Radio Frequency Engineering Laboratory

Exercise RF1: VNA, Smith-Chart

Within this lab exercise you will get familiar with vector network analysis using a network analyzer and gain practical experience in the usage of the Smith chart.

Exercise Preparation:

To prepare for this laboratory exercise the study of Chapter 2.1 “Reflections on transmission lines” and 2.2 “The Scattering Matrix” of the lecture script “VU RF Techniques” is recommended. Documents referring to the calibration and its theoretical background can be found on the home page (http://www.emce.tuwien.ac.at/hfadmin/354059/index.htm) in the file “Vector network analysis and calibration”.

Exercise execution:

Calibration:

When performing measurements with a VNA it is essential to calibrate the measurement system to remove all systematic errors. This is accomplished by applying several known circuit-elements (calibration standards) to the VNA’s DUT-connectors (= reference planes for this calibration) in a standardized procedure. If the desired device under test (DUT) is equipped with coaxial interfaces (like BNC, SMA, …) the SOLT (S…Short, O…Open, L…Load, T…Thru) calibration procedure is more or less standard because accurate calibration standards are broadly available. Otherwise, for transmission lines and structures and circuits within a PCB, another type of calibration and standards is needed to shift the reference planes “into” the PCB. These so called TRL- standards (T…Thru, R…Reflect, L…Line) are usually manufactured exclusively for a specific PCB substrate. Both sets of standards are depicted in figure 1.

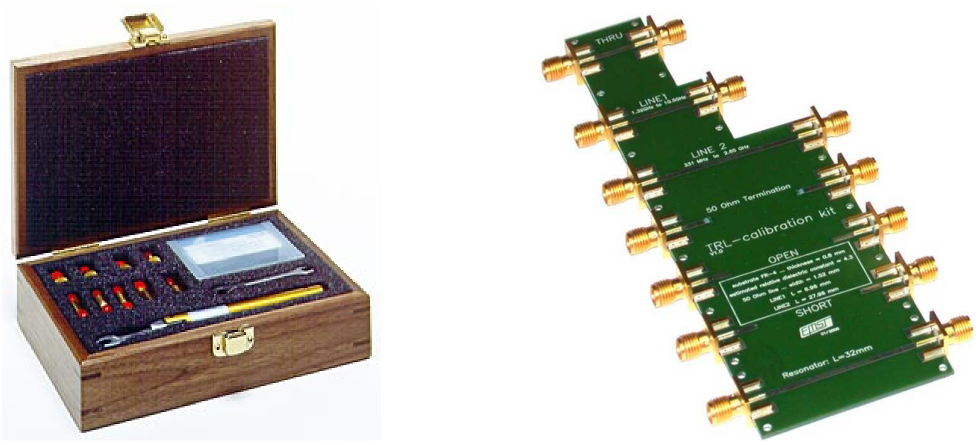

Figure 1: Calibration kit for SOLT and TRL:

Besides choosing the correct calibration procedure (depending on the interfaces of the DUT, frequency range, etc.) it is important to be aware of the following settings before performing a suitable calibration:

- Frequency range and number of frequency points
- Output and input power at the measuring ports

Dependent on the type of measurement it is not always necessary to do a complete full two port calibration. To characterize e.g. the insertion loss, it can be sufficient to perform a response calibration by directly connecting the measurement ports of the VNA.
It is beneficial to check the calibration by re-measuring the different calibration standards and verify whether the measured S-parameter data is located in the Smith-Chart where it is expected to be.
During this verification one will notice that the traces of the “open” or “short” elements are not concentrated at a single point in the smith chart as one might have expected.
Question: What causes this behavior? How can this result be interpreted? What would happen when “short and open” had been swapped during the calibration procedure? What would be the result of measurements conducted without performing any kind of calibration previously?

S-parameter Measurements:
Within this part of the exercise, the task is to characterize different devices using a VNA and to think about a possible application for these devices under test.
First of all, determine the correct calibration procedure for this task, as well as suitable frequency and signal-power settings.
Secondly, surface mounted devices (embedded within a test fixture) should be characterized by figuring out the type of component (inductor, capacitor, and resistor) as well as its frequency dependent effective value. Discuss the parasitic effects and corresponding equivalent circuit representations.

Reference Plane:
From the previous measurements as well as the calibration procedure it should be rather clear that using correct reference planes is mandatory. Although for certain measurements it can be beneficial to manipulate them. The VNA has several built in mathematical functions to do so.
Electrical delay: Manipulates the phase of the current measurement by adding a constant or a linear term.
Port Extension: This function manipulates the measured data, for example, according to a transmission line model or pre-characterized S-parameter values of test-fixtures in order to virtually shift the reference plane.
Try to apply different kinds of electrical delays and port extensions to several measurement objects during the exercises. Discus the results and compare the different capabilities of the VNA instrument.

Accuracy Analysis:
Due to imperfections of the calibration standards some residual errors remain after calibration. Consequently, these errors cause imperfectly measured impedance values close to the unity circle in the Smith-Chart. Fist, try to determine the value of different resistors using the VNA and compare the results to a multimeter measurement.

Output Power at the Test Ports:
As already mentioned above, sensitive components and instruments have to be to prevent from destruction due to test signals exceeding the devices maximum power ratings. Less critical but equally annoying are useless measurements caused by non-linear operation of any involved element (DUT or VNA). Consequently, the input power (measurement power=output power at the test ports) has to be carefully chosen! On the one hand, if the input power is set too high, harmonics will be generated which can not be analyzed by the VNA or the instrument can be destroyed! In contrast, low values cause bad SNR values for the measurement and, therefore, can cause large measurement errors. Try to estimate the losses in the s-parameter test-set and cables.