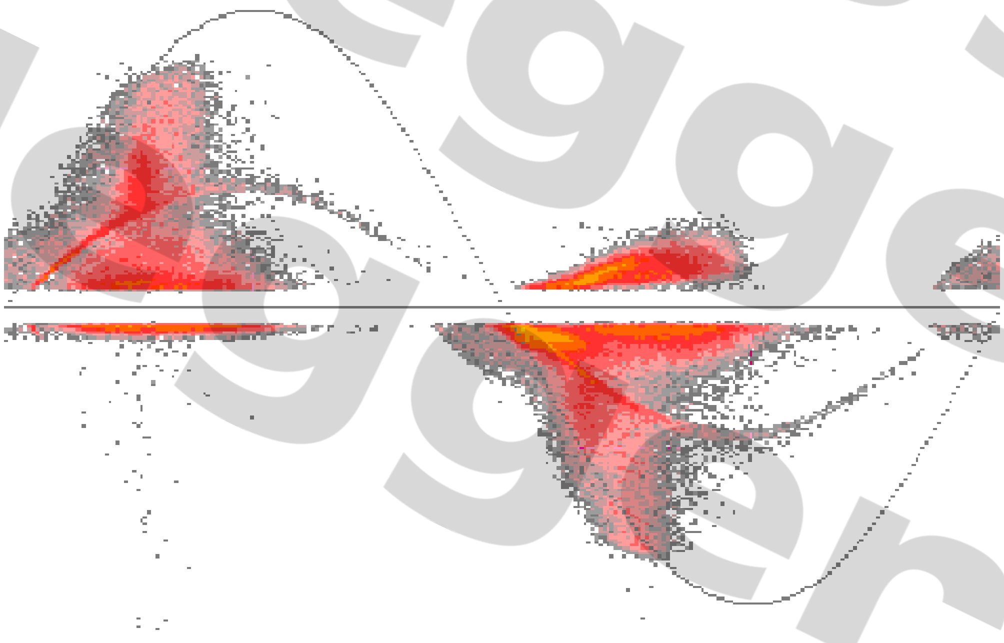
Offline PD and Tan Delta Measurements on MV/HV Cables using the ICM*flex* and ICM*system*

Ceren Gürbüz
Electrical Engineer
Power Diagnostix Systems

January 20, 2021

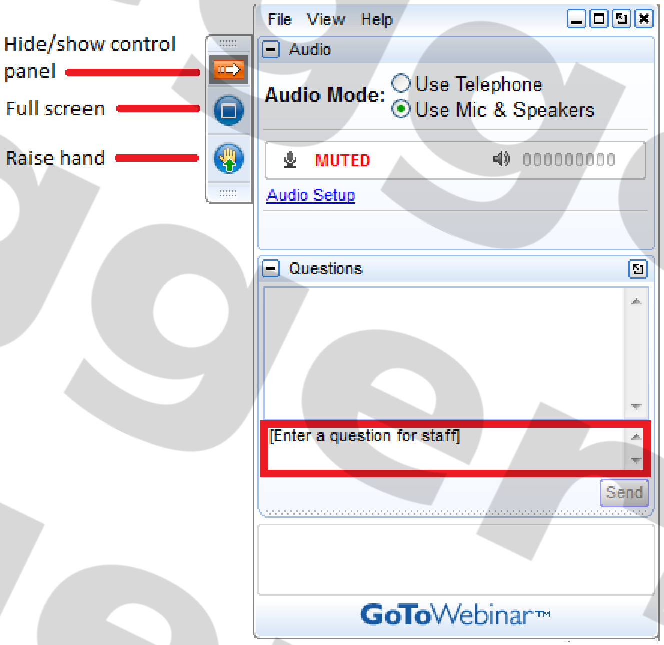


Moderator

- Markus Fockenberg
  - Power Diagnostix Senior Development Engineer

Q&A

- Send us your questions and comments during the presentation



Todays Presenter & Panelist

- Presenter:
  - Ceren Gürbüz
    - Power Diagnostix Electrical Engineer
- Panelists:
  - Daniel Hering
    - Power Diagnostix Senior Development Engineer

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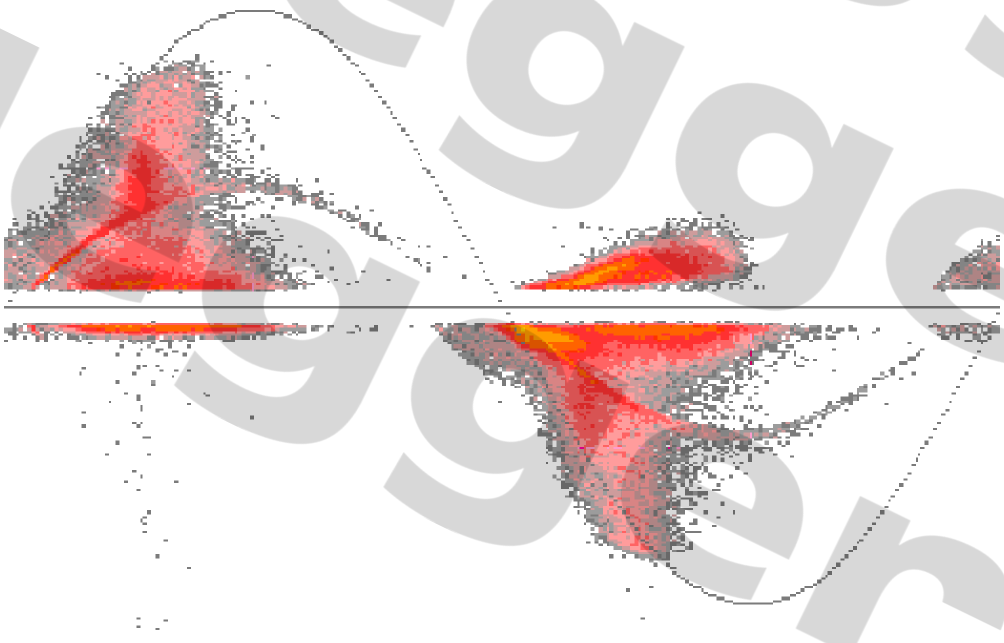
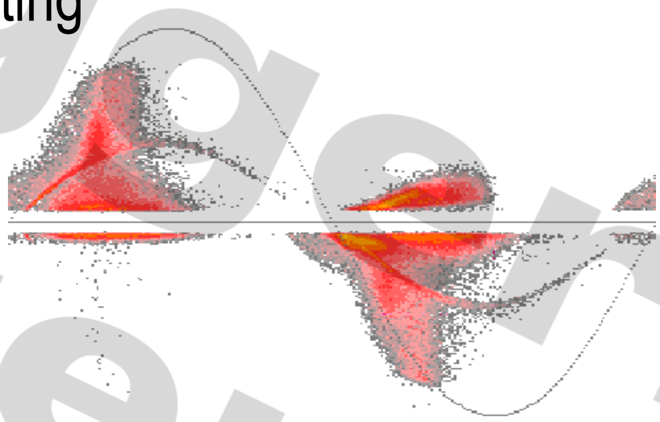


- Introduction – Why PD and Tan Delta Testing
- Normative references
- Partial discharge theory
- The ICM*flex* & Software
- Standard PD measurements
- Cable fault location
- Cable fault location using the ICM*system*



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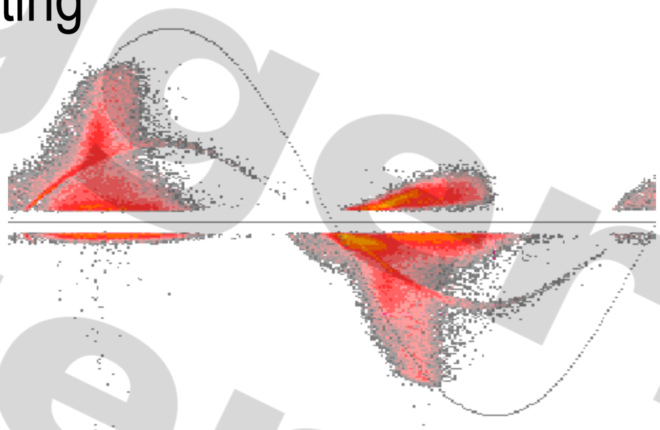

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Introduction – Why PD and Tan Delta Testing

- Partial discharge measurements are important to evaluate the existence of degradation process of insulation materials
- Quality control tests, factory acceptance tests, and field testing are required to assess the severity of partial discharge activity on cables
- The mapping of PD activity versus length of the cable allows identifying and locating discharges within the cables and accessories
- Several IEC and IEEE standards focus on testing of MV/HV Cables
- The fixed frequency (50/60 Hz) resonant test sets are excellent for service conditions; however heavy and costly
- VLF is a cost-effective, compact, and portable solution for cable tests

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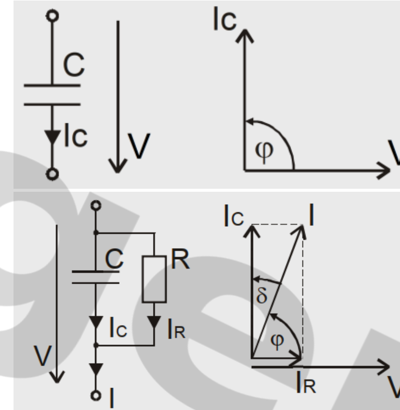
Introduction – Why Tan Delta Testing

- In general insulation materials show losses
- Magnitude of losses can be used as an indicator of insulation quality
- For transformers increase in loss factor indicates oil or paper decomposition
- For cables electro-chemical processes i.e. water-trees in polymeric cables or heavy PDs cause higher loss factor
- Tan Delta value expresses the overall quality of the insulation
- The ICM*flex* Software displays both Tanδ, Capacitance, Voltage and Frequency valu



Loss factor (Dissipation factor)

$$\tan\delta = \frac{I_R}{I_C} = \frac{P}{Q} = \frac{1}{\omega \cdot C \cdot R}$$

Quality Factor

$$QF = \frac{1}{\tan\delta} = \frac{I_C}{I_R} = \frac{Q}{P} = \omega \cdot C \cdot R$$

Power Factor

$$PF = \cos\varphi = \frac{I_R}{I}$$

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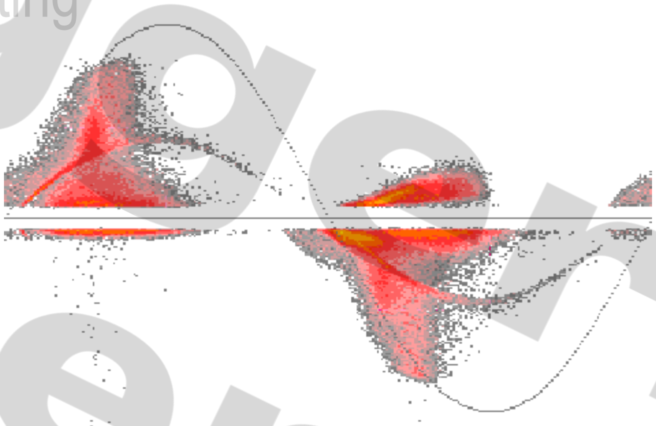

