Dielectric Permittivity Characterization Using Microstrip Ring Resonator

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@ Seminar Course

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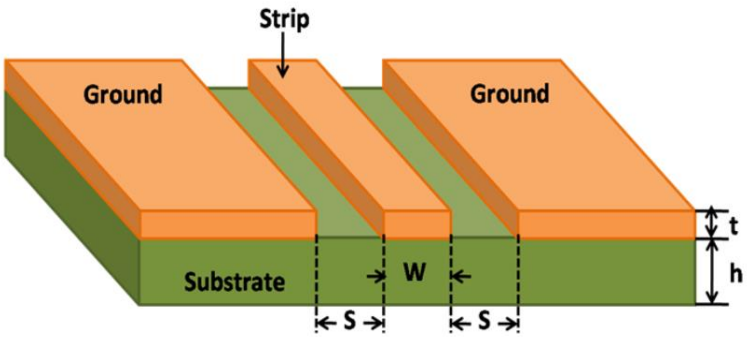
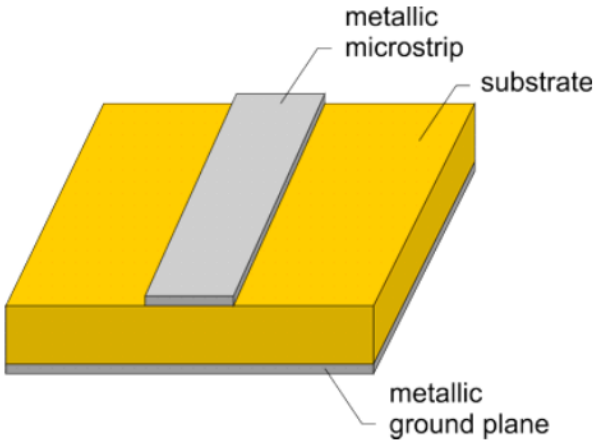
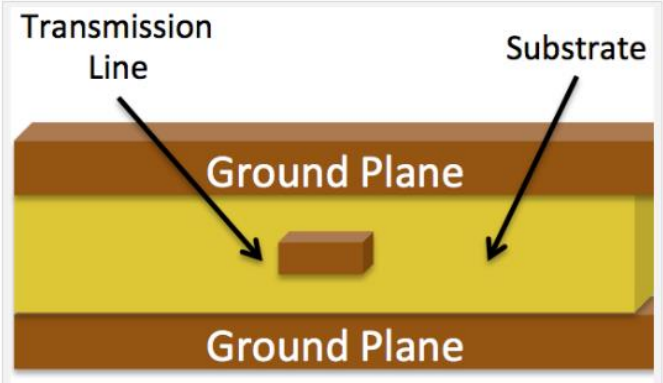
Introduction to mm-wave transmission line



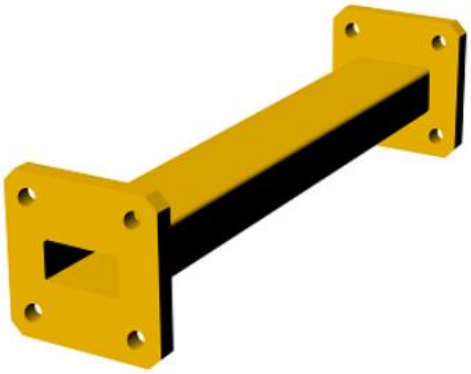
(a) Coplanar waveguide



(b) Microstrip line



(c) Stripline



(d) Rectangular waveguide

Introduction to mm-wave transmission line

<u>S Parameters:</u>

Scattering parameters can be used to define the characteristics of mm-wave transmission lines.

