# NATIONAL UNIVERSITY *of* SINGAPORE

## Faculty of Engineering
## Electrical & Computer Engineering Department

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## EE3104 Introduction to RF and Microwave Systems & Circuits

## Experiment 1

## Familiarization on VNA Calibration & S-parameter Measurement

## 1. OBJECT

The object of this experiment is to introduce the students to familiarize complex S-parameter measurement using the vector network analyzer (VNA).

## 2. INTRODUCTION

2.1 Vector Network Analyzer

At microwave frequencies, it is difficult to perform direct measurement of voltage and current at the ports of a network. Furthermore, open and short circuit terminations required for Z and Y parameter measurement may cause active microwave devices to oscillate. On the other hand, measurement of waves at microwave frequencies is easily accomplished with the aid of directional couplers and a vector analyzer. Therefore in practice, S-parameters are measured and then converted to either Z or Y parameters as required. Because S-parameter measurements are performed when the device under test (DUT) ports are terminated with a resistive load (typically 50 ohms), active DUTs are usually prevented from oscillating.

Figure 1 shows the schematic diagram of a VNA used to measure the complex S-parameters of a two-port network. The interconnections between each component of this schematic are transmission lines. It can be seen from Figure 1 that both Ports have directional couplers, and the RF stimulus is continuously switched from port 1 to port 2, usually with a solid state PIN switch. The frequency converter usually has one channel for each “raw” parameter. The all four parameters can be measured early simultaneously, and the calibration applied to the display data.

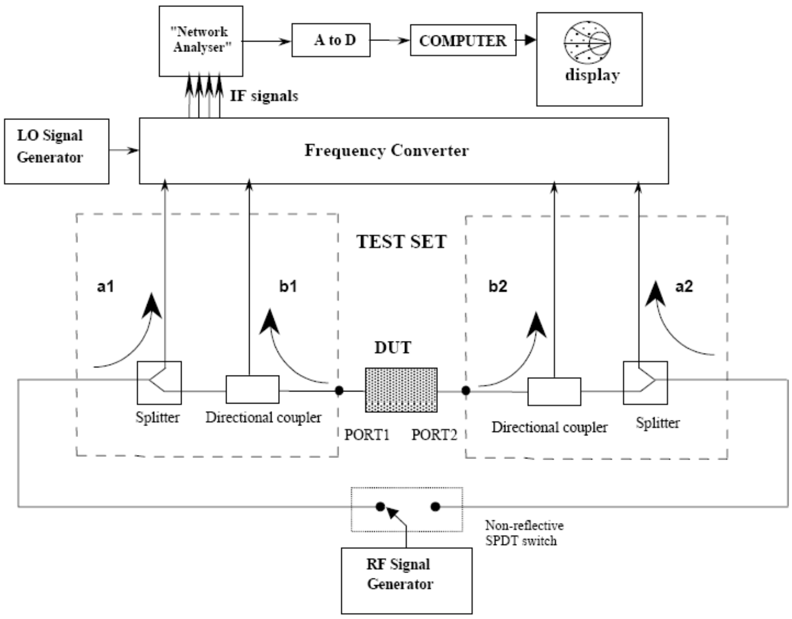


Figure 1: Simple block diagram of a VNA

## 2.1 VNA "SOLT" calibration method

A VNA measures the S-parameters of a device-under-test (DUT) over a wide frequency range. In order to make accurate measurements it is necessary to be fully familiar with calibration techniques. Calibration refers to the procedure whereby the unknown reflections and loss from cables, connectors, couplers, bias tees, etc., are determined via measurements on a series of known "calibration standard".

There are many methods these days for calibrating a VNA. The simplest to understand is the method using a short circuit, open circuit, 50Ω load and a through line. These must be precision calibrated standards with known characteristics. In the ideal case:

| | | | |
|---|---|---|---|
| SHORT | S11=-1 | OPEN | S11=+1 |
| LOAD | S11=0 | THRU | S11=0 S21=1 angle 0 |

By measuring these known standards, the errors in the measurements can be extracted. Once the errors have been calculated (as vectors) they can be eliminated from measurements of DUT. This calibration method is referred to as the "**SOLT**" method.

