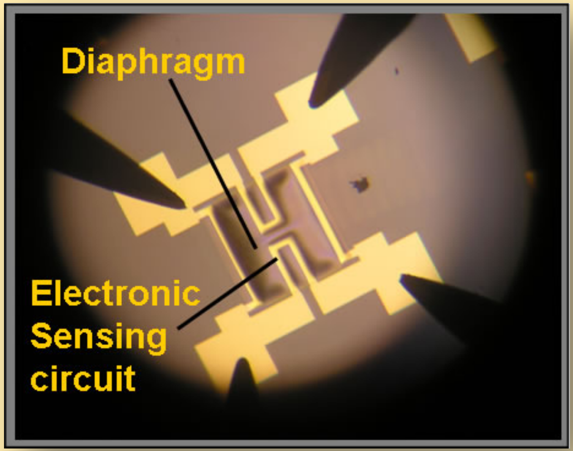
WHEATSTONE BRIDGE OVERVIEW



Unit Overview

This Wheatstone Bridge Overview provides information on the electronic circuitry of a Wheatstone bridge.

This overview will help you to understand how a Wheatstone bridge is used for sensing changes in pressure when used in a micro pressure sensor.

Objectives

- Define the variable components of the Wheatstone bridge
- Describe how the Wheatstone bridge works

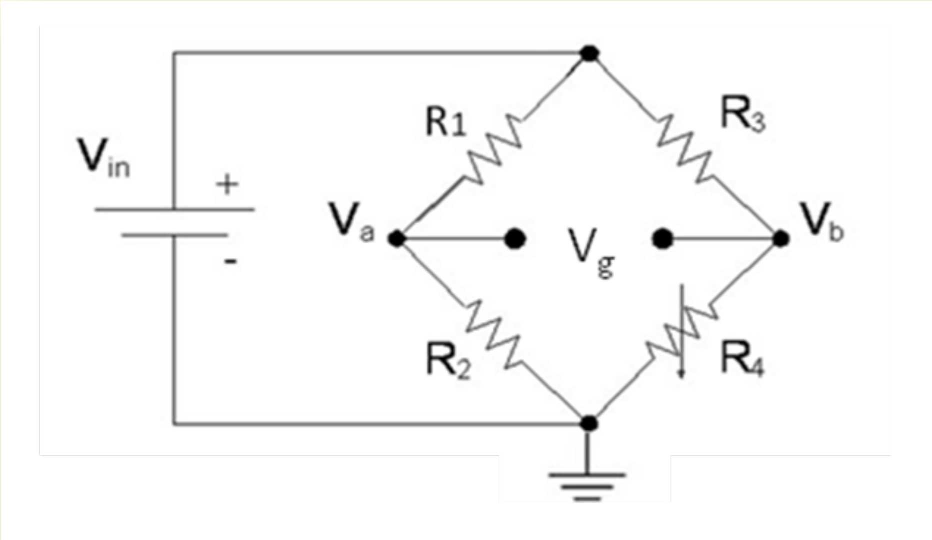
Introduction to Wheatstone Bridge

- An electrical circuit design dating back to early 1800's
- Named for its most famous user, Sir Charles Wheatstone who
  - never claimed to have invented it, but did develop multiple uses for it
  - called the circuit a “Differential Resistance Measurer”
- Invented by Samuel Hunter Christie (1784-1865)
- One of the most sensitive and precise methods of measuring small changes in resistance through its use of transducers.
- Widely used today in macro and micro-sized sensors

Sir Charles Wheatstone
National Portrait Gallery, London

The Wheatstone Bridge

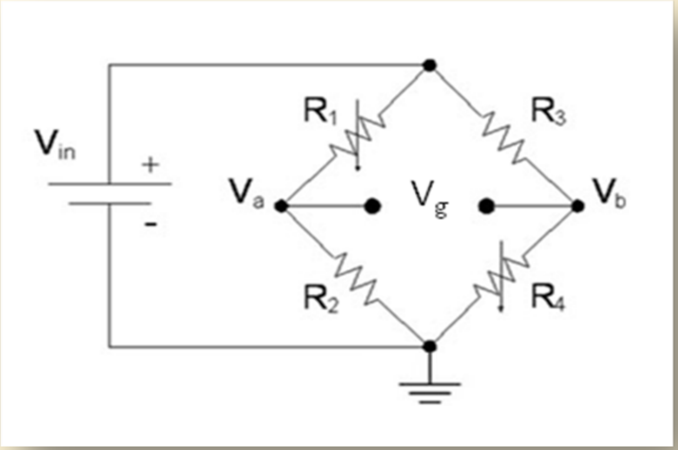
- A simple circuit used to measure small changes in resistance of a transducer.
- Classic configuration consists of four resistors
  - Three fixed value and one variable value
  - Variable resistor is the sensing element (transducer) (See R_4 in diagram below)
  - Resistance of the variable resistor changes due to a change in an environmental factor such as stress, pressure, or temperature



