Resistance

Concept

The purpose is to introduce students to basic equipment and circuit-building techniques and to investigate ohmic and non-ohmic behavior, power dissipation, temperature effect upon resistance, Kirchoff's Laws, Thevenin equivalent circuits, Norton equivalent circuits and instrumental input and output resistances. Three laboratory sessions are required.

Helpful hints and warnings

Small resistors are guaranteed to dissipate at least 1/4 Watt without suffering damage from the heat. So, for use in a circuit, assure that the power dissipated in each resistor in your circuit does not exceed this value unless instructed to do so. The fundamental definition of power dissipated within any object is $P = IV$, where P is the power in Watts, I is the current in Amperes and V is the potential difference across the object in Volts. If the object behaves ohmically within a certain range, then $V = IR$ can be used in the expression for power to yield $P = I^2R = V^2/R$.

The input resistance of a DMM (digital multimeter), R_{input}, is not infinite. Thus, a DMM will act as another resistor in series with your circuit, thereby reducing the measured potential by virtue of an inadvertant voltage divider. Usually, $R_{input} \geq 10\text{M}\Omega$.

Be careful with diodes, as they can be damaged by excessive current. Maintaining a 1kΩ resistor in series with a diode assures that the maximum current $I = (V - 0.5\text{Volt})/R$ is reasonable.

Experimental Instructions

1. Ohmic behavior of resistors

a. Measure the resistance of a resistor provided by the instructor and report the value and perceived uncertainty. All groups will measure R for the same resistor, and the instructor will provide a statistical analysis of the results.

b. Choose a small (1/4 W) resistor of $R > 2\text{k}\Omega$ and measure the resistance with the DMM. Does this measurement alone tell you that the resistor exhibits Ohmic behavior?

c. To investigate the Ohmic behavior, connect the resistor to the variable power supply. Use a DMM to measure the potential across the resistor and another to measure the current through the resistor.

(a) Vary the applied potential from 0 to 20V and plot the I versus V for 20 values of the potential. On the graph indicate your best estimate of the uncertainties in both potential and current. If the DMM reading is steady, then the uncertainty is $\pm 1/2$ the last digit. If the DMM reading fluctuates, then the uncertainty can be overestimated to be $\pm 1/2$ the maximum range of fluctuation.

(b) Is the behavior Ohmic to within the estimated error, that is, is I linear in V with a slope of $1/R$?

d. Explore the temperature dependence of the resistance of a copper-clad resistor provided by the instructor.

(a) Using the DMM to measure R and a temperature sensor based on a K type thermocouple or IR detector to measure temperature, heat the resistor using your hands and a hot-air gun. Do not exceed 50°C. Make about 10 measurements.

(b) Use the vapor above dry ice to cool your resistor. Be patient, and make several measurements. The temperature sensors will not measure temperatures below -50°C.

e. A thermistor is a special resistor with a pronounced temperature dependence to the resistance. The resistance can increase or decrease in a nonlinear fashion as the temperature increases.

(a) Use a DMM to measure the DC resistance of a thermistor.

(b) Bring the very small thermistor into contact with a temperature sensor.

(c) Vary the temperature by heating the system slightly using a hot air gun. Also, cool the system by bringing the resistor body and thermocouple into contact with a metal plate cooled by ice or dry ice.

(d) Measure R for 10 values of T and graph $R(T)$.

(e) Is R a dramatic function of T? What is meant by dramatic?

2. $I(V)$ dependence for other materials and objects

a. Measure the I(V) curves for two of the supplied objects, taking at least 10 data points. Use two DMMs to simultaneously measure I and V. Establishing good electrical contact can be difficult. Are these objects Ohmic? Knowing the geometry of the objects and exactly where you made your measurements of potential differences across the objects, estimate the inherent *resistivity* ρ of the materials and the associated uncertainty.

b. Measure the I(V) curve of a simple diode, using $-20 < V < 1$. Before you make your measurement, calculate the value of the current-limiting resistor that must in series with the diode. If too much current passes through the diode, the excessive power dissipated will lead to overheating and failure. Limit the current to 100 mA.

c. Measure the I(V) curve of a light-emitting diode (LED), limiting the current to a maximum of 20 mA. You will find that the forward bias required to make the LED conductive and bright is greater than that observed for the simple diode. After measuring the I(V) curve, gradually reduce the value of the current-limiting resistor and determine how much power can dissipate and how bright it can be before it overheats and fails. Remember that resistors have power dissipation limits!

3. Potential or voltage divider

a. Build a potential divider using the approximate values $R_1 = 200\Omega$ and $R_2 = 200\Omega$. Set the power supply to 10 V and measure the output potential of the divider and current through the load resistor across R_2 as you vary the value of the load resistance from 200Ω to $1\mathrm{M}\Omega$. Over what range of load resistance would you declare that this divider to be a reasonable "constant potential source"?

b. Make the same measurements for a divider with the approximate values $R_1 = 16\mathrm{k}\Omega$ and $R_2 = 16\mathrm{k}\Omega$. Is this a better or worse "constant potential source".

4. Thevenin equivalent potential and resistance

a. Build the complex circuit of resistors shown in the diagram provided by the instructor.

b. Determine the equivalent source potential by measuring the output potential with a high input resistance (very small electrical load) DMM.

c. Determine the equivalent source resistance by short-circuiting the output and measuring the current through this short-circuit.

d. Another way to determine the equivalent source resistance is to connect a load resistor of your choice ($200\Omega < R < 1\mathrm{M}\Omega$) and measure the output potential with the DMM.

e. Compare your measured values of V_{eq} and R_{eq} with a calculation based on values of the resistors used in your circuit.

5. Source and input resistances

a. Measure the source resistance of your power supply using the same technique as in the Thevenin analysis above.

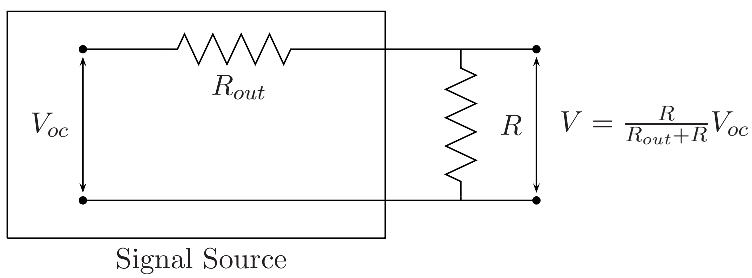

Figure 1: Measuring output resistances of instruments.

b. Determine the input resistance of the DMM in VDC mode by connecting a load resistor of your choice in series with the DMM and measuring the output potential of the power supply.

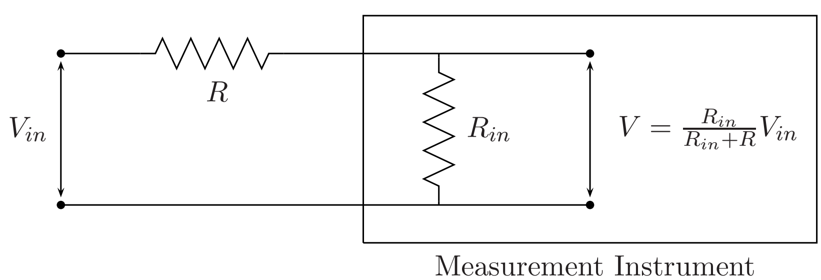

Figure 2: Measuring input resistances of instruments.

Assigned Problems

1. From Simpson

Problems 1.15, 1.18, 1.27, 1.30, 1.32, 1.42