Dielectric Spectroscopy of Solid Insulators

OMICRON Lab Webinar Series 2020

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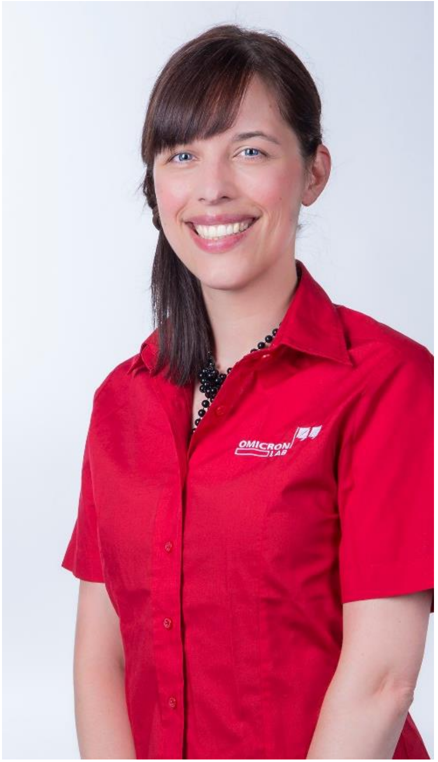

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Agenda

- Theory and measurement methods
- Introduction dielectric sample holder – DSH 100
- Measurement example using the DSH 100

Dielectric Spectroscopy of Solid Insulators

Theory and measurement methods

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Dielectric Analysis Basics

Dielectric Material Analysis: Definitions

- There are lot of terms used for the description of a dielectric material:

ε'_r $tan(\delta)$

Permittivity

Dielectric Losses

ε''_r

Dissipation Factor ? Permeability

Dielectric Constant

Permittivity ε

"Permittivity is a measure of how an electric field effects and is effected by a dielectric material." (in simple words)

- ε
  - Permittivity of material
  - Describes the interaction of a material with an external electrical field

- ε_0
  - Permittivity of space
  - Constant value 8.85×10^{-12} F/m
  - Describes the electrical field generated in vacuum

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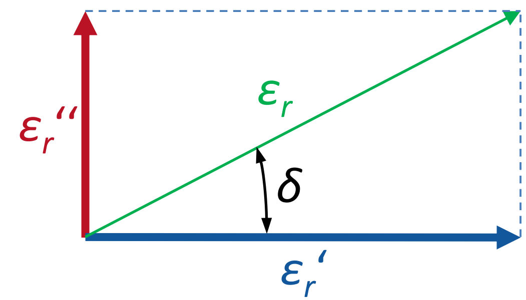
Relative Permittivity ε_r

- The absolute material permittivity ε_r is relative to the permittivity of free space ε_0

- $\kappa = \varepsilon_r = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r' - j\varepsilon_r''$



- ε_r' indicates how much energy from an external electric field is <u>stored</u> in a dielectric material
- ε_r'' indicates the <u>losses</u> within the dielectric material when an external electric field is applied.
- ε_r'' is usually much smaller than ε_r' and includes the effects of both dielectric loss and conductivity.

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Dielectric Losses *tan(δ)*

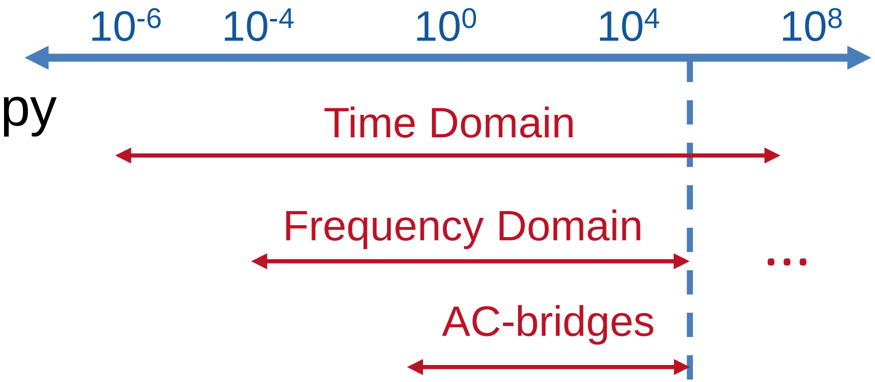
- The ratio of lost energy (ε_r'') to stored energy (ε_r') is the relative losses of a dielectric material

$$\tan(\delta) = D = \frac{\varepsilon_r''}{\varepsilon_r'} = \frac{1}{Q} = \frac{Energy\ lost\ per\ cycle}{Energy\ stored\ per\ cycle}$$

- Q is the quality factor
- Used terms for the relative losses of a dielectric material are:
  - Dissipation factor D
  - Dielectric losses tan(δ)

Dielectric Spectroscopy Techniques

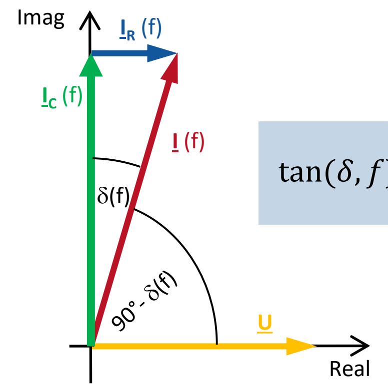
- The measurement technique for dielectric material analysis depends on the frequency range to measure
- For a frequency range from 10^{-6} Hz to 10^{8} Hz the following two measurement techniques can be used:
  - Time Domain Spectroscopy
  - Frequency Domain Spectroscopy
  - etc.



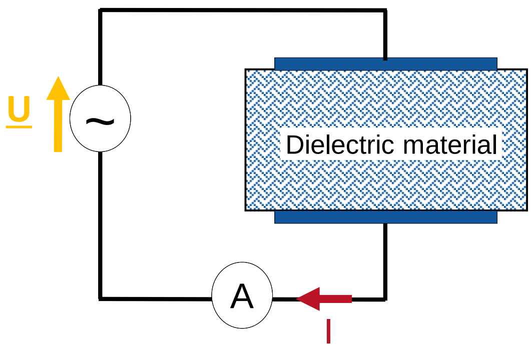
Frequency Domain Spectroscopy (FDS)

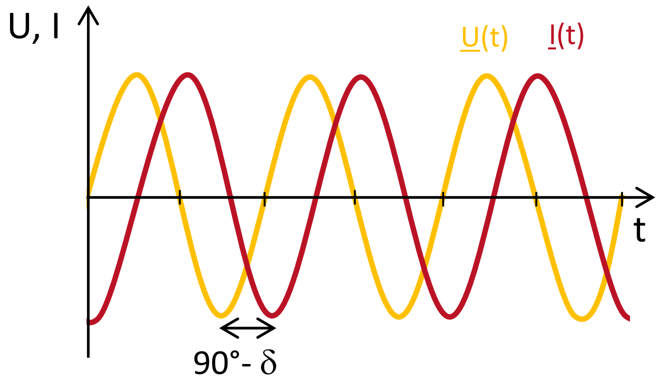
FDS Principle:

- Measures tan(δ) at different frequencies:
  - Apply sinusoidal voltage of different frequencies f1, f2, ... to a dielectric material e.g. located in a parallel electrodes test cell
  - Determine tan(δ) at the frequencies f1, f2, ...



$$\tan(\delta, f) = \frac{I_R(f)}{I_C(f)}$$





Frequency Domain Spectroscopy (FDS)

- Advantage of FDS
  - Fast and accurate at high frequencies
  - Resistant to disturbances
- Disadvantage of FDS
  - Very slow at low frequencies

Frequency	Duration of 1 sine wave
5000 Hz	0,2 ms
1000 Hz	1 ms
50 Hz	20 ms
1 Hz	1 s
0.1 Hz	10 s
10 mHz	100 s
1 mHz	16,7 min
0.1 mHz	2,7 h
10 µHz	27 h