Basic Wheatstone bridge Configuration with one transducer or sensing element (R_4)

The Wheatstone Bridge – 2 Variable Resistors

- Maximized effect of the input
- Provides the largest voltage variation as a function of the changing input
- Has 2 fixed resistors & 2 variable resistors (transducers/sensing elements)
- DC voltage source (V_{in}) such as a battery or power supply
- Output voltage (V_g) represents the difference in the transducers' resistance values to the reference resistance of the bridge configuration
- Design allows for the measurement of very small changes in the environmental factor that affects the transducers while greatly suppressing electrical noise and thus improving the "signal to noise ratio"



Basic Wheatstone Bridge Configuration with two transducers or sensing elements (R_1 and R_4)

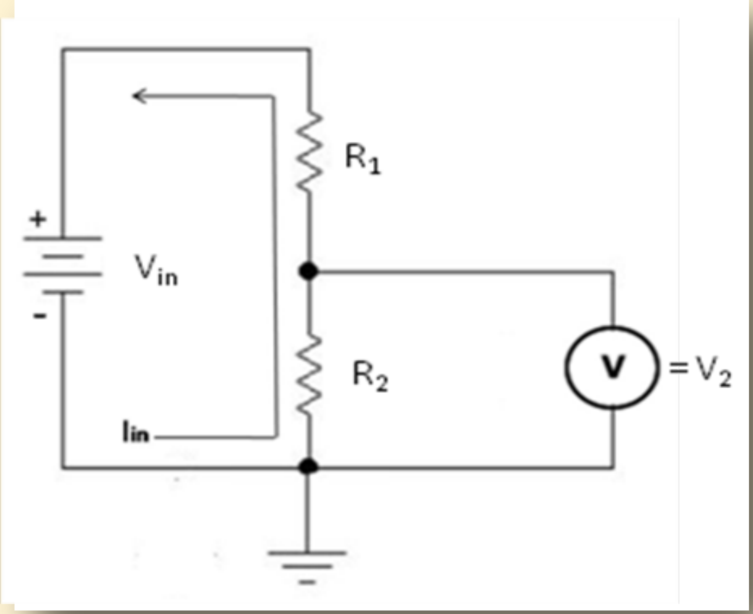
Background Circuits

- There are three concepts discussed here which are needed to understand Wheatstone bridges:
  - Resistor voltage dividers
  - Ohm's Law (I=V/R)
  - Kirchoff's Circuit Laws

Resistor Voltage Dividers

- Diagram below is made up of two resistors labeled R_1, R_2, and a power supply V_{in} (battery).
- Electron flow or current I_{in} (measured in Amperes (A)) travels from the negative terminal of the battery through the resistors to the positive terminal of the battery.

Resistive Voltage Divider



Ohm's Law

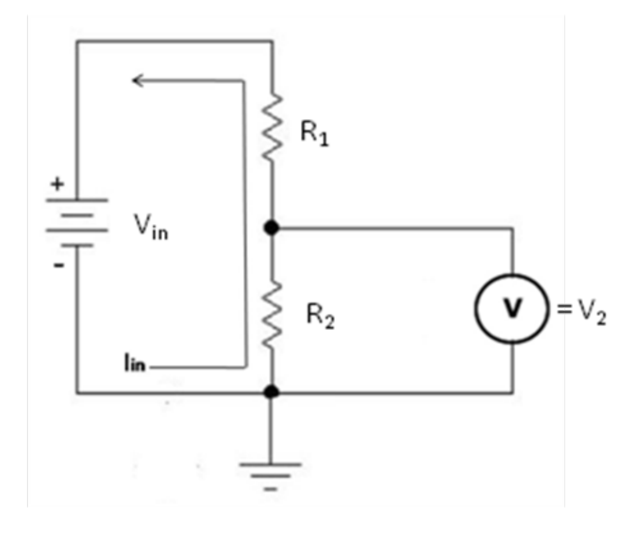
- Ohm's Law determines the voltage drop across a resistor if the resistance *R* and current *I* are both known.
- Ohm's Law states: $V = IR$
  - where *V* is the voltage across a resistor *R* that has current *I* flowing through it
- In the Resistive Voltage Divider circuit to the right, the voltage drop, V_1 across resistor R_1 is

