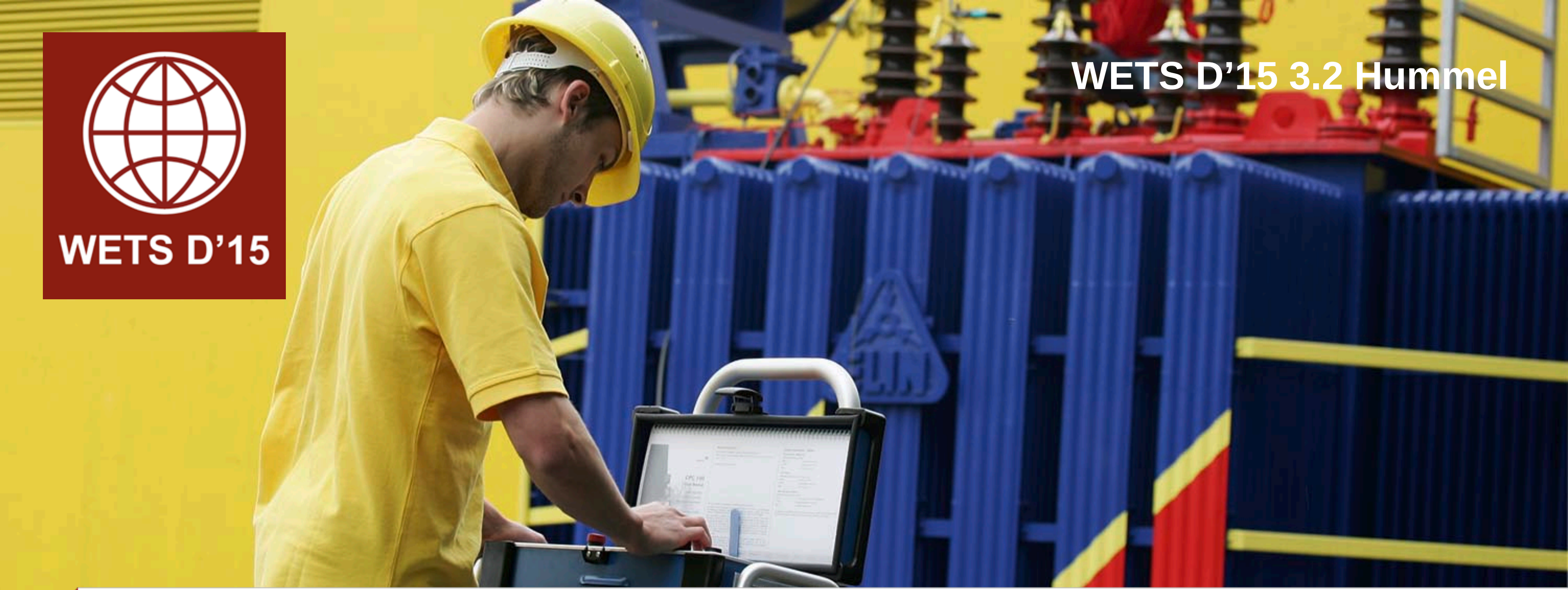


WETS D’15 Workshop

Organization: Jicable and Prospective 21OO
Palais des Congrès de Versailles, France
Thursday, 25 June 2015

PD Diagnostics on MV cables

Rene Hummel

aim of the presentation

PD detection

PD measurement

PD localization

types of testing

outline

Introduction – what are partial discharges?

How to measure?

localization:

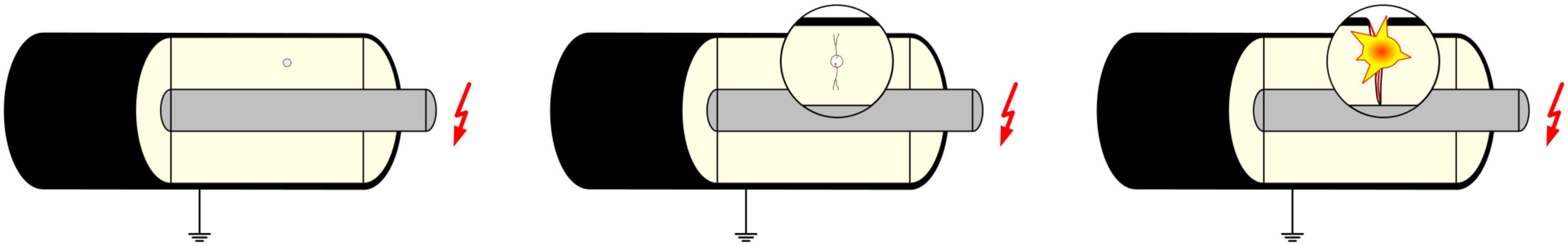
TDR – time domain reflectometry

sTDR – statistical TDR

overview of technologies in the market

What is partial discharge ?

> Partial discharge (PD) is a localized dielectric breakdown of a small portion of a solid or liquid electrical insulation system under high voltage stress.



> Definition from IEC 60270 Specification:
Localized electrical discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor.

What are partial discharges?

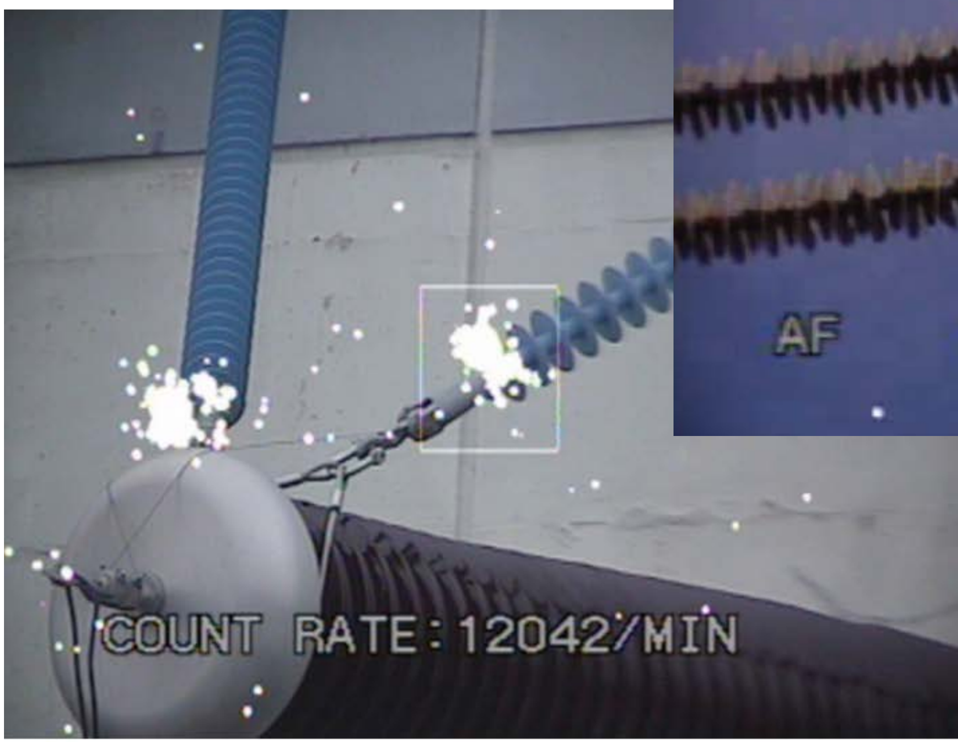
Partial discharge:

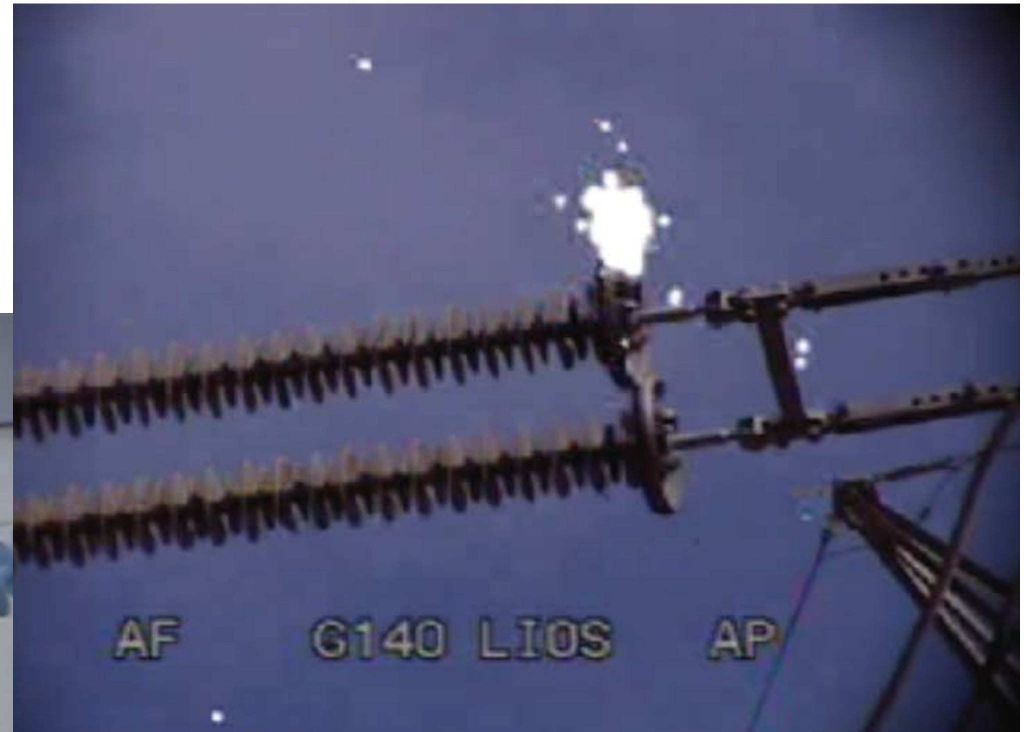
> Local electrical stress in the insulation or on the surface of the insulation

> Always generates electromagnetic signals

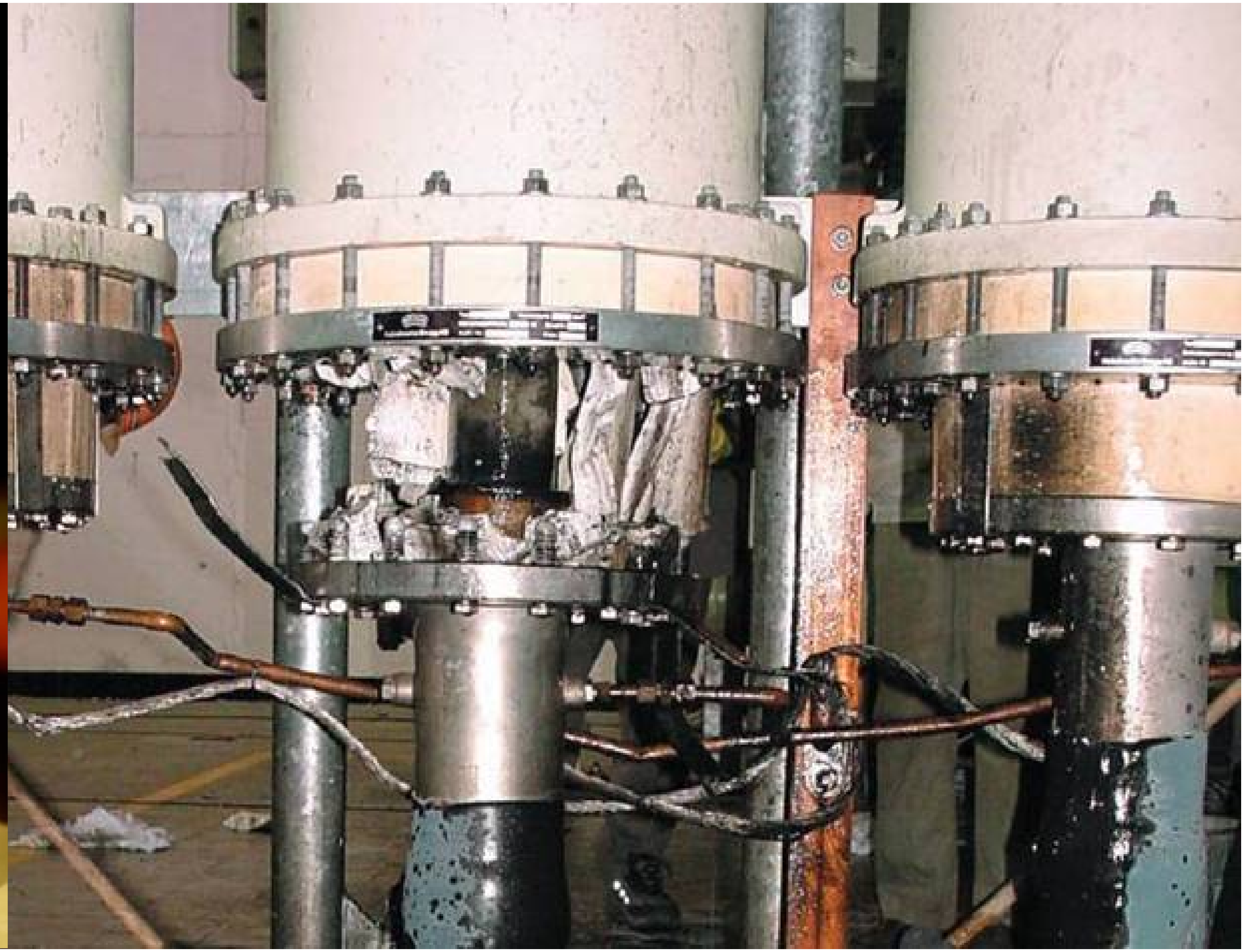
> Often accompanied by an emission of sound, light, heat and chemical reactions