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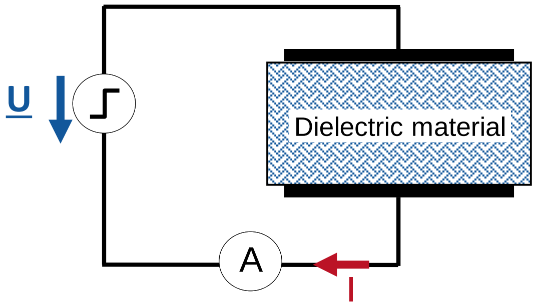
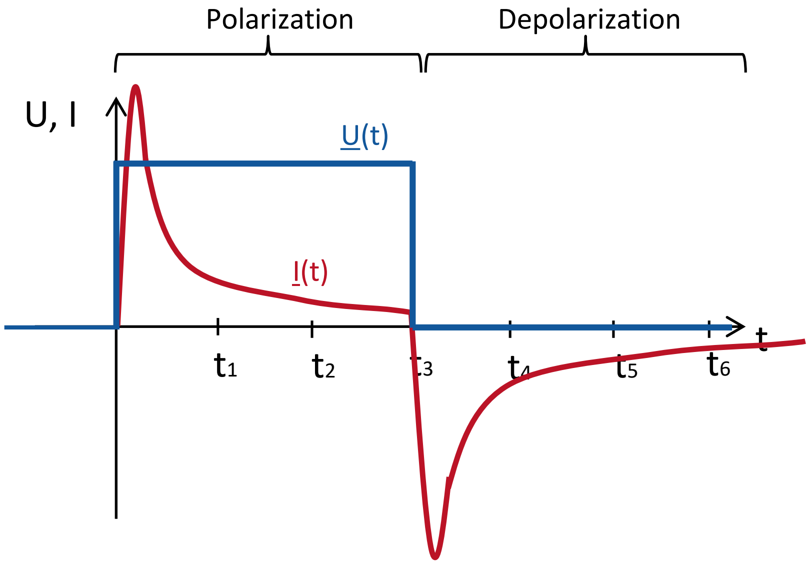
Time Domain Spectroscopy

- The time domain spectroscopy used in the SPECTANO 100 is called **PDC** measurement (**P**olarization **D**epolarization **C**urrent)
- PDC Principle
  - Apply a voltage step to a dielectric material e.g. located in a parallel electrodes test cell
  - Measure the charge current at times t_1, t_2, ...
  - Calculate the dielectric properties like ε, c, tan(δ) at the corresponding $f_1 = \frac{1}{t_1}$; $f_2 = \frac{1}{t_2}$ ... using the Fourier transformation





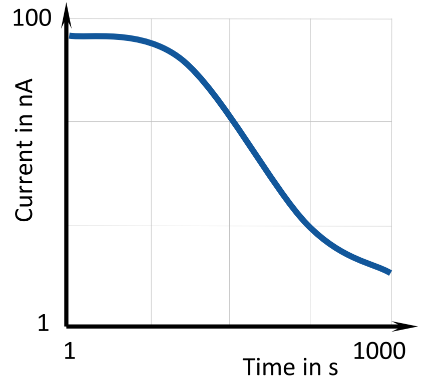
Time Domain Spectroscopy

- Advantage of PDC
  - Fast and accurate at low frequencies

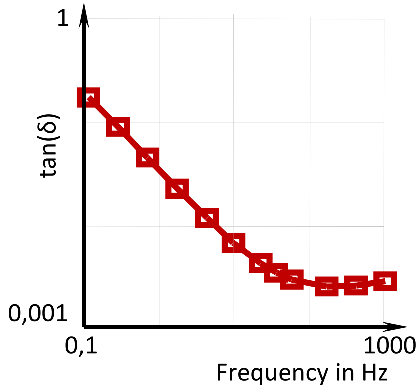
- Disadvantage of PDC
  - Inaccurate at high frequencies

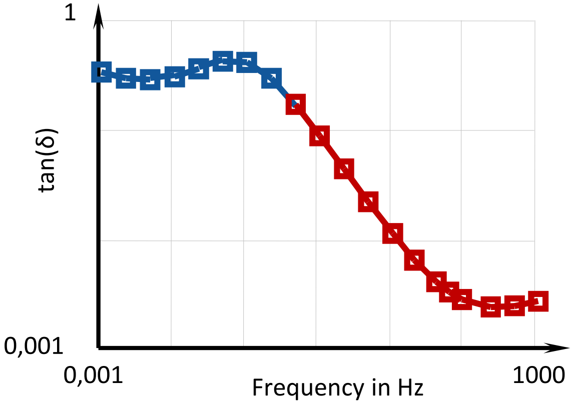
	Advantages	Disadvantages
PDC	☺ Fast and accurate at low frequencies	☹ Inaccurate at high frequencies
FDS	☺ Fast and accurate at high frequencies	☹ Very slow at low frequencies

Combination of FDS and PDC



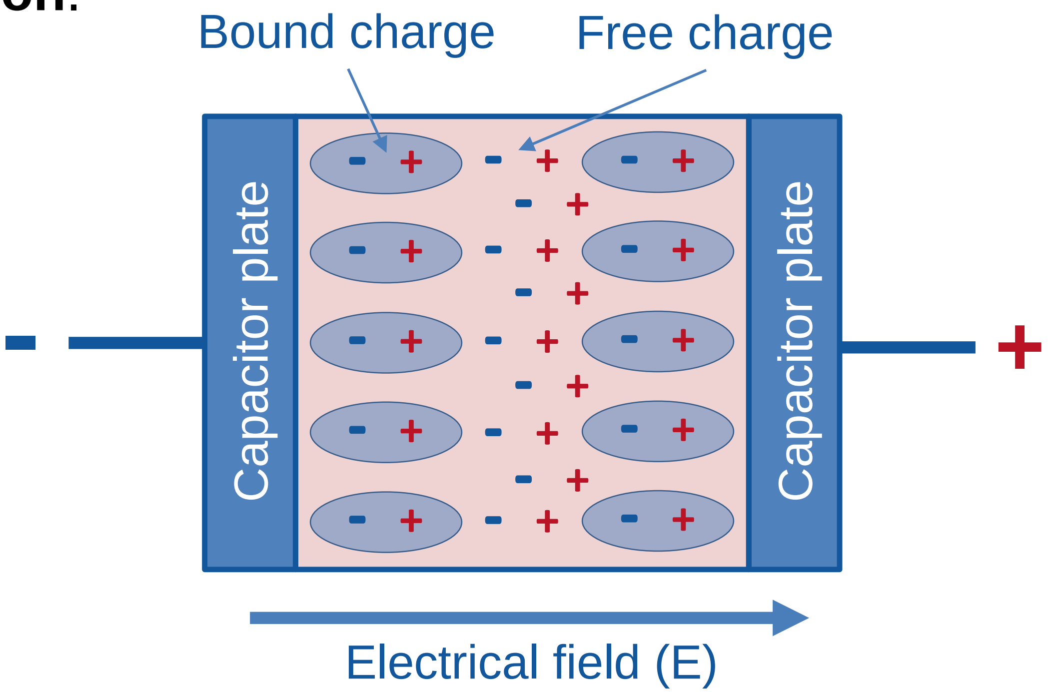
Fourier
Transformation





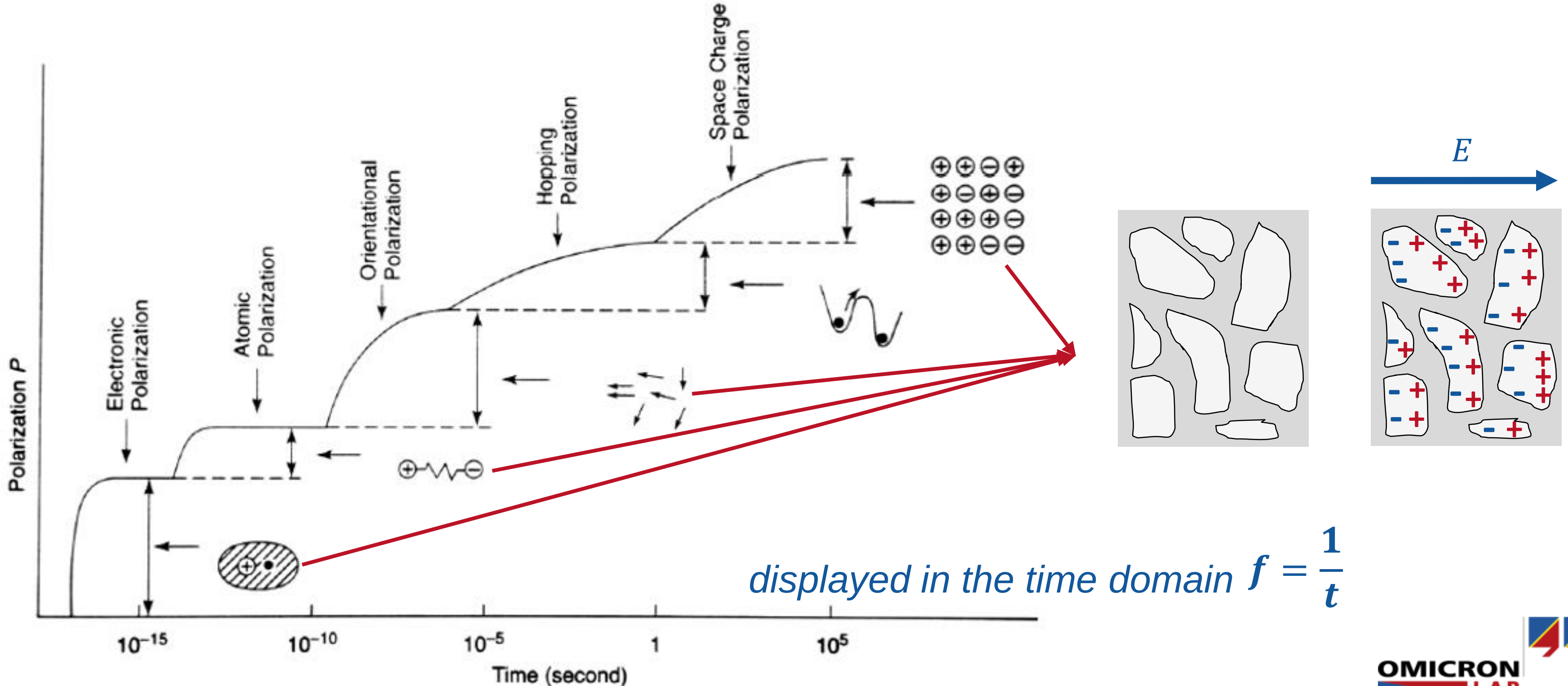
Dielectric Polarization

- When a dielectric material is placed in an external electrical field charged particles are displaced. This process is called **dielectric polarization**.



