A specialist energy consultancy

Automated Identification of SSO events

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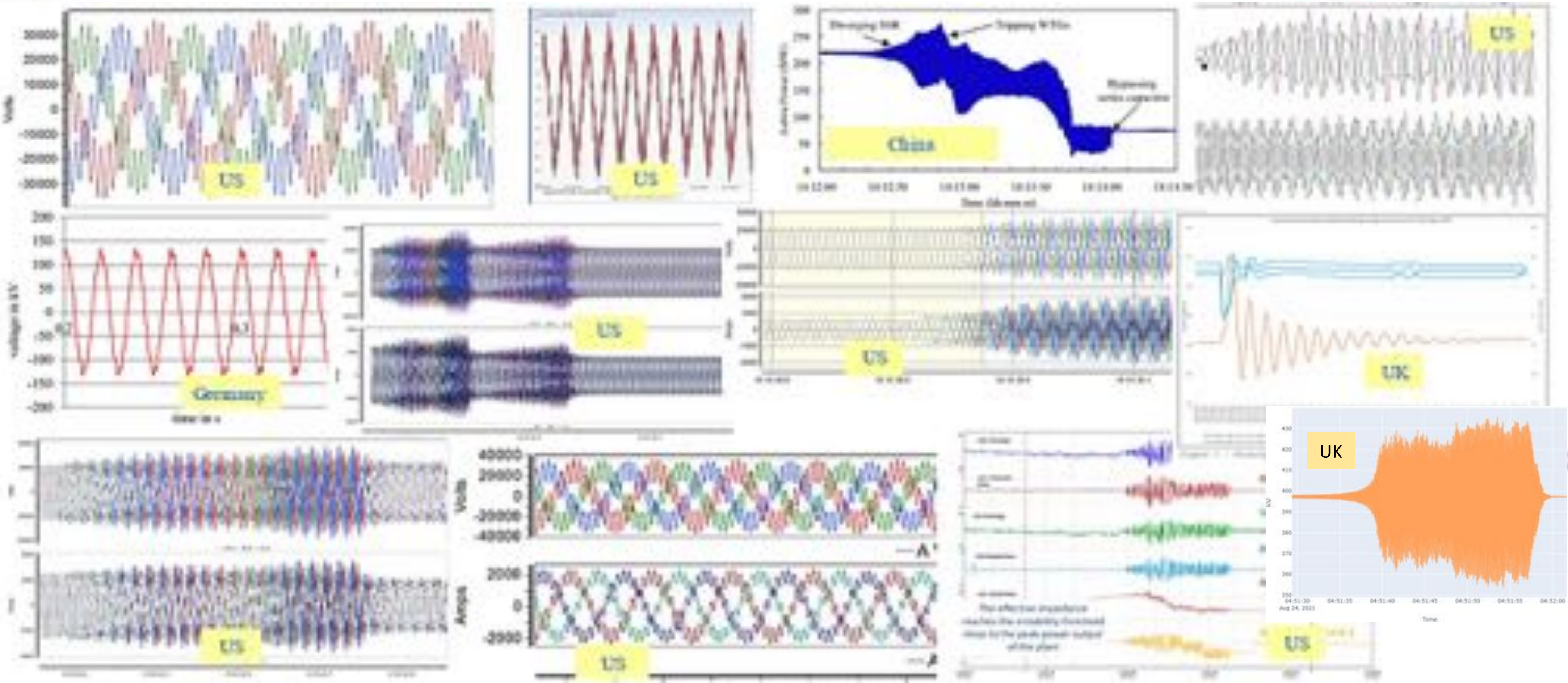
This project is exploring, developing, and testing a combination of novel frequency domain methodologies and machine learning techniques to identify potential system operating conditions which can lead to Sub-Synchronous Oscillations (SSOs) through an automated control interaction studies framework.

Subsynchronous oscillations



Source: Shahil Shah, ‘Impedance Scan Tools for Stability Analysis of IBR Grids’, G-PST/ESIG Webinar, June 30, 2022
J. Leslie, Managing Grid Stability in a High IBR Network, GPST/ESIG Webinar Series, Jan. 25, 2022

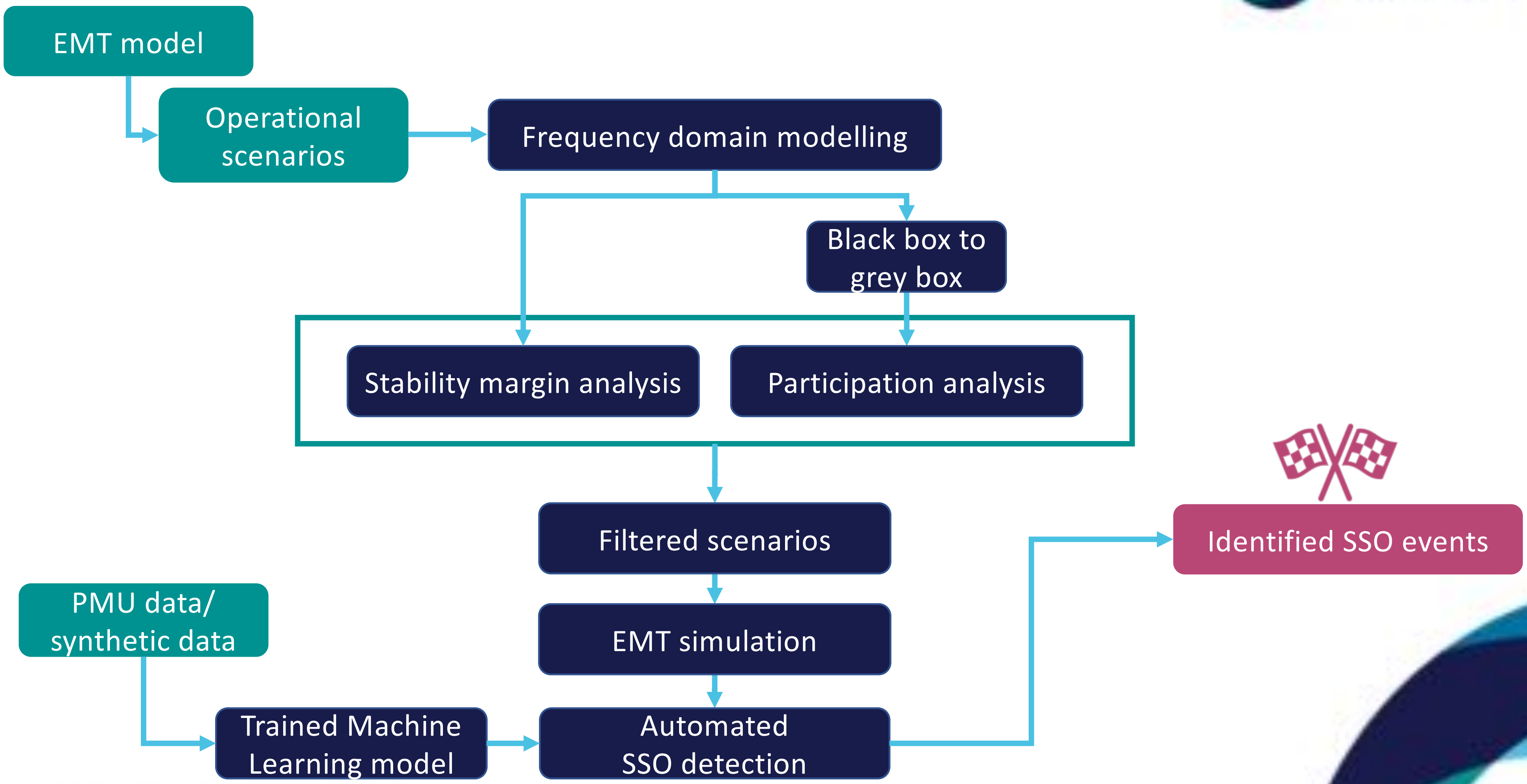
About SSOs

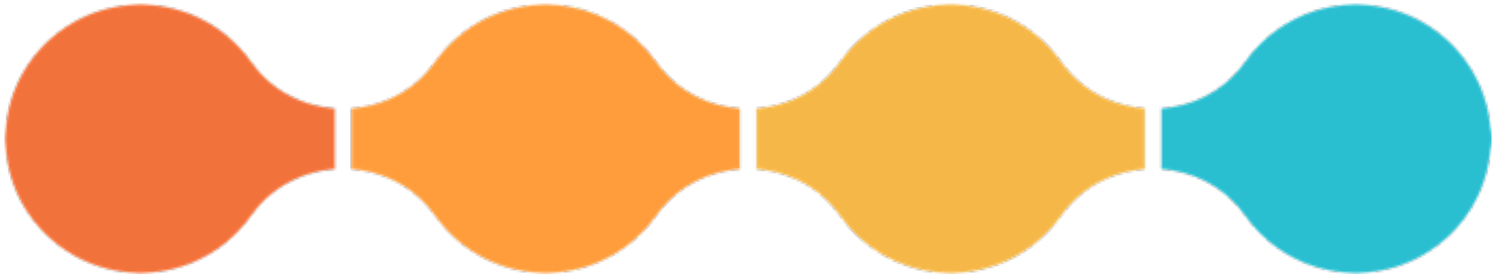
The fundamental reason for SSO in any system is the existence of poorly damped oscillatory modes, which can be induced by the interaction between different technology types.

The challenges in addressing these interactions are -

a) complex and difficult to identify without exhaustive electromagnetic transient (EMT) studies,
b) challenging to identify the equipment or assets participating in the interaction,
c) assessing the degree of participation of equipment parameters in poorly damped modes is difficult, and
d) future reinforcement decisions and network changes, such as the connection of new sites, can introduce new modes in the system, making compliance studies based on limited scenarios insufficient.

Project overview



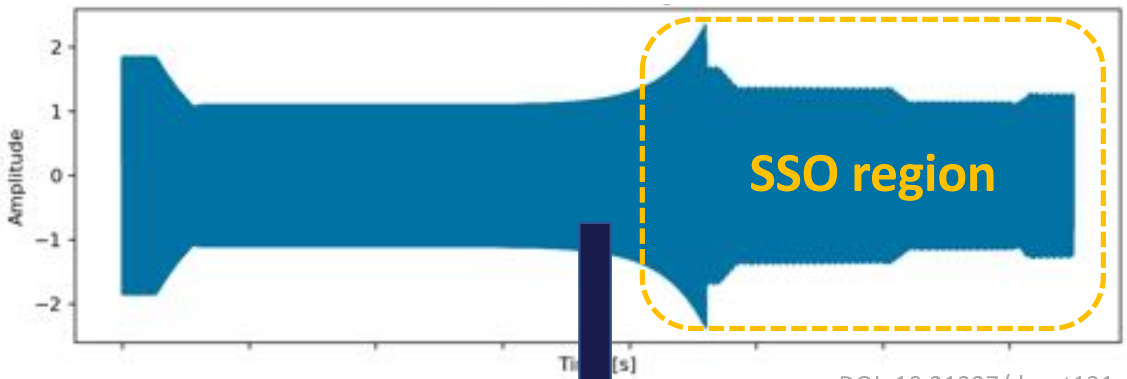


Automated identification of SSOs

Consists of three main processes -

- Signal processing of measurement data and calculation of features
- Processing calculated features to create training and testing dataset
- Train a machine learning classifier to distinguish between SSO and non-SSO events

