IDAX 300
Insulation Diagnostic Analyzer

Dielectric Frequency Response
Also known as:
Frequency Domain Spectroscopy

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Frequency Domain Spectroscopy

- Changes in insulating materials (ageing) affect the capacitance and loss factor (PF, tanδ)
- Frequency sweep, compared to traditional one-frequency Power Factor/”Doble” test, provides a lot more information on:
  - Insulation characteristics
  - Moisture/Ageing effects
  - Influence of temperature
  - Etc…

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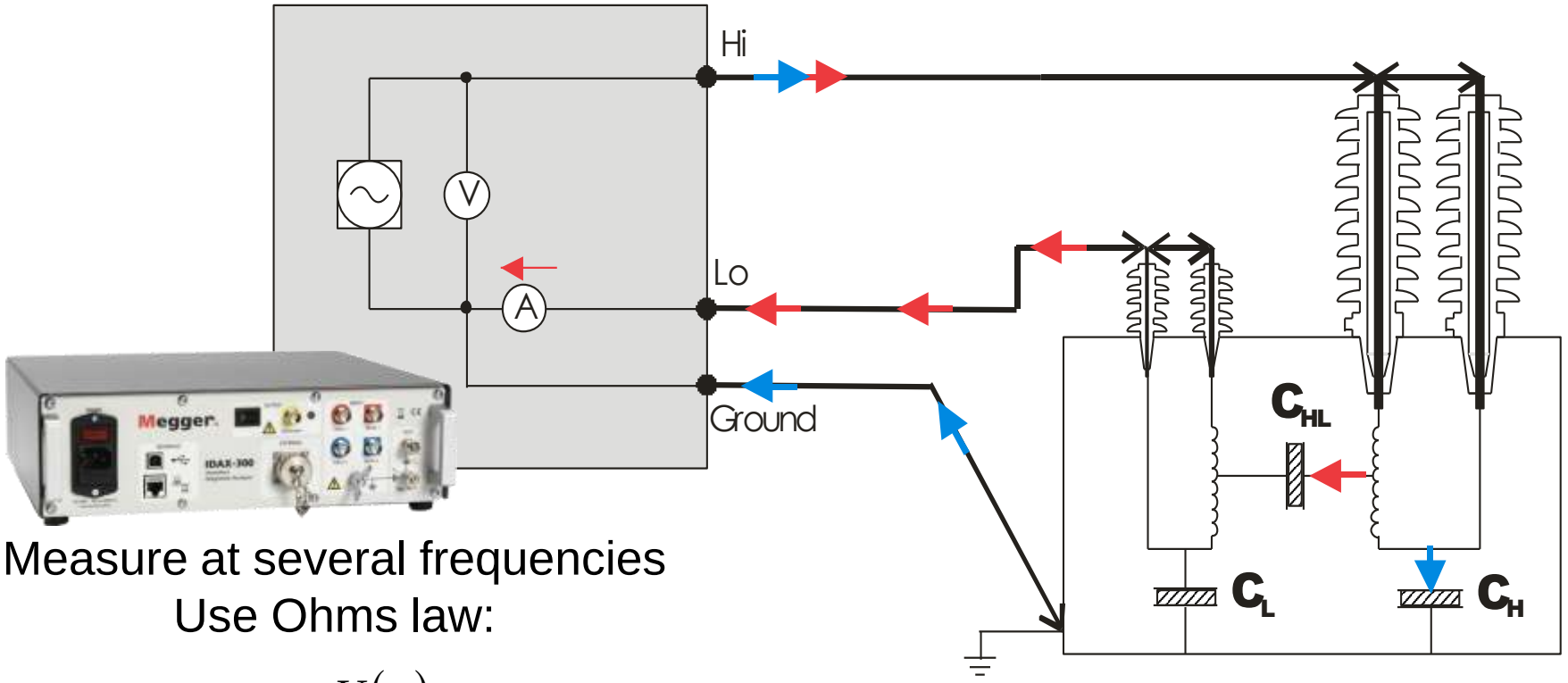
DFR/FDS measurement setup



Measure at several frequencies

Use Ohms law:

$$Z(\omega) = \frac{U(\omega)}{I(\omega)}$$

$$Z(\omega) \Rightarrow \begin{matrix} \text{C, tand, PF} \\ (\varepsilon' \text{ and } \varepsilon'') \end{matrix}$$

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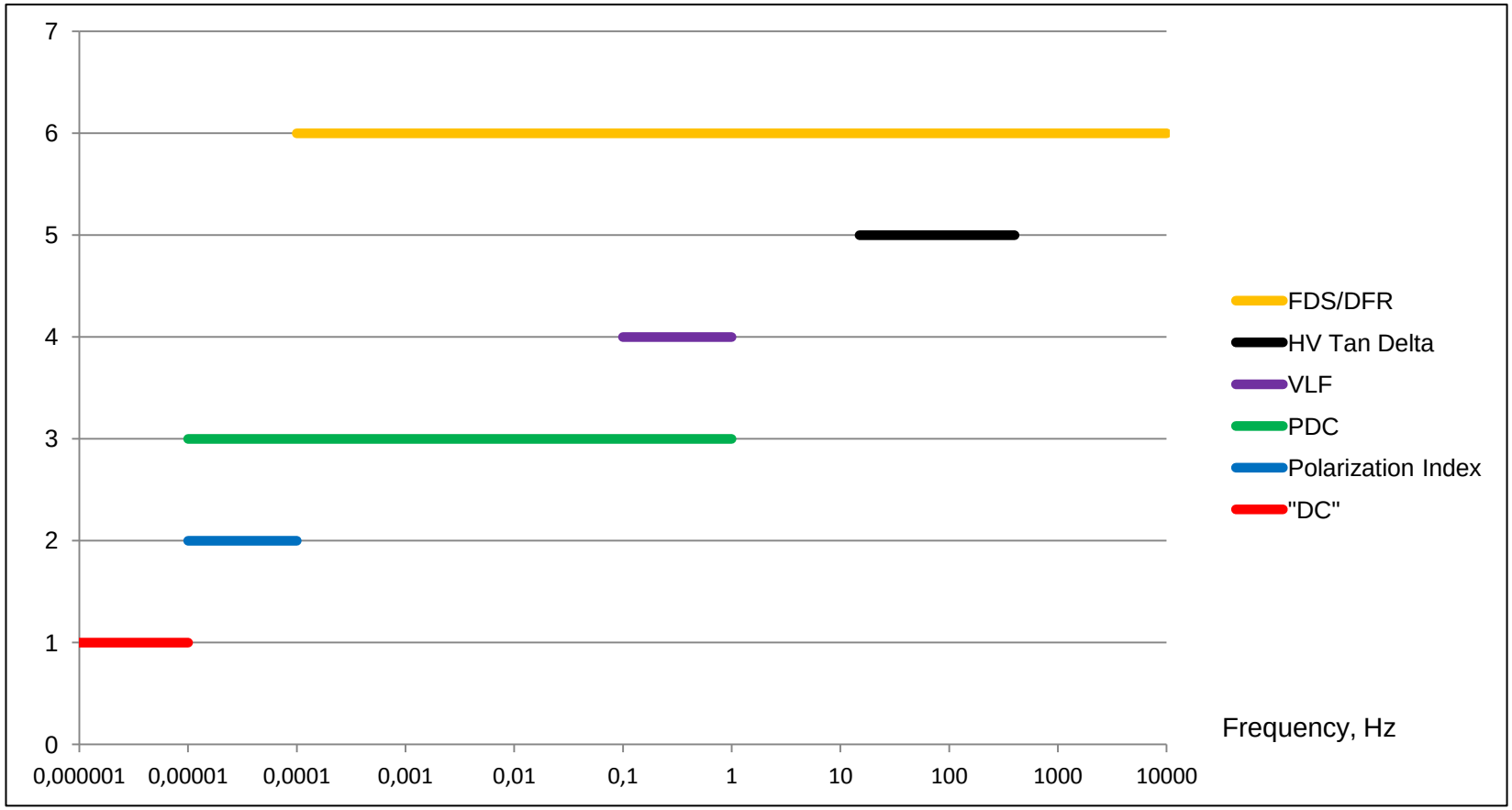
Insulation testing/Dielectric response methods



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Methods for dielectric response measurements

DC (Polarization-Depolarization Current measurements)

