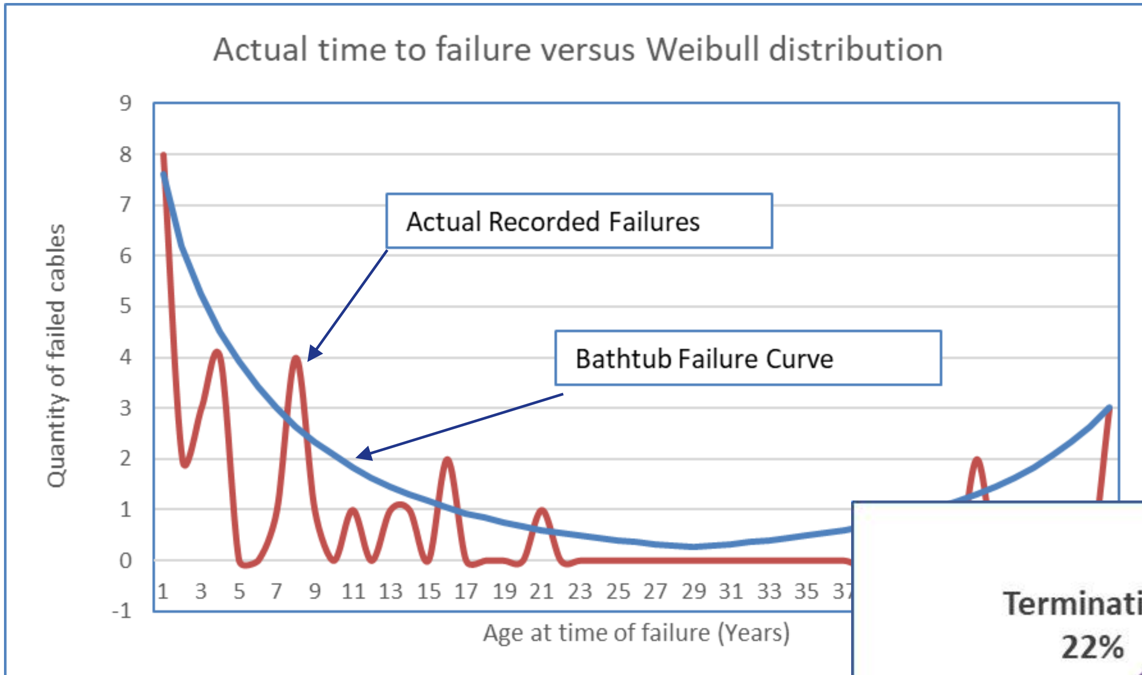
Safer, Stronger, Smarter Networks

Partial Discharge in MV Cables

IEEE Insulated Conductor Committee Meeting
Hollywood FL, October 2017

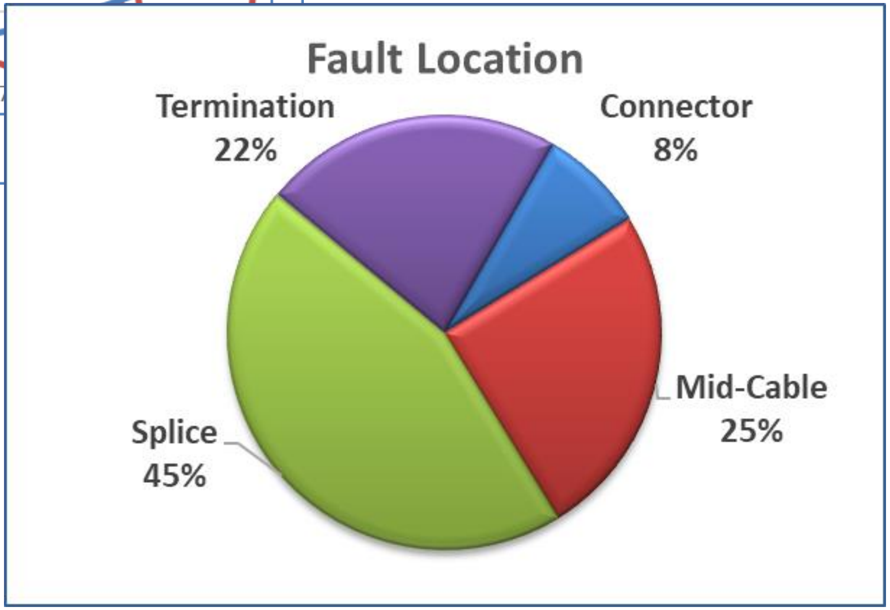
www.eatechnology.com

Failures in MV Cable



These graphs are from a research paper currently underway at the University of Connecticut.

It examines 100 forensic investigations in mv cable failure.



Takeaways:

1) Cables follow a standard bathtub failure curve with most failures occurring before 20 yrs.

2) Most failures (75%) are not in the middle of the cable.

Internal discharge in a cable

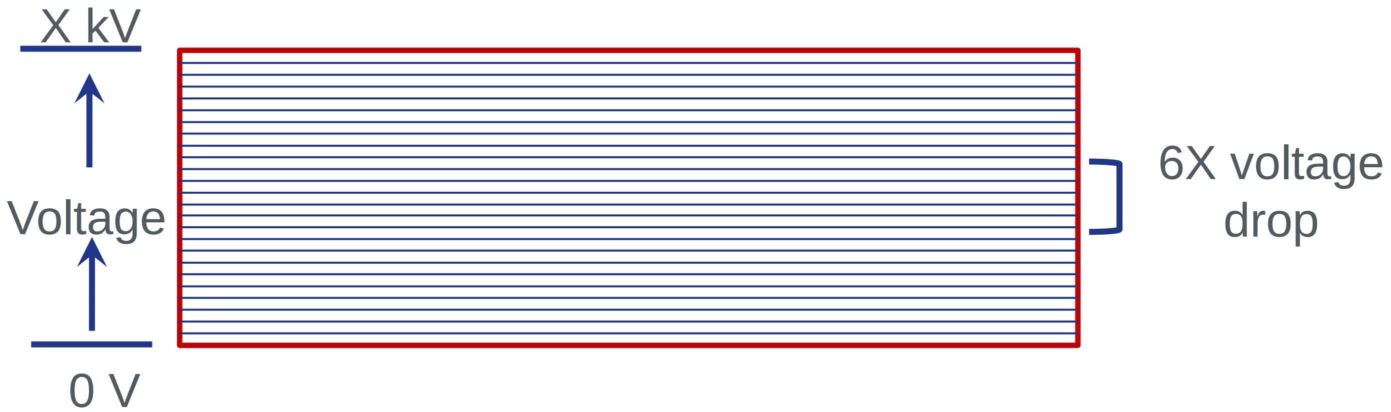
Cables & Terminations – Internal Discharge Activity

- Discharge through the insulating medium to the shield.
- No visible indication prior to failure
- Generates very little EMI and TEV due to shield grounding
- Can be detected at ground straps with RFCT

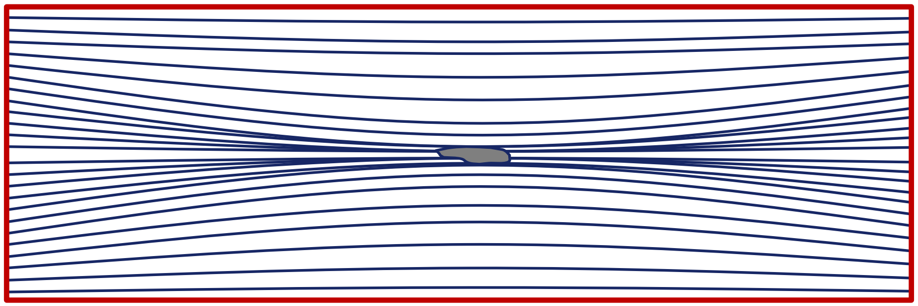
Cables & Terminations - Surface Discharge Activity

- Discharge across surface of insulation towards earth or phase to phase discharge
- Often characterised by low amplitude but very high discharge rate
- Visible signs include white powder (Insulation fillers)

Equipotential Lines

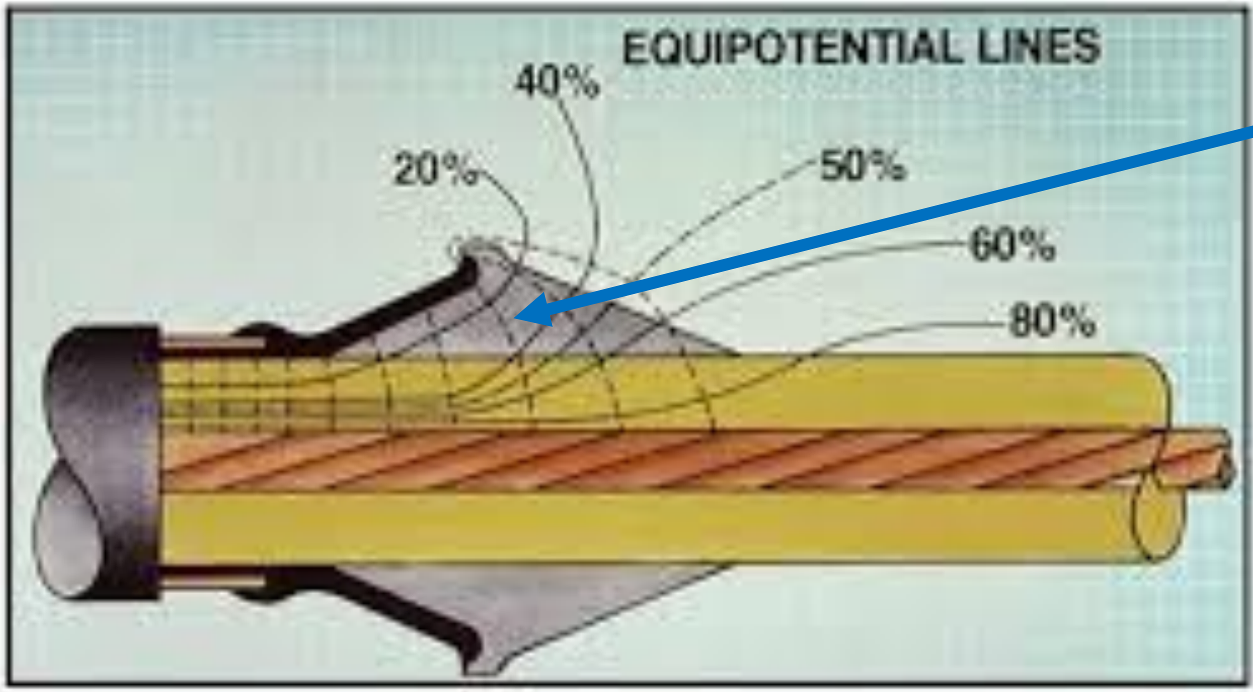


Section through a homogenous insulator showing uniform electrical stress (equipotential) lines. A line indicates where the voltage potential is constant



The same insulator with a void. The lower dielectric of the void causes a concentration of the electrical field through the void high enough to cause breakdown at working voltages

Cable Stress Control



The stress controlling components include semiconducting layers and stress cones or tubes

When the stress relief is not adequate discharge occurs.

