Measurement of dielectric properties:
(focusing on loss tangent)

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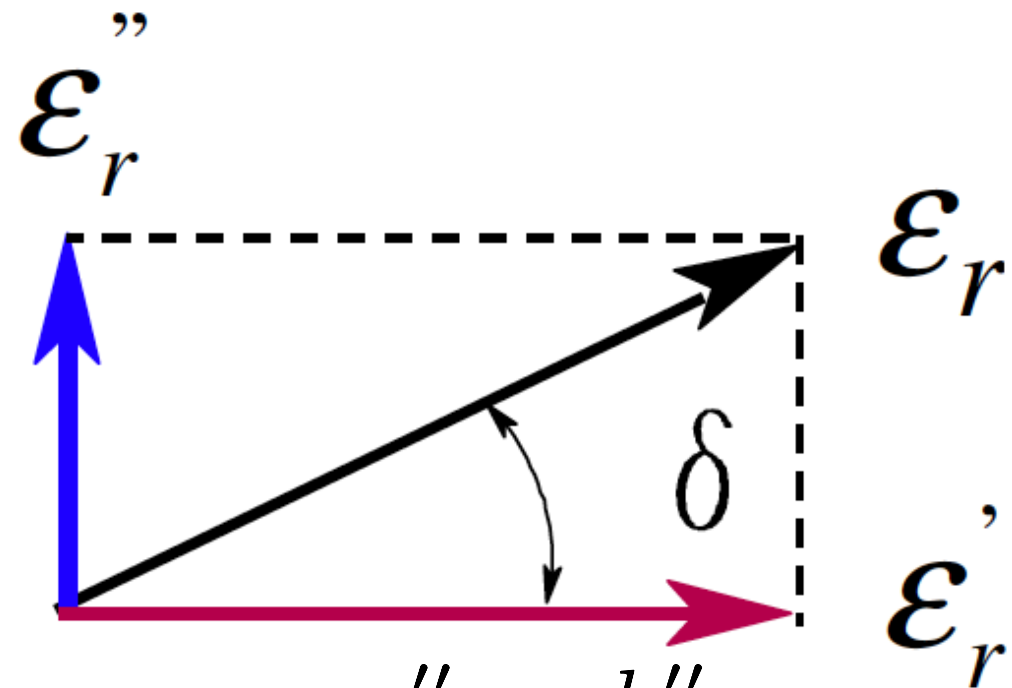
basics

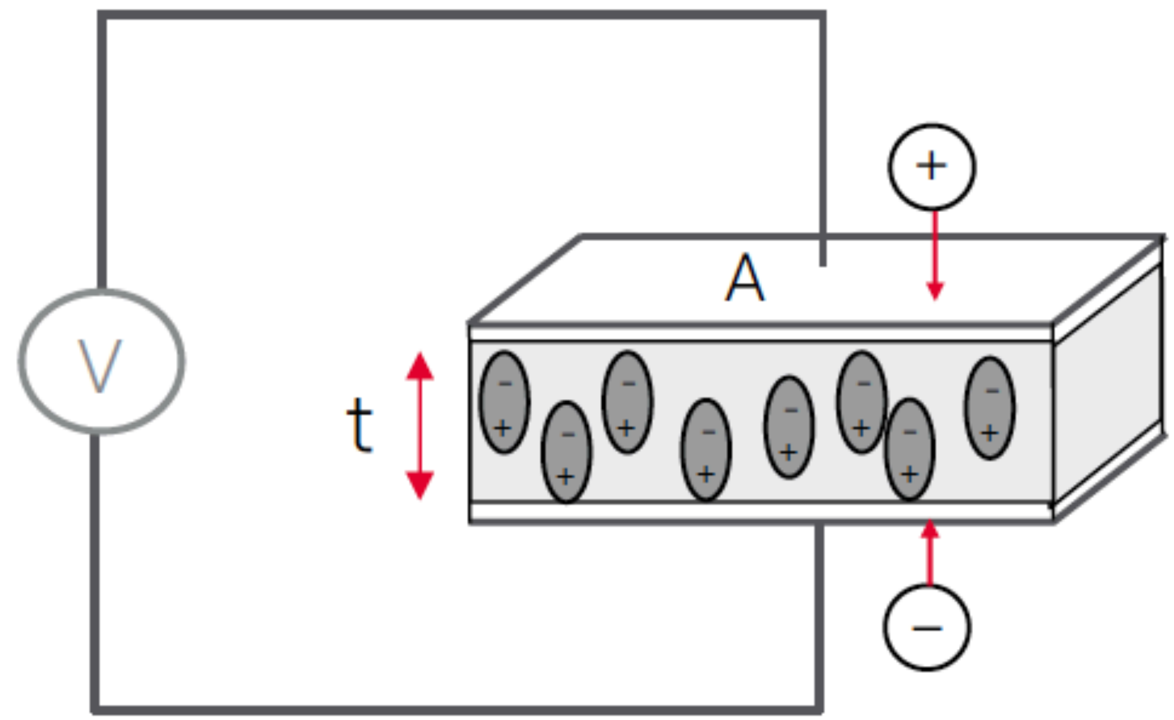


$$\tan\delta = \frac{\epsilon_r''}{\epsilon_r'} = \frac{k''}{k'}$$

$$= \frac{\text{energy lost per cycle}}{\text{energy stored per cycle}}$$

basics

static $\epsilon'_r = \dfrac{C}{C_0}$



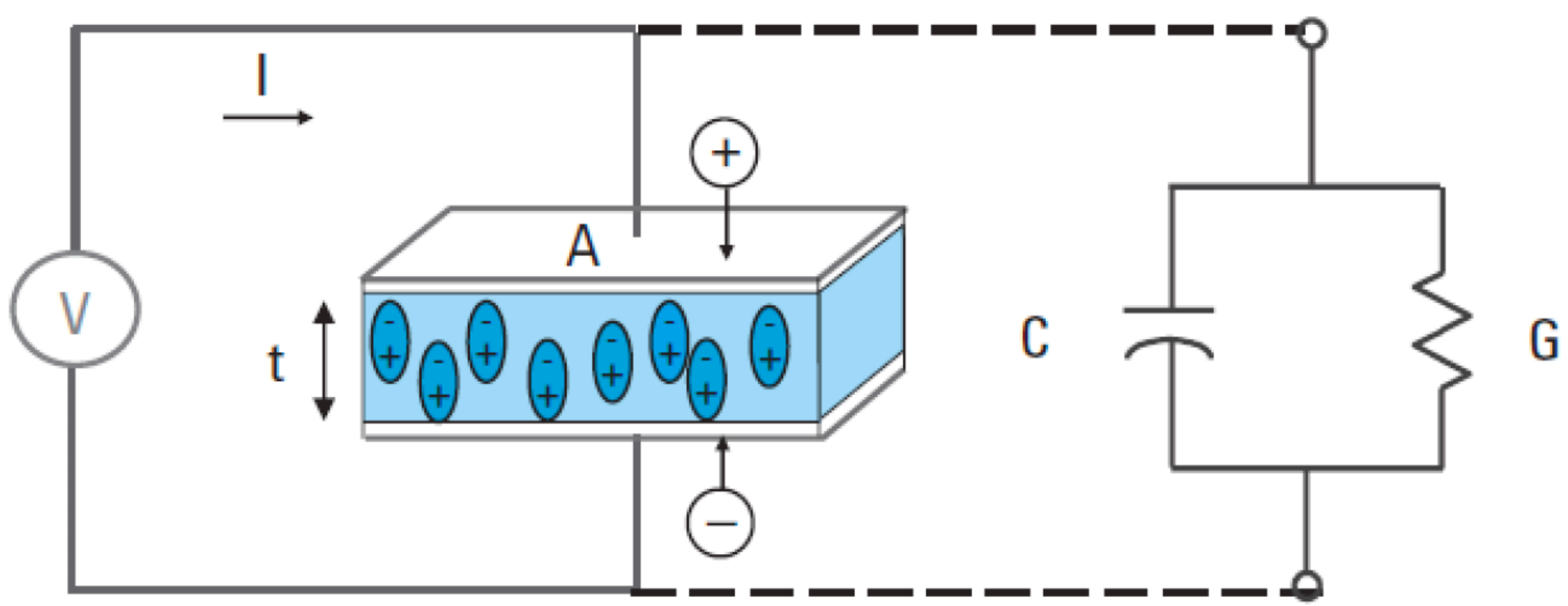
dynamic:

$$I = I_c + I_l = V\,(j\omega C_0 \kappa' + G)$$

If $G = \omega C_0 \kappa''$, then

$$I = V\,(j\omega C_0)(\kappa' - j\kappa'') = V\,(j\omega C_0)\kappa$$

$$\omega = 2\pi f$$



basics

- there can be a frequency dependence

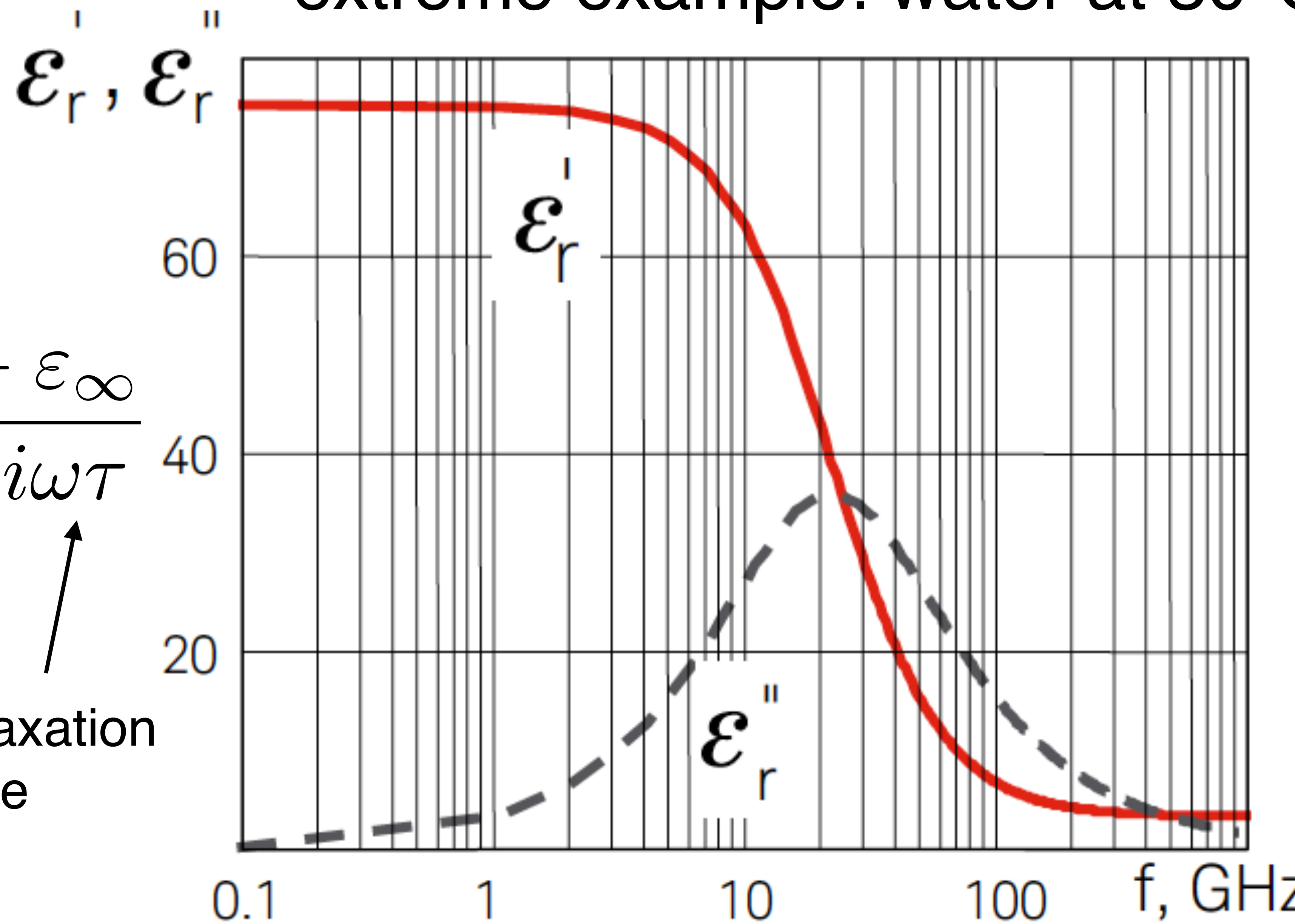
static permettivity

$$\varepsilon_r(\omega) = \varepsilon_\infty + \frac{\varepsilon_S - \varepsilon_\infty}{1 + i\omega\tau}$$

minimum (at infinite frequency)

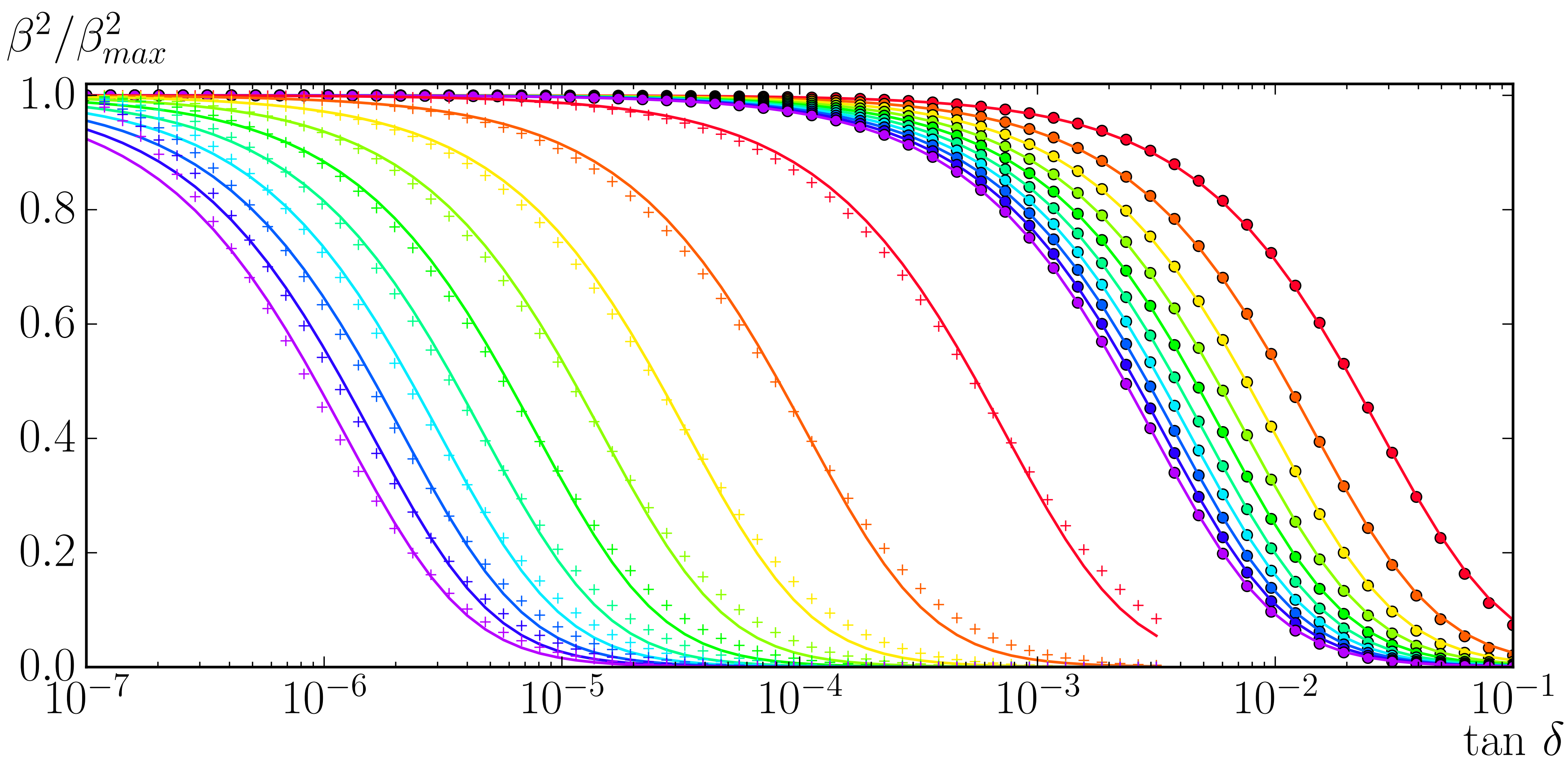
relaxation time

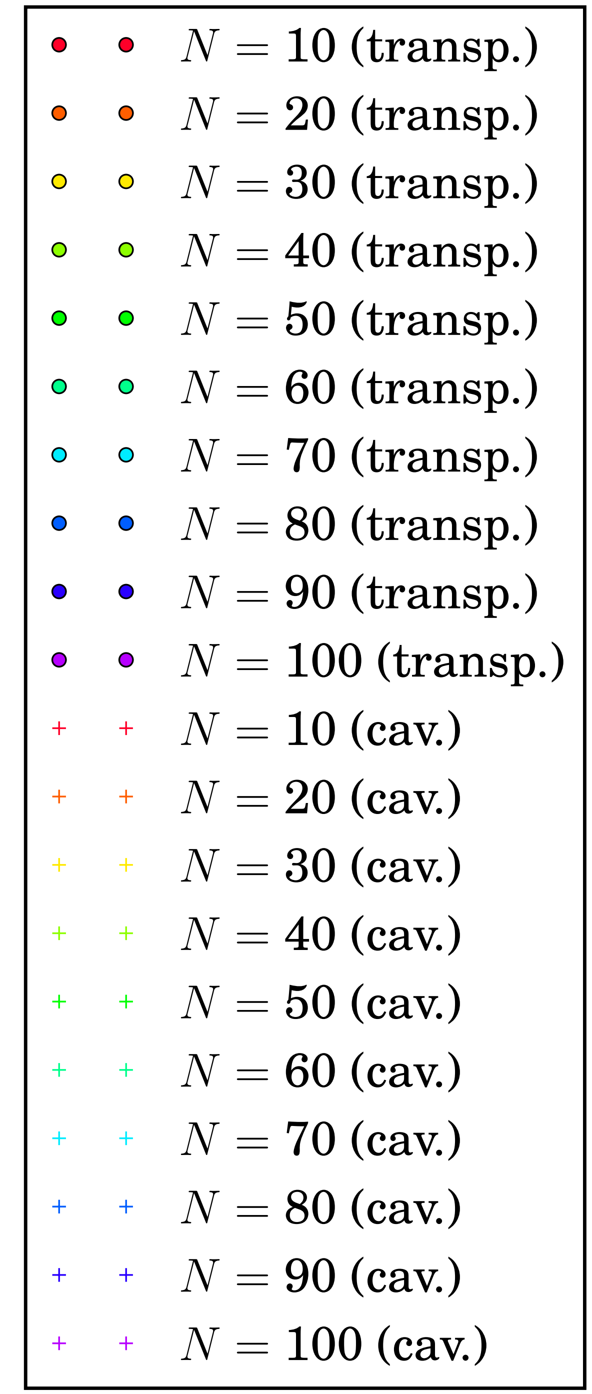
- extreme example: water at 30°C:



boost factor

- presented by A. Partsch in collaboration meeting May 2018:



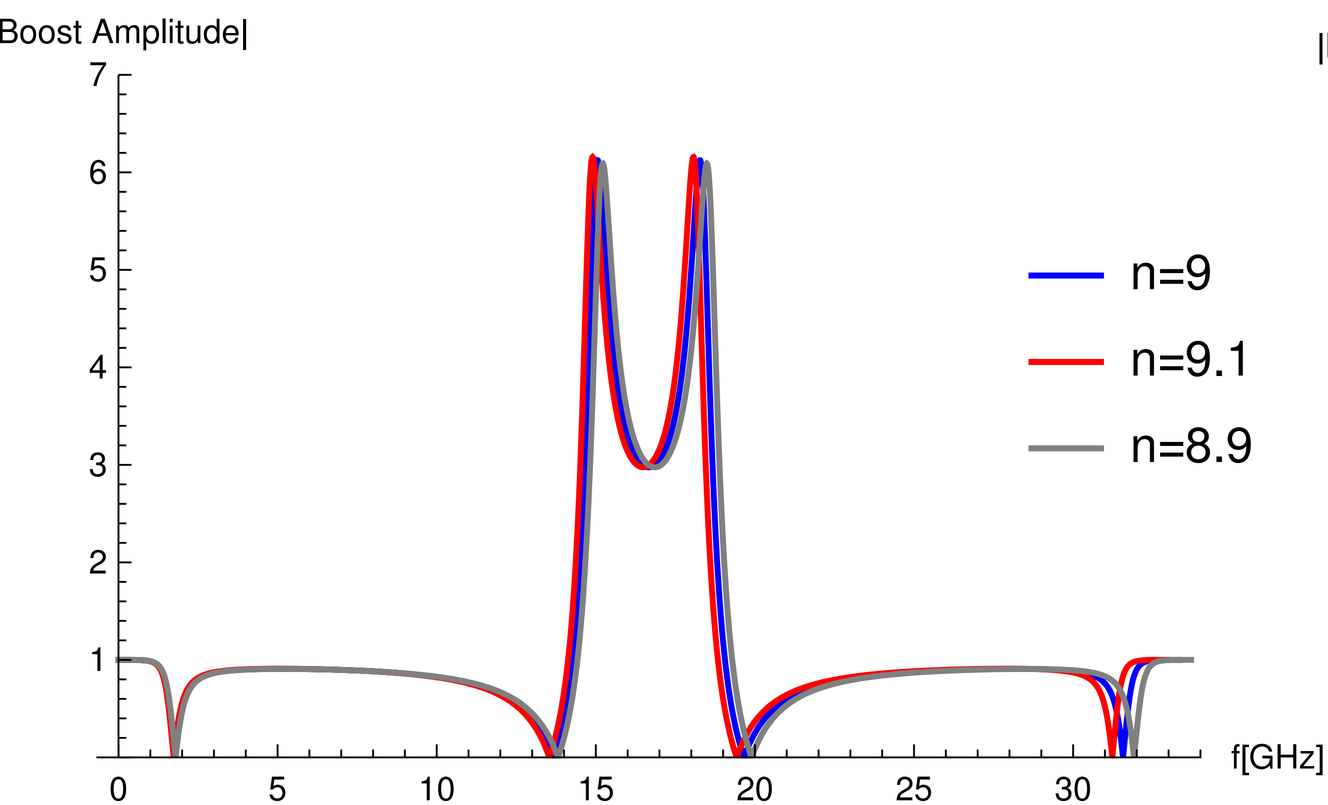


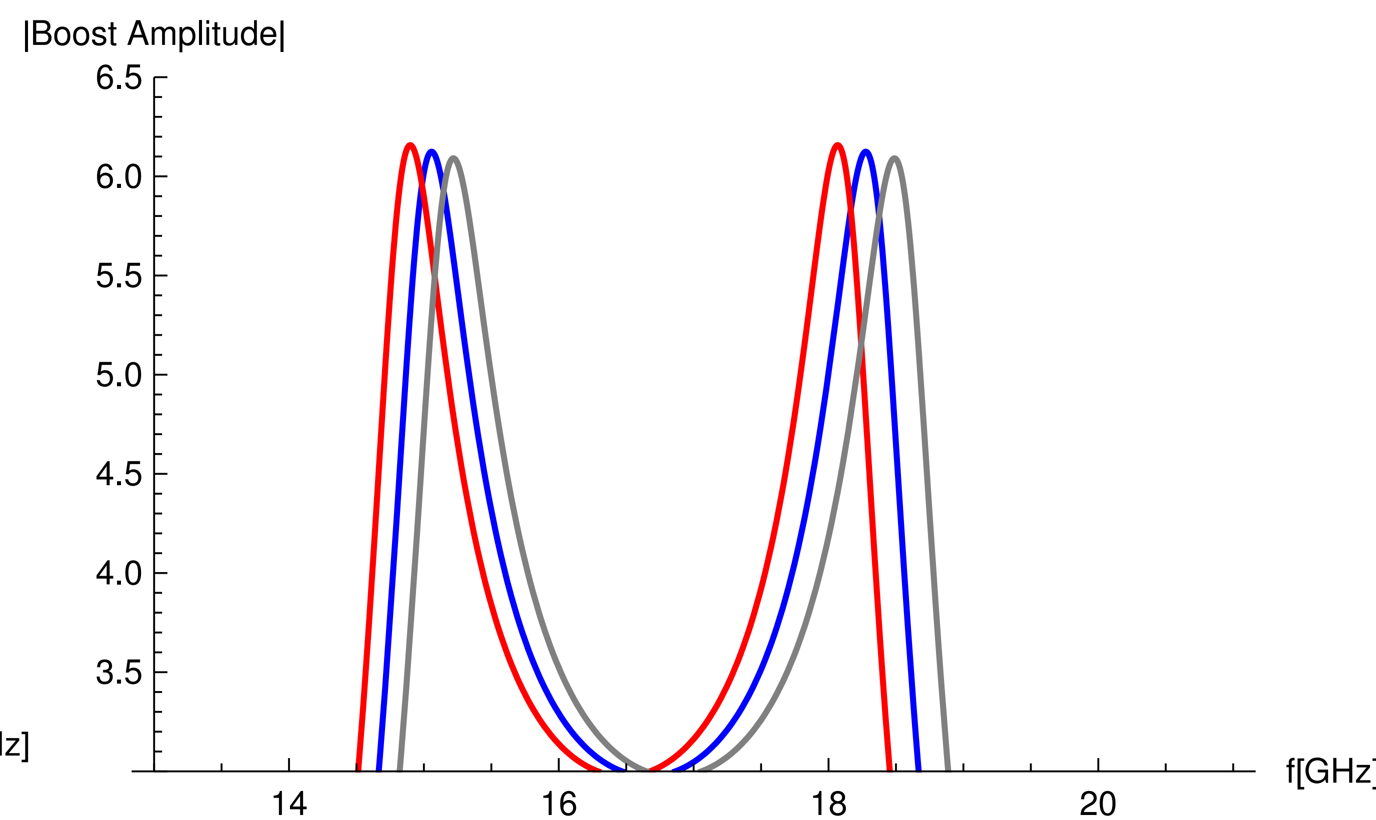
- **note**: state of the art uncertainty in tan δ measurement: ~10^{-6} (see later slides)
- 10^{-6} can make a significant difference in boost factor

boost factor

- effect of uncertainty in the real part
  - assume uncertainty of refractive index ($n=\sqrt{\epsilon\mu}$) of 0.1
  - setup with one disk and one mirror (transparent case)
  - disk thickness 1mm

