# The use of pulse shape in PD testing of cable systems at VLF

*ICC – PES, Sub. F, Fall 2010 Meeting, Scottsdale/Fountain Hills, AZ*

# Introduction

**High-pot VLF testing of power cable systems is widely used for condition assessment of Medium Voltage networks:**

- **Combined PD and VLF test spots the presence of local defects which may not break down the insulation during the high-pot test;**
- **PD testing at VLF requires advanced noise rejection techniques to be employed**

**Under VLF voltage :**

- **Internal PD have much smaller repetition rate,**
- **electromagnetic noise and external disturbances are present as well**

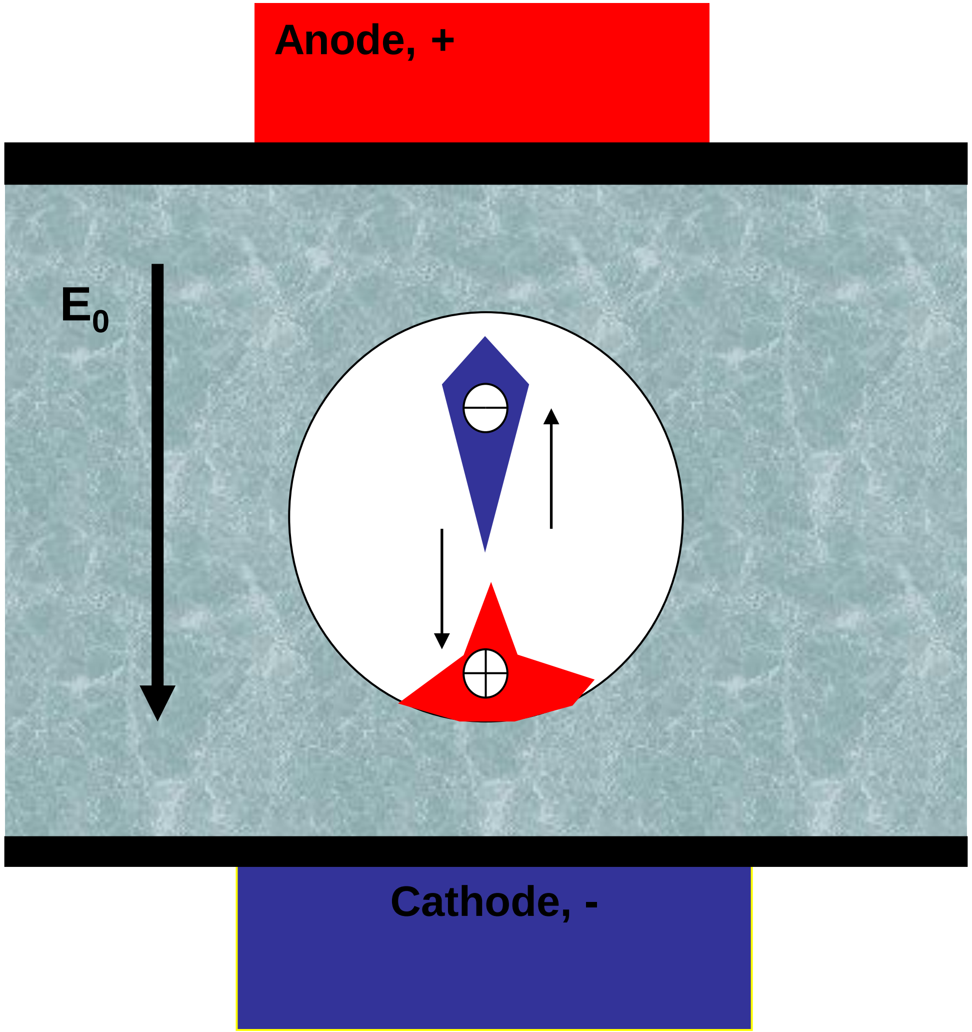
# What happens during a PD? (1)

*Let’s start with a little bit of physics:*

The PD transfers:

- Electrons to the cavity surface acting as anode

- Positive ions to the cavity surface acting as cathode



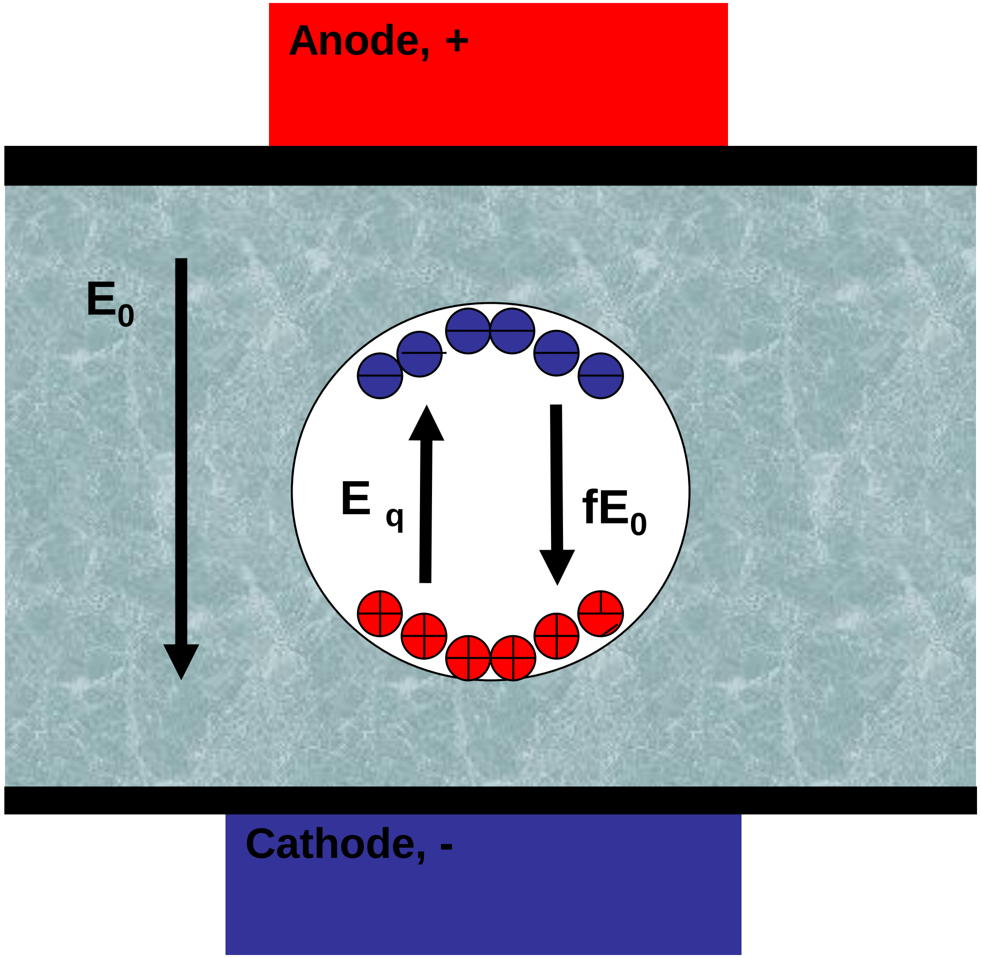
# What happens during a PD? (2)

This charge distribution generates a local field $E_q$

The local field has opposite sign to the external field (i.e., due to the external source), $fE_0$.

