DEPARTMENT OF
ELECTRICAL AND COMPUTER ENGINEERING

ECE331

Lab4: Time Domain Reflectometry

Prachthearat Ngoy
Ryan Nand

1 Pre-Lab Assignment

Objective:

The objective is to learn to locate and identify transmission line discontinuities using Time Domain Reflectometry

Theory:

Key Concepts

· Transmission line transient analysis
· Identifying and locating faults on a transmission line
· Time Domain Reflectometry resolution and accuracy factors

Procedure:

1.Pre-Lab

1. Review section 2-11 in Ulaby[4]. This section describes the transient response of a signal on a transmission line.

2. Review pages 1-4 in the Tektronix TDR Impedance Measurements application note[3]. This document offers a detailed description of the Time Domain Reflectometry technique and its theory.

3. Draw the bounce diagrams and the corresponding voltage variation versus time plot for each of the transmission line load impedance cases listed below, when $z = l\ 2$ and $t = 4T$.
(a) $ZL = \infty$
(b) $ZL = 0$
(c) $ZL = Z0$
(d) $ZL = 1/2Z0$
(e) $ZL = 2Z0$

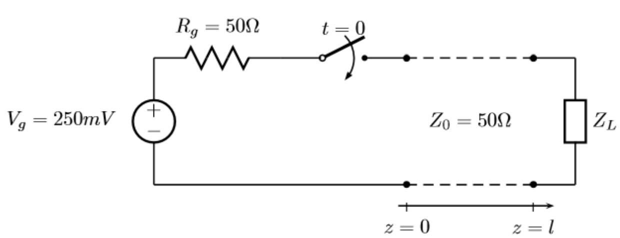


Figure 1: Transmission Line Circuit Model

2.Introduction

Transmission lines encompass all structures and media that serve to transfer energy between two points. This includes acoustic waves propagating through fluids, mechanical pressure waves in a solid, and all forms of electromagnetic signals. In this lab we will be focusing on transmission lines for guiding electromagnetic signals.

The transmission line can be modeled as a two-port device; on the input port (sending end) it receives power from a source and at the output port (receiving end) it delivers power to the load. Depending on the characteristic impedance

$Z0$ of the line, the generating source impedance Rg, and the load impedance ZL, reflections may occur. When a transmission line is terminated by a load impedance different from the characteristic impedance $Z0$ of the line, an incident wave (from the generator) and a reflected wave (from the load) exist. A reflection occurs whenever a mismatch in impedance occurs along the transmission line. We call these mismatches in impedance discontinuities in the transmission line. We will be observing the voltage reflections that occur from different transmission line discontinuities. We will learn to identify the different types of discontinues that occur and how to locate them along the transmission line based on their reflected waveforms.

2.1 Overview of Transient Response

Figure 1, which consists of a DC voltage source Vg and a series resistance Rg on the input port, connected to a lossless transmission line of length l with characteristic impedance $Z0$, and terminated by a load impedance ZL on the output port. Initially the impedance seen by the generating source is simply the characteristic impedance of the transmission line $Z0$. From this initial condition we determine the magnitude of the resulting voltage (and current) that begins to propagate down the transmission line.

$$V_1^+ = I_1^+ Z_0 = V_g \frac{Z_0}{R_g + Z_0}$$

Eq 2.1.1 Magnitude of the resulting voltage (and current)

This voltage propagates along the transmission line with a velocity up immediately after the switch has closed

$$u_p = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c}{\sqrt{\varepsilon_r}}$$

Eq 2.1.2 propagates along the transmission

When the resulting voltage reaches the output port at distance $z = l$ the instantaneous voltage at the load must remain constant and the total voltage must obey Kirchoff's law. The magnitude of the reflected voltage is determined by the reflection coefficient of the load ΓL and the incident voltage.

$$\Gamma_L = \frac{V_1^-}{V_1^+} = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad V_1^- = \Gamma_L V_1^+$$

