INTRODUCTION TO NETWORK ANALYSIS

Lab #4

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 the vector network analyzer (in our case a Keysight E5071C). 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 determined in previous lab experiments, 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 crystal detectors 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 reflected and transmitted 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 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, a microprocessor in the network analyzer mathematically removes the effects of the hardware's non-idealities, and subsequent measurements of other devices are corrected for these imperfections.

Procedure

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.

Warning: The E5071C is a static-sensitive instrument; you <u>must</u> 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 E5071C are extremely expensive, and 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 (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. In the "averaging" menu, turn on averaging, turn off averaging and select an IF bandwidth of 1 kHz. Due to the long cable length, set the sweep time to 5 seconds (under the "sweep setup" menu).

c.) To facilitate transferring the measurement data from the network analyzer to the computer, run the ee40458 shell script (available from the course web page; either " "source ee40458.sh" for bash users (default) or "source ee40458.csh" for c-shell users). This script modifies the path and some environment variables needed for software used in this course. You may want to add this to your .profile (bash) or .cshrc (csh) startup files to make these programs available automatically when you log in.

d.) Being careful to use correct connection techniques, use the precision type N calibration kit to measure a short, open, and termination on port 1. Download the results of each measurement to the workstation by running the program "readraws11 <filename>" from the command line. This produces a text file containing the measurement data in 3 columns (frequency, real part of s_{11}, imaginary part of s_{11}) that can be easily loaded into Matlab for display or manipulation.

e.) Using Matlab, obtain plots of s_{11} 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). The file "s11read.m" is available in the lab experiments section of the course website (http://www.nd.edu/~hscdlab/labexp.html). This script eases reading the downloaded s_{11} data into Matlab. 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. You may use your judgment as to which 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 filenames carefully, and save them someplace safe.

f.) Measure the microstrip circuit board and the 100 Ω GR termination. Download, plot, and save the raw s-parameters, being sure to keep careful notes about which files are which in your lab notebook. Also, be sure to save the files someplace safe.

g.) Using the network analyzer's built-in Full 1-Port calibration feature, calibrate the network analyzer and re-measure the GR 100 Ω termination and microstrip circuit. Use the program "reads11 <filename>" to download the corrected s-parameter results. Note that "reads11" includes the analyzer's corrections; using "readraws11" will download uncorrected, raw data. Load these into Matlab and prepare 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 files somewhere safe.