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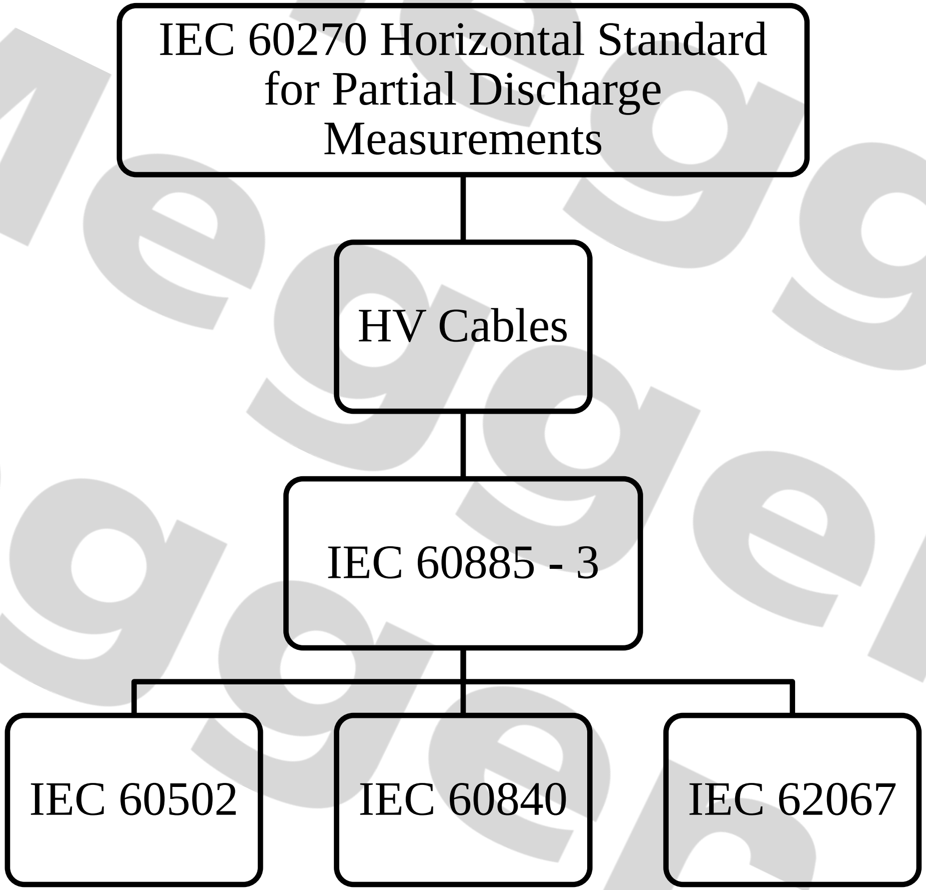
Normative references – IEC Standards for PD Testing



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Normative references – IEC Standards for PD Testing

Acceptance Testing			
Standard	Frequency	Voltage	PD Criteria
		1 kV < U < 40 kV	
IEC 60502	49-61 Hz	3.5 U / 5 min	1.73 U < 10 pC
		40 kV < U < 150 kV	
IEC 60840	49-61 Hz	2.5 U / 30 min	No PD up to 1.5 U
		150 kV < U < 500 kV	
IEC 62067	49-61 Hz	2.5 U / 30 min and 60 min	1.5 U < 10 pC

- Test voltages, sequences, and PD evaluation criteria according to cable's voltage class
- In shielded test rooms background noise level of 2pC can be obtained
- The measured PD levels should not exceed the defined limits

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Normative references – IEC Standards for PD Testing

On-site Testing			
Standard	Frequency	Voltage	PD Criteria
		1 kV < U < 40 kV	
IEC 60502	49-61 Hz 49-61 Hz DC	1.73 U / 5 min U / 24 h 4 U / 15 min	None
		40 kV < U < 150 kV	
IEC 60840	20-300 Hz 49-61 Hz	1.73 U – 2 U /1 h U / 24h	None
		150 kV < U < 500 kV	
IEC 62067	20-300 Hz 49-61 Hz	1.1 U – 1.73 U /1 h U / 24h	None

- On-site testing is mostly preferred after installation tests and no PD criteria given
- Recommended to verify performance of cable accessories
- Background noise can be from few tens up to hundred pC range

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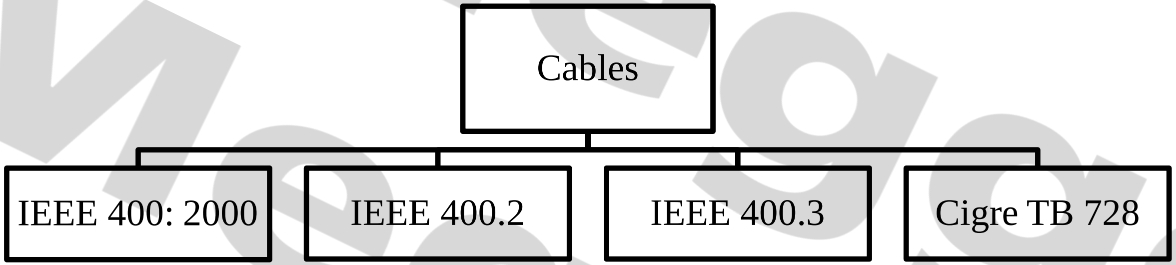
Normative references – IEEE and Cigre TB



- IEEE 400: IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5kV and Above
- IEEE 400.2: IEEE Guide for Field Testing of Shielded Power Cable Systems using Very Low Frequency
- IEEE 400.3: IEEE Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment
- The general procedures and criteria are similar to IEC standards
- Test voltage criteria for testing is at very low frequency

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Normative references – IEEE and Cigre TB

VLF Output Waveform	Cable Rating Phase-to-Phase	**Installation Test** Phase-to-Ground – U_0		**Acceptance Test** Phase-to-Ground – U_0		**Maintenance Test** Phase-to-Ground – U_0	
	kV rms	kV rms	kV peak	kV rms	kV peak	kV rms	kV peak
Sinusoidal	5	9	13	10	14	7	10
	8	11	16	13	18	10	14
	15	19	27	21	30	16	22
	20	24	34	26	37	20	28
	25	29	41	32	45	24	34
	28	32	45	36	51	27	38
	30	34	48	38	54	29	41
	35	29	55	44	62	33	47
	46	51	72	57	81	43	61
	69	75	106	84	119	63	89

- IEEE splits cable testing into three different groups with related test voltages
- In general recommended testing time according to IEEE400.2 varies between 15 and 60 min
- For maintenance testing period of 30 minutes is recommended

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Tan Delta Test Procedure (XLPE Cables)

- Tan Delta testing with VLF sinusoidal waveform
- Cable system insulation can be assessed as good, aged, and highly degraded
- The test results:
  - Tanδ at Un: Phase to ground voltage
  - Tanδ at 2Un: Phase to ground voltage
  - Voltage ramp-up: 0.5Un ⟹ Un ⟹ 1.5Un ⟹ 2Un (60 min)

Tan δ at $2V_o$	**Differential of Tan δ** tan δ $2V_o$ – tan δV_o	**Assessment**
Less than 1.2×10^{-3}	Less than 0.6×10^{-3}	Good
Greater than or = 1.2×10^{-3}	Greater than or = 0.6×10^{-3}	Aged
Greater than or = 2.2×10^{-3}	Greater than or = 1.0×10^{-3}	Highly degraded
NOTE—It has been found that copolymer dielectric materials such as TR-XLPE or silicon fluid-treated insulations exhibit different tan δ characteristics; therefore, other criteria are valid.		

IEEE
Std 400-2001

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Tan Delta Evaluation

- Tan Delta is also called as dissipation factor and a measure of losses for the dielectric
- K is the dielectric constant of the insulation
- Service aged cables are tested periodically to evaluate the degradation process or to reduce service failures

Type of insulation	K	tan δ
Impregnated paper	3.5	2.3×10^{-3}
Impregnated PPP	2.7	0.7×10^{-3}
XLPE	2.3	0.1×10^{-3}
HDPE	2.3	0.1×10^{-3}
EPR	2.8	3.5×10^{-3}

IEEE
Std 400-2001

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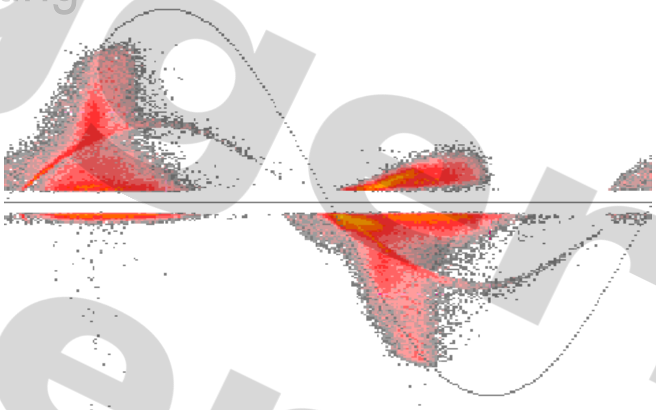
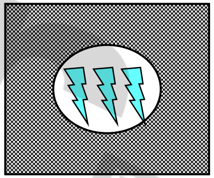


Occurrence of partial discharge

- For the occurrence of partial discharge two conditions must be met:
  - The local electric field must have reached the critical inception field ($E > E_{crit}$)
  - A free electron must be available to start the discharge avalanche
- Two main processes to derive this initial electron:
  - Ionization by photons
  - Field emission



- The statistical properties of these processes control the appearance of the PD pattern

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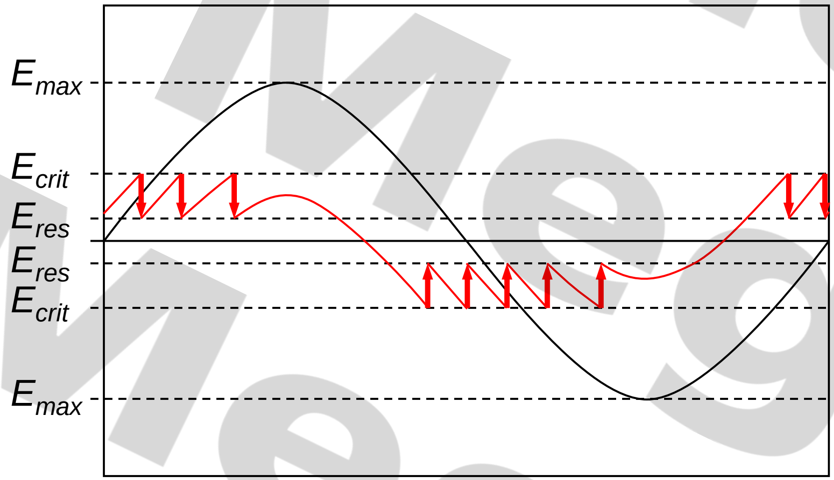
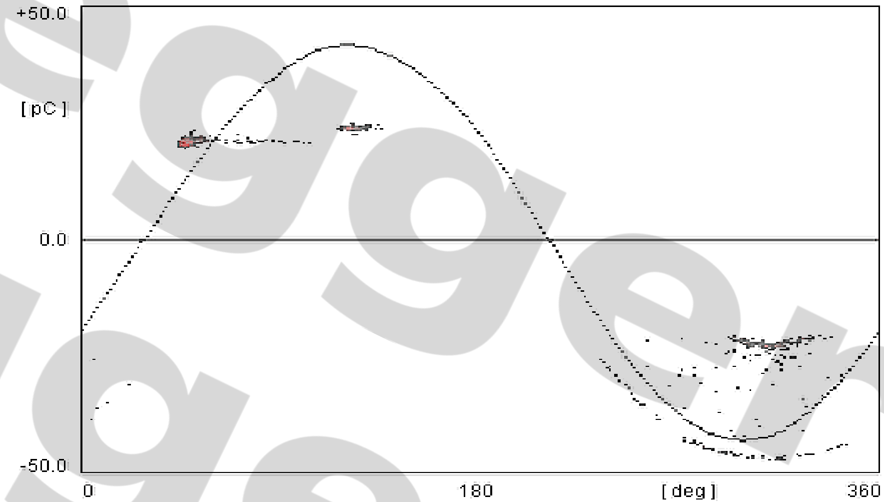
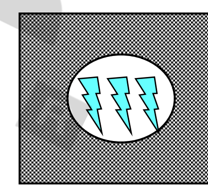
Discharges in a spherical gas inclusion





High availability of starting electron

- Regular discharge for $E > E_{crit}$
- Stable (low) discharge amplitude
- Regular partial discharge pattern