Eq 2.1.3 Reflected voltage

The reflected voltage at the load propagates along the transmission line in the direction back toward the generating source V_g. When it arrives at the input port, if $R_g \neq Z_0$, we obtain another reflecting voltage that is determined by the reflection coefficient of the source Γ_g.

$$\Gamma_g = \frac{V_1^-}{V_2^+} = \frac{Z_g - Z_0}{Z_g + Z_0}$$

$$V_2^+ = \Gamma_g V_1^- = \Gamma_g \Gamma_L V_1^+$$

Eq 2.1.4 reflection coefficient of the source Γ_g

2.2 Overview of Time Domain Reflectometry

Introduction:

Time Domain Reflectometry (TDR) measures the reflections that result from a signal traveling through a transmission line. The resulting waveform is the combination of the incident step and reflections generated when the step encounters a discontinuity. The amount of energy reflected is a function of the transmitted energy and the magnitude of the impedance change.

The TDR instrument sends out a step signal on the cable, circuit board, or integrated circuit under test. The reflection (or echo) received by the instrument is measured to find the events along the path the signal took. Reflections are caused by expected events, such as trace width or direction changes and components, and faults like bridges, shorts and open. The time delay between the incident and reflected edge can be used in locating these events.

$$\Delta t = \frac{2d}{u_p}$$

Eq 2.2.1Time delay

Theory

Measurement Range

There are a number of factors that affect the distance over which the TDR can locate features. In general the higher the step amplitude, the farther the TDR can see. Overall step width also affects the measurement range. Step width follows the setting of the internal clock rate. The longer the step width (lower frequency), the greater the range of the TDR.

Resolution Factors

Resolution determines the shortest impedance discontinuity that a TDR instrument can measure. If a TDR system has insufficient resolution then small or closely spaced discontinuities may be smoothed together and appear as a single discontinuity on the waveform. Due to round trip effects[3] $T_{Resolution} = \frac{1}{2} T_{SystemRiseTime}$. If a discontinuity is small with respect to the system rise time, the reflection will not accurately represent the impedance of the discontinuity.

Accuracy Factors

The accuracy of the measured impedance depends directly on the accuracy of the known reference impedance. All TDR measurements are relative; they compare a known impedance to unknown impedances.

3.1 Line Parameters of a Lossless Line

Introduction:

We will use Time Domain Reflectometry to determine the relative dielectric constant εr of a short length of cable..

Set up:

· Tektronix DSA8200 with 80E04 Sampling Module
· Short length of SMA-SMA cable

Procedure:

1. Connect one end of the SMA-SMA cable to channel one of the 80E04 sampling modules leaving the other end open.
2. Take a TDR measurement of the open ended SMA cable. (The procedure for taking TDR measurements can be found in appendix B.)
3. Mark the waveform with the location of the event of interest and take a screen capture of the waveform.
4. Using equations 2 and 8 calculate the SMA-SMA cable's dielectric constant.

What is the propagation velocity of the SMA-SMA cable used in experiment 3.1?

deltaT = 2d/prop delay. The deltaT measured was 8.343ns and the cable had length of 91cm. Therefore, solving for prop delay gets 218,146,949.53**.**

propdelay = c/sqrt(epsilonr) solving for epsilonr using 218,146,949.53 as the propagation delay gets 1.375 sec

What are some possible causes of inaccuracy for the method used to calculate the value of the dielectric constant in experiment 3.1?

There could be human error, such as, determining the length of the cable or following and understanding the intended procedure. Other factors could be the calibration of the device(s), or differences between the devices used to conduct the test. In this case, it would be the cable and there could be bends or cuts among the wire in random locations. In other words, one cable would have slightly different results compared to a similar length cable.

What affects a TDRs resolution, accuracy, and measurement range?

