School: New York City College of Technology

Section/ Course: EET 3120/ Sensors and Instruments

Experiment #4: Wheatstone Bridge and its Applications to Biomedical Engineering

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INTRODUCTION

Objective:

1. Troubleshoot a Wheatstone Bridge in Multisim.
2. Prototype a Wheatstone Bridge on the NI ELVIS II demo board and measure the unknown resistance of an arm.

Required Components:

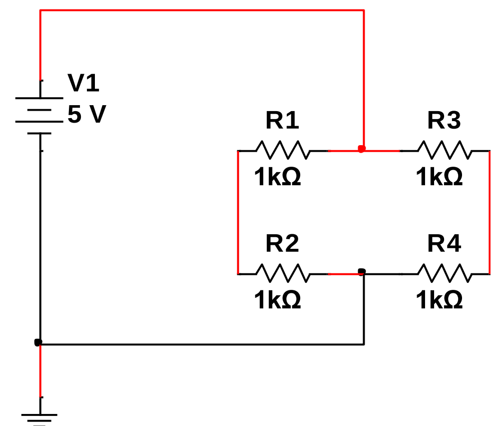
- Multisim 11.0 or higher
- NI ELVIS II
- 4- 1kΩ Resistors
- Electrodes (2 per team member)
- 2 Alligator to Alligator clips
- Connector wires

PROCEDURE

Part 1: Simulation in Multisim:-

1. Open Multisim be double clicking the shortcut on the desktop.
2. Open a new schematic by going to File➔ New➔ Schematic capture.
3. In the schematic, the circuit in figure 1 below was built.

Figure 1



4. We saved our circuit once we were done building it.
5. In Multisim we found the NI ELVIS Digital Multimeter to measure voltage in our Wheatstone Bridge.
6. To measure voltage, the V and COM were connected to the desired ports:
    a. R1 and Ground
    b. R4 and Ground
    c. R2 and R4
7. In the simulation toolbar the RUN button was clicked to measure the voltage in each case in step 6.
8. The results of the simulation will be displayed on the DMM. Record them in table 1.
    a. Are the results what you expected? **ANS** Yes, since R1 to ground is in parallel/ shunted with the voltage source we expected the voltage from R1 to Ground would be 5V. Since R3 and R4 are equal the voltage across each (2.5V) would be half of the supply voltage (5V).

Part 2: Troubleshooting in Multisim:-

1. Open the file WheatstoneBridgeExample.
2. Measure only the voltage at the same points for the bridge you built in Part 1 and record the data in Table 1.
    a. Are the results what you expected? Why/Why not?
    b. Show any calculations you used.

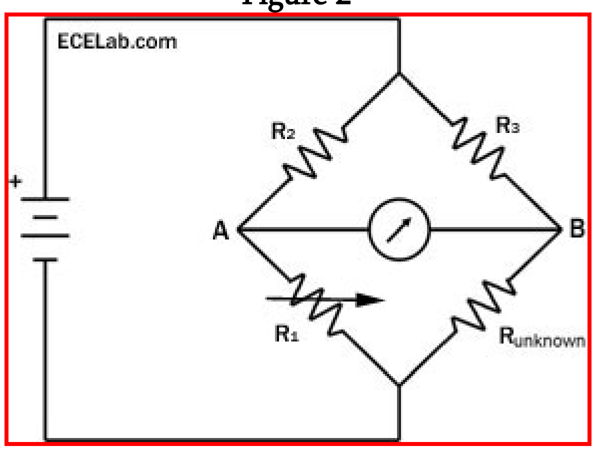
Part 3: Prototype on NI ELVIS II:-

1. With the power turned off, build the circuit you simulated in Multisim on NI ELVIS II.
2. Power up NI ELVS II and when the Instrument Launcher is open, chose the Digital Multimeter and connect the probes to measure voltage.
    a. The banana plug of the red probe is connected to V
    b. The banana plug of the green plug is connected to COM
3. Take voltage measurement the same way we took them in the simulation. Record the data in table 2.
4. Measure the resistance using the DMM for R1, R2, and R3, but DO NOT MEASURE R4 yet!
5. Calculate the resistance R4.
6. Check your calculation by measuring the actual value of R4.
7. Remove R4 and replace with two input wires.
8. Place two electrodes on left arm. Place one on the wrist and the other in a straight line before the elbow joint.
9. Hook up the alligator clips from the electrode clips to the input wires.
10. Repeat steps 3-6 to determine the unknown resistance of your arm.

