Automated Anomaly Detection in Quantum Voltage Standards Using Feature-Based Time Series Classification.

GUILLERMO SCHNEIDER

03/12/2025

INTI Instituto Nacional de Tecnología Industrial

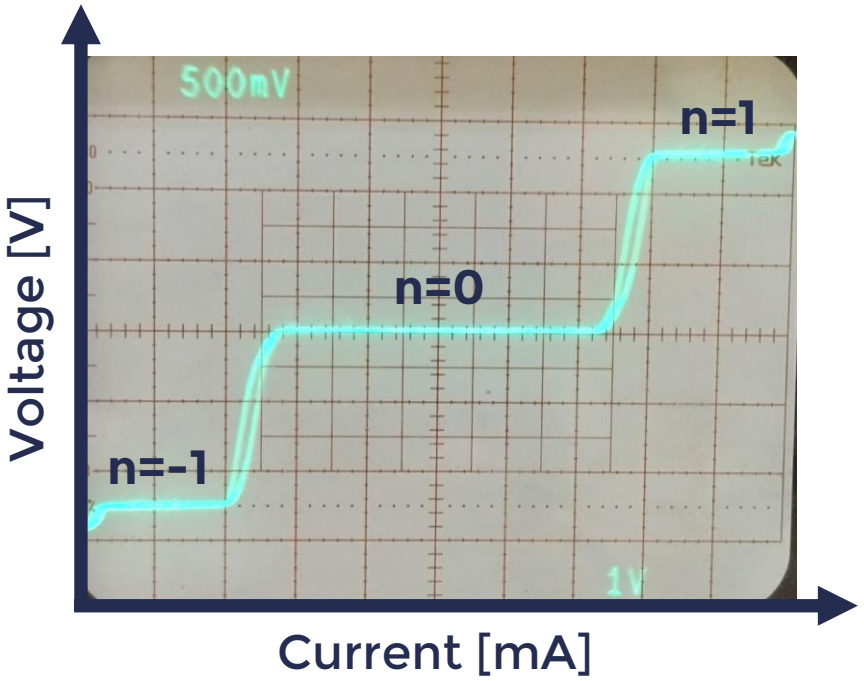
Secretaría de Industria y Comercio
Ministerio de Economía

