HERIOT-WATT UNIVERSITY

B38EM – Introduction to Electricity and Magnetism

Laboratory 2: Microstrip Transmission Line

Lab Objectives

The main aim of this experiment is to understand the concept of a microstrip transmission line and its behaviour.

Introduction

While direct measurement of a device is the most accurate way to determine its behaviour, it is often very expensive and time-consuming. With the advancement of technology through research we now have access to powerful simulation tools that allow for computer-aided engineering (CAE). These tools allow an engineer to simulate a design with very high accuracy, so that a device can be optimised before fabrication.

This lab involves using Keysight Advanced Design System (ADS) to model a microstrip transmission line along with some lumped elements to generate S-parameters.

Background

You will model a typical microstrip transmission line as shown in Fig. 1:

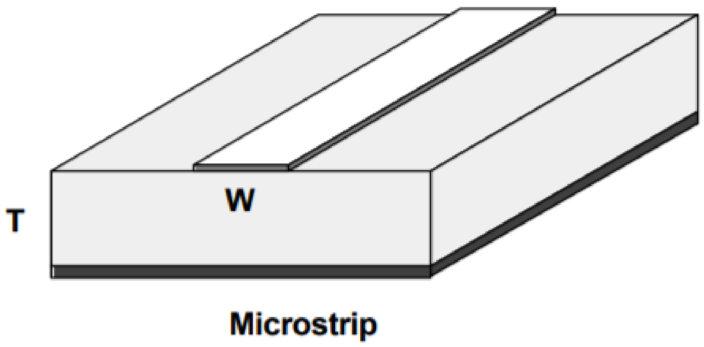

Figure 1: Microstrip Line

The transmission line is on a substrate of FR4, which due to its low cost is a very commonly used substrate. FR4 is made up of composite material composed of woven fiberglass cloth with a flame-resistant epoxy material binding the structure. A thin layer of copper foil is laminated to both sides of it. The top side is the microstrip line while the bottom side is the ground plane. This foil is either milled or etched away to form the desired microstrip pattern and then connectors are soldered on.

The connectors for this device are SMA connectors. They are coaxial RF connectors that offer excellent electrical performance of up to 17 GHz. They are usually tightened to 8lb·in with a torque wrench to ensure a good impedance match and minimise reflections.

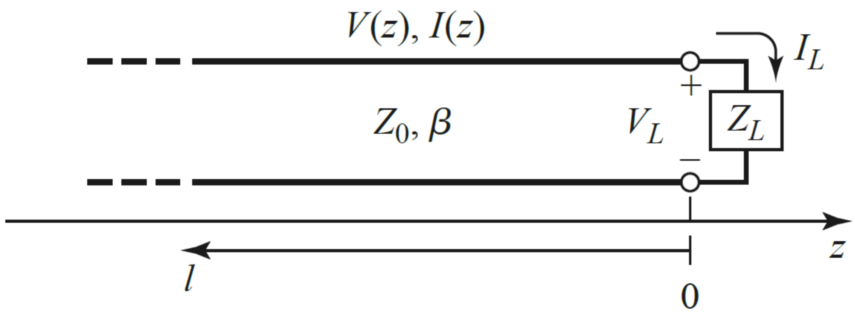

Figure 2: A transmission line terminated in a load impedance Z_L

The figure above shows an analytical model of a transmission line with a load of Z_L impedance, a voltage of V_L and Current of I_L. $V(z)$ and $I(z)$ are the total sum of Voltage and Current of the line respectively. The total voltage on the line can then be written as shown below, as a sum of incident and reflected waves.

$$V(z) = V_0^+ \mathrm{e}^{-\mathrm{i}\beta z} + V_0^- \mathrm{e}^{\mathrm{i}\beta z}$$

Where V_0^+ is the amplitude of the incident wave and V_0^- is the amplitude of the reflected wave. The amplitude of the reflected voltage wave normalised to the amplitude of the incident voltage wave is defined as the voltage reflection coefficient, Γ:

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Therefore,

$$V(z) = V_0^+ (\mathrm{e}^{-\mathrm{i}\beta z} + \Gamma \mathrm{e}^{\mathrm{i}\beta z})$$

A transmission line transfers power from a generator to a load. Maximum power is transferred for a lossless line when the load impedance is matched to the source (generator). In reality, it is close to impossible to obtain a lossless line, but we can try to be as close as possible.
When the load is mismatched, not all of the available power from the generator is delivered to the load. This “loss” is called return loss (RL), and is defined (in dB) as

$$\mathrm{RL} = S_{11} = -20 \log |\Gamma| \quad (\mathrm{dB})$$

So that a matched load ($\Gamma = 0$) has a return loss of ∞ dB (no reflected power), while a total reflection ($|\Gamma| = 1$) has a return loss of 0 dB (all incident power is reflected). Note that return loss is a nonnegative number for reflection from a passive network. If the load is matched to the line, $\Gamma = 0$ and the magnitude of the voltage on the line is $|V(z)| = |V_0^+|$, which is a constant. Such a line is sometimes said to be flat. When the load is mismatched, however, the presence of a reflected wave leads to standing waves, and the magnitude of the voltage on the line is not constant.

$$|V(z)| = |V_0^+| \left|1 + \Gamma \mathrm{e}^{2\mathrm{i}\beta z}\right| = |V_0^+| \left|1 + \Gamma \mathrm{e}^{-2\mathrm{i}\beta l}\right| = |V_0^+| \left|1 + |\Gamma| \mathrm{e}^{\mathrm{i}(\theta - 2\beta l)}\right|$$

Where $l = -z$ is the positive distance measured from the load at $z = 0$, and ϑ is the phase of the reflection coefficient ($\Gamma = |\Gamma| \mathrm{e}^{\mathrm{i}\theta}$). This shows that the voltage magnitude oscillates with position z along the line. The maximum value occurs when the phase term $\mathrm{e}^{\mathrm{i}(\theta - 2\beta l)} = 1$ and is given by,

$$V_{MAX} = |V_0^+| \, (1 + |\Gamma|)$$

The minimum value occurs when the phase term $e^{i(\theta-2\beta l)} = -1$ and is given by,

$$V_{MIN} = |V_0^+|\,(1 - |\Gamma|)$$

As $|\Gamma|$ increases, the ratio of V_{max} to V_{min} increases, so a measure of the mismatch of a line, called the voltage standing wave ratio (VSWR), can be defined as

$$\mathrm{VSWR} = \frac{V_{MAX}}{V_{MIN}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

From the equation above it is seen that VSWR is a real number such that $1 \le \mathrm{SWR} \le \infty$, where VSWR = 1 implies a matched load [1].

Lab Activity

1. **Starting ADS:** From the start menu, open ADS and create a new work space. In the new workspace create a new schematic and name it "microstrip."

