Numerical Electromagnetic Modeling of a BCDR* Test-Fixture

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*BCDR – Balanced-Type Circular Disk Resonator

Outline:

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1. BCDR design
2. Full-wave electromagnetic modelling
3. Challenges: air slots

3.BCDR Prototype and Validation

1. Design and fabrication of the BCDR prototype
2. Details of the central electrode on a PCB substrate
3. Initial validation with Teflon samples (Comparison of measured and simulated results)

4.Conclusion and Outlook

1. Advances in BCDR design for improved measurement accuracy
2. Future work in automatic mapping of measured resonant frequencies

Introduction

- **Importance of Material Characterization**
- **Benchmarking Efforts**
- **Findings from Benchmarking Reports:**

International Electronics Manufacturing Initiative

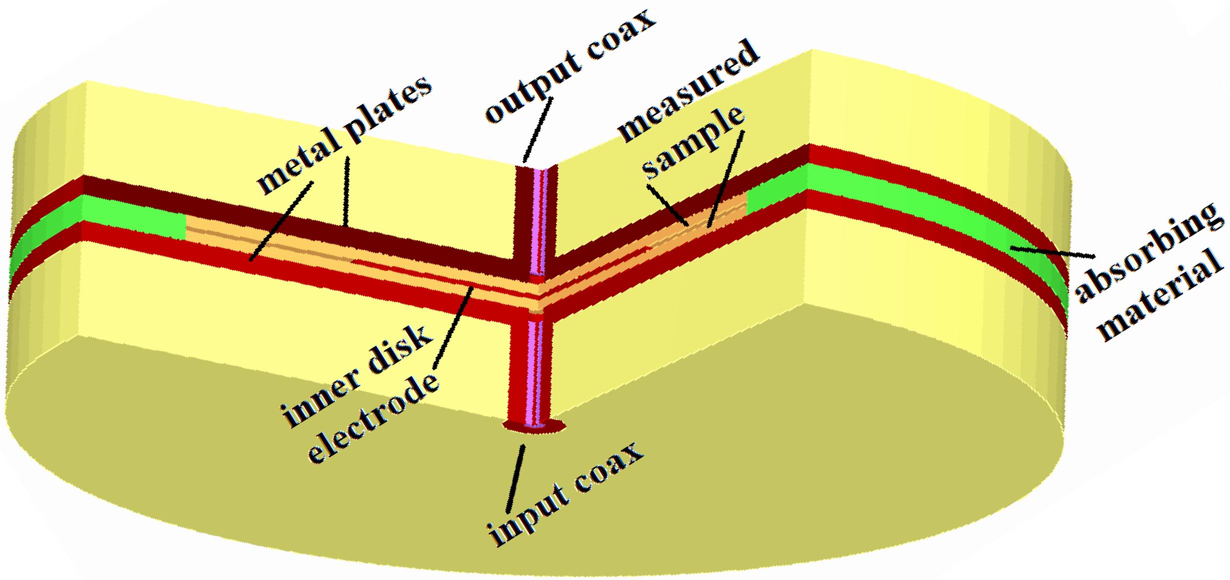
- **In-plane Permittivity Characterization:** Three commercially available methods (SCR, SPDR, FPOR) show very good agreement (within 1-2%).
- **Out-of-plane Permittivity Characterization:** BCDR method, is less reproducible and can diverge up to 10% from in-plane methods for isotropic substrates, which needs further investigation.

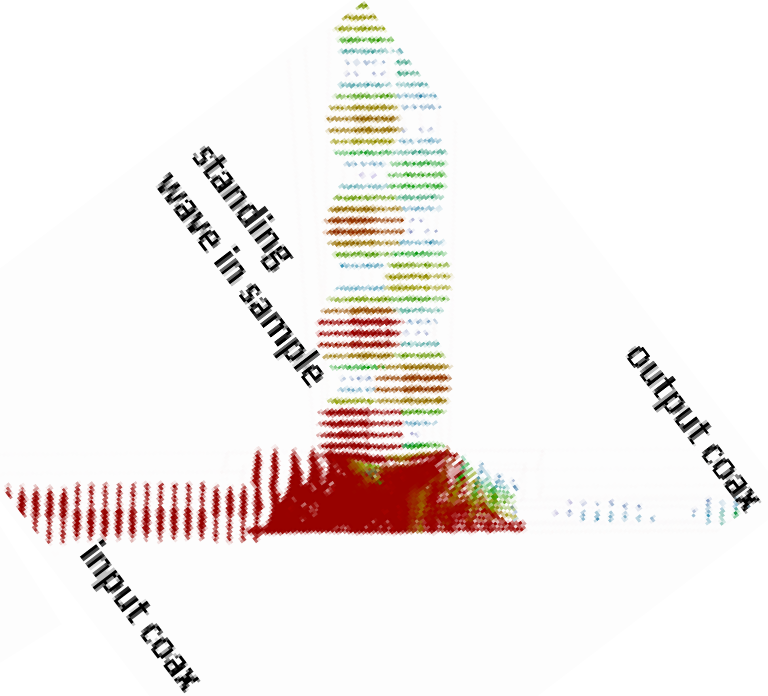
Our Contribution:

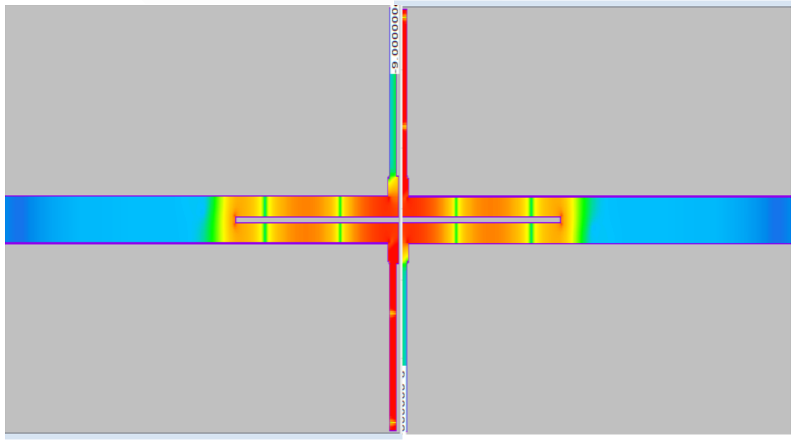
Motivated by the need to verify material isotropy and address the limitations of existing methods, we have developed an in-house BCDR test-fixture. Our objectives are to:

- Complement our existing in-plane measurement capabilities.
- Provide guidelines for future industrial applications of out-of-plane material characterization techniques.

