Laboratory #2: Introduction to Microstripline Transmission Lines, Reflection and Transmission Coefficients, and S-Parameters

I. OBJECTIVES

A microstrip transmission line is designed for nominally 50Ω. The reflection and transmission characteristics are measured and compared to theory. S-parameters are derived.

II. INTRODUCTION

Microstriplines are commonly used in printed circuit boards (PCB) to connect electrical and electronic components. They are also used to create circuit functions such as filters through special layout arrangements. A crossectional view of a microstripline is shown in Figure 1.

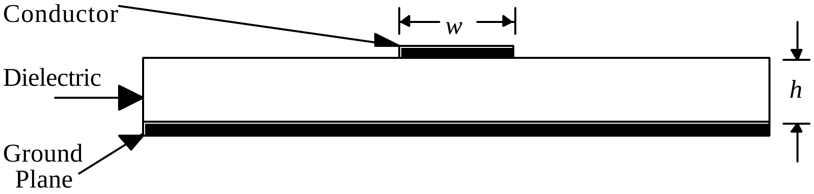

Figure 1. Crossectional View Of A Microstripline

The design equations for the characteristic impedance of a microstripline are:

Narrow strips ($w/h \leq 1$):

$$Z_o' = \frac{60\ln\left(\frac{8h}{w}+\frac{w}{4h}\right)}{\sqrt{\left[\frac{e_r+1}{2}+\frac{e_r-1}{2}\left(1+\frac{10h}{w}\right)^{1/2}\right]}} \quad \Omega, \tag{1}$$

Wide strips ($w/h \geq 1$):

$$Z_o' = \frac{\dfrac{120p}{\left[\frac{w}{h}+2.42-0.44\frac{h}{w}+\left(1-\frac{h}{w}\right)^{6}\right]}}{\sqrt{\left[\frac{e_r+1}{2}+\frac{e_r-1}{2}\left(1+\frac{10h}{w}\right)^{1/2}\right]}} \quad \Omega. \tag{2}$$

The underlying assumption is that the metal conductors are significantly thinner than the dielectric. Metal thicknesses of 137 mils (0.00137 inches) is typical for 1 oz. copper plating. Plating refers to the number of ounces of metal deposited on a flat surface per square foot. The board is made of FR-4 (or G-10) material with a nominal relative dielectric of 4.5.

In radio frequency (RF) and microwave (μ-wave) circuits, the characteristics impedance of the microstriplines are carefully controlled to prevent unwanted signal reflections caused by dissimilar impedances. As the speed of digital circuits increase, the interconnections between digital components must be carefully designed to eliminate unwanted signals caused by reflections.

One common method for measuring the reflection and transmission characteristics of any device under test (in this case a microstripline) involves the using a network analyzer. A network analyzer allows convenient measurements of signal reflection and transmission in a variety of formats. It can measure signal delay, phase, and gain of the device under test (DUT). All of these measurements are made with respect to the source and terminal impedance of the network analyzer. The default impedance of the HP8752A network analyzer is set at 50 Ω.

The signal reflected from the DUT is usually measured as a ratio to the incident signal. It can be expressed as reflection coefficient or return loss. These measurements are described mathematically as,

$$\text{Reflection coefficient} \equiv \frac{\text{reflected power}}{\text{incident power}} = \left|\frac{E_{refl}}{E_{inc}}\right| = r \quad \text{(magnitude only)}$$

$$= \Gamma \quad \text{(Reflection magnitude and phase)} \tag{3}$$

$$\text{Return loss (dB)} = -20 \log r \tag{4}$$

$$\text{Standing Wave Ratio} \equiv SWR = \frac{1+r}{1-r} \quad \text{(pronounced "}\textit{swir}\text{" as in }\textit{swirl}\text{)} \tag{5}$$

Displaying the reflection measurement in polar form on the network analyzer with a marker allows direct determination of the complex impedance of the DUT. The center of the circle represents a coefficient Γ of 0 (a perfect match, no reflected signal). The outermost circumference of the scale represents a Γ of 1 (100% reflection). The phase angle is directly read from the display. The magnitude and phase will be directly displayed in the marker data readout for any frequency.

The amount of power reflected from a device is directly related to the impedances of the DUT and the measurement instrument. Γ = 0 occurs when the DUT and the analyzer have identical impedances. A short circuit has $\Gamma = 1 \angle 180°$. Every other value of Γ corresponds uniquely to a complex device impedance. In terms of impedances,

$$\Gamma = \frac{Z_{DUT} - Z_o}{Z_{DUT} + Z_o}, \tag{6}$$

where Z_o is the impedance of the measurement instrument,
Z_{DUT} is the impedance of the DUT.

