Transmission and Attenuation of Electromagnetic Pulses

The purpose of this experiment is to acquaint you with some of the principles involved in the manipulation of electrical pulses. You will study reflections, measure the effects of termination resistances, and measure pulse propagation velocities for coaxial cables.

1. PRE-LAB

- Read Melissinos (2003) chapters 3.2 [Basic electronic equipment], 3.3 [Oscilloscopes and digitizers], and 3.4 [Simple measurements]. Pulses are ubiquitous in timing experiments, in all digital systems (computers, cell phones), and we must use transmission lines (ribbon cable, coaxial cable) to move these pulses from one place to the other. Read the files *Coax impedance* and *Characteristic impedance* on the 122 Electronics Lab web page.

- A certain transmission line attenuates pulses at a rate of 2% per meter. Derive an exact formula for the pulse amplitude as a function of distance along the cable. Make a plot of the amplitude of a pulse as a function of position along the transmission line from 0 to 200 meters. (The formula is the solution of an elementary differential equation.)

- Draw the predicted shape and amplitude of an ideal rectangular pulse of amplitude 1 volt and duration 100 nsec after it has traversed a coaxial cable 100 m long and returned following reflection from an open end.

2. INTRODUCTION

Many experiments involve the production and measurement of electrical pulses. Depending on the timescale of the signals Δt, the approaches are very different:

Δt > 1ms do with your wires whatever you want. If the signals are small, you may want to use shielded cables. (You did this in the analog LRC exercise)

1ms > Δt > 0.1μs typical for computers. Use ribbon cable, “twisted pair” or cables without termination.

100ns > Δt > 0.1ns region of interest for “fast” signals to be studied here. Cables must be terminated, or undesirable reflections will occur. In 122 Lab these types of signals are often present with photomultiplier signals but the subsequent signal processing and logic slow the signals into the middle category.

One may wish to know their rate, distribution of amplitudes, the relation of their occurrence times relative to other pulses, etc. Such measurements are done with oscilloscopes, multichannel analyzers, amplifiers, discriminators, coincidence circuits, etc.[1], which may or may not be working properly. It is essential, therefore, to gain facility in the use of test equipment such as pulse generators and oscilloscopes so that the performance of a pulse measuring apparatus can be checked, point by point. Electrical pulses are piped around a laboratory via transmission lines of one sort or another, with consequent delays, attenuations, and reflections. It is important to understand these effects and to know how to measure them. So this experiment is a study of pulses in transmission lines. You learn that you must terminate all transmission lines properly so as not to be deceived.

3. EXPERIMENTS

3.1 Shock excited oscillator EXTRA CREDIT

Let's first see what happens when you shock excite the high-Q LC resonant circuit you just built in the analog part of this lab with a pulse. Set your pulse generator for a ~250ns wide pulse. Insert that pulse into the 50 ohm resistor + one turn coil you have wound around your inductor in the LC resonant circuit. Observe the time behavior of the voltage across the LC circuit on the scope with a x10 probe. Count the number of cycles for the ringing to decay by 1/e. How is this related to Q? Do this for your variable capacitor at both maximum, and near minimum capacitance. What do you find?

3.2. Reflection of electrical pulses from discontinuities in a transmission line

In this experiment you will be using the full time resolution of your oscilloscope (200MHz bandwidth). Read the one-page "pulse generator manual" for operation of the Tektronix PG502 pulse generator, and refer to the file "PG502" for more information. Connect the Tektronix PG502 pulse generator (be sure to terminate its output with a 50 ohm termination via a T connector) to the input of your Tektronix 2022B oscilloscope by means of a BNC T connector. Before attaching your long cable, you need to set up the pulse generator and scope. Put the scope on AC coupling, about 500mV per division, 25ns time base. In order to get the time resolution needed for your experiment, you need pulse widths around 15-20ns. On the PG502 pulse generator, switch to a 5ns pulse width [pulse duration] and a convenient 10 KHz repetition rate. Adjust the variable pulse width control to get your desired pulse width [fully counter clockwise is x1]. You will find that the cleanest [most square] pulse shape occurs for pulse widths longer than ~15ns or so.

There are grey concentric knobs for output DC level in the lower middle of the panel. Adjust the "Lower" level to zero volts, and then adjust the "Upper" level for ~1 volt peak pulse height. Get your scope triggering on the leading edge of this pulse at approx 500mV level.

