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# ECE 53A: Fundamentals of Electrical Engineering I

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## Laboratory Assignment #1: Instrument Operation, Basic Resistor Measurements and Kirchhoff's Laws Fall 2007

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### General Guidelines:

- Record data and observations carefully for each lab measurement and experiment.
  - You must obtain Lab. Assistant's signature on each page of your lab data before leaving the lab. Signed pages must be included in the report.
  - Make sure you understand the experiment procedure before executing it. You must obtain enough data to complete the various parts of the procedure.
  - Request Lab Assistant's help to verify your circuit before turning on the power supplies and generators.
  - Please operate the equipment in a reasonable manner. Avoid power supply short circuits. Report failures to the Lab. Assistant.
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Parts:	Equipment:
- Resistors as needed	Breadboard Digital Multimeter (DMM) Frequency Counter Signal Generator Oscilloscope

### Objective:

The objective of this session is to learn to properly use the instruments at the lab and to verify the application of Kirchhoff's laws to simple circuits through laboratory measurements.

### Instrument Description:

#### DC Power Supply

The DC power supply is used to generate either a constant voltage (CV) or a constant current (CC). That is, it may be used as either a DC voltage source or a DC current source. You will be using it primarily as a voltage source. Recall that DC is an acronym for direct current. DC means constant with respect to time. The voltage produced by a power supply is controlled by a knob labeled **voltage**. If the power supply allows for current adjustment, current is limited by adjusting the knob labeled **current**. As long as the circuit does not attempt to draw more current than the value set by the current knob, the voltage will remain constant. Current limiting allows the power supply to be set such that the power supply does not generate more current than desired. This can be useful to prevent damage to equipment and parts which may be unable to handle excessive currents.

#### Function Generator

The function generator is used to provide voltages that vary with time. It has four primary waveforms: sine, square, triangular and ramp. There are various parameters that can be varied for each waveform, three of them are of particular interest:

1. Peak-to-peak voltage (0-10 V)
2. Frequency (0-15MHz)
3. DC offset

To set any of these features, use the knob labeled with the feature you wish to modify.

## ***Digital Multimeter***

The digital multimeter measures voltage, current and resistance. There are separate settings for measuring AC and DC values. If you examine the front panel, you will find primary functions are selected using a multi-position knob. Functions are accessed by selecting the desired measurement. For example, to measure DC voltage, you select the **DC V** option. To measure DC current, you option **DC A (or DC mA)**. The multimeter also has the capability of measuring other quantities such as resistance. There are three aligned holes (banana jacks) in the multimeter. To measure voltage, place the positive terminal in the hole marked with a **+V**, with the negative terminal in the **GND (or -V)** hole. The positive hole is red, and the negative is black. To measure current place the terminal (the terminal at which current enters the multimeter) in the hole labeled **A (or mA)**, and the other terminal in the **GND** hole. If the multimeter is not autoranging, you need to select the proper range using the knob until you identify the required range (for example: 200mV, 2V, 20V, 200V for a voltage measurement). When the value you are measuring is stable on the display, read the value.

## ***Oscilloscope***

An oscilloscope is used to view a voltage waveform on a screen. An electron beam is generated in the cathode ray tube, directed at the back of the screen, and swept in time along the X-Axis. A voltage applied to the scope probes is amplified and applied to a pair of horizontal metal plates through which the electron beam passes. This voltage deflects the beam in the vertical direction (Y-Axis). The sweep in the electron beam combined with vertical deflection results in the appearance of a waveform on the screen of the scope. The scope has two probes: one for Channel 1 and one for Channel 2. The probes are very expensive (approx. \$200 each), so please be careful with them. Each channel has a vertical placement knob used to move the waveform for that channel up and down. Each channel also has a knob used to select the vertical scale of the waveform in terms of volts per division. Divisions are the visible grid lines on the oscilloscope screen. The knob used to set the horizontal scale (in time per division) controls both channels. Some measurements made in this lab can be performed automatically using the Auto-scale feature. When you want to capture a waveform on the screen, the first thing to think of is Auto-scale. This takes the waveform at the input and displays it so that the entire peak-to-peak voltage is displayed as well as several periods. However, you must be careful with this feature and make sure the instrument has captured the right waveform you are trying to visualize. To measure voltage, push the button marked voltage which is located to the right of the screen near the top of the front panel. This will bring up a menu at the bottom of the screen, listing available voltage measurements. The first choice is to select either channel 1 or 2 for measurement. After that, you may select: Peak to Peak voltage ( $V_{p-p}$ ), average voltage ( $V_{ave}$ ), or rms voltage ( $V_{rms}$ ). By pressing the corresponding softkeys, you will automatically get the selected measurement. For more choices, press the softkey labeled Next Menu. The next menu will allow you to select other voltage measurements. Time measurements can be obtained by pressing the **Time** button (located next to the **voltage** button). This will give you the following menu options: Frequency, Period, Duty Cycle, +Width, -Width, Rise Time, Fall Time, Delay and Phase Difference. This last command, Phase Difference, is useful for computing the difference in phase between waveforms on channels 1 and 2.