BCDR Concept and Modelling



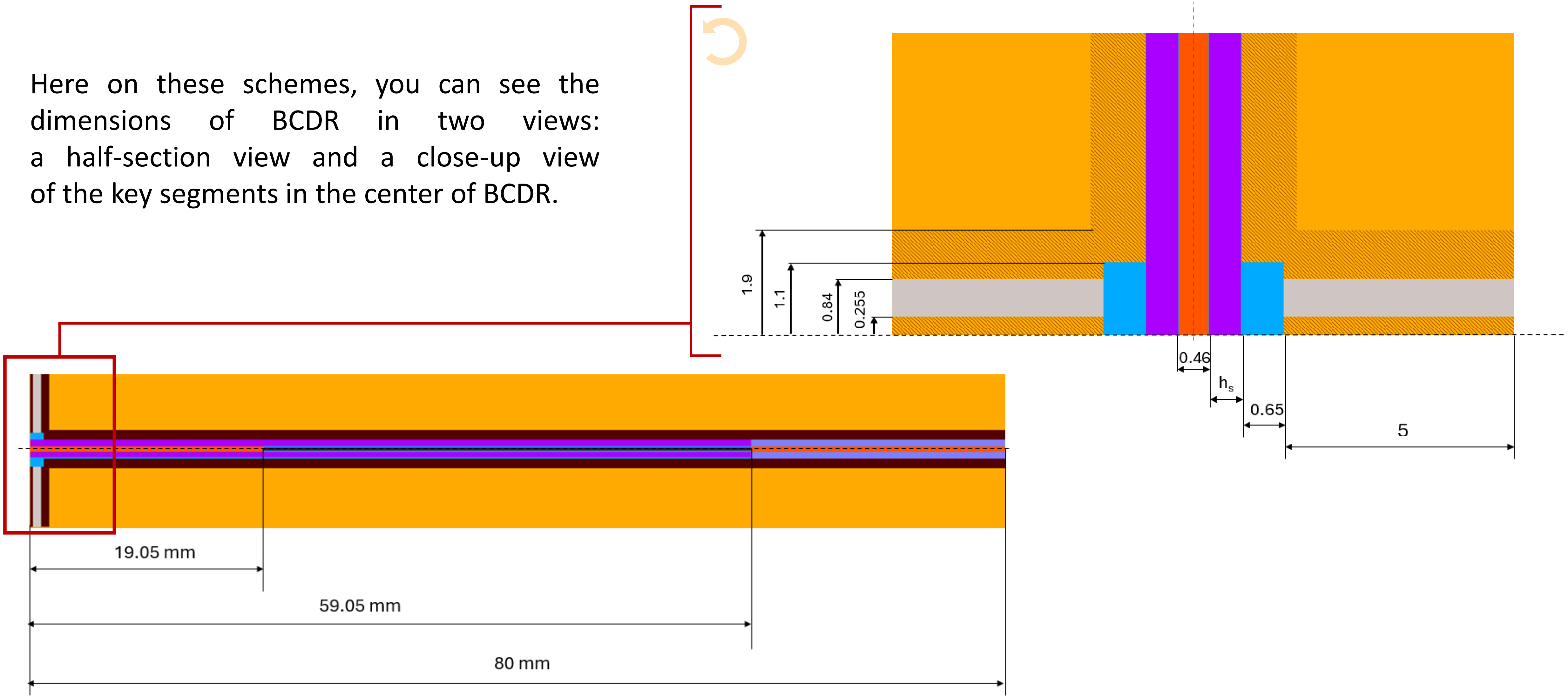




Conceptual design of BCDR (three-quarters view).

Full-wave electromagnetic modeling – BCDR dimensions

Here on these schemes, you can see the dimensions of BCDR in two views: a half-section view and a close-up view of the key segments in the center of BCDR.

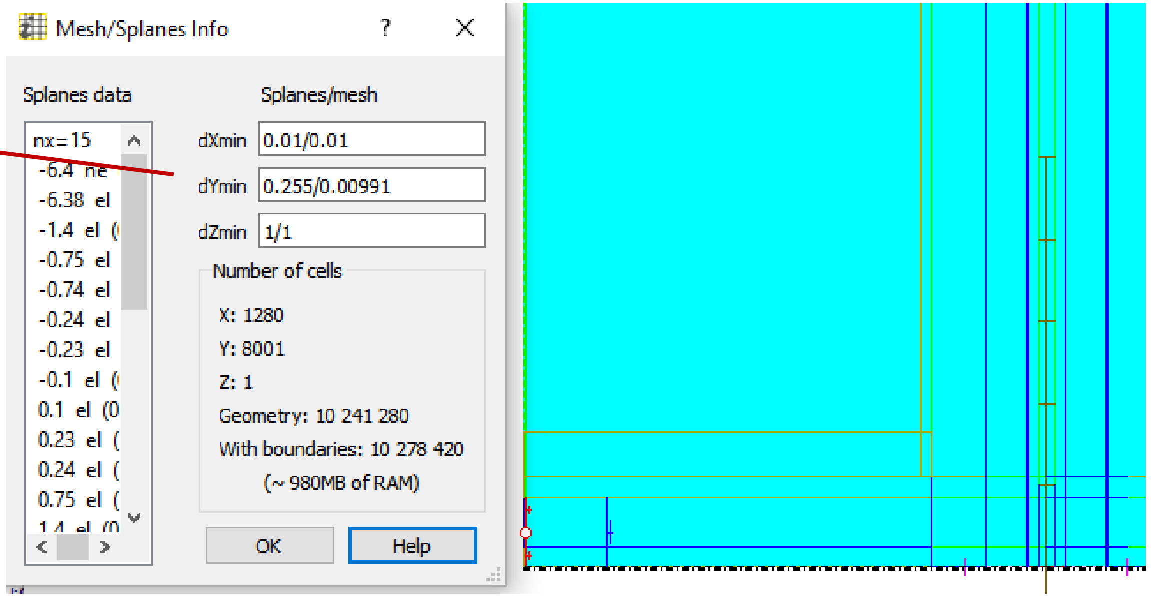


Full-wave electromagnetic modeling – mesh info

Cell size set to **0.1 mm** for X and Y dir
dXmin,dYmin doesn’t change for diffrent sample thickness (up to **0.01** mm).