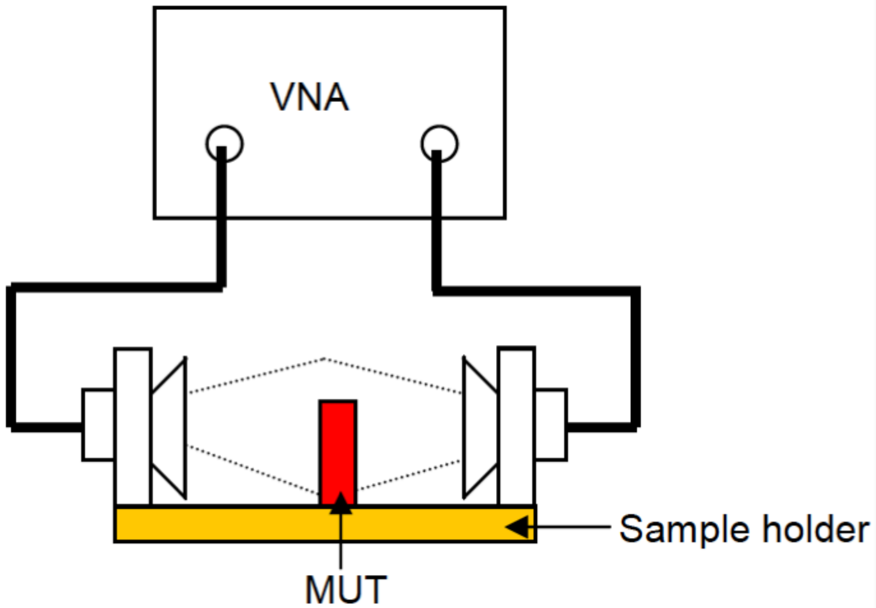
  - resonance peak moves by 500 MHz



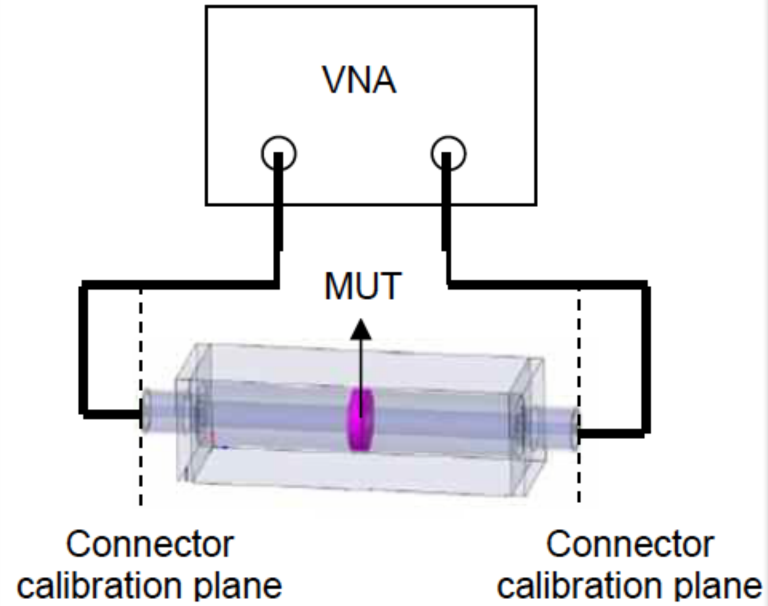


some measurement concepts

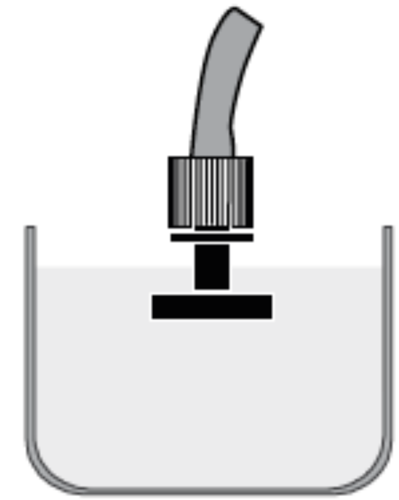
free space method



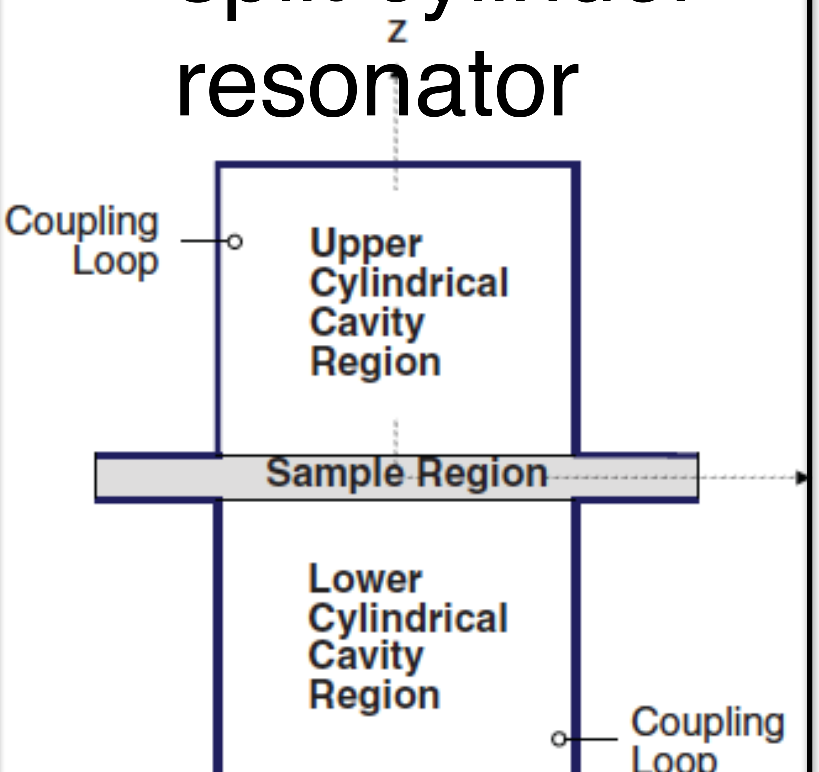
waveguide



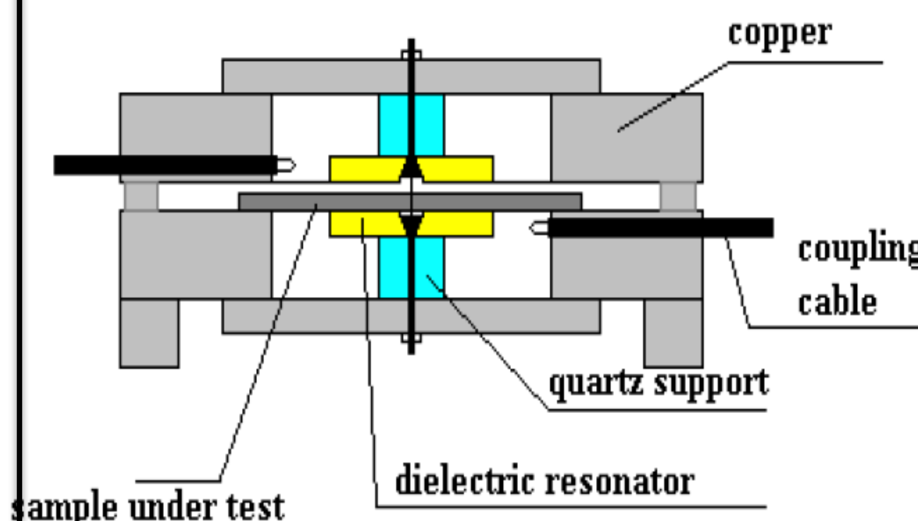
open coax



split cylinder resonator

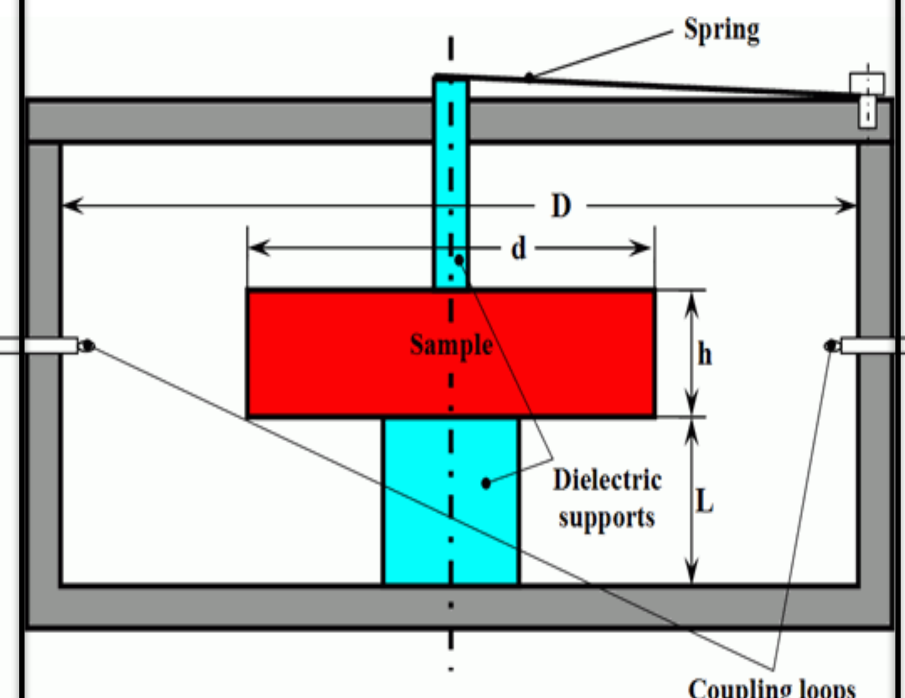


split post resonator

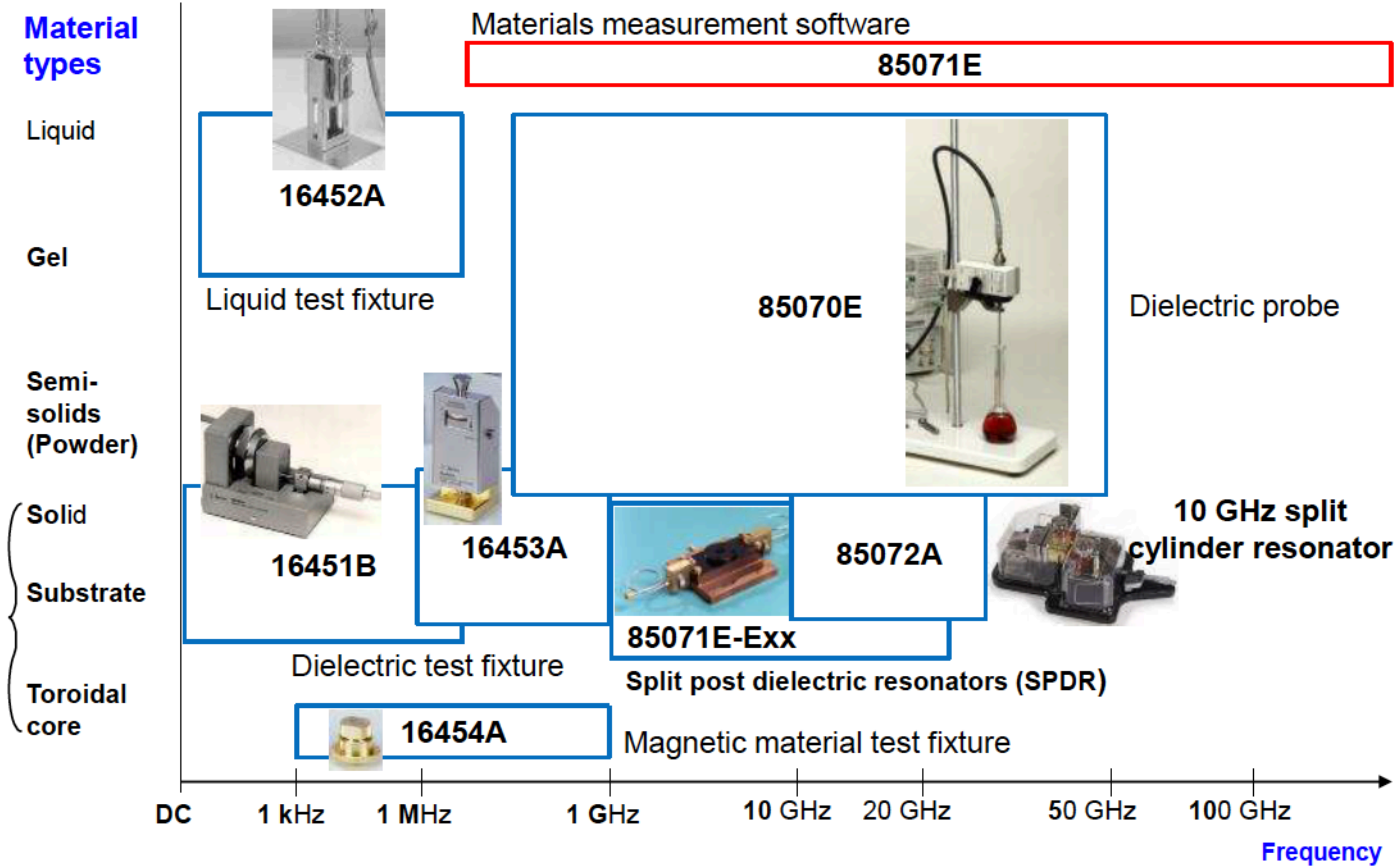


(also single post)

