Simulation-based resonant material measurement technique for precise characterization of LTCC and ULTCC materials towards 5G applications

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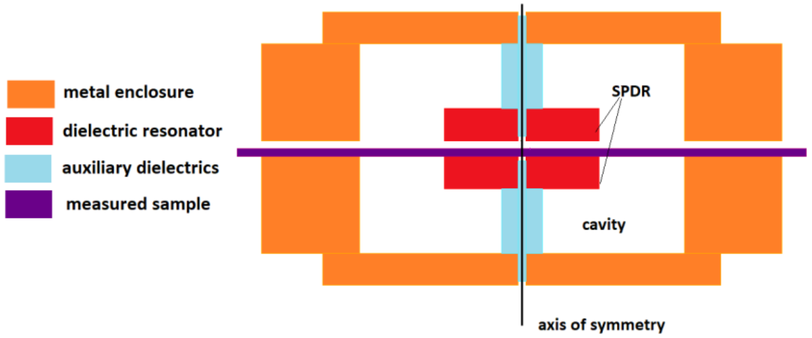
Overview

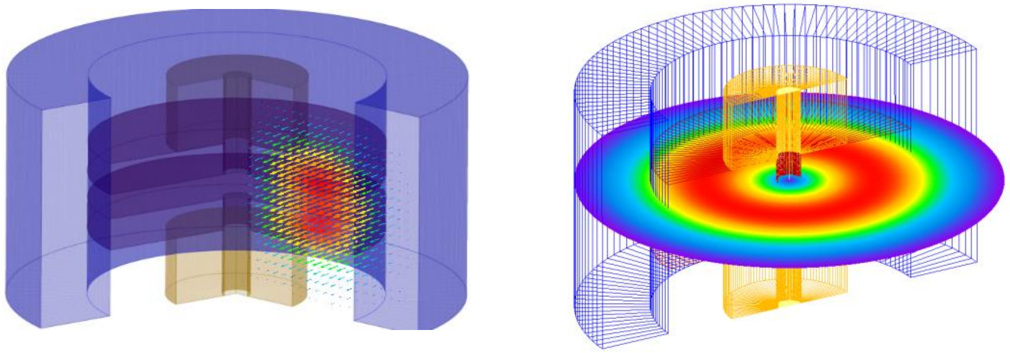
- ❑ Characterisation method - fundamentals, modelling, and measurement methodology
- ❑ LTCC and ULTCC materials
- ❑ Measurement results
- ❑ Summary

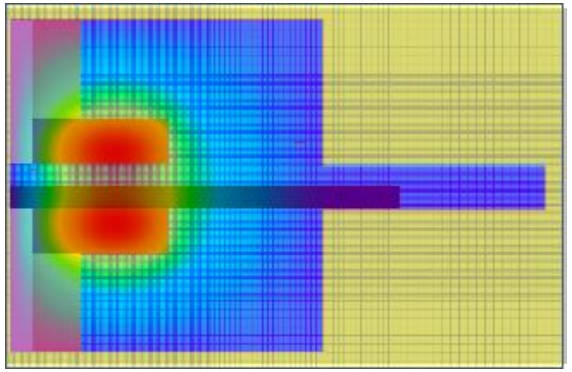
Split-Post Dielectric Resonator - basics

