

## High-Frequency Circuits

### Lab Experiment 1: Fundamental Transmission Line Theory and S-Parameters

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#### Objectives

The objectives of this lab experiment are:

- to design microstrip lines with specific characteristic impedances using first-order approximations
- to model a microstrip line as an ideal lossless transmission line
- to compare the performance of a realistic microstrip line versus its corresponding ideal transmission line model
- to design a quarter-wave transformer implemented in microstrip technology
- to get familiar with the main characteristics of the high-frequency circuit simulator Keysight ADS
- to observe in Keysight ADS the transmission and reflection performance of a 50-Ω to a 100-Ω microstrip transition
- to observe the effects and limitations of quarter-wave impedance transformers in microstrip technology using Keysight ADS

#### Components and Instrumentation

A numerical software tool: Matlab, Octave, Scilab, or something similar. The high-frequency circuit simulator Keysight ADS.

#### Theoretical Procedure

Consider a conventional microstrip line whose physical structure is shown in Fig. 1. The width of the microstrip line is  $W$ , the length is  $L$  and its metal thickness is  $t$ . The microstrip line is on a dielectric substrate with a relative permittivity  $\epsilon_r$ . The substrate height is  $H$ . Below the substrate there is a metallic ground plane whose thickness is also  $t$ . Above the microstrip structure there is free-space (or air).

If losses and metal thickness are neglected, the characteristic impedance  $Z_0$  of this microstrip line can be estimated using the following formulas [1]:

$$\text{if } \frac{W}{H} \leq 1, \quad Z_0 = \frac{60}{\sqrt{\epsilon_e}} \ln \left( \frac{8H}{W} + \frac{W}{4H} \right) \quad \Omega$$
$$\text{if } \frac{W}{H} > 1, \quad Z_0 = \frac{120\pi}{\sqrt{\epsilon_e}} \frac{1}{\left( \frac{W}{H} \right) + 1.393 + 0.667 \ln \left( \frac{W}{H} + 1.444 \right)} \quad \Omega$$

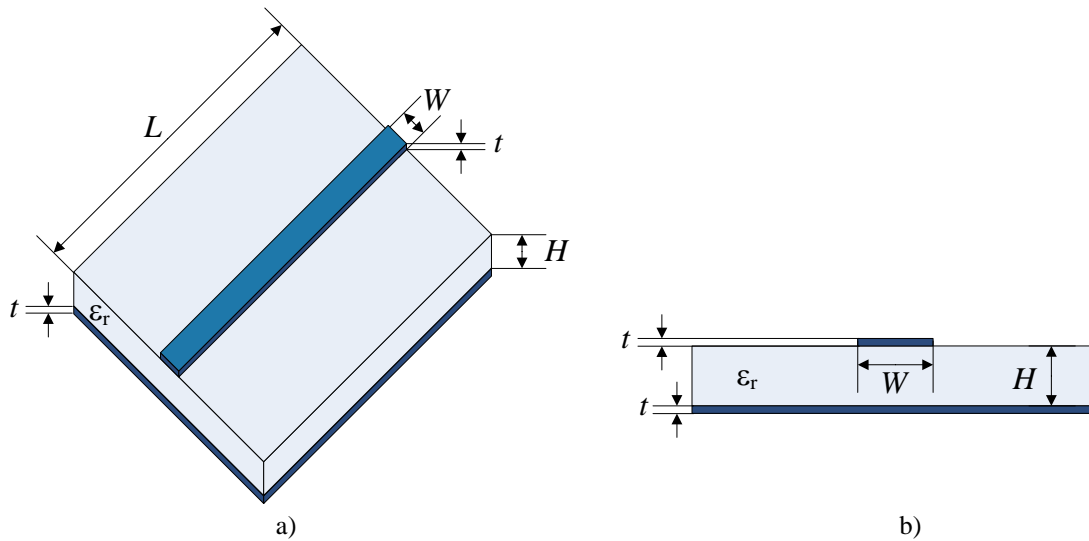


Fig. 1 Physical structure of a microstrip line: a) top view, b) cross-sectional view.

where  $\epsilon_e$  is the effective relative permittivity given by

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2\sqrt{1 + (10H/W)}}$$

The propagation velocity  $v_p$  or wave speed is calculated using

$$v_p = \frac{c}{\sqrt{\epsilon_e}}$$

where  $c$  is the speed of light in free-space.

- Neglecting losses and metal thickness, and assuming that  $\epsilon_r = 3.9$  and  $H = 60$  mil<sup>(1)</sup>, find the width  $W_1$  to achieve a 50- $\Omega$  microstrip line ( $Z_0 = 50 \Omega$ ).
- Neglecting losses and metal thickness, and assuming again that  $\epsilon_r = 3.9$  and  $H = 60$  mil, find the width  $W_2$  to achieve a 100- $\Omega$  microstrip line ( $Z_0 = 100 \Omega$ ).
- Finally, design a quarter-wave transformer to achieve a perfect match at 3 GHz between a 50- $\Omega$  transmission line and a load resistor of 100- $\Omega$ . Using the same substrate (same values for  $H$  and  $\epsilon_r$ ) calculate the corresponding width and length ( $W_T$  and  $L_T$ ) that implement in microstrip technology the quarter-wave impedance transformer.

<sup>(1)</sup> 1 mil =  $10^{-3}$  inches. This unit is commonly used in the design of printed circuit boards (PCBs), as well as in microstrip RF circuits.