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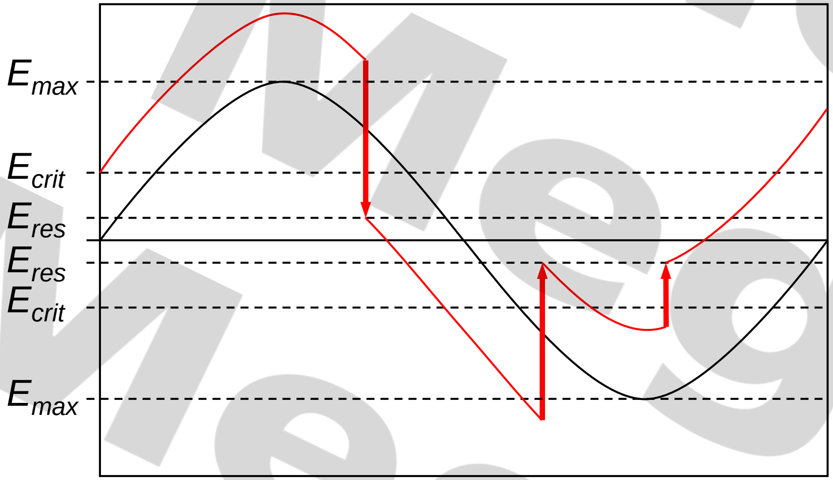
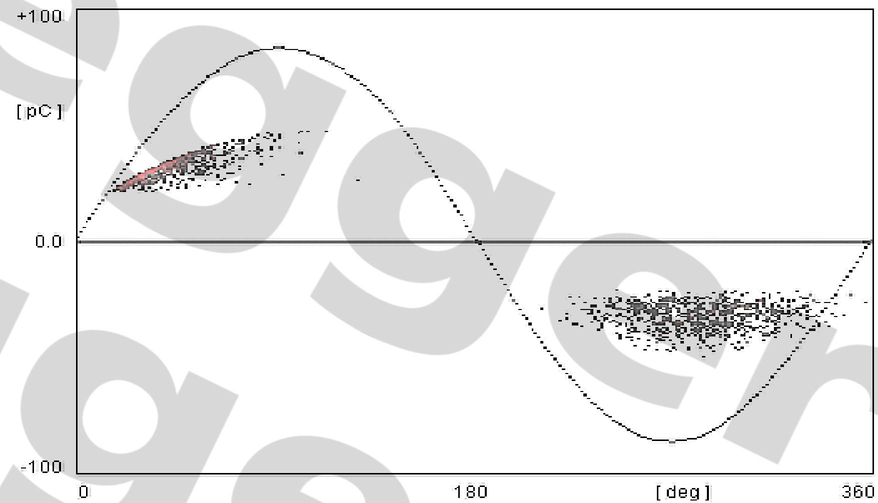
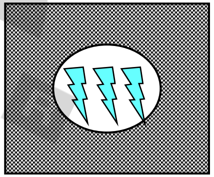
Discharges in a spherical gas inclusion





Low availability of starting electron

- Random discharge occurrence for $E > E_{crit}$
- Higher discharge amplitude
- Typical distributed PD pattern



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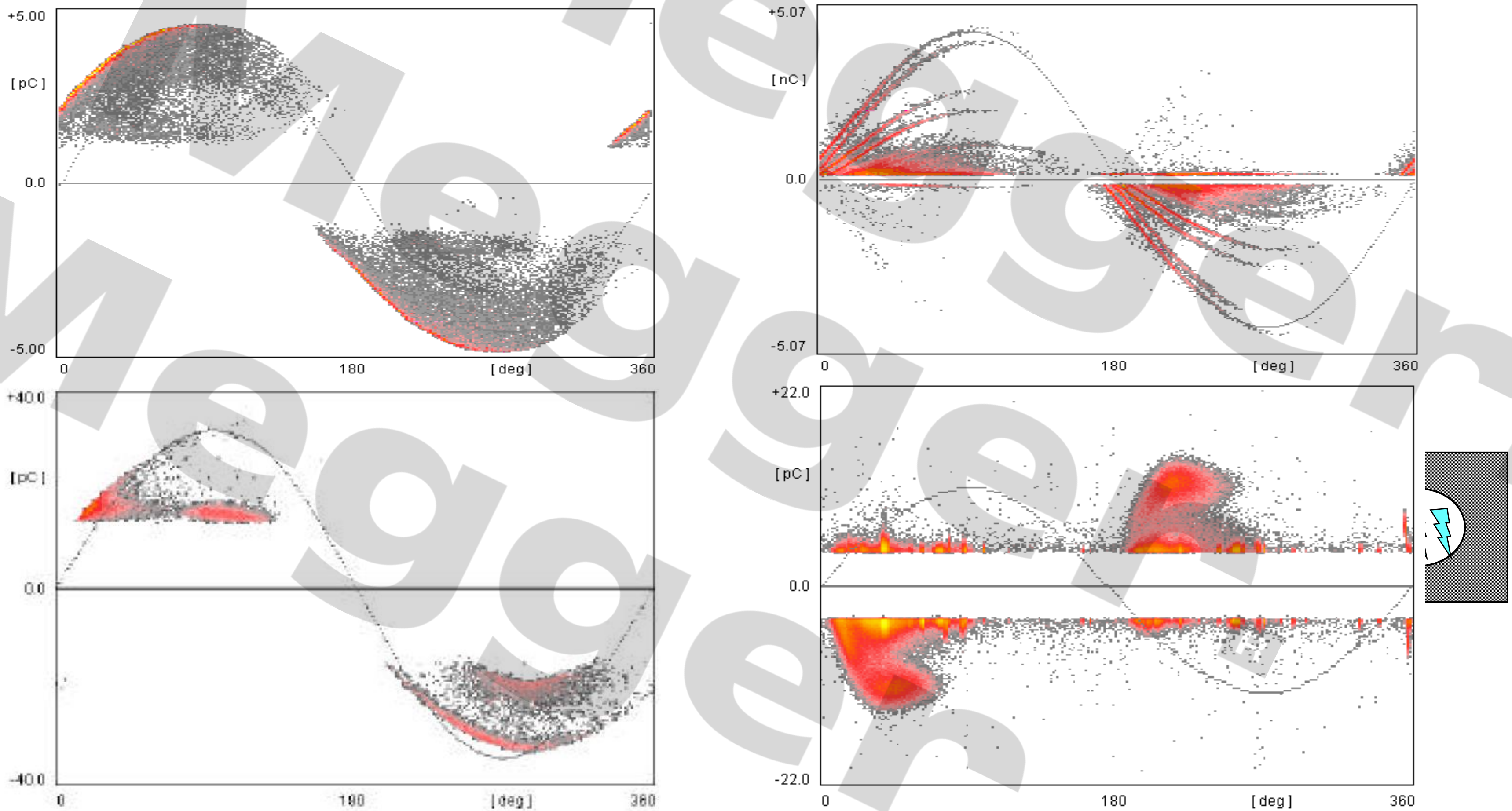
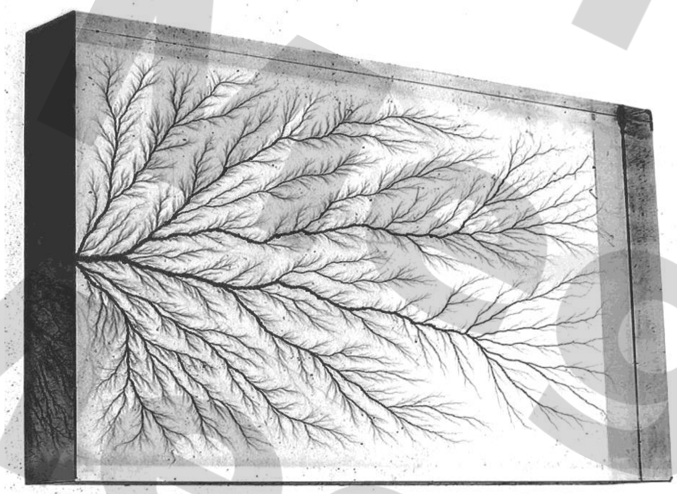
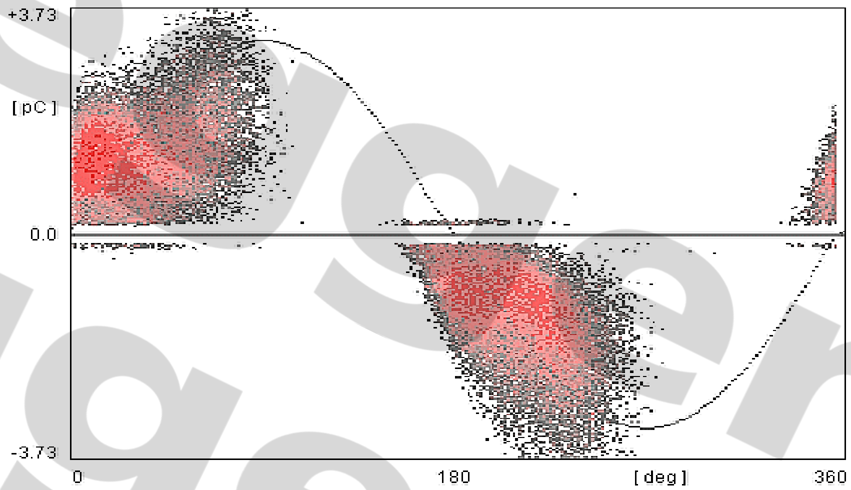
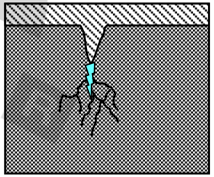


Treeing in polymeric material





Asymmetrical electrode configuration
- Initial breakup of solid material (PE, PP)
- Continues as gas discharge
- Discharge increases with tree growth



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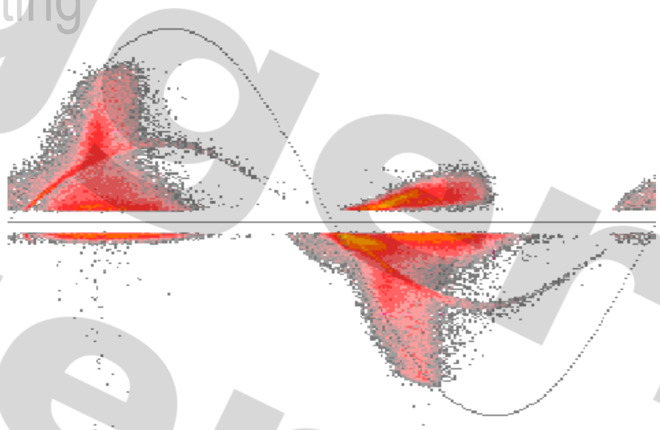

ICM*flex* – Product at a glance

- Measurement system for PD, TD, power factor, capacitance and power frequency
- Unique concept
- Acquisition box on HV potential
- PD fault location (DSO)
- VLF, 50/60Hz or resonant frequency
- Easy setup and user friendly
- Fully computer-controlled
- Bluetooth or fiber optic communication

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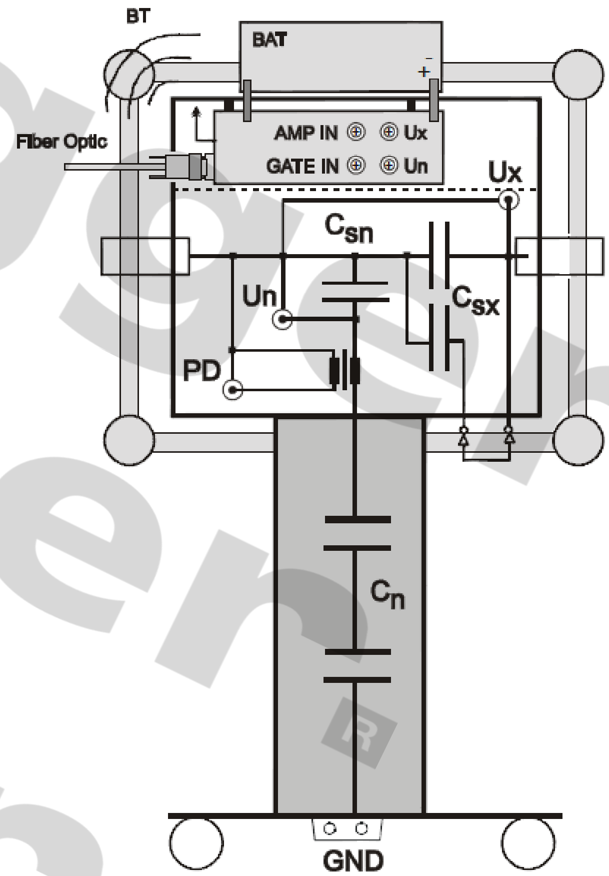
ICM*flex* – Technical details

