PD testing with Techimp's TF map technology

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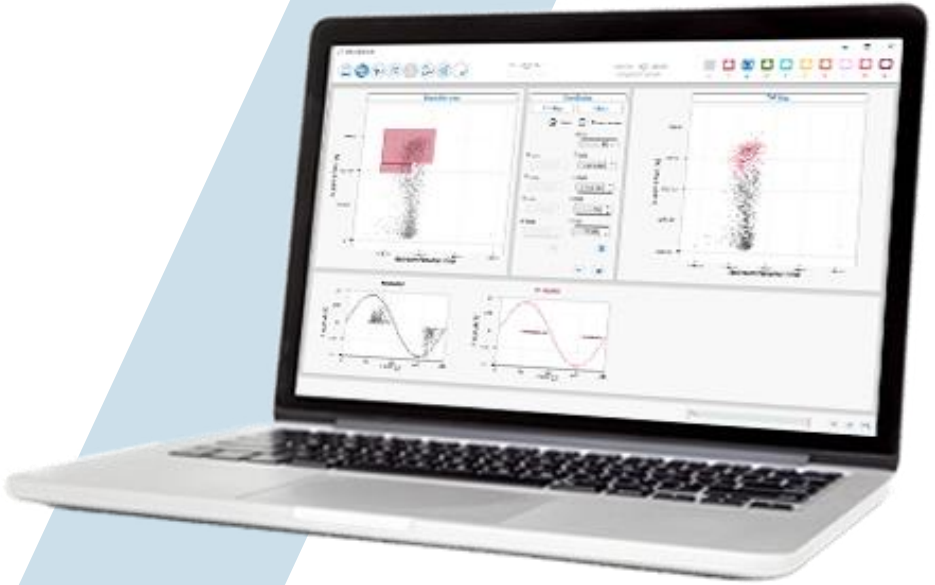
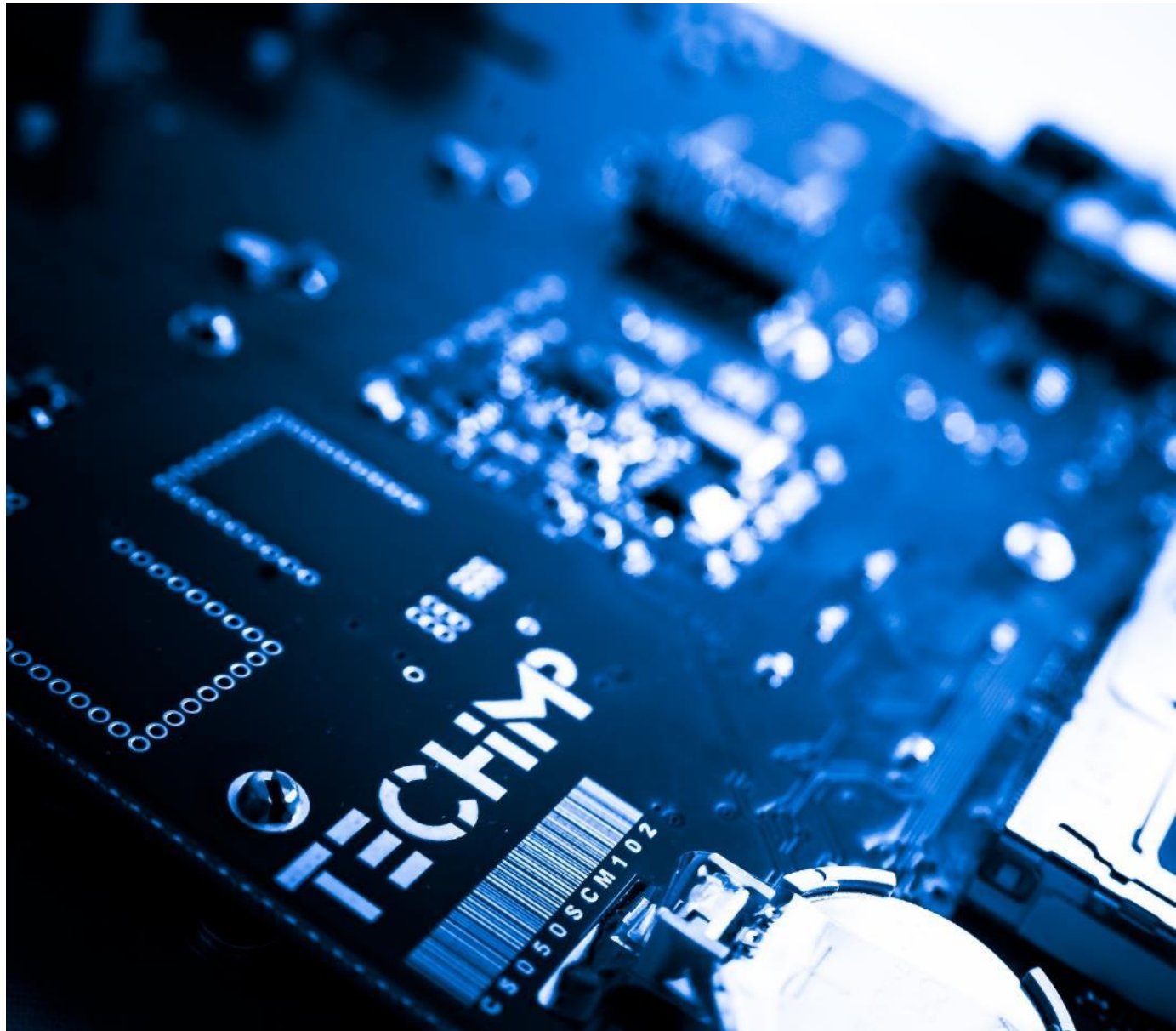


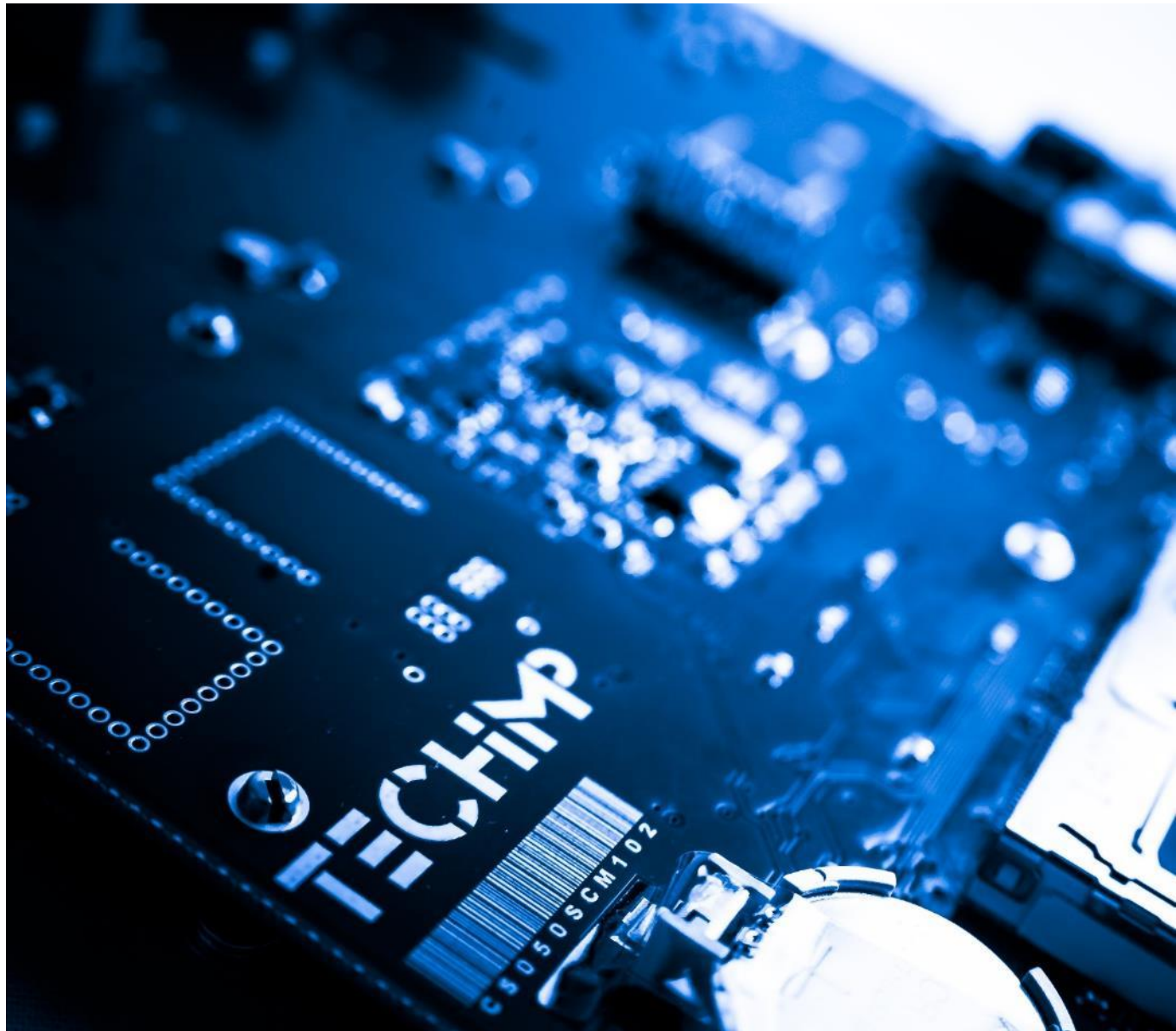
Webinar Summary

- Introduction to partial discharge
- PD test target & challenges
- PD pulse, PRPD pattern & TF map
- TF map in the standards
- PD acquisition denoising
- Data analysis and post-processing
- Examples



Introduction to partial discharge

- Partial discharge
- PD pulse
- PRPD pattern

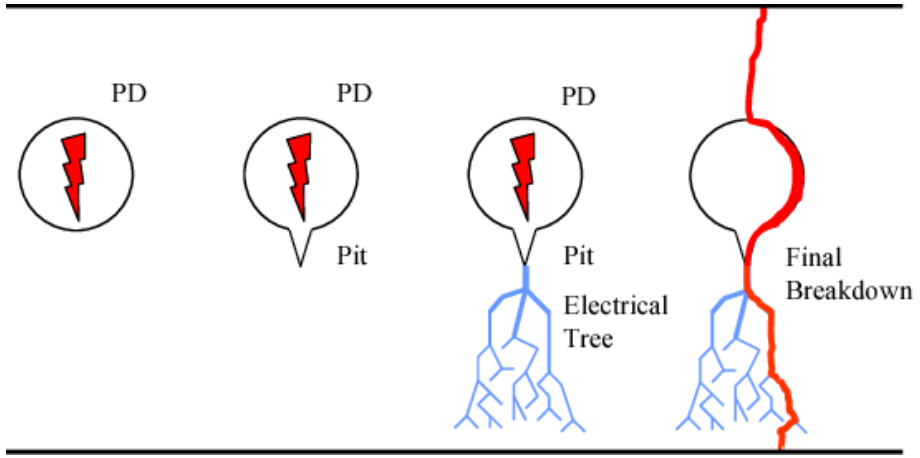


Introduction to Partial Discharge

Partial Discharge

IEC: “localized electrical discharge that only partially bridges the insulation between conductors and which can or can not occur adjacent to a conductor”

IEEE: “Localized electrical discharge that only partially bridges the insulation between conductors”

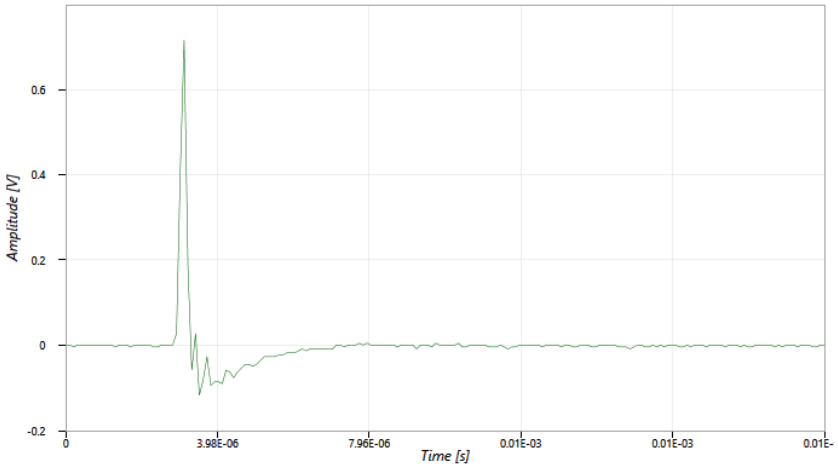


Introduction to Partial Discharge

Partial Discharge Pulse

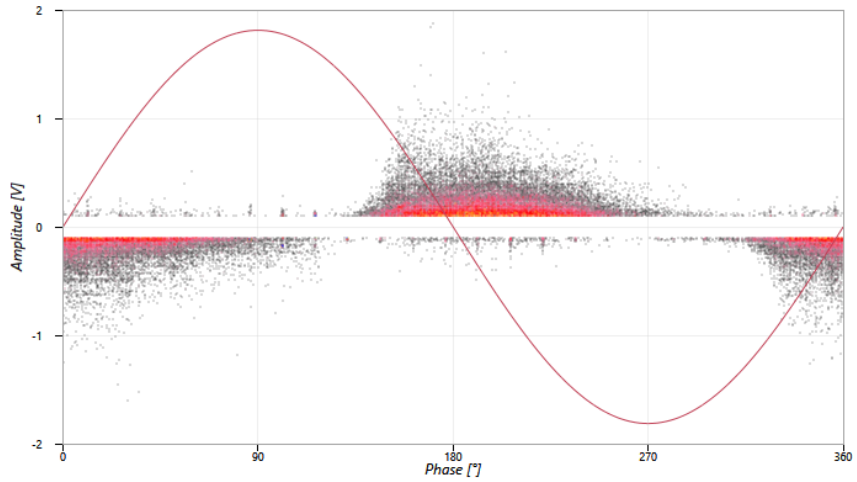
IEC: “Current or Voltage pulse that results from a Partial Discharge occurring within the object under test. The pulse is measured using suitable detector circuits, which can be introduced into the test circuit for the purpose of the test.”

IEEE: “An high frequency current or voltage pulse that results from a partial discharge. In a shielded power cable the pulse propagates away from the PD source in both directions along the cable.”



Introduction to Partial Discharge

Phase Resolved Partial Discharge Pattern



PRPD Pattern is the most common way to visualize a PD activity by plotting the PD pulses in terms of amplitude and phase angle correlate with the supply voltage.

