UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE
Department of Electrical and Computer Engineering

EXPERIMENT 6 – PRECISION RESISTANCE MEASUREMENTS

OBJECTIVES

This experiment introduces four different methods for making precision resistance measurements: Benchtop multimeter 2-wire, Benchtop multimeter 4-wire (Kelvin), Wheatstone bridge, and LCR meter

MATERIALS/EQUIPMENT NEEDED

Agilent 34461A Digital Multimeter
WINSCO GS-470 Wheatstone Bridge
SM-1102A Galvanometer
B&K LCR meter
Resistors: 1Ω, 10Ω, 1kΩ

INTRODUCTION

It is sometimes necessary to make resistance measurements – particularly of very small resistances – with precision greater than that which can be obtained with a hand held multimeter. This is frequently encountered with sensors. For example, the resistance of a strain gauge must be measured very accurately in order to determine deflection of solid materials under mechanical load. Some methods for making precision resistance measurements are discussed below;

2-wire Resistance Measurements: Multimeters function as "Ohmmeters" when operated in resistance measurement mode. Inexpensive multimeters measure resistance by applying known voltage to the unknown resistance, measuring the resulting current, and then applying Ohm's law. More accurate meters apply a known current and measure the resulting voltage. In either case, meter test leads can introduce substantial error into low resistance measurements. Because the wire leads have small, but finite resistance, voltage division occurs between the resistance being measured, and the resistance of the leads. Figure 6-1 shows a simplified schematic diagram of a meter connected to an unknown resistance ($R_{unknown}$) by two wire leads of resistance R_{lead}. Applying Ohm's law to the meter circuit:

$$\frac{V}{I} = \left(R_{unknown} + 2R_{lead} \right) = R_{measured}$$

When $R_{lead} << R_{unknown}$, the measurement error is small. For ideal, zero resistance leads, $R_{measured} = R_{unknown}$. As the value of R_{lead} approaches the value $R_{unknown}$, accurate resistance measurement becomes impossible. For extremely small resistance values, contact resistance of the probe connections is also a factor.

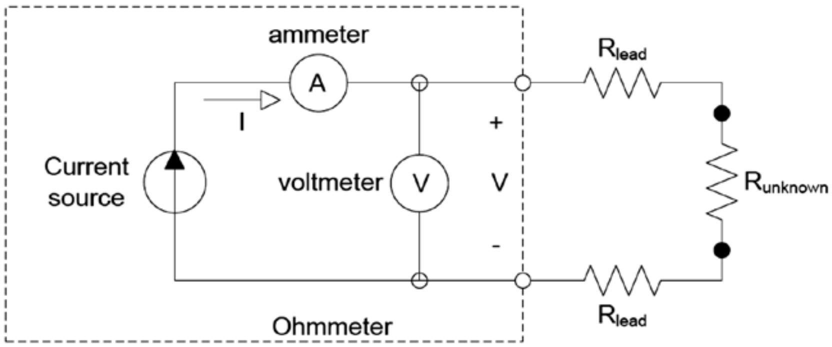

Figure 6-1 2-wire Resistance measurement

The "2-wire" resistance measurement is inherently inaccurate for low resistances because undesired voltage appears across the lead resistances due to current flowing through them. This source of error can be eliminated by supplying current to the unknown resistance by means of a separate circuit. This is known as the 4-wire, or "Kelvin" method.

4-wire Resistance Measurements: In the diagram of Figure 6-2, a separate pair of test leads is used to connect the unknown resistance directly to the Ohmmeter's internal voltage sensing circuit. As before, current flowing through the leads connected to the current source produces a voltage drop across the wires. This unwanted voltage is not included in the resistance calculation, however, because voltage is measured directly across the unknown resistance. The voltage sensing circuit draws negligible current due to high internal resistance, so voltage dropped across the voltmeter leads is essentially zero, and the voltage measured is identical to the voltage across $R_{unknown}$.

