Experiment Three
Fundamentals of Electromagnetics Lab
EECE2530/1

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Abstract

The goal of this laboratory experiment was to determine the dielectric permittivity and resonance, Q, of different microstrip line resonators by measuring the transmission of the resonators. To do this, different microstrip lines were connected to the network analyzer, and the frequency and resonance index were measured, which was then used to calculate the dielectric permittivity.

KEYWORDS: Dielectric Permittivity, Resonance, Microstrip Line, Energy Loss Mechanism, Network Analyzer, Frequency, Resonance Index

1 Equipment

Available equipment included:

- Vector Network Analyzer (HP8714)
- Microwave Dielectric Circuit Boards:
  - One Microstrip Line Resonator
  - Four Microstrips Line Resonators
  - Eight Microstrips Line Resonators
- Type N to SMA connectors
- Coaxial Cables with SMA connectors
- Plexiglass Piece

2 Pre-Lab
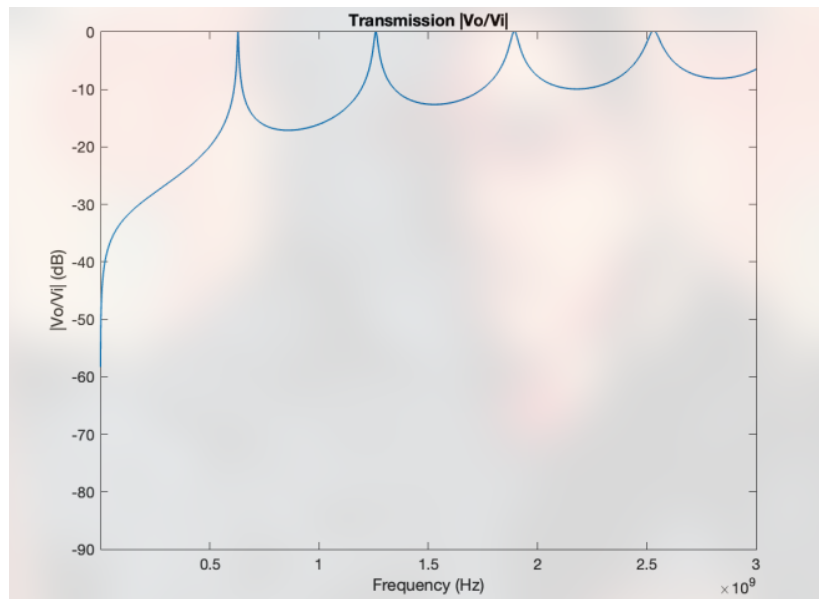
2.1 Question 1

Figure 1: The Plot from the Given Code
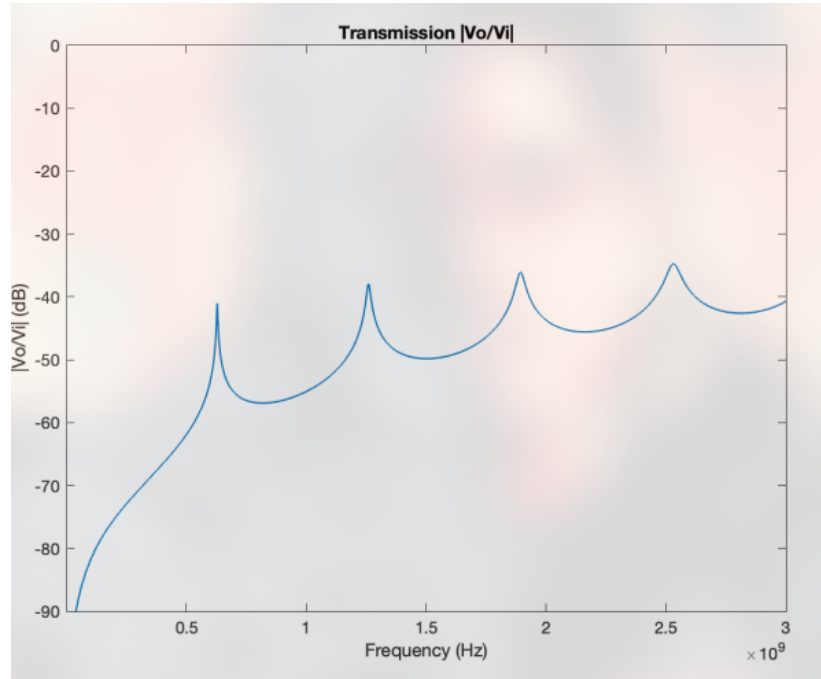
2.2 Question 2