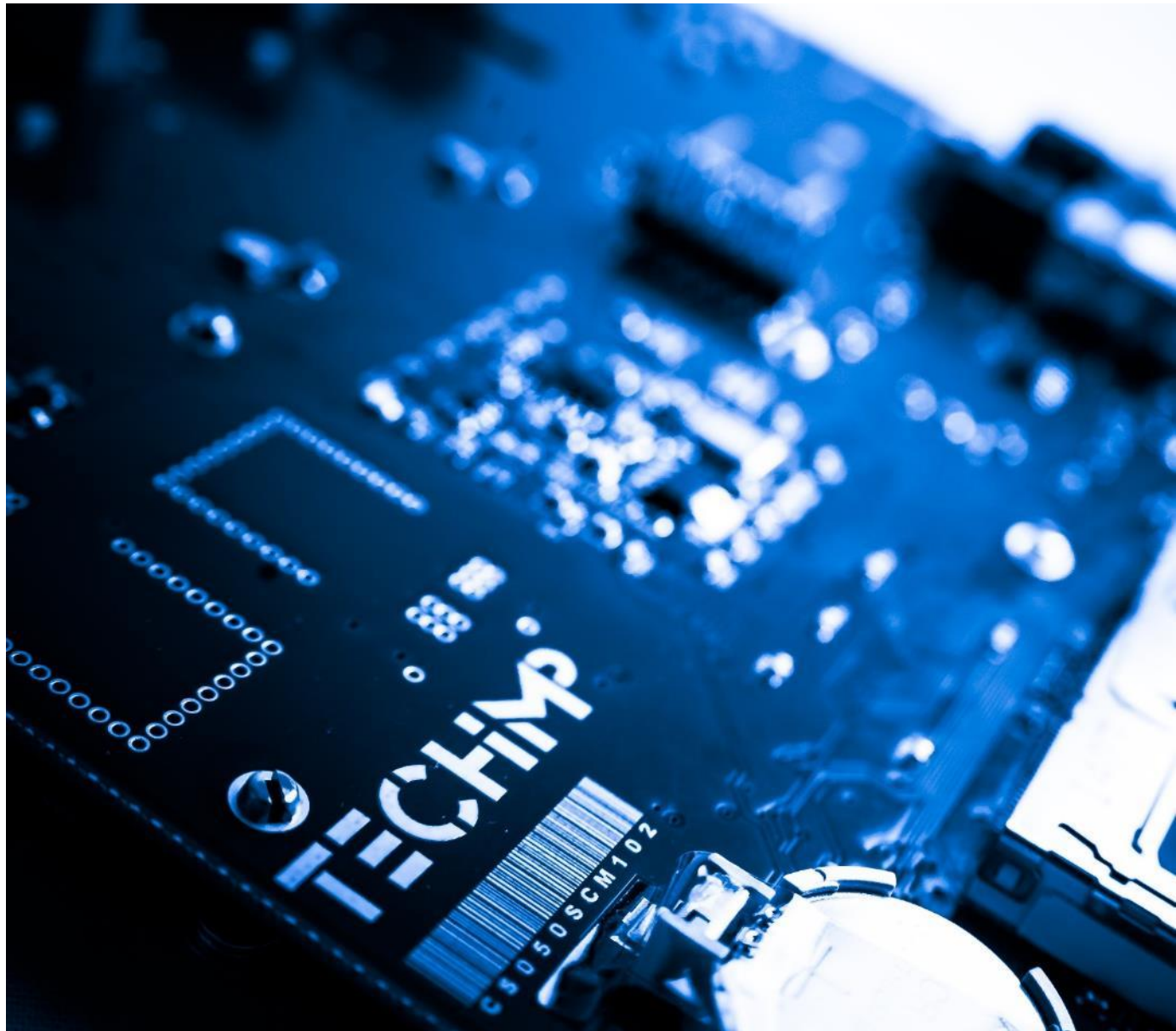
PD amplitude ⟹ discharge magnitude

PD phase angle ⟹ PD physics

PRPD pattern recognition is the key for a proper PD diagnosis.

PD test target & challenges

- PD test target
- PD test layout
- PD test sensitivity
- Noise issues & Multiple PD
- PD info extraction



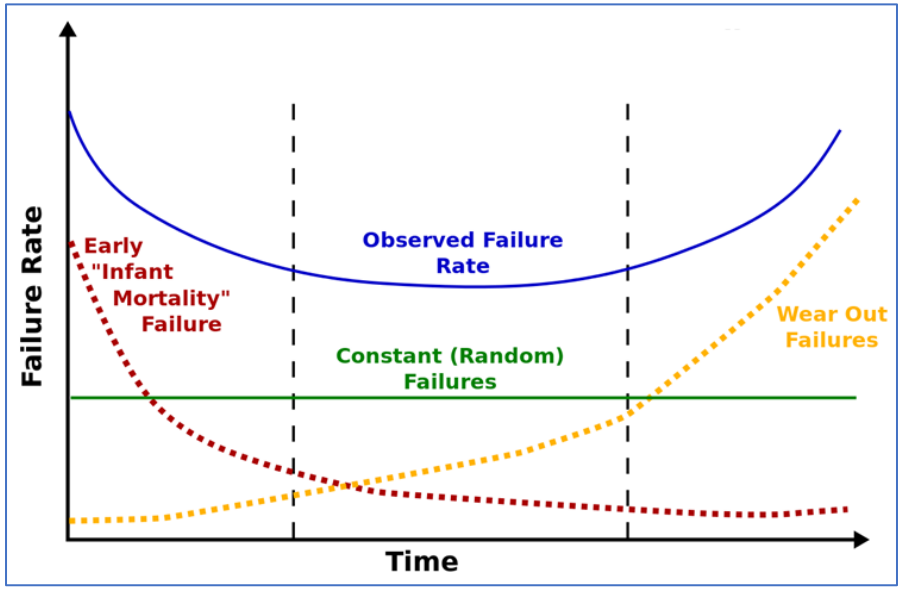
PD test target & challenges

PD Test Target

When we perform PD test our target is to find issues and defects hidden in our electrical apparatus those cannot be highlighted by other test and visual inspections.

Partial discharge test is carried out:

- **EOL test**: Before leaving the factoyr to provide flawless MV & HV electrical assets.
- **Commissioning test**: to ensure that no issues were introduced during transportation & installation.
- **On line Predictive maintenance**: to avoid unexpected faults in aged installations and plan eventual maintenance.



PD test target & challenges

PD Test Layout

Typical PD test equipments:

- Test object: MV/HV asset: cable, transformer, rotating machine, switchgear, etc.
- Voltage source: line voltage, external AC HV source (RTS, VLF, 50Hz, etc.).
- PD sensor: coupling capacitors, high frequency current transformers, antennas.
- PD detector: sampling (IEC/narrow bandwidth, UWB).

PD test target & challenges

PD Test sensitivity

One of the key point in PD testing is to perform a sensitivity test, since partial discharge test can be affected by various disturbances and external signals it is very important to prove the measuring chain performance to validate the results.

- Laboratory testing: Calibration procedure suggested by IEC 60270
- Field testing: Sensitivity test performed to check the measurement chain in real situation (proper S/N)

PD testing challenges

Noise

Especially during site testing, the measurmentcan be affected by un-wanted and un-expected signals those can cover the real PD signals

➔Common error in laboratory is to calibrate the PD detector with noise signal that covers the calibration signal

➔In the field it is possible to misunderstand noise signal for PD signal

➔By acquiring only noise we can get PRPD pattern free of PD pulses, not considering PD signal below noise level

Multiple phenomena issues

Multiple PD sources can be detected by the PD sensor and PD acquisition unit.

This lead to a super-imposion of the occurring phenomena , when studying the whole PRPD pattern without separating the single phenomenon we're focusing the attention on the biggest amplitude PD only.

PD test target & challenges

Information extraction

Whenever we are facing these problems during site testing we need a tool to:

- Boost the sensitivity
- Discard unwanted signals from the streaming
- Sort the different signals recorded

We need to analyze the signals from a different point of view, the PRPD pattern is not sufficient.

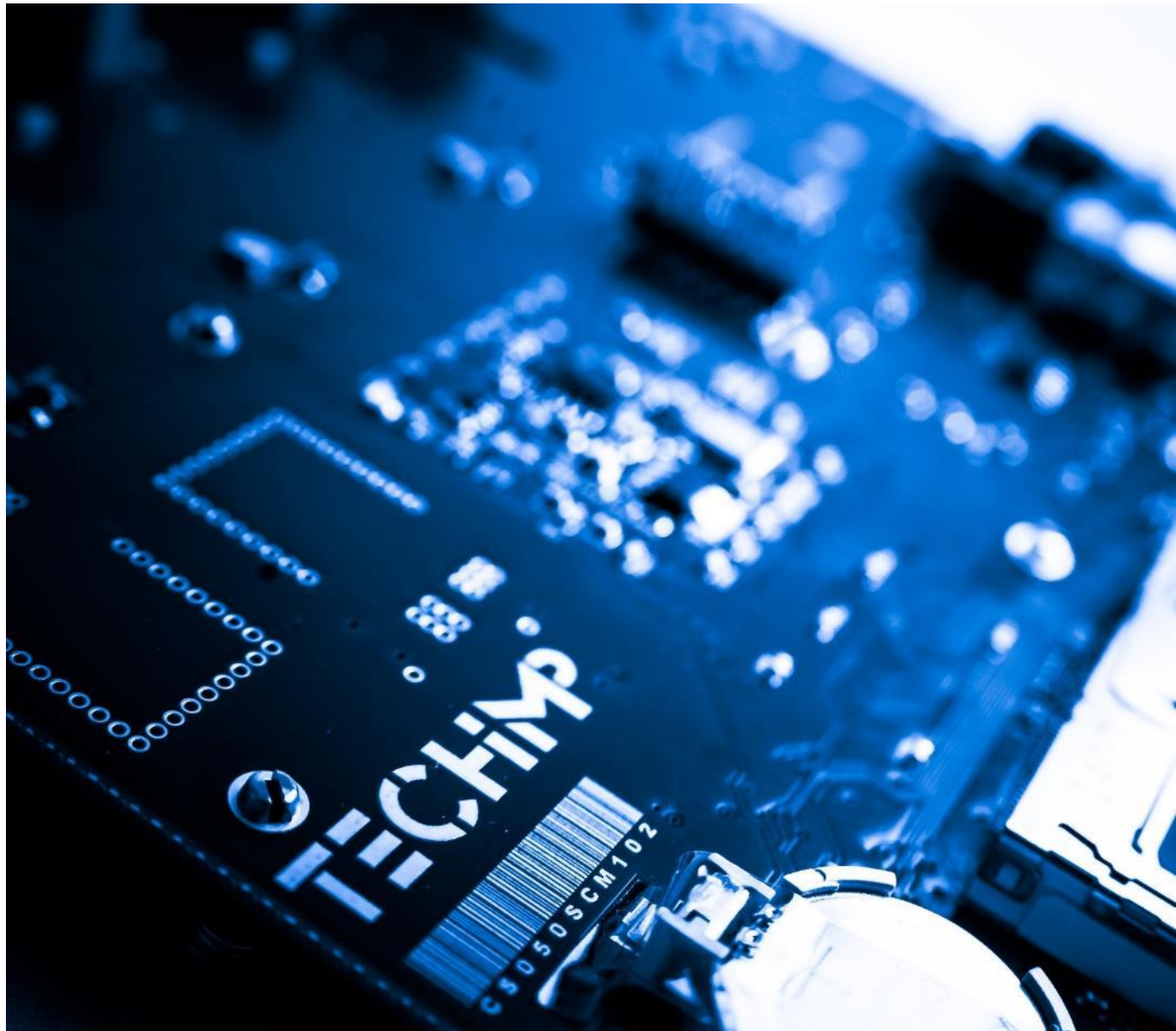
We can use for example:

- Hardware filter to clean some of the signals
- Try different sensors to use different bandwidths

Or we need a deeper study of the PD pulse information

PD pulse, PRPD pattern & TF map

- PD pulse acquisition
- From PD pulse to PRPD pattern
- Time-Frequency analysis
- TF map



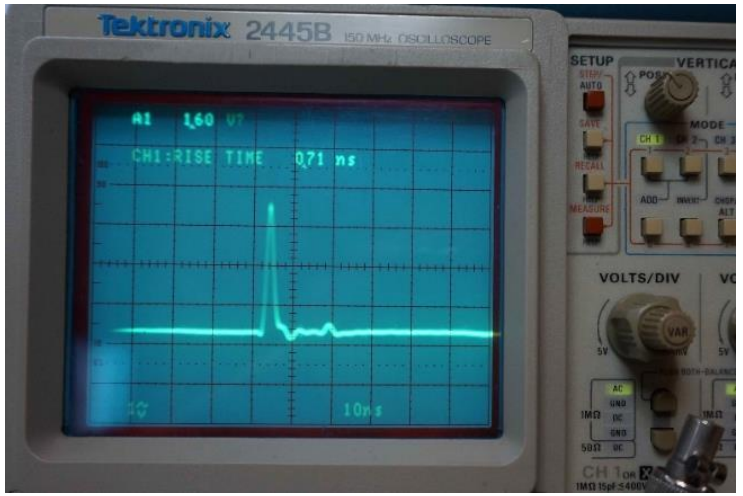
PD pulse, PRPD pattern & TF map

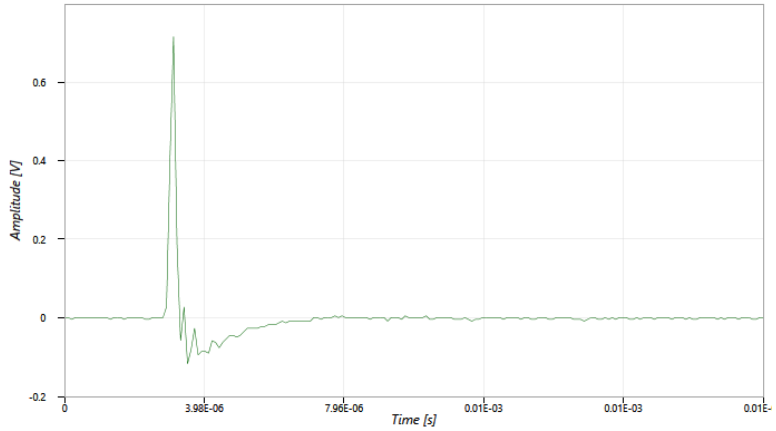
PD pulse acquisition

Every second we can sample from the signal stream a huge number of PD.

Techimp acquisition units will acquire high frequency pulses together with the related phase angles following some specific parameters:

- Minimum amplitude detected
- Maximum amplitude visualized
- Eventual software filter applied





PD pulse, PRPD pattern & TF map

PD pulse acquisition

Full scale & Trigger

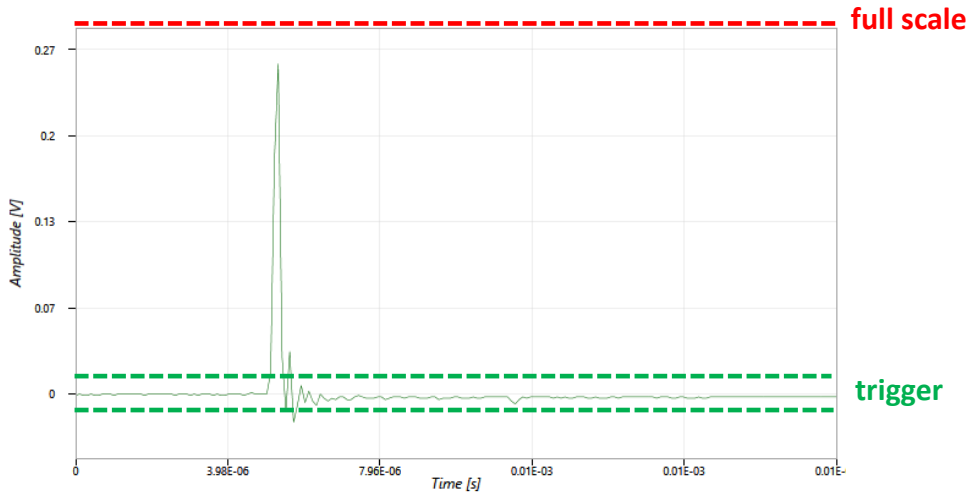
The high frequency pulse detected by the PD sensor is acquired by the instrument as per designed trigger level and full scale.

