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**Wheatstone Bridge Derivation Activity**

**Instructor Guide**

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|  | Notes to Instructor |
|  | The Wheatstone bridge derivation activity is an activity in the Micro Pressure Sensors & Wheatstone Bridge Learning Module. This activity should be assigned after the Wheatstone Bridge Overview PK. Below are the units in the Micro Pressure Sensor & The Wheatstone Bridge Learning Module:   * Knowledge Probe (KP) pretest * Wheatstone Bridge Overview PK * Modeling a Micro Pressure Sensor Activity * **Wheatstone Bridge Derivation Activity** * Wheatstone Bridge Final Assessment |
|  | Description and Estimated Time to Complete |
|  | This activity will involve using your knowledge of the Wheatstone bridge to derive the relationship between Vin (Input Voltage) and Vg  (Gauge Voltage) for a given circuit. You will also design a Wheatstone bridge layout to get the maximum effect on the gauge voltage, Vg .  It is recommended that you review the unit Wheatstone Bridge Overview if you haven't already. It will enhance your understanding of the Wheatstone bridge circuitry as you complete this activity.    Estimated Time to Complete  Allow approximately two hours to complete this activity. |

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|  | Introduction | |
|  | The Wheatstone bridge is one of the most sensitive and precise methods of measuring small changes in resistance. This is possible through its use of transducers (devices which change one form of energy into another, such as mechanical to electrical or electrical to mechanical). The Wheatstone bridge incorporates one or more electrical transducers that change resistance as a result of an environmental change or input (e.g. temperature, pressure, stress). This change is sensed by the circuitry of the Wheatstone bridge which provides a useable electrical output (voltage) representative of the input. The Wheatstone bridge is widely used today in macro-sized and micro-sized sensors.  *ac1-wb1*  *Basic Wheatstone Bridge Configuration* | |
|  | Activity Objectives | |
|  | Objectives   * Derive the mathematical relationship between output voltage (Vg, also referred to as gauge voltage) and resistance in a Wheatstone bridge circuit. * Design the orientation of the resistors on a pressure sensor membrane to maximize the effect on the gauge voltage. |

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|  | Procedure I: Derivation Activity |
|  | 1. Using basic laws of electronics (e.g. Ohm's and Kirchhoff's), derive the mathematical relationship between input voltage, Vin, vs. gauge voltage, Vg  in terms of input voltage, Vin and resistance for the circuit given below.   Vg=Vin {f(R1,R2,R3,R4)}  Hint: **Starting point would be Vg = VD – VB.**  ac1-wb1   1. Using your results from 1), above, show that the Wheatstone bridge is balanced when R3/R4 = R1/R2.    1. What values of R1, R2, R3, and R4 would yield a balanced bridge circuit?    2. Verify your mathematical derivation using these values of resistors.    3. Did your derivation yield a Vg = 0 V? If not, then find and correct the problem and repeat 2b. 2. Given a Wheatstone bridge with the following Vin and R values, what is Vg? \_\_\_\_\_\_\_\_    * Vin = 10 volts    * R1 = 75 Ω    * R2 = 100 Ω    * R3 = 100 Ω    * R4 = 75 Ω 3. If R2 and R3 are both variable resistors (transducer elements) and continue to increase above 100 Ω, what effect would it have on Vg? |

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|  | *Answers to Procedure I Questions*: |
|  | 1. Using basic laws of electronics (e.g. Ohm's and Kirchhoff's), derive the mathematical relationship between input voltage, Vin, vs. gauge voltage, Vg  in terms of input voltage, Vin and resistance for the circuit given below.   Vg=Vin {f(R1,R2,R3,R4)}  Hint: **Starting point would be Vg = VD – VB.**  ac1-wb1 |

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|  | 1. Using your results from 1), above, show that the Wheatstone bridge is balanced when R3/R4 = R1/R2.    1. What values of R1, R2, R3, and R4 would yield a balanced bridge circuit?   *Answer: Answers will vary, but the ratios should be correct. For example, a correct answer would be R*1 *= 50 Ω, R*2 *= 100 Ω, R3= 5 Ω, R4 = 10 Ω.*   * 1. Verify your mathematical derivation using these values of resistors.   2. Did your derivation yield a Vg = 0 V? If not, then find and correct the problem and repeat 2b. *Participants should be able to use this step to verify that their derivation, as well as their calculations are correct.*  1. Given a Wheatstone bridge with the following Vin and R values, what is Vg? \_-1.43 volts    * Vin = 10 volts    * R1 = 75 Ω    * R2 = 100 Ω    * R3 = 100 Ω    * R4 = 75 Ω 2. If R2 and R3 are both variable resistors (transducer elements) and continue to increase above 100 Ω, what effect would it have on Vg?   ***Answer: Vg would become more negative*** |