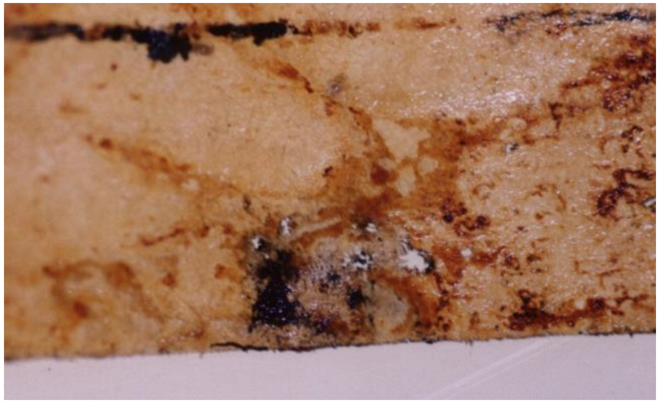
Cable partial discharge is a classic example of local concentration of electrical stress.

Cable terminations and splices have carefully designed components to distribute the electrical stresses equally.

Cable Partial Discharge Examples

Treeing

Voids / Carbonisation



Damage from flashover to screen

Erosion from PD

Offline Test Equipment - Test Van

Transformer

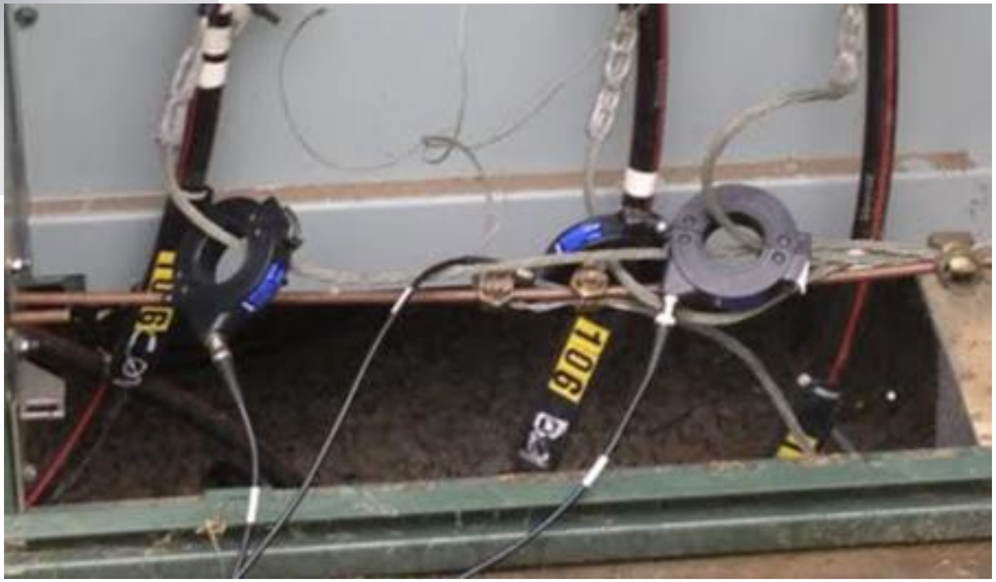
Test bushings

VLF generator

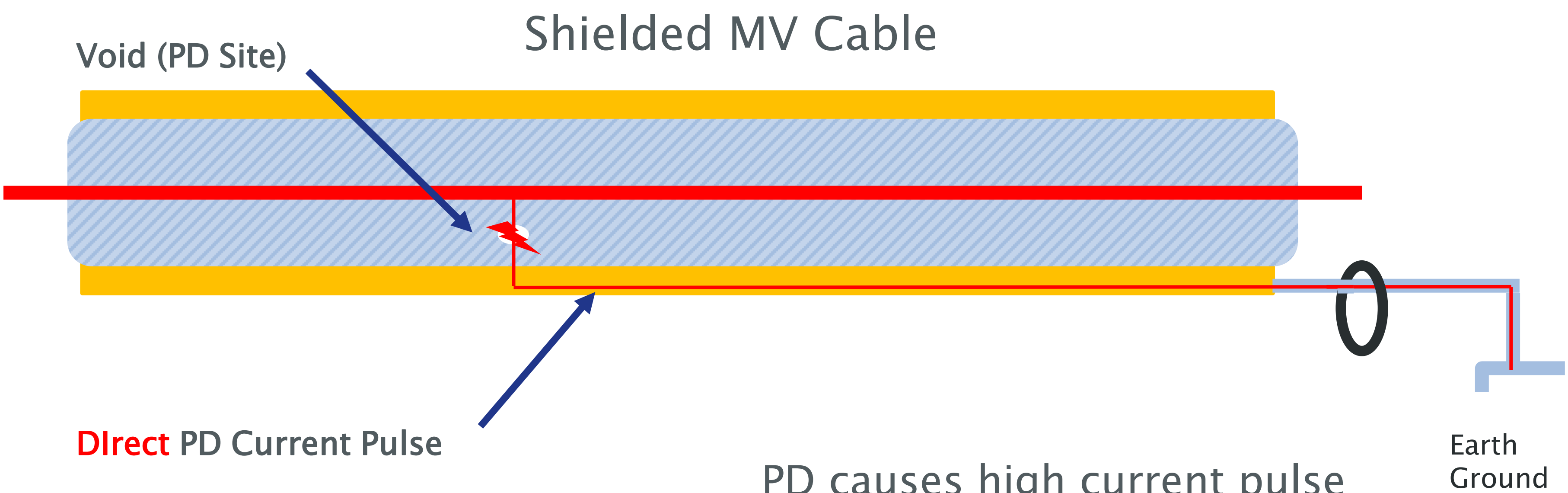
Detector filter (allows LV detection lead to be connected to HV Supply and filters Hz)