- Strenghts
  - Shorter measurement time for very low frequencies
- Weaknesses
  - More sensitive to AC interference (about 10μA max)
  - More sensitive to DC interference (about 10nA max)
  - Limited frequency range (PDC only)
  - Data conversion necessary (combined PDC+DFR only)
  - Discharge before measurement may be needed

AC (Dielectric Frequency Response measurements)

- Strenghts
  - Less sensitive to AC interference (about 500 μA max)
  - Less sensitive to DC interference (about 1 μA max)
  - Wide frequency range
  - No discharge necessarry
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  - Longer measurement time for very low frequencies

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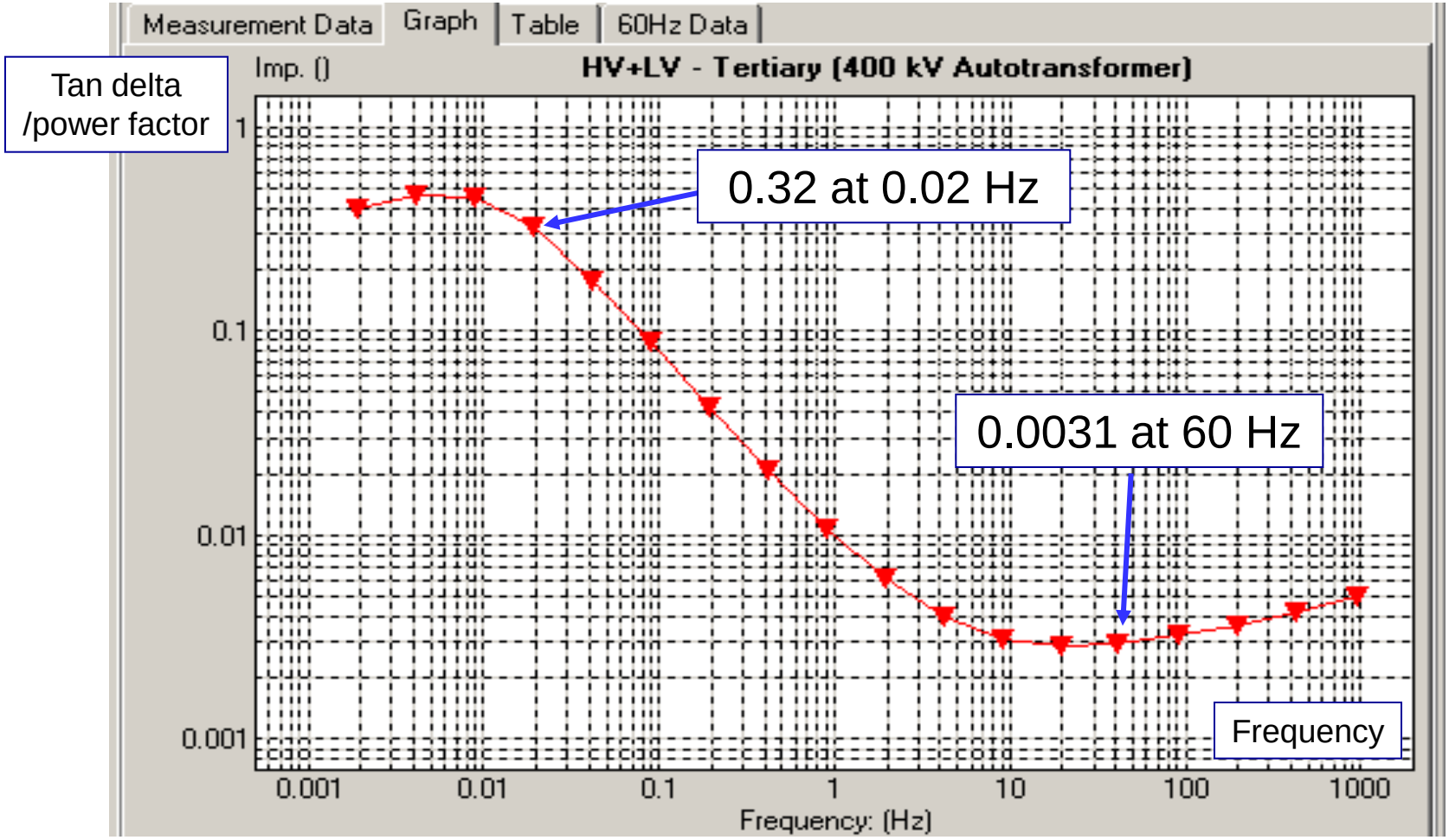
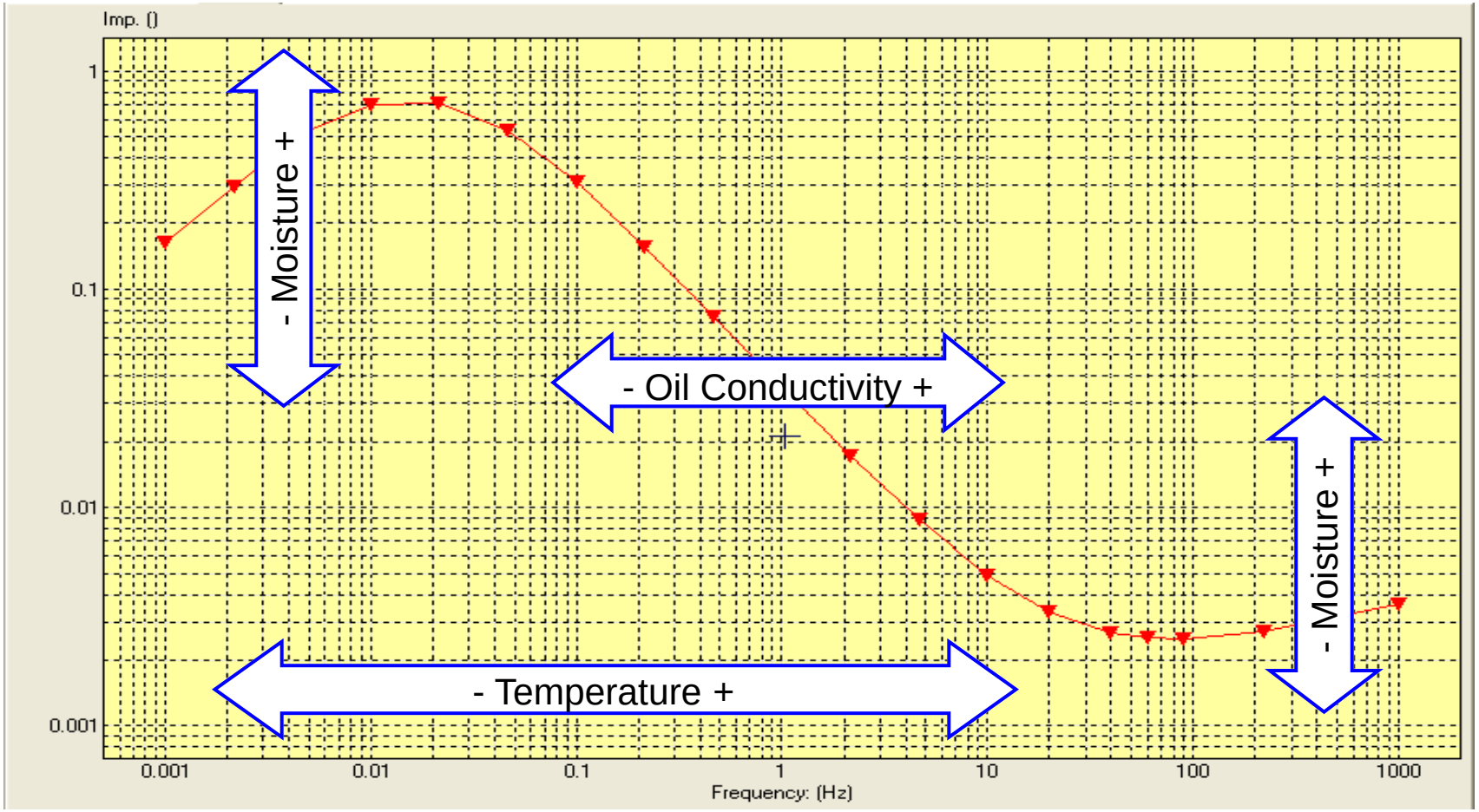
Dielectric Frequency Response

