Th1D-5

Novel Q-Choked Sapphire Sandwiched Resonator for Wide-Band Measurements of Flat Dielectric Samples

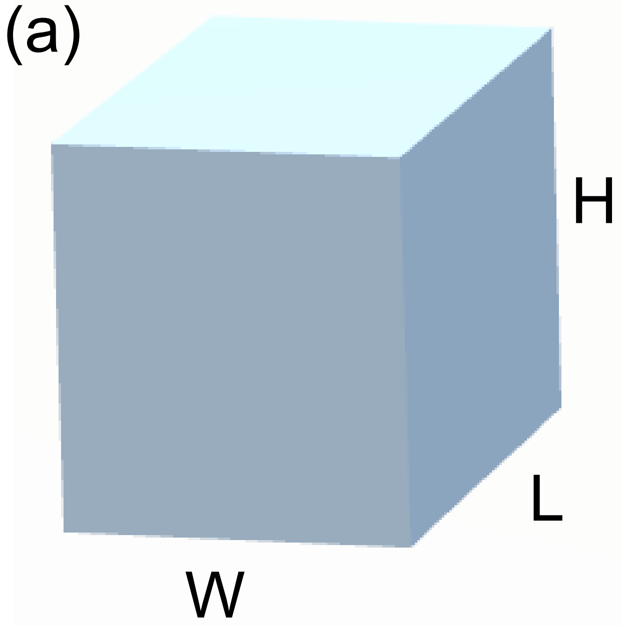
Wojciech Gwarek, Malgorzata Celuch, Lukasz Nowicki

Outline

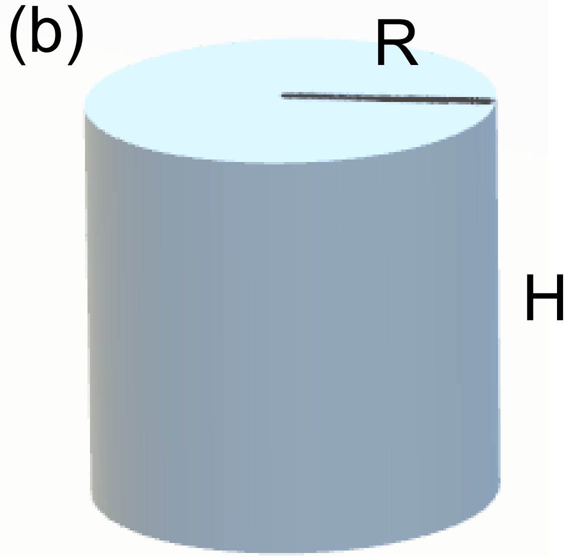
- Basic Theory of Resonantors
- New Test Measurement device

  Q-Choked Sapphire Sandwiched Resonator (Q-SSR)
  - Construction
  - EM Field distribution
  - Measurement procedure
- Results on reference COP sample
  - (Comparison with other methods)
- Conclusions

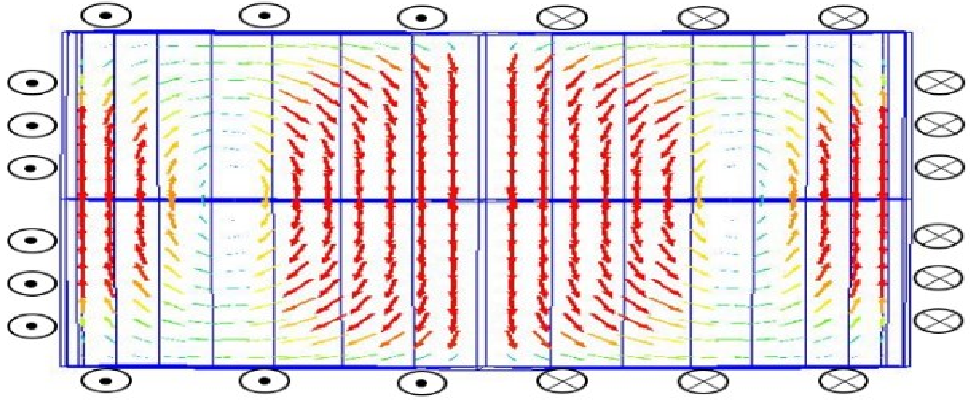
Resonator Method Theory



Theoretical model
of rectangular resonator



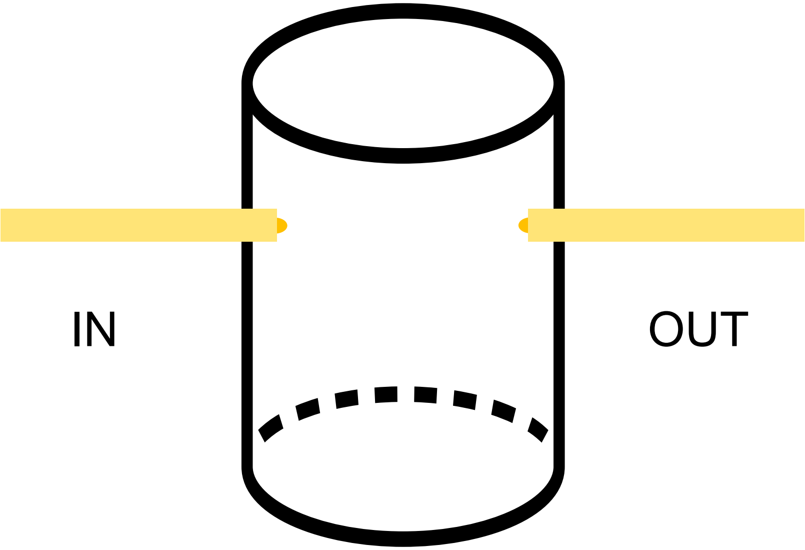
Theoretical model
of cylindrical resonator

