Physics 375, Laboratory 4
Transmission Lines

Overview

The purpose of these experiments is to investigate the effects of long transmission lines on signals and to understand how interfaces at cables ends affect signal quality.

Background

A transmission line consists of two conductors one to carry the signal out, and another to return the current to the source. The transmission line is continuous and can be described by an inductance per unit length L_0 and a capacitance per unit length C_0. An analysis of the dynamics of a wave traveling along the line gives a velocity for the signal equal to :

$$v = \sqrt{\frac{1}{L_0 C_0}} = \sqrt{\frac{1}{\varepsilon\mu}}$$

where ε and μ are the susceptibility and permeability of the material between the two conductors, in a vacuum this is equal to the speed of light.

The impedance of a transmission line can also be derived from the dynamics of a wave traveling along its length. The impedance of a line is

$$Z_0 = \sqrt{\frac{L_0}{C_0}}$$

and is independent of the frequency. The transmission line acts like a fixed resistive load but in fact the energy is going into the electric and magnetic fields instead of heat.

How the line ends is very important to understand what will happen to a signal. A cable that is open at the end will cause a reflection of the incident wave back down the cable. A cable that is shorted will reflect the negative of the wave back to the source. For an arbitrary terminating imedance Z the relation between the impedances and the magnitude of the reflected wave is:

$$\frac{Z}{Z_0} = \frac{V_{inc} + V_{ref}}{V_{inc} - V_{ref}}$$

If the reflected wave is zero then $Z = Z_0$. Some of the signal will be transmitted into the treminating load, and the relation between the transmitted and incident signal is:

$$\frac{V_{tr}}{V_{inc}} = \frac{2Z}{Z_0 + Z}$$

1. Coaxial Cable Speed

RG-58 is a cable with a single conductor wrapped by another conductor. Connect the function generator (50 Ω output square wave), oscilloscope, and long (50’ or 100’) cable to a circuit board:

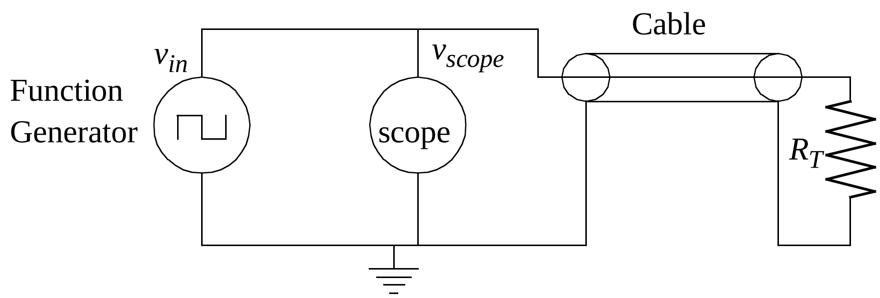

Figure 1: Transmission Line Circuit

Without connecting the cable, set the frequency to 200 kHz and the amplitude to 1 V. This is effectively a cable of zero length and the amplitude is $v_{in} + v_{ref} = 2 * v_{in}$. Turn on the duty cycle and adjust it so that the square wave is high for 1 μs and low for the remainder of the time. Attach the cable without any terminating resistor and describe the signal shape observed. Use the cancellation with the reflection to estimate the time for the signal to travel down the cable and back again. What is the speed of a signal in the cable compared to the speed of light?

2. Coaxial Cable Impedance

Place a 10 kΩ resistor in as the load resistor for the circuit in figure 1. Measure the amplitude of the reflection by using $v_{scope} = v_{in} + v_{ref}$. Repeat this measurement for resistors of 1 kΩ, 330 Ω, 100 Ω, 47 Ω, 22 kΩ, 10 Ω, and 0 Ω. How does your estimated impedance of this cable compare to an expected value of 50 Ω?

3. Stereo Speaker Cable

Repeat parts 1 and 2 with a stereo speaker cable instead of the coaxial cable. What is the speed and impedance of the stereo speaker wire (300Ω is expected)? Why is there always some reflection in this circuit? Add resistors in before the cable like in figure 2. Observe the amplitude of the signal and reflection, if any. Treat the cables as resistors of the appropriate impedance, and show why both cables are now correctly terminated.

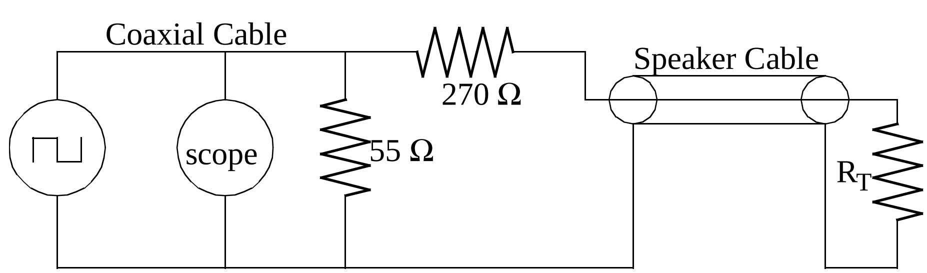

Figure 2: Impedance Matching