- Dissipation Factor Changes with Frequency

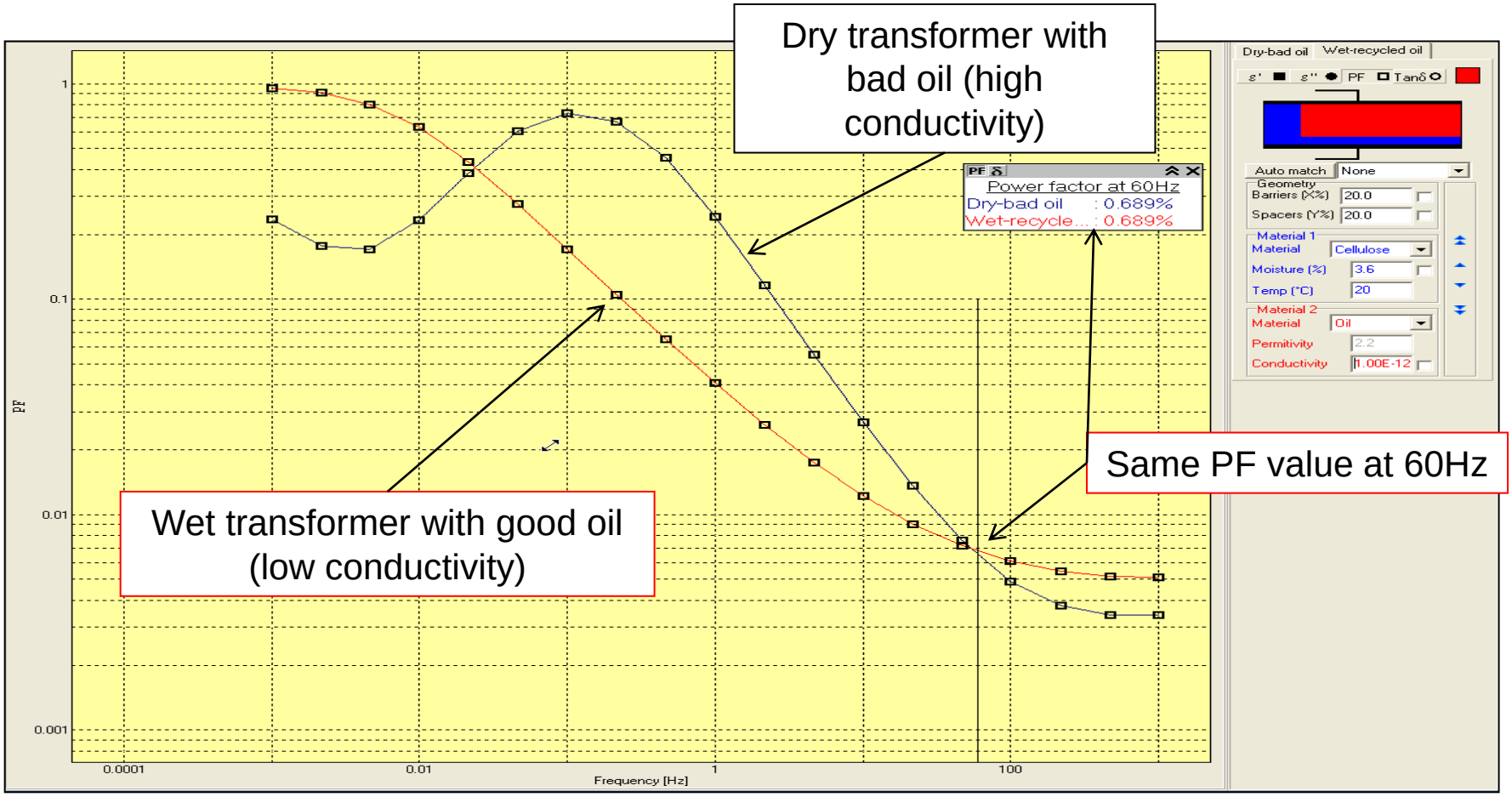


What affects the response?

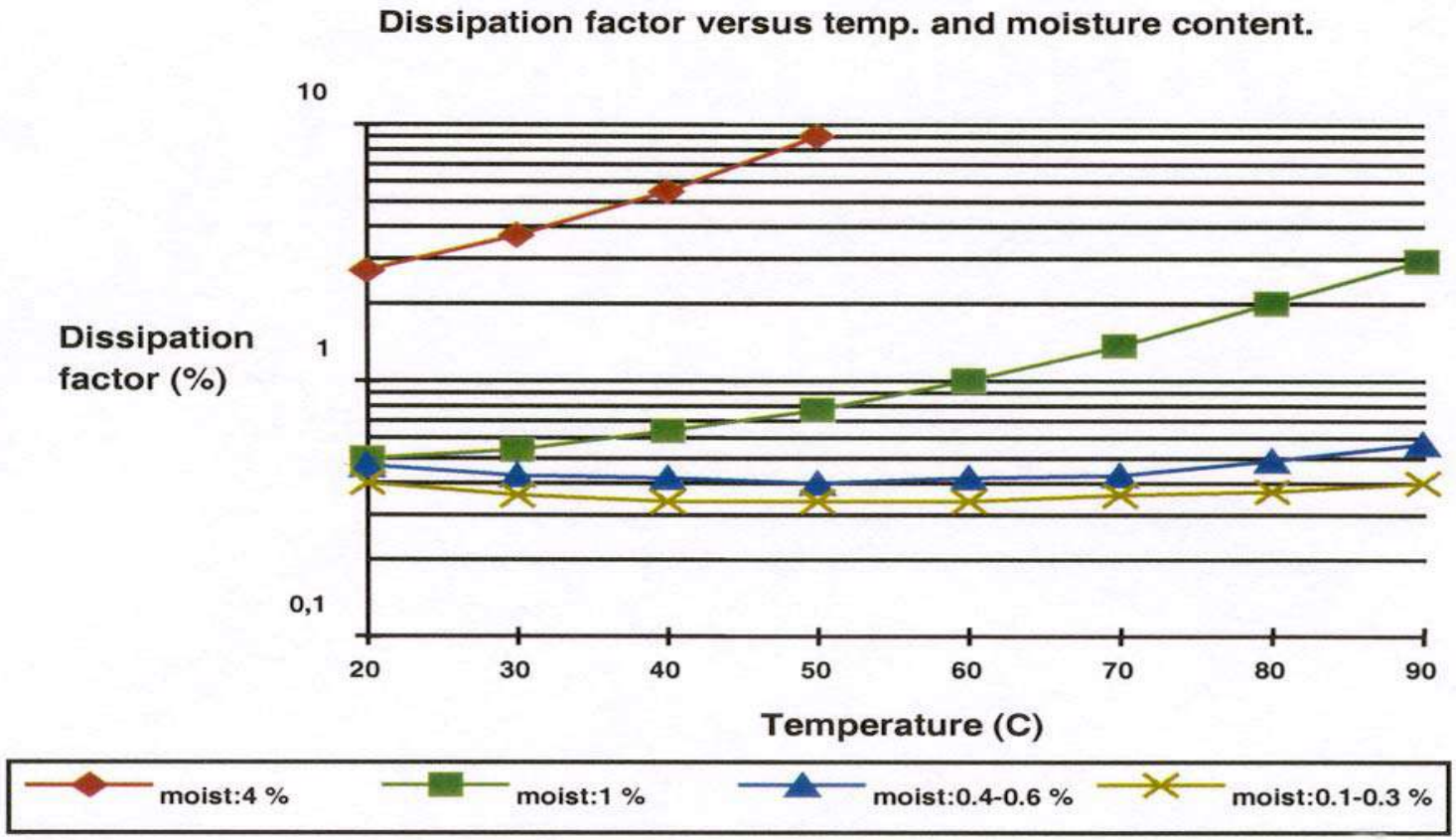


Dielectric Frequency Response

- Single value @ 0.7% is not sufficient to make the right decision
- Dielectric Frequency Response tells the story!