$$V_1 = I_{in}R_1$$

- The voltage drop, V_2 across resistor R_2 is

$$V_2 = I_{in}R_2.$$

  - A voltmeter measures across R_2 with one lead at ground and the other connected between R_1 and R_2



Resistive Voltage Divider

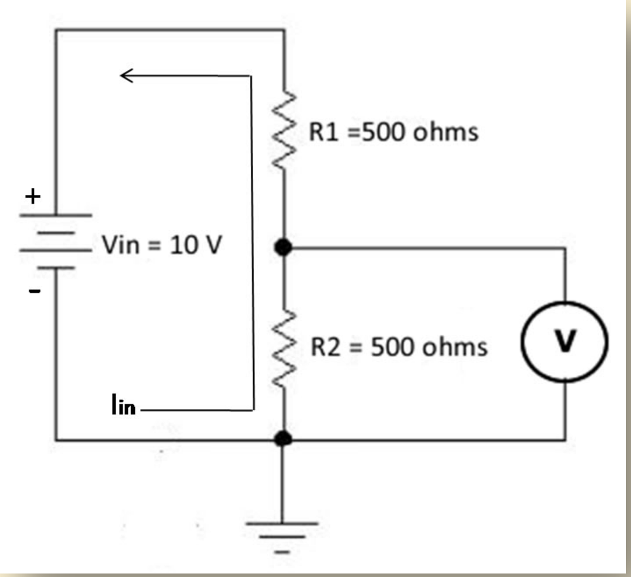
Ohm's Law cont…

Let's put some numbers to this Voltage divider circuit and check out our calculations.

Using Ohm's Law, calculate I_{in},V_1 and V_2

$$I_{in} = \frac{V_{in}}{R_t}$$

I_{in} is the current which flows through the circuit
V_{in} is the voltage applied to the circuit
R_t is the total resistance that the current flows through



Now try it!

Ohm's Law cont…

Let's see how you did:

The total circuit resistance R_t = $R_1 + R_2$

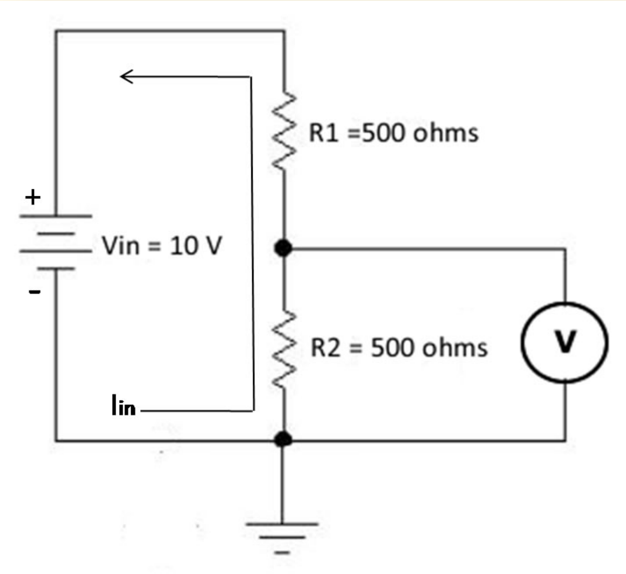
$$I_{in} = \frac{V_{in}}{R_t} = \frac{10volts}{R_1 + R_2} = \frac{10volts}{500\Omega + 500\Omega} = \frac{10volts}{1000\Omega} = \frac{10volts}{1k\Omega} = 10mA$$