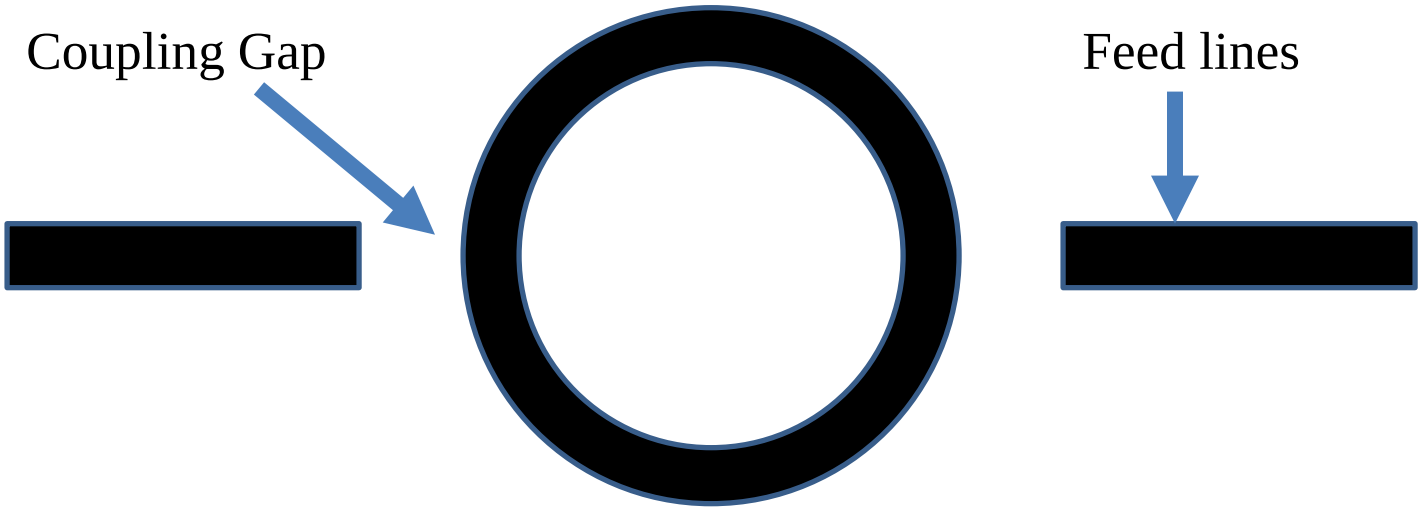
$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

S11 and S22 are Reflection Coefficients;
S12 and S21 are Transmission Coefficients.

When a_1=0: $S_{12} = \frac{b_1}{a_2} = \frac{V_1^-}{V_2^+}$ $\quad S_{22} = \frac{b_2}{a_2} = \frac{V_2^-}{V_2^+}$

When a_2=0: $S_{11} = \frac{b_1}{a_1} = \frac{V_1^-}{V_1^+}$ $\quad S_{21} = \frac{b_2}{a_1} = \frac{V_2^-}{V_1^+}$

Analysis and modeling of ring resonator



- The ring resonator is a T-line formed in a closed loop;
- The basic circuit consists of the feed lines, coupling gaps and the resonator;
- Power is coupled into and out of the resonator through feed lines and coupling gaps;
- The coupling gap should be large enough to form “weak/loose coupling”, meaning that the gap capacitance is negligibly small.

Analysis and modeling of ring resonator

1. Establish resonance:

$$2\pi r = n\lambda_g$$

- ✓ r : mean radius of the ring;
- ✓ λ_g : the guided wavelength;
- ✓ n : the mode number.

2. The n_{th} resonance occurs at:

$$f_n = \frac{nc}{2\pi r\sqrt{\varepsilon_{eff}(f)}}$$

- ✓ f_n : nth resonant frequency;
- ✓ c : light speed;
- ✓ ε_{eff} : effective dielectric constant.

3. The effective dielectric constant at the nth resonance can be given by:

$$\varepsilon_{eff} = \frac{nc^2}{2\pi r f_n}$$

Analysis and modeling of ring resonator

For the Microstrip:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[(1 + 12\frac{h}{w})^{-1/2} + 0.04(1 - \frac{w}{h})^2], \frac{w}{h} < 1$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 12\frac{h}{w})^{-1/2}, \frac{w}{h} \geq 1$$

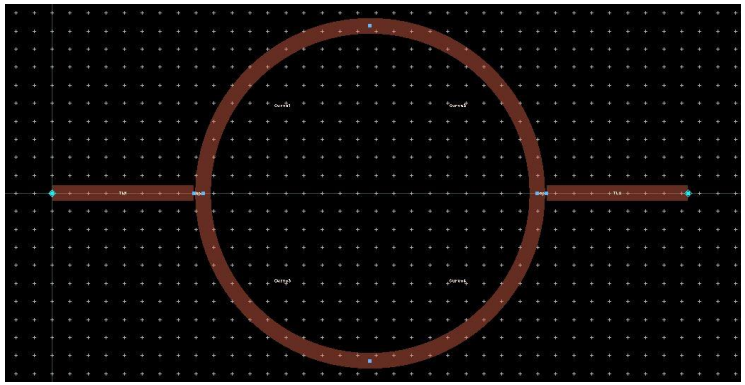
- h: thickness of the substrate;
- W: width of the MSL.

