ECE 451

Automated Microwave Measurements Laboratory

Experiment 05 - PNA Series Analyzers – Time-domain Reflectometry

1 Introduction

CAUTION: Vector Network Analyzers (VNAs) are very delicate instruments and must be handled accordingly. It can be severely damaged by electrostatic discharge (ESD). Therefore, before making any connections to the measurement ports, be sure to discharge (ground) your body by grasping the outer conductor of the measurement port or the metal part of the coaxial cable attached to the port. Also, any device being attached to either port must be discharged; that includes both the outer and inner conductors. Never touch the center conductor of the measurement ports. **Often times, you can just use a static wrist strip to ground yourself when handling the PNA or anything connected to it. This is preferable.**

In this laboratory session, we will be using a modern network analyzer to perform microwave measurements, **just as an engineer would in a real work environment**. In doing so, we are introducing the 10-term and 12-term error models for two-port measurements.

You will learn how well sophisticated RF/microwave measurement systems are hidden from the users by just some simple button presses. It provides simple procedures and elegant ways to save time and effort when a measurement is needed. But it also takes away the insights and could leave a lot of troubles for the users when something malfunctions or when the users fail to interpret mere tabulated numeric values obtained by the machine.

You will be walked through the necessary procedure to perform 2-port measurements and learn to interpret the data. You will also learn how to get 4-port measurements with 2-port network analyzer using symmetry and reciprocity properties. You will then be introduced to perform time-domain reflectometry (TDR) measurement using VNA and the important correlation between frequency- and time-domain characterizations.

2 Background

Time-domain reflectometry (TDR) using VNA

The measurement technique of time domain reflectometry (TDR) was introduced in the early 1960's and works on the same principle as radar. A pulse of energy is transmitted down a cable. When that pulse reaches the end of the cable, or a fault along the cable, part or all of the pulse energy is reflected back to the instrument. TDR measurements are made by launching an impulse or a step into the test device and observing the response in time. By measuring the ratio of the input voltage to the reflected voltage, the impedance of simple discontinuities can be calculated. The position of the discontinuity can also be calculated as a function of time by applying the velocity of propagation along the transmission line. The type of discontinuity (capacitive or inductive) can be identified by its response.

Then, in the 70's, it was shown that the relationship between the frequency domain and the time domain could be described using the Fourier Transform. The Fourier Transform of the network reflection coefficient as a function of frequency is the reflection coefficient as a function of time; i.e., the distance along a transmission line. It was possible to measure the response of a DUT in the frequency domain and then mathematically calculate the inverse Fourier Transform of the data to give the time domain response.

Even though the VNA provides a TDR-like display, there are differences between traditional TDR and VNA time domain techniques. The transform used by the VNA resembles time domain reflectometry, however, the analyzer makes swept frequency response measurements and mathematically transforms the data into a TDR-like display. In low-pass mode, which supports both impulse and step TDR responsem thus, is used in this experiment, the VNA measures discrete positive frequency points, extrapolates DC, and assumes that the negative frequency response is the conjugate of the positive, i.e., that the response is Hermitian[1]. Band-pass mode, which only supports impulse TDR response, is beyond the scope of this couse, thus, will not be discussed here.

[1] A complex-valued function $H(s) : \mathbb{C} \mapsto \mathbb{C}^m$ is Hermitian iff $H(s^*) = H^*(s)$

S-parameter matrix properties

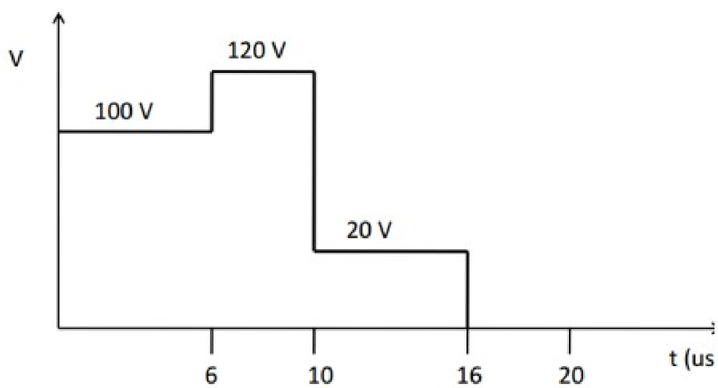
Basic knowledge about S-parameter matrix of a lossless, passive network has been introduced in lectures. In this lab, you will testify the symmetry and reciprocity theory applied to S-paramter matrix. You should be able to identify Figure 1 as symmetric as well reciprocal while Figure 2 only satisfies reciprocity. They will be measured in the lab.