THEORETICAL BACKGROUND

The standard method to determine the value of a particular resistor is to connect it in a circuit and to measure the current (I) in the resistance, the voltage across it (V) and find the value of the resistance from Ohm's law: $R = \frac{V}{I}$. However, the ammeter and the voltmeter introduction to a circuit alter the voltage and current values so the determined values of resistance will not be the same as the actual values. When the effects of the voltmeter and ammeter cannot be neglected, it is still possible to make accurate measurements of the resistance by means of a circuit called a Wheatstone bridge, invented by Charles Wheatstone (1802-1875). The Wheatstone bridge is used for finding the value of an unknown resistance by comparing it with the know ones. A battery of e.m.f is applied to the circuit, and a current emanates from the battery. Currents exist in each of the resistors and in the galvanometer. The current exist in the galvanometer because there is a difference of potential betweens points A and B in the circuit. The potential is caused by the different currents in the different resistors. Figure 2 below shows the Wheatstone Bridge in its most common diamond configuration.

Figure 2



RESULTS

Table 1: Voltage Measurements across the Wheatstone Bridge **(Multisim Simulations)**

	V across R1 to Ground	*V across R4 to Ground*	*V across R2 and R4*
Part 1	5V	2.5V	224.56μV
Part 2	4.9179V	2.4537V	4.53mV

For part 1 in table 1, all the resistors in the Wheatstone bridge were equal (1000 Ω/1 kΩ). Therefore, all the results above were expected. Since R1 to ground branch is in parallel/ shunted with the voltage source we expected the voltage from R1 to Ground would be 5V, but for the actual circuit the voltage across R1 to ground was 4.9179V. Since R3 and R4 was both equal (1kΩ); the voltage across each (2.5V) would be half of the supply voltage (5V). The voltage across R2 and R4 are similar in magnitude (2.5V), but differ in sign. So, one cancels the other causing the voltage across R2 and R4 to be almost zero. I the results shown in table 1 we expect there would be some difference between the results. Since, the components and instruments in a simulation are ideal; while component in reality will cause errors.

Table 2: Wheatstone Bridge Measurements for Actual Circuit

	R1 to Ground	*R4 to Ground*	*R2 to R4*	*R1 (Ω)*	*R2 (Ω)*	*R3 (Ω)*	*Calculated R4 (Ω)*	*R4 Actual (Ω)*
Circuit	4.9179V	2.4537V	4.53mV	990.6 Ω	982.5 Ω	985.7 Ω	981.25 Ω	981.9 Ω
Arm	4.9196V	4.9014V	2.4527V	990.6 Ω	982.5 Ω	985.7 Ω		8.107 MΩ

In table 3 the row designated for **Circuit** contains the results for a Wheatstone Bridge built from actual components. The resistors R1, R2, and R3 are all suppose to be 1kΩ resistors (just like part 1 of this experiment), but in reality this is not so. Therefore, the actual values of these resistors were measured, using the NI ELVIS II Digital Multimeter. The resistance for each was recorded in table 2 to be used to calculate the value of R4 later, using the voltages measured across R1 to Ground and R2 to R4.

If we take a look at the results from table 1(Part 1Row) and table 2 (Circuit Row). We could say that the results are almost identical, and that would be expected. The results in table 1 are all ideal, but the results in table 2 are actual results which will vary due to wear and tear of components; like the resistors and the NI ELVIS workstation.

The column highlighted in red contains the calculated values of the unknown resistor R4. The formula we used to calculate these values is: $\mathbf{R4} = \frac{\left(\frac{Vg*R3}{Vs}\right)+\left(\frac{R2*R3}{R1+R2}\right)}{1-\left(\frac{Vg}{Vs}\right)-\left(\frac{R2}{R1+R2}\right)}$. Where **Vg** is the voltage across R2 to R4, **Vs** supply voltage/voltage across R1 to Ground, and known resistance values of R1, R2, and R3. The equation to find R4 was transposed from the following equation used to find the voltage across the Wheatstone Bridge:

$$Vg = \left(\frac{R4}{R3+R4} - \frac{R2}{R1+R2}\right) * Vs$$

- Example of this formula in action: $R4 = \frac{\left(\frac{Vg*R3}{Vs}\right)+\left(\frac{R2*R3}{R1+R2}\right)}{1-\left(\frac{Vg}{Vs}\right)-\left(\frac{R2}{R1+R2}\right)}$ ➔

$$\frac{\left(\frac{4.53*10^{-3}V\times 985.7\Omega}{4.9179V}\right)+\left(\frac{982.5\Omega\times 985.7\Omega}{990.6\Omega+982.5\Omega}\right)}{1-\left(\frac{4.53*10^{-3}}{4.917V}\right)-\left(\frac{982.5\Omega}{990.6\Omega+982.5\Omega}\right)} ➔ \frac{0.90795\Omega+490.8267\Omega}{1-(9.2112*10^{-4})-0.49795} ➔ \frac{491.73465}{0.50113} = \mathbf{981.25\Omega}$$

When obtain different voltage measurements once we changed the value of resistor R4 from 981.9Ω to the resistance of our left arm. One change we observed was the voltage across R4/the left arm. The voltage across R4 now an arm, changed from 2.4537 V to 4.9014V, 4.9014V which is almost equal the supply voltage of 4.9196V, because the resistance of the arm is so large it acts as an open in the branch causing all the voltage to drop across the resistor R4.

The second change we could observe in table 2 was the voltage across R2 to R4. The voltage changed from 4.53mV to 2.4527V. This change was due to the fact that the voltages across R2 and R4 respectively, are no longer close in magnitude. However, the sign are still different. The voltage across R2 is still half the supply voltage (approximately 2.4598V) since none of the resistors in that branch was changed, but the voltage across R4 (now an arm with very high resistance almost an open circuit) has a voltage drop of 4.9014V. The sum of these two voltages will give us the voltage across R2 to R4: $\mathbf{V_{R2\text{-}R4} = (-V_{R2}) + V_{R4}}$➔ (-2.4598V) + 4.9014V = **2.4416V.**