This can be used to characterize the dielectric substrate.

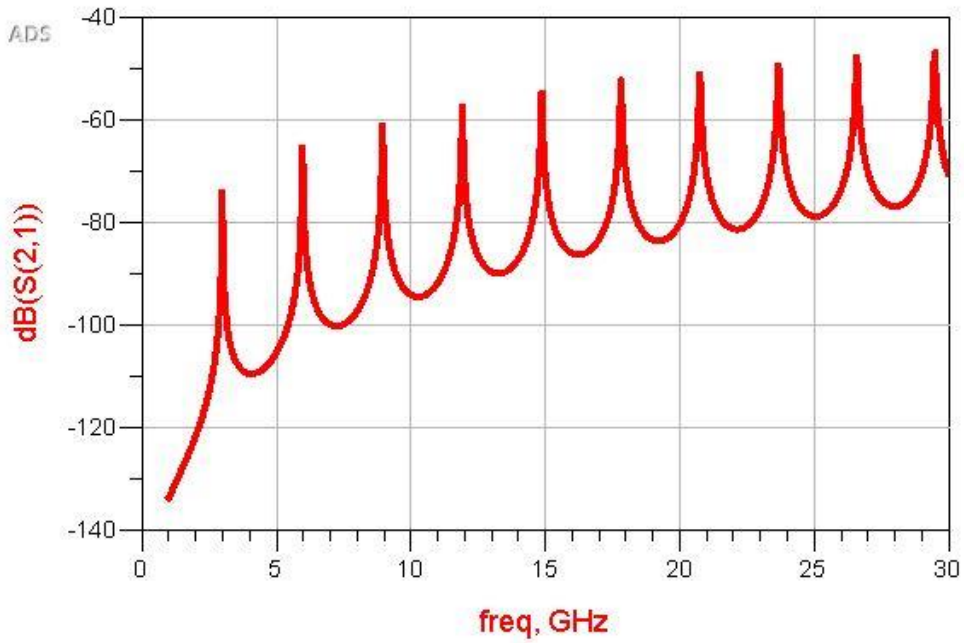
Analysis and modeling of ring resonator

- example 1 -- set up a ring resonator working at 3*n GHz resonances:

- Layout:

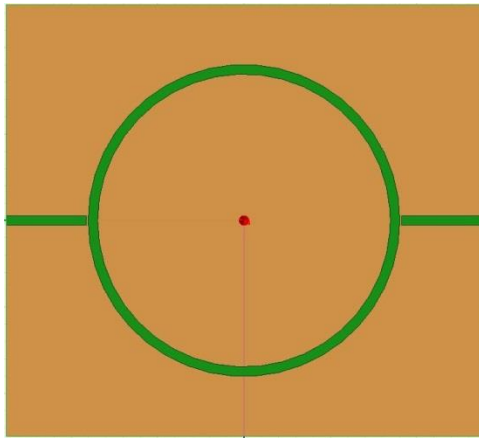


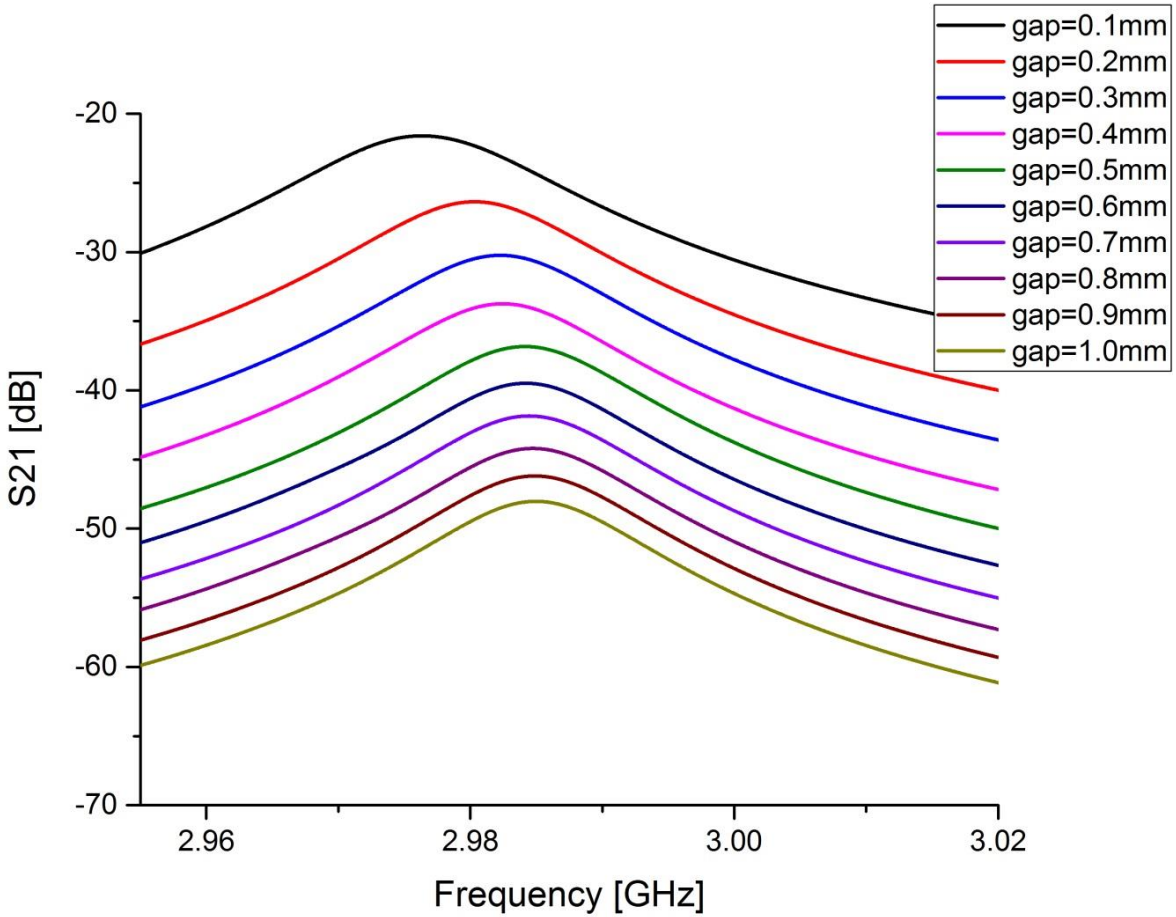
- Results:



Analysis and modeling of ring resonator

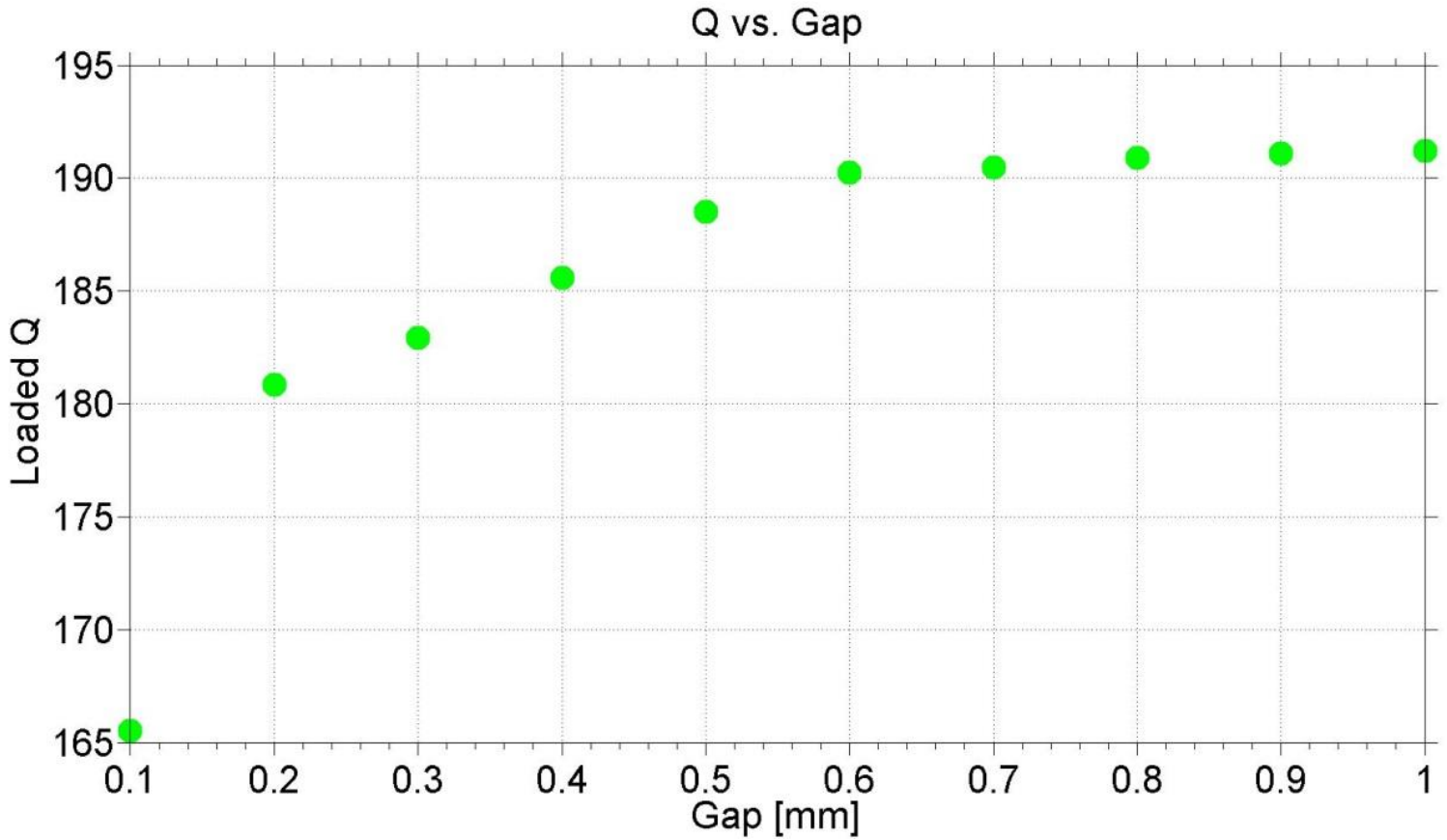
- Use HFSS for details verifications – Zoom in the fundamental resonant frequency and change the sizes of the coupling gaps.





Analysis and modeling of ring resonator

- Extract QL;
- Plot QL vs. Gap.



Dielectric permittivity characterization mechanism using resonator

- Complex permittivity:

$$\varepsilon^* = \varepsilon' + j\varepsilon''$$

Where the real component ε' is related to the stored energy within the material, and the imaginary component ε'' is related to the energy loss within the material.

$$\varepsilon' = \varepsilon_0 * \varepsilon_r$$

$$\varepsilon_0 = 8.854 \times 10^{-12}\ F/m$$

$$\varepsilon'' = \varepsilon' * \tan\delta$$

where ε_0 is the free space permittivity.

Dielectric permittivity characterization mechanism using resonator

- Q-factor:

✓ High Q means low loss;

✓ Q is often difficult to calculate precisely. Measure it directly using S-parameters;

✓ Q_u, Q_L, and Q_e:

$$\frac{1}{Q_L} = \frac{1}{Q_u} + \frac{1}{Q_e}$$

Q_L is measured by $f_n / \Delta f$ at the 3dB;

Q_u is the desired parameters;

Q_e is related to the coupling.

Dielectric permittivity characterization mechanism using resonator

- For the MSL resonator:

$$\frac{1}{Q_0} = \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_r}$$

Where:

Q_0 is the total Q-factor;

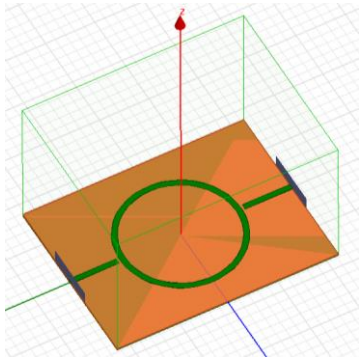
Q_c is the Q-value associated with the conductor loss;