Thus, the local field reduces the internal field (i.e., the field inside the cavity).

$$E_i = fE_0 - E_q$$



# Main differences between PD under DC and AC

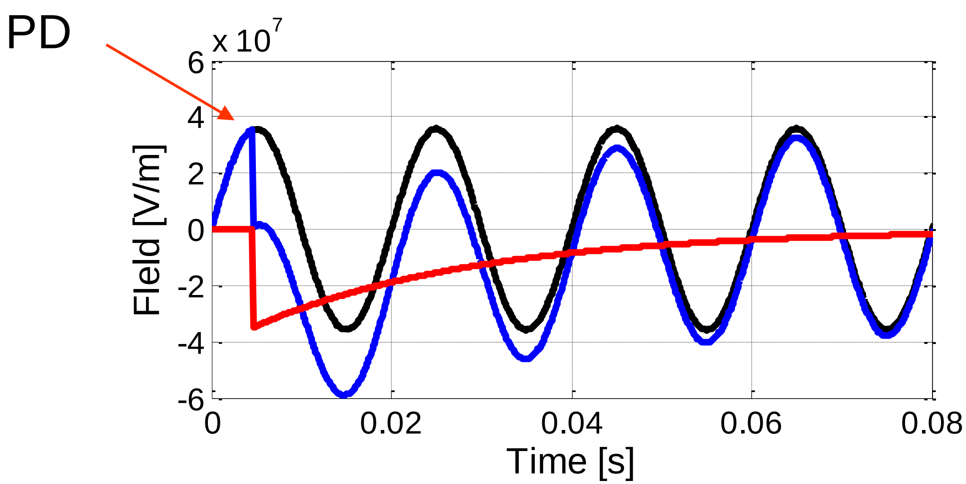
Space charge generated electric field

The charge deployed by previous discharge activity, $\boldsymbol{q_{SC}}$, decays by processes such as drift along the cavity walls, diffusion into the dielectric bulk and neutralization. In a first approximation:

$$q_{SC} = q_{SC\,0} \cdot e^{-\Delta t/\tau};$$

| | |
|---|---|
| $q_{SC\,0}$ | = Space charge just after the last PD |
| $\Delta t$ | = Time elapsed since the last PD |
| $\tau$: | = Time constant |

Example: τ=25ms; Voltage frequency = 50 Hz.




$f_A \cdot E_0$ = Background field

$E_q$ = Space-charge-generated electric field

$E_i$ = Field inside the cavity

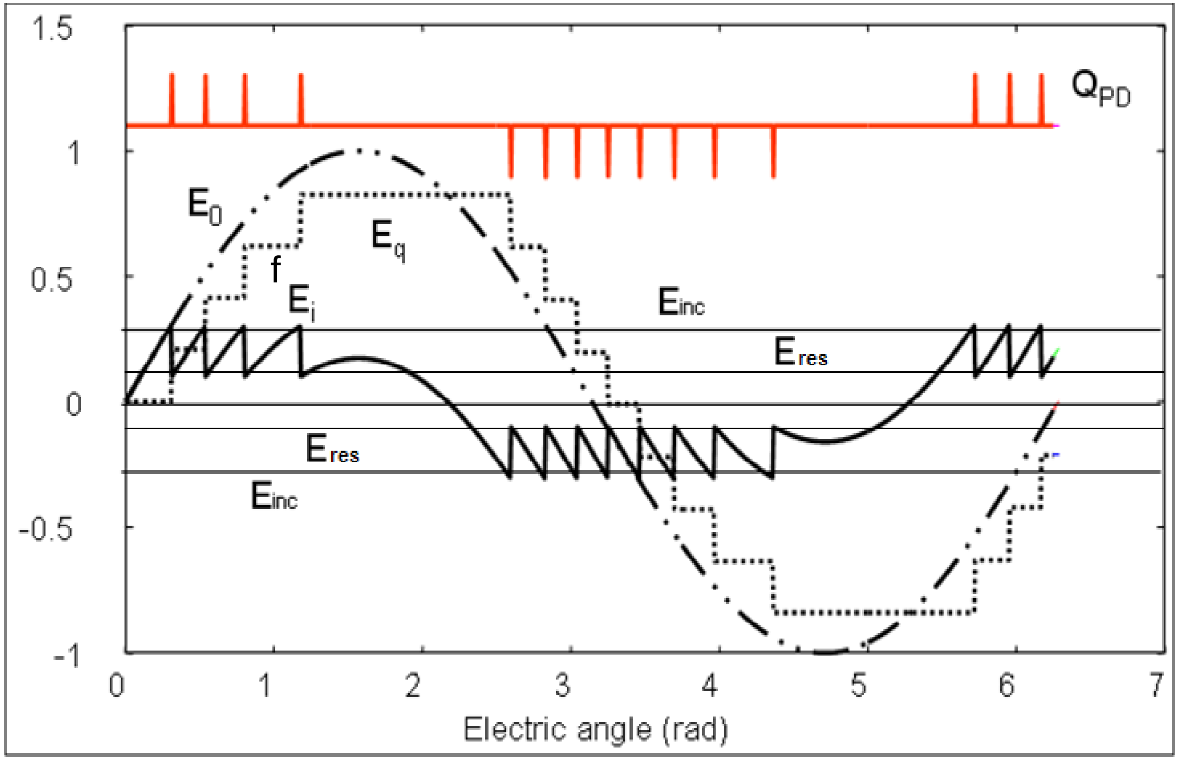
# Main differences between PD under DC and AC

## Simplistic PD description

Hypotheses:

•Infinite electronic availability (PD always occurs when $E_i$=$E_{inc}$)

•No charge diffusion ($E_q$ constant between subsequent PD)




•$E_{inc}$, inception field

•$E_{res}$, residual field

•$fE_0$ = $fE_{max}$*sin(2*pi*freq*t), field due to the applied voltage.

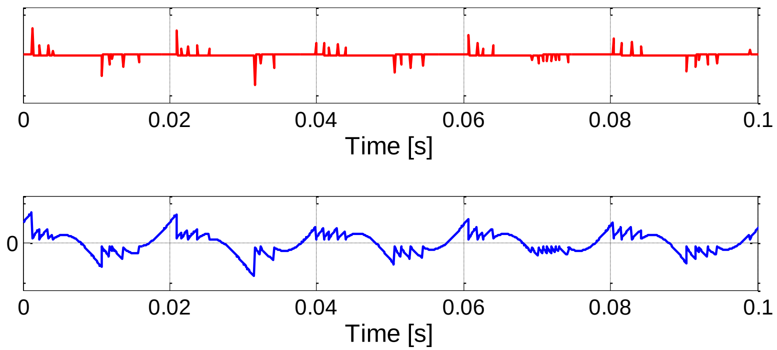
•$E_q$, local field, due to the charge distribution, changes after each PD.