Polarization processes

- Depending on the frequency different polarization types occur



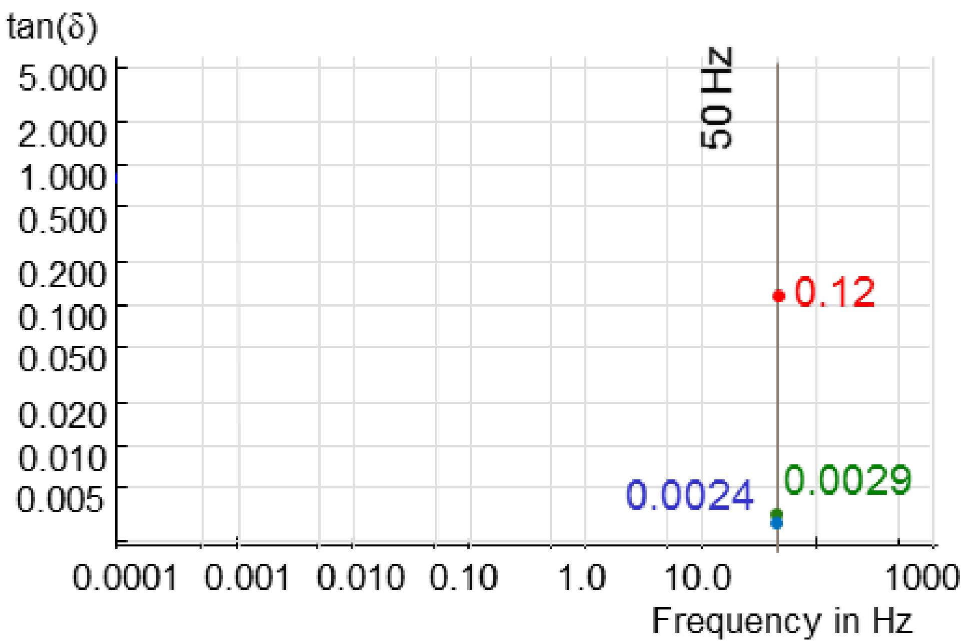
displayed in the time domain $f = \frac{1}{t}$

Why is dielectric material analysis in comparison to common analysis methods as tan(δ) 50 Hz so important?

...and will compare it with good and bad materials
50 Hz Analysis

Tan(δ) 50 Hz Analysis = Common “type” of insulation material measurement

tan(δ), C at 50 Hz:

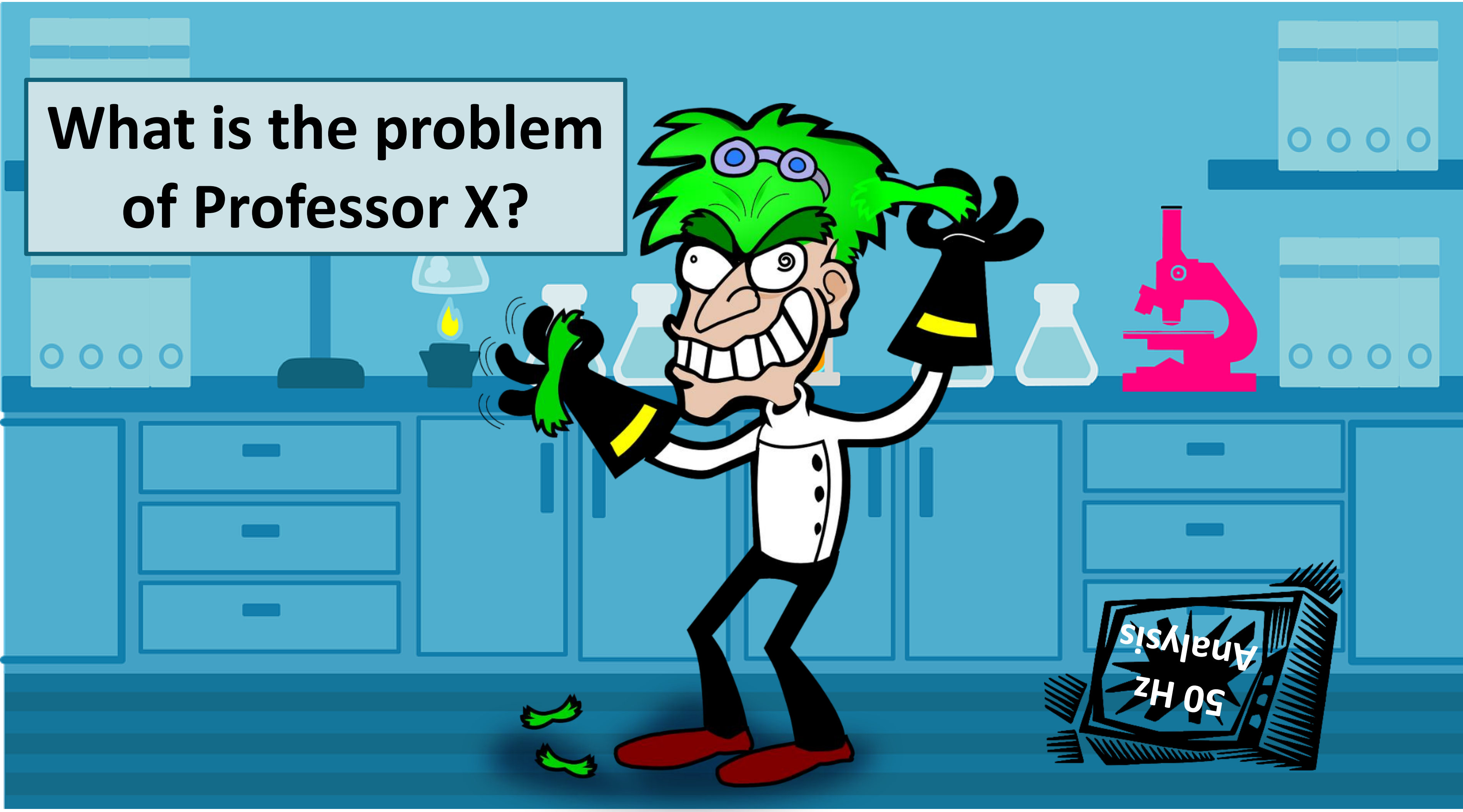


I will control it again!

