IMPI's
57TH ANNUAL MICROWAVE POWER SYMPOSIUM (IMPI 57)

Microwave Characterization of Liquids with Resonant Methods

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Outline

- Motivation
- Measurement techniques
  - Cavity resonators
  - New Fabry-Perot open resonator
- Measurement results
- Temperature dependent measurements
- Summary

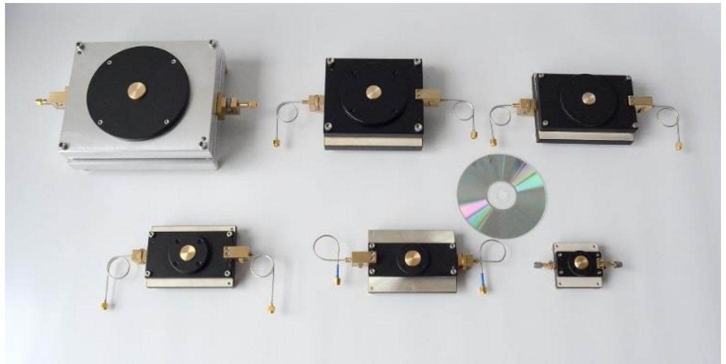
Motivation

- Dielectric characterization of "loose" materials
  - Liquids
  - Powders
- Electronic coolants
- Food industry
- Raw materials producers
- Characterization with resonant methods
- Wideband characterization in 1 – 50 GHz
  - Cavity devices
  - Fabry-Perot Open Resonator

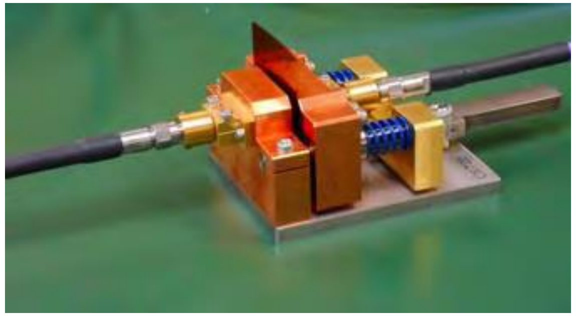
Materials characterization (1)

- Resonant methods well established for materials characterization
- International initiatives benchmarking existing materials characterization methods (iNEMI: www.inemi.org)
- Resonant methods are proven to be the most accurate among microwave material characterisation methods

Family of Split-Post Dielectric Resonators



Fabry-Perot Open Resonator



Split-Cavity Resonator

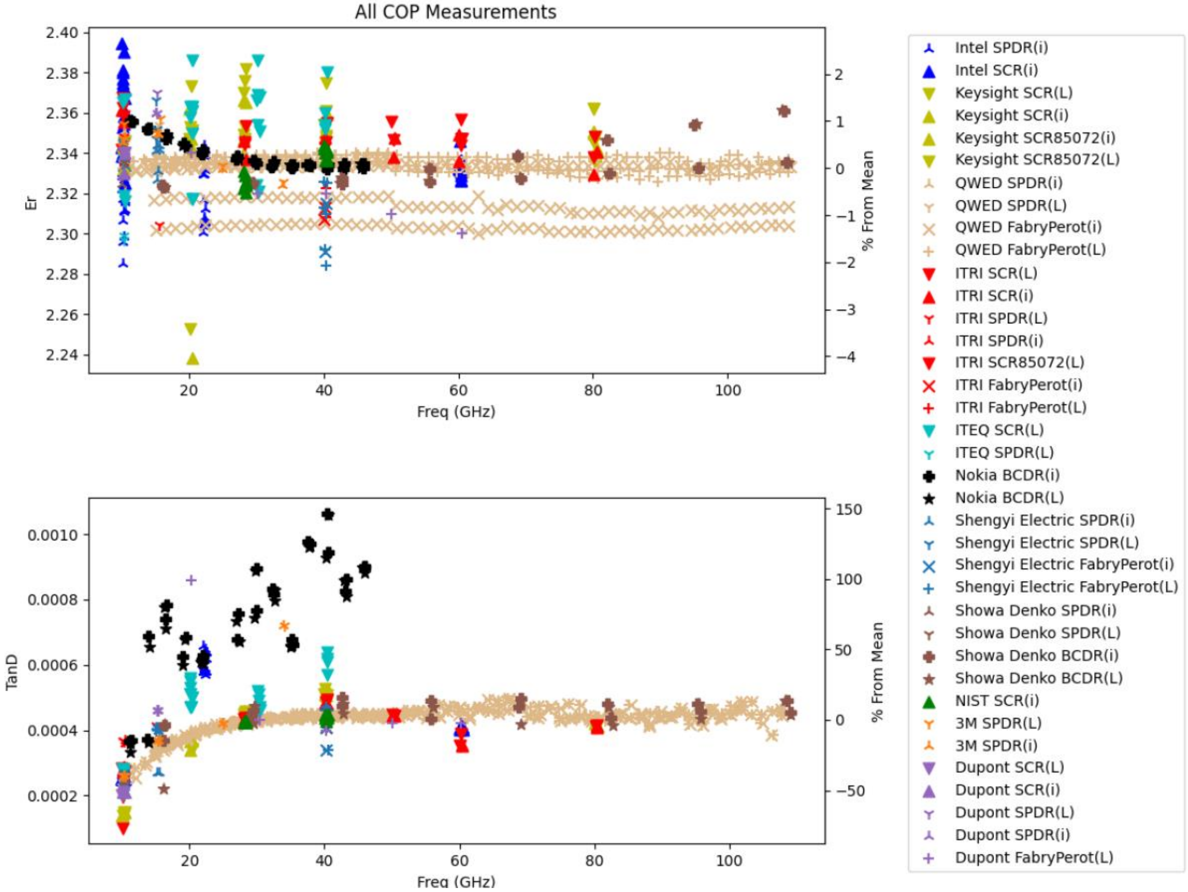
Balanced Circular Disk Resonator

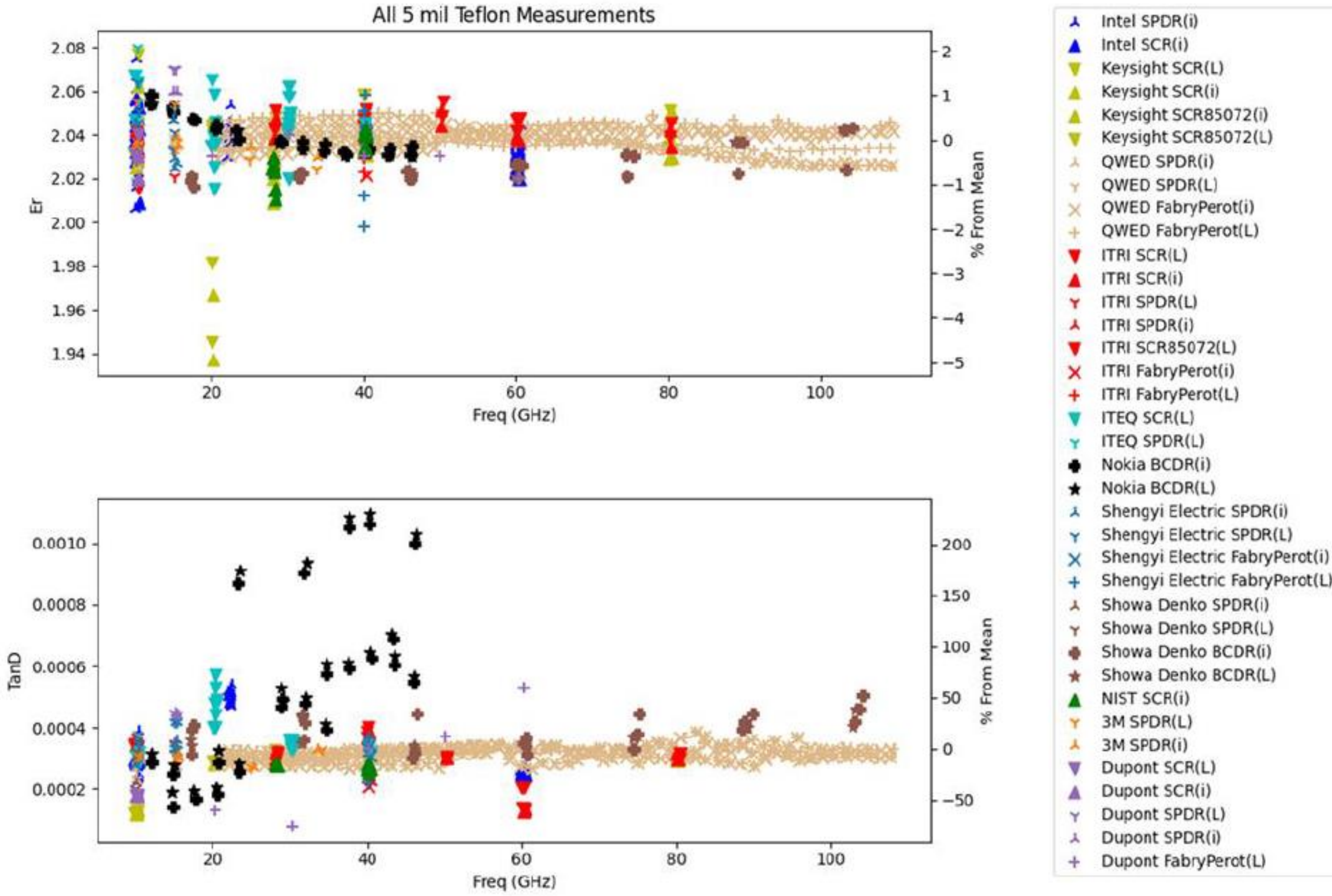
Materials characterization (2)

iNEMI ***5G/mmWave Materials Assessment and Characterization*** **project results**