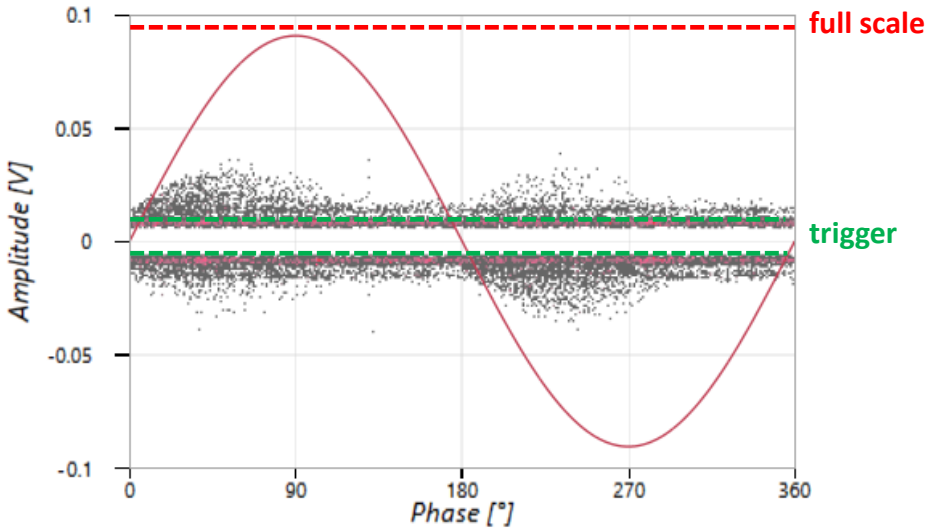
Different acquisition parameters will lead to a different acquisition in terms of detectable amplitude and repetition rate.

Full Scale: maximum amplitude visualized by the acquisition unit

Trigger: minimum amplitude detected by the acquisition unit

Teh very same values of trigger level and amplitude will be used to build the PRPD pattern.





PD pulse, PRPD pattern & TF map

PD pulse acquisition

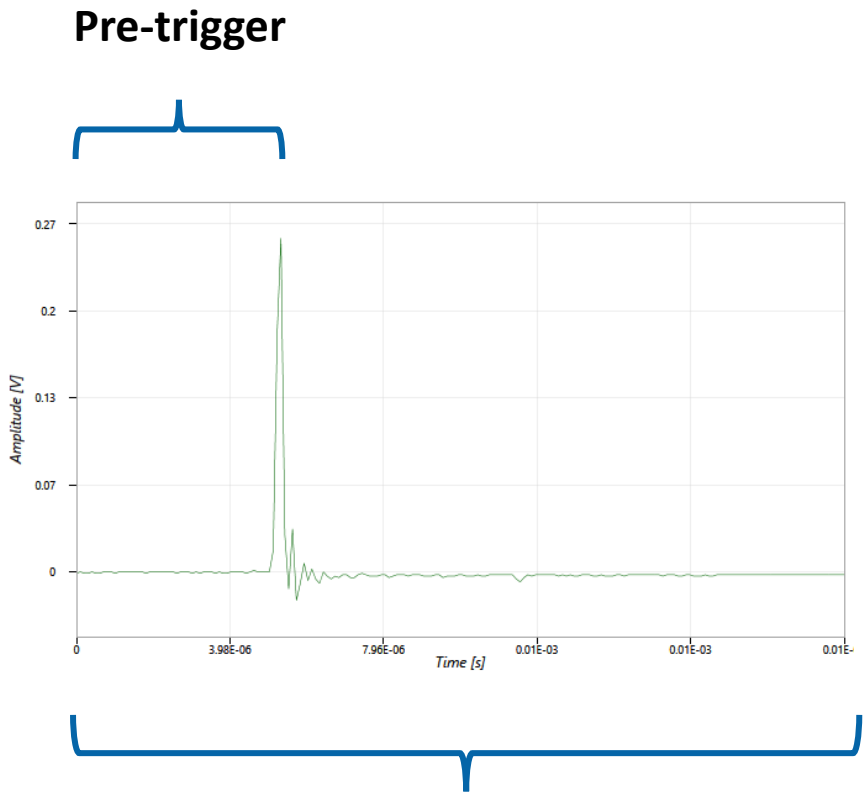
Timelength & Pre-trigger

Techimp approach is not limited to peak amplitude and polarity record. A full waveform shape is acquired, the timelength of such waveform and its pre-trigger are acquisition parameters selectable by the user.

Timelength: total length of the acquisition windows [µs]

Pre-trigger: timelength recorded before the peak [%]

Acquisition parameters



PD pulse, PRPD pattern & TF map

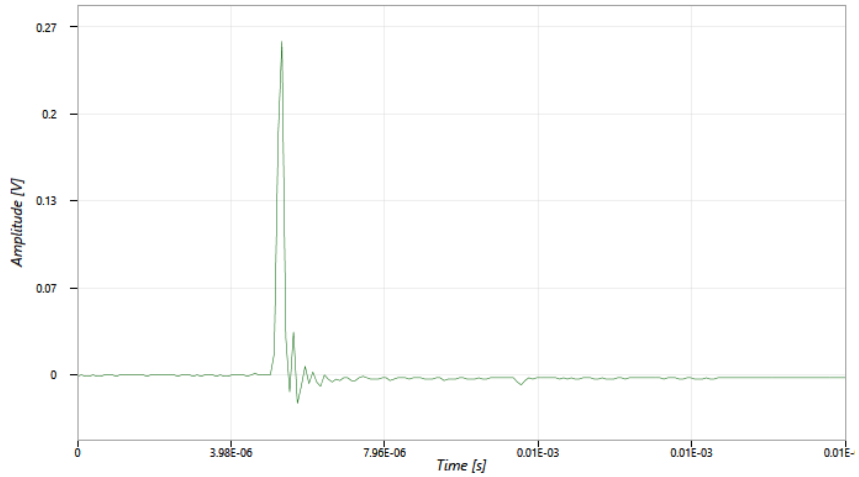
PD pulse acquisition

All the previous steps lead to the acquisition of a PD pulse with certain timelenght, pretrigger full sclae and trigger level.

We have now the desired PD pulse to be analyzed and from the pulse shape we will extract **pulse amplitude and polarity.**

Amplitude peak [mV or pC]

Pulse polarity (peak bend positive or negative)



PD pulse, PRPD pattern & TF map

PD pulse acquisition

From the signal stream the instrument will then acquire pulses those exceed the trigger level for timelenght duration and saving pretrigger portion before the moemnt the stream exceeds the trigger level

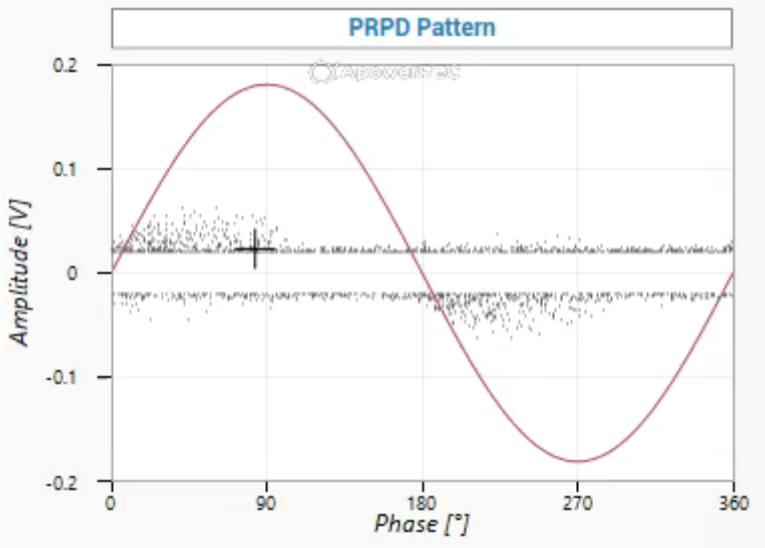
Each acquired pulse will be then plot as a point in the PRPD pattern as well in the TF map.

PD pulse, PRPD pattern & TF map

From PD pulse to PRPD pattern

Each PD pulse that exceed the trigger level is recorded by the PD acquisition as per the current acquisition parameters settings: full scale, trigger, timelength & pre-trigger.

Together with the pulse details the PD acquisition unit saves the phase angle of the applied voltage when the PD take place.



PD pulse, PRPD pattern & TF map

Time Frequency analysis

Classic PD acquisition unit does not save further info about the PD pulse, Techimp has introduced in the late 90's a further level of analysis to characterize each PD pulse with 2 new indexes

Normalized PD signal $\tilde{s}(t) = s(t) \Big/ \sqrt{\int_0^L s(\tau)^2 \, \mathrm{d}\tau}$

Eq. Frequency $F = \sqrt{\int_0^\infty f^2 \left|\tilde{S}(f)\right|^2 \mathrm{d}f}$

Gravity Center of the normalized signal $t_0 = \int_0^L t\tilde{s}(t)^2 \, \mathrm{d}t$

Eq. Timelength $T = \sqrt{\int_0^L (t - t_0)^2 \tilde{s}(t)^2 \, \mathrm{d}t}$

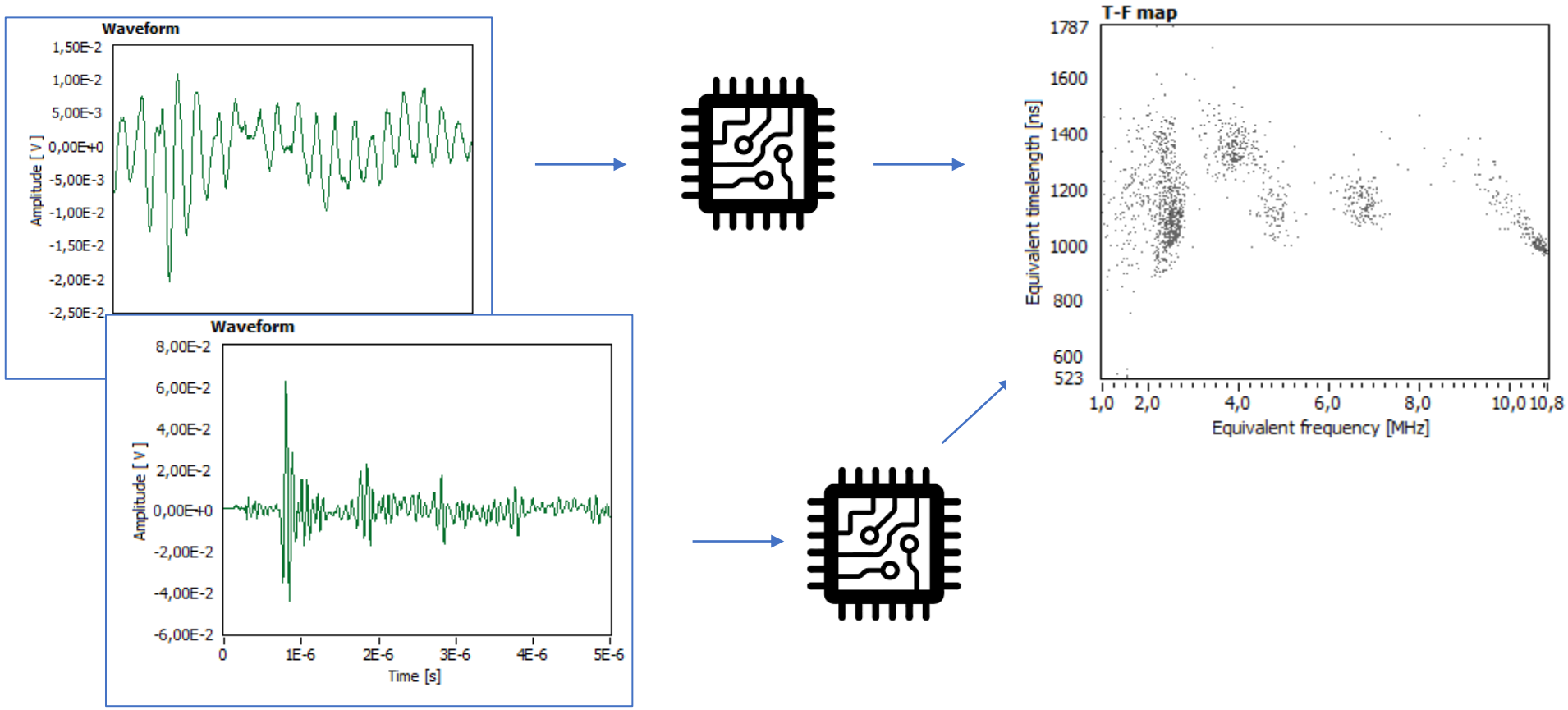
TF analysis approach allows the signals detected, sampled and acquired to be collected into homogeneous clusters based on the shapes of the signals.

Each cluster is related to signals coming from the same sources, characterized by similar shape parameters.

PD pulse, PRPD pattern & TF map

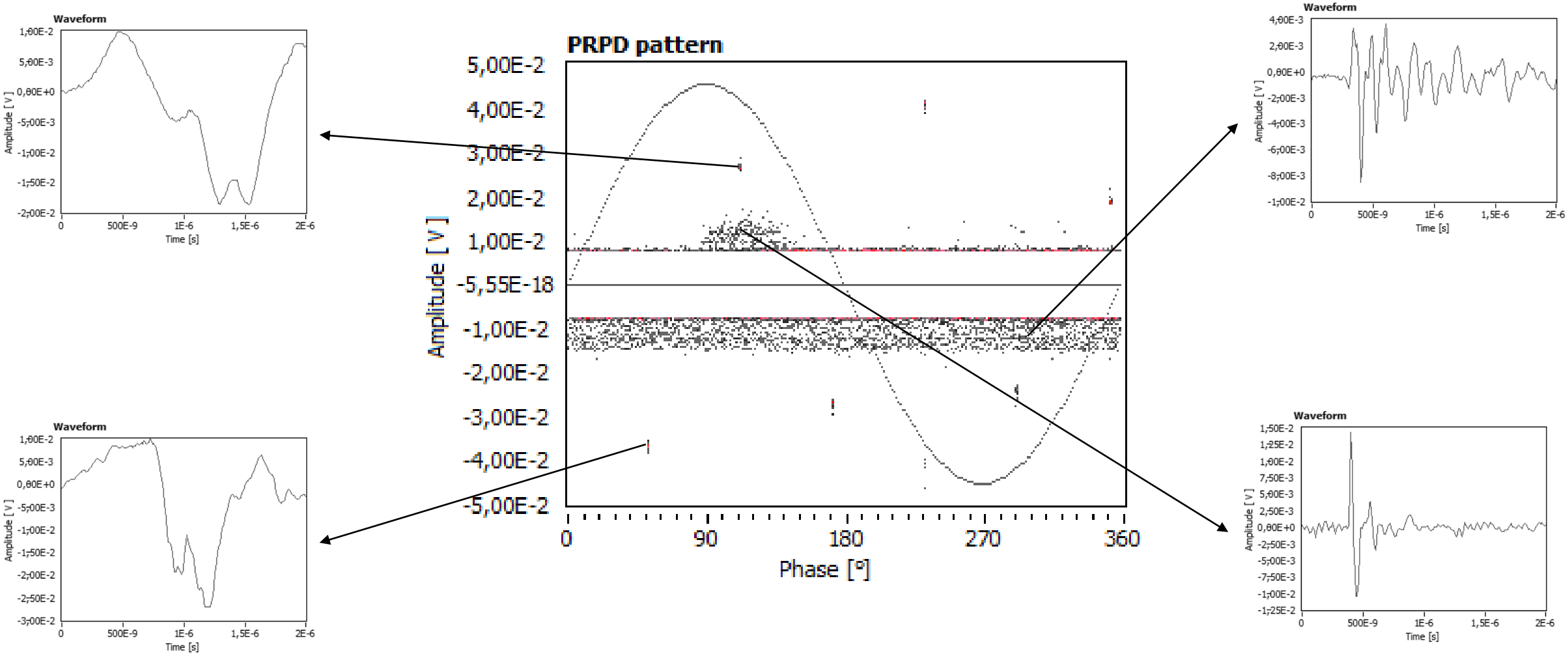
TF map

Eq. Timelength & Eq. Frequency analysis can be applied for the thousands of pulses acquired each second, the pulse shape is traslated in 2 mathematical parameters those can be easily managed by computing algorithms to build the TF map.



