SCHULICH
School of Engineering
UNIVERSITY OF CALGARY

ENGG 225

Fundamentals of Electrical Circuits and Machines

Laboratory #1

Laboratory Equipment and Measurement Methods

1 Introduction

The purpose of this laboratory is to become familiar with common electronic laboratory instruments, including the oscilloscope, handheld digital multimeter, function generator, and the laboratory breadboard. These are all instruments that you will be using in later lab sessions. In this lab, you will learn to use some important features of this equipment and learn how to make various important measurements.

1.1 Learning Outcomes

At the end of this lab session, you will be able to set up and use the equipment in the following ways:

- use the laboratory breadboard to wire and make measurements on simple electric circuits;
- use the oscilloscope's internal function generator to generate sinusoidal voltage waveforms of various frequencies and amplitudes, with and without a DC offset;
- use the oscilloscope to view and make measurements on AC voltages;
- use the digital multimeter to measure DC voltages and currents, and AC RMS voltages.

1.2 Acknowledgments

The course instructors for ENGG 225 greatly acknowledge the University of Calgary Engineering Endowment Fund for substantial funding toward the purchase of important high-quality laboratory test equipment and supplies needed to enhance the learning value of the laboratories in the course.

2 Laboratory Equipment

The lab space allocated to ENGG 225 consists of two adjoining labs on the first floor of the Engineering Complex G-block in rooms ENG 124 and ENG 130. Each lab station in these labs is equipped with two main pieces of equipment: an "instrument sled" and a "laboratory breadboard".

The instrument sled is a collection of the most-commonly used test equipment mounted in the movable plastic rack shown in Fig. 1. The instruments include a digital oscilloscope, a digital multimeter, a waveform function generator, and a DC power supply. You will be making use of some or all of these instruments in this and later labs.

Fig. 1. The "Instrument Sled"

The second major piece equipment at each lab station is the laboratory breadboard shown in Fig. 2. There are three key features of the breadboard that you will use. One is the circuit prototyping area, on which you will be placing and interconnecting circuit elements, the other is for DC power sources for your circuits. DC voltage sources of +5 V, +15 V, and -15 V are available. The third feature is a selection of BNC connectors and “banana” sockets to facilitate easy connection of the devices on the Instrument Sled to your circuits.

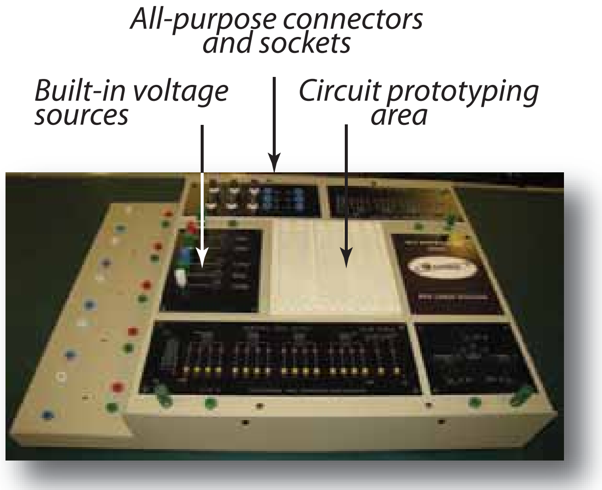

Fig. 2. The “Laboratory Breadboard”

2.1 The Oscilloscope

The oscilloscope is an instrument that draws measured waveforms on the screen. The oscilloscope displays how a signal varies as a function of time. The vertical (Y) axis represents voltage or amplitude, and the horizontal (X) axis represents time. An oscilloscope renders waveforms on the screen by repeatedly “’painting” an image on the screen by sweeping from left to right. The sweep rate is user-adjustable to suit the particular waveform. Most oscilloscopes can measure two different signals, normally labeled Channels 1 and 2.