## ***Breadboards/Prototyping boards (Proto-boards)***

Solderless breadboards are the most typical option to prototype electronic circuits. A prototype is an initial real implementation of a circuit. It is used to evaluate a design and test actual performance under certain test conditions. Breadboards usually consist of a rectangular plastic enclosure. On the surface of a breadboard, there are many holes for plugging in components (refer to Fig. 1).

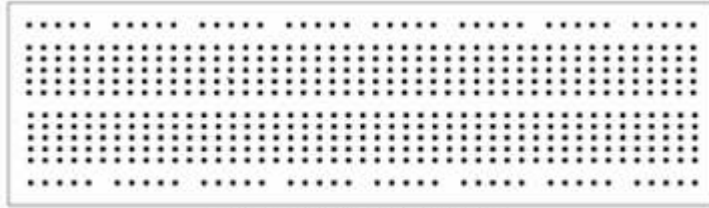


Figure 1. Typical Breadboard

The breadboard consists of metal strips running underneath the enclosure as shown in Fig. 2. These strips are used as interconnection points (nodes) to build circuits. They can be accessed through the appropriate holes.

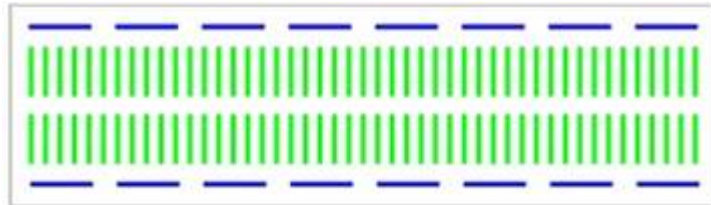


Fig. 2. Breadboard Internal Connections

The horizontal strips shown in Fig.2 are often used for power supply voltages (i.e.  $V+$ ,  $GND$ ) and the vertical strips are for the components.

***Procedure:***

Discuss with your team how you would go about measuring voltage across and current through a resistor using the multimeter. How would you place the leads? The following hints may be helpful:

1. As a voltmeter, the multimeter must (ideally) have infinite resistance.
2. As an ammeter, the multimeter must (ideally) have zero resistance.

If not sure about the measurements connection, ask the Teaching Assistant (TA).

## **II. Experiment - Resistance Measurement**

Most resistors have four colored bands. The first three bands indicate the nominal value of the resistor and the fourth band indicates the tolerance in value. The first two bands form the mantissa, and the third the exponent of 10.

Color	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	0

The tolerance band is typically either gold or silver. A gold tolerance band indicates that the measured value will be within 5% of the nominal value. A silver band indicates 10% tolerance. For example a resistor with color code brown-black-red-silver indicates a nominal value of 1 k $\Omega$ . The first two bands (brown-black) produce the mantissa (10) and the third band (red) is the exponent of ten ( $10^2 = 100$ ). So the value is  $10 \times 100 = 1K$ . Since the tolerance band is silver, we can expect the measured value of the resistor to be between 900 $\Omega$  and 1100 $\Omega$ .

1. Select 5 different resistors (write down their color coded values ).
2. Place the resistors in the bread board at your lab station.
3. Set the multimeter to measure resistance. To do this, select the ohmmeter function. Determine the actual values of the resistor. The words ``actual" and ``measured" may be used interchangeably.
4. Compute the percent difference between the actual (measured) value of the resistors and their nominal value as indicated by its color code.

## **III. Measuring the Resistance of Your Body**

1. Holding one probe between the thumb and forefinger of each hand, measure the resistance of your body between your hands. Squeeze the probes tightly so that good contact is established. Record the value of your body's resistance.
2. Considering that a current of 100-200 mA through your heart will almost certainly kill you, how much voltage across your hands would be lethal?

## **IV. Experiment: DC measurement and Ohm's Law**

Record each measured value.