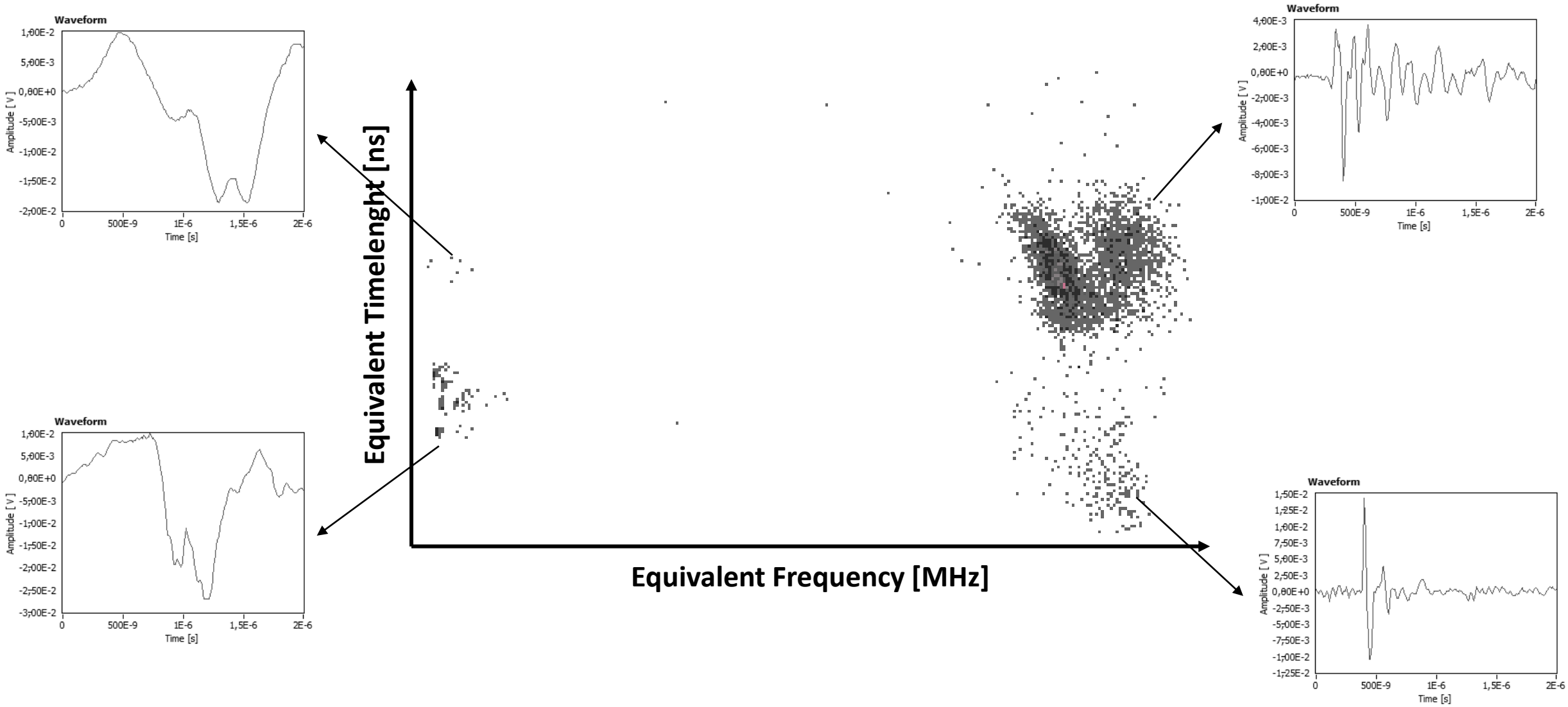
PD pulse, PRPD pattern & TF map

From the PRPD pattern to the pulse shape



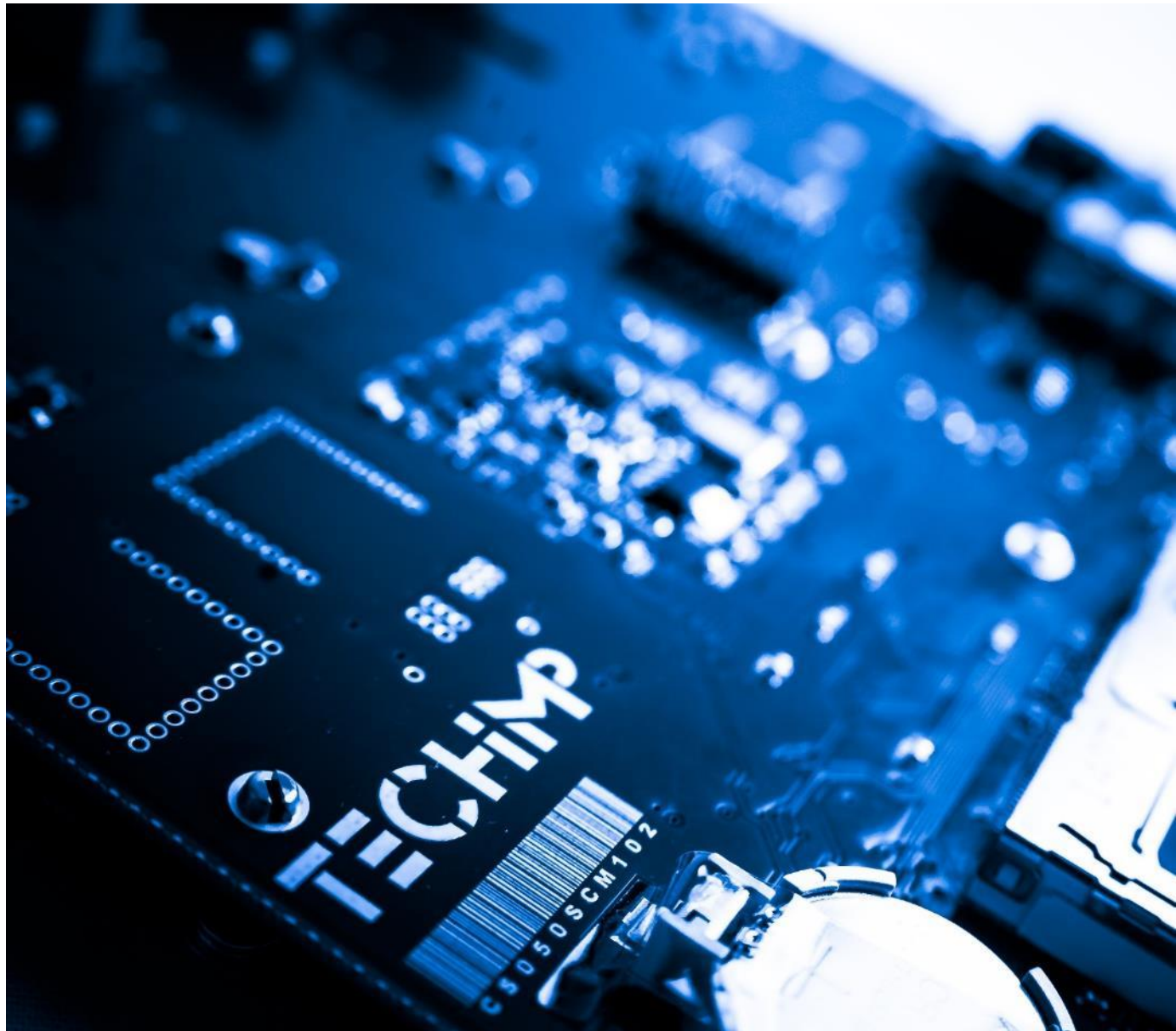
PD pulse, PRPD pattern & TF map

From the TF map to the pulse shape



TF map in the standards

- IEC 60034-27
- IEEE 1434-2014

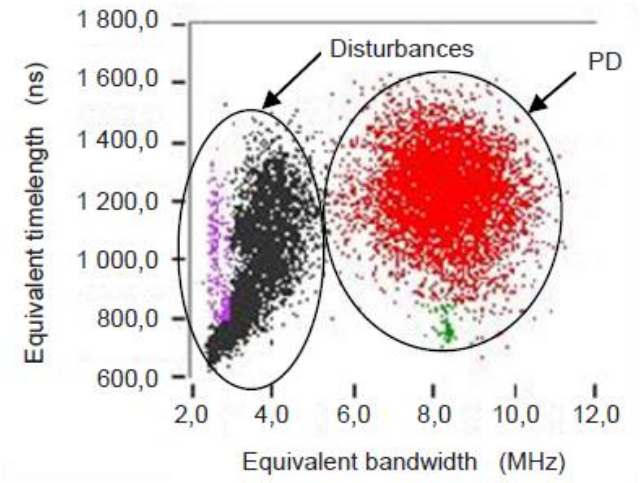


TF map in the standards

IEC 60034-27-2:

On-line partial discharge measurements on the stator winding insulation of rotating electrical machines

<< Time and frequency domain separation can be developed through a pulse shape analysis to produce the so-called "TF" map that plots the equivalent time length of the pulses versus their equivalent frequency content >>

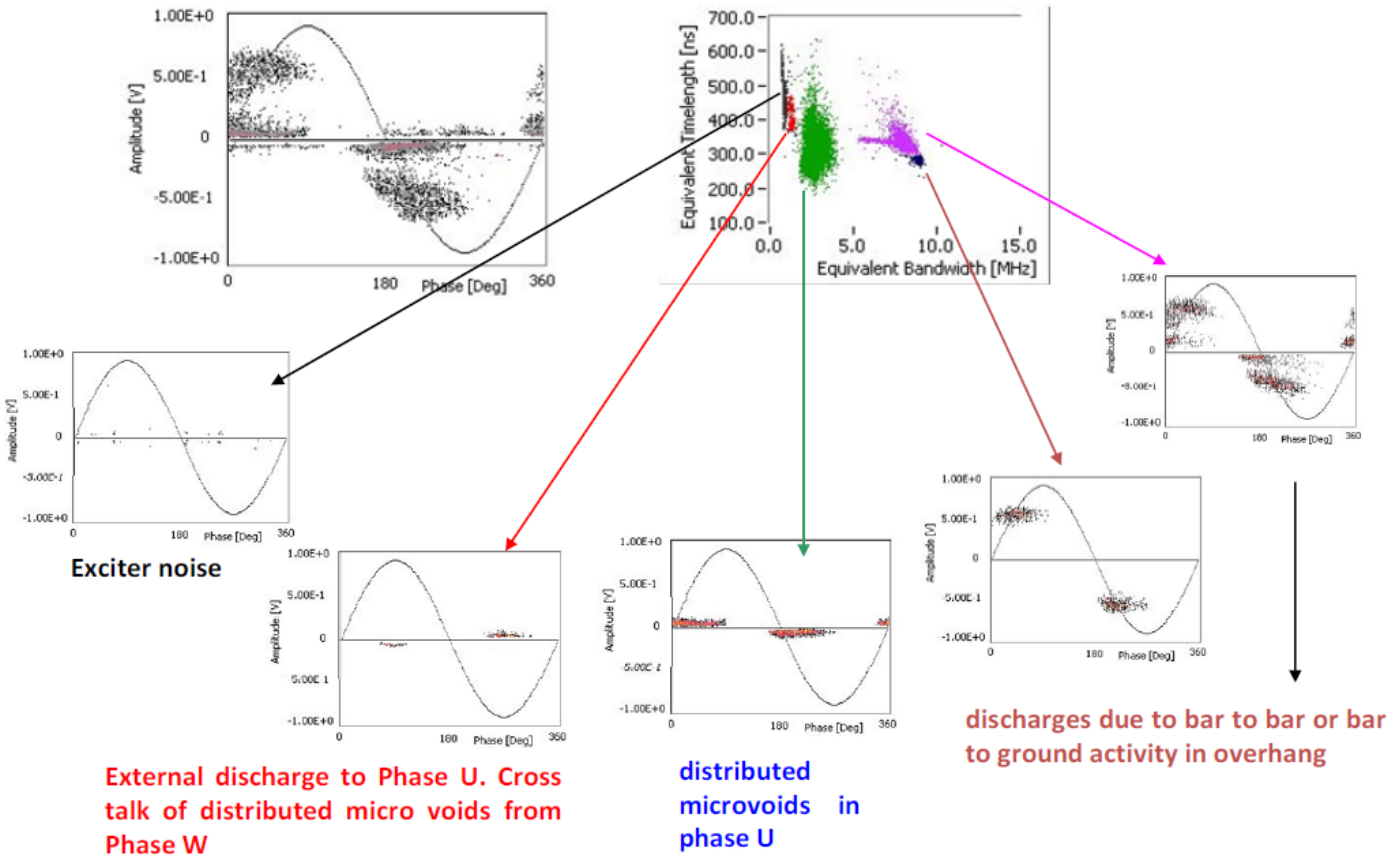


<< disturbances will often appear as a cluster of pulses that is in a position, which is distinctly different from stator winding PD, and can thus be identified and suppressed from the PD pattern >>

TF map in the standards

IEEE 1434-2014

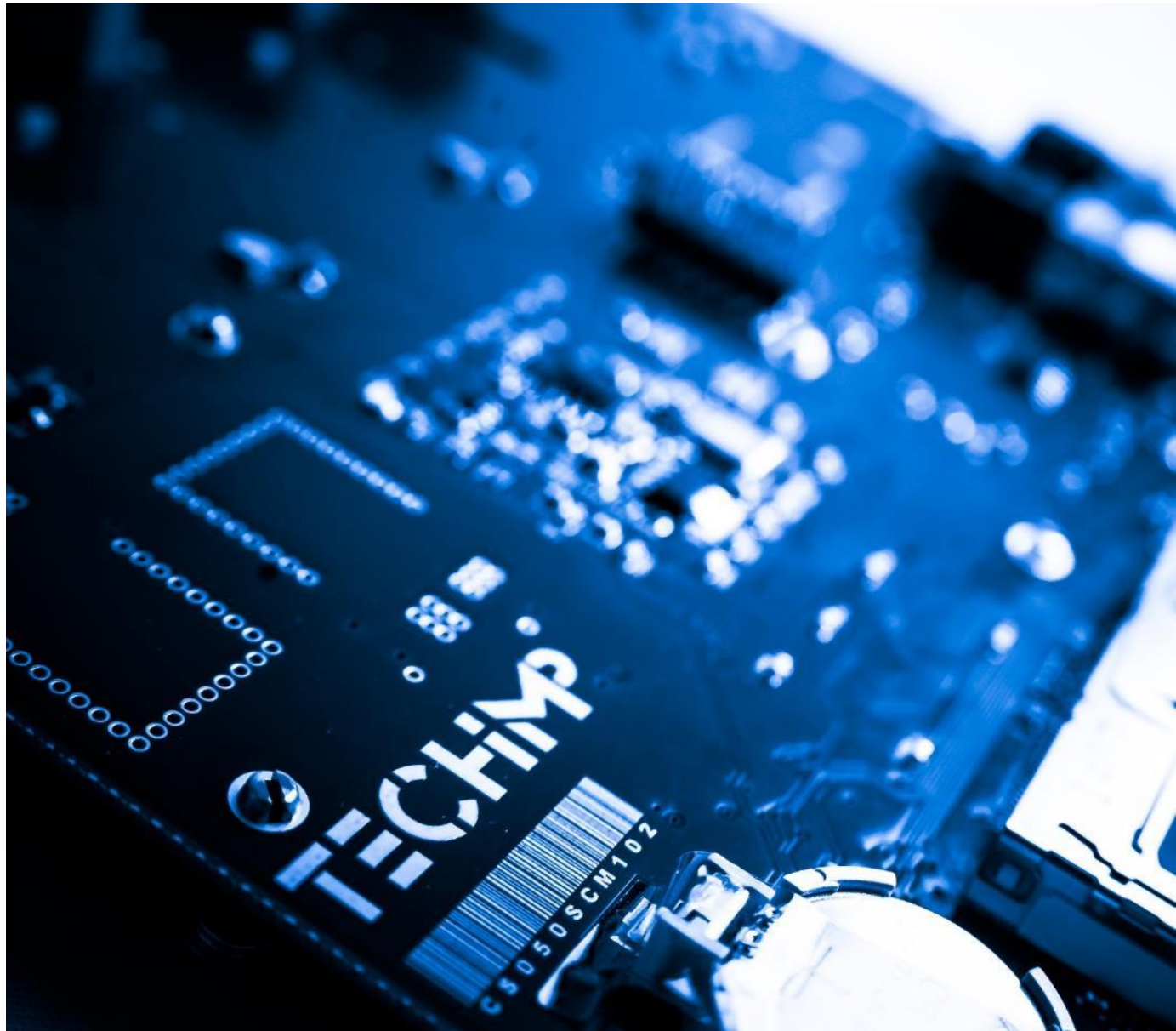
IEEE Guide for the measurement of Partial Discharge in AC Electric Machinery