Figure 2: Graph from Modified Equation 7

After modifying equation 7, the plot changes to the one shown below, showing that the transmission never exceeds 0[dB]. After including the reflection coefficient in the calculation, the peaks of 0 reduced to peaks of around -35 to -40 [dB]. The peaks also have varying heights and do not all peak at 0.

%Correction of Eq7 VoVi = @(x) (Eq7(x).*1).*(1+RL1(x));

2.3 Question 3

Figure 3 below shows traces for $C = 5 \cdot 10^{-13}$[F], $C = 5 \cdot 10^{-12}$[F] and $C = 10 \cdot 10^{-12}$[F]
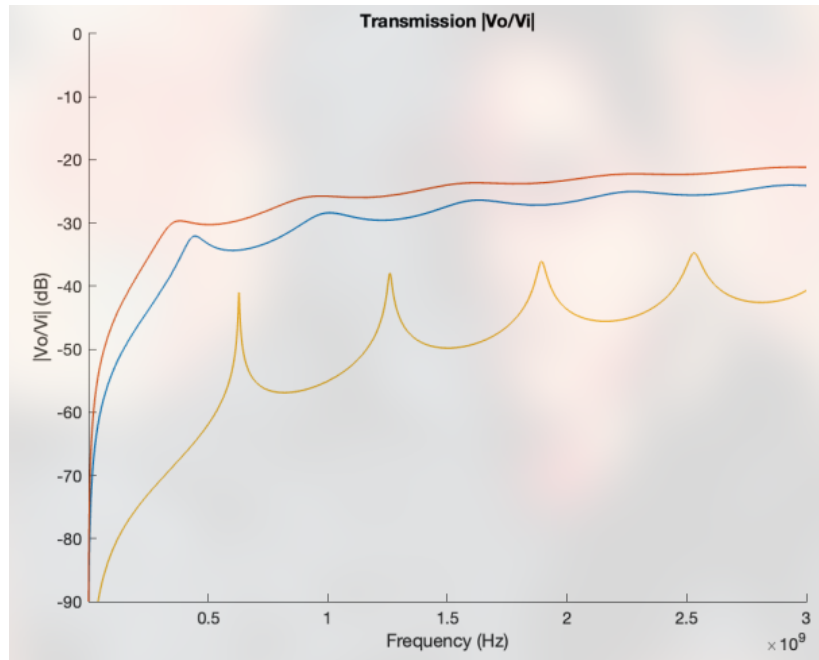
4

Figure 3: Traces for 3 C Values

For the first peaks, a higher capacitance value widens the FWHM. However, the value of the frequencies for which this zone occurs reduces in magnitude. Increasing the capacitance also increases the reflection because it creates an impedance mismatch which leads to a higher dB value on the y axis. This corresponds to a larger reflected wave. Increasing the capacitance also reduces resonances.
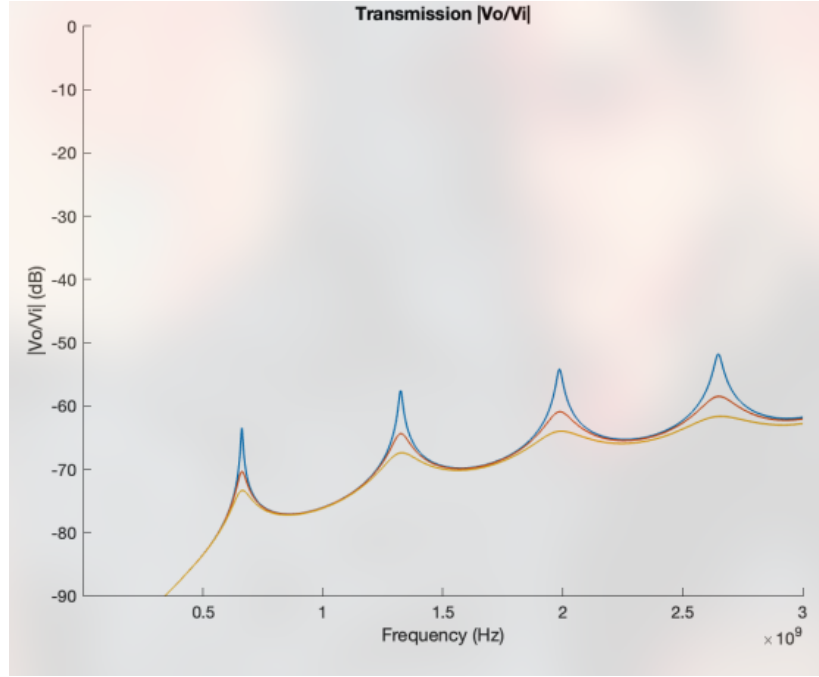
2.4 Question 4

