Non – Conventional PD – Measurements

IEC TC42 WG14

Michael Muhr

Institute of High Voltage Engineering
and System Management

University of Technology Graz

PD – Measurements

PD – location and detection

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Important diagnostic tool as nondestructive test

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Quality assurance for insulation systems

Macroscopic-physical effects by partial discharges

- Dielectric losses
- Pressure wave, sound
- Heat
- Light
- Chemical reaction
- High frequency wave

PD – Measurements

Detection methods

- Conventional electrical measurement
  - Integration at frequency domain
    - Narrow-band
    - Wide-band
  - Integration at time domain
- Electrical measurements with high frequencies
  - HF / VHF method – 40 MHz to 300 MHz
  - UHF method – 300 MHz to 3 GHz
- Acoustic measurements – 10 kHz to 300 kHz
- Optical measurements – ultraviolet – visible – infrared range
- Chemical measurement

PD – Measurements (Sensors)

Electric

electromagnetic wave-guide

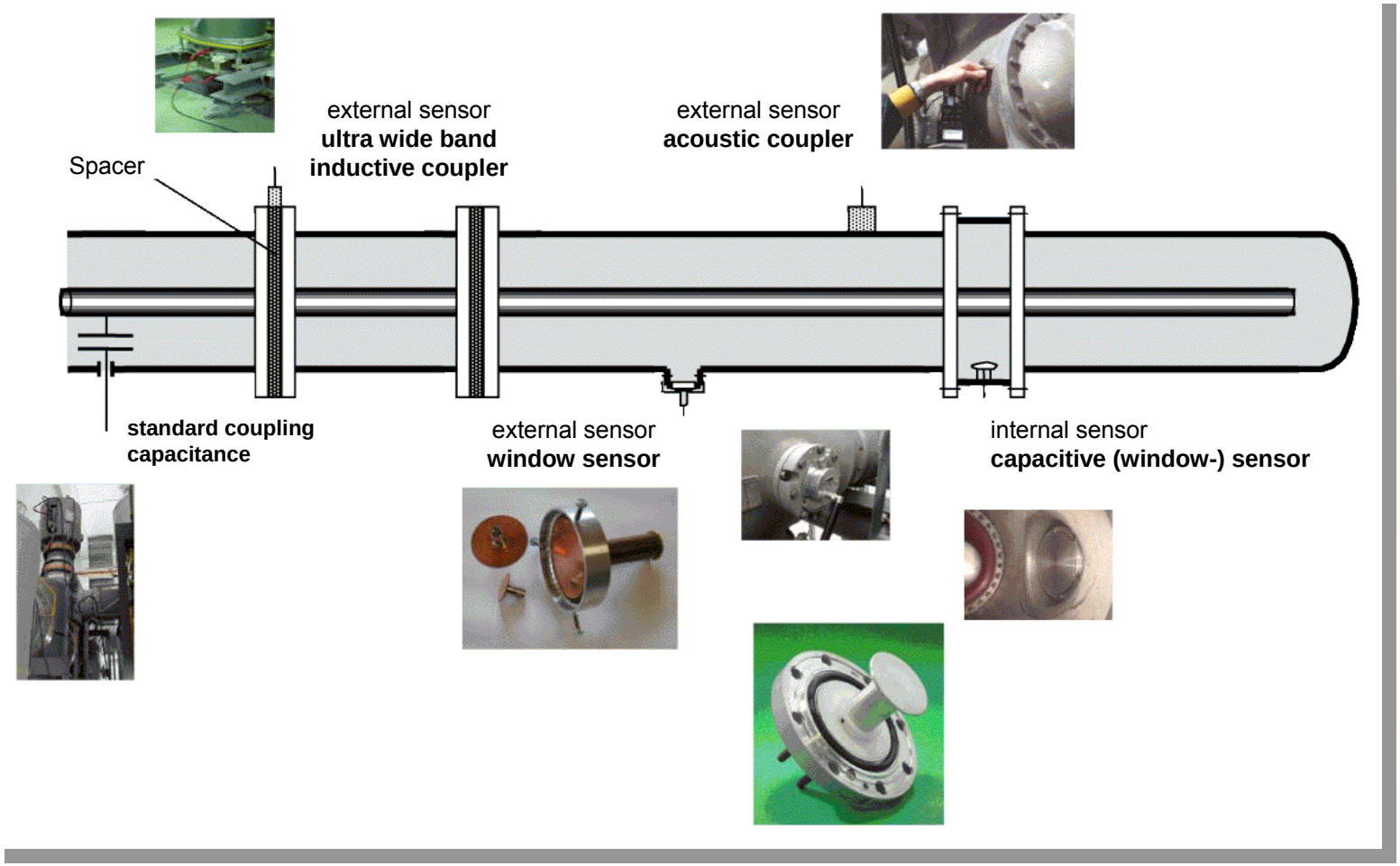
Acoustic

piezoelectric transducer

Optical

modulation-interferometer

PD – Measurements (GIS – PD – Decoupling)



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PD – Measurements (UHF)

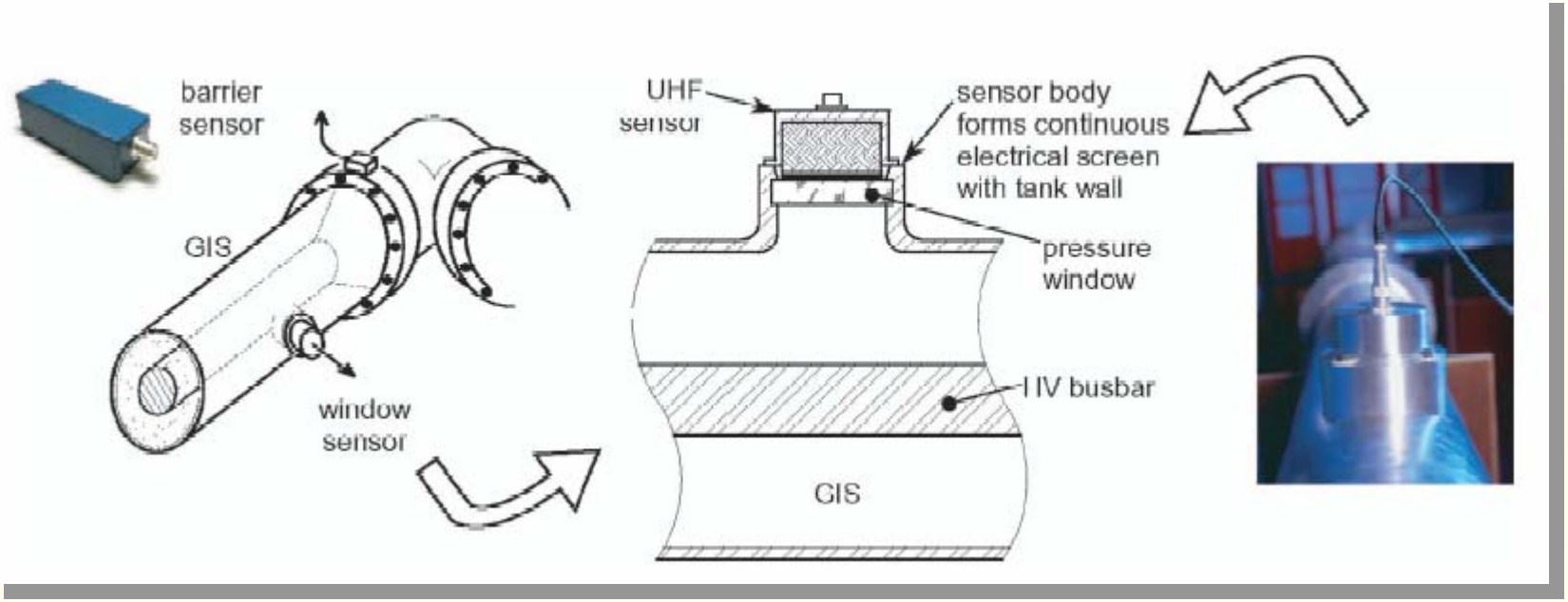
UHF – Partial Discharge Detection

- Transient electromagnetic waves (TEM, TE and TM modes) generated by partial discharges
- Frequency range 300 MHz to 3 GHz
- Measuring technique
  - Narrow band-bandwidth appr. 5 MHz
  - Wide band-frequency range 300 MHz to 1,5 GHz
- In 420 kV plants – upper critical frequency 1 GHz
- In 123 kV plants – upper critical frequency 1,5 GHz