The voltage drop, V_1 across resistor R_1 is

$V_1 = I_{in}R_1$ or $10mA*500\ \Omega = 0.01A*500\ \Omega = 5V$

The voltage drop, V_2 across resistor R_2 is

$V_2 = I_{in}R_2$ or $10mA*500\ \Omega = 0.01A*500\ \Omega = 5V$



Kirchoff's Law

Kirchhoff's voltage law, states that the sum of the voltage drops across a collection of resistors arranged in series within a circuit is equal to the applied voltage (V_{in}).

$$V_{in} = I_{in}R_1 + I_{in}R_2 = I_{in}\left(R_1 + R_2\right)$$

or

$$V_{in} = V_1 + V_2$$

Notice that the previous problem shows this to be true:

10 v (V_{in}) = 5 v + 5v

Kirchoff's Law cont…

The voltage drop across a specific resistor in series with other resistors is the fraction of that resistor to the sum of the series resistors, multiplied by the applied voltage.

The formula is derived on the right.

$$I_{in} = \frac{V_{in}}{R_1 + R_2}$$

$$V_2 = I_{in} R_2 = \frac{V_{in}}{R_1 + R_2} R_2$$

$$V_2 = \frac{R_2}{R_1 + R_2} V_{in}$$

Applying the values of the previous circuit, we get:

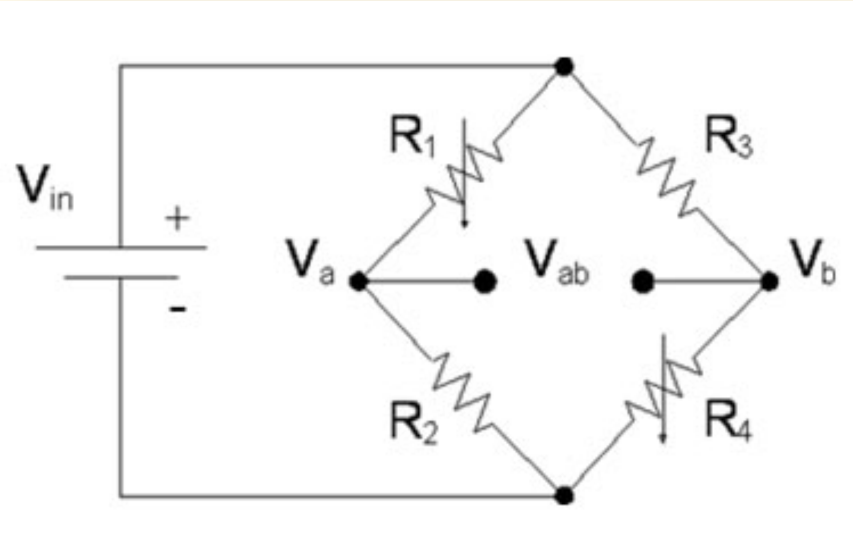
$$V_2 = \frac{500\Omega}{500\Omega + 500\Omega} 10V = 5V$$

Kirchoff's Law cont…

Wheatstone bridge has two such voltage dividers connected in parallel

Analysis of the *resistive voltage divider* circuit can be applied to the Wheatstone bridge circuit.

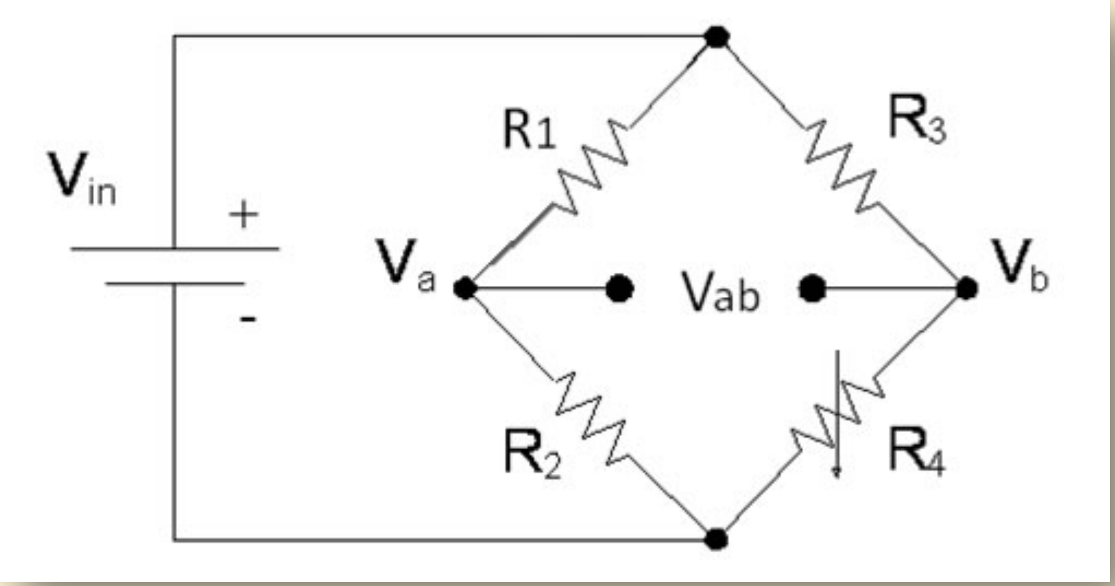
Identify the two voltage divider circuits in the circuit below,



