

Experiment 09 - Advanced Technique

1 Introduction

In many S-parameter measurements, one wishes to obtain data for only a subsection of the entire system under test. A test fixture may be required between the normal coaxial calibration planes and the DUT; it may be useful to see the DUT performance with a certain matching network in place, it may be desired to see what the subsystem performance would be when the given DUT is inserted, etc.. In such cases, direct measurements of the DUT can not be performed. Figure 1 shows a simple yet concise illustration of the scenario. Here is an interesting work, measuring and modeling an on-wafer CMOS inductor, closely related to what is described in this Experiment: <http://ieeexplore.ieee.org/document/5498302/>

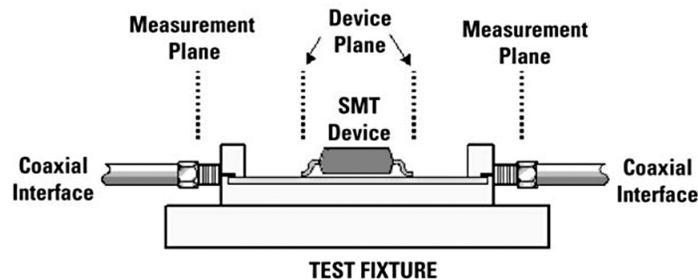


Figure 1: In-fixture measurement. Image originally from [1]

In the previous Experiment, you learned to use TRL calibration to remove the effects of all discontinuities between the so-called *measurement plane* and the *device plane* shown in Figure 1. In this Experiment, we will investigate more techniques that allows to separate and extract the data. The first technique is *port extension*. The second technique you will learn is, in fact, the general problem of which port extension is only a simplified case, provide more accurate result for measurements with a fixture included, the *de-embedding* technique.

You will practice with these techniques on the microstrip student unknown, which you are much familiar with by now; an impedance transformer embedded exactly the same way as the microstrip student unknown shown in Figure 2 and a 2-port meander line filter embedded between 2 traces shown in Figure 3. Note that they are not 50-ohm traces.

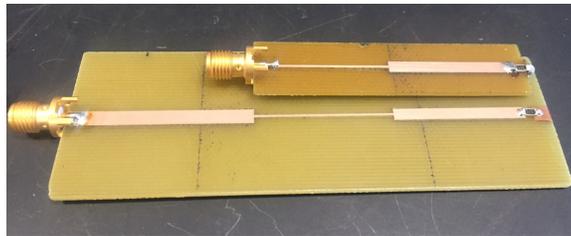


Figure 2: Embedded and non-embedded impedance transformer

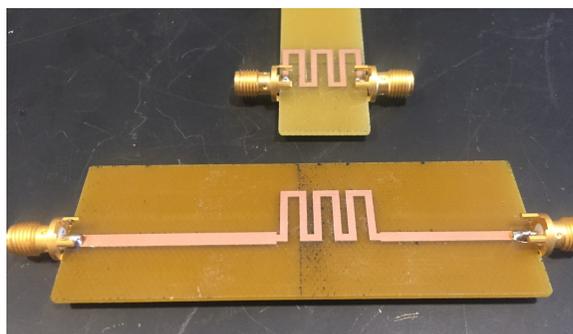


Figure 3: Embedded and non-embedded meander line filter

2 Background

Port-extension

The classical de-embedding problem is the removal of the effects of a fixture or wafer probe. If one can treat the fixture/probe as a simple length of 50 ohm transmission line, then the problem reduces to one of shifting the reference planes, known as port extension. The familiar SOLT calibration is performed with coaxial standards, an *electrical delay* is then added to effectively extend the measurement plane through the connector and out to the desired point on the microstrip line where the device plane is, thereby obviating the need for difficult-to-build microstrip standards. This has two potentially serious drawbacks: (1) the coax-to-microstrip transition discontinuity, and (2) non ideal transmission line characteristics of the microstrip line, such as attenuation and dispersion. Neither of these effects are characterized and removed by this technique. Hence, this simple technique usually works best in measurements where the frequencies involved are not too high.

S-parameter De-embedding

Figure 4 shows de-embedding workflow with Agilent VNA.