PD – Measurements (UHF)

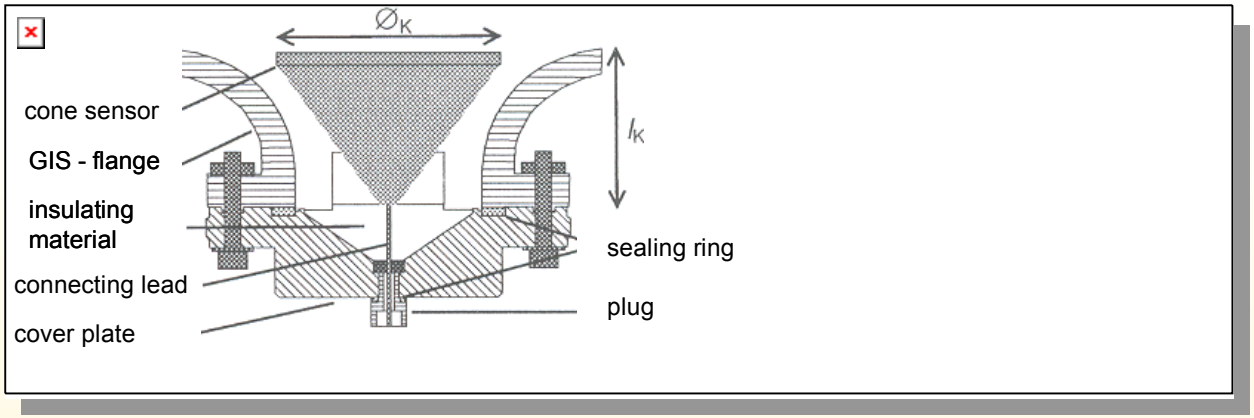
- Sensors
  - Conventional UHF sensors
    - Disc sensor
    - Cone sensor
  - Mobile UHF-window sensor
  - Field grading electrodes

PD – Measurements (UHF)

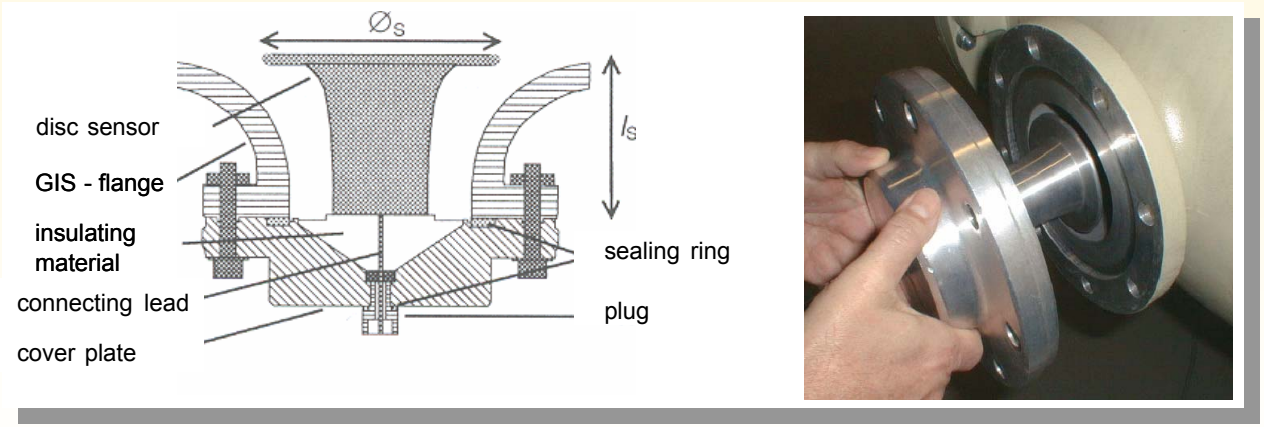


Externally mounted barrier and window sensors for GIS

PD – Measurements (UHF)



Sectional view and mounting of an UHF PD cone sensor



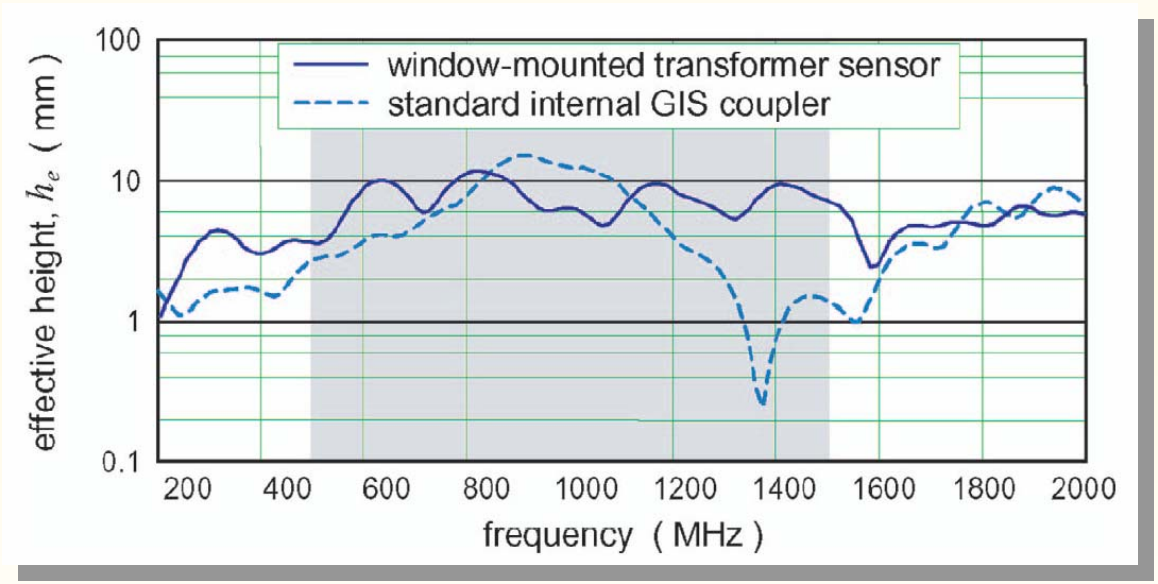
Sectional view and mounting of an UHF PD disk sensor

PD – Measurements (UHF)

- Damping dependent by
  - Frequency
  - Geometrie
  - Conductor material
  - Mode type
    - 1-2 dB / km (TEM, TE)
    - 4 dB / km (TM)
  - Reflection and refraction

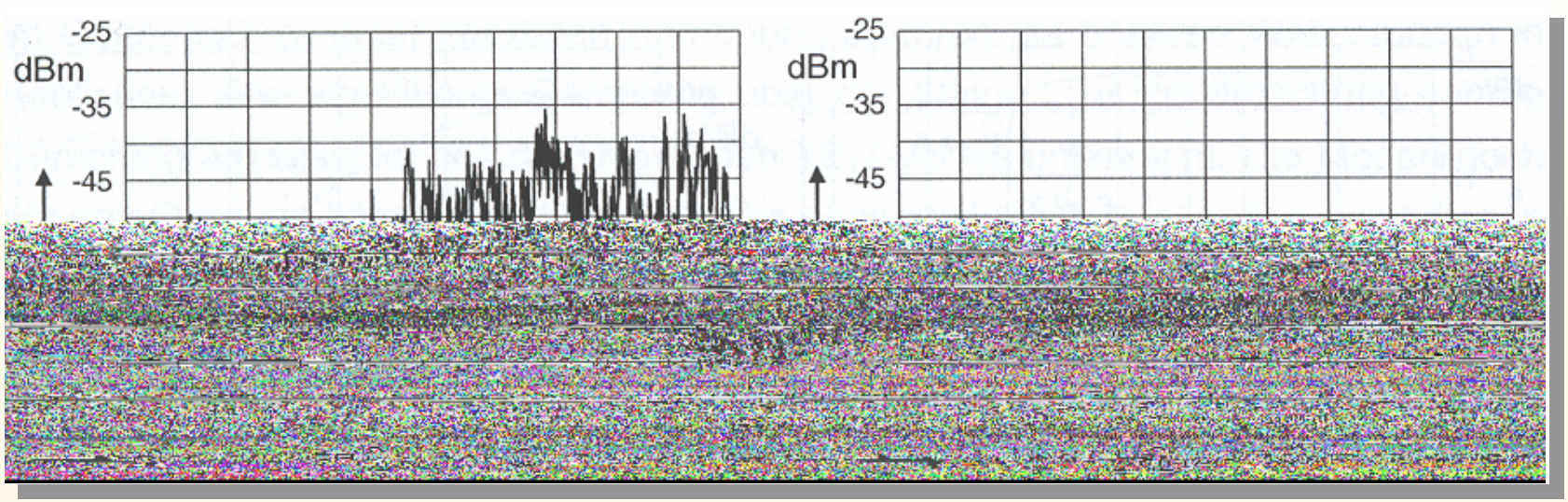
PD – Measurements (UHF)

