Experiment 2: Instrumentation and Oscilloscope Introduction

Part 1: Multimeter, Ammeter and Breadboards

In this lab we will become familiar with three instruments that you will use throughout the semester: the Ammeter, the Multimeter and "Breadboards". An *ammeter* is a device used to measure the current, that is the the flow of electric charge in a conductor. The SI unit of current is the Ampere (or "Amp"): 1 Ampere = 1A = 1 coulomb per second. The flow of current is determined by the resistivity of the conductor, and a device that assigns a specific resistance in a circuit is called a resistor (R).

The typical resistor used here is a carbon resistor that is usually marked with colored bands to indicate its resistance in Ohms (Ω) (see Figure 1). Each color has a value associated with it. A table of the color code is given below. To be able to read the color code, first orient the resistor as shown in the figure so that it "reads" from left to right. The first band on the left is called the "A" band, while the last band is called the "D" band. The D band is usually either gold or silver. The value of the resistance (in Ohms) is $AB \times 10^C \pm D\%$. The D band represents the tolerance of the resistor, i.e. how close its actual resistance is to the nominal value given by the formula. A gold band denotes a tolerance within $\pm$ 5%, a silver band denotes within $\pm$ 10%, while no band denotes within $\pm$ 20%. For example, if the bands in Figure 1 are yellow-gray-red-silver, then it has a value of $48 \times 10^2 \pm 10\%$ Ohms, or $4800 \pm 480\Omega$. The resistor color codes are as follows: Black = 0, Brown = 1, Red = 2, Orange = 3, Yellow = 4, Green = 5, Blue = 6, Violet = 7, Gray = 8, White = 9.

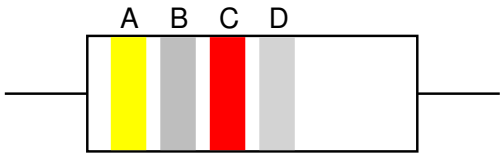


Figure 1: A carbon resistor with four colored bands.

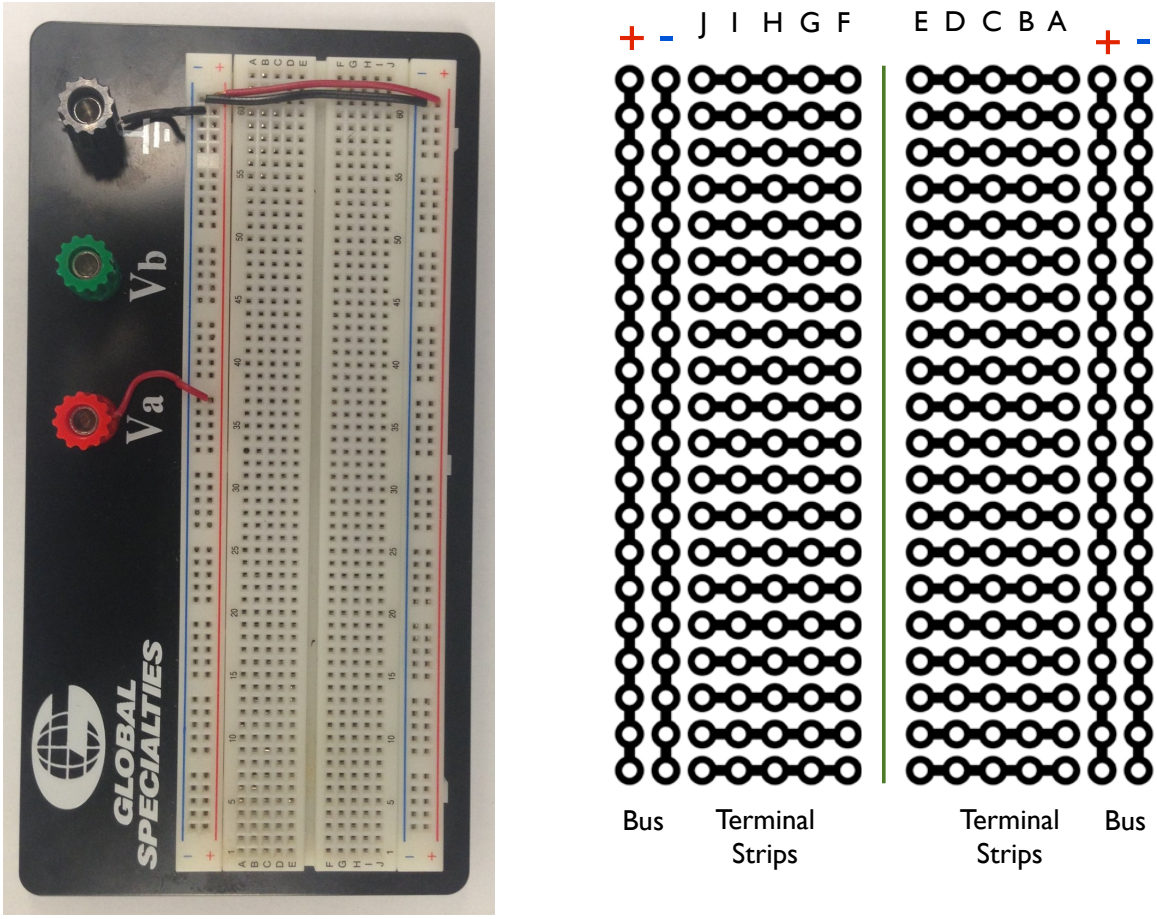
To measure the current, the ammeter must be in the circuit, so electrons flow through the meter. In practice, this means cutting the circuit at the place where you want to measure the current. In this lab we will use an analogue ammeter. The TA will instruct you on how to use it.