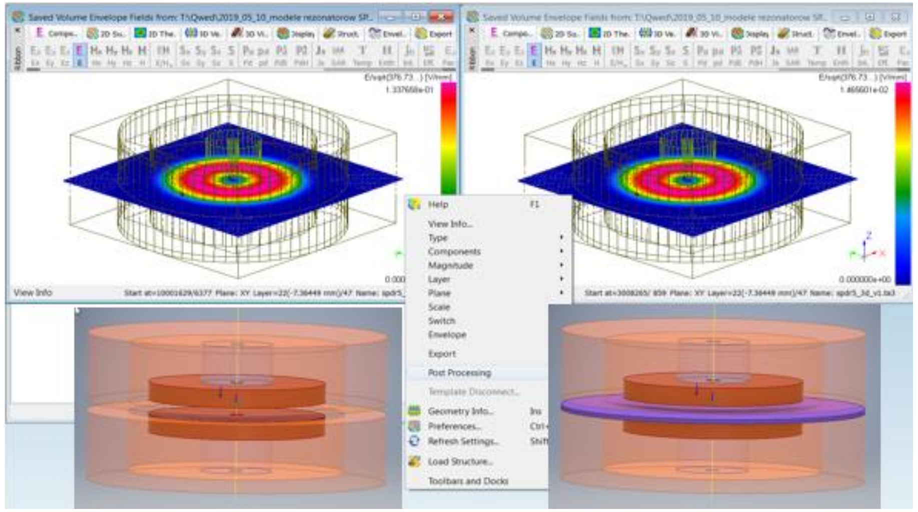


- resonant mode with EM fields mostly confined in and between those ceramic posts
  → minimial losses in metal enclosure
- E-field tangential to SUT
  → air slots between SUT and posts have negligible effect
- H-field is only vertical at the side wall of the enclosure → circumferential currents
  → no radiation through slot
  → easy SUT insertion through slot, no dismantling
- Field patterns remain practically unchanged

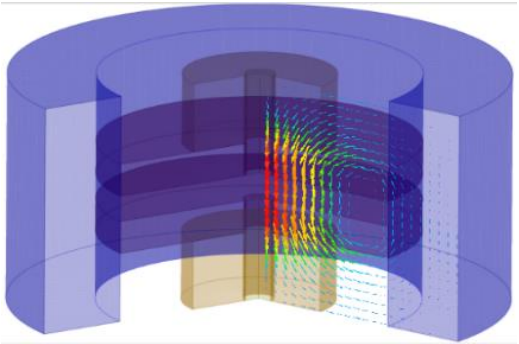
Electric field







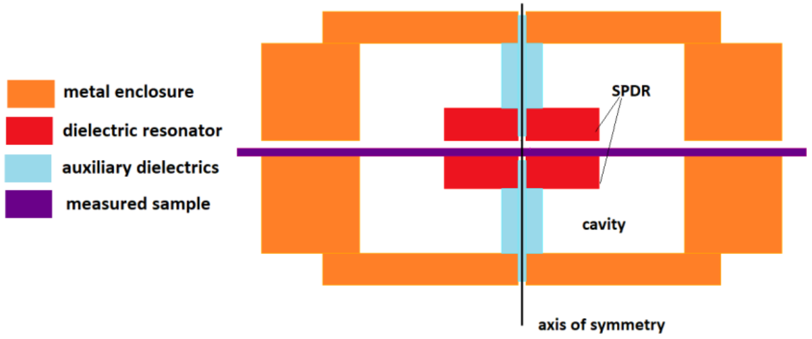
Magnetic field



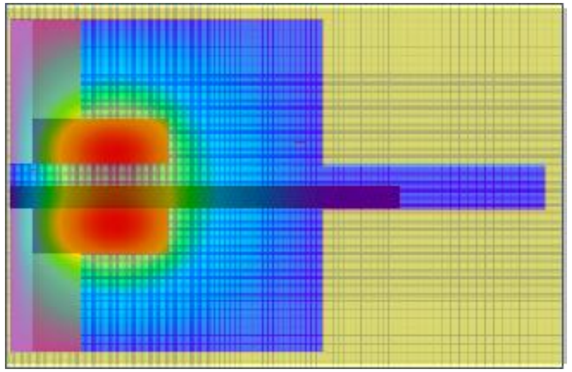
Sample in strong E-field nearly constant between the two posts

For laminar dielectrics and high-resistivity semiconductors

Split-Post Dielectric Resonator - modelling



Electric field



Field patterns remain practically unchanged but resonant frequencies and Q-factors change, providing information about SUT material parameters