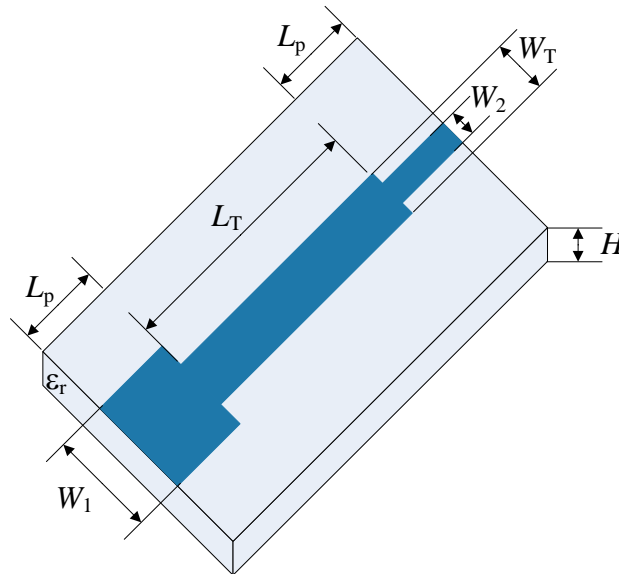


Fig. 2 Quarter-wave impedance transformer matching two microstrip lines of widths  $W_1$  and  $W_2$ .

### Simulation Procedure

Using the high-frequency circuit simulator Keysight ADS, now you will implement and simulate the components you designed in the theoretical procedure. For the ideal lossless transmission line, use ADS' component TLINP (2-Terminal Physical Transmission Line). For the microstrip line, use ADS' component MLIN (Microstrip Line).

- Implement in ADS an ideal lossless 50- $\Omega$  transmission line. Define the input and output ports with reference impedances of 50  $\Omega$ . Assuming that this line has a length of 1,500 mil, plot the corresponding S-parameters of the line ( $|S_{11}|$  and  $|S_{21}|$  in dB, from 10 MHz to 10 GHz in linear scale).
- Implement in ADS the 50- $\Omega$  lossless microstrip line you designed in step a) of the theoretical procedure. Make sure you are using the correct microstrip substrate in ADS (MSUB). Define the input and output ports with reference impedances of 50  $\Omega$ . Assuming that this line has a length of 1,500 mil, plot the corresponding S-parameters of the line ( $|S_{11}|$  and  $|S_{21}|$  in dB, from 10 MHz to 10 GHz in linear scale). Compare these plots with those obtained in the previous step.
- Implement in ADS the 100- $\Omega$  lossless microstrip line you designed in step b) of the theoretical procedure. Make sure you are using the correct microstrip substrate in ADS. Define the input and output ports with reference impedances of 100  $\Omega$ . Assuming that this line has a length of 1,500 mil, plot the corresponding S-parameters of the line ( $|S_{11}|$  and  $|S_{21}|$  in dB, from 10 MHz to 10 GHz in linear scale).
- Implement in ADS the microstripline that corresponds to the quarter-wave transformer you designed in step c) of the theoretical procedure. Make sure you are using the correct microstrip substrate in ADS. Define the input and output ports with reference impedances of 50  $\Omega$  and 100  $\Omega$ , respectively. Plot the corresponding S-parameters of this microstrip line ( $|S_{11}|$  and  $|S_{21}|$  in dB, from 10 MHz to 10 GHz in linear scale). Verify that a good matching is achieved at 3 GHz (make



- a zoom on the plots of  $|S_{11}|$  and  $|S_{21}|$  in dB around 3 GHz).
- e. Implement in ADS the circuit illustrated in Fig. 2, using the dimensions you found in the steps a), b) and c) of the theoretical procedure and taking  $L_p = 900$  mil. Define the input and output ports with references impedances of  $50\ \Omega$  and  $100\ \Omega$ , respectively. Plot the corresponding S-parameters of the line ( $|S_{11}|$  and  $|S_{21}|$  in dB, from 10 MHz to 10 GHz in linear scale). Verify that a good matching is achieved at 3 GHz (make a zoom on the plots of  $|S_{11}|$  and  $|S_{21}|$  in dB around 3 GHz). What happens if you vary the length of the input/output lines,  $L_p$ ?
  - f. Finally, simulate the same circuit of the previous step but now incorporating losses and the two step transitions. For the dielectric losses, use a loss tangent  $\tan(\delta) = 0.01$ . For the metallic losses, assume that all metal traces (including the ground plane) are made of copper with conductivity  $\sigma = 5.8 \times 10^7$  S/m and thickness  $t = 0.6$  mil =  $15.24\ \mu\text{m}$  (half-ounce copper). For the two step transitions in Fig. 2, insert a couple of ADS components MSTEP (Microstrip Step in Width). Plot the corresponding S-parameters ( $|S_{11}|$  and  $|S_{21}|$  in dB, from 10 MHz to 10 GHz in linear scale; make a zoom on the plots of  $|S_{11}|$  and  $|S_{21}|$  in dB around 3 GHz). Compare these plots against those obtained in the previous step.

## Report

Write a report including all the theoretical calculations, simulation procedures, the required plots you obtained, as well as your comments related to the results you obtained, your general conclusions and references. Include in your report the corresponding ADS schematics for each circuit you implemented.

## Deadline and Assessment

The deadline for submitting the report via email ([erayas@iteso.mx](mailto:erayas@iteso.mx)) is on March 24, 2020. The report can be written either in English or in Spanish.

This lab experiment can be realized in teams of up to 3 students. The report evaluation will be based on the following criteria:

Quality of the report	30%
Accuracy of the theoretical analysis	30%
Simulation procedures	40%

If the report is written in acceptable English, extra points of up to 5% can be granted on the evaluation.

## References

- [1] K. C. Gupta, R. Garg, and R. Chadha, *Computer-Aided Design of Microwave Circuits*. Norwood, MA: Artech, 1981.