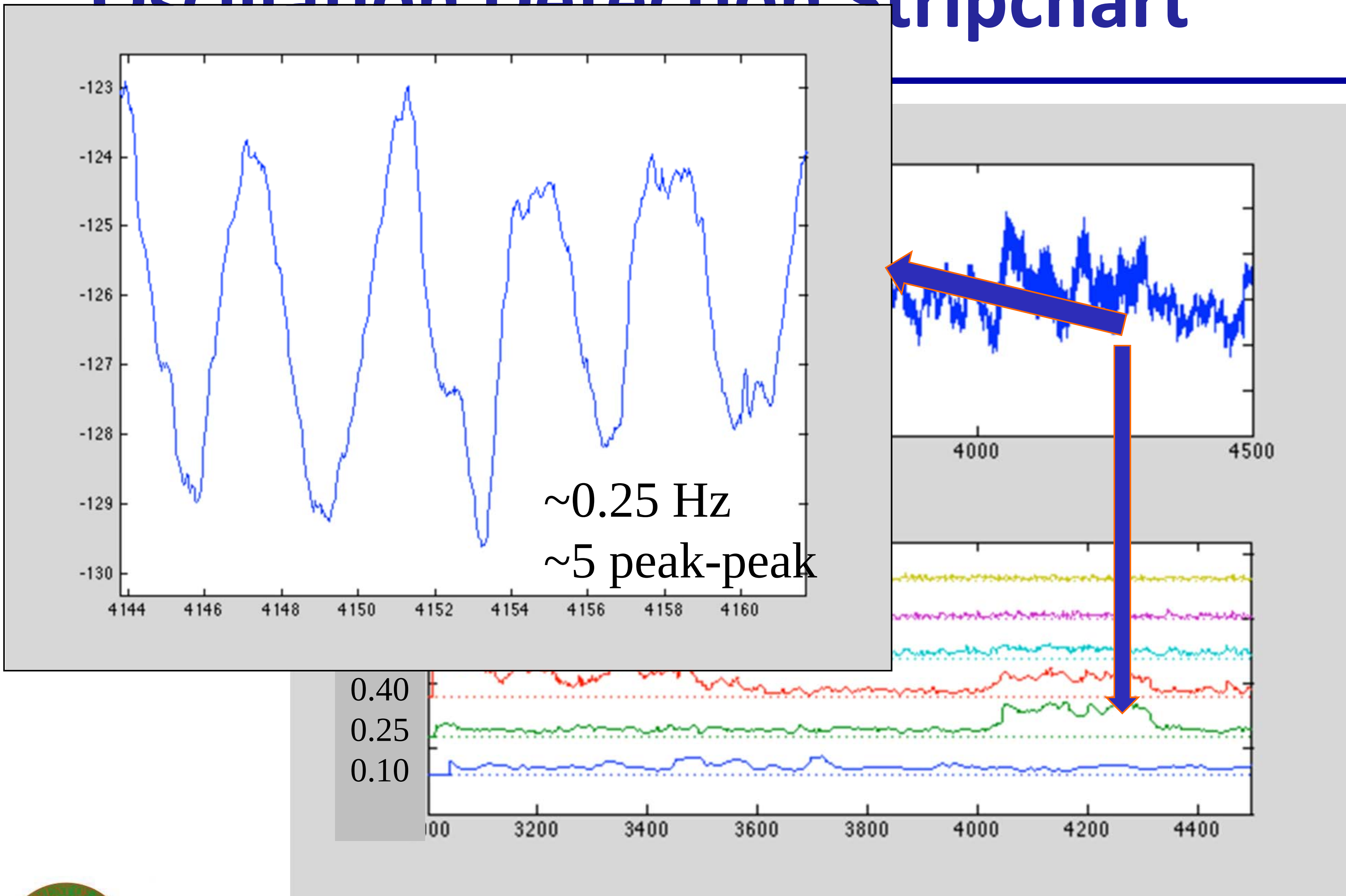
Frequency Detection Stripchart



Oscillation Detection Stripchart



Oscillation Detection Stripchart



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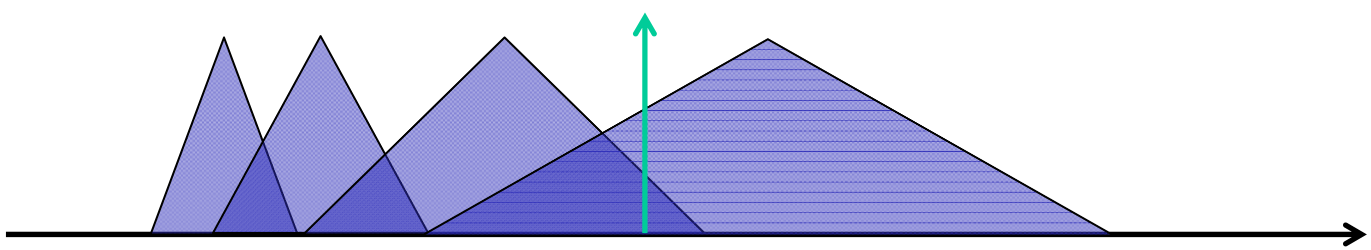
Next Step

- Next, design characteristics of detection filters that allow correlating detection signals to better distinguish oscillation frequency and amplitude.



filter characteristics