Online Test Equipment – Hand Carried

RFCT Installed on Ground Straps



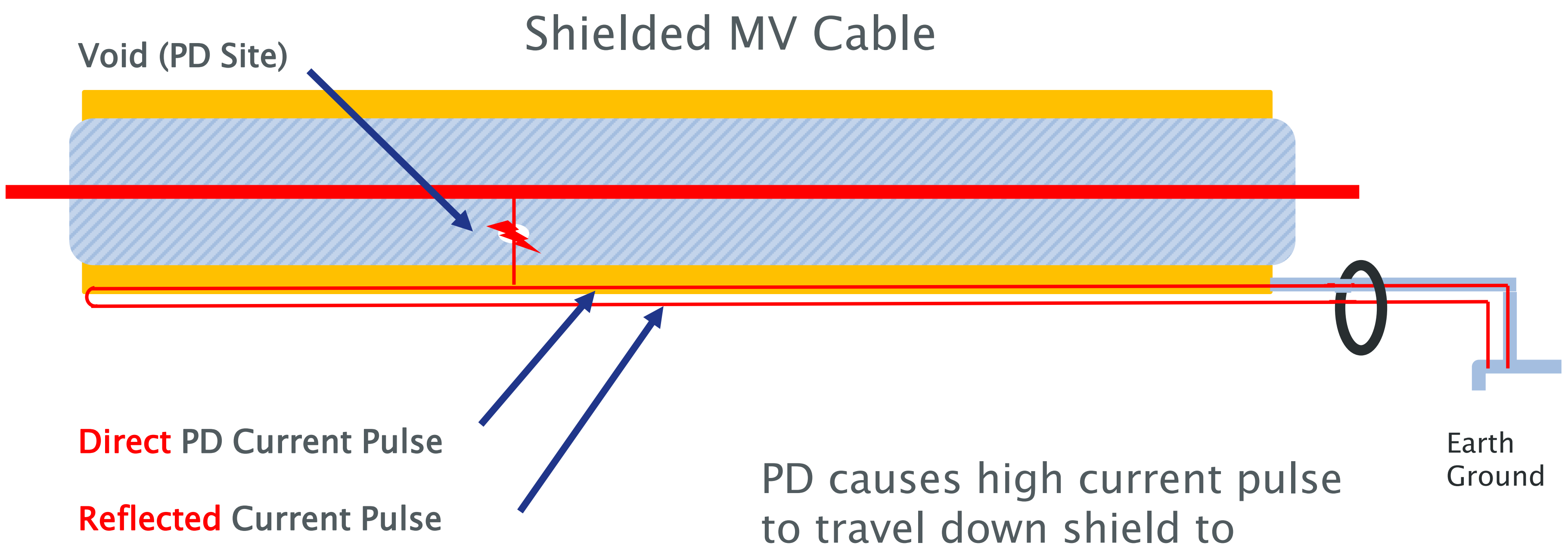
RFCT based testing of cables



PD causes high current pulse to travel down shield to ground strap

Instrument measures current pulse on ground strap

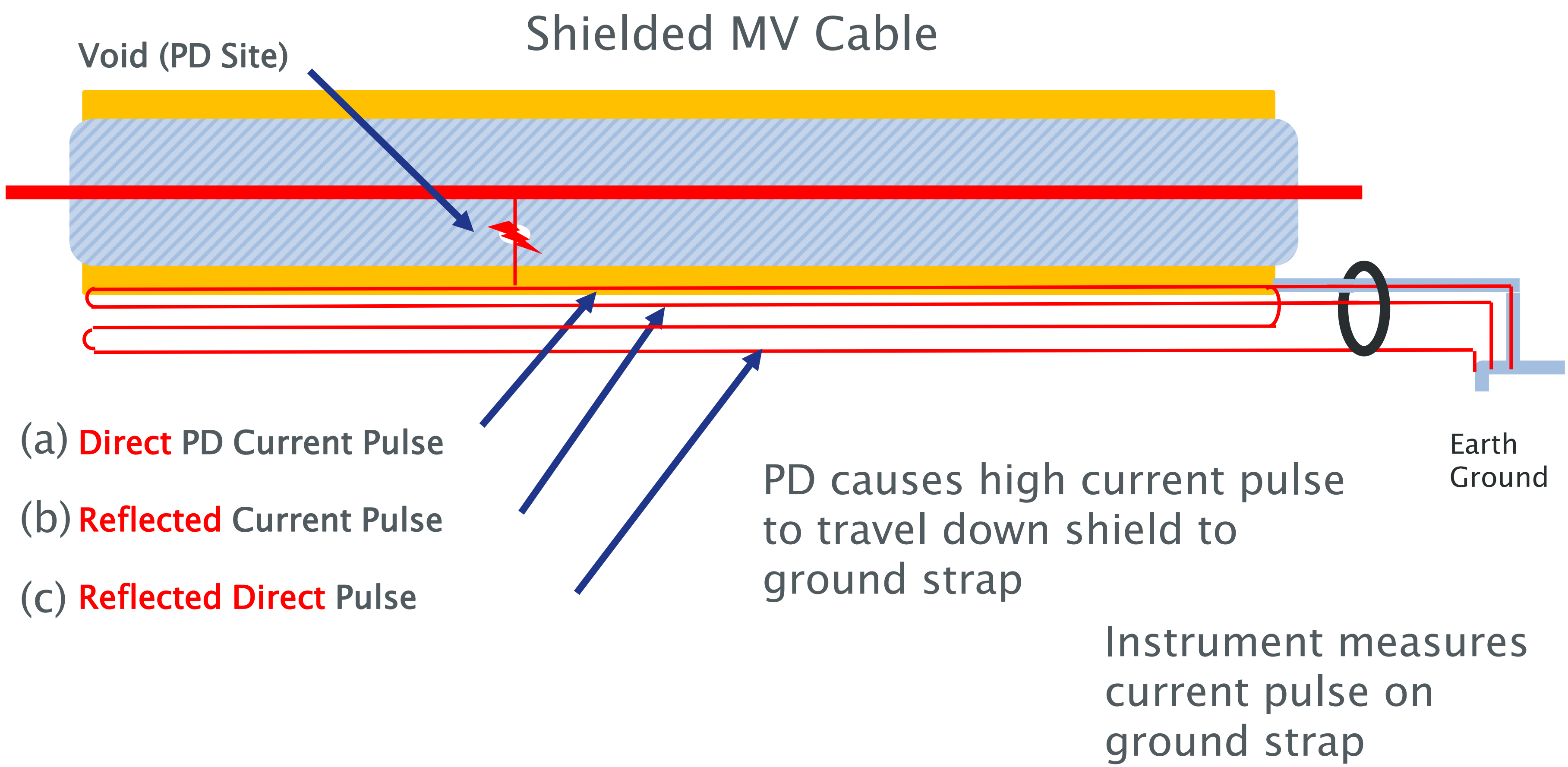
RFCT based testing of cables



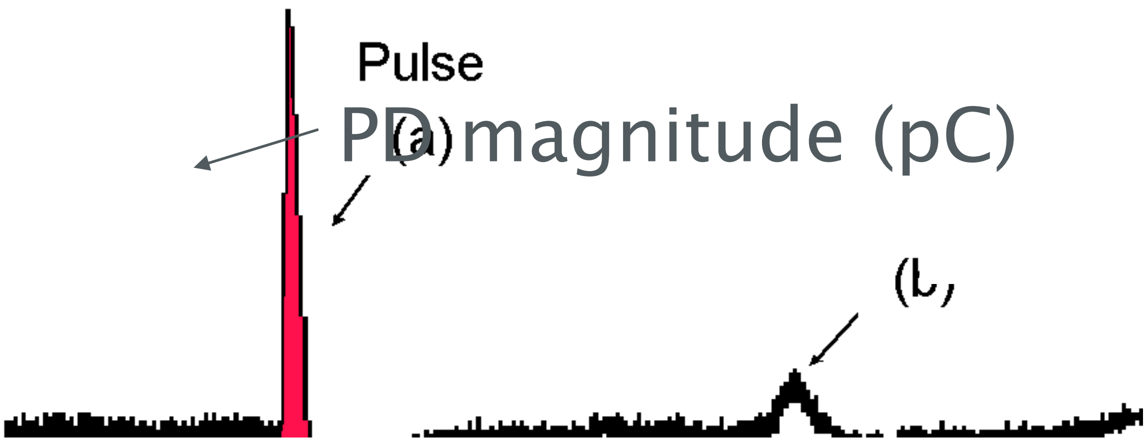
PD causes high current pulse to travel down shield to ground strap

Instrument measures current pulse on ground strap

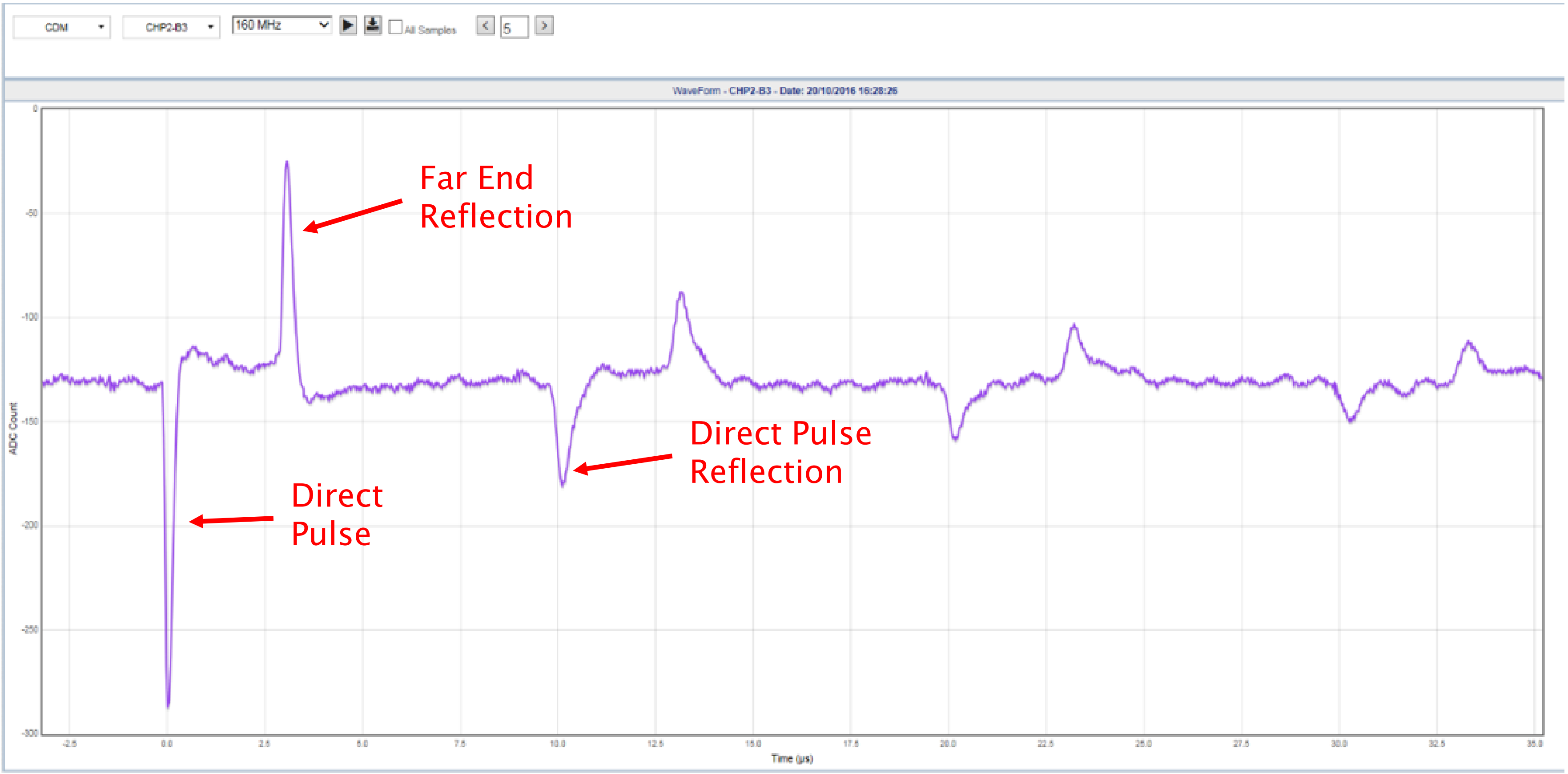
RFCT based testing of cables



Results and Interpretation - Partial Discharge Magnitude

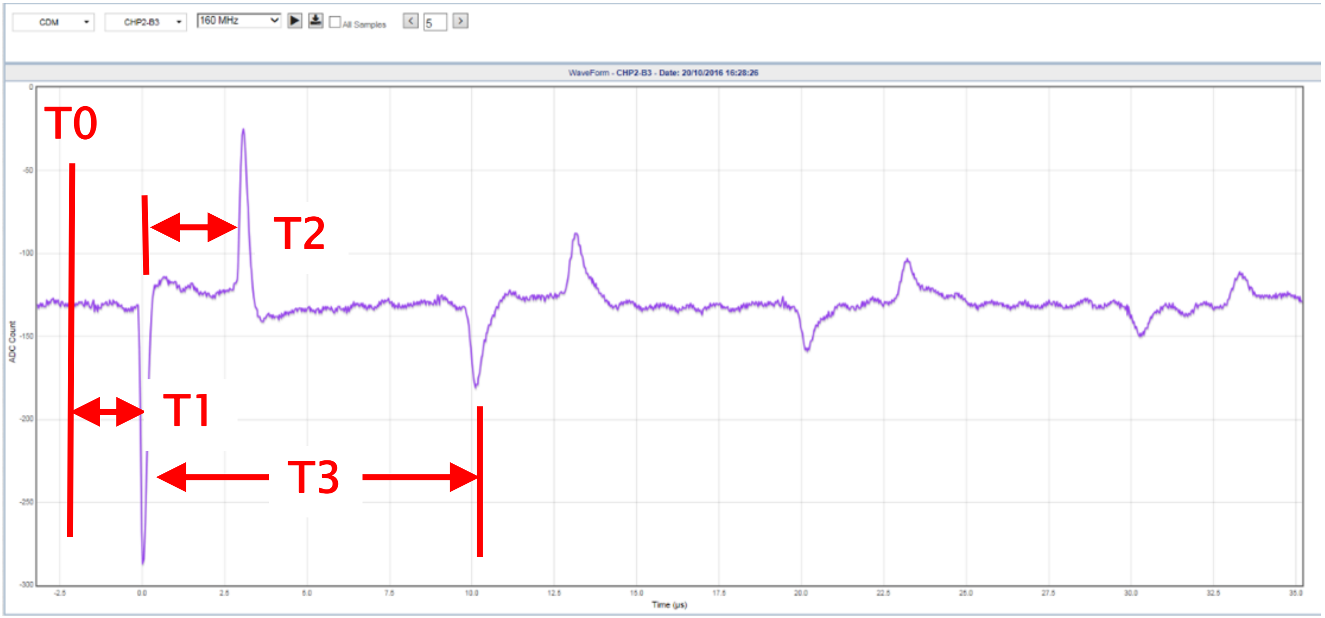


Results and Interpretation – Pulse Components



-2.5 0 Time (us) 35

Results and Interpretation – Distance to PD Site



−2.5 0 Time (us) 35

T0 = Time actual pulse occurs (not measurable)