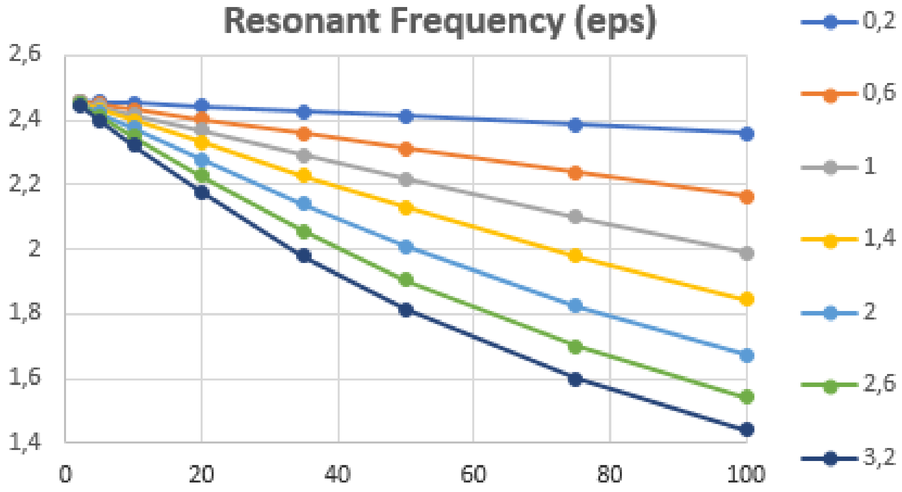
SUT of $\varepsilon_s = \varepsilon_s' - j\,\varepsilon_s''$ is inserted into DR: resonant frequency changes from f_e to f_s and Q-factor changes from Q_e to Q_s.

Non-linear functions – a need for electromagnetic modelling

$$\frac{f_e - f_s}{f_e} \approx \frac{h}{2C} \iint_S \left[\varepsilon_s'(x,y) - 1\right] \left|E(x,y)\right|^2 dS$$

$$\frac{1}{Q_s} - \frac{1}{Q_e} \approx \frac{h}{C} \iint_S \varepsilon_s''(x,y) E^2(x,y)\, dS$$

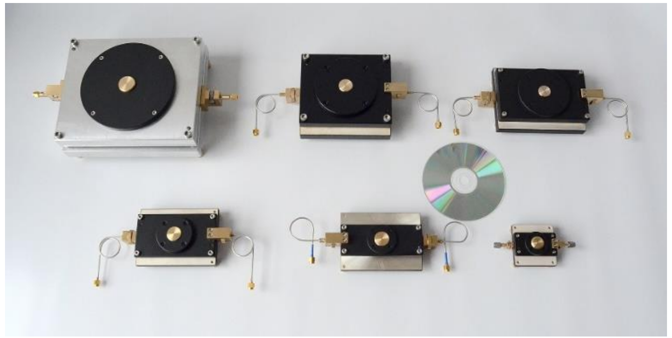
$$C = \iiint_V \left|E(x,y)\right|^2 dV$$



QuickWave BOR simulations of 2.5GHz SPDR – ***economies in computer effort by 10^3 or more compared to 3D simulations***

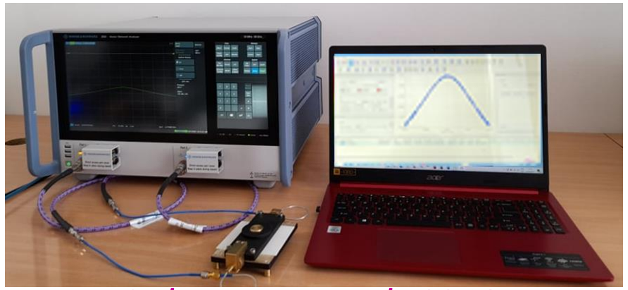
Data for dedicated software for material parameters extraction

