

### Transmission Lines and Time-Domain Reflectometry

**Overview:** This is the lab 2 procedure. It should be read before coming to the lab but the procedure is to be done during the lab visit. Different types of transmission lines are studied, including coaxial cable, two wire lines, and microstrip. Also the impedance, and other parameters are measured and analyzed.

#### Equipment List:

- Capacitance meter
- AEA 20/20 Time Domain Reflectometer
- RG58 50 ohm coax (several lengths, read wire type off side of cable)
- RG59 75 ohm coax (read wire type off side of cable)
- Box of sand
- Two wire transmission line (lamp cord), adjust length by cutting it
- Terminations:
  - 2-adapters (see photo)
  - Various resistors, capacitor, inductor
  - BNC-T
  - Several transmission lines (from above)
- Computer with TDR Converter software (also available on the lab website)

#### I. Transmission Lines

1. Using the capacitance meter, measure the capacitance of the RG58 coax and two wire (lamp cord) transmission lines. Record the capacitance of each line and measure its length. What is the capacitance  $C'$  per meter? Compare the measured data to your prelab calculations. Give percent error.
2. Plot the capacitance versus distance of the coaxial and two wire transmission lines on a single graph. Properly label the axes, include a legend, and write a caption for this graph.

Want to find out more? Capacitance can be used to determine the location of a broken wire, and inductance can be used to determine the location of a short circuit. Several very inexpensive (and simple!) circuits can be used to make this measurement. See <sup>1</sup>, available on the lab website.

3. Measure the capacitance of the two-wire line buried in sand. How does burying it affect the capacitance and therefore the impedance? The inductance stays constant when the two-wire line is buried.
4. Measure the resistance  $R$  of the longest RG58 coaxial cable. What was your calculated value of  $Z_0$  for RG58? How can an approximately  $Z_0 = 50$  ohm cable have almost  $R=0$  resistance? Explain the difference between  $R$  and the characteristic impedance  $Z_0$ .

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<sup>1</sup> Y. Chung, N. Amarnath, C. Furse, J. Mahoney, "Capacitance and Inductance Sensors for Location of Open and Short Circuited Wires," submitted to *IEEE Trans Instrumentation*

## II. Time Domain Reflectometry

### 1. Understanding the AEA 20/20 TDR



The 20/20 is an application specific Time Domain Reflectometer (TDR) used to diagnose issues with video, telco, and general wire line systems. It can be used to determine directly the impedance of a transmission line as a function of distance. And is helpful in determining the location of faults such as: opens, shorts, impedance mismatches and degraded cable lengths.

Standard scientific TDR's plot the response of transmission line as voltage versus time. This same information is used in the 20/20 but the information must be de-embedded using some simple relations. (Refer to capturing and converting data)

*Hand Held Step TDR*

### 2. Setting up the TDR

The 20/20 is design to provide data capture on the computers in the microwave lab via a custom serial port cable attached to six of the computers. The cable is black with a 1/8 inch stereo-phono jack as in Figure 1

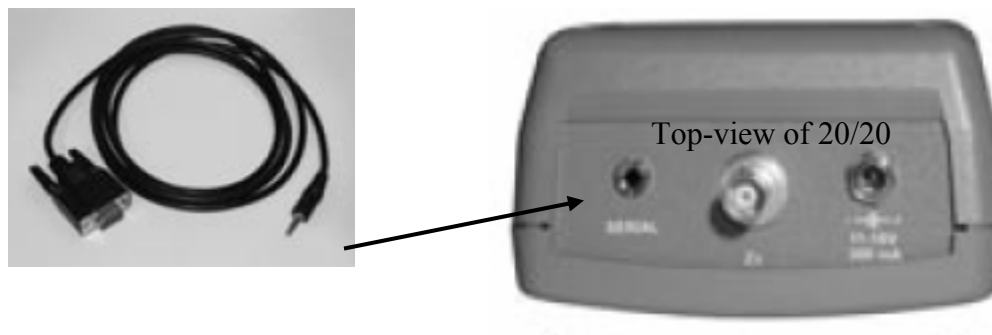


Figure 1 - Serial cable and jack

Connect the serial cable to the TDR and plug the power supply in to start using the 20/20.

