Oscilloscope and Cable Termination Techniques

The oscilloscope is widely used in physics laboratories as a measurement and analysis tool. We will investigate the basic properties of the Tektronix TDS2014 Oscilloscope and the cables that attach to such devices. This lab does not require a formal write-up. Instead, submit answers to every question asked along the way. Hand-drawn diagrams of oscilloscope traces (or photos) are acceptable, and should be labelled clearly.

Introduction:

Typically in an experiment we are attempting to measure a quantity in the form of voltage or current. First we determine whether the quantity in question is intrinsically electrical or if we need to convert the quantity into an electrical form. For example, the voltage drop across a diode is intrinsically electrical, while atmospheric pressure needs to be converted into voltage or current for automated readings on a computer. Although this appears straightforward, invariably all electrical signals are accompanied by noise. The broadest definition of noise is any kind of (electrical) signal you do not want. Consider tuning a radio to a frequency where you hear more than one broadcasting station. Less obvious noise is the slight hum you can hear between musical tracks on your media player or computer. It is therefore relevant to consider techniques for reducing the noise content of a signal we want to measure. We will begin by looking at how our signal is being transmitted into our measurement devices. Later, in the next lab, we will look at how lock-in amplifiers can help improve the signal-to-noise ratio.

The most common of cables found in a laboratory are coaxial, where the signal is sent on a central wire that is shielded from external effects by a surrounding conductor that is usually held at ground. Coax wire is often referred to by the connector on the end of it (e.g., BNC, SMA, LEMO), but the wire itself will have a categorization (e.g., RG-58, RG-59). Different wire types (and connectors) will work well up to different radio/microwave frequencies (and, frequently, voltages).

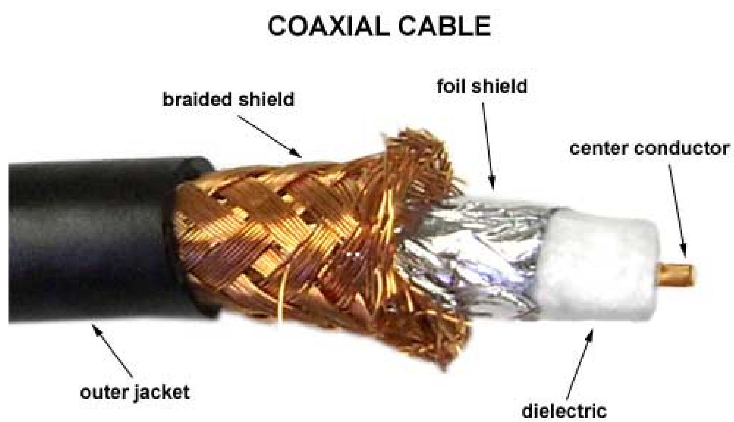

Figure 1: common coaxial cable

A fundamental property of a coaxial cable is the characteristic impedance, Z_o. For common cables

$$Z_o = \sqrt{\frac{L}{C}}$$

with L representing inductance and C the capacitance, per unit length. Typical values range from 50Ω to 100Ω and are specified in a non-obvious fashion by the number of the cable. Note that this impedance is *not* what you will measure if you simply hook an ohmmeter along the shield or centre conductor: there you'll just measure the length times the series resistance per unit length, R, of a cable. This series resistance can have a dominant impact on signal attenuation if the cable run gets extreme. (See Section 6.2.3 of *Building Scientific Apparatus* fourth edition.)

We will be working with RG-58 coaxial cables, which have a characteristic impedance near 50Ω. As mentioned earlier, we want to minimize noise in our experiment and the cables are part of our experiment. Cables should be coax to minimize cross-talk and interference. A coax cable should be terminated with a resistance equal to Z_o, or else ringing will occur.

References:

- J.H. Morre, C.C. Davis, and M.A. Coplan, Building Scientific Apparatus, 4th ed., Cambridge University Press, New York, NY, 2009 pp. 388-401
- Manual,Oscilloscope, TDS1000 and TDS2000 Series Digital Storage Oscilloscope, Tektronix
- Manual, Function Generator, Model DS335, Stanford Research Systems
- P. Horowitz and W. Hill, The Art of Electronics, 2nd ed., Cambridge University Press, New York, NY, 1989

Objectives:

This experiment is broken into three main parts.

