In this laboratory exercise, explore some of the concepts we have discussed in class, as well as a few that we have yet to discuss. This set up will remain available to you so that you can repeat measurements, or make new ones. The goal is for you to be able to discuss qualitatively, and quantitatively, the concepts of

- wave propagation
- impedance & impedance matching
- reflection & transmission coefficients
- attenuation.

This experiment might suggest how technicians find flaws and breaks in cable transmission lines!

A coaxial cable or coax (pronounced "co-ax") has a characteristic impedance, Z_1, and voltage waves and pulses can propagate. The coax should, in principle, be connected to a second coax, with another impedance, Z_2. However, this second coax should really be infinite in length, and we'd like to vary Z_2, and this is too difficult to realize in practice. Instead, we use different "terminating" resistors (R_{TERM}), which have precisely the same effect as a second coax (so R_{TERM} is a proxy for Z_2). In class, we discuss what happens when a wave (or pulse) propagating in one medium encounters a different medium. Your task is to see how if this model is a good description of the wave propagation in the coax cable, and if not, how to extend the model.

Equipment at hand:

- Function generator: generates pulses and waveforms. Connect at one end of the coax cable.
- Oscilloscope: measure the voltage at each end of the cable. A long (about 100 m or more) transmission lines or coaxial cable (coax). They all have different impedances, and all have connectors on both ends. Examine a piece of coax - ask the instructor.

  Model of a coax cable:

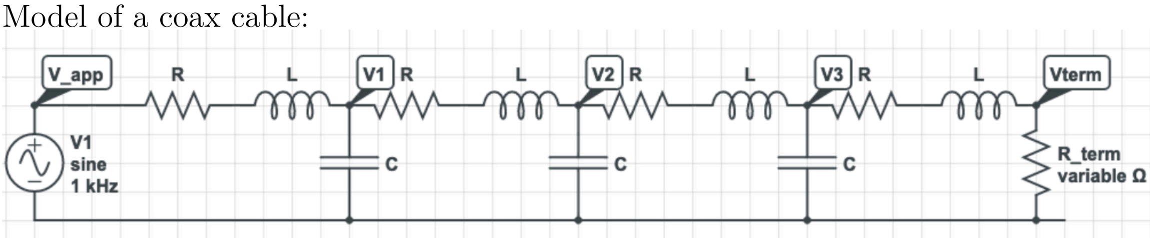
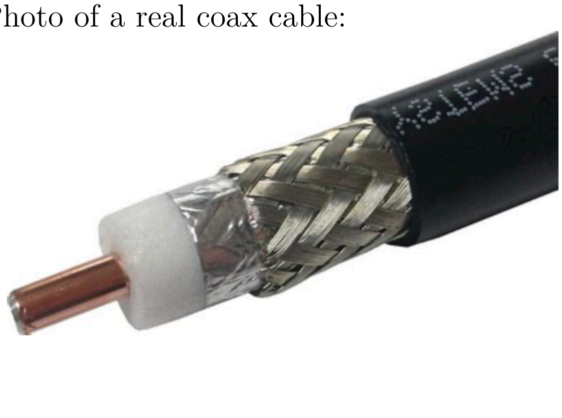


  Photo of a real coax cable:



- Resistors to terminate the coaxial cable.
- Multimeter: to measure the value of the terminating resistance(s).
- Lots of short coax cables (negligible addition to length of main coax), connectors

Some terminology: If the center cable and the outside braided cable of the coax cable are connected by a resistor R_{TERM} at one end, we say "the cable is terminated" by R_{TERM} ohms. If $R_{TERM} = 0\,\Omega$, we say the cable is "short circuited' or "shorted" at that end. If R_{TERM} is infinite, we say the cable is "open". For the special case when R_{TERM} is equal to the impedance of the cable, we say the line is "correctly terminated" or "impedance matched."

Experiment 1:
Measure the speed of propagation of a voltage pulse in your cable.

Description: Apply a voltage pulse to one end of the cable with the function generator, and use channel 1 of the oscilloscope to measure the observe the pulse and its reflection after one round trip. You will have to decide how wide to make the pulse and decide and how often the pulse repeats.

Prediction & Questions: Discuss with your group how long it takes for a voltage pulse to propagate down and back along the coax cable. Record your group's questions and predictions.

Discussion: Are your experimental findings in accord with your predictions? If not, can you resolve the discrepancies?

Other questions: Record other questions that occur to you about this phenomenon. Perhaps they will be addressed later on in the lab. If not, they will be a guide for further study. For instance, how does this pulse propagate? How do the electrons move? How does ac current differ from dc current? Why use a pulse? What else do you want to ask?

Experiment 2:
Measure the size of the voltage signal at each end of the coax cable, relative to the voltage pulse applied by the function generator, as a function of varying R_{TERM}.

Description: Apply a voltage pulse to one end of the cable with the function generator, and use channel 1 of the oscilloscope to measure the observe the pulse and its reflection after one round trip, as you change the terminating resistance (resistor connected across the other end of the cable). Record the voltages and the resistances. Repeat for the voltage at the terminating resistor (use channel 2 of the oscilloscope).

Predictions & Questions: Discuss with your group the size and polarity of a square voltage pulse that has propagated (A) down the coax cable when the cable and (B) down and back along the coax cable, when the cable is terminated by different resistances. Record your group's questions and predictions.

Discussion: Are your experimental findings in accord with your initial and possibly revised predictions? Does the sign agree with your prediction? The size? What about limiting or extreme cases? As soon as you have recorded your values, ask an instructor to check that your values are reasonable. We discussed "dispersion" in class. What, if anything, do we assume about the dispersion relation for this system?

This third experiment provides further challenge and fun, if you're interested. It used to be assigned when the course was offered as PH424/524 and we may not have time for it this year. But if you're interested, you can try it!

Experiment 3 (*optional for PH424, required for PH524*):

Description: Generate standing waves in the coax cable and vary the frequency so that you can detect nodes and antinodes (or at least amplitude variations) at each end of the cable for the open and shorted terminating cases. You can explore further by varying R_{TERM}. Use single-frequency sinusoidal waves rather than the pulse (which is a superposition of voltage waves of different wavelengths and frequencies) in this experiment. Decide which frequency range to use (1 Hz, 1 kHz, 1 MHz?), and whether you should vary the frequency by a factor of 2 or 3 or 4 or so in the chosen range or whether to vary it by orders of magnitude.

Prediction & Questions: Discuss with your group the voltage between the center and ground (shield) in a semi-infinite (extends from $x = \infty$ to $x = 0$), perfect (resistanceless) transmission line in which a sinusoidal wave of frequency f propagates in this line at speed c, reflects off the end (call this $x = 0$) and propagates back. Consider cases when the terminating resistance is zero and when it is infinite. Record your predictions, in particular the voltage recorded when the oscilloscope is located at $x = L$ (qualitative, quantitative, sketches, ...). How would this voltage change as f is slowly changed? What would happen if the transmission line is resistive? This takes a little effort to model quantitatively, but at least discuss qualitatively before you do the experiment.

Discussion: Model in Mathematica (or other) to show that your experimental results may be predicted theoretically.