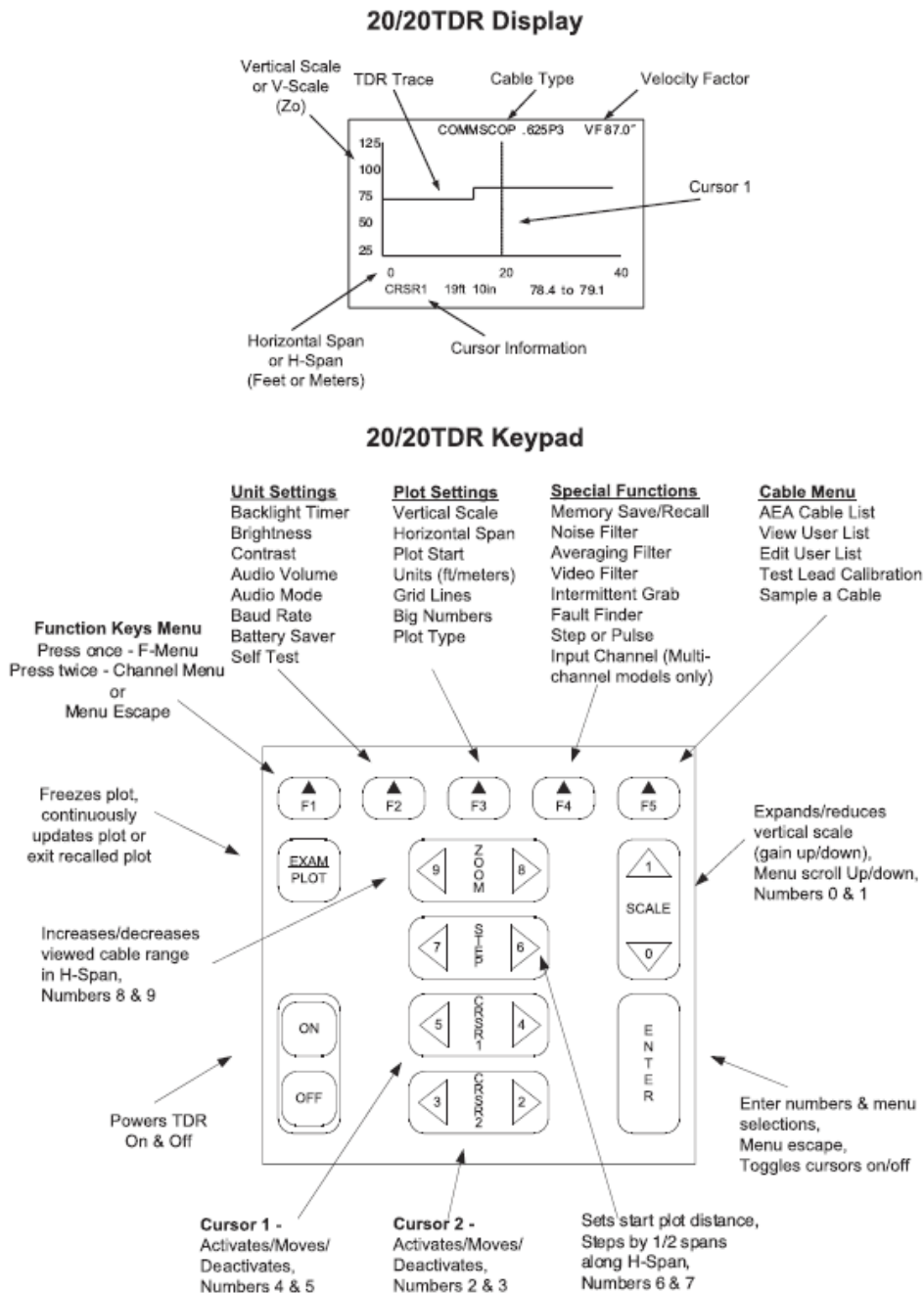


Figure 2 – Display and keypad functions

- Using the display and keypad overview in Figure 2 select the cable type to be used by pressing **F5**, scrolling to **->VIEW USER LIST** using the **SCALE** keys ( numbers: 1, 0 ). Enter the user list by pressing the left **ZOOM** key (number: 8)

and scroll to a cable type with desired values of characteristic impedance ( $Z_0$ ), column 5 and Velocity factor(VF), column 6. (The listed descriptions are unimportant)

- Then press **ENTER** to set the selected Cable type and **F1** to view to measurements.
- Experiment with the **ZOOM** and **SCALE** keys to get the best view of the TDR response. In general, for the cables in the lab a setting of 160 feet allows for viewing of transients on the line.
- Use the cursor keys **CRSR1** and **CRSR2** to more exactly mark transitions and verify that the selected values for VF and  $Z_0$  make sense.