Figure 3

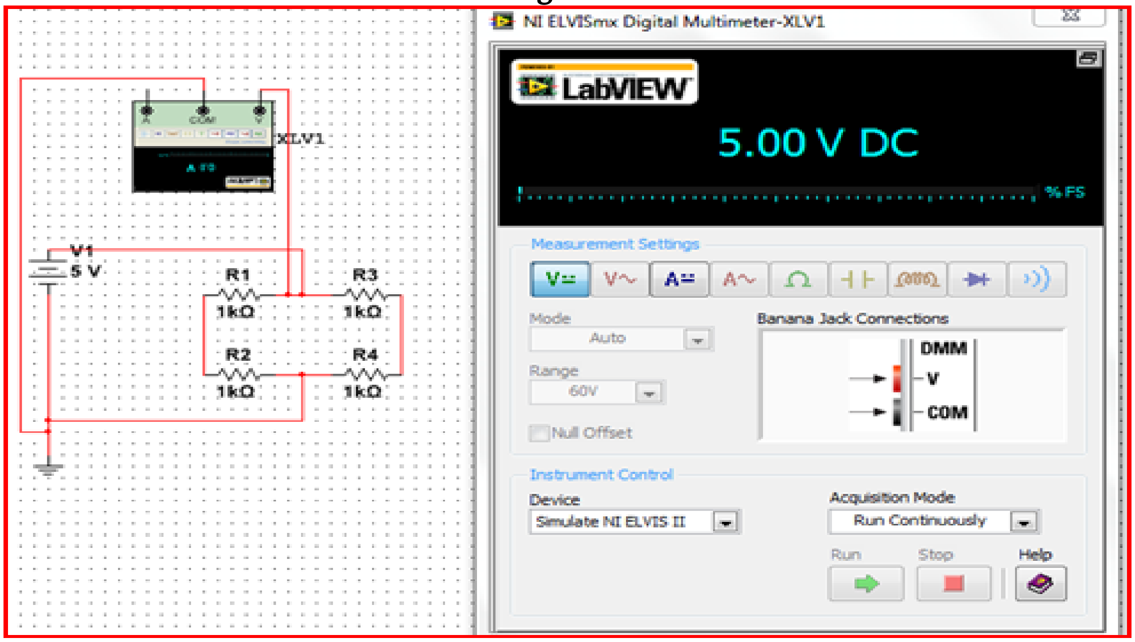
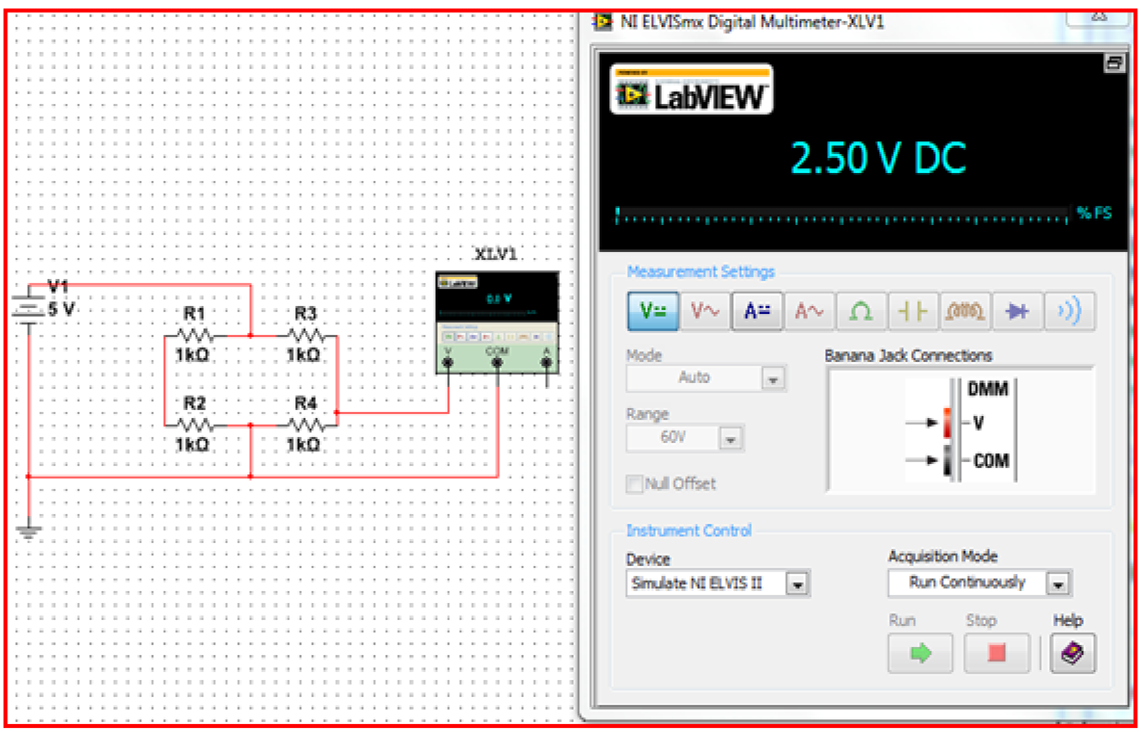


Figure 3 above is the Multisim result of the Wheatstone Bridge circuit in Figure 1; it shows the voltage across **R1 to Ground**.

Figure 4



Figures 4 above is the Multisim result of the Wheatstone Bridge circuit in Figure 1; it shows the voltage across **R4 to Ground**

