Teaching Time Domain Reflectometry in EMC course

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Abstract

Linking research with teaching has been a long term idea that has guided many university professors [1-4]. This has caused creation of new professional courses at our university. One of the examples is the graduate elective course of Electromagnetic Compatibility (EMC). In order to review and expand the knowledge of the students, in our EMC lectures we have included the topics, simulations and demonstrations related not only to basic signal integrity issues, but also to applications of time-domain reflectometry (TDR). In this way the students have had a chance to deepen their knowledge of some topics covered in electromagnetics. In this paper we discuss the application of TDR in electromagnetics and the way to do experiments, simulations and testing.

Introduction

Time Domain Reflectometry is a powerful technique in which a pulse is generated to propagate down a cable, after which the reflected signal returns to the generator and is then interpreted based on its shape, phase, and delay. The results can be used to determine the length of a cable, if and where there is an open circuit, what kind of load a cable is terminated with, and even the relative permittivity and permeability of a dielectric. TDRs are used in a wide range of applications including aviation and naval craft troubleshooting where there are often miles of cable and a technician can accurately pinpoint a malfunction.

TDRs are powerful troubleshooting tools and the interpretation of the results can help the emerging engineer gain mastery over transmission line theory. TDRs are expensive, but fortunately a simpler version can be easily assembled using a signal generator and an oscilloscope [5]. In addition to these items you will need a set of BNC connectors and of course, a cable to test it.

The EMC course has attracted many students who are working in the nearby automotive and military companies. The students have understood from this course how to do analysis of behavior of transmission lines controlled by various signals, especially by fast pulses

The TDR can be used in two ways—as a short pulse or a step pulse TDR. The short pulse TDR sends fast, very short pulses into the transmission line network under investigation—the resultant incident and reflected pulses are observed on the scope to determine the transmission line delay and possible network discontinuity locations. When the transmission line is properly matched, no reflections are observed. The time resolution of such a system is limited to the incident pulse width, which is close to a doubled value of the incident pulse rise time. Discontinuity types can be determined from the shape of the reflected pulses, although the interpretation process can be difficult.

In contrast to short pulse TDR, step pulse TDR sends long, step-like pulses into the network under investigation—the resultant reflected waves are observed superimposed atop the incident pulses. Time resolution for this approach is limited only by the rise time of the incident pulses. This improves the system resolution—an improvement over the constraints of the short pulse approach. In step-pulse TDR, it is easier to interpret discontinuity types. Moreover, in modern TDR systems, supporting software can be used to help identify discontinuities.

At our University, we have integrated material related to TDR into two graduate courses—High Frequency Electronics, and Electromagnetic Compatibility (see Appendices A). Indeed, concepts of TDR have become vital, “backbone” subjects for these courses.

I. Principles of Time Domain Reflectometry

Figure 1 shows the basic structure of TDR as implemented using a high input-impedance oscilloscope. A step generator sends its pulse into the transmission system under test. The step generator’s impedance matches that of the transmission-line connection, so the only reflections expected are from the circuit under test. The incident wave, which is one-half the open-circuit step voltage, is transmitted toward the circuit under test. When this signal encounters any discontinuity, including unmatched impedance of the circuit under test, a reflected voltage wave is produced. This reflected voltage is propagated back to the generator and added to the incident wave. The reflected wave can be positive or negative.

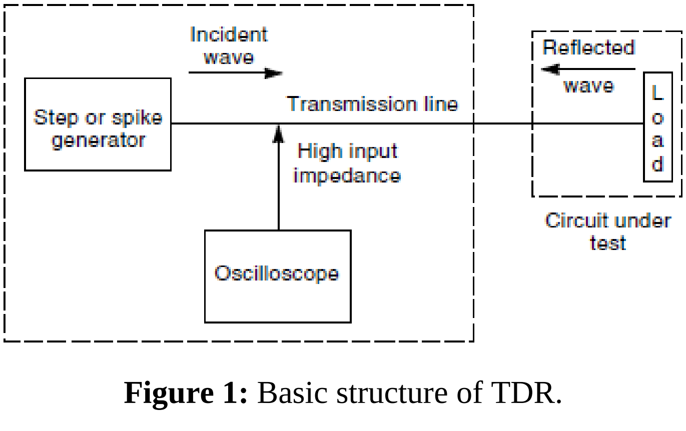

Figure 1: Basic structure of TDR.