When measuring a signal with an oscilloscope, it is important to understand that the signals all must use ground as the reference. The ground clip of the probe (or the metal casing of a BNC connector) is connected to earth ground inside of the oscilloscope. This means that if you place the ground clip of the probe on part of your circuit that is not grounded, you will be short-circuiting that part of the circuit to ground. Fig. 3 below shows the proper connection of the oscilloscope to a circuit. Fig. 4 demonstrates the improper connection of an oscilloscope to a circuit, and shows the effect with R_2 being effectively eliminated from the circuit. This will give you incorrect voltage measurements and can possibly bring damage to either the equipment, yourself, or both!

2.2 The Function Generator

The function generator is an important test device that can produce sinusoidal, square, and triangular waveforms, with adjustable amplitudes, frequencies, and DC offsets. The function generator shown in Fig. 1 is such a device, but we will instead be using the function generator that is built right into the oscilloscope, thanks to its convenience and relative ease of use.

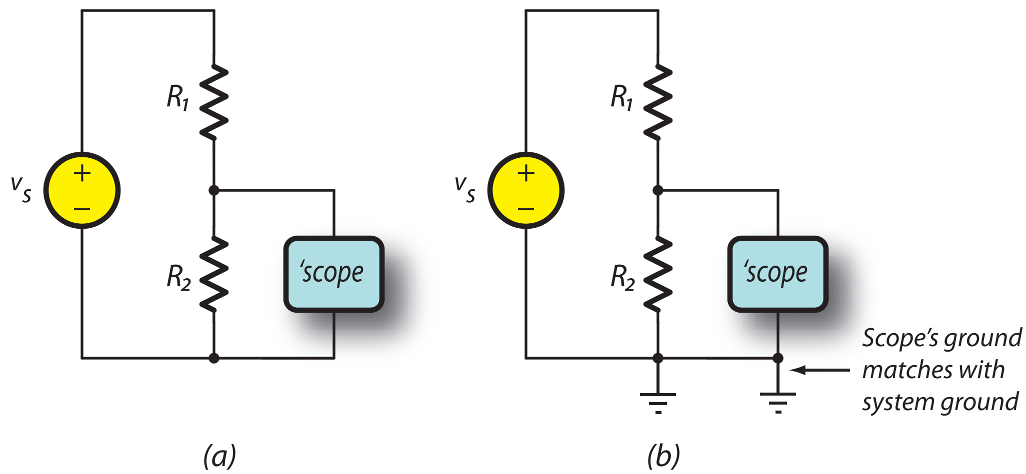

Fig. 3. Proper oscilloscope measurement: (a) physical connection to circuit; (b) equivalent electrical connection

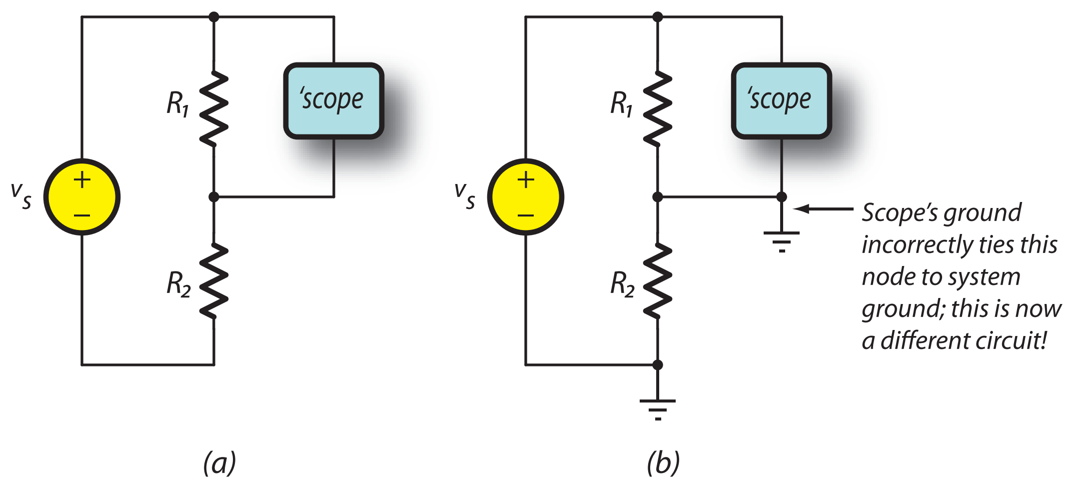

Fig. 4. Improper oscilloscope measurement: (a) physical connection to circuit; (b) equivalent electrical connection – note R_2 is shorted out