Figure 5

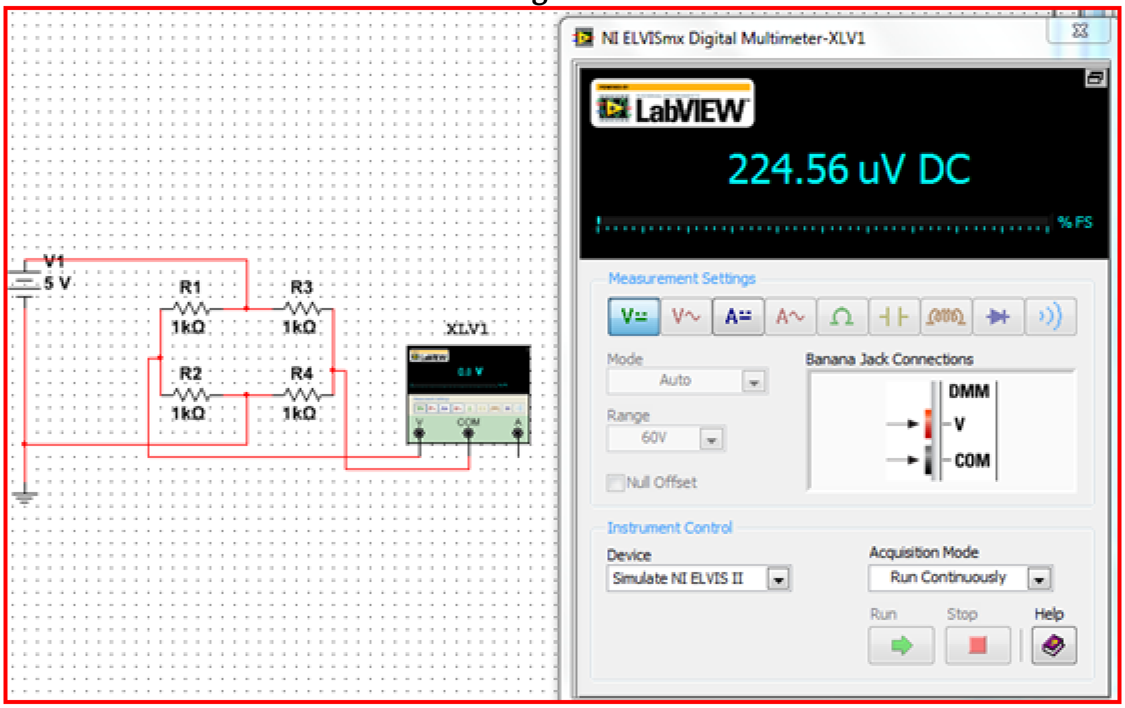


Figure 5 above is the Multisim result of the Wheatstone Bridge circuit in Figure 1; it shows the voltage across **R2 to R4**

Figure 6

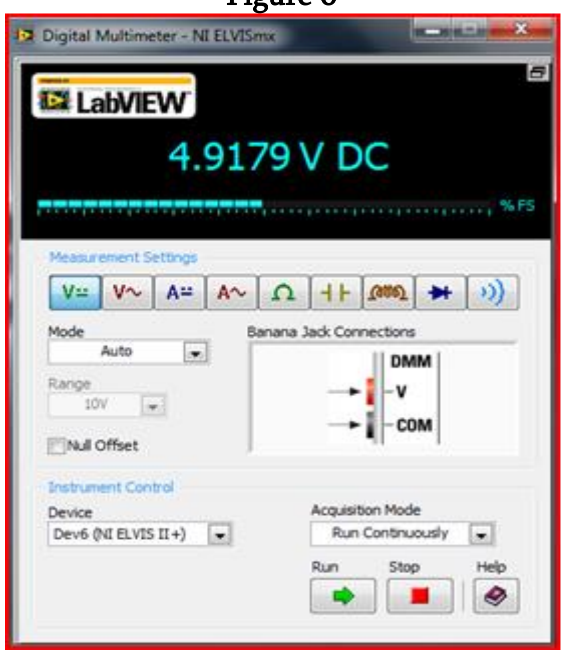


Figure 6 above is the actual/real world results of the Wheatstone Bridge circuit in Figure 1; it shows the voltage across: **R1 to Ground**

Figure 7

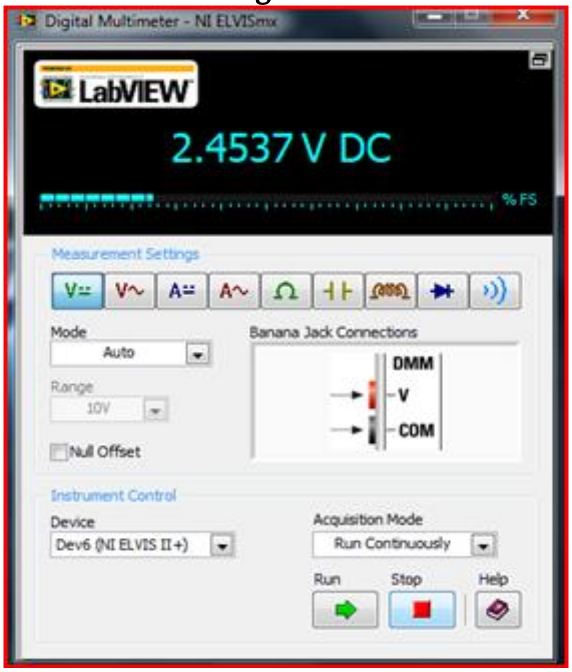


Figure 7 above is the actual/real world results of the Wheatstone Bridge circuit in Figure 1; it shows the voltage across: **R4 to Ground.**

