

## Coaxial Cable Properties

### Introduction

Coaxial cable is used for pulse transmission, where the wire and shield (separated by a dielectric) serve as a waveguide allowing small signals to be transmitted with minimal distortion. It has characteristic impedance ( $Z$ ), capacitance ( $C$ ), and inductance ( $L$ ). The formulas for capacitance and inductance are:

$$C = \frac{2\pi\epsilon}{\ln(b/a)} \times \ell \quad (1)$$

$$L = \frac{\mu}{2\pi} \ln\left(\frac{b}{a}\right) \times \ell \quad (2)$$

where  $a$  and  $b$  are the radii of the wire and shield respectively,  $\epsilon$  and  $\mu$  are the permittivity and permeability of the dielectric, respectively, and  $\ell$  is the length of the cable. The characteristic impedance ( $Z_c$ ) is then:

$$Z_c = \sqrt{\frac{L}{C}} = \frac{1}{2\pi} \sqrt{\frac{\mu}{\epsilon}} \ln\left(\frac{b}{a}\right) \quad (3)$$

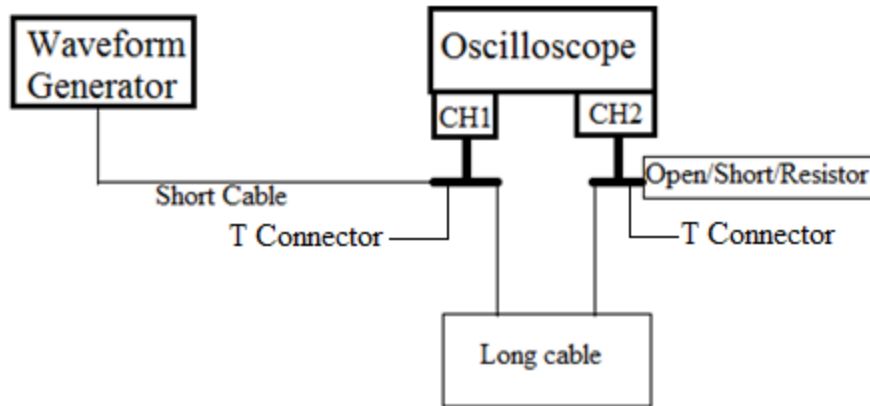
The relationship between  $Z_c$  and the load impedance  $Z_L$  affects the transmission response of the coaxial cable to signals. The ratio between  $Z_c$  and  $Z_L$  determines the reflection coefficient, which is the ratio of the current reflected at the end of the cable to the current incident on the end.

Reflection Coefficient: 
$$\Gamma = \frac{Z_L - Z_c}{Z_L + Z_c} \quad (4)$$

The reflection coefficient can vary between 0 and 1. If  $Z_c = Z_L$ , the reflection coefficient = 0.

### Setup (Figure 1)

Set the waveform generator to **pulse a 30-ns wide signal at 3 kHz with a peak-to-peak voltage of 4V**. The oscilloscope should be set with an appropriately small time division. Send the pulse through a short (1-2m) length of coax cable and observe it on **CH1** of the oscilloscope before it enters the long (10m+) cable, to be observed on **CH2**.



**Figure 1: Apparatus**

### Part I: A wave inside the cable

The T-connector on **CH2** can be left open, connected to a shorted end, or connected to a 50  $\Omega$  resistor. Try each of these arrangements and observe and record the signal from the oscilloscope. Use the following points for analysis in your lab report.

- 1a. Explain the path the pulse travels when the T-connector on **CH2** is open? Shorted? 50  $\Omega$  resistor?
- 1b. Using formulas 1, 2, 3 and 4, predict the behavior of the pulse depending on the boundary conditions at the end of the cable.
- 1c. Using the time between pulses and the measured length of the cable, calculate the velocity of the signal within the cable. Demonstrate this using oscilloscope measurements and associated uncertainty.
- 1d. When do the pulses observed on **CH1** appear positive? Negative? Both positive and negative?

### Part 2: Multiple reflections

Attach a 1k $\Omega$  resistor between the short cable and the **CH1** T-connector. Repeat observations using an open, shorted, and 50 ohm resistor on the **CH2** T-connector.

- 2a. How does the pulse travel within the cable with the addition of the 1k $\Omega$  resistor?
- 2b. How is the amplitude of the displayed pulses affected by the 1k $\Omega$  resistor?
- 2c. Why does the signal behave differently compared to **Part 1** for an open or shorted termination of the cable?
- 2d. Increase the pulse width of the signal and observe the changes in the display, notably the amplitude of the first pulse.

### Part 3: Increasing Pulse Width

With the 1k $\Omega$  resistor still attached between the CH1 T connector and the short cable, increase the pulse width until successive pulses overlap. The reflected pulse will arrive before the end of the input pulse. If the pulses last until the amplitude of the reflections approach zero, the cable itself will begin to act as a capacitor.

The RC time constant ( $\tau$ ) is the time required to charge or discharge a capacitor, through a resistor, by  $1/e$  (approximately 63.2%) of the difference between the initial and final value. It is equal to the product of the resistance (in ohms) and the capacitance (in farads). By measuring both the time constant and resistance of the system, the capacitance of the coax cable can be calculated. **Calculate uncertainties for all measurements.**

- 3a. Measure the RC time constant of the system with the 1 k $\Omega$  resistor and an open end on the **CH2** t-connector. Use this to calculate the capacitance of the cable per meter. Compare this to the theoretical value found with equation (1).
- 3b. Using the experimental value for capacitance (C) and the theoretical calculation for inductance (L), calculate the characteristic impedance ( $Z_c$ ) of the cable.
- 3c. Compare the experimental values to the theoretical values found and discuss potential sources of error and uncertainty.

### Part 4: Standing Waves

Change the wave generator signal to sinusoidal. Leaving the cable end open, attempt to create a standing wave within the long cable. Set the signal wavelength as either half or all of the long cable length and alter the frequency.

- 4a. Describe the conditions for a standing wave to occur within the long cable using oscilloscope measurements and screenshots.
- 4b. Use the reflection coefficient formula to explain how the boundary conditions of the long cable permit a standing wave to form. How could a standing wave form without the 1 k $\Omega$  resistor?