Ca. **980 MB** of RAM in V2D Project.
Simulation Time using a Qprony* postprocessing tooks:
2 minutes and 19 seconds.

Mesh info (basic configuration):



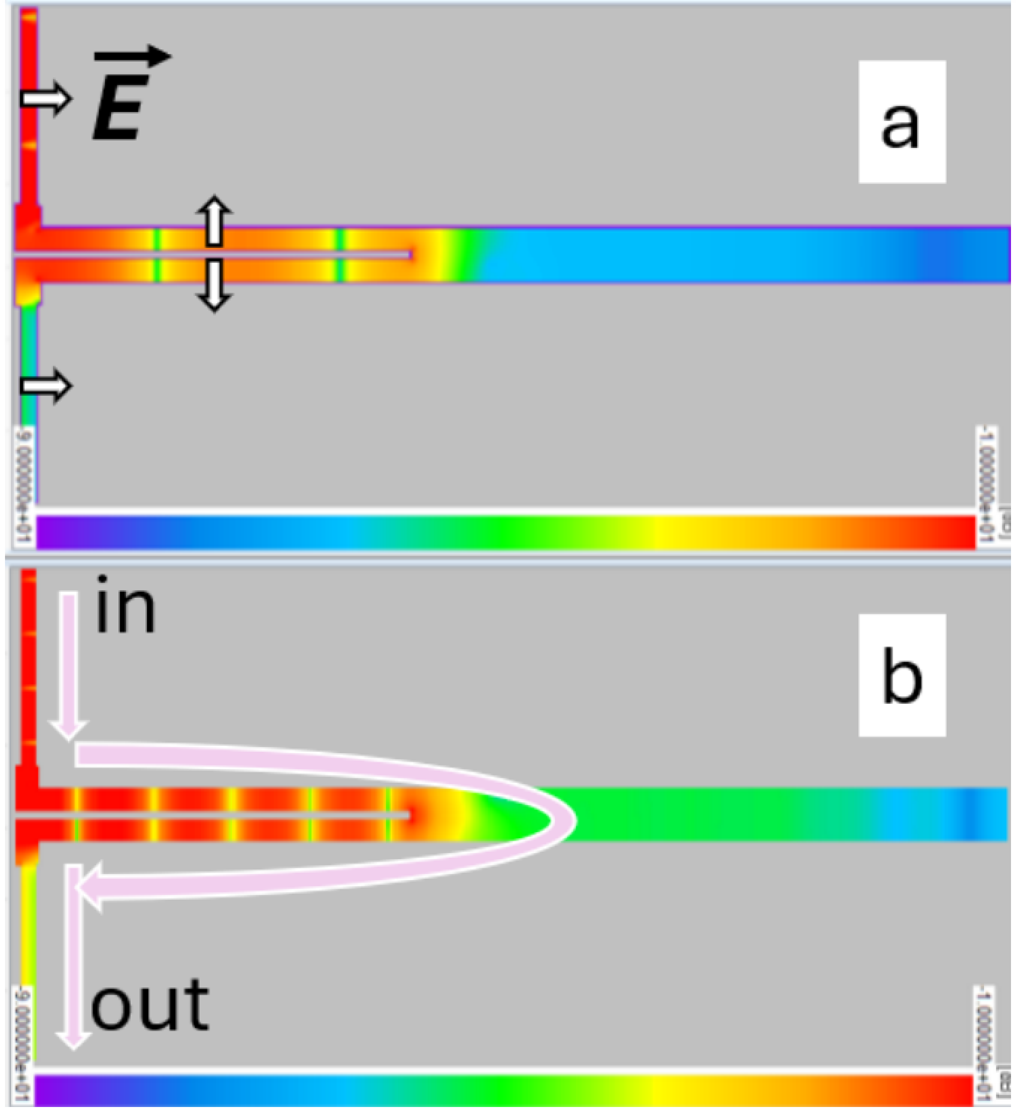
nx=15
-6.4 ne
-6.38 el
-1.4 el (
-0.75 el
-0.74 el
-0.24 el
-0.23 el
-0.1 el (
0.1 el (0
0.23 el (
0.24 el (
0.75 el (

dXmin: 0.01/0.01
dYmin: 0.255/0.00991
dZmin: 1/1

Number of cells
X: 1280
Y: 8001
Z: 1
Geometry: 10 241 280
With boundaries: 10 278 420
(~ 980MB of RAM)

Qprony* - implement of Generalized pencil-of-function method method by Prof. M. Mrozowski.

Full-wave electromagnetic modelling



Envelope of the electric field intensity in one-half of the vertical cross-section of the dielectric-loaded BCDR at (a) **40.49 GHz** and (b) **95.06 GHz**;

- white arrows in (a) indicate the field direction,
- pink arrows in (b) - direction of energy flow

Full-wave electromagnetic modelling

Notably, the distance between the axis and the inner electrode's edge approximates one wavelength.

