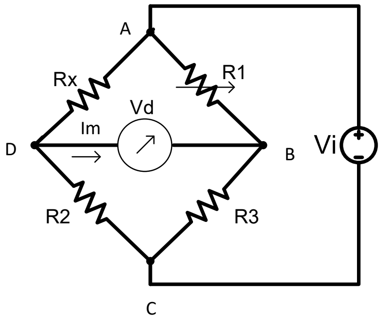
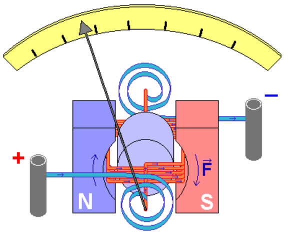


ENEE4304 Instrumentation and Measurements

L9
Variable conversion elements



Outline

- Variable Conversion Elements
- Bridge circuits:
  - ➢DC Bridges
  - ➢AC Bridges
- Other circuits

Need for Variable Conversion

- For sensor outputs that are initially in some non-voltage form, conversion to a measurement signal that is in a more convenient form can be achieved by various types of variable conversion element in the measurement system.
- Bridge circuits are a particularly important type of variable conversion element, and these will be covered in some detail.
- Following this, the various alternative techniques for transducing the outputs of a measurement sensor will be covered.

Need for Variable Conversion

- Outputs from measurement sensors that take the form of voltage signals can be measured using the voltage indicating and test instruments
- However, in many cases, the sensor output does not take the form of an electrical voltage.
- Examples of these other forms of sensor output include translational displacements and changes in various electrical parameters such as resistance, inductance, capacitance and current.
- In some cases, the output may alternatively take the form of variations in the phase or frequency of an a.c. signal.

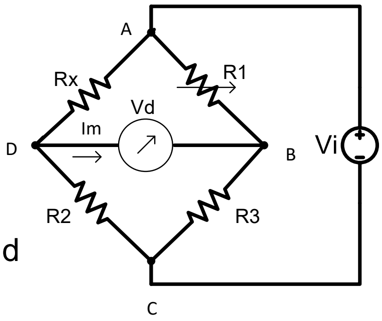
Bridge Circuits

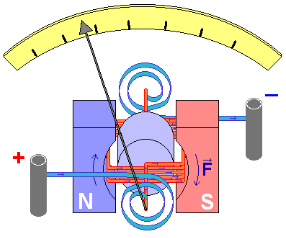
- Bridge circuits are used very commonly as a variable conversion element in measurement systems and produce an output in the form of a voltage level that changes as the measured physical quantity changes.
- They provide an accurate method of measuring resistance, inductance and capacitance values, and enable the detection of very small changes in these quantities about a nominal value.
- They are of immense importance in measurement system technology because so many transducers measuring physical quantities have an output that is expressed as a change in resistance, inductance or capacitance

- The displacement-measuring strain gauge, which has a varying resistance output, is but one example of this class of transducers.
- Normally, excitation of the bridge is by a d.c. voltage for resistance measurement and by an a.c. voltage for inductance or capacitance measurement.
- Both null and deflection types of bridge exist, and, in a like manner to instruments in general, null types are mainly employed for calibration purposes and deflection types are used within closed-loop automatic control schemes.

Null-type, d.c. bridge (Wheatstone bridge)

- A null-type bridge with d.c. excitation, commonly known as a Wheatstone bridge, has the form shown below.
- The four arms of the bridge consist of the unknown resistance Rx, two equal value resistors R2 and R3 and a variable resistor R1 (usually a decade resistance box).
- A d.c. voltage Vi is applied across the points AC and the resistance R1 is varied until the voltage measured across points BD is zero.
- This null point is usually measured with a high sensitivity galvanometer.



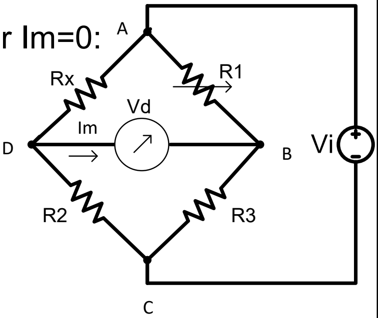


Null-type, d.c. bridge (Wheatstone bridge)

- Normally, if a high impedance voltage-measuring instrument is used, the current Im drawn by the measuring instrument will be very small and can be approximated to zero.
- If this assumption is made, then, for Im=0:

$$V_d = \frac{R_2}{R_x + R_2} V_i - \frac{R_3}{R_1 + R_3} V_i$$

$$V_d = V_i \left(\frac{R_2}{R_x + R_2} - \frac{R_3}{R_1 + R_3} \right)$$

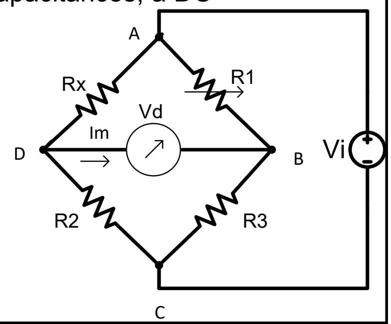


At balance:

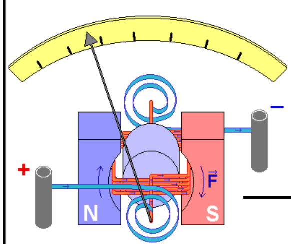
$$V_d = 0 \Rightarrow R_x = R_1 \frac{R_2}{R_3} \longrightarrow \text{Known, constant}$$

Null-type DC Wheatstone bridges are used for accurate resistance measurement

- The bridge is balanced when the voltage V_d is adjusted to **zero** by tuning R_1 while R_2 and R_3 are known and kept constant.
- The null-detector is usually some type of galvanometer
- The unknown resistance value can then be computed using the values of the other resistances
- Since there are no inductances (coils) or capacitances, a DC source is sufficient
- This type of bridge is used for **strain gage** measurements