Tan Delta vs temperature and moisture



Source; ABB, ”Bushing diagnostics and conditioning”, 2000

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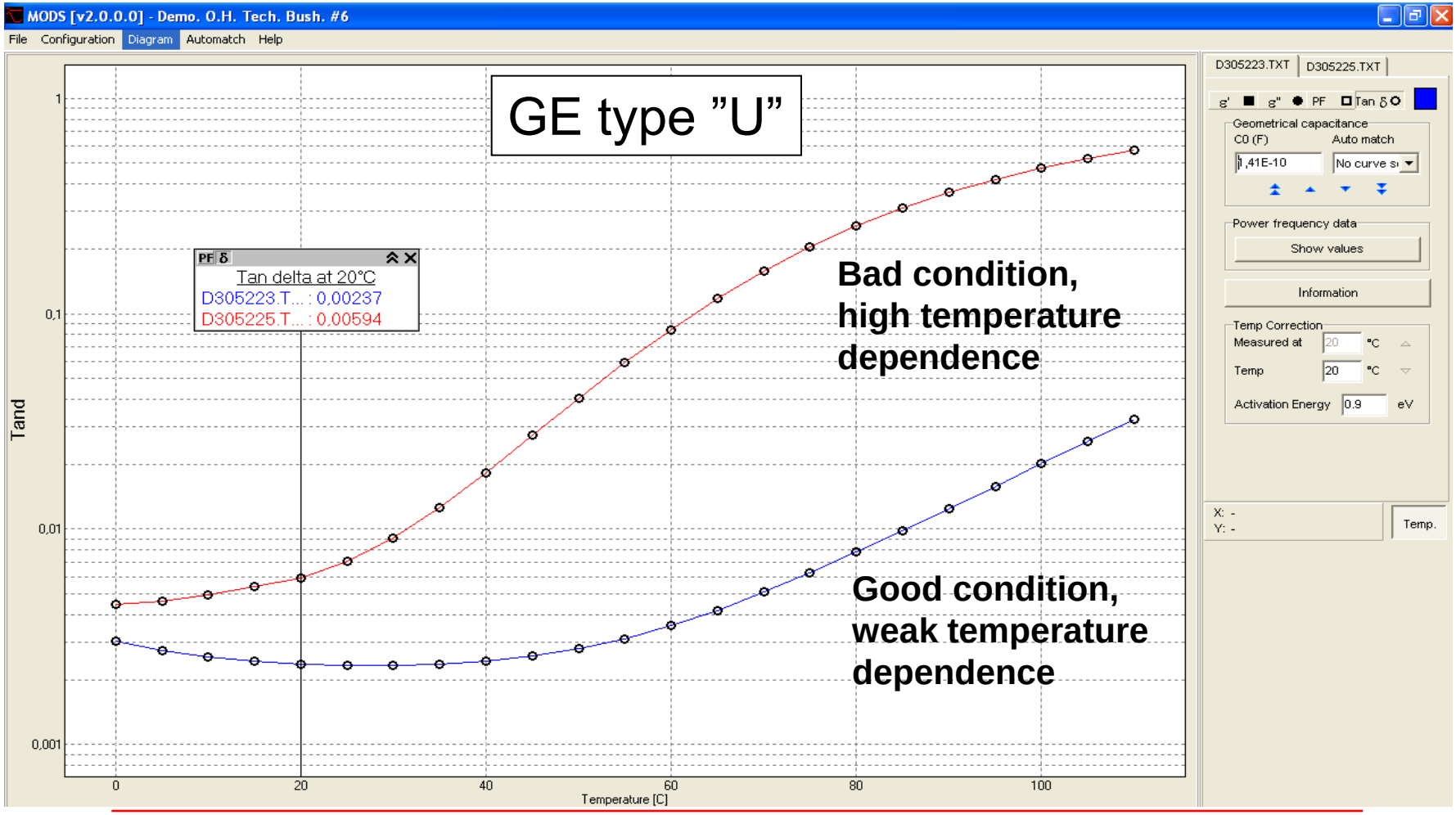
Tan delta vs temperature



Why measure moisture?

- A transformer with low moisture content is like a person in good condition
  - A transformer can be loaded with confidence without risk for catastrophic failure.
  - A person can work hard without risk for heart attack
- A wet transformer is like an overweight person in bad condition
  - The transformer owner has to limit load to avoid bubbling (explosion risk).
  - Moisture in insulation increases the rate of aging
  - The person can not run the marathon...

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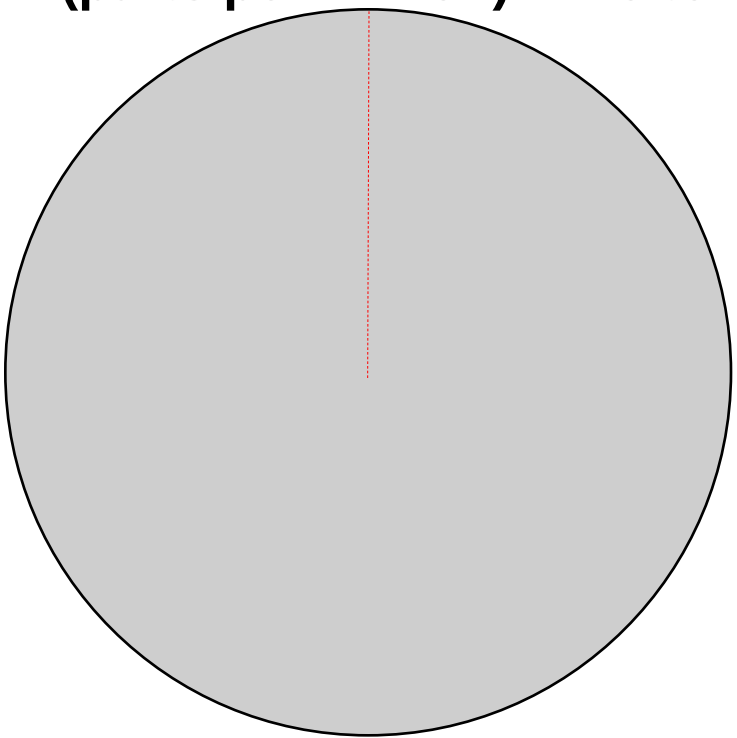
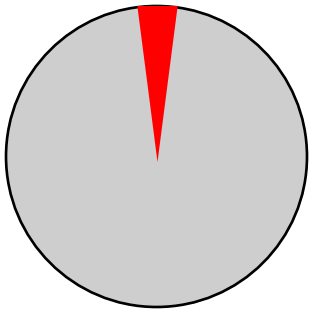
Moisture in Power Transformers

- Power transformer insulation consists of oil impregnated cellulose and free oil. Almost all water is in the cellulose:
  - 25 tons of oil with water content of 20 ppm = 0,5 kg
  - 2.5 tons of cellulose with 3% water content = 75 kg

20ppm (parts per million) in 25 tons of oil



3% water in 2.5 tons of cellulose



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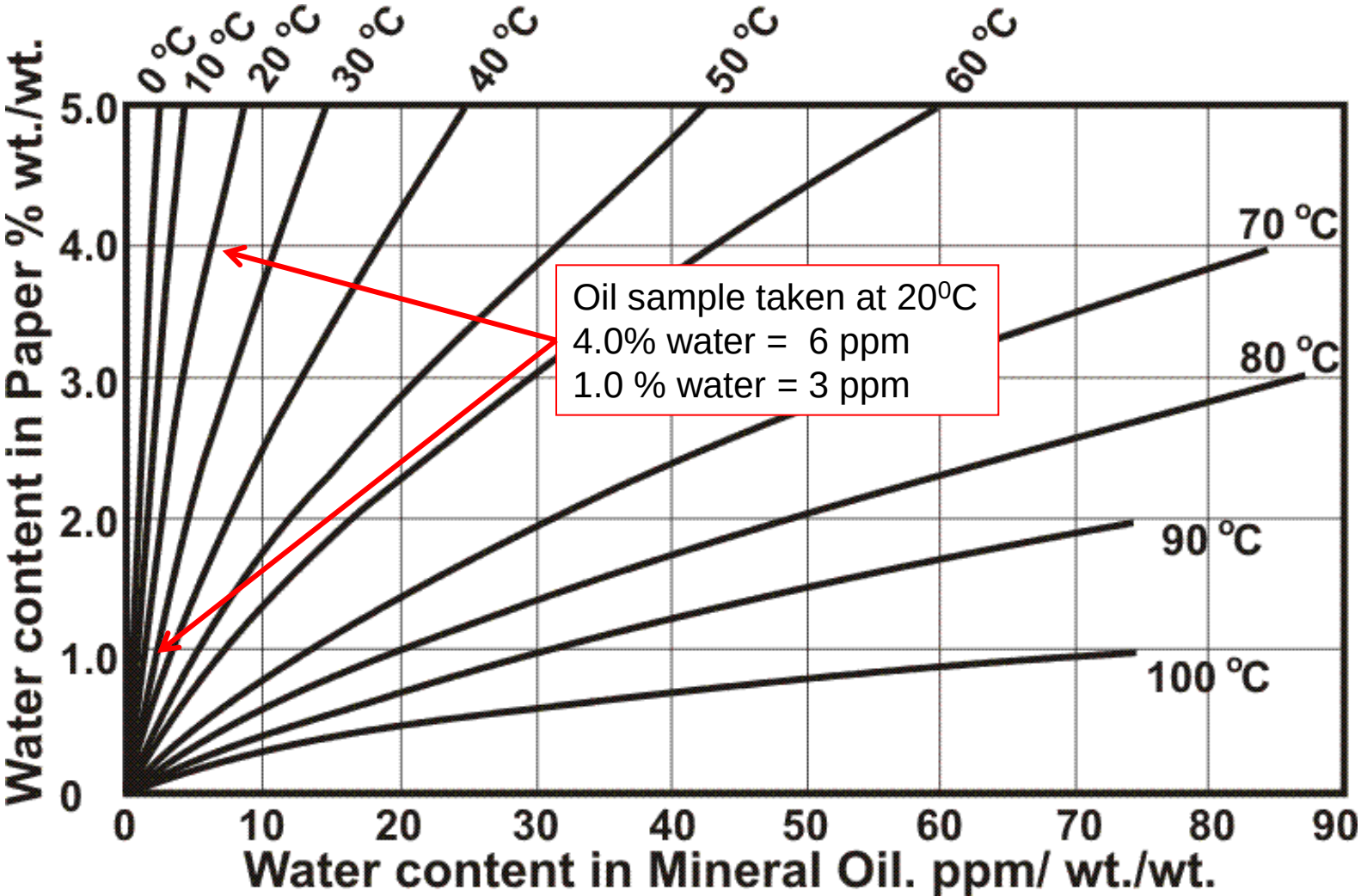
  - Aged oil resolves higher amounts of water than new oil
  - Small moisture concentration makes sampling difficult