Evidence of partial discharges





Breakdown of cable and termination



Evidence of partial discharges

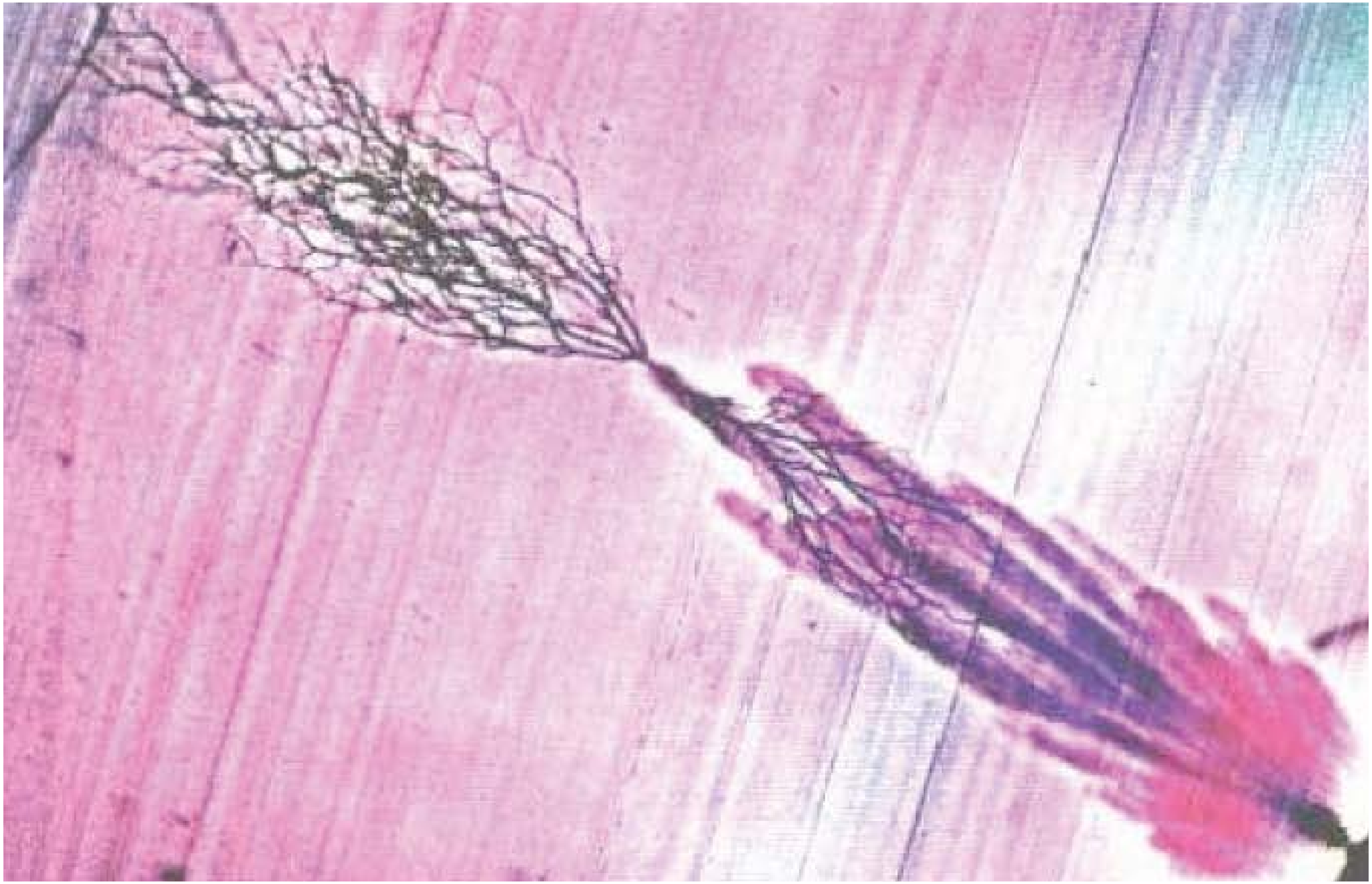
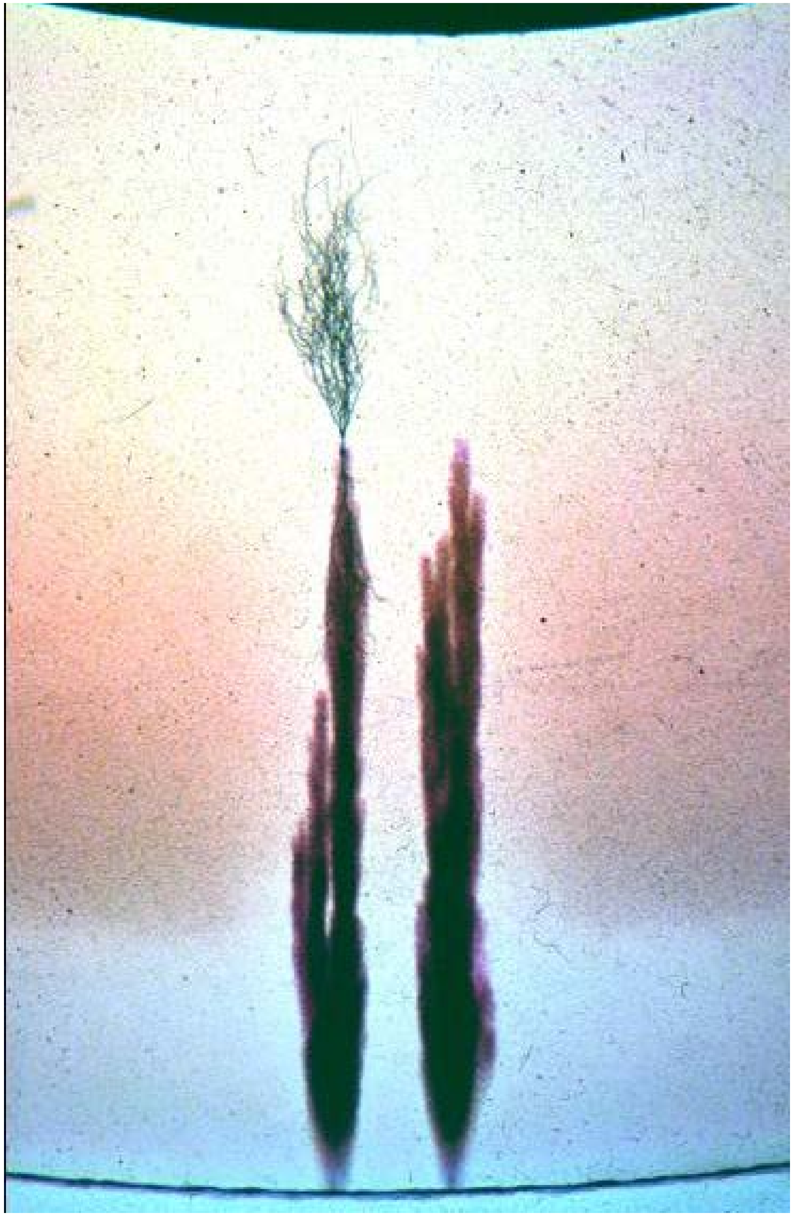


photo: IPH Berlin

Electrical treeing in PE



Evidence of partial discharges

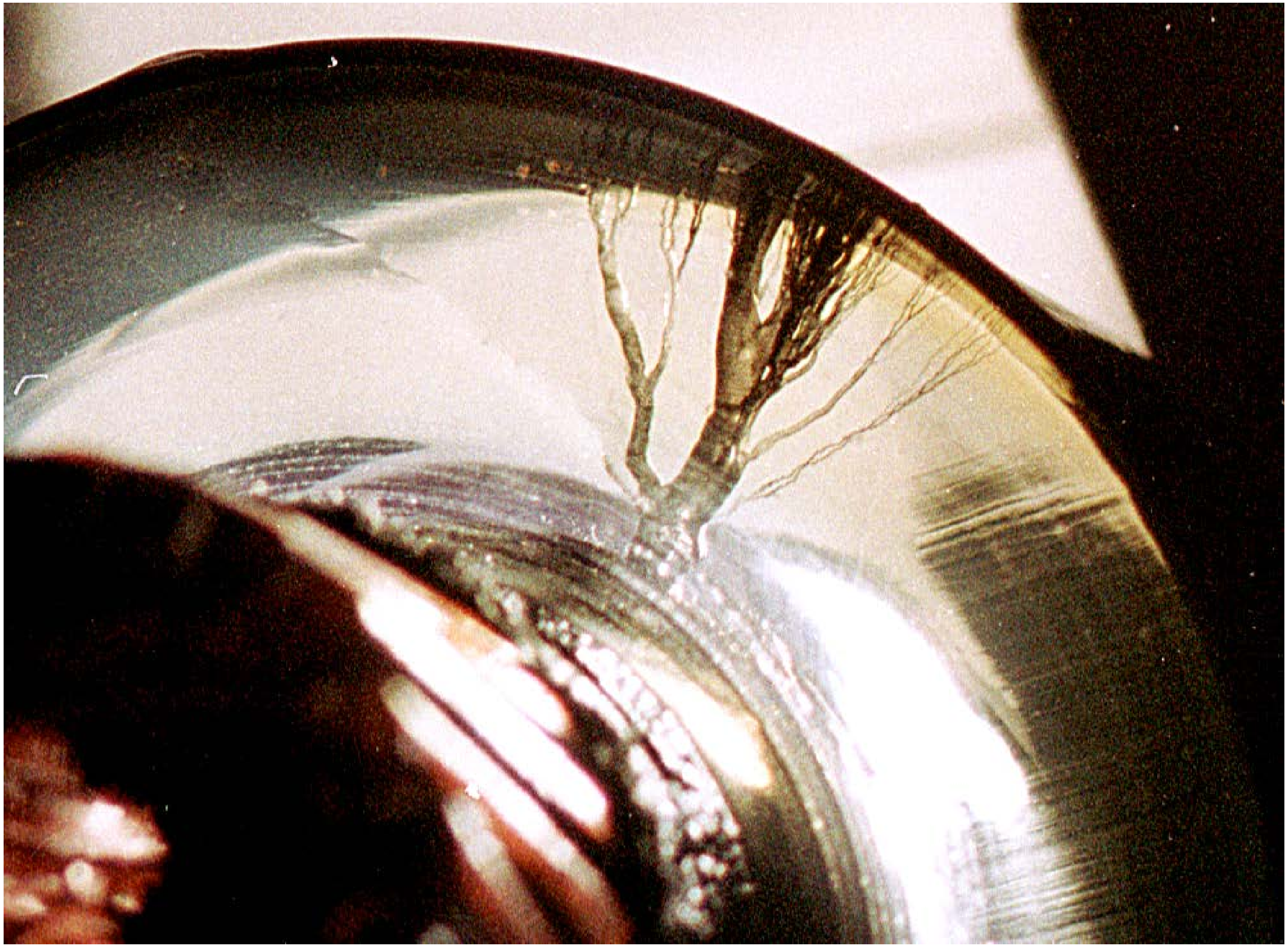
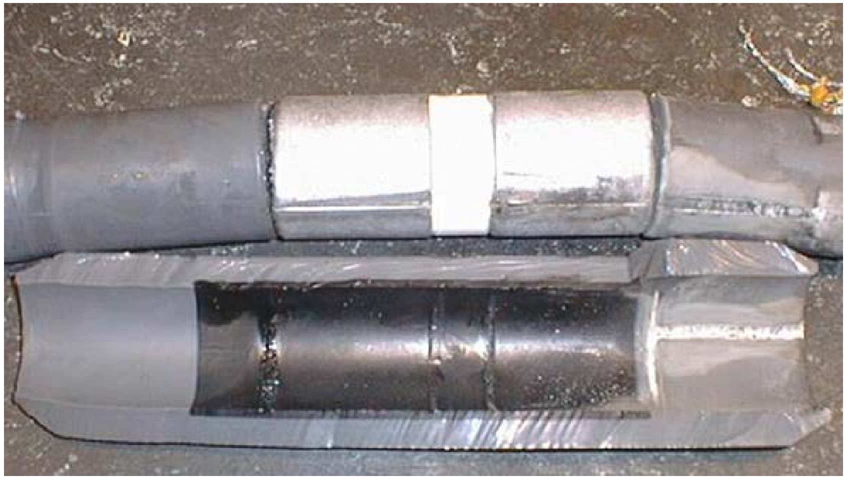
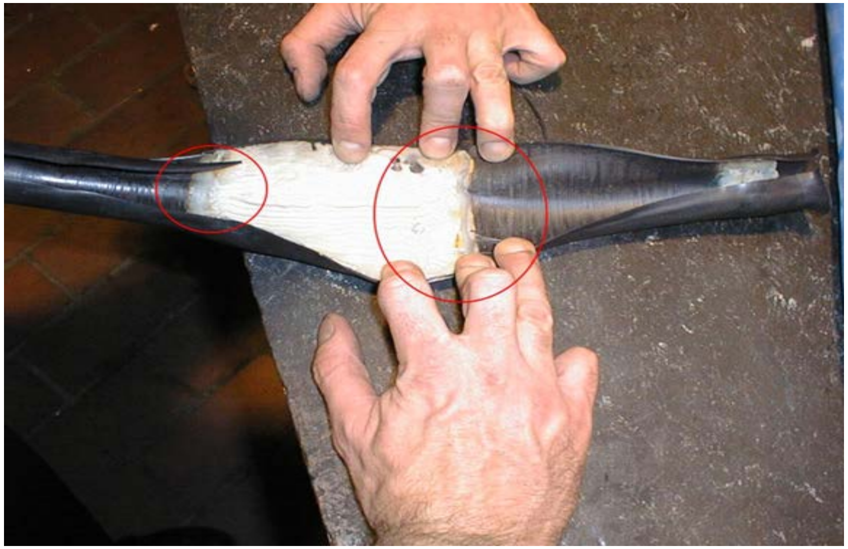
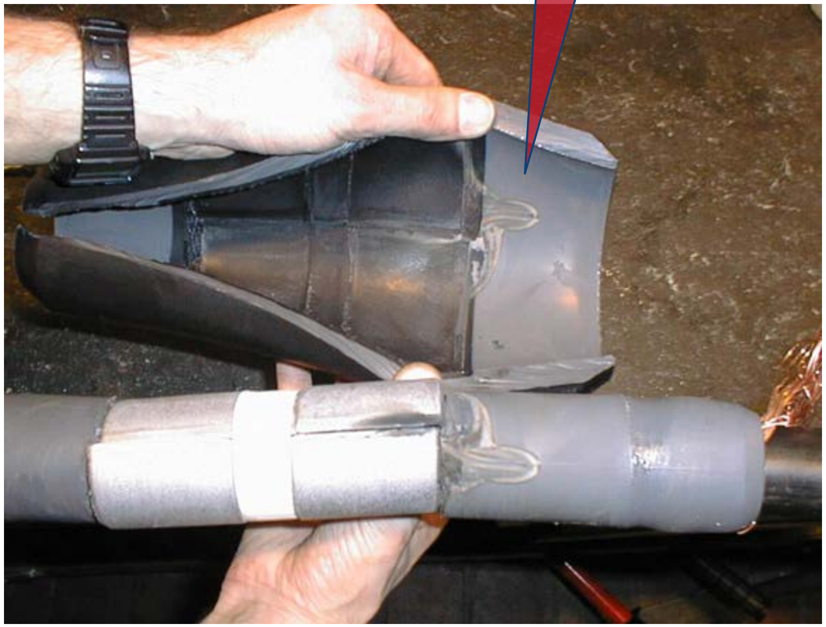