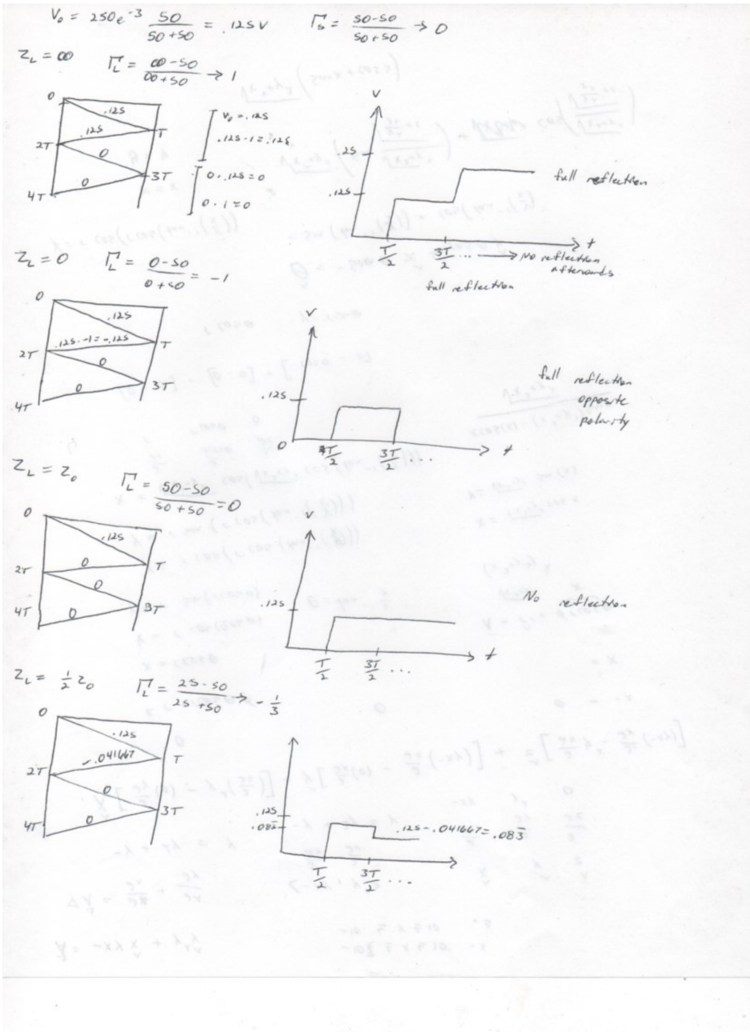
Several factors can affect the measurement range, but the most important are step width and amplitude. The higher the amplitude the further the measurement range, same with the width. The wider/longer the width of the step (lower frequency) the greater the range.

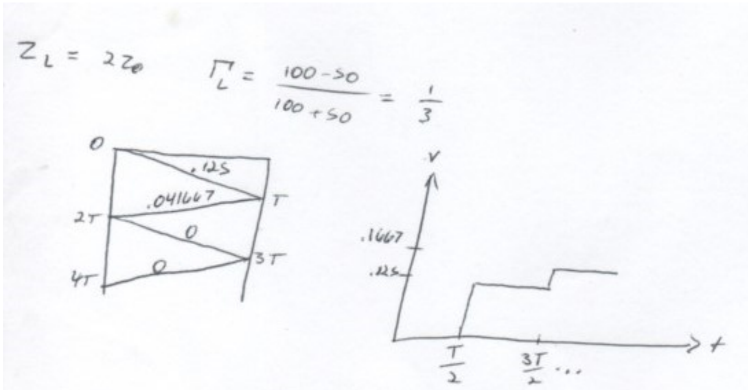
For resolution, if the discontinuity is smaller than the rise time, the discontinuity is ignored. Therefore, it does not show as a result, which can lead to wrong conclusions.

Accuracy is relative to the known impedance. A known impedance is compared to an unknown impedance

Where does the 2 come from in equation 8?

