Laboratory 2

Instrument Familiarization and Basic Electrical Relations

Required Components:

- 2 1kΩ resistors
- 2 1MΩ resistors
- 1 2kΩ resistor

2.1 Objectives

This exercise is designed to acquaint you with the following laboratory instruments which will be used throughout the semester:

- The Oscilloscope
- The Digital Multimeter (DMM)
- The Triple Output DC power Supply
- The AC Function Generator

During the course of this laboratory exercise you should also obtain a thorough working knowledge of the following electrical relations:

- Series and Parallel Equivalent Resistance
- Kirchoff's Current Law (KCL)
- Kirchoff's Voltage Law (KVL)
- Ohm's Law
- The Voltage Divider Rule
- The Current Divider Rule

The experiments to be performed during this laboratory are also designed to introduce you to two very important instrument characteristics:

- The output impedance of a real source
- The input impedance of a real instrument

2.2 Introduction

A thorough explanation of the proper use of each of the instruments above will be presented when you come to the laboratory. You should already be familiar with the basic electrical relations listed above; however, a quick review will follow.

2.2.1 Series and Parallel Equivalent Resistance

It can be shown that when resistors are connected in series the equivalent resistance is the sum of the individual resistances:

$$R_{eq} = R_1 + R_2 + \ldots + R_N \tag{2.1}$$

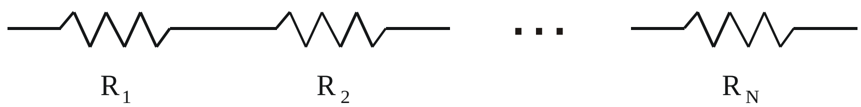

Figure 2.1 Series Resistors

For resistors connected in parallel,

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_N} \tag{2.2}$$

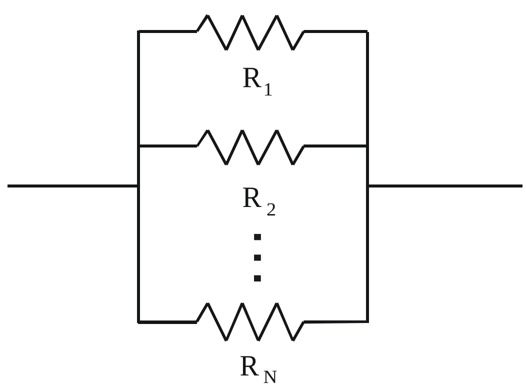

Figure 2.2 Parallel Resistors

For two resistors in parallel, Equation 2.2 can be written as:

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \tag{2.3}$$

2.2.2 Kirchoff's Voltage Law (KVL)

Kirchoff’s Voltage Law (KVL) states that the sum of the voltages around any closed loop must equal zero:

$$\sum_{i=1}^{N} V_i = 0 \tag{2.4}$$

For example, applying KVL (starting at point A) to the circuit shown in Figure 2.3 gives:

$$-V + V_1 + V_2 = 0 \tag{2.5}$$

or

$$V = V_1 + V_2 \tag{2.6}$$

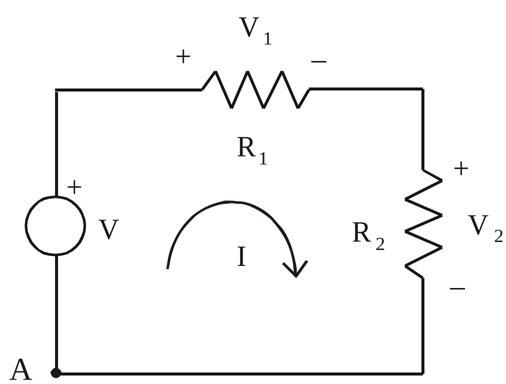

Figure 2.3 Kirchoff’s Voltage Law

2.2.3 Kirchoff's Current Law (KCL)

Kirchoff’s Current Law (KCL) states that the sum of the currents entering (positive) and leaving (negative) a node must equal zero:

$$\sum_{i=1}^{N} I_i = 0 \tag{2.7}$$

For example, applying KCL to the circuit shown in Figure 2.4 gives:

$$I - I_1 - I_2 = 0 \tag{2.8}$$

or

$$I = I_1 + I_2 \tag{2.9}$$

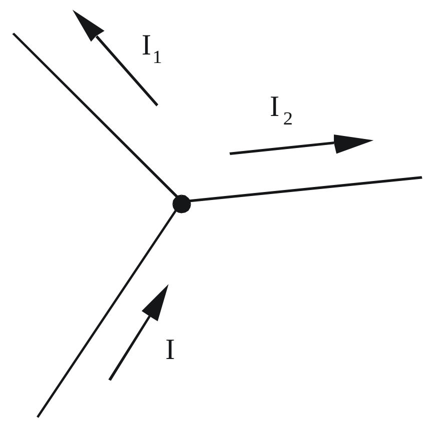

Figure 2.4 Kirchoff's Current Law

2.2.4 Ohm's Law

Ohm's Law states that the voltage across an element is equal to the resistance of the element times the current through it:

$$V = IR \tag{2.10}$$

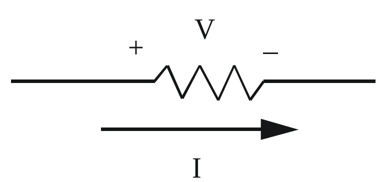

Figure 2.5 Ohm's Law

2.2.5 The Voltage Divider Rule

The voltage divider rule is an extension of Ohm's Law and can be applied to a series resistor circuit shown in Figure 2.6.

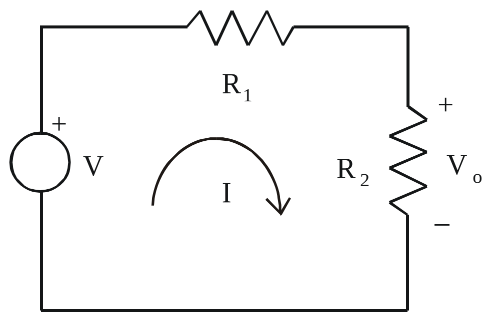

Figure 2.6 Voltage Division

The current flowing in the circuit is

$$I = \frac{V}{R_{eq}} = \frac{V}{R_1 + R_2} \tag{2.11}$$

Applying, Ohm's Law, the voltage across R_2 is

$$V_o = IR_2 \tag{2.12}$$

Thus the voltage divider relation is

$$V_o = V\left(\frac{R_2}{R_1 + R_2}\right) \tag{2.13}$$

2.2.6 The Current Divider Rule

The current divider rule is can be derived by applying Ohm's Law to the parallel resistor circuit shown in Figure 2.7.

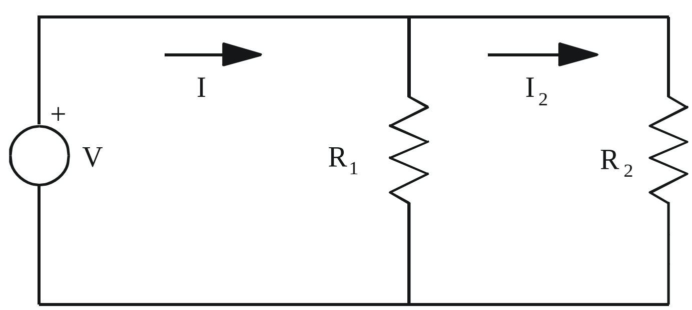

Figure 2.7 Current Division

The current flowing from the voltage supply is:

$$I = \frac{V}{R_{eq}} = \frac{V(R_1 + R_2)}{R_1 R_2} \tag{2.14}$$

Applying Kirchoff's Voltage Law around the outside loop gives:

$$V = I_2 R_2 \tag{2.15}$$

Substituting Equation 2.15 into 2.14 gives:

$$I = \frac{I_2(R_1 + R_2)}{R_1} \tag{2.16}$$

Solving for I_2 gives the current divider relation:

$$I_2 = I\frac{R_1}{R_1 + R_2} \tag{2.17}$$

2.2.7 Root-Mean-Square Values

When dealing with AC signals, voltage and current values can be specified by their root-mean-square (rms) values. An rms value is defined as the square root of the average of the square of a signal integrated over one period. For current and voltage, the rms relations are:

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T I^2 dt} = \frac{I_m}{\sqrt{2}} \quad \text{and} \quad V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 dt} = \frac{V_m}{\sqrt{2}} \tag{2.18}$$

where I_m and V_m are the amplitudes of sinusoidal current and voltage waveforms. Rms values are useful for power calculations. For example, the average AC power dissipated by a resistor can be calculated with the same equations that are used with DC signals:

$$P_{avg} = V_{rms} I_{rms} = R I_{rms}^2 = V_{rms}^2 / R \tag{2.19}$$

2.2.8 Real Sources and Meters

When analyzing electrical circuits on paper the concepts of ideal sources and meters are often used. An ideal voltage source has zero output impedance and can supply infinite current. An ideal voltmeter has infinite input impedance and draws no current. An ideal ammeter has zero input impedance and no voltage drop across it. Laboratory sources and meters have terminal characteristics that are somewhat different from the ideal cases. The terminal characteristics of the real sources and meters you will be using in the laboratory may be modeled using ideal sources and meters as illustrated in Figures 2.8 through 2.10

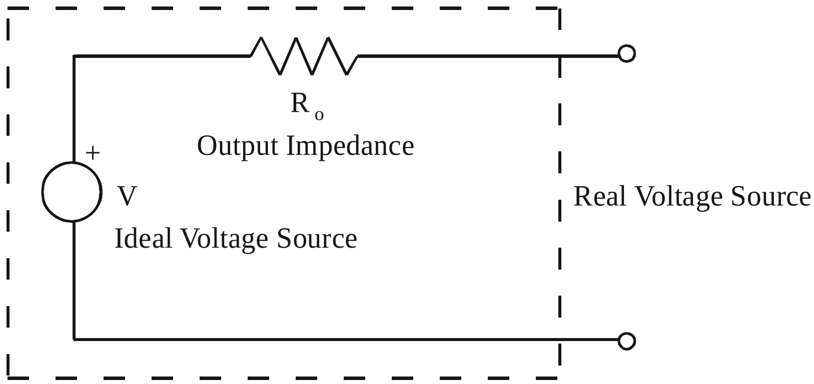

Figure 2.8 Real Voltage Source with Output Impedance

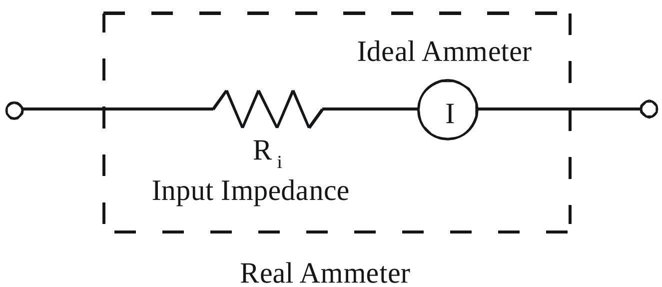

Figure 2.9 Real Ammeter with Input Impedance

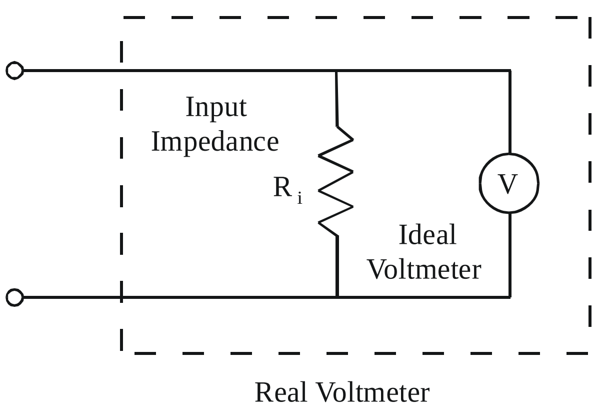

Figure 2.10 Real Voltmeter with Input Impedance

In some instances as you will see, the input impedance of a meter or the output impedance of a source can be neglected and very little error will result. However, in many applications where the impedances of the instruments are of a similar magnitude to those of the circuit serious errors will occur.