photo: IPH Berlin

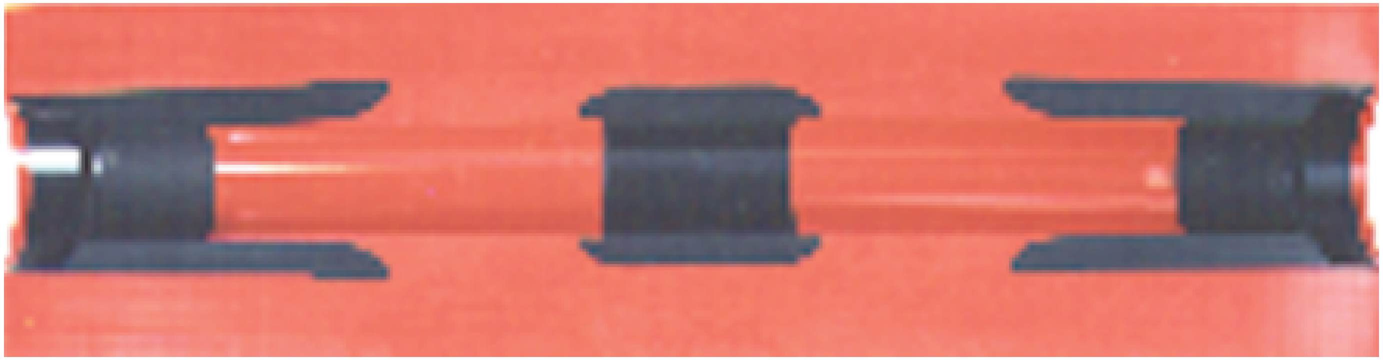
Evidence of partial discharges

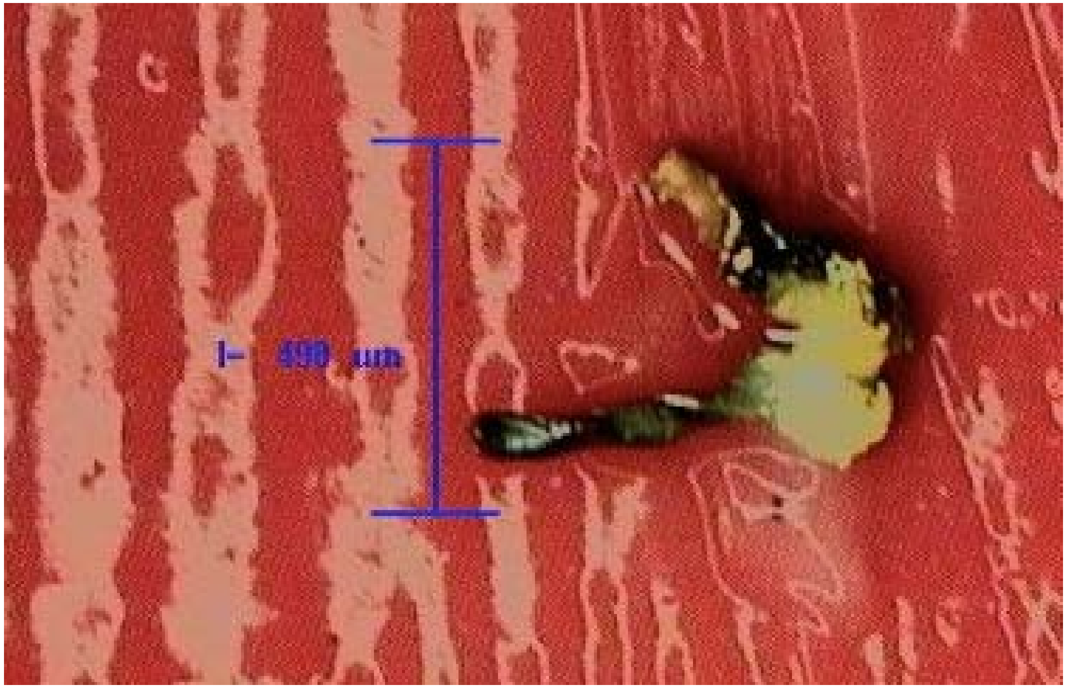






Evidence of partial discharges





Video ...

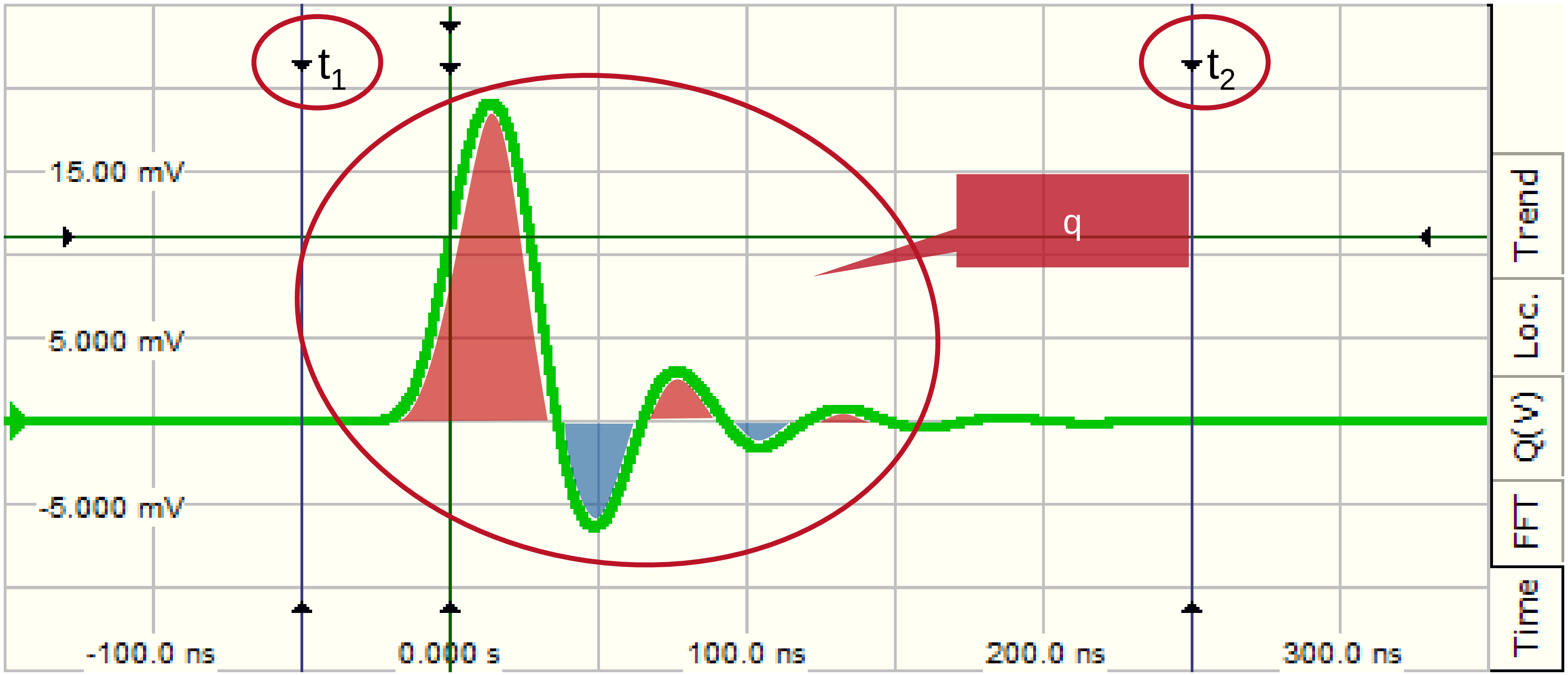
video: IPH Berlin

How to measure?

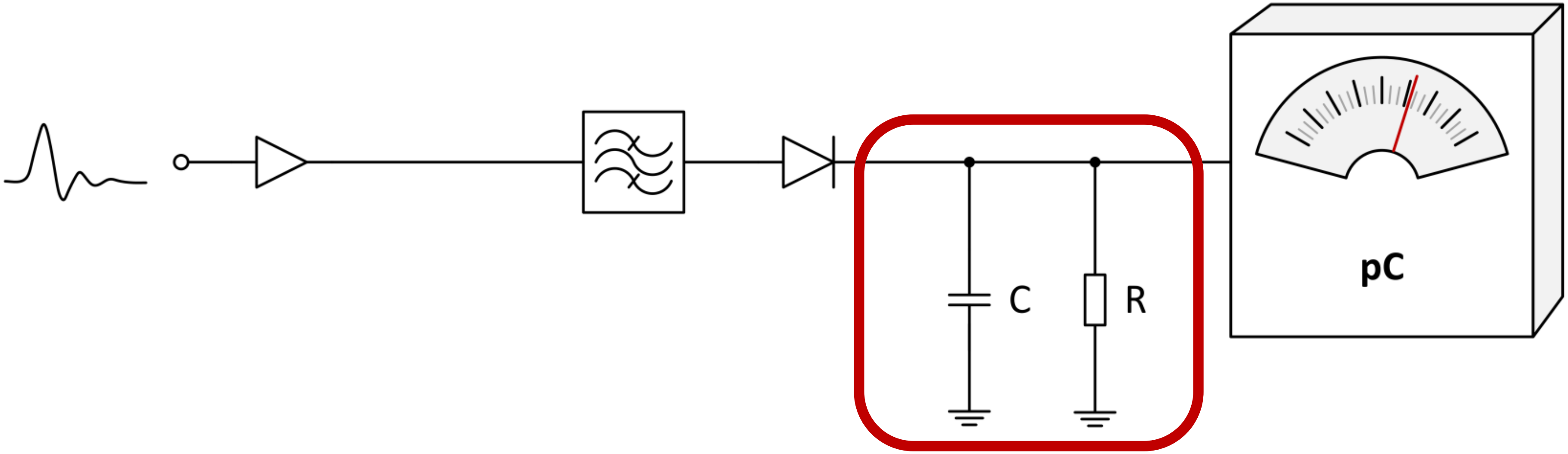
Charge – How to measure?

> Time Domain Integration

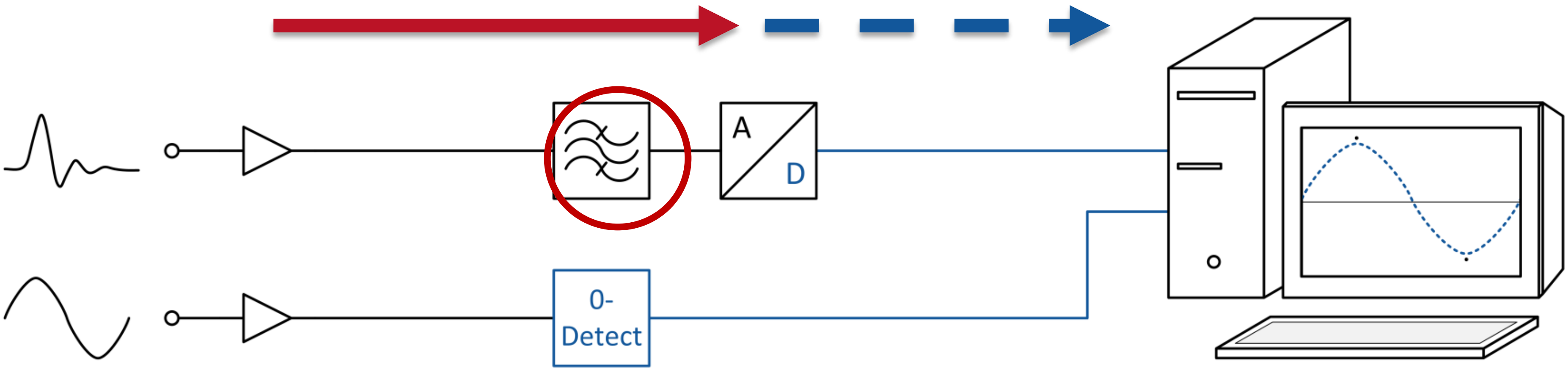
$$q = \int_{t1}^{t2} i(t)dt = \frac{1}{R} \int_{t1}^{t2} u(t)dt$$