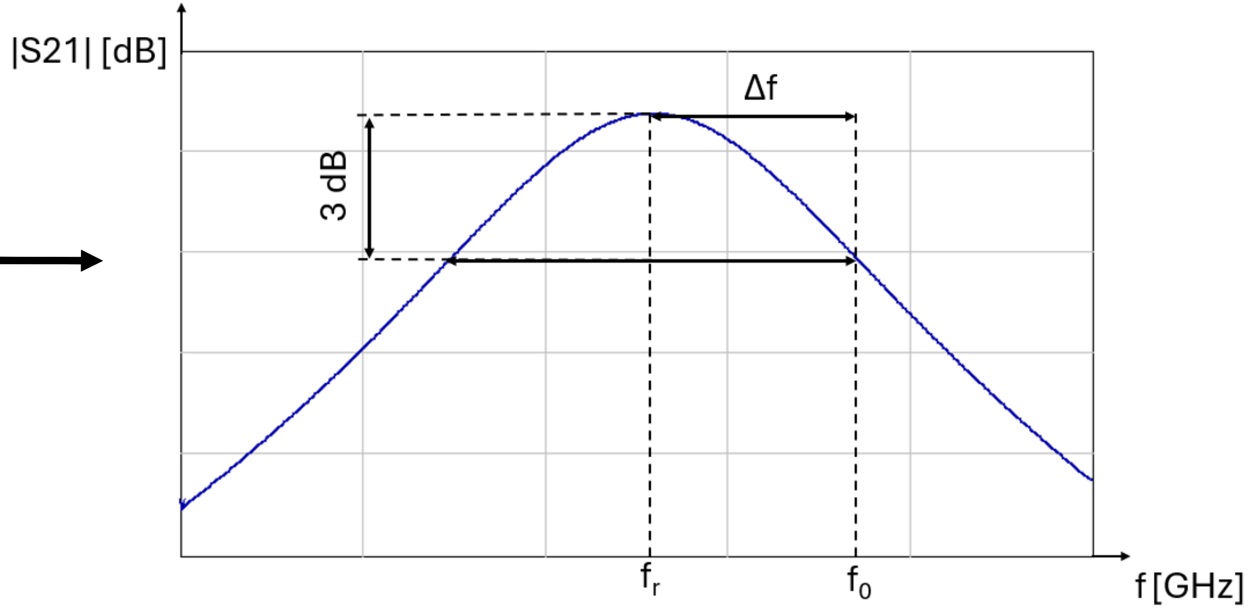


Cylindrical resonator with TE_{011} mode:
vertical cross-section of a simple cavity
indicating magnetic field lines and directions
of currents in the cavity walls
From our last paper:

M. Celuch, M. Olszewska-Placha, L. Nowicki and W. Gwarek, "A Novel Q-Choked Resonator for Microwave Material Measurements Alleviating Sample Thickness Limitations of Existing Techniques," in *IEEE Microwave and Wireless Technology Letters*, vol. 34, no. 6, pp. 845-848, June 2024, doi: 10.1109/LMWT.2024.3397912

Resonator Method Theory



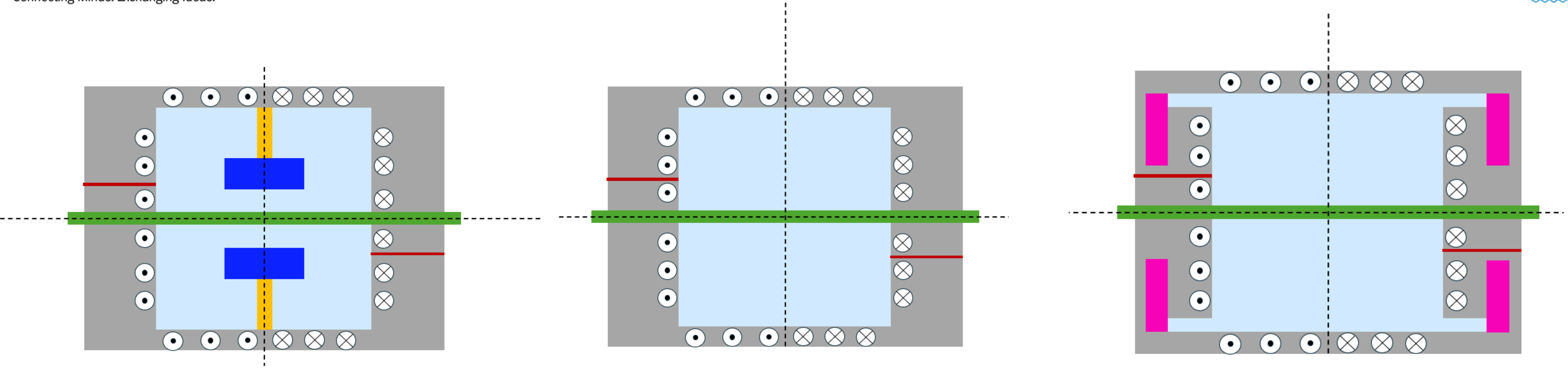


zoom around one of the resonances, illustrating the meaning of resonant frequency and 3-dB bandwidth

For canonical geometries, the eigenvalue problem can be solved analytically; for example, for a cylinder of radius R, height H, and homogeneously filled with a lossless non-magnetic dielectric of dielectric constant Dk we obtain equation:

$$f_{r,mnp} = \frac{c}{\sqrt{Dk}} \sqrt{\left(\frac{k_{mn}^{(,)}}{\pi R}\right)^2 + \left(\frac{p}{H}\right)^2},$$

Vertical cross-section of cylindrical resonators



Split-Post Dielectric Resonator (SPDR)

Split Cylinder Resonator (SCR)