Figure 8

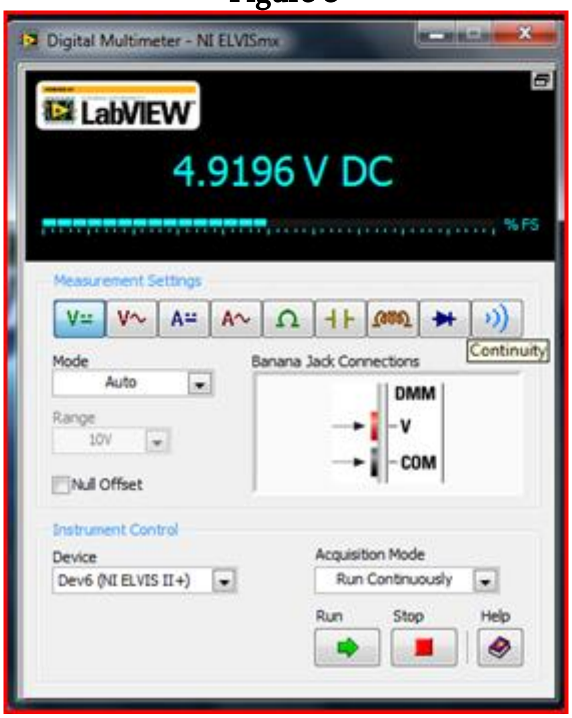


Figure 8 is the Actual Result of the Wheatstone Bridge circuit in Figure 1(with resistance of R4 replaced by the resistance of a left arm); it shows the voltage across: **R1 to Ground**

Figure 9

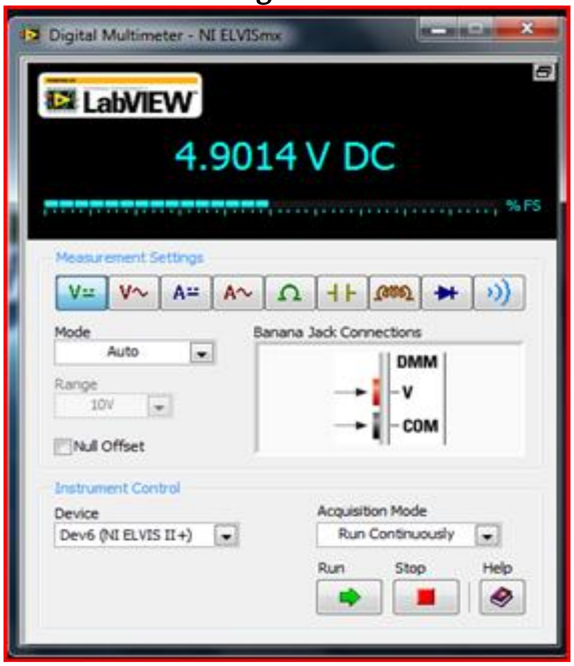


Figure 9 is the Actual Result of the Wheatstone Bridge circuit in Figure 1(with resistance of R4 replaced by the resistance of a left arm); it shows the voltage across: **R4/arm to Ground**