1. Set the DC power supply to provide 5 V as shown in the digital display on the power supply front panel.
2. Set the multimeter to measure DC voltage, making sure the leads are set for voltage, not current measurement.
3. Measure the voltage using the multimeter.
4. Disconnect the multimeter from the power supply and connect the oscilloscope leads to the power supply.
5. Adjust the volts/division knob on the oscilloscope until the voltage appears on the screen. (This should occur around 1 volt/division.)
6. Measure the voltage by using the automatic measuring features of the oscilloscope.
7. Using the same screen, measure the voltage by hand, i.e. count the divisions and multiply by the number of volts per division. (This number can be found in the upper left corner of the screen.)
8. Set the DC power supply to 0 V.
9. If the power supply allows current limiting, set the current to 50 mA.
10. Connect a  $220\Omega$  resistor to the power supply.
11. Connect the multimeter across the resistor and set it to measure DC voltage.
12. Measure the current through the resistor using the multimeter. Use the circuit of figure 1.

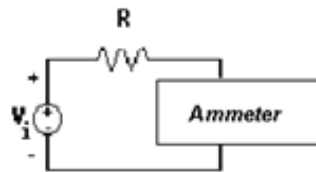


Figure 1. Resistor current measurement circuit

13. Increase the voltage (slowly) across the resistor. Repeat voltage and current measurements (perform 10 observations for voltages between 1V and 5V). Record your measurements. Using Ohm's law, determine the resistance value for each measurement. What is the average resistance? Does it correspond to the nominal value?
14. Be careful with the DC power supply leads. Avoid letting them touch at all times. When they touch, a short circuit is formed. Consider what would happen if you shorted the wall socket, or a car battery! Short circuits can be dangerous, and care should be taken to avoid them.

## V. Voltmeter

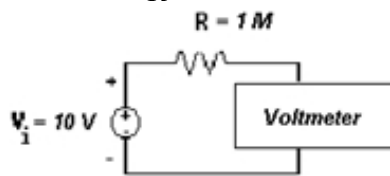
An ideal voltmeter has infinite resistance: It is an open circuit. Although it is impossible to make a physical voltmeter with infinite resistance, a properly designed voltmeter exhibits a very large internal input resistance. In some experiments, it is important to take into account the finite, non-ideal, internal resistance. To determine the internal resistance of the voltmeter, set up the circuit shown in figure 2. The voltmeter reads the voltage across itself, which includes its internal

resistance. Since the circuit has only a single branch, the current flowing through the resistor also flows through the voltmeter. The current is given by the equation:

$$I = \frac{V_s - V_M}{R} \quad (1)$$

From Ohm's Law, if we know the current ( $I$ ) and the voltage ( $V_M$ ) we can compute  $R_M$ .

$$R_M = \frac{V_M}{I} = \frac{V_M}{\frac{V_s - V_M}{R}} = \frac{R V_M}{V_s - V_M} \quad (2)$$



**Figure 2.** Circuit for measuring voltmeter resistance.

1. Select a  $1\text{ M}\Omega$  resistor.
2. Measure its value using the multimeter.
3. Set the power supply to provide  $10\text{ V}$  (Remember, **always measure the voltage provided by the power supply with either the voltmeter or the scope. Do not rely on the digital display on the front panel of the power supply.**)
4. Assemble the circuit in Figure 2.
5. Record the voltage measured by the voltmeter
6. Compute the internal resistance of the voltmeter using the appropriate equation.

## VI. Ammeter

An ideal ammeter has zero resistance so that the circuit in which it has been placed is not disturbed. An ideal ammeter is a short circuit. However, as with the voltmeter, no ammeter can ever be ideal, and therefore all ammeters have some (hopefully) small internal resistance. To determine the resistance of the ammeter, you can use the circuit in Figure 1. According to Ohm's Law, the current in this circuit will be  $I = V/R$  where  $R = R + R_M$ . So the current can be found using the equation:

$$I = \frac{V_s}{R + R_M} \quad (3)$$

By using the known quantities  $I$ ,  $V_s$  and  $R$ , we can solve for the unknown quantity  $R_M$ .

In the procedure that follows it is extremely important that you take precise and accurate measurements. Record each measurement as precisely as the instrument will allow.

1. Select a  $100\ \Omega$  resistor. Measure and record its actual value.
2. Design a circuit to measure the internal resistance of the ammeter (i.e. assemble the circuit of Figure 1). Set the multimeter to the ammeter mode for dc current measurement.

3. Use the oscilloscope to measure the voltage across the DC power supply.
4. Measure the value of the current using the ammeter.
5. Determine the value of  $R_M$  from the appropriate equation.