A voltmeter is an instrument specifically designed to measure the electric potential difference between two points in a circuit. This electric potential difference, commonly denoted ΔV, is also referred to as "voltage" with the SI unit of volt (V). For now, you can think of the voltage as the difference in electric potential energy (PE) of a "test" charge moving between two points. The voltmeter measures the voltage between two points in a circuit/system, such as across a resistor or a battery. A *multimeter* is an instrument that combines the ammeter and the voltmeter to measure various functions such as voltage, current, and resistance. In this lab we will use a digital multimeter (DMM) as our voltmeter.

Becoming familiar with these instruments is crucial. Here you will learn the basics of these instruments, measuring resistance, voltage, and current of some simple circuits. The circuits will be built making use of a "breadboard". A breadboard is a base used for constructing "prototype" circuit designs. It consists of perforated plastic block with numerous conducting "contact points" under the perforations (holes). These contact points allow the breadboard to be solderless and reusable, making it easy to construct temporary prototype circuits. A typical breadboard is shown in Figure 2a. The layout of the contact points is shown in Figure 2b.

A typical breadboard is made up of two areas: Terminal Strips and Bus Strips. Terminal strips are the main areas of the breadboard and hold most of the electronic components of the circuit, such as the resistors. The terminal strips are separated by a notch (indicated by the green line in Fig. 2b) that runs parallel through the middle of the breadboard, usually along the long side. The contact points on the left and right side of the notch are connected in a radial pattern of rows, with five points in an individual row being electrically connected. The columns of the contact points on the right and left sides of the notch are labeled (from right to left) A through E and F through J, respectively.

The Bus Strips provide power to the circuit components. They consist of two parallel columns (labelled $\pm$ in Fig. 2b) running down both the left and right sides. Each column is electrically connected. "Jump wires" are used to transfer signals from the Bus strips to the main terminal strips.



(a) (b)

Figure 2: (a) A simple breadboard used in the lab. (b) Breadboard schematic outlining the contact points in detail.

Part 1 Procedure: Before beginning, it is important to mention some safety and measuring rules. First of all, do not hook up any power to your circuit until you have finished assembling it and the laboratory instructor has checked it out. When measuring the current or voltage of a system that you are not familiar with, always set your Ammeter or Multimeter to maximum scale and work your way down so that you do not overload the meter. Also, always make sure your polarities are correct, and always turn the power off when changing the configuration of the circuits. The red terminal on the Multimeter should be connected to the higher voltage. The red terminal on the Ammeter should be connected to the higher voltage so that current flows into the red terminal and out of the black terminal, back to the rest of the circuit.

1. Construct the simple circuit shown in Figure 3a. Make sure that the polarity of the meters is correct (if any meter gives a negative reading, you have to reverse the connection). Note that the resistor R, the Ammeter A, and the power supply are all in series with each other, while the Multimeter (V) is "parallel" to R. [Hint: It is usually less confusing if you first construct all the components that are in series and then add the components that are placed in parallel. For this case, construct the series circuit of the power supply, Ammeter, and resistor. Then connect the Multimeter across the two ends of the resistor.]

2. Using the multimeter measure the value of the resistor. Write down the color code for this resistor.

3. Vary the voltage on the power supply until the Multimeter (V) across the resistor reads 1.0 Volt. Record the current in the circuit using the Ammeter.