2.3 The Digital Multimeter (DMM)

The digital multimeter on the Instrument Sled is an accurate all-purpose ammeter, voltmeter, and ohmmeter with a digital readout.

An ammeter measures current *through* a circuit element, a voltmeter measures the voltage *across* a circuit element, and an ohmmeter measures the resistance of a resistor or interconnection of resistors.

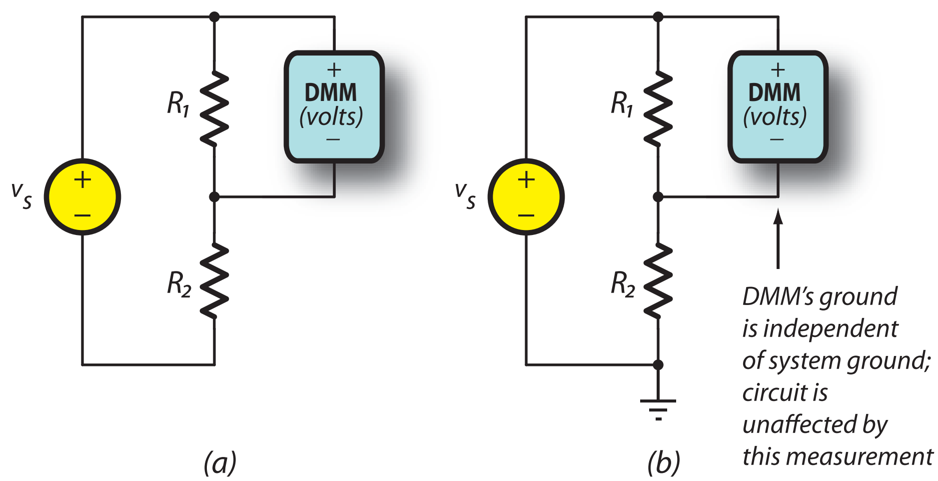

Fig. 5. Voltage measurement with a multimeter: (a) physical circuit connection; (b) equivalent electrical connection

For making voltage measurements, a multimeter can be used to measure the difference in potential between *any* two points in a circuit. Unlike an oscilloscope, the measurements do not always have to be measured using ground as the reference. Its ground connection is not in common with other AC-powered instruments on the instrument sled. Fig. 5 demonstrates the use of the multimeter to measure the difference in potential between two points. As shown, R_2 is not short-circuited as it is when making the same measurement with the oscilloscope.

When making a current measurement with a multimeter, it is important to remember that the current must be measured *through* a circuit element and *not across* it. This requires that the circuit be broken in some place and the ammeter be inserted in series with a circuit element. The proper measurement of current in a circuit is shown in Fig. 6. The ammeter will display a positive value of current in this case.

Resistance measurements should *never be made on an energized circuit*, as the meter can easily be damaged. The multimeter uses its own internal voltage source to measure and calculate resistance; external sources will interfere with this.