II. Applications of Time Domain Reflectometry and Time Domain Transmissometry

As early as 1939, geologists identified a relationship between the dielectric properties of soil, rock, and their moisture content. Time domain reflectometry offers a methodology for capitalizing on these dielectric relationships.[6-11] Primary applications of time domain reflectometry and transmissometry include the following [1-3].

1. Conductor length and return loss determination
2. Finding short and open connections in cables
3. Location of bad splices, loose connectors, and crimps
4. Location of moisture and water in cables
5. Measurement of cable parameters, such as characteristic impedance, losses, and propagation velocity
6. Determining signal integrity, and performing failure analysis of printed circuit boards used in high speed digital and analog circuits,
7. Evaluation of micro strip connections,
8. Computer network cable tests,
9. Characterization of integrated circuit packages,
10. Sensing liquid levels.

III. Simulation

As shown in the accompanying figures, simulation provides unparalleled ability to explain the dynamics underlying TDR. The line length used to reproduce the waveforms for all of the figures is 14 meters; the unit delay is 23.3 cm/ns. Figure 2a shows a PSpice/MultiSim simulation circuit for a matched source. Figure 2b shows the temporal simulation result. Figure 2c provides an oscilloscope screen picture of the waveforms affiliated with an open ended transmission line input. Figure 3 reveals similar results in relation to an unmatched load. Figure 4 shows the use of a narrow pulse reflectometer to test the signal integrity of longer cables applied in computer networks. Figures 5a to 5c show various input and output waveforms affiliated with various loads. More results are discussed in our paper [3].

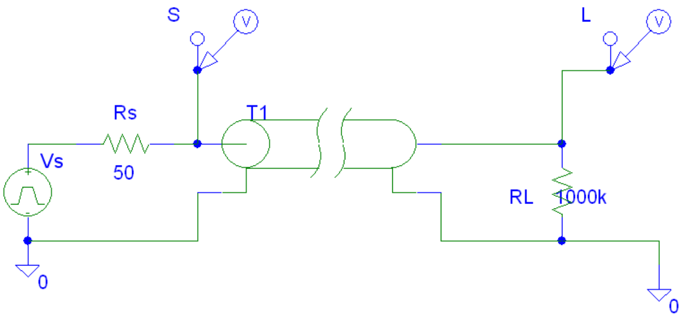

Figure 2a: PSpice/MultiSim model of an open ended transmission line (TL) with a long pulse applied. The source is matched.

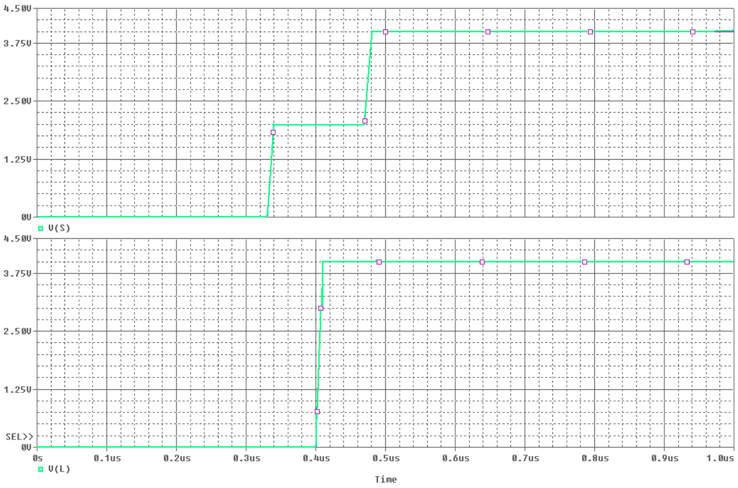

Figure 2b: PSpice/Multisim simulation results for the circuit shown in Figure 2a.