4. Repeat Procedure 2 for voltage reading of 2.0, 3.0, 4.0, and 5.0 Volts.

5. Record your raw data in a table.

6. Repeat the entire experiment, but this time with a slight variation to the circuit as shown in Figure 3b.

7. You should have a total of two sets raw data tables by the end of this part.

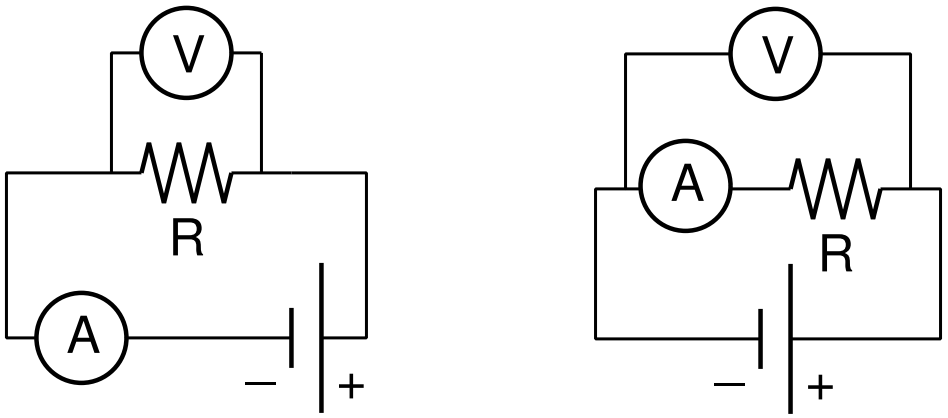


Figure 3: (a) Simple Circuit - R is the resistor, A is the Ammeter, and V is the Multimeter. (b) A variation of the circuit.

Part 2: Introduction to the Oscilloscope

Using an oscilloscope is an extremely useful skill, so it is important that you have the time to study the instrument alone, without having to worry about other additional physical concepts in an experiment as well. Although this portion of the experiment looks lengthy, the procedure is very basic, straightforward, and short. The following is a detailed description of most of the functions and features of an oscilloscope. It would be ideal to read the section carefully before coming to laboratory, and then go through the procedure steps while using the oscilloscope to look at very simple voltage signals. In your oscilloscope write-up, describe what you performed in the laboratory in a clear and concise manner, while answering the questions given in the procedural steps.

The oscilloscope is the most useful and versatile electronic instrument. It acts as a voltmeter with many added capabilities. Instead of just measuring a numerical voltage value at a point in a circuit, it allows you to follow the changes of voltage as a function of time. Thanks to a "trigger" mechanism, voltage signals can be displayed as stationary waveforms on a screen.

For much of the 20th century, oscilloscopes were constructed with analog circuitry and cathode-ray tube (CRT) displays, but the oscilloscopes you are likely to encounter will be digital, with LCD displays rather than CRTs. However, the controls on a digital oscilloscope are based on those of an analog oscilloscope, so it important to understand how an analog oscilloscope operates. A very basic description of the insides of an oscilloscope follows. An electron gun produces a beam of electrons, which is focused on a fluorescent screen. The beam travels through two sets of deflection plates; one set deflects the beam in the x -direction, the other set deflects the beam in the y -direction. The potential difference between the deflection plates is determined by the voltage signal entering the oscilloscope input. This potential difference causes the beam to be deflected up or down by a certain amount proportional to the input voltage. Thus, the oscilloscope acts as a voltmeter on the y-axis. If another voltage is generated to ramp repeatedly, and applied to the x deflection plates, the light beam will be repetitively deflected across the screen. This allows variations in time of the incoming voltage signal to be seen. This ramping voltage applied to the x deflection plates is called the sweep.

A typical front panel of an oscilloscope can be seen in Figure 4. The most obvious feature of the oscilloscope is a screen divided into many squares by an overlying grid (for a digital oscilloscope, the grid only appears when the device is on, of course). The vertical axis on the grid represents the voltage of an incoming signal, while the horizontal axis, in most cases, represents time. Most oscilloscopes have two input channels; incoming voltage signals enter the oscilloscope through these channels. Having two input channels is useful because it allows the user to look at two different signals (e.g. at different points of a circuit) at one time. Under the VERTICAL heading, each channel has a knob that controls Volts per Division (VOLTS/DIV). Turning this knob will change the vertical scale of the displayed signal. The knob labeled POSITION moves the voltage signal display up and down on the screen. Each channel also has a MENU button that brings up the channel menu, and turns the waveform display on or off.

The controls under the HORIZONTAL heading perform other functions. As mentioned previously, the horizontal direction on the oscilloscope represents time. The scale knob controls Seconds per Division (SEC/DIV), determining the amount of time displayed. For example, if the setting is 0.1 ms, this means that the oscilloscope is sweeping at a rate such that each square or division represents 0.1 millisecond of time. Similar to the vertical controls, there are many numerical settings to accommodate a large range of incoming voltage signal frequencies.

