# Basic Elements in Measurement

Sensing Element → Signal Conditioning Element → Signal Processing Element

- Input Measurand

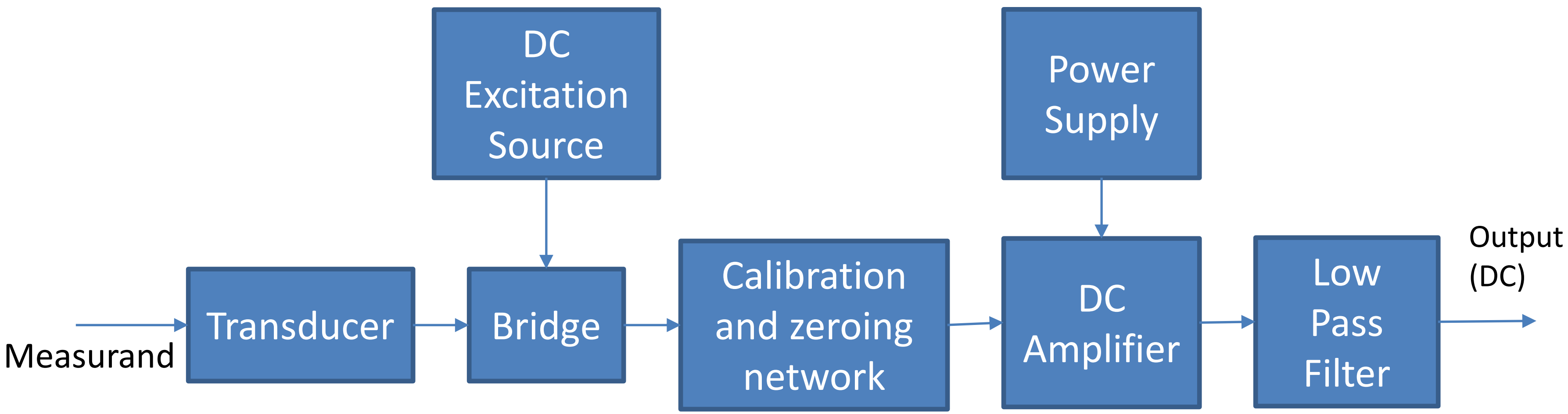
- Output
- Electrical Output

# Signal Conditioning

- The Measurand, which is basically a physical quantity as is detected by the first stage of the instrumentation or measurement system.
- The first stage, with which we have become familiar, is the "Detector Transduces stage''.
- The quantity is detected and is transduced into· an electrical form in most of the cases.
- The output of the first stage has to be modified before it becomes usable and satisfactory to drive the signal presentation stage which is the third and the last stage of a measurement system.
- The last stage of the measurement system may consist of indicating, recording, displaying, data processing elements or may consist of control elements.

# Basic structure of D.C. Signal Conditioning

- The signal conditioning or data acquisition equipment in many a situation be an excitation and amplification system for Passive transducers.
- Signal conditioning circuits are used to process the output signal from sensors of a measurement system to be suitable for the next stage of operation.




D.C. Signal Conditioning System

# Wheatstone Bridge (W.B.)

It is the most commonly used d.c. bridge for measurement of resistance.

This bridge is used for measurement of small resistance changes that occur in passive resistive transducer like strain gauges, thermistors and resistance thermometers.

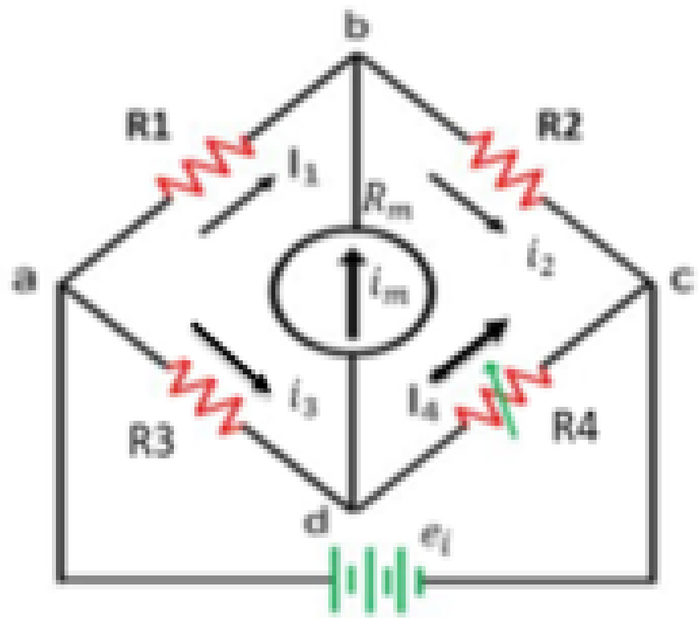



Fig.1 Wheatstone Bridge

# Wheatstone Bridge (W.B.)

- Figure 1 shows the basic circuit of a Wheatstone bridge, which consists of four resistive arms with a source of emf (a battery) and a meter which acts as a detector.