1. **Introduction to the Tektronix 2000-series Oscilloscope**. You will study the characteristics and a few features of the oscilloscope.

2. **Study of cable termination**. You will study the effects of a cable's termination on signal transmission.

3. **Study of a noisy signal**. You will breadboard up a simple LED transmitter and observe its (noisy) response on the oscilloscope.

Laboratory Procedure Part 1: Introduction to the Oscilloscope

Read pages 17 - 23 of the Tektronix 2000-series Oscilloscope manual. Determine and discuss appropriate settings (amplitude scale, timing scale, trigger settings, acquisition mode, coupling, other?) if you are looking at a 3 MHz, .1V_{rms} sine wave. How does V_{rms} relate to V_{pp} and V_{max}? Produce a 3.0 MHz, .1V_{rms} sine wave, and connect the "MAIN" signal of the signal generator to channel 1 on the scope. Confirm the signal looks as expected (if it doesn't, explain why!).

Define and describe the three acquisition modes of the oscilloscope (as in manual). Which mode would you choose for the following three signal examples:

1. You want to detect a muon entering a detector. The particles do not enter a detector at a constant rate and when you do get a muon in the detector you get a short current pulse.

2. A 2 kHz, 1V TTL signal from a function generator.

3. An extremely noisy 60 Hz, 1V_{pp} sine wave.

Laboratory Procedure Part 2: Proper Termination

We will be using different cables for connecting instruments. It is reasonable to consider the effect of these cables. Using the signal generator, obtain a $\approx$2 MHz square wave at 1V_{pp}. Look at the signal on the scope (channel 1) using a 3 foot BNC cable.

Accurately measure the length of a very long BNC cable and then attach it to the same channel on the scope as the signal. What happened to the scope trace? Explain in terms of round-trip pulse time along the cable and derive the speed of light in the cable (propagate uncertainties!). Connect the "free" end of the long BNC cable to channel 2 and observe the signal there in conjunction with the signal at the tee. Did the signal on channel 1 change? Would you expect it to? Explain what you see on channel 2. Now, disconnect channel 2 and terminate the "free" end of the long BNC cable with a 50 Ω resistor.

Explain any changes in the scope reading. Provide scope traces as appropriate. Replace the 50 Ω resistor with the pass through terminator and connect this end to channel 2 on the scope. Again explain any changes in the scope reading and provide scope traces as appropriate. In the follow-up lab you will consider signals going into a lock-in amplifier. If it takes 10 “travel periods” to wash out or not care about lousy termination, figure the maximum frequency you want to run the lock-in (Note: $\leq$ 100 kHz for other reasons).

Laboratory Procedure Part 3: A Follower Circuit and a Noisy Signal

Hook up the following circuit using a 1KΩ resistor. Drive it at 2kHz sine wave, 5V_{pp} with a 2V_{pp} offset from the SRS signal generator. Observe the signal in the photodiode detector (PD) on channel 2 of the scope. This light detector outputs current, hence the attached 10kΩ terminator for voltage conversion. Trigger on the signal generator TTL out. Move the PD far enough from the LED to muddy the signal.

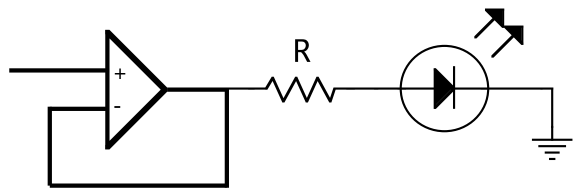

Figure 2: LED circuit diagram

Try some averaging on the scope (page 54-55 manual). What effect do the room lights have, and how can you diagnose it (beyond just seeing what happens when you turn off the room lights)?

Lab Report

This lab does not require a full formal report. Instead, submit a report with a few paragraphs providing context for each section of this lab. Also supply explanations where requested in the procedure.

Specifically address the following questions and points as well:

1. Define and describe capacitance,inductance and cross-talk. Consulting the references will help here.
2. What is the input impedance of a Tektronix 2014 Oscilloscope? Discuss why this value was chosen.
3. What is the output impedance of an SRS function generator? Does it actually change when you ask for “Hi-Z”, or does something else? Why was this value chosen, and why is knowing this value necessary to explain the DC limit (consider a square wave of frequency 0 Hz) of signals down the cable?
4. Why is there a follower as part of the LED circuit? Given the earlier part of this lab, how would you improve the follower for higher-frequency operation?