$TE_{01\delta}$ mode dielectric resonators

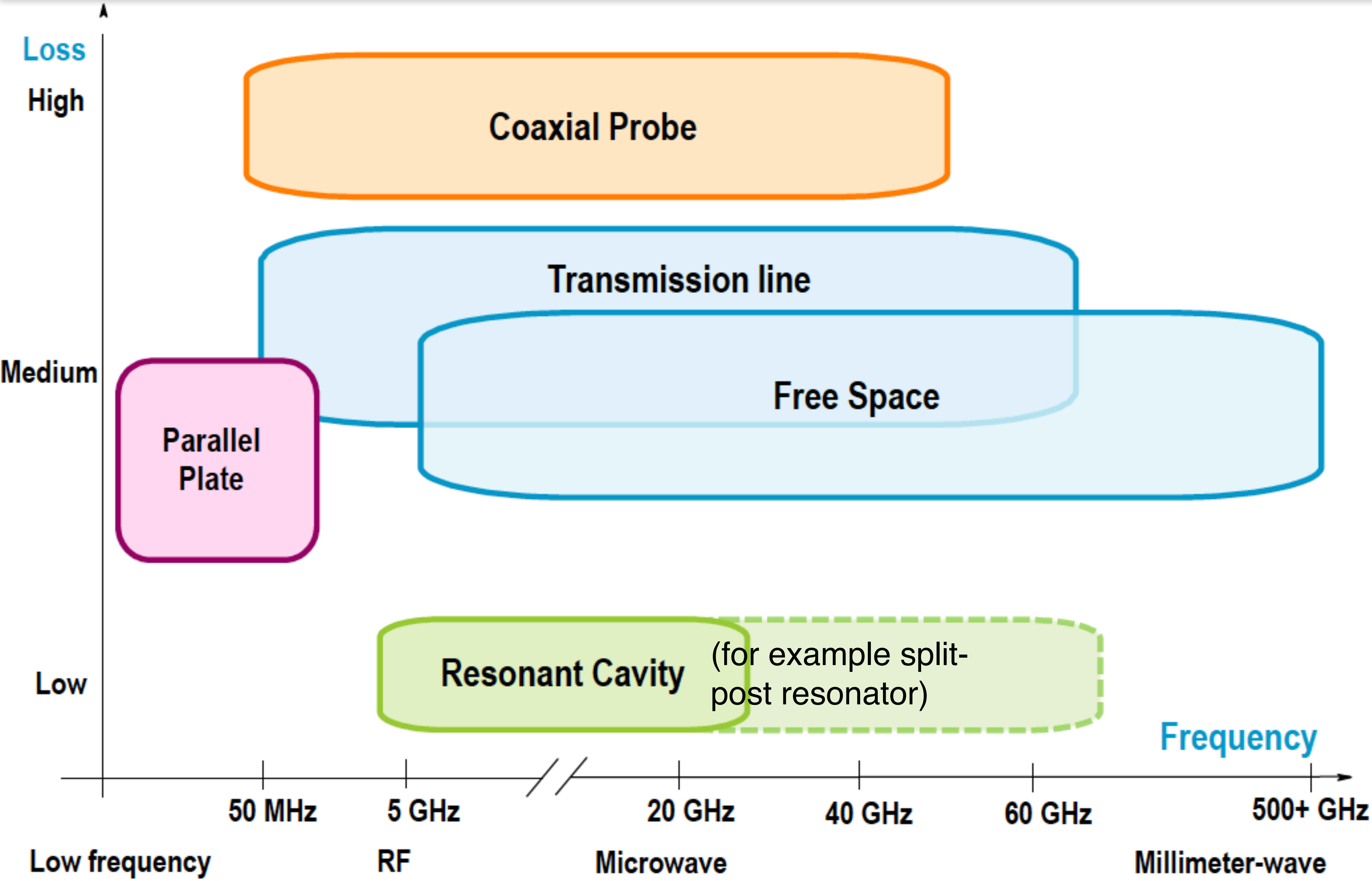


comparison



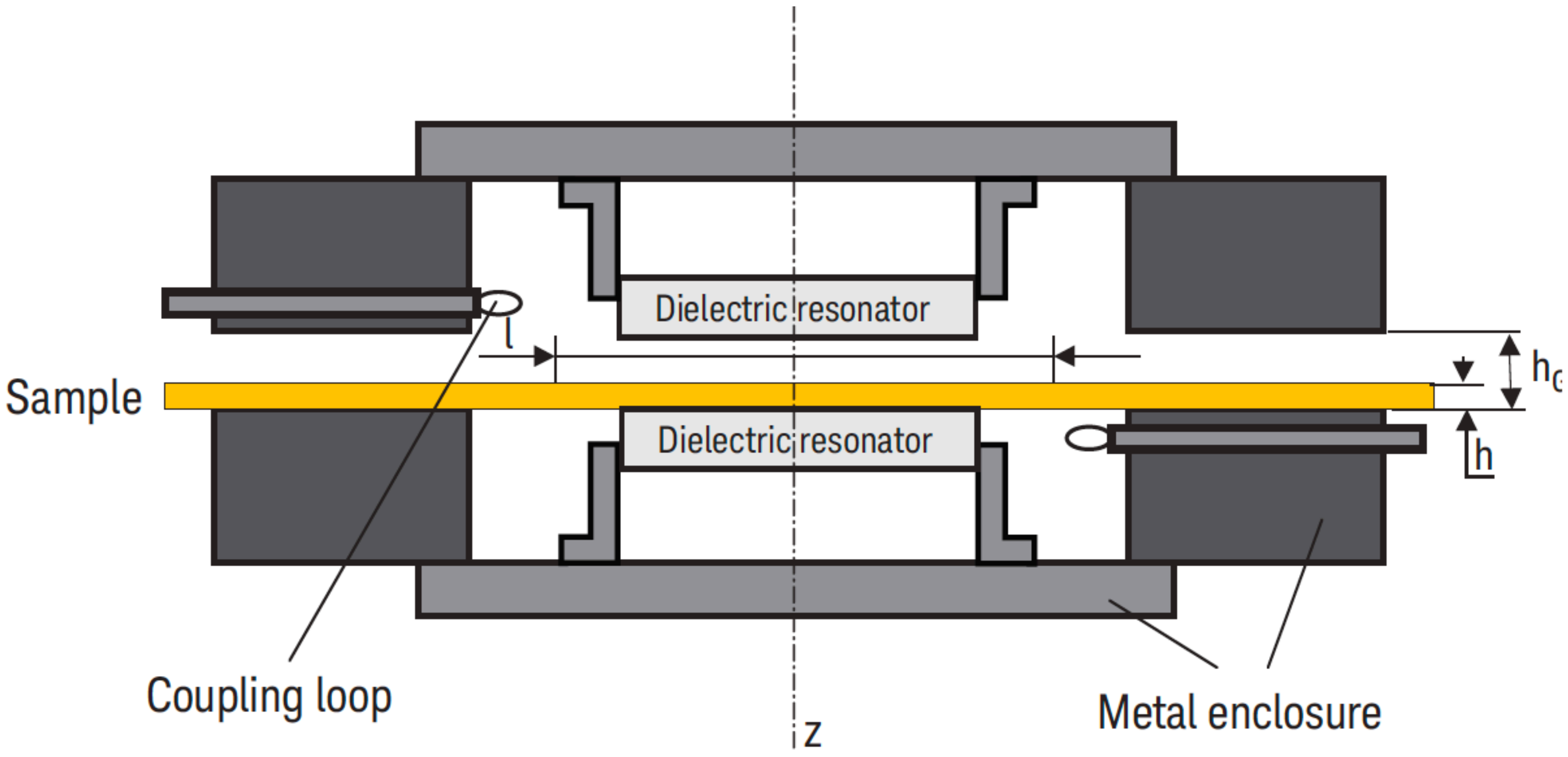
(plot stolen from an Agilent Technologies talk)

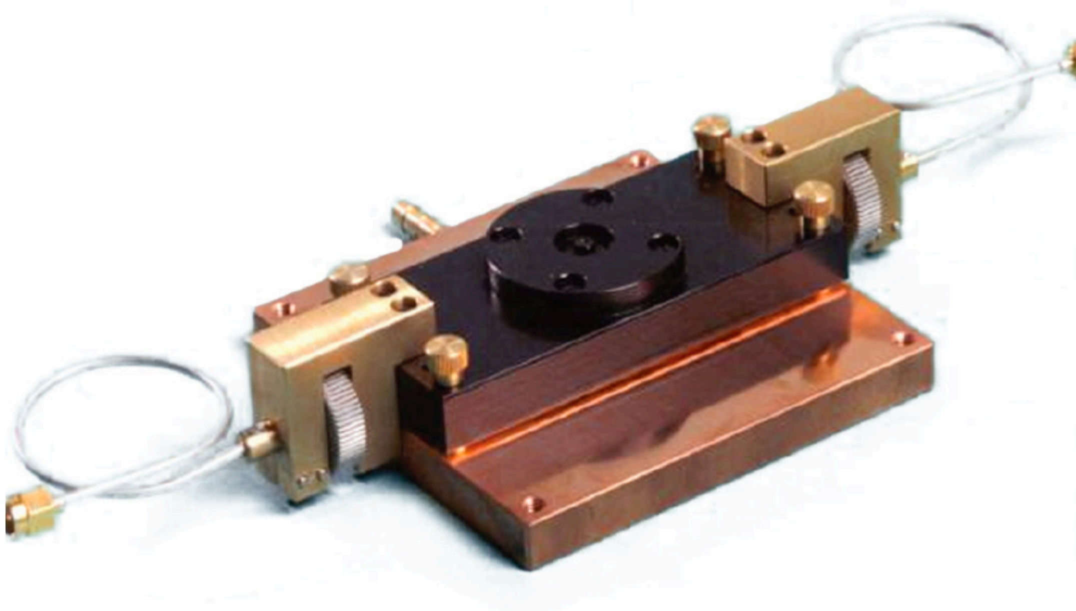
comparison

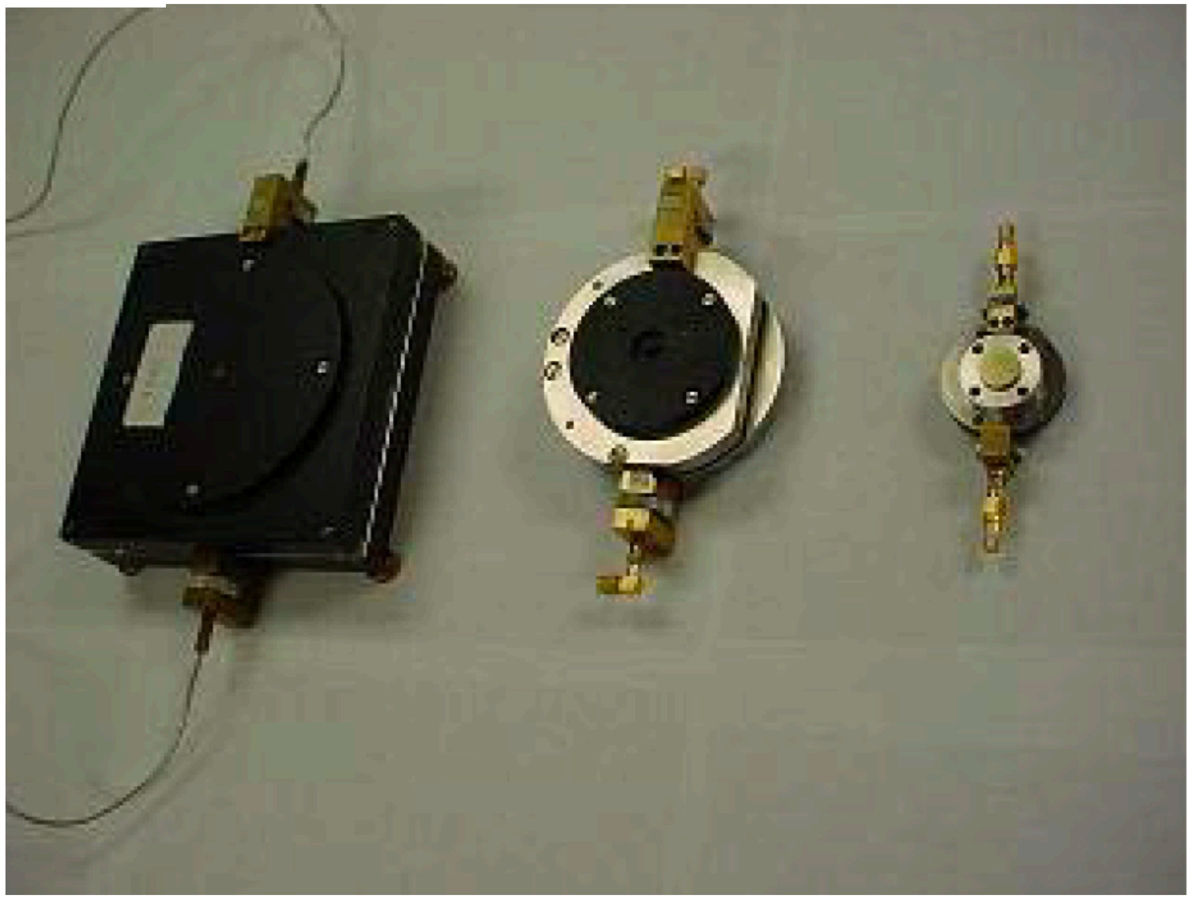


(plot stolen from an Agilent Technologies talk)