To facilitate computations, the normalized (in this case normalized to 50 Ω) impedance is,

$$Z_N = \frac{Z_{DUT}}{Z_o} = \frac{1+\Gamma}{1-\Gamma}. \qquad (7)$$

S-parameters are commonly used to characterize high frequency circuits. S-parameters (or Scattering-parameters) basically are two-port characteristics of the DUT. Additionally, insight into the behavior of traveling waves are readily deduced from S-parameters.

S-parameters can readily be found using the schematic of the test set-up shown in Figure 2.

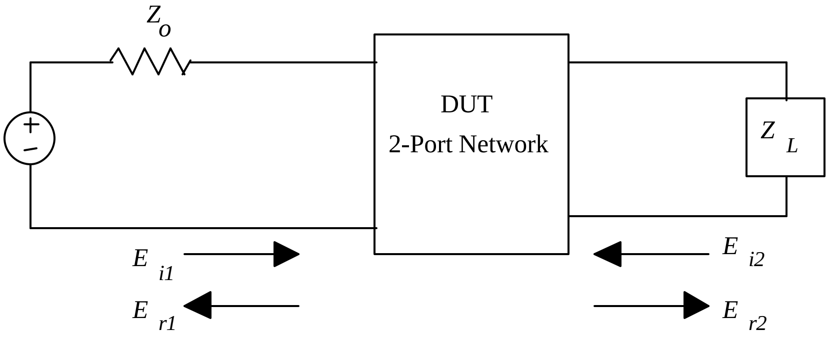

Figure 2. Two Port Network Used For S-Parameter Measurements

Define new variables with respect the a characteristic impedance of the measurement instrument,

$$a_1 = \frac{E_{i1}}{\sqrt{Z_o}}, \qquad a_2 = \frac{E_{i2}}{\sqrt{Z_o}},$$
$$b_1 = \frac{E_{r1}}{\sqrt{Z_o}}, \qquad b_2 = \frac{E_{r2}}{\sqrt{Z_o}}. \qquad (8)$$

S-parameters relates these four waves as follows:

$$\begin{aligned} b_1 &= S_{11}a_1 + S_{12}a_2 \\ b_2 &= S_{21}a_1 + S_{22}a_2 \end{aligned}. \qquad (9)$$

For S_{11}, the output port of the DUT is terminated (with Z_o = 50 Ω) and the ratio of b_1 to a_1 is measured,

$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} . \tag{10}$$

Terminating the output port of the DUT with the impedance of the measurement instrument is equivalent to setting $a_2 = 0$ since a traveling wave incident on this load will be totally absorbed. S_{11} is the input reflection coefficient of the DUT.

The forward transmission through the DUT is the ratio of b_2 to a_1. This could either be the gain of the amplifier or the attenuation of a passive network,

$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} . \tag{11}$$

By terminating the input side of the network, we set $a_1 = 0$ and can then measure the output reflection coefficient, S_{22} , and the reverse transmission coefficient, S_{12} , defined as,

$$S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0} , \tag{12}$$

and

$$S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0} . \tag{13}$$

S-parameters are typically expressed as a magnitude and phase.

III. PROCEDURE

A. Calibrate the Network Analyzer

Calibration of the network analyzer may be necessary due to the many adapters and SMA pigtails used.

B. Determine the Transmission and Reflection Coefficients of the Filters Provided

Plot the magnitudes of the transmission coefficient, reflection coefficient, and *SWR* of the circuits over a frequency range that clearly shows the passband and the stopband. Find the nominal S_{11} , S_{21}, and *SWR* of the circuits in the passband and the stopband. Determine the impedance of the circuits in the passband and the stopband.

C. Design a Microstripline

Design a microstripline using the board and copper tape provided. Determine the theoretical impedances of a microstripline constructed from the sizes of copper tape provided.

Construct two microstriplines of different impedances. Design one of the microstriplines to be nominally 50 Ω.

D. Measure the Microstripline

Determine the transmission and reflection coefficients of the two microstriplines constructed. Plot the magnitudes of the transmission coefficient, reflection coefficient, and *SWR* of the microstriplines. Find S_{11} , S_{21}, and *SWR* of the microstripline at 55 MHz, 330 MHz, and 1 GHz. Determine impedances of the microstriplines at 55 MHz, 330 MHz, and 1 GHz using the measured reflection coefficients.

E. Comment On Your Results