

Physics 182 Experiment #8, The Voltage Divider

Purpose

We will be re-examining Kirchoff's laws, but this time we will be working with a time dependant signal. This will lead us to a new tool, the oscilloscope, which allows us to visualize time dependant voltage. In addition, we will determine the resistivity of a material, a property which is intrinsic to the material and determines how hard it is to drive electrons through a sample of the material, in this case a wire.

Introduction

Two weeks ago we studied Kirchoff's laws with a static voltage applied to our circuits. We were able to use these laws to determine the currents through each circuit element and the voltages at each point in the circuits. This week we will look at a simple circuit, the voltage divider, which is composed of two resistors in series. The voltage divider has an output voltage that is a specific fraction of the applied voltage that is determined by the resistors composing the divider.

As an added complexity we will be using an oscilloscope to "see" the voltage as a function of time at various places in the circuit. The oscilloscope is one of the most flexible and useful pieces of measurement equipment available to us. We will be examining our simple circuit with this complex instrument to gain familiarity with the oscilloscope so that we can concentrate on the physics in experiments to come.

Background

We will be measuring a circuit fragment known as a voltage divider. It is built by connecting two resistors in series (See figure1).

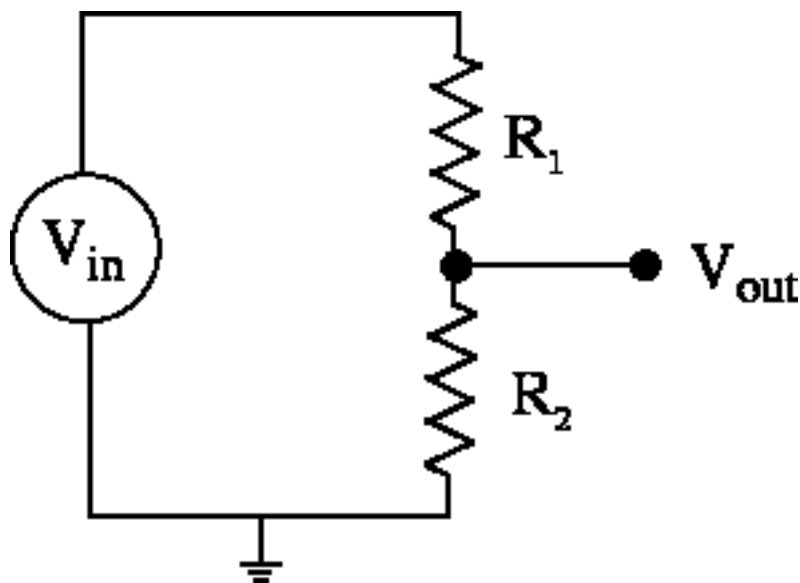


Figure 1.

If we apply a voltage, V_{in} , across the two resistors a current flows which is equal to the applied voltage divided by the effective resistance of the series combination of the two resistors,

$$I = \frac{V_{in}}{R_1 + R_2}.$$

As a consequence of the current flowing through the second resistor we can measure a voltage across it, V_{out} . This output voltage is,

$$V_{out} = IR_2 = \frac{R_2}{R_1 + R_2} V_{in}.$$

V_{out} is a fraction of V_{in} determined by the two resistors. Note that we are defining ground, the zero of our electrostatic potential energy to be at the bottom of the circuit.

We can use this relationship to determine an unknown resistance in series with a known resistance by applying a known voltage and measuring the resulting output voltage. Since,