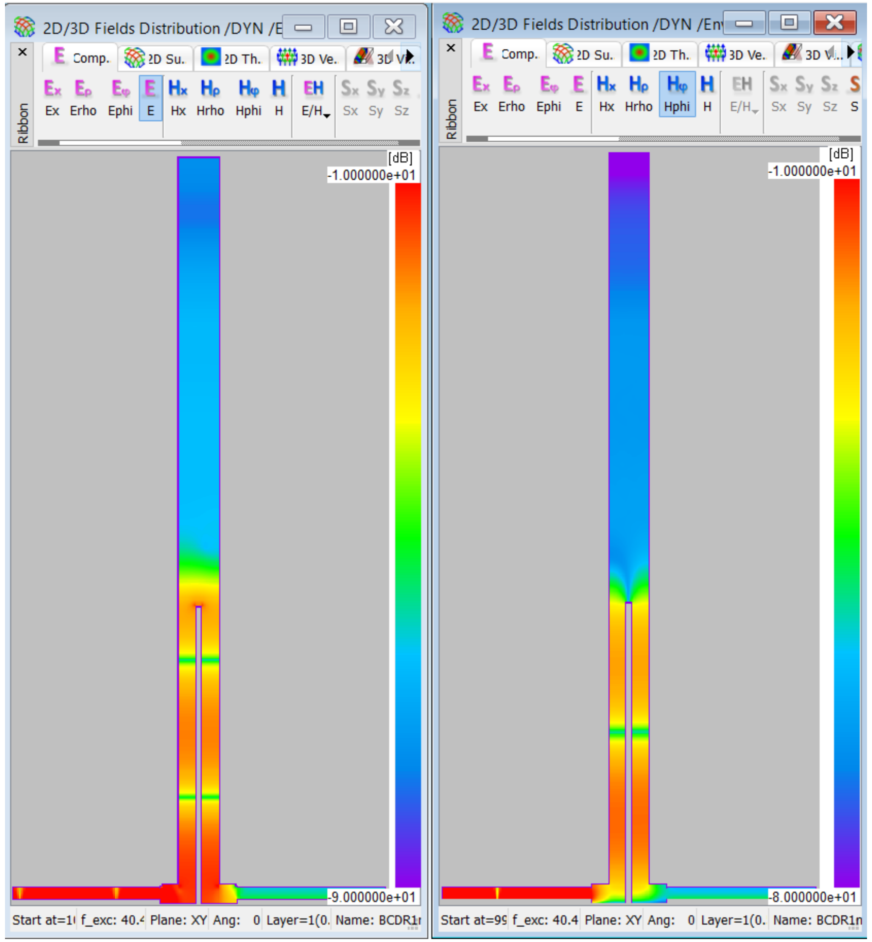


Fig.1.3. Envelope of |E| (left) and Hphi fields in logarithmic scale (-10 to -80 dB) in the BCDR described by the red curve of Fig1.2 at 40.49 GHz

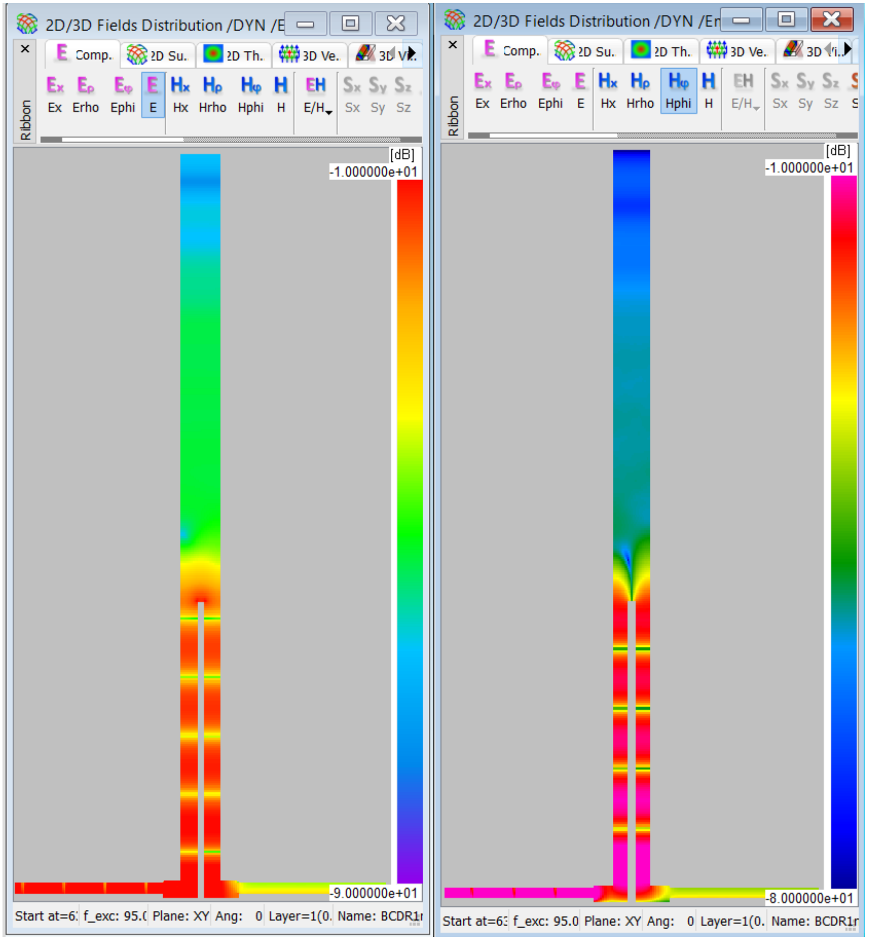
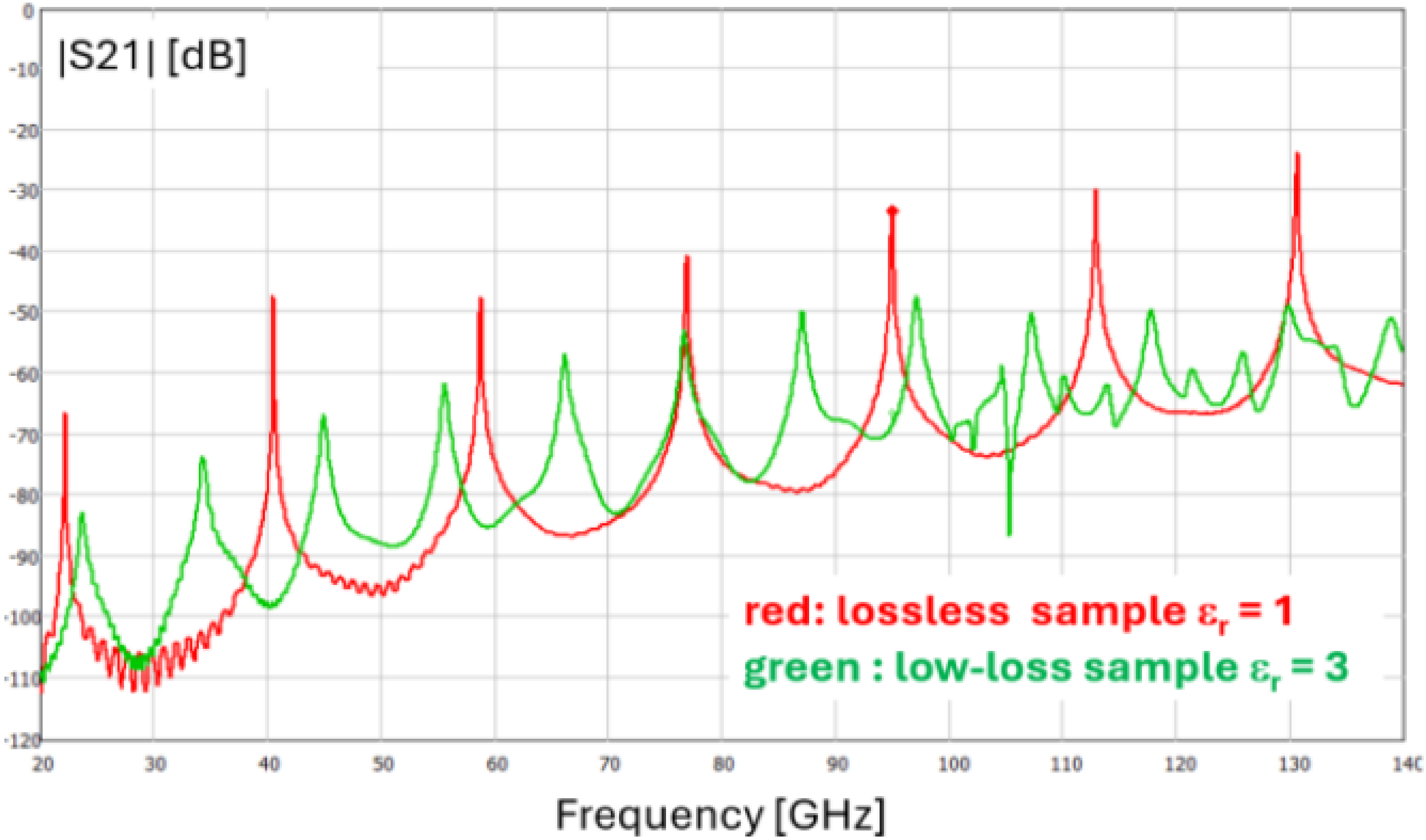