Family of SPDR test-fixtures

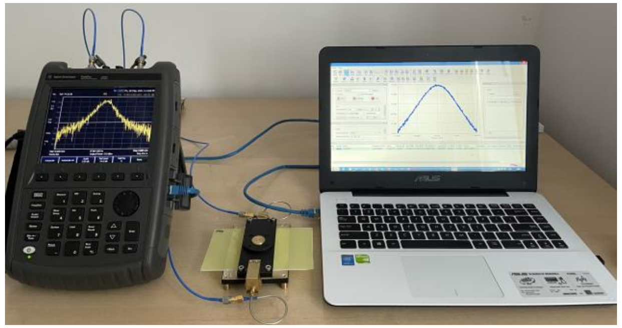


Split-Post Dielectric Resonator – measurements

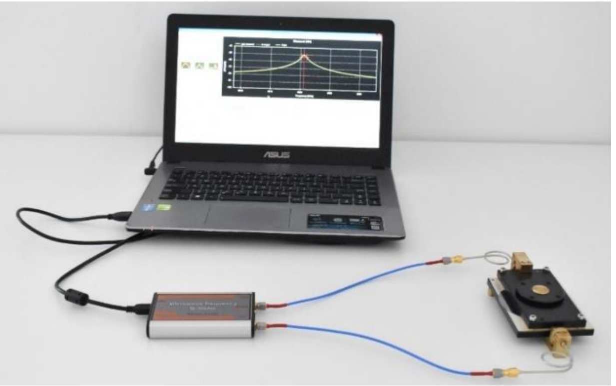
Measurement setups



Laboratory-scale VNA

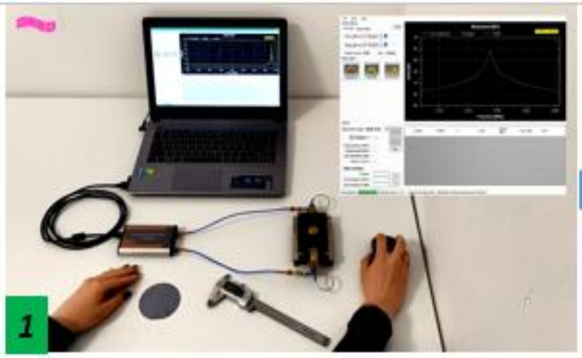


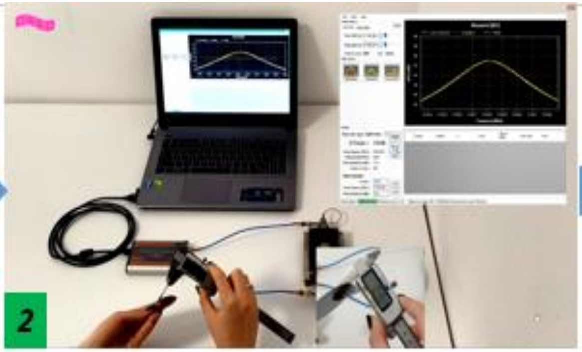
Hand-held VNA



Portable Microwave Q-Meter

Operation workflow – with the use of Q-Meter

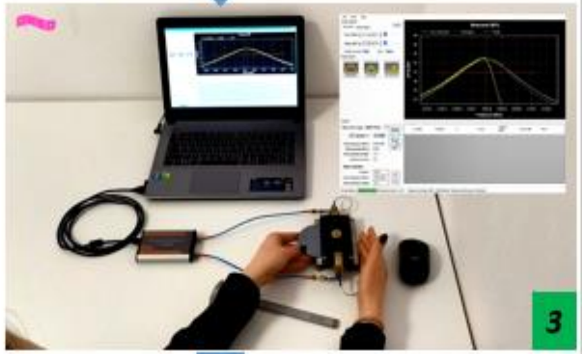




2. Measure thickness of the sample

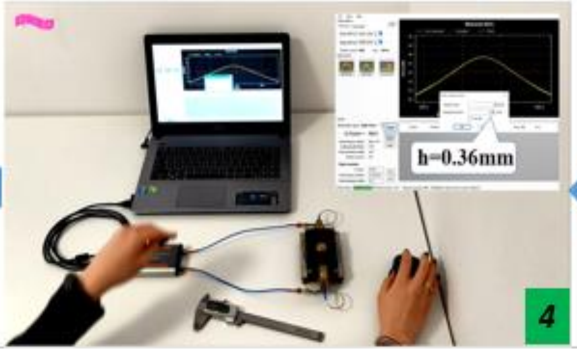
0. Connect the SPDR to Q-Meter using SMA cables.
Connect Q-Meter to PC using USB cable.

1. Measure "empty SPDR" – app invoked measurement.

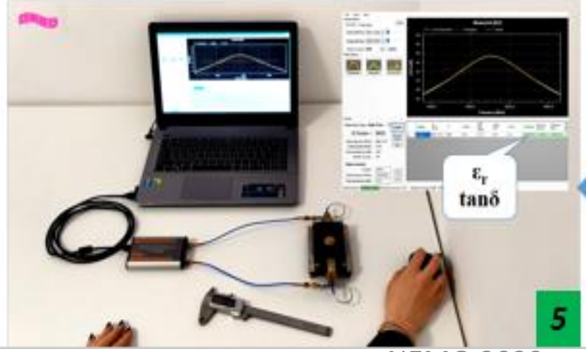


3. Insert the sample into SPDR

Total measurement time: 30sec



4. Insert the sample thickness into the PC app



5. Material parameters are extracted automatically

SPDR measurements – accuracy and uncertainty

- Rigorous EM modelling behind the SPDR software and dedicated calibration of each device unit allows achieving accuracy of:
  - ±0.15% for dielectric constant (Dk)
  - ±3% (or $2 \cdot 10^{-5}$, whichever is higher) for loss tangent (Df)

- Measurement uncertainty (resulting from uncertainty of sample thickness evaluation, resonant frequency and Q-factor extraction) needs to be evaluated as it may degrade the overall measurement error

SPDR measurements for reference materials

- SPDR validated on reference materials:
  - Sapphire
  - Fused silica
  - Glass

	Sapphire		**Fused silica**		**Glass**	
SPDR	Dk	Df	Dk	Df	Dk	Df
10GHz	9.4 ± 0.3%	0.00006 ± $2 \cdot 10^{-5}$	3.82 ± 0.5%	0.000053 ± $2 \cdot 10^{-5}$	7.12 ± 0.5%	0.0125 ± 3%
15GHz	-	-	3.81 ± 0.5%	0.000240 ± $2 \cdot 10^{-5}$	6.87 ± 2%	0.0171 ± 3%