### 3. Capturing and Converting data

The 20/20 TDR uses the application *TDR PC VISION* to capture data from the handheld device. The icon shown in Figure 3 should be on the desktop of the lab systems.



Figure 3 - TDR PC Vision Icon

The TDR PC Vision software can be used to configure the 20/20 TDR and capture the data from the screen. By default the software open to the data capture pane shown in Figure 4.

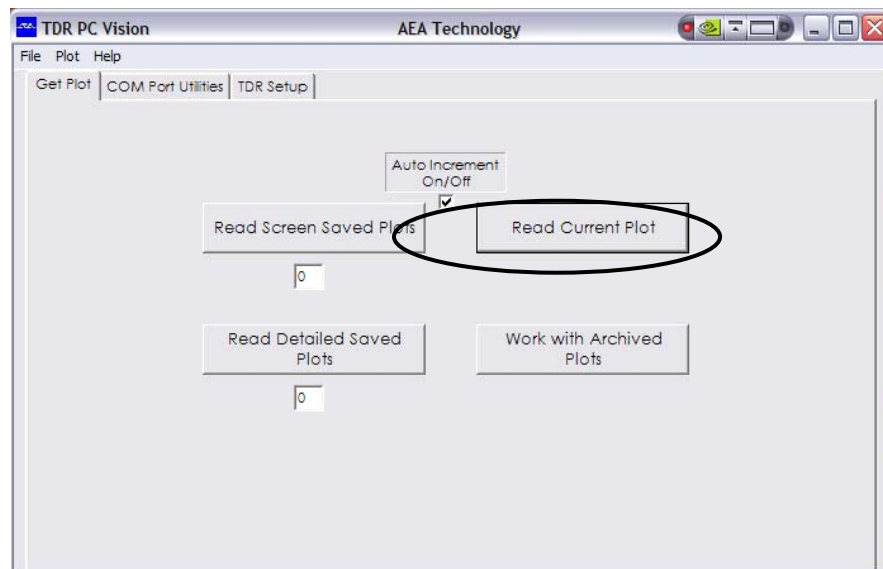


Figure 4 – TDR Vision window

Click on the **Read Current Plot** to capture data and display a graph window as seen in Figure 5