Analog PD measurement systems

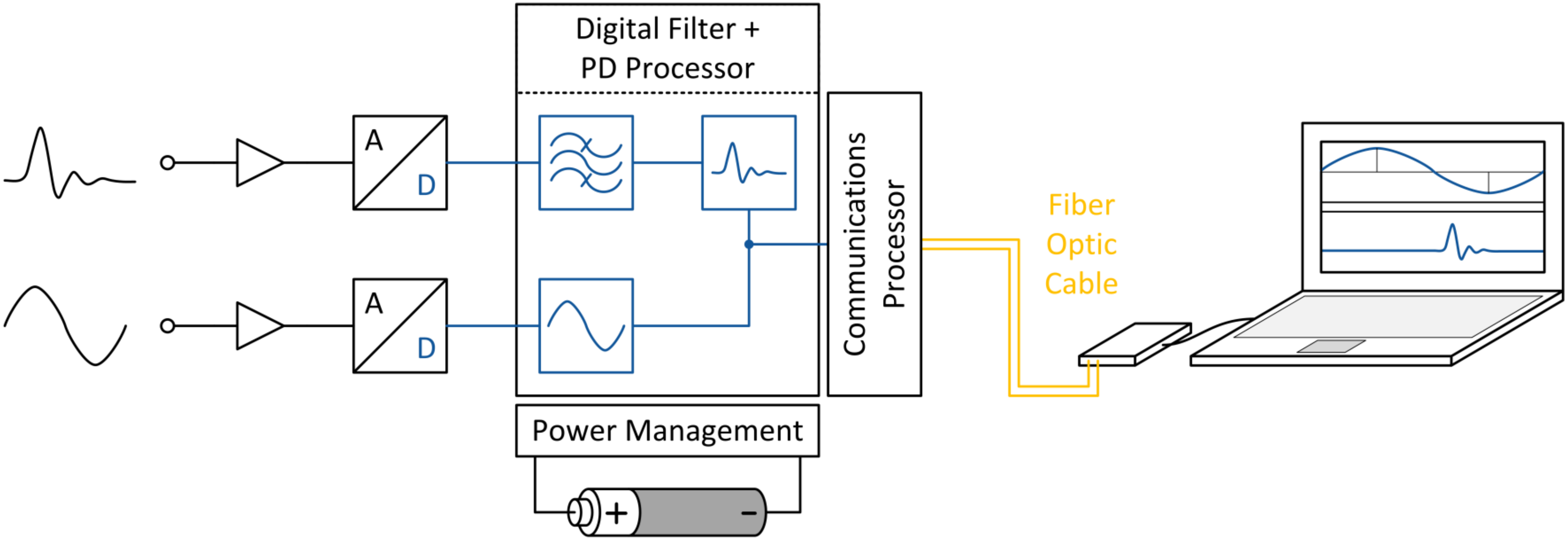


"Digital" PD measurement systems



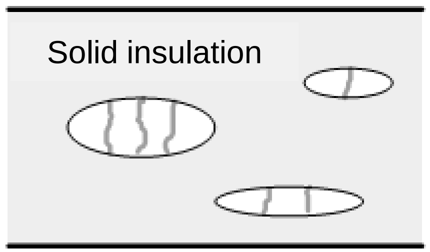
Filter is analogue!

”Digital PD measurement system with digital filtering

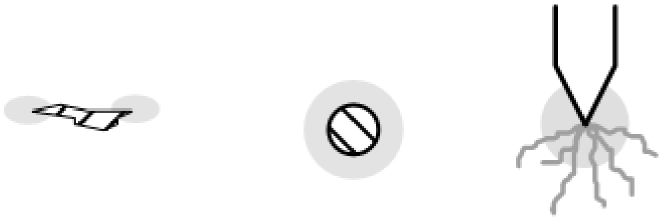


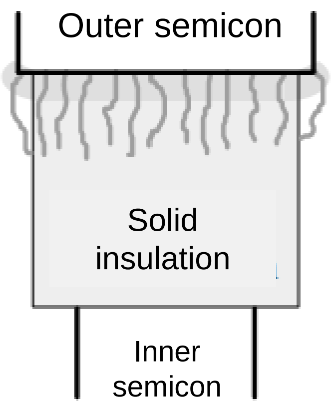
Types of PD

- > Internal PD
  - > Void discharges, „electrical treeing“



- > External PD
  - > Corona
  - > Surface discharges





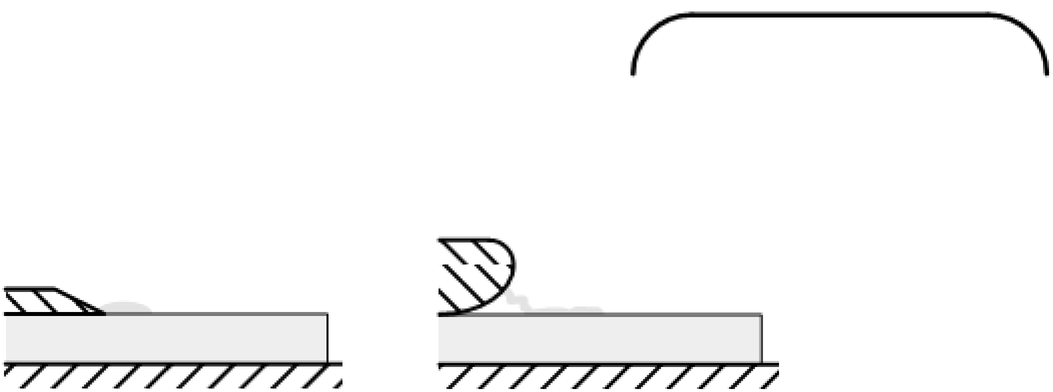
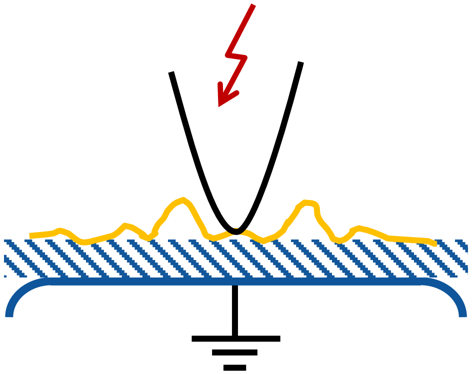
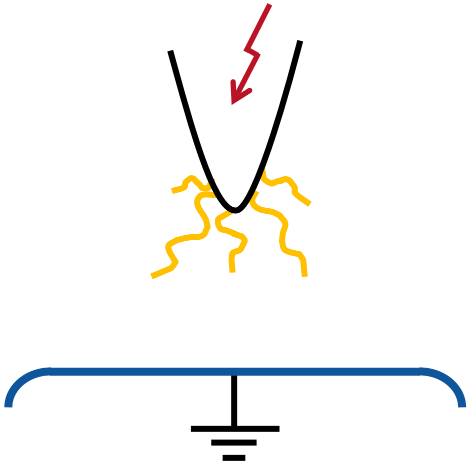


Image Source: Andreas Küchler – Hochspannungstechnik

External PD

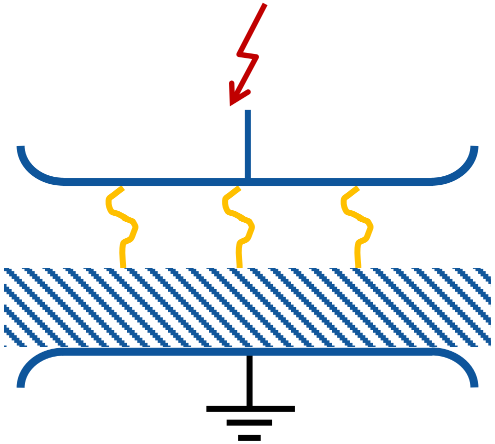


Surface discharge

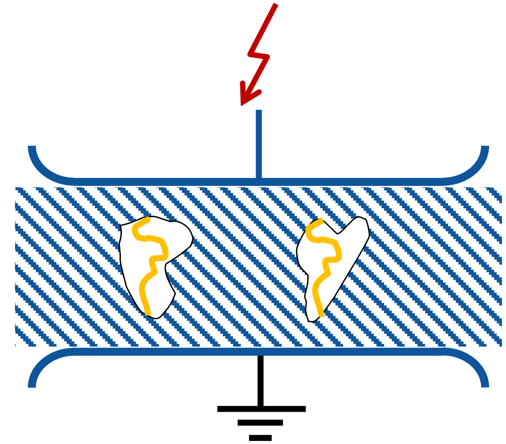


Corona discharge

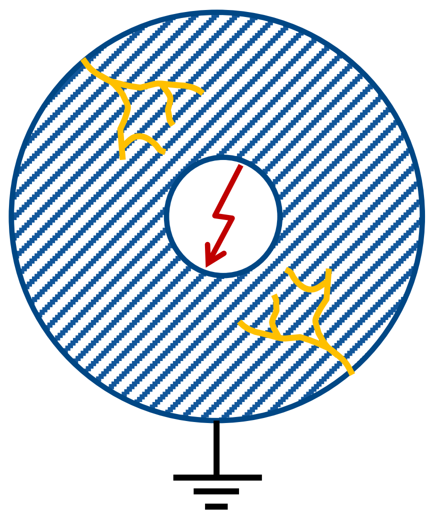
Internal PD



Internal discharge
in laminated material

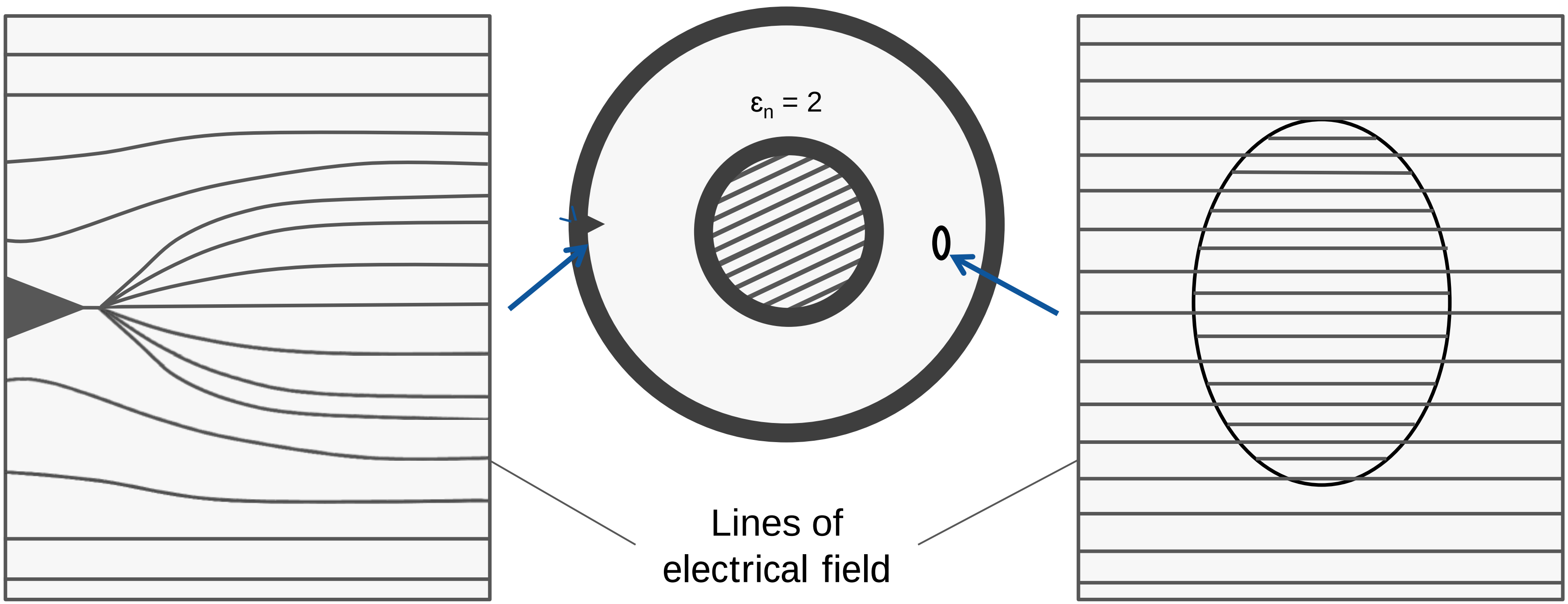


Cavity / void discharge



Treeing

PD classification

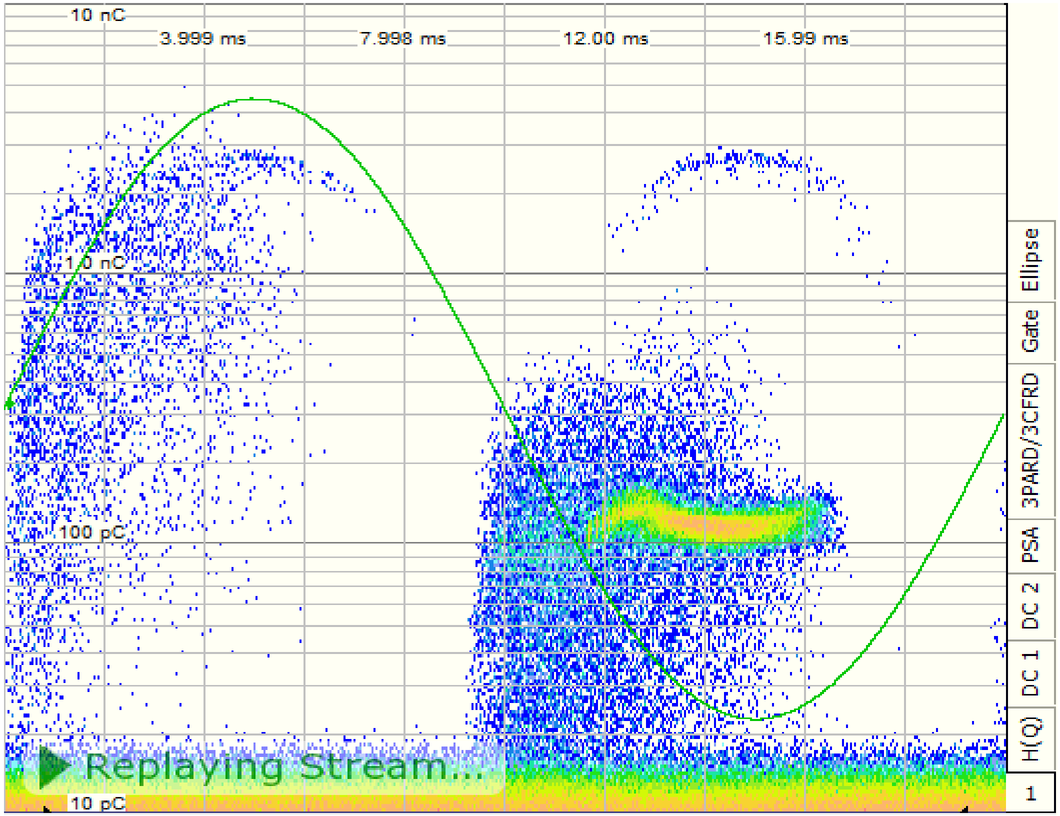


Semicon layer protrusion
(stress concentration at the tip)