### **VII. Measurement of Time Varying Sources**

In this section, we will be using the function generator to provide a time-varying voltage to be measured using the oscilloscope.

**Important:** The function generator has an internal resistance of  $50\Omega$ . The voltage displayed on its front panel is the voltage that would appear at its terminals if it were connected to a  $50\Omega$  load. Under open circuit conditions, the voltage across the terminals of the function generator is **twice** as large as the value indicated on its front panel. This is an important concept and often misunderstood.

If you are located at a lab station that has no printer, complete items 15-17 after one of the lab stations containing a printer becomes vacant.

1. Set the function generator to produce a 10 kHz square wave with 4 Vp-p and 50% duty cycle.
2. Connect the oscilloscope channel 1 probe to the leads on the function generator.
3. Locate the **VERTICAL** section on the front panel of the oscilloscope. It is the section which includes the connections of the scope probes to the scope.
4. Press the softkey labeled **1**. A menu will appear on the bottom of the scope screen. The items that appear on this menu are: channel activation, coupling, bandwidth limiter, inversion, vernier, and probe calibration. Examine the setting for **probe**. It should be on **10**. If it is not, set the **probe** value to **10**. This tells the scope that the probe reduces the signal strength by a factor of 10. All of the scope probes in this lab are "10x" probes. It is a good idea to get in the habit of checking the probe setting at the beginning of each lab.
5. Press Auto-Scale on the oscilloscope to view the signal produced by the function generator.
6. Using the automatic features of the oscilloscope, determine the peak-to-peak voltage. Observe that the measured peak-to-peak voltage is approximately **twice** the peak-to-peak voltage shown on the front panel of the function generator.
7. Using the automatic features of the oscilloscope, determine the frequency, and the period of the square wave voltage.
8. Measure the peak-to-peak voltage by hand, i.e. count the vertical divisions from the minimum to the maximum and multiply by the number of volts per division. The **volts per division** setting is shown in the upper left corner of the scope screen.
9. Using the same screen, measure the period of the square wave, i.e. count the number of horizontal divisions in one period of the sine wave. The **time per division** setting is shown at the top-right-center of the scope screen.
10. Using the formula  $\text{frequency} = 1/\text{period}$ , determine the frequency of the square wave.
11. Connect the function generator across a  $50\Omega$  resistor. Leave the settings on the function generator unchanged.
12. Connect the oscilloscope channel 1 probe across the resistor (and function generator).

13. Press *Auto-Scale* on the oscilloscope to view the signal produced by the function generator.
14. Using the automatic features of the oscilloscope, determine the peak-to-peak voltage. Observe that the measured peak-to-peak voltage is approximately **the same** as the peak-to-peak voltage shown on the front panel of the function generator. Hence, the voltage at the terminals of the function generator is **load dependent**. Whenever you use the function generator to provide a voltage waveform and desire a specific amplitude, you **must** use either the multimeter or the scope to set the desired voltage because the value shown on the front panel of the function generator is valid only for a 50  $\Omega$  load.
15. Press the **Print/Utility** softkey on the scope. It is located to the right of **Autoscale**. Then press the **RS-232 Menu** softkey. Make sure the **resolution** is set to **low**. Press the **previous menu** softkey.
16. Turn on the printer. Wait a few moments and then press the **print screen** softkey on the scope. A printout of the waveform shown on the scope screen should result. Feel free to use the printer to obtain scope traces as needed to document your laboratory experiments.
17. Compare the values for the peak-to-peak voltage and frequency that were 1) specified by the function generator, 2) measured by the oscilloscope and 3) measured by hand. Do the measurements made by hand differ from those made by the oscilloscope? Which do you think are more accurate? Justify your answer.

### ***Kirchhoff's Laws - Design and Simulation:***

1. Design 2 voltage divider and 2 current divider circuits using a 6-volt source and:
  - a. Two different resistors.
  - b. Two equal resistors.

**Make sure the resistor values selected in (a, b) and their associated currents correspond to power levels below the maximum resistor power rating (1/4 W typical).**
2. Design a non-series parallel (bridge) circuit similar to the circuit in Fig. P1.39 of the Textbook. Substitute the power supply with 6-volts and the resistors as follows:  $3\Omega \rightarrow 2.2\text{ K}\Omega$ ,  $6\Omega \rightarrow 4.7\text{ K}\Omega$  and  $4\Omega \rightarrow 3.3\text{ K}\Omega$ . Select values of  $R_1$  and  $R_2$  such that  $i > 0$  mA. Find  $R_1$  and  $R_2$  to obtain  $i = 0$  mA. Is it possible to find more than 1 set of values  $\{R_1, R_2\}$  that satisfy this condition?

