

Experiment 03 - Automated Scalar Reflectometry Using LabVIEW

1 Introduction

After our encounter with the slotted line, we are now moving to a slightly more sophisticated measurement technique that was popular in the early 1980s.

As has been motivated in the lecture, scattering parameters provide the best way to characterize a linear network at microwave frequencies because reference impedances like 50 ohms are possible to manufacture over a broad frequency range even at those high frequencies (unlike shorts and opens). The scattering matrix provides a complete description of the network as seen at its ports, just like Z and Y parameters, but while the impedance and admittance matrices relate the total voltages and currents at the ports, the scattering matrix relates the voltage waves incident on the ports to the waves scattered from the ports. In fact, scattering parameters are merely a linear transformation of Z or Y matrices. In addition, these scattering parameters can be measured directly with the use of a vector network analyzer. In this lab, you will be measuring $|S_{11}|$ with a scalar network analyzer (SNA). While phase information is not available with SNA, these magnitude measurements can provide some insights into the behavior of devices. And hence, SNA was popular in the early 80's for applications in which return loss, $RL = 20 \log |S_{11}|$, is fairly enough to characterize the DUT. They are now obsolete and replaced by vector network analyzer (VNA) which can provide complete S-parameter data sets (including magnitude as well as phase). You will learn about and use VNA in later experiments when we move to modern measurement techniques.

This lab will also be the first time you will be using the student unknown. Each student unknown is a 50-ohm termination connected in parallel to a shorted stub of a different length (see Figure 3). Use this knowledge to determine if the measurements you take in this lab make sense.

We learned how to use LabVIEW to automate our measurement in Experiment 1. Seeing the advantages of this automation process, we will once again use LabVIEW, this time to automate the measurements of $|S_{11}|$. Through this process, we are essentially building a SNA from simple microwave components and LabVIEW code. In this experiment, we will also use measurements of two well-characterized devices, a short and an open, to perform some error correction on the measurements of our student unknown.

You will write **two** simple programs in LabVIEW. The first program will be written to measure the incident and reflected power of a device under test (DUT) as a function of frequency and to calculate the ratio of these two. The value will then be used to calculate $|S_{11}|^2$ in dB. The second program will be written to read the stored measured data and to make simple scalar error corrections on the DUTs. The corrected DUTs' data will then be plotted in this program.

2 Background

Directional coupler

In the lecture, you have been introduced to directional couplers, they are one of the most important microwave components for measurement.

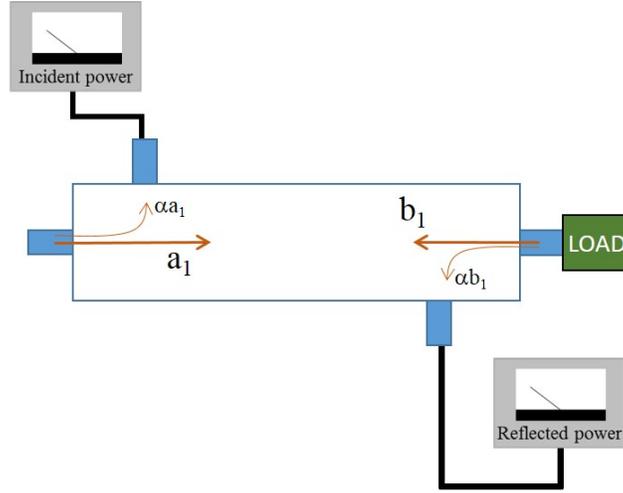


Figure 1: Principle of power measurement using directional coupler

Figure 1 shows the basic principle of the HP 778D directional coupler that we will use in this experiment. When the excitation is fed into input end of the coupler, a small portion, $\alpha < 1$, of the incident wave a_1 will be directed to another port where we will measure it. This wave reaches to the load end, gets to reflect back. On its way reflecting back to the source, a small portion, also $\alpha < 1$, of the reflected wave b_1 will be directed to another port where we can capture it the same way we did at the input end. Reflection coefficient of the load can then be calculated using

$$|\Gamma| = \frac{P_{refl}}{P_{inc}} = \frac{|b_1|^2}{|a_1|^2}$$

1-term error correction

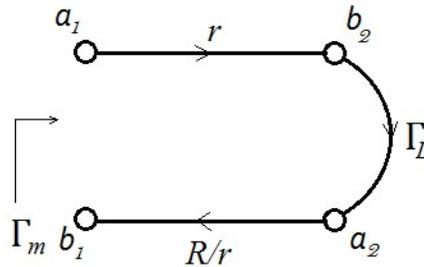


Figure 2: Coupler principle

As we all know it is impossible to make perfect test set equipment for measurements. Errors due to many sources will be introduced into our measurement. Fortunately, many of them are deterministic, meaning they can be predicted and controlled. Error corrections are introduced to eliminate these deterministic noise out of our measurement. The simplest error correction model is depicted in Figure 2 where only *Reflection Tracking (R)* error is taken into account. It is the summation of errors caused by variations in magnitude and phase flatness versus frequency between the test and the reference signal paths. They are usually called tracking (frequency response) errors[1]. The equation relating the measured reflection coefficient Γ_m with the actual one Γ_L is, in 1-term error correction model, given by