Here use one-port measurement to simply explain this SOLT method. In order to analyze how error correction is achieved, the sources of error must be identified and represented as a mathematical model. The sources of error for one-port measurement are shown below in figure 3 and they are:

(1) LEAKAGE in the non-ideal directional bridge/coupler.
(2) REFLECTIONS in the test components before the DUT
– Cables, adaptors etc.
(3) NON-50Ω impedance of the system itself.
– Source/Load MATCH
(4) Losses in the whole setup
– Transmission or tracking error

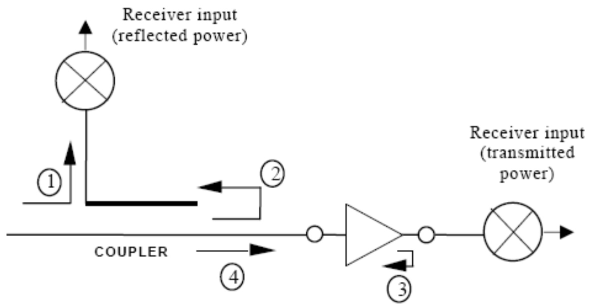

Figure 3: Errors in the one-port measurement system

All these various unwanted signal components are lumped together into what is known as an error model. The one-port error model is shown as Figure 4; each signal is a branch in a signal flow chart. The 3 error terms are:

$E_{DF}$ is the DIRECTIVITY term

$E_{RF}$ is the REFLECTION TRACKING term

$E_{SF}$ is the SOURCE MATCH term

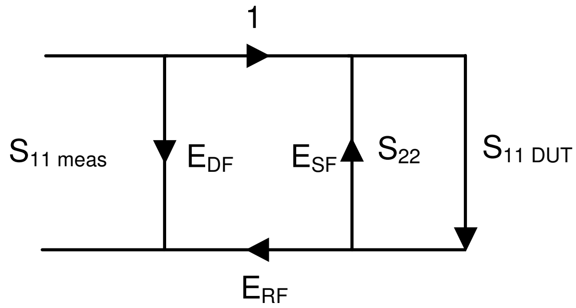

Figure 4: One-port error model flow chart

Referring to the one-port error model, the three error vectors can be found by measuring the three calibration standards [S11=+1 (open), S11=-1 (short) and S11=0 (load), and solving simultaneous equations as follows:

$$S_{11meas} = E_{DF} + \frac{S_{11DUT} E_{RF}}{1 - E_{SF} S_{11DUT}} \quad (1)$$

For the LOAD measurement: $S_{11meas} = E_{DF}$ (2)

For the OPEN measurement: $S_{11meas} = E_{DF} + \frac{E_{RF}}{1 - E_{SF}}$ (3)

For the SHORT measurement: $S_{11meas} = E_{DF} - \frac{E_{RF}}{1 + E_{SF}}$ (4)

Once the values (magnitude and phase) of the error terms are known at each frequency, the computer within a modern VNA can correct them out and display the true value of $S_{11DUT}$.

Figure 2 is an example of S21 (0.5 dB per division) and S11 (10 dB per division) for a thru line, BEFORE/AFTER calibration (the reference line is 0 dB).

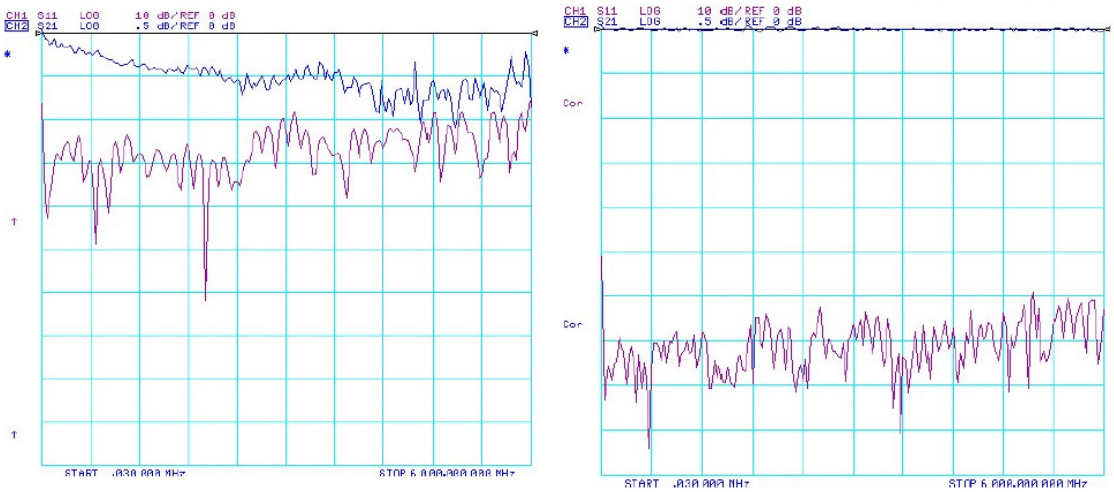


Figure 2: $S_{21}$ and $S_{11}$ for a thru line, BEFORE/AFTER calibration (the reference line is 0 dB).

