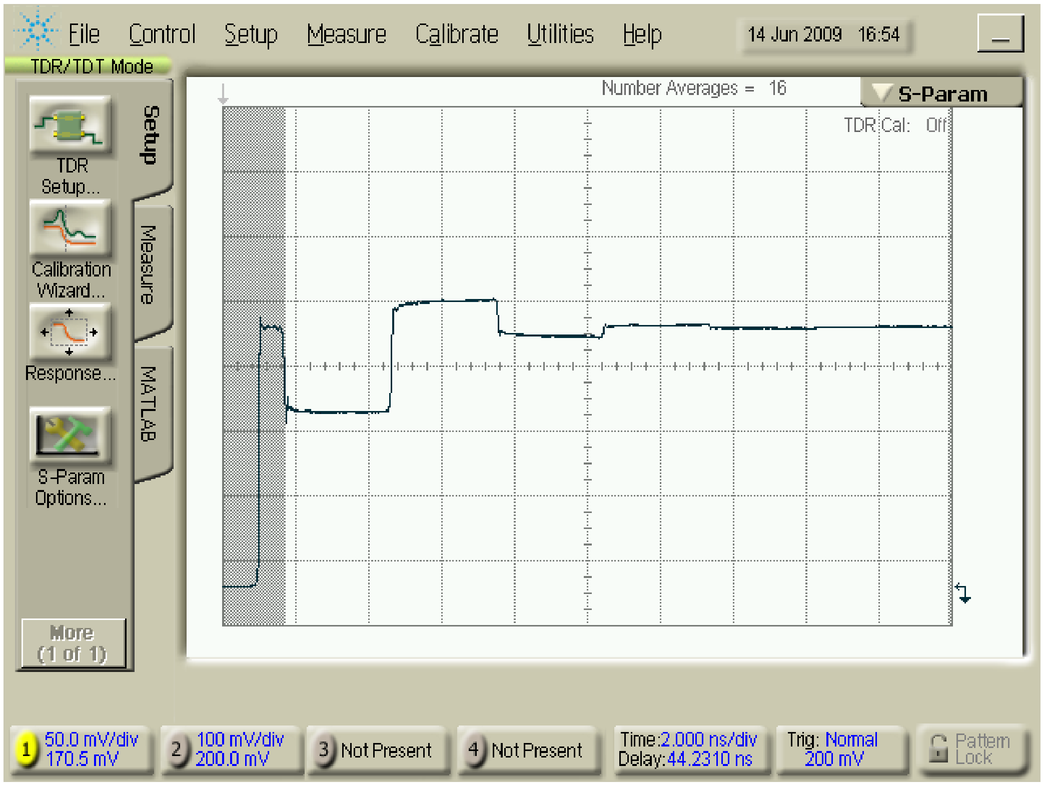

Time Domain Reflectometry

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1 Introduction

The goal of this lab is to familiarize the students with the time domain reflection (TDR) measurement. As discussed in today's lecture, TDR involves launching a fast-rise pulse to the device under test (DUT) and monitoring what comes back.

TDR is a time-domain complement to network analyzer measurements. It characterizes a single port — equivalent to S_{11}/S_{22}[1].

As you probably well know, for a linear time-invariant (LTI) system there is a fixed relationship between frequency and impulse responses:

$$H(s) = \int_{-\infty}^{\infty} h(t)e^{-st}\,dt \tag{1}$$

where $h(t)$ is the impulse response and $H(s)$ is the frequency response for $s = i\omega$.

