ERROR CORRECTION FOR NETWORK ANALYSIS

Lab #4

The purpose of this lab is to gain familiarity and understanding of the systematic error correction techniques that are almost universally applied in vector network analysis and are implemented in firmware in most modern network analyzers, including the Keysight E5080B network analyzers in the laboratory.

The usual procedure for making network analyzer measurements is to perform a calibration procedure. This 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*. 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.

Typical imperfections that the calibration procedure can remove from measurements are frequency dependencies and non-idealities in the directional couplers internal to the network analyzer, impedance mismatch effects of the network analyzer's microwave source, impedance mismatch of the test cables, and electrical discontinuities due to any connectors or adapters in the measurement path. The main restriction on the types of errors that the calibration procedure can correct is that they must be repeatable (i.e. *systematic* errors) and present for the measurement of all of the standards. Figure 1 (next page) shows the basic procedure for a 1-port calibration. The standards most often measured for a 1-port calibration standards at modest microwave frequencies are the short, open, and matched termination. Based on the measurements made of each of these standards, the values of the components in the error adapter flow graph (edf, esf, and erf) can be computed. Once these values are found, the s-parameters can be corrected for these non-idealities by solving the equation:

$$s_{11a} = \frac{(s_{11m} - edf)}{erf + esf(s_{11m} - edf)}$$

where s_{11m} is the directly-measured (or *raw*) s-parameter, s_{11a} is the "actual" (corrected) s-parameter, and erf, esf, and edf are the error adapter coefficients. For two-port measurements (such as for an amplifier, transistor, or other "transmissive" device, additional calibration standards are required, but the basic idea remains the same as in this one-port example.

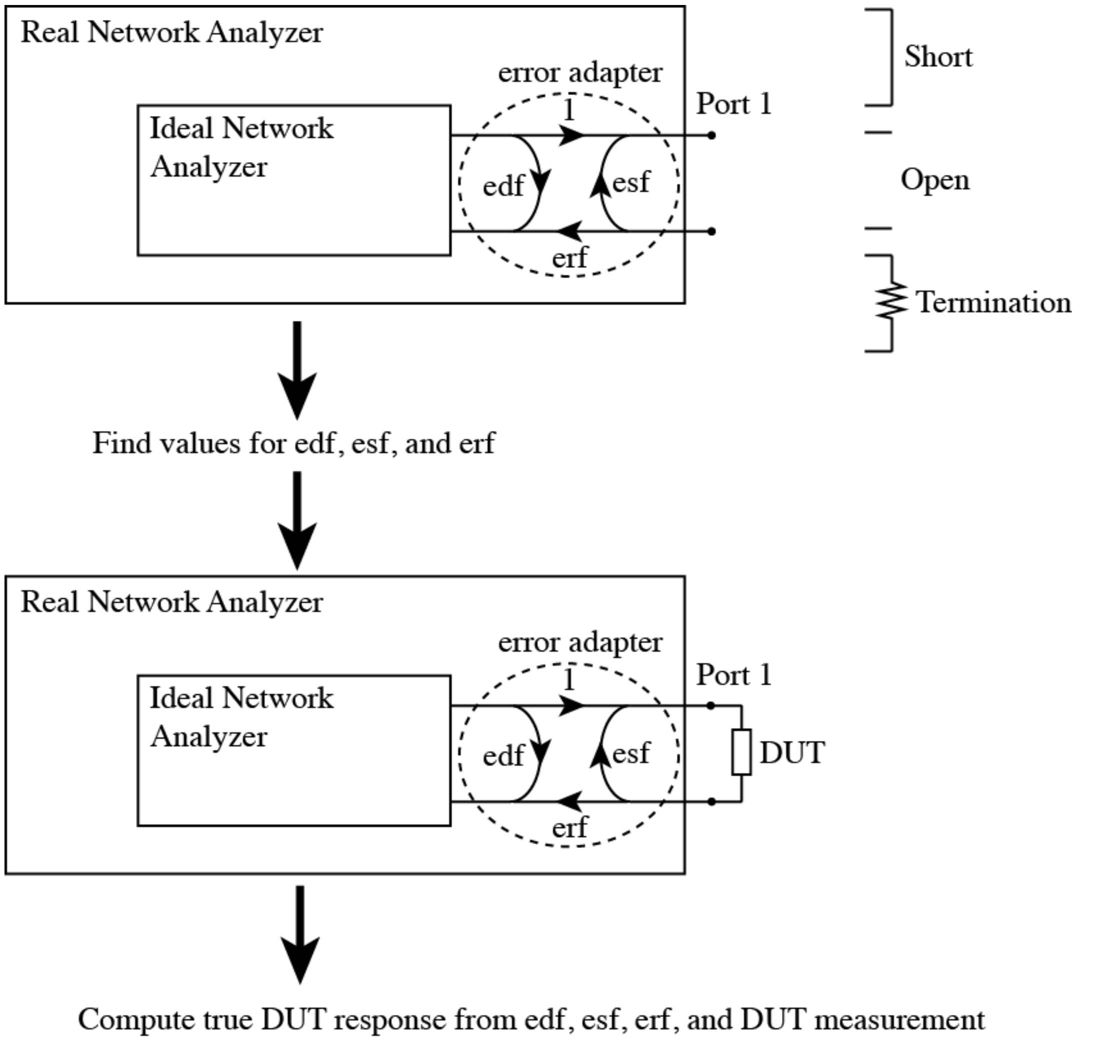

Figure 1. Outline of basic calibration procedure for vector network analysis.

a. Using the flow graph for the 1-port error adapter in Figure 1, derive expressions relating the coefficients of the error adapter to the measured s_{11} of the calibration standards. You may find Mason's rule to be helpful with these derivations. You may further assume that the calibration standards are ideal, that is, that s_{11} for a short is –1, s_{11} for an open is +1, and s_{11} for a matched termination is 0. Keep in mind that all of the coefficients and measurement results contain phase information, and are thus complex numbers.
b. From the flow graph of the error adapter, derive the expression given earlier in the lab that relates the actual s_{11} of the device (s_{11a}) to the measured s_{11} (s_{11m}).
c. Implement the one-port error correction model in Matlab to compute s_{11a} from s_{11m}, erf, edf, and esf as a function of frequency. Your code should accept the calibration measurement and the DUT measurement vectors from Lab #3 as input, and produce a corrected measurement vector as output. Please include the source code for your correction procedure in your lab notebook.

d. Using your correction procedure, compute and plot corrected s_{11} values vs. frequency for the microstrip stub circuit and the 100 Ω GR termination measured in Lab #3. Compare the results to those obtained using the network analyzer's built-in calibration feature in last week's lab. How do they compare, and what are the potential sources of any differences you observe? Look carefully at the data, describe any discrepancies between your corrected data and what was obtained using the VNA's internal calibration, and suggest possible sources of error that give rise to these discrepancies.
e. Comment on the error correction procedure and any limitations it may have. Are there any types of errors that this error adapter model is not capable of compensating for? Are there any parameters to which the calibration procedure is extremely sensitive, giving rise to potential repeatability problems?