- The detector is usually a current sensitive galvanometer.

- Measurement may be carried out either by balancing the bridge or by determining the magnitude of unbalance.

There are two ways in which W.B. can be used:

1) Null Type 2) Deflection Type

# Wheatstone Bridge (W.B.)

**1. Null Type Wheatstone bridge:**

- When using this type of measurement, adjustments are made in various arms of the bridge so that the voltage across the detector is zero and hence no current flows through it.
- When no current flow through detector, the bridge is said to be balance.

Under Balance Condition:

$$R_1 = R_2\ (R_3/R_4)$$

- Resistance *R1* represents the resistance of a resistive transducer whose value depends upon the physical variable being measured.
- The ratio of resistors *R3* and *R4* is fixed for a particular measurement.

# Wheatstone Bridge (W.B.)

- In instrumentation work, it is the change ΔR1 in the transducer resistance *R1* which *is* to be found.
- The change unbalances the bridge and therefore resistor R2 has to be adjusted by an amount ΔR2 to restore balance.

Under Rebalance Condition

$$R_1 + \Delta R_1 = (R_2+\Delta R_2)(R_3/R_4) = R_2(R_3/R_4) + \Delta R_2\ (R_3/R_4)$$

$$= R_1 + \Delta R_2\ (R_3/R_4)$$

$$\Delta\ R_2 = \Delta R_1\ (R_4/R_3)$$

Some applications such as temperature measuring systems (where the resistance, *R1* of the transducer changes on account of temperature), an automatic bridge balancing control system may be used as shown in Fig. 2.

# Wheatstone Bridge

- When there is change in resistance *R1,* it produces a voltage output which is amplified and applied as an error signal to the field winding of a d c. motor.
- The motor is coupled to a moving contact. This movable contact is actuated so as to reduce the unbalance and hence the error voltage.
- When the bridge is balanced, there is no error voltage and therefore there is no voltage, across the field winding of the motor. The motor stops and thus the slider comes to rest.
- The read out scale be calibrated in resistance change values or in terms of temperature or any other physical variable being measured.