<< The data are displayed in terms of pulse width and bandwidth for the purpose of separating different PD sources from the insulation system and discriminate from external noise sources >>

PD acquisition denoising

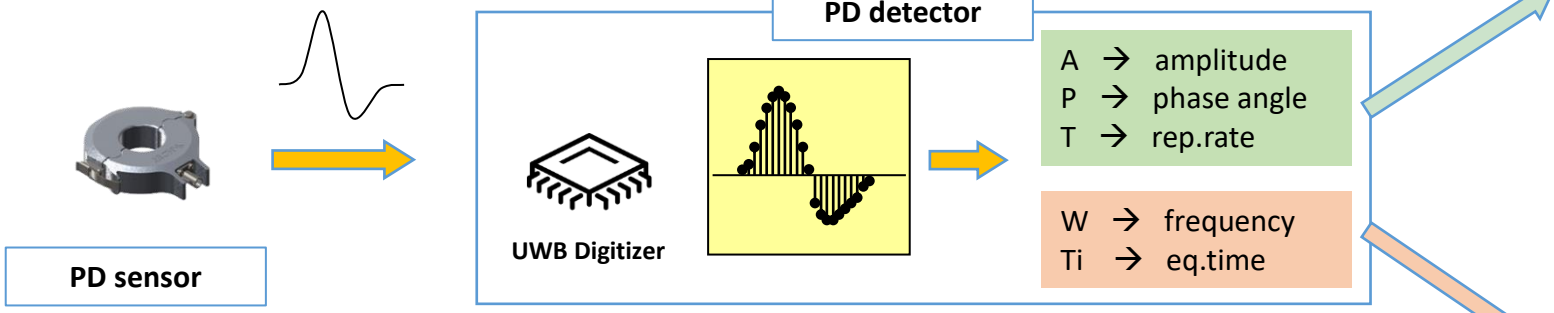
- PD signal flow
- Utilization of HW&SW filter
- Acquisition Parameters

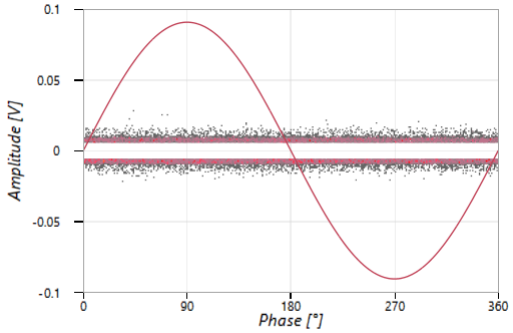


PD acquisition denoising

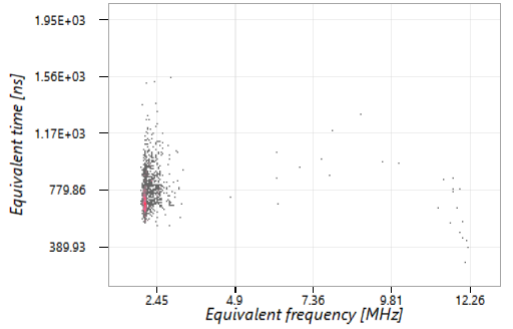
PD signal flow

PD acquisition chain





PRPD Pattern



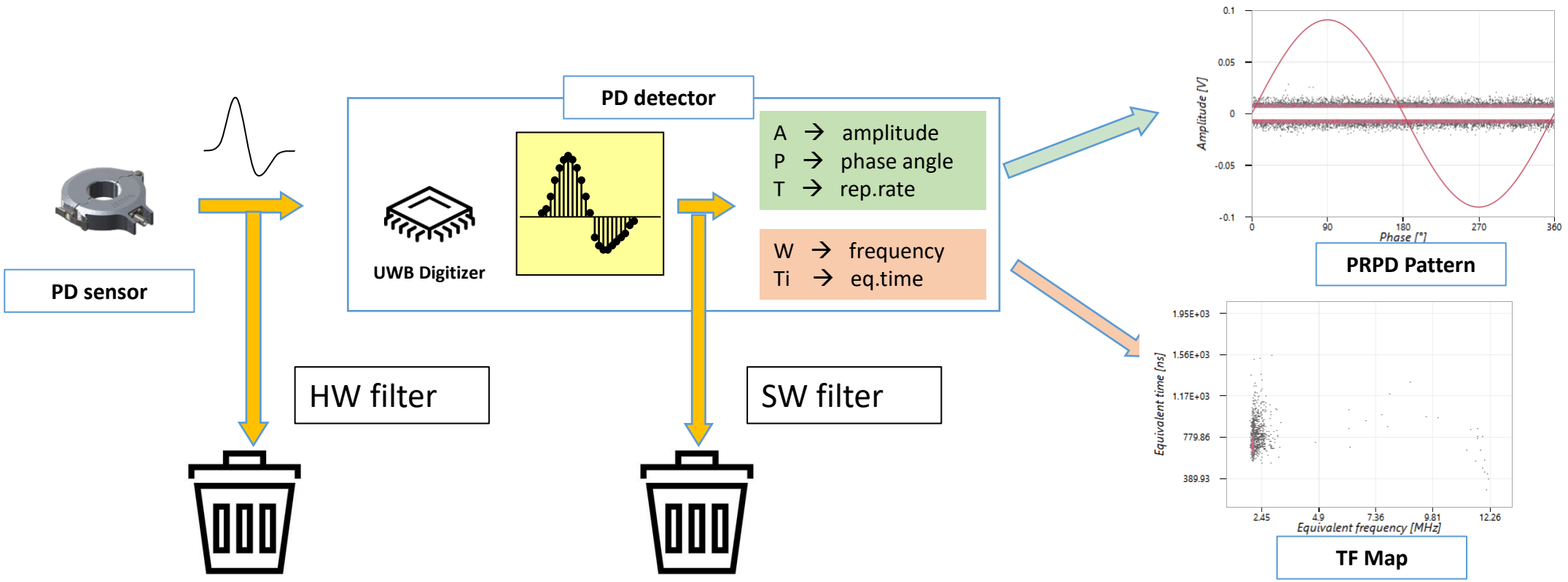
TF Map

PD acquisition denoising

Utilization of HW & SW filter

When performing PD testing, due to the complex electrical system involved, background/exciter noise and external disturbances may affect the readings, leading to a decrease of the S/N.

PRPD pattern and TF map help us to identify and separate these unavoidable phenomena and they can be filtered out by using HW and SW filter in order to increase the measurement sensitivity.

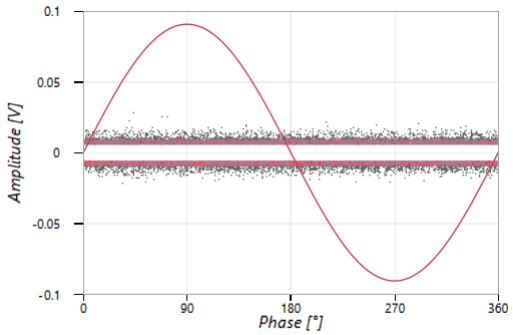


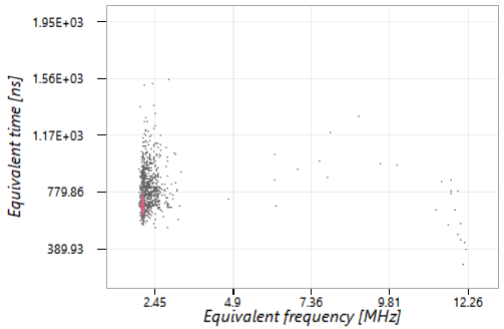
PD acquisition denoising

Utilization of HW & SW filter

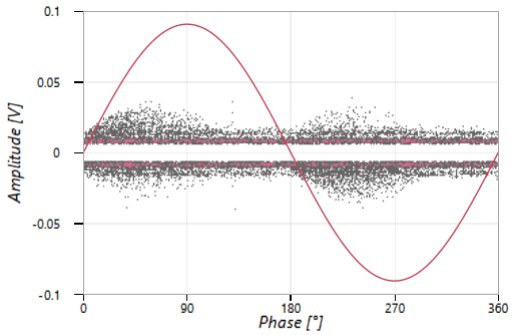
HW/SW FILTER → > S/N

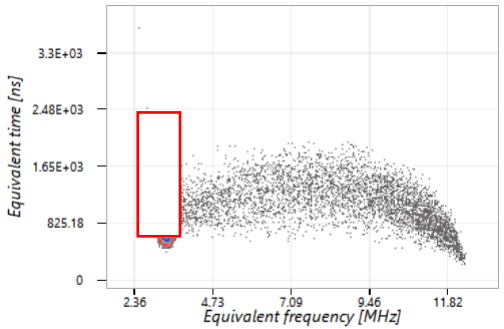
before filtering





after filtering





PRPD Pattern

TF Map

PD acquisition denoising

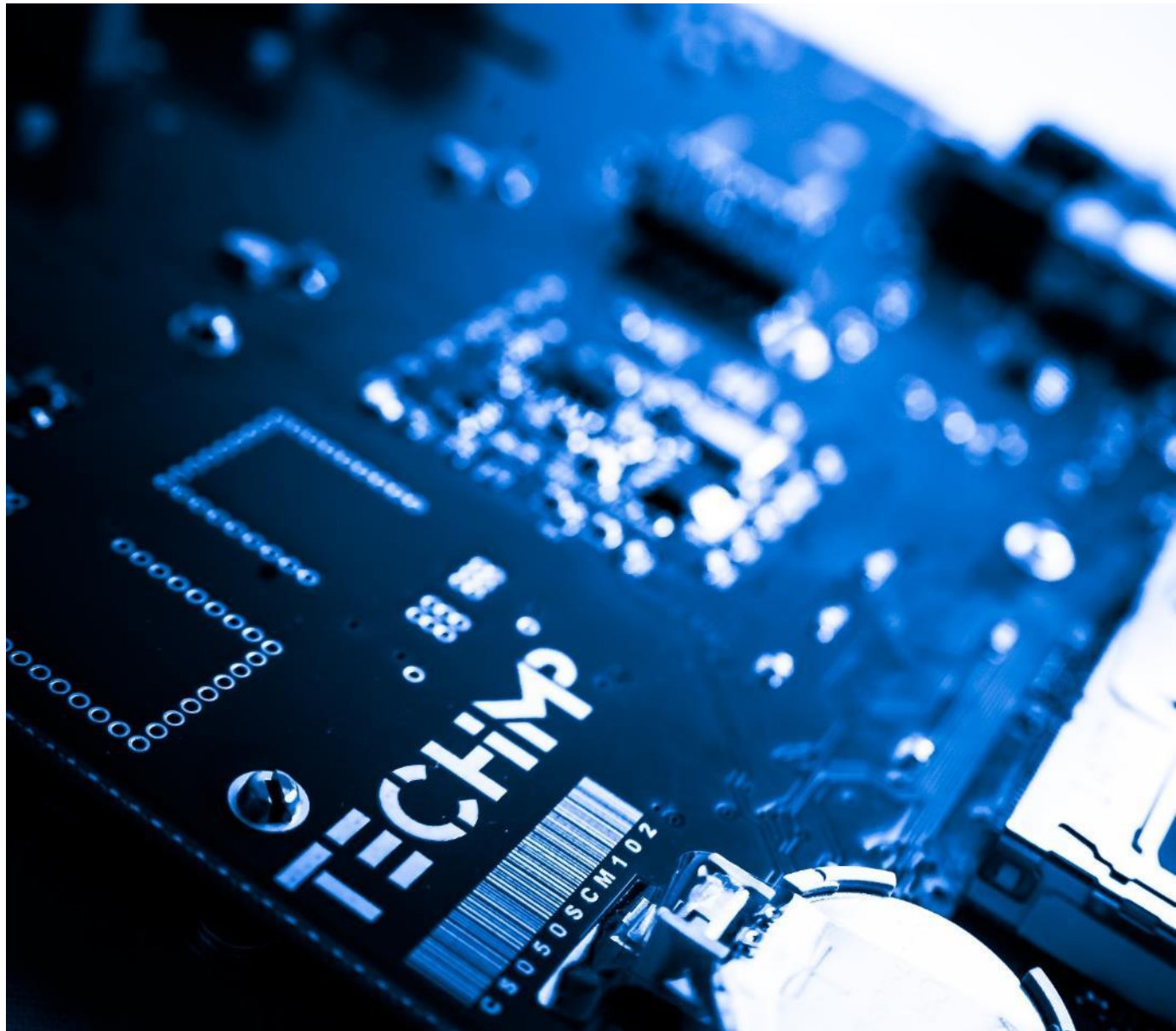
Acquisition Parameters

PD analysis starts during the acquisition process. During this stage, for a completed PD acquisition session is suggested to perform a full set of data acquisition by tuning the following acquisition parameters:

- Full Scale & Trigger Level: to investigate the available full range;
- Timelength: using this parameter is possible to improve the cluster separation of different PD source in the TF map;
- Pre-trigger: this parameter might allow to get PD pulse reflection for a post processing localization of a PD source.