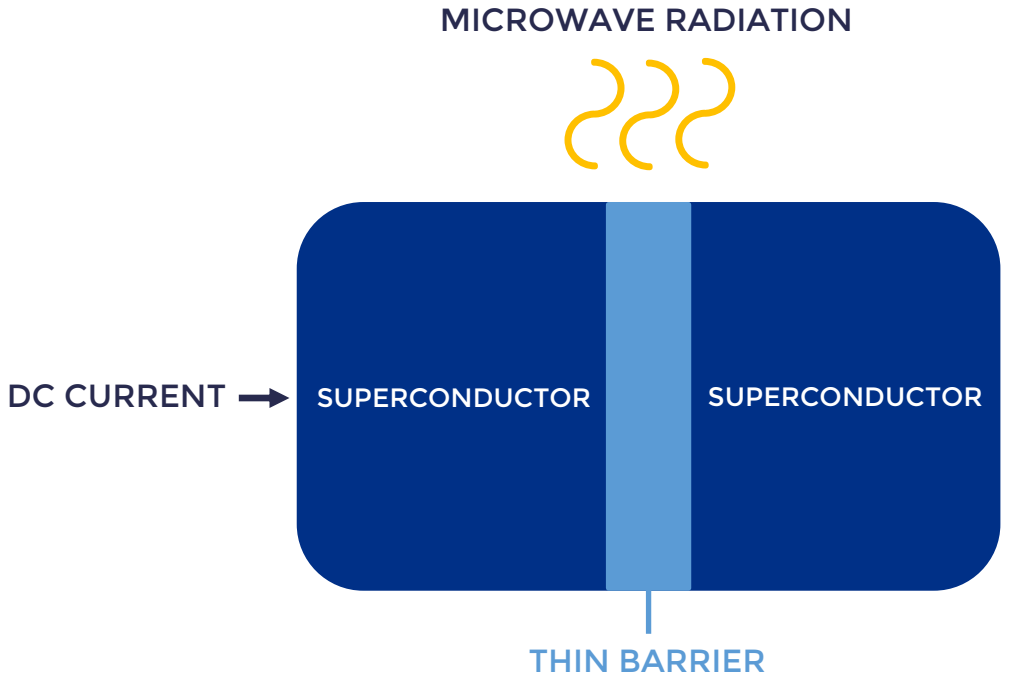
TÜBİTAK

Josephson Effect

Voltage steps: $V_J = n\frac{h}{2e}f = n\frac{f}{K_J},\ n = \pm1, \pm2, \ldots$

Josephson constant: $K_J = \frac{2e}{h}$

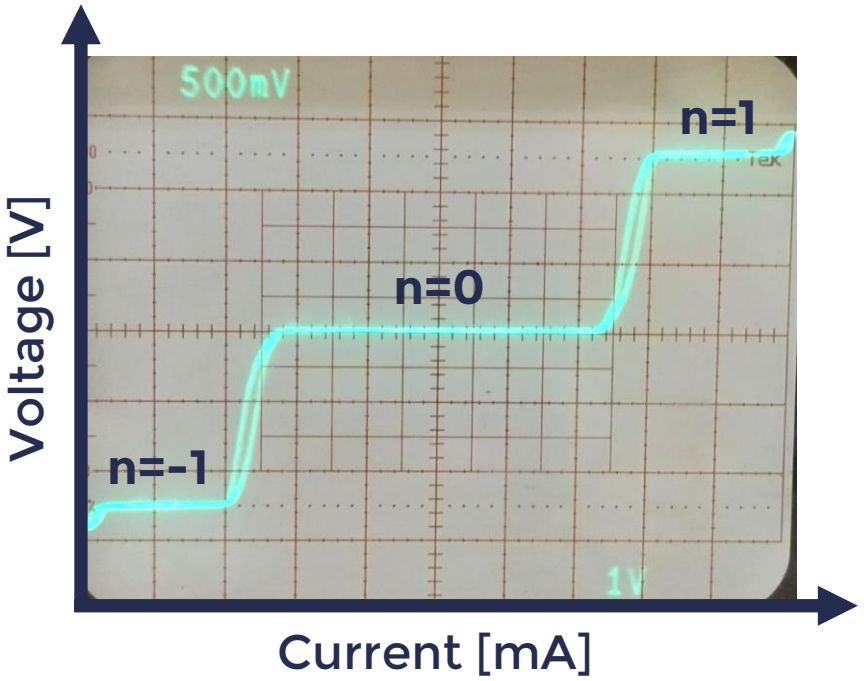




Josephson Effect

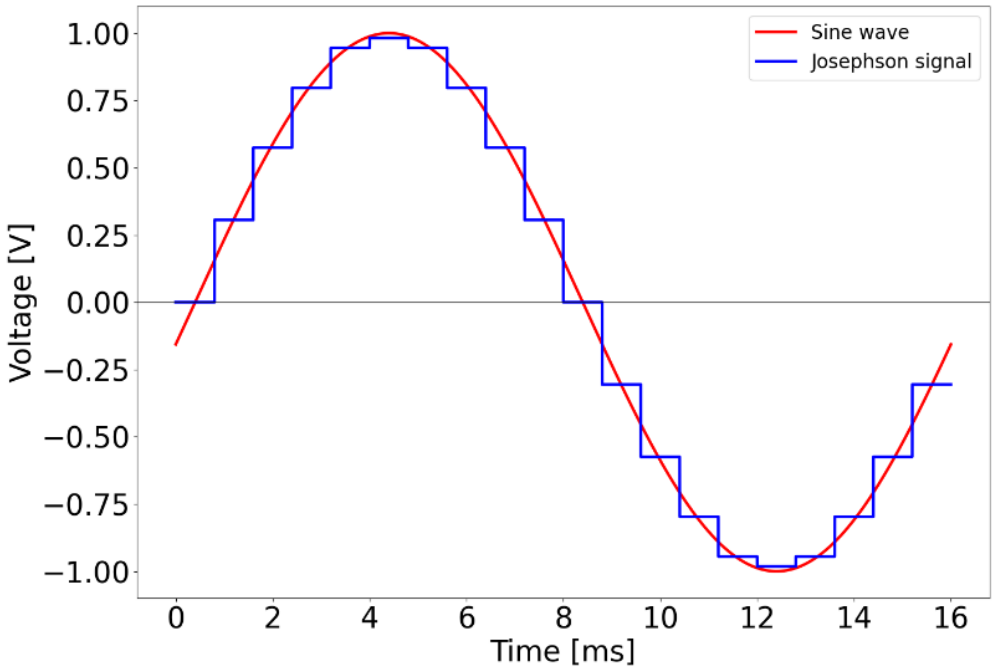
Voltage steps: $V_J = n\frac{h}{2e}f = n\frac{f}{K_J},\ n = \pm1, \pm2, \ldots$

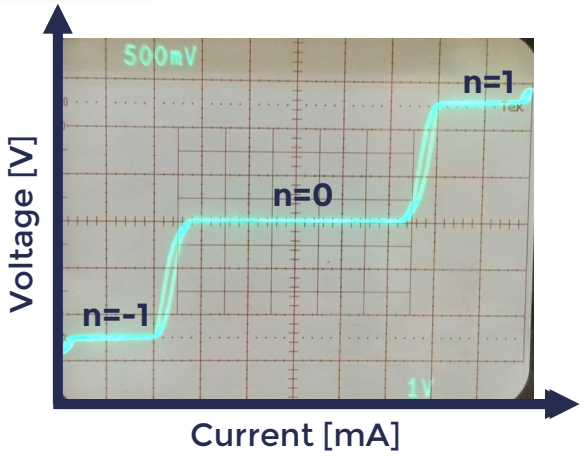
Josephson constant: $K_J = \frac{2e}{h}$

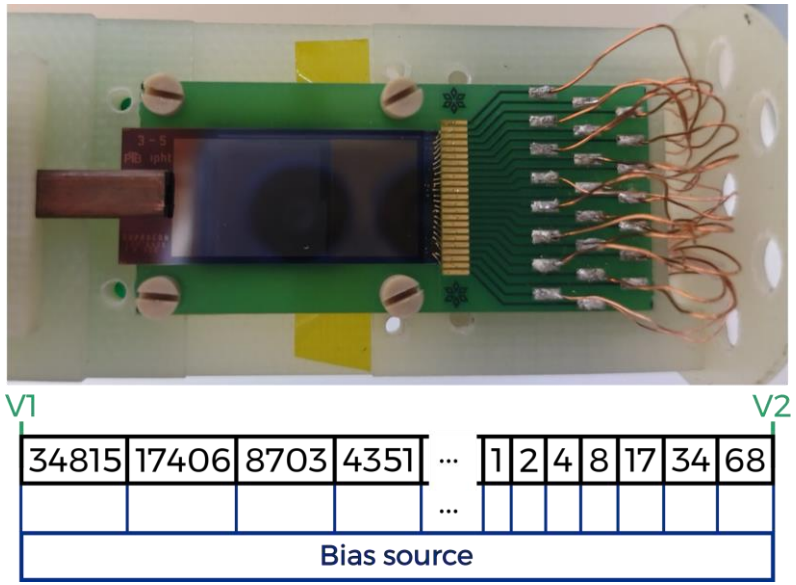


Programmable Josephson Voltage Standard (PJVS)

PJVS: Superconductor multi-bit DAC. Produces very stable time-stepwise approximated signals with calculable RMS values.







INTI PJVS System

A: Cesium atomic clock signal

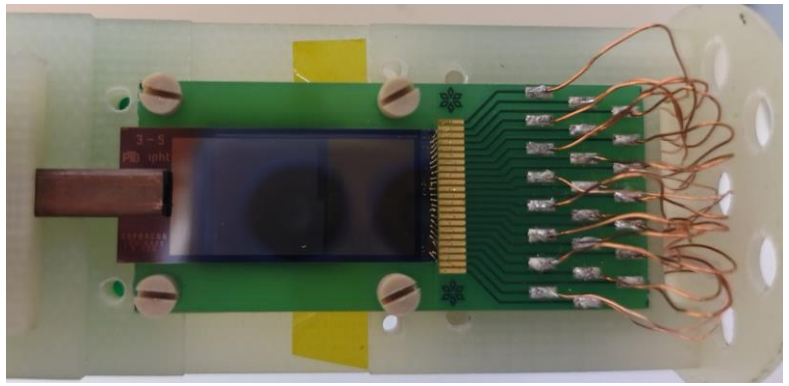
B: Microwave synthesizer (70 GHz)