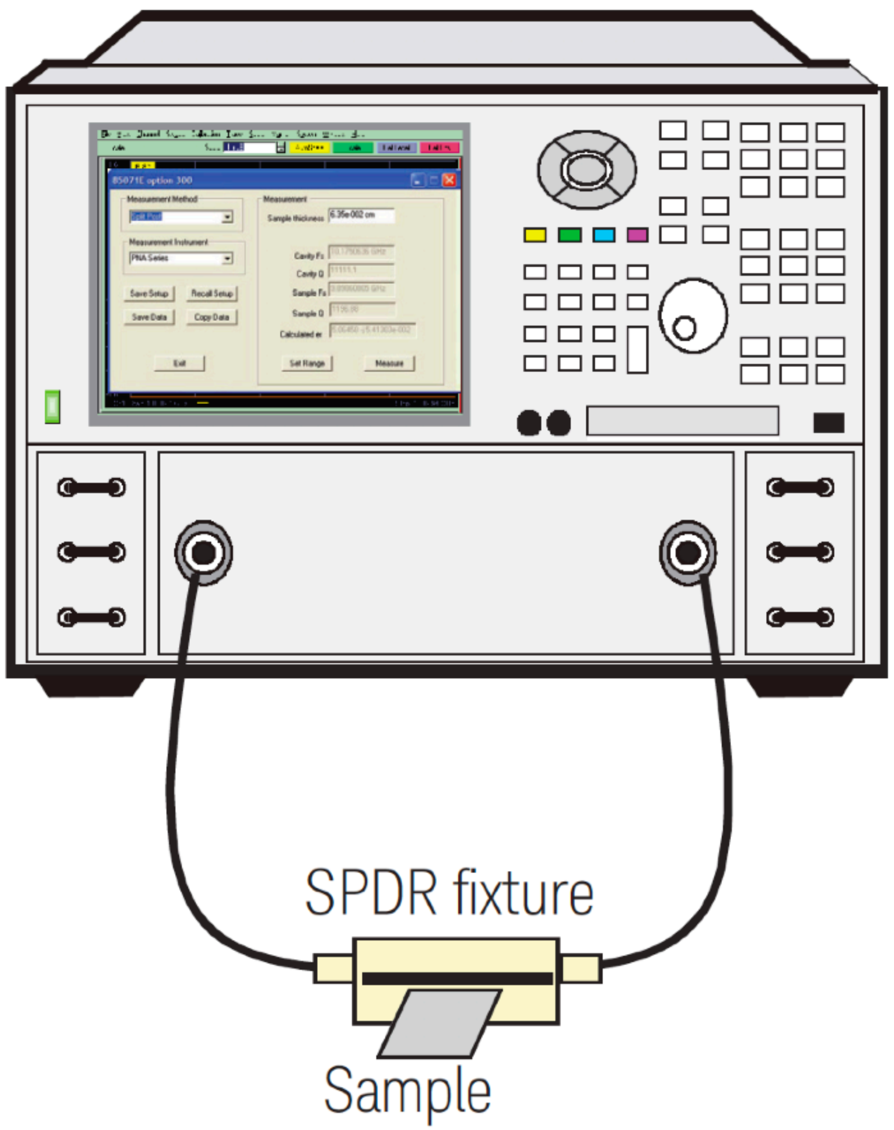
split post method



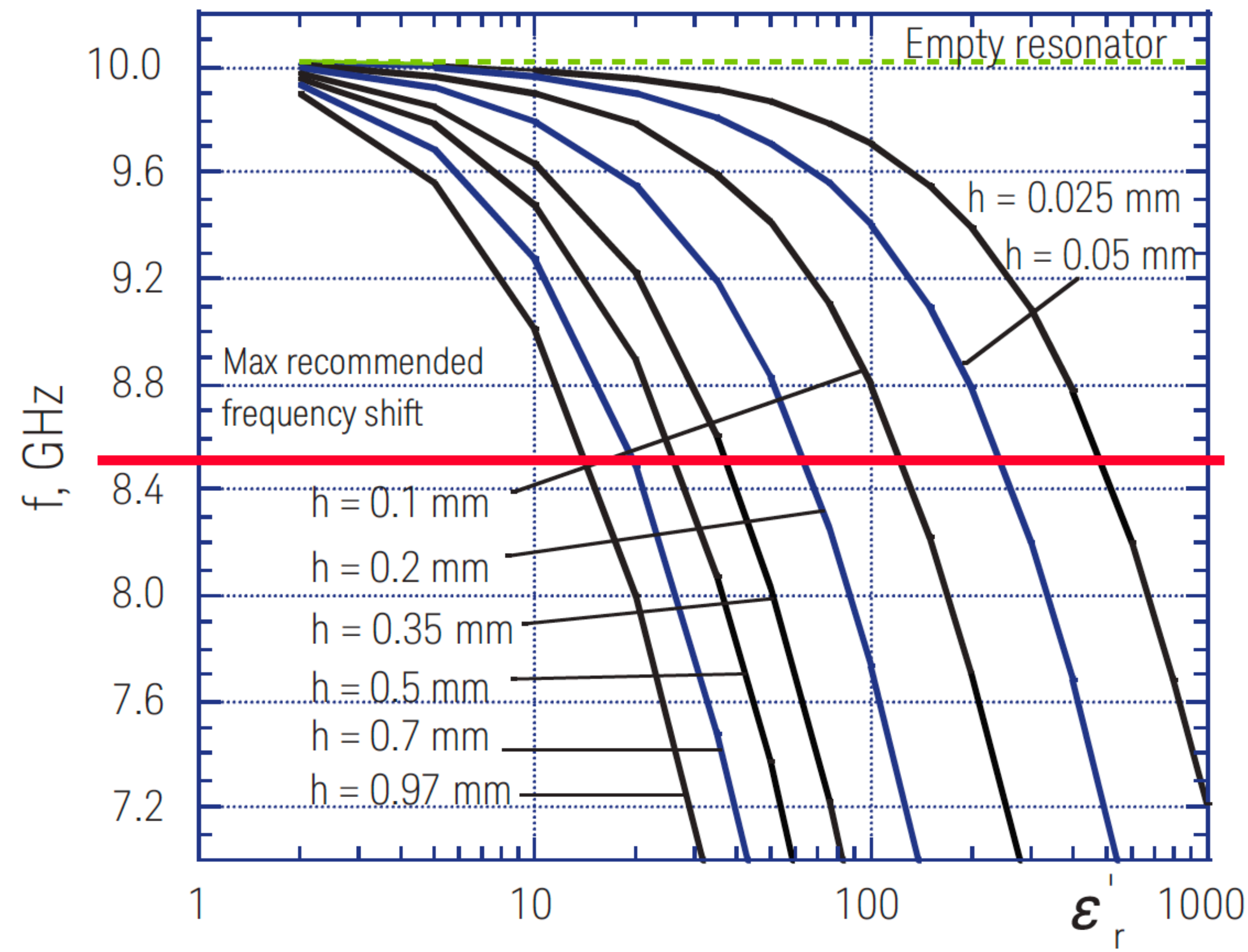




split post method



- example: 10GHz resonator



$$\varepsilon'_r = \frac{1 + f_0 - f_s}{h f_0 K_s(\varepsilon'_r, h)}$$

f_0 = empty resonance frequency
f_s = resonance frequency with sample
K_s = some function specific to SPDR

split post method

unloaded
Q factor

Q factor
with dielectric

losses for
empty fixture

$$\tan\delta = \frac{Q^{-1} - Q_{DR}^{-1} - Q_{c}^{-1}}{p_{es}}$$

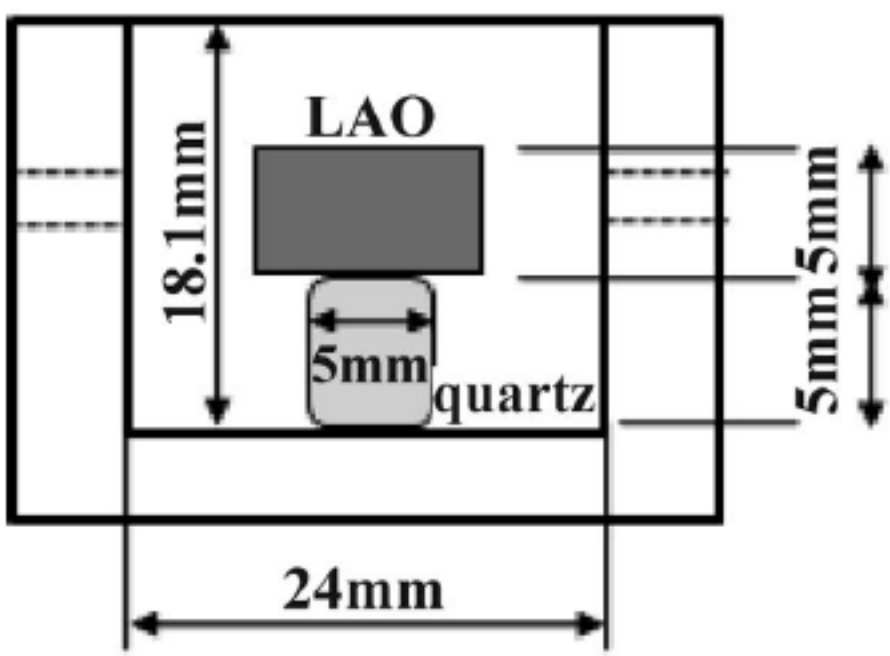
energy filling factor (depends
on ϵ' and K function)

results from literature about LAO

IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS, AND FREQUENCY CONTROL, VOL. 57, NO. 10, OCTOBER 2010 2243

Intrinsic Microwave Dielectric Loss of Lanthanum Aluminate

Takeshi Shimada, Koji Ichikawa, Tetsuro Minemura, Hiroki Yamauchi, Wataru Utsumi, Yoshinobu Ishii, Jonathan Breeze, and Neil McN. Alford