Over 1000 measurement points in total

Round 1





Spread of Dk: ±2%

Measurement methods (1)

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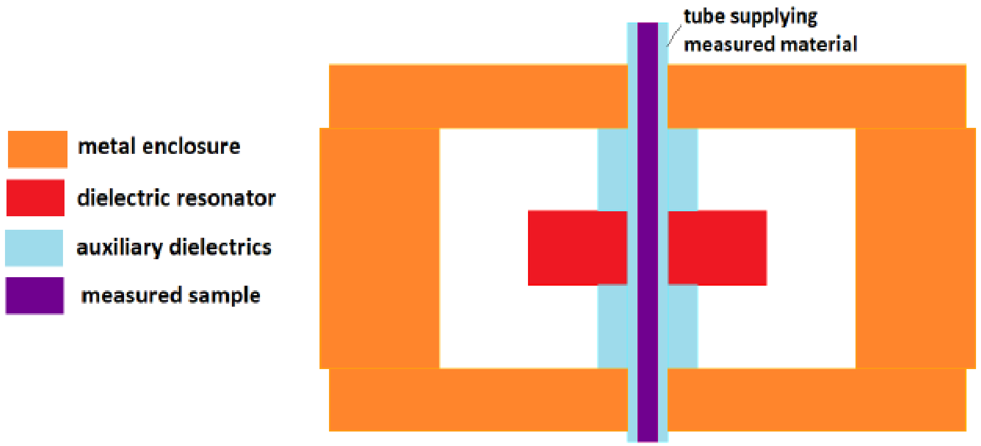
Resonant methods are proven to be the most accurate among microwave material characterisation methods

Low frequency dielectric resonator cavities



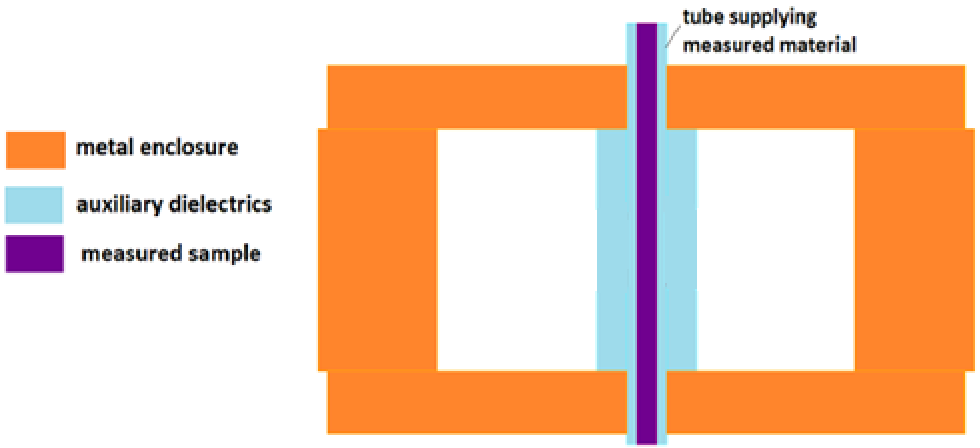
Schematic concept of the dielectric resonator cavity

Dielectric resonator cavity at 1 GHz

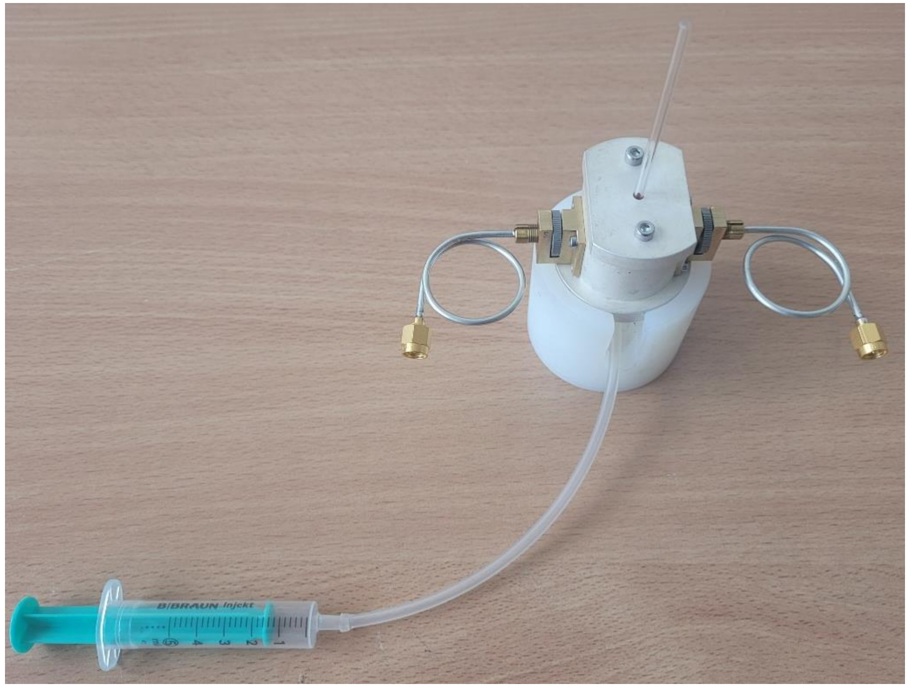
Measurement methods (2)

Resonant methods are proven to be the most accurate among microwave material characterisation methods

Higher frequency cavity resonators



Schematic concept of the resonance cavity

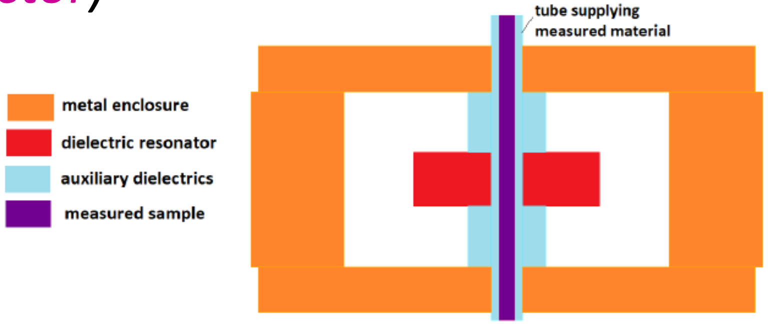


24-GHz Cavity resonator

(with fused silica tube, rubber tube and syringe)

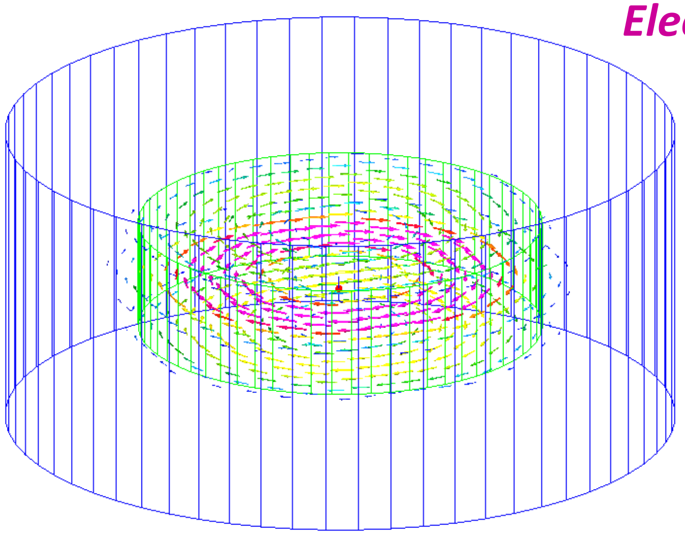
Measurement methods (3)

- $TE_{01\delta}$ resonance mode *(described with resonant frequency and Q-factor)*
- Electric field mostly confined within the dielectric pill
- Circumferential electric field
  → no issues with galvanic connection of the lid
- Zero electric field at $\rho=0$
  → no risk of supressing resonance if lossy sample is inserted