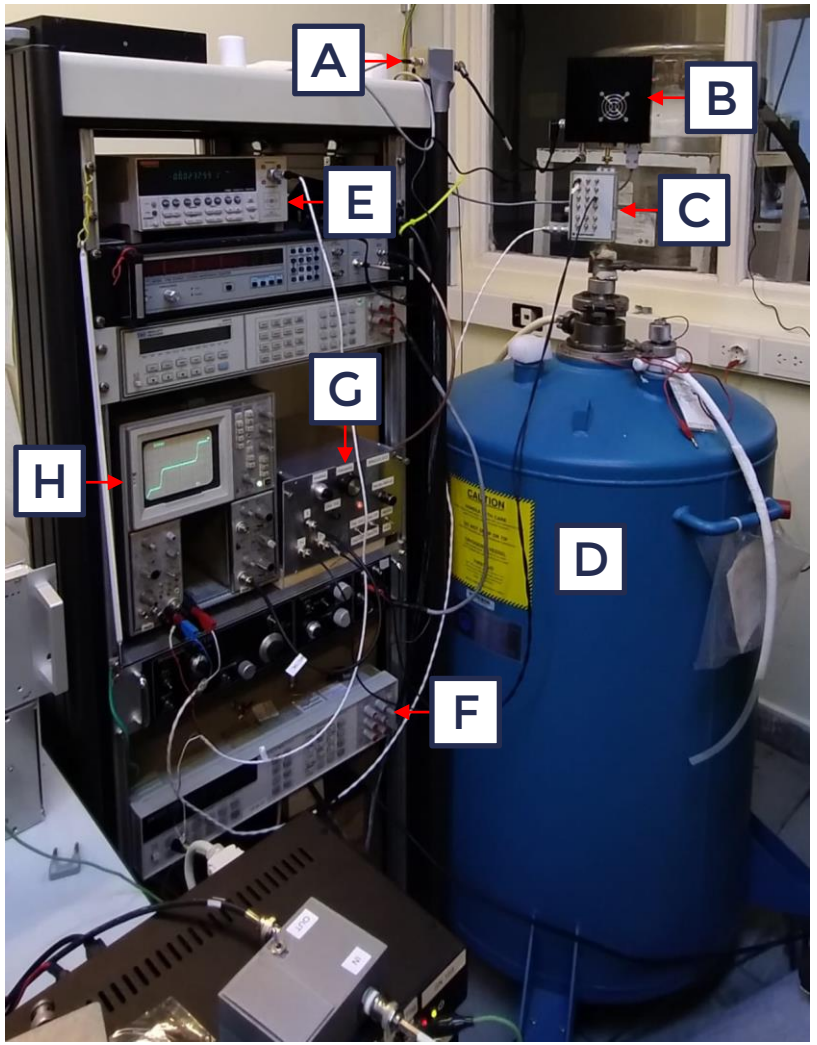
C: Cryogenic probe

D: Dewar where the Josephson chip is cooled to 4.2 K

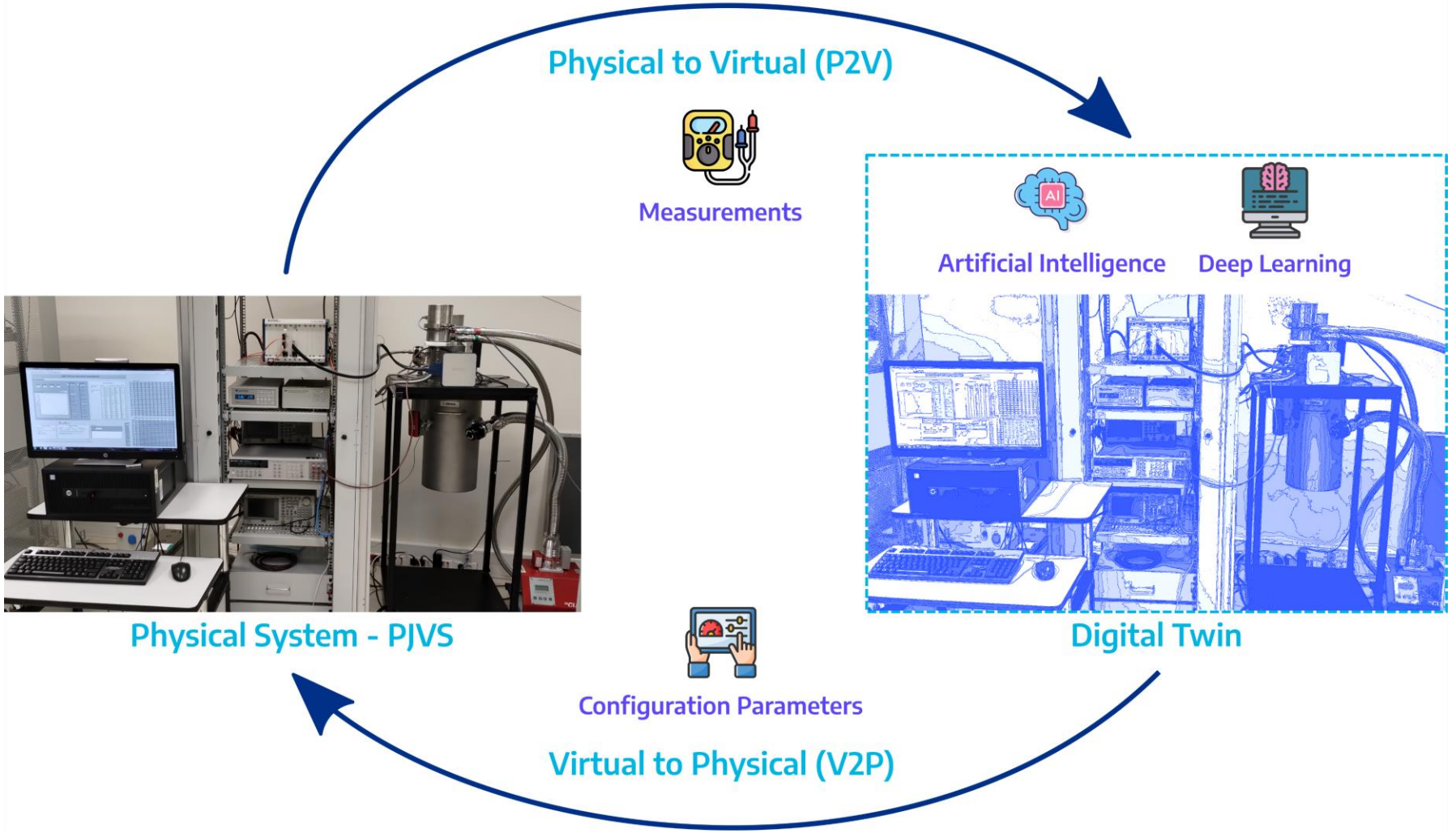
E: Digitizers

F: Bias source

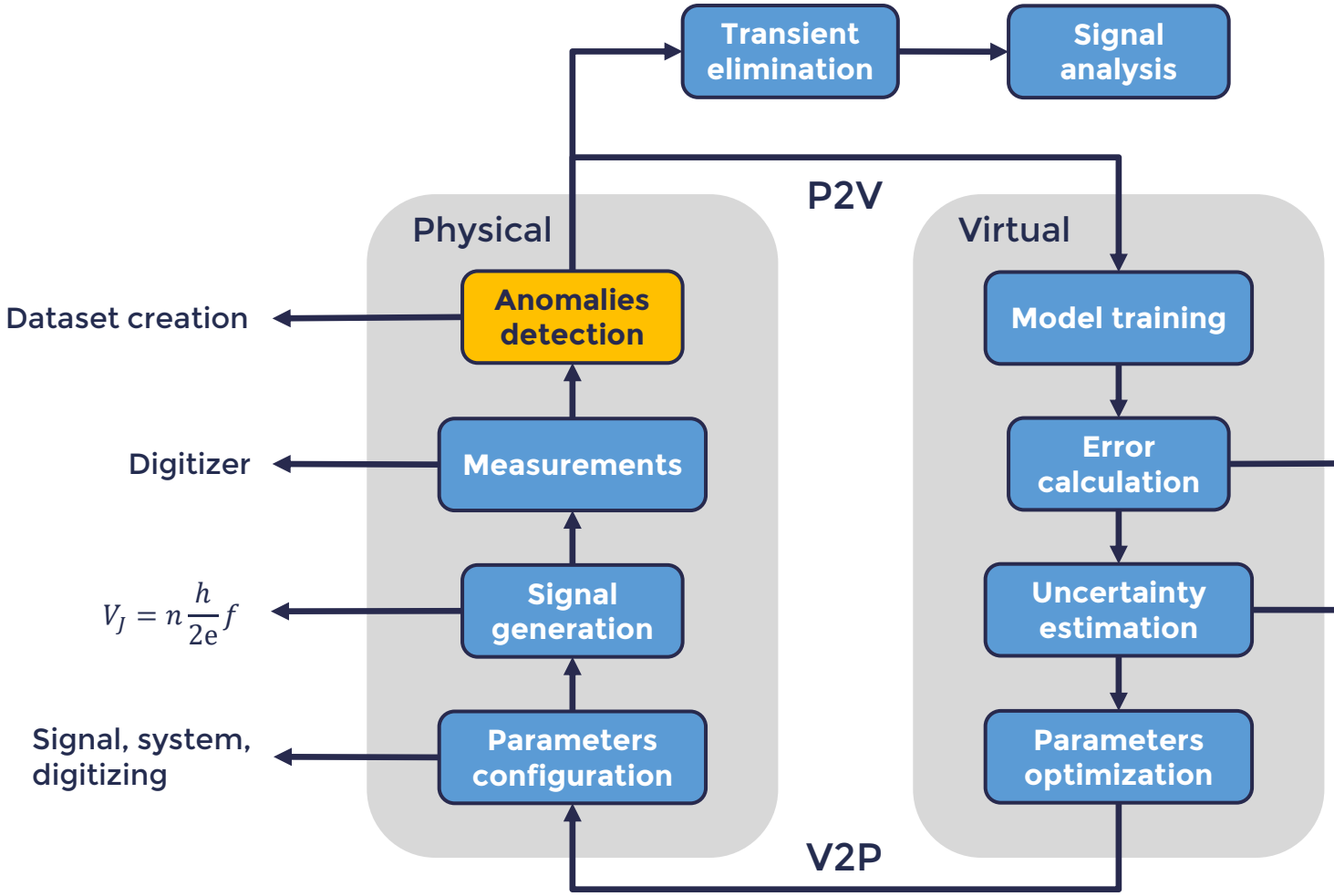




Quantum Voltage Standard Digital Twin



Proposed Methodology

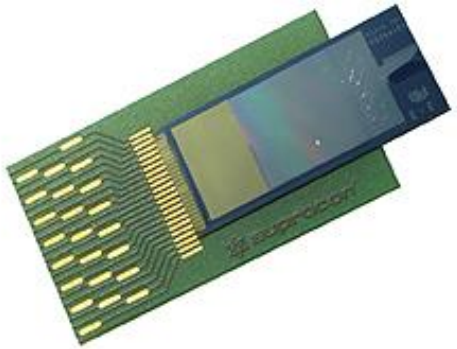


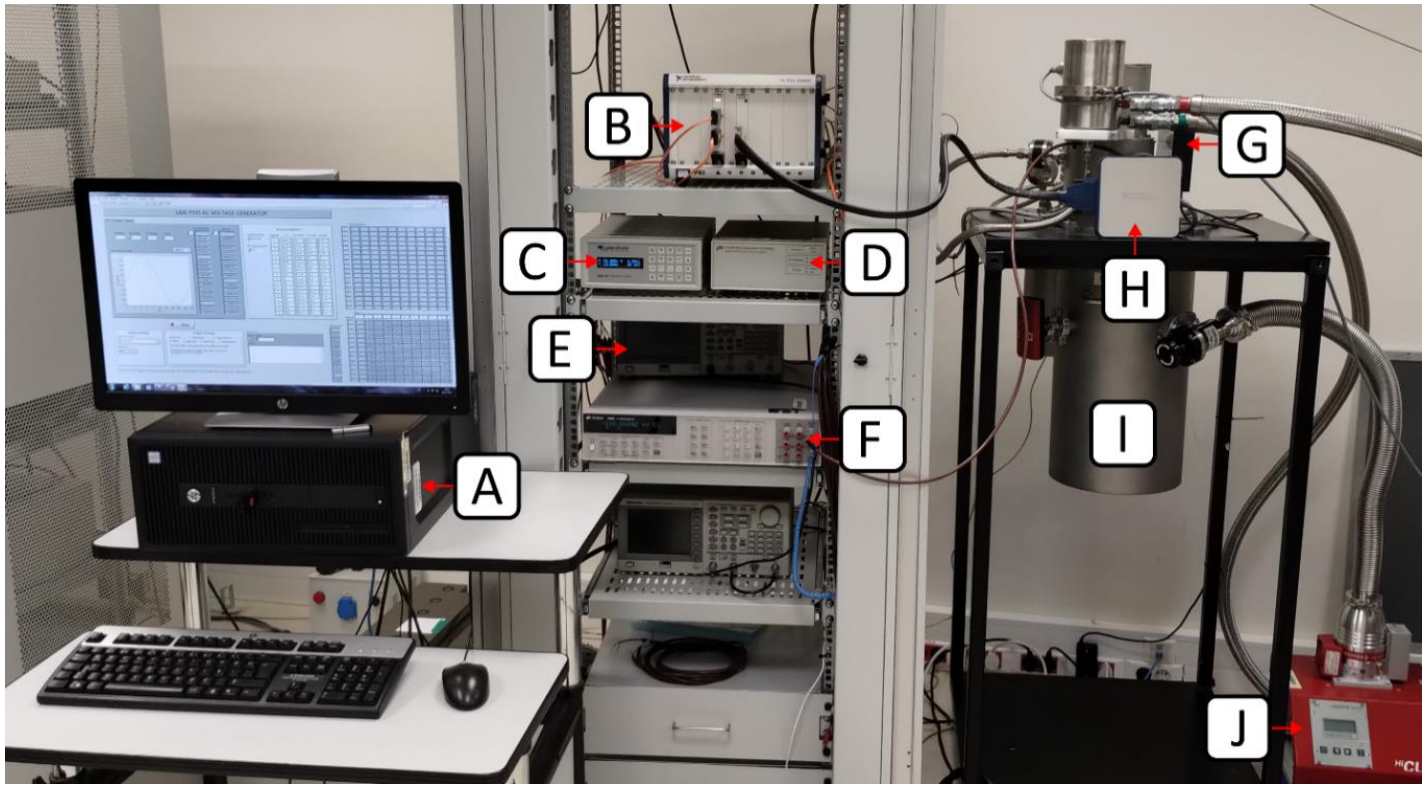
$V_{PRED} - V_{PJVS}$ (Validation)

Inputs: Monte Carlo Method (GUM compliant)
Model: Monte Carlo Dropout Method
Total = $\sigma_{input} + \sigma_{model}$

TÜBITAK UME PJVS System

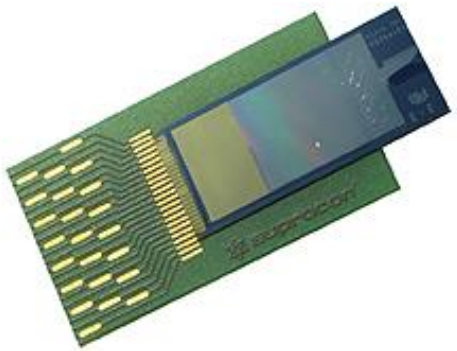
A: PC with PJVS software
B: Bias source
C: Temperature controller
D: Rubidium atomic clock
E: Arbitrary Waveform Generator
F: Digitizer
G: Microwave synthesizer
H: Resistors box
I: Cryocooler where the Josephson array is cooled below 4.2 K
J: Turbomolecular pump