However what is measured by the TDR (or TDT) is not an impulse response, but a close approximation to a step response. The relationship between impulse and step responses is:

$$a(t) = \int_{-\infty}^{t} h(\tau)\,d\tau \tag{2}$$

2 Lab Equipment

In this lab you will use Agilent 86100C oscilloscope mainframe with 54754A dual-channel TDR/TDT plugin. In our measurements we will characterize a collection of devices:

1. SMA tee, 50 Ω load, cable;
2. 2.5 GHz terminator;
3. 18 GHz terminator;
4. A "special" 18 GHz terminator;
5. A printed circuit board (PCB) with several microstrip lines;
6. An unusual 3 dB attenuator;

[1] Time domain transmission (TDT) measurement will characterize S_{21}/S_{12}

7. Two low-pass filters: K&L 5IL41-60/H1000-O/O and Mini-Circuits SLP-100.

WARNING: TDR plugin module inputs are precision 3.5 mm connectors. These connectors are quite fragile and sensitive to mishandling. To protect them we have mounted SMA "connector savers". Please do not remove them. When attaching hardware to "connector savers", do not use SMA wrenches — only your fingers!

WARNING: Wideband sampling scope inputs on 54574A plugin are very sensitive and can be easily damaged by excessive voltages or static electricity. Before connecting any coaxial cable to the connectors, momentarily short the center and outer conductors of the cable together. Avoid touching the front-panel input connectors without first touching the frame of the instrument.

3 Exercises

Before you start all the measurements, select `Setup`, `Default Setup` to reset the instrument to known conditions. Next, under `Setup`, `Mode` select `TDR/TDT Mode`. You should see the TDR waveform on channel one.

3.1 SMA tee

The SMA tee measurement setup is shown in Figure 1. The male connector of the tee is connected to the test port. One output of the tee is terminated with 50 Ω load, and another is connected to a 12" white cable.

Once the signals are connected, you will see multiple reflections, spaced by the roundtrip propagation on the cable.

3.1.1 Questions

1. Measure the electrical length of the cable/tee assembly: ____________

2. Homework: save and print out the screen image. On a printout, label each segment of the waveform and write a short paragraph/sentence explaining what causes each feature.

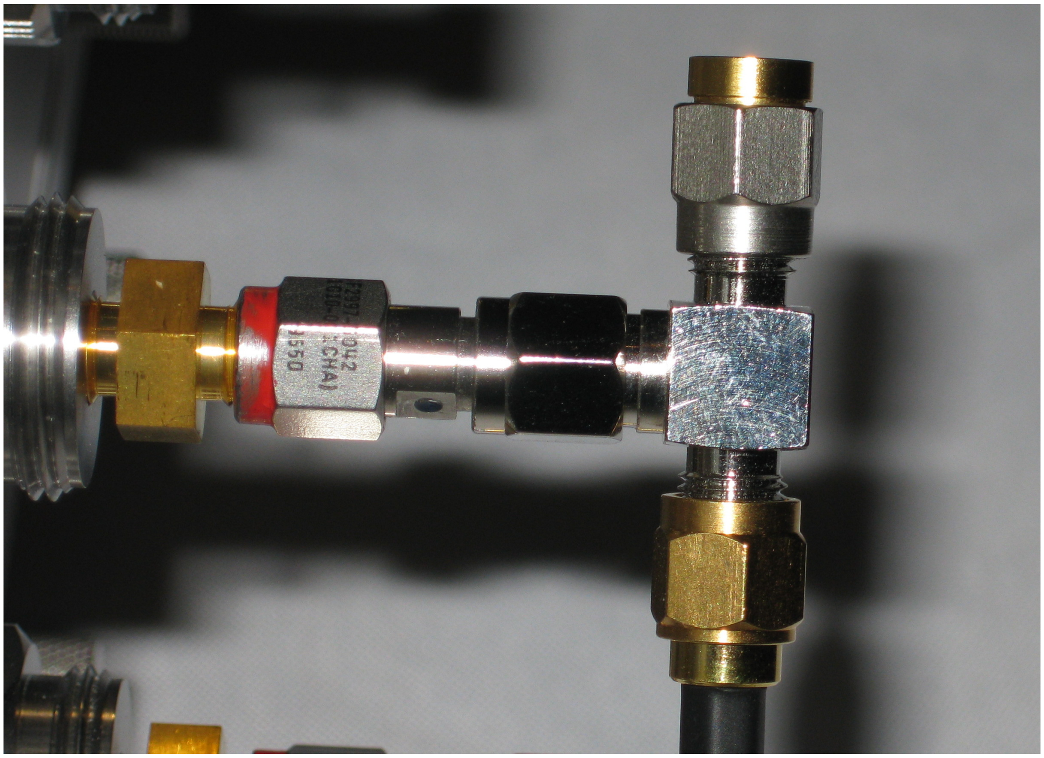

Figure 1: SMA tee connector setup.