Water In Oil Analysis

Oil samples taken at low temperatures have low accuracy because the water has migrated to the paper



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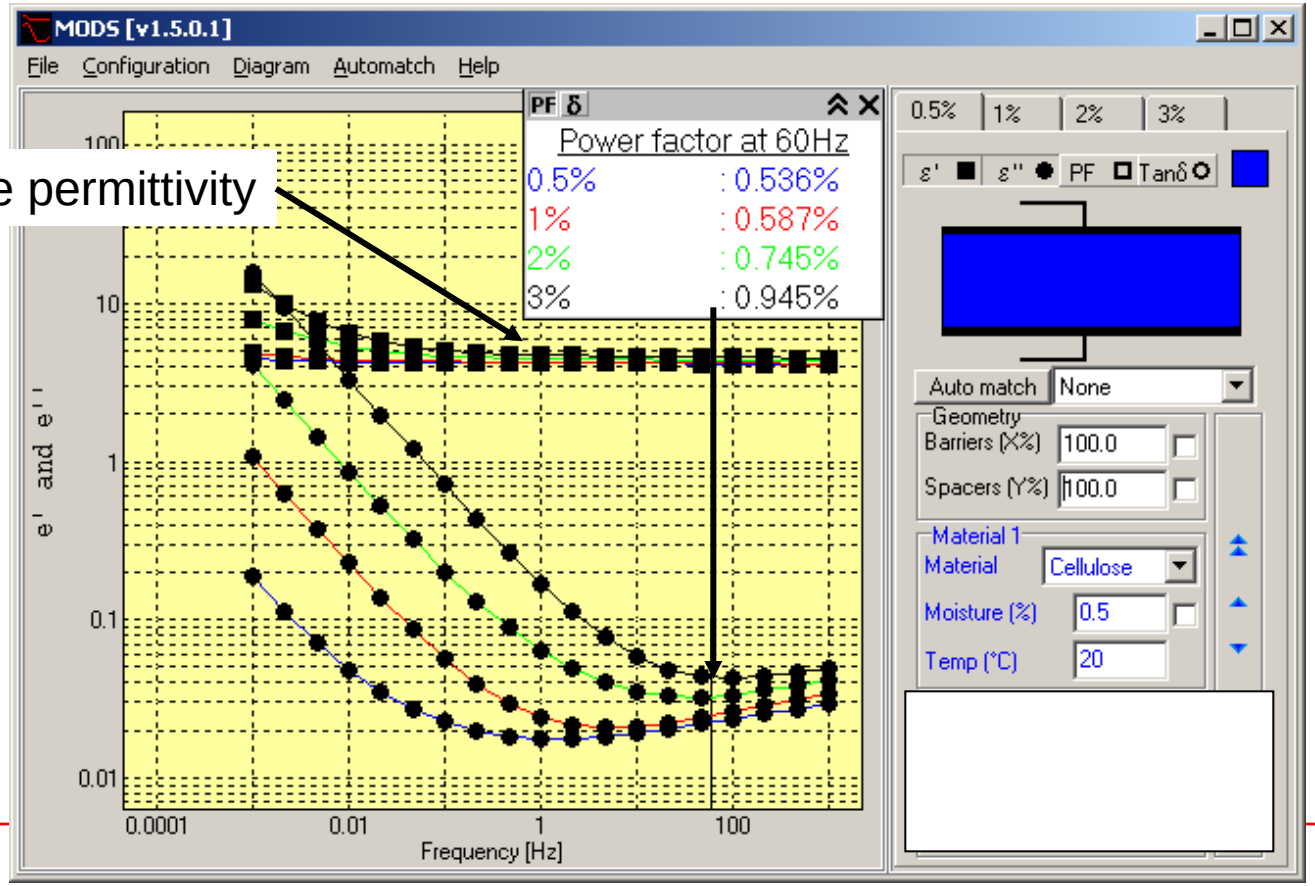
- Moisture changes the dielectric properties of the cellulose paper/pressboard

Water Changes Paper

- Water changes the insulation properties of the paper



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- Moisture accelerates ageing

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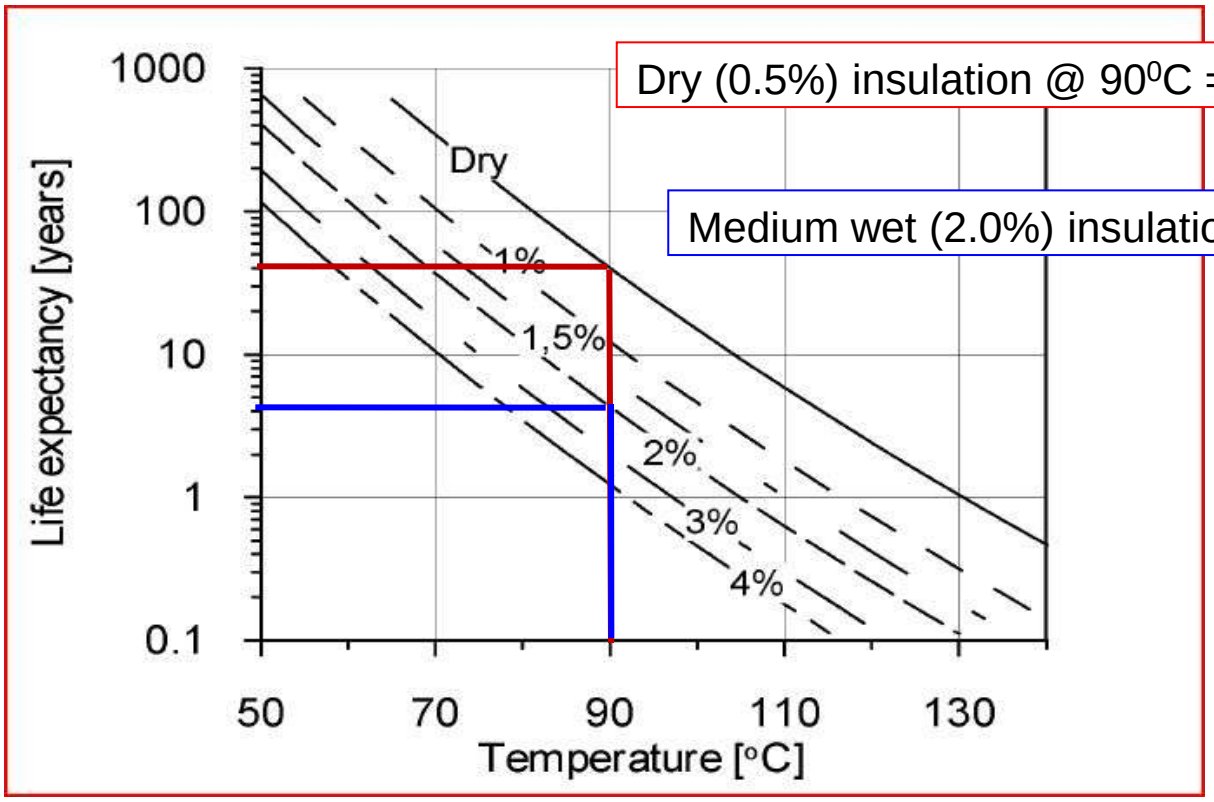