Wheatstone bridge with 2 variable resistors

Wheatstone Bridge and Difference Voltage

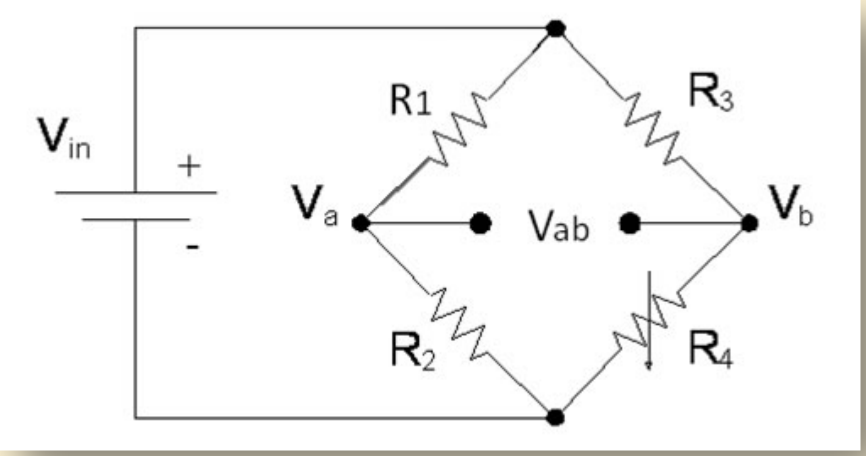
This figure shows the schematic circuit diagram of a Wheatstone bridge. The resistor pair R_1 and R_2 is a *resistive voltage divider* and resistors R_3 and R_4 form another voltage divider in parallel with R_1 and R_2.



Wheatstone bridge with one variable resistor

Wheatstone Bridge and Difference Voltage cont…

The circuit is sensitive to the difference in voltage between node-**a** and node-**b**. V_a *and* V_b can be explained by:



Wheatstone bridge with one variable resistor

$$V_a = \frac{R_2}{R_1 + R_2} V_{in}$$

$$V_b = \frac{R_4}{R_3 + R_4} V_{in}$$

$$V_a - V_b = V_{ab} = \left(\frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) V_{in}$$

