

Experiment 03 - Automated Scalar Reflectometry Using BenchVue

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.

For this experiment we will be using an automation software called BenchVue. We learned how to use LabVIEW to automate our measurement in Experiment 1. Now we are switching to its advanced version with better user interface and greater simplicity. The first part of this lab would ask you to automate the measurements of $|S_{11}|$. To do this, you need to build a SNA from simple microwave components along with your BenchVue code. The second part of the lab would further improve the measurements in Matlab by using the two well-characterized devices (a short and an open) to perform error correction on the measurements of our student unknown.

You will write in both BenchVue and Matlab (optional) to complete this lab. The first part will be written in BenchVue 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 in Matlab (or the software of your choice) 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.

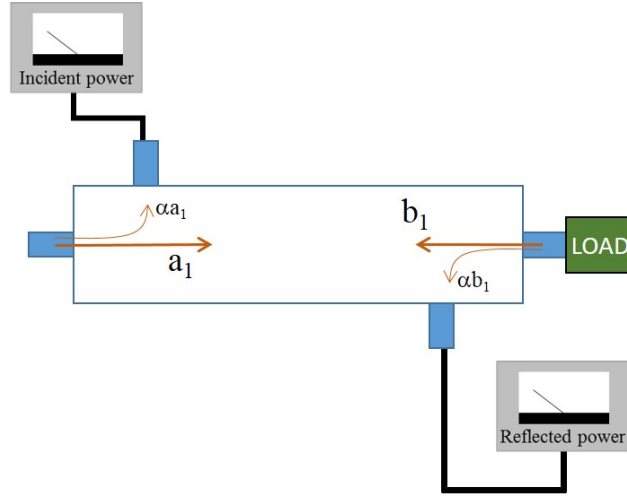


Figure 1: Principle of power measurement using directional coupler

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

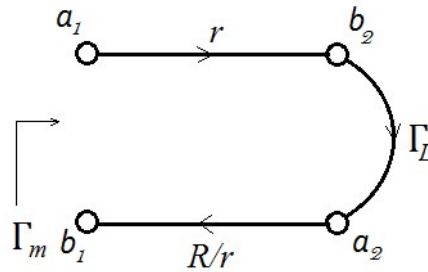


Figure 2: 1-term error model

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. 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.

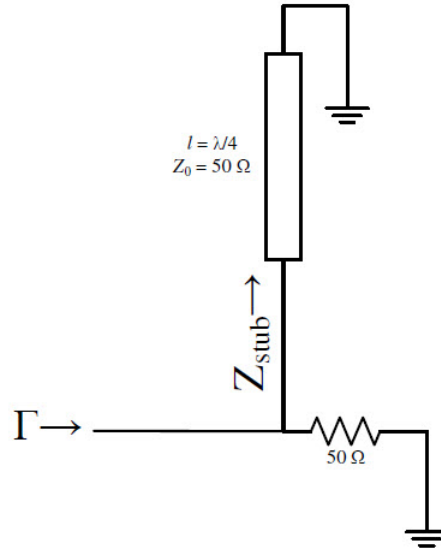


Figure 3: Example Student Unknown

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 its output voltage.

4 Equipment

- Agilent MXG Analog Signal Generator (N5183A).
- Keysight Digital Voltmeters (DVMs) (34461A).
- Dual Directional Coupler (HP778D).
- Keysight 8474B Crystal Detectors
- 3.5 mm to N-type connector.
- 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: BenchVue, Matlab (or the software of your choice).

5 Procedure

- 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:
 - Repeat Experiment 1 with the detectors that you are about to use in this experiment.
 - Based on what you have collected, figure out the expression to relate the input power and the output voltage of the detectors.
- Connect the instruments as shown in Figure 4. The measurements should be made over the 500 to 1,500MHz frequency range for every 5MHz (201 points) at 5dBm (or another appropriate power level within the square-law region of your detector).