$$\Gamma_m = R\Gamma_L$$

R can then be obtained using a single measurement of a known standard termination.

3 Pre-lab

1. An unknown load is made up of a 50 ohm termination in parallel with a quarter-wavelength shorted stub at frequency f_0 as pictured in Figure 3. This structure is the same as the student unknown. What is Z_{stub} ? What is Γ assuming the source impedance is 50 ohms? Calculate the return loss? You should be able to answer these questions without the use of a calculator.

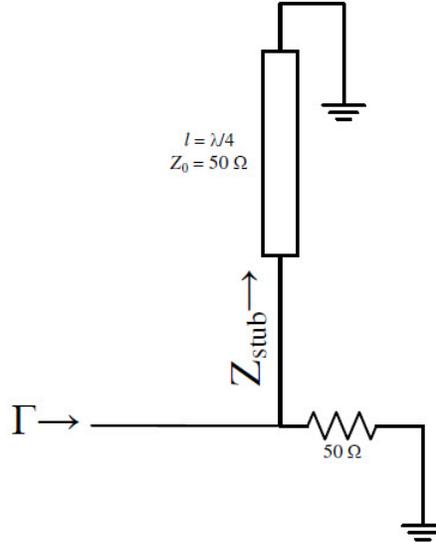


Figure 3: Example Student Unknown

2. Using the same structure as in Figure 3, assume that we double our operating frequency (i.e. $2f_0$). What is Z_{stub} ? What is Γ assuming the source impedance is 50 ohms? Calculate the return loss? You should also be able to answer these questions without the use of a calculator.
3. As mentioned above, we will calculate $|S_{11}|$ by taking the ratio between reflected and incident power. However, no power meters are available for use. Instead, we will only use the square-law detectors and DVMs in Experiment 1 to capture the voltage signals. How do we find the desired powers using collected voltages? Write down the expression relating input power and output voltage?

4 Equipment

- HP Microwave Source (8350 Sweep-Oscillator).
- HP Digital Voltmeters (DVMs) (3457A).
- Dual Directional Coupler (HP778D).
- Keysight 8474B Crystal Detectors
- N-type, BNC cables.
- N-type terminations.
- 15 foot N-type cable.
- Student Unknown (**Be sure to denote which unknown you used in your report!**).
- Software: NI LabVIEW.

5 Procedure

1. Make sure you answered question 3, *pre-lab*. If you have not, here is what you need to do before you dive into this experiment:
 - (a) Repeat Experiment 1 with the detectors what you are about to use in this experiment.
 - (b) Based on what you have collected, figure out the expression to relate the input power and the output voltage of the detectors
2. Connect the instruments as shown in Figure 4. The measurements should be made over the 300 to 1,300MHz frequency range for every 5MHz (201 points) at 5dBm (or another appropriate power level within the square-law region of your detector).