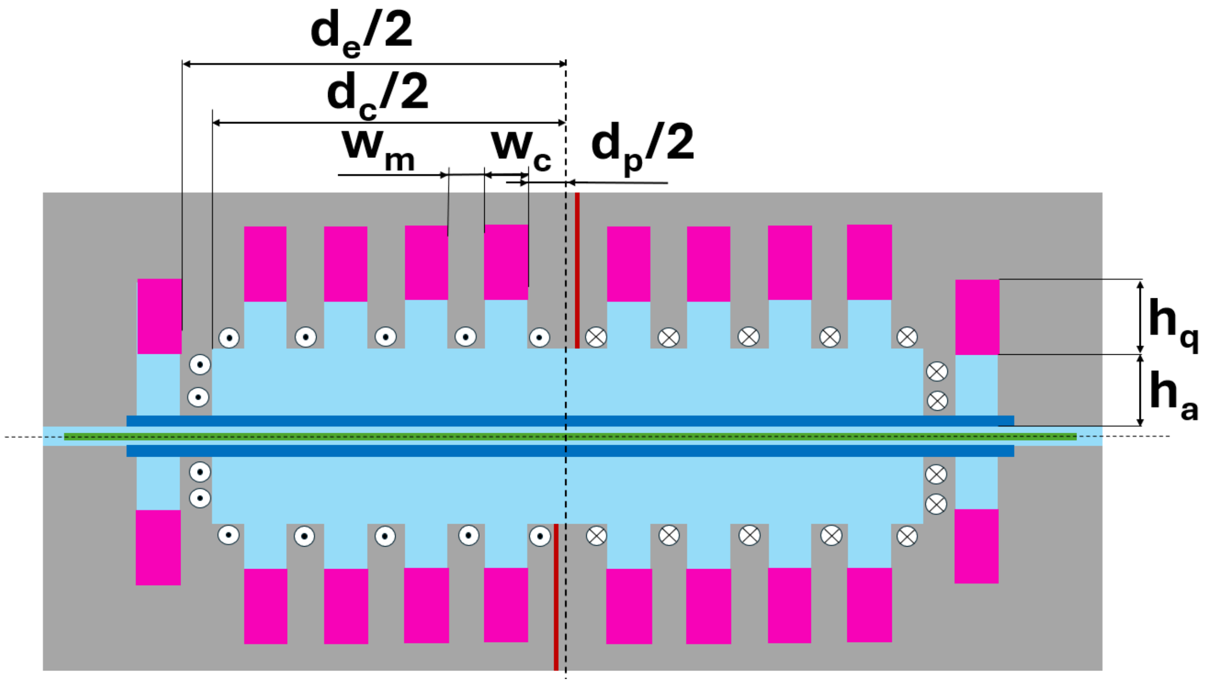
Q-Choked Split Cylinder Resonator (Q-SCR)

The Q-Choke is a cavity modification that suppresses unwanted resonant modes while preserving the TE_0np measurement mode.

It uses symmetric radial slots near the top and bottom of the cavity, which do not disturb TE_0np modes but interrupt current paths of spurious TEmnp (m > 0) and TM modes. These currents are redirected into radial channels terminated with lossy pockets, where the unwanted energy is dissipated. This structure acts as a choke, selectively damping undesired modes without affecting measurement performance.