Void
(field strength doubling)

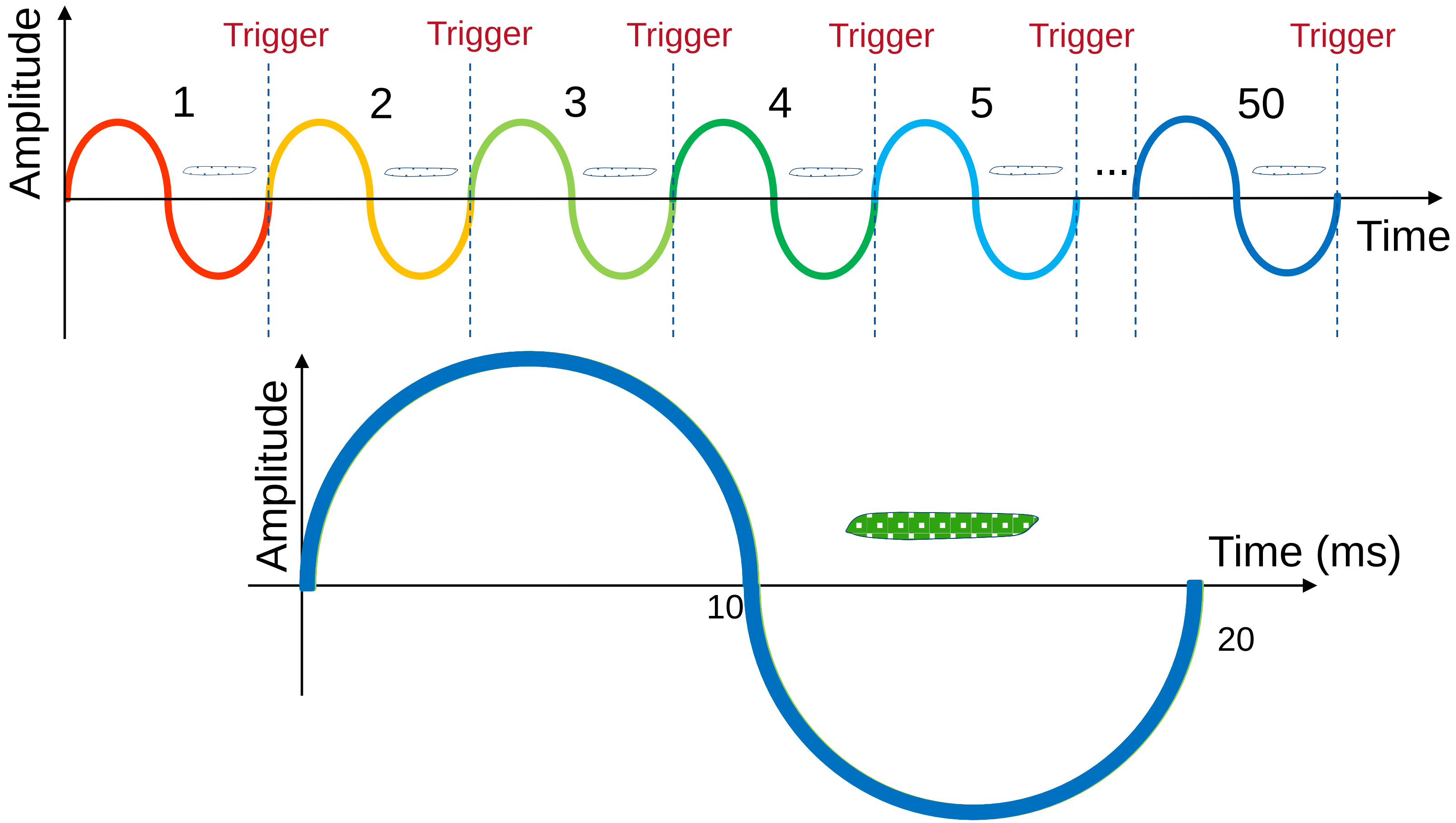
Phase resolved partial discharge PRPD

PRPD correlation between PD pulses and voltage phase
PD nature might be identified



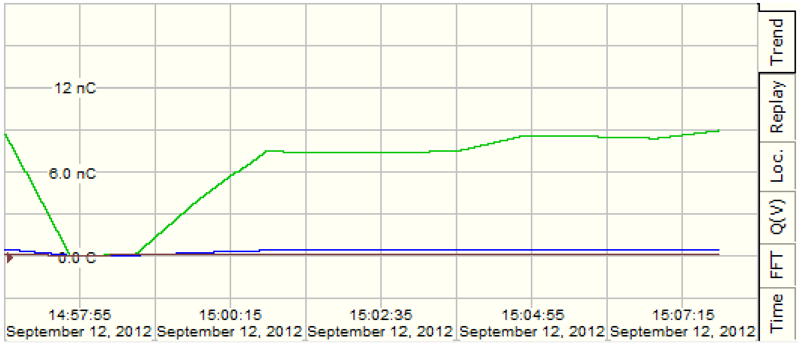
Phase resolved partial discharge – PRPD

> How is a PRPD created?

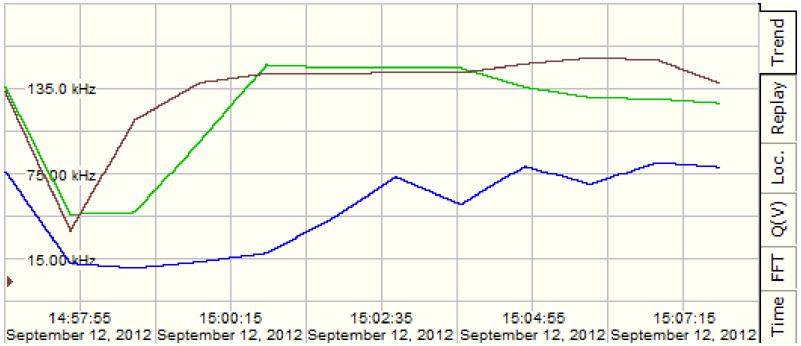


Further ways of PD analysis – Trend

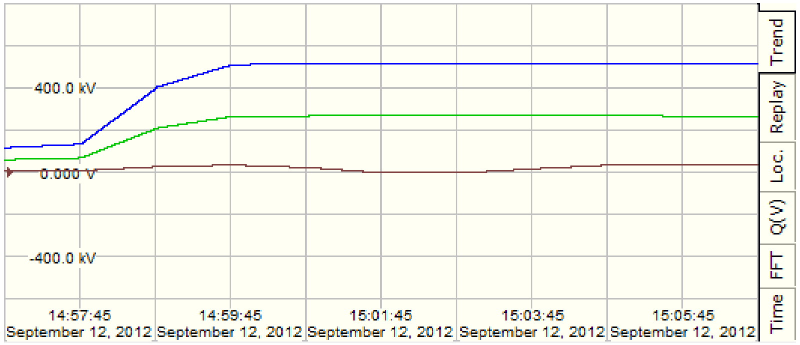
Charge vs. time



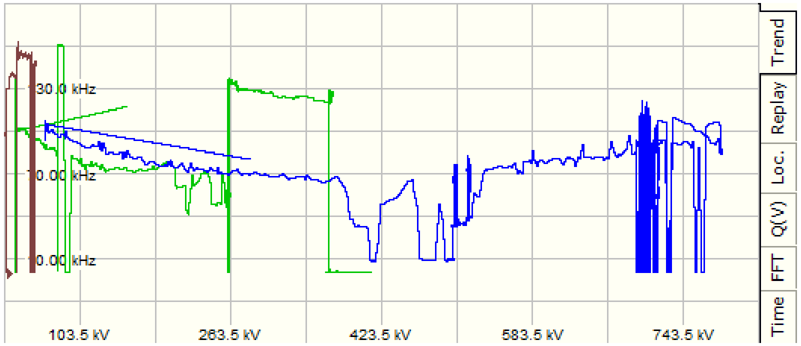
PD repetition rate vs. time



Applied voltage vs. time

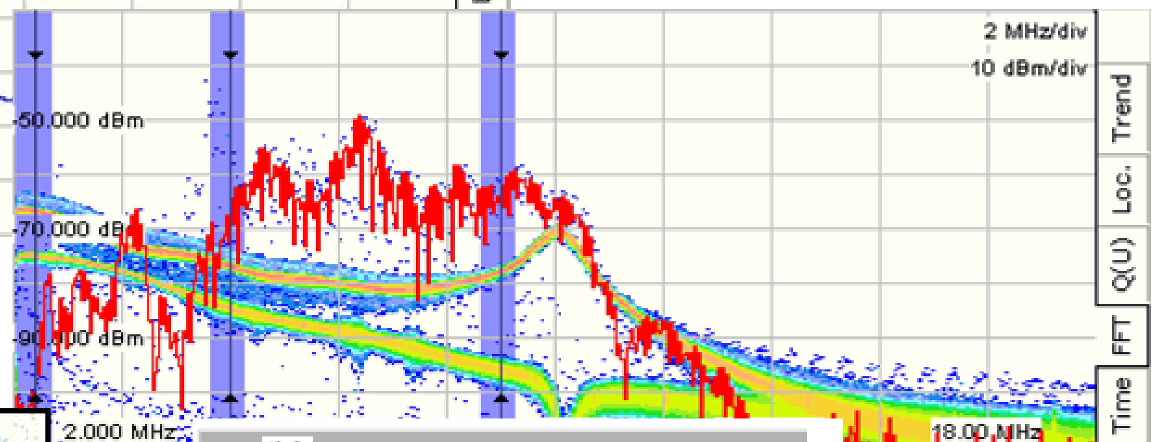


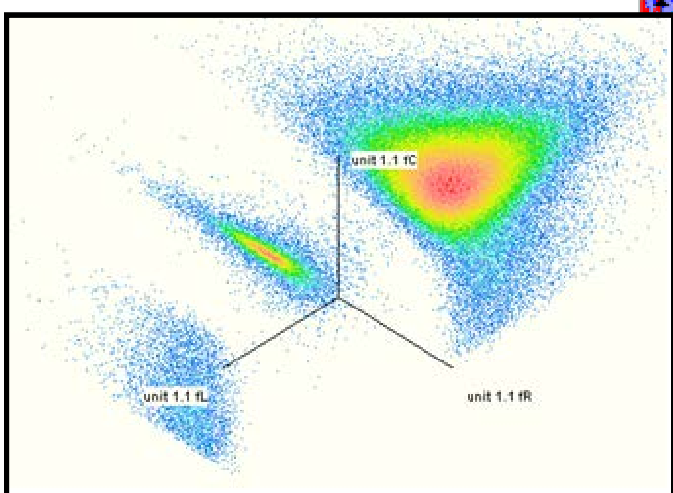
PD repetition rate vs. applied voltage

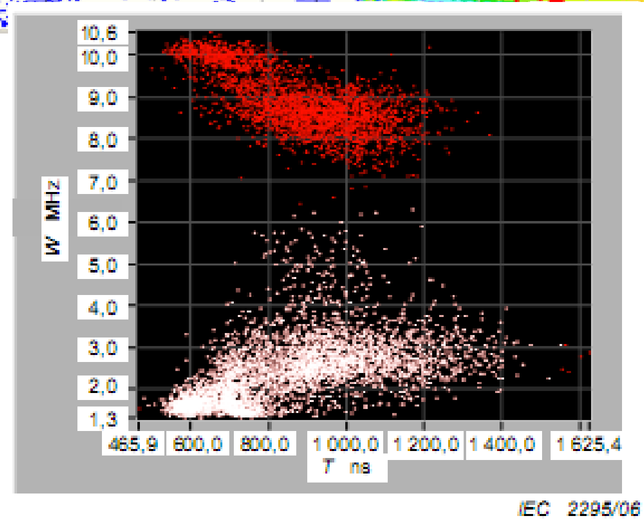


Further ways of PD analysis – 3CFRD (3 Center Frequency Ratio Diagram)

> Pulse Shape Analysis: 3CFRD or Time/Frequency map







T/W map

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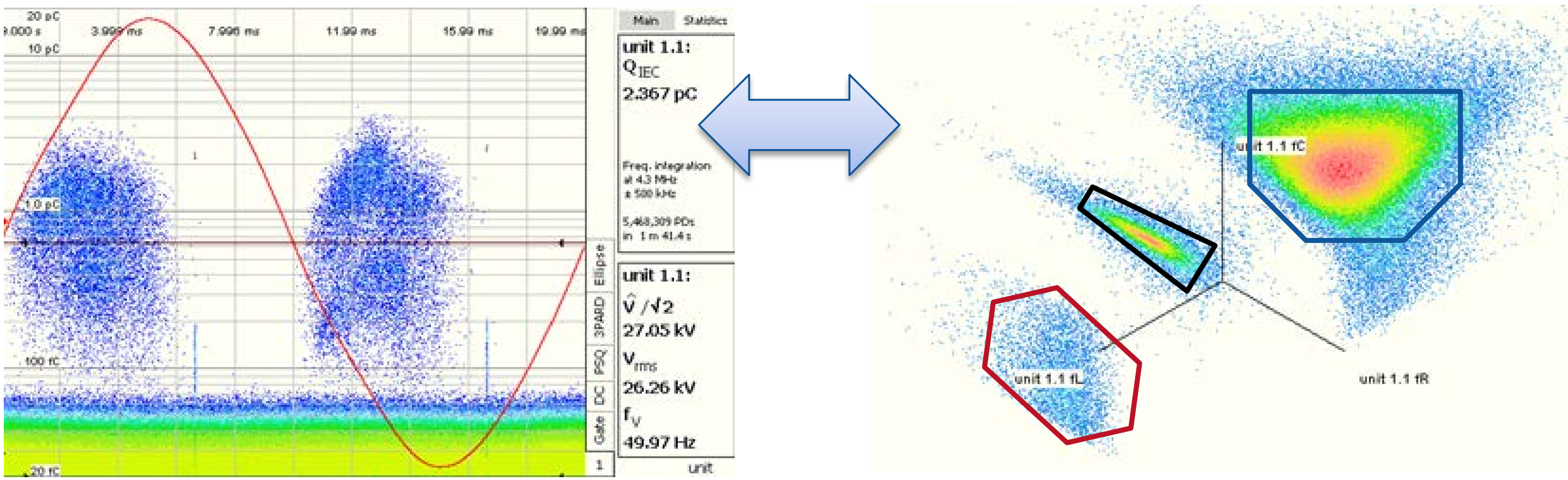
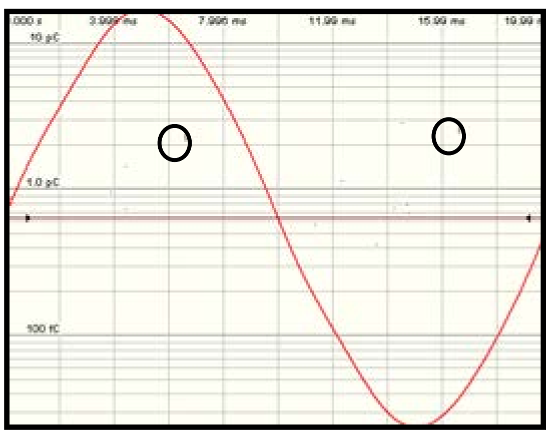
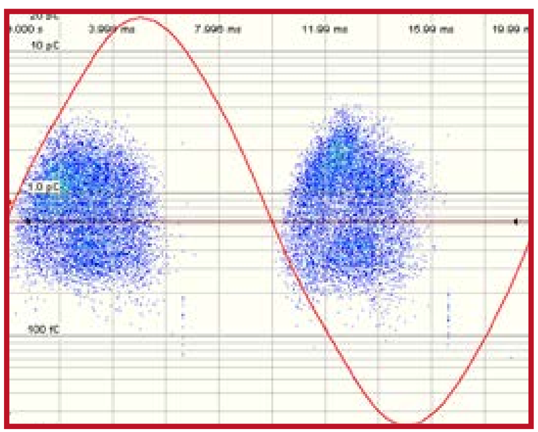
Influence of inverse gating on external disturbances