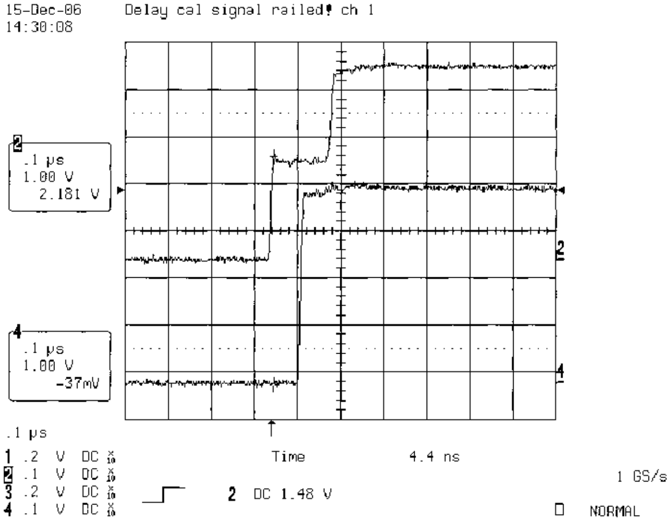

Figure 2c: Oscilloscope screen shot of voltage waves affiliated with an open-ended transmission line with a matched source. Input – Channel 2 (upper curve) shows the incident step and reflected step. The time between the incident and reflected step is the delay time introduced by signal as it passes through length of the line and then returns the length of the line—a doubled TL delay. Output – Channel 4 (lower curve) shows the doubled incident wave level with a long pulse applied by the source, delayed about 60 ns due to the length of the line. The distance between steps of Channel 2 is 2 times TL delay time, measurements.

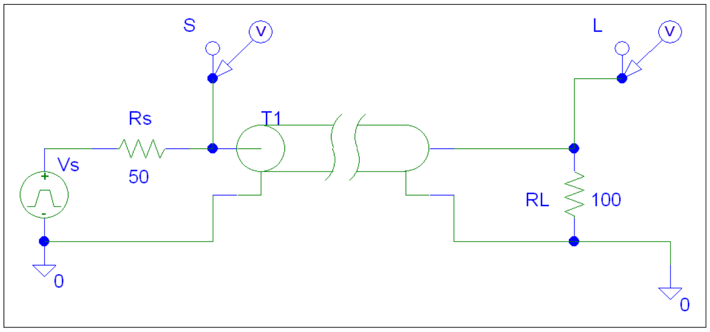

Figure 3a: PSpice/Multisim circuit to test reflection from the unmatched load of the transmission line ($R_{\text{load}} = 100\Omega$). The source is matched.

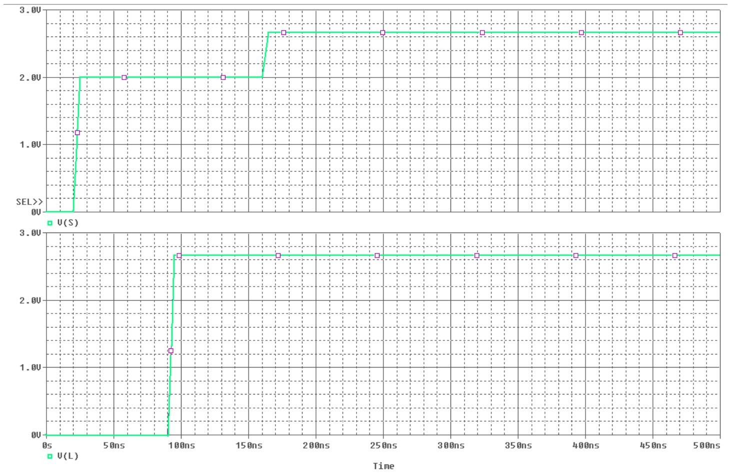

Figure 3b: Temporal simulation of the circuit of Figure 3a using PSpice/Multisim.