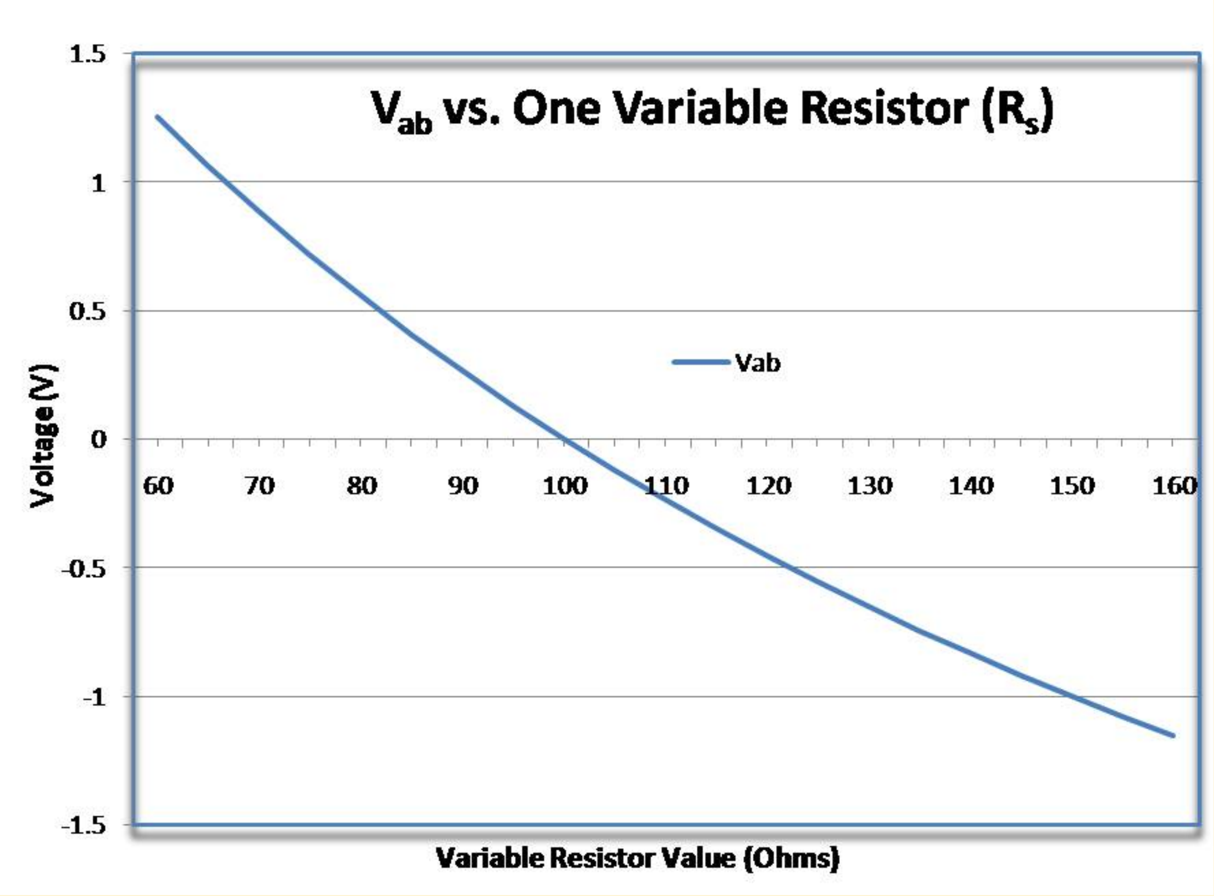
Wheatstone Bridge and Difference Voltage cont…

- Bridge is balanced when V_{ab} = 0 volts
- This occurs when $R_1/R_2 = R_3/R_4$
- In a typical sensing device, a variable resistor R_4 (R_S) is used
- Other three resistors are fixed
- Wheatstone bridge is initially balanced with all of the R's having the same resistance value by design, including R_S (the resistance of the sensing element).
- Value of R_S changes when the external environment changes thus affecting V_{ab} as

$$V_{ab} = \left(\frac{R_2}{R_1 + R_2} - \frac{R_S}{R_3 + R_S} \right) V_{in}$$

One Variable Resistor

Assuming the transducer resistance R_S is initially 100 Ω, and $R_1 = R_2 = R_3 = 100$ Ω, then V_{ab} can be plotted versus R_S.



Bridge is balanced when
R_S = 100 Ω
V_{ab}=0 volts

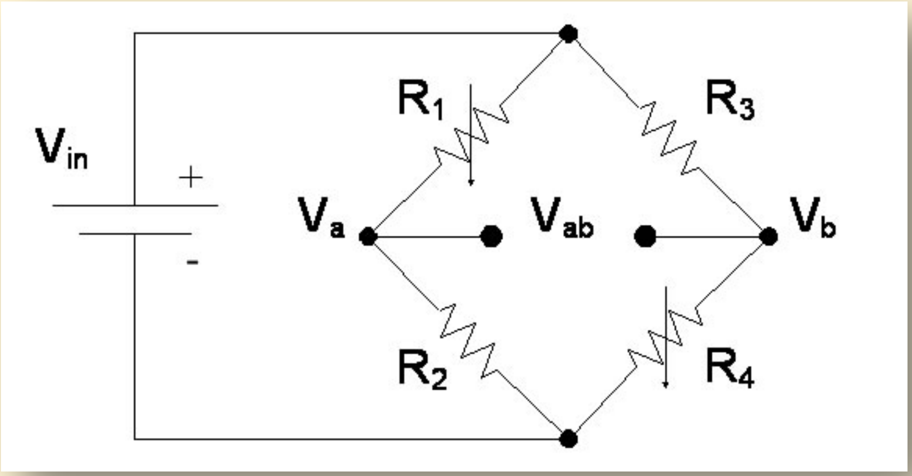
Changes in the environment affects resistance creating an unbalanced bridge