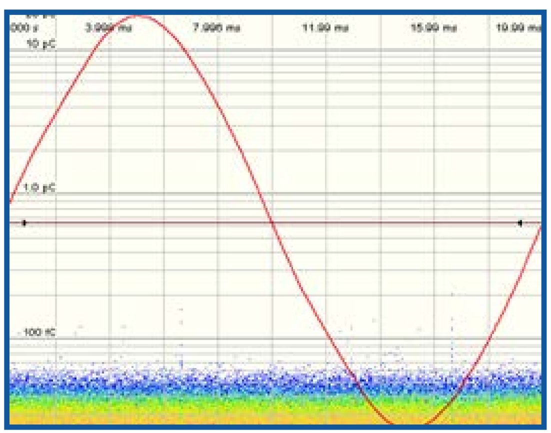
External disturbance



PD



Noise



Localization

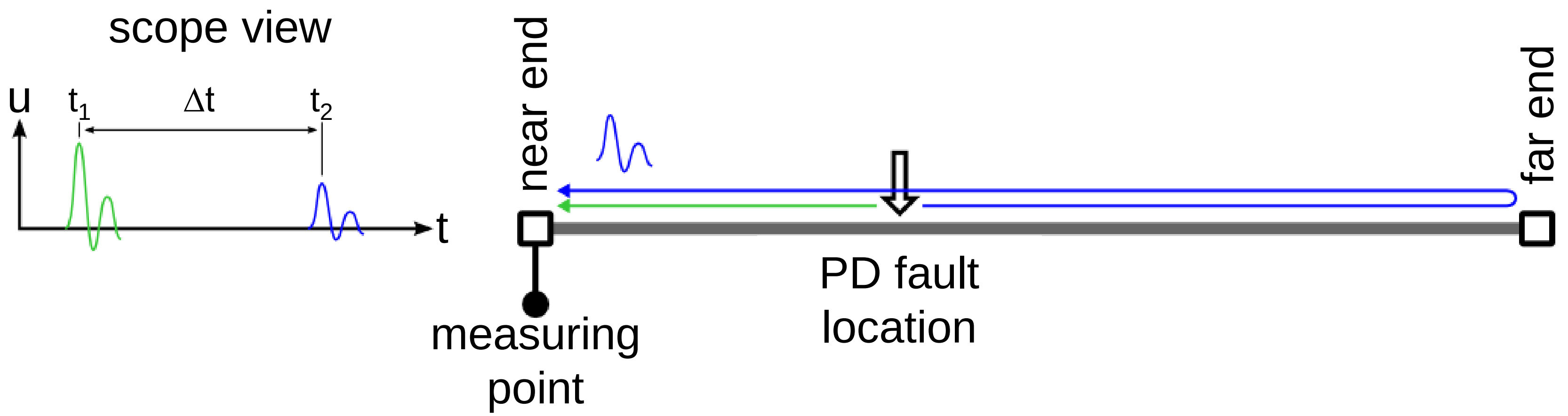
TDR – Time domain reflectometry

> A single PD pulse on an expanded test objects (cable) causes traveling waves in both directions

> Pulses reaching the far cable end will be reflected

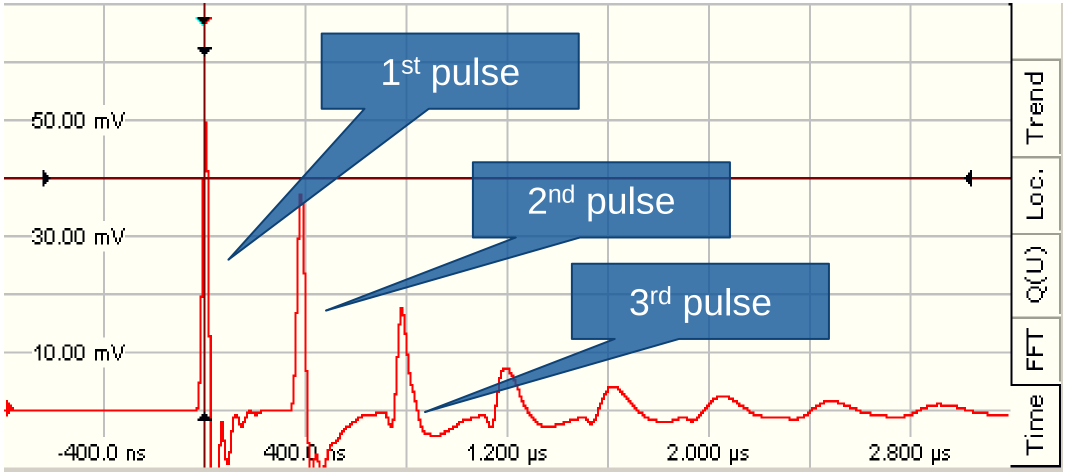
> The reflected pulse will also be measured at the near end

> The time delay of these 2 pulses depends on the PD fault position



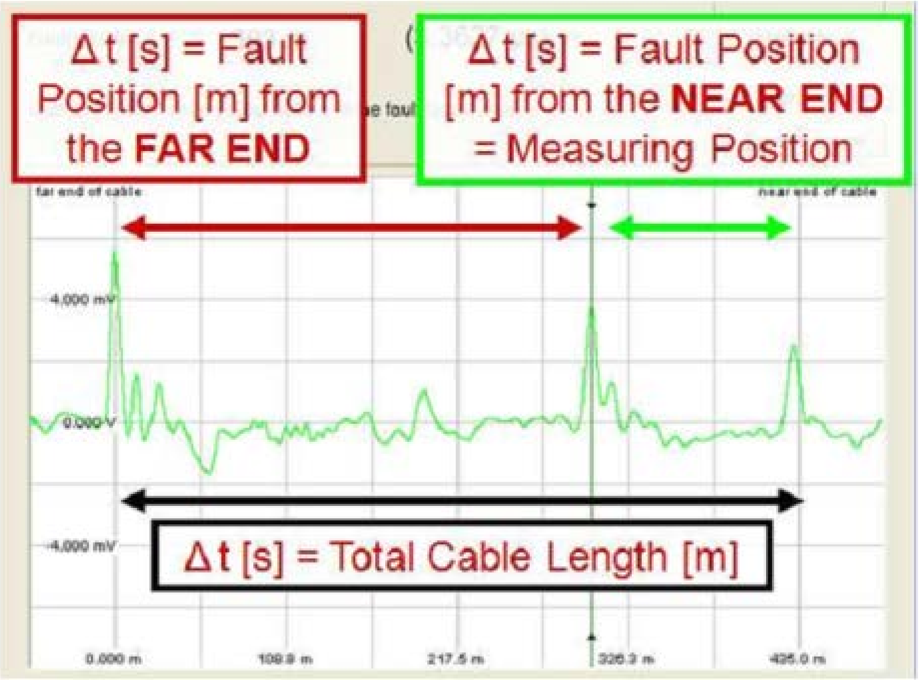
TDR Curves for calibration and for PD

- Calibration
  - equal distances between echos (partial reflections from joints possible)



- PD
  - typically 2 different time distances

Calculation of fault position



PD fault position from

> Far End

$$l_{fault} = v_{PD} \cdot \Delta t / 2$$

> Near End

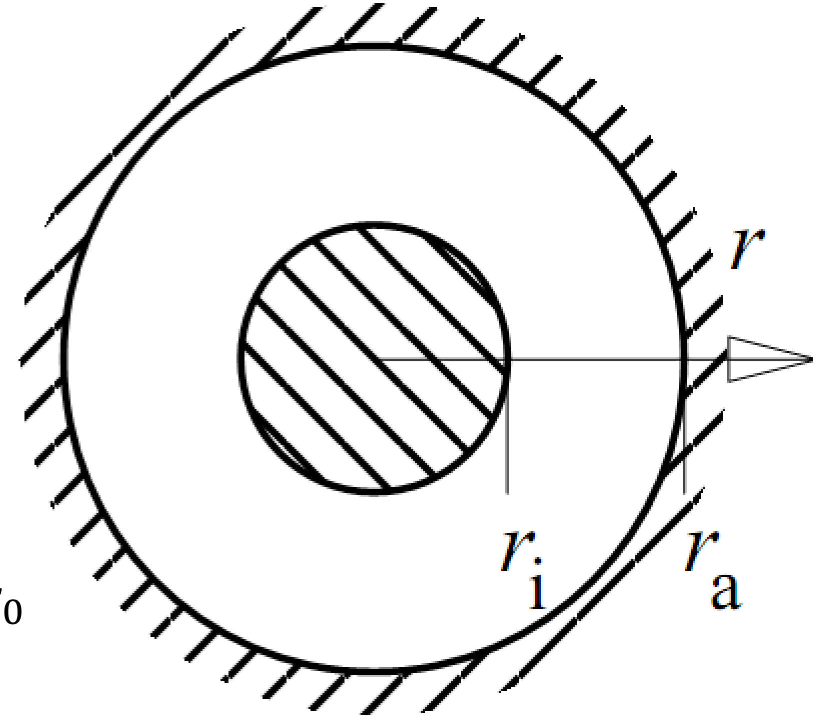
$$l_{fault} = L - v_{PD} \cdot \Delta t / 2$$

PD propagation speed

If v is unknown it can be found during calibration

> if cable length is known

> if only a single type of cable is tested



$$v = \frac{1}{\sqrt{\varepsilon_{r,res} \cdot \varepsilon_0 \cdot \mu_r \cdot \mu_0}} = \frac{1}{\sqrt{\varepsilon_{r,res}}} \cdot c_0$$

Travelling speeds and capacities in specific cable types

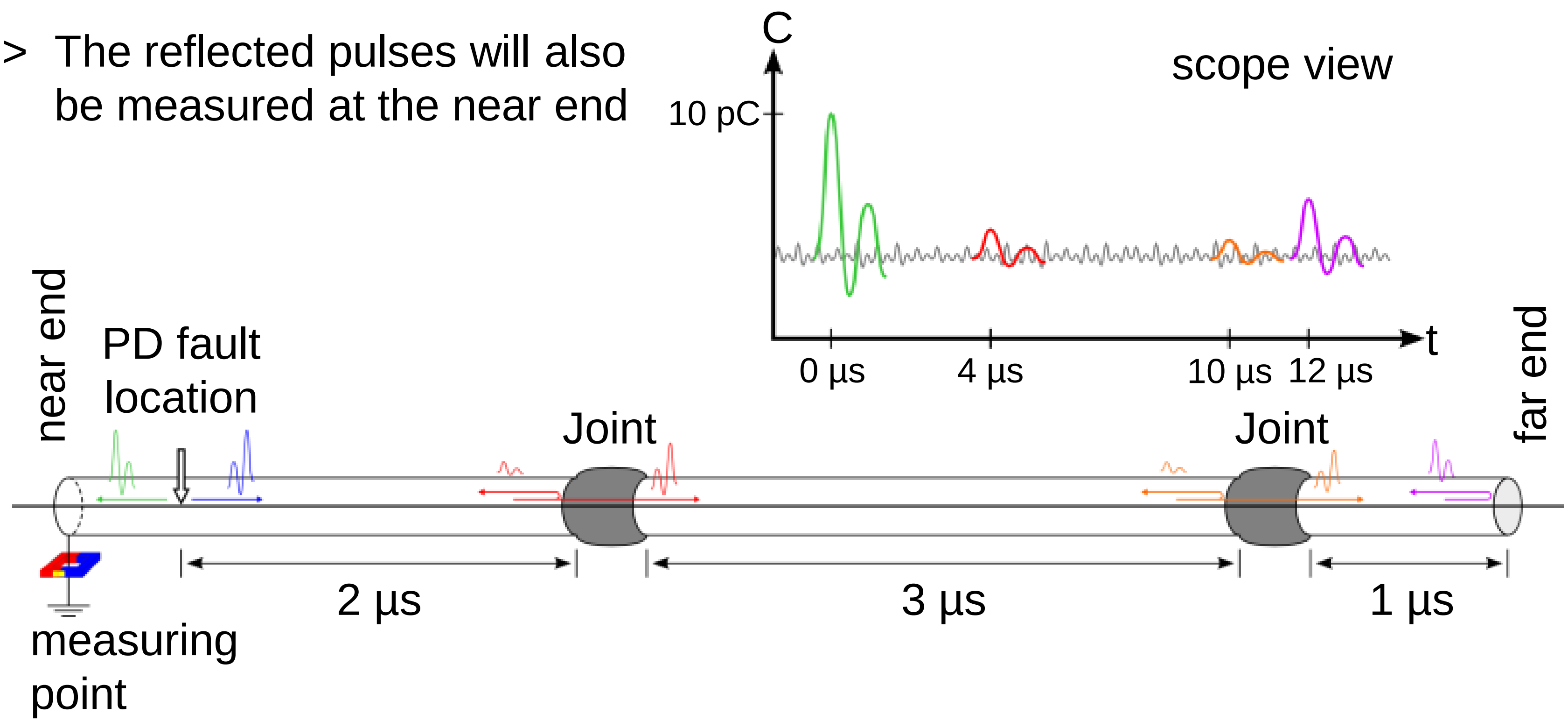
Cable type	Typical travelling speed in m/µs	Typical capacity in nF/km For conductor cross sections in mm²:						
		120	240	500	630	1200	1600	2500
XLPE 10kV	154-160	350	450	610	630	-	-	-
XLPE 20kV	164-170	240	300	400	-	-	-	-
XLPE 30kV	170-176	160	210	280	-	-	-	-
XLPE 60kV	174-176	-	-	-	236	-	-	-
XLPE 110kV	174-176	-	121	163	177	271	301	378
XLPE 150kV	~181	-	-	-	-	225	-	-
XLPE 220kV		-	106	143	155	236	260	294
XLPE 400kV		-	-	-	119	171	188	226
EPR 10kV	130-134	~300	500	-	-	-	-	-