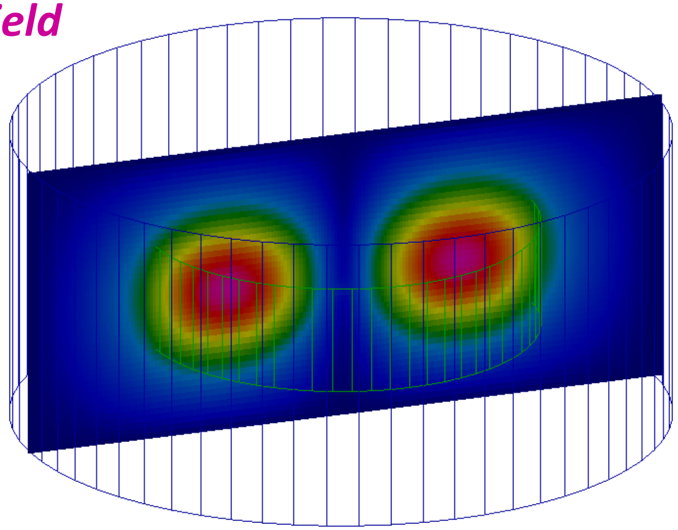


Resonance mode within dielectric resonator cavity *

Electric field

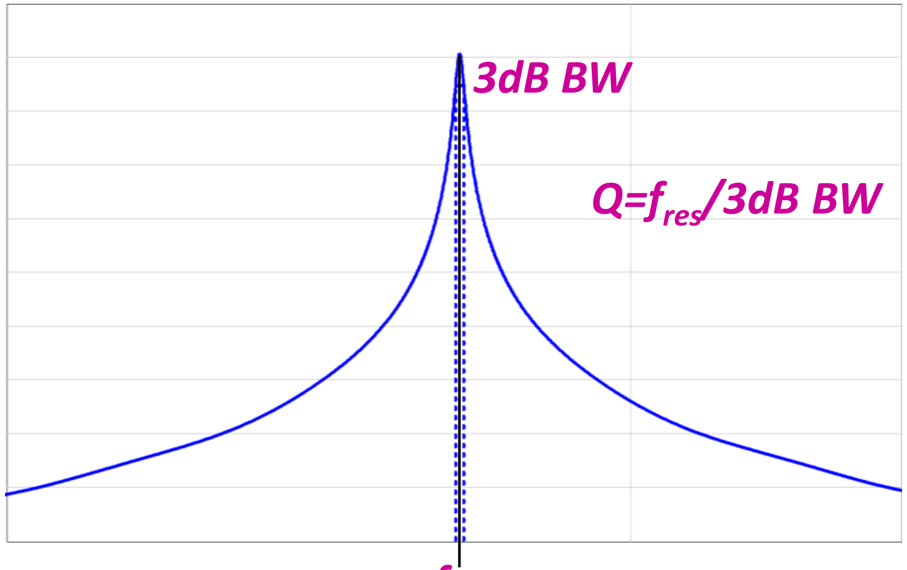


Vector view



Amplitude view (cross section)

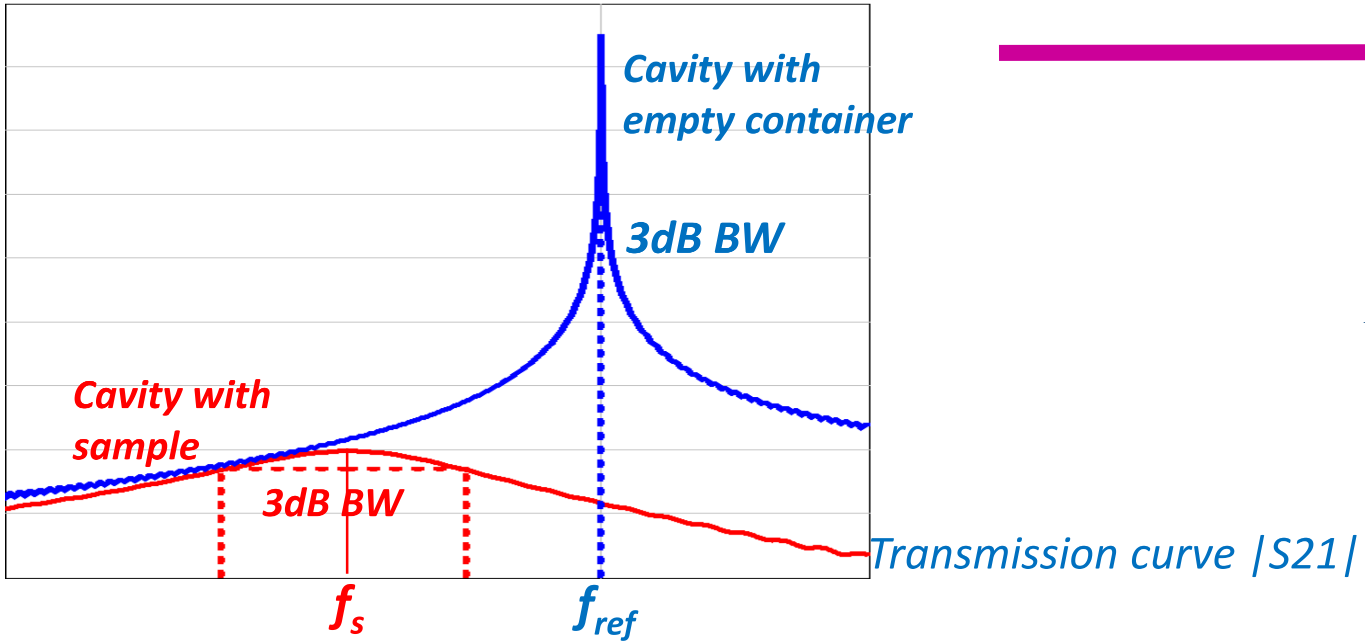
Transmission curve |S21|

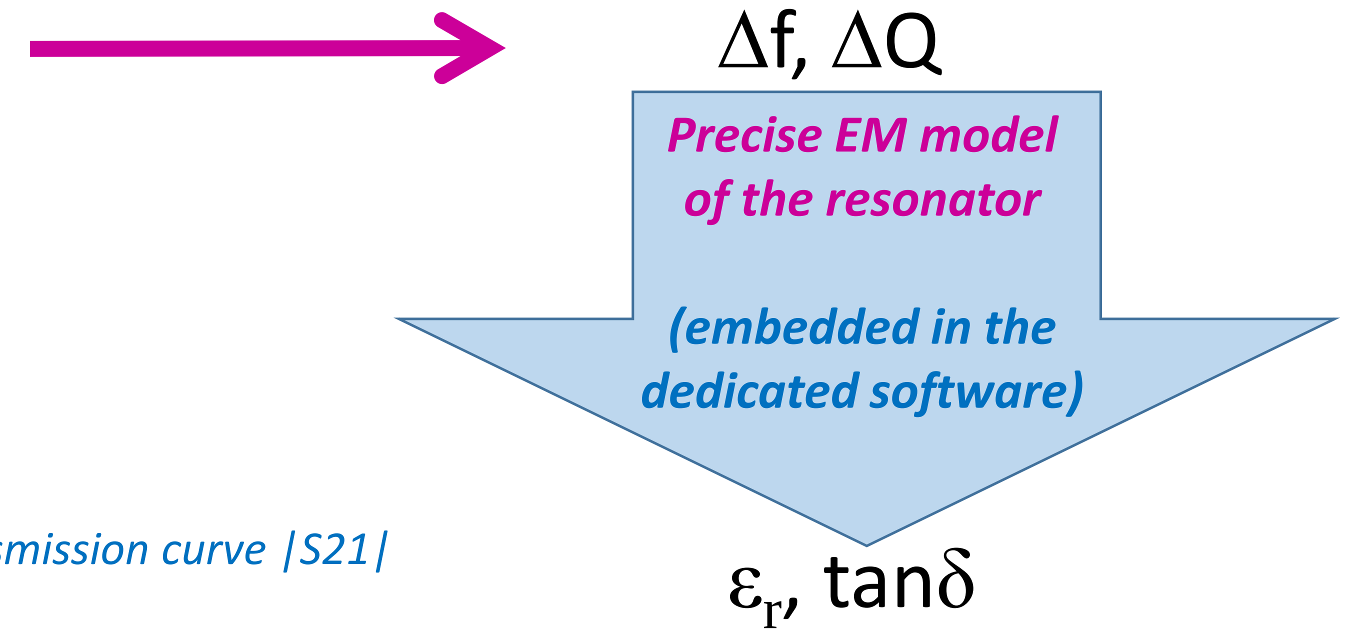


*** Obtained with QuickWave 3D software***

Measurement methods (4)

- Two/three stage measurement
- Reference measurement – cavity with empty container (f_{ref} and Q_{ref})
  → the inner diameter of the container/container needs to be precisely calibrated
- Measurement of sample-loaded cavity (f_s and Q_s)
- Scalar measurement of transmission curve (|S21|) is typically sufficient