Figure 4: Question 4 Graph

Increasing the tan delta increases the FWHM and also decreases the value of the *y*-axis, showing that there are more reflections. This is expected, as introducing a loss tangent as a material property should cause more loss, and thus more reflections.

3 Introduction & Objectives

We began this experiment by setting up the network analyzer to show the Smith Chart output of the microstrip lines for frequencies from 300[MHz] to 3[GHz]. The impedance of the microstrip lines was observed and compared to the 50[Ω] impedance of the network analyzer.

For each resonator, we measured the transmitted signal for three different resonators, taking note of the resonant frequencies, f_o , and full width at half maximum, FWHM, for the first two resonance indexes of each.

A plexiglass piece was placed on top of the 4 microstrip parallel-plate resonator, and the resonant frequency and full width at half maximum were recalculated. The transmission was compared to that of the resonator without the plexiglass on top.

The transmission of each resonator was compared to one another, and the measurements were used to calculate the dielectric permittivity, ε_{eff} , and the resonance, Q using the equations shown below. The dielectric permittivity and resonance were

calculated separately for each of the three resonators and the transmission with the plexiglass.

$$f_o = \frac{nc}{2d\sqrt{\varepsilon_{eff}}} \rightarrow \varepsilon_{eff} = \left(\frac{nc}{2df_o}\right)^2$$

$$Q = \frac{f_o}{FWHM} = \frac{f_o}{\Delta f}$$

4   Results & Analysis

The results can be tabulated in the following manner:

	Resonant Frequency 1 ($f_{o,1}$)	FWHM 1 (Δf)	Resonant Frequency 2 ($f_{o,2}$)	FWHM 2 (Δf)
1 Microstrip	544[MHz]	451-655=204[MHz]	945[MHz]	$1100 - 804 = 206$[MHz]
4 Microstrip	530[MHz]	497-553=56[MHz]	2.23[GHz]	$2.238 - 2.221 = 17$[MHz]
4 Microstrip Parallel Plate	2.067[GHz]	2.134-2.036=98[MHz]	N/A	N/A
4 Microstrip Parallel Plate with Plexiglass	2.053[GHz]	2.069-2.031=38[MHz]	N/A	N/A

We then use the above obtained values, in tandem with given values:

$$\begin{cases} c = 2.9979 \cdot 10^8 \left[\frac{m}{s}\right] \\ d = .089[m] \end{cases}$$

and the formulas from above, with n as the resonant index, to get the following values:

	$\varepsilon_{eff,1}$	$\varepsilon_{eff,2}$	Q_1	Q_2
1 Microstrip	9.535	12.639	2.628	3.193
4 Microstrip	10.045	2.23	9.464	131.176
4 Microstrip Parallel Plate	.660	—	21.092	—
4 Microstrip Parallel Plate w/Plexiglass	.669	—	54.026	—

5   Conclusion

5.1   Questions

a. Using the Smith Chart output, discuss how well-matched the microstrip lines are to the 50[Ω] impedance of the Network Analyzer.