STDR – Statistical time domain reflectometry

> A single PD pulse on an expanded test objects (cable) causes traveling waves in both directions

> Pulses will be reflected in the far cable end **but partly also on every joint**

> The reflected pulses will also be measured at the near end

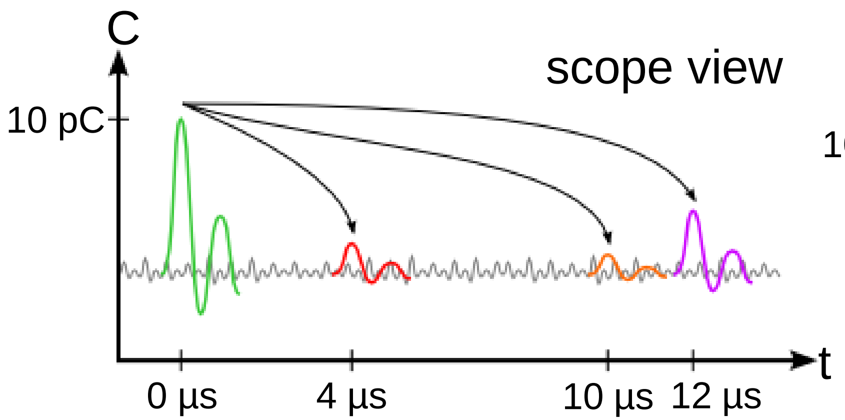


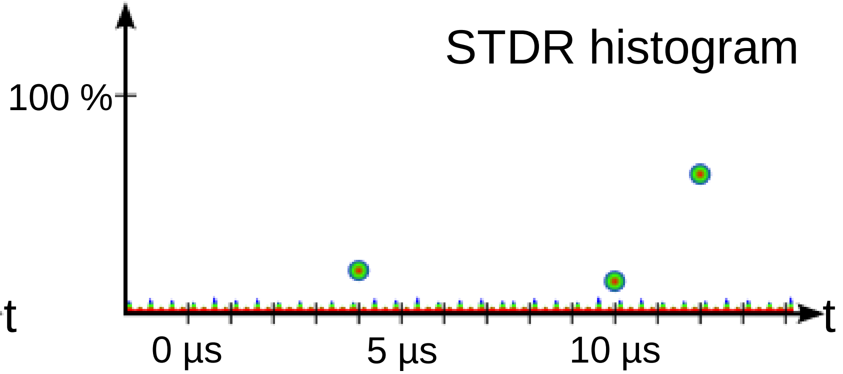
Assumption – Joints: 80% signal transmission; 20% signal reflection

STDR – Statistical time domain reflectometry

- Specific impulses are correlated to all measured impulses
- The results of this correlation
  - time difference between impulses
  - relative amplitude of the correlated impulse

  are drawn into the STDR histogram





overview of technologies in the market

technologies in the market

very low frequencies (VLF)
0.01 Hz – 0.1 Hz – some Hz

↓

offline

↓

mostly on-site testing

↓

close to power frequencies
50Hz / 60Hz - 20Hz to 300Hz

↓

offline or online

↓

in factory or on-site testing

↓

technologies in the market

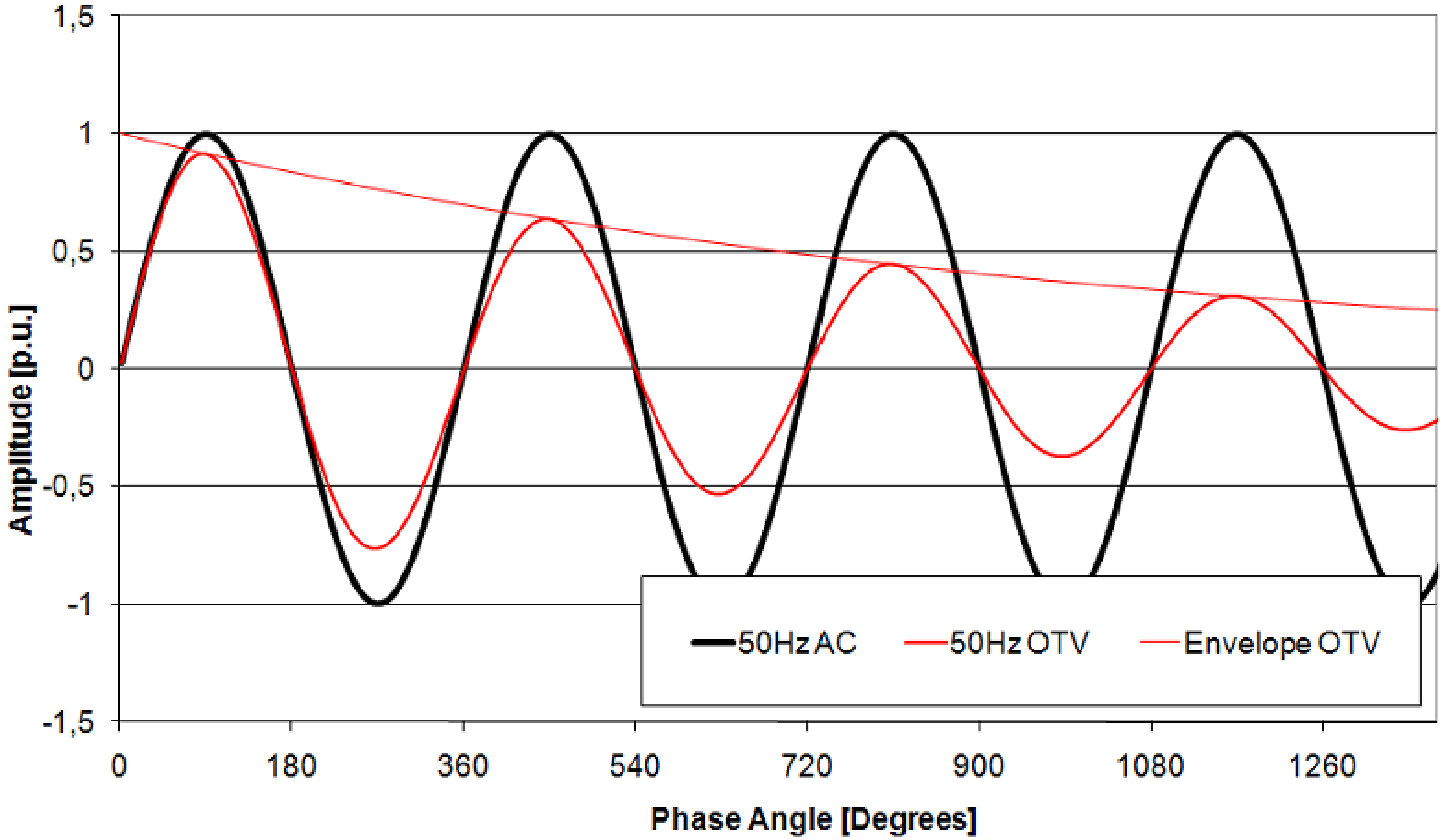
sinus wave
cosin rectangular
damped AC

sinus voltage

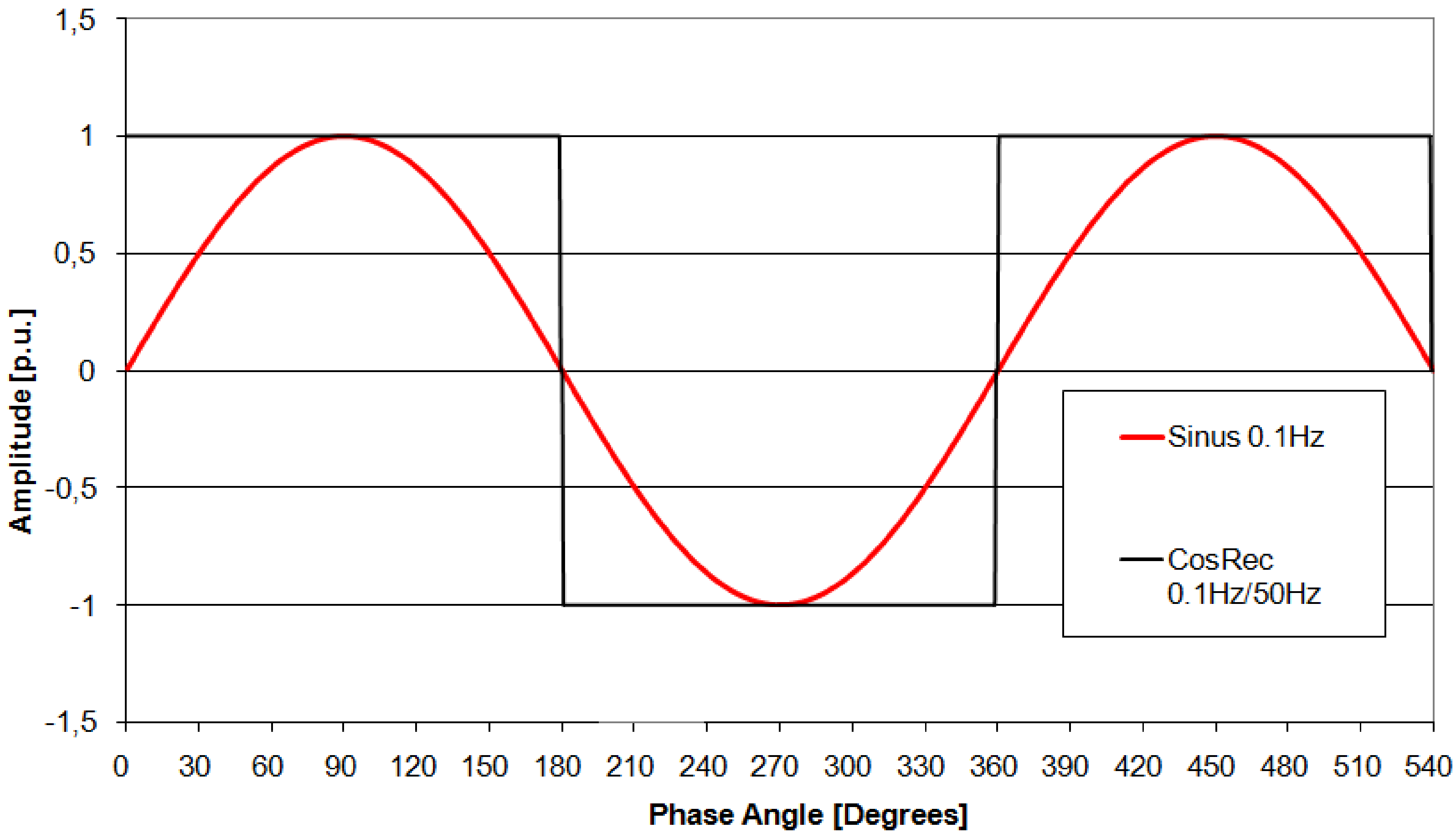
mostly with coupling capacitor

coupling capacitor or
high frequency current
transformer (HFCT)