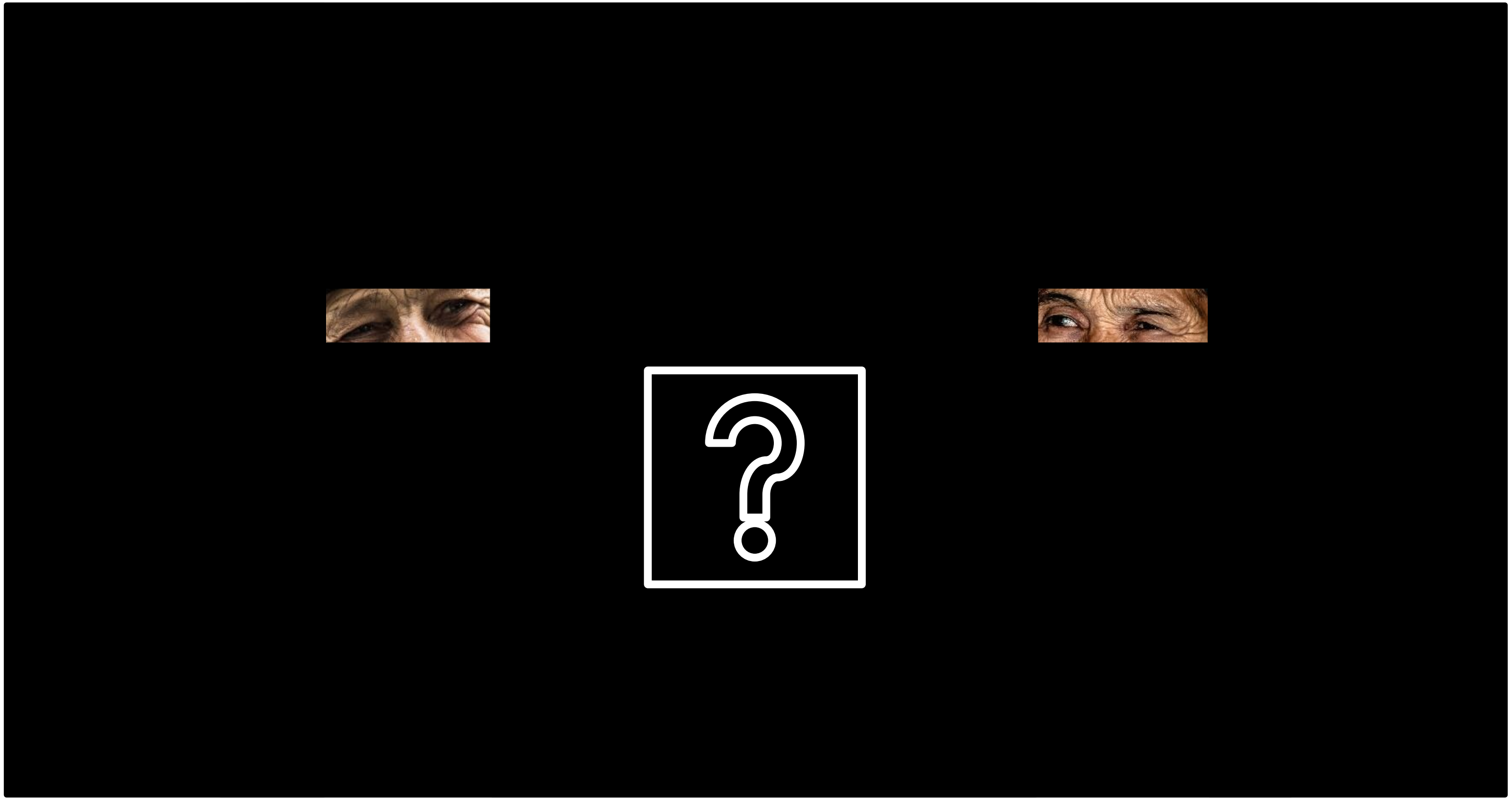
- Bad material
- Good material
- Probe

NO, NO, NO! I can’t find the error!!

What is the problem of Professor X?



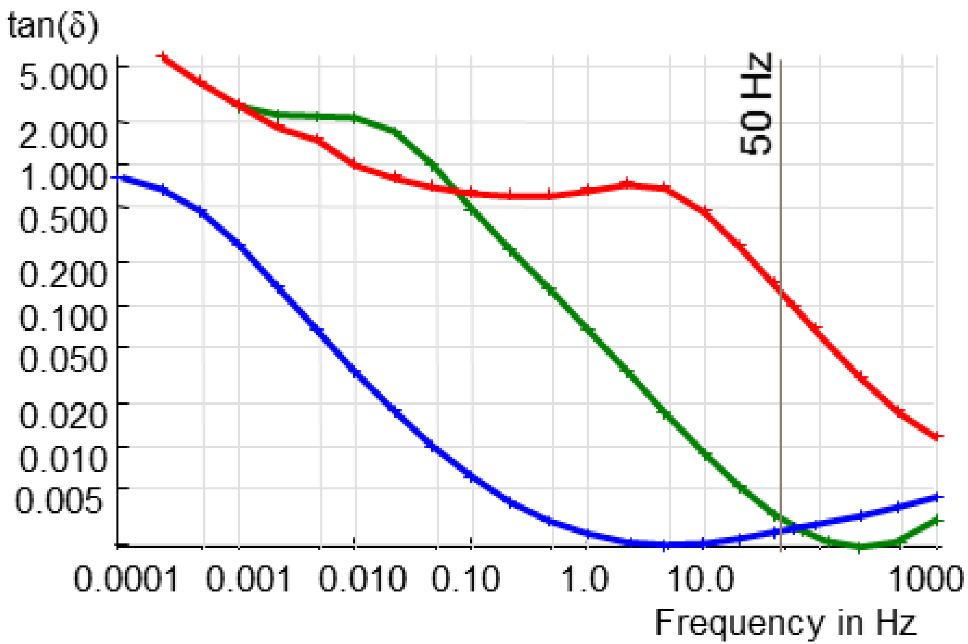
Importance of Dielectric Material Analysis



Importance of Dielectric Material Analysis (cont.)

Importance of Dielectric Material Analysis (cont.)

Dielectric response: (tan(δ), C, ε at kHz...µHz)



red: bad material = aged
blue: good material = normal (dry)
green: probe = wet and thus inaccurate/faulty

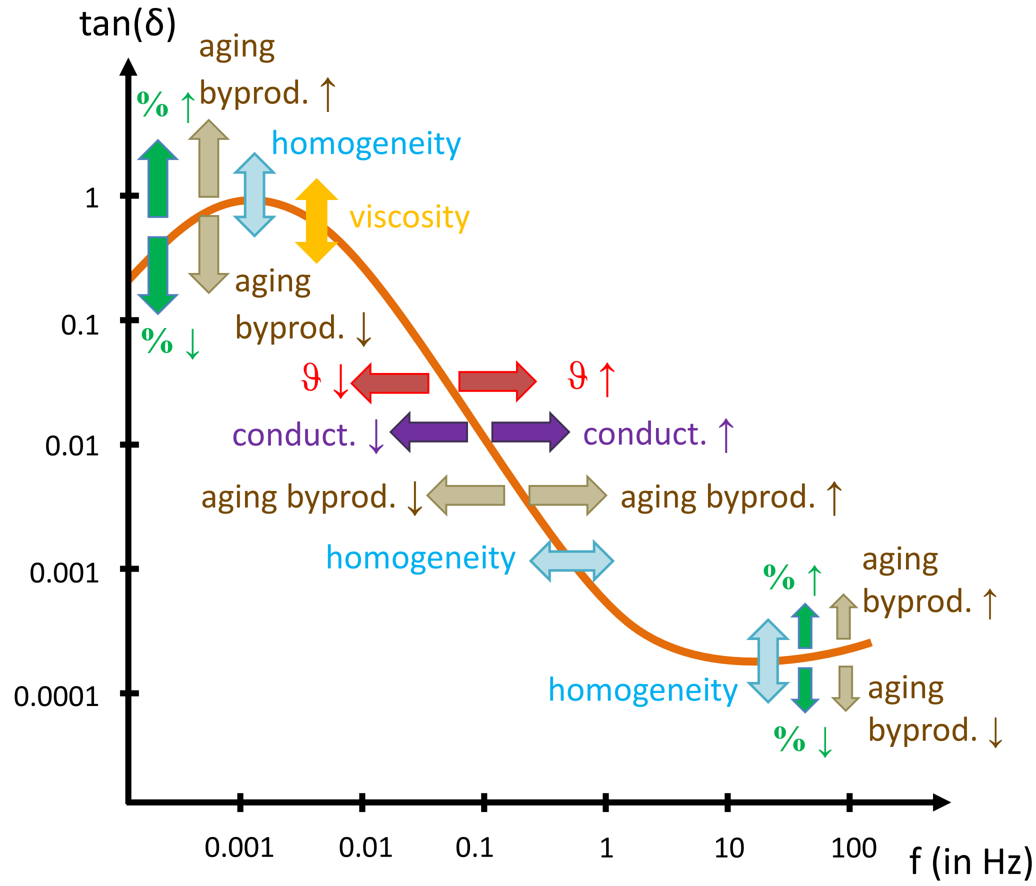
- Separation of effects due to large frequency range
- Detailed analysis possible

Factors influencing the dielectric response

Possible influence factors:

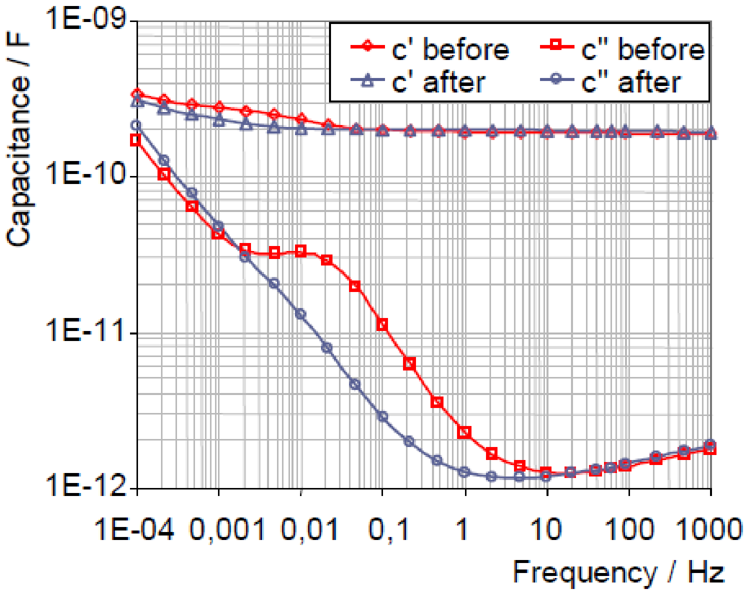
- Temperature
- Humidity or moisture
- Homogeneity
- Conductivity e.g. oil
- Aging byproducts
- Viscosity e.g. during curing
- Structure