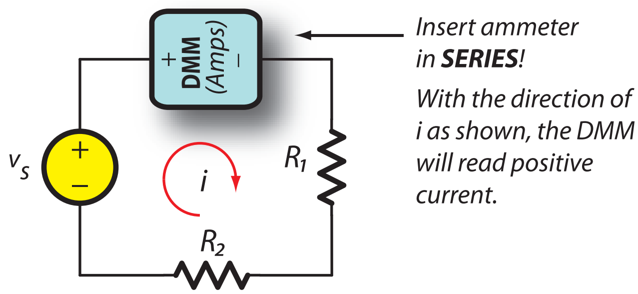

Fig. 6. Current measurement with a multimeter

2.4 The Laboratory Breadboard

The laboratory breadboard is shown in Fig. 2. The prototyping area is designed to allow for very quick and easy assembly of simple circuits. For added convenience, the breadboard also has built-in DC power sources, and numerous general-purpose connectors.

The prototyping area indicated in Fig. 2 consists of two main types of white "socket strips," as shown in Fig. 7 and described as follows.

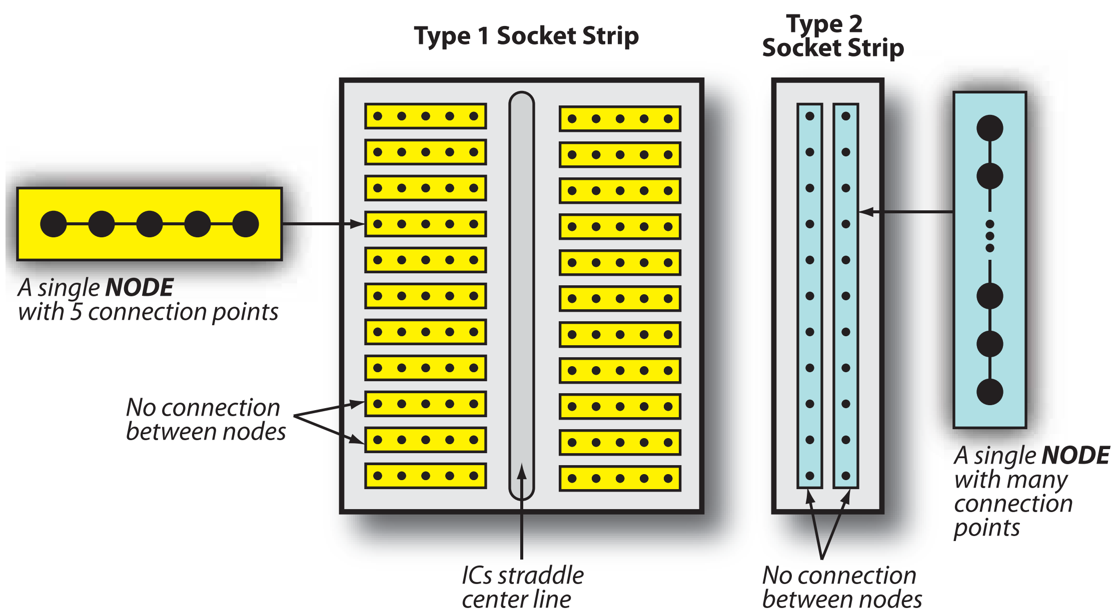

Fig. 7. Socket strips that make up the prototyping area

1. The Type 1 socket strips consist of parallel rows of five horizontally-connected holes, as shown. The shaded areas indicate how the holes are connected together

electrically. It may be helpful to think of each of these shaded areas as a single electrical "node" with 5 connection points. The vertical center line in a Type 1 socket strip electrically separates the left and right sets of nodes. Although useful for building any circuit, these socket strips are designed to accommodate integrated circuits (ICs), which are inserted in such a way that the IC straddles the center line. This allows you to conveniently connect to pins on both sides of the IC. You will learn more about this in Lab #3 with the operational amplifier.

2. The Type 2 socket strips consist of two electrical "nodes" with connection points along the whole height of the strip, as indicated by the shading. These types of socket strips are designed to distribute common signals, almost always simply a power source and ground, to parts of your circuit in the Type 1 strips on either side.

To assemble a circuit on the breadboard, place the leg of a component or wire into one of the holes. The holes are designed so that they will hold the leg securely in place and make an electrical connection. A connection between two components is created when their legs are put into holes in a horizontal "node" (for Type 1) or vertical "node" (for Type 2).