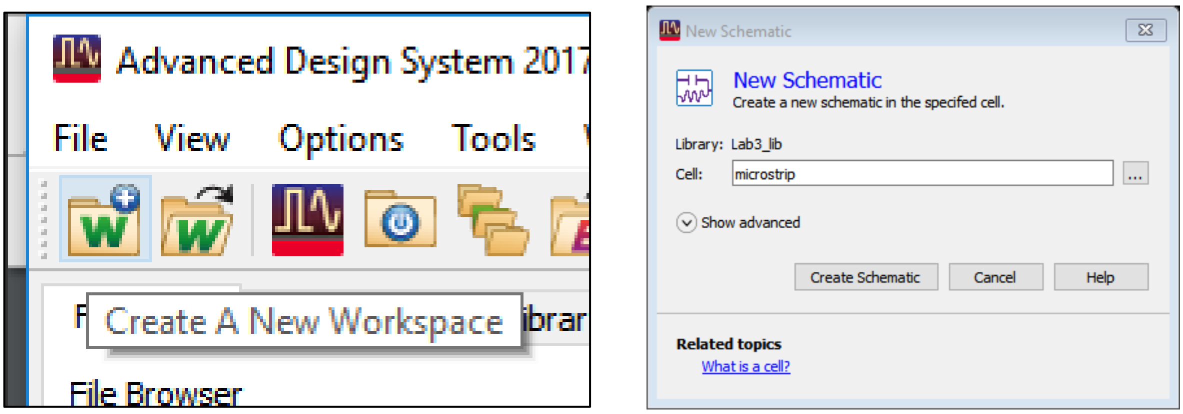

Figure 3: Workspace tool and New schematic window

2. **Defining Substrate:** To create the microstrip substrate, we must define the parameters of the substrate that the microstrip line is on, such as permittivity, loss tangent, thickness among others. It can be found in the **TLines-Microstrip** library as shown in Fig. 4. Click 'MSUB' icon, a window will pop up asking for layout resolution, choose millimetres layout. Set the following parameters:

Table 1: FR4 Substrate Parameters

Parameter	Value	Description
H	1.56 mm	Substrate thickness
Er	4.8	Relative dielectric constant
T	0.02 mm	Conductor thickness

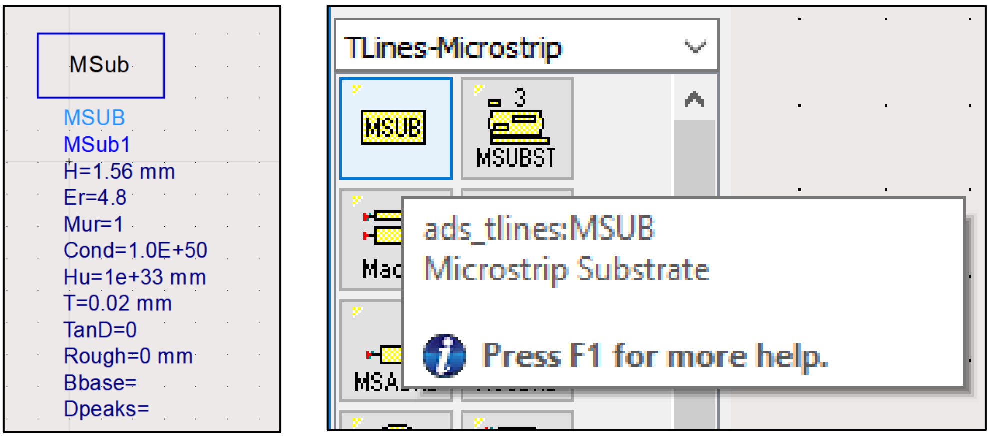

Figure 4: Substrate tool in ADS

3. **Calculate dimensions for 50 Ohm microstrip line**: Click ‘Tools -> LineCalc -> Start LineCalc’, and input substrate parameters as in Fig. 5 below,