•$E_i$ = $fE_0$ – $E_q$ , total field inside the cavity

# Main differences between PD under DC and AC

**AC or varying voltage:**

- Sinusoidal voltage at industrial frequency → Repetition rate is generally higher than under DC (up to hundreds of pulses per second), due to:



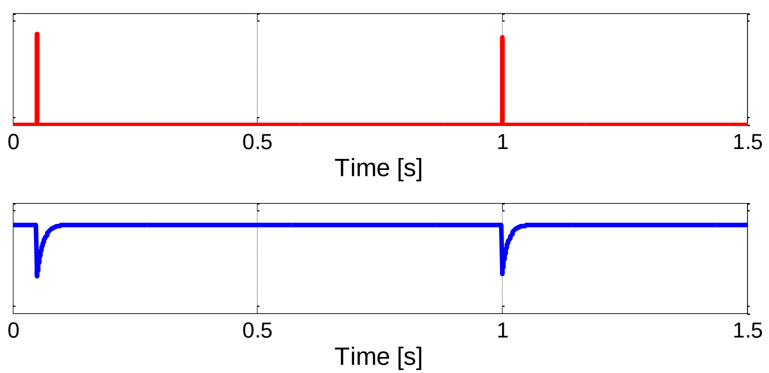

- **Time varying background field;**
- **Polarity inversions;**

**$I_{PD}$= PD current pulses**

**$E_i$ = Field inside the cavity**

**DC:**

- Voltage constant → Low repetition rate (typically one discharge per second or less)




- **Charge from previous PD reduces the internal field;**
- **No polarity inversions;**

**$I_{PD}$= PD current pulses**

**$E_i$ = Field inside the cavity**

# *ULTRA WIDE BAND APPROACH FOR PARTIAL DISCHARGES MEASUREMENTS*

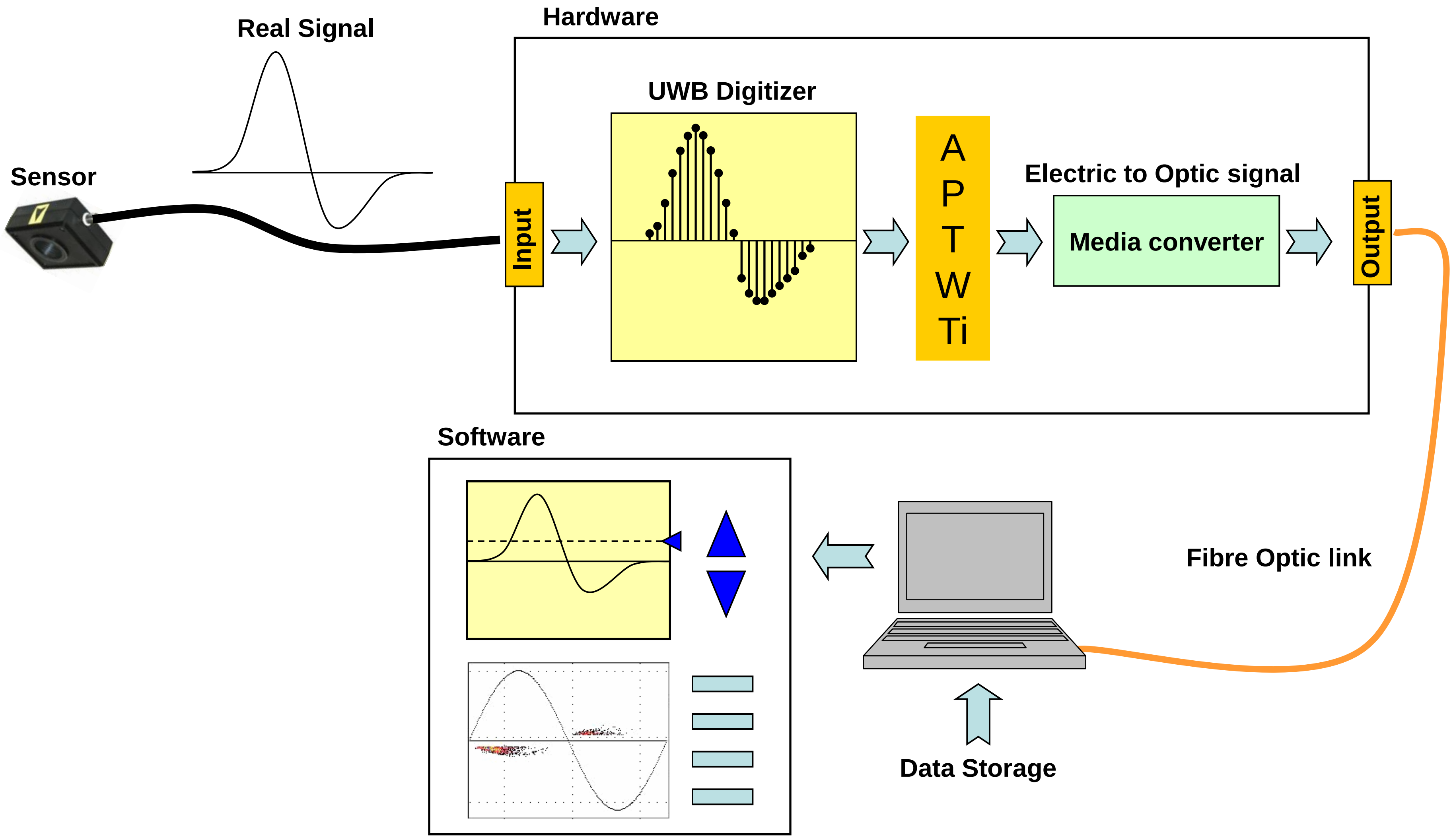
**Ultra Wide Band acquisition allows:**

- **Classification by "Time – Frequency" mapping of acquired pulses**
- **Phenomena separation (Noise, Disturbances, Multiple PD activities, etc.)**
- **Real-time Noise rejection based on pulse shape characteristics**
- **Single phenomenon identification**
- **Localization (various techniques)**

