Characterization of Coaxial Cables

Materials:

Equipment:	Qty
50-meter RG58 coaxial cable with BNC connectors	1
Short coaxial cable with BNC connectors	1
Function Generator	1
Pulse Generator	1
Oscilloscope	1
Digital Camera/Diskette	1
BNC couplers	2
Closed Circuit Terminator	1
50 Ω terminator	1
Tape meter	1

1. Characteristic Impedance, Reflection Coefficient and Propagation Speed

Determine the characteristic impedance Z_o and reflection coefficient R of the coaxial cable. Compare experimental propagation speed in a coaxial cable to calculated value.

Theory:

Coaxial cables have characteristic impedances. To avoid signal loss by reflection as the signal encounters boundaries, e.g. another device, impedance of the coaxial cable should be matched with the device. If the impedance at the boundary is not matched with the coaxial cable, part of the signal introduced gets reflected. The reflection coefficient is obtained by comparing the amplitudes of the introduced and reflected pulses. Pulses introduced in coaxial cables propagate in a constant speed. A pulse is introduced at the beginning of a coaxial cable is observed at a later time at the end of cable.

1. Measure the actual lengths of the coaxial cable using the tape meter.
2. Turn on both the pulse generator and oscilloscope.
3. Connect one end of the short coaxial cable to the output of the pulse generator. To its other end, attach a BNC coupler and connect to one channel of the oscilloscope. The impedance of the oscilloscope's channels can be set to 50Ω or 1 MΩ. Choose 50Ω for this channel.
4. Introduce a square pulse in the coaxial cable. Set the oscilloscope such that the pulse is seen on the display screen. The oscilloscope should be triggered by the channel in step 1.
5. Connect one end of the 50-m coaxial cable to the BNC coupler from step 1. To its other end, attach the second BNC coupler with the 50Ω terminator to a second channel on the oscilloscope. Set the impedance of this channel to 50 Ω.
    - Examine the pulse at the beginning (1st channel) and end (2nd channel) of the 50-m cable. Take a picture/save plot of the data.
    - Compare the shape and amplitude of the pulse at the beginning and end of the cable.
    - Explain what happens to the pulse as it travels in the coaxial cable from beginning to end and what happens to the pulse as it reaches the end of the cable.

6. Remove the 50Ω terminator from the BNC coupler at the end 50-m coaxial cable and replace with the short circuit terminator. This case is similar to wave reflection in a string with the other end fixed/closed.
   - Examine the pulse at the beginning and end of the 50-m cable. Why is there a second pulse observed at the beginning of the cable? Take a picture/save plot of the data.
   - Compare the shape and amplitude of the pulse at the beginning and end of the cable.
   - Explain what happens to the pulse as it travels in the coaxial cable from beginning to end and what happens to the pulse as it reaches the end of the cable.

7. Remove the BNC couple from the end of the 50-m cable and connect it directly to a second oscilloscope channel. Set the impedance of this channel to 1MΩ. This case is similar to wave reflection in a string with the other end open.
   - Examine the pulse at the beginning and end of the 50-m cable. Why is there a second pulse observed at the beginning of the cable? Take a picture/save plot of the data.
   - Compare the shape and amplitude of the pulse at the beginning and end of the cable. Note the transit time, the time difference in the falling edge of the introduced and reflected pulses.
   - Explain what happens to the pulse as it travels in the coaxial cable from beginning to end and what happens to the pulse as it reaches the end of the cable.

Guide Questions:

1. What is the characteristic impedance Z_o of the RG-58 coaxial cable based on your data?
2. What is the reflection coefficient for the different boundary conditions at the end of the 50-m coaxial cable; terminator with 50Ω resistor, closed ended and open ended?
3. Compare the experimental propagation speed ($c = 2L/t$) of the pulse in the cable from the calculated value ($c = (\varepsilon\mu_o)^{-1/2}$), where $L \approx 50$m is the length of the cable, t is the pulse transit time obtained from the falling edges of the pulse and the reflected pulse observed at the beginning of the cable with the other end open, ε is the dielectric constant in the cable, and μ_o is the magnetic permeability of vacuum.

2. Multiple Reflection, Loss Coefficient and Capacitance

Observe multiple reflection inside a coaxial cable. Determine nthe loss coefficent in a coaxial cable as a pulse travels longer distances. Compare the experimental value of the capacitance of the coaxial cable to calculated value.

Theory:

Multiple reflection is observed within coaxial cables when both ends do not match the characteristic impedance of the cable. As a pulse gets reflected back and forth, it travels longer distance and the amplitude decreases due to attenuation. The loss coefficient may be obtained from the amplitude of the pulse as it travels longer distances.

1. Turn on both the pulse generator and oscilloscope.
2. Connect one end of the short coaxial cable to the output of the pulse generator. To its other end, attach a BNC coupler and connect to one channel of the oscilloscope. The impedance of the oscilloscope's channels can be set to 50Ω or 1 MΩ. Choose 1MΩ for this channel.
3. Introduce a square pulse in the coaxial cable. Set the oscilloscope such that the pulse is seen on the display screen. The oscilloscope should be triggered by the channel in step 1.