Figure 1: The Samtec Golden Standard Reference Board

Figure 2: Single microstrip line with discontinuities

3 Pre-lab

1. Suppose a TDR having a source impedance of 50Ω is attached to a 50Ω coaxial cable having some unknown length and load resistance. The dielectric of the cable is Teflon ($\epsilon_r = 2.1$) and the open circuit voltage of the TDR is a pulse of duration $10\mu s$. The recorded voltage at the input to the line is shown below:



   (a) Determine length of the line.

   (b) Determine the unknown load resistance.

2. In the experiment, you are measuring a 4-port device that is reciprocal and has some obvious symmetry depicted in Figure 1. Explain how you would these use 3 following 2-port measurements to obtain all 16 S-parameters of device.

	Port 1	Port 2
Measurement 1	1	2
Measurement 2	1	3
Measurement 3	1	4

3. Suppose we have a 1-port device S-parameter of which we want to collect, between the result obtained from 3-term error correction and that from 12-term error correction, which one is better? Explain?

4 Equipment

- Agilent E8358A Network Analyzer.
- Agilent 85032F SOLT N-type Calibration Kit.
- Agilent 85052D SOLT 3.5 mm Calibration Kit.
- N-type Student Unknown (use the same one you have used so far.)
- Microstrip line with discontinuities.
- Coupled microstrip line.

5 Procedure

Part 1 - Measure N-type Student Unknown - 300MHz to 1.3GHz

You are recommended to obtain about 201 points for good resolution.

- Measure S_{11} using a one-term error correction (**Response**) and save the data to Touchstone[2] file.
- Measure S_{11} using a three-term error correction (**1 Port Solt**) and save the data.

  Plot all data on both mag-phase plot and Smith Chart. Compare S_{11} from 2 measurements above and also compare with $|S_{11}|$ you obtained in Experiment 3. Comment on the result.
- Now, collect the data to verify your answer in *Pre-lab* section, question 4 by measuring S_{11} of the student unknown again, but this time, using a 12-term calibration. Comment on the result.

Part 2 - Measure Microstrip line with Discontinuities - 300kHz to 6GHz

Perform a 12-term (**2 Port Solt**) calibration then measure the transmission line. Save the data to Touchstone file. Plot the data on both mag-phase and Smith Chart for your report. **Keep this data as you will need it later in the course**.

Part 3 - Measure Coupled Microstrip lines - 300kHz to 9GHz

Perform a 12-term (**2 Port Solt**) calibration. Then measure the coupled microstrip line. Collect needed data and import them into ADS, create a set of new variables named ***CL_Sij*** where i and j are the ports as indicated in Figure 1. Assign them with the associated measurement data you just collected. Plot all of them on Smith Chart for your report. Comment on the S-parameter of the coupled line you just gather.

Part 4 - TDR using Agilent E8358A VNA - Lowpass mode

Follow the instruction in to perform TDR measurement for the microstrip line with discontinuities in part 2. Obtain the following measurement

- TRD impulse response when the line is terminated with an open.
- TDR impluse reponse when the line is terminated with a match load.
- TDR step response when the line is terminated with a short.
- TDR step response when the line is terminated with a match load.

Comment on what you observe for each TDR response.

[2]http://cp.literature.agilent.com/litweb/pdf/genesys200801/sim/linear_sim/sparams/touchstone_file_format.htm

6 Conclusion

1. Discuss the physical interpretations of the additional error terms, L, T, and X. Are the 10- and 12-term corrected data sets the same? Is this result to be expected? What measurements might require the X term? (Refer to Ch. 3 of Dunsmore for insights.)

2. Examine the S-parameter that you obtained from Part 1. Is your student unknown:

   (a) very lossy? Why or why not?

   (b) active? Why or why not?

   (c) frequency dependent? Why or why not?

   Answer the above questions by

   - Just looking at Smith Chart.
   - Just looking at mag-phase plot.