Data analysis and post-processing

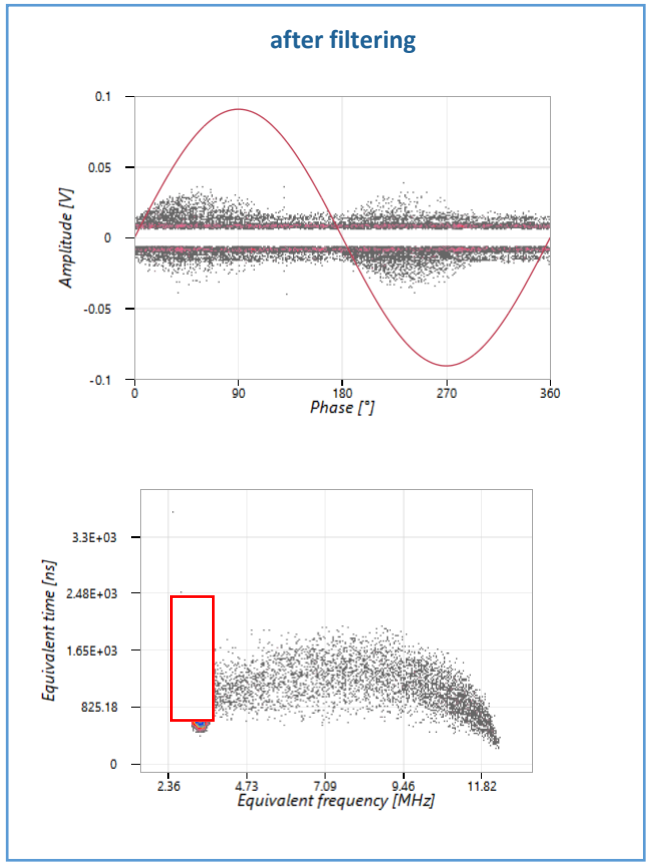
- Postprocessing tools: SID action
- PD phenomena trending
- TF map info

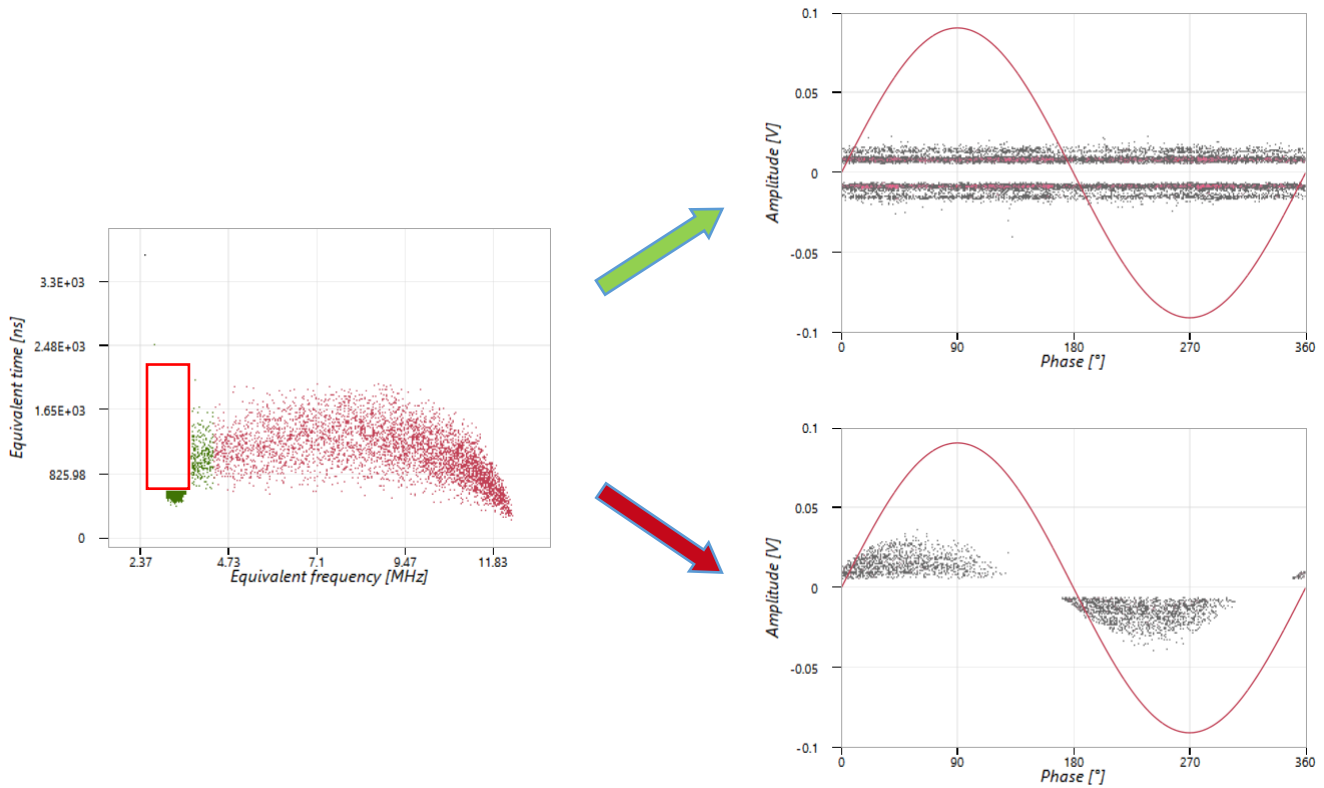


Data analysis and post-processing

Postprocessing tools: SID approach

Separation: separate each different cluster on the TF map in order to highlight hidden phenomena and study the relative sub-pattern properties

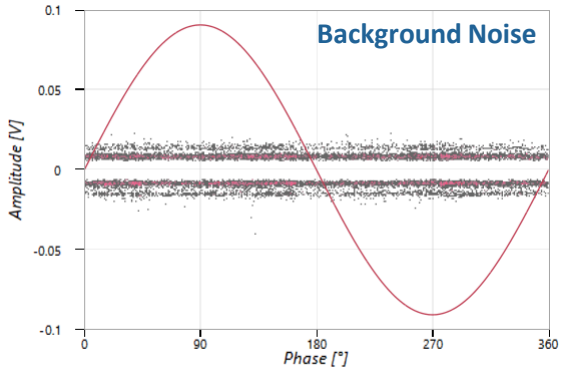


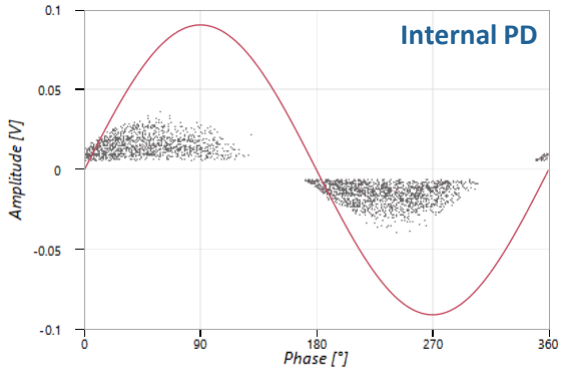


Data analysis and post-processing

Postprocessing tools: SID approach

Identification: identify each sub-pattern as noise, external disturbance or PD source





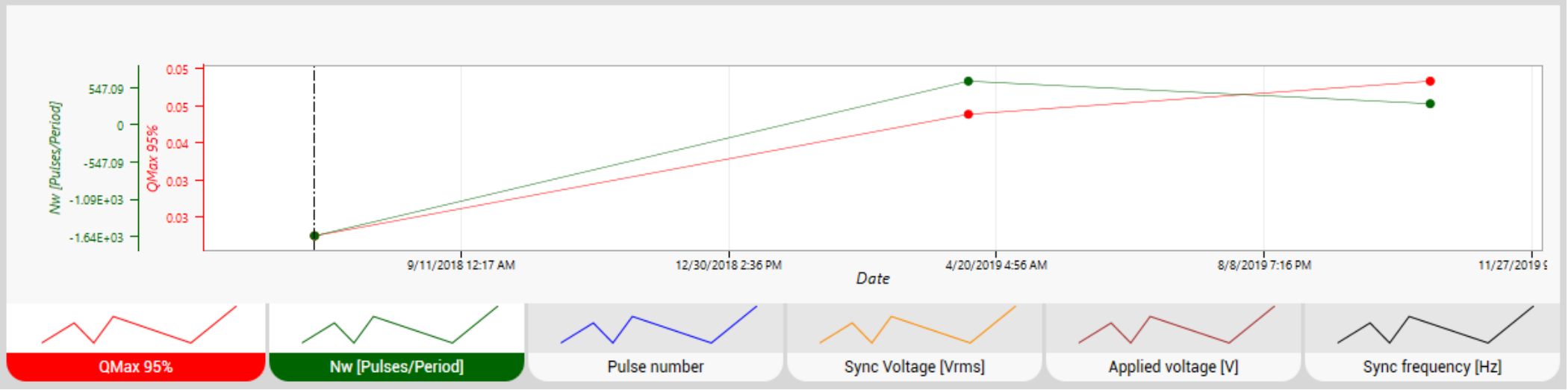
Positive	Parameter	Negative
0.0359	QMax [V]	0.0383
0.0266	QMax95% [V]	0.0258
0.0158	QMean [V]	0.0141
0.0063	QMin [V]	0.0055
0.0174	Alpha [V]	0.0155
2.7466	Beta	2.4010
2075	N	2787
3.5	N/s [1/s]	4.7
0.1	Nw	0.1
129.4	Max phase [°]	178.6
0.0	Mean phase[°]	0.0
-12.7	Min phase [°]	-9.8

Data analysis and post-processing

PD phenomena trending

As the identification of a PD phenomenon, the PD evolution over the time plays a key role for a correct diagnosis and can be evaluated in terms of amplitude and repetition rate of the detected phenomenon

by monitoring this two parameters over the time we can have a proper idea of the PD source behavior affected from external stress (load, temperature, humidity, mechanical etc.)



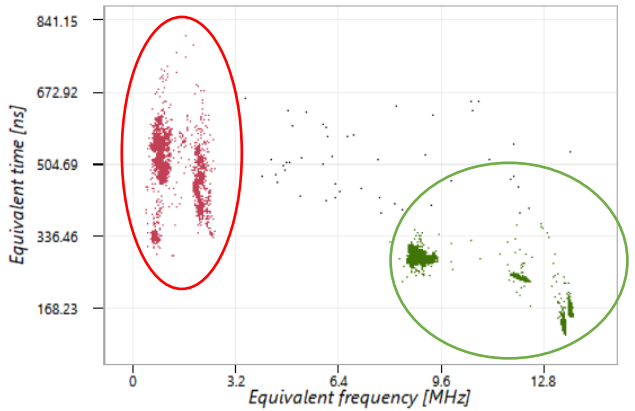
Data analysis and post-processing

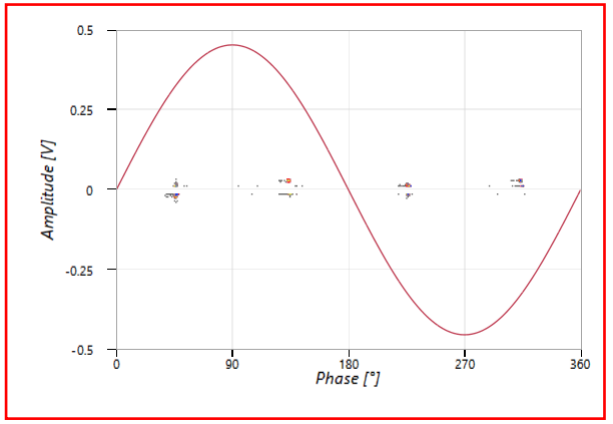
TF map info

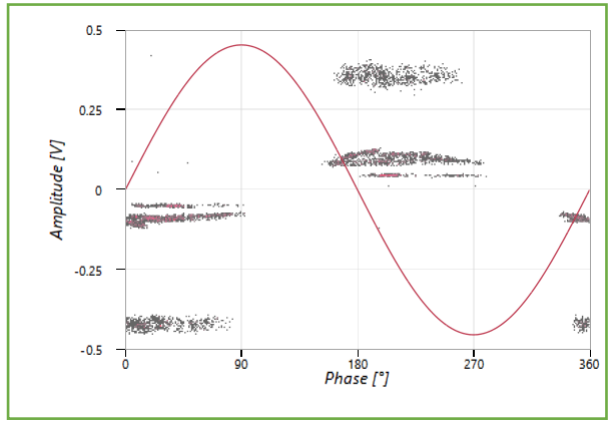
TF map could be used as postprocessing tool giving us useful informations as:

Exciter Noise: very low frequency cluster

Corona Discharge: low spread cluster





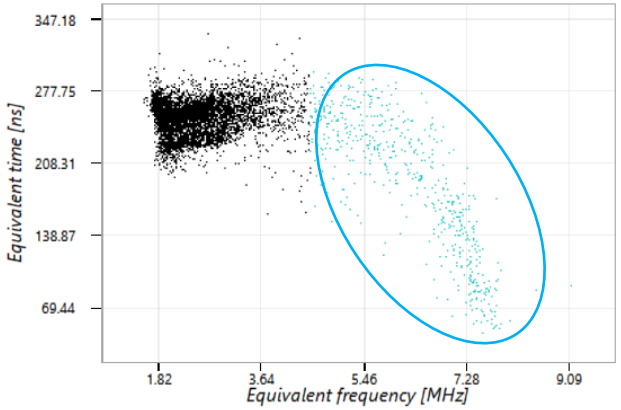


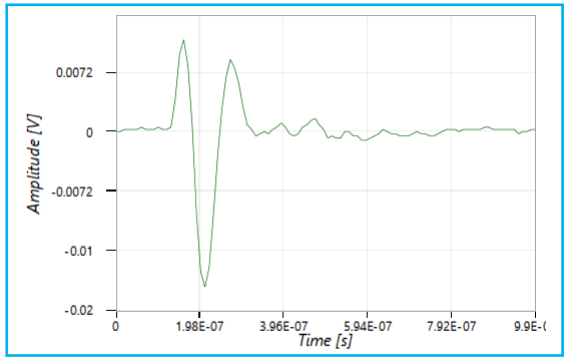
Data analysis and post-processing

TF map info

TF map could be used as postprocessing tool giving us useful informations as:

Fast PD Pulse: high frequency components not affected by attenuation, PD source nearby the detection point

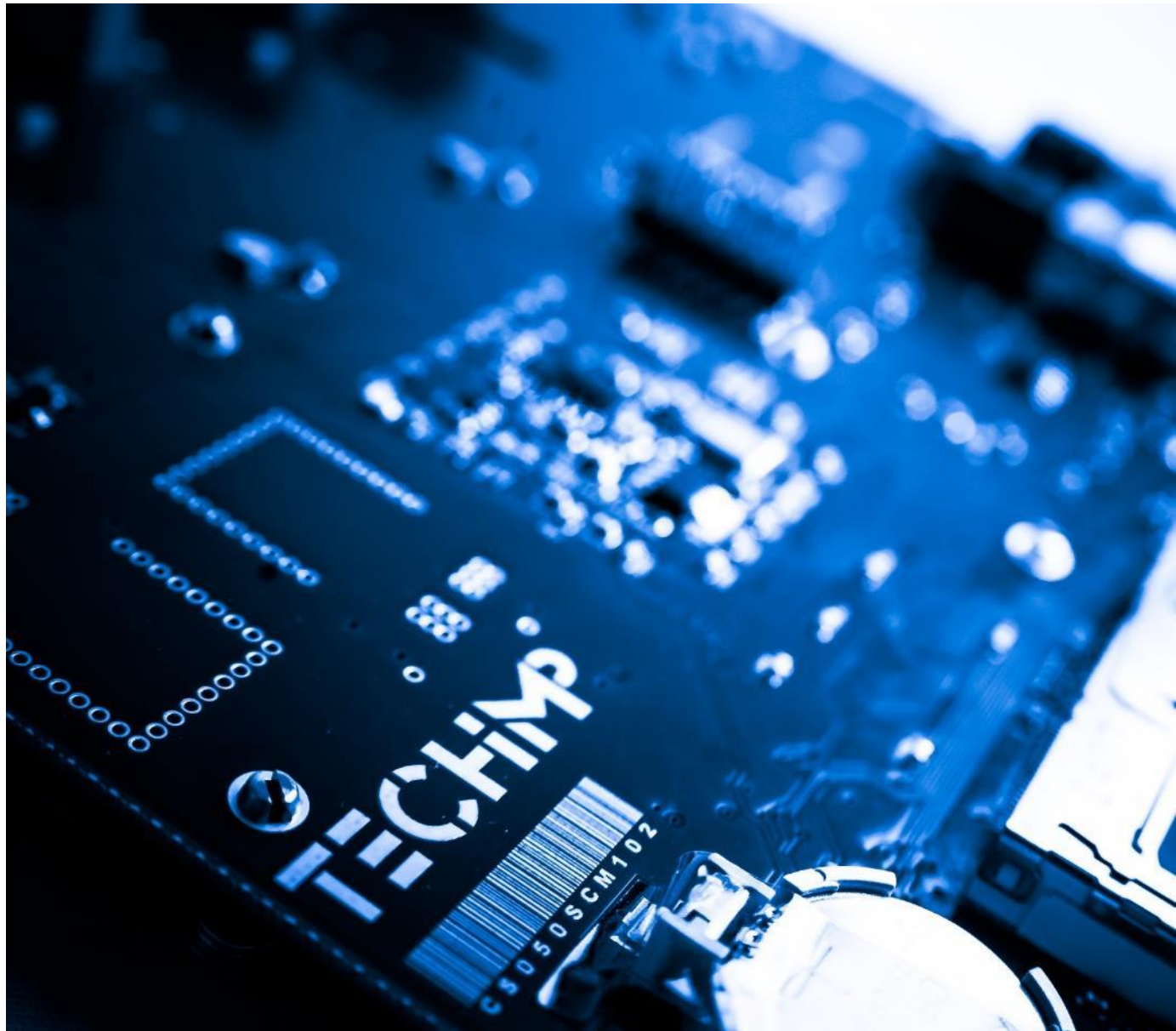




Pulses characterized by high frequency are probably sourced nearby the detection point.

