INTRODUCTION TO NETWORK ANALYSIS

Lab #3

The purpose of this lab is to gain a familiarity and understanding of basic vector network analysis. The lab also serves as an introduction to the use of a vector network analyzer (in our case, a Keysight E5080B). The network analyzer is an extremely versatile and powerful piece of equipment that is commonly used in high-frequency laboratories to characterize the electrical performance of many different types of components and systems, including active electrical devices like diodes and transistors, passive components such as capacitors and resistors, circuits such as amplifiers and mixers, and radiating components such as antennae.

Background

As seen previously in class and the previous lab, the measurement of impedance at microwave frequencies fundamentally depends on the ability to measure incident and reflected signals from a device under test. In a previous lab, we made a simple scalar reflectometer using a diode detector and a directional coupler. The basic structure of the network analyzer is similar to the simple reflectometer we investigated; a microwave source is coupled to the device under test through a directional coupler and the incident and reflected signals are analyzed to determine the reflection and transmission coefficients. The vector network analyzer takes this measurement one step further than the scalar reflectometer, using heterodyne techniques to allow the extraction of phase, as well as magnitude, information from the incident and reflected signals.

The usual procedure for making network analyzer measurements is to first calibrate the instrument, and then make the desired measurements. The calibration procedure consists of measuring a series of known calibration standards. Based on the measurements of these known standards, a model of the performance characteristics of the microwave hardware internal to the network analyzer can be constructed. This model is sometimes called an *error model* or the *error adapter*. The details of the error model calculations will be examined in next week's lab. After this model has been generated from the measurement of the calibration standards, the network analyzer's software mathematically removes the effects of the hardware's non-idealities, and subsequent measurements of other devices are corrected for these imperfections.

In this laboratory, we will collect the data necessary to perform the 1-port error correction, in order to gain an appreciation for the process and the significance of the corrections for typical measurements. **Note: please watch the video demonstration before coming to lab.**

Procedure

Warning: The E5080B is a static-sensitive instrument; you must discharge any static charge on your hands by touching the outer shell of the port connector before making any connections. You should also avoid touching the center pin of the cables connected to the network analyzer to avoid accidental static damage. In addition, the calibration standards and adapters associated with the E5080B are precision devices and are expensive, so caution must be used at all times to use proper technique when connecting and/or disconnecting the cables or adapters.

a. Connect a 15 foot RG-8A/U cable to the network analyzer test port 1. Normally, it is good practice to use the shortest length of cable possible. But by using a long cable in this lab, the loss and additional phase introduced by such a long cable makes the corrections more "interesting."

b. Set up the network analyzer to measure the calibration standards. For this lab, set the instrument to measure over the frequency range from 300 kHz to 3 GHz with 201 data points. These settings are accessed by pressing the "Freq" button, then using the "Start Frequency" and "Stop Frequency" softkeys. The number of points can be set by pushing the "Sweep" button, and using the "Number of Points" softkey. To set up the noise reduction in the analyzer, press the "Avg BW" button. Turn off averaging (averaging is turned on or off by the smaller softkey to the left of the "averaging" softkey; a green box indicates that averaging is on, a gray one indicates that averaging is off. Select an IF bandwidth of 1 kHz.

c. Being careful to use correct connection techniques, use the precision type N calibration kit to measure a short, open, and termination on port 1. Please see the demo video for an example of how to do this. Import the results of each measurement into to Matlab, using the k5080bread_raw.m Matlab script. This script connects to the instrument, and will download the measured data. The format of the command is "[x,y]=k5080bread_raw". This puts the frequencies of the measurement in the vector x and the measured reflections (uncorrected) in y. Since this is a vector measurement, y is complex. Be sure to run the script for each element in the cal kit (open, short, and termination) and save the data in a different vector (since you'll need the measured data from all three). I recommend saving the Matlab workspace after each measurement, just in case something goes wrong with the measurement download (if the measurement fails, you'll need to exit Matlab and re-start it).

d. Using Matlab, make plots of the measured s_{11} (for a one port measurement like this, s_{11} is the same as Γ) for each of these standards (a dual-trace plot with the magnitude and phase of s_{11} is one common format; a plot of real and imaginary parts of s_{11} vs. frequency is another). Be sure to set the axis scaling to something reasonable—setting the mag/phase plot to have the magnitude on the left y axis and the phase on the right y axis is often helpful (Note: Matlab plots angles in radians; you may wish to convert to degrees for easier interpretation). You may use your judgment as to which style of plot provides the most useful data for a particular standard. You will use these data to implement your own correction routine in next week's lab, so be sure to note the vector names carefully.

e. Using the same techniques, measure the microstrip stub circuit (the same as last week's lab) and the 100 Ω GR termination. Download, plot, and save the raw measured s-parameters, being sure to keep careful notes about which vectors correspond to which measurements in your lab notebook. Also, be sure to save the Matlab workspace someplace safe (you will need this data for next week's lab).

f. Using the network analyzer's built-in Full 1-Port calibration feature, calibrate the network analyzer. The demo video shows the details of calibration. You access the calibration functions with the "Cal" button, followed by the "Basic Cal…" softkey. Select the "Type N (50)" for the connector, "85032B/E" for the cal kit (this matches the standards we have), and be sure that only "Port 1" is selected. For the gender of the port, the analyzer is asking for the gender of the end of the cable (not the gender of the standards). Use "Male" for the cable we are using. Cal type should be set to "OSL" ("OSL" stands for open, short, load; this tells the analyzer what types of standards we will use). Press "Next" and the analyzer will guide you to measure an open, short, and broadband load.

Being careful to connect them properly, attach each standard and press the appropriate button. Press “Finish” when everything has been measured.

g. With the analyzer calibrated, we can now make calibrated measurements of devices. Use the analyzer to make calibrated measurements of the microstrip stub circuit and the 100 Ω GR termination. Use the Matlab script “[x,y]=k5080bread_corr” to import the calibrated/corrected s-parameter results. Note that “k5080bread_corr” has the same syntax as the k5080bread_raw script, but it uses the analyzer’s internal corrections; using “k5080bread_raw” will download uncorrected, raw data. Once these measurements are imported into Matlab, make plots of the corrected data. These will be compared to the results of your own error model calculations in next week’s lab, so be sure to save the Matlab workspace and data somewhere safe.