T1 = Time for direct pulse to travel to RFCT (not measurable)

T2 = Time between direct pulse and reflected pulse arrival at RFCT

T3 = Time between direct pulse and direct reflected pulse arrival at RFCT

$$\text{Distance to PD} = ((T3 - T2) / 2) * ((2 * L)/T3)$$

Direct connected online systems

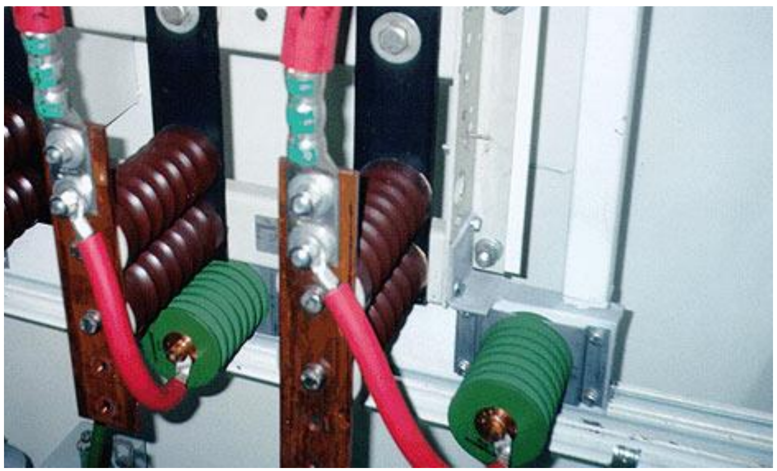
On-Line systems

Direct connected online systems use permanently installed HV capacitors and current transformers to measure PD directly.

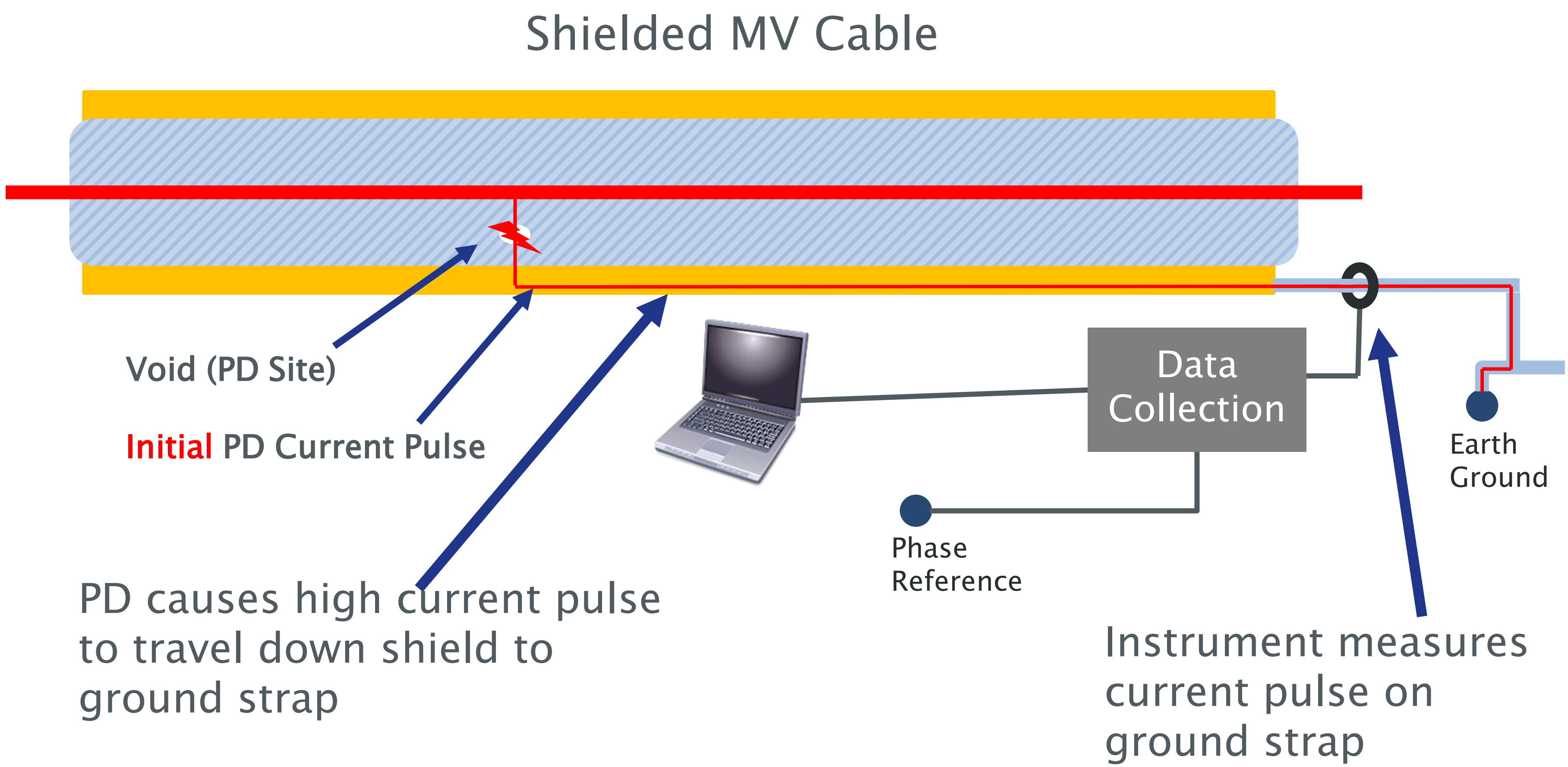
- Periodic or 24x7 monitoring with alarming
- Typically include remote communications
- Can include humidity and load monitoring
- Can be used for Rotating machines, Metal clad switchgear, MV/HV Cables, and Transformers