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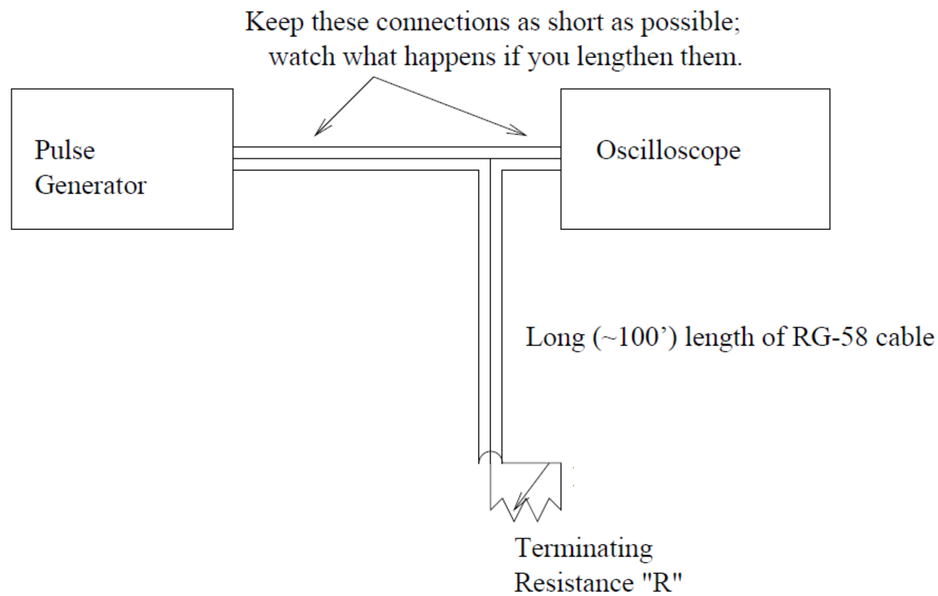
[1] Oscilloscopes display the signals V (t) vs. t. Multichannel Analyzers (MCA's) sort signal events of different heights into bins in histograms. Amplifiers enlarge the signal but may also alter it's shape. Charge sensitive preamplifiers produce an output voltage proportional the amount of charge generated in a detector. Discriminators emit a logic (square V(t) shape) signal if the input exceeds a certain threshold. Coincidence units produce a logic pulse if two (or more) inputs overlap in time.

Now attach a long RG58 cable to the third end of the T, as shown in Figure 1. Observe the primary pulse from the pulser and describe the pulse reflected from the end of the cable when the end is 1) open, 2) shorted, and 3) terminated with a resistor “termination” with values of 50, 75, and 95 ohms (color coded), in order to determine the characteristic impedance of RG58 cable. Remember to graph the observed waveforms in your notebook and label both time and amplitude axes! Save the waveforms on a memory stick for your lab book if you like. You will typically see one reflection. Why not more? Hint: You terminated the pulse generator in 50Ω at its output. Take this generator termination off and see what happens.



The dark green RG 58 cables in the lab are supposed to be about 19.7m long (but you should check if the length is not marked on the cable!); one light green cable is labeled 50 feet. There are enough of these long cables for 14 simultaneous experiments.

3.2. Speed and attenuation of pulses in transmission lines.

Determine the velocity of pulses in the cable by measuring the difference in the arrival time of the direct and reflected pulses at the oscilloscope. Expand the scope sweep timescale so you just see two pulses (you emitted pulse and the return reflected pulse having traveled twice the length of the cable). Use the dual cursor on your scope to accurately measure the time delay of the leading edge of your pulses <u>at the same relative amplitude</u>. *Record sufficient data and other information to permit an accurate assessment of the random and the systematic errors in your determinations.* Compare the velocity in the cable with the velocity of light in vacuum, and explain the cause of the difference.

Extra credit: Measure the attenuation of RG58 cable by comparing the *amplitude* of the pulse reflected from the open end of the cable with and without an additional length joined by a BNC connector. (Note that this strategy isolates for measurement the effect of the delay in the cable from possible complicating effects of the discontinuities in the circuit at the connections to the oscilloscope and pulse generator.)

4. ANALYSIS

1. Determine the characteristic impedance Z for RG58 coaxial cable.

2. Determine the velocity of propagation V_{prop} for RG58 coaxial cable. Express this as a fraction of the velocity of light in vacuum (this ratio is called the "velocity factor" of the cable) and compare your value with the published values. Assess the random and systematic errors.

3. Determine the attenuation in dB/m for RG58 coaxial cable. Compare your coefficients versus published values. Assess the random and systematic errors.

References:

[1] Melissinos chapter 3.2

[2] W. Leo, Techniques of Nuclear and Particle Experiments (Springer, 1992).

[3] G. Bekefi and A. Barrett, Electromagnetic Vibrations, Waves and Radiation (MIT Press, 1977).