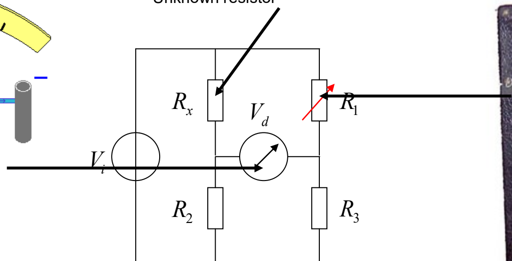


Measurement procedure using Galvanometer and decade resistor box



Galvanometer

Unknown resistor



Decade Box

$$V_d = \frac{R_2}{R_x + R_2}V_i - \frac{R_3}{R_1 + R_3}V_i$$

$$V_d = V_i\left(\frac{R_2}{R_x + R_2} - \frac{R_3}{R_1 + R_3}\right)$$

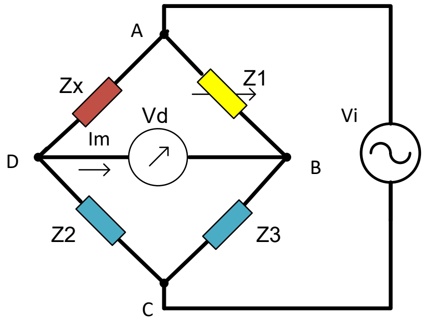
At balance:

$$V_d = 0 \Rightarrow R_x = R_1\left(\frac{R_2}{R_3}\right)$$

Known, constant

Null-type AC Wheatstone bridge for impedance measurement

- The bridge is balanced when the voltage V_d is adjusted to zero by tuning Z_1, Z_2 or Z_3



$$Z_x Z_3 = Z_1 Z_2$$

Equality of Magnitudes

$$|Z_x| = \left|\frac{Z_1}{Z_3}\right| |Z_2|$$

Equality of Phases

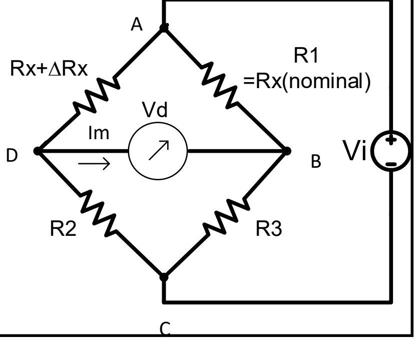
$$\varphi_x = \varphi_1 - \varphi_3 + \varphi_2$$

Deflection type DC Wheatstone bridge

- A deflection-type bridge with d.c. excitation is shown. This differs from the Wheatstone bridge mainly in that the variable resistance R1 is replaced by a fixed resistance of the same value as the nominal value of the unknown resistance Rx.
- As the resistance Rx changes, so the output voltage Vo=Vd varies, and this relationship between Vo and Rx must be calculated.
- This relationship is simplified if we again assume that a high impedance voltage measuring instrument is used.

$$V_d = \frac{R_2}{R_x + R_2} V_i - \frac{R_3}{R_1 + R_3} V_i$$

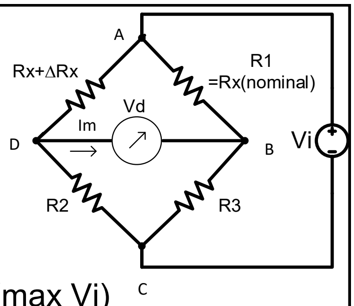
$$V_d = V_i \left(\frac{R_2}{R_x + R_2} - \frac{R_3}{R_1 + R_3} \right)$$



Example

- A certain type of pressure transducer, designed to measure pressures in the range 0–10 bar, consists of a diaphragm with a strain gauge cemented to it to detect diaphragm deflections.
- The strain gauge has a nominal resistance of 120 and forms one arm of a Wheatstone bridge circuit, with the other three arms each having a resistance of 120. The bridge output is measured by an instrument with infinite input impedance.
- If, in order to limit heating effects, the maximum permissible gauge current is 30 mA, calculate the maximum permissible bridge excitation voltage.
- If the sensitivity of the strain gauge is 338 mΩ / bar and the maximum bridge excitation voltage is used, calculate the bridge output voltage when measuring a pressure of 10 bar.

Example solution



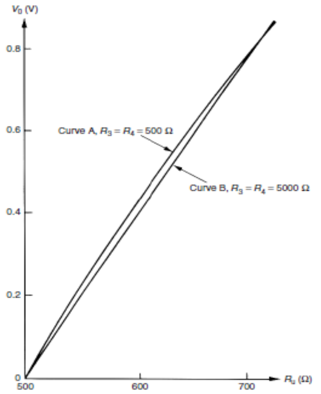
- R1 = R2 = R3 = 120 Ω
- I1= 30 mA
- Hence:
- Vi = 0.03*(120 +120)= 7.2 V <== (max Vi)
- For a pressure of 10 bar applied, ΔRx= 338 mΩ / bar *10 bar= 3.38 Ω, i.e. Rx=Rx(nom) + ΔRx=123.38 Ω
- $Vo = Vi\left(\frac{Rx}{Rx+R3} - \frac{R1}{R1+R2}\right)$
- $Vo = 7.2\left(\frac{123.38}{123.38+120} - \frac{120}{120+120}\right)$=50mV.
- This means that if ΔR is changed by 3.38 Ω, Vo is changed by 50 mV

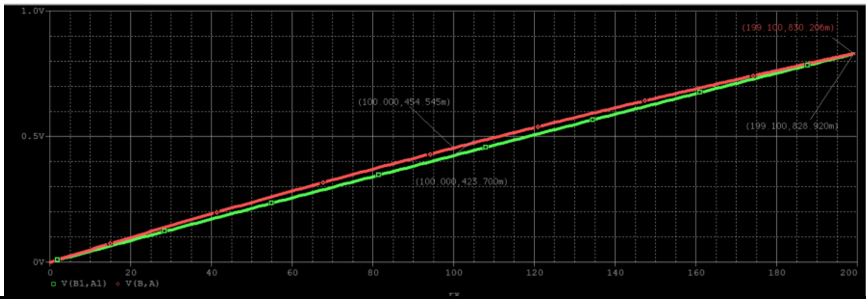
- We can calculate sensitivity of Vo with respect to ΔRx
- $\Delta V_o = V_o' - V_o = \frac{V_i . \Delta R_x}{R_x + \Delta R_x + R_3}$
- $\frac{\delta V_o}{\delta R_x} = \frac{V_i}{R_x + R_3}$ for $\delta R_x \ll R_x$
- This expression describes the measurement sensitivity of the bridge. Such an approximation to make the relationship linear is valid for transducers such as strain gauges where the typical changes of resistance with strain are very small compared with the nominal gauge resistance.
- However, many instruments that are inherently linear themselves at least over a limited measurement range, such as resistance thermometers, exhibit large changes in output as the input quantity changes, and the approximation cannot be applied.