Direct connected systems

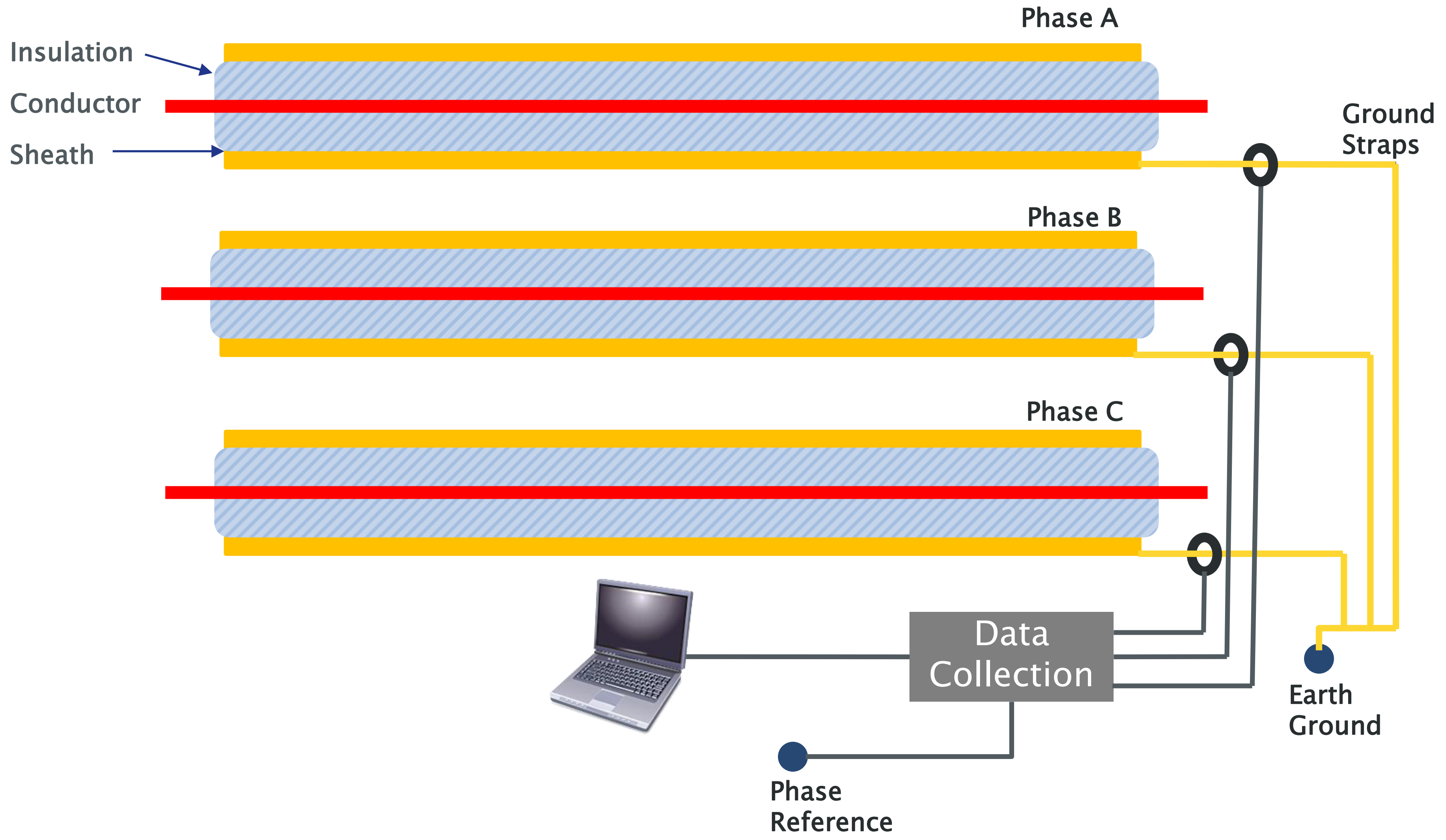
PD Couplers



RFCT based testing of cables

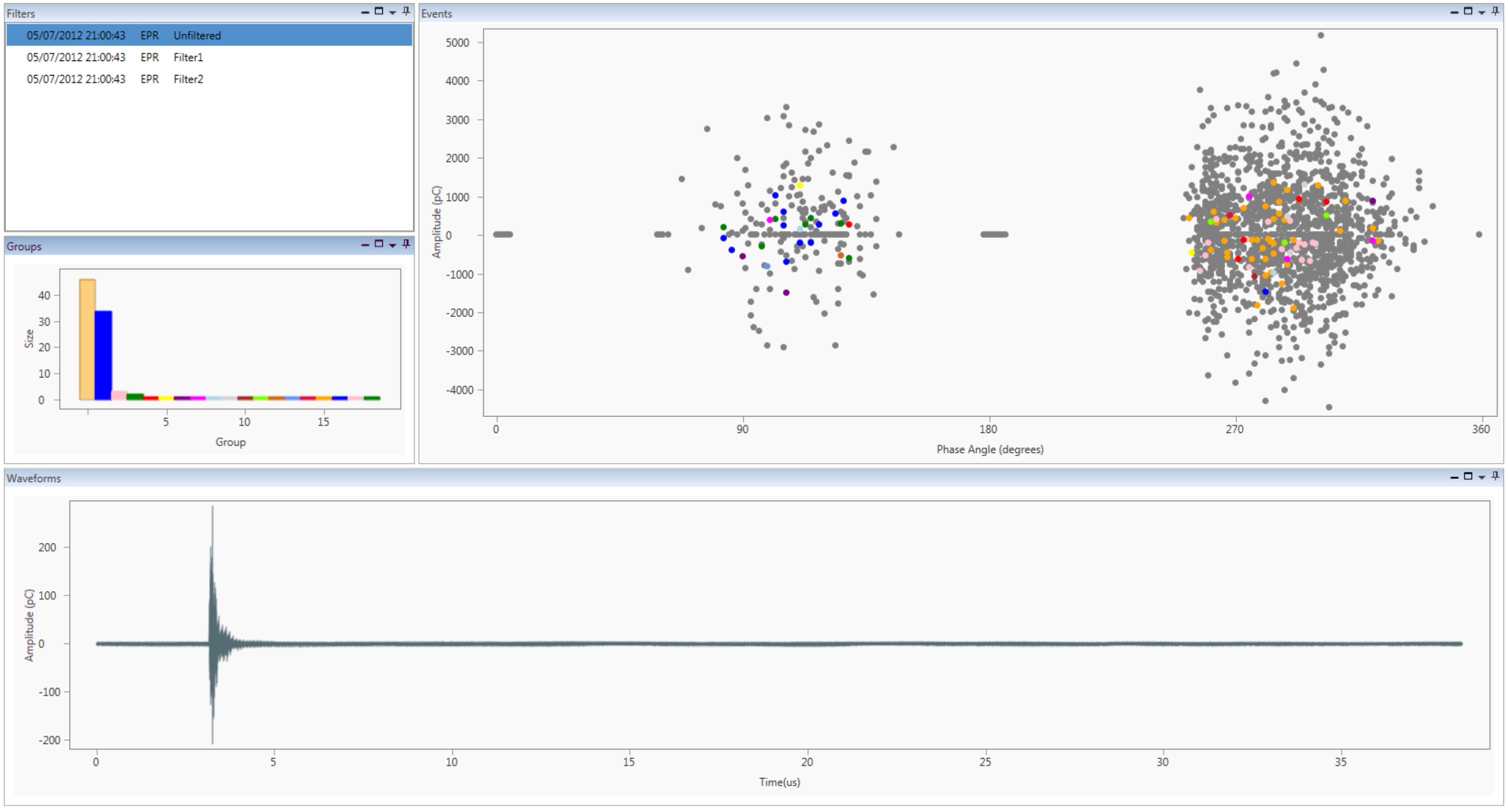


Practical application of spot testing



Analyzing Data – Two crucial pieces of data

Picking Milliamps of PD out of Kiloamps of current is not trivial. Two key pieces of information are vital

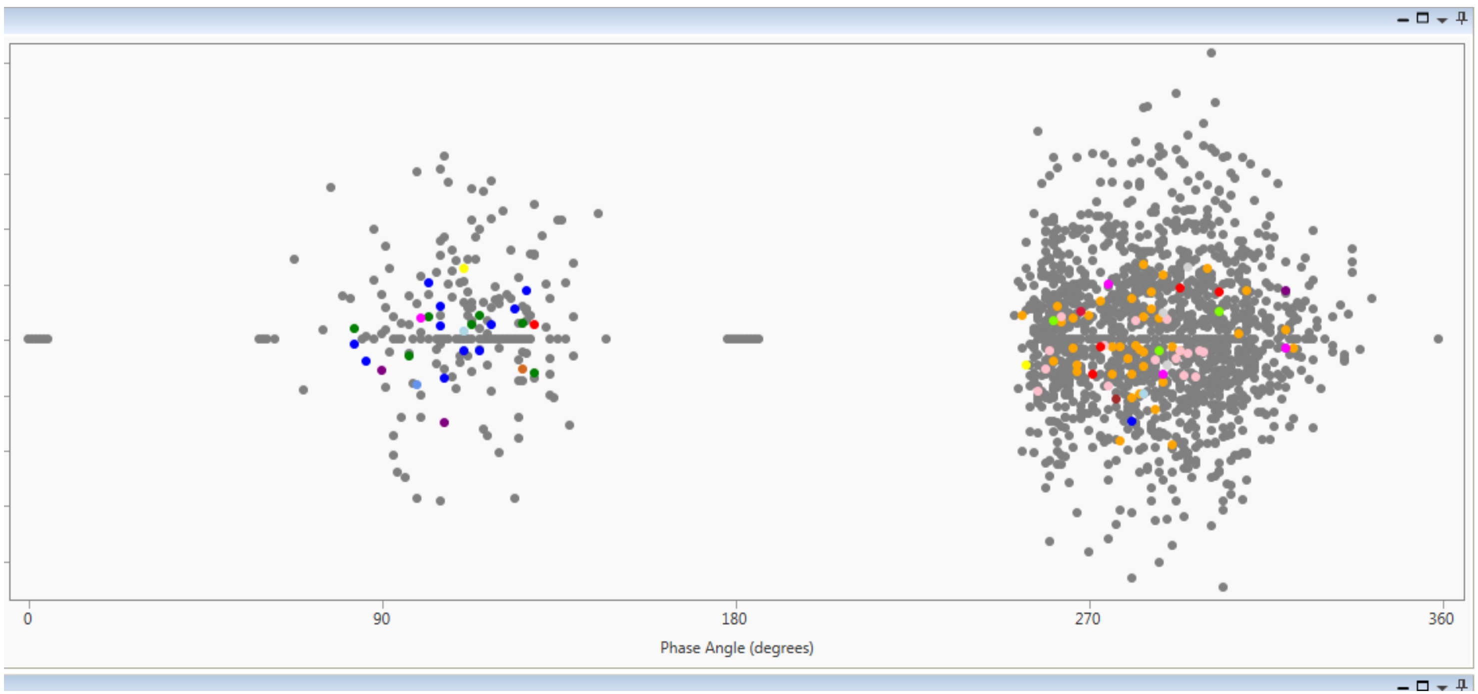


Analyzing Data – Phase Resolved Plots

One sign of recognizable PD Activity is clustering of points on the phase resolve plot at a distance of 180° apart