- Sensivity
  - Facility configuration
  - Failure location
  - Location of the sensor
  - Measurement equipment



Frequency response of the window-mounted sensor compared with a UHF coupler for GIS. The shaded region defines the specified operating band of 500 to 1500 MHz

PD – Measurements (UHF)



Spectrum of a loose particle measured with a window sensor

a) Without flange extension

b) With flange extension of 10 cm

PD – Measurements (UHF)

Sensitivity of developed UHF sensors

PD – Measurements (UHF)

- Calibration

  Sensitivity verification

  - Comparison conventional measurement-UHF measurement

  Pulse generator

  - Demands of rise time and duration can be done

- Field of application
  - GIS, GIL
  - Transformer monitoring

PD – Measurements (UHF)

POWER TRANSFORMER
bushing tap

MONITORING SYSTEM

Decoupling unit with bushing tap adapter

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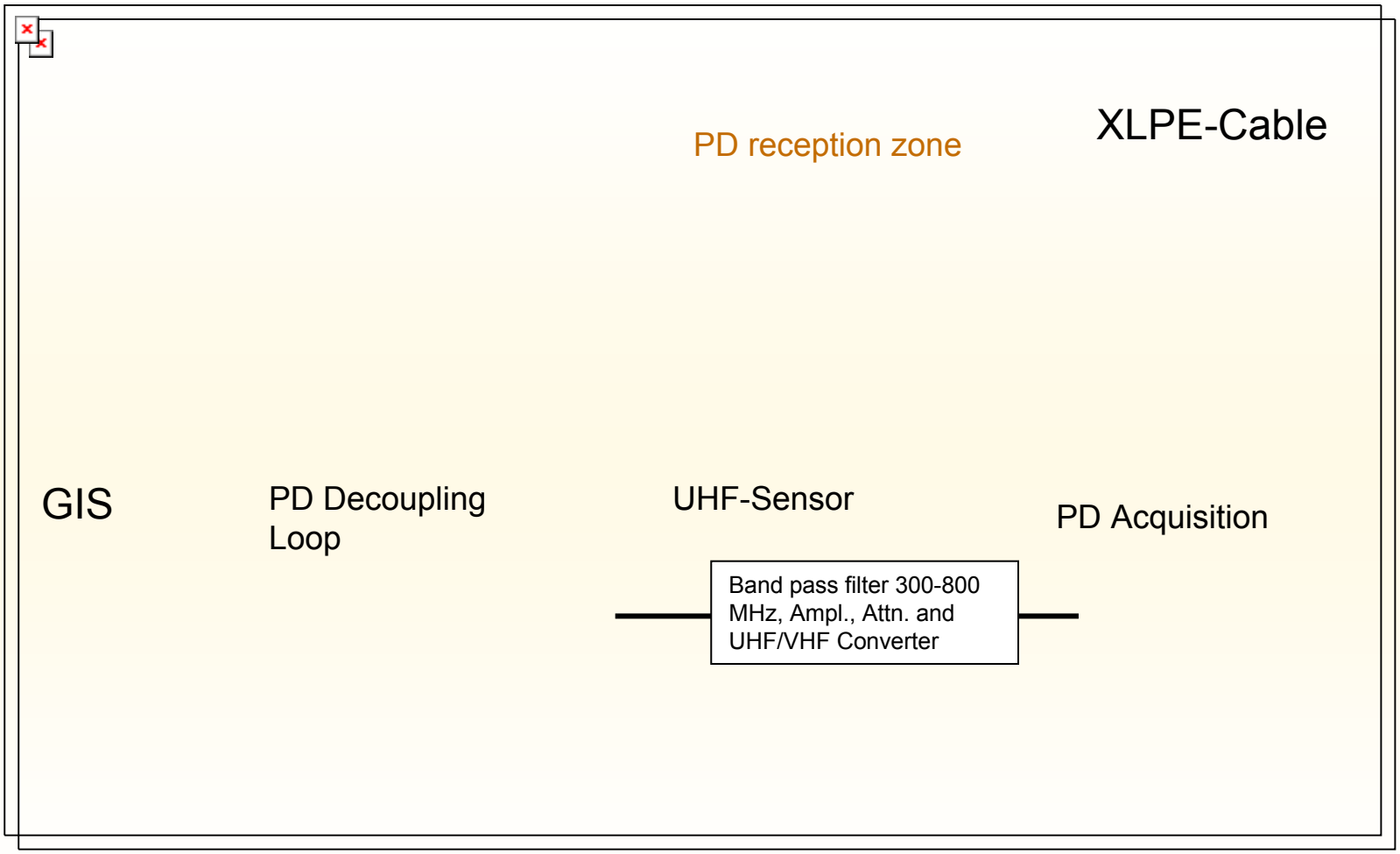
PD – Measurements (UHF)



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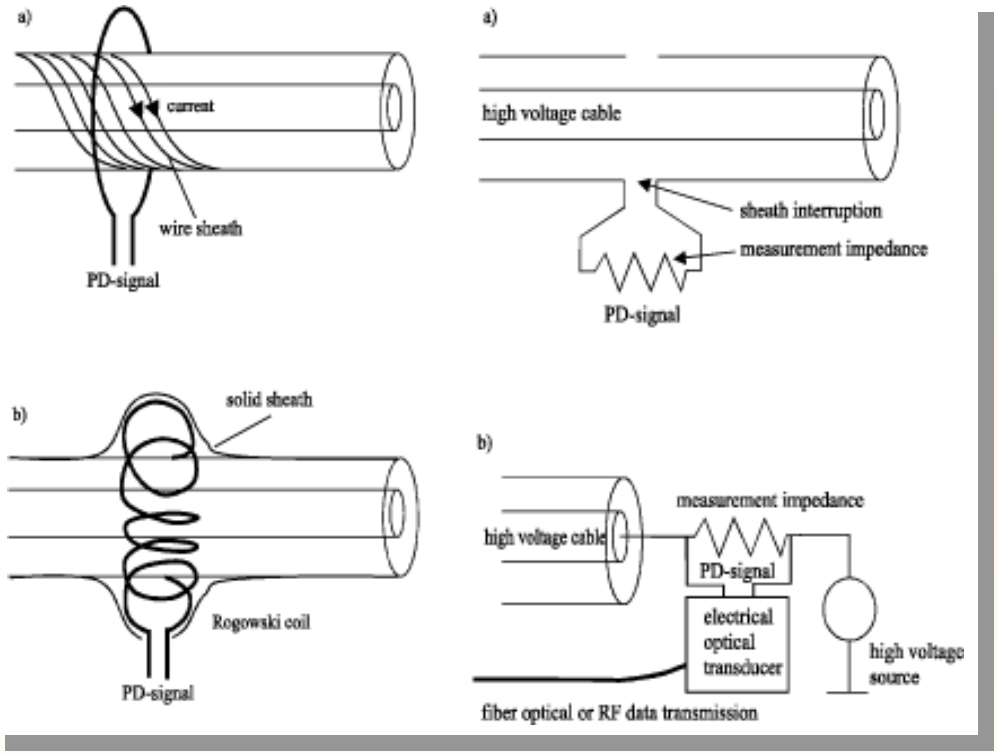
PD – Measurements (HF / VHF)

HF / VHF – Partial Discharge Detection

- PD's in polymeric insulations shows a duration of several nanoseconds. Transformation in frequency domain. Frequency spectrum up to 100 MHz
- Measurements technique
  Frequency range 40 MHz to 300 MHz
  - Narrow-band, band width < 2 MHz
  - Wide-band, band width > 50 MHz

PD – Measurements (HF / VHF)