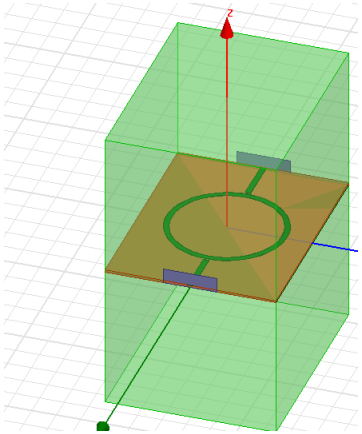
Q_d is the Q-value associated with the dielectric loss;

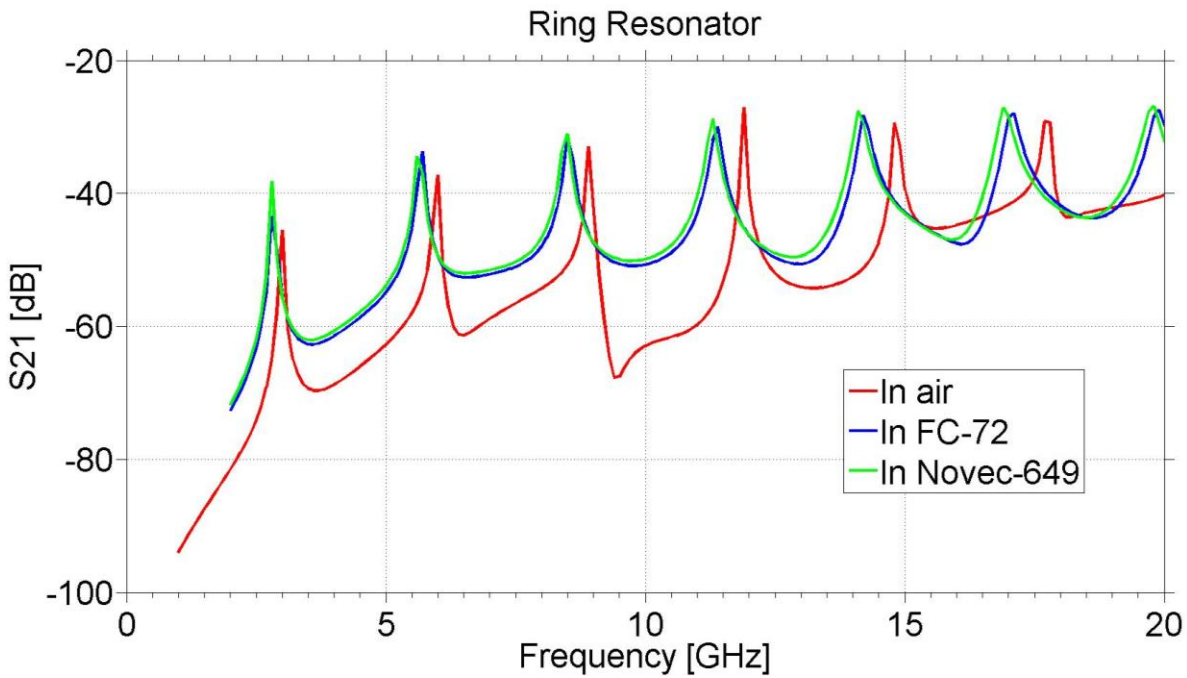
Q_r is the Q-value associated with the radiation loss.

Characterization of complex permittivity of dielectric fluids

- If the ring resonator is immerged in the dielectric fluids, what will happen?







Characterization of complex permittivity of dielectric fluids

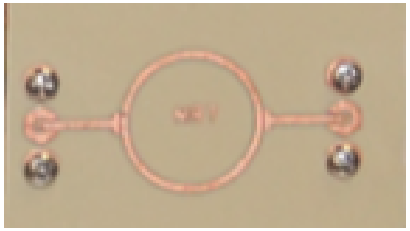
Resonator operates in dielectric fluids:

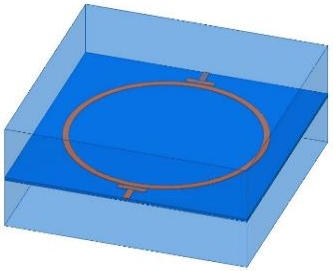
- 1. Resonant frequencies make shifts;
- 2. The insertion loss make changes.