The 2 is from the idea that the reflection wave has to travel back the same length that it traveled in the forward direction, which would be a length of d. Therefore, there has to be a multiplication of 2 for traveling twice the distance.





3.2 Identifying Transmission Discontinuities

Introduction:

We will use Time Domain Reflectometry to identify the nature of different transmission line discontinuities

Set up:

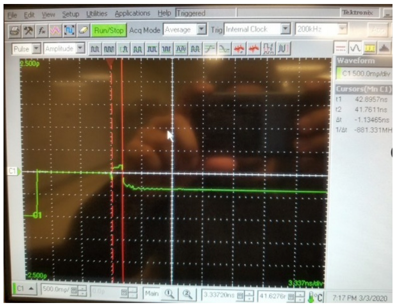
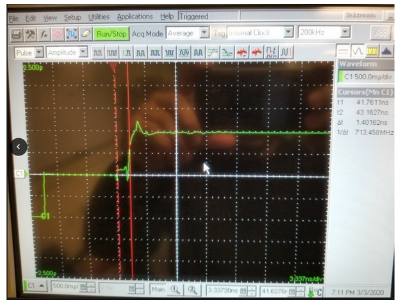
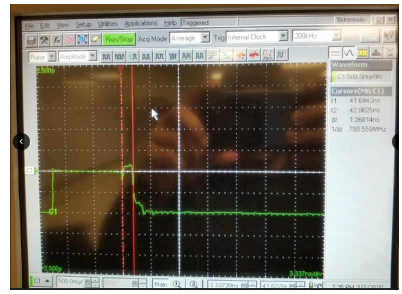
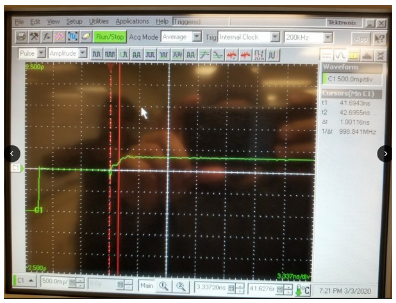
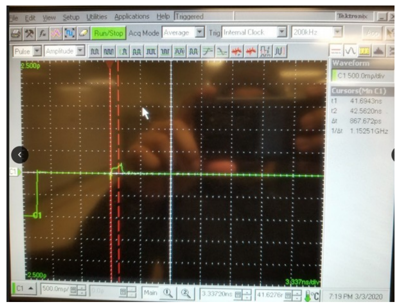
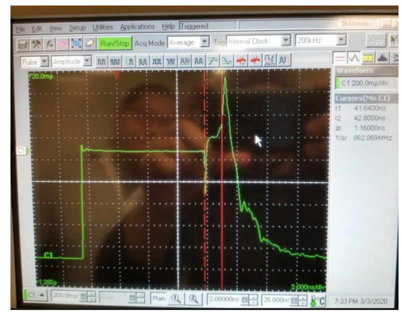
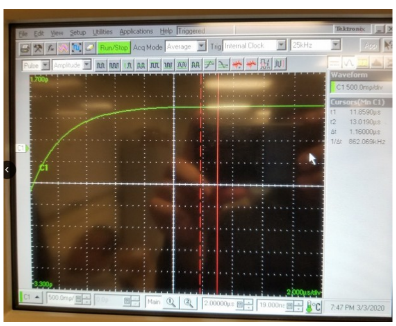
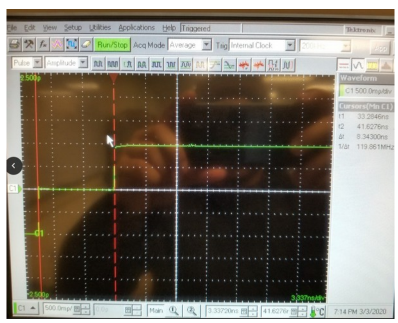
- Tektronix DSA8200 with 80E04 Sampling Module
- Short length of SMA-SMA cable
- TDR Measurement board2

Figure 1: TDR Measurement Board

Procedure:

1. Connect one end of the SMA-SMA cable to channel one of the 80E04 sampling modules.
2. Connect the second end of the SMA-SMA cable to the input port on the TDR Measurement Board.
3. Take a TDR measurement of each input port on the TDR demo board. (The procedure for taking TDR measurements can be found in appendix B.)
4. Mark each waveform with the location of the event of interest and take a screen capture of each waveform observed.