- Sensors
  - Capacitive
  - Inductive
  - Electromagnetic

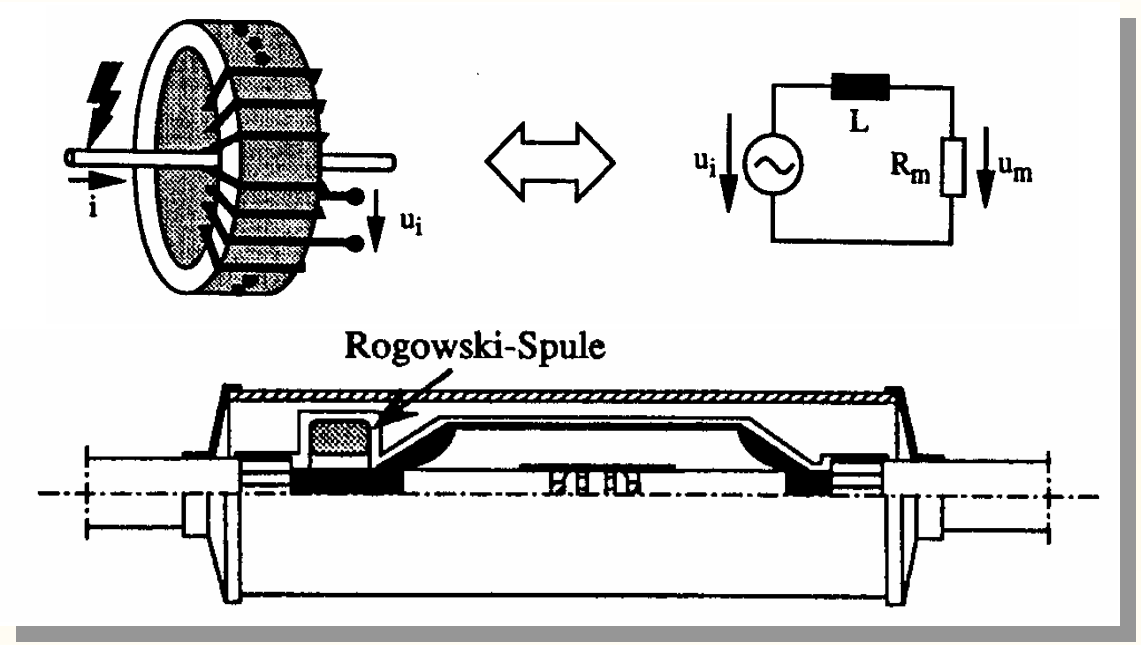


Used PD sensors

PD – Measurements (HF / VHF)

- Rogowski-coil

  Frequency range 1-40 MHz

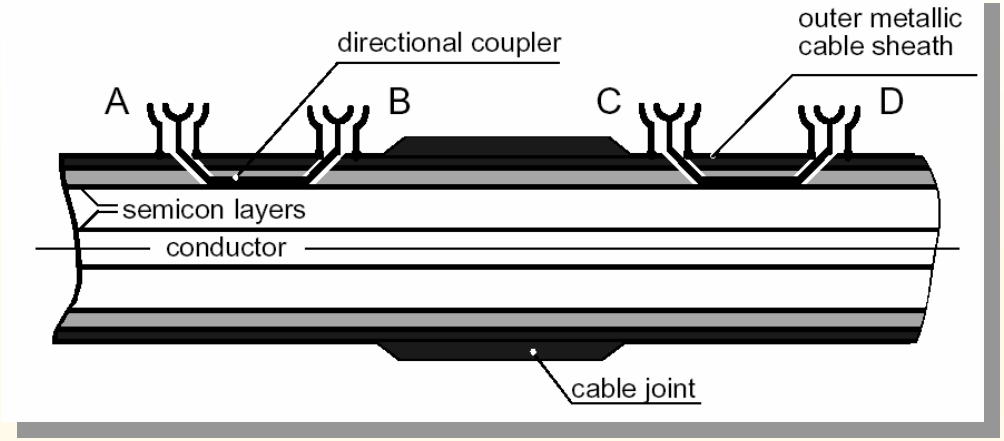


Schematic representation of a Rogowski coil to the inductive PD detection and the equivalent network as well as example of use (inside a joint)

PD – Measurements (HF / VHF)

- Directional coupler

  Frequency range 2-500 MHz



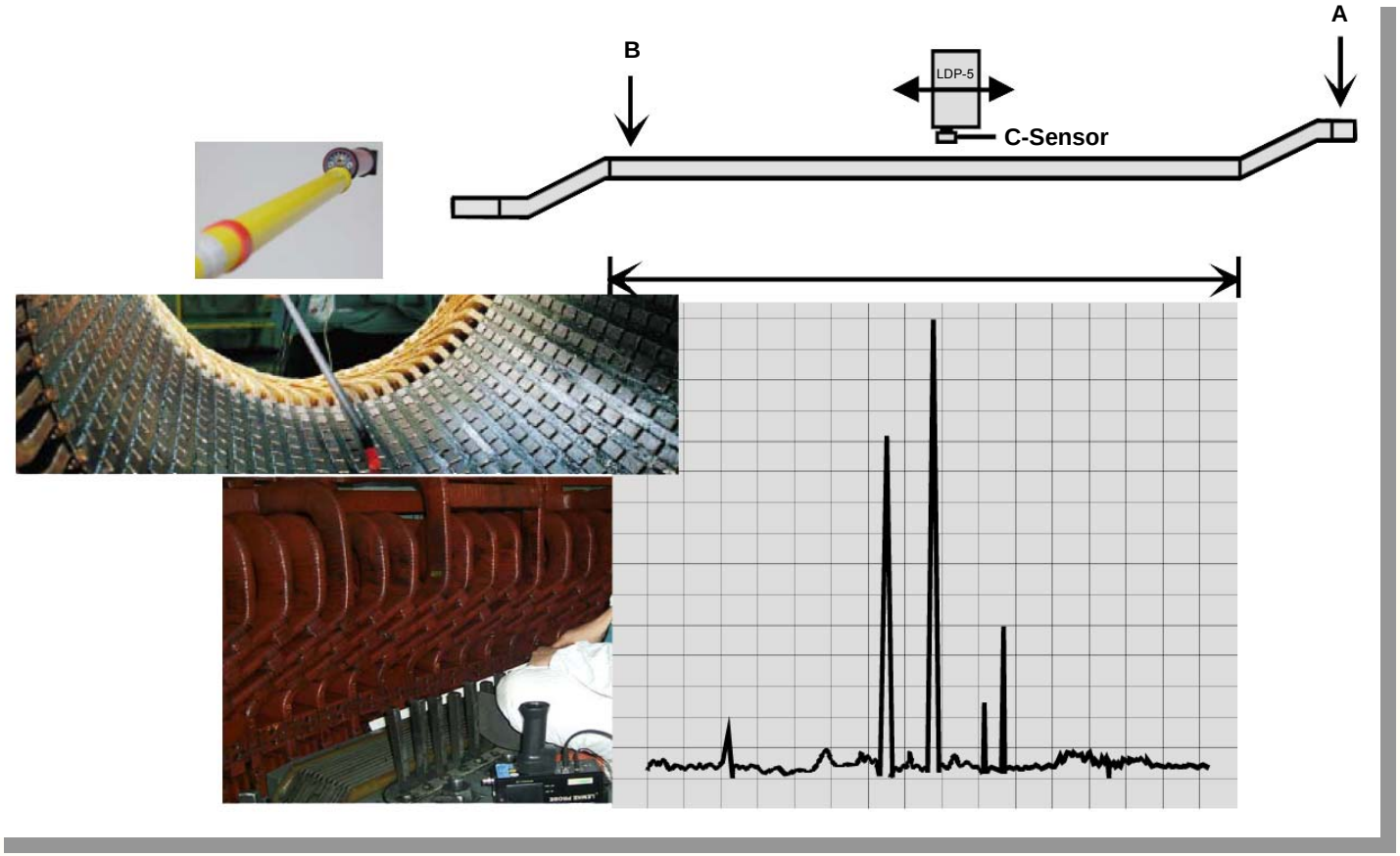
Principle of the coupler sensor

- Film electrodes
  - Capacitive sensor
  - Frequency range 1-50 MHz
  - Sensitivity 1 pC to 10 pC
- Yoke-coil
  - Inductive sensor
  - Frequency range 2-50 MHz
  - Sensitivity 10 pC

PD – Measurements (HF / VHF)

- Damping
  - Geometric proportions
  - Discontinuities
  - Impulse form
- Calibration
  - By means of two sensors with equal behaviour
- Application
  - High voltage cables
  - Transformers