SSO identification problem



DOI: 10.21227/dvrr-t131

Metric using generic signal properties

Possible approaches from literature

Wavelet Transform

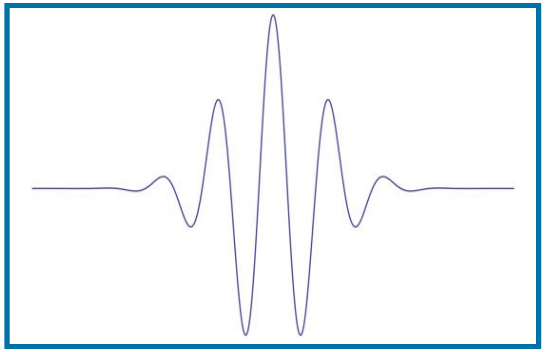


Image courtesy of
JonMcLoone on Wikipedia

Shapelet Transform

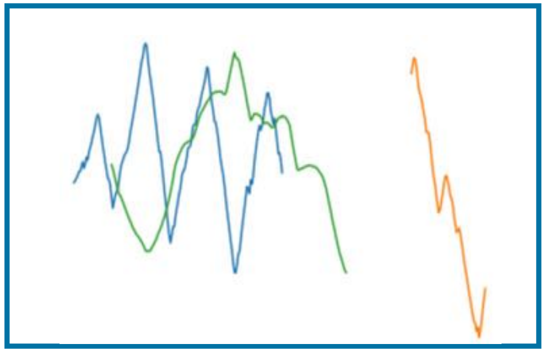


Image courtesy of sktime

Fourier Transform

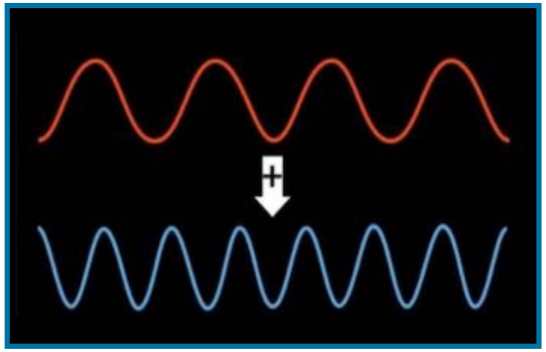
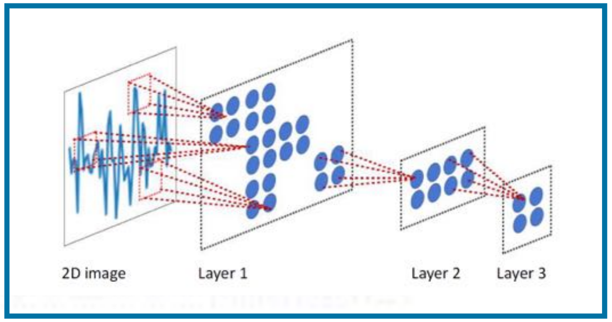


Image courtesy of
Christine Daniloff on MIT News

Convolutional Neural Networks



DOI: 10.48550/ARXIV.2012.12183

Extended Kalman Filter

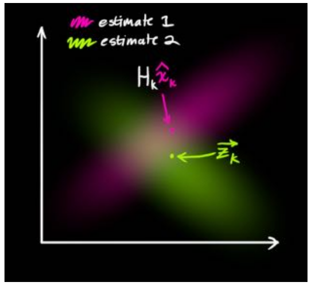
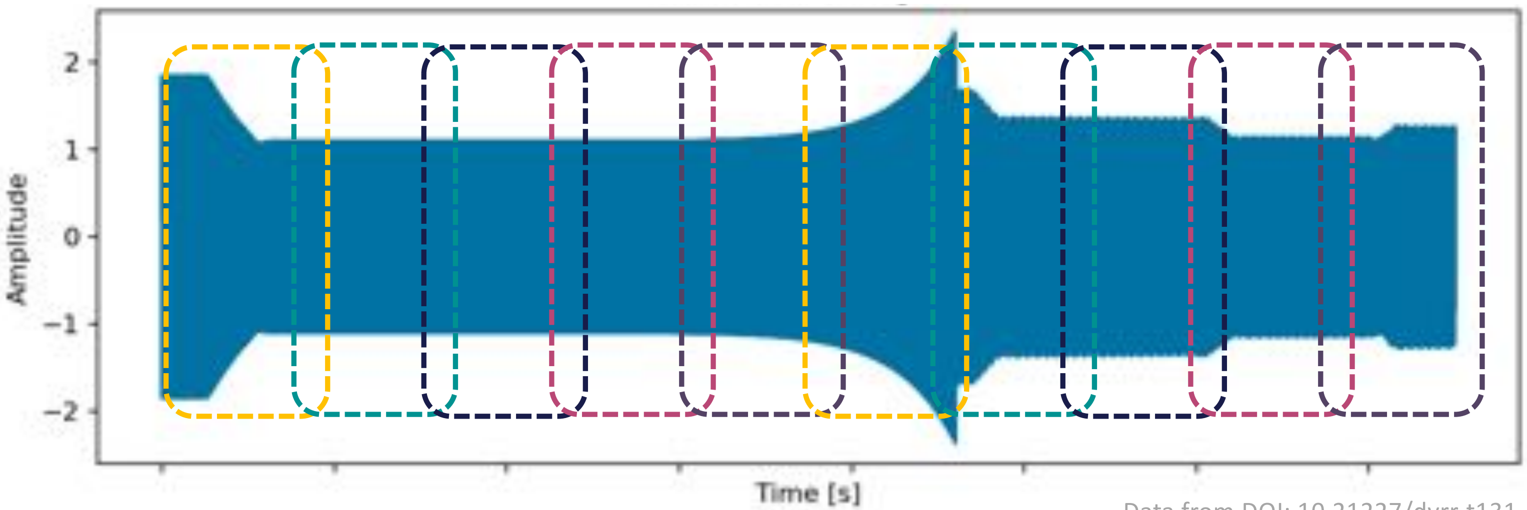


Image courtesy of bzarg.com

Our approach

- Combine different signal processing methods that extract features and use data driven method to learn the difference between SSO and non SSO regions.
- Four different features are computed for this purpose
- The features help to capture the underlying trend in the signal
- These are used to train a machine learning classifier
- Based on a consensus approach, the final outcome is decided

Our solution

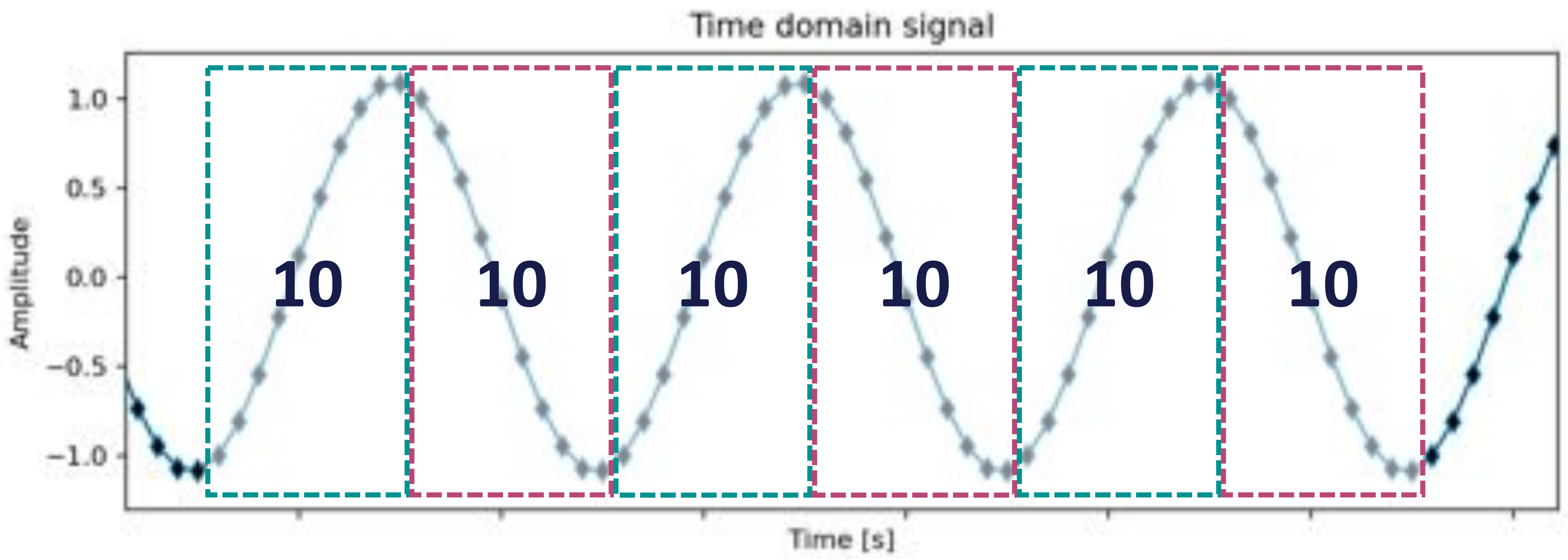


Data from DOI: 10.21227/dvrr-t131

Calculate four features (F1, F2, F3 and F4) from time domain signals and train a machine learning model. Once trained, the model will identify any SSO events from a time domain response.

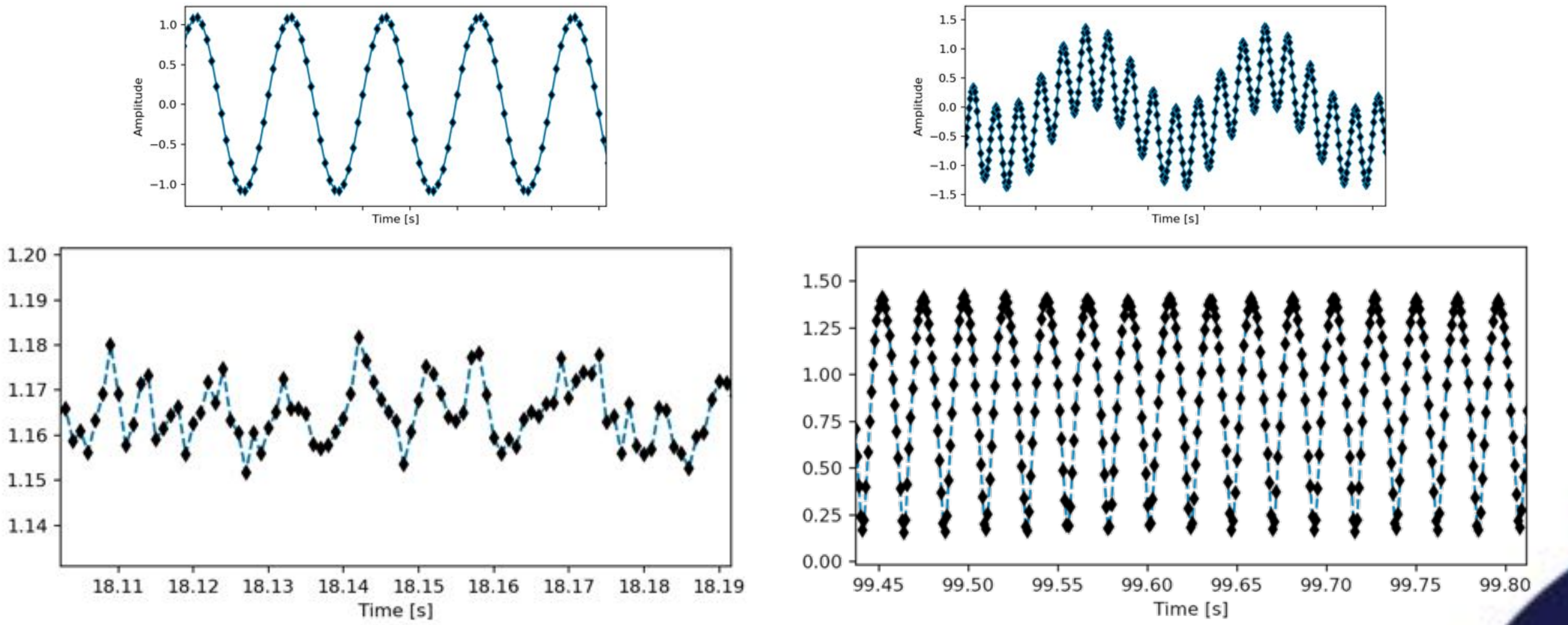
F1: Trend
F2: Envelope Volatility Index (EVI)
F3: Length of Stationary Subsequences (LSS)
F4: Fourier Transform Index (FTI)