Lookup Tables

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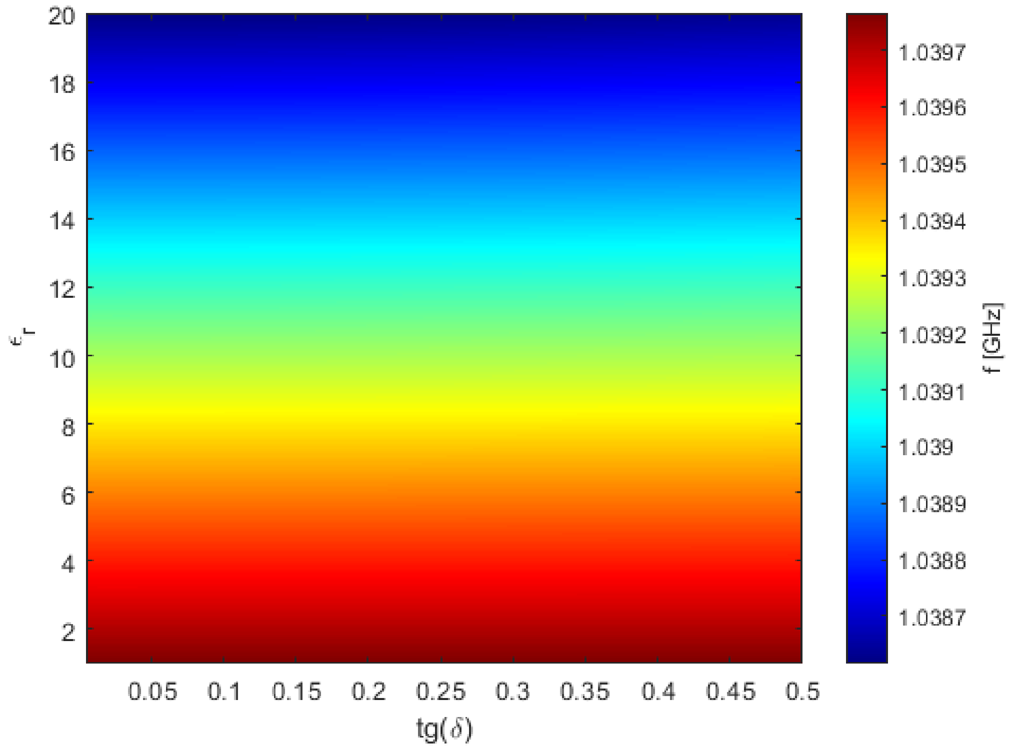
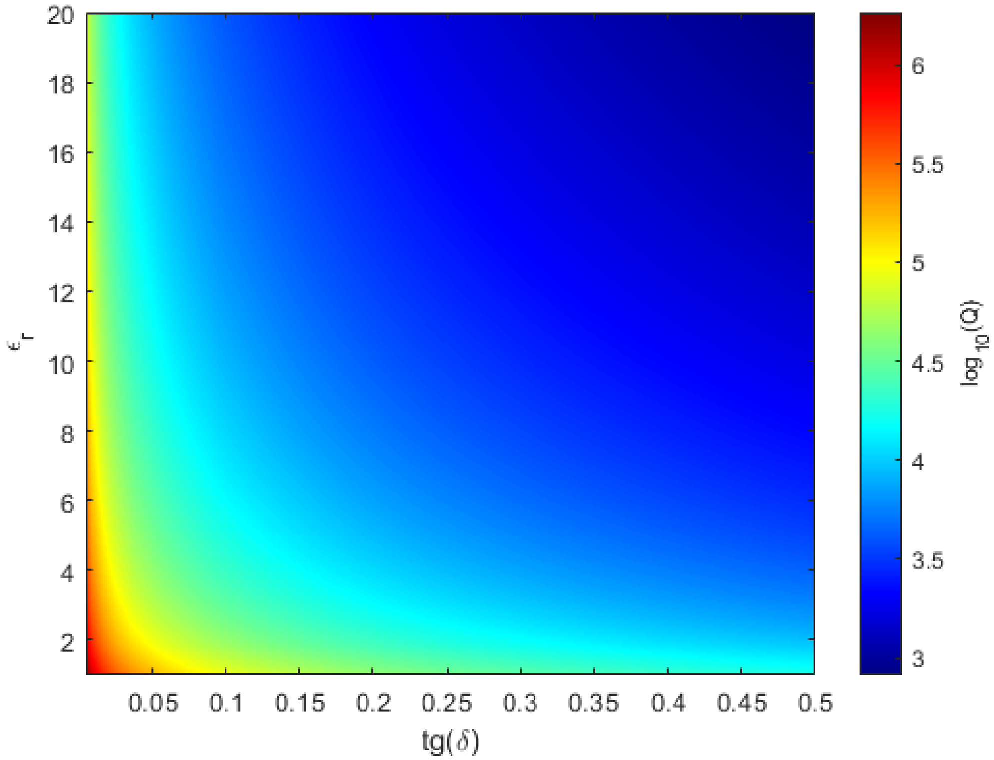
In a low-loss regime, resonance frequency depends mostly on the Dk,

whereas the Q-factor decreases with both Dk & Df.



Resonance frequency



Q-factor (log-scale)

Measurement methods (5)

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Low frequency dielectric resonator cavities
Dielectric resonator cavity at 2.5 GHz

Specification

Fluid diameter < 16 mm

$TE_{01\delta}$: f = 2.45 GHz (Q = 29,400)

$TE_{02\delta}$: f = 5.16 GHz (Q = 27,200)

Higher frequency cavity resonators
24-GHz Cavity resonator

Specification

Fluid diameter < 3 mm

TE_{011}: f = 23.8 GHz (Q = 14,200)

Measurement methods (5)

IMPI's 57th Annual Microwave Power Symposium (IMPI 57)

Low frequency dielectric resonator cavities
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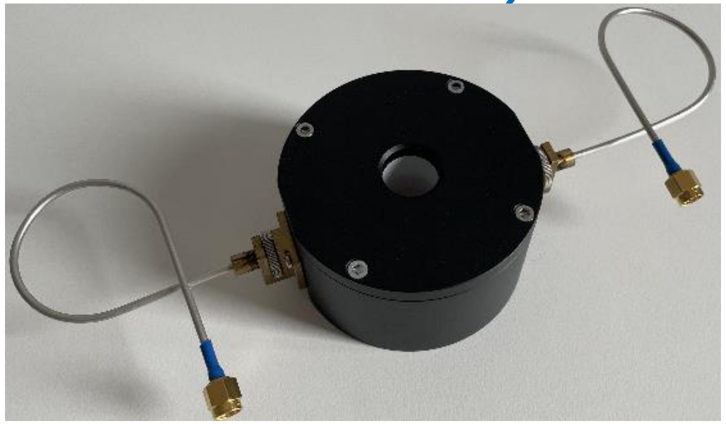

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Higher frequency cavity resonators
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Fabry-Perot Open Resonator

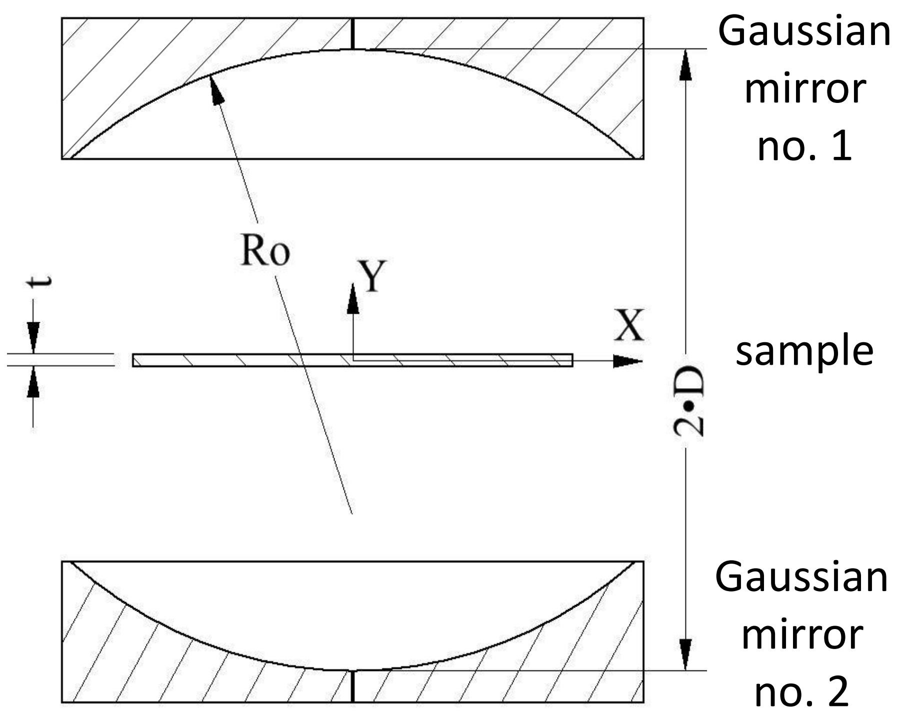
Single solution for 15-50GHz

f ↑ manufacturing tolerances of FS tubes ↑
prohibitively large ***Din*** variation
uncertainty of the measurement ↑