Amplitude
In pC
Around 0

0

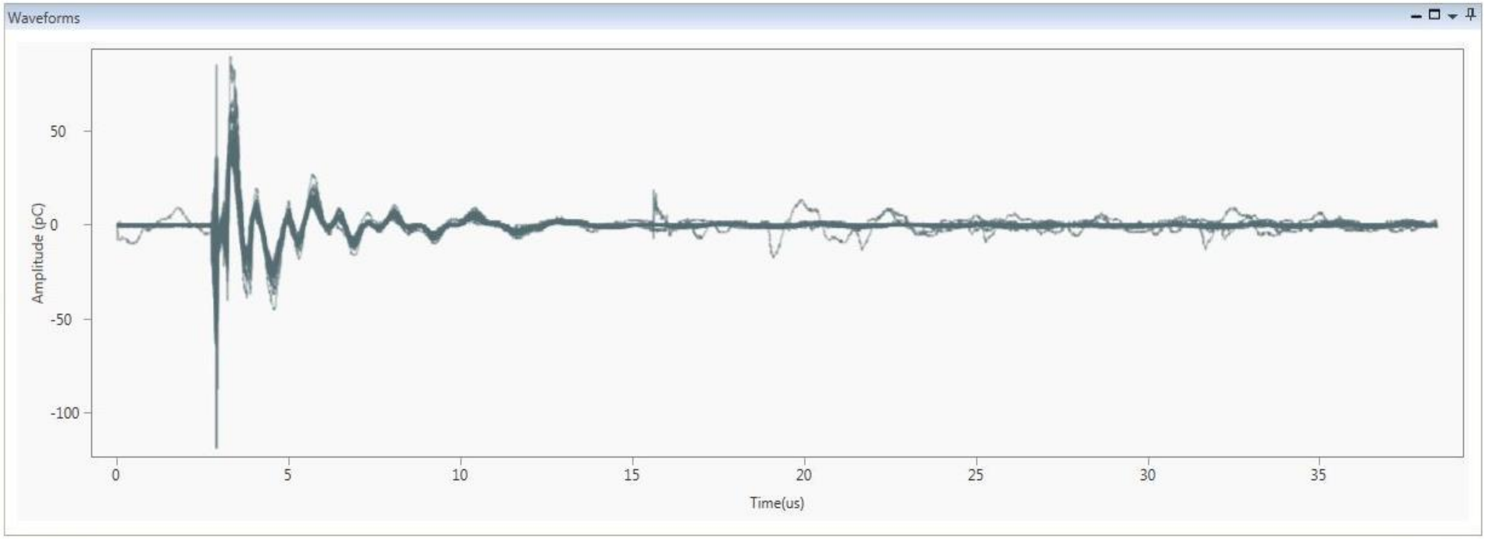


1 Cycle wide (16.66 ms)

Analyzing Data – Waveforms

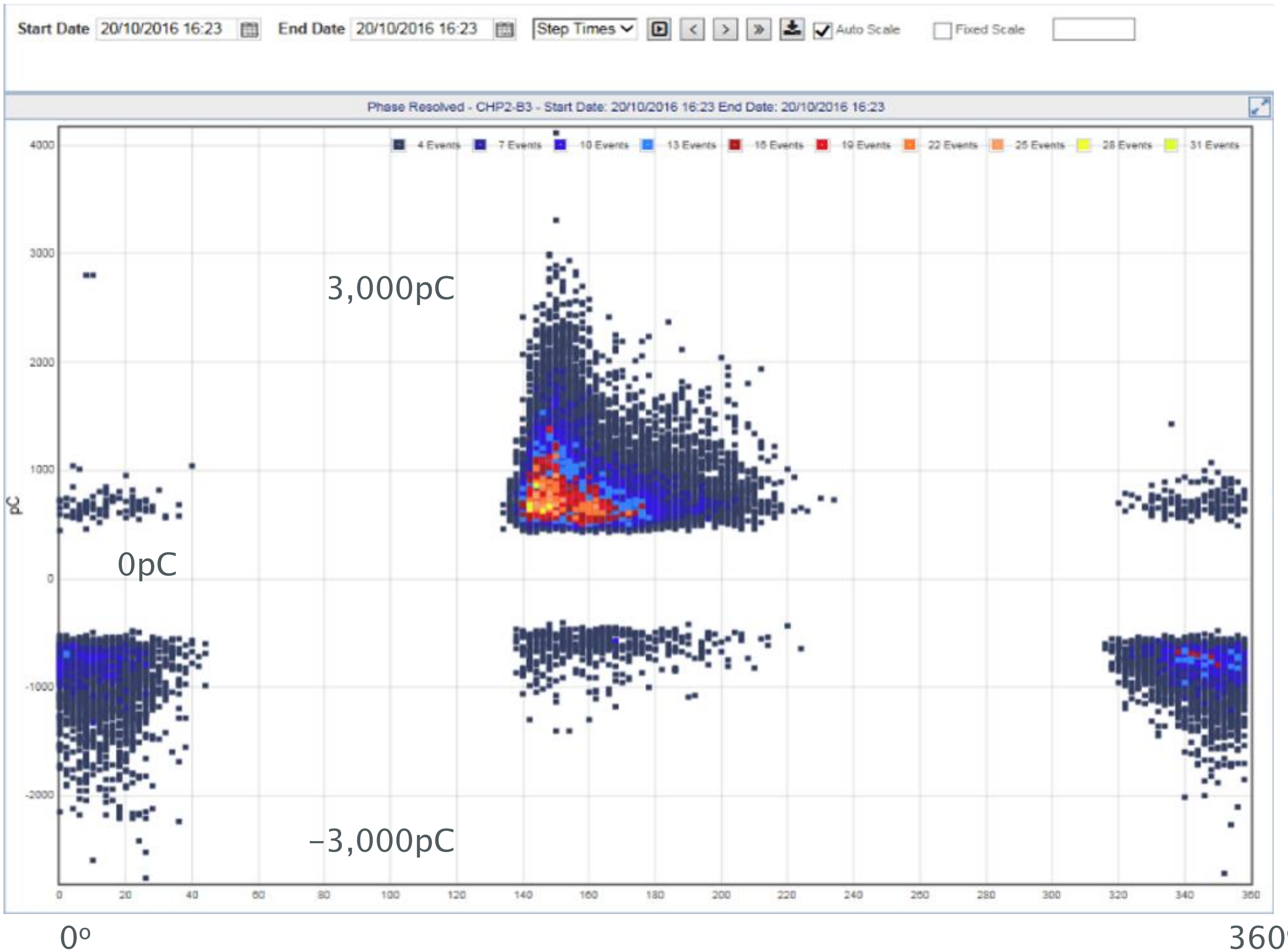
A typical waveform from online Cable PD testing should have a large unipolar pulse indicating the discharge

Amplitude
In mA
Around 0



Very fast time base (40 uS)

Activity – Actual PD Phase Plot

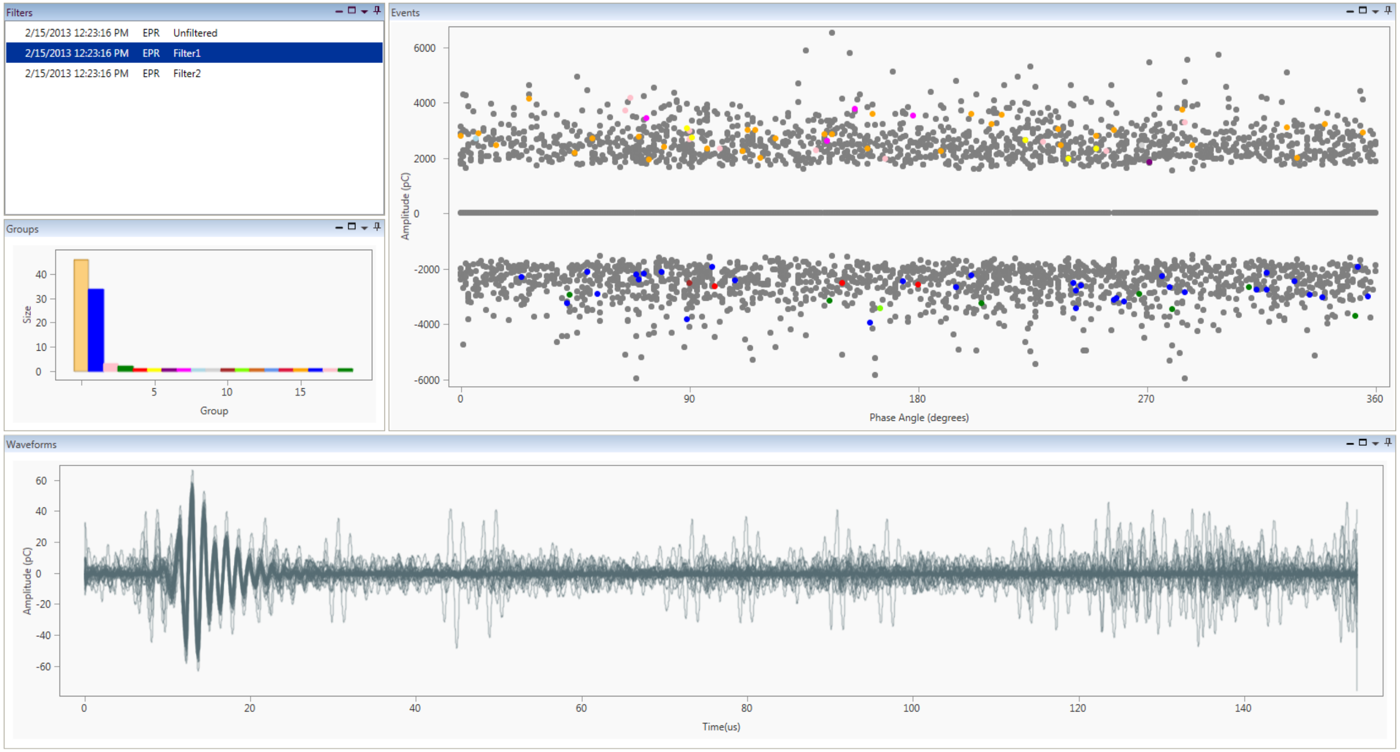


Non-PD Patterns – Random Noise

Background Noise

- Below is an example of background interference, which is characterized by random activity along the Phase Resolve plot.

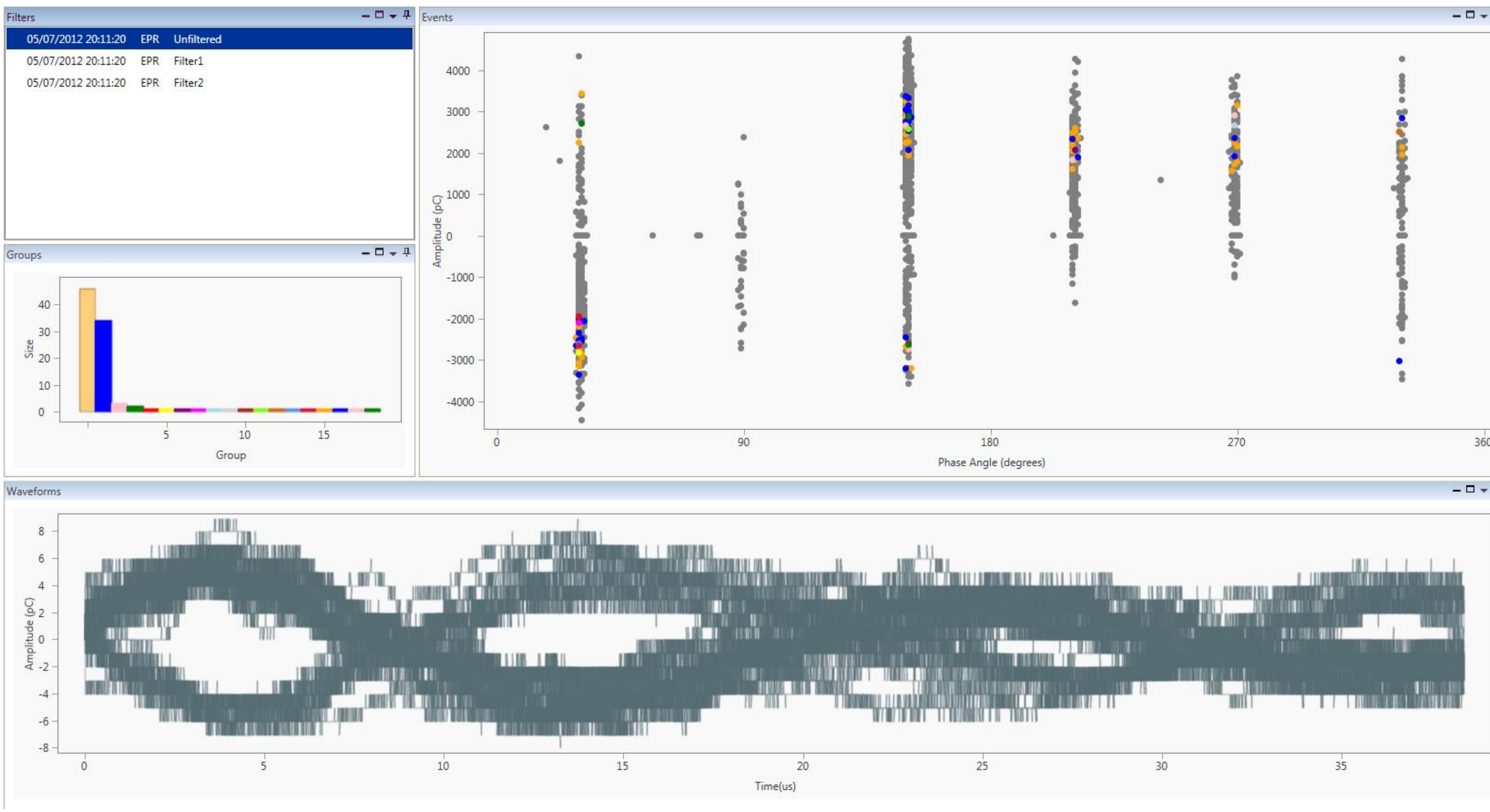
- Background interference may be caused by a number of sources including radio masts and DC light fittings.