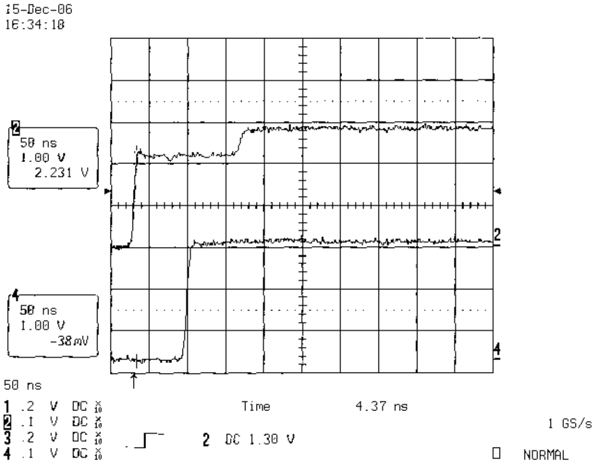

Figure 3c: Oscilloscope screen shot of waveforms affiliated with the circuit of Figure 3a.

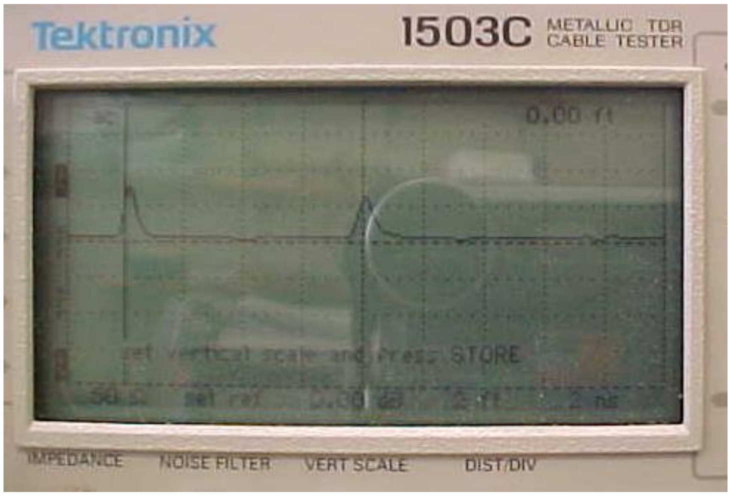

Figure 4: Test signal related to a narrow pulse TDR to test the signal integrity of longer cables applied in computer networks using a Tektronix oscilloscope.

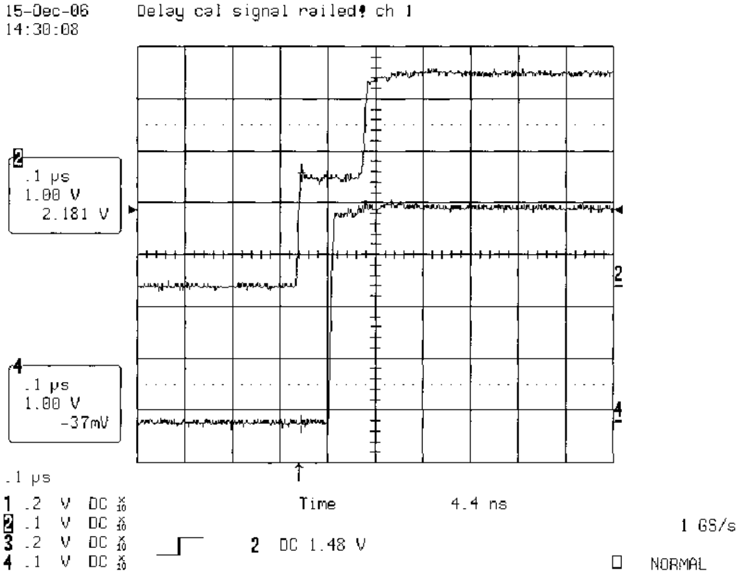

Figure 5a: These results pertain to step pulse TDR in relation to an open ended transmission line. Input – Channel 2 shows both the incident and reflected step, separated by a doubled TL delay). The source is matched to the line. Output – Channel 4 shows the doubled incident wave level, delayed (60 ns or 23.3 cm distance from generator), and a long pulse applied by the signal generator. The distance between steps of Channel 2 are twice the transmission line delay time. The line length is 14 meters, and the unit delay is 23.3 cm/ns.