- Fully computer controlled via Bluetooth or fiber optic cable (921 kBit/s)
- 30/50/100/150kV$_{rms}$ systems available
- 2x16 bit synchronous voltage measurement
- PRPD pattern resolution 8x8x16 bit
- Time domain signal analysis (100MS/10ns)
- Cable fault location
- Analog pulse gating via disturbance input
- Software with PRPD /PD Scope / PD Fault Location Display / Record (Tanδ Display)



ICM*flex* – Technical details

Rated Voltage U_r (RMS)	Rated Current I_r (RMS)	Frequency Range f	Reference Capacitor C_n	Shunt Capacitor C_{sn}	Shunt Capacitor C_{sx}
20 kV	1 A	2–265 Hz	1000 pF	2 µF	5 µF/30 µF
30 kV	5 A	2–265 Hz	1000 pF	3 µF	10 µF/100 µF
30 kV	100 mA	0.02–0.2 Hz (2–265 Hz)	1000 pF	3 µF	40 µF/400 µF
50 kV	1 A	2–265 Hz	500 pF	2.5 µF	10 µF/100 µF
50 kV	100 mA	0.02–0.2 Hz (2–265Hz)	500 pF	4 µF	40 µF/400 µF
100 kV	1 A	2–265 Hz	1000 pF	10 µF	10 µF/100 µF
100 kV	100 mA	0.02–0.2 Hz (2–265 Hz)	1000 pF	10 µF	40 µF/400 µF
150 kV	1 A	2–265 Hz	1000 pF	15 µF	10 µF/100 µF
150 kV	100 mA	0.02–0.2 Hz (2–265 Hz)	1000 pF	15 µF	40 µF/400 µF

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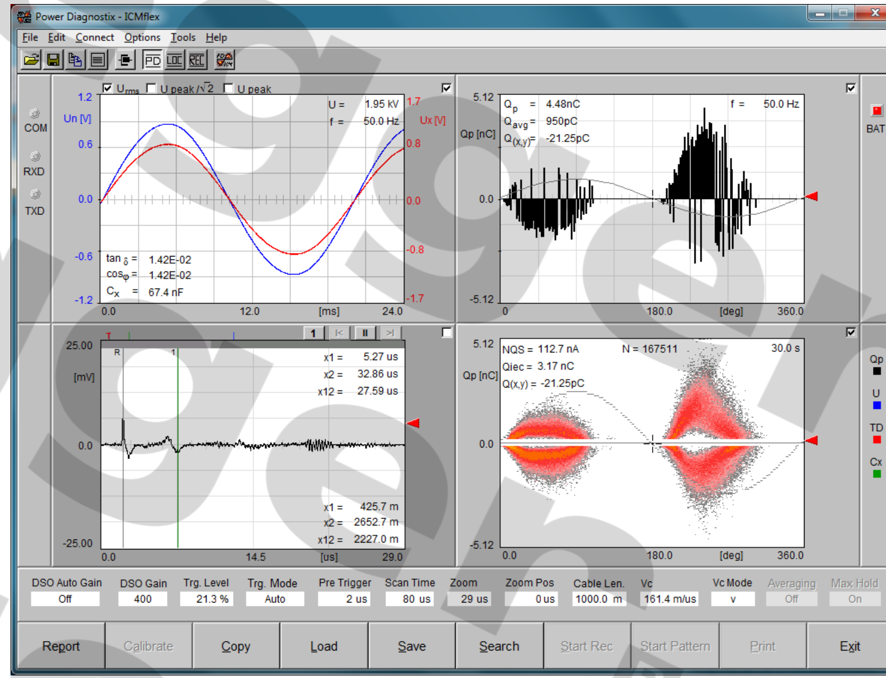
Optional HV Filter

- T-Filter of second order
- Suitable for multiple HV sources
- Embedded HFCT on HV potential
- Required for cable fault location as a reflection point for TDR

Type	Rated Voltage U_r (RMS)	Rated Current I_r (RMS)	Frequency Range f	Filter Config.	Blocking Capacitor C_b	Damping Factor @100 kHz
T30/1	30 kV	1 A	DC–300 Hz	L-C-L	6.7 nF	>100
T50/1	50 kV	1 A	DC–300 Hz	L-C-L	10 nF	>100
T100/1	100 kV	1 A	DC–300 Hz	L-C-L	10 nF	>100
T100/70	100 kV	70 A	DC–300 Hz	L-C-L	10 nF	>100
T150/1	150 kV	1 A	DC–300 Hz	L-C-L	10 nF	>100

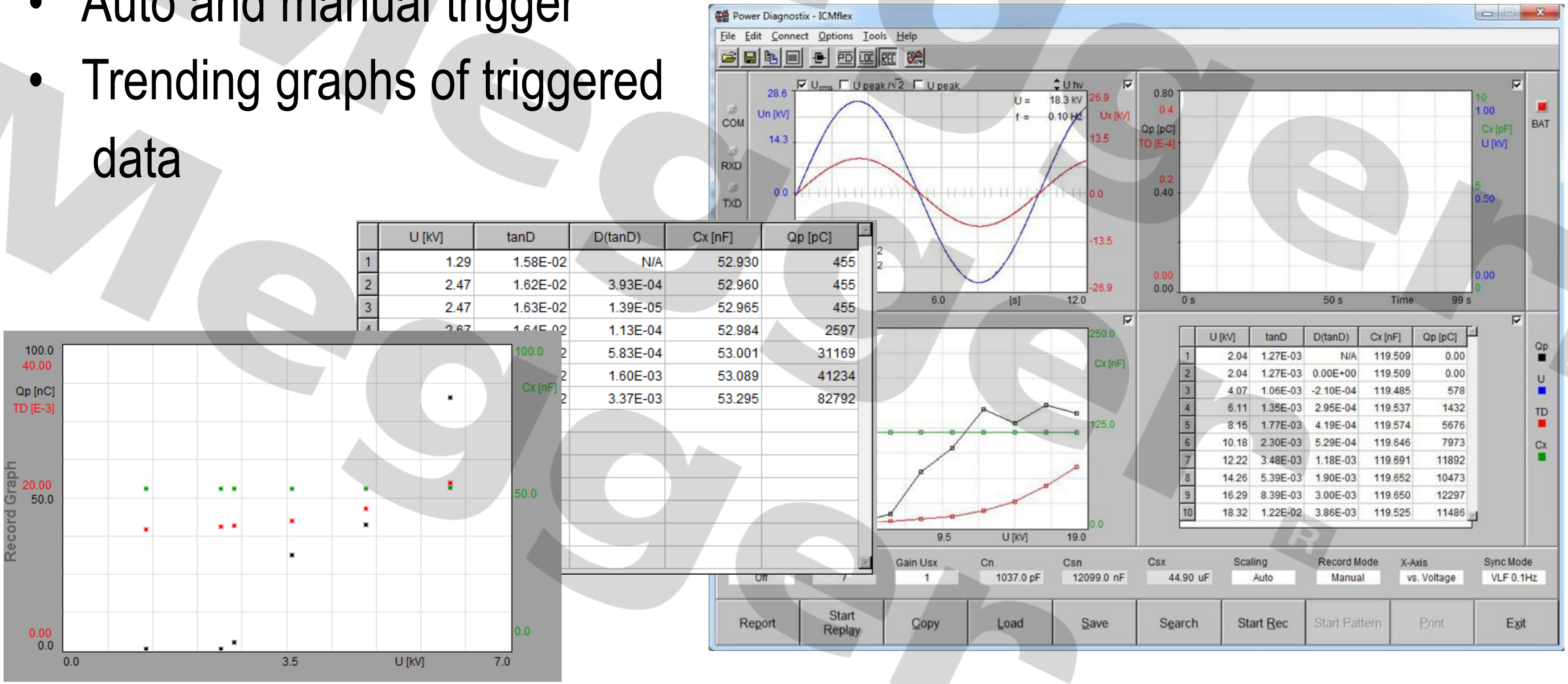
ICM*flex* – Software

- All-in-one operation panel
- Direct access to all relevant instrument settings
- Multiple graphs updated simultaneously
- Data recording vs. time and vs. voltage
- Test automation
- Export data format .xls, .xlsx, .html



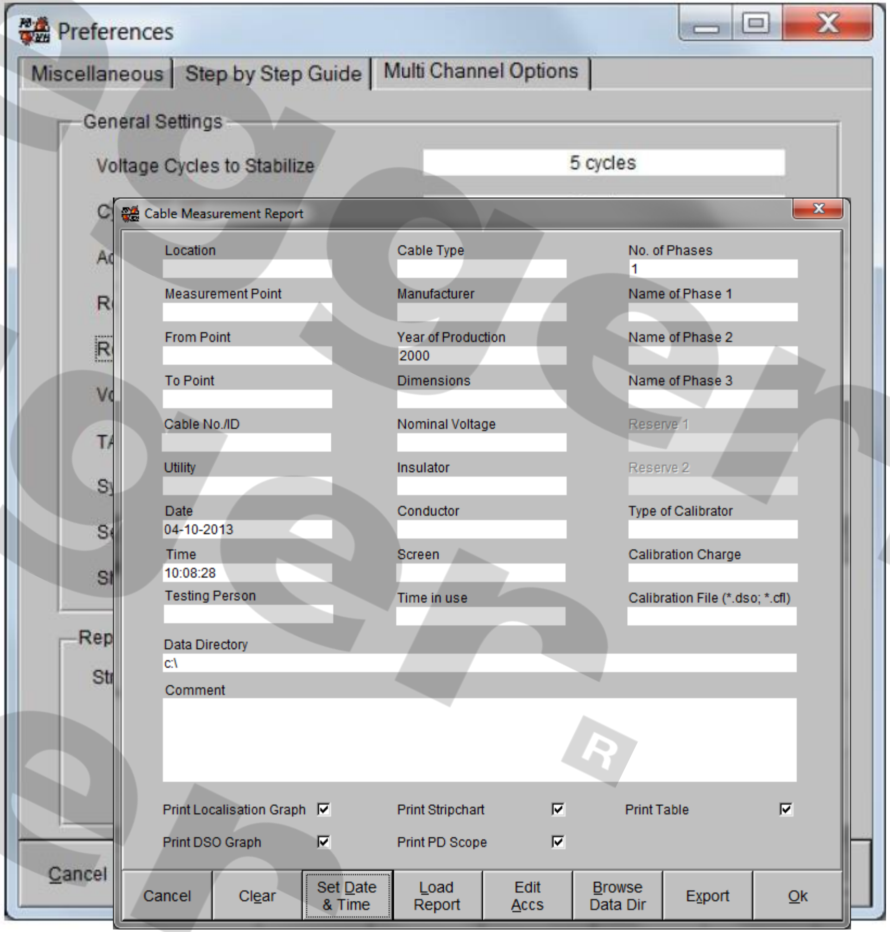
PD & TD Recording

- Auto and manual trigger
- Trending graphs of triggered data



ICM*flex* – Step by Step Guide

- Implemented into the ICMflex standard software
- Simplifies measurements
- Guided steps prior and during measurements
- Customized reporting tool
- Export data format .xls, .xlsx, .html



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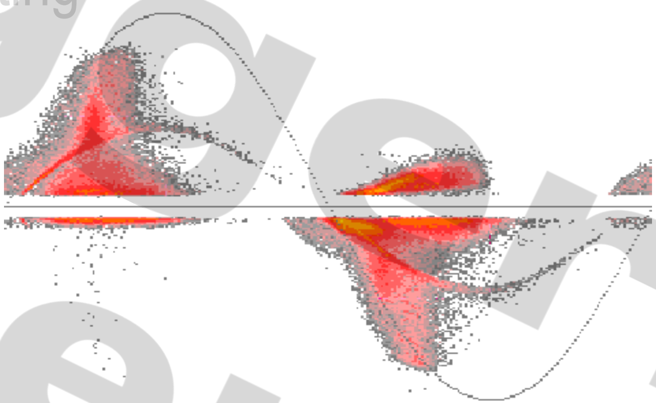