## 3. <u>EQUIPMENTS</u>

HP 8753D Network Analyzer (30 KHz ~ 6 GHz)
SOLT calibration Kit
Device under test: band-pass filter, 10dB attenuator
Cables and adaptors

## 4. <u>EXPERIMENT</u>

4.1 <u>General Preparation and Information</u>

The instrumentation will be configured for you. Please note that the VNA, cables and adaptors are extremely expensive. Further, the connectors are easily damaged by carelessness and negligence. The onus is on you to handle with care. Ask if in doubt.

In the instructions that follow for the VNA HP 8753D: ***BOLD ITALIC ARIAL*** font means a front panel button; whereas *ITALIC ARIAL* means a screen menu selection.

Switch on VNA HP 8753D, press ***Start***, set the start frequency as 1 GHz, and then press ***Stop***, set the start frequency as 6 GHz.

4.2 SOLT Calibration

(1) Press ***CAL***, choose *CALIBRATION MENU*. There are several options in the screen as *S11 1-PORT, S22 1-PORT, FULL 2-PORT, TRL 2-PORT* etc. Here we choose *FULL 2-PORT*, and then there are *REFLECTION, TRANSMISSION* and *ISOLATION* in the side of the VNA screen.

(2). Press *REFLECTION* first, you will see 6 options in the screen. They are:
*FORWORD: OPEN, SHORT, LOAD;*
*REVERSE: OPEN, SHORT, LOAD.*

a. Connect calibration kit OPEN to port 1 using top wrench, and then click the *FORWORD: OPEN*, wait a while until the label underlined;
b. Replace the calibration kit OPEN from port 1 with calibration kit SHORT, and then click the *FORWORD: SHORT*, wait a while until the label underlined;
c. Replace the calibration kit SHORT from port 1 with calibration kit LOAD, and then click the *FORWORD: LOAD*, wait a while until the label underlined;
d. Connect calibration kit OPEN to port 2 using top wrench, and then click the *REVERSE: OPEN*, wait a while until the label underlined;
e. Replace the calibration kit OPEN from port 2 with calibration kit SHORT, and then click the *REVERSE: SHORT*, wait a while until the label underlined;
f. Replace the calibration kit SHORT from port 2 with calibration kit LOAD, and then click the *REVERSE: LOAD*, wait a while until the label underlined;
g. Press *STANDARDS DONE*. I, and wait for a while until the VNA internal computing process done.

(3) Press *TRANSMISSON* button beside the screen, and then connect the 2-port calibration kit THRU to port 1 and port 2. You can press *DO BOTH FWD + REV*, and the VNA will run the transmission calibration automatically.

(4) Remove the design kit from port 1 and port 2, and then press *ISOLATION* button beside the screen.

a. Press *OMIT ISOLATION*, wait a while until the label underlined;
b. Press *ISOLATION DONE*.

(5) Press *DONE 2-PORT CAL* to finish the whole full 2-port calibration procedure.

(6) Press *SAVE/RECALL* to save your cal data. Save it to a blank record and rename it as "EE3104" so you can recall it easily in the future.

4.3 Device Measurement

a) Band-pass Filter

Connect the 2-port band-pass filter to port 1&2 of VNA, press ***MEAS*** in the VNA control panel, and then choose *S11, S22, S21, S22* beside the VNA screen to observe its S-parameter performance.

b) 3-dB Attenuator

Connect the 2-port 3-dB attenuator to port 1&2 of VNA, press ***MEAS*** in the VNA control panel, and then choose *S11, S22, S21, S22* beside the VNA screen to observe its S-parameter performance.

(Note: You can Press ***FORMAT*** in the VNA control panel, and then choose *LOG/MAG, PHASE, SMITH CHART, POLAR* beside the VNA screen to decide the display format of your observation.)

## 5. QUESTIONS

5.1 Observe/sketch all the S-parameter for THRU connection after SOLT calibration.

5.2 Observe/sketch all the S-parameter of Band-pass Filter. (Freq range: 1~6GHz)

5.3 Observe/sketch all the S-parameter of the 10-dB attenuator. (Freq range: 1~6GHz)

5.4 During the calibration, what are the values of S12 and S21 for the OPEN, SHORT and LOAD circuit calibration measurements and S11 and S22 for the THRU calibration measurements?

## 6. REFERRENCES

[1] D. M. Pozar, Microwave Engineering, $2^{nd}$ Edition, John Wiley, 1998, Chapt. 4, Section 4.3.

[2] G.Gonzalez, Microwave Transistor Amplifiers – Analysis and Design, $2^{nd}$ Edition, Prentice-Hall, 1997, Chapt. 1, Section 1.9.