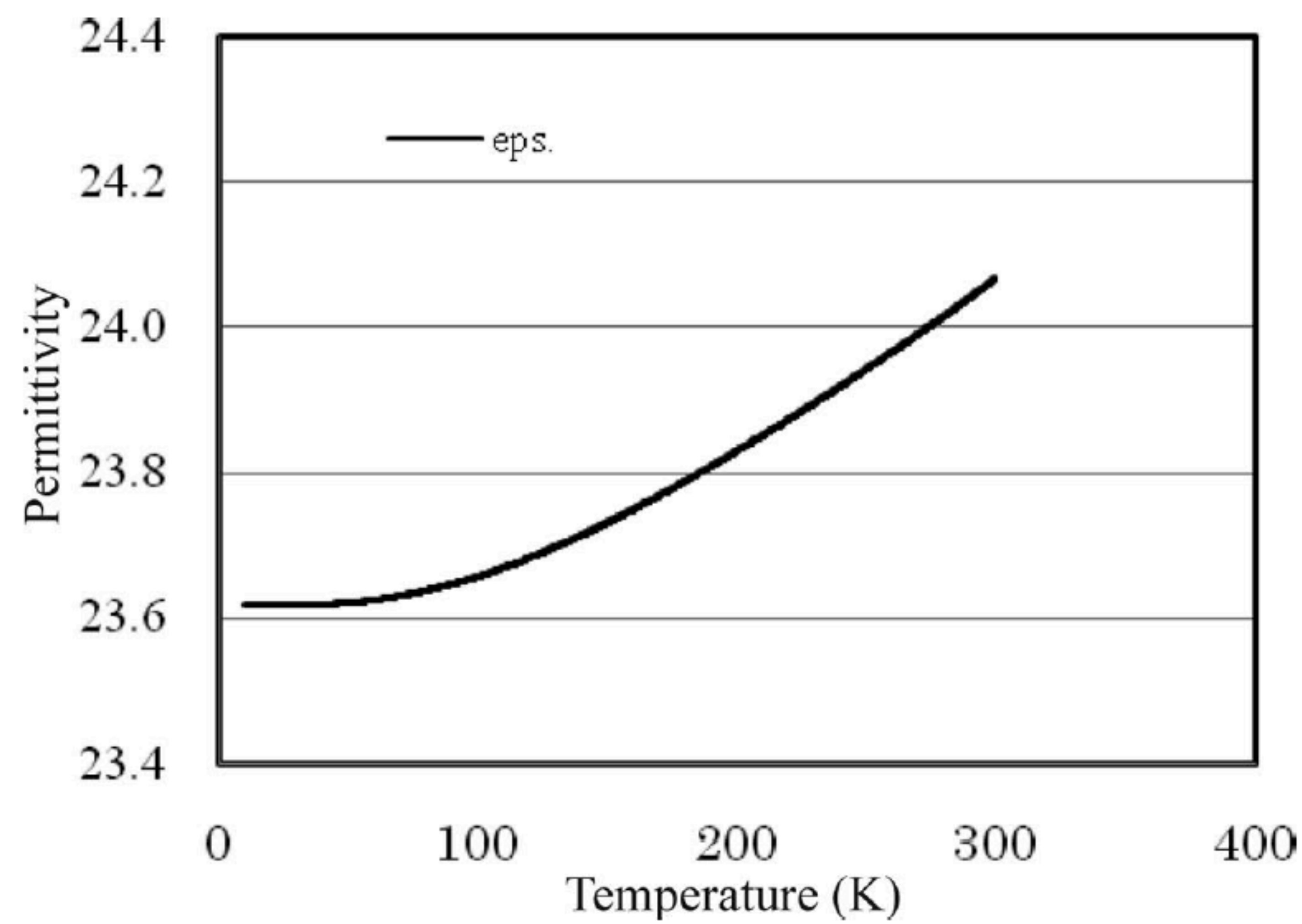
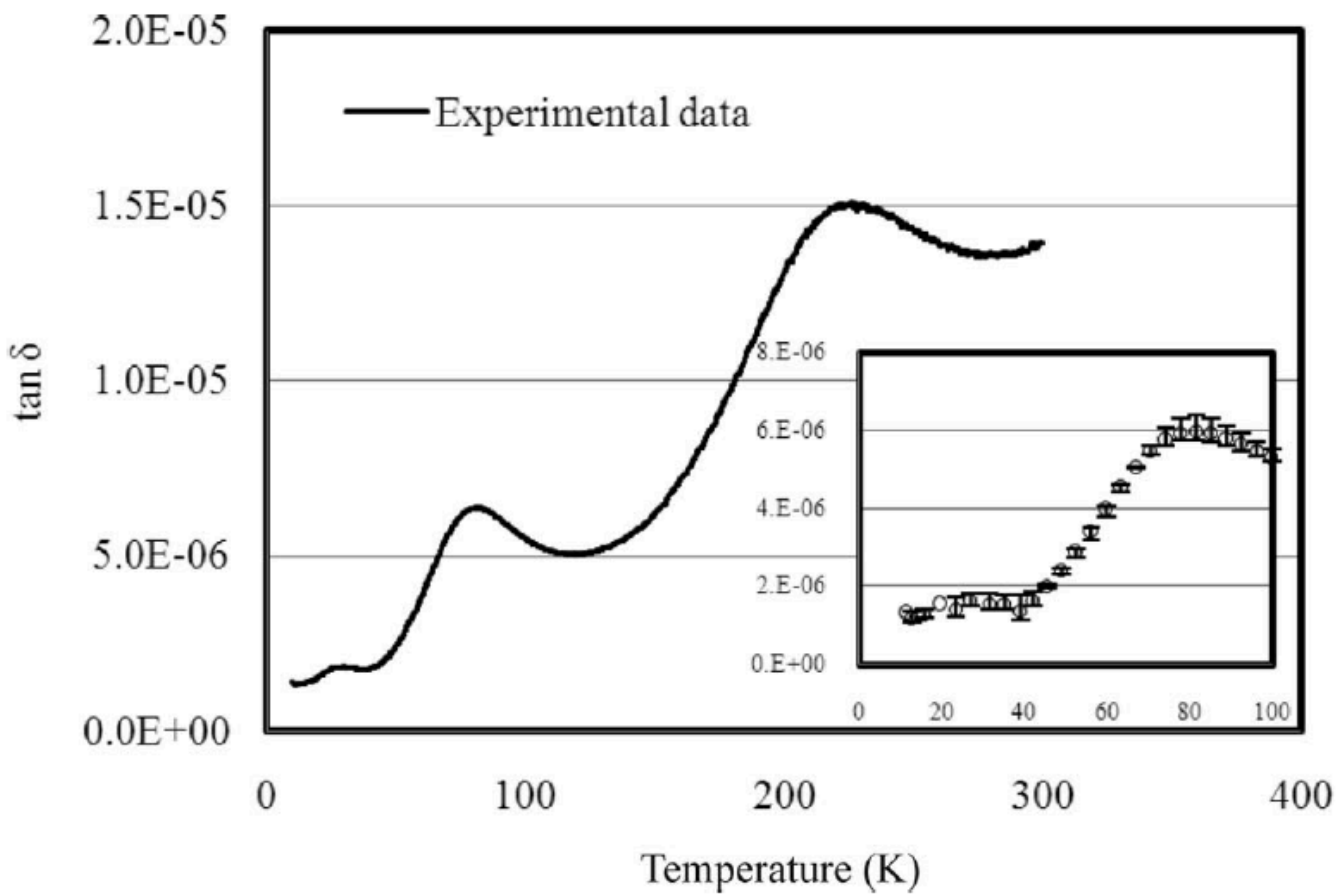


Fig. 2. Temperature dependence of permittivity of $LaAlO_3$.

results from literature about LAO



- double-peak structure at 82K and 226K:

  Sparks et al. showed that the intrinsic dielectric loss followed a two-phonon difference process, whereby a microwave photon is absorbed in the process of exciting an acoustic phonon to the optical phonon branch near the Brillouin zone boundary
- if I understand the paper well, this plot also shows a theoretical curve from a calculation

results from literature about LAO

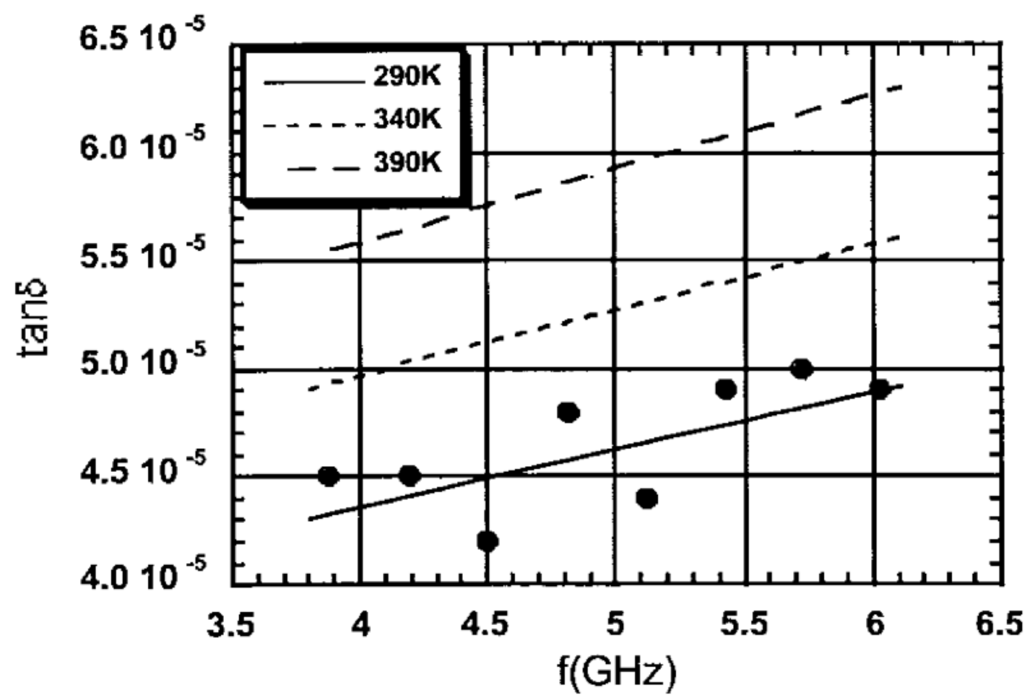
comments/questions:

- the paper does not use the word “uncertainty”
- from their plot it looks like $\tan\delta = 6 \cdot 10^{-6} \pm 20\%$ at 77K which is almost too good
- it’s done at 7 GHz, what about other frequencies?
- is the theoretical calculation very precise?

- Krupka et al (2012) (ref TH6D-7)
  - method: split post and superconducting single post resonators
  - result: $\tan\delta = 4 \cdot 10^{-5} \pm 50\%$ (at 10GHz, 77K)
  - seems to contradict the Shimada paper (slide 13) by 1.9 sigma