$$V_{out} = \frac{R_?}{R_1 + R_?} V_{in}$$

$$V_{out}(R_1 + R_?) = R_? V_{in}$$

$$V_{out} R_1 = R_? V_{in} - R_? V_{out}.$$

$$V_{out} R_1 = R_?(V_{in} - V_{out})$$

$$R_? = \frac{V_{out}}{(V_{in} - V_{out})} R_1$$

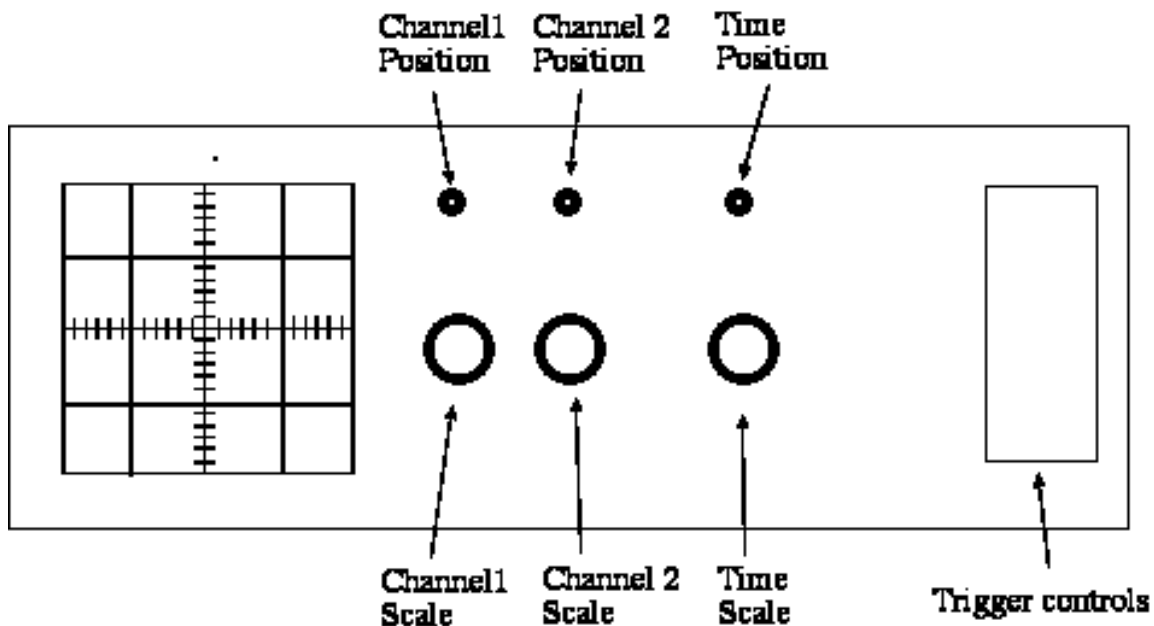
Our experiment this week will involve connecting known resistors to unknown resistors in the voltage divider configuration and measuring V_{out} for a known applied V_{in} , and using the resulting data to determine the unknown resistances.

We will also be using this technique to measure the resistivity of a wire. Resistivity is related to the resistance of a material by the geometry of the object measured. For a sample of a given resistivity, ρ , cross sectional area, A , and length, l , the resistance is,

$$R = \rho \frac{l}{A}.$$

The resistivity is an intrinsic property of a material. The resistivity of a block of copper is the same as the resistivity of a piece of copper wire. If the wire is long and has a small cross sectional area then its resistance will be large compared to a cubic block made of the same amount of material.

The final piece of background you will want before starting this experiment is a brief description of an oscilloscope. An oscilloscope measures and displays voltage as a function of time. The oscilloscopes you will be using have three inputs; channel 1, channel 2, and trigger in. The first two are connected to your circuit at two points. The third input is connected to a function generator that will be used to drive your circuits with a sine wave voltage signal. The trigger tells the oscilloscope when to start taking data. If the sine waves that appear on the screen of your oscilloscope move across the screen you are having a problem with the trigger. Ask your TA to help you if this happens. You should not worry about setting up the trigger yourself. Besides the trigger controls there are three sets of controls on the front of the oscilloscope. Two of these sets of controls set up the scale on which you will be measuring voltage on the vertical axis of the oscilloscopes screen. The third set of controls sets the timebase on the horizontal axis of the screen. You can control both the scale and the origin, or position, of the two vertical voltage scales and the horizontal time scale. You will want to play around with all of these in order to get the best possible measurements of the voltages in this experiment.