- $\frac{\delta V_o}{\delta R_x} = \frac{V_i}{R_x + R_3}$ for $\delta R_x \ll R_x$
- In such cases, specific action must be taken to improve linearity in the relationship between the bridge output voltage and the measured quantity.
- **One common solution to this problem is to make the values of the resistances R2 and R3 at least ten times those of R1 and Rx(nominal).**
- The effect of this is best observed by looking at a numerical example.

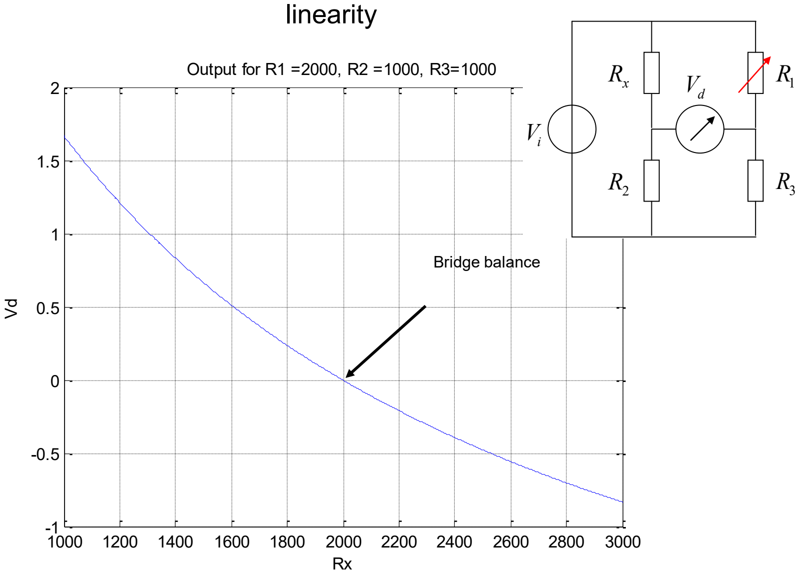
- Consider a platinum resistance thermometer with a range of 0°–50°C, whose resistance at 0°C is 500 and whose resistance varies with temperature at the rate of
- 4Ω /°C. Over this range of measurement, the output characteristic of the thermometer itself is nearly perfectly linear. (N.B. The subject of resistance thermometers is
- discussed later)
- Taking first the case where R1 = R2 = R3 = 500Ω and Vi = 10 V, and applying equation for Vd:
- $at\ 25\ degree\ \ C\ \ \ ,\Delta Rx = 25 * 4 = 100\Omega$
- $Vo = 10\left(\frac{600}{1100} - \frac{500}{1000}\right)$ =455mV
- $at\ 50\ degree\ \ C\ \ \ ,\Delta Rx = 50 * 4 = 200\Omega$
- $Vo = 10\left(\frac{700}{1200} - \frac{500}{1000}\right)$ =833mV

- We notice the non linear nature of the output, since for interval 0-25 deg C ==> ΔVo=455 mV while for interval 25-50 deg C ΔVo=833-455=378 mV
- Now choose R=5000 Ω and Vcc=26.1V (in orderv to have 833 mV at 50 deg C)
- $Vo = 26.1\left(\frac{600}{5600} - \frac{500}{5500}\right)$ =423mV at 25 deg C
- $Vo = 26.1\left(\frac{700}{5700} - \frac{500}{15000}\right)$ =833mV at 50 deg C
- Now for interval 0-25 deg C ==> ΔVo=424 mV while for interval 25-50 deg C ΔVo=833-424=409 mV which much better

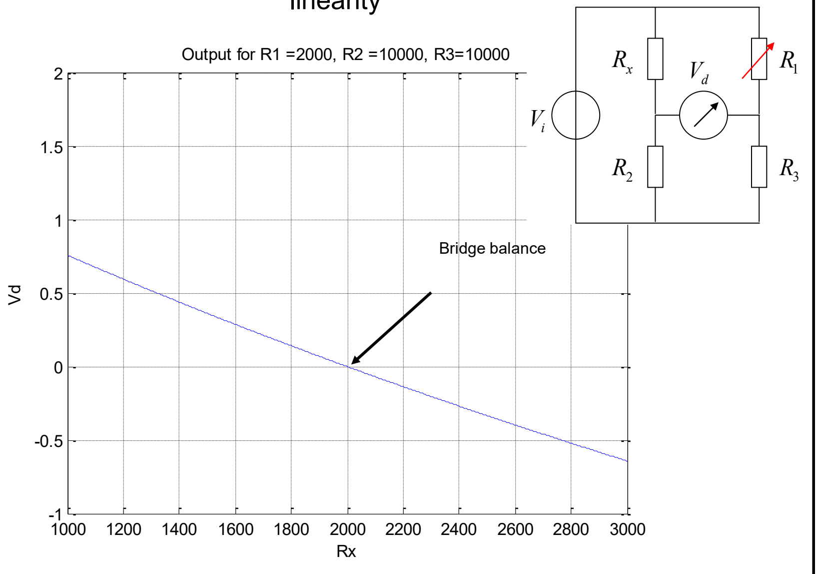




Output (deflection) for R_2, R_3 = 1,000 Ohm showing significant non-linearity



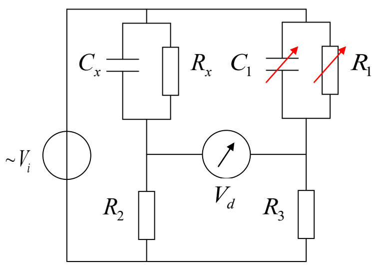
Output (deflection) for R_2, R_3 = 10,000 Ohm showing reduced non-linearity



AC bridges

- Bridges with a.c. excitation are used to measure unknown impedances.
- As for d.c. bridges, both null and deflection types exist, with null types being generally used for calibration duties.