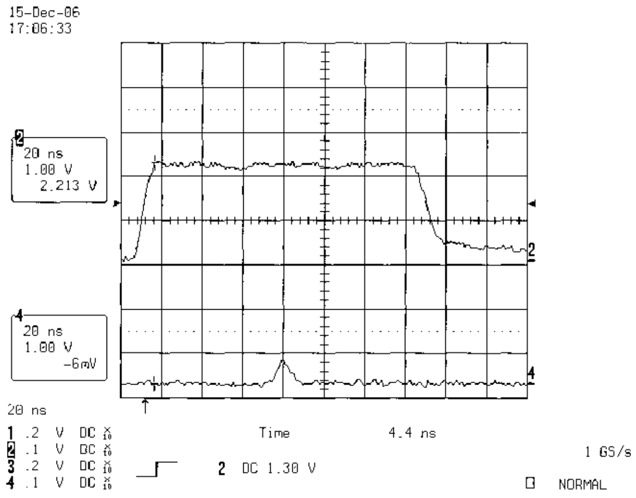

Figure 5b: Step pulse TDR in relation to reflection from the shorted load of the TL (source is matched to the line (R_{load} = a short consisting of one inch of wire). The line length is 14 meters, and the unit delay is 23.3 cm/ns.

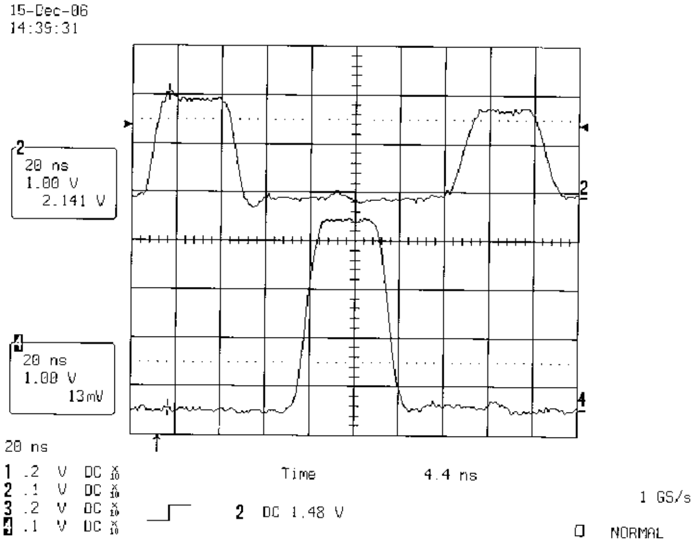

Figure 5c: Narrow pulse TDR. This illustration shows a screen shot in relation to an open-ended TL, with a short pulse applied to show a “radar effect,” or echo.(Channel 2 – input; a doubled amplitude output is observed on Channel 4). Note the effects of the losses due to the transmission line, the echo is slower and smaller. The distance between pulses of Channel 2 are twice the TL delay time. The measured unit delay yields 20cm/ns. The line length is 14 meters, and the unit delay is 23.3 cm/ns.

Time domain reflectometers are applied to check the Signal Integrity when the signals, including triggering pulses are supposed to be undistorted when they pass through various types of transmission lines connecting electronic circuits and systems. Signal distortions could cause false triggering or distorted signals may not be detected correctly. Besides, the distorted pulse signals can created more potential for radiation from unshielded parts of the circuits or systems.

Meaurement

The measurement results of the twisted pair cables are presented to enhance theory and simulations applied to show the radiated emissions, crosstalk effects and shielding,

The circuit includes the single wire above the ground cable (GENERATOR WIRE), which is connected to the Spectrum Analyzer internal generator sweeper (to 1.5 GHz), and parallel twisted pair cable with four outputs (two NEAR END and two FAR END). The four output signals are measured and registered by means of the Spectrum Analyzer. The simple cable structures were chosen to limit the effects of potential installation problems related to grounding and existence of cable "tails". The signals used to test include: sine waves, pseudo-random waves, fast pulses, and high voltage narrow pulses. Measurement results are presented in [12].