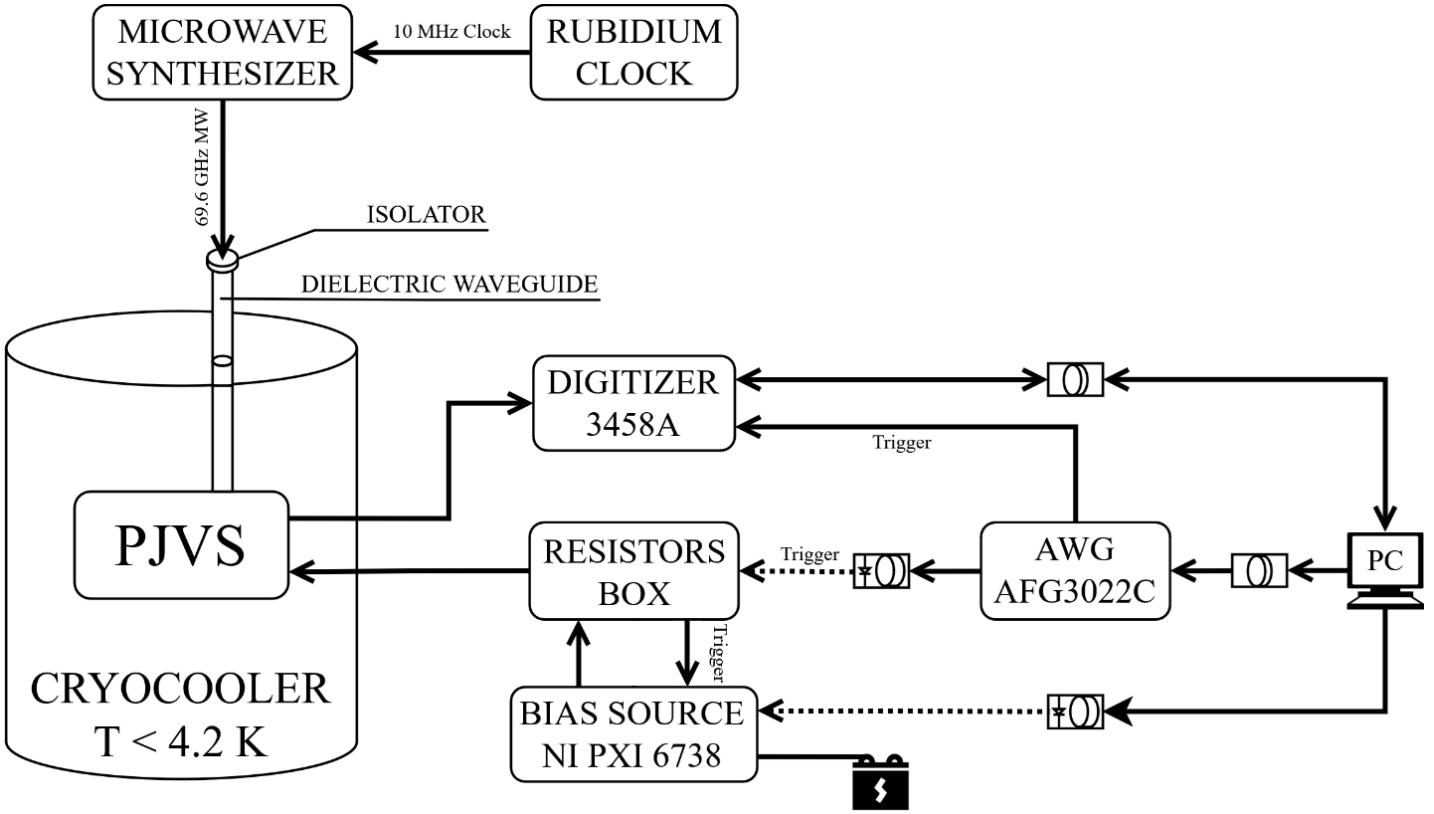




TÜBITAK UME PJVS System

A: PC with PJVS software
B: Bias source
C: Temperature controller
D: Rubidium atomic clock
E: Arbitrary Waveform Generator
F: Digitizer
G: Microwave synthesizer
H: Resistors box
I: Cryocooler where the Josephson array is cooled below 4.2 K
J: Turbomolecular pump