Fig.1.4.Envelope of |E| (left) and Hphi fields in logarithmic scale (-10 to -80 dB) in the BCD described by the red curve of Fig1.2 at 95.06 GHz

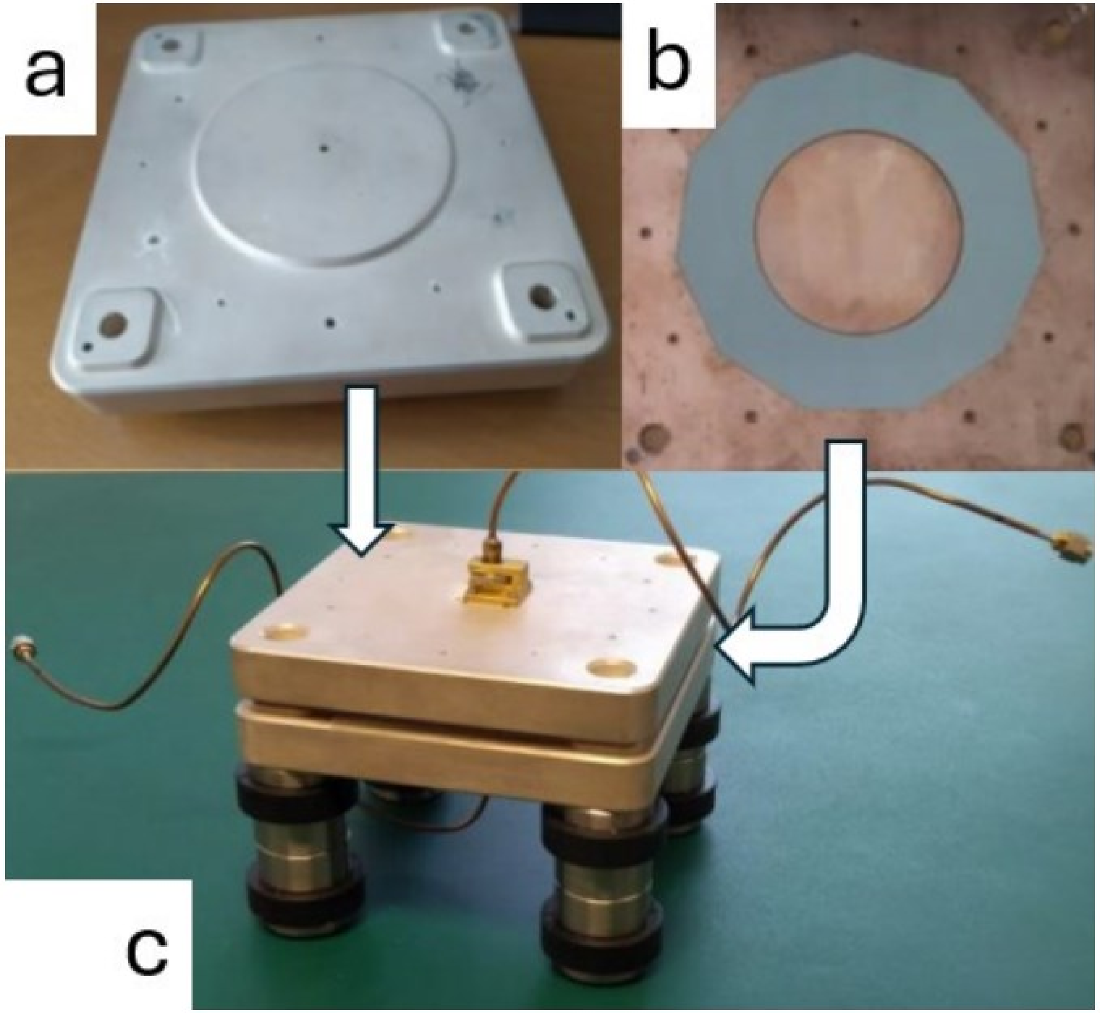
with the distance between the axis and the inner electrode's edge approximately two and a half wavelengths

Full-wave electromagnetic modeling – first simulations



Simulated transmission through an example BCDR (inner electrode diameter **16 mm**, thickness **0.2 mm**) when a pair of samples (each **0.4** mm thick) is made of air (green) and low-loss dielectric (red).