Null-type Parallel-Resistance-Capacitance bridge for capacitance and dissipation factor measurement



$$Z_x Z_3 = Z_1 Z_2$$

$$Z_x = \frac{R_x \frac{1}{j\omega C_x}}{R_x + \frac{1}{j\omega C_x}} = \frac{R_x}{1 + j\omega R_x C_x}$$

$$Z_3 = R_3 \} \text{Known, fixed}$$

$$Z_1 = \frac{R_1 \frac{1}{j\omega C_1}}{R_1 + \frac{1}{j\omega C_1}} = \frac{R_1}{1 + j\omega R_1 C_1}$$

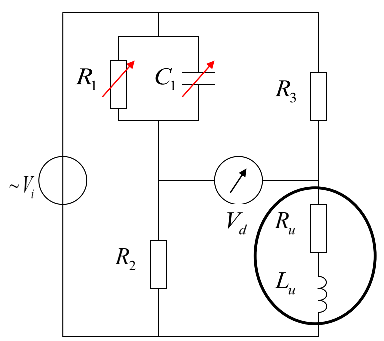
$$Z_2 = R_2 \} \text{Known, fixed}$$

$$\left.\begin{aligned} \text{Re}: R_x &= R_1 \frac{R_2}{R_3} \\ \text{Im}: C_x &= C_1 \frac{R_3}{R_2} \end{aligned}\right\} \text{Independent of } \omega$$

$$\frac{R_x}{1 + j\omega R_x C_x} = \frac{R_2}{R_3}\left(\frac{R_1}{1 + j\omega R_1 C_1}\right)$$

$$R_x R_3 \left(1 + j\omega R_1 C_1\right) = R_1 R_2 \left(1 + j\omega R_x C_x\right)$$

Maxwell bridge to measure inductance, resistance and quality factor of low quality coils (Q<10)



$$Z_1 Z_u = Z_3 Z_2$$

$$Z_u = R_u + j\omega L_u$$

$$Z_1 = \frac{R_1 \frac{1}{j\omega C_1}}{R_1 + \frac{1}{j\omega C_1}} = \frac{R_1}{1 + j\omega R_1 C_1}$$

$$\left.\begin{aligned} Z_2 &= R_2 \\ Z_3 &= R_3 \end{aligned}\right\} \text{Known, fixed}$$

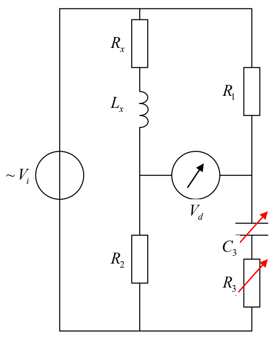
$$\left(R_u + j\omega L_u\right)\left(\frac{R_1}{1 + j\omega R_1 C_1}\right) = R_2 R_3$$

$$R_1 \left(R_u + j\omega L_u\right) = R_2 R_3 \left(1 + j\omega R_1 C_1\right)$$

$$\left.\begin{aligned} \text{Re}: R_u &= \frac{R_2 R_3}{R_1} \\ \text{Im}: L_u &= R_2 R_3 C_1 \end{aligned}\right\} \text{Independent of } \omega$$

$$Q \equiv \frac{\omega L_u}{R_u} = \omega R_1 C_1$$

Hay bridge to measure inductance, resistance and quality factor of high quality coils (Q>10)



$$Z_x Z_3 = Z_1 Z_2$$

$$Z_x = R_x + j\omega L_x$$

$$Z_3 = R_3 + \frac{1}{j\omega C_3} = \frac{1 + j\omega R_3 C_3}{j\omega C_3}$$

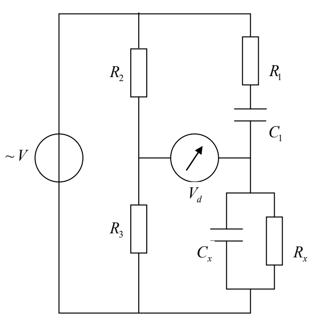
$$\left.\begin{aligned} Z_1 &= R_1 \\ Z_2 &= R_2 \end{aligned}\right\} \text{Known, fixed}$$

$$\left(R_x + j\omega L_x\right)\left(\frac{1 + j\omega R_3 C_3}{j\omega C_3}\right) = R_1 R_2$$

$$\left(R_x + j\omega L_x\right)\left(1 + j\omega R_3 C_3\right) = j\omega R_1 R_2 C_3$$

$$\boxed{L_x = \frac{R_1 R_2 C_3}{1 + \omega^2 R_3{}^2 C_3{}^2} \qquad R_x = \frac{\omega^2 R_1 R_2 R_3 C_3{}^2}{1 + \omega^2 R_3{}^2 C_3{}^2} \qquad Q = \frac{\omega L_x}{R_x} = \frac{1}{\omega R_3 C_3}}$$

Wien bridge for frequency measurement



$$Z_2 Z_x = Z_3 Z_1$$

$$Z_2 = R_2 \} \text{Known, fixed}$$

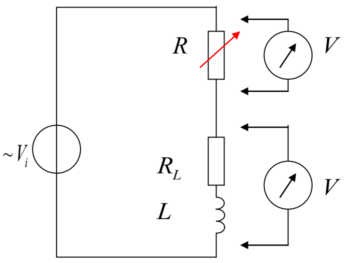
$$Z_x = \frac{R_x \dfrac{1}{j\omega C_x}}{R_x + \dfrac{1}{j\omega C_x}} = \frac{R_x}{1 + j\omega R_x C_x}$$

$$Z_3 = R_3 \} \text{Known, fixed}$$

$$Z_1 = R_1 + \frac{1}{j\omega C_1} = \frac{1 + j\omega R_1 C_1}{j\omega C_1}$$

$$\boxed{\omega^2 = \frac{1}{R_1 C_1 R_x C_x} \qquad R_x = R_3\left(\frac{1 + \omega^2 R_1{}^2 C_1{}^2}{\omega^2 R_1 R_2 C_1{}^2}\right) \qquad C_x = \frac{R_2 C_1}{R_3\left(1 + \omega^2 R_1{}^2 C_1{}^2\right)}}$$

The coil characteristics inductance and series resistance can be measured by equalizing the voltage across a variable resistor and the coil itself



$$Z_L = R_L + j\omega L$$
$$Z_R = R$$

$$V = i\left(R_L + j\omega L\right) = iR$$

$$|V| = i\left(\sqrt{R_L^{\,2} + (\omega L)^2}\right) = iR$$

$$R_L^{\,2} + (\omega L)^2 = R^2$$

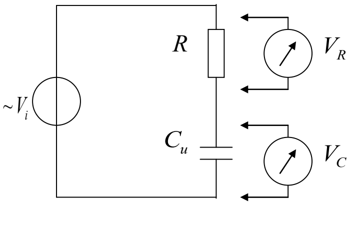
$$\boxed{L = \frac{1}{\omega}\sqrt{R^2 - R_L^{\,2}}}$$