Non-PD Patterns – VFD Noise

Machine Noise

- Data captured on circuits which have rotating machines operating on them will contain some machine noise
- Machine noise is characterized by vertical lines spread across the phase resolved plot

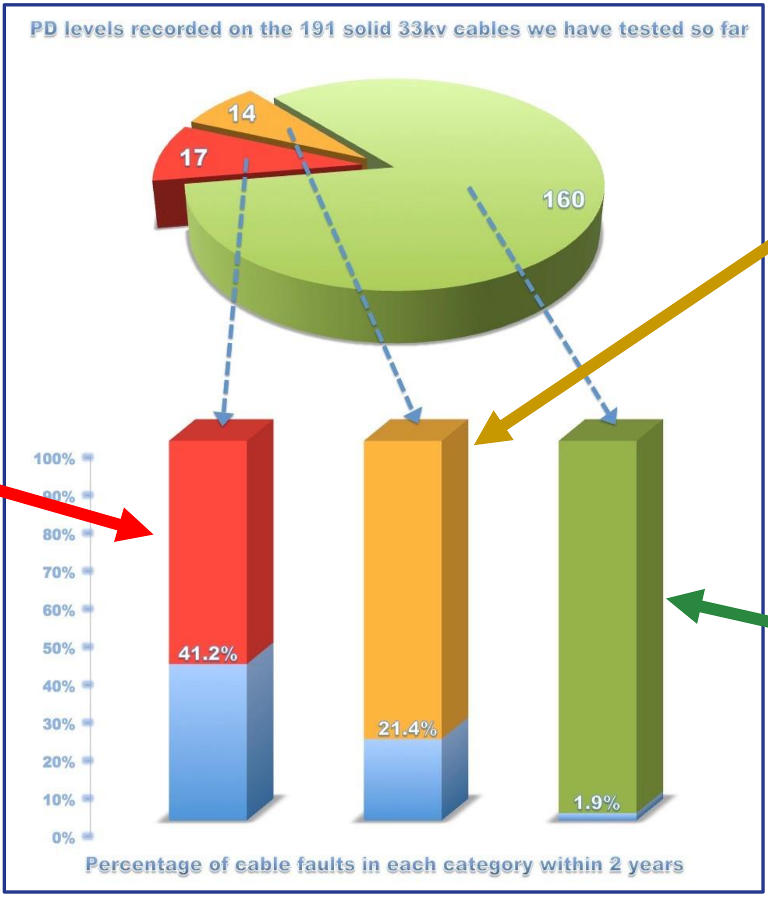


Evaluation Scale

Comments	Color Code	XLPE Cable	XLPE Accessories	PILC Cable	PILC Accessories
Discharge within "acceptable" limits.		0-250pC	0-500pC	0-2500pC	0-4000pC
Some concern, more frequent monitoring recommended.		250-500pC	500-2500pC	2500-7000pC	4000-10000pC
Major concern, locate PD activity and repair or replace.		>500pC	>2500pC	>7000pC	>10000pC

Field Example #1 – ENWL (UK)

UK utility Electricity North West Limited (ENWL) undertook a two year evaluation of RFCT based on-line testing that condition assessment of 191 33KV cables on their network over a two year period.



7% rated RED (no problems)

<40% of those failed within 2 years

7% rated Amber (no problems)

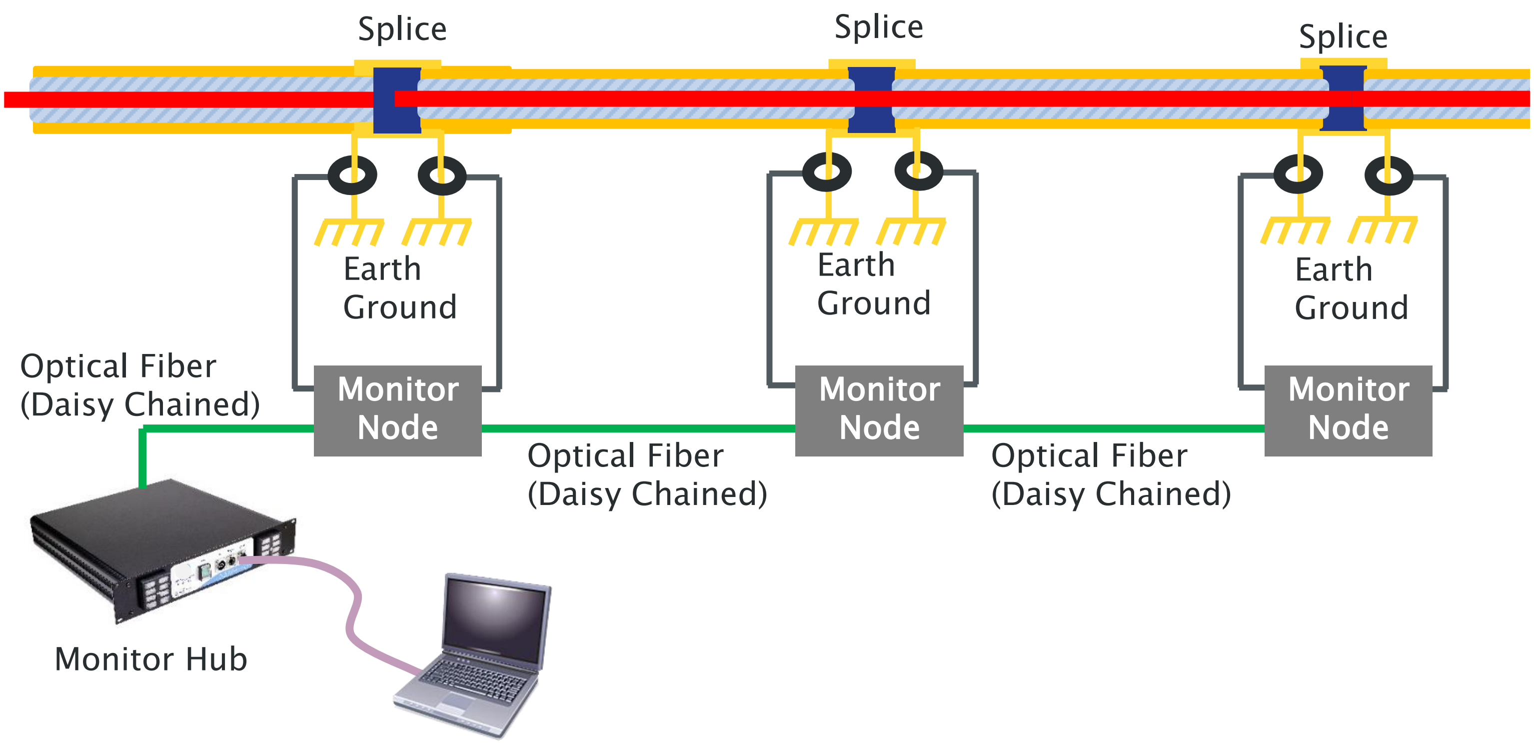
<21% of those failed within 2 years

84% rated GREEN (no problems)

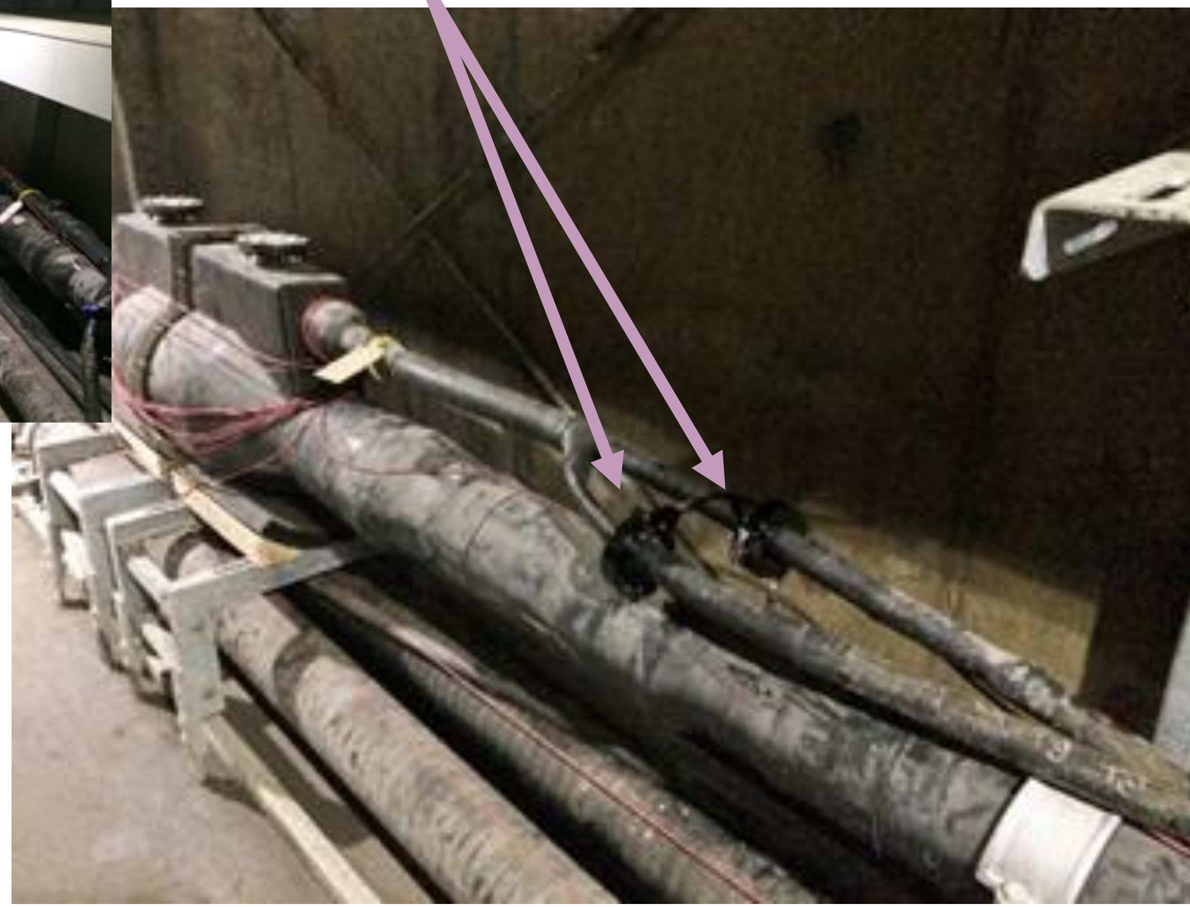
>2% of those failed within 2 years

Field Example #2 – (Hangzhou China)