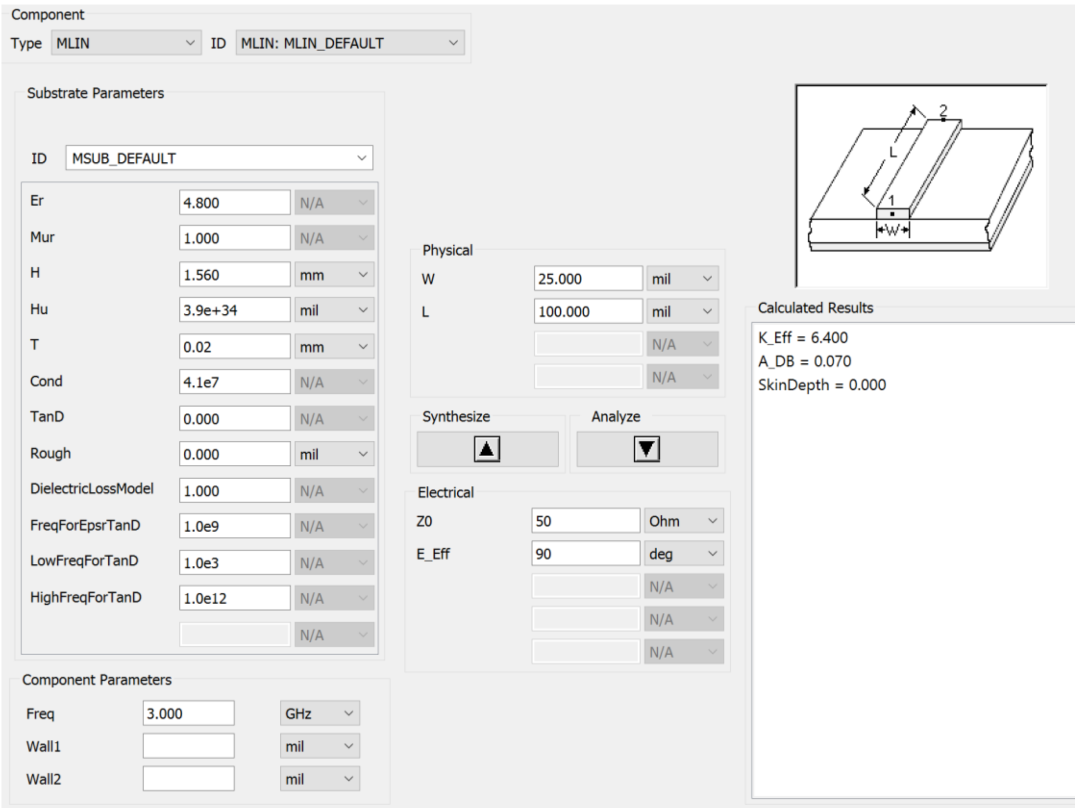

Figure 5: Calculate Microstrip Line Impedance

Change the unit to ‘mm’, and click ‘Synthesize’, you will get the width (W) of the microstrip line in ‘mm’. You will also get the length (L) of the line that corresponding to the phase delay at the selected frequency (in this case, 3 GHz).

Students should practise the above and make a screen shot of the calculated microstrip line dimension.

4. **Drawing Microstrip lines:** Place 1 microstrip line (icon 'MLIN') on the schematic and give it the same width and length as calculated in step 3.

5. **Defining ports terminals**: Switch to the **Simulation-S_Param** library and place two terminations on the schematic as shown below, and use the 'insert wire' to connect the microstrip transmission line with the two terminals. Terminations represent the measurement ports on a network analyser.

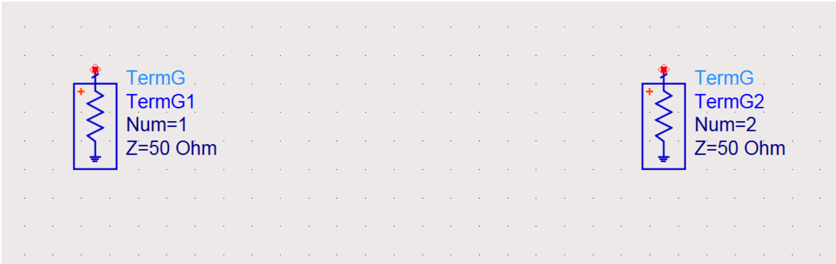

Figure 5: ADS circuit showing Termination

6. **Simulate project:** Click 'SP' to place an 'S-parameters' icon in the schematic as in Fig. 7, and double click it to set the frequency range and step for simulation. From the simulation tab click on **Simulate** or **F7** to simulate the circuit. Doing this generates the S-parameters for this circuit. **Print this schematic out and include it with your report**.

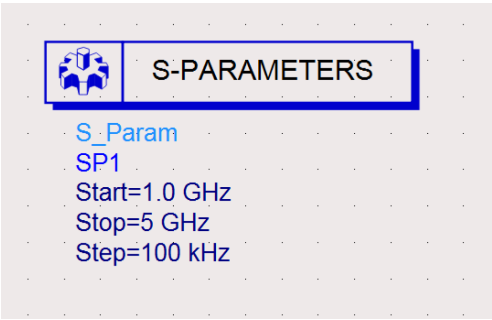

Figure 7: ADS S-parameter simulation settings

7. **Plot Results**: Use the **Rectangular Plot** tool to open a plot area and select the output S-parameters as shown below. A message will pop up asking how you want to represent data, select dB and confirm.

