Dielectric Permittivity Characterization Using Microstrip Ring Resonator

Ya Guo
@ Seminar Course
03/23/2016
Contents

1. Introduction to mm-wave transmission line
2. Analysis and modeling of ring resonator
3. Dielectric permittivity characterization mechanism using resonator
4. Characterization of complex permittivity of dielectric fluids
Introduction to mm-wave transmission line

(a) Coplanar waveguide

(b) Microstrip line

(c) Stripline

(d) Rectangular waveguide
Introduction to mm-wave transmission line

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

\[
\begin{bmatrix}
S_{11} & S_{12} \\
S_{21} & S_{22}
\end{bmatrix}
\begin{bmatrix}
a_1 \\
a_2
\end{bmatrix}
= 
\begin{bmatrix}
b_1 \\
b_2
\end{bmatrix}
\]

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 \( a_2 = 0 \):
\[
S_{11} = \frac{b_1}{a_1} = \frac{V_1^-}{V_1^+} \quad S_{21} = \frac{b_2}{a_1} = \frac{V_2^-}{V_1^+}
\]
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:
   ✓ \( r \) : mean radius of the ring;
   ✓ \( \lambda_g \) : the guided wavelength;
   ✓ \( n \) : the mode number.

2. The \( n \)th resonance occurs at:
   ✓ \( f_n \) : nth resonant frequency;
   ✓ \( c \) : light speed;
   ✓ \( \varepsilon_{\text{eff}} \) : effective dielectric constant.

\[
2\pi r = n\lambda_g
\]
\[
f_n = \frac{nc}{2\pi r \sqrt{\varepsilon_{\text{eff}}(f)}}
\]

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

\[
\varepsilon_{\text{eff}} = \frac{nc^2}{2\pi rf_n}
\]
Analysis and modeling of ring resonator

For the Microstrip:

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

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( 1 + 12 \frac{h}{w} \right)^{-1/2}, \frac{w}{h} \geq 1
\]

- 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 \( \varepsilon' \) is related to the stored energy within the material, and the imaginary component \( \varepsilon'' \) is related to the energy loss within the material.

\[ \varepsilon' = \varepsilon_0 \ast \varepsilon_r \]

\[ \varepsilon_0 = 8.854 \times 10^{-12} \text{ F/m} \]

\[ \varepsilon'' = \varepsilon' \ast \tan \delta \]

where \( \varepsilon_0 \) 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?