The Transmission, Reflection and Attenuation of Electromagnetic Pulses

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The purpose of this experiment is to acquaint you with some of the principles involved in the manipulation of electrical pulses.

PREPARATORY PROBLEMS

1. Derive an expression for the characteristic impedance of a coaxial cable with a central wire of radius a, a cylindrical sheath of radius b, and with the space between the inner and outer conductors filled by a non-conducting medium with a dielectric constant κ.

2. 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.)

3. Draw the predicted shape and amplitude of an ideal rectangular pulse of amplitude -1 volt and duration 10 nsec **after** it has traversed a coaxial cable 10 m long and returned following reflection from an open end.

INTRODUCTION

Many experiments involve the production and measurement of electrical pulses. One may wish to know their rate, distribution in amplitude, the relation of their occurrence times to those of other pulses, etc. Such measurements are done with amplifiers, discriminators, multichannel analyzers, coincidence circuits, etc., 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.

EXPERIMENTS

REFLECTION OF ELECTRICAL PULSES FROM DISCONTINUITIES IN A TRANSMISSION LINE

a) Connect the BNC Model 8010 pulse generator to the input of a digital oscilloscope by means of a T-connector and attach a long RG-58 cable to the other third side of the T, as shown in Figure 1. Use the fixed output on the pulse generator to produce pulses of amplitude -0.8 Volt, the fastest possible rise time, shortest possible duration ($\sim$ 10-30nsec), and a reasonably low repetition rate ($\sim$ 10kHz). Set the oscilloscope vertical amplifier control to 500mV/div, the sweep speed (commonly called the time base) to 50nsec/div, and the trigger to internal, normal, and negative slope. 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, 3-terminated by a variable resistor with values in the range from $\sim$ 0 ohms to $\sim$ 1000 ohms. Vary the potentiometer to find the characteristic impedance Z of RG-58 cable. Record at least 16 measurements of Z, made as independently as possible from each other by changing ohm meters, potentiometers, scope settings and recording personnel.

b) Connect another piece of cable to the end of the first cable by clip leads (i.e. a very bad connector) and observe the effects of the discontinuity in the transmission line. **Remember to graph the observed waveforms in your notebook and label both time and amplitude axes!** You will typically see one reflection. Why not $n+1$? Hint: Pulse generators have an internal resistance too.

SPEED AND ATTENUATION OF PULSES IN TRANSMISSION LINES

Measure the attenuation of RG-58 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 pulser.)

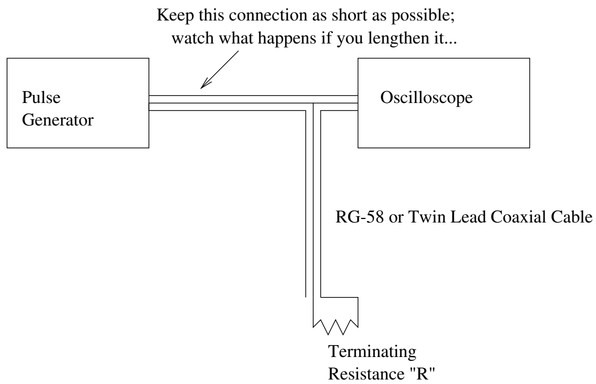

FIG. 1: Experimental setup to test the effect of various terminating resistances on the transmission and reflection of electrical pulses in coaxial cable.

Determine the velocity of pulses in the added cable by measuring the difference in the arrival time of the direct and reflected pulses at the oscilloscope. Make 16 independent measurements of the propagation time for 100 feet of cable and determine an error from the spread of these measurements. Next, use four different lengths of RG-58 cable (share with the other experimental setups) to obtain additional data for the speed of the pulses. Record sufficient data (through independent measurements) 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. Repeat at least 4 measurements with RG-59 transmission cable and determine the velocity using two cable lengths.

PROPAGATION OF CW IN A TRANSMISSION LINE

Explore the phenomena of a sinusoidal continuous wave (CW) propagating in a transmission line with various terminations and frequencies. Produce a graph of attenuation versus frequency for RG-58 transmission line utilizing the full range of your sine wave generator. A common means of expressing attenuation is in dB/100 ft where $\mathrm{dB} = 20\log\left[V_{out}/V_{in}\right]$ when the cable termination is matched to its characteristic impedance. (e.g. -3dB corresponds to an attenuation of power by 50%) Connect the cable as before but look at the far end with channel-2 of your oscilloscope, terminate.

ANALYSIS

Determine from your data the velocities and attenuation coefficients (percentage loss per meter of line) of RG-58 and RG-59. Compare your coefficients versus published values. Assess the random and systematic errors.

1. The partial differential equations for the voltage between the inner and outer elements of a coaxial transmission line carrying a signal.
2. The fraction of the energy of a pulse reflected at the junction of two coaxial cables with different radii of the inner and outer conductors.

[1] Bekefi, G., and Barrett, A. 1977, Electromagnetic Vibrations, Waves, and Radiation, MIT Press.
[2] French, A. Vibrations and Waves, Norton, 1971.
[3] Leo, W.R., Techniques of Nuclear and Particle Experiments, Springer, 1992

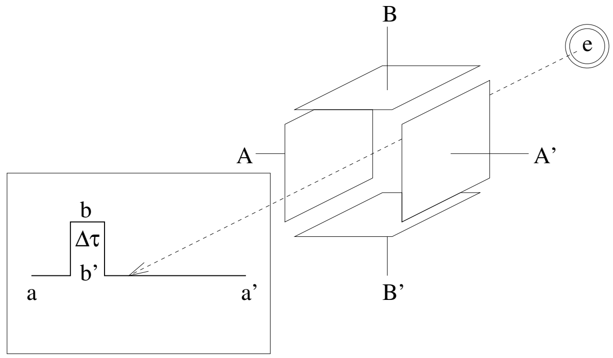

FIG. 2: Diagram of an oscilloscope

VISUALIZATION OF ELECTRICAL SIGNALS BY OSCILLOSCOPES

A hot wire in the cathode ray tube emits electrons, which are accelerated by an annular anode by about 20 kV. Two pairs of crossed capacitors then deflect the electron beam (AA' horizontally, BB' vertically). The fluorescent screen emits green light when hit by the electron beam. By applying a linearly rising voltage to AA' a horizon line is produced on the screen (aa'). The (amplified or attenuated) signal applied to BB' produces a vertical deflection bb' for the time duration of $\Delta\tau$. This process is started by the trigger, which is initiated by a signal becoming larger than the threshold (adjusted by the knob control), which can be positive or negative.

EQUIPMENT LIST

Manufacturer	Model	Description
HP-Aglient	54601A	100 MHz Digital Oscilloscope
BK Precision	4011A	5 MHz Function Generator
BNC	8010	Pulse Generator (3.5ns rise, 10ns width) www.b
100' RG-58U	290-1020-ND	50Ω coaxial cable
100' RG-59U	290-1032-ND	75Ω coaxial cable