**•It can be applied on-line, off-line at power frequency, RTS and VLF**

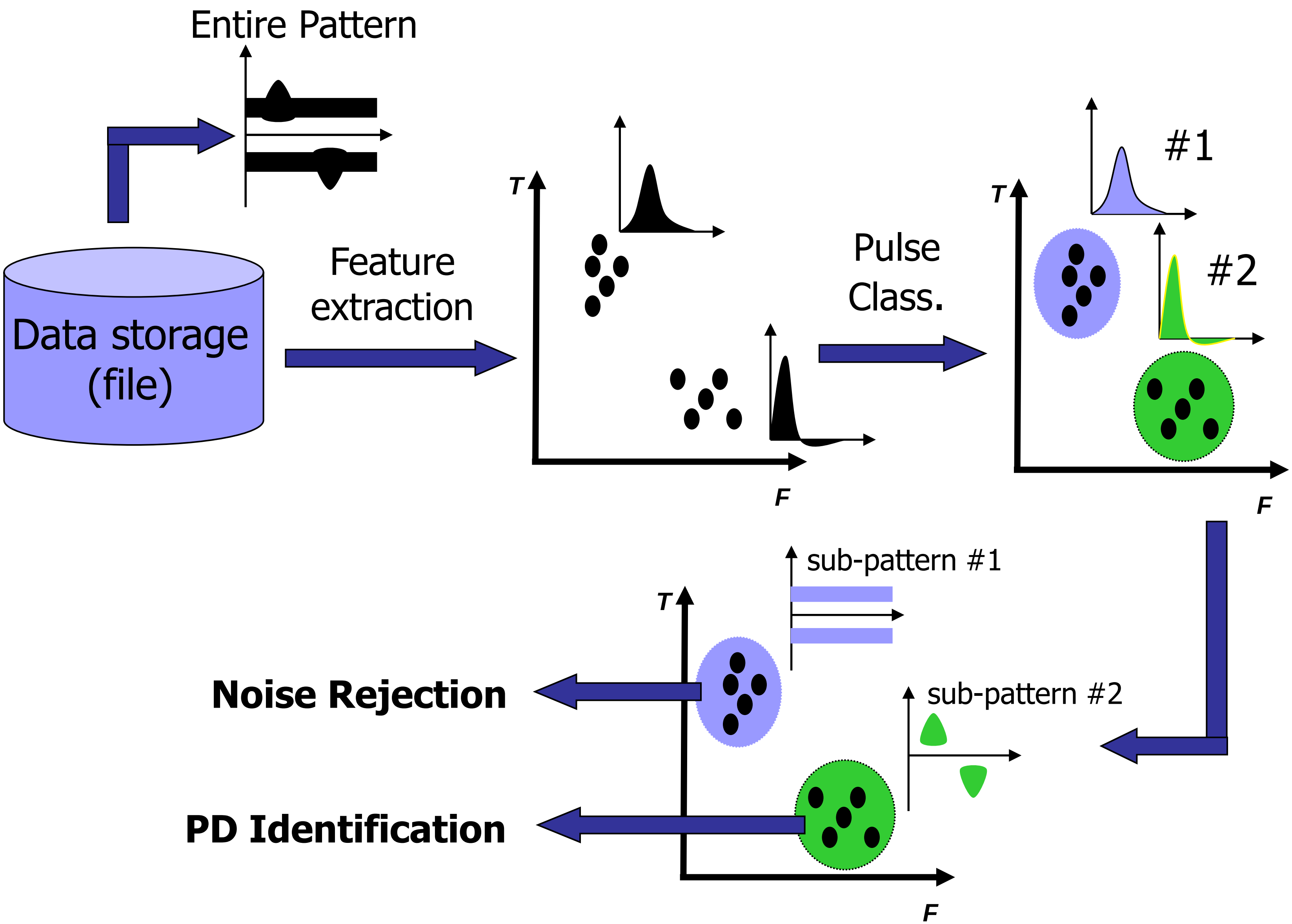
# Separation

## Innovative diagnostics by means of PD measurements: System Layout



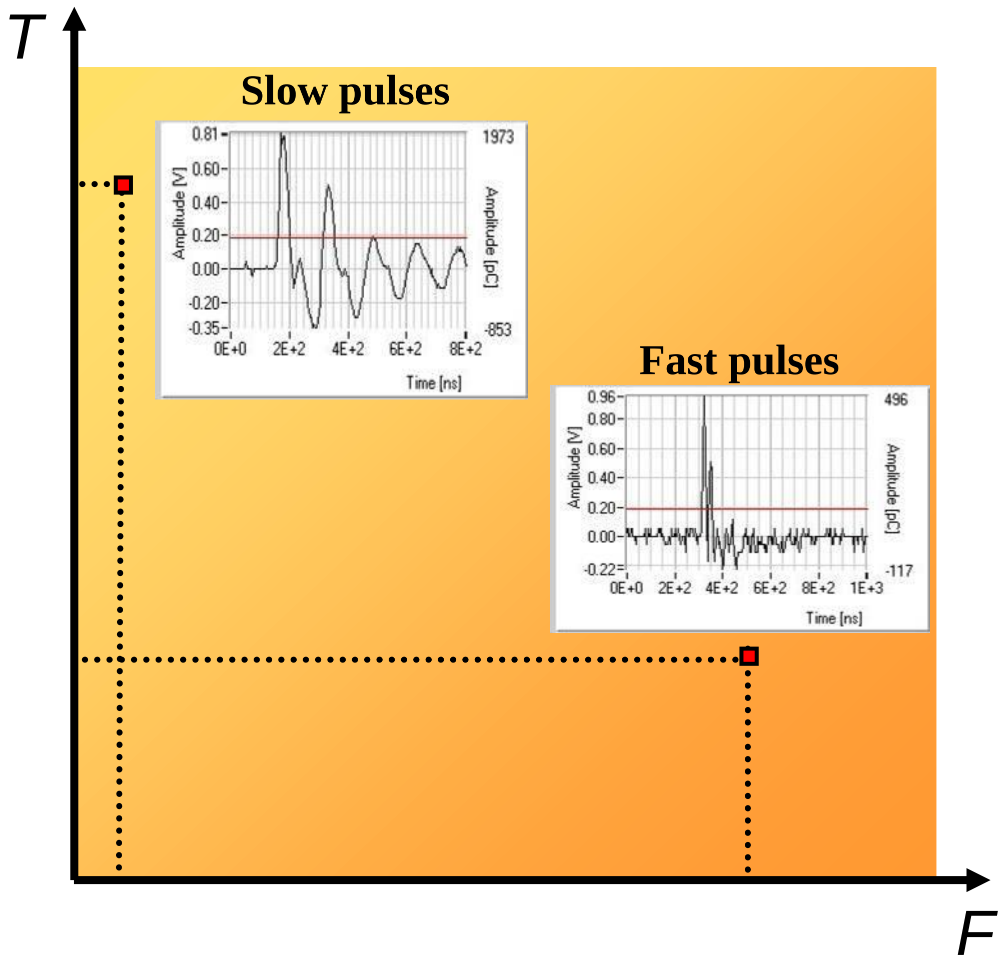
# Separation

## Innovative diagnostics by means of PD measurements: Data Flow



# Classification by T-F mapping

## Each acquired pulse is represented with 2 parameters




Normalization of the pulse

$$\tilde{s}(t) = s(t) / \sqrt{\int_0^L s(\tau)^2 \, d\tau}$$

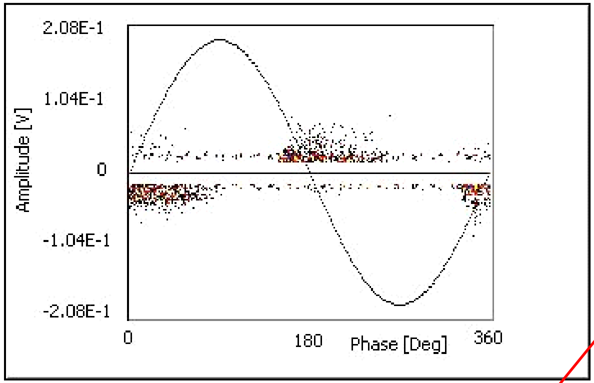
$$\begin{cases} \begin{cases} t_0 = \int_0^L t\tilde{s}(t)^2 \, dt \\ T = \sqrt{\int_0^L (t - t_0)^2 \tilde{s}(t)^2 \, dt} \end{cases} \\ F = \sqrt{\int_0^\infty f^2 \left|\tilde{S}(f)\right|^2 df} \end{cases}$$