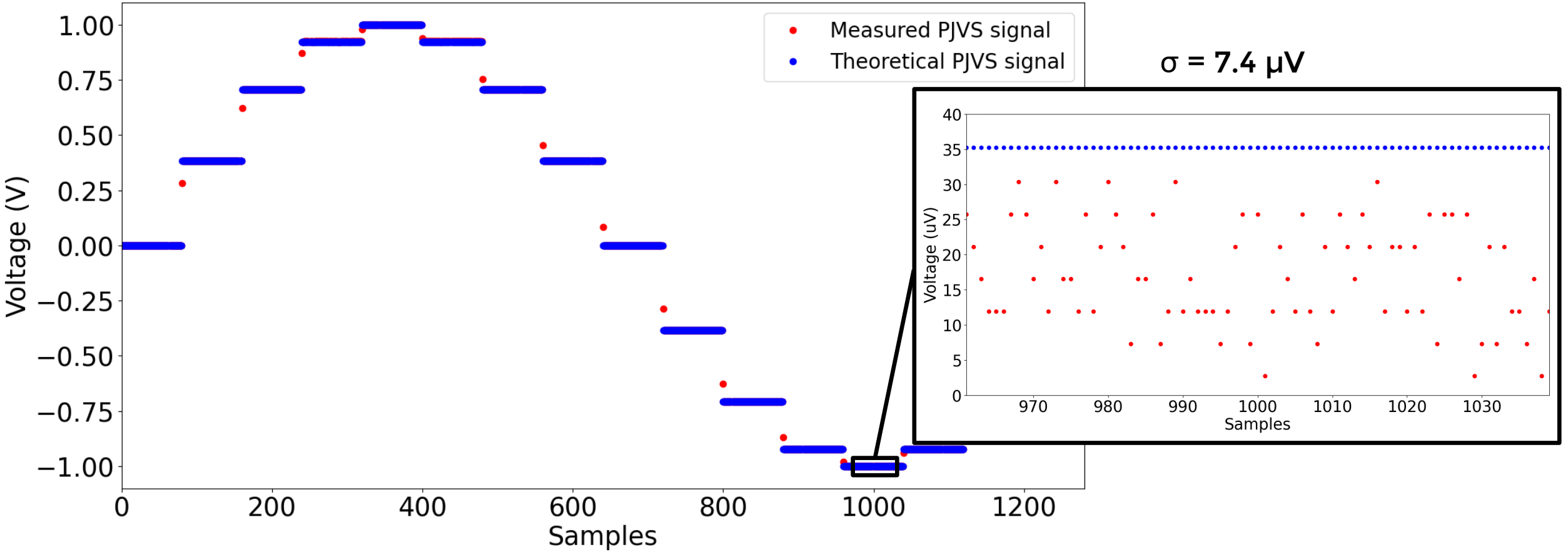


Measurements Performed

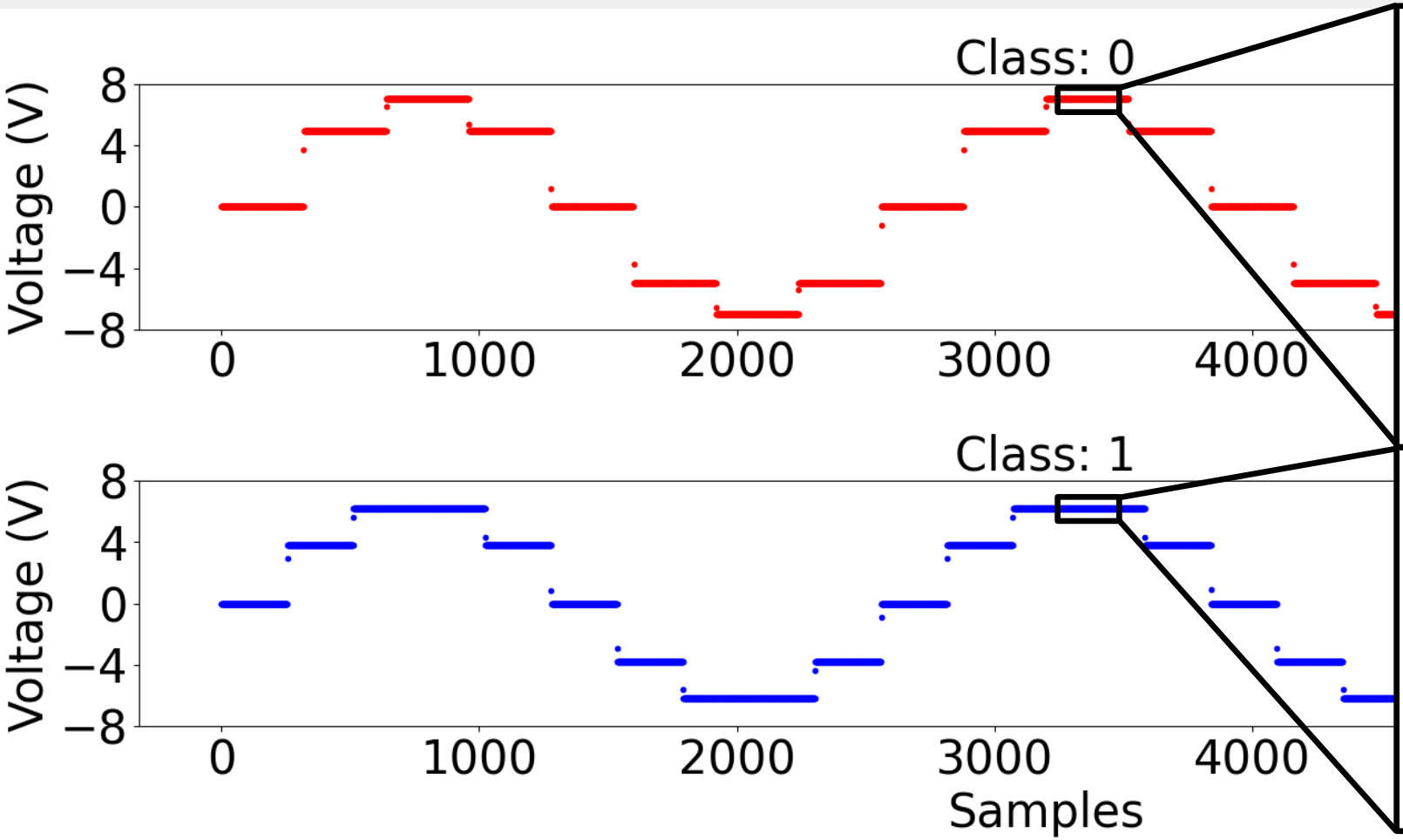
- 1388 sine wave approximated signals
- 5 periods per signal
- Signals stored as time series

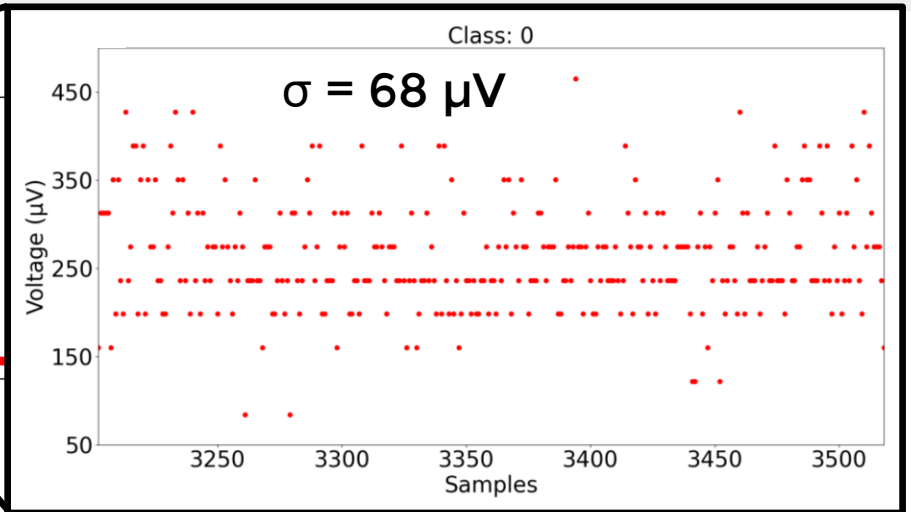
Parameter	Min value	Max value	Number of changes
Peak to peak amplitude [V]	1	19.7	21
Signal frequency [Hz]	7.8125	125	5
Number of steps	8	20	4
Sampling frequency [kHz]	10	50	4