⚠ kind of influences depend on material

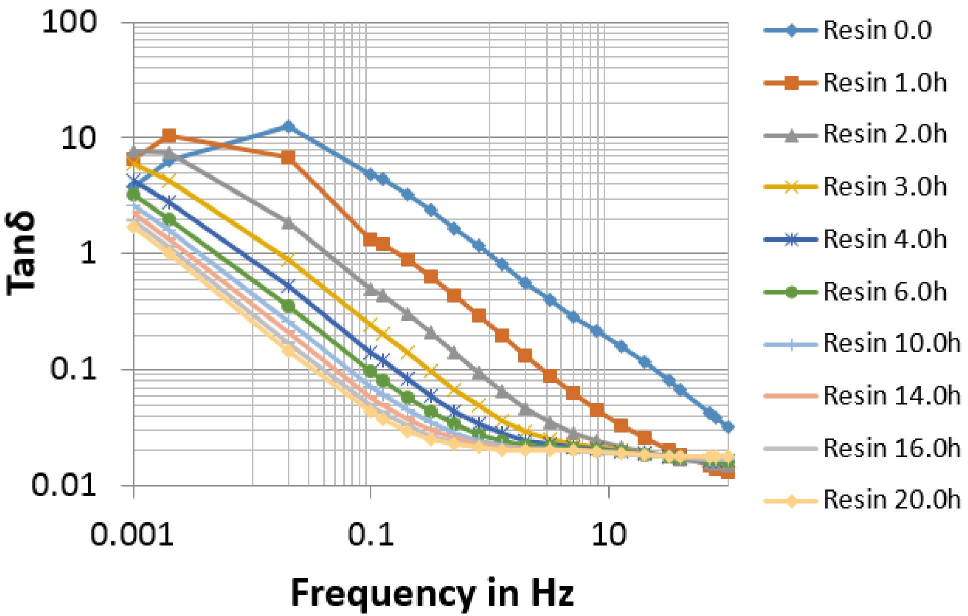


Typical Dielectric Material Curves

Pressboard disk before & after pressing with 10kg weights for 2 month

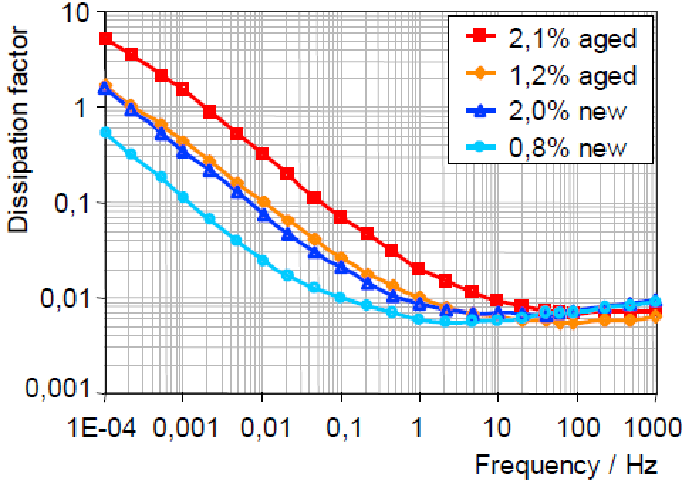


Epoxy resin curing process

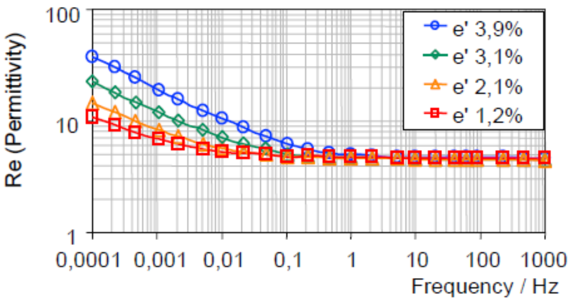


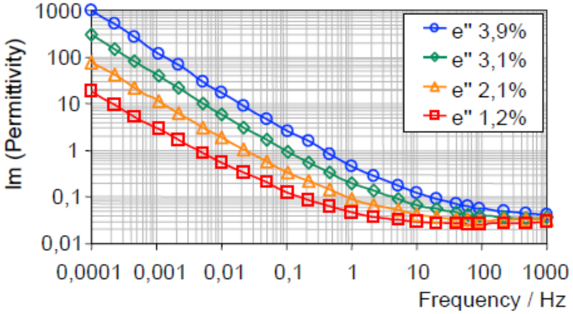
Why are C and ε dielectric material properties?

Tanδ for new and aged pressboard with similar moisture content at 20°C



Permittivity of aged pressboard with different moisture content at 20°C





Importance of dielectric analysis

- To detect aging or changes of dielectric material structure / composition before material is used in the field
- Aging or changes of the dielectric material can lead into
  - Wrong electrical behavior
  - Changes of electrical specification
  - Reduction of dielectric strength
  - Reduction of longevity
  - Avoid short circuits e.g. in high voltage equipment and thus faster aging
  - Reduction of humidity or temperature stability

Dielectric Material Analysis: Applications

Measures dielectric parameters like losses (tanδ), relative permittivity (ε) or capacitance (C) to characterize easily

- Nanomaterial and material composites
- Dielectrics used as insulations in cables and high voltage assets
- Polymers, epoxy, insulation paper/cellulose, glasses or thin films
- Insulation liquids like mineral oil or silicone

Dielectric Spectroscopy of Solid Insulators

Introduction dielectric sample holder – DSH 100

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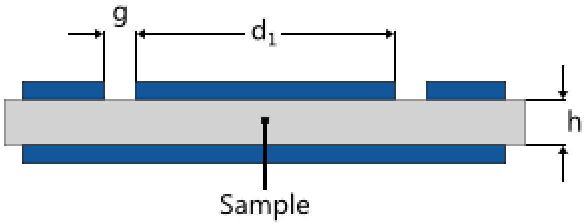
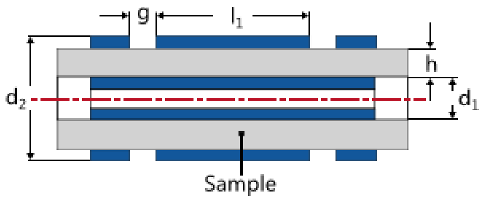
Typical Test Cell Types

- The test cell type for the dielectric material analysis depends on
  - The used dielectric spectroscopy techniques
  - Material under test (liquid, powder, solid, granulate...)