This results in a voltage proportional to resistance change

Two Variable Resistors

Adding another variable resistor results in a more sensitive circuit

Where R_1 and R_4 are both variable resistors

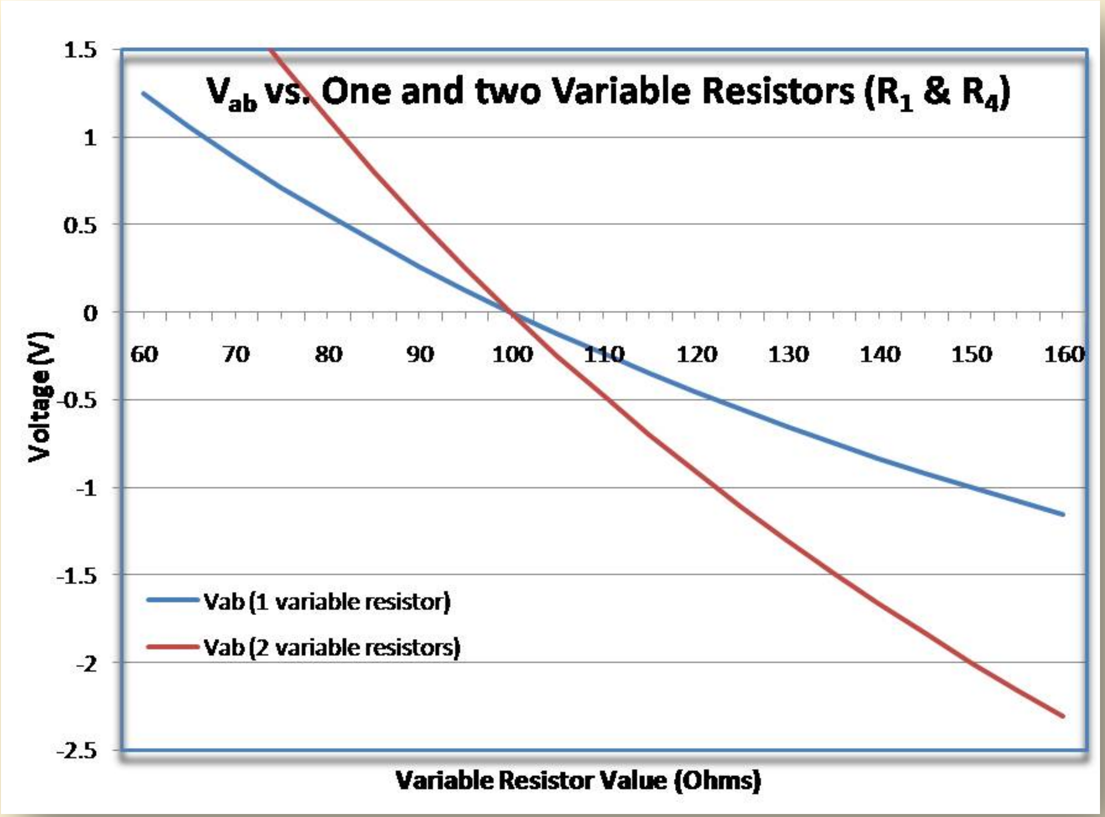


Wheatstone bridge with two variable resistors

If the R_1 and R_4 resistors are both variable and react in the same manner to an external environmental change, then the effect on the output voltage, V_{ab} is multiplied!