BCDR Prototype and Validation



Photos of the BCDR prototype:

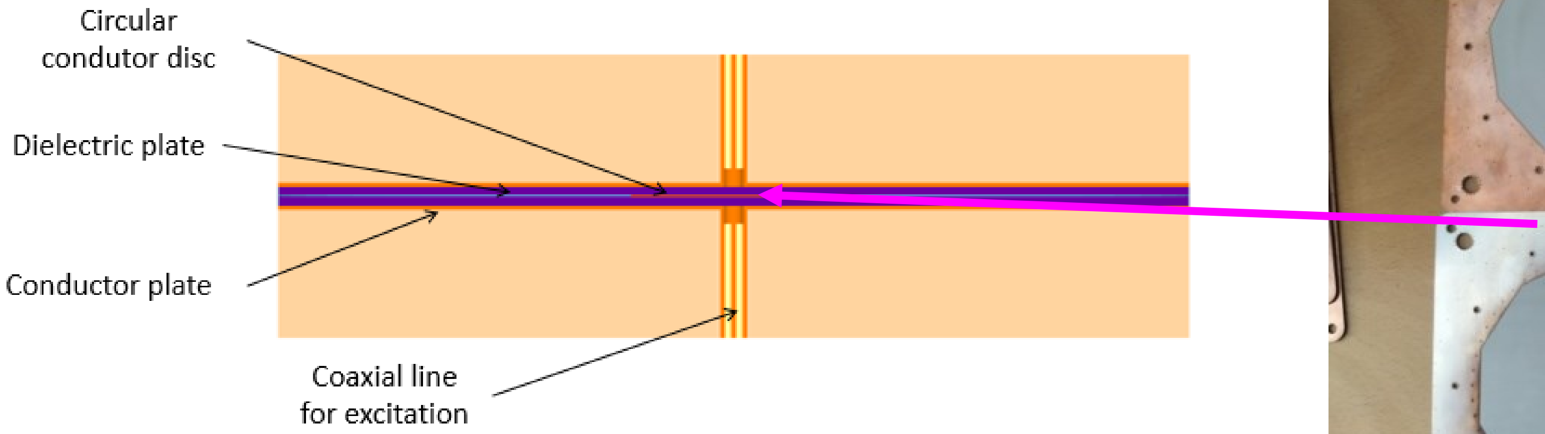
(a) bottom surface of the upper electrode,

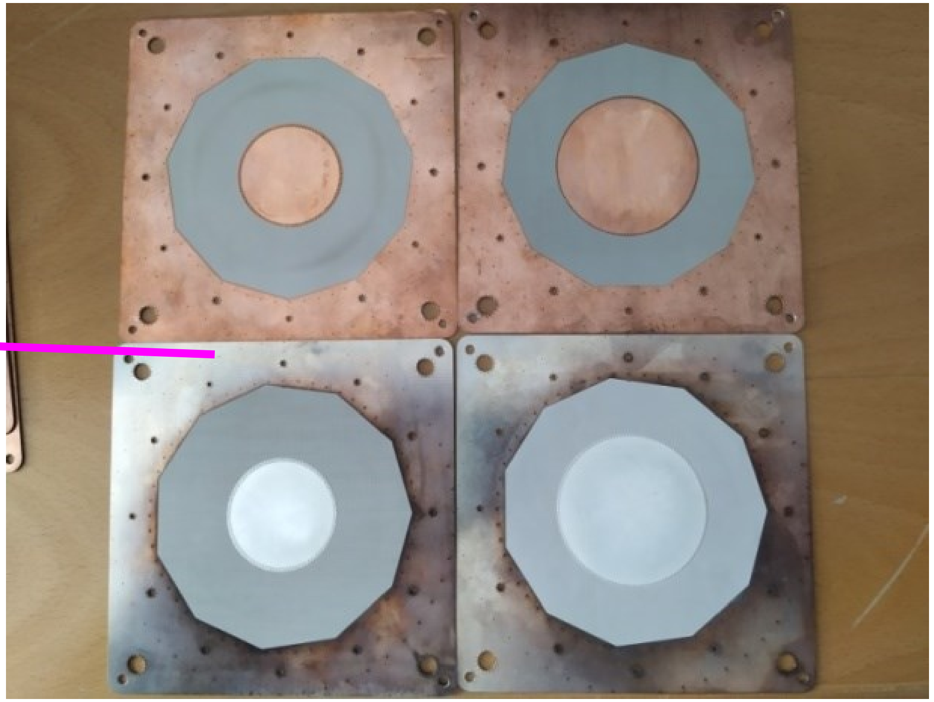
(b) central electrode,

(c) complete device with I/O cables.

- larger thickness of the central electrode limits the measurement frequency range, but is not critical in terms of the measurement accuracy,
- central positioning of the central electrode is critical, in terms of both the accuracy and the frequency range,
- losses in the central electrode have negligible influence on the overall losses of the structure.

Details of the central electrode on a PCB substrate





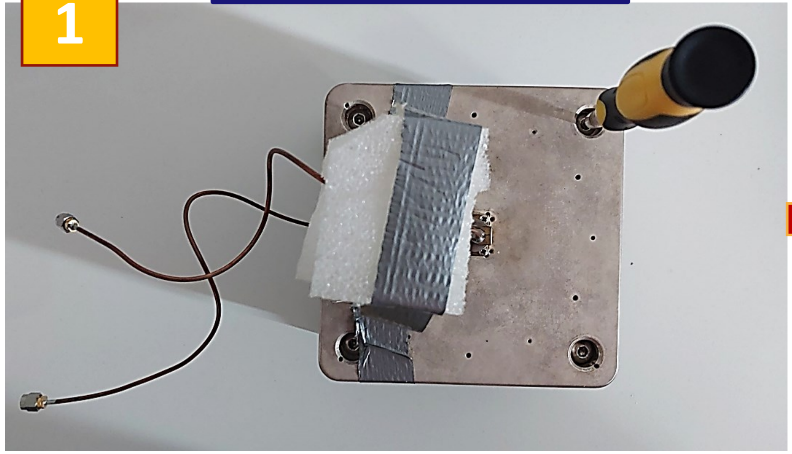
Examples of inner electrodes processed in microwave PCB substrates

Radius of Electrode: 19.05 mm
Substrate: Taconic TLC-32-0310-C1/C1
Substrate Thickness: 0.78 mm (0.92 mm including metal layers)
Metal Removal: Metal around the electrodes has been removed in a polygonal area to break axial symmetry and limit cylindrical mode reflections.
Positioning Holes: The substrate is equipped with holes for correct positioning with respect to the BCDR center.
Vias: A row of closely spaced 0.5 mm vias along the outer edge.