As an example of the effect of input impedance, if you use an oscilloscope or multimeter to measure the voltage across R_2 in Figure 2.6, the equivalent circuit is:

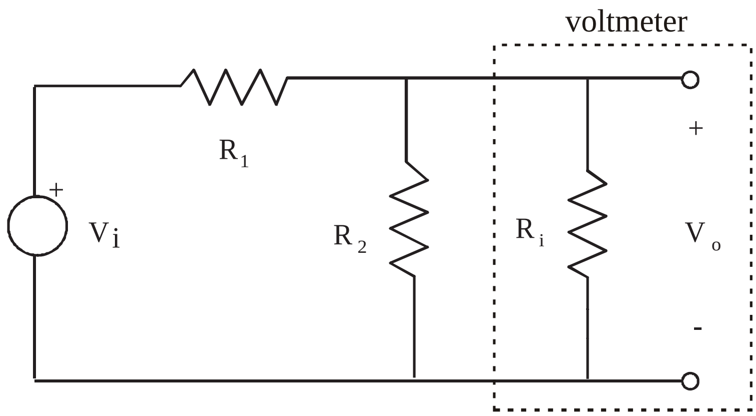

Figure 2.11 Effect of Input Impedance

The equivalent resistance of the parallel combination of R_2 and R_i is:

$$R_{eq} = \frac{R_2 R_i}{R_2 + R_i} \quad (2.20)$$

Therefore, the actual measured voltage would be:

$$V_o = \frac{R_{eq}}{R_1 + R_{eq}} V_i \quad (2.21)$$

If R_i is large compared to R_2 (usually the case), $R_{eq} \approx R_2$ and the measured voltage (V_o) would be close to the expected ideal voltage division result of $\frac{R_2}{R_1 + R_2} V_i$. However, if R_2 is not small compared to R_i, the measured voltage will differ from the ideal result based on Equations 2.20 and 2.21.

If you know values for V_i, R_1, and R_2 in Figure 2.11, and if you measure V_o, you can determine the input impedance (R_i) of the measuring device using the following analysis. Equation 2.21 can be solved for R_{eq} giving:

$$R_{eq} = \left(\frac{V_o}{V_i - V_o}\right) R_1 \tag{2.22}$$

Knowing R_{eq}, we can determine the input impedance by solving for R_i in Equation 2.20:

$$R_i = \frac{R_{eq} R_2}{(R_2 - R_{eq})} \tag{2.23}$$

2.3 Circuit Troubleshooting Advice

When your circuits don't work properly in this and future Labs (and in your Project), always go through the following set of checks to help diagnose and fix any problems:

(1) Verify that your breadboard circuit is constructed properly based on the circuit schematic or wiring diagram by checking each connection, making sure the breadboard is being used properly per Figure 1.2 in Lab 1.

(2) Use the continuity-check feature of the multimeter to verify that wiring and connections are good between all source and terminus pins.

(3) Make sure power and ground are available where needed on the breadboard, and include jumper wires between the top and bottom power and ground rows if necessary.

(4) Make sure you have common grounds among your circuit and all instrumentation being used (power supply, function generator, multimeter, oscilloscope).

(5) Check the power supply voltage with the multimeter to make sure it is at the correct level.

(6) Take voltage measurements in different parts of the circuit to make sure values match what is expected.

And for additional troubleshooting advice, especially for more-complicated circuits and the Project, see Section 7.4 in Lab 7 and Section 15.5 in Lab 15.

2.4 Laboratory Procedure / Summary Sheet

Group: ____ Names: ____________________________ ________________________________

____________________________ ________________________________

(1) Select five separate resistors whose nominal values are listed below. Record the band colors for each resistor in the table below. Then connect each resistor to the multimeter using alligator clips and record the measured value for each resistor.

Resistor	Band Colors	Measured Value (Ω)
R_1: 1kΩ		
R_2: 1kΩ		
R_3: 2kΩ		
R_4: 1MΩ		
R_5: 1MΩ		

Make sure you keep track of each of the five resistors (e.g., by laying them out in order on the table with labels, or in the breadboard).