**uncertainty for Dk is due to sample thickness variation*

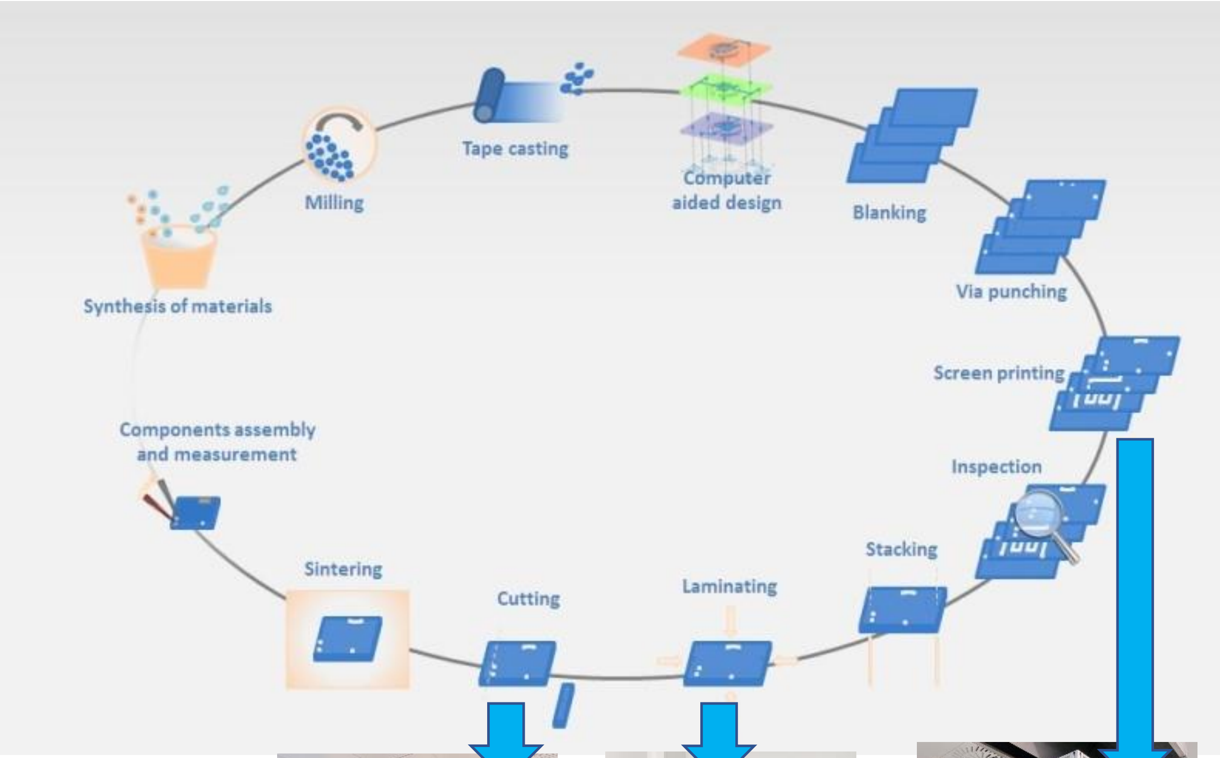
LTCC and ULTCC materials (1)

- Low temperature co-fired ceramics (LTCC) and novel ultra-low temperature co-fired ceramic (ULTCC) materials
- Application to demanding 5G and 6G systems
- Gaining continuously growing interest due to:
  - Lowered sintering temperature (compared to HTCC),
  - keeping compatibility with already existing fabrication methods.
- LTCC and ULTCC materials are foreseen to deliver enhanced
  - manufacturing flexibility,
  - miniaturization,
  - packaging degree,
  - lower production cost,
  - higher sustainability,
  - environmental friendliness.

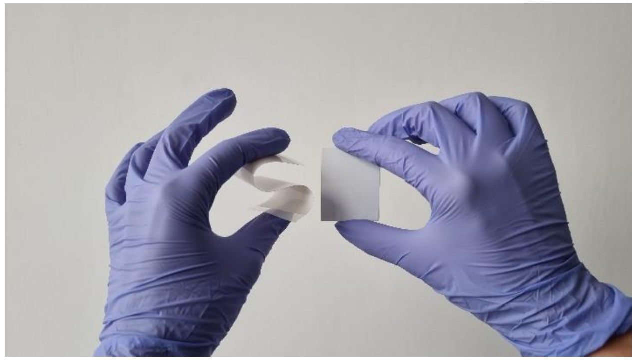
- Needed: Precise characterization with regards to complex permittivity (used in the electromagnetic design of telecommunication components).