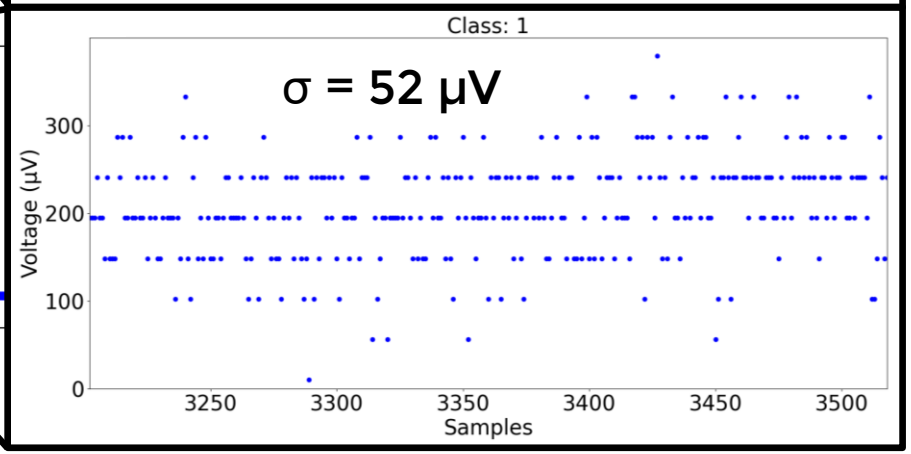
Comparison – Theoretical vs Measured



Training Dataset
Signals labelling and anomaly injection

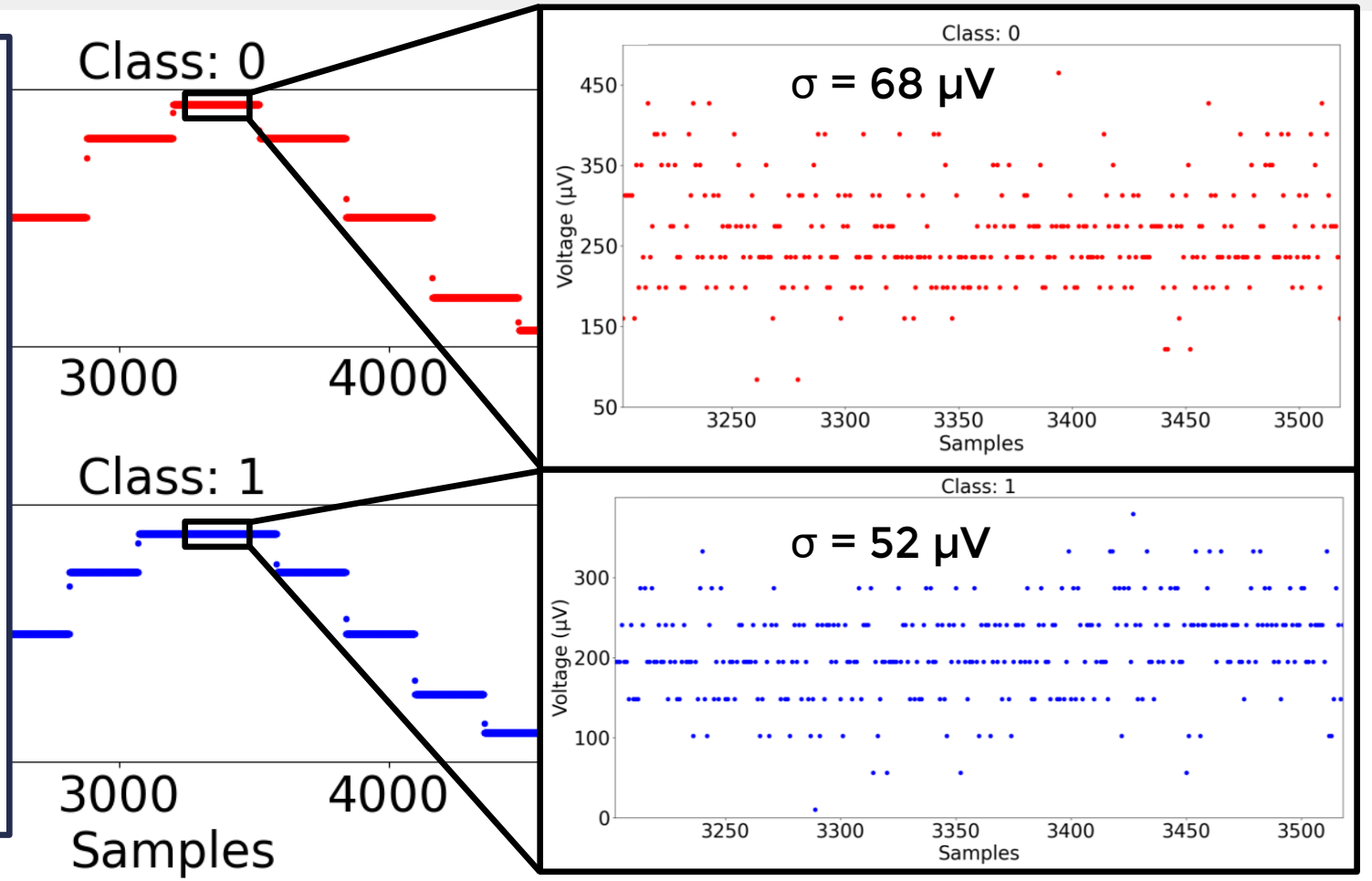




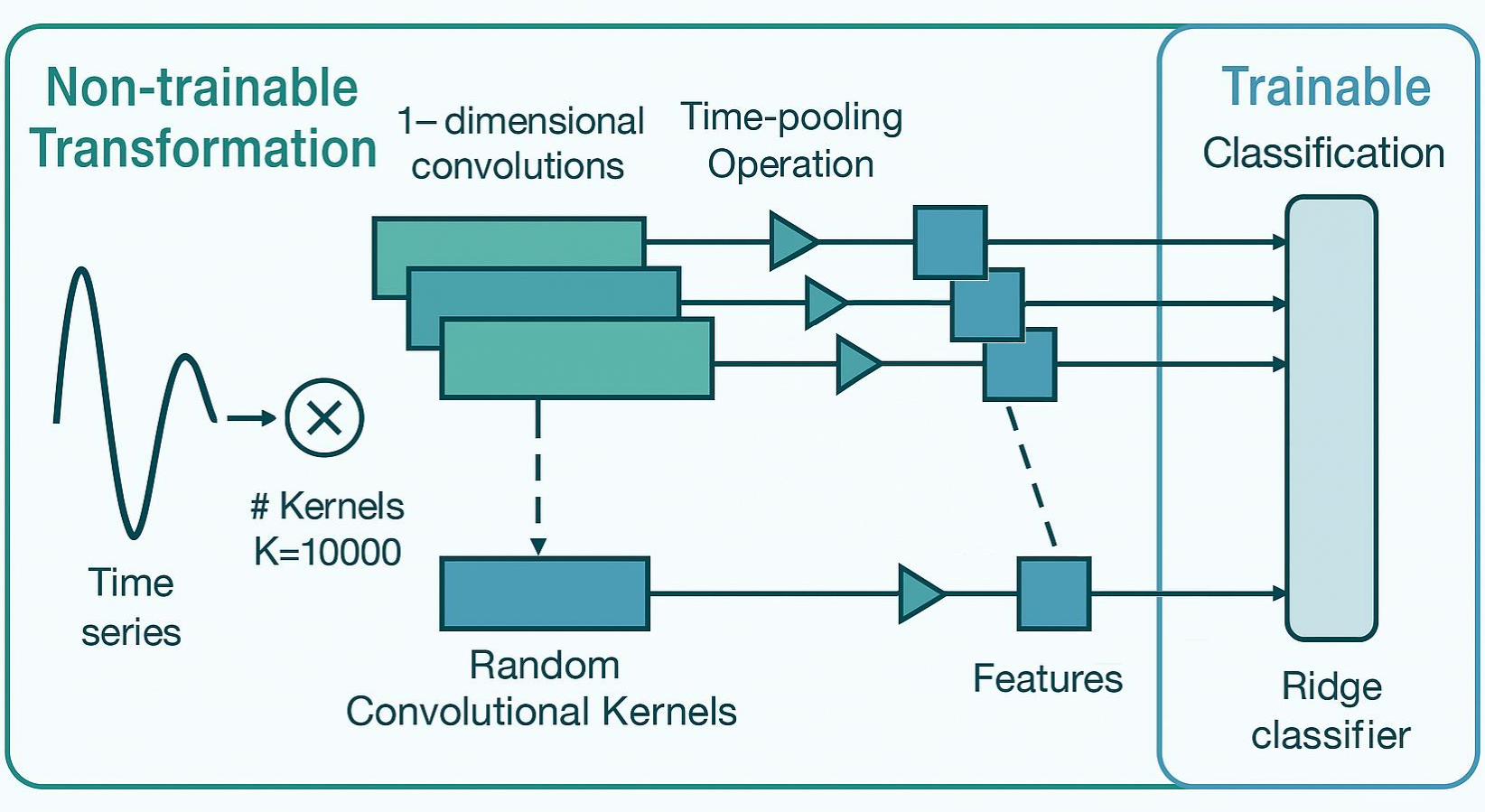


Training Dataset
Signals labelling and anomaly injection

- White noise
- Power-line interference
- DC offsets
- Step instabilities



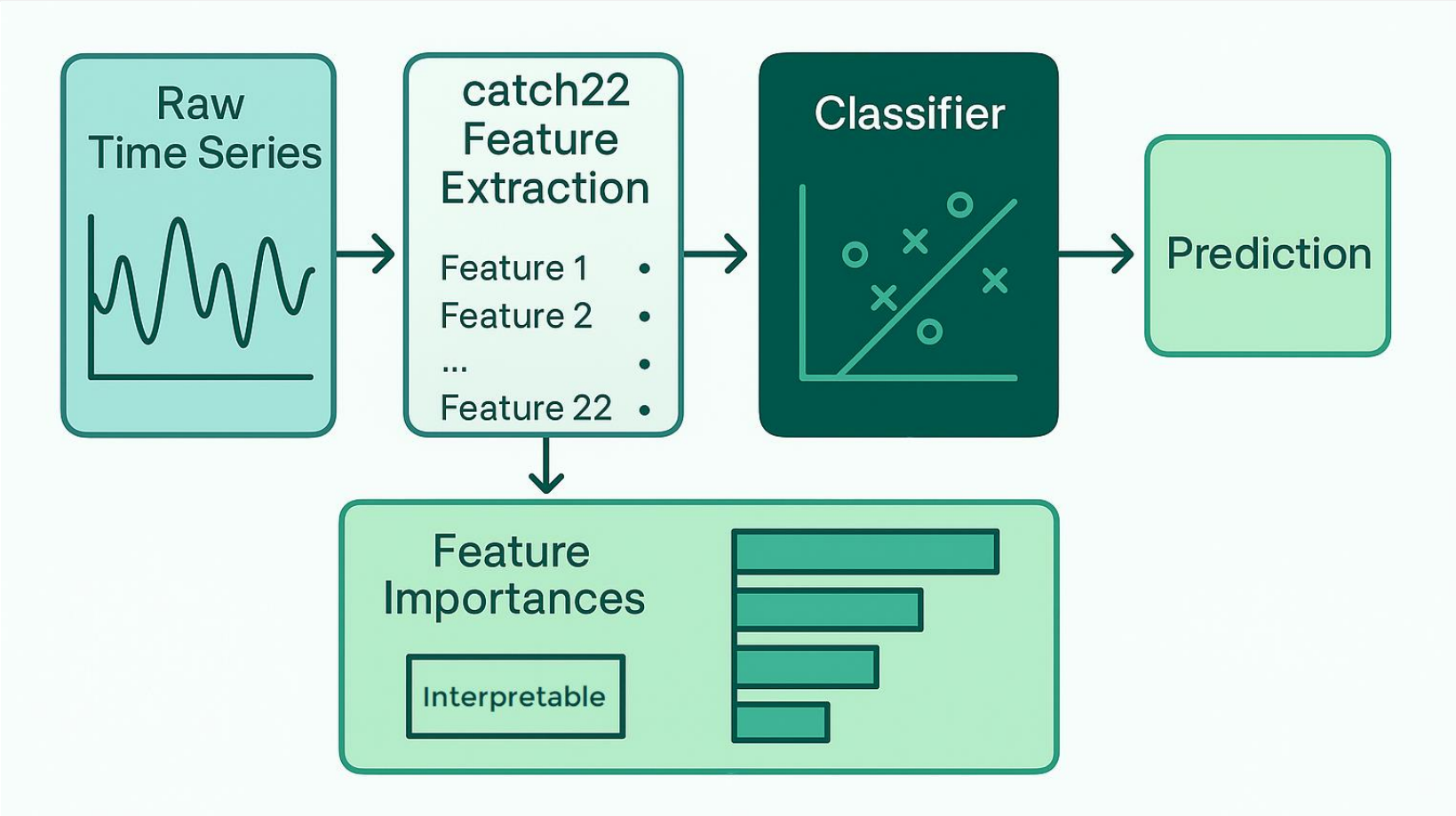
Classifier model
Random Convolutional Kernel Transform (ROCKET)



Dempster et al. (2020). ROCKET: Exceptionally Fast and Accurate Time Series Classification Using Random Convolutional Kernels

Baseline model

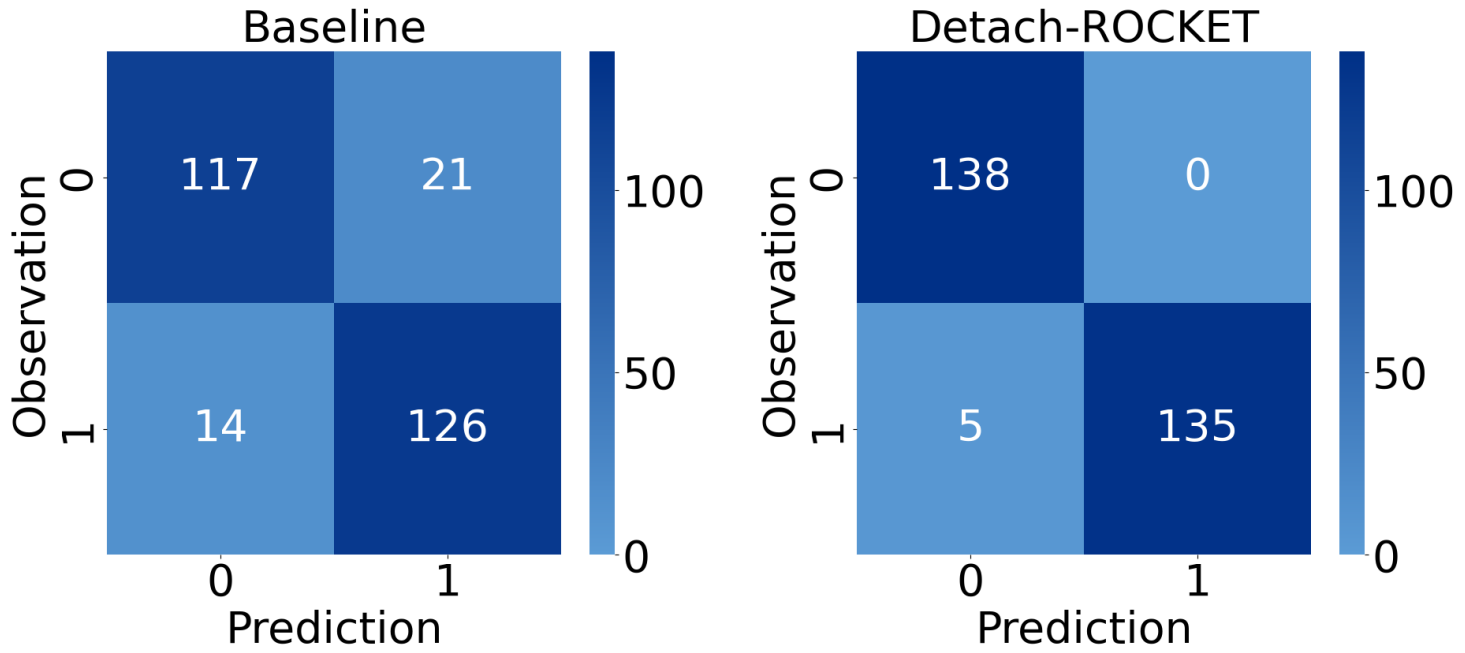
CAnonical Time-series CHaracteristics (catch22) + Logistic Regressor



Lubba et al. (2019). catch22: CAnonical Time-series CHaracteristics

Classification Results

Model	Training Accuracy [%]	Testing Accuracy [%]	False Positives Rate [%]	False Negatives Rate [%]
Baseline	90.27	87.41	15.22	10.00
Detach-ROCKET	99.73	98.20	0.00	3.57



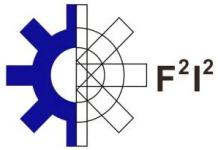
Conclusions and Future Work

- We successfully apply the ROCKET transformation to classify measurements of a PJVS.
- The model achieved excellent accuracy on testing datasets.
- The False Positives Rate was 0%
- Allows automated anomaly detection in our PJVS, which will improve data collection for our digital twin.
- Transferable to other time-series metrology systems where high-accuracy signal analysis is critical.

- Extend the characteristics of the measurements (amplitude, number of steps).
- Benchmarking other time series classification models.

ViDiT

www.vidit.ptb.de



Cracow University of Technology

UNIVERSITÀ DEGLI STUDI DI PADOVA

The project (22DIT01 ViDiT) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

EURAMET

Thank you!
Questions?

Eng. Guillermo Schneider
INSTITUTO NACIONAL DE TECNOLOGÍA INDUSTRIAL

Quantum Metrology Departament
Technical Direction of Physical Metrology
O. S. of Scientific and Industrial Metrology
O. G. of Metrology and Quality

INTI Instituto Nacional de Tecnología Industrial

| gschneider@inti.gob.ar
| **www.inti.gob.ar**