(2) Now construct the voltage divider circuit shown using resistors R_1 and R_2 listed above and set V_i to 10 Vdc using the DC power supply. **When using a power supply or function generator, always adjust the supply voltages before making connections to the circuit. Also be very careful to check that the power and ground leads are not touching when power is applied. This creates a short that can blow a fuse or damage the device.**

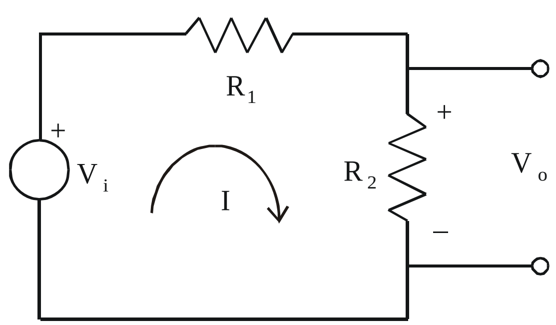

Figure 2.12 Voltage Divider Circuit

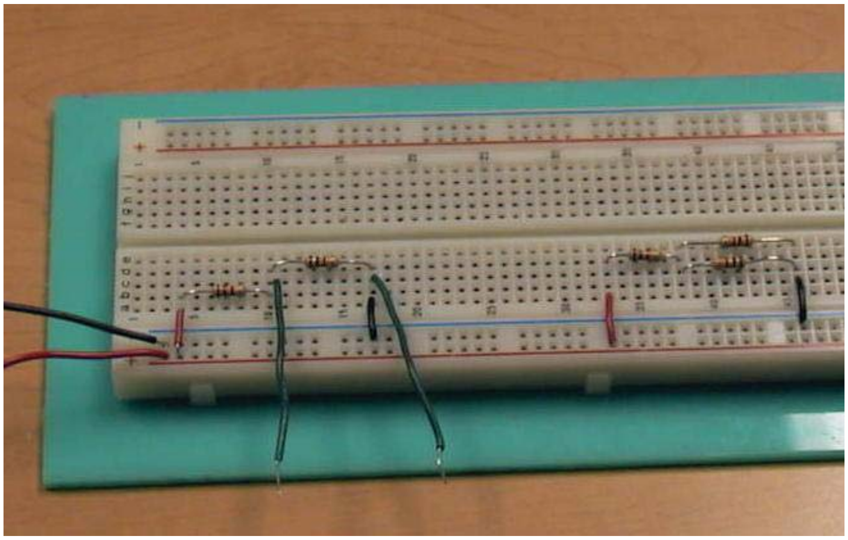

Figure 2.13 Breadboard layout for voltage divider (left) and current divider (right)

After reading all of the information below, complete the table at the top of the next page by measuring or calculating the appropriate values. In your calculations, use the actual (measured) values for R_1 and R_2.

For information on how to use the oscilloscope, see the "instrumentation for powering and making measurements in circuits" video on the Lab Book website (mechatronics.colostate.edu/lab_book.html) and refer to the "How to Find a Signal on an HP54602A Oscilloscope" procedure in Section 3.4.9 of Lab 3.

Note – Make sure you always have a common ground attached to your power supply, circuit, and o-scope when taking voltage measurements with the o-scope.

Remember from Lab 1, to measure current with the multimeter, you must put the meter in series with the element of interest. So to measure the current through the resistors R_1 and R_2, you must pull out the connected ends of R_1 and R_2 and attach the meter probes between the exposed ends.

Note – Be very careful when using the ammeter feature of the multimeter. If you don't place the meter in series with an element, and you put the leads across an element instead, you can burn out the meter's fuse and/or damage the device.

For circuit trouble-shooting advice, please refer to Section 2.3.

Data for the circuit and instructions on the previous two pages:

	Input Voltage V_i (V)	**Output Voltage V_o (V)**	**Current (mA)**
Calculated	10 V		
Multimeter			
Oscilloscope			*

* compute the current using the voltage value measured

(3) Repeat part 2 using the same resistors R_1 and R_2 but using the function generator to drive the circuit at 1KHz with a 3V amplitude (6V peak-to-peak) sine wave. See the video demonstrations on the Lab Book website to see how everything is connected. If an error message appears on the function generator display during power up, just press any button and wait briefly for the message to clear.

NOTE - If using the Philips PM5193 function generator, be sure to connect to the lower "OUTPUT" jack (not the upper "TTL OUT" jack).