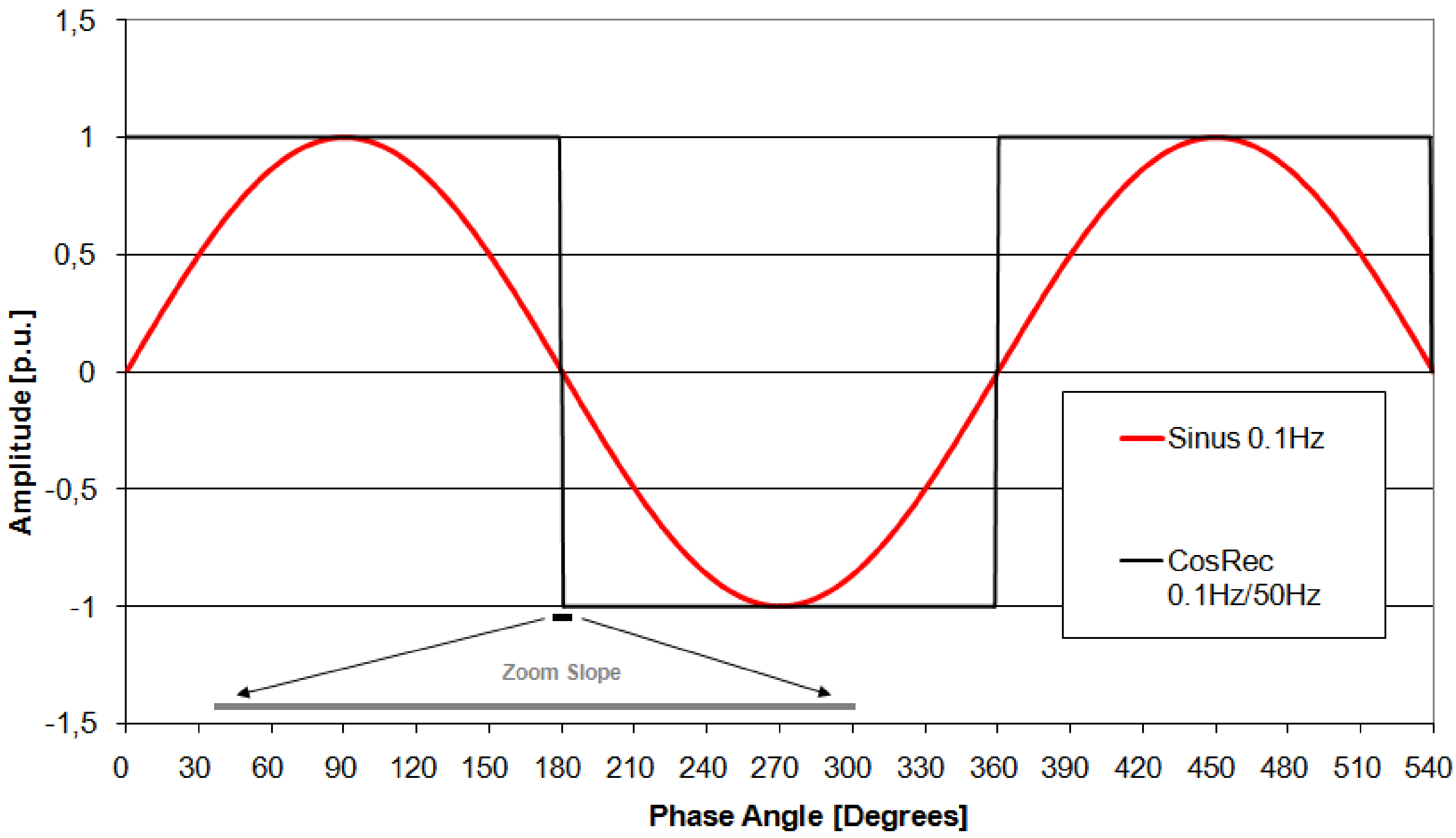
voltage types



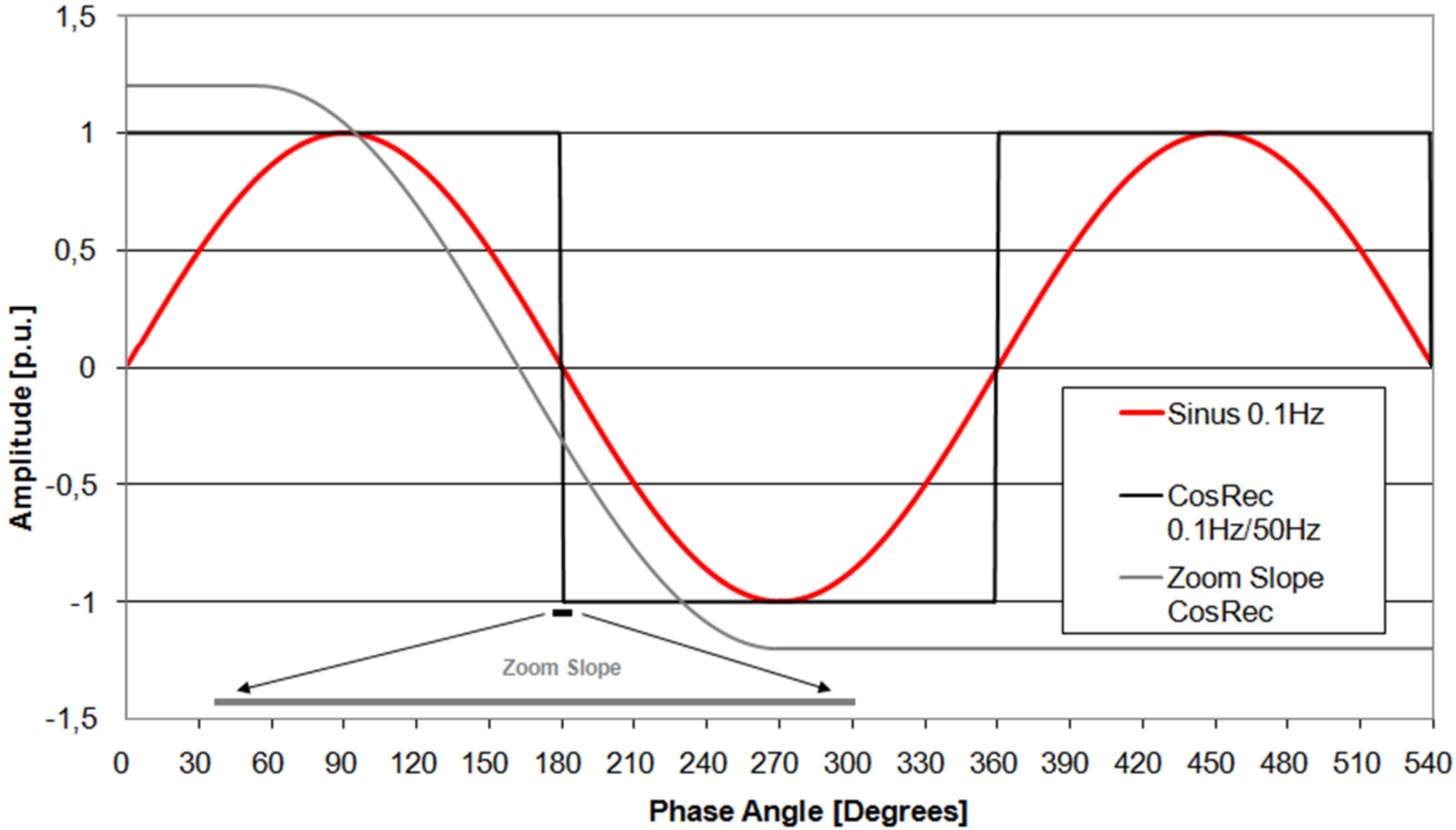
Cosinus rectangle - CosRec



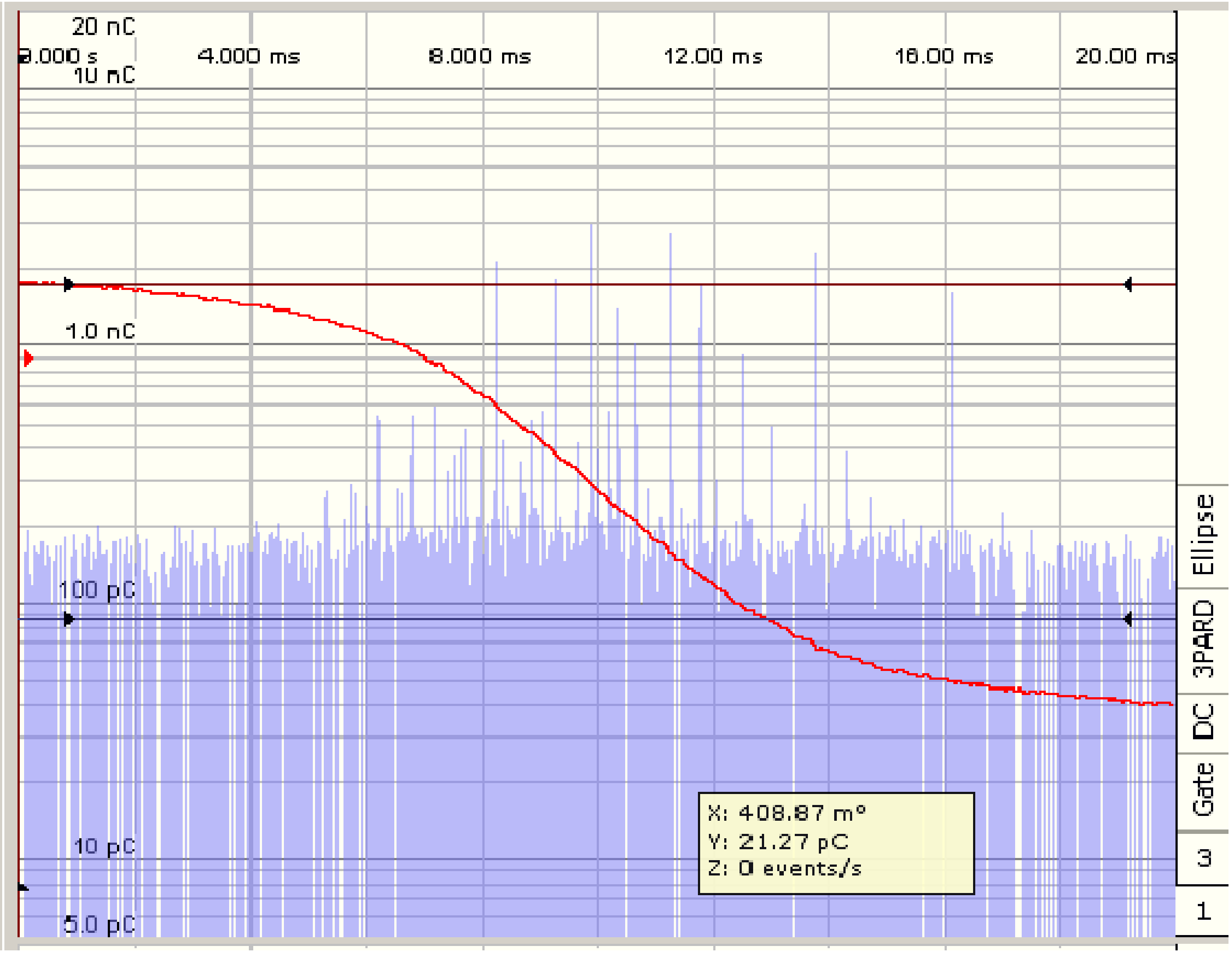
CosRec – Zoom on falling slope



CosRec – Zoom on falling slope



CosRec – PD only in slopes



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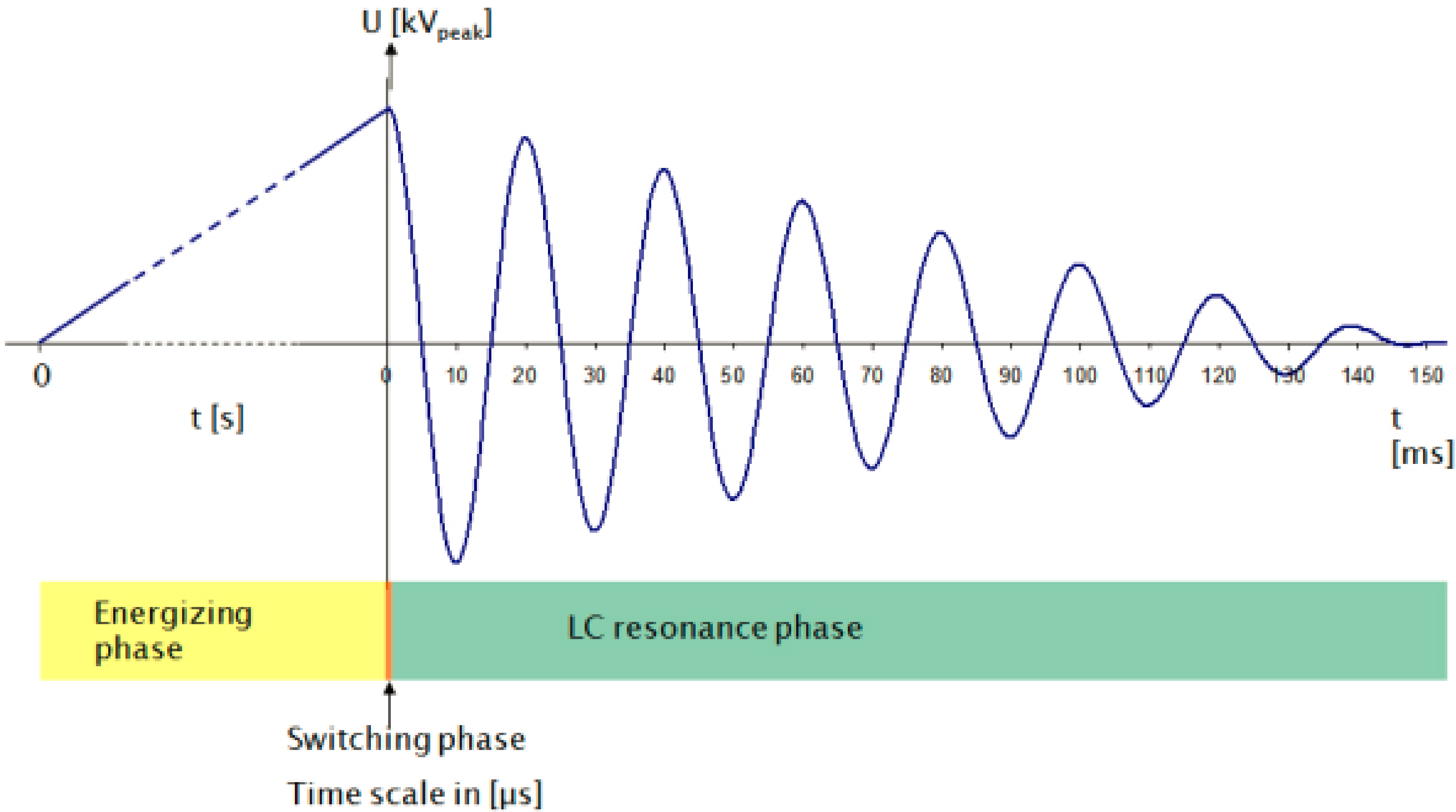
damped AC



source: http://hvgrid-tech.com

standards

IEC60885-3

IEC 60840

IEC 60502-2

IEEE 400 documents (.1 , .2 , .3, .4 , .5)

CENELEC HD620 S1

CIGRE guides

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