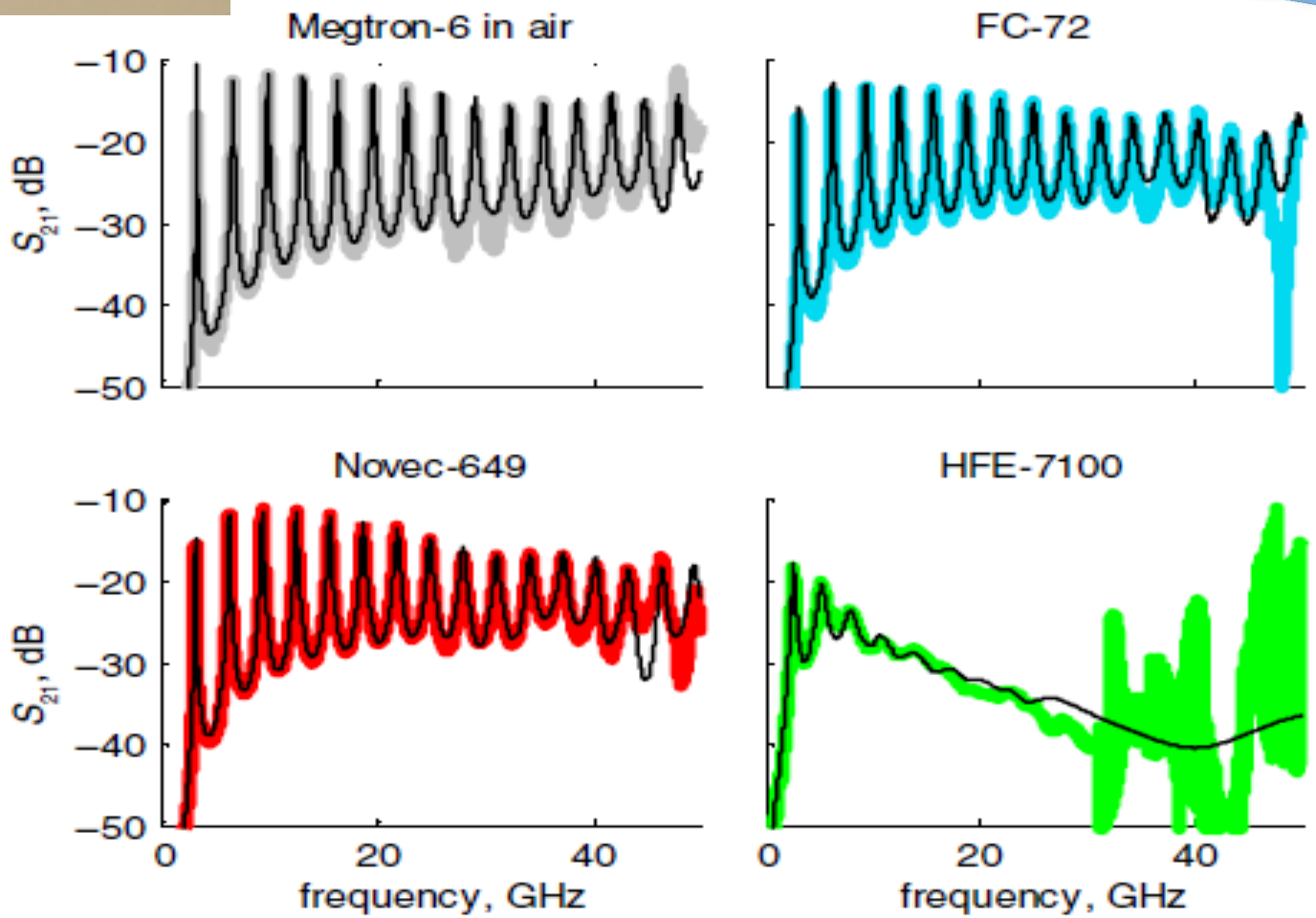
Characterize the complex permittivity of dielectric fluids:

- Measure the ring resonator in fluids;
- Use HFSS to provide simulated insertion loss to fit the measured insertion loss;
- Extract the relative permittivity and loss tangent of fluids.