What types of transmission line discontinuities are there and what does their corresponding waveform look like?

 Figure 3.1.a Undermatch	 Figure 3.1.b Open	 Figure 3.1.c Short
 Figure 3.1.d Overmatch	 Figure 3.1.e Match	 Figure 3.1.f Inductor
 Figure 3.1.g Capacitor	 Figure 3.1.h Open Cable	

What types of transmission line discontinuities are there and what does their corresponding waveform look like?

Open - The waveform looks like two steps (the wave doubles in magnitude because all of the generated wave was reflected).

Short - The waveform goes back to zero after the generated wave flows. This is because all of the generated waveform is reflected, but with negative polarity. So it cancels out the magnitude.

Capacitive load - The waveform has a positive slope which eventually flattens out. This is due to a capacitor charging from the generated waveform. As it charges the reflection increases to the point where the capacitor is fully charged. At that time, the reflected waveform is double in magnitude of the generated waveform because like an open circuit it is all reflected back.

Inductive load - This waveform is the opposite of the capacitive waveform but with slight differences. After the generated waveform the reflected waveform decreases to zero. Therefore, the waveform has a negative slope after the generated waveform and flattens out to zero magnitude. This is similar to the short waveform.

Undermatch resistance load - This waveform has a dip in magnitude after the generated waveform. Due to reflection with a negative polarity.

Overmatch resistance load - This waveform has a gain in magnitude due to reflection.

Matched resistance load - This waveform does not change after the generated waveform. This is because nothing is reflected and everything is delivered to the load.

Can you determine the characteristic impedance of each of the transmission lines on the TDR Demo Board? If so, what are they?

Yes, Just following the example of the screenshots from our test. Also the calculations for the reflection coefficients.

What determines the characteristic impedance of a transmission line?

The initial impedance seen by the generating source is the characteristic impedance of the transmission line**.**

What are possible causes of a fault along a transmission line?

Faults are things like open, short, or bridging. So some possible causes are bad connections, bad wire insulation (opening in insulation causing shorts), bridging could be unintended connections due to bad wiring. Typically, these come along when the engineering designs and quality of products are bad.

3.3 Mystery Box

Introduction:

In this experiment we will extend our understanding of Time Domain Reflectometry by using only observed waveforms to determine the nature and location of a transmission line discontinuity.

Set up:

1. Connect one end of the SMA-SMA cable to channel one of the 80E04 sampling modules.
2. Connect the second end of the SMA-SMA cable to the input port of the Mystery Box.
3. Take a TDR measurement of the Mystery Box and a screen capture of the waveform observed. (The procedure for taking TDR measurements can be found in appendix B.)
4. Record all changes in impedances and their corresponding location along the transmission line in a table in your lab notebook.
5. Using the data obtained from the TDR waveform sketch an equivalent simplified transmission line circuit model, similar to figure 1, for the observed waveform. (You do not need to include capacitive or inductive effects in your model.)

