

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.

Useful links:

1. Electrostatic Discharge (ESD) protection notes from Keysight

2 Background

Time domain reflectometry (TDR) [1]

When compared to other measurement techniques, time domain reflectometry provides a more intuitive and direct look at the DUT's characteristics. Using a step generator and an oscilloscope, a fast edge is launched into the transmission line under investigation. The incident and reflected voltage waves are monitored by the oscilloscope at a particular point on the line. This echo technique reveals at a glance the characteristic impedance of the line, and it shows both the position and the nature (resistive, inductive, or capacitive) of each discontinuity along the line. TDR also demonstrates whether losses in a transmission system are series losses or shunt losses. All of this information is immediately available from the oscilloscope's display. TDR also gives more meaningful information concerning the broadband response of a transmission system than any other measuring technique.

The step generator produces a positive-going incident wave that is applied to the transmission system under test. The step travels down the transmission line at the velocity of propagation of the line. If the load impedance is equal to the characteristic impedance of the line, no wave is reflected and all that will be seen on the oscilloscope is the incident voltage step recorded as the wave passes the point on the line monitored by the oscilloscope. If a mismatch exists at the load, part of the incident wave is reflected. The reflected voltage wave will appear on the oscilloscope display algebraically added to the incident wave.

The reflected wave is readily identified since it is separated in time from the incident wave. This time is also valuable in determining the length of the transmission system from the monitoring point to the mismatch. Recall that, reflection coefficient is defined by

$$\Gamma = \frac{V_r}{V_i} = \frac{Z_{load} - Z_0}{Z_{load} + Z_0}$$

Knowledge of V_i and V_r , as measured on the oscilloscope, allows Z_{load} to be determined in terms of Z_0 , or vice versa.

One of the advantages of TDR is its ability to handle cases involving more than one discontinuity. An example of this is shown in Figure 1. It is seen that the two mismatches produce reflections that can be analyzed separately. However, accuracy decreases as you look further down a line with multiple discontinuities

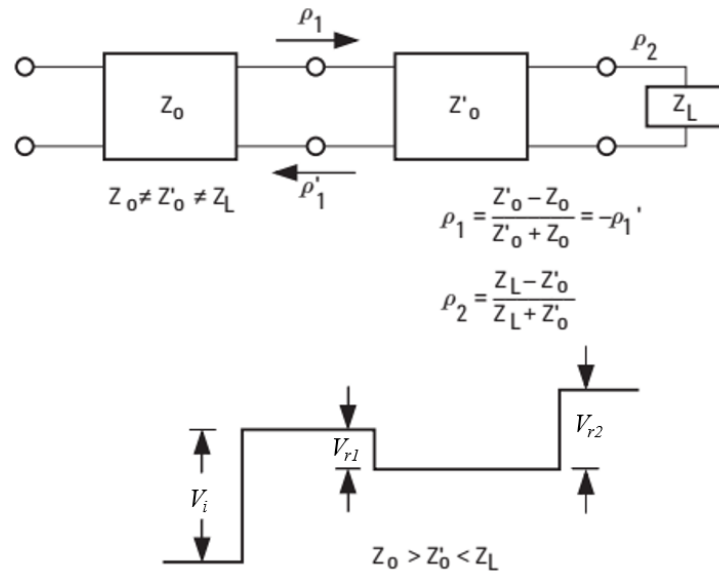


Figure 1: Cables with multiple discontinuities

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-parameter matrix. You should be able to identify Figure 2 to be symmetric and reciprocal while Figure 3 only satisfies reciprocity. They will be measured in this experiment.



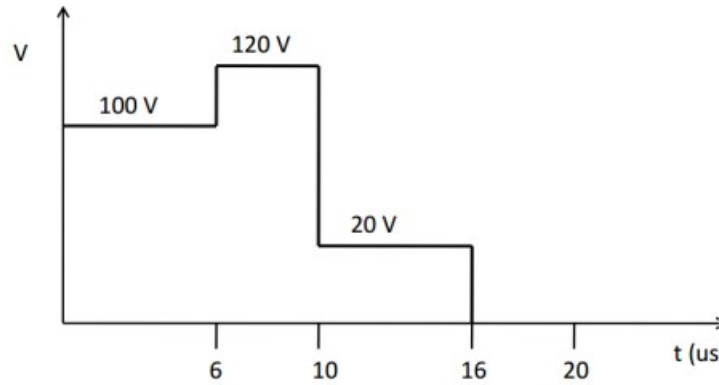
Figure 2: The Samtec Golden Standard Reference Board



Figure 3: 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 2. Explain how you would use the following 03 2-port measurements to obtain all 16 S-parameters of device. (numbers in the table are corresponding to that denoted in Figure 2)

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

4 Equipment

- CMT S5085 Compact VNA.
- Agilent 86100A Infiniium DCA High Bandwidth Oscilloscope.
- 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 201 points for good resolution while saving measurement time.

- Measure S_{11} using a one-term error correction (**Response**) and save the data to Touchstone¹ 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.

¹http://cp.literature.agilent.com/litweb/pdf/genesys200801/sim/linear_sim/sparams/touchstone_file_format.htm

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 - 20kHz to 8GHz

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 2. 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 - Measure TDR using Agilent 86100A Oscilloscope

Follow the instruction in Agilent 86100A tutorial (on the website) to perform TDR measurement for the microstrip line with discontinuities in part 2. Obtain the following measurement

- TRD step response when the line is terminated with an open.
- 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. Use TDR response when the line is terminated with a match load to derive TDR impedance to approximate characteristic impedance of each segment of the discontinuity microstrip line. Verify your derived result with that from the scope (which can be obtained by directly placing markers on the response when the line is still connected).

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.
3. Why must care be taken when obtaining TDR response using VNA? What is the difference between low-pass and band-pass mode TDR using VNA?

References

- [1] Keysight Technologies. Time domain reflectometry theory. Application note 5966-4855E, 2015.