more found in literature about Sapphire

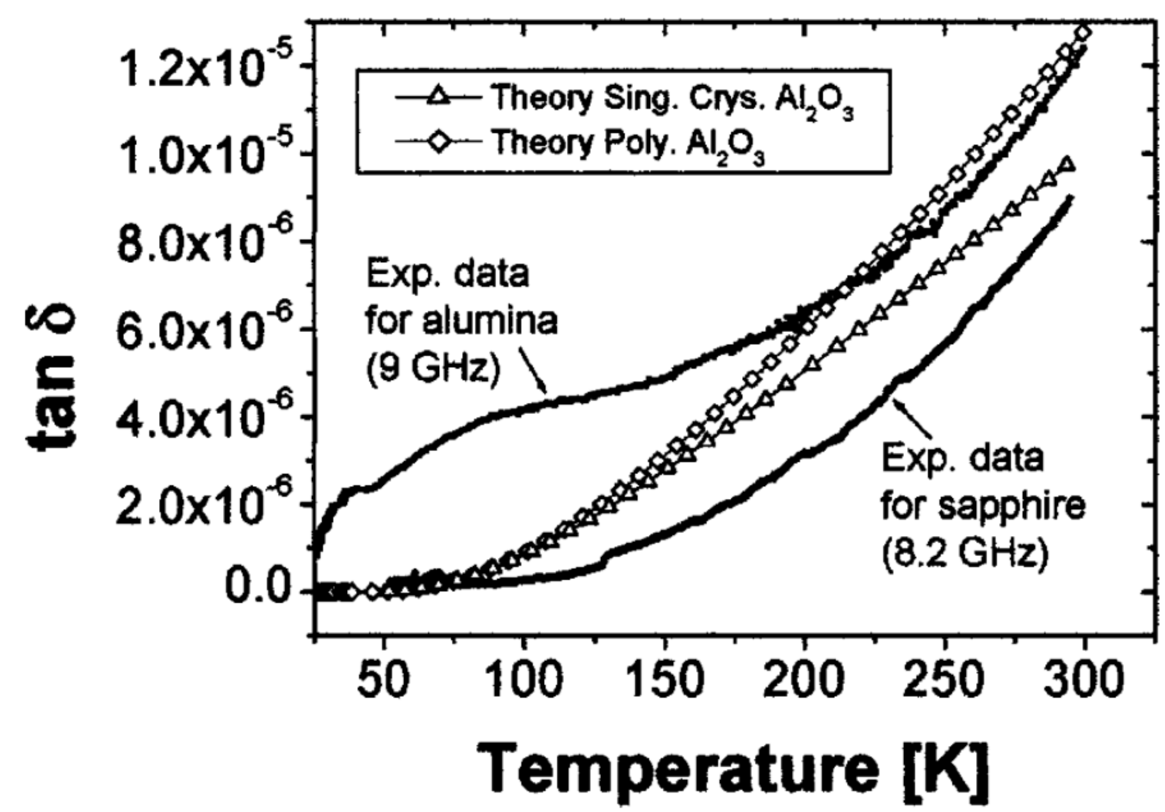
- Krupka et al (1999) (IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 47, NO. 6, JUNE 1999)
  - method: split post resonator, whispering gallery modes, 5 GHz



- the lines are fits of the scattered measurement points

Fig. 6. Results of dielectric loss tangent measurements versus frequency for low-loss ceramic as determined with whispering-gallery-mode dielectric resonator technique.

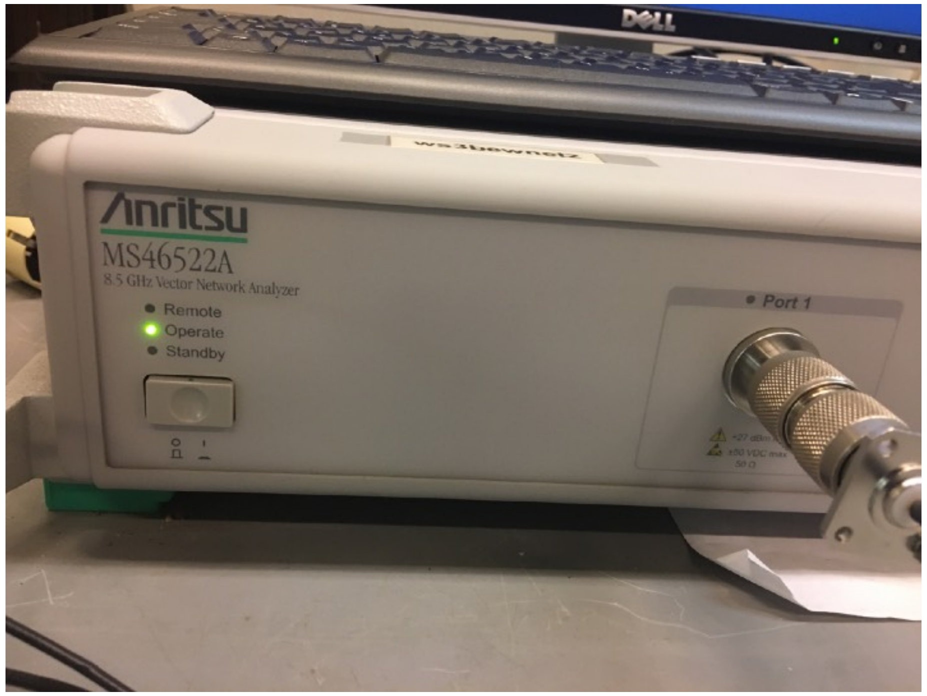
- Aupi_etal_JAP95_2639_2004
  - method: TE01δ Resonator
  - result: 1.0e-5 @ 9GHz, 300K



available equipment

- U Hamburg:
  - network analyzern(Rohde&Schwarz ZVA-67)
  - split post resonators at 2 Frequenies (ordered)
- people: Stephan Martens, Christoph Krieger

- RWTH Aachen, Physics Institute IIIA
  - network analyzer (8.5 GHz)
  - (probably need to buy a better one)

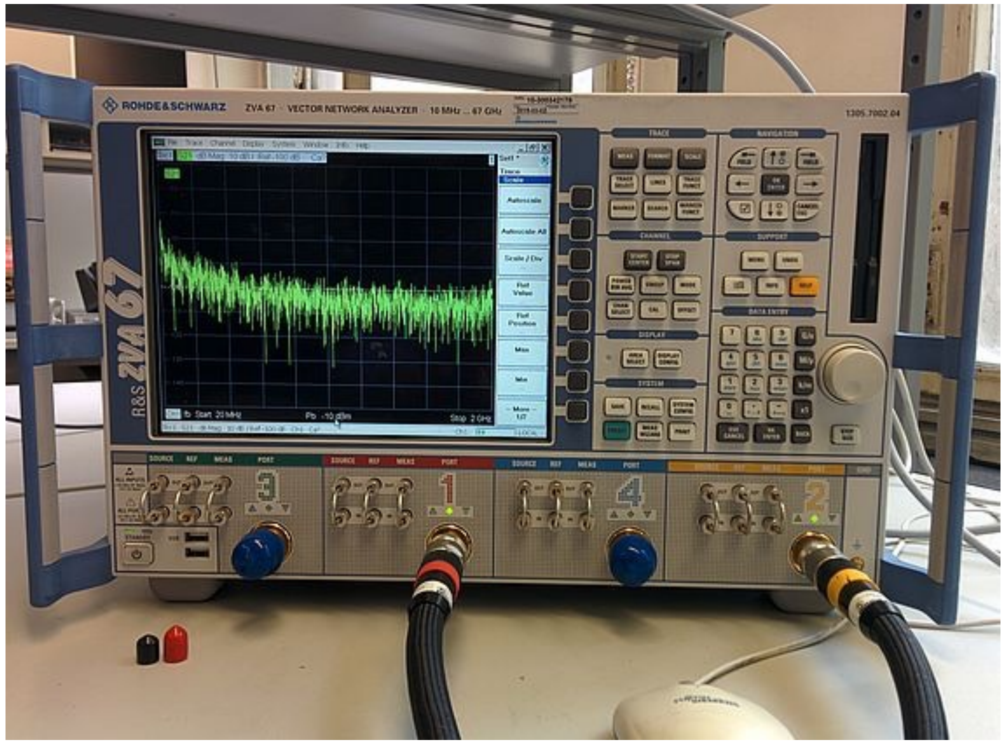


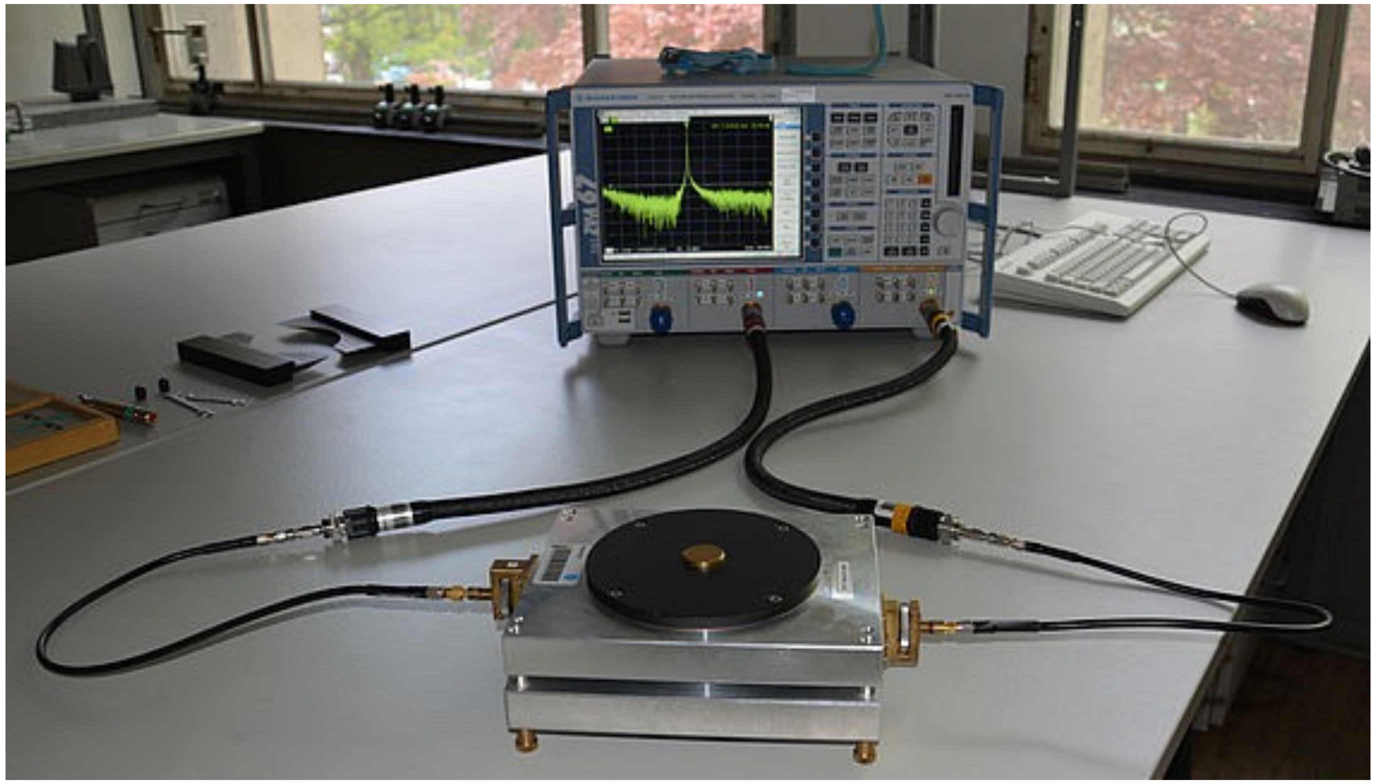
- people:
  - electronics lab engineers
  - new student + postdoc to be found

available equipment

IHF Institute of High Frequency Technology | RWTH AACHEN UNIVERSITY

- RWTH Aachen, IHF institute
  - network analyzer (67 GHz)
    Rohde&Schwarz ZVA-67
  - split-post dielectric resonators
    1 GHz and 5GHz





some questions under discussion

- uncertainties seem to be large, how to reduce them?
- how reproducible are results? Does the measurement concept depend stongly on the MUT dimensions?
- how precise do we need to measure this? (need more simulation studies)
- no result (or measurement device) above 15 GHz found in literature
- how to measure compound materials (tiled disks with glue)