When wiring your circuit, you will be provided with wire in a variety of colours along with some wire cutters/strippers. Wire is also available in a tray on every instrument sled. If you need to cut a fresh piece of wire, or snip the end off of a used wire, use the wire strippers to strip about $\frac{1}{4}$-inch (6 mm) of insulation off of each end; be sure to keep this relatively short so that excess exposed wire does not touch what it shouldn't in your circuit.

3 Pre-lab Exercises

There are no pre-lab exercises for this lab.

4 Procedure

4.1 Breadboarding and Measurements on a Simple Circuit

In this part of the experiment, you will gain some experience in using the prototyping area on the breadboard to connect circuit elements in series and parallel, and how to connect the test equipment to your circuit for perform various simple voltage, current, and resistance measurements. This experience should help you get a quick start to Lab #2 where you will be building more complex circuits based on series and parallel resistor combinations.

Begin by building the circuit shown in Fig. 8 on the prototyping area as follows.

1. Lay out four resistors in series on a Type I socket strip (Fig. 7). For this, you may select separate and conveniently spaced horizontal "nodes" on the socket strip to connect the resistors end-to-end in such a way. (Remember that a circuit element in series with another means that they are connected at a node *with no other circuit element connected to that node.*)

   To make a series connection of two resistors, insert one end of each resistor into the same "node". Then select another nearby "node" to join the other end of one of these resistors to form a series connection with another. Try to make your circuit look like that in Fig. 8.

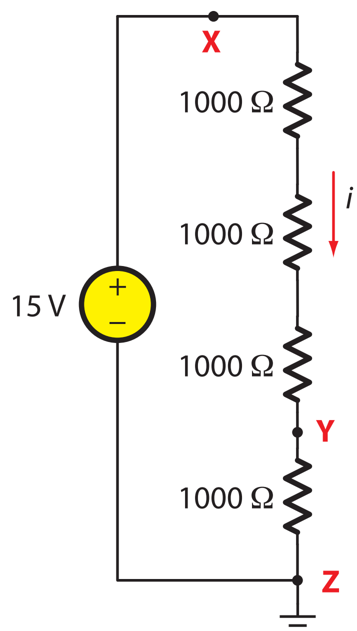

Fig. 8. Voltage, resistance, and current measurement

2. Use connecting wire (one red and one black) to connect the +15 V power source on the breadboard to your series circuit. Connect the black wire from the "GND" on the breadboard to node **Z** in your circuit, and connect the red from +15 V to node **X** of your circuit.

3. Use one red and one black connecting cable to connect the "banana" sockets on the DMM to two "banana" sockets at the top of the breadboard. On the DMM, insert the red banana plug into the red socket labeled $V\Omega$ at the top-right corner of the DMM. Insert the black banana plug of the black cable into the black socket labeled "LO" immediately below $V\Omega$ on the DMM.

Now perform the following voltage, resistance, and current measurements on your circuit, and answer the following questions.

1. Switch on the DMM and the breadboard (the breadboard's switch is near the power cord at the right rear). By default, the DMM is set to measure DC volts. Use a red and black connecting wire to reach from the red and black connection wires at the top of the breadboard to nodes **X** and **Z**, respectively, in your circuit. This will be the voltage v_{XZ}. Disconnect the two connecting wires from nodes **X** and **Z**, and reconnect them now measure v_{ZX}. Record both of these voltages. How are they similar or different?

2. Now perform two different resistance measurements. *Remember that resistance measurements should be made only only on non-energized circuits.* Temporarily disconnect both connection wires to the voltage source.