PD – Measurements (HF / VHF)



PD-Localisation with Field-Sensors

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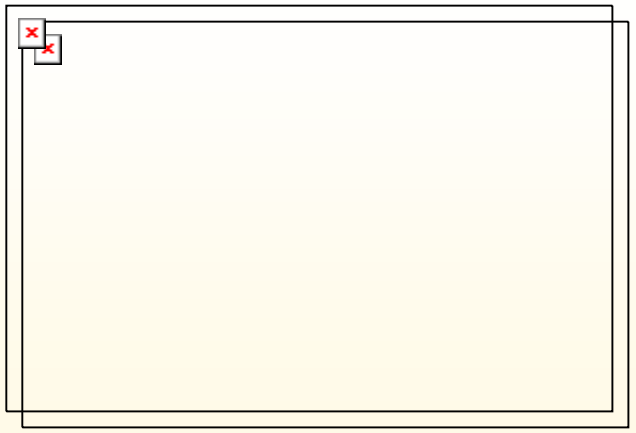
PD – Measurements (Acoustic)

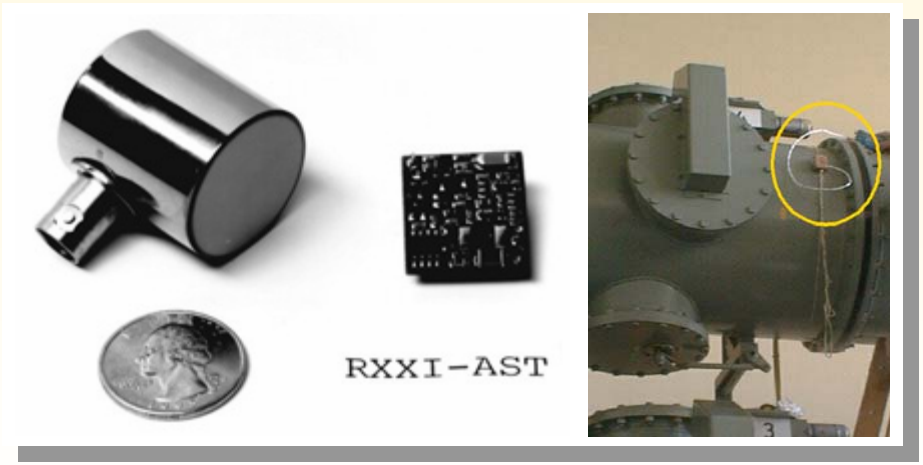
- Acoustic Partial Discharge Detection
  - Acoustic signal as a result of the pressure build-up caused by the generated spark in the insulation
  - Frequency spectrum 10 Hz up to 300 kHz
  - Different wave types (longitudinal and transversal waves) with different propagation velocities
- Measurement Technique
  - Microphones and ultrasonic directional microphones
  - Sound sensors, accelerometers and piezo-electric converters

PD – Measurements (Acoustic)

- Sensors
  - Piezo-electric (sound emission)
  - Structure-born sound-resonance
  - Accelerometer
  - Condenser microphones
  - Opto-acoustic sensor



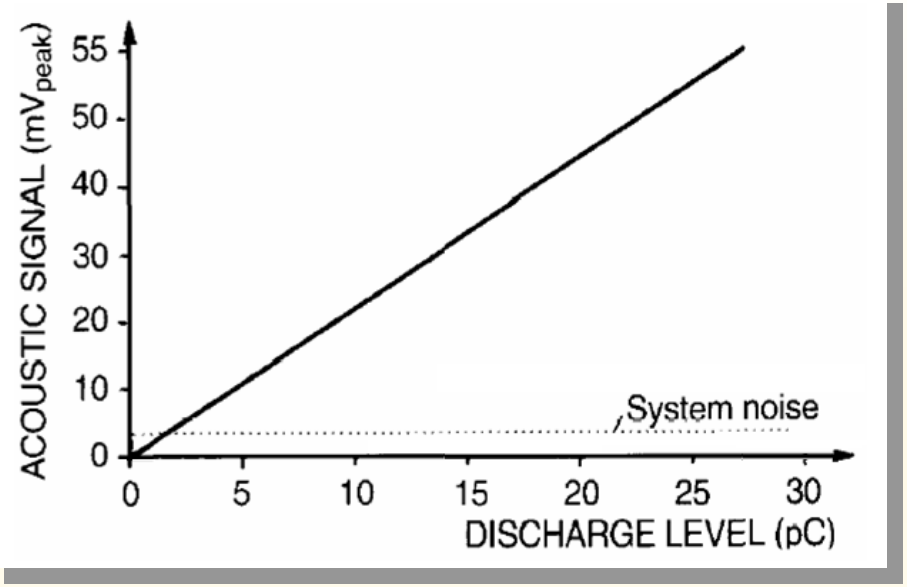
Ultrasonic measuring instrument with directional microphone



PD acoustic sensor

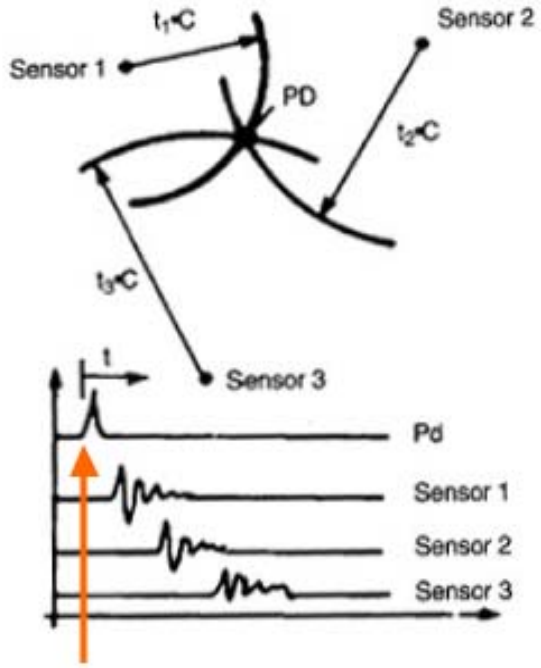
PD – Measurements (Acoustic)

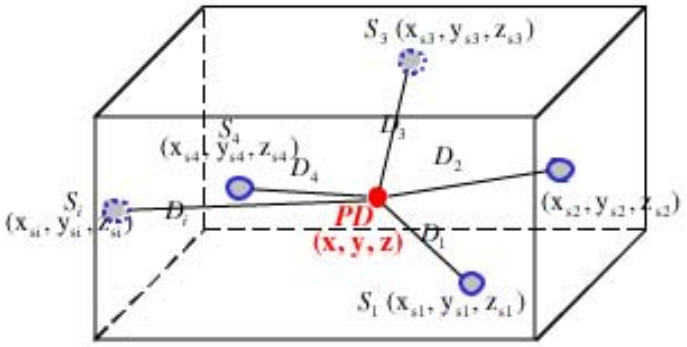
- Damping
  - Equipment dispersion
  - Construction
  - Insulation structures
  - Point of origin
  - Gas pressure
  - Encapsulation material
  - Absorption during a medium to another
  - Geometrical spreading of the wave
- Sensitivity



Example: Sensitivity of the acoustic PD detection in 300 kV GIS

PD – Measurements (Acoustic)





$$(x-x_{s1})^2+(y-y_{s1})^2+(z-z_{s1})^2=(v_s\cdot T_{S1})^2$$
$$(x-x_{s2})^2+(y-y_{s2})^2+(z-z_{s2})^2=(v_s\cdot T_{S2})^2$$
$$(x-x_{s3})^2+(y-y_{s3})^2+(z-z_{s3})^2=(v_s\cdot T_{S3})^2$$

- All acoustic method
- Mixed electric-acoustic method

PD – Measurements (Acoustic)

- Calibration
  - Normally not possible
  - Function control with a wide-band acoustic pulse
- Field of application
  - High voltage cables
  - GIS
  - Transformers
  - Overhead lines

PD – Measurements (Acoustic)

- A disc-shaped UHF-sensor for a standardized valve (DN 80) was installed in service
- Transient recorder with 3 GHz analoge bandwidth
- No amplification of the UHF-signals

- 380/220 kV, 200 MVA single-phase transformer

IEH S. Tenbohlen

PD – Measurements (Chemical)