   The microstrip lines were all well matched to the 50 ohm impedance of the network analyzer. The display showed concentric circles that slowly got smaller in radius until they terminated at the center point on the Smith chart, which indicates a scenario with matched impedance.

b. How do the resonators differ from each other? Are the peaks the same?
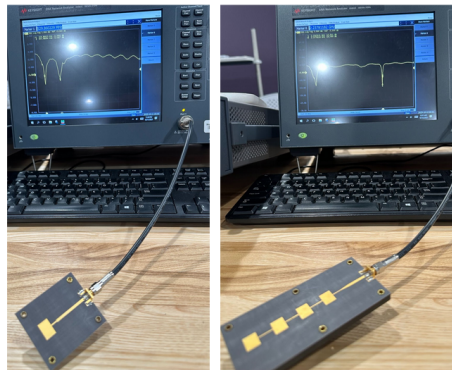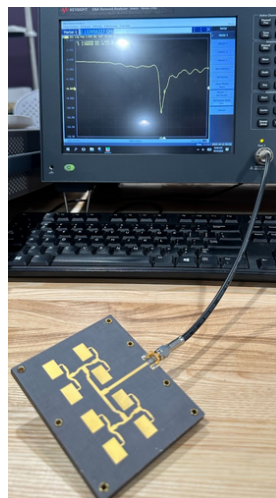

Figure 5: 1 and 4 Microstrip Lines

Figure 6: 4 Parallel Plate Microstrip Lines

As evident from figures 5 and 6, all of the resonators differ in length and shape, causing the resonant frequencies to be different. The peaks are not the same as shown in the images above. The larger resonators have a larger wavelength due to the increase in the length of the transmission line.

c. Find dielectric permittivity. Compare with the value you extrapolate from Eq. 1 [shown below], using h, w and d at page 10

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12\frac{h}{w}}}; \quad h = .00127[m], \quad w = .001168[m]$$

We can use the following table to calculate ε_r:

	$\varepsilon_{eff,1}$	$\varepsilon_{eff,2}$
1 Microstrip	9.535	12.639
4 Microstrip	10.045	2.23
4 Microstrip Parallel Plate	.660	—
4 Microstrip Parallel Plate w/Plexiglass	.669	—

From here, we get:

	$\varepsilon_{r,1}$	$\varepsilon_{r,2}$
1 Microstrip	12.131	16.174
4 Microstrip	12.796	2.6041
4 Microstrip Parallel Plate	.5566	—
4 Microstrip Parallel Plate w/Plexiglass	.5683	—

Here, we can see that, for the single microstrip and quad microstrip, the actual values are greater than the effective, while, for the parallel plate and plexiglass ones, the values are slightly smaller than the effective permittivity.

d. Place a piece of plexiglass on top of one of the microstrip line resonators. How does the transmission change? How do you explain your result?

As evident by figure 7, placing plexiglass on top of the microstrip line resonator changes the dielectric constant of the microstrip structure, causing the transmission characteristics to change. The transmission changes by resonating at a lower frequency and at a smaller half-power bandwidth. This is likely due to the added loss from adding a dielectric.

Figure 7: Plexiglass Peaks

e. The resonators have different gaps. Is there any systematic change in the Q as a function of gap size?

As the number of resonators increased, the gap size decreased. This led to a higher experimental Q value as shown in the results chart for each resonator.

f. If the resonance Q does not change much between the resonators, what would you conclude about the relative importance of the two sources of energy loss in the resonators (dielectric and ohmic)? Can you estimate what the dielectric loss tangent is, assuming that ohmic losses are small compared to the dielectric?

If the resonance Q does not change much between the resonators, we could conclude that the relative importance of dielectric and ohmic sources of energy loss in resonators is about the same in all resonators. The energy loss would be pretty consistent between the different resonators, indicating the dielectric properties of the resonators' conducting materials are similar. We estimate the dielectric loss tangent to be around 0.02.

5.2   Summary

In this lab, we learned how to find the effective permittivity using the relative permittivity and characteristics of a transmission line. Using the Vector Network Analyzer (VNA), we found the resonant frequency of each of 3 microstrip resonators. We then proceeded to find the half power bandwidth at the −3[dB] level from the peak, and used the observed values to calculate the effective permittivity of the various resonators. We also calculated the Q factor, which defines the shape of the resonance curve, for all 3 resonators and their resonant frequencies in the range of 300[MHz] to 3[GHz]. This experiment allowed us to see firsthand the effect that different shapes and layouts of microstrips can have on the effective permittivity, Q factor, and resonant frequency, as is evident from the results we found above.