Complete the table below by measuring or calculating the appropriate values. In your calculations, use the actual (measured) values for R_1 and R_2. Use rms values for all table entries. **Be aware that the Lab multimeters cannot detect or measure small I_{rms} currents accurately.**

	Input Voltage (V_{rms})	**Output Voltage (V_{rms})**	**Current (I_{rms} in mA)**
Calculated	$\frac{3V}{\sqrt{2}}$		
Multimeter			*
Oscilloscope			*

* compute the current using the voltage value measured

(4) Repeat part 2 (V_i = 10 Vdc) using R_4 and R_5 in place of R_1 and R_2. In this case, the impedances of the instruments are close in value to the load resistances and therefore affect the measured values. Sketch the equivalent circuit for the instruments (voltage supply, and voltmeter or oscilloscope) and the attached circuit. Use this schematic to explain differences between actual (measured) and theoretical values.

Complete the table below by measuring or calculating the appropriate values. In your calculations, use the actual (measured) values for R_4 and R_5.

	Input Voltage (V)	**Output Voltage (V)**	**Current (mA)***
Calculated			
Multimeter			
Oscilloscope			

***: compute the current using the voltage value measured since current cannot be measured directly on an oscilloscope and since the currents are too small to measure on the NI ELVIS.**

(5) Construct the current divider circuit shown below using resistors R_1, R_2, and R_3 listed in part 1. Set the source V to 6 Vdc.

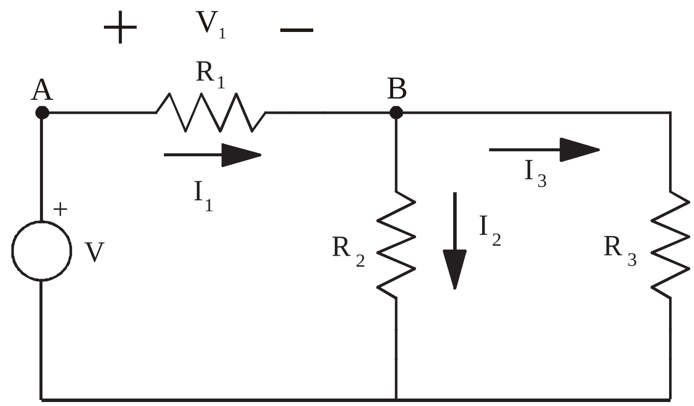

Figure 2.14 Current Divider Circuit

Complete the table below by measuring or calculating the appropriate values. In your calculations, use the actual (measured) values for R_1, R_2, and R_3.

	I_1 (mA)	I_2 (mA)	I_3 (mA)
Calculated			
Multimeter			
Oscilloscope	*	*	*

* **Compute the current using the voltage values measured. See Section 3.2.4 in the next Lab for more information on how to measure the voltage across R_1. Alternatively, measure the voltages at nodes A and B (relative to ground) and manually subtract the values.**

(6) Repeat part 5 with a 3 V amplitude 500 Hz sine wave ($V = 3\sin(1000\pi t)$).

Complete the table below by measuring or calculating the appropriate values. In your calculations, use the actual (measured) values for R_1, R_2, and R_3. Use rms values for all table entries.

	I_{1rms} (mA)	I_{2rms} (mA)	I_{3rms} (mA)
Calculated			
Multimeter	*	*	*
Oscilloscope	*	*	*

*** compute the current using the voltage value measured**

Normally, the input impedance of a meter or the output impedance of a source can be neglected and very little error will result. However, in some applications where the impedances of the instruments are of a similar magnitude to those of the circuit, serious errors will occur.

LAB 2 QUESTIONS

Group: ____ Names: ____________________________ ________________________________

____________________________ ________________________________

(1) Describe how you read resistor values and tolerances.

(2) Derive formulas, using the voltage divider and current divider rules, for the following voltage and current in Figure 2.14, using V, R_1, R_2, and R_3 only.

V_1 = ____________________________ I_3 = ____________________________

(3) From the data collected in Part 4, calculate the input impedance of the oscilloscope and the voltmeter.

Z_{in} (scope) = ____________________________

Z_{in} (DMM) = ____________________________

Hint: Use Equations 2.22 and 2.23. Also, if using the attenuator probe, be sure to account for the probe's impedance (see Section 3.3 in Lab 3).

(4) The AC wall outlet provides 110 V_{rms} at 60Hz. Sketch and label one period of this waveform.

(5) Using a function generator and three 1 kΩ resistors design a circuit that will supply both a 6V p-p output and a 2V p-p output. Show your work below.