LTCC test materials

LTCC substrate fabrication scheme



Flexible tape to substrate

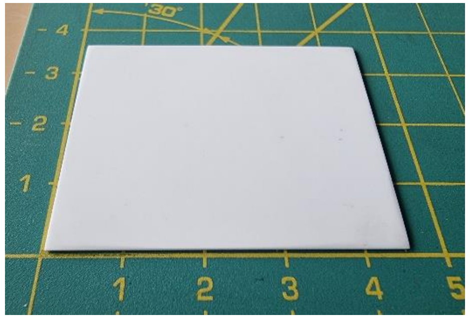


Test samples

$CuB_2O_4\_LiBO_4$

35 x 45 mm

$Zn_4B_6O_{13}\_Zn_2SiO_2$



35 x 45 mm

Expected by chemical composition: Dk= 5-6
Df= 0.0005-0.01

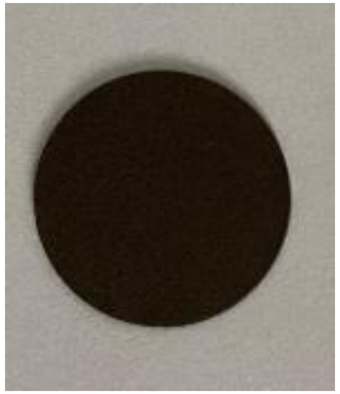
ULTCC test materials

ULTCC material fabrication scheme

- Materials have been prepared according to the conventional ceramic procedure:
  - solid state synthesis of oxide components,
  - ball milling,
  - uniaxial pressing of pellets.
- Sintering at 610-650° C for 1 - 2h.
- ULTCC samples are based on new ceramic materials with a low dielectric permittivity:
  - Li_2WO_4 with 4 wt.% $CuBi_2O_4$,
  - $LiBO_2$ with 4 wt.% AlF_3-CaB_4O_7.
- Expected to have low dielectric constant and loss tangent, making them good candidates for laminar substrates for components dedicated to 5G systems.

Test samples

Li_2WO_4+4% $CuBi_2O_4$



ϕ=20 mm

$LiBO_2$+4%$AlF_3CaB_4O_7$

ϕ=20 mm

Expected by chemical composition: Dk= 4-6.5
Df= 0.0005-0.005

Measurements results

SPDR measurements

Sample	Frequency [GHz]	Average thickness [mm]	Dielectric constant (Dk)	Loss tangent (Df)
CuB_2O_4_$LiBO_2$	10	0.715	**5.28**	**0.007434**
$Zn_4B_6O_{13}$_Zn_2SiO_2	10	0.69	**5.86**	**0.000550**
Li_2WO_4+4% $CuBi_2O_4$	15	0.485	**5.39**	**0.001592**
$LiBO_2$+4%AlF_3-CaB_4O_7	15	0.55	**4.50**	**0.003512**

Measurement uncertainty due to sample thickness variation

Sample	Minimum thickness [mm]	Dk	Df	Maximum thickness [mm]	Dk	Df	Uncertainty of Dk ± [%]
CuB_2O_4_$LiBO_2$	0.65	5.70	0.007557	0.78	4.93	0.007318	**7.94**
$Zn_4B_6O_{13}$_Zn_2SiO_2	0.65	6.16	0.000555	0.73	5.60	0.000545	**4.98**
Li_2WO_4+4% $CuBi_2O_4$	0.47	5.53	0.001600	0.5	5.26	0.001583	**2.57**
$LiBO_2$+4%AlF_3-CaB_4O_7	0.53	4.63	0.003539	0.57	4.38	0.003486	**2.93**

Summary

- ❑ Resonant-based method for complex permittivity measurement of laminar dielectrics has been discussed
- ❑ Test materials of LTCC and ULTCC have been fabricated and measured
- ❑ Materials composition have been chosen to achieve low complex permittivity, making the materials promising candidates for 5G substrates
- ❑ SPDR measurement results confirm expectations for complex permittivity
- ❑ Test samples thickness needs to be rigorously controlled to keep measurement uncertainty low

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M-ERA.NET

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Thank you for attention!

Questions?

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