Series resistance of the coil *RL* measured with a DVM

Approximate method of measuring capacitance

- Measure the AC Voltages **for a known input frequency** across resistor R and capacitor C

$$Z_C = \frac{1}{j\omega C}$$
$$Z_R = R$$



$$|V_C| = i\frac{1}{\omega C}$$
$$|V_R| = iR$$

$$\frac{|V_C|}{|V_R|} = \frac{1}{\omega RC}$$

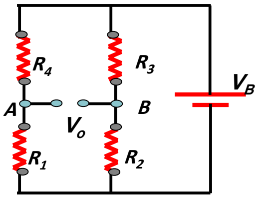
$$\boxed{C = \frac{1}{\omega R}\frac{|V_R|}{|V_C|}}$$

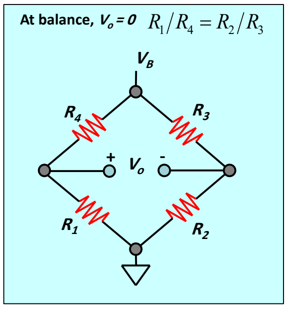
Resistance measured with a DVM

Deflection Bridges with More than one variable element

Resistance Bridges: Deflection Type Measurement

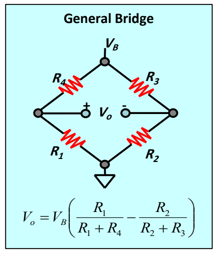
- For the majority of sensor applications employing bridges, the deviation of one or more resistors in a bridge from an initial value is measured as an indication of the magnitude (or a change) in the measured variable. In this case, the output voltage change is an indication of the resistance change.
- Because very small resistance changes are common, the output voltage change may be as small as tens of millivolts, even with V_B = 10V (a typical excitation voltage for a load cell application).

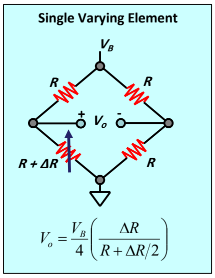


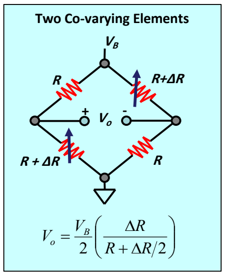


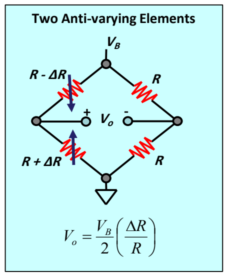
Deflection Type Resistance Bridges: Variable Resistance Configurations

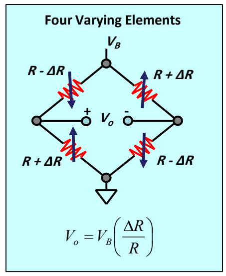
- ❑ In many bridge applications, there may be two, or even four elements which vary.
- ❑ Note that since the bridge output is directly proportional to V_B, the measurement accuracy can be no better than that of the accuracy of the excitation voltage.





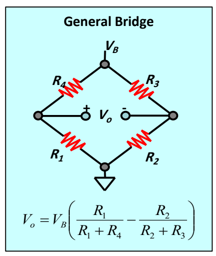


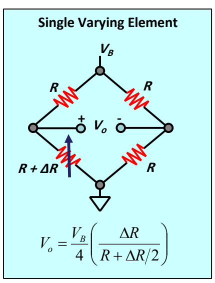


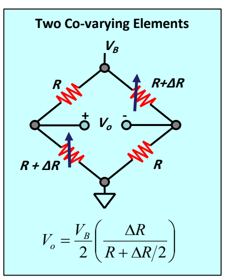


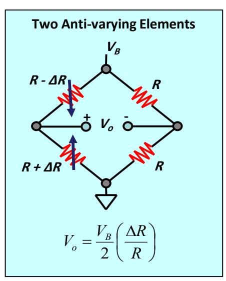
Deflection Type Resistance Bridges: Variable Resistance Configurations

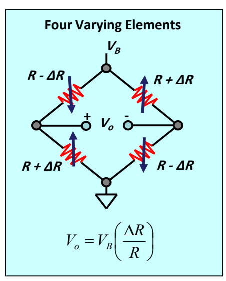
- ❑ In each case, the value of the fixed bridge resistor, R, is chosen to be equal to the nominal value of the variable resistor(s).
- ❑ The deviation of the variable resistor(s) about the nominal value is proportional to the quantity being measured, such as strain (in the case of a strain gage) or temperature (in the case of an RTD).





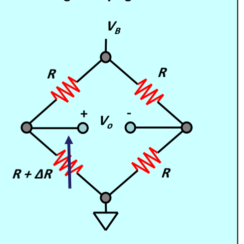






Deflection Type Resistance Bridges: Single Varying Element Configurations

- The single-element varying bridge may be used for temperature sensing using RTDs or thermistors.
- This configuration is also used with a single resistive strain gage. All the resistances are nominally equal, but one of them (the sensor) is variable by an amount *ΔR*.
- The relationship between the bridge output and *ΔR* is not linear. Since there is a fixed relationship between the bridge resistance change and its output, software can be used to remove the linearity error in digital systems.
- Alternative bridge configurations can also be used to linearize the bridge output directly.



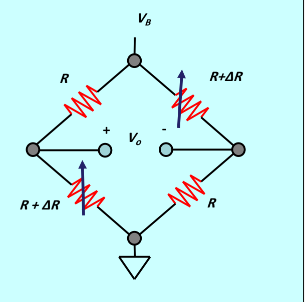
$$V_o = \frac{V_B}{4}\left(\frac{\Delta R}{R+\Delta R/2}\right)$$

Deflection Type Resistance Bridges: Two Co-varying Elements Configurations

- In this configuration, both elements change in the same direction. The nonlinearity is the same as that of the single-element varying bridge, however the gain is twice that of the single-element varying bridge.
- The two-element varying bridge is commonly found in pressure sensors and flow meter systems.

$$V_o = V_B\left(\frac{R+\Delta R}{2R+\Delta R} - \frac{R}{2R+\Delta R}\right)$$

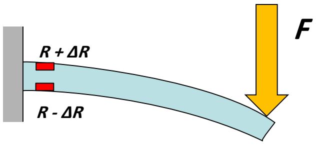
$$= V_B\left(\frac{\Delta R}{2R+\Delta R}\right)$$



$$V_o = \frac{V_B}{2}\left(\frac{\Delta R}{R+\Delta R/2}\right)$$

Deflection Type Resistance Bridges: Two Anti-varying Elements Configurations

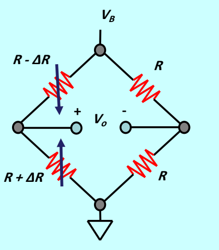
- This configuration requires two identical elements that vary in opposite directions. This could correspond to two identical strain gages: one mounted on top of a flexing surface, and one on the bottom.