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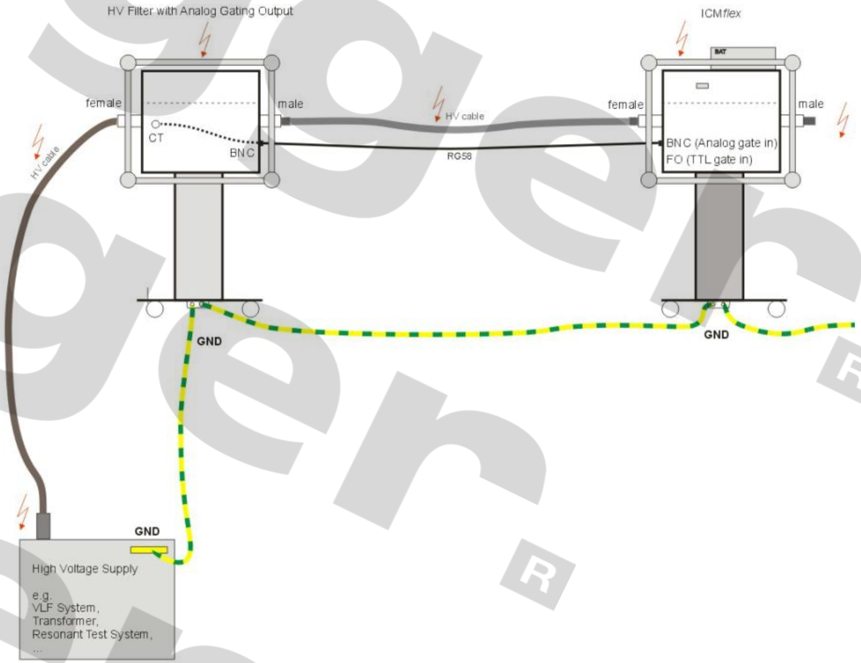
How to connect

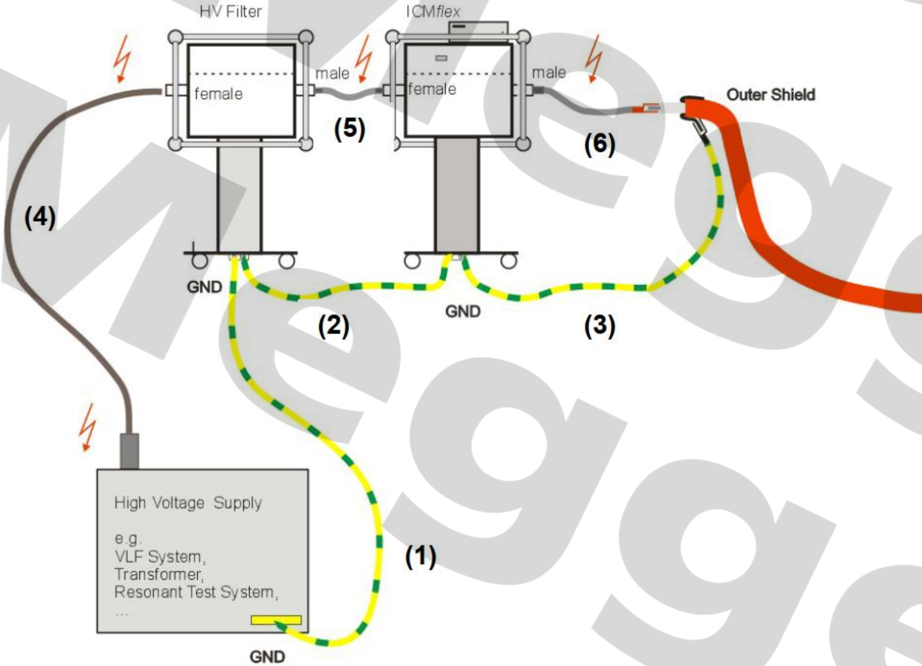
- It can be used with any fixed or portable HV power supply
  - Transformers
  - Hipots
  - Resonant test systems
  - Motor Generator Sets
  - VLF Systems

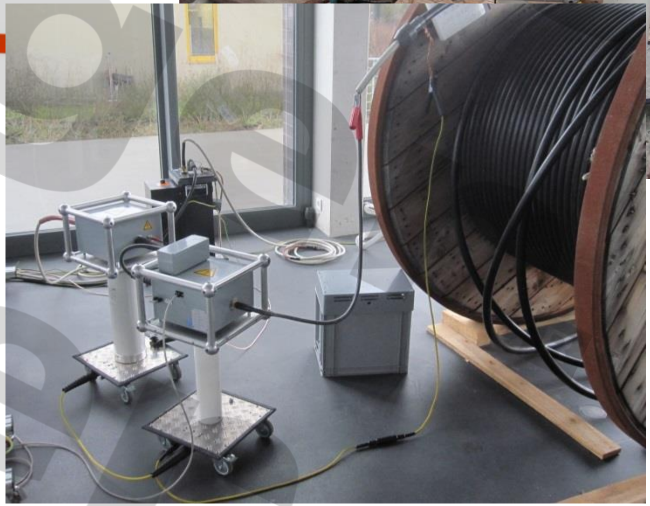
  (cos/square & Sine wave)



ICM*flex* – Connections

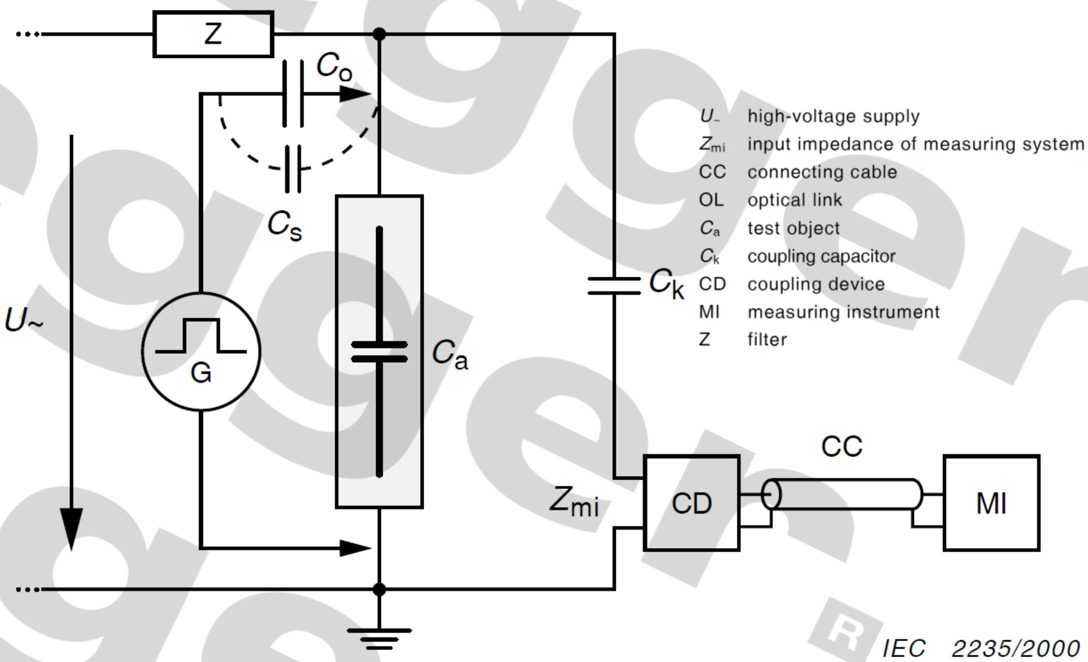
Measurement setup





IEC60270 compliant calibration

- PD measurements are relative
- Charge impulse is generated using a step voltage and an injection capacitor
- Charge impulse calibrator connected across the test object to simulate an equivalent discharge



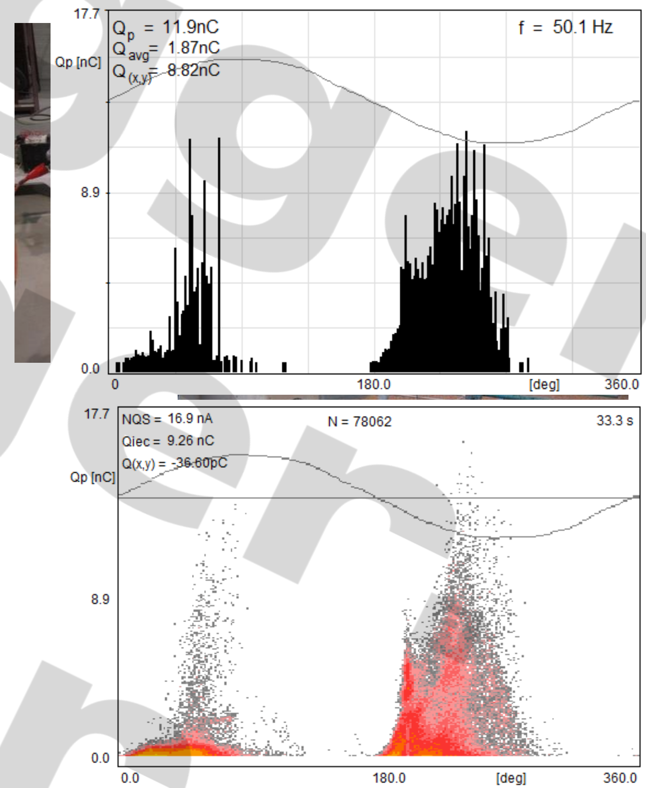
Calibration Procedure

- Calibration of the apparent charge
- The D.u.T has a capacitance against the ground shield (for MV/HV Cables 200pF/m to 425pF/m)
- Injected pulse is strongly attenuated
- The overall attenuation factor (k-factor) of the circuit must be compensated by calibration
- For lab applications acceptance level of typically 2pC to 10pC
- On-site measurements 100pC to 2nC (below 1MHz acc. to IEC60270)

ICM*flex* – PD Measurements

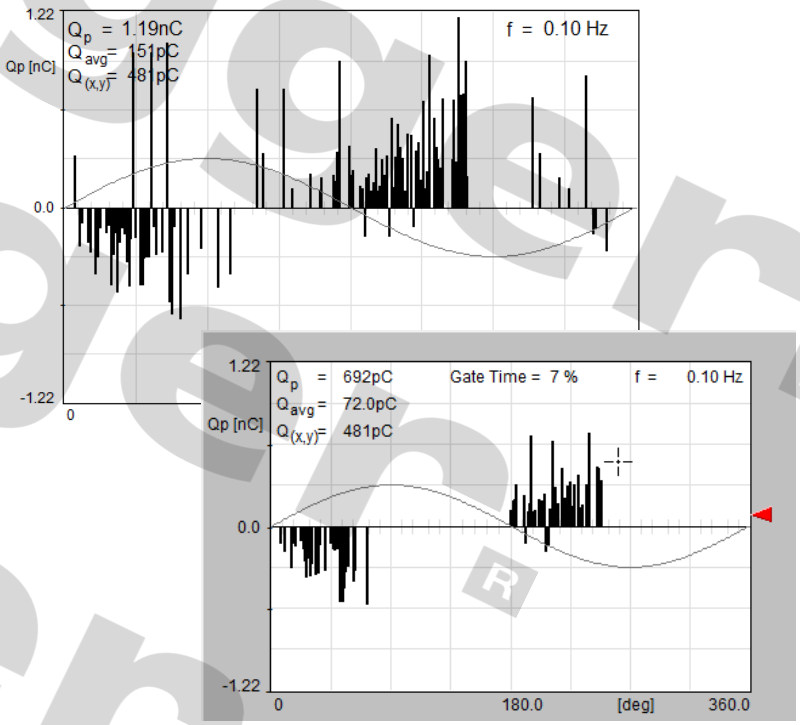
Standard PD Measurements

- Before switching on the voltage noise floor should be observed
- The next step is switching on the voltage and finding the inception voltage
- According to IEEE400.3 a healthy cable would not show a sign of PD before reaching 2Un.
- Once the PD is reached the PD pattern can be mapped
- PRPD can be then compared with typical patterns from known PD origins



Noise Cancellation

- Embedded HFCT in the HV Filter e.g. T50/1
- The bandwidth of the gating signal is set to 2-20 MHz
- Disturbance from VLF switching pulses, IGBT's, thyristor firing
- Phase stable pulse
- Excessive gating times must be prevented