Dry (0.5%) insulation @ 90^0C = 40 Years

Medium wet (2.0%) insulation @ 90^0C = 4-5Years

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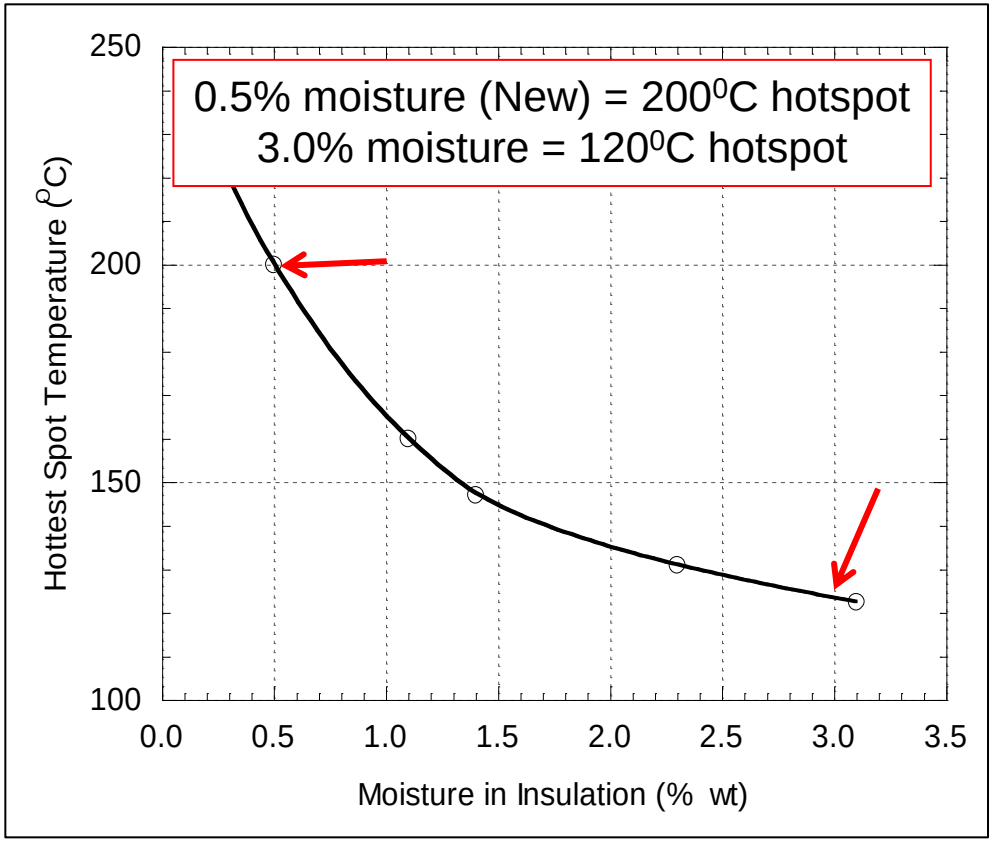
- Moisture changes the dielectric properties of the cellulose paper/pressboard
- Moisture accelerates ageing
- Moisture limits loading capability

Moisture in Power Transformers

- Moisture determines the maximum loading/hot-spot temperature for bubble inception (see e.g. IEEE Std C57.91-1995)
- Knowing moisture content allows for correct decision
  - Leave as-is
  - Dry-out
  - Replace
  - Scrap or Relocate?



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Interpretation of moisture content
(IEC 60422/IEEE C57.106)

< 2.2%	Dry
2.2 – 3.7%	Moderately wet
3.7 – 4.8%	Wet
> 4.8%	Extremely wet

Interpretation of moisture content of solid insulation (% of weight water per weight cellulose):

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Interpretation of moisture content

combining various standards…

- < 1% New transformer
- < 2% Dry insulation
- 2 - 3% Moderately wet
- 3 – 4.5% Wet
- > 4.5% Excessively wet insulation

Interpretation of moisture content of solid insulation (% of weight water per weight cellulose):

Moisture levels in practice...

1.0 %

2.6 %

?

4.2 %

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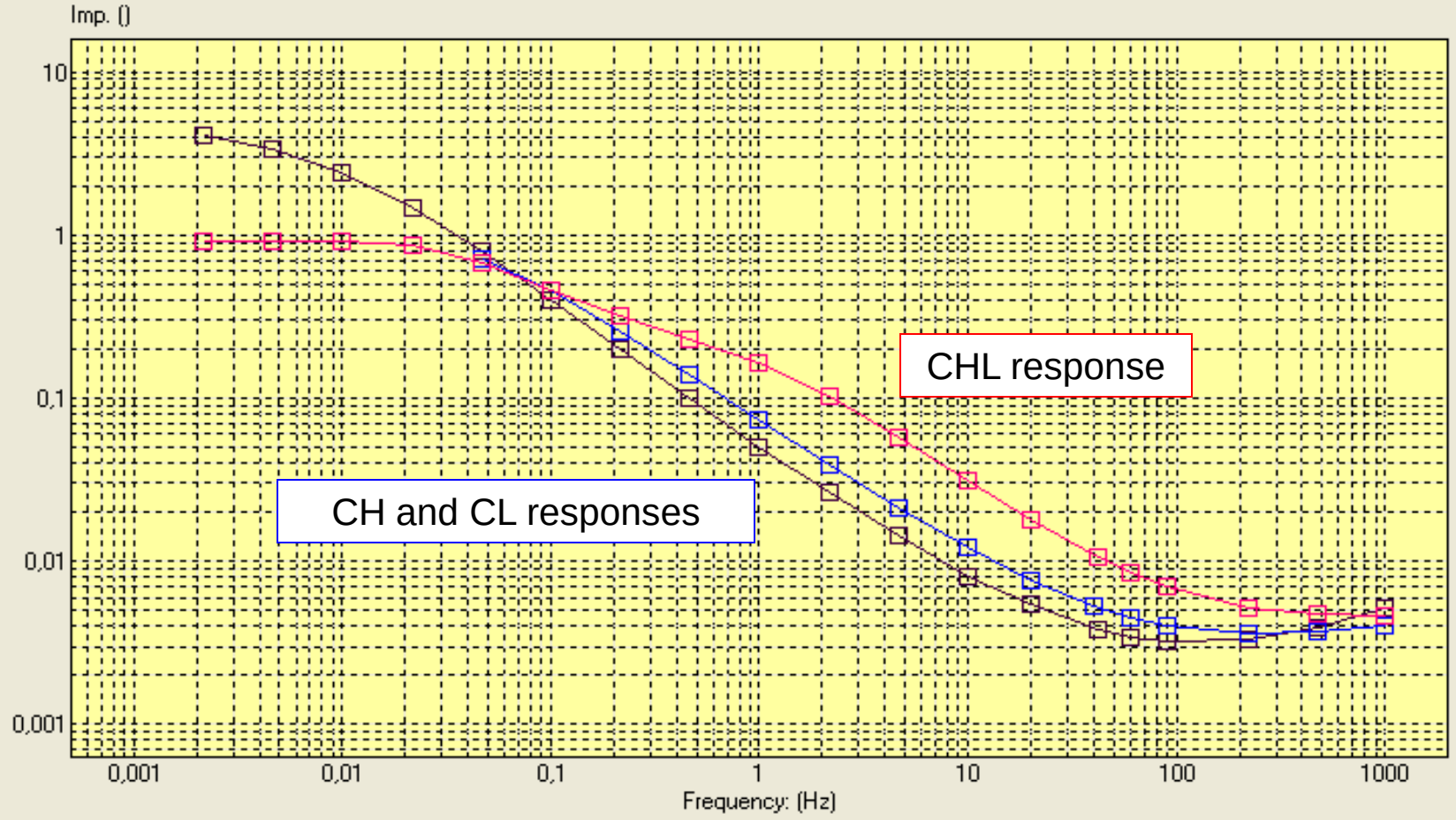
Dielectric Frequency Response

- Investigating irregular shapes



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DFR analysis – irregular responses

A measured irregular shape is not a mishap – It is information!