BCDR Prototype and Validation – Measurement procedure

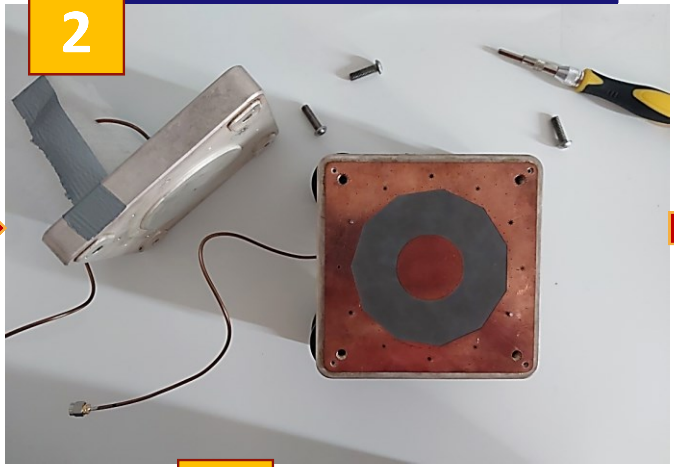
1

Remove Screws



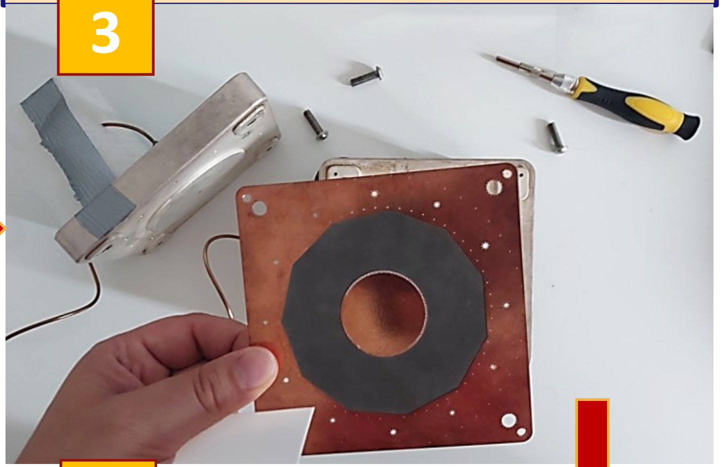
2

Remove Upper Electrode



3

Lift the inner electrode and place the sample under it



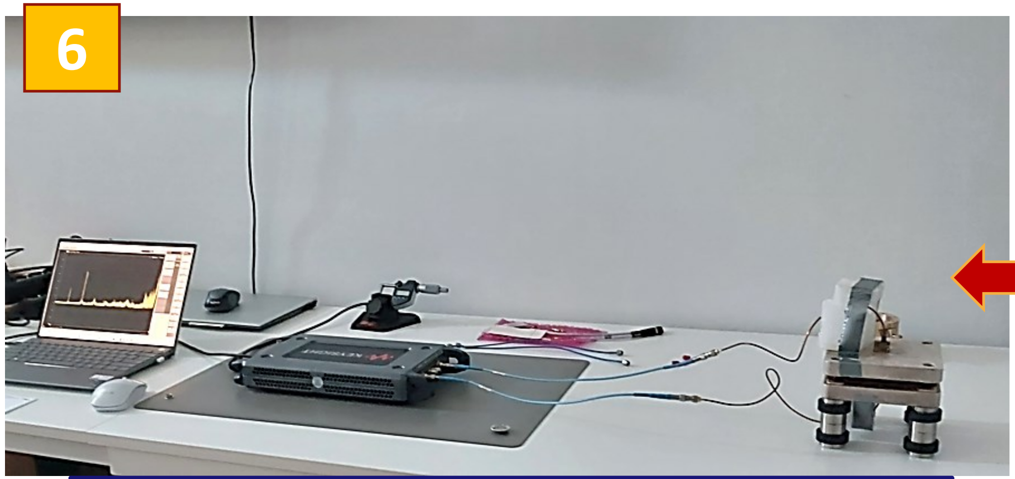
4

Place a similar sample over the inner electrode

5

Align and Secure Electrode

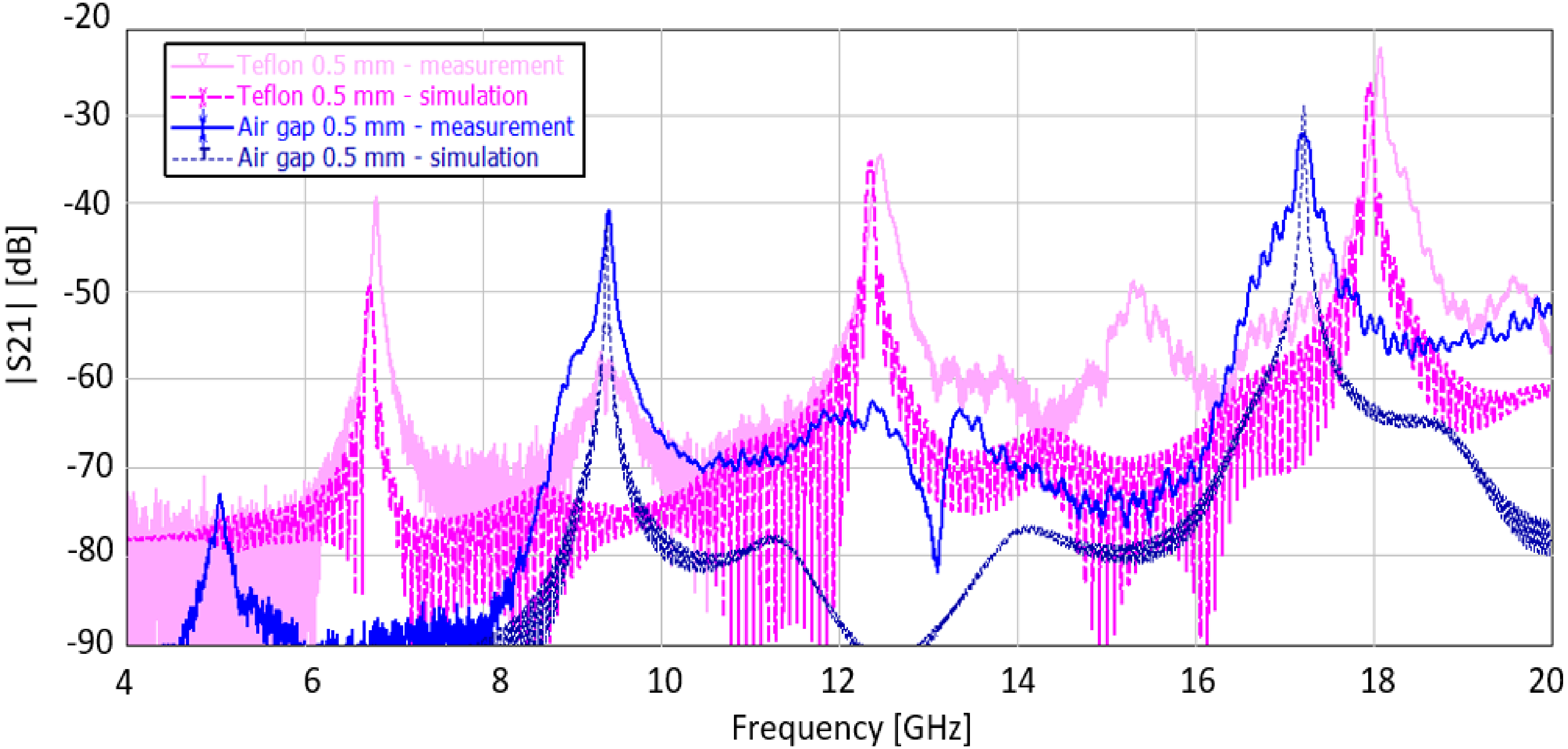
6



Extract Resonant Frequency and Q-Factor

Initial validation with Teflon samples

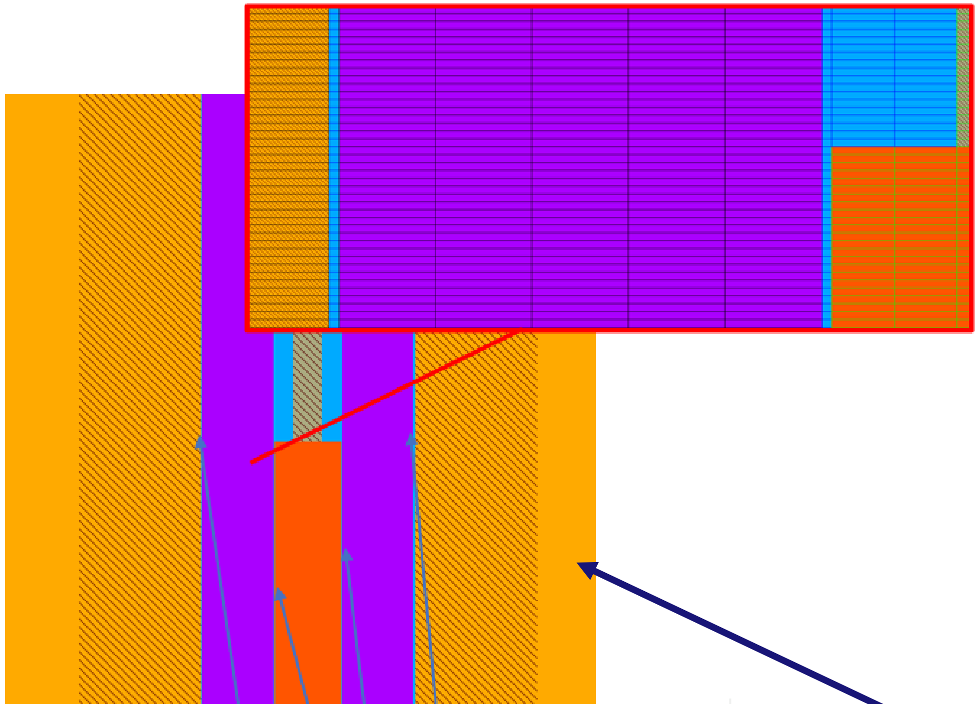
EXPERIMENT



Comparison of measurements and simulations of 0.5 mm Teflon (assuming permittivity 2.054) and 0.5 mm air gap.

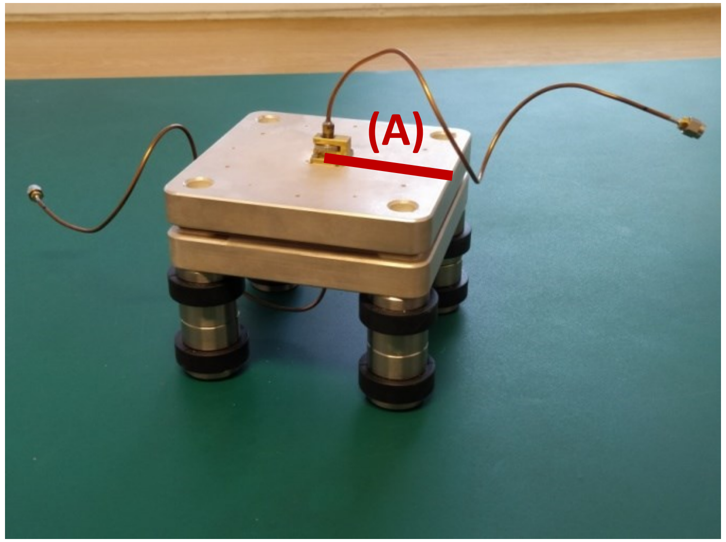
The frequency results for simulation and measurement agreed for an air gap of 0.5 mm. However, a mismatch can be seen when measuring Teflon. The surface roughness of the electrodes as well as the sample itself is the main reason for its out of tune. More precisely, **the air slots** created between them.

Model with air slots correction



Air slots added above&bottom of the sample

- Air gaps have been added above and below both samples and their dimension is fixed by snapping planes



Cross-section (A)

For 0.5 mm Teflon, an air slot was calculated, which is **0.014764 (±0.000858) mm** width
-> The ongoing work is based on the extraction of the permittivity of an unknown 0.5 mm thick sample.

Conclusion and Outlook

1. Parameterized BCDR models implemented in 2D BoR and 3D FDTD EM software with Qprony postprocessing are effective tools for exploring and validating novel resonator designs, which are critical for enhancing measurement capabilities.
2. The primary objective is to develop a robust and accurate setup for measuring the *out-of-plane component of complex permittivity* in the GHz frequency range.
3. A novel design featuring a thick central electrode processed on a double-sided PCB substrate has been introduced. This design facilitates easier centering within the BCDR prototype, contributing to improved measurement precision.
4. Initial **validation** efforts have demonstrated good agreement between the modeled and experimental results, specifically using a reference Teflon material. This confirms capabilities of the new design. To improve accuracy of measurements we add to model an air slots which provides
5. Within the context of the M-ERA.NET I4Bags project, ongoing work focuses on developing a computer application aimed at **automatically measured resonant frequencies and Q-factors of BCDR-loaded samples.** This application will convert these measurements into the complex permittivity of the samples.

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I4Bags

5G_Foil

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Thank you!

If you have questions feel free to ask by email…

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