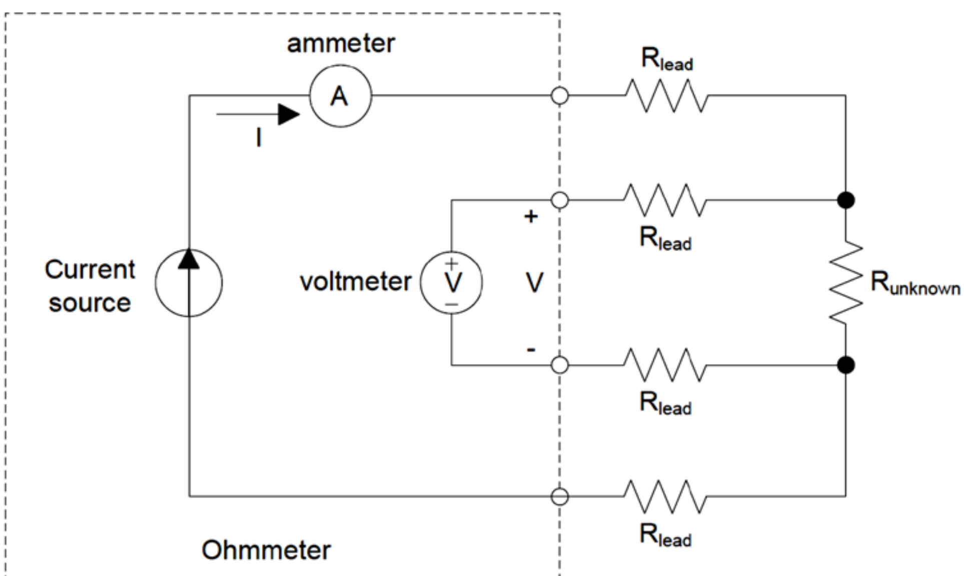

Figure 6-2 4-wire Resistance measurement

Wheatstone Bridge Resistance Measurements: The Wheatstone bridge circuit of Figure 6-3 is used to obtain accurate resistance measurements for a large range of resistance values. A battery provides the source of current flow, while a galvanometer measures very small currents. The basic principle of operation is that when the bridge is "balanced", $R_1/R_2 = R_3/R_{unknown}$. In this condition, the voltages at nodes A and B are equal, and the galvanometer current is zero. The general procedure is, therefore, to select appropriate values for R_1 and R_2, and then adjust variable resistor R_3 to obtain an indication of zero on the galvanometer. Unknown resistance can then be calculated from the equation:

$$\frac{R_1}{R_2} = \frac{R_3}{R_{unknown}} \Rightarrow R_{unknown} = \frac{R_2 R_3}{R_1}$$

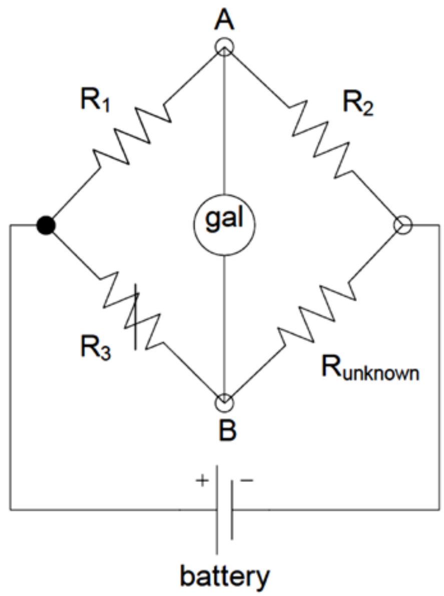

Figure 6-3 Wheatstone bridge circuit

Note: When using the Wheatstone bridge, always begin with R_1 and R_2 set to high values to minimize current drain on the battery, and to protect the sensitive galvanometer from damaging over-current.

PRELAB

1. A meter being used for a 2-wire resistance measurement has an internal current source of 1mA. If the meter's test leads have equal resistances of 0.06Ω, what is the measured resistance for:
   a. A resistor of actual value 0.5Ω?
   b. A resistor of actual value 1kΩ?
2. Calculate the percentage of error for parts1a and 1b above. Remember the percentage of error is calculated as $\%error = \left|\frac{R_{actual} - R_{measured}}{R_{actual}}\right| \times 100\%$
3. Refer to the Wheatstone bridge diagram of Figure 6-3. If the galvanometer indicates zero when R_1=110Ω, R_2=10Ω, and R_3 is set at 2.97kΩ, what is the value of $R_{unknown}$?
4. Refer to the Wheatstone bridge diagram of Figure 6-3. If R_1=1Ω, R_2=111Ω, $R_{unknown}$= 1Ω, R_3 is set at 1kΩ, and the battery is 9V:
   a. What is the current flowing through the galvanometer? Use 60Ω for the internal galvanometer resistance in calculations.
   b. The measurement range of the galvanometer is +/- 500µA. What is the ratio of galvanometer current to its maximum range of 500µA?
   c. Is there danger of damage to the galvanometer with these resistance values?