*S(f)* is the Fourier transform of *s*

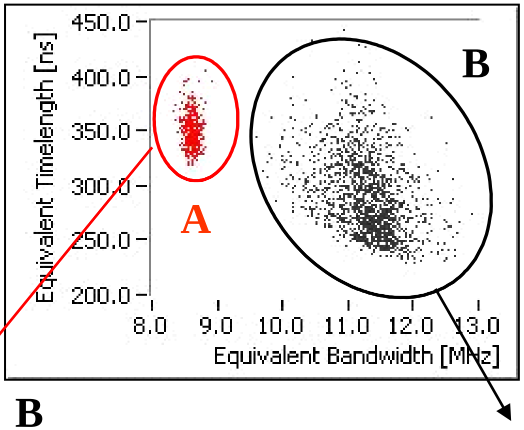
*L* = time length of the pulse

# Example of data processing #1

**Entire PD pattern**

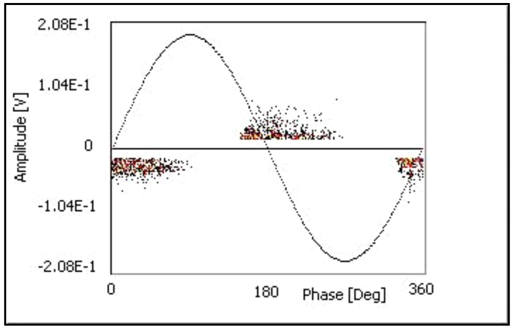



**T-F Map**

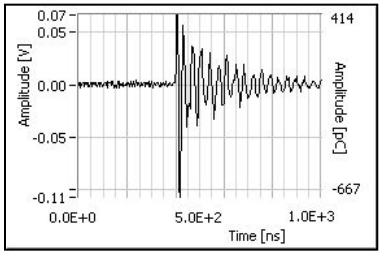


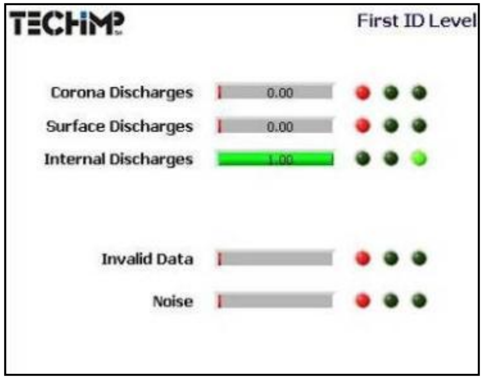

**A**

**Sub-pattern A**



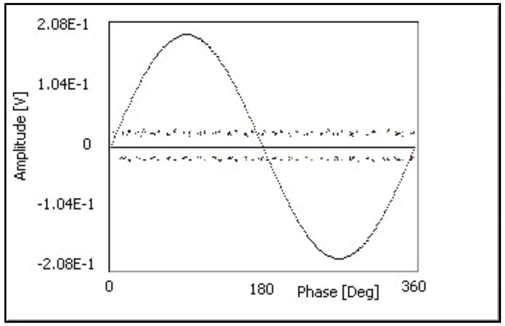

**Waveform A**



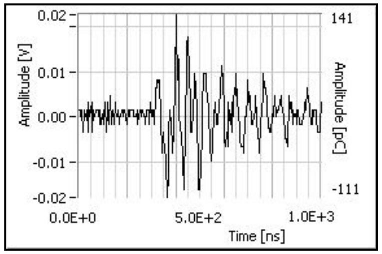



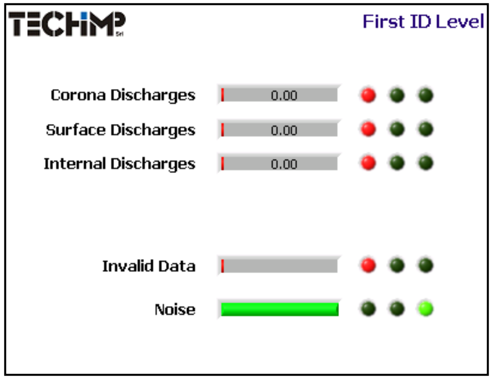

**B**

**Sub-pattern B**




**Waveform B**

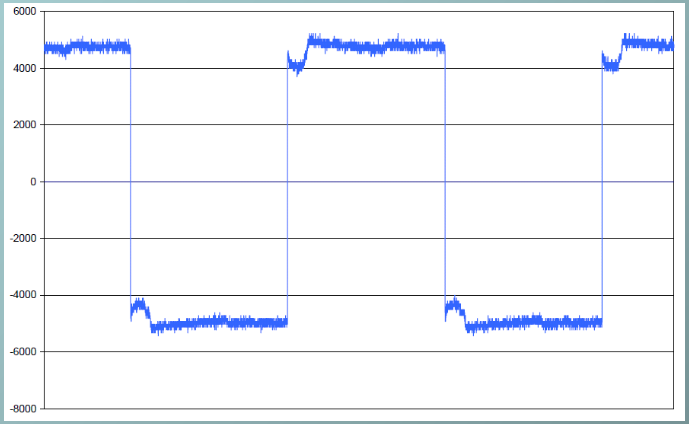


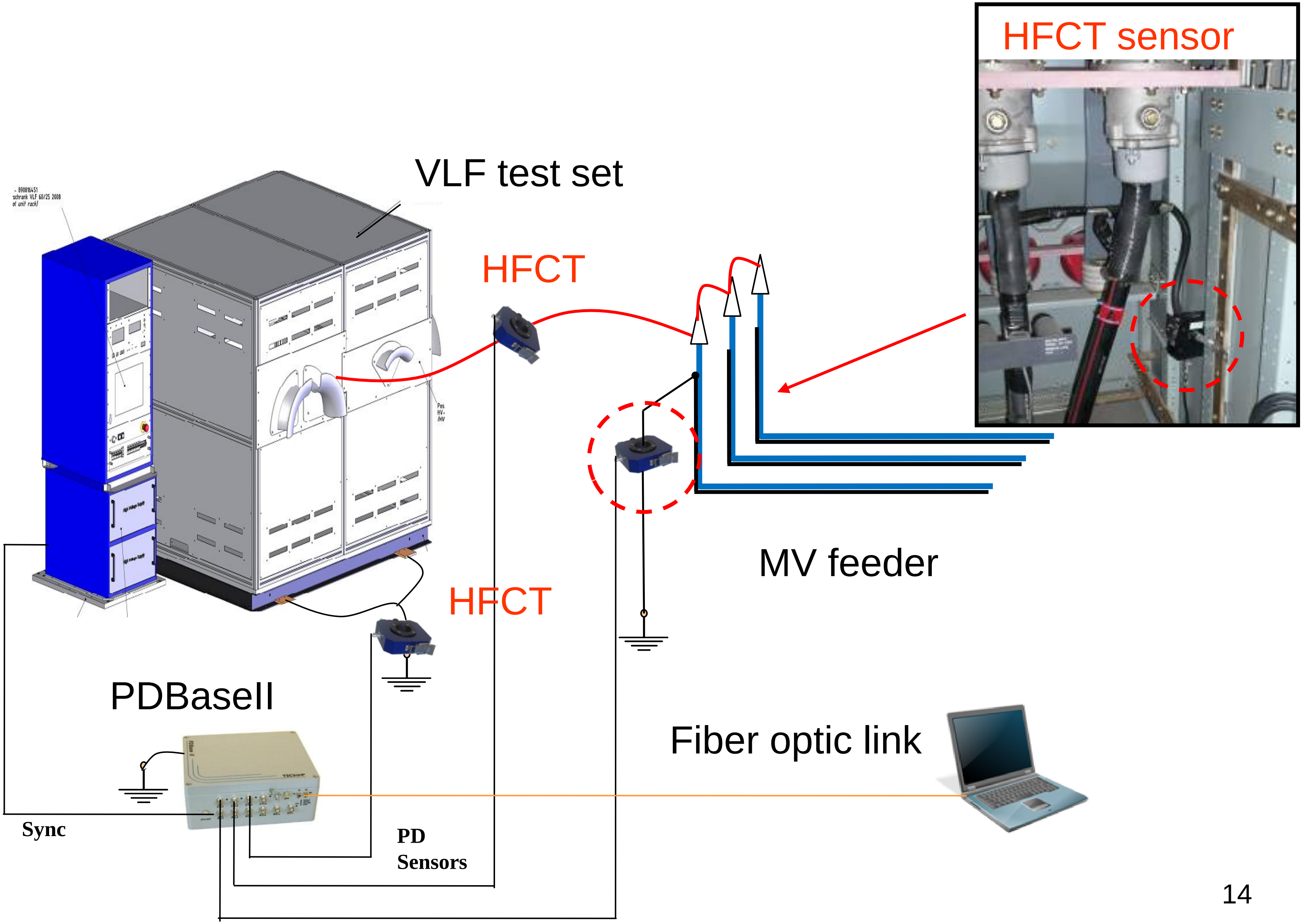
# Case Study #1: MV feeder, VLF off-line PD test