Feature 1: Trend



F1: 10 + 10 + 10 + 10 + 10 + 10 = 60

Feature 1: Trend



F1: ↓ **F1: ↑**

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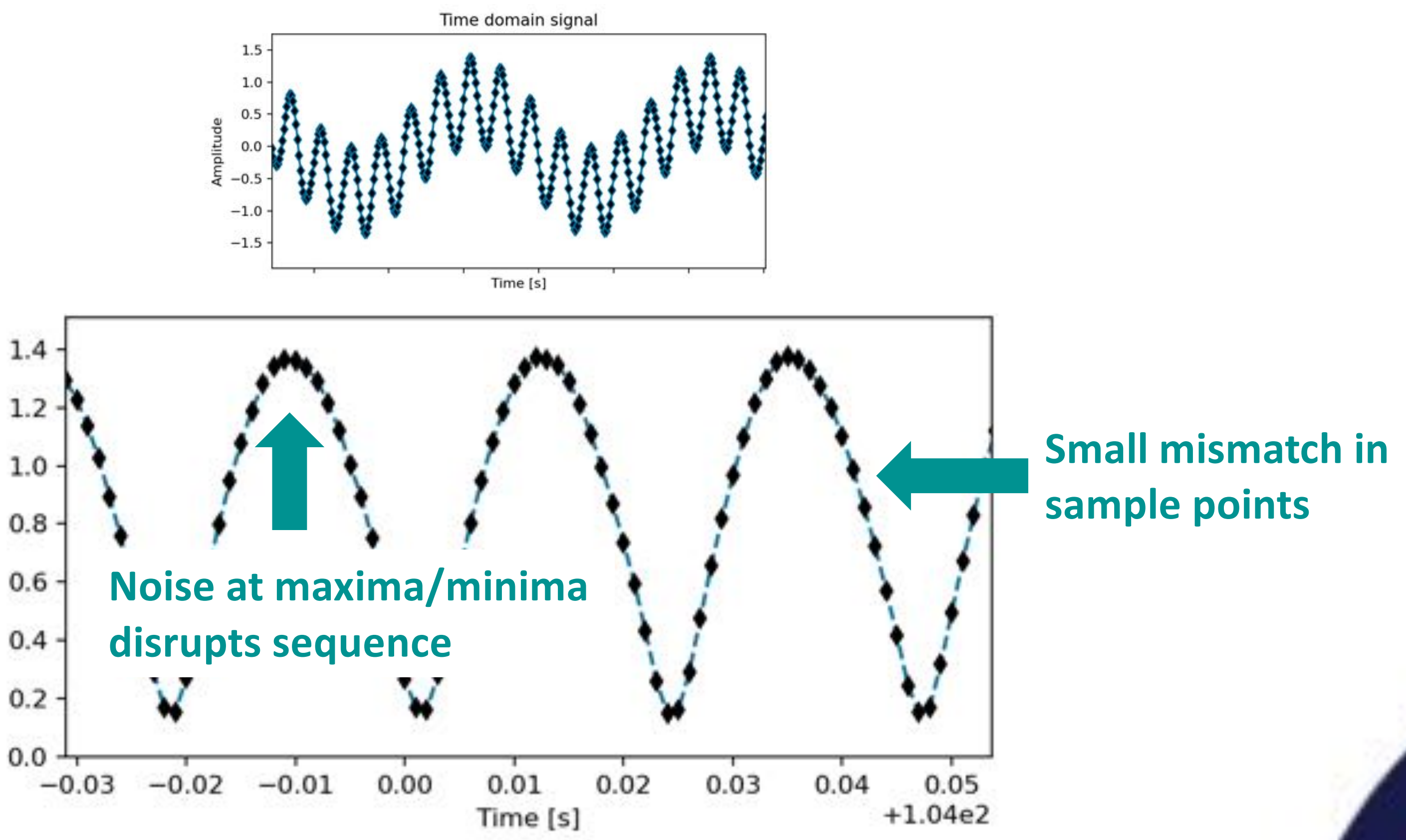
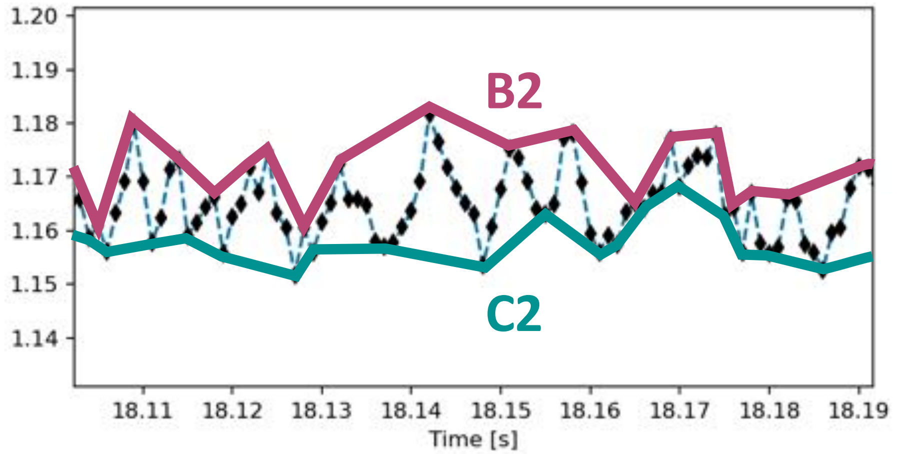
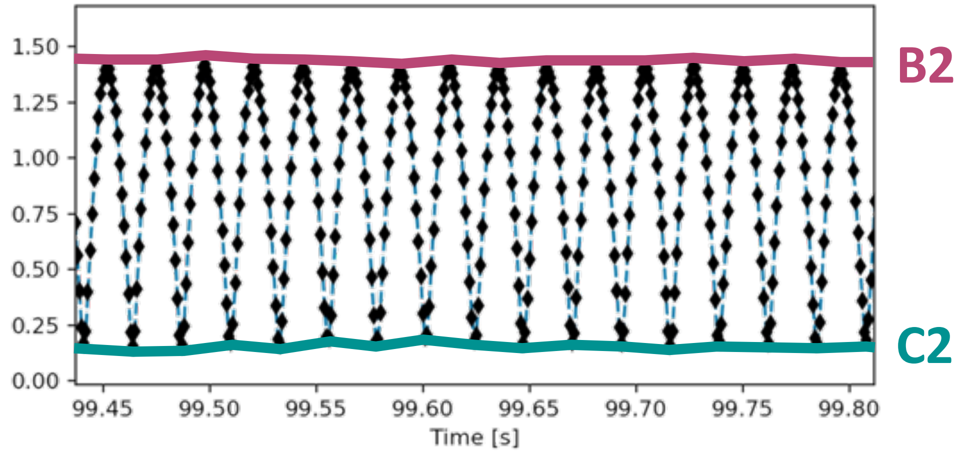
Feature 1: Improvements



Feature 2: EVI





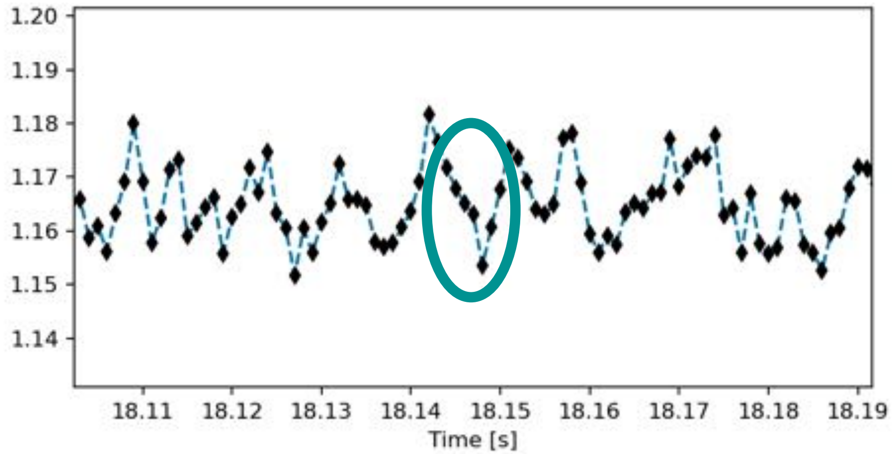
F2: ↑

F2: ↓

$$F2 = \sqrt{\frac{var(\boldsymbol{B2})}{var(\boldsymbol{A})}} \cdot len(\boldsymbol{B2}) + \sqrt{\frac{var(\boldsymbol{C2})}{var(\boldsymbol{A})}} \cdot len(\boldsymbol{C2})$$

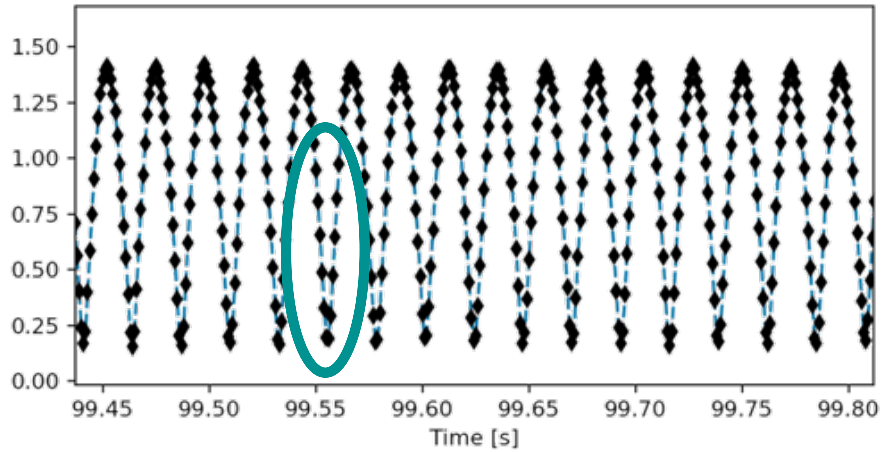
Feature 3: LSS

Smaller deviations between samples



F3: ↑

Bigger deviations between samples

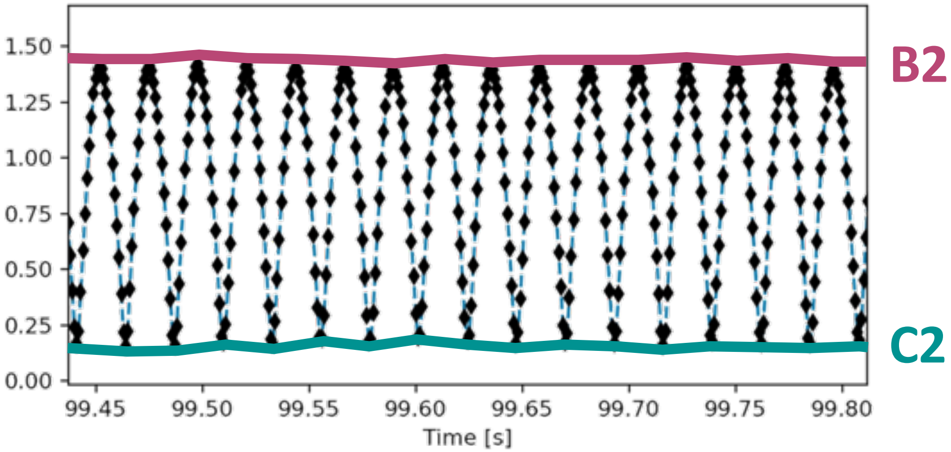


F3: ↓

F3 is the number of points that satisfy: $\frac{|A_i - A_{i-1}|}{A_i} \leq \varepsilon$