- Such a configuration could be used for measuring force, pressure, stress, strain, etc. It produces a linear output, and it has twice the gain of the single-element configuration.

$$V_o = V_B\left(\frac{R+\Delta R}{2R} - \frac{R}{2R}\right)$$

$$= V_B\left(\frac{R+\Delta R - R}{2R}\right)$$



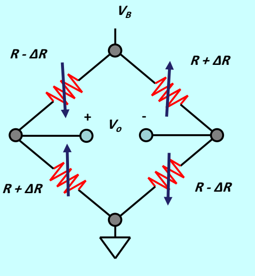
$$V_o = \frac{V_B}{2}\left(\frac{\Delta R}{R}\right)$$

Deflection Type Resistance Bridges: Four Varying Elements Configurations

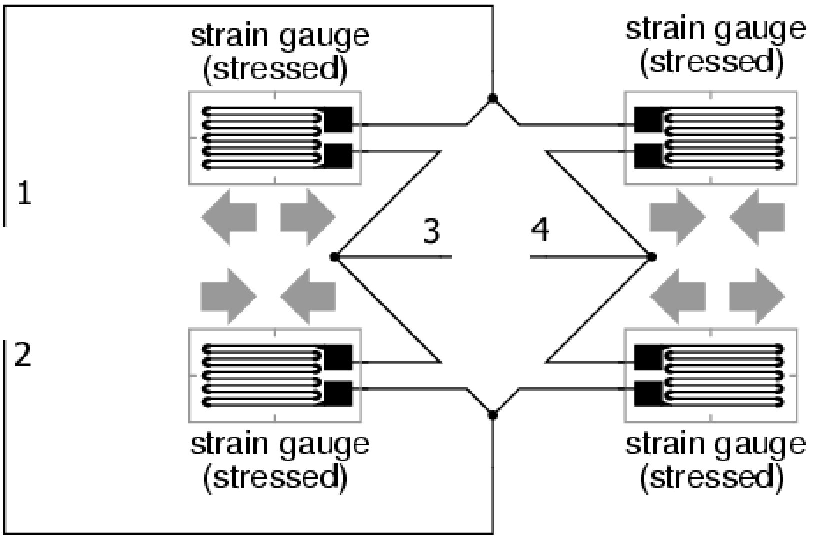
- The four varying elements bridge produces the most signal for a given resistance change and is inherently linear.
- It is an industry-standard configuration for load cells used in electronic scales which are constructed from four identical strain gages.

$$V_o = V_B\left(\frac{R+\Delta R}{2R} - \frac{R-\Delta R}{2R}\right)$$

$$= V_B\left(\frac{R+\Delta R - R+\Delta R}{2R}\right)$$

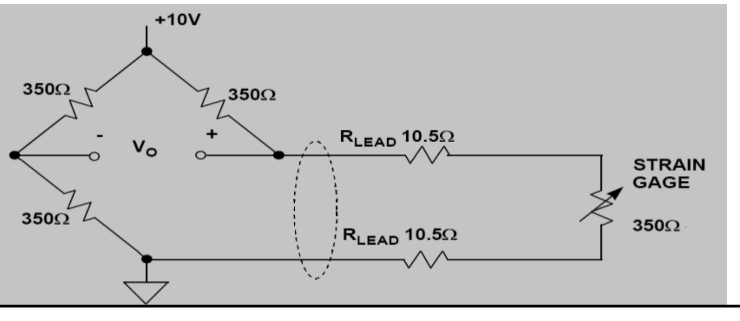


$$V_o = V_B\left(\frac{\Delta R}{R}\right)$$



Example: Errors Produced by Wiring Resistance in Remote Resistive Bridge Sensor

- A **350Ω** nominal resistance strain gage is used as a sensing element in a single varying element Wheatstone bridge.
- The gauge is connected to the rest of the bridge circuit by **100 feet of 30 gauge twisted pair copper wire with a resistance of 0.105 Ω /ft, at 25°C** and a temperature coefficient of **0.385%/°C**.
- The full scale variation of the strain gage resistance (with flex) above its nominal 350 Ω value is **+1%.** **Calculate the offset error in the bridge output due to the lead resistance.**



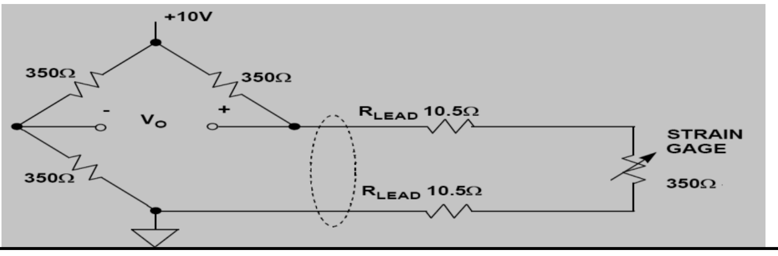
Errors Produced by Wiring Resistance in Remote Resistive Bridge Sensor

Offset error due to lead resistance

- The resistance of each 100 ft copper cable **is Rlead=100 ft x 0.105 Ω /ft = 10.5Ω**, and the total lead resistance in series with the 350Ω strain gage is therefore 21 Ω at 25°C.
- The bridge output voltage is simply the difference between the output of two voltage dividers, each driven from a +10V source.