   - On the DMM, press the front-panel switch labeled "$\Omega 2W$". The DMM will now be measuring resistance. With the DMM connected to nodes **X** and **Z**, measure and record the total series resistance of the circuit. Let this value be R_A. Reverse the DMM's connections to nodes **Z** and **X**. Does the value of resistance change? Should it? Briefly explain.
   - Next, place a short-circuit (i.e., a wire) *in parallel* with the lower-most resistor in Fig. 7 (i.e., between nodes **Y** and **Z**). Again measure and record the total resistance between nodes **X** and **Z**. Let this value be R_B.

3. Finally, perform the following two current measurements. *Turn the breadboard's power switch off.* Disconnect the DMM's connecting wires to your circuit, and arrange to measure current on the DMM pressing the front-panel buttons "SHIFT" and then "DC I". You will need to move the red banana connector on the DMM from its current position to the red banana socket labeled "I" *below* the black "LO" socket.

   - First, remove the short-circuit between nodes **Y** and **Z** in your circuit. Reconnect the voltage source's "GND" wire to node **Z** of your circuit. Connect the DMM's red connecting wire to +15 V on the voltage source, and the black connecting wire to node **X**.

> **Warning!** *There is always a risk of connecting an ammeter incorrectly, resulting possibly in high currents, overheated components, and blown fuses. Please ask a teaching assistant to check your circuit before hitting the switch!*

If all is safe, turn the breadboard's power switch back on, and measure the current. Let this value be i in Fig. 8.

- Using the values of v_{XZ} and R_A measured above, calculate the expected value of i. Comment on the comparison between this value and the measured value of i, and express in terms of an error percentage.

- Turn off the breadboard's power. Disconnect the DMMs connection wires between the +15 V source and node **X**, and once again directly connect the +15 V source to node **X**. Connect the ammeter's red connection wire to node **Y** and the black to node **Z**. *Have a TA check this!* If all is well, hit the switch. Measure and record the current.
  - Based on your measurement here, what can you say about the internal resistance of an ammeter? Briefly explain.

4.2 Measurements using the Oscilloscope

Below are some common measurements that are made using an oscilloscope. The Agilent oscilloscopes installed in the Instrumentation Sleds are powerful, yet easy to use. You will explore a tiny subset their functionality to gain some familiarity with the types of measurements that you will be making starting in Lab #3.

The oscilloscope serves a dual function device, one being that of a powerful oscilloscope, the other being a very flexible and easy-to-use function generator. You will use both functions. The output of the function generator is the BNC connector beside the power switch.

First, set up the function generator as follows.

1. Connect the output of the function generator to channel 1 of the oscilloscope using a black coaxial cable with the BNC connectors on each end (cable shown at right).

2. Press the "Wave Gen" button in the Tools area on the main panel of the oscilloscope. It will turn bright blue, and the settings menu will appear at the bottom of the display.

3. On the menu at the bottom of the display, press the "Waveform" button, and a large list of choices for waveform types will appear. For this and most other menu items, you may cycle through the large list of choices using the "Selection" knob, which is prominently displayed on the main panel with an illuminated circular arrow. Once you have selected a sine wave, press the Selection knob to set your choice.

4. There are several other settings to make on the function generator. In the menu at the bottom of the display, press "Offset," and use the Selection knob to set this to 0.0 V. Similarly, set the Frequency to 2.0 KHz, and adjust the Amplitude to 400 mV peak-to-peak.

Now set up the oscilloscope to make some measurements and simple tests.

1. Locate and press the "1" button on the oscilloscope. It should be illuminated. Note that the knobs immediately above and below this button are important: the one above is the **vertical scale** (volts/division) control, and the one below is the **vertical position** control.

2. When you press the "1" button, a menu appears at the bottom of the display. Press the menu button to set DC coupling, and press the "Probe" button and select the 1× setting. Once again, use the Selection knob to cycle through the choices, and press the knob to make your selection.

3. If the sine wave on the display becomes unstable, adjust the "Trigger level" knob (just above and to the right of the Selection knob) until it stabilizes. (This ensures that the sine wave is rendered from left to right on the display starting only at times when the waveform voltage is equal to the trigger level. The trigger level appears momentarily as a solid line on the waveform display.)