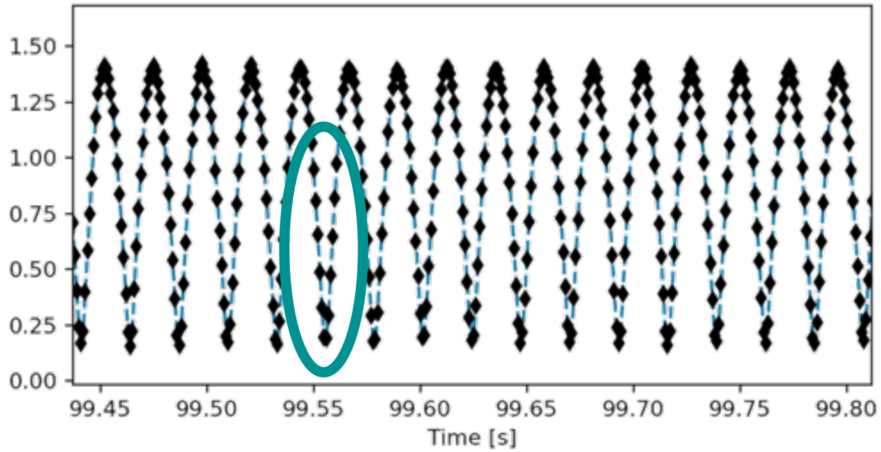
Feature 2 vs 3

Inter-peaks



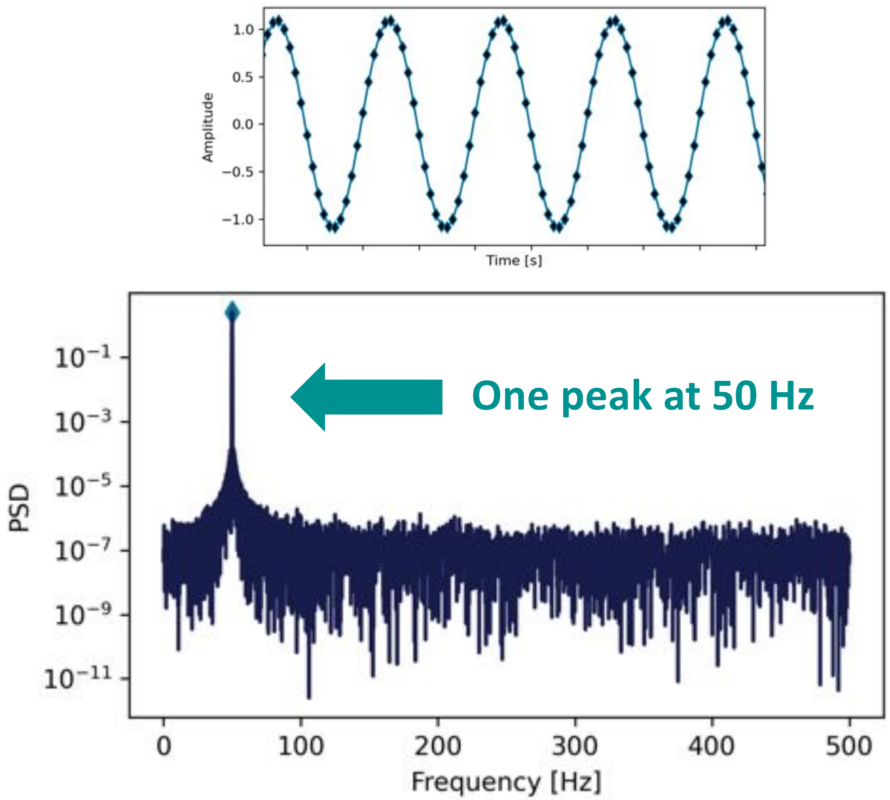
F2: ↓

Inter-samples

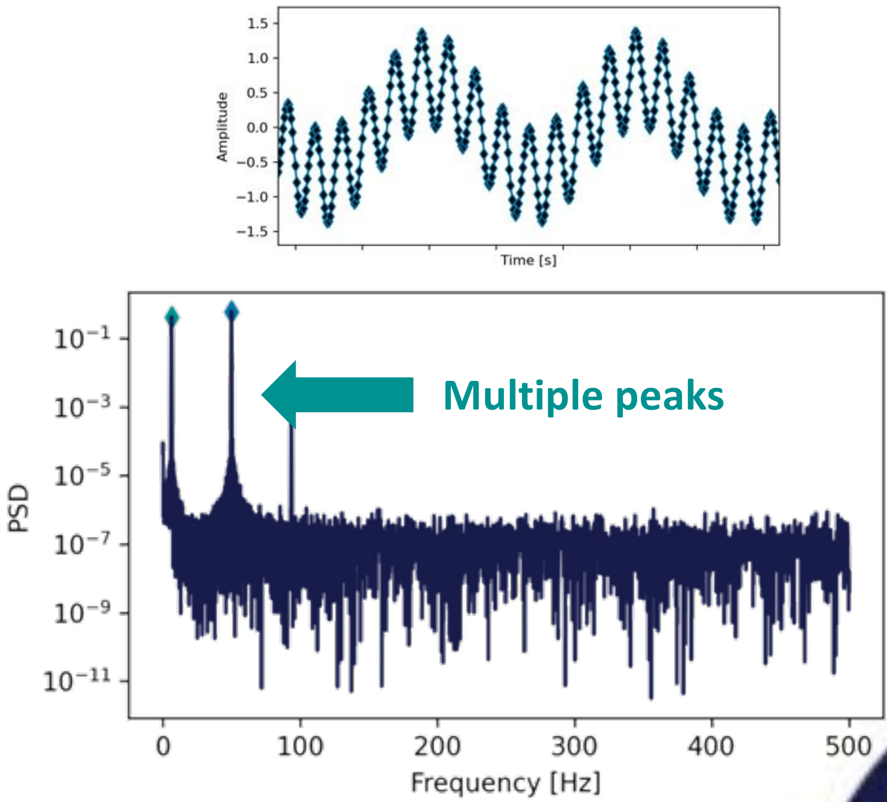


F3: ↓

Feature 4: FTI

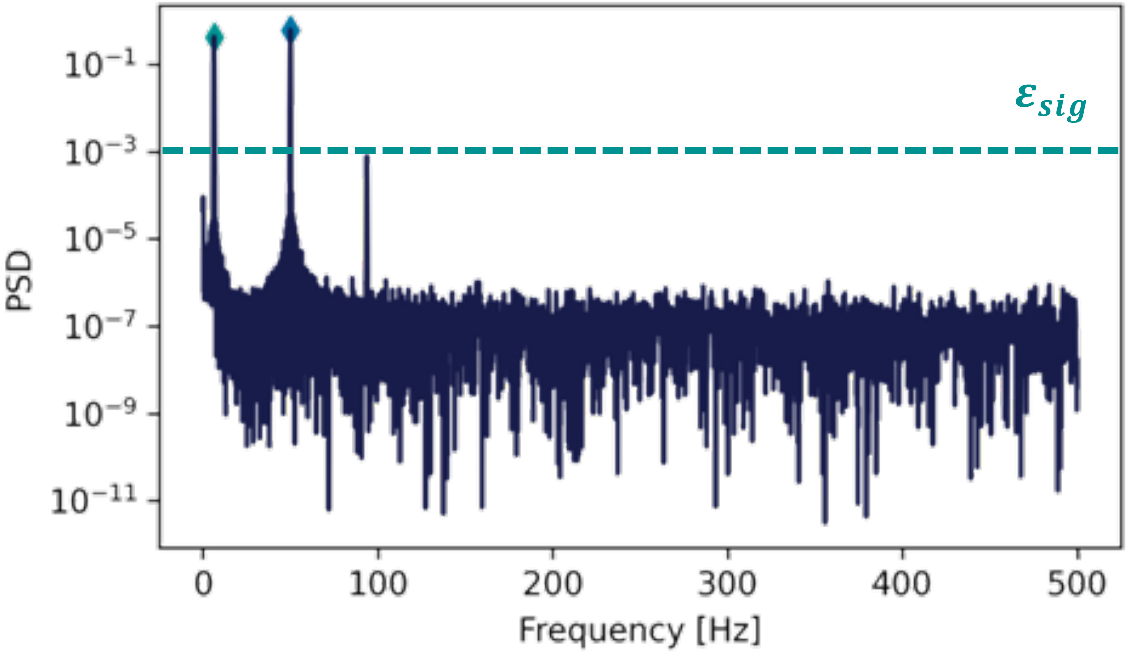


F4: ↓



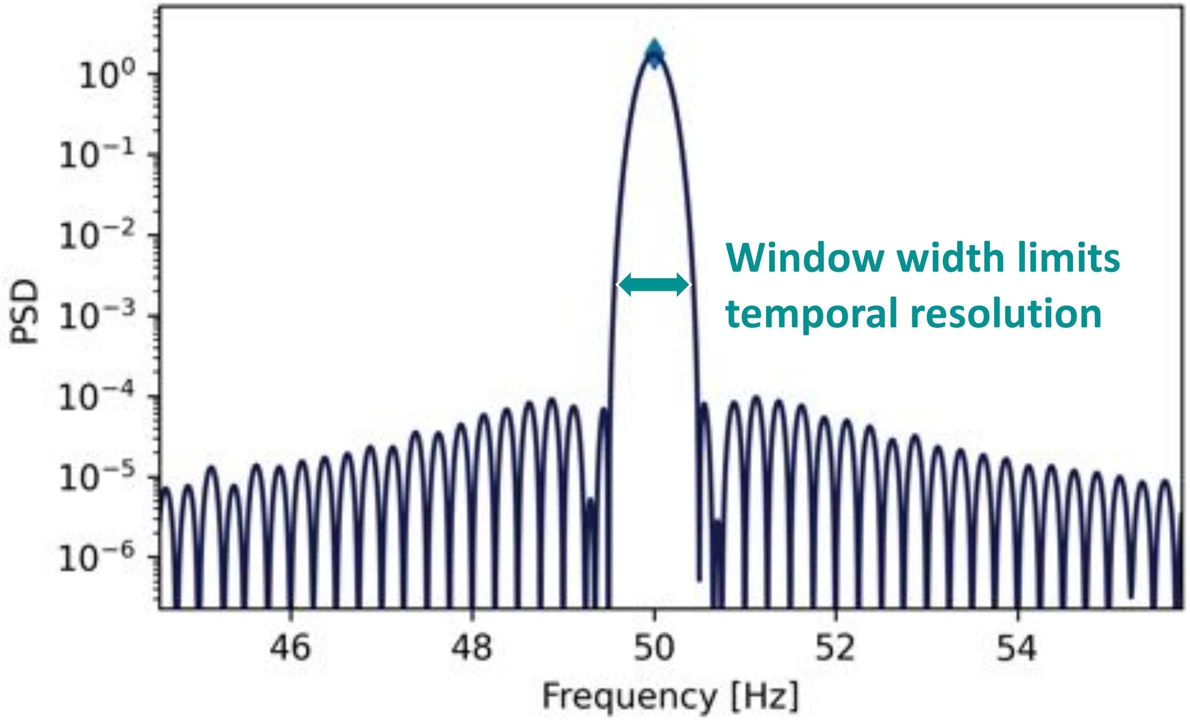
F4: ↑

Feature 4: FTI



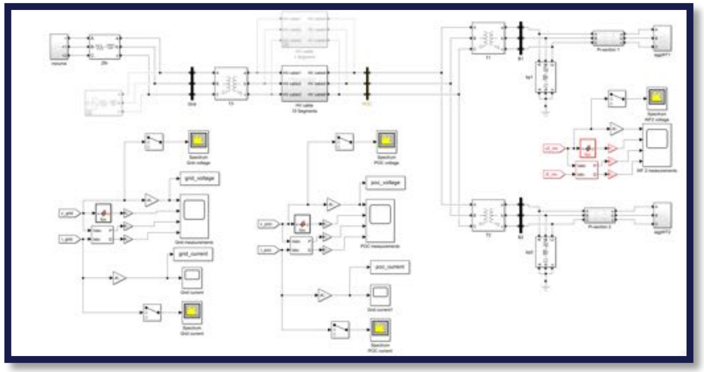
$$F4 = \sum_{f_i \in F_{sig}} \frac{PSD(f_i)}{PSD(f_0)}$$

Feature 4: Challenges



Time vs frequency

Data sources



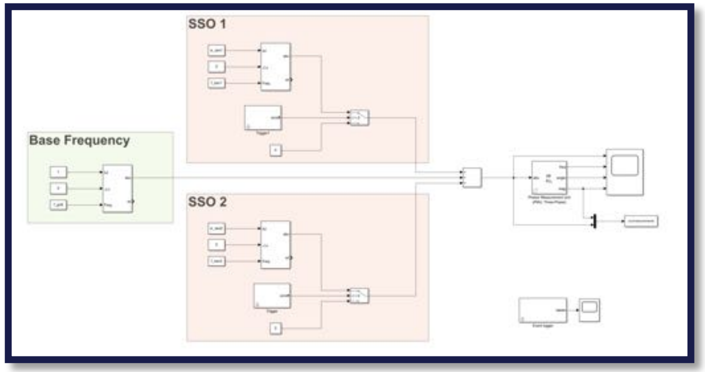
IEEE dataset

(used in presentation)

DOI: 10.21227/dvrr-t131OI

CIGRE model

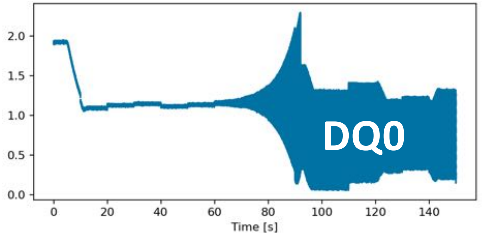
(used for training)

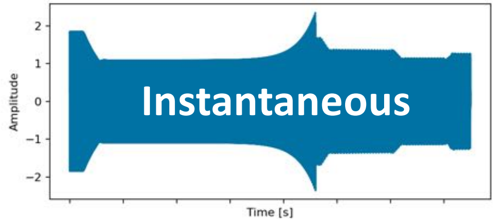


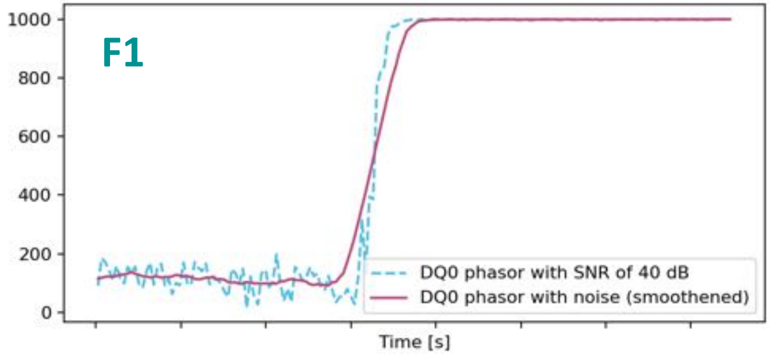
Artificial SSO generator

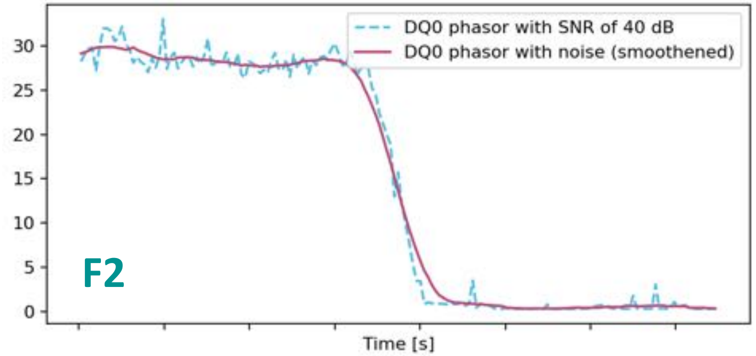
(used for feature development)