Chemical Partial Discharge Detection

- Determination of decomposition products in the insulating material caused by pd's
- Oil analysis – generating of gases
- Air pd's – NOX, ozone
- Sensors and analyzers
  - H_2
  - DGA
  - Ozone
  - Gas analysis
- Calibration – not possible, chemical analysis
- Field of application
  - Transformer diagnosis
  - Rotating machines
  - Gas-insulated switchgears

PD – Measurements (Chemical)

Fehlerart	$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$
PD	-	<0,1	<0,2
D1	>1	0,1 – 0,5	>1
D2	0,6 – 2,5	0,1 – 1	>2
T1	-	>1	<1
T2	<0,1	>1	1 – 4
T3	<0,2	>1	> 4

IEC DGA Gas ratio values

- PD partial discharges
- D1 discharges with low energy
- D2 discharges with high energy
- T1 temperatures T < 300° C
- T2 temperatures 300° C < T < 700° C
- T3 temperatures T > 700° C

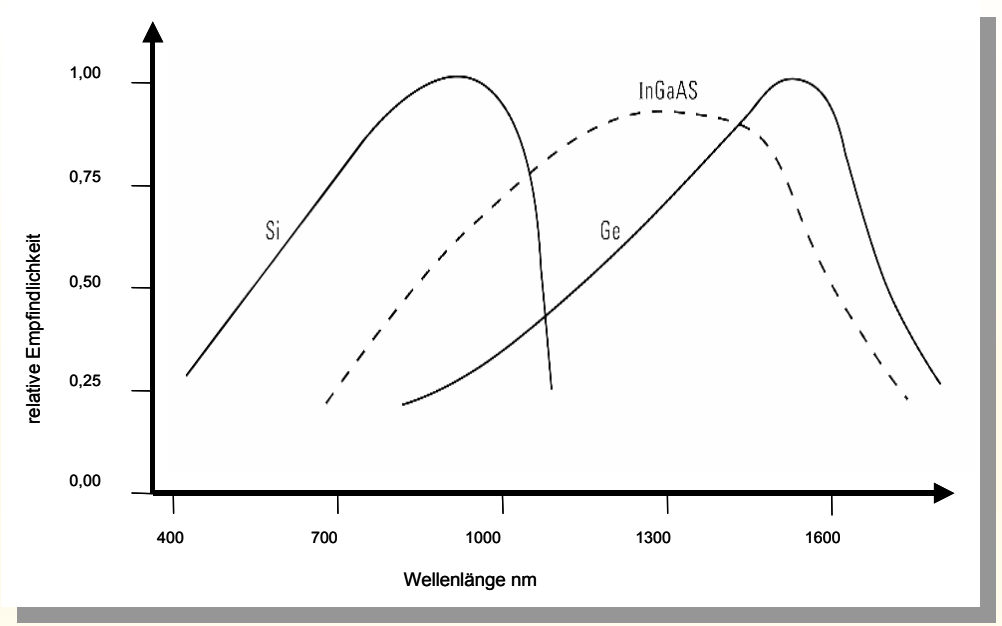
PD – Measurements (Optical)

Optical Partial Discharge Detection

- Based upon the detection of light produced during the discharge
- Measurement technique
  - Ultraviolet
  - Visible
  - Infrared
  - Surface detection
  - Detection inside of the equipment

PD – Measurements (Optical)

- Sensors
  - UV-corona
  - Night vision
  - Low-light enhancer
  - Photodiode, photomultiplier (with fibre optic cable)



Relative spectral sensitivity as a function of the wavelength of different detector materials

PD – Measurements (Optical)

- Damping
  - Operational equipment
  - Absorption, dispersion, refraction
  - Geometry
  - Scattered light
  - Medium
- Sensitivity
  - Dependent from the equipment configuration, location of the defect, location of the sensor, cable connection, measuring instrument
- Calibration
  - Not calibratable
- Field of application
  - Localisation of detective regions

PD – Measurements (Optical)

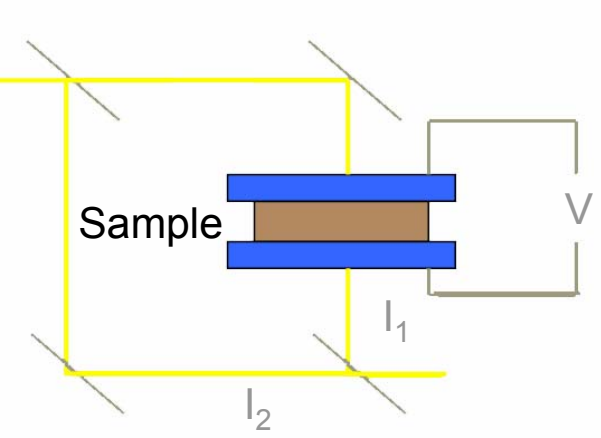
Modulation Interferometer for direct PD Signal Field Sensing:

- Light passes through a medium with an electric field applied across the material, the light will experience a phase shift
- Applied Inorganic $LiNbO_3$ Mach-Zehnder Interferometer (Organic Polymer Films under development)
- Bandwidth: 1 Hz – 10 GHz
- DFB Laser drives Single Mode Optical Fiber

Transmittance:

$$T(V) = \cos^2\left(\frac{\Phi_0}{2} - \frac{\pi}{2}\frac{V}{V_\pi}\right)$$

Application: directly fitted above semicon layer (joint, cable) or in GIS tube



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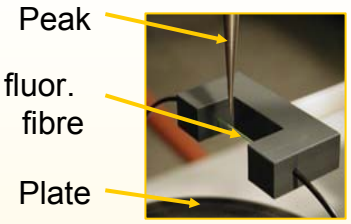
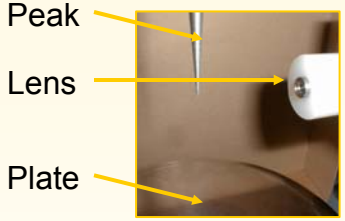
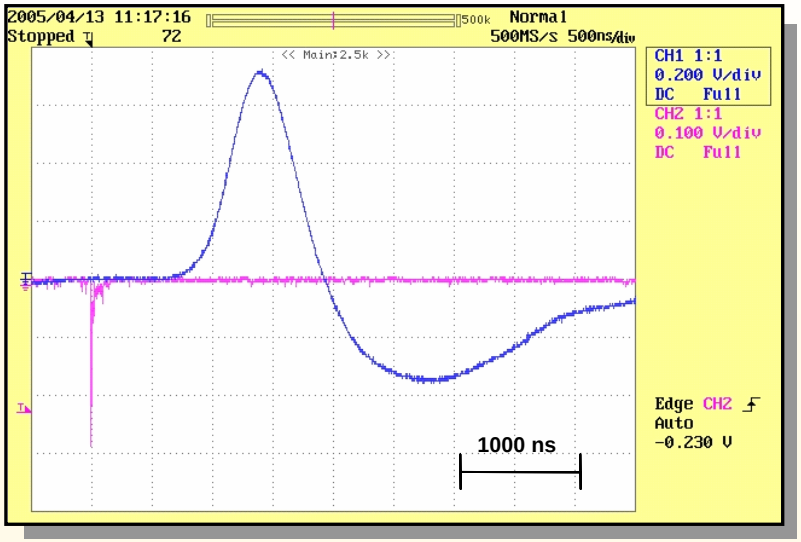
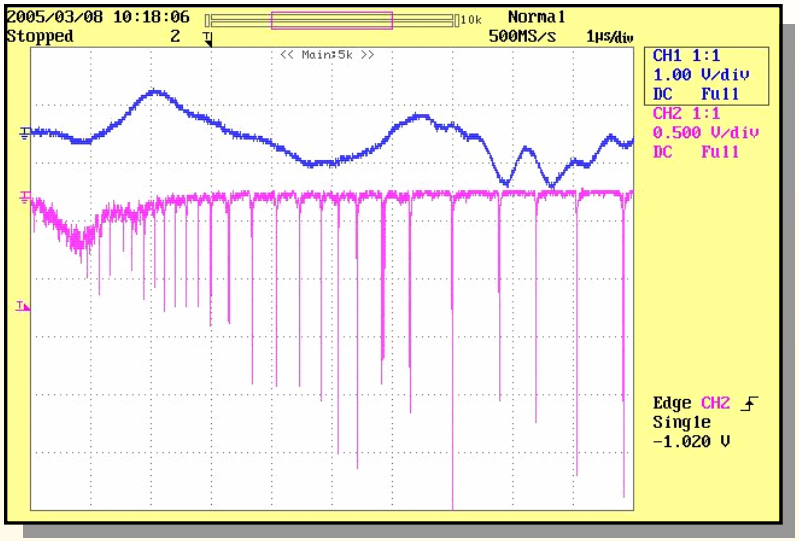
PD – Measurements (Optical)