3.2 2.5 GHz terminator

Remove and disassemble the tee setup. In the TDR lab kit there is a 2.5 GHz terminator (labeled as such). Connect the terminator to channel 1. Zoom in on the response of the DUT.

3.2.1 Questions

1. Measure maximum impedance in the terminator: ____________

2. Measure minimum impedance in the terminator: ____________

3. Measure the DC impedance of the terminator: ____________

4. Homework: estimate the return loss of this terminator.

3.3 18 GHz terminator

Remove the 2.5 GHz terminator and replace it with the 18 GHz load — you've used it in the SMA tee setup. Repeat the measurements performed in Section 3.2.

3.3.1 Questions

1. Measure maximum impedance in the terminator: ____________
2. Measure minimum impedance in the terminator: ____________
3. Measure the DC impedance of the terminator: ____________
4. Homework: estimate the return loss of this terminator.

3.4 Special terminator

Now let's measure the specially labeled 18 GHz terminator.

3.4.1 Questions

1. Measure the DC impedance of the terminator: ____________
2. Homework: can you guess why the DC impedance is at this value? What conclusions can you draw about the internal structure of the attenuator?

3.5 Microstrip PCB

In the device kit we have a special test PCB with several microstrip lines. Start your measurements from the thin line, continue with the wider one and finish the with widest. For each line measure electrical length, and impedance. Note the locations of the discontinuities on the board.

3.5.1 Questions

1. Line 1: ____
2. Line 2: ____
3. Line 3: ____

3.6 Inmet 3 dB attenuator

Connect the 3 dB Inmet attenuator to channel 1. Place the good 18 GHz terminator on the output port of the attenuator.

3.6.1 Questions

1. Is the response in agreement with what you would expect: ______________
2. Measure the DC impedance of the assembly: ______________
3. Measure the DC impedance without the terminator: ______________
4. Homework: what is causing this response from a resistive attenuator?

3.7 Low-pass filters

Measure and document (save screen image to a file) the TDR responses of the two low-pass filters. For the k&L filter you will need to use the male-to-male SMA barrel. Place a 18 GHz terminator on the filter output ports before the measurement.

3.7.1 Questions

1. Estimate the damping time for the K&L filter: ______________
2. Estimate the damping time for the Mini-Circuits filter: ______________
3. Homework: think of an explanation of the difference between the initial responses of the two filters.

4 Glossary

Glossary

damping time

For a decaying response is the time it takes the signal envelope voltage to decay by e^{-1}. 6

device under test (DUT)

A common abbreviation of the system being measured or tested. 2, 3

linear time-invariant (LTI)

A type of dynamic system with properties of linearity and time invariance. Linearity is mathematically defined follows: if $y_1(t)$ is the response to input $x_1(t)$ and $y_2(t)$ — to $x_2(t)$, then input $a_1x_1(t) + a_2x_2(t)$ will produce output $a_1y_1(t)+a_2y_2(t)$. Time-invariance means that shifting input in time will shift the output correspondingly, that is applying $x(t-T)$ produces $y(t-T)$. 2

printed circuit board (PCB)

2, 5

time domain reflection (TDR)

A measurement of device characteristics, obtained by launching a fast-rise pulse to the device and observing the reflection signals. 2, 3, 7

time domain transmission (TDT)

A two-port extension of TDR where device response is observed at a different port from the pulse-excited one. 2