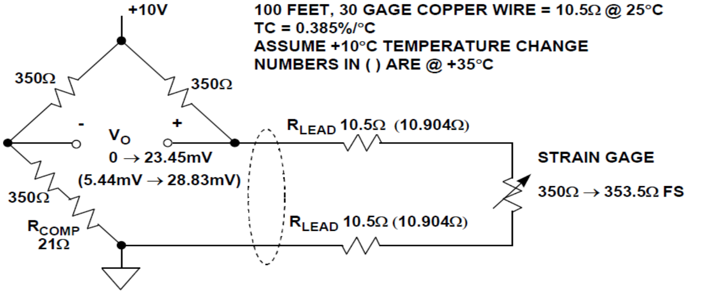
$$V_o = V_B\left(\frac{R_1}{R_1+R_4} - \frac{R_2}{R_2+R_3}\right) = 10\left(\frac{350+21}{700+21} - \frac{350}{700}\right) = 0.14563\text{ V}$$

- When the load on the gauge is zero, the bridge would have an output offset voltage of **145.63mV** for a nominal strain gage resistance of 350Ω.



Errors Produced by Wiring Resistance in Remote Resistive Bridge Sensor

- **If a 21Ω compensating resistance R_{COMP}** is used as shown to compensate for the lead resistance, <u>**Calculate the full scale bridge output at 25°C and the percentage zero error (offset error) and the sensitivity error (gain error) due to a +10°C temperature rise in the cable.**</u>



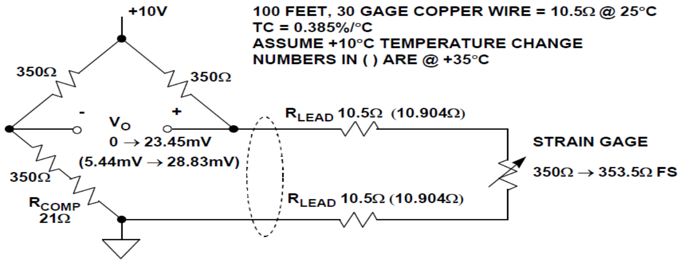
Errors Produced by Wiring Resistance in Remote Resistive Bridge Sensor

Full scale bridge output at 25°C

- **The full scale bridge output voltage takes place when the gauge resistance is of 350 Ω + (350 Ω × 1%) = 353.5 Ω**

$$V_o = V_B\left(\frac{R_1}{R_1+R_4} - \frac{R_2}{R_2+R_3}\right) = 10\left(\frac{353.5+21}{703.5+21} - \frac{350+21}{700+21}\right) = 0.02345$$

- The full scale output of the bridge at 25°C is **23.45 mV**.



Example: Errors Produced by Wiring Resistance in Remote Resistive Bridge Sensor

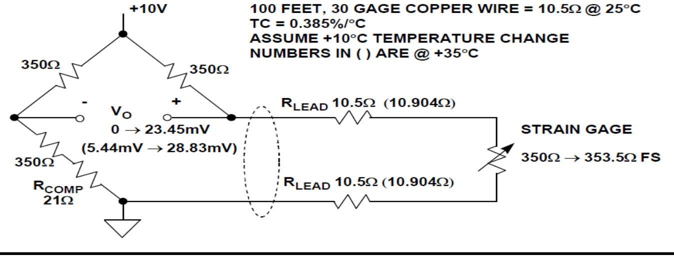
Zero error (zero offset) due to 10°C

With +10°C temperature rise, ΔR_{LEAD} = 10 × (0.385/100) × 10.5 = 0.404 Ω, R_{LEAD} = 10.5 Ω + 0.404 Ω = 10.904 Ω.

Total lead resistance in series with the gauge = 2 × 10.904 = 21.808

$$V_o = V_B\left(\frac{R_1}{R_1+R_4} - \frac{R_2}{R_2+R_3}\right) = 10\left(\frac{350+21.808}{700+21.808} - \frac{350+21}{700+21}\right) = 0.005434$$

With the compensating resistance, an offset error of 5.434 mV is present at 10°C temperature rise which is (5.343/23.45) **= 23.2%** of full scale output.



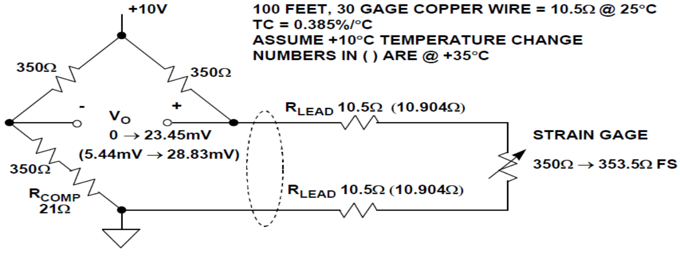
Errors Produced by Wiring Resistance in Remote Resistive Bridge Sensor

Gain error due to 10°C temperature rise

- The full scale bridge output at 35°C is calculated based on a gauge resistance of 350Ω + (350Ω × 1%) = 353.5Ω. The lead wire resistance, however, is (2 ×10.904Ω = 21.808Ω

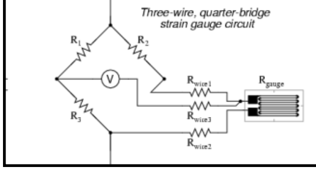
$$V_o = V_B\left(\frac{R_1}{R_1+R_4} - \frac{R_2}{R_2+R_3}\right) = 10\left(\frac{353.5+21.808}{703.5+21.808} - \frac{350+21}{700+21}\right) = 0.02883$$

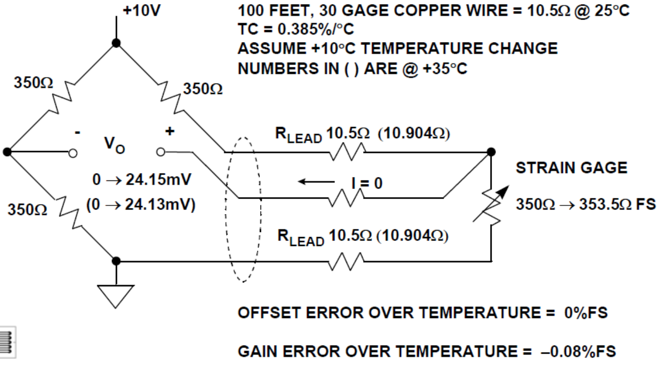
- The full scale output due to 10°C temp rise is 28.83 mV giving a deflection from zero load of (28.83 - 5.434 = 23.396 mV) with an error of (23.396 – 23.45 = -0.054 mV) or (-0.054/23.45) = -0.23% of full scale output



Error Reduction in remote single varying element bridge : Three Wire Sensing

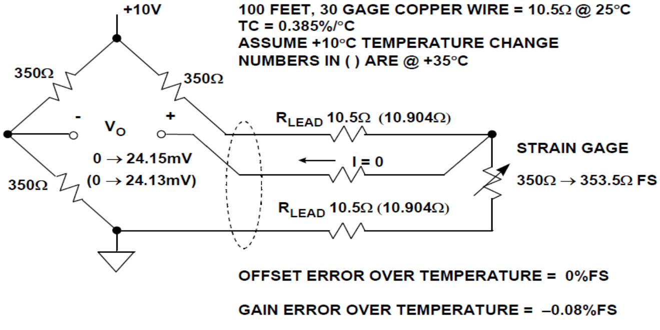
- The effects of wiring resistance on the bridge output can be minimized by the 3-wire connection.
- The sense lead measures the voltage output of a divider: the top half is the bridge resistor plus the lead resistance, and the bottom half is strain gage resistance plus the lead resistance.