PROCEDURE

1. Obtain three resistors that will be used as "unknowns": ~1Ω, ~10Ω, and ~1KΩ. Call them R_{X1}, R_{x2}, and R_{x3} respectively. The resistors are labeled with nominal values. But all resistors have tolerances, and will have values different from nominal when measured with precision.
2. Record the labeled values for R_{X1}, R_{x2}, and R_{x3} in Table 6-1.
3. Use the hand held multimeter from your lab kit to measure resistances and record the values in Table 6-1.
4. Use the digital multimeter for 2-wire resistance measurement. Measure and record the values in Table 6-1.
5. Referring to the user's manual, configure the digital multimeter for 4-wire resistance measurement. Measure resistances R_{X1}, R_{x2}, and R_{x3}, and record the values in Table 6-1.
6. Locate a WINSCO GS-470 Wheatstone bridge apparatus, an SM-1102A Galvanometer, a decade resistance box and a 9 volt battery.

Note: The galvanometer has three terminals. The black terminal is common. G0 is the low impedance input (60Ω≤G0≤105Ω). G1 is the high impedance input (1.5KΩ≤G1≤2.0KΩ). Always begin by making connections to the "G1" and "-" terminals to prevent burning out the galvanometer. Connection to the "G0" input may be made after the bridge has been brought closer to balance in order to increase galvanometer current, if desired.

7. Connect the Wheatstone bridge circuit as shown in Figure 6-3 using the WINSCO GS-470 Instructions. (A DC power supply set at ~10V may be substituted for the 9V Battery.)
8. Zero the galvanometer by turning the adjustment screw at the bottom of the meter window before making measurements.
9. Given the range of the decade resistance box and the approximate values of unknown resistances, calculate values for R_1, R_2 and R_3 (using values obtainable with the GS-470 for R_1 and R_2) that will approximately balance the bridge for unknowns R_{X1}, R_{x2}, and R_{x3}.
10. Measure resistances R_{X1}, R_{x2}, and R_{x3}, and record the values in Table 6-1. Remember to multiply the decade box resistance by the scaling factor R_2/R_1 to obtain $R_{unknown}$.
    a. Set R_1, R_2, and R_3 to their calculated values. This is accomplished by closing rocker switches on the Wheatstone bridge unit to "short" appropriate resistors.
    b. Press and hold the "BATT" button to energize the circuit. Always close the battery switch first.
    c. Press and hold the "GALV" switch and observe the galvanometer's deflection.
    d. Immediately release both momentary switches. If switches are held closed for too long, the resistors will heat and change values.
    e. Adjust the decade box resistance. The direction of galvanometer deflection indicates whether the decade box resistance must increase or decrease.
    f. Repeat these steps until a null is obtained.
11. Use the LCR meter to measure R_{X1}, R_{x2}, and R_{x3}, and record the values in Table 6-1.
    a. Set the LCR meter for DCR (DC Resistance) measurement.
    b. Connect the LCR meter to the resistor using the clips, and read DC resistance from the meter display.

DATA/OBSERVATIONS

Table 6-1: Measured Resistances

	R_{X1}	R_{X2}	R_{X3}
Nominal			
Handheld Meter			
2-wire Multimeter			
4-wire Multimeter			
Wheatstone Bridge			
LCR Meter			

INSTRUCTOR'S INITIALS: DATE:

POST-LAB

1. Using the 4-wire digital multimeter measurements as the "actual" resistance values, produce a bar graph showing %error vs. nominal value and the other measurement methods for R_{X1}, R_{X2} and R_{X3}. See the example of Figure 6-4.

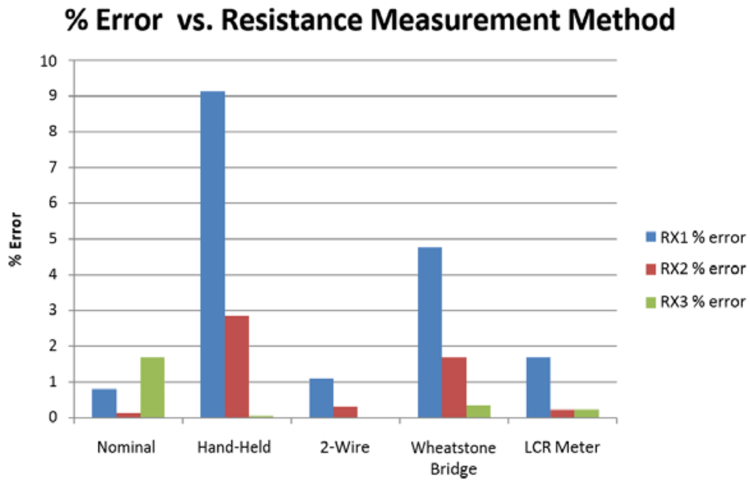

Figure 6-4 Example of %error comparison chart

2. Discuss the effect on %error of higher vs. lower unknown resistances.
3. What are some sources of error with the Wheatstone bridge set-up?
4. How can accuracy of the Wheatstone bridge be improved by appropriately adjusting the ratio R_2/R_1?

Be sure to include all items from the post-lab exercise above in your written lab report.