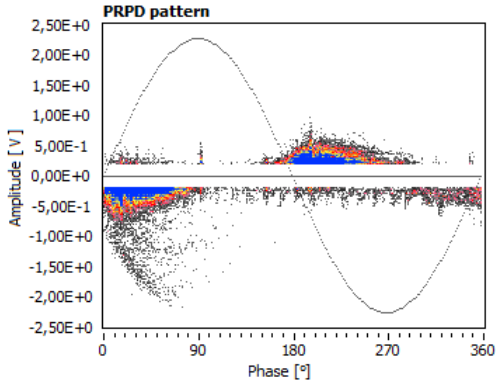
Examples

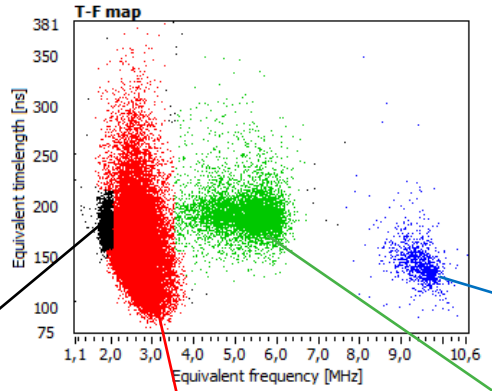
- A) Generator post processing
- B) HV cable live stream
- C) Motor post processing
- D) Generator live stream
- E) MV cable online test



Example A

Generator post processing



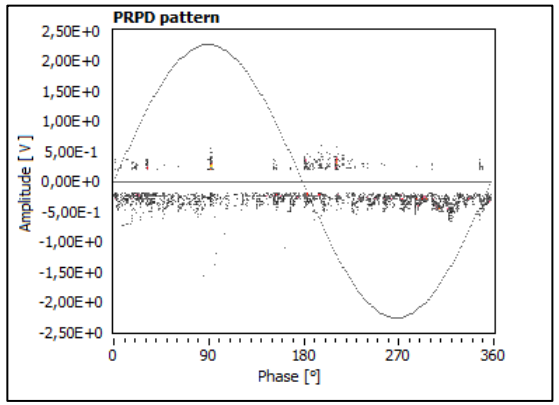


Asset: *Synchronous Generator*

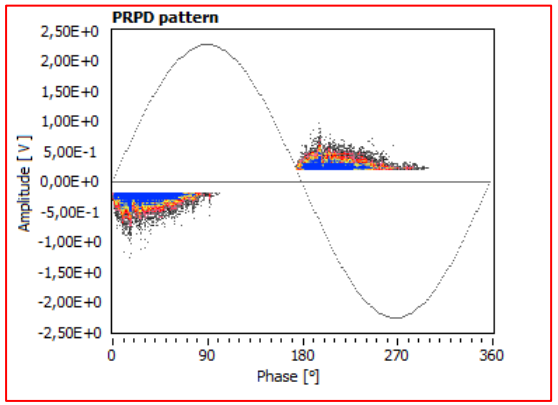
Rated Power: *20.1 MVA*

Test Type: *Online PD Maintenance Test*

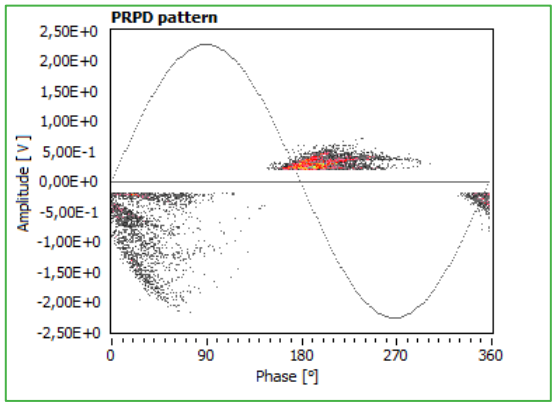
PD sensor: *Coupling Capacitors*



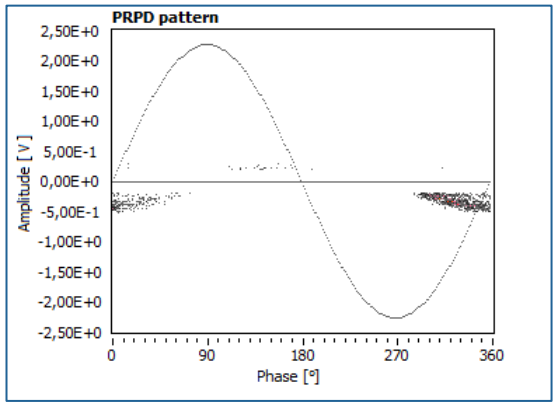
Background/Exciter Noise



Slot Discharges



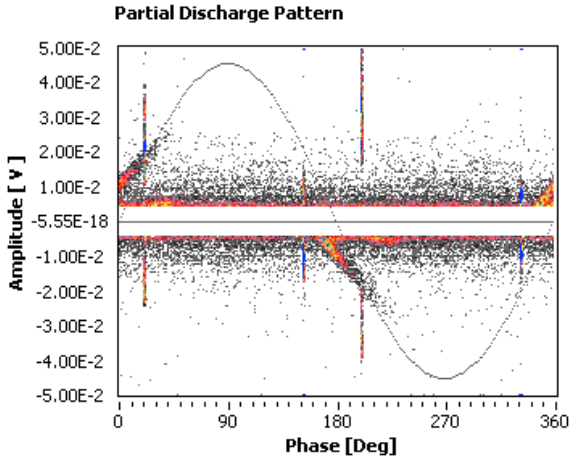
Embedded Delaminations

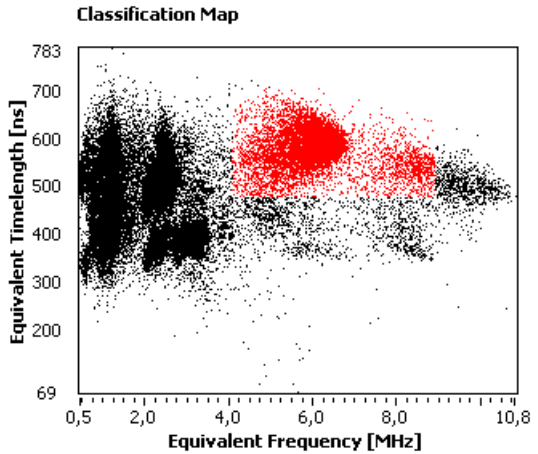


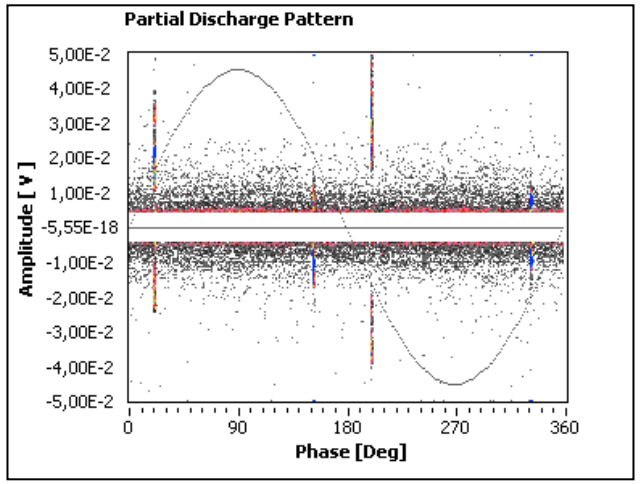
Crosstalk

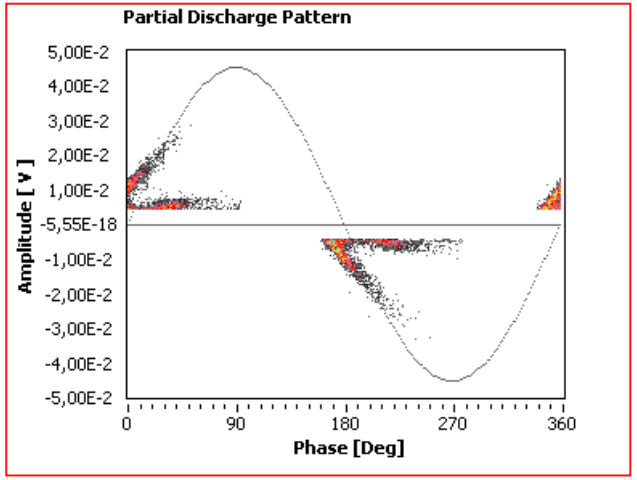
Example B

HV Cable Offline test









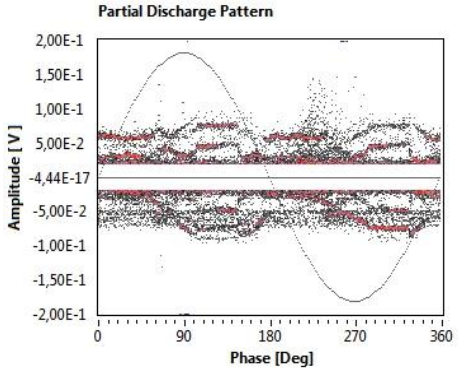
During the 1 hour HVAC the PD appeared just few seconds, not possible to prepare and tune filtering.

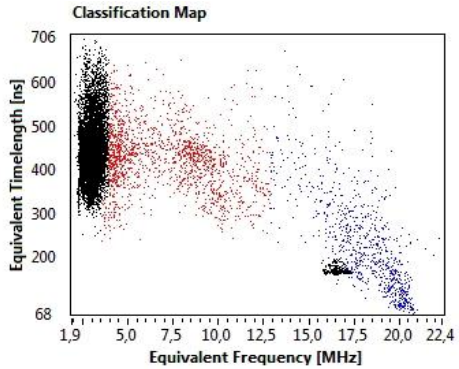
Thanks to the “acquire PRPD pattern” function the PD mixed with noise was saved together with its TF map.

From the TF map it was possible to extract the PD information from the acquired data to show the evidence of the occurring phenomena.