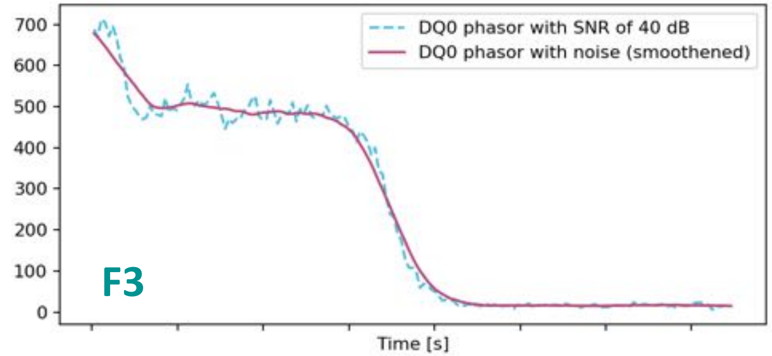
IEEE demo

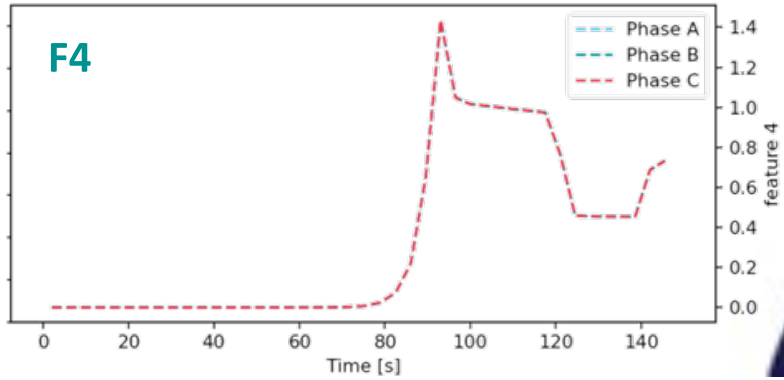

DQ0
2.0
1.5
1.0
0.5
0.0
0
20
40
60
80
100
120
140
Time [s]


Instantaneous
Amplitude
2
1
0
−1
−2
Time [s]

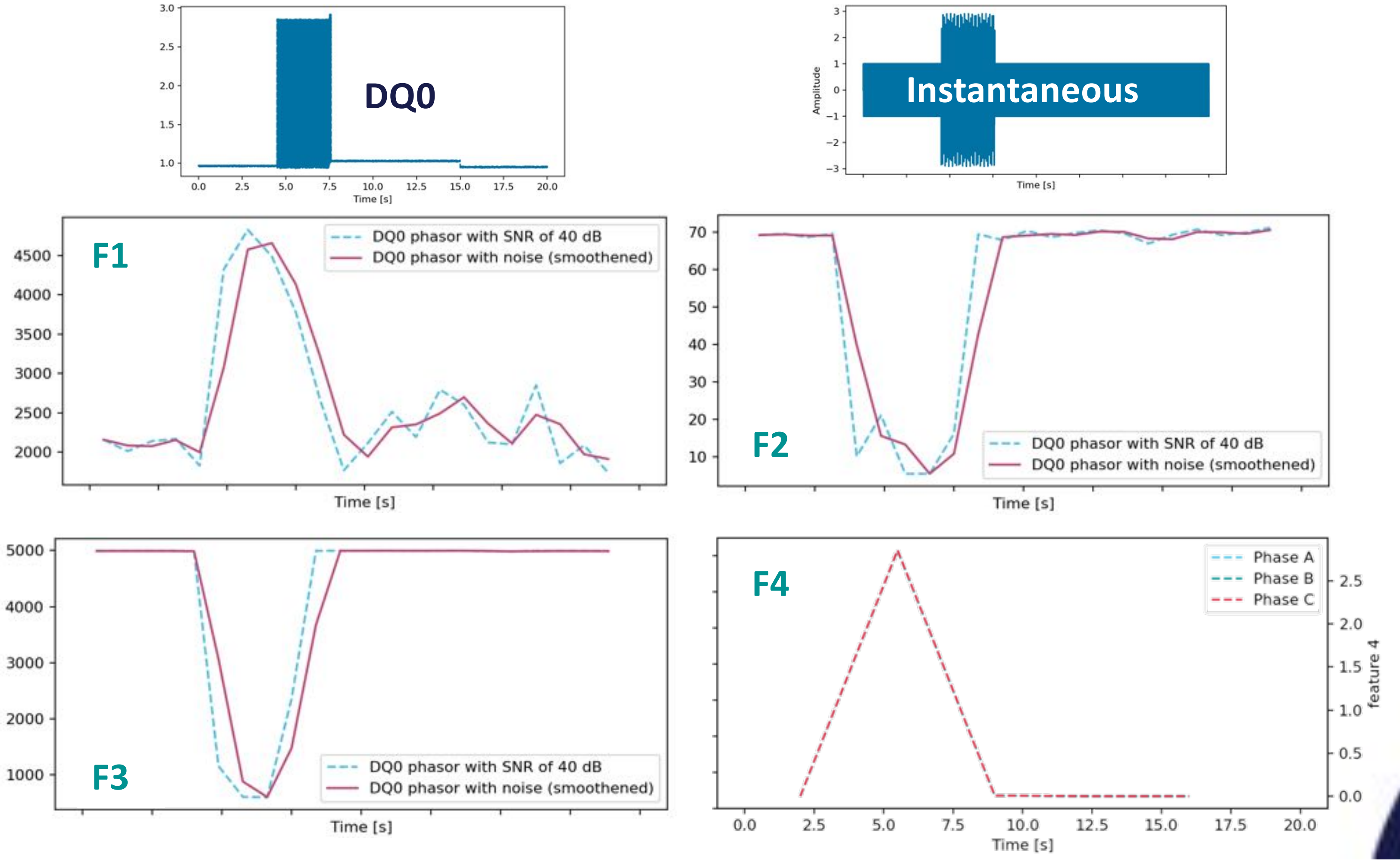

F1
1000
800
600
400
200
0
DQ0 phasor with SNR of 40 dB
DQ0 phasor with noise (smoothened)
Time [s]


F2
30
25
20
15
10
5
0
DQ0 phasor with SNR of 40 dB
DQ0 phasor with noise (smoothened)
Time [s]

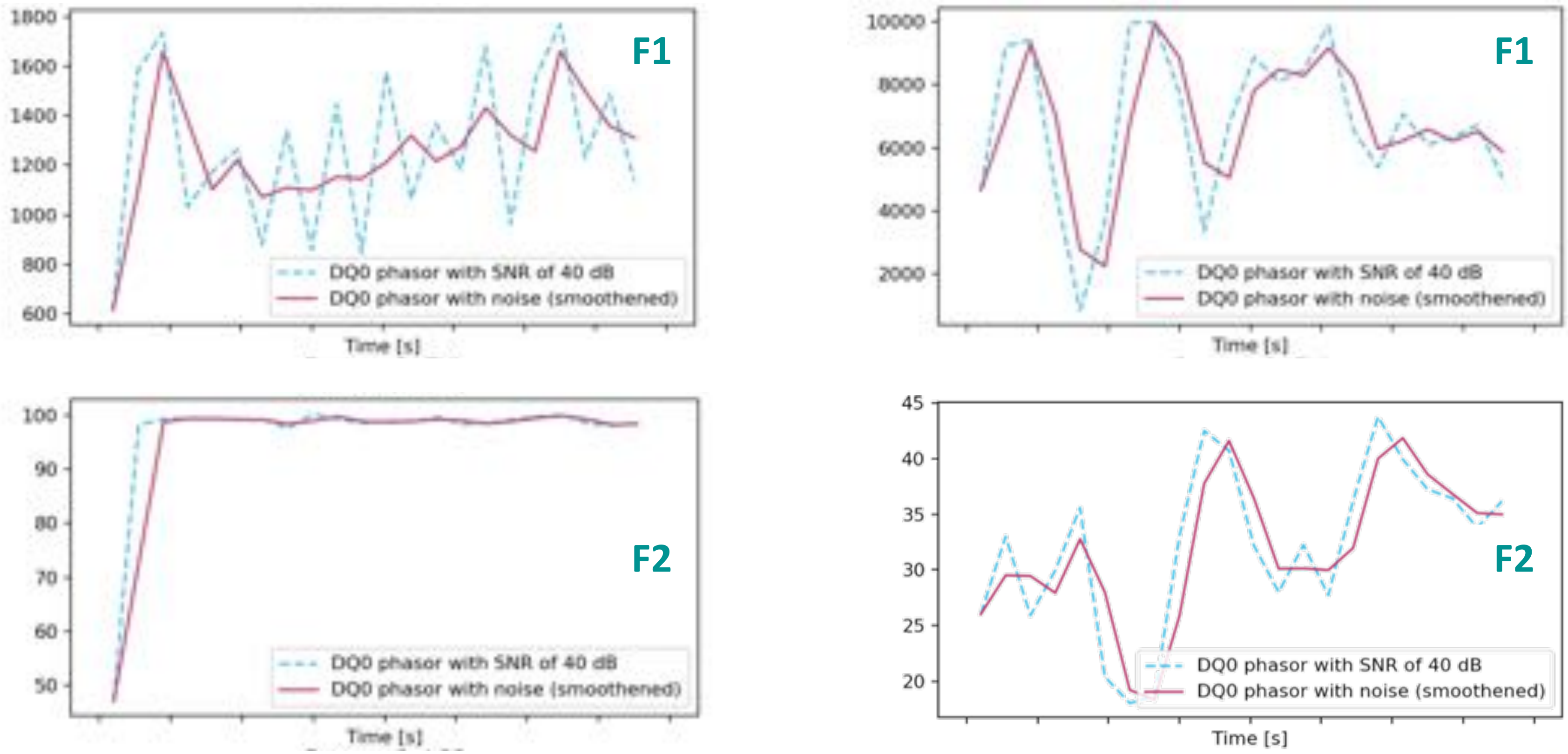

F3
700
600
500
400
300
200
100
0
DQ0 phasor with SNR of 40 dB
DQ0 phasor with noise (smoothened)
Time [s]


F4
Phase A
Phase B
Phase C
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
feature 4
0
20
40
60
80
100
120
140
Time [s]