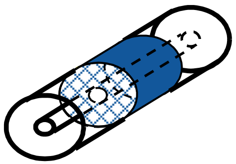
Parallel Plate with guard ring



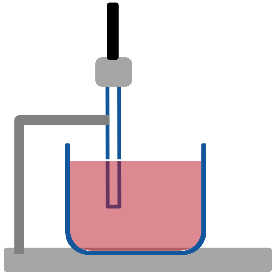
Cylindrical



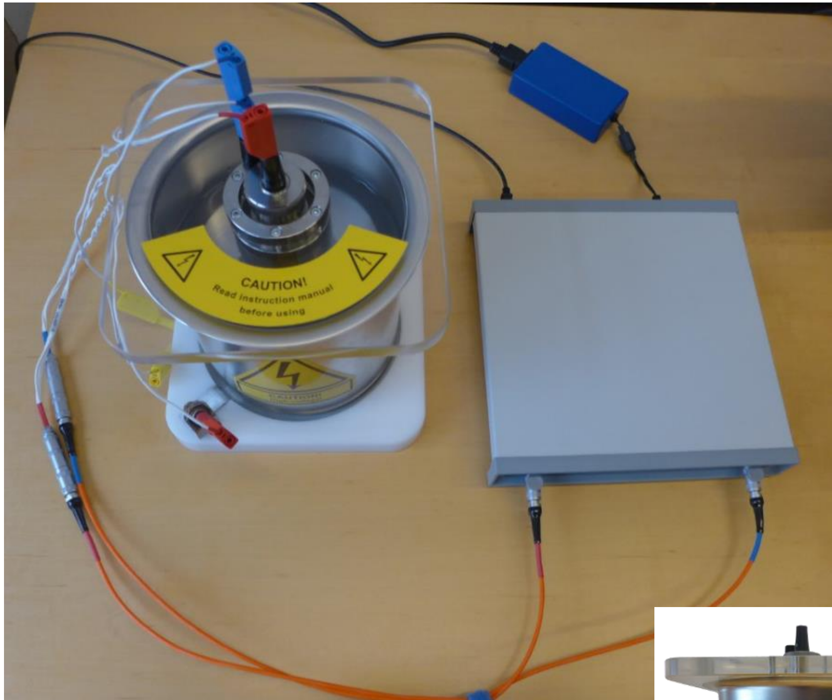
Transmission Line

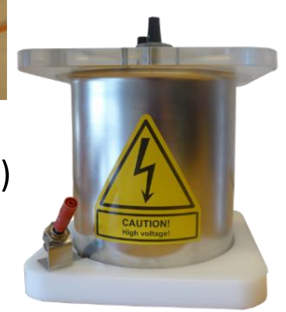


Coaxial Probe

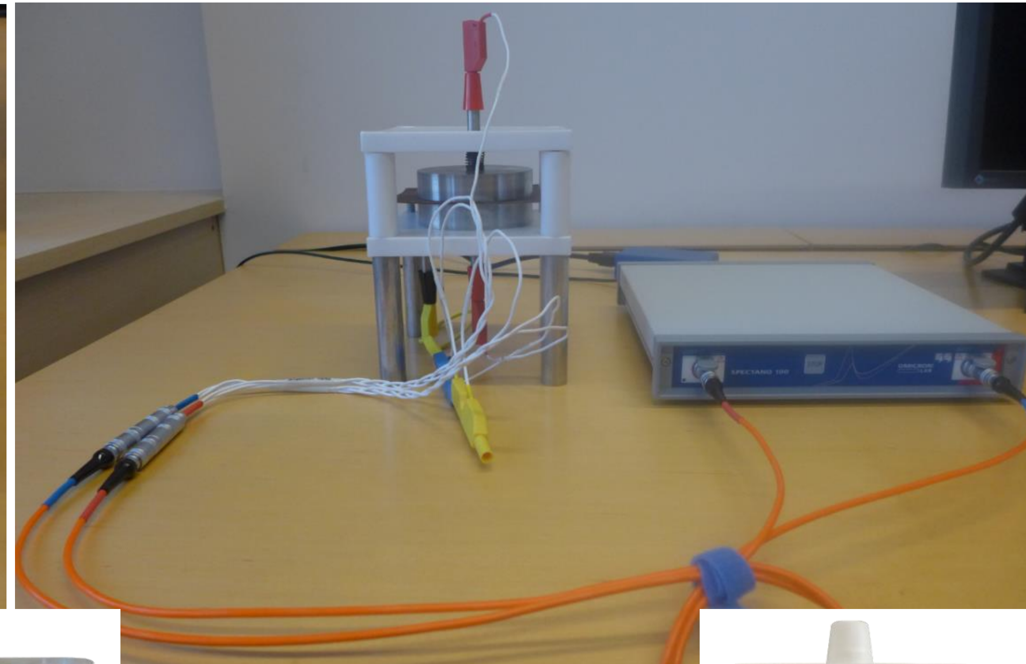


Typical Test Cell Types





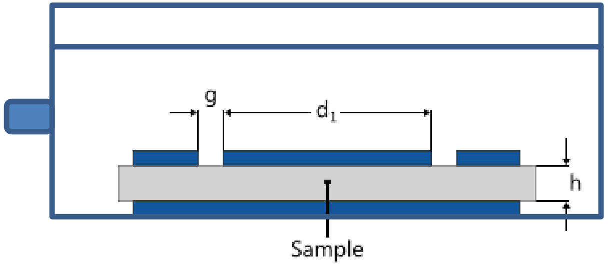
TC12 Transformer Oil Test Cell (cylindrical)
by OMICRON electronics



Disc electrode with guard ring
by TU Munich

DSH 100 – Dielectric Sample Holder for solid material

- Cooperation project with the **Tony Davies High Voltage Laboratory University of Southampton**



- Test cell type
  - Disc electrode with guard ring
  - Shielding mechanism included
  - Disposable electrodes (usable for curing processes)
  - Easy adjustment of air gap for air reference measurement
  - Usable for voltages ≤ 200 V_{peak} (AC + DC)
  - Usable frequency range 5 µHz to 5 MHz
  - Option: Temperature control system

Sample Holder DSH100 – Features

- Housing, connection & environmental control

- Shielding for precise measurements
- Triaxial connection for
  - Low current (pA)
  - Capacitances down to 10 pF
- Temperature control
  - Heating pad
  - PT-100 temperature sensor

Sample Holder DSH100 – Features

- Electrical Parameters

Maximum Operation Voltage (AC/DC) ≤ 200 V_{peak}

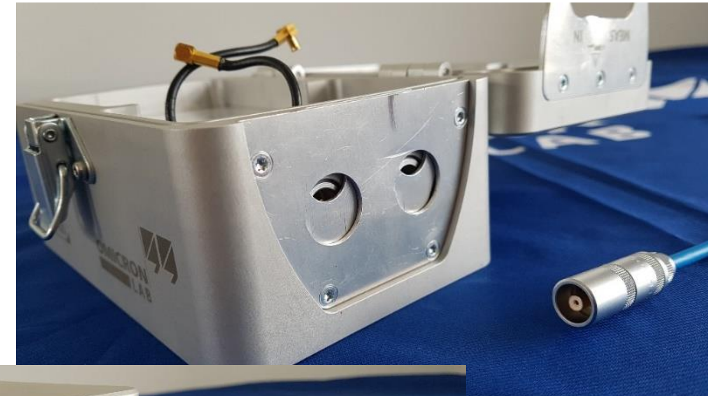
Maximum current (AC/DC) ≤ 50 mA_{peak}
Usable frequency range 5 µHz to 5 MHz

Sample thickness 0.1 mm to 20 mm

Sample size 50 mm x 50 mm to 70 mm x 70 mm

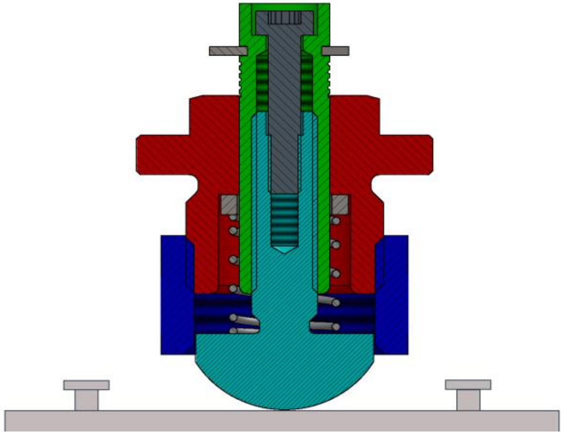
Sample Holder DSH100 – Features

- Safety interlock mechanism



Sample Holder DSH100 – Features

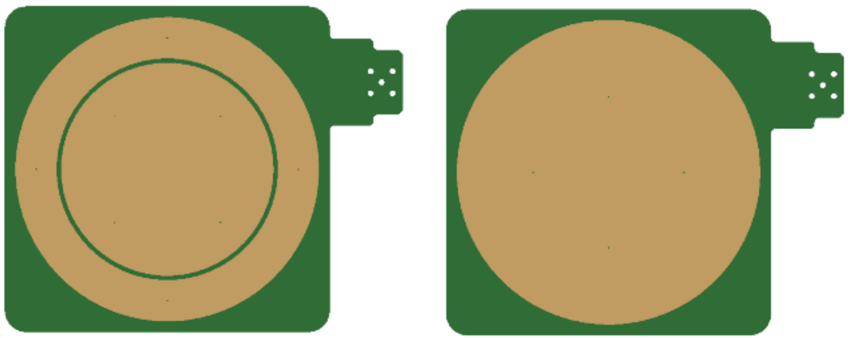
- Tensioner to control pressure



- Spring force:10N, 50N and 100N
- Ensures proper electrical contact
- Constant force (scaling)
- Reproduceable results
- Exchangeable design