The trickiest part about the oscilloscope is "triggering." So far we have discussed vertical signals and horizontal sweep: those are what we need for a display of voltage versus time. But if the horizontal sweep doesn't catch the input signal at the same time (assuming the signal is repetitive), the display will be a mess - a flickering picture of the input waveform superimposed over itself at different times. Another result of improper triggering is the voltage signal "moving" on the screen, rather than being stationary so that measurements can be made. The TRIGGER MENU contains a number of different settings about trigger sources and modes. Setting the triggering control on AUTO mode should be satisfactory for our purposes. If this doesn't work, you can try the NORMAL mode while adjusting the LEVEL knob.

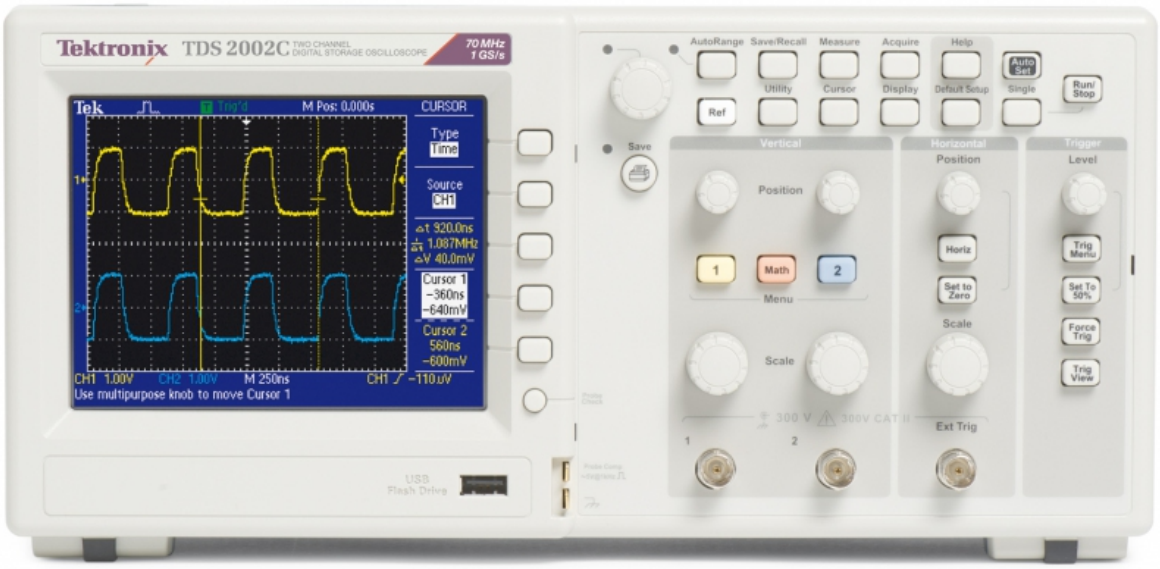


Figure 4: A sample oscilloscope - Tektronix TDS 2002C model used in class.

Part 2 Procedure: We will acquaint ourselves with the oscilloscope front panel controls, and then make some observations. We will observe a DC voltage signal from a power supply, and an AC voltage signal from a function generator.

1. With nothing connected to the front of the oscilloscope, find the power switch and turn it on. Wait for the oscilloscope to "boot up and show the grid, then press the AUTOSET button near the top right. After a few seconds, the display should show two fuzzy horizontal lines. These lines are a "picture" of the voltage over a certain amount of time - each channel shows zero since nothing is connected. Press the CH1 MENU button several times and observe how the waveform turns on and off. Note the "1" at the left of the waveform display; this marks the zero voltage level for channel 1. Use the channel 1 POSITION knob to move the display up and down. Note the right side of the display; these menu options change when different menus are selected and are controlled by the unlabeled buttons closest to the screen. With the CH1 menu set, make sure the following settings are selected: [Coupling: DC, BW Limit: OFF, Volts/Div: Coarse, Probe: 1X]. Select the CH2 menu and make sure the settings are the same.

2. Connect the sine wave output of the function generator to Channel 1 of the oscilloscope. You will need to use a BNC cable.

3. Now, put a DC voltage signal from the power supply into Channel 2. You will need another BNC to banana jack adapter. The oscilloscope should now be connected properly to the function generator and the power supply.