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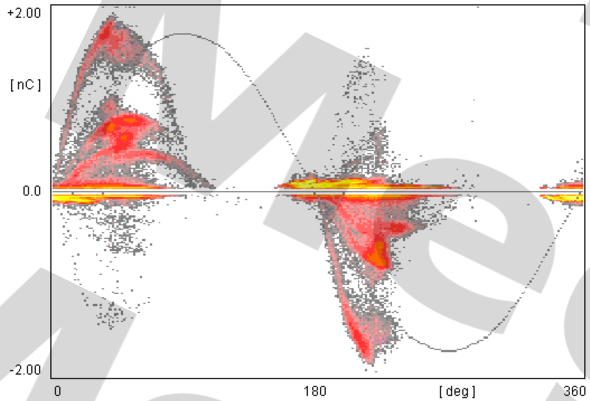
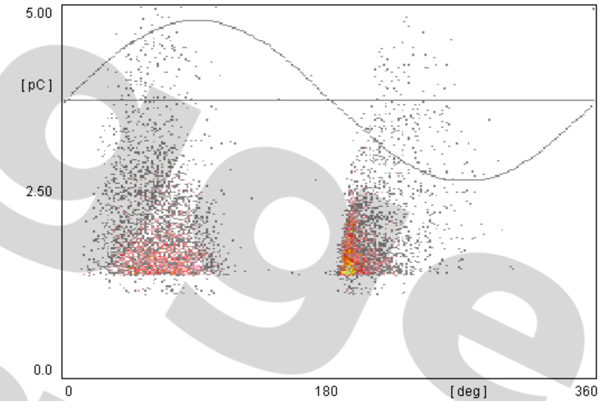
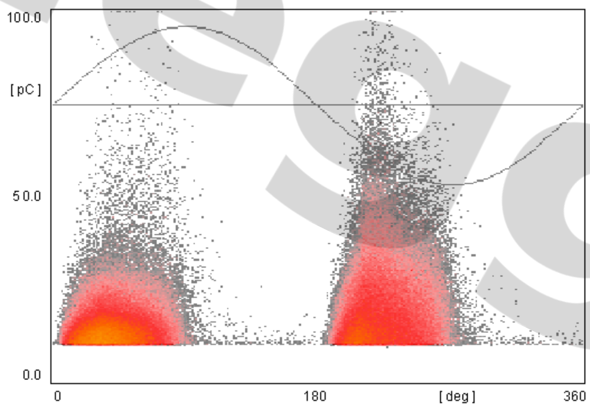
Cable Insulation – PRPD Examples



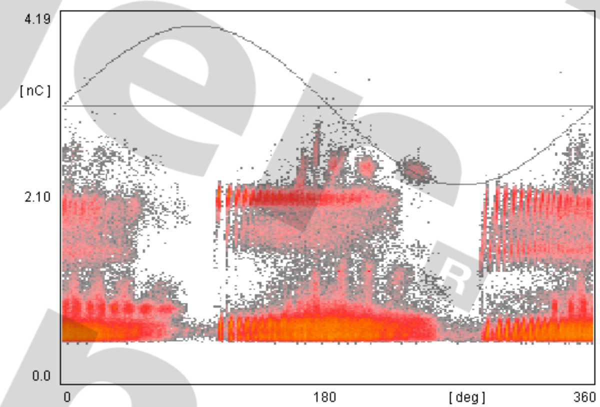
Several Flat Cavities in Silicon Fat due to Improper Mounting Procedures



Discharges in Wrapped XLPE Joint (Measured at 10MHz)

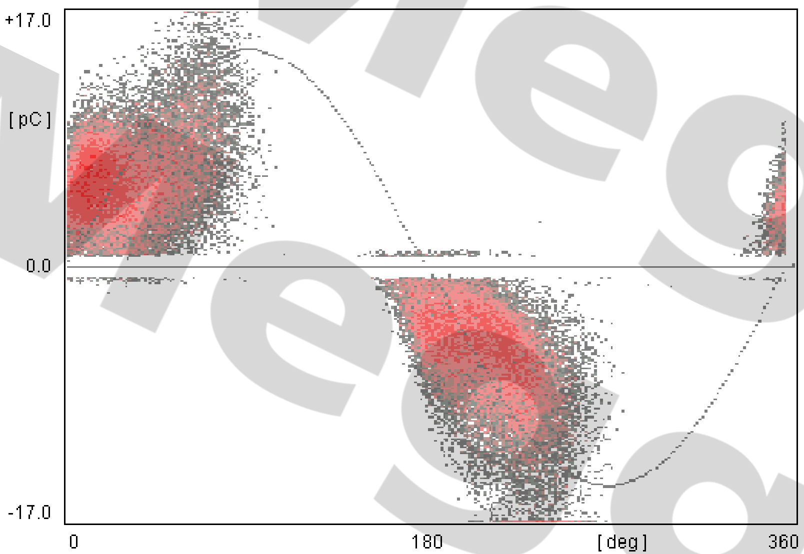


Delamination of the Outer Semiconductive Layer of a Prefabricated EPR Joint

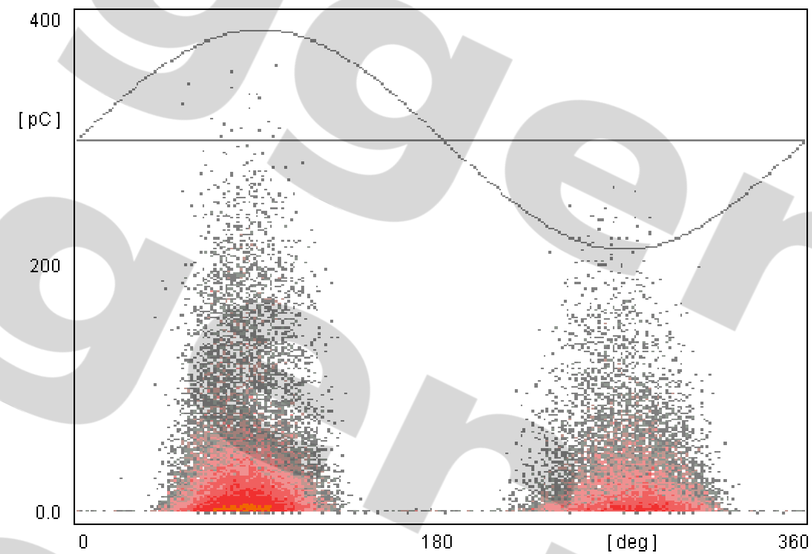


Contact Problem of the Field Control of a Wrapped Termination

Cable Insulation – PRPD Examples



Treeing in XLPE



Corona Discharge

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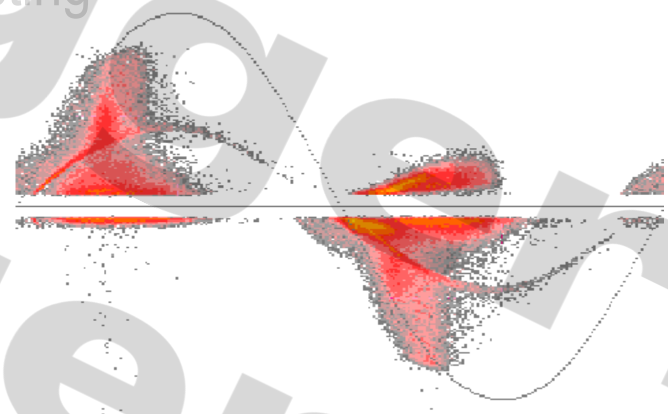
Offline PD and Tan Delta Measurements on MV/HV Cables

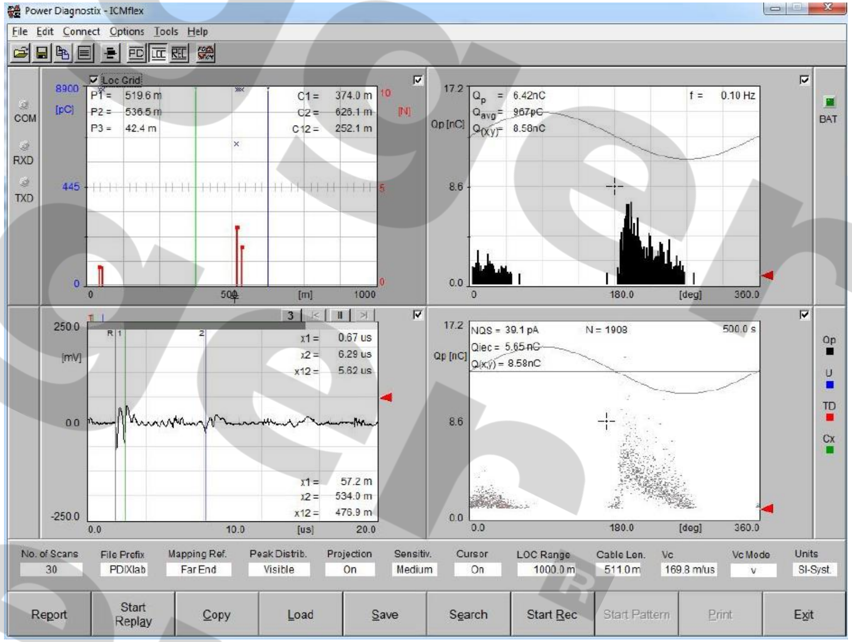
- Introduction – Why PD and Tan Delta Testing
- Normative references
- Partial discharge theory
- The ICM*flex* & Software
- Standard PD measurements
- **Cable fault location**
- Cable fault location using the ICM*system*



ICM*flex* – Cable Fault Location

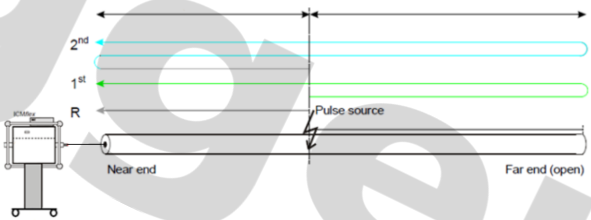
Overview

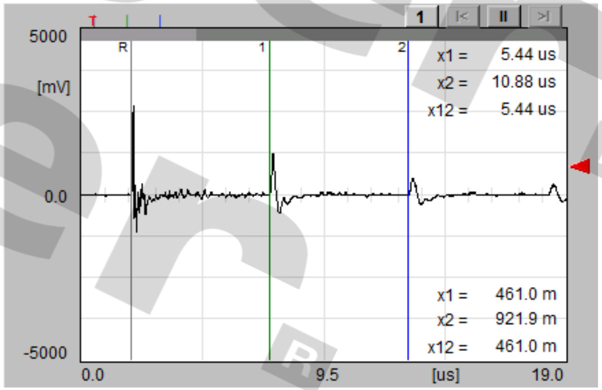
- Time domain reflectometry principle
- 8 bit, 100MSamples
- Precision:1m ±0.1% of the cable length
- Display range: 2 - 320µs
- Phase resolved PD pattern
- Display of PD accumulation vs. cable length (LOC graph)



TDR Principle

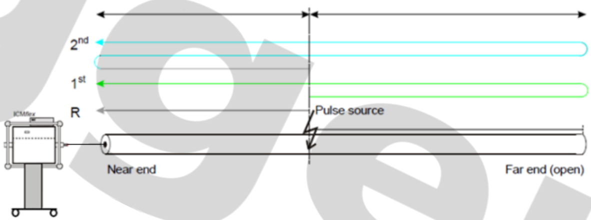
- Based on travel time of pulses along a conductor
- Cable behaves as a signal conductor
- Cable details are must be known:
  - Length of the cable
  - Pulse velocity of the cable
- Infinite impedance necessary for useful reflections