Sample Holder DSH100 – Features

- Electrode design

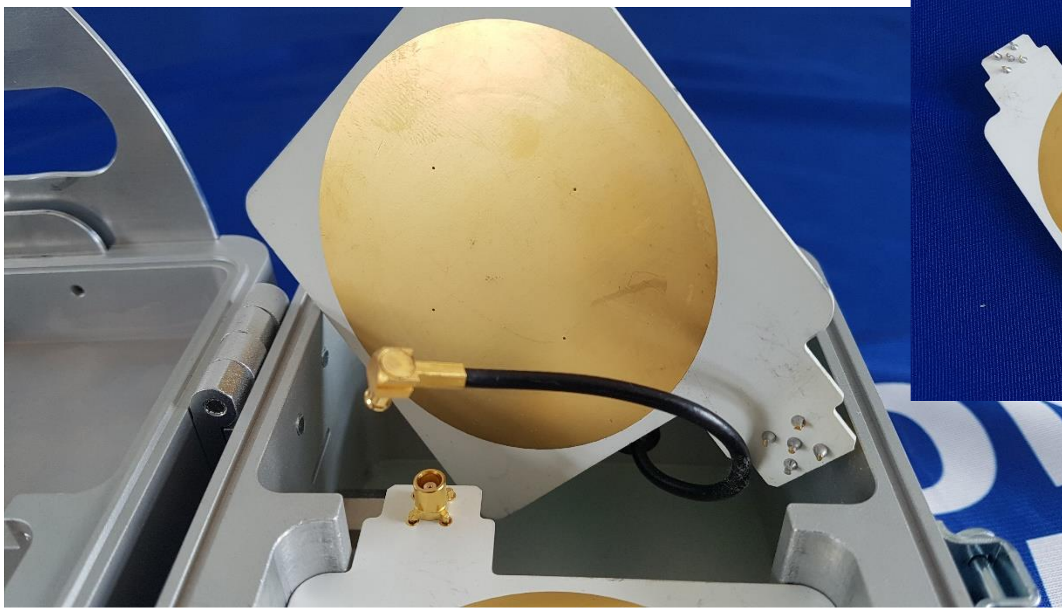


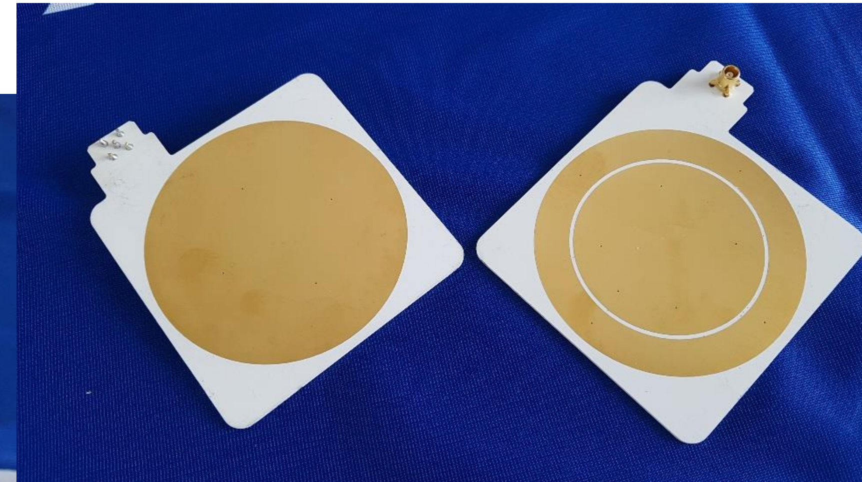
Top/Input electrode: Ø 70 mm
Bottom/Measurement electrode
with guard ring: Ø 49 mm
Guard ring width / gap: 9.5 mm / 1 mm

- Exchangeable and disposable electrodes with guard ring
- Thin multilayer Printed Circuit Board (PCB) with gold coating (1.55mm thick)
- Electrode material allows deformation for proper contact to non-flat, rigid samples
- Designed according to IEC 250 and ASTM D150-11 standards

Sample Holder DSH100 – Features

- Electrode design





Exchangeable and cost-effective

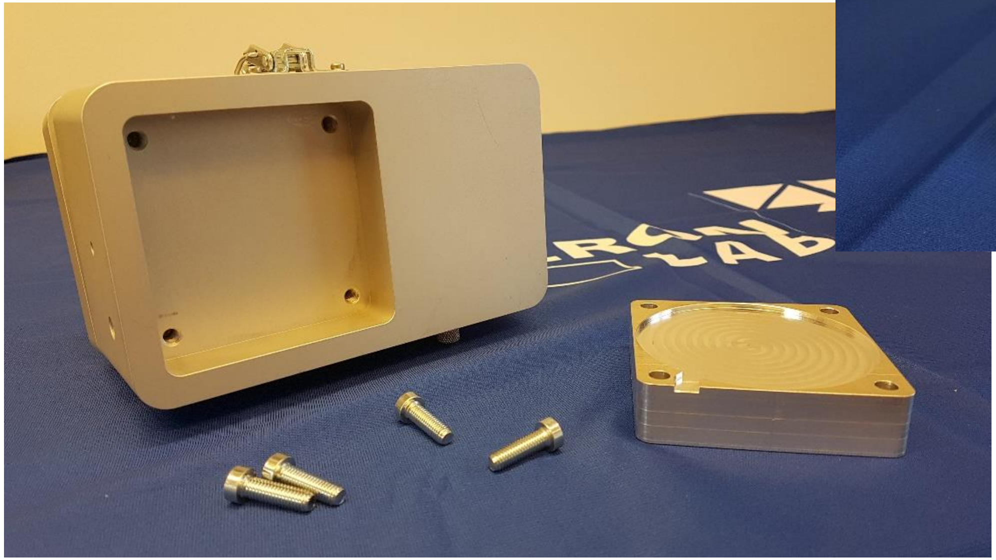
Sample Holder DSH100 – Features

- Spacer

Spacer for air-reference measurement
thickness: 0.8 mm / 1 mm / 1.55 mm

Sample Holder DSH100 – Features

- Option: Heating pad and temperature sensor



Sample Holder DSH100 – Features

- Environmental Conditions

Operating temperature:	-55 °C to +200 °C
Operating relative humidity:	≤ 95 % non-condensing
Maximum altitude:	2000 m

- General

Dimensions (w x h x d)	165 mm x 108 mm x 118 mm
Weight	2.5 kg

Supports measurements in accordance with:

ASTM D150
IEC 62631-2-1 (2018)
IEC 62631-3-1 (2016)

Triaxial connectors:	LEMO plug

Sample Holder DSH100

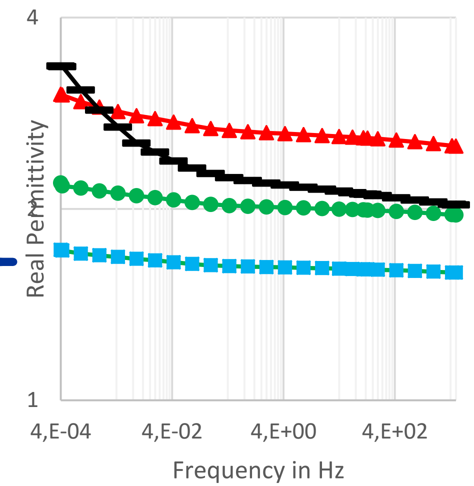
- Factors leading to a reduced accuracy

Accurate dielectric measurement results requires:

Accurate dielectric analyzer

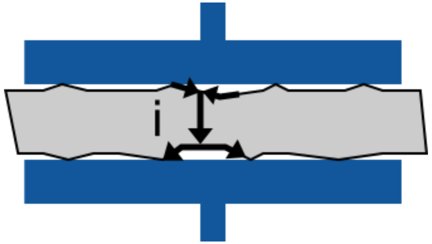
Unique and planar sample surface

Accurate sample holder with planar, parallel electrodes

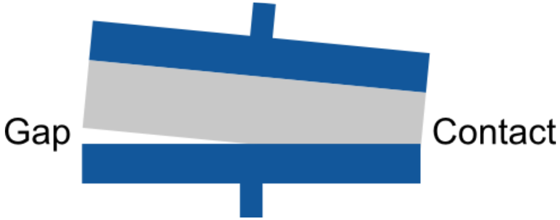


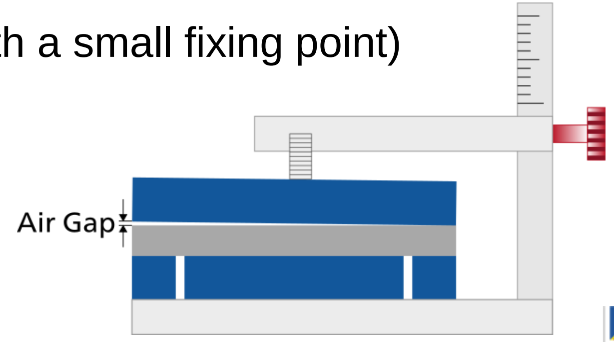
Sample Holder DSH100

- Factors leading to a reduced accuracy
  - Electrical contact: Reasons for poor electrical contact (air pockets)



  - Sample and electrode surface
    - Uneven sample or electrode surface
    - Scratches or contaminations on the sample or electrode surface like finger-prints, dust or oxide layers
  - Sample holder design
    - Tilting of the upper electrode (usually mounted with a small fixing point)
    - Deviations of the micrometer or sample thickness