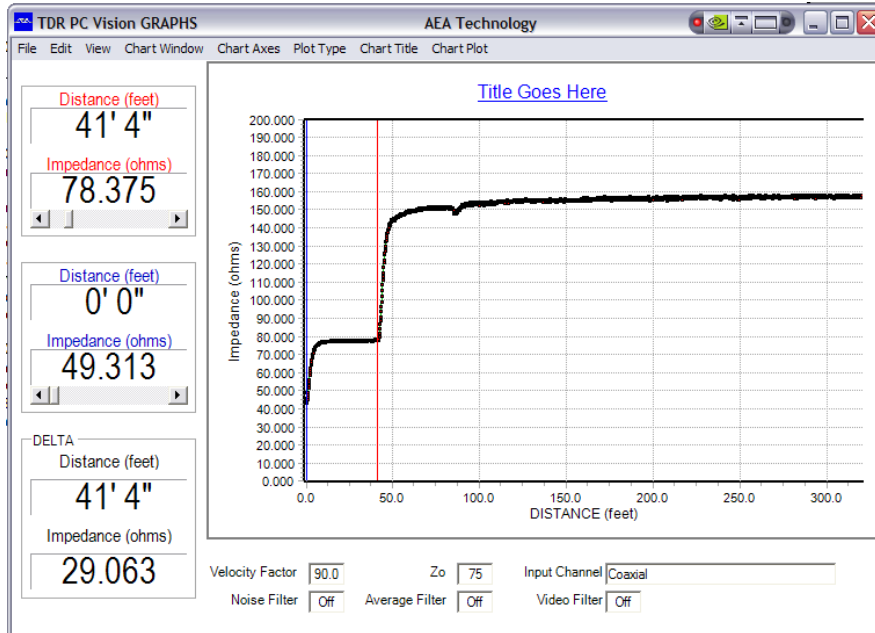


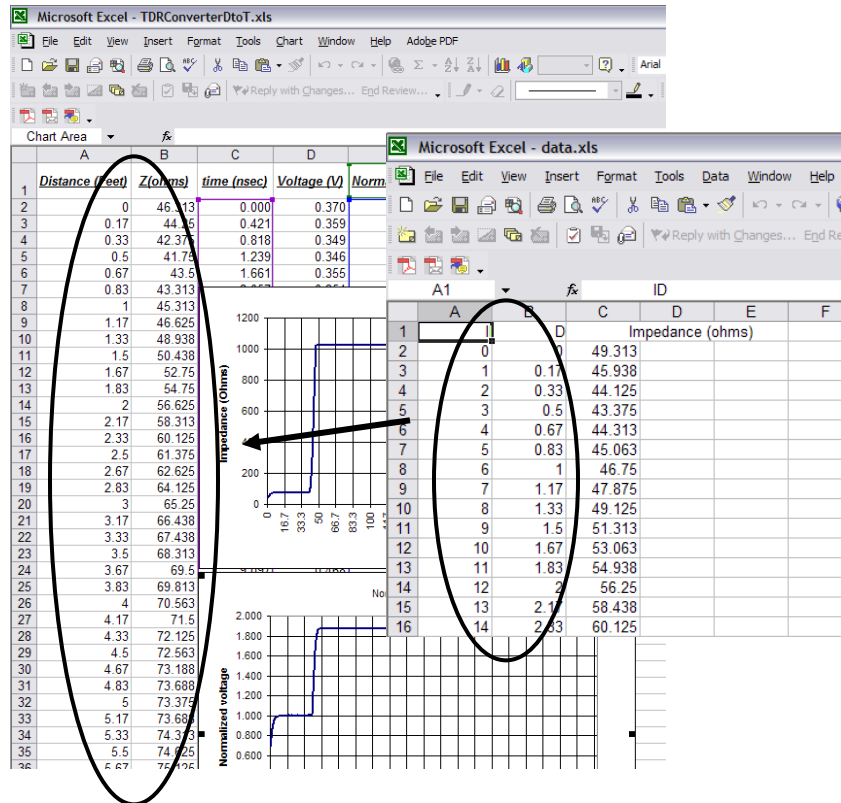
Figure 5 – TDR Vision Graphs

Now that the graph is generated the data can be exported to an EXCEL file to be processed to recover voltage verses time graphs as follows:

- Select the file menu -> Export data -> EXCEL
- Save the file noting the name and location you used
- Launch the EXCEL sheet you just created. It will look as follows:

	A	B	C	D	E	F
1				Impedance (ohms)		
2	0	0		49.313		
3	1	0.17		45.938		
4	2	0.33		44.125		
5	3	0.5		43.375		
6	4	0.67		44.313		
7	5	0.83		45.063		
8	6	1		46.75		
9	7	1.17		47.875		
10	8	1.33		49.125		
11	9	1.5		51.313		
12	10	1.67		53.063		
13	11	1.83		54.938		
14	12	2		56.25		
15	13	2.17		58.438		
16	14	2.33		60.125		

- Open the EXCEL file TDRConverterDtoT.xls located in the TDR files folder on the desktop. It will look as follows:



- Paste the data from B2 through C1922 of your data file into the cells of A2 through B1922 of the TDRconverter file. Now you have data in a format that can be compared to a bounce diagram.

#### 4. Results

Use the TDR to measure and record the results from the following loads:

NOTE: The TDR has an impedance of 79 ohms!!!! Connect an RG59 (75 ohm) cable to the TDR, and then connect these loads on the end of the RG59 cable. Use the homemade adapter shown to plug in resistors and the short circuit. Use pre-built capacitors and inductors.

- Matched Load (75  $\Omega$  resistor)
- Open Circuit
- Short Circuit
- Resistors
- Inductor (use pre-built inductor).
- Capacitor (use pre-built capacitor).



Verify that these match the expected results in your prelab.

Use the TDR reflection diagrams for a variety of resistors to verify that:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

g) RG58 50  $\Omega$  transmission line that is open at the end (connected to the RG59 75  $\Omega$  line that is connected to the TDR). This creates tandem transmission lines, and you should observe multiple reflections. Number each reflection you see on the TDR response, and explain them.

h) Next, create a more complicated network including a T junction of two cables. There are several possible assemblies, one of which is shown in figure 6. Observe and record the TDR waveforms from at least three different configurations of T-junction transmission lines with various loads. Explain the reflections that you see. Hint: Start simple, such as the configuration in figure 6, and replace the matched terminations with other loads one at a time.