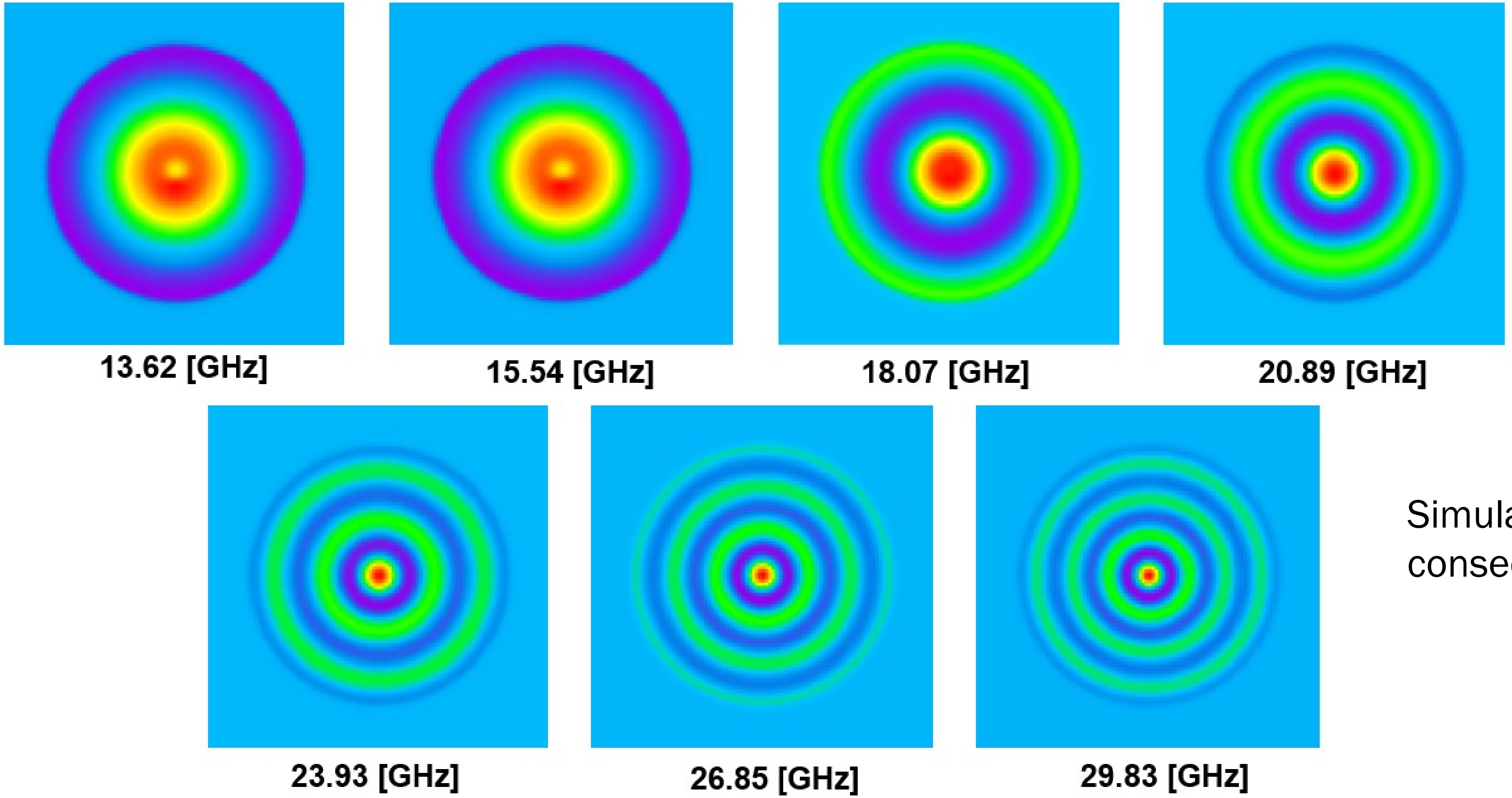
The Proposed Q-SSR At a Glance

Parameter	Symbol	Value	Description
Sapphire disk diameter	d_s	50.8	Diameter of monocrystal sapphire plate
Sapphire disk height	h_s	0.4	Thickness of sapphire plate
Cavity half-height (one-sided)	h_c	3	Height of one half of the cavity
Cavity diameter	d_c	41.2	Internal cavity diameter
Central post diameter	d_p	8	Diameter of the central post
Inner diameter of external choke	d_e	46	Inner diameter of external corrugation (Q-choke outermost ring)
Metal teeth width (Q-choke)	w_m	1.9	Width of the metal 'teeth' in the Q-choke
Air corrugation width (Q-choke)	w_c	2.1	Width of the air gaps in the Q-choke
Air corrugation height	h_a	5	Height of the air part of the Q-choke
Absorbing material height	h_q	5	Height of the lossy PLA material in the Q-choke
Relative permittivity (sapphire)	ε_r	≈9.399	In-plane permittivity of the sapphire
Loss tangent (sapphire)	tanδ	$\approx 1.33 \times 10^{-5}$	Loss tangent of sapphire plate
Q-Choke structure	—	5 rings	4 corrugated in bottom/cover + 1 external corrugation



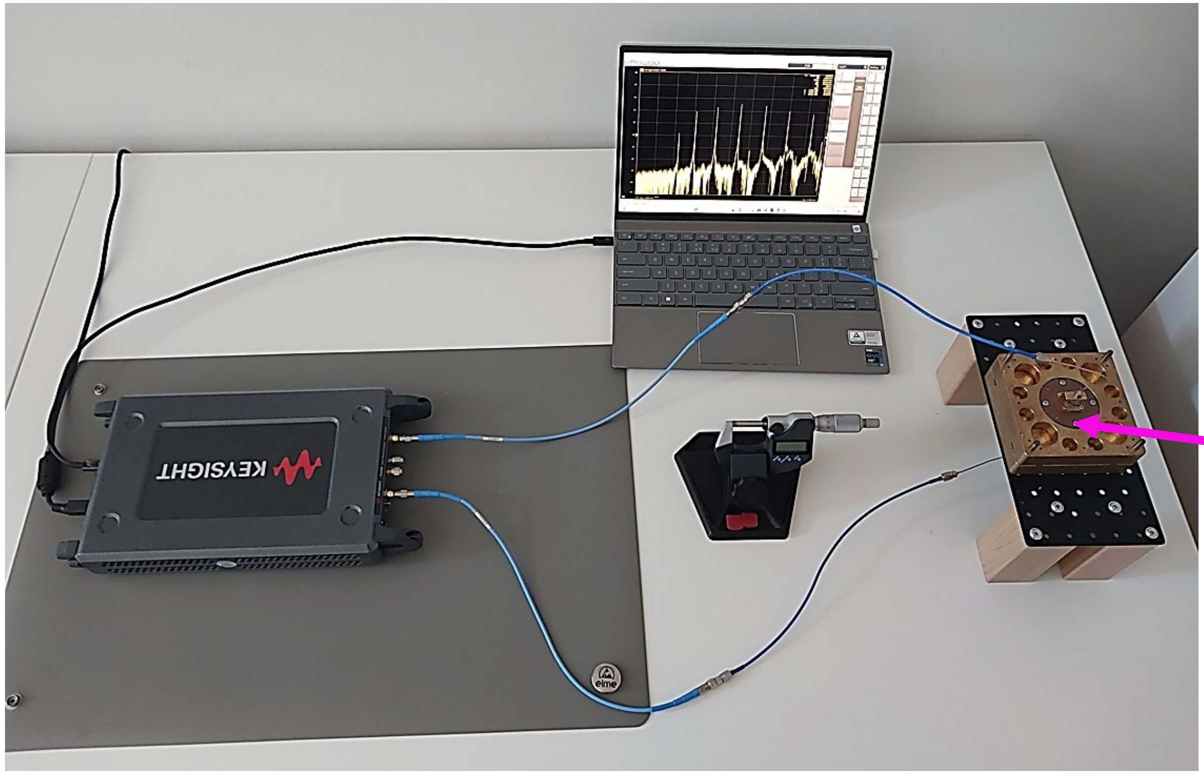
Vertical cross-section of cylindrical resonators Q-SSR proposed herein

Electric field distribution in Q-SSR



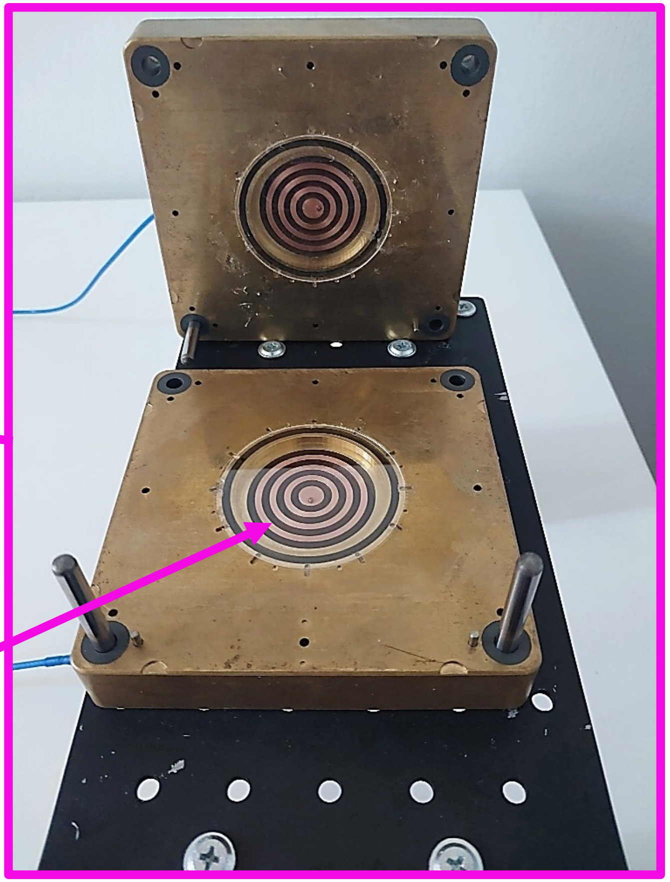
Simulated distribution of Hz at consecutive resonant frequencies