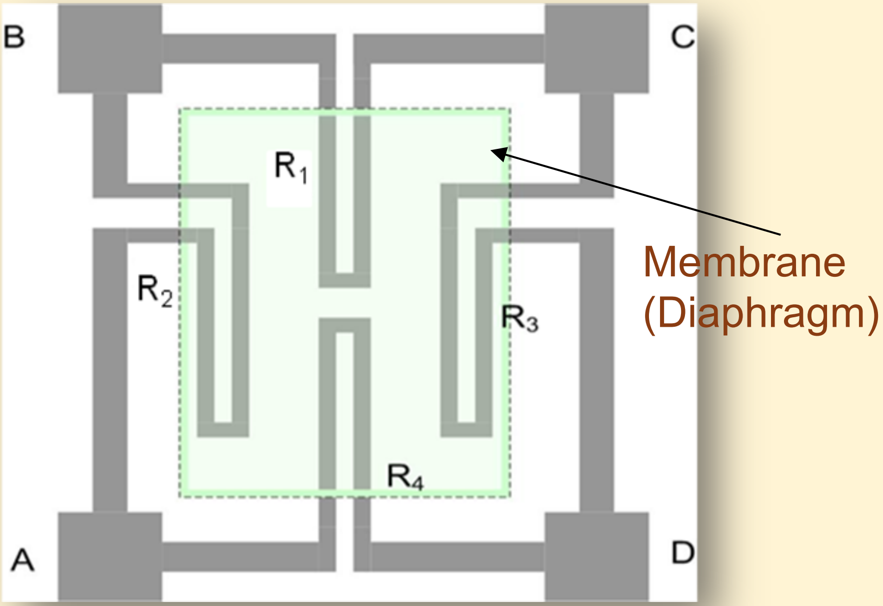
Two Variable Resistors

Graphing V_{ab} as a function of the variable resistances of R_1 and R_4 (in this case changing by the same amount while the other two, R_2 and R_3 remain constant at 100Ω) results in the following graph.

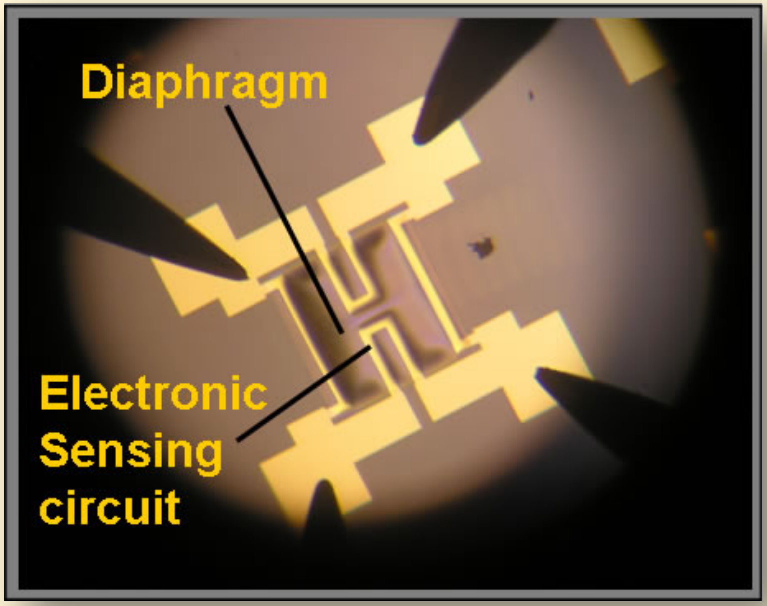


Wheatstone Bridge as a Micro Pressure Sensor

When the Wheatstone bridge is used in a micro pressure sensor, the resistors are oriented such that R_1 and R_4 are variable under the stress of a flexible membrane on which they are made.



Wheatstone bridge as a Pressure Sensor



Micro Pressure Sensor illustrating the Wheatstone bridge and the Silicon Nitride Membrane (Diaphragm)

Calibration

- To calibrate a Wheatstone bridge as a pressure transducer, a series of known pressure differences is applied to the sensing element(s).
- The output voltage (V_{ab}) is measured using a voltmeter
- V_{ab} versus pressure is plotted
- When an unknown pressure is applied and the output voltage read, the calibration curve of V_{ab} vs. *Pressure* can be used to determine the actual pressure.

Summary

- Wheatstone bridge is a simple circuit used to measure transducer responses by measuring changes in voltage.
- Basic circuit analysis is used to determine the resistance when the bridge is balanced.
- Any changes in transducer resistance cause the bridge to be unbalanced providing a voltage roughly proportional to the change in resistance and corresponding to the change in pressure.
- A voltmeter measures the output of the Wheatstone bridge which can be equated to a corresponding pressure.
- In a micro pressure sensor where the Wheatstone bridge is the sensing circuit, its output can be amplified and processed to send information or to initiate a mechanical response.

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