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|  | Procedure II: Design a Wheatstone Bridge for a Micro Pressure Sensor |
|  | In the case of a pressure sensor, all resistances are designed with the same geometries, therefore, all the resistors have the same resistance values and the circuit is initially balanced and Vg (gauge voltage) is zero.  Variable resisters in the bridge change due to stress on the resistor's material. This is due to the fact that resistance is a function of the resistor's material (resistivity or *ρ*), length (*L*) and cross sectional area (*A*):  *R= ρ (L/A)*  When metal is stressed, it stretches (for instance, a gold resistor on a pressure sensor membrane). The length, *L,* increases, which results in an increase in resistance, *R.* The cross-sectional area, *A,* decreases; however, *ρ* does not change as it is a property of the material.  In a micro pressure sensor, the Wheatstone bridge can be fabricated so that two of the four resistors are effectively stressed when the membrane is stretched. The stress on the other two resistors is ineffective or negligible. Such fabrication will result in a response from the Wheatstone bridge that is sensitive to small changes in pressure. All four resistors on fabricated on the membrane. Why? Because there is also a temperature dependence of resistance and you want all of the resistors exposed to the exact same temperature environment. All four resistors should be of the same length, width and thickness so they are balanced under no stress. Most pressure sensor systems have an offset circuit to make up for slight variations in the fabrication process.  Questions   1. For maximum effect on the gauge voltage, Vg, which two resistors in the schematic (left) could be variable and which two resistors could be fixed? 2. Using the image to on the right, how would you orient the resistors (narrow gray lines) on a membrane (green in the right image)?    1. On the schematic, indicate the variable resistors with an arrow.    2. ac1-wb1On the pressure sensor diagram, label the four resistors on the diaphragm and the electrical nodes (A, B, C, and D), indicating Vin and Vg connections.   diaphragm |
|  | *Answers to Procedure II Questions*: |
|  | 1. For maximum effect on the gauge voltage, Vg, which two resistors in the schematic (left) could be variable and which two resistors could be fixed?   ***Answer: There are two possible combinations:***   * 1. ***Variable resistors - R2 and R3, fixed resistors – R1 and R4.***   2. ***Variable resistors – R1 and R4, fixed resistors – R2 and R3.***  1. Using the image to on the right, how would you orient the resistors (narrow gray lines) on a membrane (green in the right image)?    1. On the schematic, indicate the variable resistors with an arrow.    2. On the pressure sensor diagram, label the four resistors on the diaphragm and the electrical nodes (A, B, C, and D), indicating Vin and Vg connections.   ***Answer:***  ***In the event that the membrane is stressed, you want to orient two diagonally opposing resistors to experience a minimum stress and the other two opposing resistors to be oriented for maximum stress.***   1. ***Variable resistors - R2 and R3, fixed resistors – R1 and R4.***   ***diaphragm-ans_a***  ***b. Variable resistors – R1 and R4, fixed resistors – R2 and R3.***  *diaphragm-ans_b* |
|  | **Post-Activity Questions**  Here is an example of a pressure sensor Wheatstone bridge in a circular configuration. This is the circuit you will build if you complete the "Pressure Sensor Model” Activity. This bridge is created by stretching a balloon membrane across an open can and applying a graphite circuit to the membrane. Note, resistors R2 and R3 are configured parallel to the edge of the can, and hence, will not stretch as the membrane expands. R1 and R4 resistors are configured over the open part of the membrane or can, parallel to the radius, and will be subject to the highest tension (stretching) and experiencing the greatest piezoresistive effect.  Wheatstone_two_sensor   1. Based on the schematic given above, write the equation for Vab in terms of resistance and Vin. 2. Sketch a graph that shows the relationship between Vab and Variable Resistance (Rv). 3. How would the graph change if R2 and R3 were variable and R1 and R4 were fixed? (Justify your answer with formulas and/or a graph.) |

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|  | *Answers to Post-Activity Questions*: |
|  | 1. Based on the schematic given above, write the equation for Vab in terms of resistance and Vin.            1. Sketch a graph that shows the relationship between Vab and Variable Resistance (Rv).   graph-answer_2 |
|  | 1. How would the graph change if R2 and R3 were variable and R1 and R4 were fixed? (Justify your answer with formulas and/or a graph.)     ***Since R2 is now variable and R4 fixed, R2 will increase; therefore Vab will increase in the positive direction. The graph in question 2 should now show Vab increasing positively as variable resistance increases.*** |
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