Q-SSR – Measurement Setup



Q-SSR prototype as used in the measurement setup

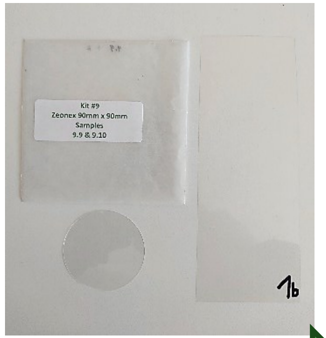
Corrugates
(copper rings partially
filled with carbon)



dismantled open for revealing its inner construction with a Q-Choke.

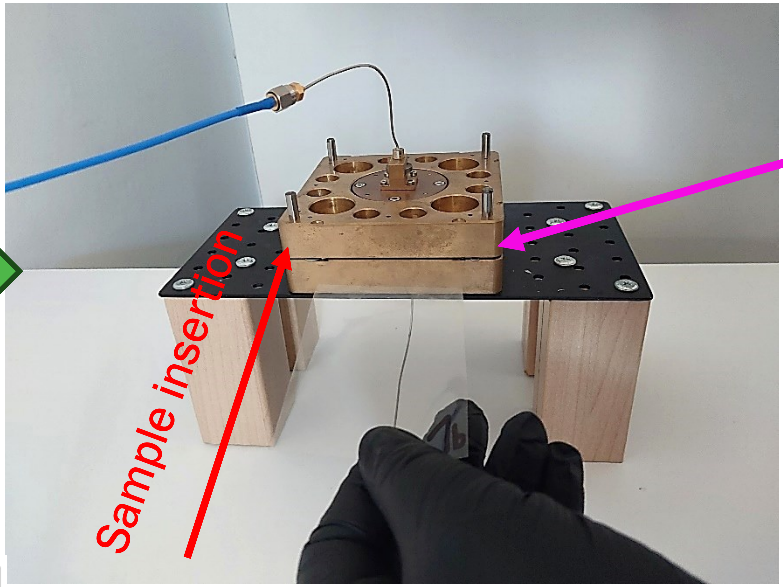
Measurement Procedure

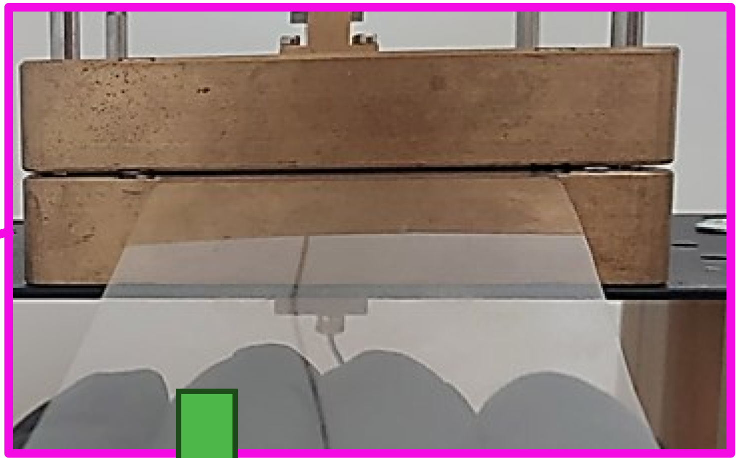
1. Measure the resonant frequencies and corresponding Q-factors of the Q-SSR without any sample inserted.