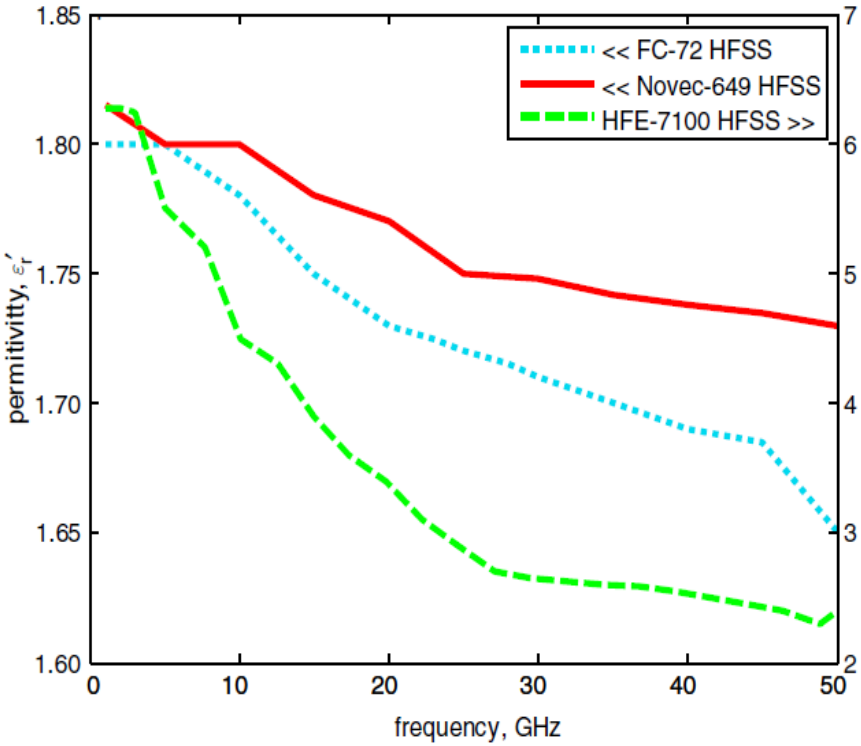
Characterization of complex permittivity of dielectric fluids

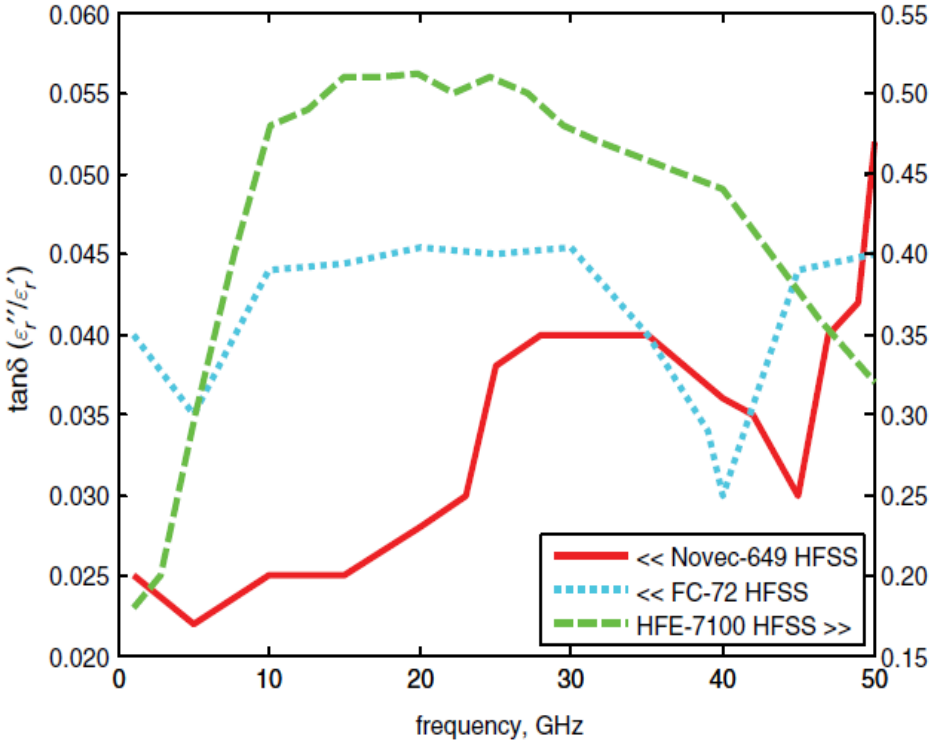






Characterization of complex permittivity of dielectric fluids





Thanks!

Any Questions?