PD – Measurements (Optical)



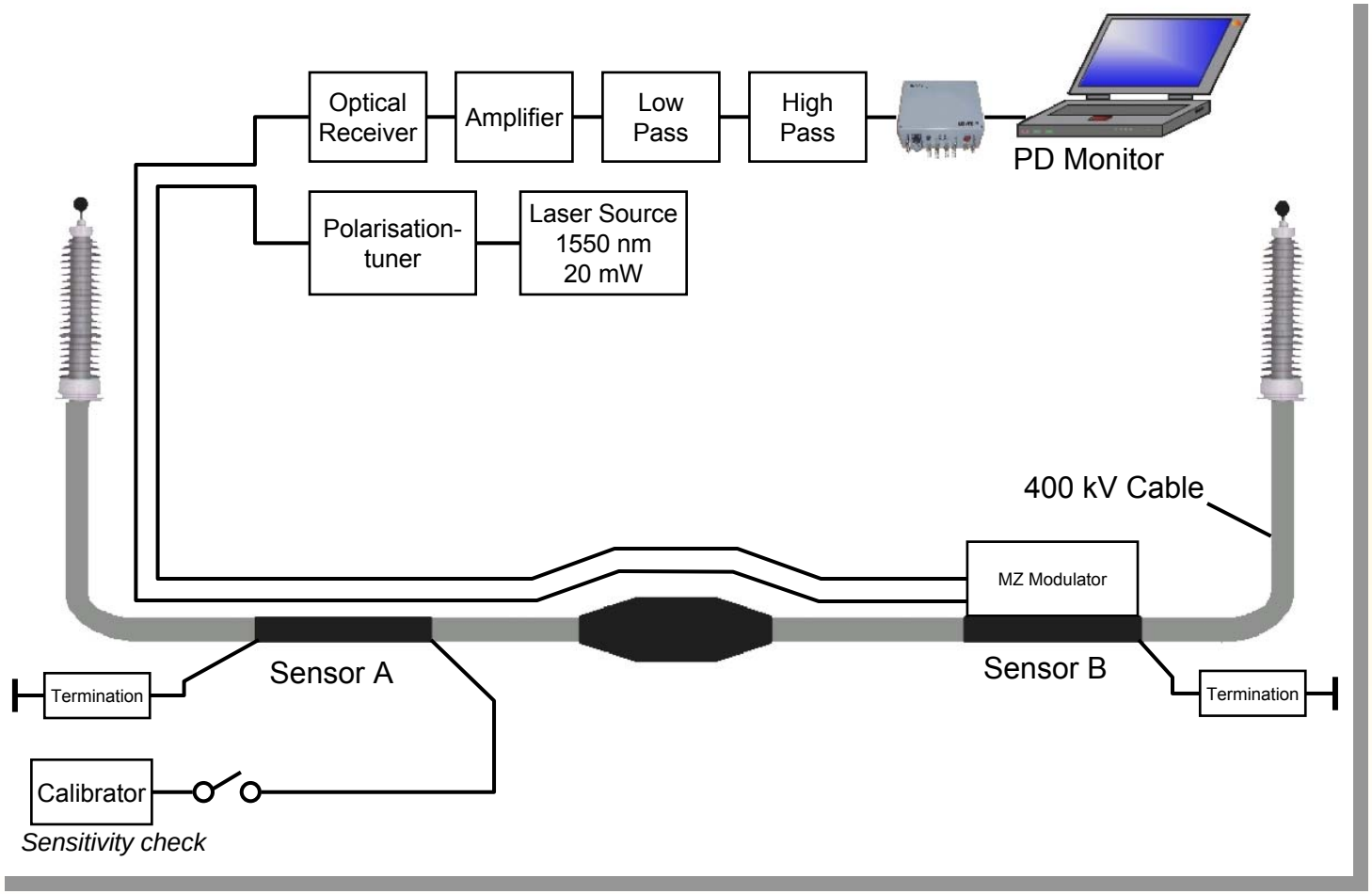


conventional detected PD-Signal

optical detected PD-Signal

Comparison conventional (band limited) and optical detected PD signal

PD – Measurements (System Setup)



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PD – Measurements

method	frequency	sensor*)	sensitivity	calibration
UHF	0,3 GHz – 3 GHz	0,5 – 1,5 GHz 0,05 pC **)	< 1 pC in the laboratory 4 - 5 pC	no***) sensitivity verification
HF / VHF	20 MHz – 300 MHz	0,5 – 80 MHz 1 pC	< 1 pC in the laboratory 10 pC on-site	no***)
acoustic	10 Hz – 300 kHz (1 MHz)	30 – 120 kHz < 1 pC **)	< 1 pC in the laboratory 5 pC on-site	no***) sensitivity verification
optical	200 – 1100 nm (wave length)	200 – 850 nm 0,5 pC **)	< 1 pC in the laboratory 3 pC on-site	no***)
chemical	-	-	yes/no - decision	no

*) Application example

**) Measuring sensitivity if charges pulses are directly injected

***) during model arrangements in the laboratory a calibration with the conventional electrical measurement is possible.

IEC Proposal

"Non-conventional PD-measurements"

In the past few years, there has been the development of many so-called non-conventional PD measurement methods. Partial discharges (PD's) generate pressure waves, sound, light and electromagnetic waves. These physical effects can be detected by different sensors and so there is the possibility to detect PD's with non-conventional methods besides the conventional electrical measurement. The main method for PD measurement is electromagnetic (HF/VHF/UHF) and acoustic measurements. Also, there have been a lot of papers published using these methods. Therefore, IEC TC42 has in the meeting of September 1st, 2005 in Beijing, decided to proceed with this new work item called "Measurement of PD's by electromagnetic (e.g. UHF) and acoustic methods" and to form a new working group for this task. As convener of this new WG, Prof. M. Muhr, Austria, has been proposed and voted and also six countries have agreed to provide a team member. The task of this new WG is to collect all the used applications of these methods to compare them with each other and to look at their frequency range. Another differentiation of the measuring technique is if it is a narrow bandwidth or a wide band frequency measurement technique. This work will also include the use and the techniques of the different sensors, their frequency range and their sensitivity. Also, it will investigate the issue of the methods, the possibility of PD location and if a calibration or in minimum a sensitivity check is possible. The WG will start with the electromagnetic methods and after finishing will move forward to the acoustic methods.

IEC Purpose and Justification

a) The specific aims and reason for the standardization activity, with particular emphasis on the aspects of standardization to be covered, the problems it is expected to solve or the difficulties it is intended to overcome.

b) The main interests that might benefit from or be affected by the activity, such as industry, consumers, trade, governments, distributors.

c) Feasibility of the activity: Are there factors that could hinder the successful establishment or general application of the standard?

d) Timeliness of the standard to be produced: Is the technology reasonably stabilized? If not, how much time is likely to be available before advances in technology may render the proposed standard outdated? Is the proposed standard required as a basis for the future development of the technology in question?

e) Urgency of the activity, considering the needs of the market (industry, consumers, trade, governments etc.) as well as other fields or organizations. Indicate target date and, when a series of standards is proposed, suggest priorities.

f) The benefits to be gained by the implementation of the proposed standard; alternatively, the loss or disadvantage(s) if no standard is established within a reasonable time. Data such as product volume of value of trade should be included and quantified.

g) If the standardization activity is, or is likely to be, the subject of regulations or to require the harmonization of existing regulations, this should be indicated.