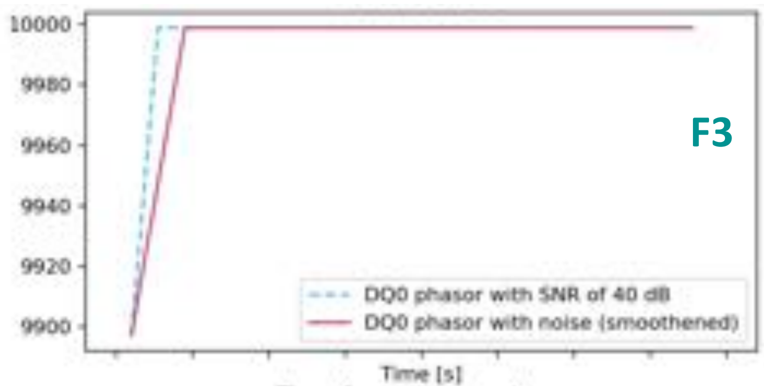
Artificial SSO generator demo

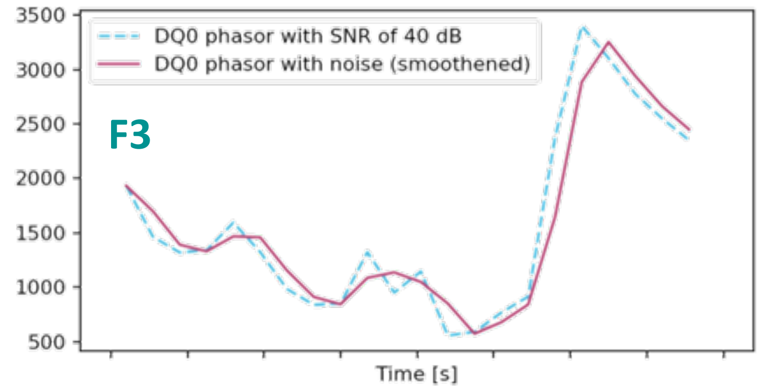


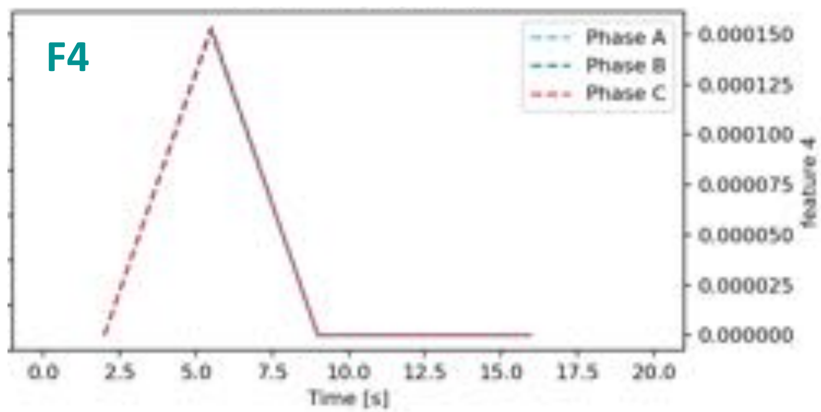
CIGRE demo (features 1 and 2)

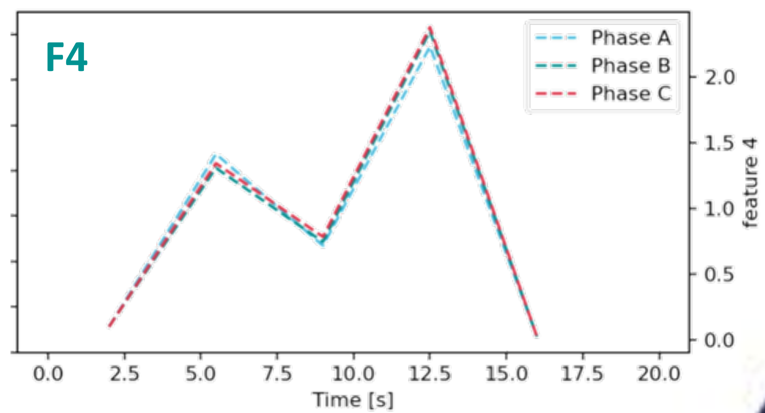


CIGRE demo (features 3 and 4)