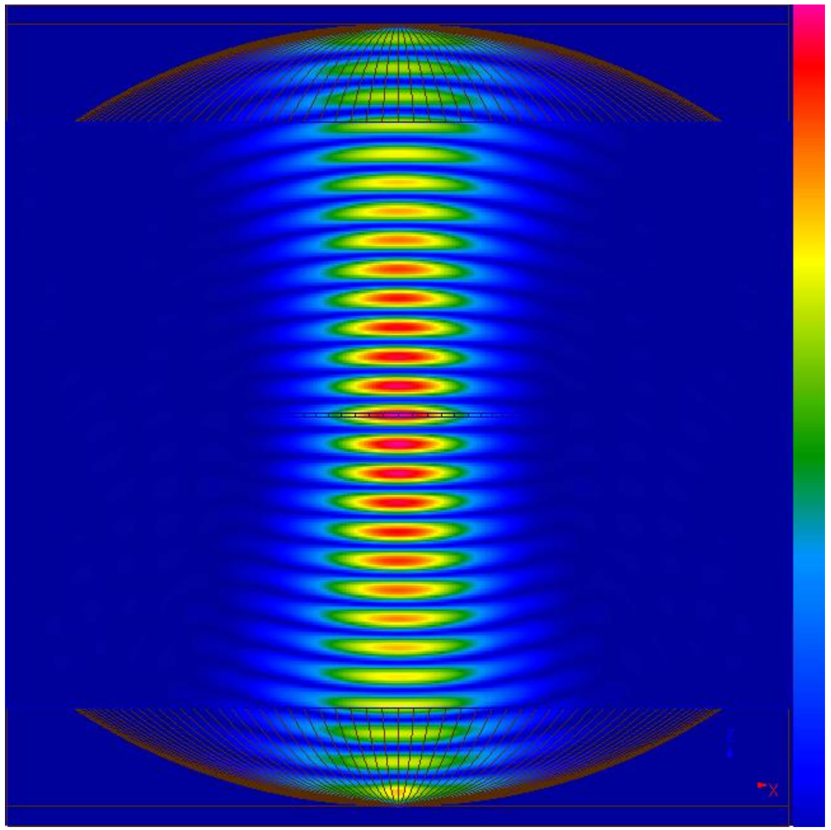
Fabry-Perot Open Resonator

Fabry-Perot Open resonator

Bridging the gap between classical resonant methods and free space methods



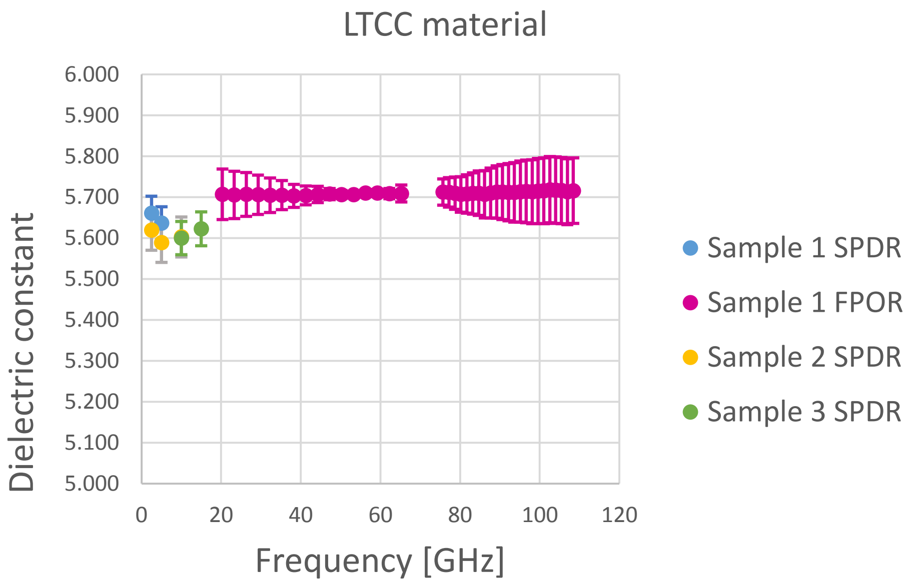
*Gaussian **TEM00q** modes*

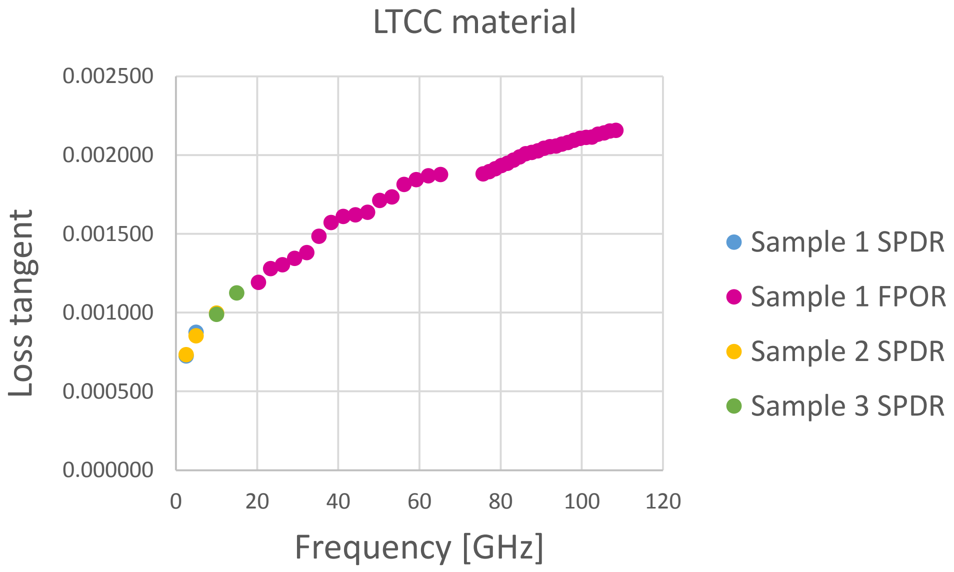


Electric field distribution - simulation model in QuickWave software

FPOR for sheet dielectrics characterization

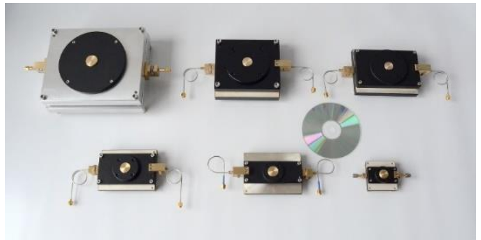
LTCC and ULTCC materials' characterisation activities in ULTCC6G_EPac