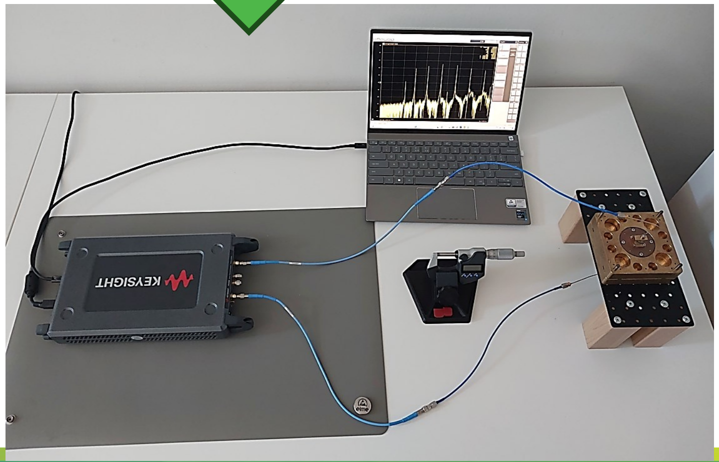
Samples under Test

2. Input sample into Q-SSR Gap

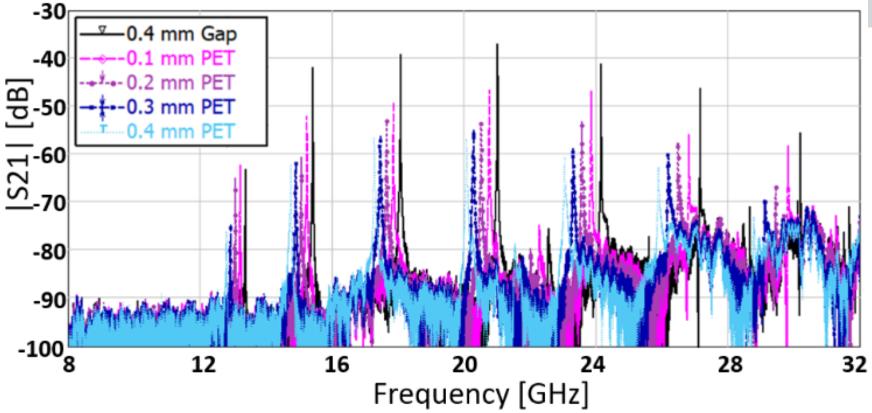




3. Measure the resonant frequencies Q-factors of the Q-SSR with sample under test

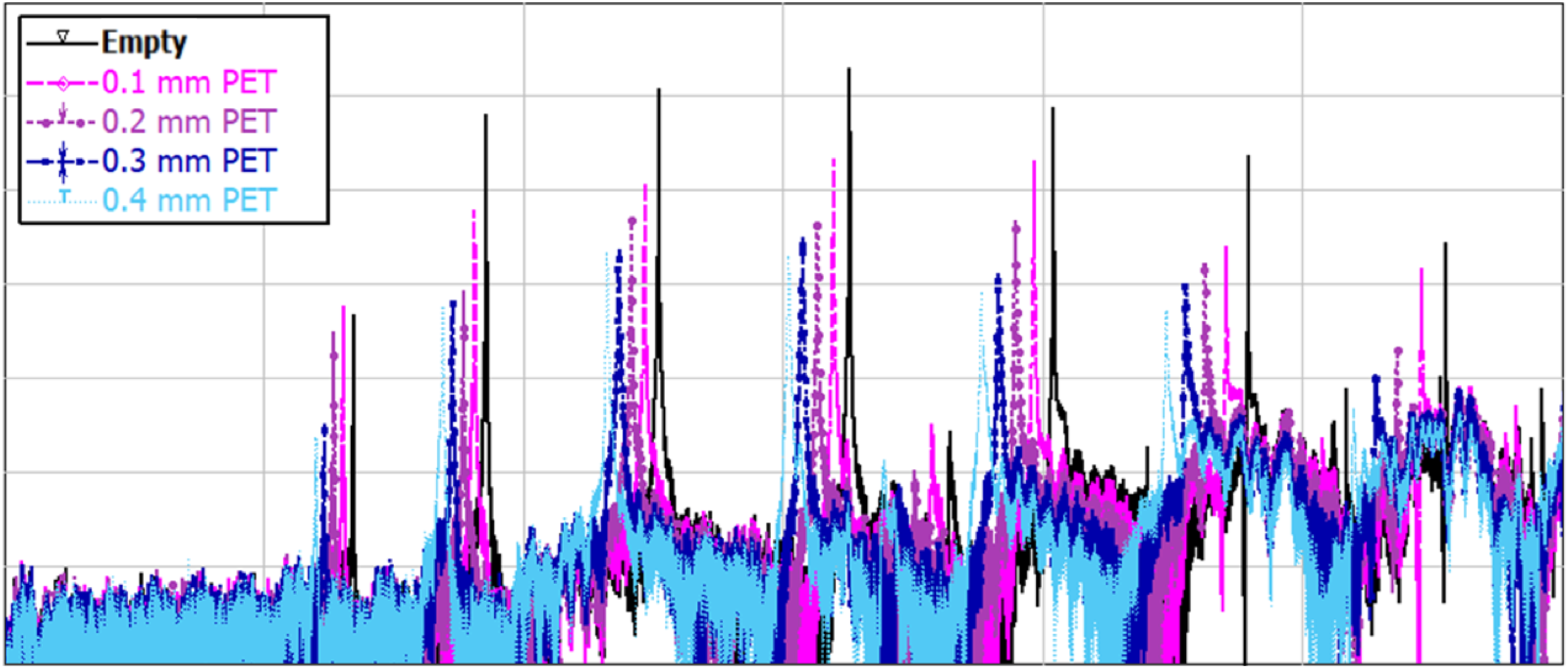


4. Dedicated software Calculate a Dielectric constant ε and loss tangent tanδ



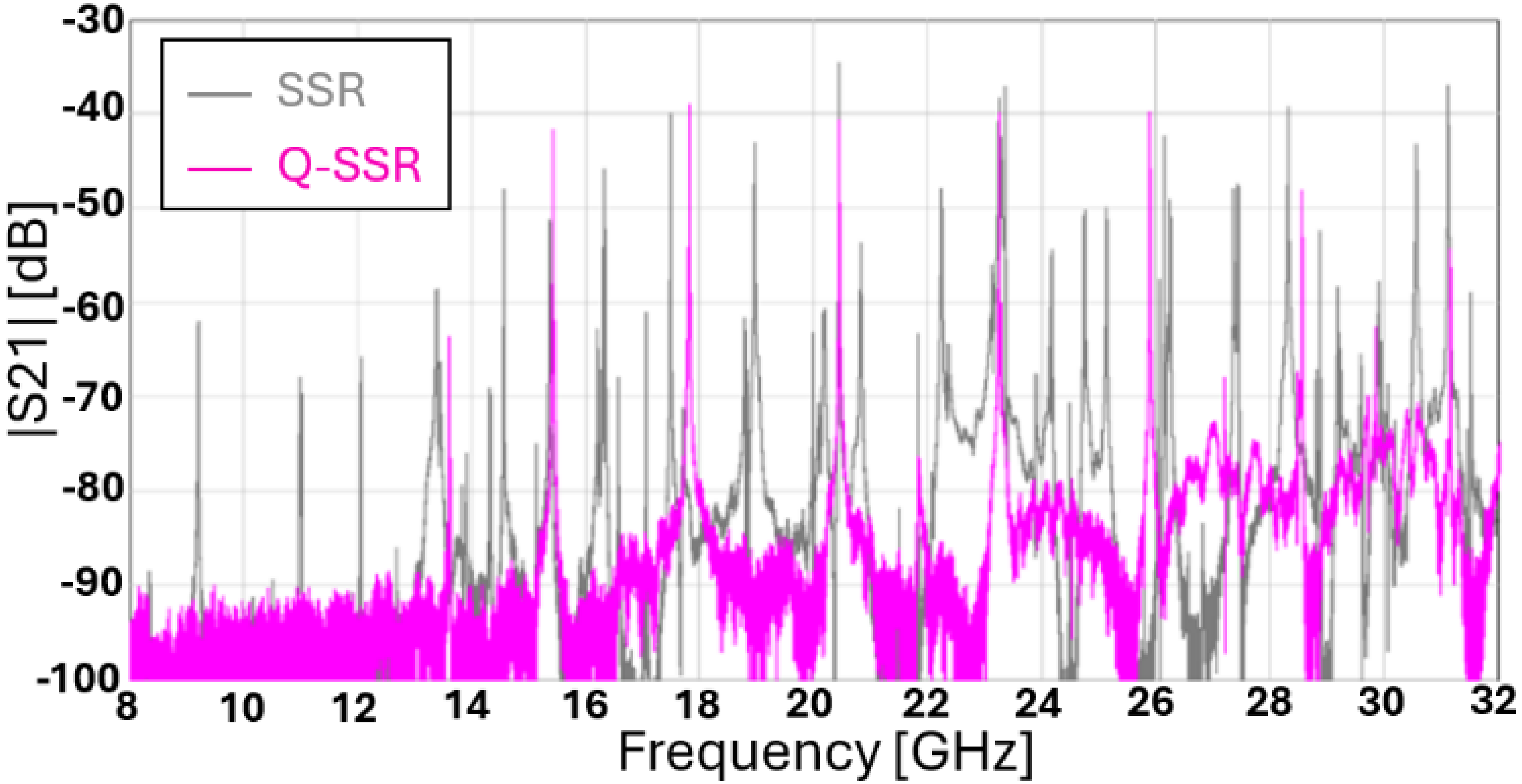
5. Example of 4 PET Samples measured on Q-SSR