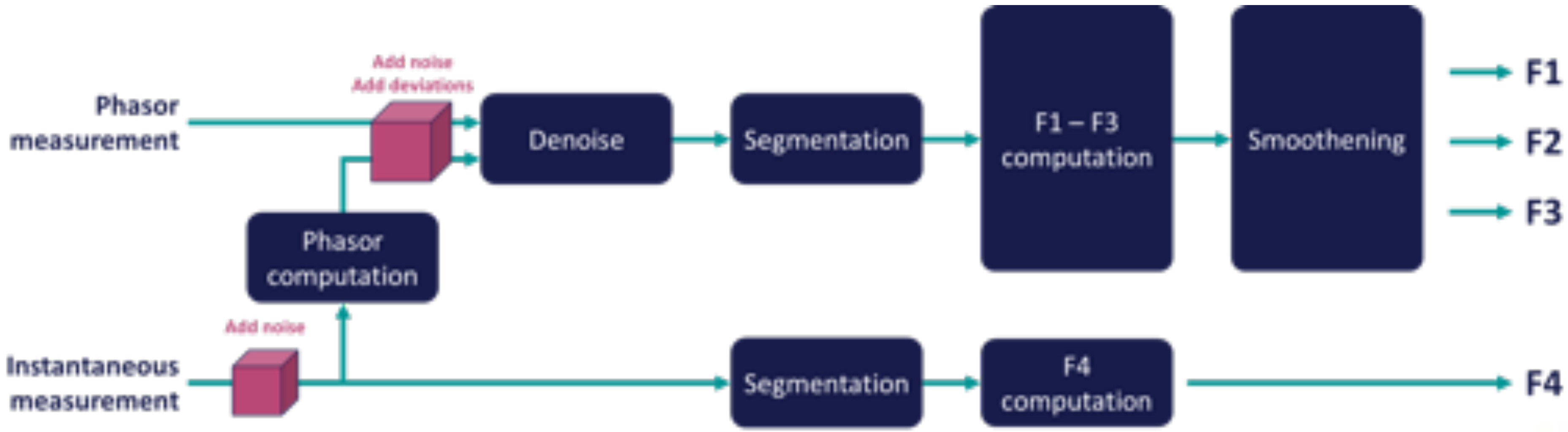




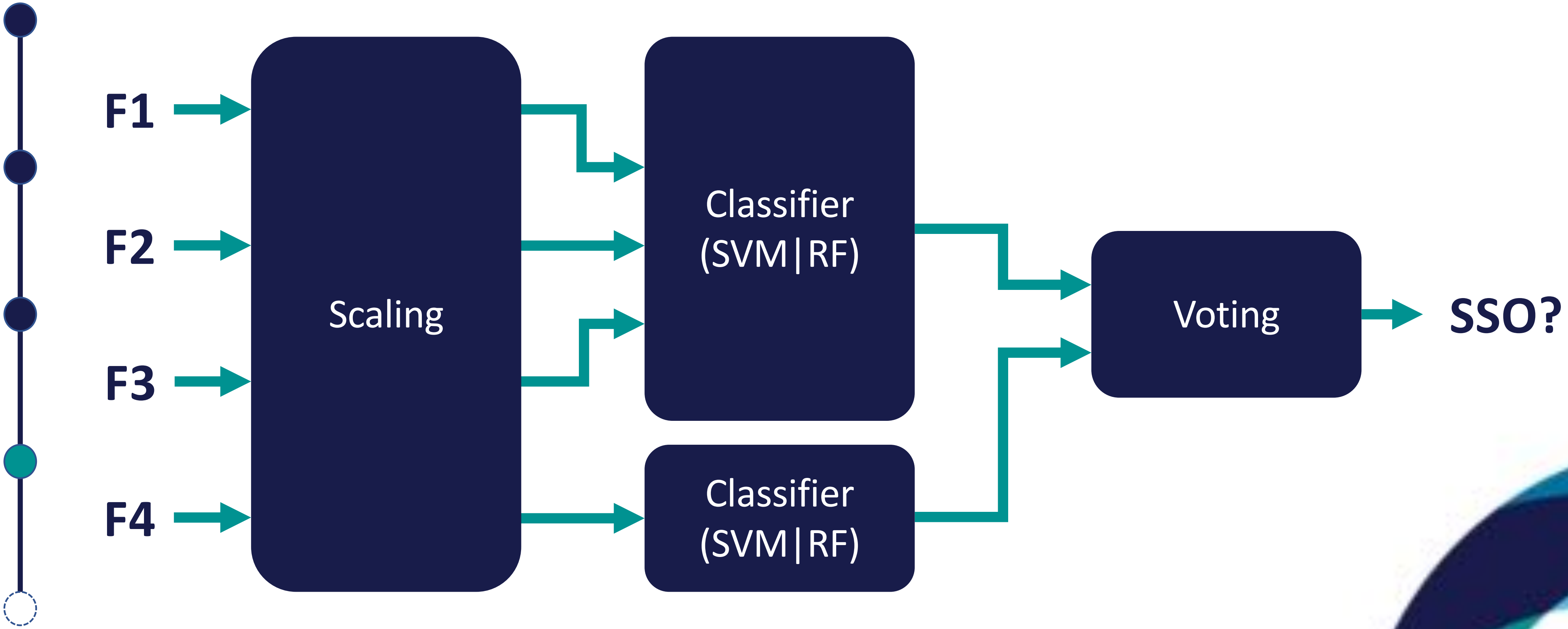




Feature Engineering Pipeline

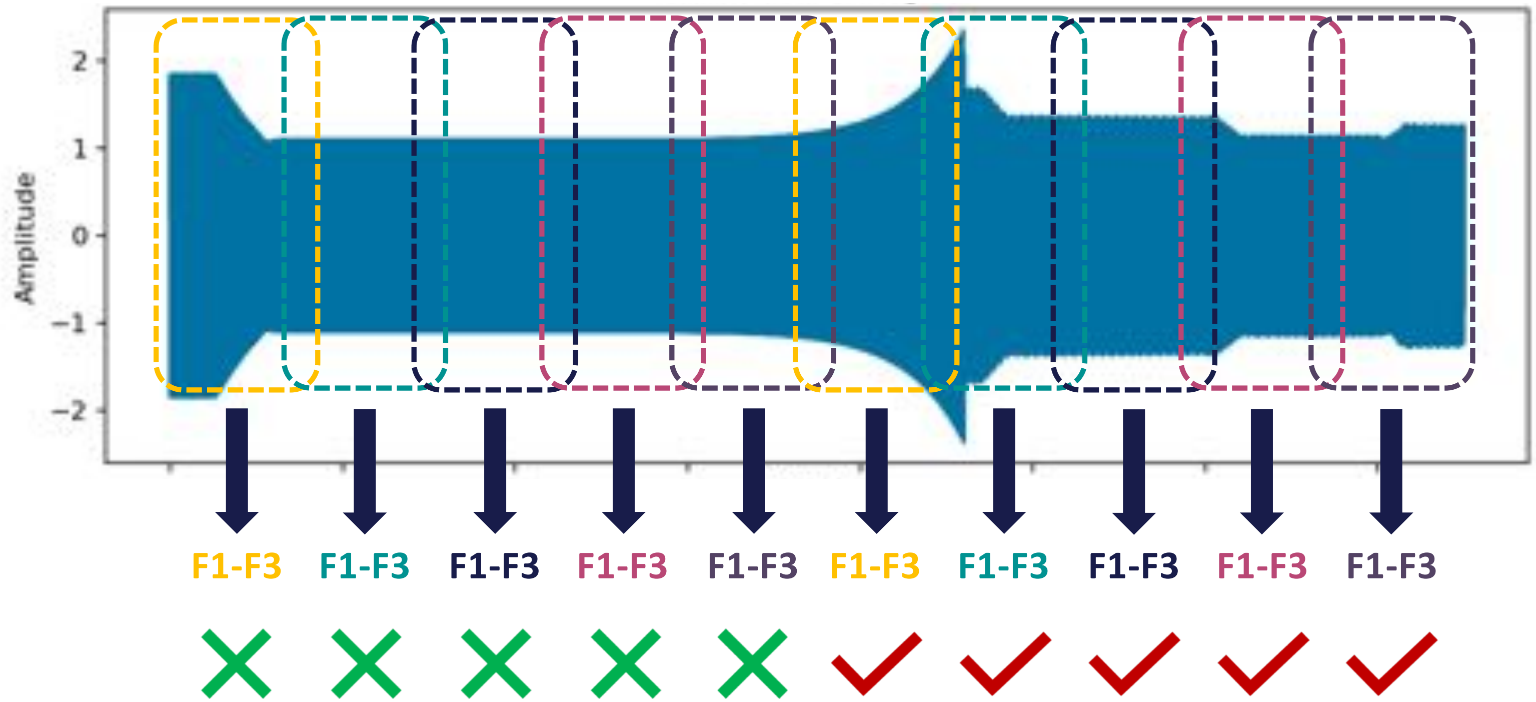


Pipeline – continued



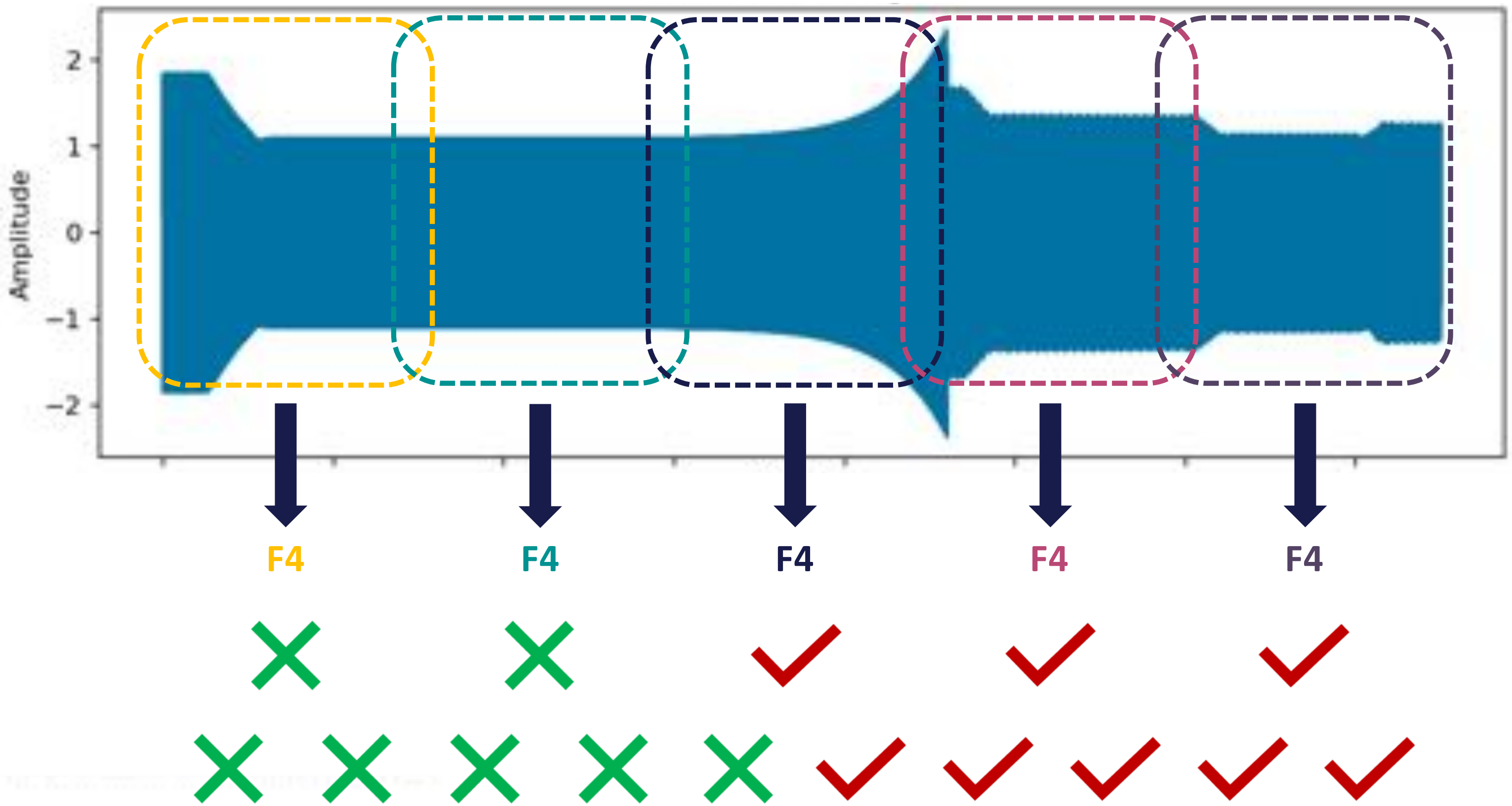
Predicting events

The features are computed using default settings, i.e., a segment duration of 1 second for features 1 – 3

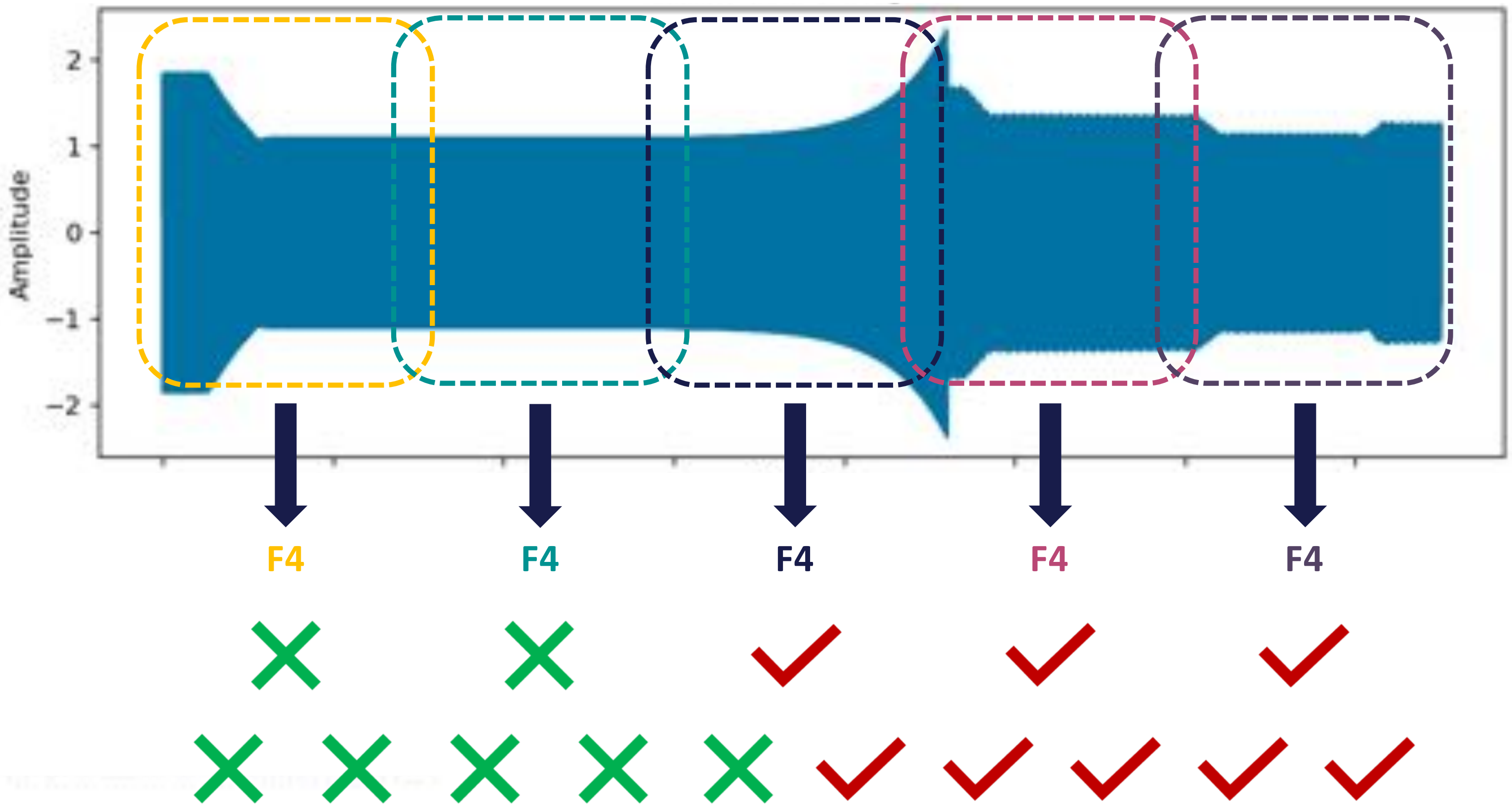


Predicting events

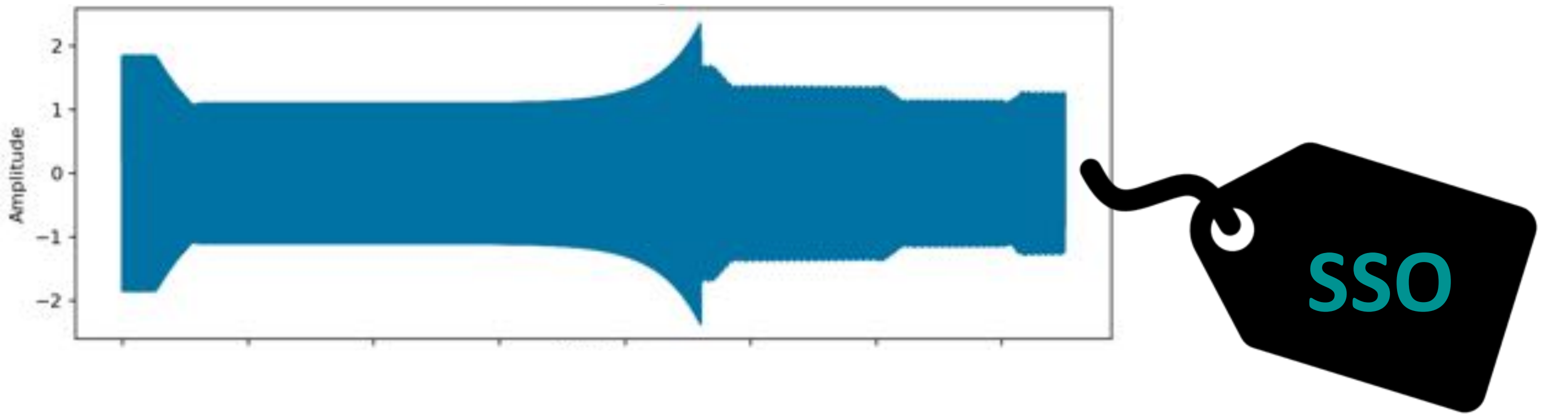
Feature 4 is computed using a 4-second window