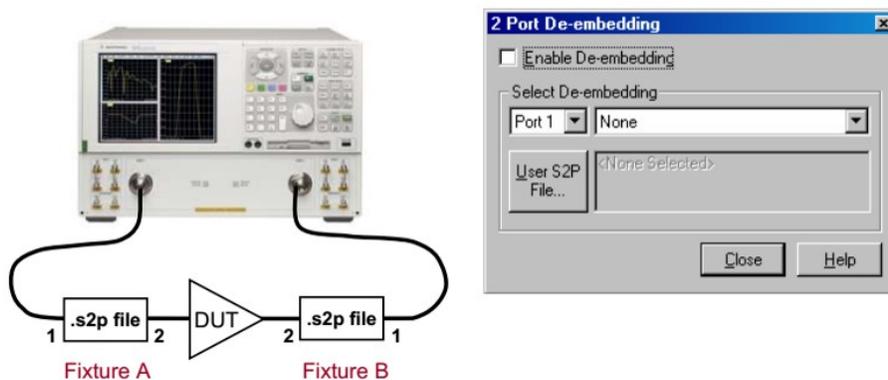


Figure 4: De-embedding technique with Keysight/Agilent VNA. Chart originally from [2]

De-embedding technique is based on cascading different blocks of S-parameters. It is known from the nature of S-parameter that it can **not** be cascaded directly. The most common way to deal with cascaded blocks of S-parameters is to convert them to T-parameter. T-parameter of the DUT is then computed and converted back to S-parameter as shown in Figure 5.

Multi-port de-embedding techniques make use of more complicated formulas and hence, will not be discussed here.

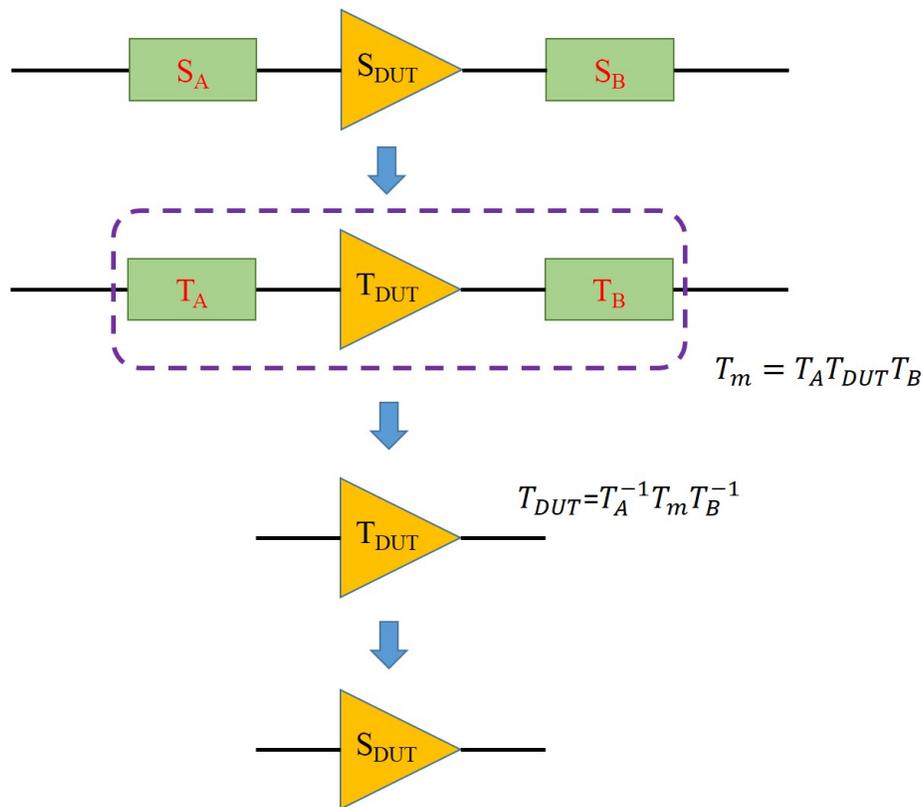


Figure 5: 2-port de-embedding formulation

3 Pre-lab

1. If the microstrip student unknown were embedded after a 1.5in 100Ω microstrip line, would the port extension method be able to shift the reference plane?
2. Write conversion formulas between S- and T-parameter? Why cannot S-parameter be used to cascade multiple blocks while T-parameter can?
3. Use Problem 1, Homework 3 or your intuition to prove that a 50-ohm ideal transmission line measured at frequency f under a 50-ohm system has S-parameters as

$$S = \begin{bmatrix} 0 & e^{-j2\pi f\tau} \\ e^{-j2\pi f\tau} & 0 \end{bmatrix}$$

where τ is the delay by which signal propagates along the line. Plot $\text{phase}(S_{21})$ versus frequency f **qualitatively** and show where τ appears in your plot.

