

Laboratory #1: Network Analysis - Open, Short, and Matched Load

I. OBJECTIVES

The objective of this experiment is to become acquainted with the Agilent 8510C Network Analyzer. Demonstrate your ability to calibrate the network analyzer and measure:

- Impedance
- S-parameters
- VSWR

Be able to use the Log-Mag, and Polar Plot options.

The results of the analyses are experimentally verified using a network analyzer. S_{11} and SWR are found.

II. INTRODUCTION

One common method for measuring the reflection and transmission characteristics of any device under test (in this case open, short, and matched loads) 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 or equivalent network analyzer is set at 50Ω .

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,

$$\begin{aligned} \text{Reflection coefficient} &\equiv \frac{\text{reflected power}}{\text{incident power}} = \frac{|E_{refl}|}{|E_{inc}|} = \rho \quad (\text{magnitude only}) \\ &= \Gamma \quad (\text{Reflection magnitude and phase}) \end{aligned} \quad (9)$$

$$\text{Return loss (dB)} = -20 \log \rho \quad (10)$$

$$\text{Standing Wave Ratio} \equiv SWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad (\text{pronounced "swir" as in swirl}) \quad (11)$$

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 $|\Gamma|$ 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. $\Gamma = 0$ occurs when the DUT and the analyzer have identical impedances. A short circuit has $\Gamma = 1 \angle 180^\circ$. Every other value of Γ corresponds uniquely to a complex device impedance. In terms of impedances,

$$\Gamma = \frac{Z_{DUT} - Z_o}{Z_{DUT} + Z_o}, \quad (12)$$

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 50Ω) impedance is,

$$Z_N = \frac{Z_{DUT}}{Z_o} = \frac{1 + \Gamma}{1 - \Gamma}. \quad (13)$$

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 3.

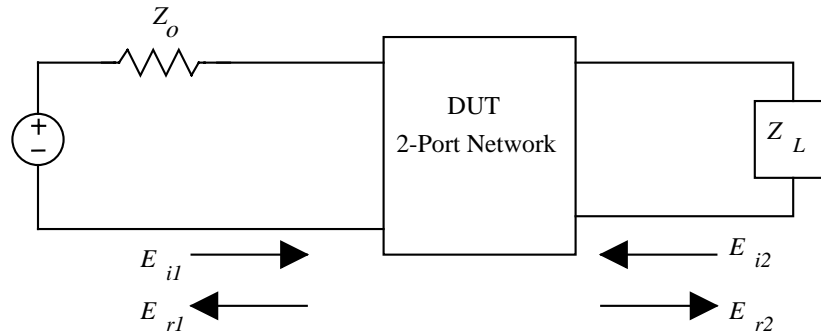


Figure 3. Two Port Network Used For S-Parameter Measurements

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

$$\begin{aligned} a_1 &= \frac{E_{i1}}{\sqrt{Z_o}}, & a_2 &= \frac{E_{i2}}{\sqrt{Z_o}}, \\ b_1 &= \frac{E_{r1}}{\sqrt{Z_o}}, & b_2 &= \frac{E_{r2}}{\sqrt{Z_o}}. \end{aligned} \quad (14)$$

S-parameters relates these four waves as follows:

$$\begin{aligned} b_1 &= S_{11}a_1 + S_{12}a_2 \\ b_2 &= S_{21}a_1 + S_{22}a_2 \end{aligned} \quad (15)$$

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

$$S_{11} = \left. \frac{b_1}{a_1} \right|_{a_2=0} \quad (16)$$

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,

$$S_{21} = \left. \frac{b_2}{a_1} \right|_{a_2=0} \quad (17)$$

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,

$$S_{22} = \left. \frac{b_2}{a_2} \right|_{a_1=0} \quad (18)$$

and

$$S_{12} = \left. \frac{b_1}{a_2} \right|_{a_1=0} \quad (19)$$

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

TO measure impedance. On the FORMAT menu, press Smith Chart. On the MENU menu, press MARKER> Use the thumb dial to move the marker to the frequency you are interested in (printed on the top left side of the screen). You will also two numbers followed by Ω This is the impedance (real and imaginary) in ohms. For more markers, press marker, and choose another number. You can have up to 5 markers at a time (on different frequencies)

TO see the reflection coefficient (S_{11} only in our case) on the FORMAT menu, press LOG MAG. Press MENU (on the FORMAT menu), and this will give you many options for what to print. Originally, it is showing LOG MAG, and the value (at the frequency marked with the marker) is shown in the upper left corner. Other options are LIN MAG, SWR, REAL, IMAG, POLAR, etc.

TO see the Standing Wave Ratio on the FORMAT menu, press SWR. Press MENU (on the FORMAT menu), and this will give you many options for what to print.

To change to the scale of a graph, on the RESPONSE menu, press SCALE, and turn the thumb knob until the graph looks like you want it to. Alternatively, choose a scale on the number pad (then press x1 on the number pad).

To get a hard copy on the plotter:

1. Put paper in the plotter/printer Turn on plotter (back left side).
2. On AUXILLARY menu (bottom of Network analyzer panel), Press COPY, Plot to Printer, specify what to plot (ALL).

III. PROCEDURE

- A. *Find equations for the S-parameters for the following simple circuits: 1.*
 - a) Short
 - b) Open
 - c) Matched Load (S12 and S21 are meaningless)
- B. *READ the presentation on Network Analysis*
- C. *Determine Γ and SWR for the loads provided*
 1. *Measure the Γ and SWR of the simple circuits provided from 10 MHz-3 GHz. Use the Log- Mag, and Polar Plot Options. Use markers at 49 MHz, 900 Hz and 2.4 GHz Compare to your expected values.*
 2. *Plot at least one of your plots on the plotter in Log-Mag format.*
 3. *Carefully save written instructions/notes on how to make these measurements (because you will be making them AGAIN).*
 4. *Summarize your results. How well do your results agree with expected results?*