Wideband FPOR solution

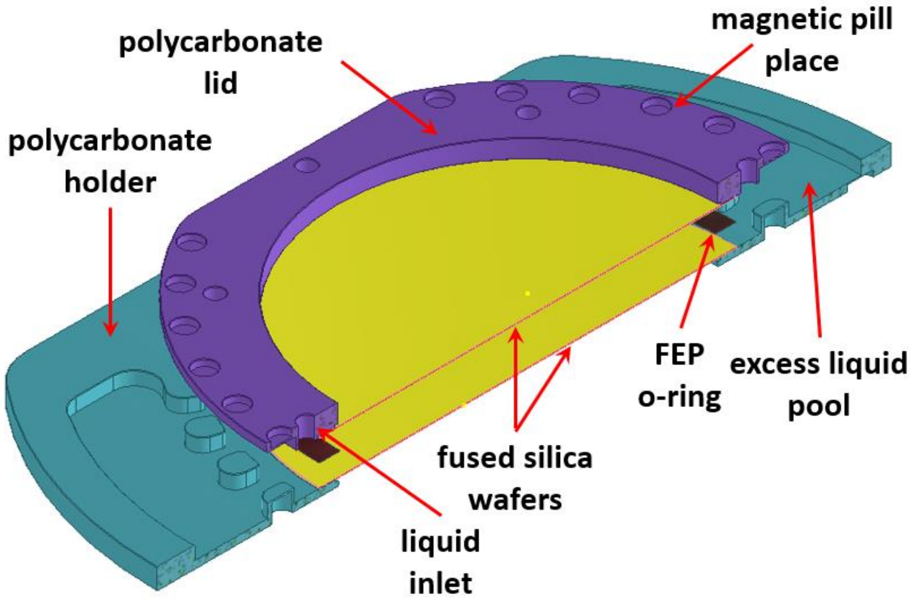
Family of SPDR fixtures

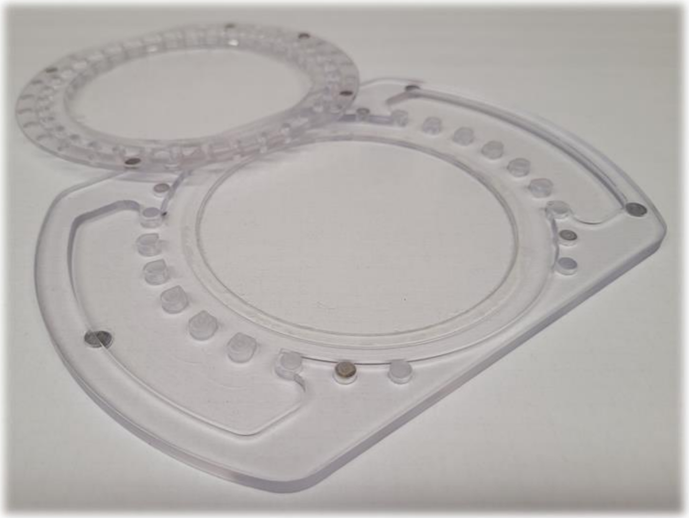


***Ultra-Low Temperature Co-fired Ceramics for 6th Generation Electronic Packaging* (ULTCC6G_EPac) project**

FPOR for fluids characterization

Fabry-Perot open resonator with a dedicated fluid container





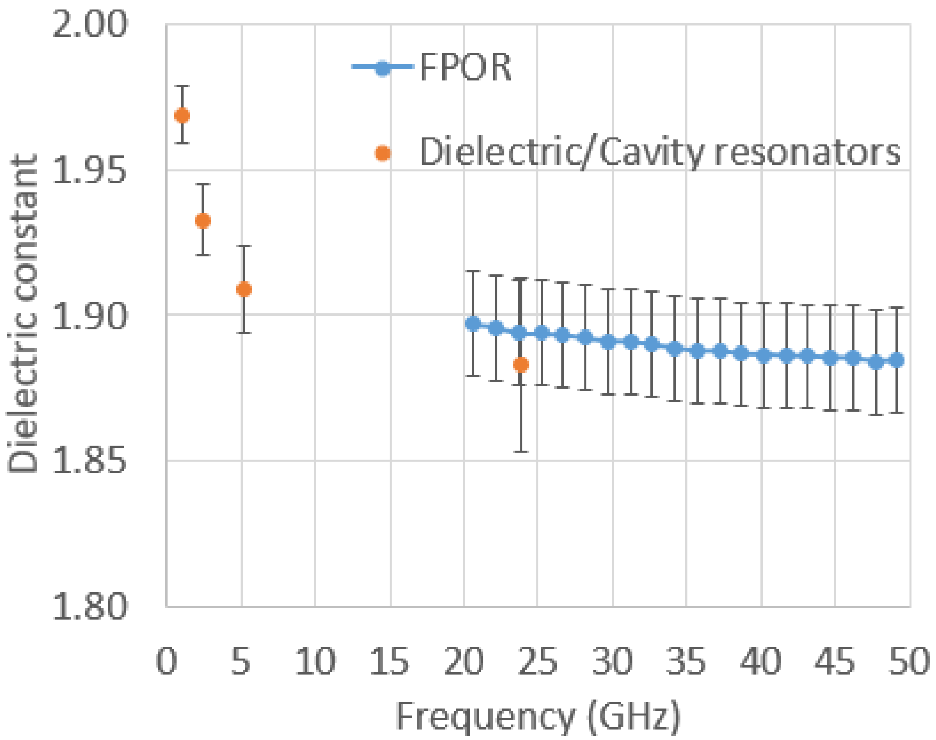
Specification

Fluid thickness: 100-400 μm
Frequency: 15-50 GHz

Requires dedicated EM model and measurement software

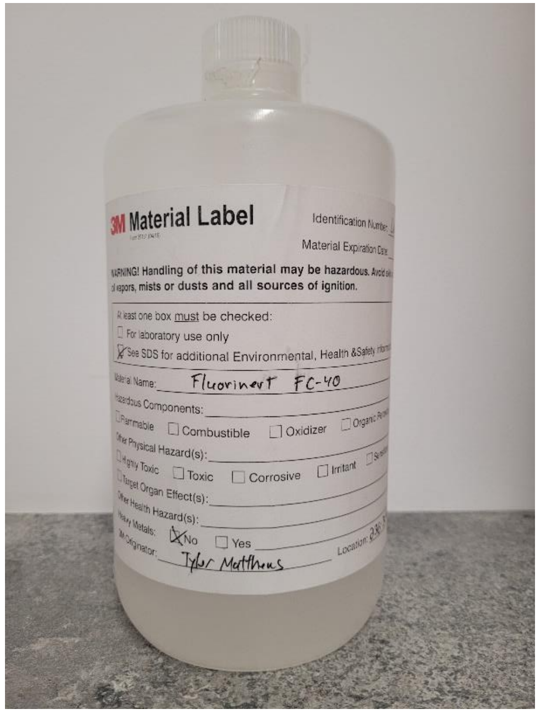
Measurements results - electronic coolants

Low-loss liquids typically exhibit dispersive properties at microwaves (Debye-like relaxation)

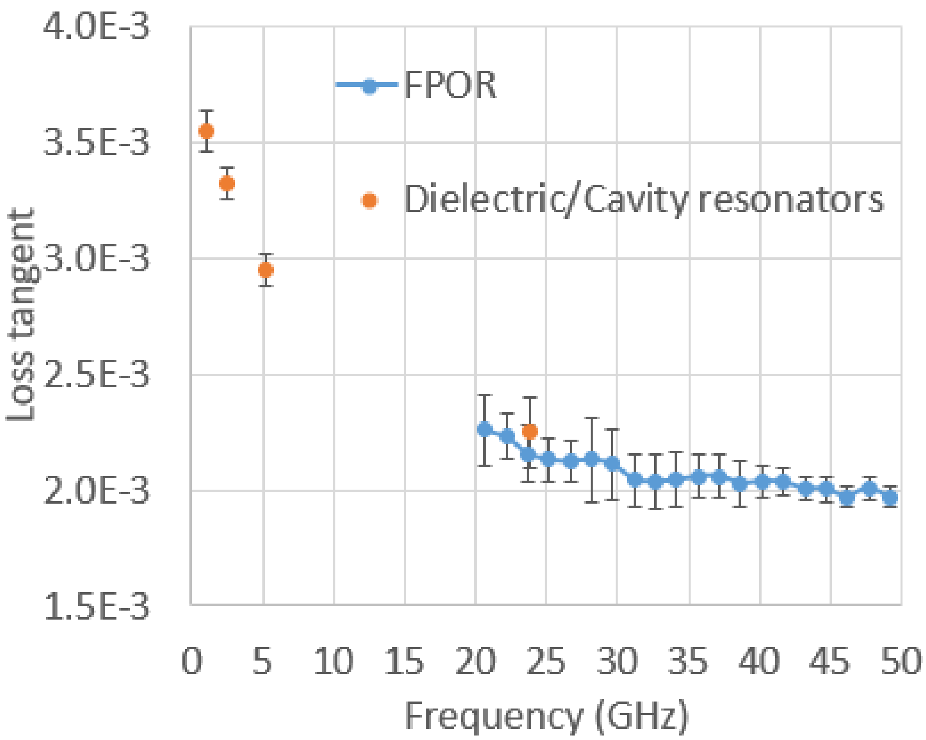


Dielectric constant

Uncertainty of Dk <1%

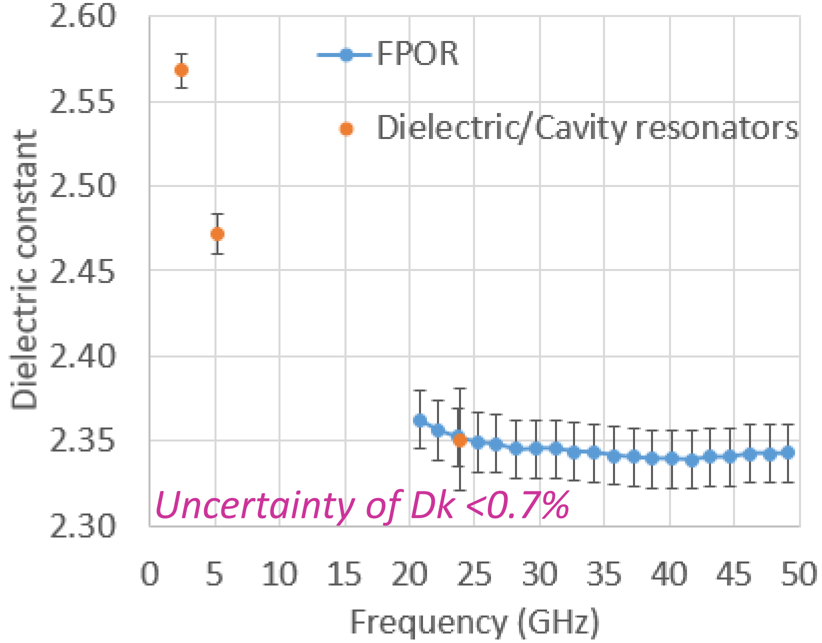


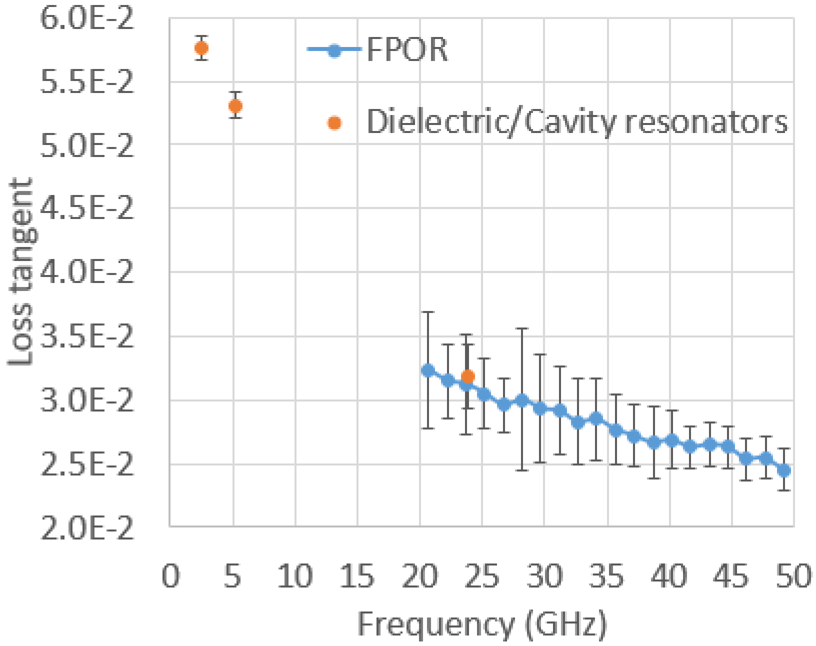
Fluorinert (3M FC-40)