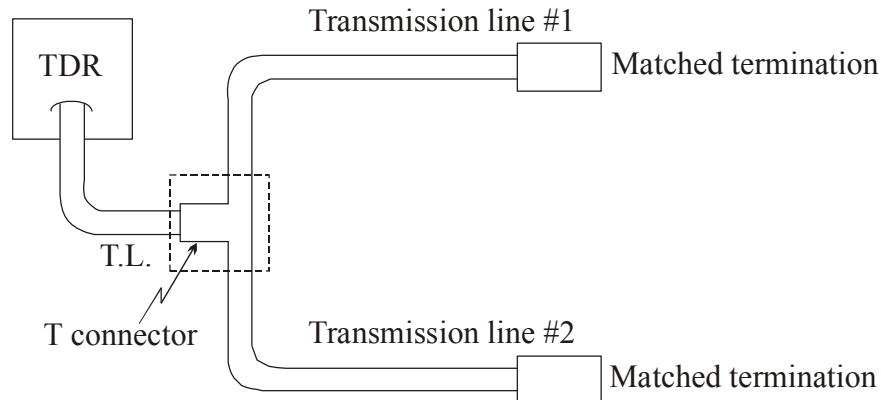


Figure 6. TDR connected to a parallel combination of transmission lines.

The impedance observed at the junction is the parallel combination of the characteristic impedance of Transmission line #1 and #2. If both transmission lines #1 and #2 are 50 $\Omega$ , the parallel combination will be 25 $\Omega$ . Therefore, the load presented at the T connector will be 25 $\Omega$ , and the reflection coefficient will be

$$\Gamma = \frac{25\Omega - 75\Omega}{25\Omega + 75\Omega}$$

### Discussion and Conclusions:

- ◆ Discuss the objectives of the lab, and (hopefully) how you have met these. Give specific and/or qualitative discussion.
- ◆ Describe reasons for inconsistencies
- ◆ Application: A cardiac pacemaker has a battery pack implanted in the shoulder with a long electrical wire going to the heart. This wire is attached to the heart and provides a shock (from the battery pack) in order to pace or defibrillate the heart. Potential sources of failure of this wire include breakage any place along the wire or disconnection at the battery pack or the heart. If a capacitance sensor or TDR could be built small enough to fit inside the battery pack, describe how they might be used to determine where the failure had occurred.

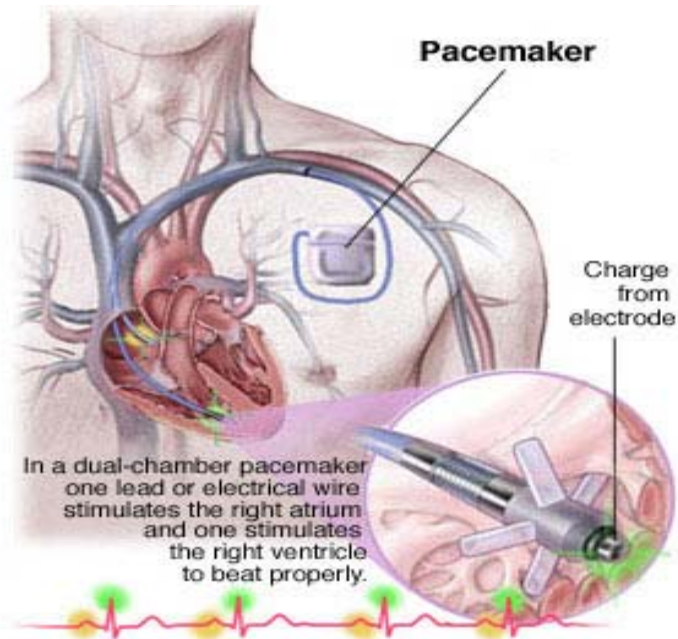


Figure 5: Cardiac Pacemaker (From Medtronic)

**Weekly Formal Report:**

Write a 1-page summary of this lab that answers the application question above. Include at least one figure that “proves” your conclusion. You do NOT need to include a complete set of TDR plots in your formal report (but should in your lab notebook).