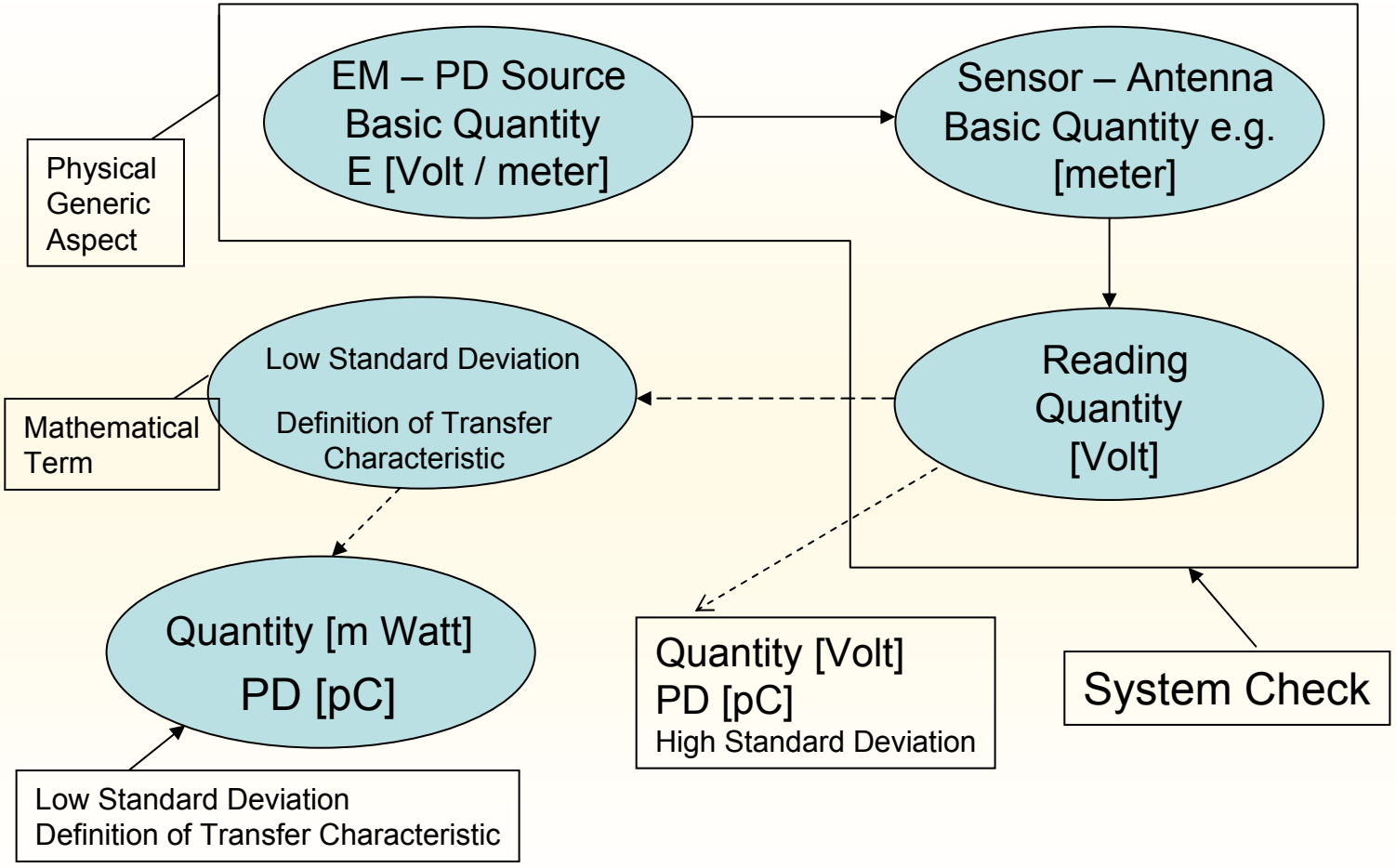
"Non – Conventional PD – Measurements"
Extraction of Generic Terms 1

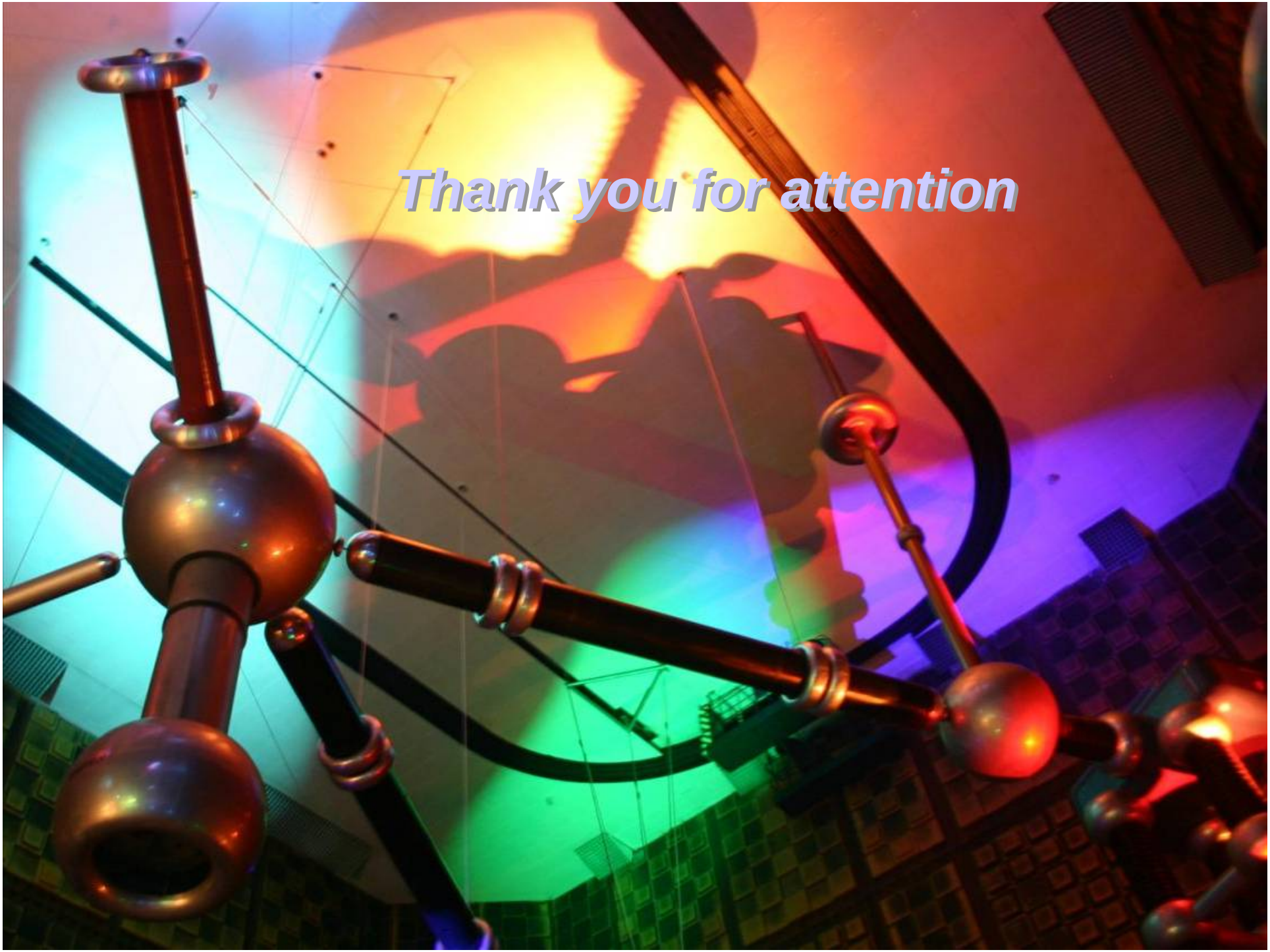
- Description of EM PD phenomena
  - PD occurrence in discharging defects
  - Frequency/time behaviour
  - Specifics of HV components
  - Applicability for detection
- Sensoring
  - Types, parameters, positioning
- Transmission aspects
  - Relation between EM behaviour of the HV component, sensor characteristic in the EM field and the measuring system characteristics
  - Definition of suitable reading parameters
- System check(s)
  - Sensor sensitivity
  - Performance check
  - Sensitivity check

"Non – Conventional PD – Measurements"
Extraction of Generic Terms 2

- Standardization:
  - Definition between PD [pC] and Correlating quantity
  - Requirements of the Instruments
  - System check
- Problems to be solved
  - Quantity of EM - PD Source e.g. E [Volt/meter]
  - Quantity of Sensor / Antenna e.g. [meter / square meter / gain]
  - Quantity of Instrument Reading e.g. [m Volt / m Watt_dBm / p Joule]
  - Definition of correlating Quantity between PD [pC] and Instrument Reading / Conditions: definable transfer function (a +b x^2 + c x^3 + …..) / (n + m y^2 + o y^3 ……) and low standard deviation
- No Standardization
  - Applicable sensors
  - Test and measuring Configurations
  - Interpretation – Task of the Component Panels

"Non – Conventional PD – Measurements"
Extraction of Generic Terms 3

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