4 Equipment

- Agilent E8358A VNA.
- Agilent 85052D 3.5mm SOLT calibration kit.
- Embedded 1-port microstrip student unknown, 1-port impedance transformer.
- Embedded 2-port DUT.
- 3.5mm cables.
- N-type to 3.5mm adaptors.

5 Procedure

Part I - Port extension: 300kHz - 4GHz

The microstrip student unknown and the impedance transformer will be measured first. In order to bypass the 1.5-in microstrip line embedded between the actual DUT and the SMA port using port extension, we need to know the electrical corresponding to that 1.5-in microstrip line. We will measure it in 2 different ways.

1. Calibrate the VNA from 300kHz to 4GHz using SOLT.
2. Connect the TRL REFLECT standard to Port 1. Set display to “SMITH CHART”. Dial in the appropriate amount of ELECTRICAL DELAY so that the displayed impedance is “balled up” around that of an open (somewhere between 350 and 500 picoseconds should work). You now have determine the electrical delay of the 1.5in microstrip line. Explain why is this true? What is the value you found?
3. With the electrical delay added, you now can connect the DUTs and measure them. If it is the microstrip student unknown, make sure you have the same one you used last time. Save the data and compare it against your measurement in the previous Experiment. If it is the impedance transformer, you have the non-embedded one as shown in Figure 2 to compare with.
4. You will now measure the electrical delay of the 1.5in microstrip line by a different way. Reset any electrical delay on any port (if any) to 0. Connect the THRU standard to 2 ports of the VNA. Set display of S21 to “PHASE”. Use question 3, *pre-lab*, put 2 markers at any two points to collect data and compute the electrical delay. Note that since the THRU is 3in, two times longer than the REFLECT, or the “obstacle” between the DUT and SMA connectors, the electrical delay found in this step should be halved to give the effective value for shifting the reference plane.
5. With the delay corresponding to 1.5in microstrip line added to port 1, you can now measure your micstrip student unknown again. Collect the data.
6. Compare the electrical delay values found in step 2 vs step 4? Compare the microstrip student unknown measurement in step 3 and step 5? Which one do you think is more accurate? Which one is more convenient? Why?

Part II - De-embedding: 300kHz - 6GHz

In this part, we will encounter with a more general case of embedding DUT where the “obstacles” are no longer a simple piece of 50-ohm transmission line. As shown in Figure 3, the meander line filter (DUT) is embedded between 2 traces. As depicted in Figure 4, we need to measure 2 fixtures between the DUT first.

1. Calibrate the VNA with SOLT calibration from 300kHz to 6GHz.
2. Measure the non-embedded filter. Obtain the S-parameter.
3. Now, we will start the fixture measurement process. First, obtain the S-parameter for the 2 fixtures. You should have two .s2p files before moving on.
4. Connect the DUT and start de-embedding process.
5. Go to **Calibration > Fixturing Selection > 2 port De-embedding**. A dialog as in Figure 4 will pop up. Choose proper port and *recall* the correct .s2p files you have saved earlier. Check the “Enable De-embedding” box before you exit from this window.
6. Go to **Calibration > Fixturing ON/OFF** to turn on the de-embedding feature.
7. Obtain the result, compare with that from step 2.

6 Conclusion

1. What are pros and cons of the de-embedding technique?
2. Does your direct measurement of DUTs (both 1-port and 2-port) agree very well? If not, what could be the sources of discrepancies?

References

- [1] Hiroyuki Maehara, “Using VNA Calibration Capabilities to Achieve Extremely Accurate Built-in Spectrum Measurements,” <http://www.mpdigest.com/2016/11/22/using-vna-calibration-capabilities-to-achieve-extremely-accurate-built-in-spectrum-measurements/>, nov 2016, [Online; accessed 30-Mar-2017].
- [2] Agilent Technologies, Inc., “Modern Measurement Techniques for Testing Advanced Military Communications and Radars,” 2006.