**Apparatus: Medium voltage cable feeder**
**Voltage level: 15 kV**
**Location: USA**

T-F map separation allows PD phenomena to be detected during off-line VLF tests performed with **cosine-rectangular** voltage



# 1. Measurement Setup

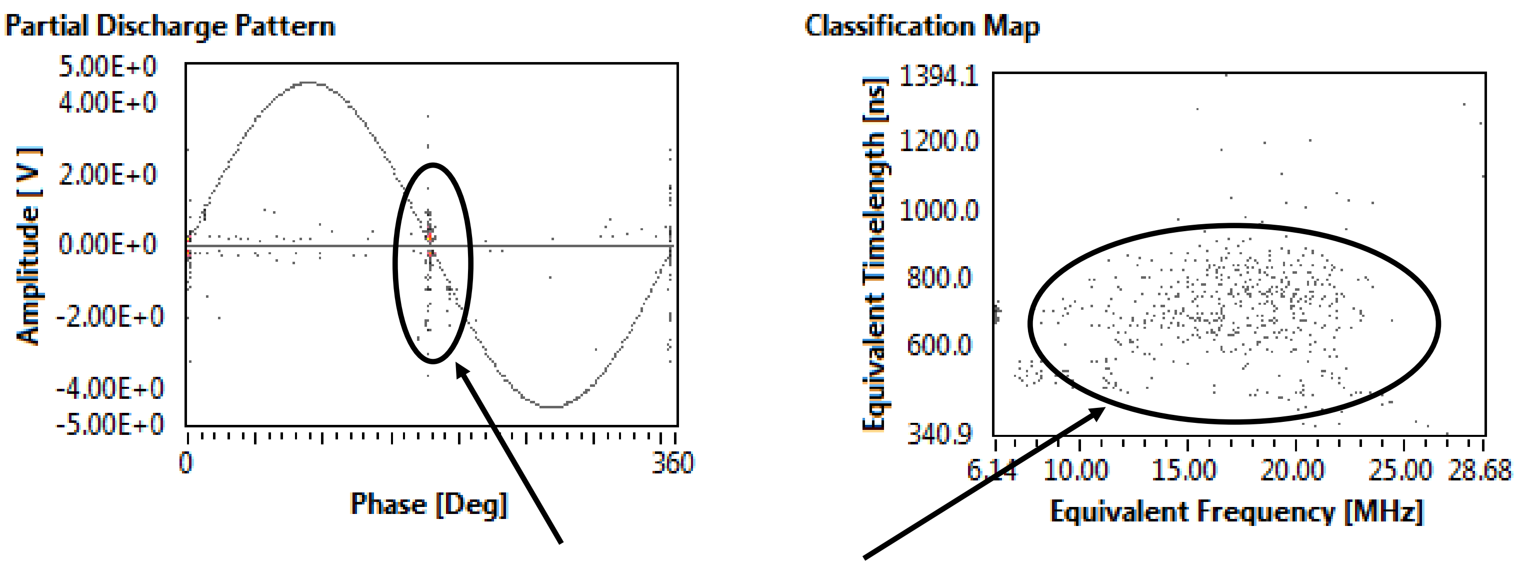


# 2. Dry test

**Step 1: Dry test**

- **The VLF supply is energized with no cable connected;**
- **PD phenomena coming from the VLF are acquired (VLF supply fingerprint)**

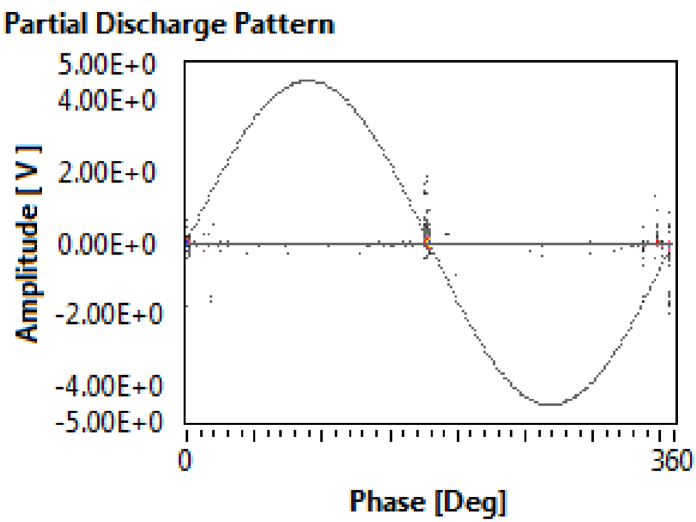
**Results:**

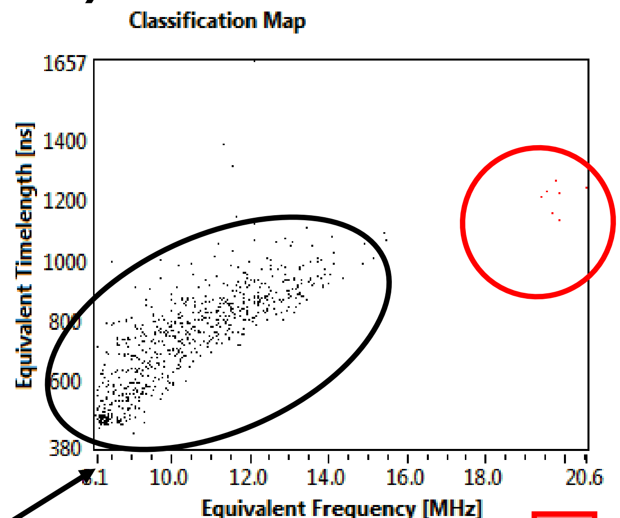



**PD from the VLF supply**

**Step 2: PD test**

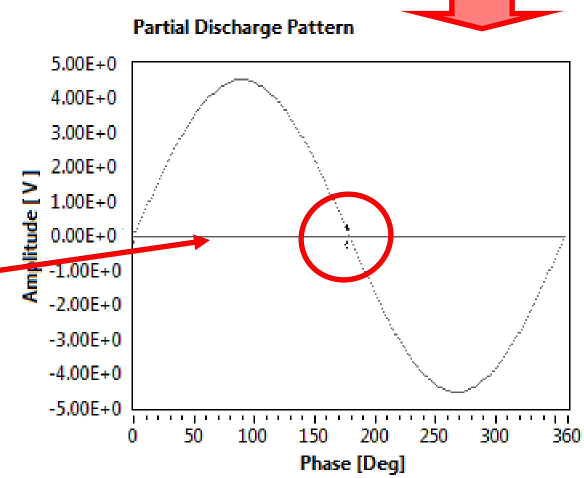
- The feeder is connected to the VLF supply;
- New PD phenomena can be acquired and recognized as coming from the EUT (cable feeder)