Predicting events



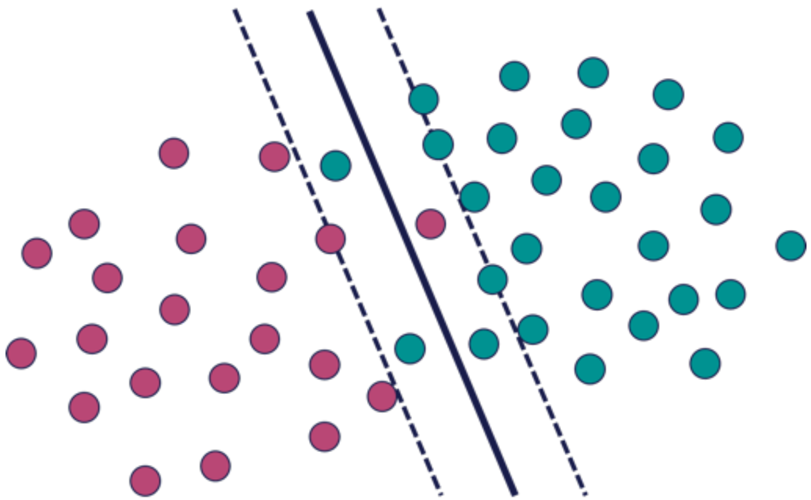
Predicting events

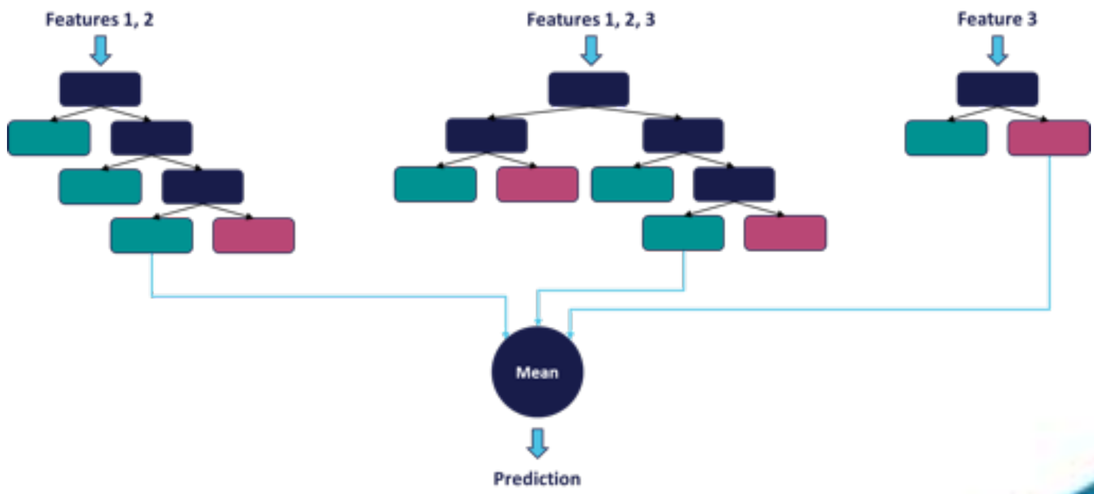


7 non-SSO

8 SSO

Classifier methods

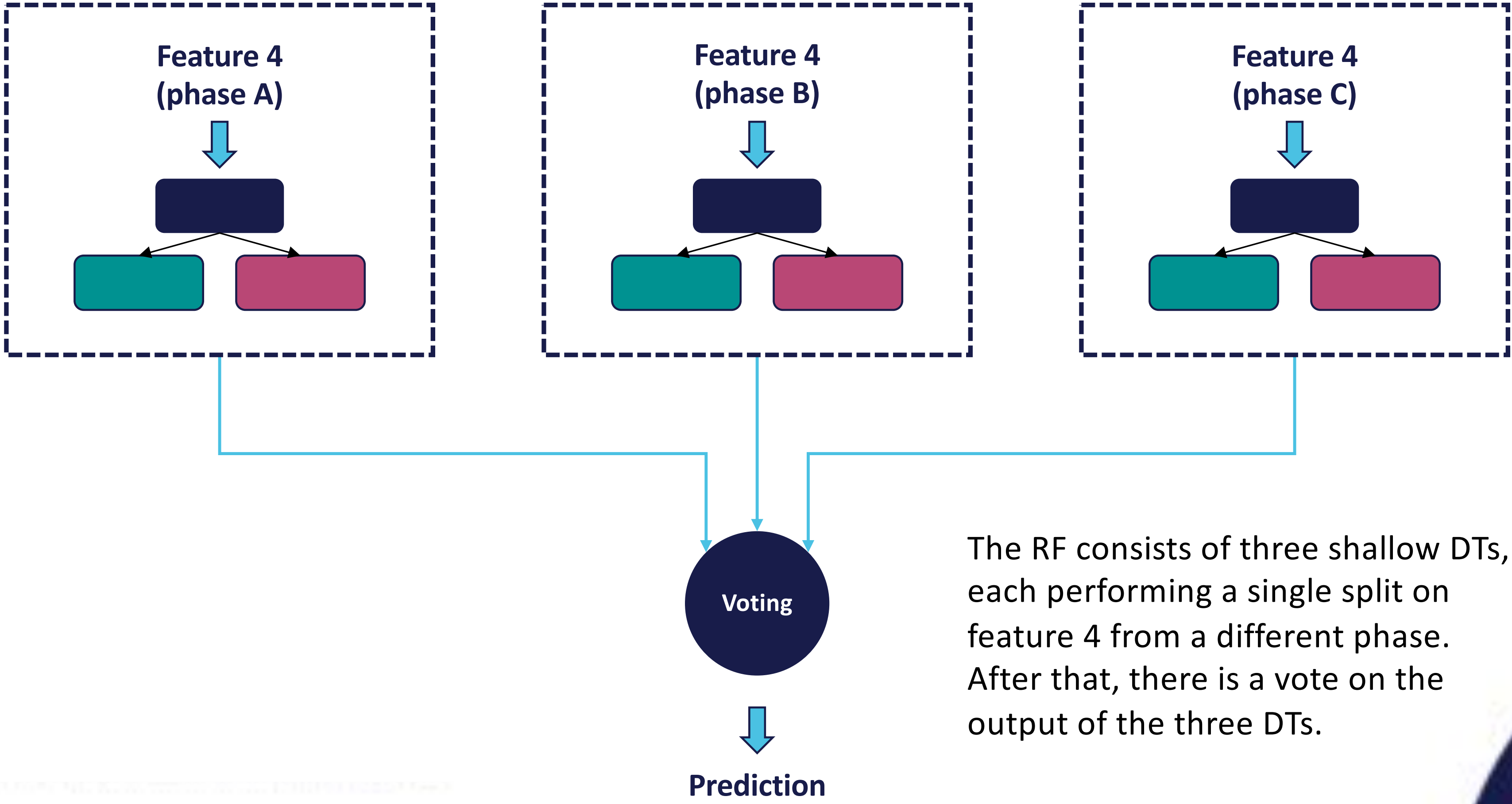




Support Vector Machine (SVM)

Random Forest (RF)

Optimised RF

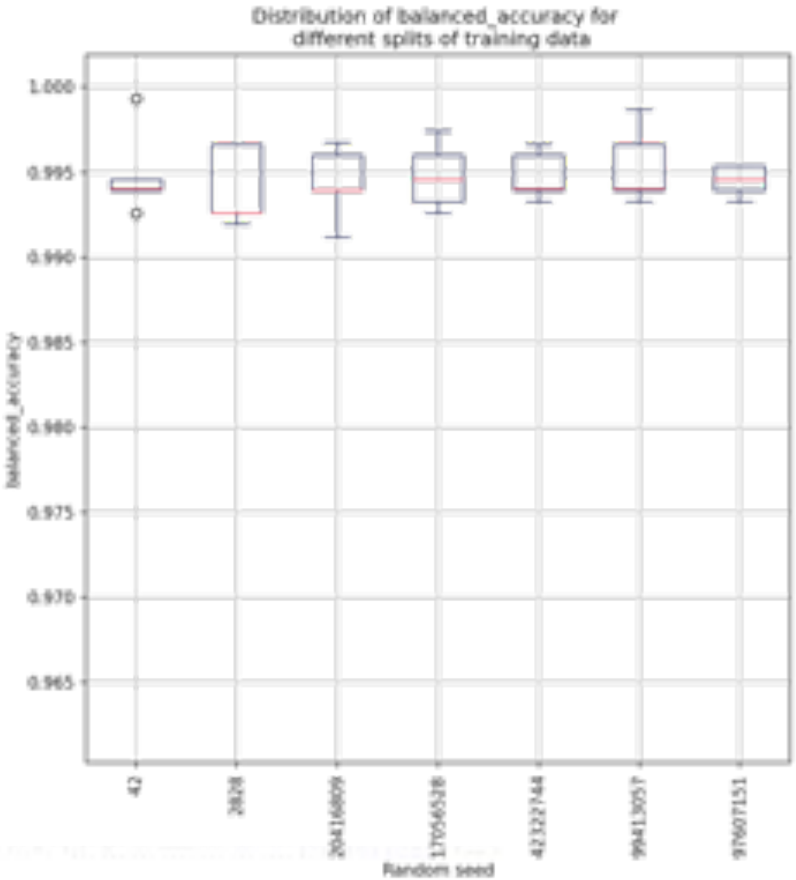


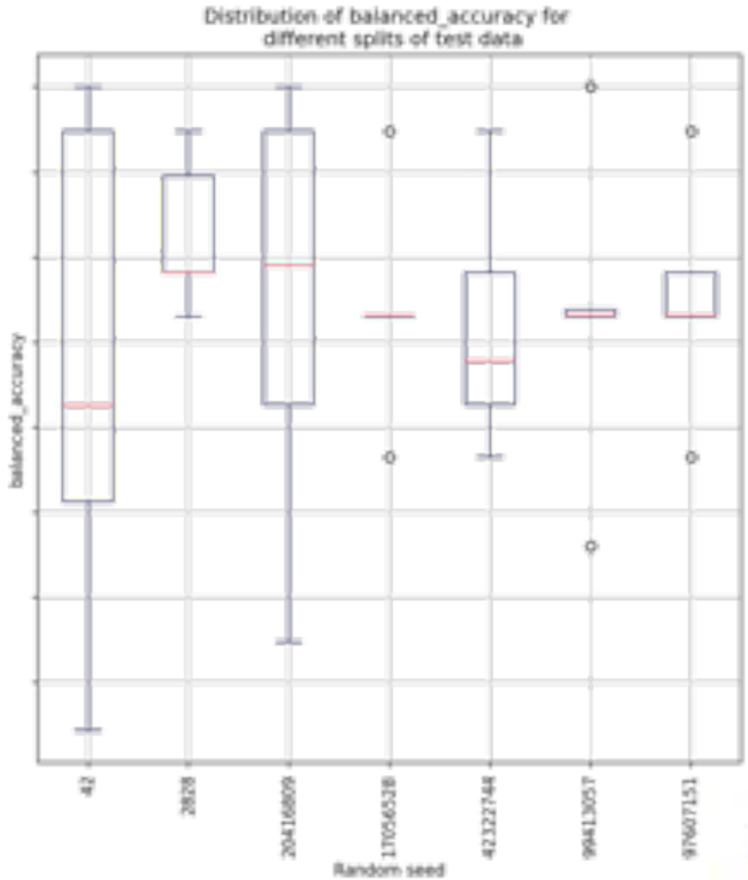
The RF consists of three shallow DTs, each performing a single split on feature 4 from a different phase. After that, there is a vote on the output of the three DTs.

SVM classifier: Features 1 – 3

$$Recall = \frac{TP}{TP+FN}$$

$$Balanced\ Accuracy = \frac{Recall_A + Recall_B}{2}$$

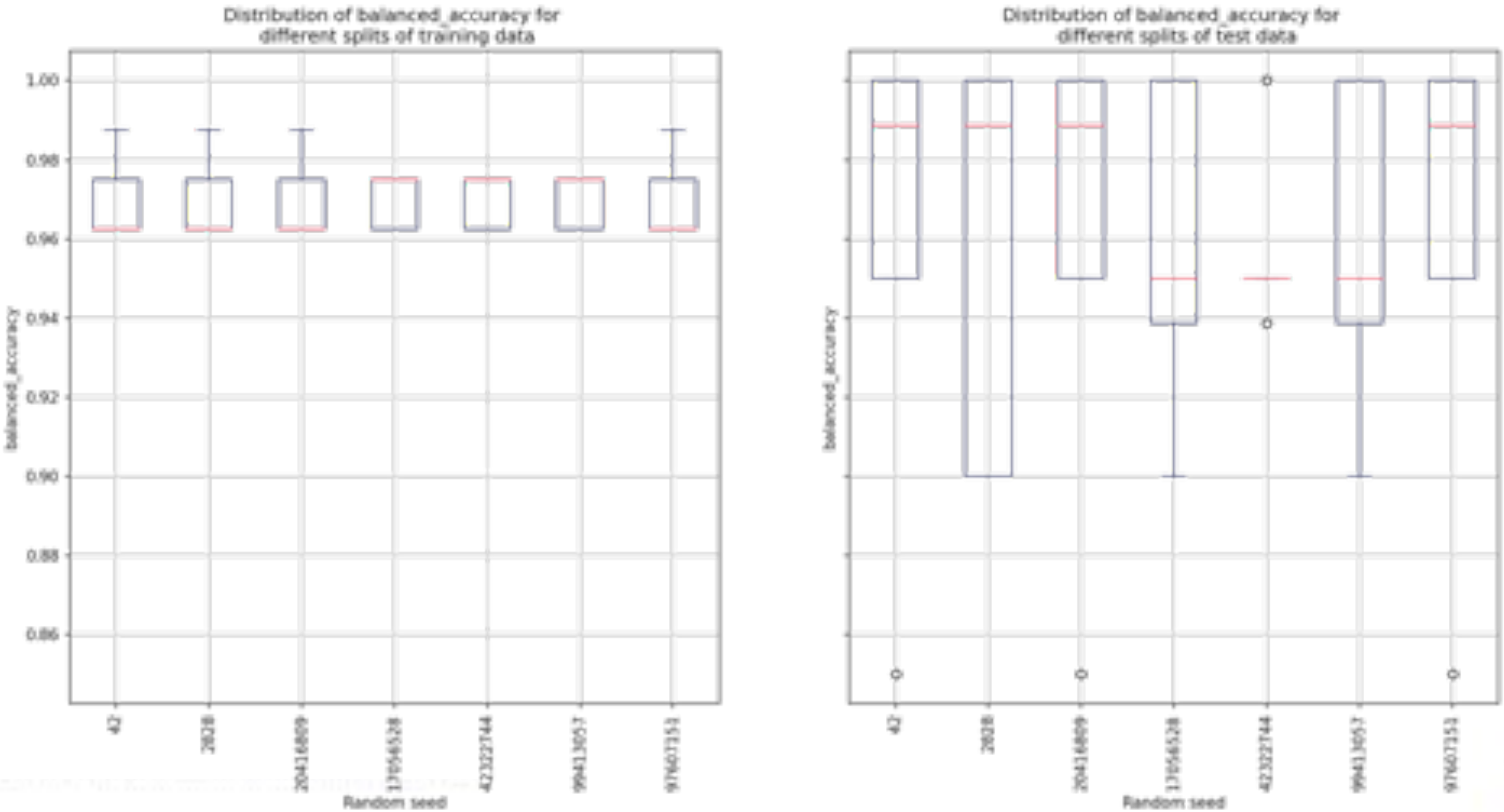




RF Classifier: Feature 4

$$Recall = \frac{TP}{TP+FN}$$

$$Balanced\ Accuracy = \frac{Recall_A + Recall_B}{2}$$



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Thank you for listening!

For any questions, please contact me at

diptargha@tneigroup.com