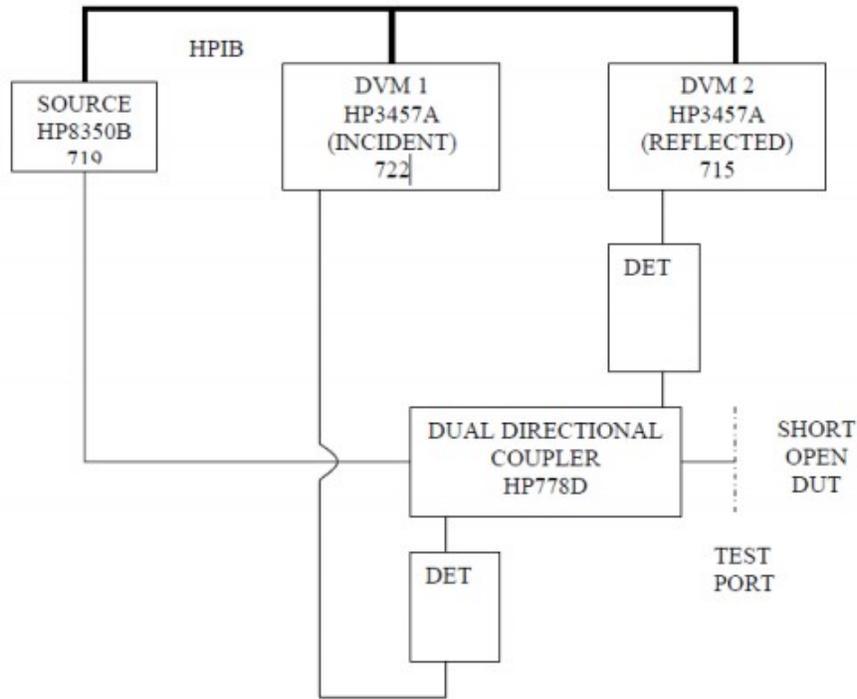


Figure 4: Scalar Reflectometer Setup

3. Write a program to measure incident and reflected detector voltage data over the 300 to 1,300 MHz frequency range, changing the measured voltage values to power in dBm at each frequency. In the for loop that measures outputs at each frequency, fill three arrays: (a) incident power in dBm, (b) reflected power in dBm, and (c) the ratio of **reflected to incident** power in dB (to take the ratio, subtract the incident from the reflected power values in dBm). When finished with the measurement loop, the program should store all three arrays in a LVM file for each device.

You are not required to write the program from a blank VI. You can and should copy and rename the first program written in Experiment 1 and then modify it to meet your new purpose.

Look at the flowchart for this program in Figure 5 and you will notice that we need to sweep the frequency at constant source output power (in the previous lab, we swept the power at a constant frequency). Your program should create the following four sets of arrays and save all of them together in an LVM file for each run. It should also display incident power, reflected power, and ratio, each versus frequency.

DUT	File name
N-type short	short.lvm
N-type open	open.lvm
Student unknown	studut.lvm
15-ft shorted coaxial cable	scx.lvm

5. Write a second program, which reads the LVM files created above. In order to perform corrections, the program must read three sets of files: the short measurement, the open measurement, and the DUT measurement (see LabVIEW tutorial 2). The program will use the short and open measurement data to perform the 1-term error correction on the DUT measurement. The program should display the corrected data as a function of frequency. Six sets of corrected $|S_{11}|$ data that are listed below are required for each device under test.

Remember that there are two devices under test (DUTs)—your student unknown, and shorted 15-foot coaxial cable. Therefore, the second program must run two times. You should be able to design your VI Front Panel such that all six corrections are clearly labeled and displayed.

- Short corrected: Reflected power of DUT corrected with reflected power of short ($\text{refpwr_dut} - \text{refpwr_short}$)
 - Open corrected: Reflected power of DUT corrected with reflected power of open ($\text{refpwr_dut} - \text{refpwr_open}$)
 - Average corrected: Reflected power of DUT corrected with an average of reflected powers of short and open ($\text{refpwr_dut} - (\text{refpwr_short} + \text{refpwr_open})/2$)
 - Ratio short corrected: Ratio of DUT corrected with ratio of short ($\text{ratio_dut} - \text{ratio_short}$)
 - Ratio open corrected: Ratio of DUT corrected with ratio of open ($\text{ratio_dut} - \text{ratio_open}$)
 - Ratio average corrected: Ratio of DUT corrected with an average of ratios of short and open ($\text{ratio_dut} - (\text{ratio_short} + \text{ratio_open})/2$)
6. **Obtain a screenshot of your Front Panel after running your program with the student unknown and a screenshot of your Front Panel after running your program with the 15-foot cable.**
- You should now have a total of 2 screenshots from the first program and 2 screenshots from the second program.
7. From your corrected $|S_{11}|$ in dB plot of the shorted cable, determine the one-way attenuation of the cable at 300, 800, and 1,300 MHz. **Include a table of these values for attenuation in your report. Put markers on your data to show where these values come from to get full credit.**

6 Conclusion

- Compare the uncorrected data from step 3 with the corrected one from step 5 for both student unknown and the shorted 15-foot cable. Explain the discrepancies (if any).
- How can we improve this calibration?
- Compare the result between step 5a, 5b and 5c. Do the same for the result from step 5d, 5e and 5f. Explain why should we prefer the average correction (5c,5f)?
- Given that the three-term error model is exact, is the one-term correction used in this lab more accurate for high or low reflect loads? (Hint: What is being modeled in the three-term error model that is not being modeled in the one-term and how does this relate to reflections? You could also mathematically show the effects of a variable α on Γ by evaluating $\frac{\partial \Gamma}{\partial \alpha}$.)

References

- [1] Hewlett Packard Application Note 221A, “Automating the HP 8410B Microwave Network Analyzer,” jun 1980.