Separation

PD from the VLF supply




PD coming from the EUT

# Case Study #2: MV feeder, on-line and VLF off-line PD test

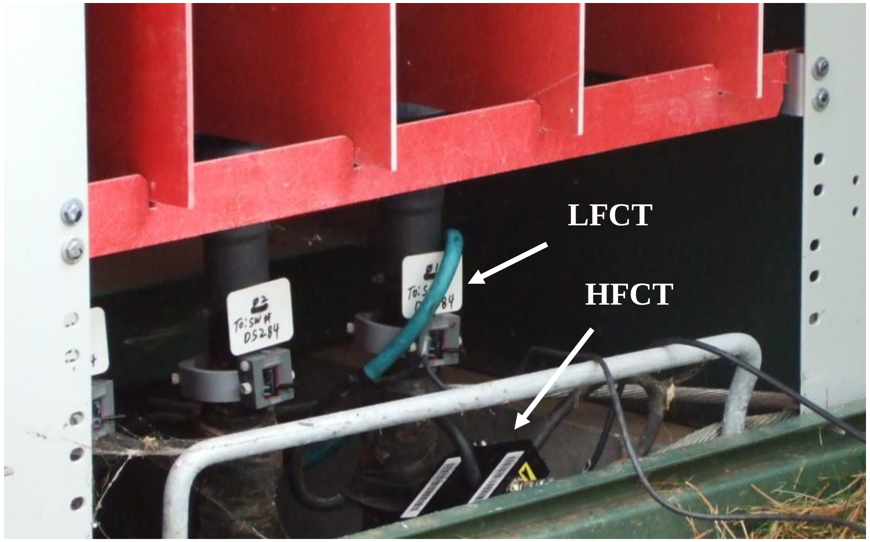
**Apparatus: Medium voltage cable feeder**
**Voltage level: 14kV**
**Location: USA**

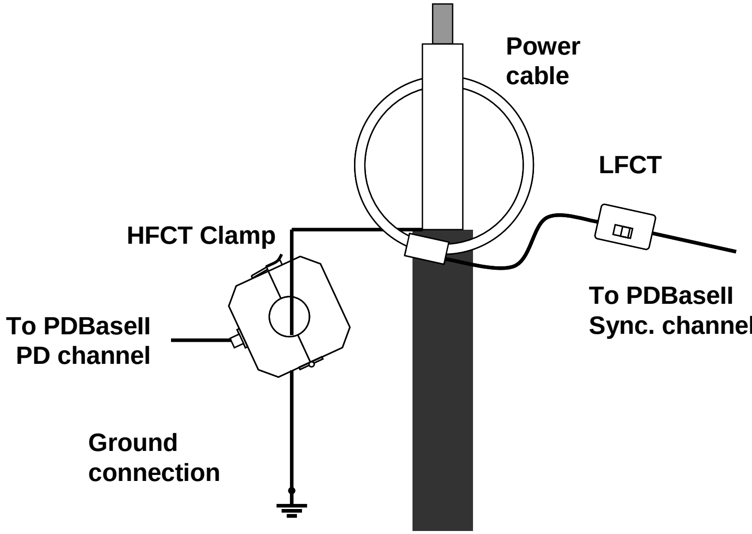
Application of PD phenomena separation by T-F mapping, on-line and at sinusoidal VLF

# 1. Measurement Setup

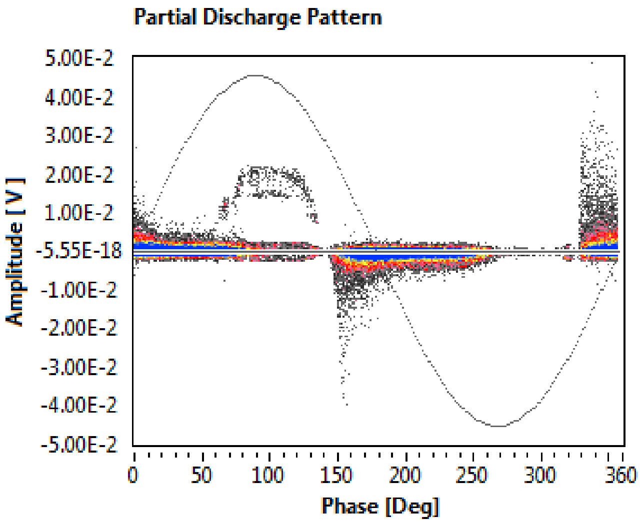
PD signals:
HFCT (High Frequency Current Transformer) clamped around the ground lead of the cable termination

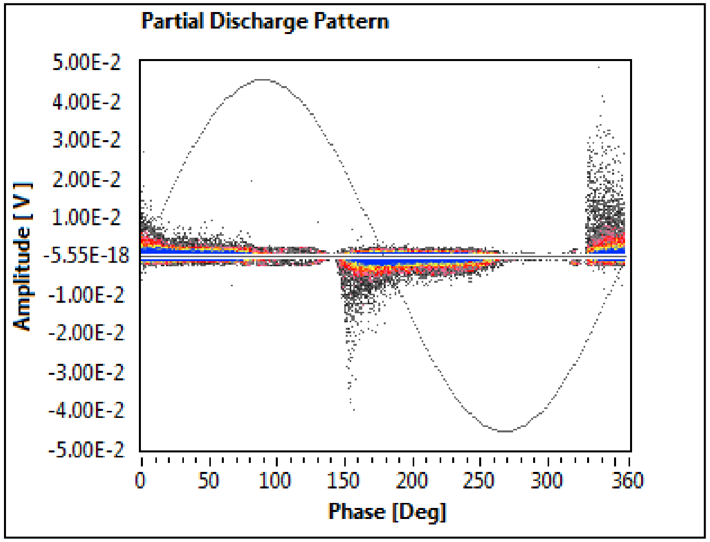
Synchronization signal:
- ❑ through a Low Frequency Current Transformer clamped around the cable termination for on-line measurement
- ❑ through a capacitive divider for the off-line VLF test