4. Connect one end of the 50-m coaxial cable to the BNC coupler from step 1. To its other end, attach the second BNC coupler with the short circuit terminator to a second channel on the oscilloscope. Set the impedance of this channel to 50 Ω.
    - Examine the pulse at the beginning (1st channel) of the 50-m cable. Take a picture/save plot of the data.
    - Describe the shape and amplitude of the pulse as it gets reflected back and forth inside the coaxial cavity.
5. Remove the BNC couple from the end of the 50-m cable and connect it directly to a second oscilloscope channel. Set the impedance of this channel to 1MΩ.
    - Examine the pulse at the beginning of the 50-m cable. Take a picture/save plot of the data.
    - Describe the shape and amplitude of the pulse as it gets reflected back and forth inside the coaxial cavity.

Guide Questions:

1. Compare the multiple reflection observed in closed and open ended coaxial cable.
2. For the open ended cable, plot the amplitude of the introduced and reflected pulses as a function of the distance traveled (*L, 2L, 3L,* etc) and determine the loss coefficient of the coaxial cable.
3. Compare the experimental capacitance ($C=L/cZ_o$) of the coaxial cable with calculated value $C = L\dfrac{2\pi\varepsilon}{\ln r_o/r_i}$, where r_o and r_i is the diameter of the outer and inner conductors of the cable, respectively.
   Research on the value of the diameters for RG-58 coaxial cables.

3. Resonance

Find the first three resonance frequencies with the cable end open by introducing a sinusoidal signal and measuring the signal at both ends of the cable.

Theory:

Standing waves and resonance can be observed when sinusoidal waves interfere in the coaxial cavity. With both ends of the cable open (1M Ω), the waves observed at the beginning and end of the cable should have the same amplitude. For the fundamental and third harmonic (and odd-numbered harmonic) frequencies, the waves observed at the beginning and end of the coaxial cable are out-of-phase. The waves observed at the beginning and end of the coaxial cable are in phase for the second harmonic (and even-numbered harmonic) frequency(/ies).

1. Turn on both the function generator and oscilloscope.
2. Connect one end of the short coaxial cable to the output of a pulse generator. To its other end, attach a BNC coupler and connect to one channel of the oscilloscope. The impedance of the oscilloscope's channels can be set to 50Ω or 1 MΩ. Choose 1MΩ for this channel.
3. Introduce a sinusoidal wave in the coaxial cable. Set the oscilloscope such that the wave is seen on the display screen. The oscilloscope should be triggered by the channel in step 1.
4. Connect one end of the 50-m coaxial cable to the BNC coupler from step 1. Connect the other end directly a second oscilloscope channel. Set the impedance of this channel to 1MΩ.
5. Increase the frequency of the sinusoidal wave from the lowest until an out-of-phase wave of the same amplitude as the introduced wave is observed at the end of the cable. Note this frequency as the fundamental frequency. Take a picture/save the plot of the waves.

6. Increase again the frequency of the sinusoidal wave until an in-phase wave of the same amplitude as the introduced wave is observed at the end of the cable. Note this frequency as the second harmonic frequency. Take a picture/save the plot of the waves.
7. Increase again the frequency of the sinusoidal wave until another out-of-phase wave of the same amplitude as the introduced wave is observed at the end of the cable. Note this frequency as the third harmonic frequency. [The harmonic frequencies you may obtain is limited by the highest frequency the function generator can provide. Obtain other harmonic frequencies if possible.] Take a picture/save the plot of the waves.

Guide Questions:

1. Why should the beginning of the cable be open-ended? Would you observe standing waves if the beginning of the cable is short-ended?
2. Why are the waves observed at the beginning and end of the cable out-of-phase for the fundamental and third harmonic (and odd-numbered harmonic) frequencies? Why are the waves observed at the beginning and end of the cable in-phase for the second harmonic (and even-numbered harmonic) frequency(/ies)?
3. Draw the amplitude of the standing waves in the length of the cable for the 1st three resonant frequencies with both ends of the cable open. How are the wavelengths (λ_1, λ_2, and λ_3) of the first three resonant frequencies related to the length L of the cable? Give the general relationship of the wavelength λ_n to the length L of the cable for the nth harmonic frequency. Give the general relationship of the frequency f_n to the propagation speed c and length L of the cable for the nth harmonic frequency. Calculate f_1, f_2 and f_3 and compare to values obtained experimentally.
4. Is it possible to have standing waves if the beginning of the cable is open-ended and the end of the cable is short-ended? If yes, what would be the amplitude of the wave at the end of the cable? Would the waves at the beginning and end of the cable be out-of-phase or in-phase for the fundamental frequency? 2nd harmonic (and even-numbered harmonic) frequency(/ies)? 3rd harmonic (and odd-numbered harmonic) frequency(ies)?
5. Draw the amplitude of the standing waves in the length of the cable for the 1st three resonant frequencies with the beginning of the cable open-ended and the end of the cable close-ended. How are the wavelengths (λ'_1, λ'_2, and λ'_3) of the first three resonant frequencies related to the length L of the cable? Give the general relationship of the wavelength λ'_n to the length L of the cable for the nth harmonic frequency. Give the general relationship of the frequency f'_n to the propagation speed c and length L of the cable for the nth harmonic frequency.