Measurements taken on PET samples



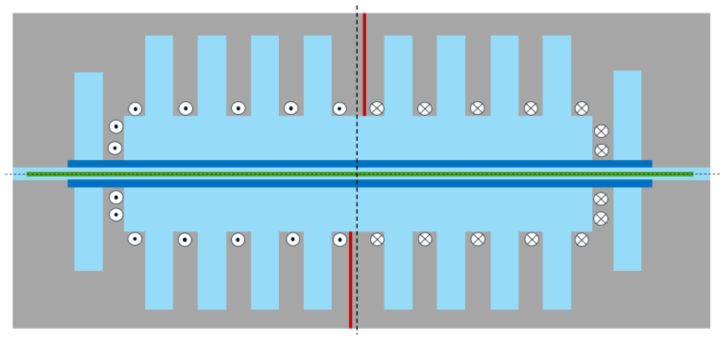
Measured transmission through the Q-SSR prototype, empty and loaded with 1÷4 samples of PET foils, each ca. 0.1 mm thick.

How Q-Choke works

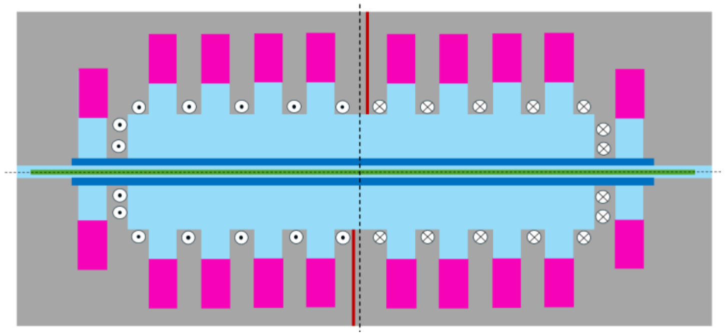


Measured transmission through Q-SSR and SRR (without the choke).

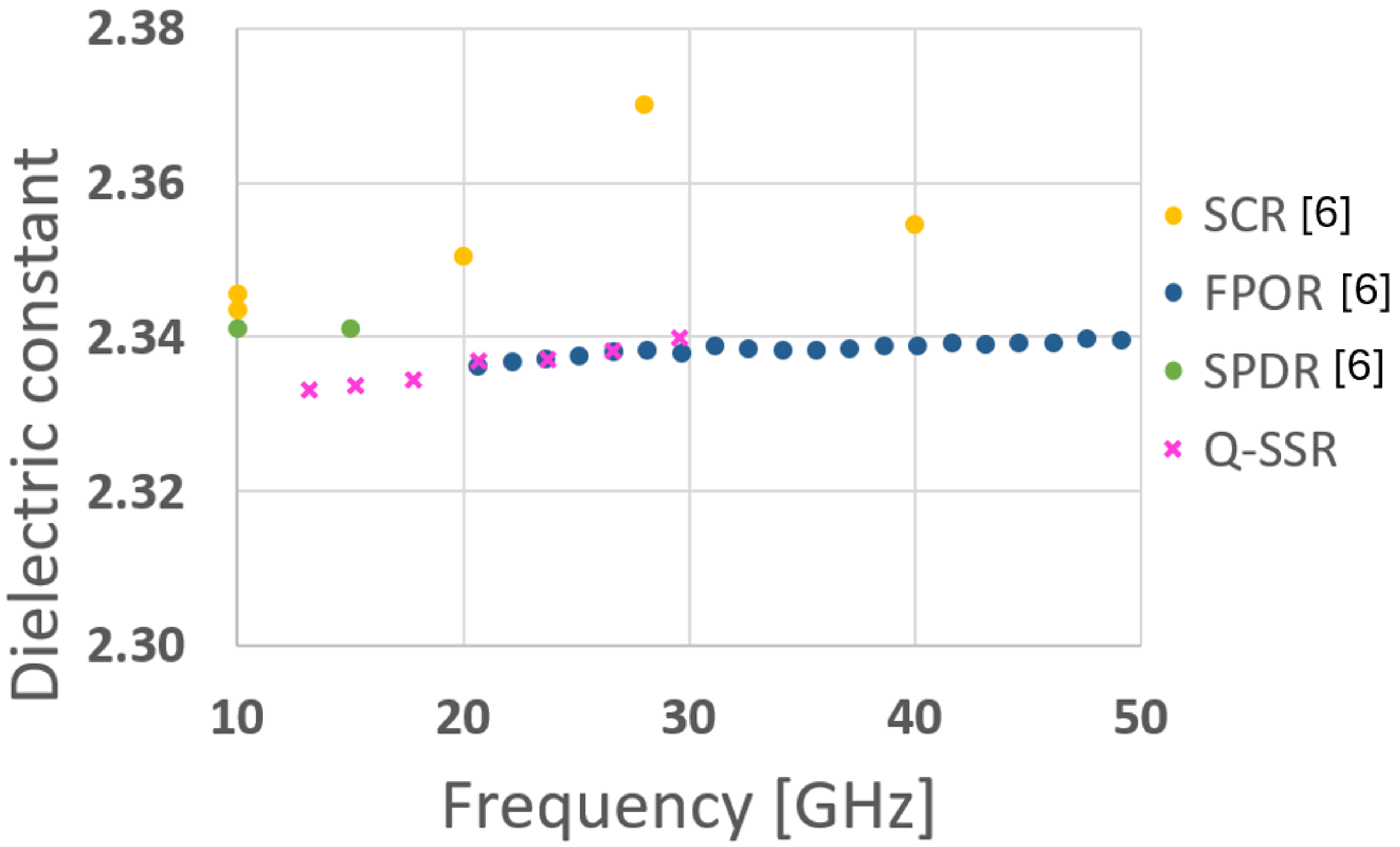
SRR (without the choke).