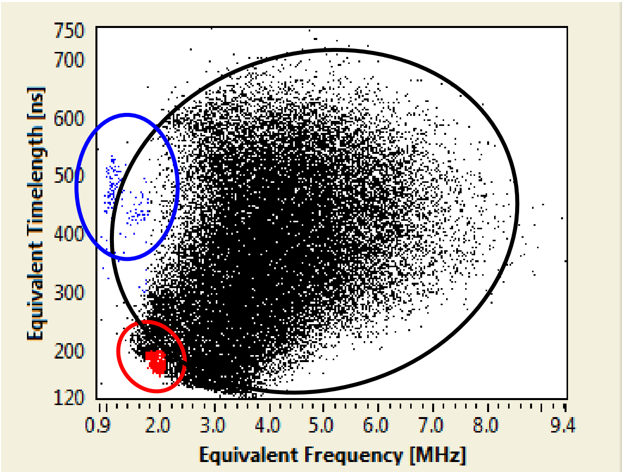



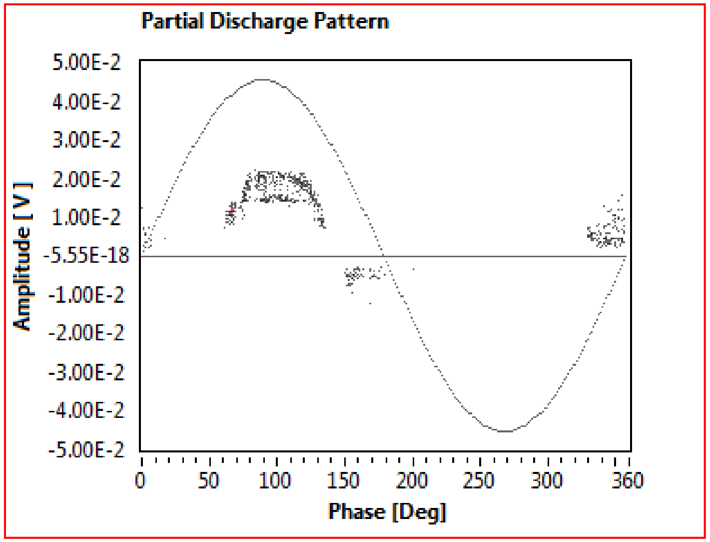
**Step 1: On-line 14kV (phase to ground) @ 60 Hz;**
**Feeder supplied by the grid (no loads connected)**




**Internal PD (black cluster high repetition rate)**



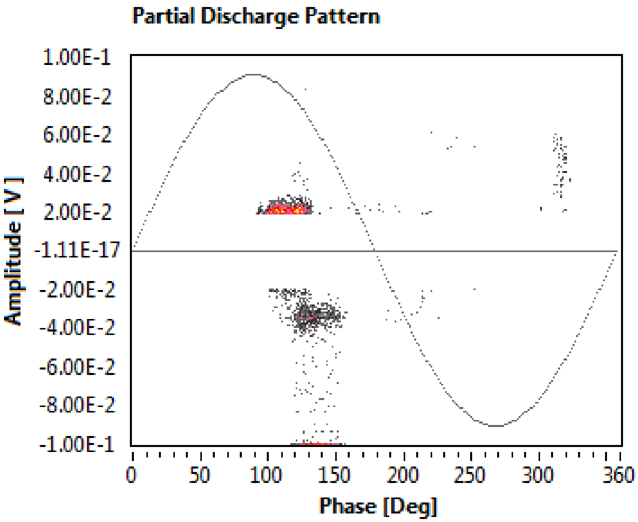



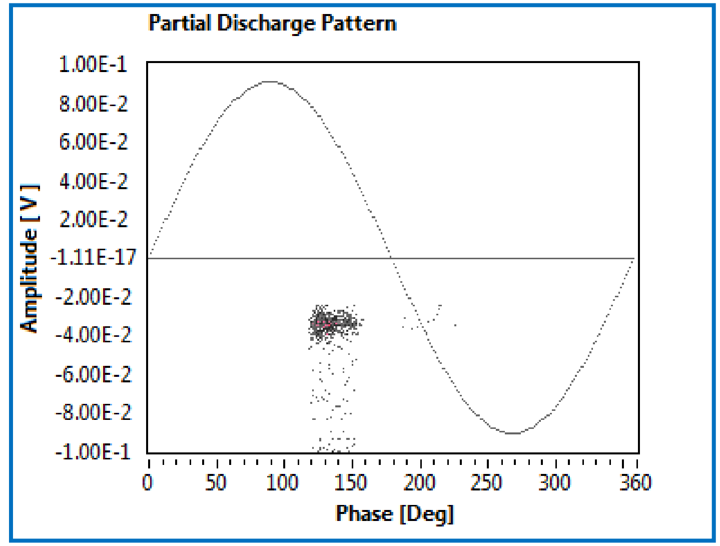

**Corona PD (red cluster, low repetition rate)**

# 3. Off-line VLF test

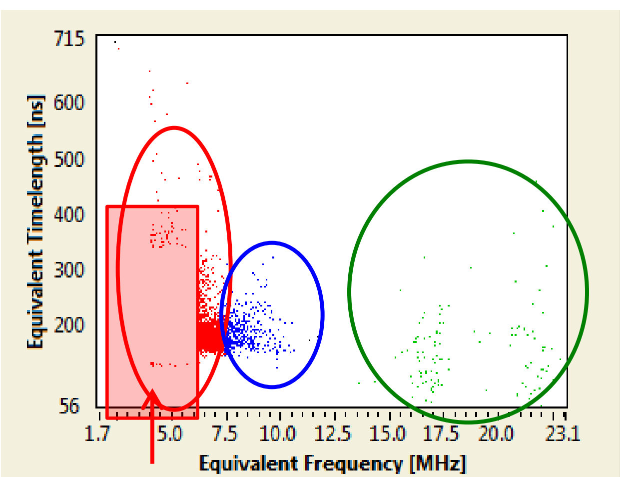
**Step 2: Off-line 23kV (phase to ground) @ 0.1 Hz;**

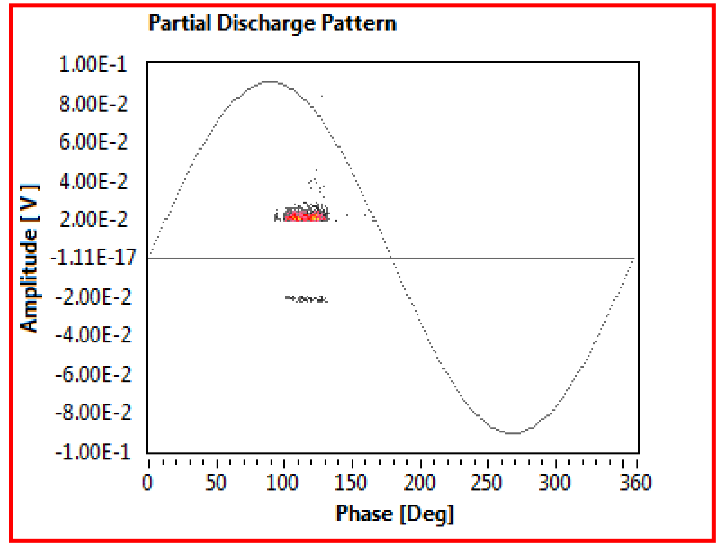
**0.1 Hz sine-wave compact VLF unit**




**Internal PD (blue cluster)**




**Corona PD (red cluster)**

**Real-time filter**

# Conclusions

- The decomposition of the pulse frequency and time characteristics allows:
  - Enhanced noise rejection
  - PD **separation**
  - PD **location**
  - PD source **identification** by artificial intelligence methods

- Real-time pulse selection based on PD pulse characteristics (in time and frequency domains) allows separation of signals coming from different sources to be performed, in order to focus on PD activity coming from the cable system under test

Thank you !