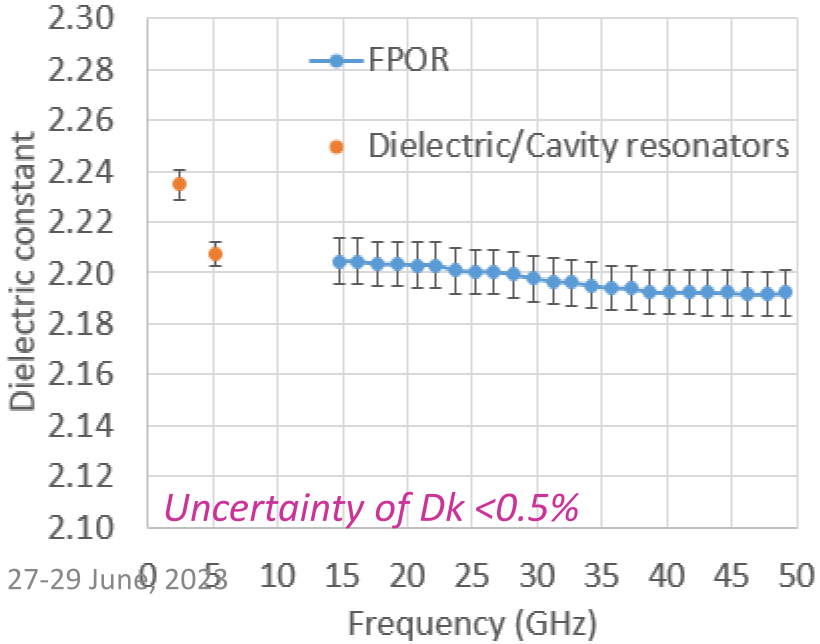
Loss tangent

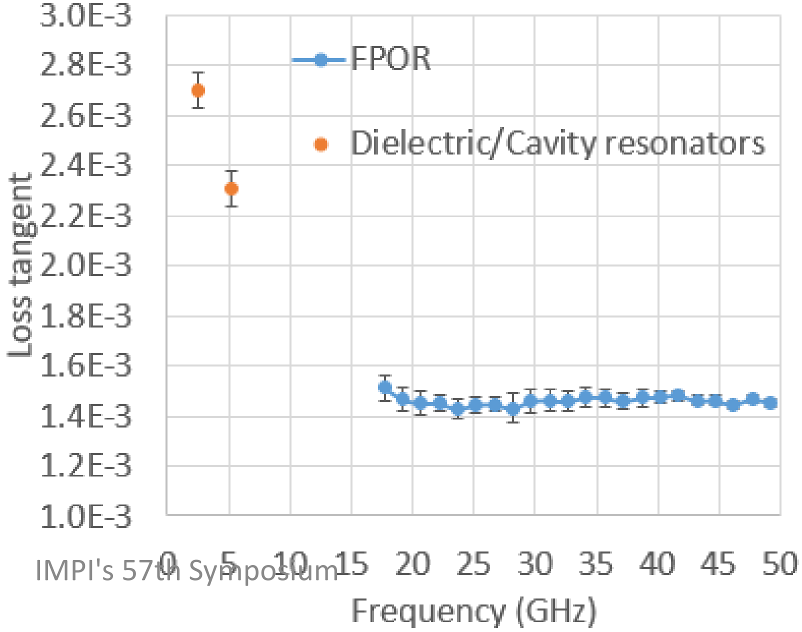
Measurements results - oils





Canola oil





Engine oil

Temperature measurements (1)

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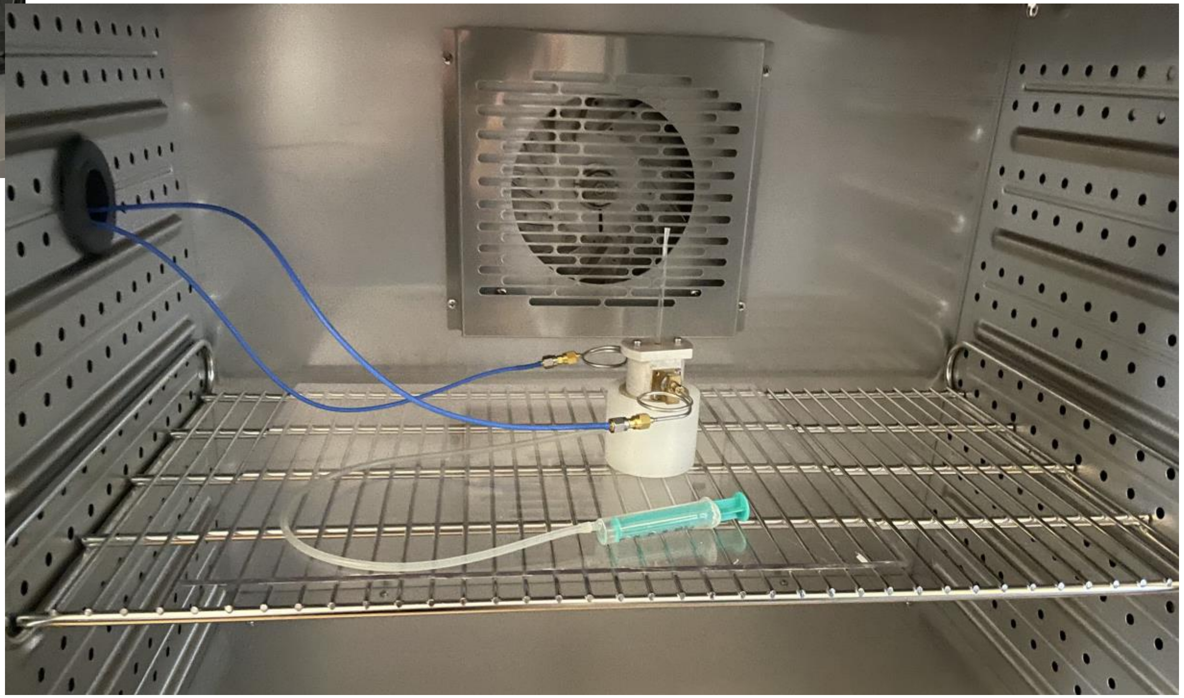
Dielectric characterization versus temperature