In this laboratory experiment, you will build a total of five circuits.

Using the values of the voltmeter and ammeter internal resistance that you measured in Lab 1, use PSpice to simulate the four circuits and compare the results to the theoretical and measured values. Do not forget to draw the circuits with the nodes labeled as they were coded in PSpice.

### ***IX. Experiment - Voltage Divider***

1. Obtain resistors for your designed values from the parts bin. If you do not find the exact values, recalculate the (theoretical) associated currents and voltages and include them in your report.
2. Measure the resistor values using the multimeter as an ohmmeter.
3. Build the voltage divider circuit using the resistors on a lab breadboard.
4. Set the power supply to 6V. Use the voltmeter to ensure the proper setting.



5. Using the voltmeter, measure the voltage across each resistor. Record these values, as always, and verify Kirchhoff's Voltage Law (KVL).
6. Comment on the accuracy of measurements made considering the internal resistance of the voltmeter.
7. Create a table presenting theoretical and measured voltages along with percent error. Consider whether your theoretical values for the voltages across each resistor should include the effect of the voltmeter internal resistance. **Important Note:** When you are calculating percent error, you should avoid cases in which the theoretical value is zero since the percent error is meaningless. To calculate percent error between theoretical and experimental verification of KVL, use the source voltage as the reference. For example, in the measurements made in this section, the theoretical value (and measured value!) for the voltage across the supply is 6V. The measured value is the same as the theoretical value because you used the voltmeter to set the power supply voltage to 6V. To obtain the KVL measured voltage, you can add the voltage across resistors. Compare with 6V.
8. Repeat the procedure for the equal-value resistors voltage divider.
9. Perform step 8 for 2 resistors of 10 M $\Omega$  each. In this case, do you need to include the effect of the voltmeter ?

## ***X. Experiment - Current Divider***

1. Obtain resistors for your designed values from the parts bin. If you do not find the exact values, recalculate the (theoretical) associated currents and voltages and include them in your report.
2. Measure the resistor values using the multimeter as an ohmmeter.
3. Build the current divider circuit using the resistors on a lab breadboard.
4. Set the power supply to 6V. Use the voltmeter to ensure the proper setting.
5. Measure the voltage across the resistors. Record this value.
6. Configure the multimeter to measure current. Remember that this requires two things: Remove the terminal of the red probe from the voltage/resistance measuring receptacle and insert it in the current measuring receptacle on the front panel of the multimeter. Then press the DC current button, also on the front panel of the multimeter.
7. Measure the current through the 6V source. Remember that you have to **break** the circuit and insert the ammeter in **series** with the 6V source to allow the current to flow through the ammeter.
8. Measure the current through each resistor.
9. Verify Kirchhoff's Current Law (KCL). Remember that a theoretical value of zero produces a meaningless percent error.
10. Repeat the procedure for the equal-value resistors divider circuit.
11. Repeat the procedure for the equal-value resistor current divider with 2 resistors of 10 $\Omega$  each. **NOTE: Before you perform the measurements for this current divider, place a 10K $\Omega$  resistor in series with the current divider in order to avoid exceeding the resistors power rating.** Make sure you record the voltages across the series 10K $\Omega$  resistor and the voltage of the current divider. Verify Kirchhoff's Voltage Law (KVL).

12. *Comment on the accuracy of the current measurements made (consider the internal resistance of the ammeter).*

### ***XI. Experiment - Bridge Circuit***

1. *Obtain resistors close to your designed values from the parts bin. If you do not find the exact values, recalculate the (theoretical) associated currents and voltages and include them in your report.*
2. *Measure the resistor values using the multimeter as an ohmmeter.*
- 3.

*Build the bridge circuit using the resistors on a lab breadboard.*

4. *Set the power supply to 6V. Use the voltmeter to ensure the proper setting.*
5. *Measure the voltage across each resistor. Record these values.*
6. *Configure the multimeter to measure current. Remember that this requires two things: Remove the terminal of the red probe from the voltage/resistance measuring receptacle and insert it in the current measuring receptacle on the front panel of the multimeter. Then press the DC current button, also on the front panel of the multimeter.*
7. *Measure the current  $i$ . Remember that you have to **break** the circuit and insert the ammeter in **series** with the  $3.3\text{K}\Omega$  to allow the current to flow through the ammeter.*
8. *Verify Kirchhoff's Voltage Law (KVL).*
9. *Repeat the procedure for all the designed values for the bridge circuit.*