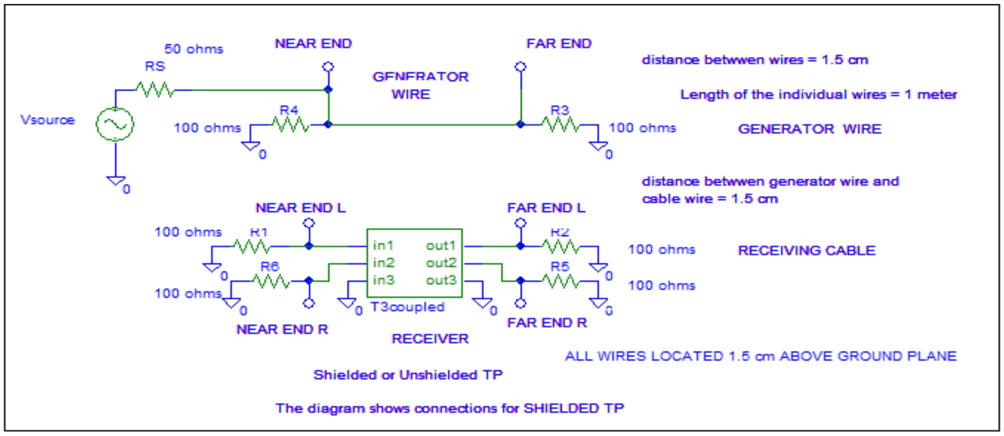

Fig. 4 Measurement circuit diagram (The Shielded Twisted Pair, STP, is shown, Unshielded Twisted Pair, UTP, does not include the third bottom ground connections)

Student Participation in Experiments

The students attending the EMC (Electromagnetic Compatibility) course have a chance to participate in demonstrations of experiments and they could also get familiar with all instruments to measure the most important parameters of the signals. In the same course, the other experiments have been also included, as described in the listed references [12] . In addition to measurements, the students use PSPICE software program to model the twisted-pair transmission lines and make some predictions.

Conclusions and how the Students Benefit from this Approach

The experiments introduced in the course with TDR and simulation exercises have made the course material easy to understand and fun to learn the application of EMC theory. The course evaluations on the course outcomes received very good results.

The described project measurements and their interpretation appeared to be very helpful to our graduate students, who work for aviation and automotive industry. They could apply some of the demonstrated ideas in their company.

Time domain reflectometry is a critical, and underrated, component of electrical engineering education. Yet it is a relatively straightforward matter to provide students with the fundamentals they need to understand and use these important techniques. Transmission line, signal behavior and integrity are taught in EMC course. This paper provides an overview of TDR fundamentals, application of TDR and how TDR can be used to simulate and test transmission line.

References

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Appendix A

Re: ECE 546 Electromagnetic Compatibility Course Level: Graduate, **Total Credits**: 4

Textbook: C. R. Paul, *Introduction to Electromagnetic Compatibility*, J. Wiley, Recent Edition.

Topics:

- Overview of EMC
- EMC Requirements (i, j)
- Review of Electromagnetic Principles (a, e)
- Distributed and Lumped Components
- Signal Spectra and Spectrum Measurements (a, e, k)
- Intro to EMC Pre-compliance and Compliance Tests, Component and System Level Measurements (e, k)
- Radiated Emissions and Susceptibility (a, e)
- Conducted Emissions and Susceptibility (a, e)
- Crosstalk (a)
- Shielding and Guarding (a)
- Electrostatic Discharge (a)
- Introduction to System Design (a, e, i, j, k)
- Introduction to Signal Integrity (a)

Biography

Subra Ganesan (ganesan@oakland.edu) is a Professor of Electrical and Computer Engineering at Oakland University and Director of Real Time Embedded DSP Systems Lab. He joined the university in 1984. After graduating from Indian Institute of Sciences Bangalore India, he served at universities in Germany, and Canada and Indian research laboratory as a scientist. He does research work in collaboration with TI, Free Scale, and a few automotive companies and US army. His research areas include DSP, Embedded Systems, Real Time Systems, Condition-based Maintenance, and Optimization.

Andrew Rusek (rusek@oakland.edu) is a Professor of Engineering at Oakland University in Rochester, Michigan. He received an M.S. in Electrical Engineering from Warsaw Technical University in 1962, and a PhD. in Electrical Engineering from the same university in 1972. His post-doctoral research involved sampling oscillography, and was completed at Aston University in Birmingham, England, in 1973-74. Dr. Rusek is very actively involved in the automotive industry with research in communication systems, high frequency electronics, and electromagnetic compatibility. He is the recipient of the 1995- 96 Oakland University Teaching Excellence Award