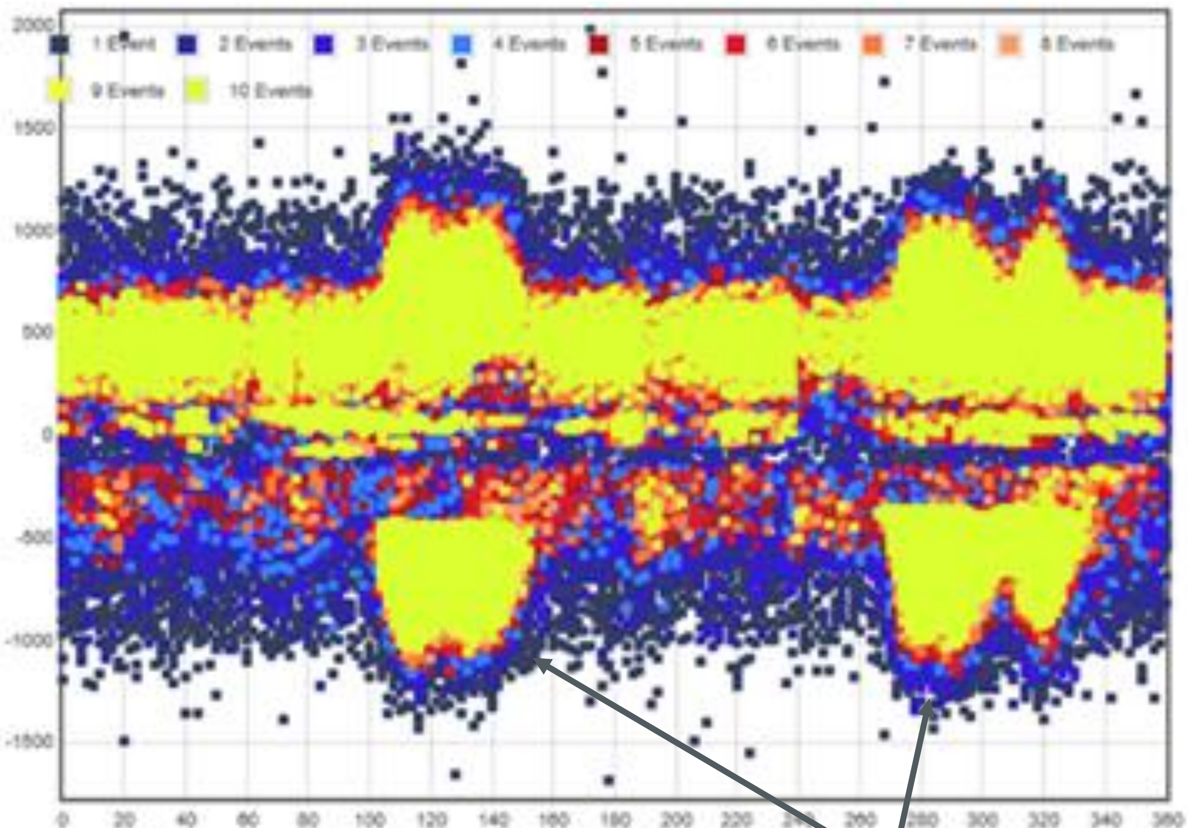
3.4 Km 220 KV Cable with 4 Grounded Splice Points and 4 ground points between splices.



Field Example #2 – (Hangzhou China)



Field Example #2 – (Hangzhou China)



Amplitude (pC)

Colors signify frequency of events

PD Events(180 degrees apart)

Phase Angle (360 degrees)

Field Example #3 – (INEOS Scotland)

Two 1km 33KV 3 conductors per phase with 2 splices each.

New splices put in service Sept 2016.

2 of 18 cables had low level PD measured with VLF prior to energization.

Full time PD measurement using RFCT installed

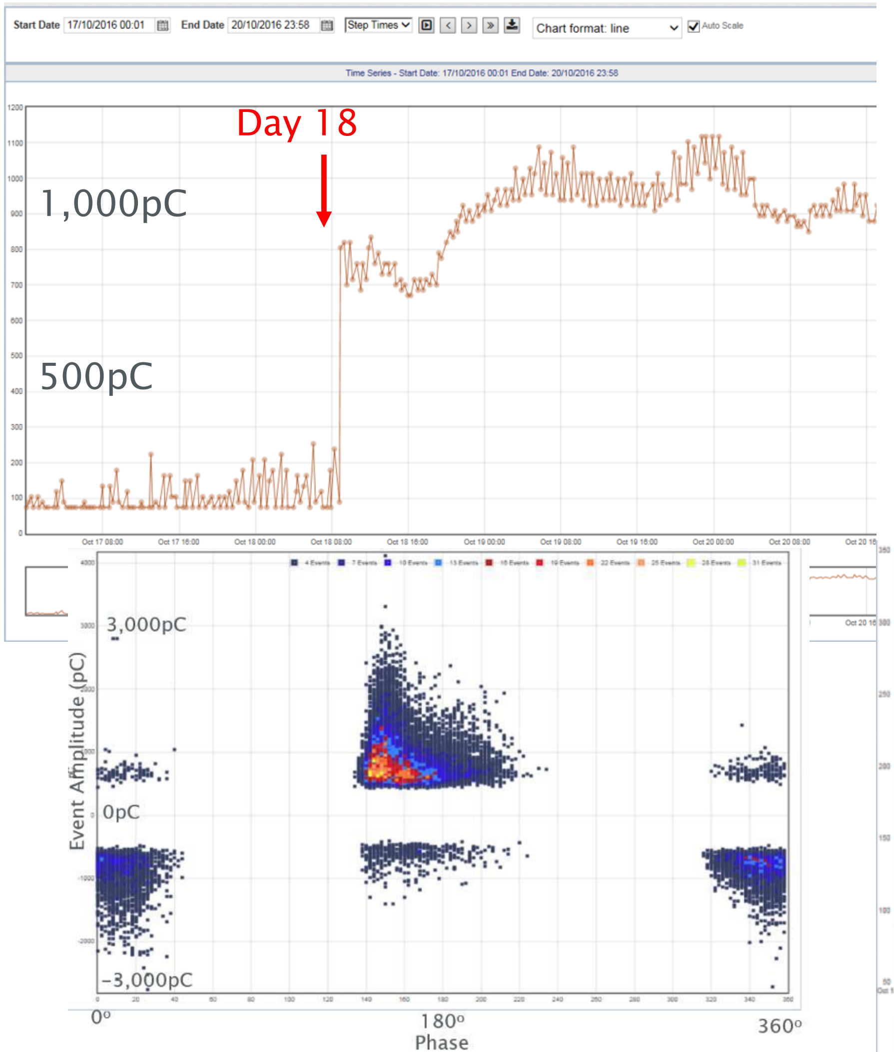
For the first 11 days, No PD troubling detected.

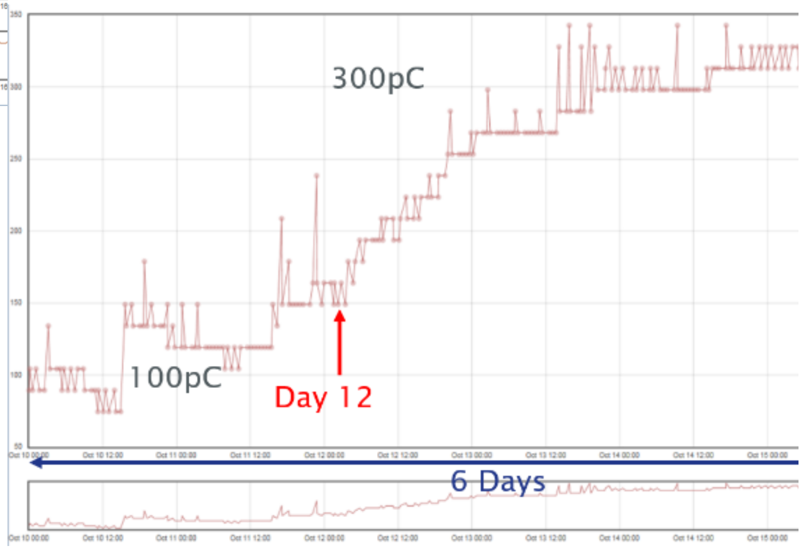
On **day 12**, one of the suspect cables started exhibiting PD

On **day 18**, the other suspect cable started exhibiting PD

Field Example #3 – (INEOS Scotland)

- Very sudden onset of PD
- Very distinct PR plots
- Clear waveforms
- Both located using TDR while online
- <u>PD on a third cable started after 28 days</u>





Conclusions

- Online RFCT based testing is a viable method for finding partial discharge in MH, HV, and EHV cables
- Periodic testing of MV cables while in service finds a high percentage of damaged cables prior to failure
- Full time monitoring of EHV cables may be required due to more extensive grounding systems
- Evaluation of data requires more than just amplitude. High quality filtering, analysis of phase resolved plots and analysis of waveforms is needed to discriminate PD from noise