- CH and CL has expected oil-paper response
- CHL looks “different” with higher losses at mid-frequencies
- Contamination/conductive layer between windings?
- This particular transformer had a history including an LTC replacement due to seriously burned contacts...

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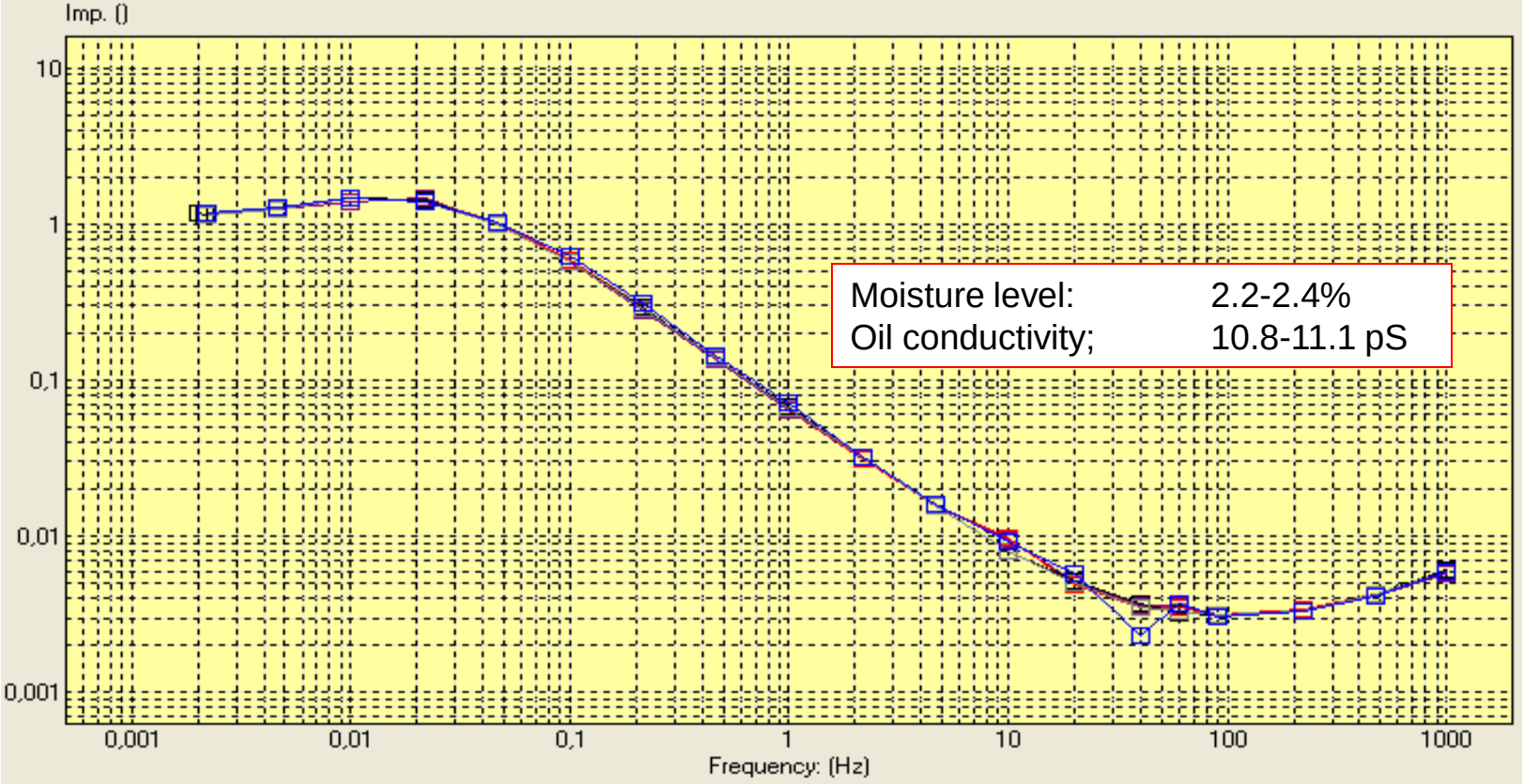
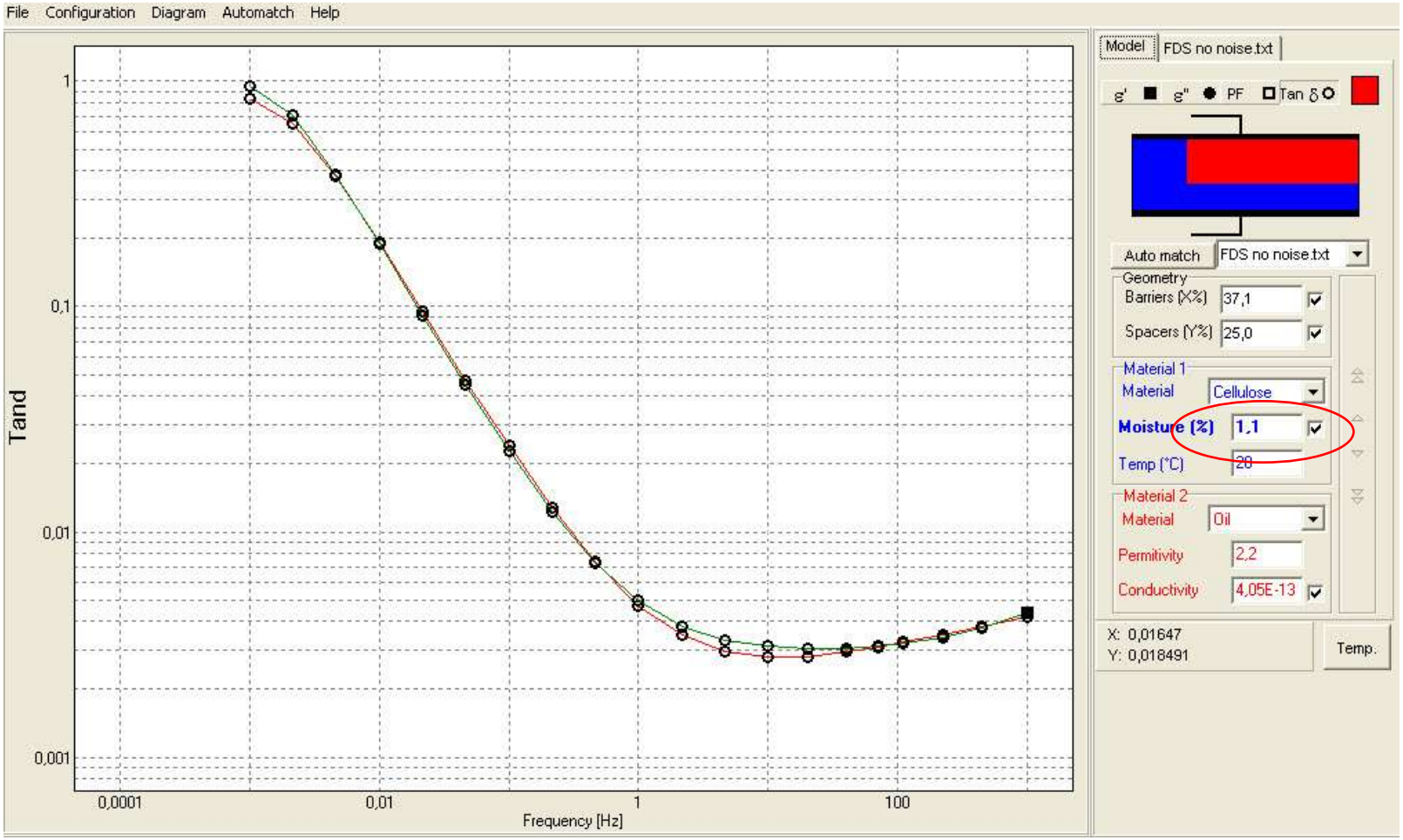
AC DR measurements with noise