4. Turn on the power supply and function generator. Set the function generator frequency to 1500 Hz. On the oscilloscope, use the horizontal scale knob to set the horizontal scale to 1 ms/DIV, and adjust the CH1 vertical scale knob until a sine wave is visible on the display. Note that the lower left of the display shows the volts per division setting for each channel, and the center bottom shows the time per division. If the signal is small and noisy, you should increase the amplitude setting on the function generator. If you do not see a stationary sine wave, you may need to adjust the trigger settings in order to stabilize the display, or press the AUTOSET button. Make sure the current knob from the power supply is turned above zero in order to get a voltage.

5. Turn off the CH1 waveform display and make sure CH2 is still on. Set the power supply to 2 V and adjust the CH2 vertical scale knob setting until a line appears on the screen. Use the CH2 POSITION knob to move the "2" at the left of the screen to the middle of the display; note that a status line appears at the very bottom of the display telling you how far off you are. Find the VOLTS/DIV setting that positions the signal at the first grid line above the center line. Now slowly increase the voltage output on the power supply to 5 V. What happens to the line on the screen? Change the vertical scale settings (VOLTS/DIV settings) in both directions and describe what happens. Also, adjust the vertical position setting accordingly in order to view the CH2 signal.

6. Oscilloscopes have two coupling modes, AC and DC. Oscilloscopes are normally operated in DC-coupled mode, allowing you to see the exact voltage on the screen. AC-coupling removes all the DC components of the waveform, centering the wave on the zero volts making it easier to see any fine details of the waveform. Sometimes you may want to see a small AC signal, perhaps electrical "noise", riding on a large DC voltage. In this case, you can change the Coupling setting in the CH1/CH2 menu to AC. What happens to the DC voltage display when the CH2 coupling is changed to AC?

7. Turn off the CH2 display and turn CH1 back on. You are now looking at the AC voltage waveform coming from the function generator. Adjust the oscilloscope so that only a few cycles of the sine wave appear on the screen. This can be done by changing the value of the SEC/DIV setting (the horizontal scale knob). How would you determine the frequency of the sine wave using the oscilloscope? Here are a few hints: Remember that you can horizontally move the signal (i.e. in time) with the horizontal POSITION knob. This will enable you to align the peaks of the sine wave with the grid lines so as to determine how long it takes for one cycle to be completed. Also, the SEC/DIV settings can be changed so that it may be easier to align the peaks of the waveform to the grid, or fit several complete cycles of the waveform between the grid lines. Using one or both of these methods, determine the frequency of the sine wave using the oscilloscope.

8. Press the CURSOR button to bring up the CURSOR menu. Set the "Type" to "Time" and the "Source" to CH1. In CURSOR mode, dotted lines appear on the screen that can be used to measure either voltage or time, and the knob on the top left corner controls the position of the cursors. You can select between the two cursors by selecting the appropriate one from the CURSOR menu. Position the cursors to mark out one period of the sine wave. Write down the Delta (Δt - the distance between the cursors) and calculate the frequency.

9. Adjust your SEC/DIV and VOLTS/DIV settings so that several cycles of the sine wave are visible. Now press the MEASURE button to bring up the MEASURE menu. You may need to change the Source and Type settings in order to select CH1 Freq., which will produce a measurement of the frequency. Compare this frequency value to a) the value indicated on the function generator, b) the value found using cursors, and c) the value found by estimating visually. They should all be roughly the same. Which value would you deem to be most accurate? Explain Why.

10. The amplitude of the signal now needs to be determined. Write down the amplitude and peak-to-peak values for the sine wave by a) estimating visually, b) using the cursors, and c) using the MEASURE menu (peak-to-peak only). Discuss the differences between the results, if any.

A full lab report is not necessary for this lab. Answer the questions on the following page and turn it in with your signed datasheet.

PHYS 221, Lab 2 Questions

Name: **CWID:**

Write your answers on a separate sheet and attach your signed datasheet when turning it in. You must show all of your work for full credit. Make it clear to me you understand what you're doing. Any graphs or tables should be made via computer software and attached to this handout.

Answer the following questions using the data you acquired from this experiment. Make sure to include the questions from the Oscilloscope section (part 2).

1. Using the color codes, what is the expected resistance of the resistor? Verify that the actual value is within the tolerance given by the color code by using the Multimeter. What color code would designate a 1 $k\Omega$, 10% resistor?

2. Plot V versus I using both of your data set. You may plot both data sets on the same graph if they are clearly and neatly labeled. Prove that the slope of the best-fit line of your data is equal to the resistance R. This is referred to as Ohm's Law; $V = IR$. Using the best-fit line and Ohm's Law, find the measured resistance for each resistor. Compare any differences. What are the sources of error?

3. If the two experimental values of R that you have obtained are different from each other, which one is closest to the nominal value found using the Multimeter? Why are the experimental values different from each other? Which circuit should give a more accurate reading of the actual resistance