4. Locate the time-scale knob on the oscilloscope (upper-left corner of the oscilloscope controls), and adjust it until two periods of the sine wave appears over the horizontal axis on the display.

5. Adjust the vertical scale for Channel 1 on the oscilloscope so that the waveform is the maximum size that will fit vertically on the display (without clipping). You may need to adjust the vertical position knob for Channel 1. Record the vertical and horizontal scales given at the very top of the display.

6. Use the oscilloscope to obtain an accurate measure of the amplitude by pressing the "Meas" button. At the bottom of the display, press measurement "Type". Use the Selection knob to cycle through the many choices to locate Peak-Peak, and press the knob to make the selection. The peak-to-peak voltage will be displayed on the screen. Record this value. Similarly, use the same measurement Type menu to choose the period T of the waveform. Record the value of T. Is this value what you expect? Explain.

7. Press the "1" button again, and switch the coupling setting to AC coupling in the menu at the bottom of the display. (AC coupling refers to the option of blocking any DC component of your signal, so that the oscilloscope is rendering only the AC component.) Note and explain any changes to the displayed waveform.

8. Switch the coupling back to DC coupling.

9. Press the “Trigger” button on the oscilloscope, located immediately above the Selection knob. Use the Selection knob to change the trigger source to Channel 2 (the menu item is labeled simply “2”). Record what happens and explain why.

10. Change the trigger source back to Channel 1.

4.3 AC/DC Measurements using the DMM

1. Now using a BNC “T” adaptor (shown below left) and a BNC-to-Banana adaptor (shown below right), connect a second coaxial cable so that you may simultaneously measure your signal on the oscilloscope and the DMM, as follows.

   - Disconnect the coaxial cable from the oscilloscope’s Channel 1 input, and connect the BNC “T” adaptor in its place. Reconnect the coaxial cable to one of the BNC connectors on the “T” adaptor.
   - Connect one end of the second coaxial cable to the other BNC connector on the “T”. Attach the the other end to the second coaxial cable to the BNC-to-Banana adaptor. Study the banana adaptor, and note the small black tab to indicate which of the two banana plugs is the ground. Insert the banana plugs into the DMM banana sockets with the black tab nearest the “LO” (black) input, and the other other plug in the $V\Omega$ (red) socket.

2. Measure and record the AC and DC voltages of the sine wave with the DMM while the signal is still shown on the oscilloscope:

   - To measure DC voltages, press the “DC V” button on the DMM. In this position, the DMM displays the DC voltage determined by *time-averaging* the actual voltage over a short period of time.
   - To measure AC voltages, press the “AC V” button on the DMM. In this mode, the DMM reads the *RMS (“root-mean-square”) voltage* V_{rms}. As we shall see in later lectures, this is related to the peak-to-peak voltage V_{pp} according to $V_{rms} = \frac{1}{2\sqrt{2}} V_{pp}$. Compare your measured value with what you expect.

3. On the oscilloscope, arrange to add 400 mV of DC offset to the sinusoidal signal by pressing the "Wave Gen" button. In the menu at the bottom of the screen, press the "Offset" button, and use the Selection knob to add 400 mV of DC offset. As you adjust the knob, you may notice that the waveform display becomes unstable. Once the 400 mV setting is complete, you may need to adjust the vertical position and Trigger level to stabilize the display.

4. On the oscilloscope, press the "Meas" button button, and set the measurement "Type" to "Select AVG - N cycles". This will allow you to accurately measure the DC offset of a signal. Record this value. Record the DC voltage with the DMM, and compare.

5. Finally, press the illuminated "1" button again on the oscilloscope, and select AC coupling, as you did in an earlier test. Briefly describe what happens to the displayed waveform. Estimate how many vertical divisions on the display that the waveform shifted, and use the vertical scale setting at the very top of the display to estimate the total voltage shift.

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