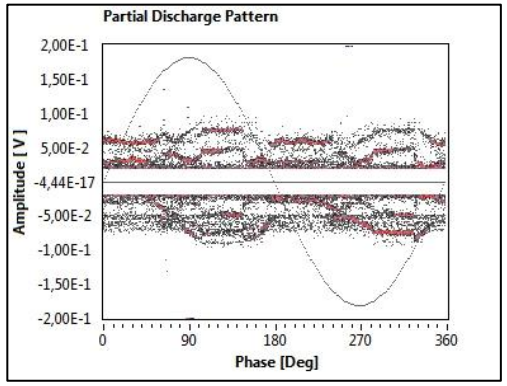
Example C

Motor phase A

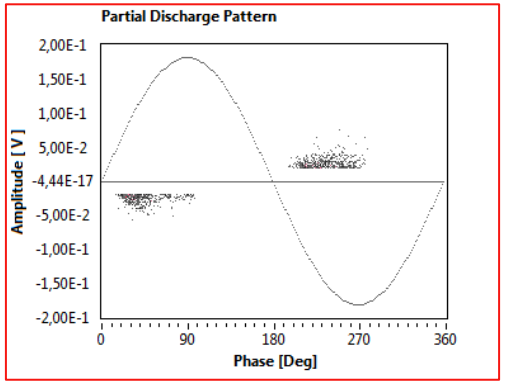




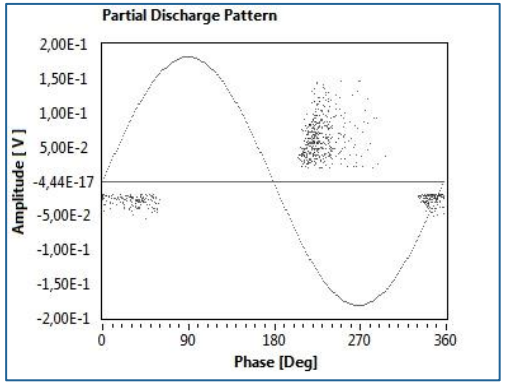
Electronic noise



PD phenomenon 1

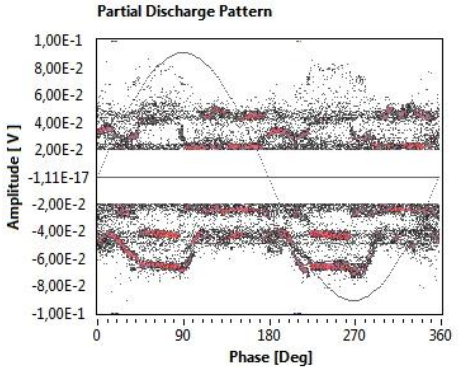


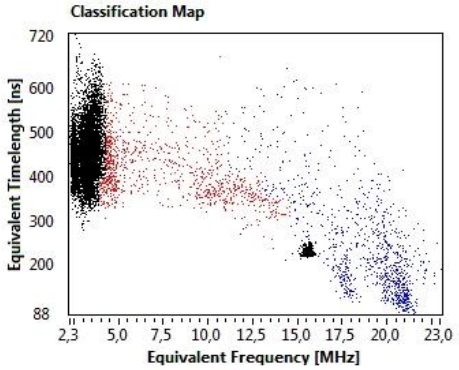
PD phenomenon 2



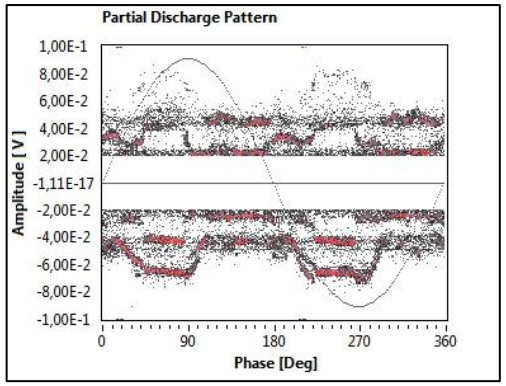
Example C

Motor phase B

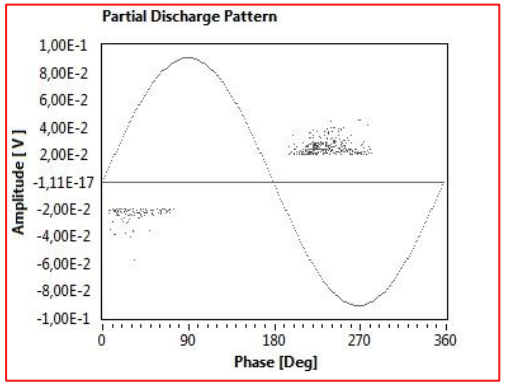




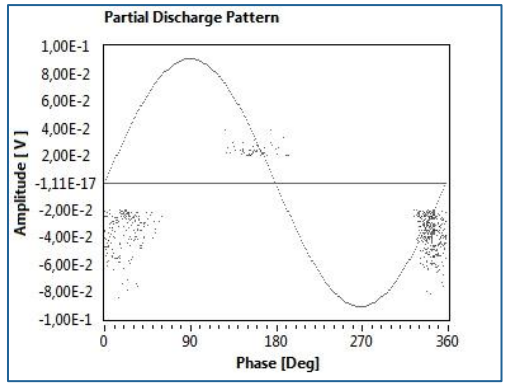
Electronic noise



PD phenomenon 1

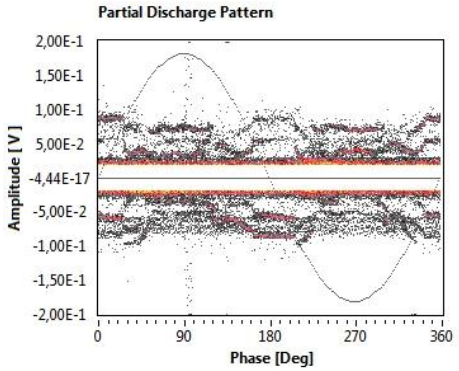


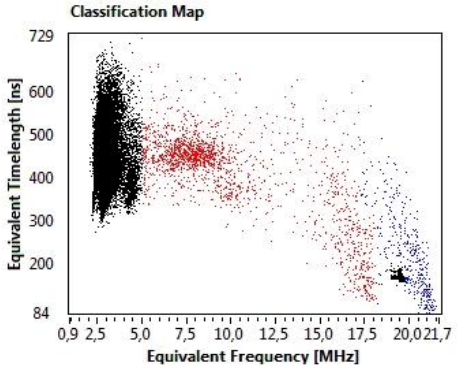
PD phenomenon 2



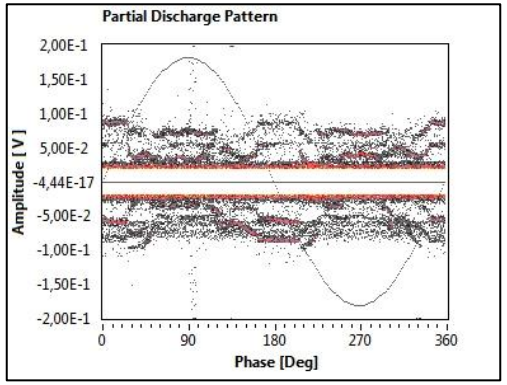
Example C

Motor phase C

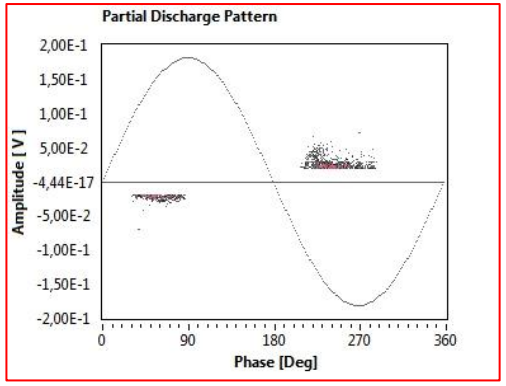




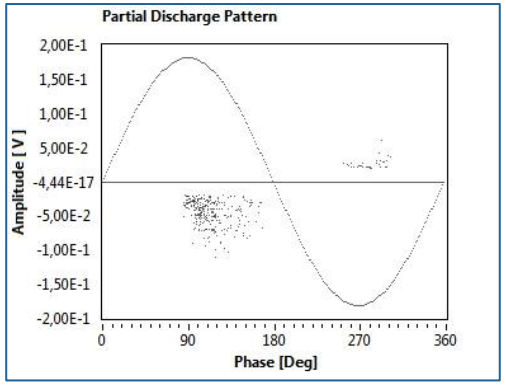
Electronic noise



PD phenomenon 1



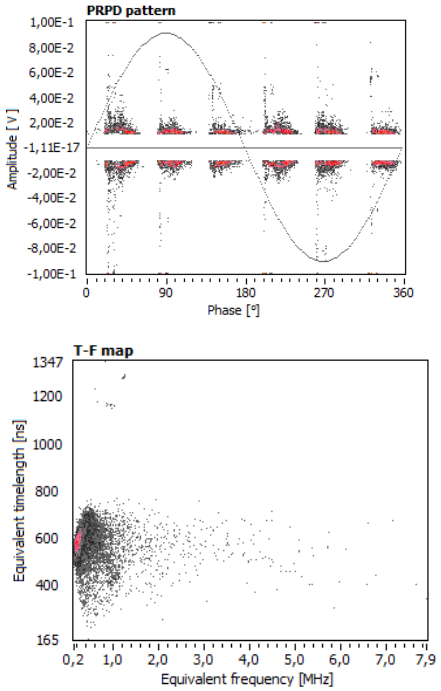
PD phenomenon 2



Example D

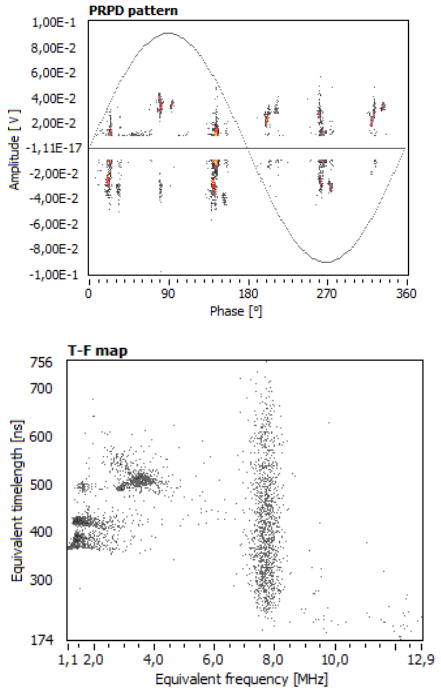
Generator

On line PD test performed thanks to permanent capacitive couplers (hybrid coupler with HFCT…direct circuit)



From the PRPD we can see a strong electronic noise source, from TF map informations it can be observed a very low frequency domain of the related pulses

HW filter HP 2.5MHz



The PRPD pattern is slightly cleaner and from the TF map new clusters of pulses are now visible

On line separation of the PD clusters with TF map

Example D

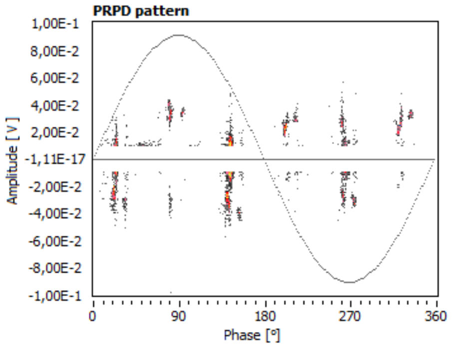
Generator

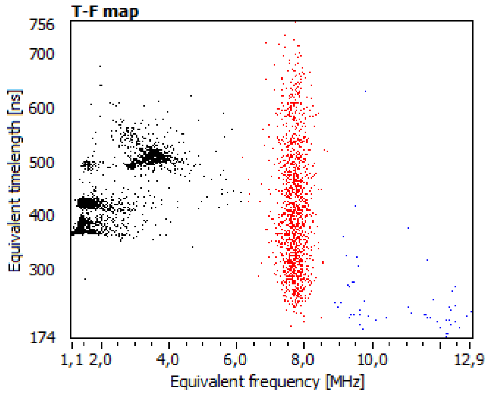
It is possible to drag and drop areas while performing the PD test

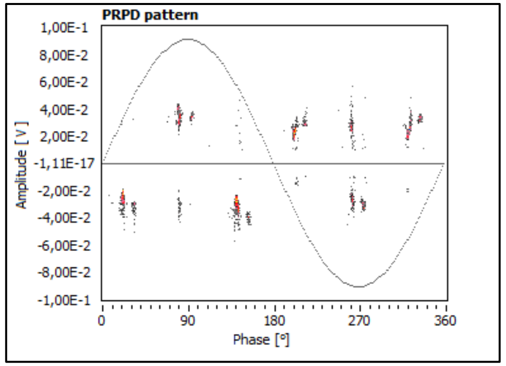
➔ Investigation on different clusters

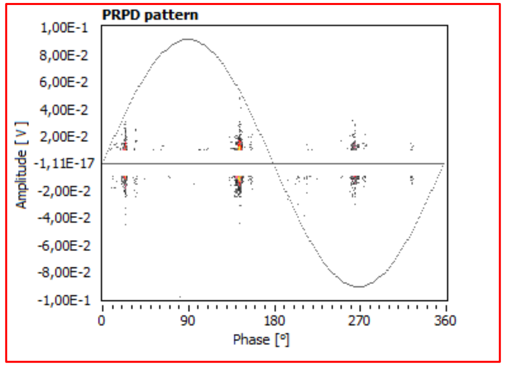
➔ Possible PD at higher frequencies

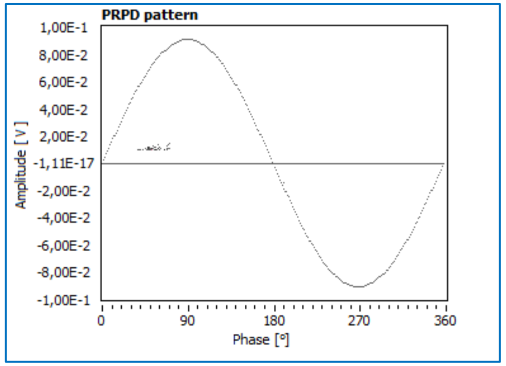
➔ Further focus on the detected phenomena







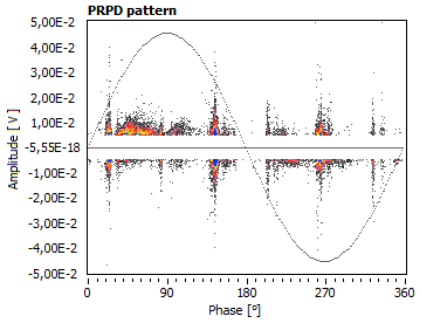


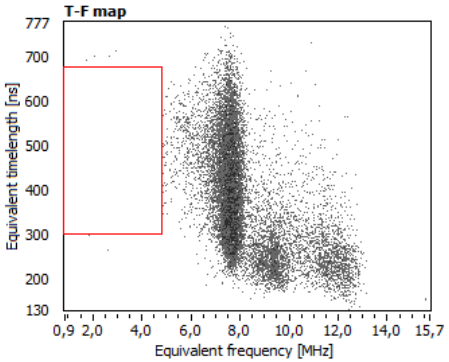


Example D

Generator

Evidences from the on line separation suggest the possible pd at higher frequencies

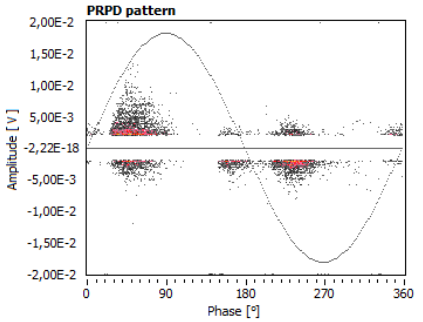


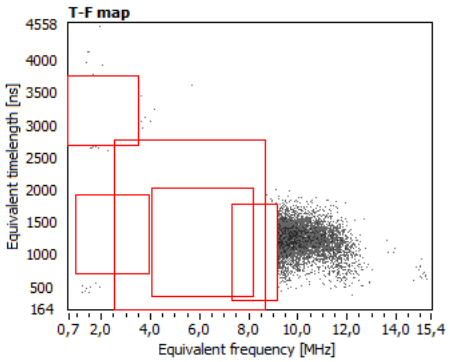


Remove low frequency disturbances with customized TF map filters and reduce trigger level

The PD phenomena is now evident, another separation session confirms that the clusters at 8Mhz are due to noise only

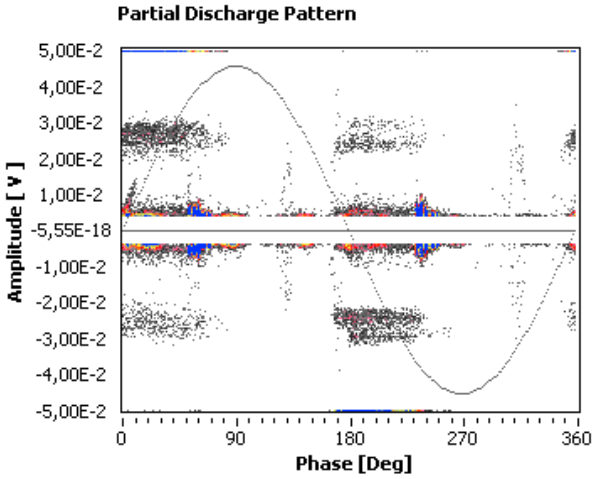
Fine tuning of TF map filters

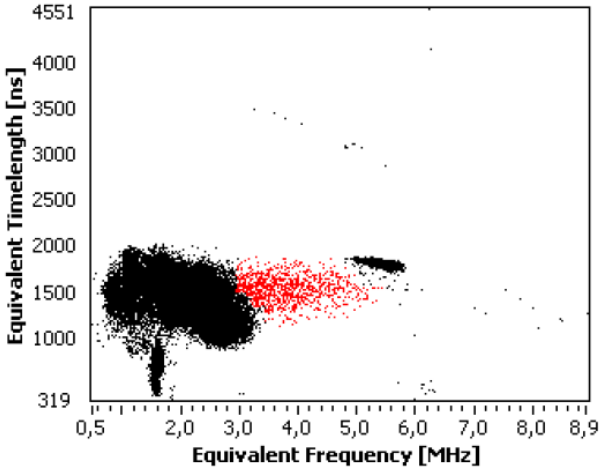


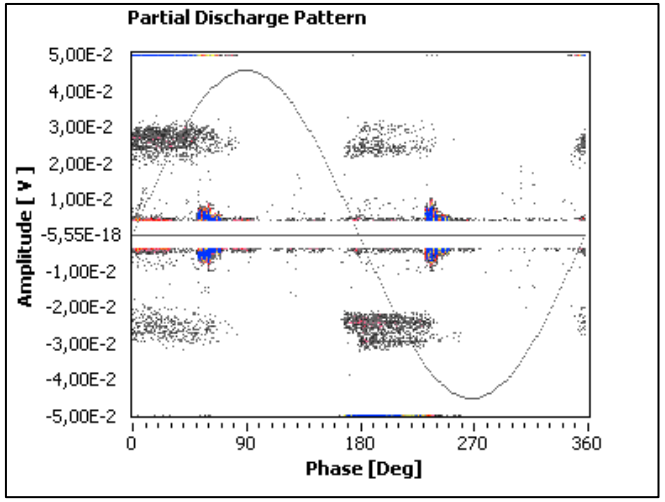


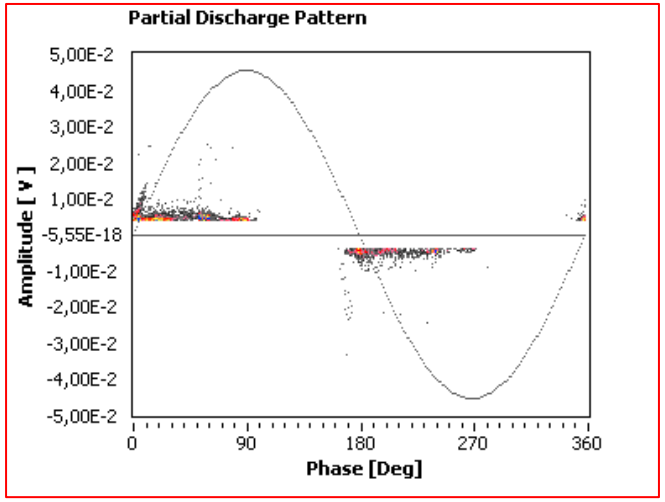
Example E

MV cable on-line test










Question
& Answer