

Experiment 08 - TRL calibration

1 Introduction

In previous experiments, you have been familiar with SOLT calibration method. This experiment is to get you hands-on experience with TRL calibration method. In homework 4, you were asked to design a TRL calibration set to remove the effect of 1.5-in microstrip lines on both sides of a 2-port DUT. You will first characterize your TRL standards then use it to measure the DUT. You will learn how to define your designed TRL set in a VNA before using it.

You will also measure a microstrip student unknown which is kept from direct access by a 1.5-in microstrip line as shown in Figure 1. Like the coaxial student unknown (with which you are by now well familiar), this microstrip version consists of a reasonably well-matched termination and a tuning stub providing a large impedance variation versus frequency. The stub is now open-ended, however, unlike the shorted coaxial stub.

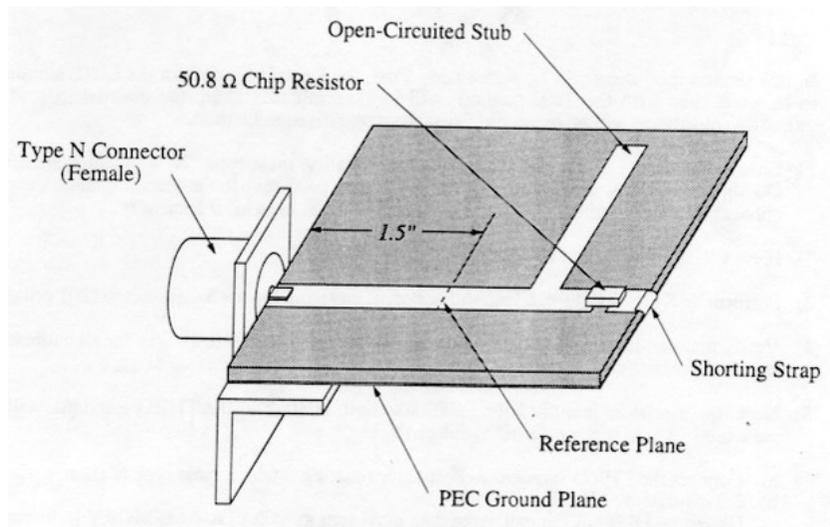


Figure 1: Microstrip student unknown

If your designed TRL calibration set does not perform as expected, you can use the ECE451 in-house TRL calibration set which you have used in Experiment 6. This TRL set consists of 2 identical REFLECT standards of 1.50 in long, a THRU standard of 3.00 in long and a LINE standard of 3.75 in long. However, keep in mind that the in-house TRL calibration set is not guaranteed to work over the frequency range of interests in this experiment even though it shares the same effect of shifting your reference plane 1.5 in from the SMA connectors towards the DUT.

2 Background

The SOLT vector error correction model was shown to be very effective in characterizing and removing systematic measurement errors. With this method, systematic errors are characterized through measurement of calibration standards, for which the actual responses are known. The accuracy obtainable is largely dependent upon the accuracy to which these actual responses are known. For coaxial measurements, suitable calibration standards with known impedances are readily available—short, open, and matched terminations are commonly used. In non-coaxial measurements, however, it is much more difficult to build standards with impedances which are easily

characterized. This is particularly true in microstrip line, where short circuits are inductive, open circuits radiate energy, and purely resistive loads are hard to build.

Measuring a microstrip line based DUT is facing two potentially serious difficulties: (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 SOLT especially if the DUT is embedded between microstrip line traces.

The TRL calibration method uses transmission line standards instead of discrete impedance standards to obtain the terms of a two-port error model. Its math is more complicated but the result is elegant yet accurate.

3 Pre-lab

1. What is the electrical delay between your LINE and THRU standards? Show ADS simulation and/or necessary calculations of your TRL design to support your answer.
2. It is important to keep the relative electrical length of the LINE compared to the THRU between 0 and 180°. Why or why not do you think this is true?
3. Show the relative phase between your LINE and THRU standards in your design? (**Hint:** In Figure 2, $\frac{b_2}{c}$ could give the relative phase between LINE and THRU)

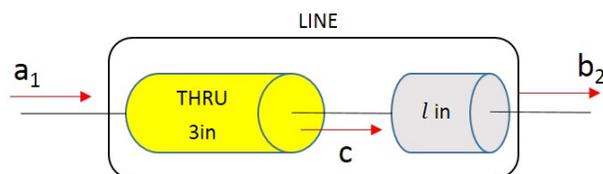


Figure 2: LINE standard break-down equivalent circuit

4 Equipment

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

5 Procedure

Part I - Characterize TRL standards: 1GHz - 6GHz

In this part, you will measure your LINE, THRU, REFL as DUTs to study their characteristics.