5 measurements with 20, 100, 220, 390 and 620 µA injected 50 Hz noise



AC DR measurement with low noise



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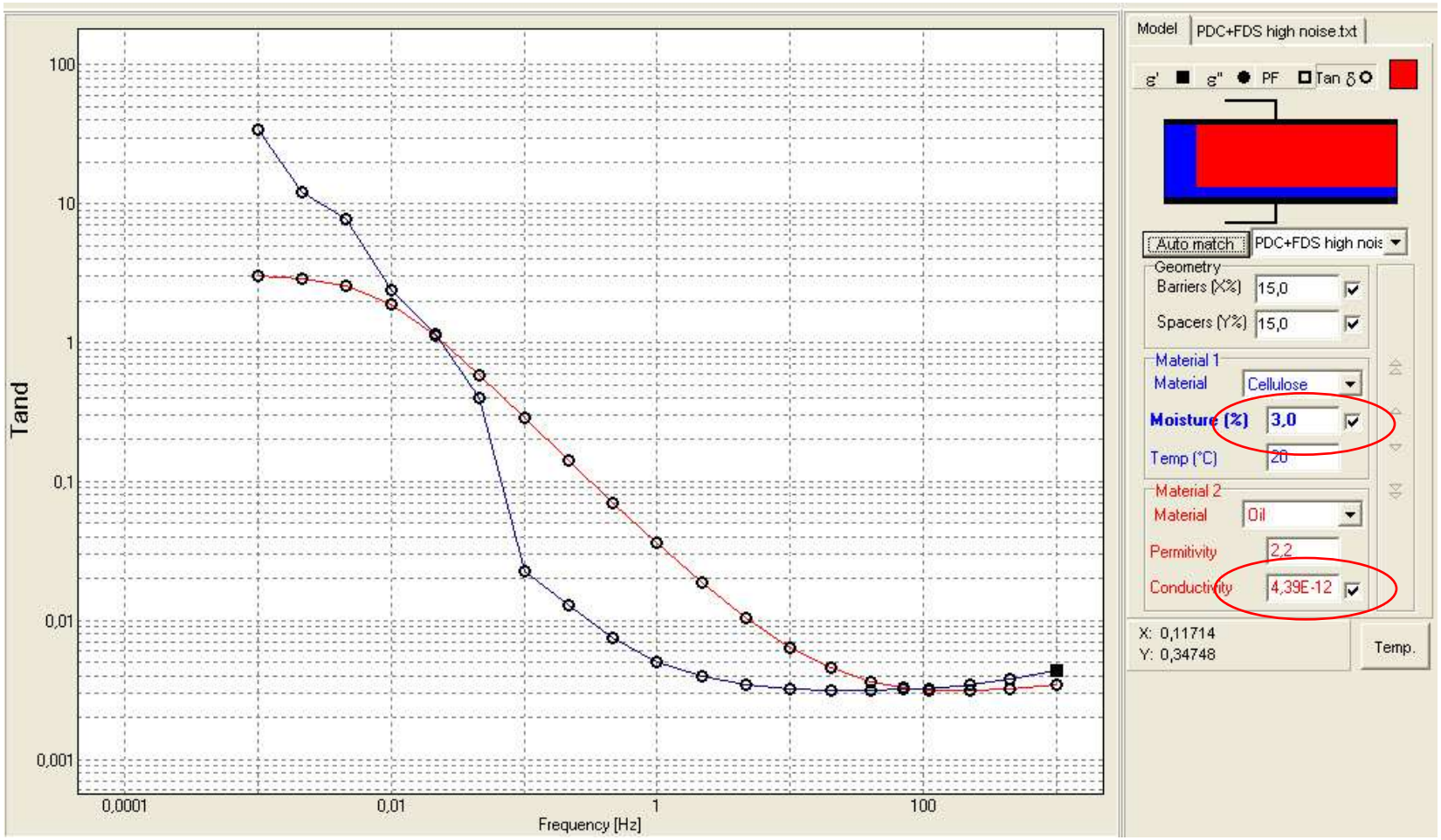
DC+AC DR measurement with 90 µA noise



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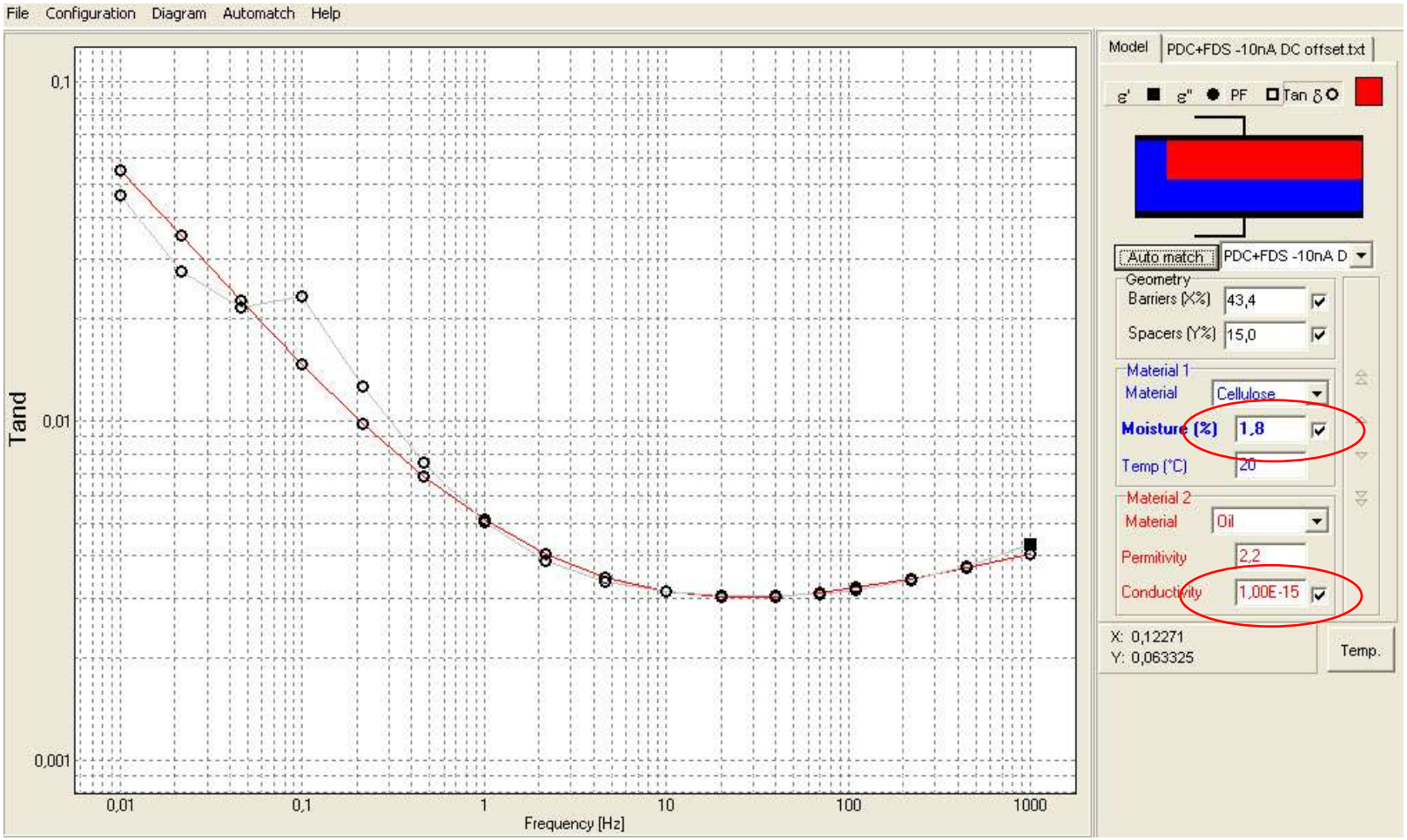
DC+AC DR measurement with 10nA DC offset



Summary and conclusions

- Dielectric response measurement is an excellent tool for insulation diagnostics
- Moisture assessment using DFR and transformer insulation modeling is a generally accepted standard measurement method
- DFR is capable of identifying other issues like contamination/sludge and/or conductive layers
- DFR can be used to estimate the temperature dependence in the insulation material
- Transformer outage time is expensive and it is necessary to minimize measurement time/frequency range as much as possible. Try to avoid measuring at very low temperature
- 2-ch simultaneous measurement is a good way to shorten effective measurement time on 3-w transformers
- AC and DC interference is common in substation environment – Choose a DR method with low noise susceptibility