Q- SRR (with the choke).

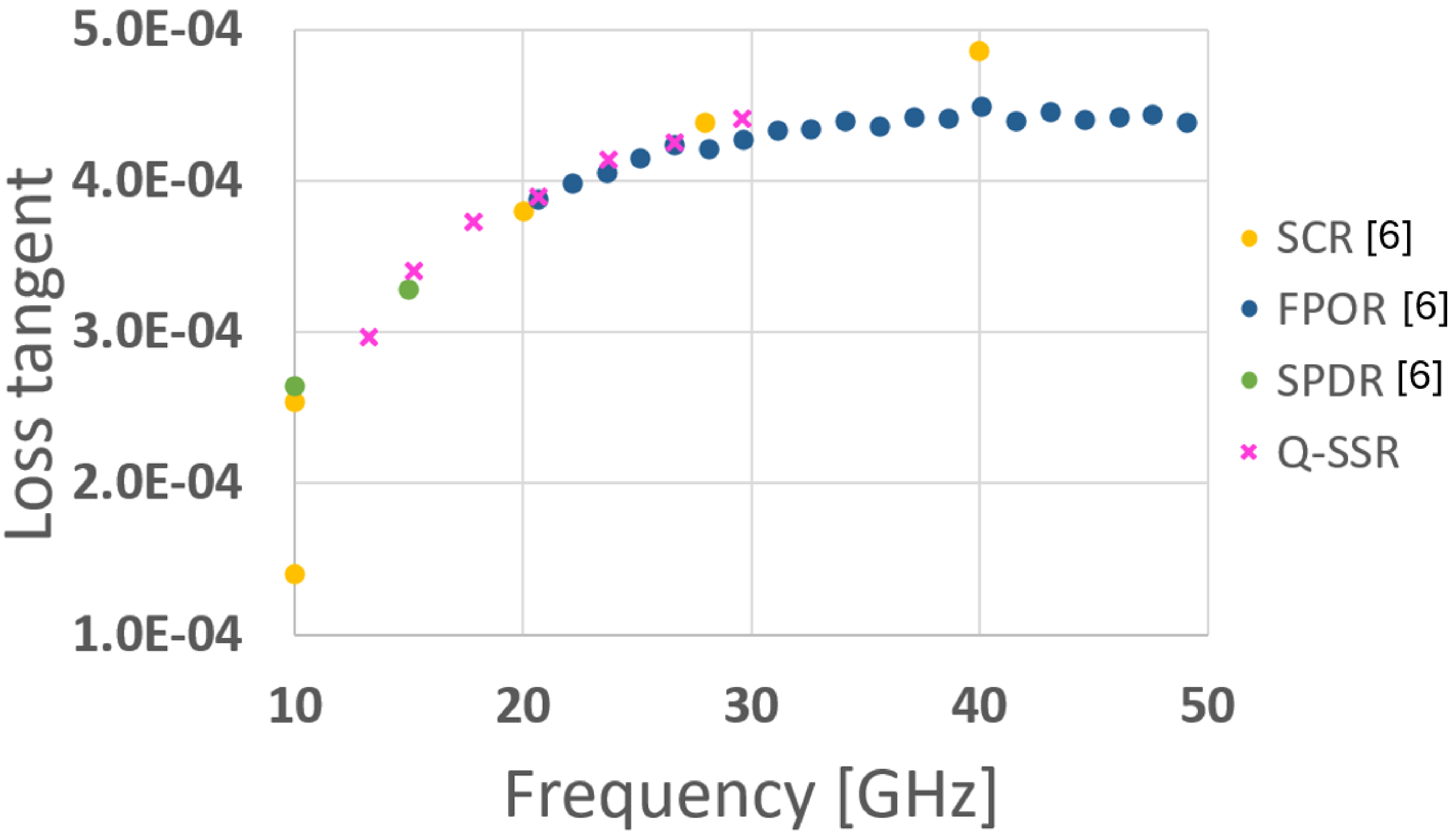


Comparison of Q-SSR to other methods



Validation of the proposed Q-SSR for an industrial COP sample – Dielectric constant ε

Comparison of Q-SSR to other methods



Validation of the proposed Q-SSR for an industrial COP sample – Loss tangent tanδ

Summary

- **New Concept Introduced:**

Developed and validated a new **Q-Choked Sapphire Sandwiched Resonator (Q-SSR)** for dielectric material characterization

Key Advantages:

- Combines **simplicity and precision** of SPDRs
- Enables **multi-resonance measurements** (6–7 modes)
- Covers a **broad frequency range** (at least 1:2.5 ratio)

- **Bridging the Gap:**
- Fills the frequency space between **traditional SPDRs** and **emerging FPOR** instruments
- Validated over the **12–30 GHz** band

- **Prototype Validated & Next Steps:**
- First prototype successfully built and tested
- Additional units under design for further expansion

- **Impact Potential:**
- Aims to become a **practical, go-to solution** for precise, broadband dielectric measurements of flat samples
- Poised to be a **valuable tool for the microwave measurement community**

Acknowledgments

This work was supported by the Polish National Centre for Research and Development under contracts M ERA.NET3/2021/83/I4BAGS/2022 (M-ERA.NET I4Bags project) and InnovativeSMEs/4/100/5G_Foil/2023 (EUREKA-Eurostars 5G_Foil project).

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