PC with control app

VNA

Climatic chamber with cavity resonator @24GHz

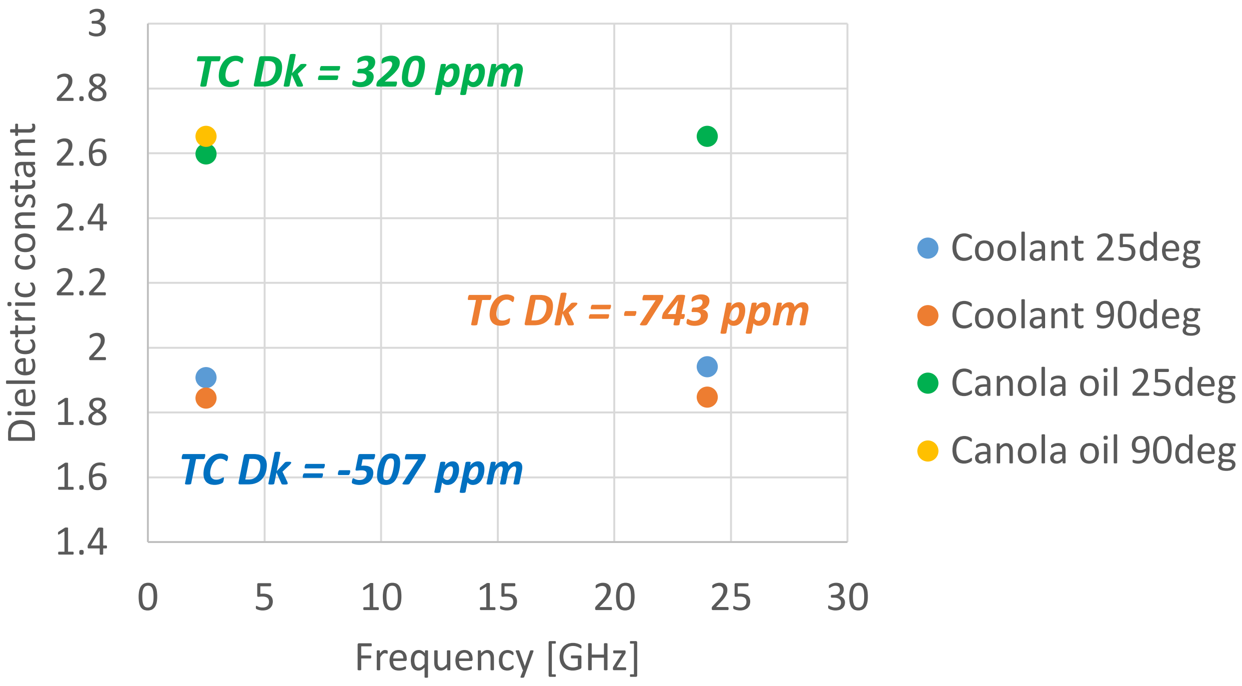


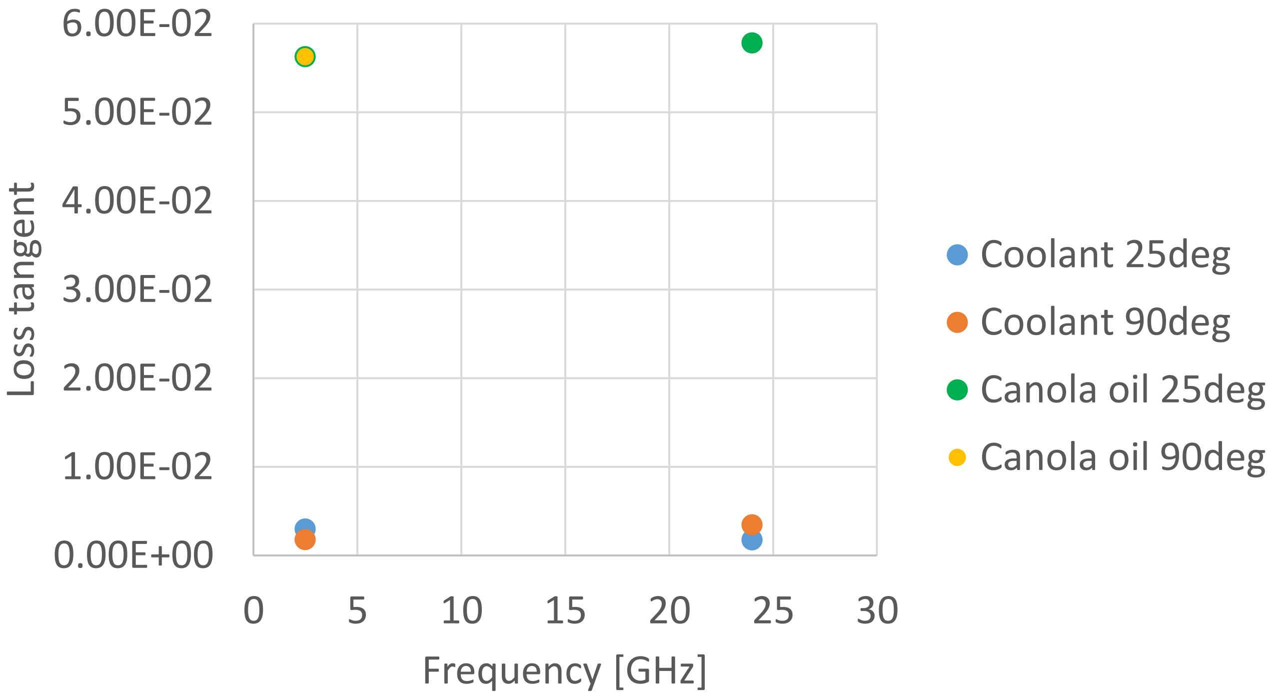
- ✓ ***Material parameters versus frequency***
- ✓ ***TC of dielectric constant of liquid***

Temperature measurements (2)

Dielectric characterization versus temperature

coolant liquid and canola oil





Uncertainty of Dk due to variation of diameter of quartz tube
@2.5 GHz – 0.1% *@24GHz – 0.7%*

Sand and saline water

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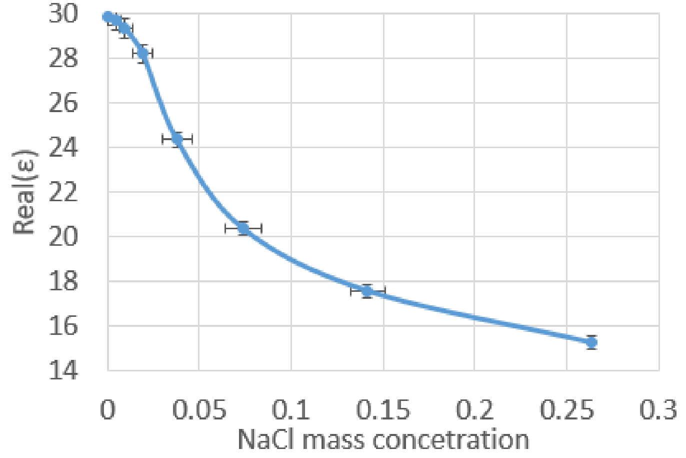
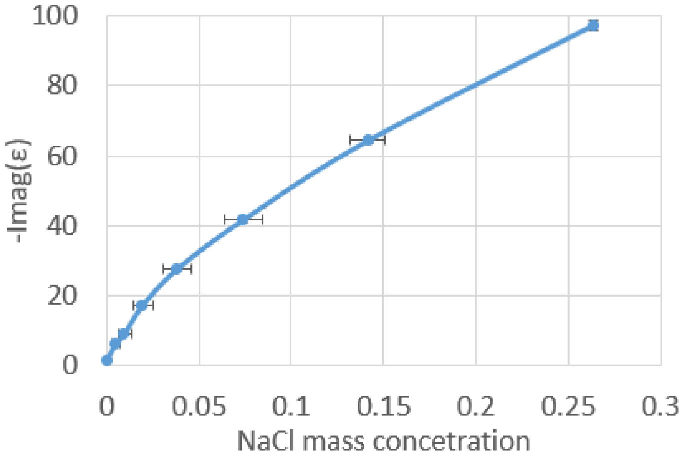
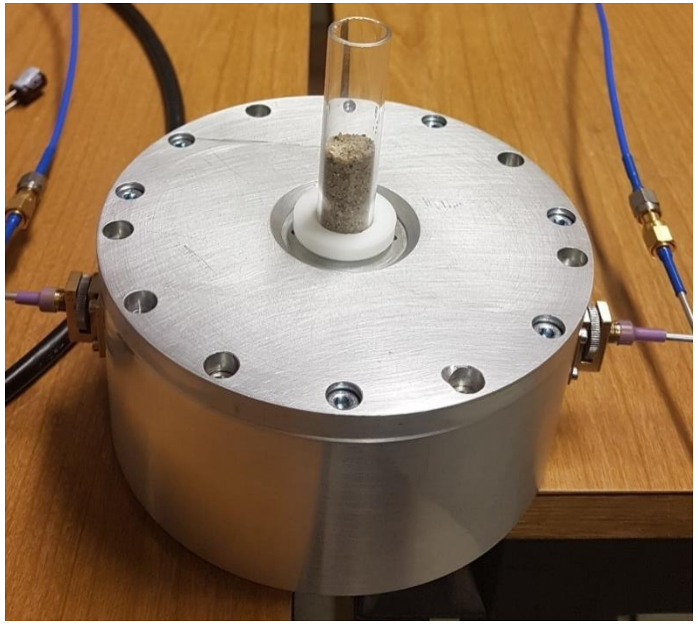
Intrinsic properties of mixture components can be evaluated (e.g. using Maxwell-Garnett model)

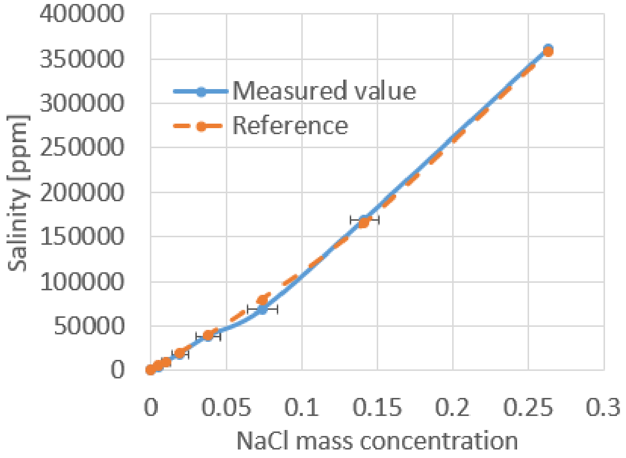


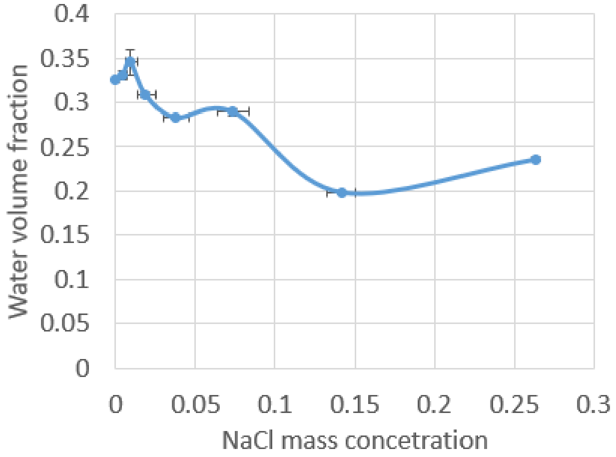


T = 22 ^{0}C



Dielectric resonator (1.04 GHz)





Summary

- Resonant cavity methods for fluids characterisation has been presented and discussed
- New Fabry-Perot open resonator has been presented and applied to liquid materials measurements
- Three liquid materials have been characterised within 1 – 50GHz frequency range
- Good agreement between the methods is observed
- Dielectric/Cavity methods are well applied for temperature measurements and TC extraction

Acknowledgement

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*under **M-ERA.NET3/2021/83/I4BAGS/2022** contract*

Ultra-Low Temperature Co-fired Ceramics for 6th Generation Electronic Packaging

Ion Implantation for Innovative Interface modifications in BAttery and Graphene-enabled Systems

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Thank you for the attention!

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