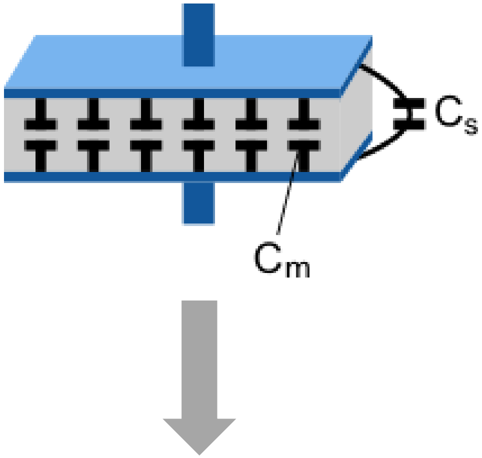




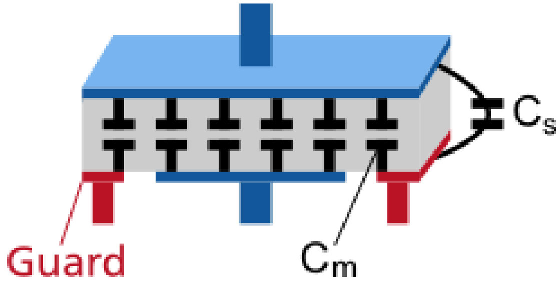
Sample Holder DSH100

- Factors leading to a reduced accuracy
  - Stray Capacitances
  - Sample deformation

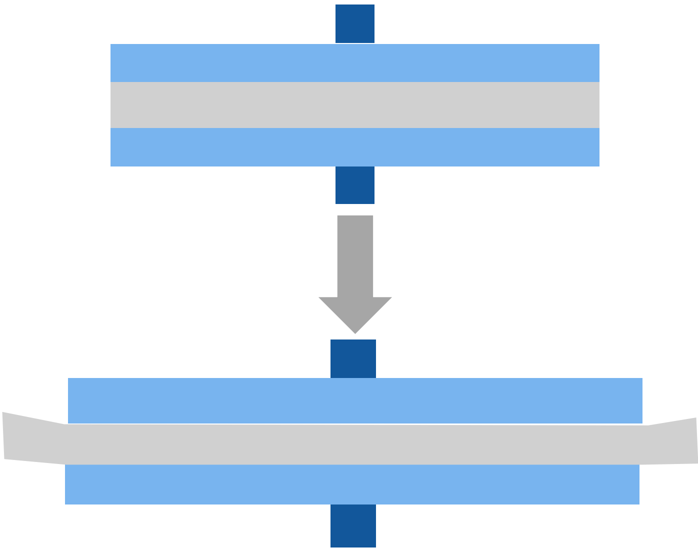
Disk electrode without guard ring



Disk electrode with guard ring

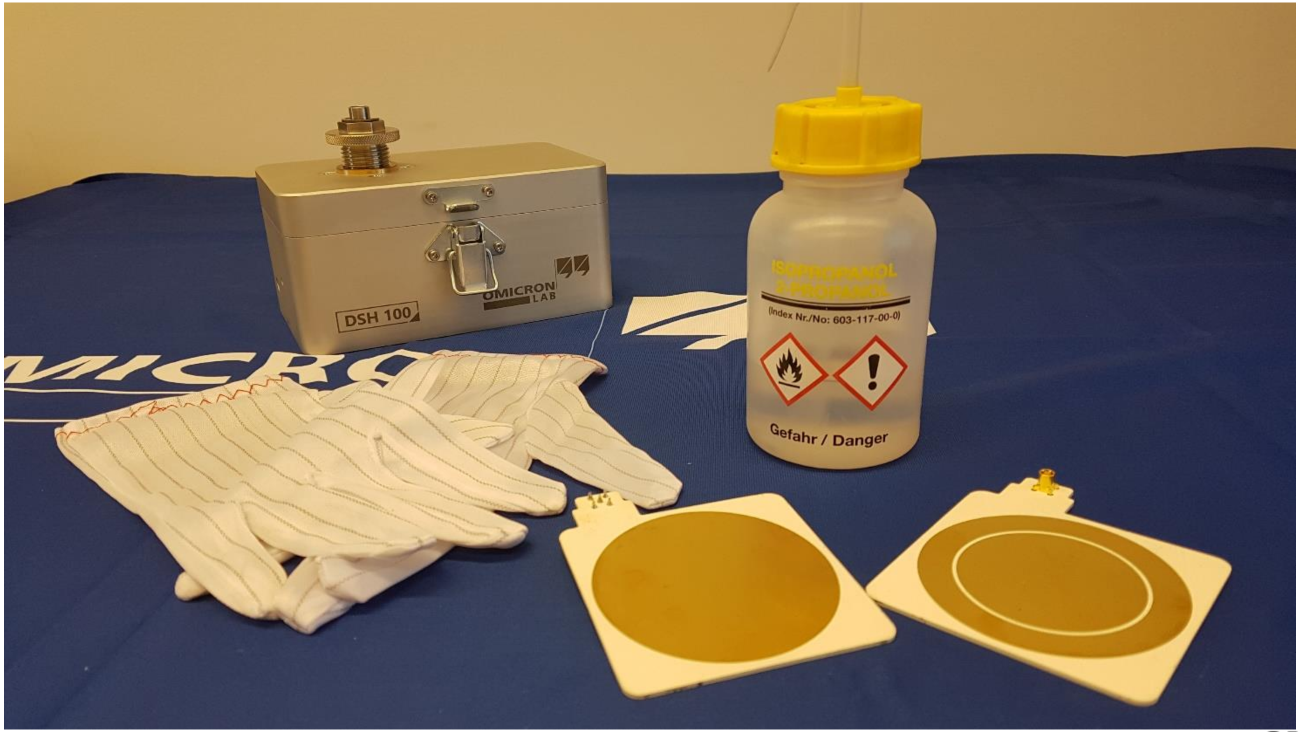


$$C_{measured} = C_m + C_s$$



Sample Holder DSH100

- Working with dielectric material:

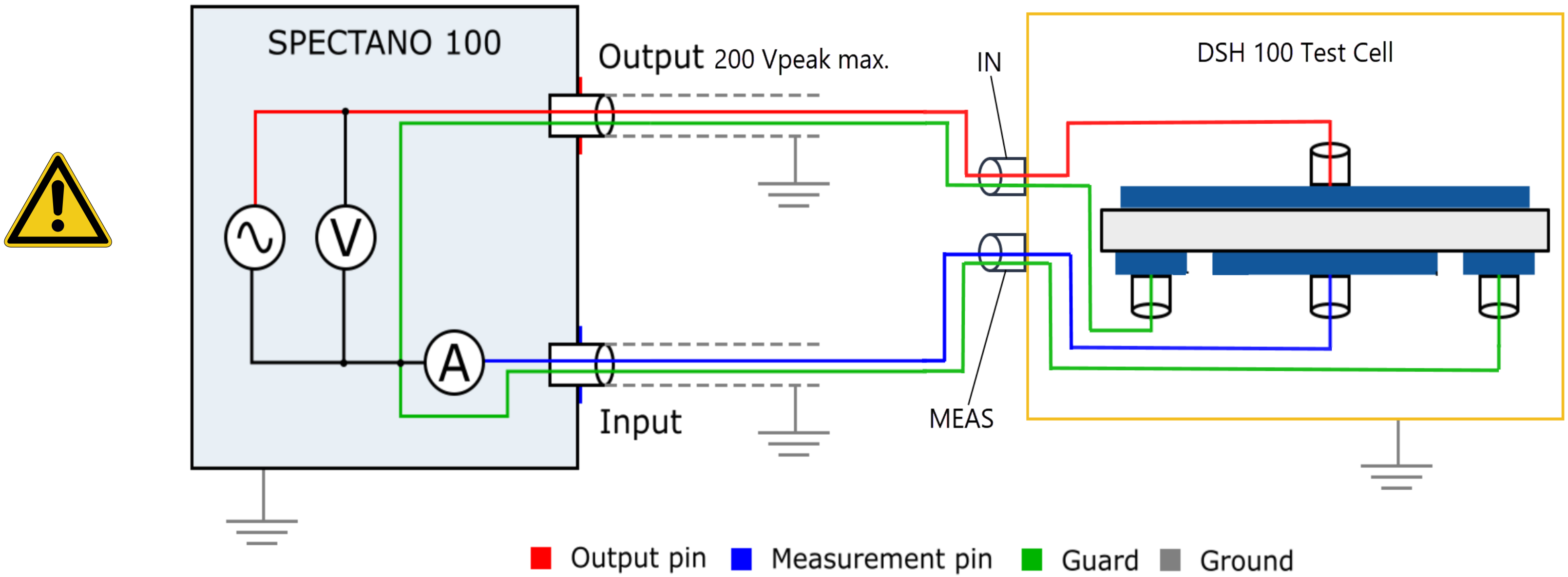


Dielectric Spectroscopy of Solid Insulators

Measurement example using the DSH 100

Measurement example using the DSH 100

- Measurement set up:



Thank you for your attention!

Feel free to ask questions via the Q&A function...

If time runs out, please send us an e-mail and we will follow up.

You can contact us at: info@omicron-lab.com

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