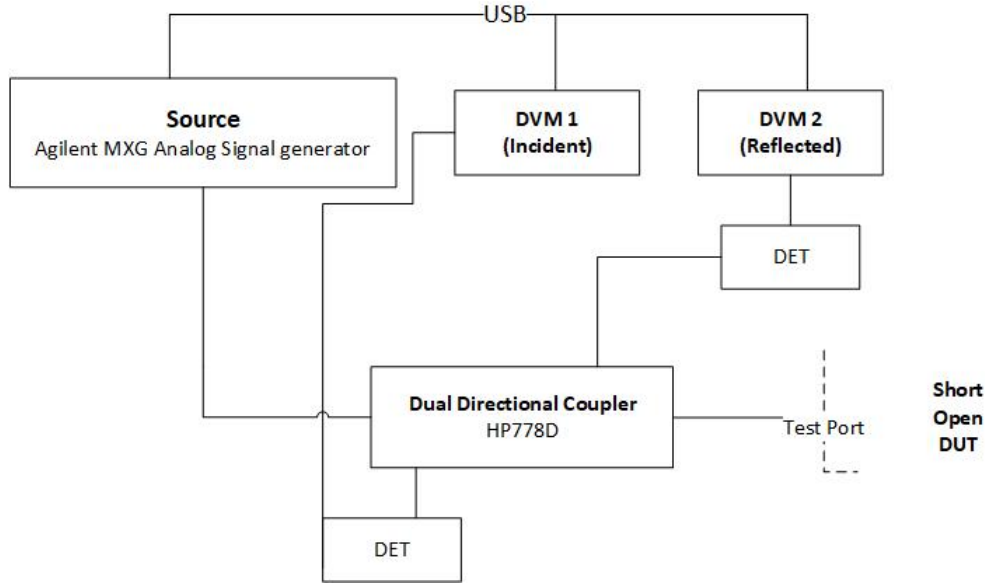


Figure 4: Scalar Reflectometer Setup

- Write a program to measure incident and reflected detector voltage data over the 500 to 1,500 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, measure and compute 3 components : (1) incident power in dBm, (2) reflected power in dBm, and (3) 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 these data in a mtlab file for each device.
 - Look at the flowchart for this program in 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 data sets and save all of them in .csv file for each run. It should also display incident power, reflected power, and ratio, each versus frequency.

Data Sets:

- Sweeping frequency
- Incident power
- Reflected power
- Power ratio

- Run the program four times, measuring $|S_{11}|$ for a short, an open, a student unknown, and a shorted 15-foot coaxial cable. Your program needs to have the following four data sets. Take screenshots of BenchVue's data display window for each run ($|S_{11}|$ versus frequency).

Data Sets:

- N-type short
 - N-type open
 - Student unknown
 - 15-ft shorted coaxial cable
5. In your choice of software (e.g Matlab), open the .csv 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. 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. Show all six corrections below in your report and clearly label them.
- (a) Short corrected: Reflected power of DUT corrected with reflected power of short ($\text{refpwr_dut} - \text{refpwr_short}$)
 - (b) Open corrected: Reflected power of DUT corrected with reflected power of open ($\text{refpwr_dut} - \text{refpwr_open}$)
 - (c) Average corrected: Reflected power of DUT corrected with an average of reflected powers of short and open ($\text{refpwr_dut} - (\text{refpwr_short} + \text{refpwr_open})/2$)
 - (d) Ratio short corrected: Ratio of DUT corrected with ratio of short ($\text{ratio_dut} - \text{ratio_short}$)
 - (e) Ratio open corrected: Ratio of DUT corrected with ratio of open ($\text{ratio_dut} - \text{ratio_open}$)
 - (f) 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. From your corrected $|S_{11}|$ in dB plot of the shorted cable, determine the one-way attenuation of the cable at 500, 1000, and 1,500 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

1. 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).
2. How can we improve this calibration?
3. 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)?
4. 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 $\frac{\partial \Gamma}{\partial \alpha}$.)