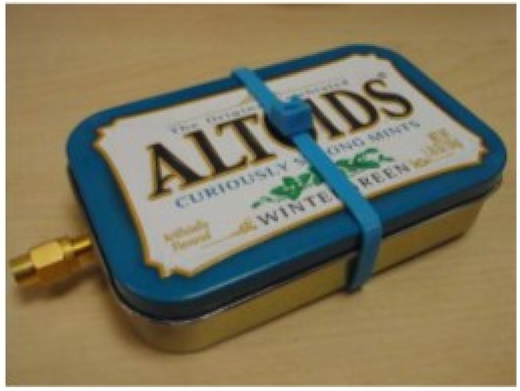


Figure 2: Mystery Fault Box

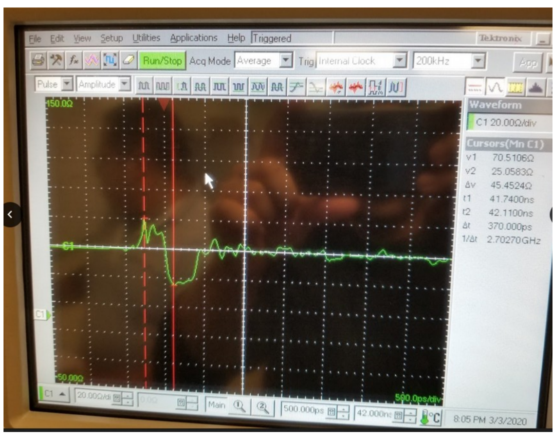


Figure 3.3.a Mystery Box 1

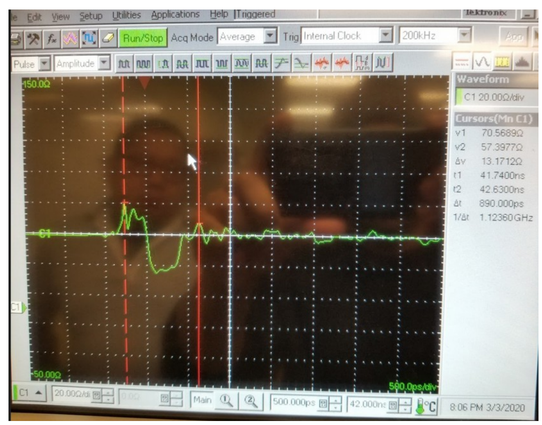


Figure 3.3.b Mystery Box 2

The Characteristics of the mystery box look like it has 3 impedances.

Z1, Overmatch by about 20-25 Ohm
Z2, Undermatch by about 40-50 Ohm
Z3, Overmatch by about 20-25 ohm to make the entire transmission line match.

Follow the example from the TA LAB Example. Figure 3.3.c

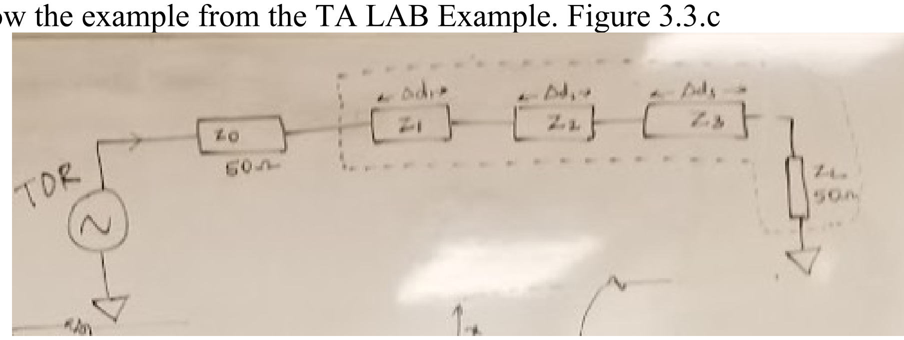


Figure 3.3.c Mystery Box configuration

Conclusions

We learn alot from this lab. I feel that this lab is really relevant to real life situations. Learning about the transmission line and how it works. Really re-enforce the reasoning for being in this engineering electromagnetic.

The last part was a little confusing. To determine the impedance of the mystery box. The TA had to go over the characteristic impedance a few times for us to determine the approximate value of the total impedance. In reality the 3 load is pretty much useless because we still have the 50 characteristics in the end.

Overall, we really have a positive outlook over the entire EMag lab. We just thought that the lab report was due on Tuesday night, not on Monday night. Having the exam and the lab report due on the same day is really a lot of work.