Error Reduction in remote single varying element bridge : Three Wire Sensing

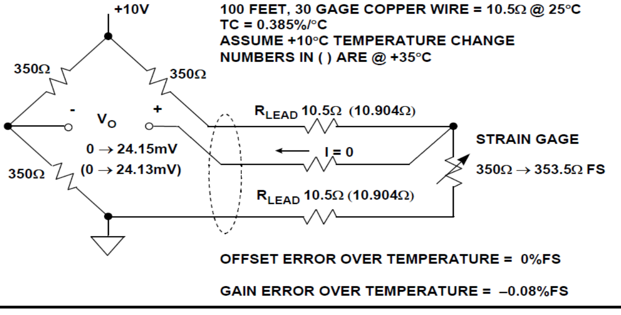
- The nominal sense voltage is independent of the lead resistance. When the strain gage resistance increases to full-scale (353.5Ω), the bridge output increases to +24.15mV.



Error Reduction in remote single varying element bridge : Three Wire Sensing

Gain error due to 10°C temperature rise

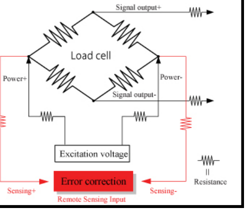
- Increasing the temperature to +35ºC increases the lead resistance by +0.404Ω in each half of the divider.
- The full-scale bridge output voltage decreases to +24.13mV because of the small loss in sensitivity, but there is no offset error. The gain error due to the temperature increase of +10ºC is therefore only –0.02mV, or –0.08% of full-scale.



Kelvin Sensing

(for all element varying Bridge)

- However, all-element varying bridges generally are housed in a complete assembly, as in the case of a load cell.
- When these bridges are remotely located from the conditioning electronics, special techniques must be used to maintain accuracy.
- **Of particular concern is maintaining the accuracy and stability of the bridge excitation voltage.**
- The bridge output is directly proportional to the excitation voltage, and any drift in the excitation voltage produces a corresponding drift in the output voltage.
- For this reason, most all-element varying bridges (such as load cells) are six-lead assemblies: two leads for the bridge output, two leads for the bridge excitation, and two *sense* leads.
- This method (called Kelvin or 4-wire sensing)

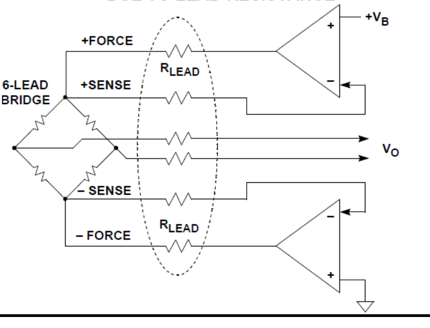


Kelvin Sensing

(for all element varying Bridge)

- This method (called Kelvin or 4-wire sensing) is shown in Figure
- The sense lines go to high impedance op amp inputs, thus there is minimal error due to the bias current induced voltage drop across their lead resistance.
- The op amps maintain the required excitation voltage to make the voltage measured between the sense leads always equal to VB.
- Although Kelvin sensing eliminates errors due to voltage drops in the wiring resistance, the drive voltages must still be highly stable since they directly affect the bridge output voltage.
- **In addition, the op amps must have low offset, low drift, and low noise.**

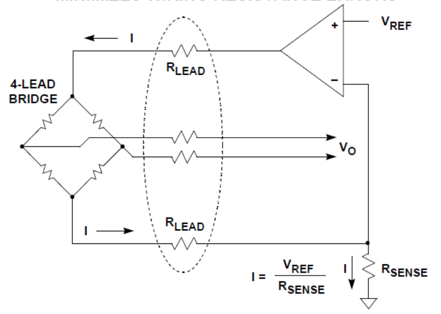
KELVIN (4-WIRE) SENSING MINIMIZES ERRORS DUE TO LEAD RESISTANCE



The constant current excitation

- The constant current excitation method shown in Figure is **another method for minimizing the effects of wiring resistance on the measurement accuracy**.
- However, the accuracy of the reference, the sense resistor, and the op amp all influence the overall accuracy.

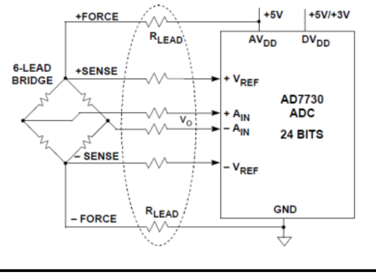
CONSTANT CURRENT EXCITATION
MINIMIZES WIRING RESISTANCE ERRORS



Ratio-metric technique

- A very powerful *ratio-metric* technique which includes Kelvin sensing to **minimize errors due to wiring resistance and also eliminates the need for an accurate excitation voltage** is shown
- The AD7730 ADC can be driven from a single supply voltage which is also used to excite the remote bridge.
- Both the analog input and the reference input to the ADC are high impedance and fully differential.
- By using the + and – SENSE outputs from the bridge as the differential reference to the ADC, there is no loss in measurement accuracy if the actual bridge excitation voltage varies.

DRIVING REMOTE BRIDGE USING KELVIN (4-WIRE)
SENSING AND RATIOMETRIC CONNECTION TO ADC



Extra S/C Assignment #2

Temperature is to be measured in the range of 250°C to 450°C with an accuracy of ±2°C. The sensor is a resistance that varies linearly from 280 Ω to 1060 Ω for this temperature range. Power dissipated in the sensor must be kept below 5 mW. Develop analog signal conditioning that provides a voltage varying linearly from −5 to +5 V for this temperature range. The load is a high-impedance recorder.