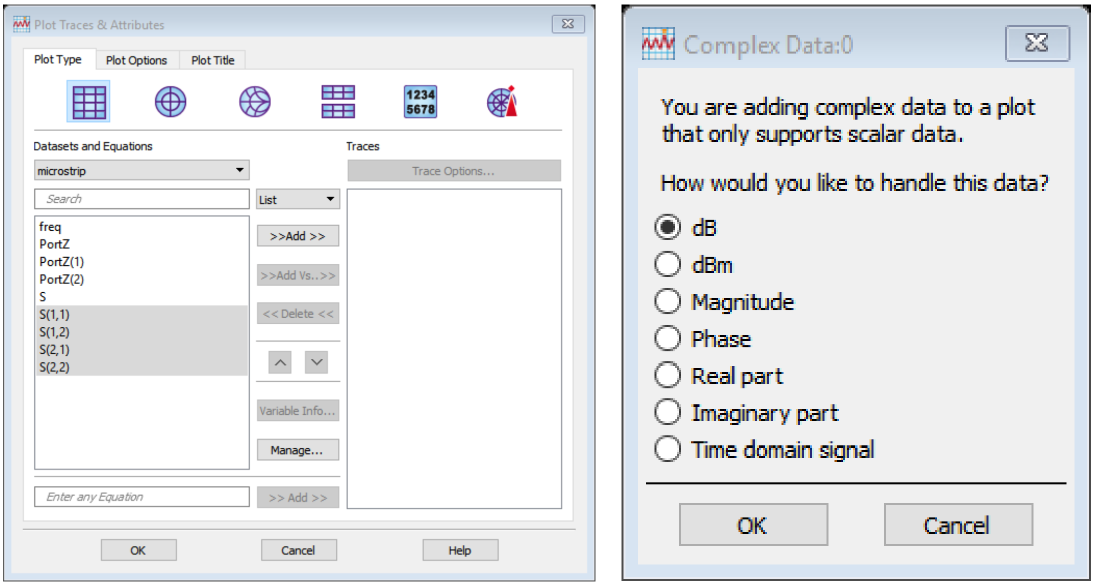

Figure 6: Selecting plot data

8. **View results:** Use the **New Line** tool under the **Marker** tab to insert a line marker at the lower point of the curve. Include the plot in the report.

9. **Change line width and redo the simulation**: Change the line width of the microstrip transmission line to '1mm', and redo the simulation. Screenshot the s-parameters in the report, and put a 'line mark' at 3 GHz.

Exercises

1. From the results obtained in Step 8, over which frequency range is our model accurate? Why do you think this is true?
2. What might account for the differences between simulation and measurement results?
3. From the results obtained in Step 9, calculate the Voltage Standing Wave Ratio of the microstrip line at 3 GHz.

Lab Report:

The report should be typed and not more than 5 pages including figures (this excludes, an appendix, cover page, etc.). Please note that screen shots from the ADS simulator are encouraged in your report. The report should not re-state the goals and the procedures as contained within this document. All your observations must be clearly indicated, along with comparisons to theoretical values. Comparisons should also be thoroughly discussed where needed. Your conclusion should be a general assessment of the verification of the theory and should indicate what you have learned while completing the laboratory activity. Sparsely commented reports will be sparsely rewarded.

Marking Scheme:

Lab Activity:

1.	Screen record of an ADS schematic, and 50 Ohm line calculation	**(2 marks)**
2.	Graph results of each parameter S11, S22, S12, S21 for Step 8	**(2 marks)**
3.	Graph results of each parameter S11, S22, S12, S21 for Step 9	**(2 marks)**
4.	**Exercise 1**	**(3 marks)**
5.	**Exercise 2**	**(2 marks)**
6.	**Exercise 3**	**(4 marks)**

Overall Lab Report Mark: **(10 marks)**

Criteria:

- General organisation
- Overall readability/understanding of the reported information
- Overall quality

Total Marks: 25

References

[1] POZAR, D. M. (1997). Microwave engineering. New York, Wiley.