Figure 10

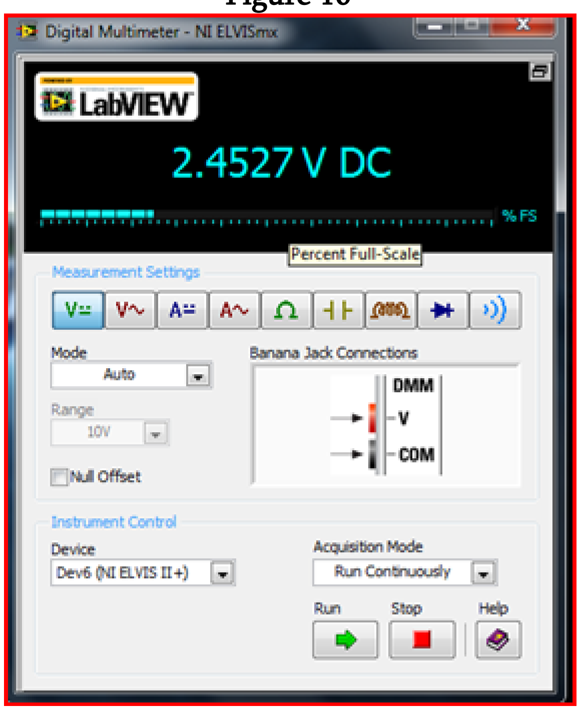


Figure 10 is the Actual Result of the Wheatstone Bridge circuit in Figure 1(with resistance of R4 replaced by the resistance of a left arm); it shows the voltage across: **R2 to R4/arm**

Figure 11

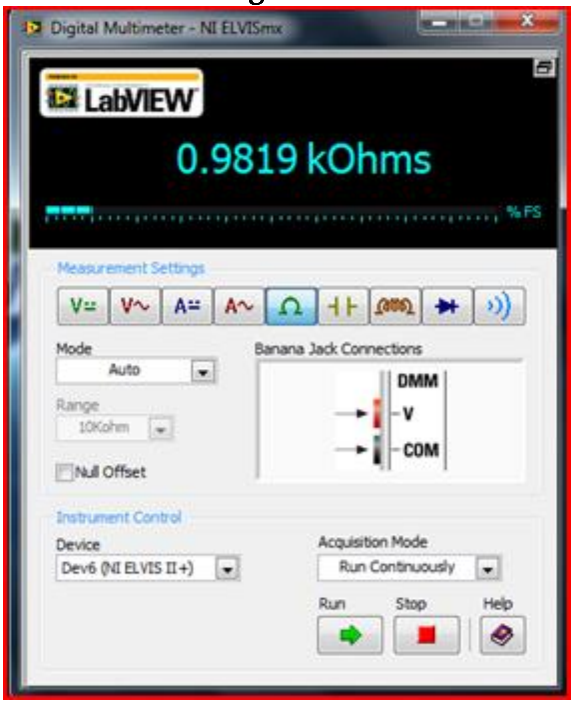


Figure 11 shows the actual resistance (measured by the DMM) of resistor R4.

Figure 12

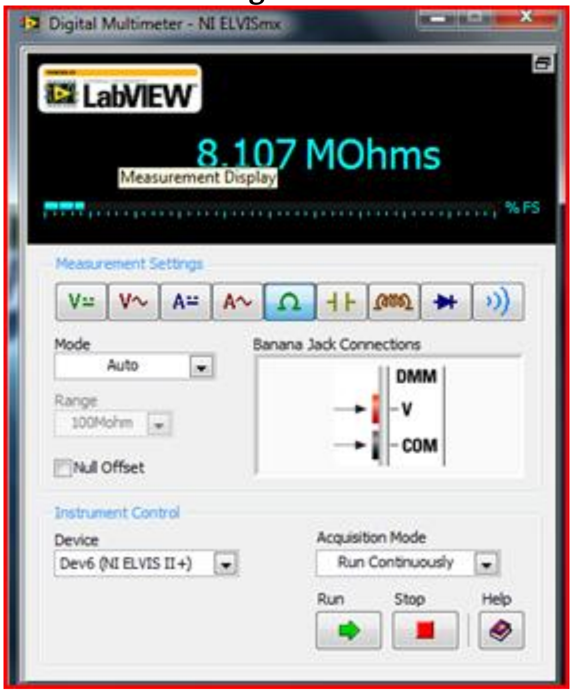


Figure 12 shows the actual resistance (measured by the DMM) of the left arm that replaced R4.

CONCLUSION

After completing this experiment I can see why the Wheatstone Bridge is used as a transducer with certain sensors. It is definitely better (for some applications) than a voltage divider.

We could not perform Part 2 of this experiment because we could not find the Multisim file WheatstoneBridgeExample. The steps of part 2 suggest that there should have been be a circuit already built, by the software developers. Which students would have to analyze. We asked the technician but she as well failed to find it. Multisim automatically opens with a blank schematic window, so, step 2 ➔ Part 1 could be removed.

REFERENCES

EET 3120 Sensors and Instrument Laboratory Manual, Developed and Edited by Professor Viviana Vladutescu, Spring 2015