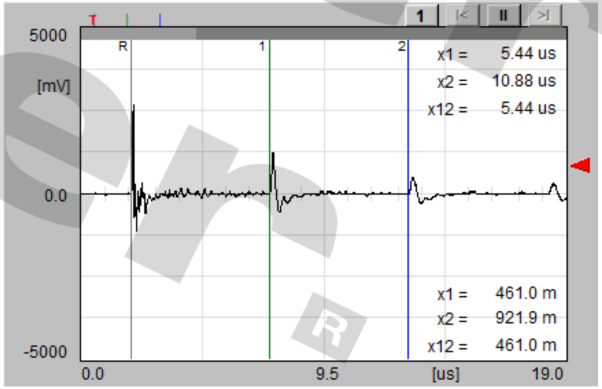




TDR Principle

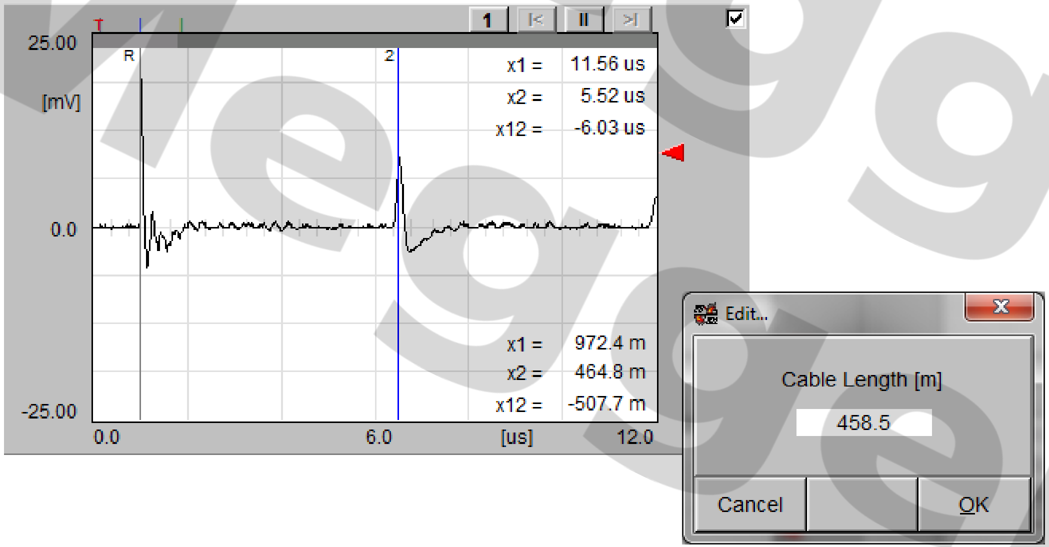
- Each pulse occurring over the cable length is reflected to the opposite end when reaching the end-terminations
- Location form the PD origin to both near and far end can be computed by the different arrival times of the signal reflections at the coupling unit
- The first three reflections captured by the measuring impedance are important
- The pulses undergo HF-effects i.e. attenuation, dispersion due to insulation system (semi-conductive layers)





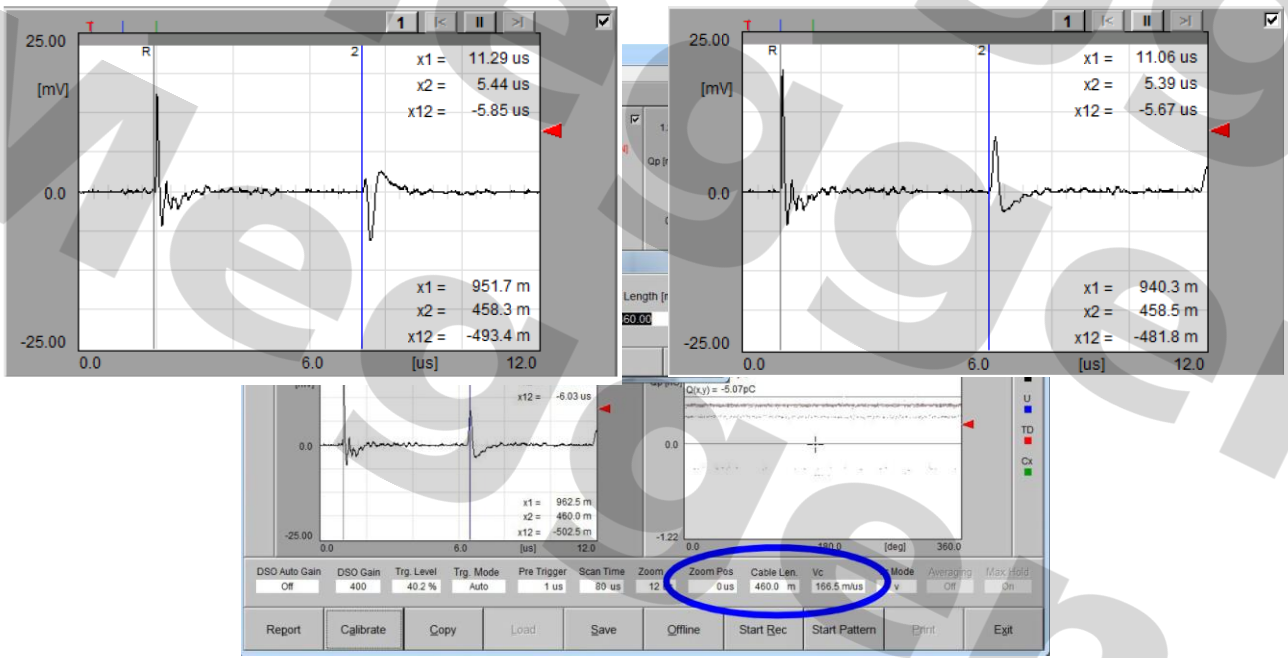
Calibration Procedure

- Calibration of the apparent charge
- Calibration of the cable length / pulse velocity
- Cursors must be positioned correctly



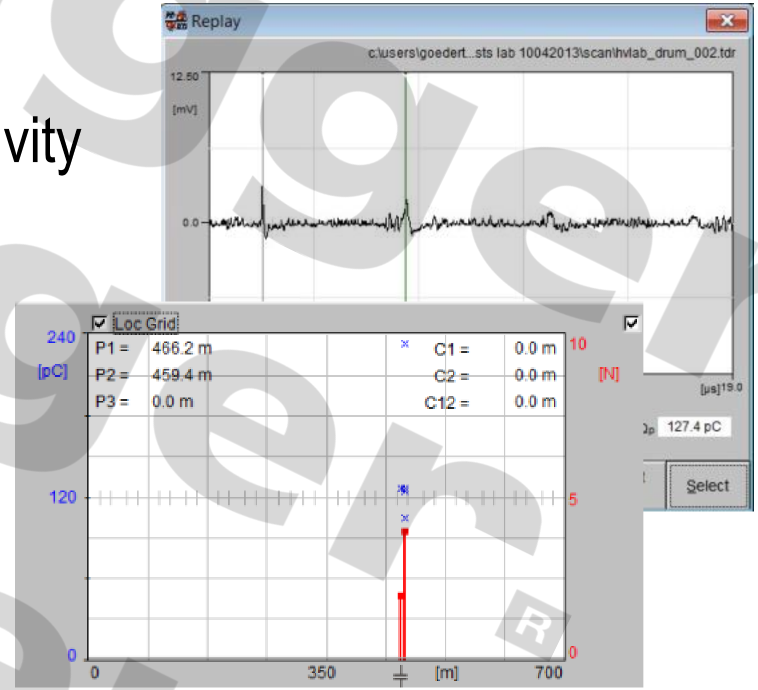
ICM*flex* – CFL Calibration procedure

- For calibration of the cable length cable terminations are disconnected on both sides



ICM*flex* – Cable Fault Location

- Cursors must be positioned correctly
- LOC diagram summarizes the PD activity
- The result of events are added and displayed as the total amplitude



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ICM*flex* – Sample package

Testing MV or HV cables

PD&TD measurements and Cable Fault Location

-1 x ICMflex acquisition unit with selected options

-1 x RC50/F (Reference capacitor up to 150kV$_{rms}$)

-1 x T50/1 (HV filter for up to 150kV$_{rms}$)

-1 x CAL1B (PD calibrator)

-1 x GST1 (optional for gating)

-1 x HFCT50/10 (optional for gating)

-1 x USBPFOC cable + 1 x Set of cables

- Introduction – Why PD and Tan Delta Testing
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- Standard PD measurements
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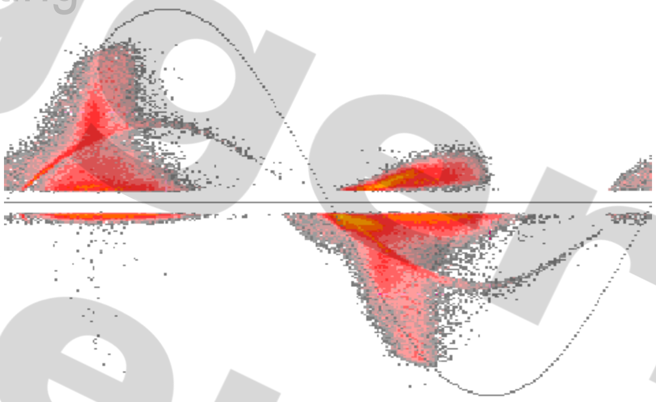
- Cable fault location using the ICM*system*



Megger

PD by Megger®
Power Diagnostix Systems

The ICM*system*

Product at a glance

- Advanced state of the art PD & TD measurement and analysis tool
- High end signal pre- and post-processing
- Highest modularity and robustness
- Simultaneous real time acquisition on up to 10 input channels
- Measurements under AC and DC
- Integrated acoustic PD location functions
- Integrated cable fault location feature
- All in one measurement system

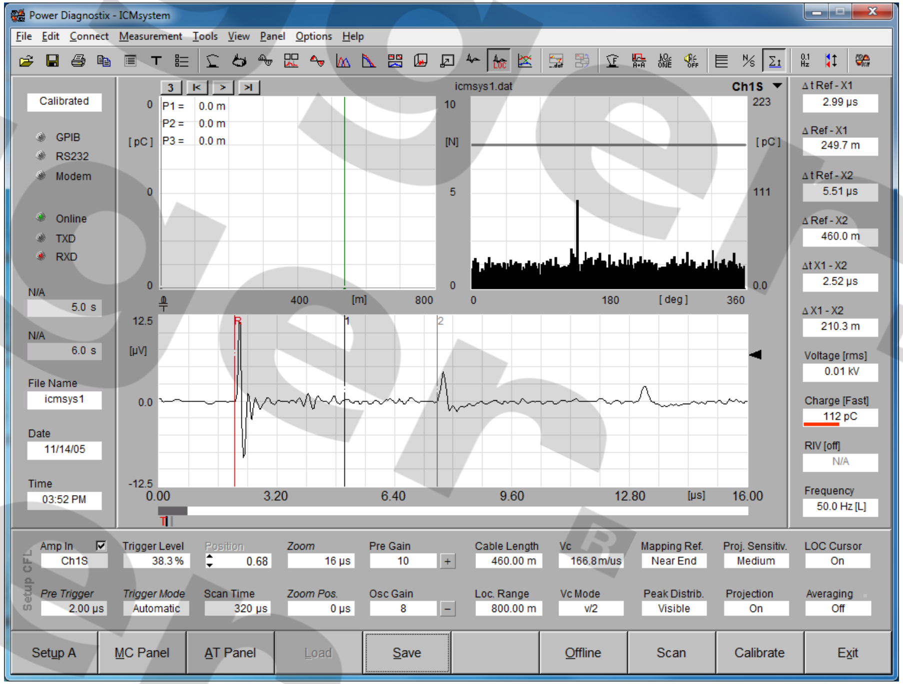
LPD by Megger®
Power Diagnostix Systems

The ICM*system* – Cable Fault Location

Technical Data

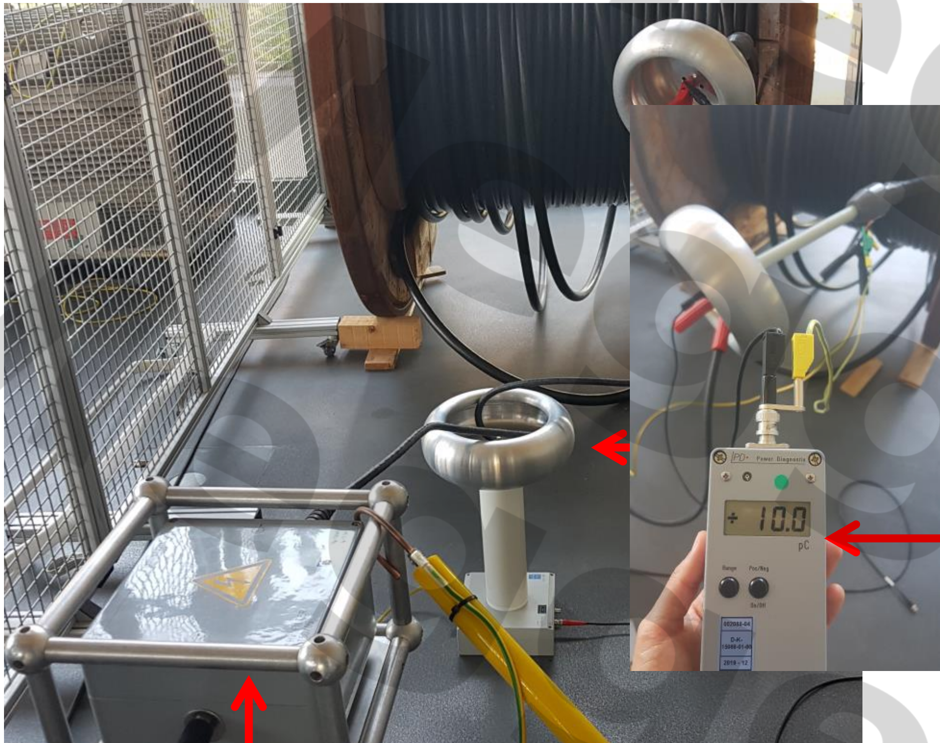
- 0 to 100% of input signal (step width in 3.125%)
- ±8bit A/D converter
- 100MSamples/s (reduced sample rates 25MS, 50MS)
- 1m + 0.1% of the length cable localization precision
- Cable length 10 to 5000m