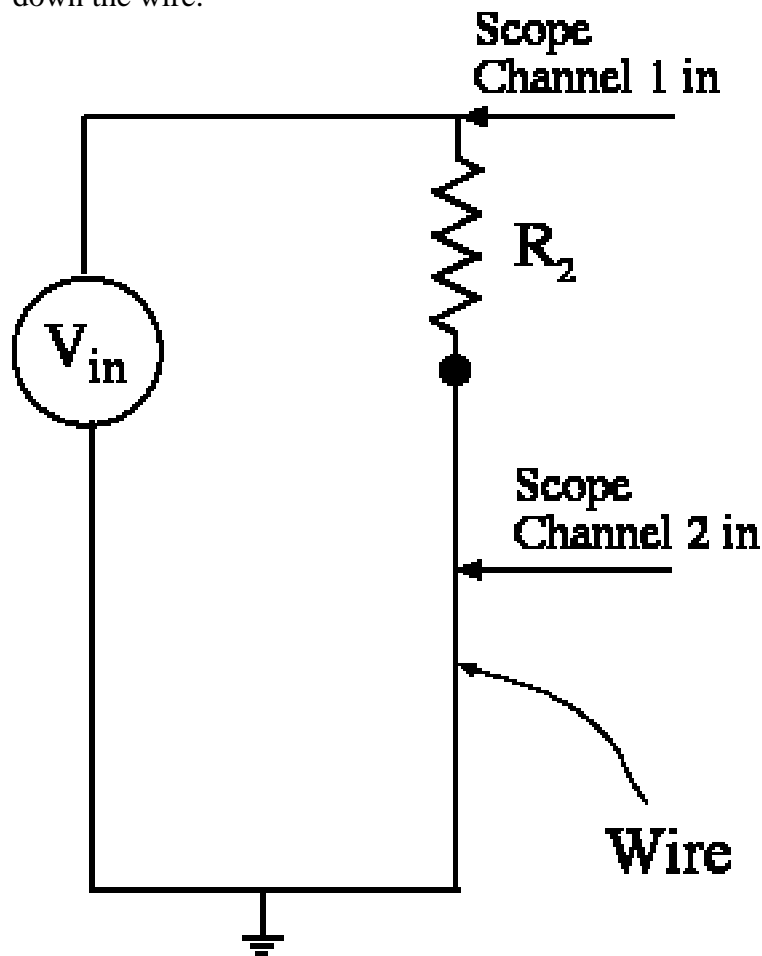


Recipe

- 1) Connect the output of the function generator to the input of channel 1 of the oscilloscope. Make sure that the output high is connected to the red input and output low is connected to the black input.
- 2) Turn on the function generator. Set the output frequency scale to 1 kilohertz. Adjust the frequency dial so that it is set to 5.
- 3) On the oscilloscope set the channel 1 amplitude to 2 volts and the timescale to 50 microseconds. You should see a nice sine wave going across the screen.
- 4) We now want to set the origin for our vertical axis. Underneath the knob that sets the scale there is a switch that has three positions; AC, Ground and DC. Set this switch to ground. This grounds the input, making the input signal zero volts. You should now see a flat line going across your screen. Above the scale knob is a smaller knob which controls the vertical position of the trace. Turn this knob until the flat line is lined up with the centerline of the grid, or reticule, of the oscilloscope screen. This will make the vertical center of the screen the zero of voltage. Do this for both Channel 1 and Channel 2. Now, set both knobs to DC.
- 5) On the function generator there are two small knobs; amplitude and offset. The amplitude knob controls how big the difference between the top and the bottom of the sine wave is. The offset knob shifts the wave up and down in voltage. Adjust these knobs so that you have a sine wave which is 4 vertical divisions in amplitude, centered on the screen. If your vertical scale is 2 volts you have a sine wave which varies from minus 4 volts to plus 4 volts. We call this an 8 volt, peak to peak signal.
- 6) We now want to measure the frequency of our sine wave. Adjust the time scale until you have ten or more periods of sine wave on screen. Above the knob that controls the time scale is a smaller knob that controls the horizontal position. Move this knob until the leftmost edge of the signal on the screen, the scope trace, is lined up with the leftmost reticule line on the screen. Now, by counting the number of divisions that correspond to a number of periods of your wave and multiplying by the time per division on your scale knob you can figure out the time per oscillation. The reciprocal of this is just the frequency. Record the frequency of your sine wave on your data sheet.
- 7) Use the digital multi-meter to determine the resistance of resistor 1, record this resistance. Now connect resistors 1 and 2 on the board in series. Connect the function generator so that the output high is connected to resistor 1 at the top of the divider and output low is connected to resistor two at the bottom of the voltage divider. Connect input 1 of the oscilloscope so that it measure across the two resistors, the red input at the top and the black input at the

bottom. Connect input 2 of the oscilloscope across resistor 2 with the red input at the point in the divider where the two resistors are connected, the middle of the divider, and the black input at the bottom of the divider. The output low of the function generator and both of the low or black inputs of the oscilloscope should be connected. We call this sharing a common ground. Look at the circuit diagram in figure 1 if you need help figuring out how this should look.

- 8) Adjust the vertical scales of channels 1 and 2 to make voltage measurements as accurately as possible. You may want to shift the curves downward with the position control to align the bottom edge of the signal with a reticle division and then move the time position so that the top of the sine wave corresponds to the center of the screen where the reticle has subdivision. Record the two peak to peak voltages. Use these voltages with your measurement of resistor 1 to determine the resistance of resistor 2. Record this resistance.
- 9) We want to make the same measurement, but using a wire where we can make contact to the wire and measure the voltage as a function of position going down the wire.



- 10) Apply a voltage of 10 Volts peak to peak across your circuit. Using the oscilloscope, measure the voltage drops across R_2 and the wire and just the

wire itself. By subtracting the voltage drop across the wire from that across R_2 and the wire you can determine the voltage drop across R_2 . Use this and the resistance of R_2 to determine the current flowing through the circuit, I . Record this value.

- 11) Now use the oscilloscope to measure the Voltage as a function of position along the wire. Take a reading every 4 centimeters. Make sure to press the contact firmly onto the wire. Plot the data on a piece of graph paper as you are taking it. You will want to change the oscilloscope scale and position for each measurement. As you plot it you will notice that the data, while generally following a line, has a good deal of scatter about the line. Record your data.
- 12) Use the micrometer in the lab to measure the diameter of the wire. Assuming that it is round, calculate its cross sectional area. Record this value.

Analysis

For your report

- 1) Graph your Voltage as a function of position data. Calculate the slope of the line in Volts/Meter.
- 2) Divide this slope by the current flowing through the wire. Your answer should have units of Ohms/Meter. Now, multiply by the cross-sectional area of the wire. This is the resistivity of the wire.

Questions

- 1) We used the slope of the line that fits our measurements of voltage as a function of position to calculate the resistivity. Why didn't we just take two points and measure the voltage difference between them?
- 2) Use your first and last measurements of voltage versus position to calculate the resistivity. How large is the deviation of this value from that determined by the slope of the line?
- 3) The resistivity of pure copper is 17 nano-Ohm-meters. How much more resistive than copper is the wire?

Data Sheet

Frequency = _____

R_1 = _____ R_2 = _____

I = _____

A = _____

Table 1

Data Point	Position (meters)	Voltage (Volts)
1		
2		
3		
4		
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