1. Calibrate the VNA as usual by SOLT in the frequency range of interest.
2. Go to **Scale > Electrical Delay** to make sure that **no** electrical delay is added to the measurement.
3. Now, measure the REFL in your TRL set. Save the data.
4. Switch to measure the THRU, save the data. Leave the THRU connected.

5. We now will testify your answer in question 4, *pre-lab*. Since the THRU and the LINE are exactly same transmission lines except for their lengths, their phases should look similar but a phase shift corresponding to an electrical delay of the LINE w.r.t to the THRU. It means if we remove the electrical delay in your answer to question 4, *pre-lab*, from the measurement of the LINE, their phases be overlapped. Here is how to obtain that with the VNA

- First, display phase(S21) on the active trace.
- Now, we will save the active trace into the VNA. Under the **TRACE** menu, click on **Math/Memory**. Press “**DATA -> MEMORY**”. Then select “Memory trace” in Trace view options. Now, the current trace displays phase(S21) of THRU measurement.
- Replace the THRU with the LINE, you should see the active trace remains unchanged since it is showing the data from memory, not directly from the measurement.
- Go to **TRACE > NEW TRACE > S21** to open a new trace, this new trace, by default will show the measurement data. Display phase(S21) again, you should see 2 traces on the screen, one is the shifted version of the other.
- Now, make sure your active trace is the phase(S21) of the LINE, go to **SCALE > ELECTRICAL DELAY** and add the electrical delay you have in question 4, *pre-lab*. You should see the current active trace shifts and overlaps with the memory trace. This confirms the relative electrical delay between the LINE and the THRU. Note that in practice, the electrical delay will not as exactly same as what you have calculated. Comment on this discrepancy.

Take a screenshot of what currently shows on the screen and include it along with the actual value for electrical delay you put in to your report to show that by removing the electrical delay from the LINE, you get the THRU data.

Remember to save the LINE measurement then plot the S parameters to compare the data of THRU and LINE measurement against your simulation in Homework 4.

6. One important aspect of using TRL calibration is that the **relative** phase of the LINE w.r.t the THRU should be maintained between singularity phase jumps. Use your LINE and THRU data to extract it and plot it in ADS. Based on the relative phase plot, does your LINE meet the operating requirement over the interested frequency range?

Part II - Measure embedded DUT using TRL calibration: 1GHz - 6GHz

You now will define your TRL calibration kit and use it to measure the embedded DUT. To define a new TRL cal kit, do as follows

1. First bring up the **Calibration > Advanced Modify Cal Kit** menu. A new pop-up window must show up.
2. Click **Insert New**, in “Kit Name”, write “ECE451_TRL” and in “Kit Description”, write the last names of your group members.
3. Under “Connectors”, click **Add or Edit**. In the new pop-up window, write “SMA” in Connector Family, click Gender Male, and write frequency from 0 to 8999 MHz. Leave default values of 50 ohms for **Z0** and COAX for **Media**. Then click “OK” to exit the window.
4. At the bottom, click on **Add** and add **OPEN** and in the new pop-up window, fill the following in the appropriate place. Label REFLECT, set **C0 - C3** to 0. **Delay** is 0 psec. This will add REFLECT standard in to your cal kit.
5. To add the THRU and LINE, choose THRU option. The only difference in between them is that you have to set the **Delay** for the LINE to the value you got from **Part I**. Make sure you label the LINE as LINE (not as THRU).
6. Now you must have three standards in your Edit kit mini window.

7. Now, in the same window change the **Class Assignments** to TRL then click **Edit**, in the new pop-up window, assign each of the standards. For example, Choose **TRL THRU** in **Calibration Kit Class** and select and add THRU from the “Unselected Standards” to “Selected Standards”. Do the same process for TRL REFLECT and TRL LINE.
8. In **Calibration Reference Z0** option, choose **LINE Z0**. In **Test Port Reference Plane**, choose **THRU STANDARD**. Then click **Ok** and exit from the Class Assignments window. Also click **Ok** and exit from Edit kit window.

Now, you have your TRL cal kit defined, you are ready to perform TRL calibration and measure the DUT.

Note: Make sure the active trace where you are doing measurement has **no** Electrical Delay.

- Measure the microstrip student unknown. Save the data.
- Measure the 2-port DUT, save the data.

Part III - Measure embedded DUTs from 300kHz - 9GHz

Measure the DUTs again using the same TRL cal set you have used above, but this time, do it over a wider frequency range, i.e. 300kHz - 9GHz. What would you expect about the measurement this time? Does the result meet your expectation?

6 Conclusion

1. Carefully present the relative phase between your LINE and THRU standard. Comment on the result. Would your TRL design work well in the frequency range of interest?
2. Show S parameters of DUTs you measure, is the result expected? Does it testify your conclusion in question 1?