for 80µs & Vc = 140m/µs



Testing of MV/HV cables

Calibration Procedure



The HV cable between CC50B/V and D.u.T

CC50B/V

The calibrator CAL1A

The preamplifier RPA1L

The 50kV HV filter

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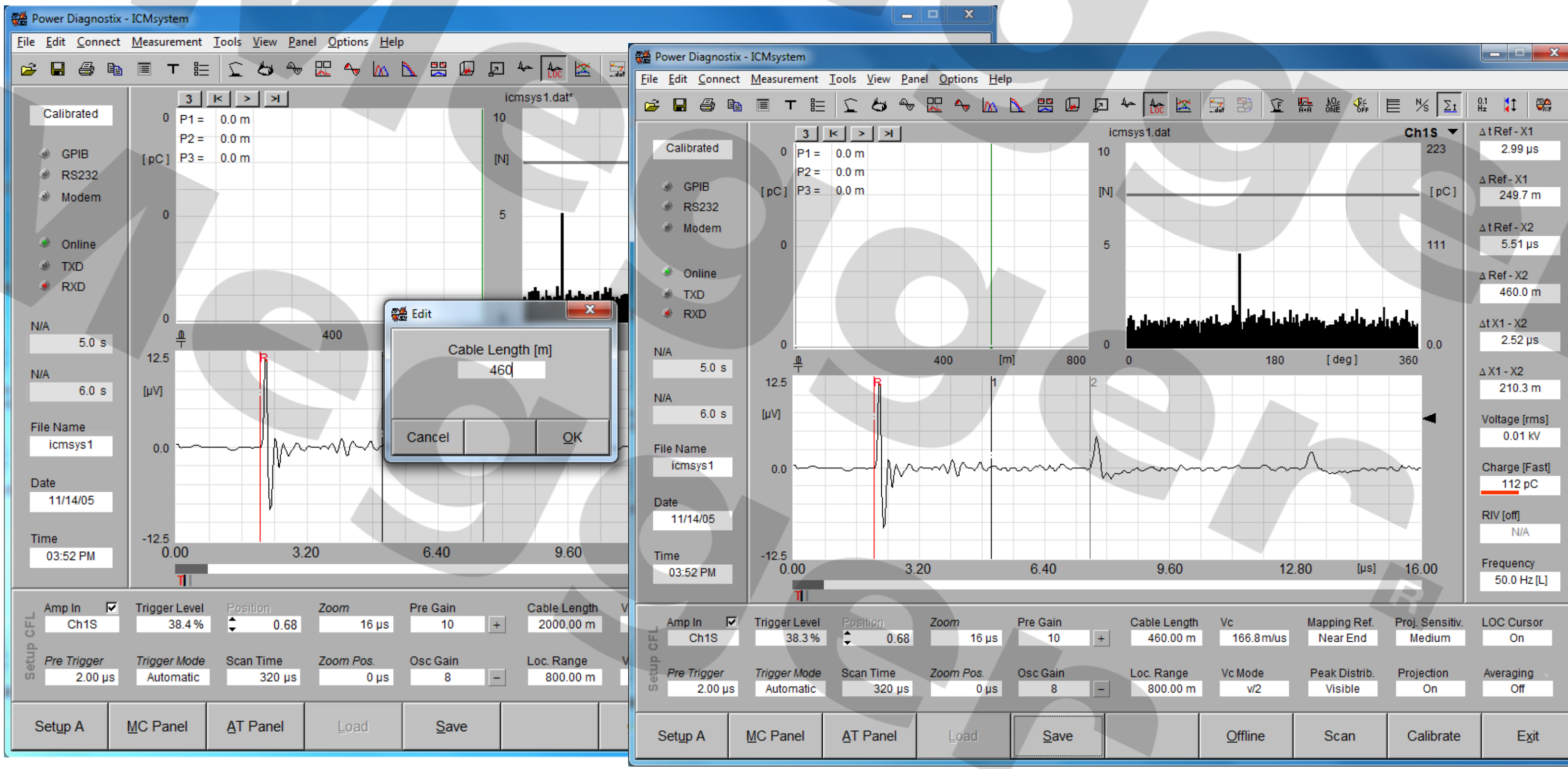
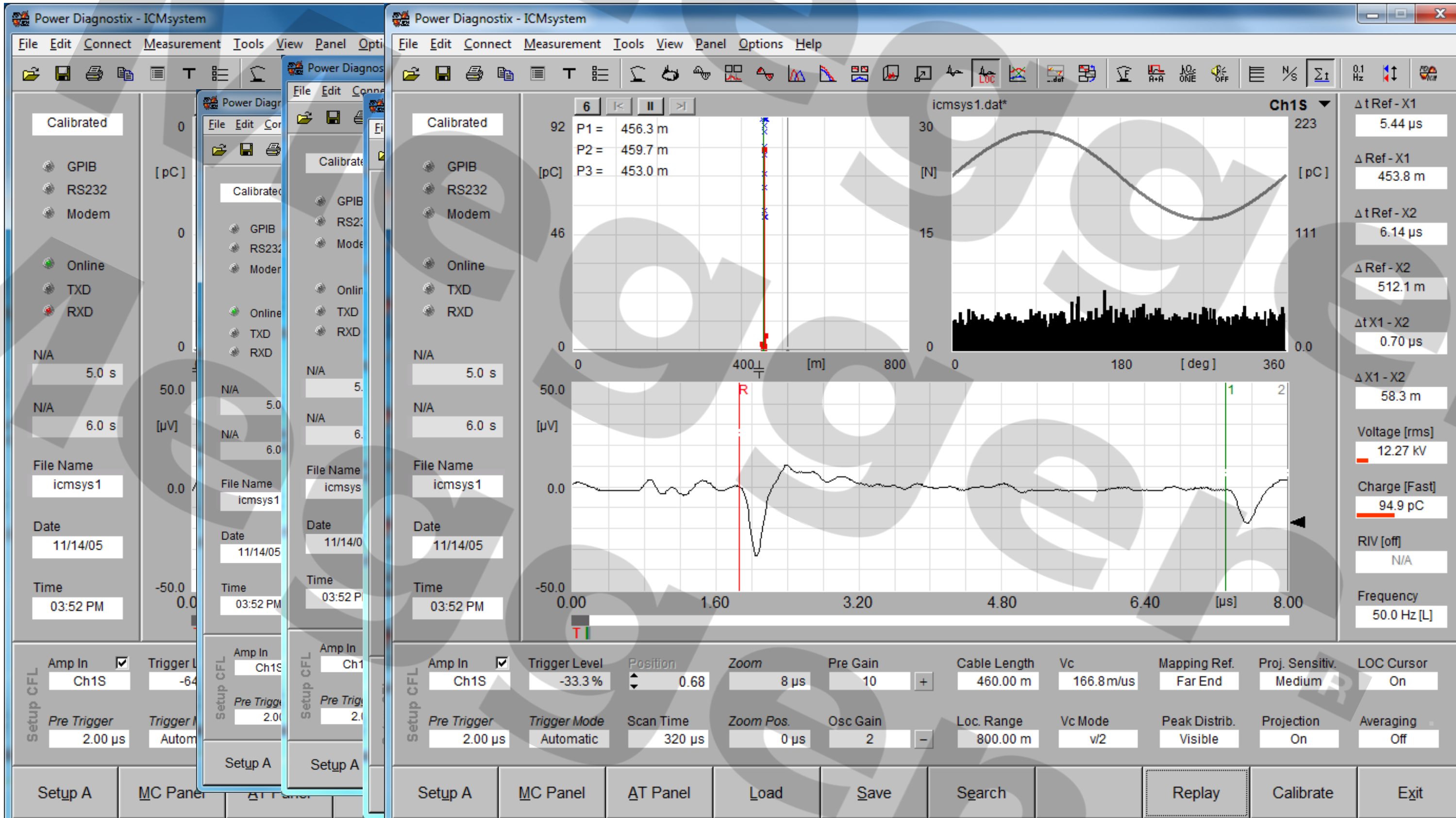
- Cursors must be positioned correctly



ICMsystem – Cable Fault Location



Configuration for MV/HV cables

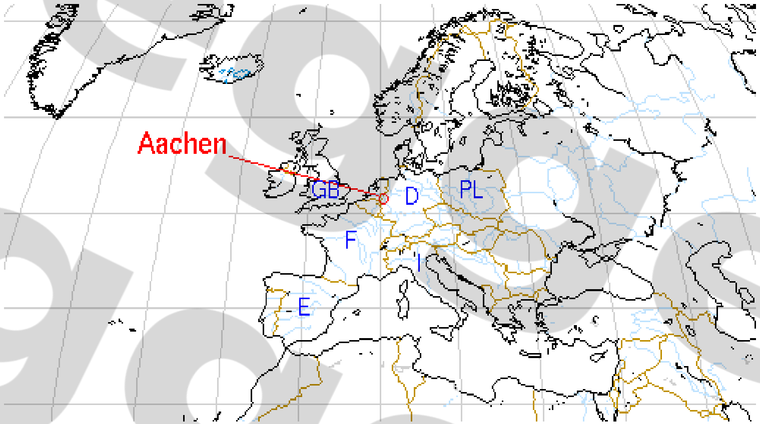
Minimum configuration:

- The ICM*system* acquisition unit with DSO for CFL
- 1 x coupling capacitor CC100D/V or
- Quadrupole CIT4M/Vxxx (2-12µF)
- 1 x preamplifier RPA1L
- PD calibrator CAL1A or CAL1B
- The ICM*system* Software

Full configuration:

- Spectrum Options (for noise elimination)

Thank you for your attention!



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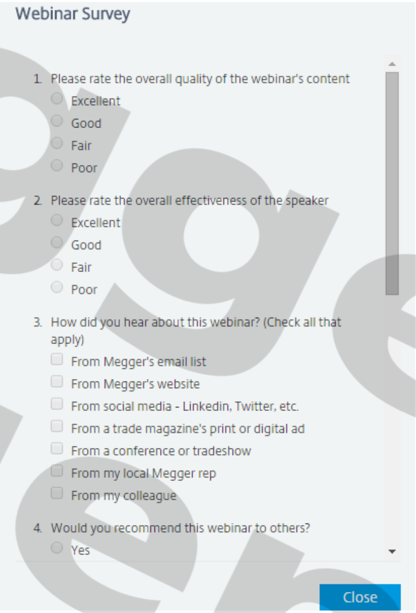

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