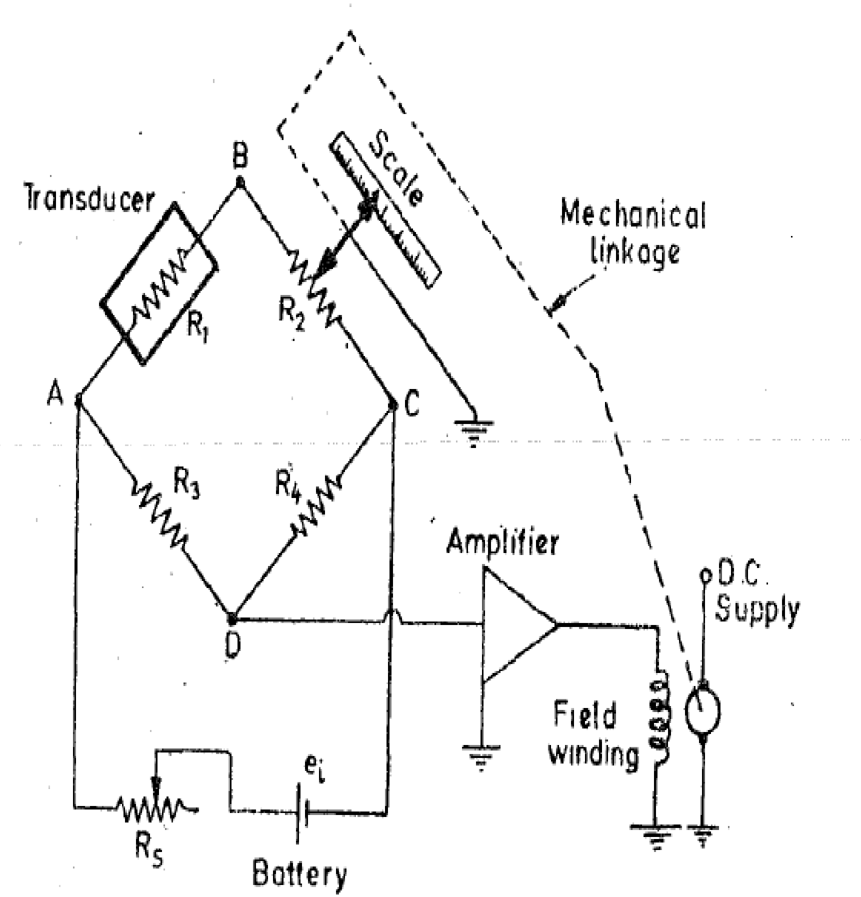



Fig. 2 : Self (Automatic) Balance Wheatstone Bridge

# Wheatstone Bridge

**2. Deflection Type**

- The null type Wheatstone Bridge is accurate but the problem with this *bridge* is that balancing, even if done automatically, is not instantaneous. Therefore this bridge is unsuitable for dynamic applications where the changes in resistance are rapid.

- For measurement *of r*apid changing input signals, the Deflection type Bridge is used. When the input changes, the resistances R1 producing an unbalance causing a voltage to appear across the meter.

- The deflection of meter is indicative of the value of resistance and the scale of the meter may be calibrated resistance directly.

- For static inputs, an ordinary galvanometer may be used. However for dynamic inputs, output signal may be displayed by a cathode ray oscilloscope or may be recorded by a recorder.

# Wheatstone Bridge

## 2. Deflection Type

- The deflection type bridge circuit is provided with a zero setting arrangement as shown in Fig *3.* The series resistance *Rs* is used to change the bridge sensitivity.

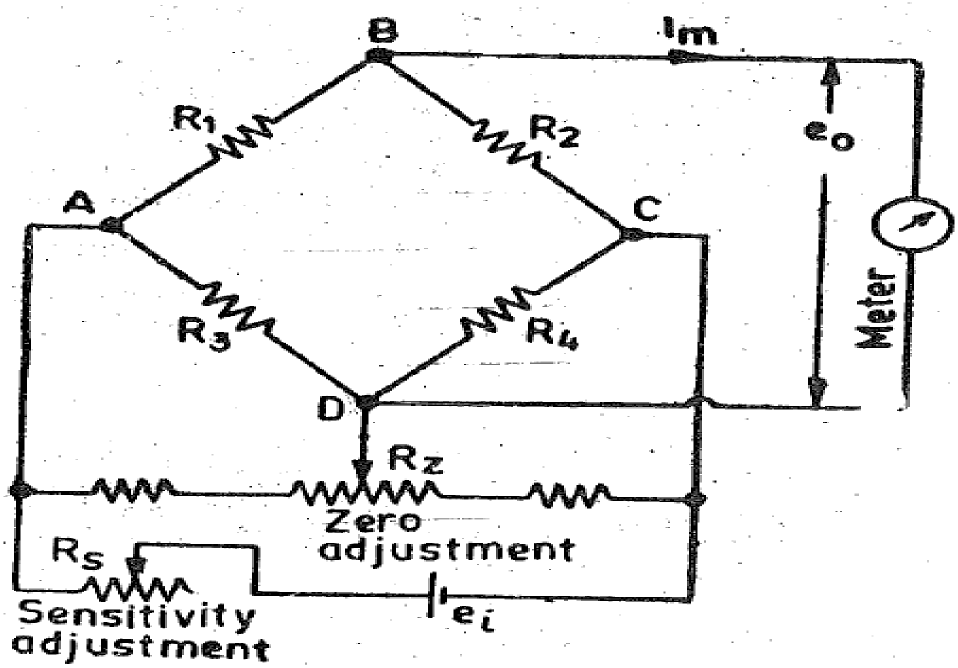



Fig. 3: Deflection Type Wheatstone Bridge provided with zero adjustment and sensitivity adjustment arrangements

# Wheatstone Bridge

- When a deflection type bridge is used, the bridge output on account of the unbalance may be connected either to a high input impedance device or to a low input impedance device.

- If the output of the bridge is connected directly to a low impedance devices like a current galvanometer or a PMMC instrument, a large current flows through the meter. In this case, the bridge is called a Current Sensitive Bridge.

- In most of the applications of deflection type bridge, the bridge output is fed to an amplifier which has a high input impedance and therefore the output current $i_m = 0$. This would also be the case if the bridge output is connected to a CRO or a digital voltmeter. The bridge thus used is a Voltage Sensitive Bridge.

# Voltage Sensitive Bridge

Let us assume that the input impedance of the meter is infinite and therefore $i_m = 0$.

Hence $i_1 = i_2$ and $i_3 = i_4$,
output voltage $e_0$ = voltage across terminals B and $D$

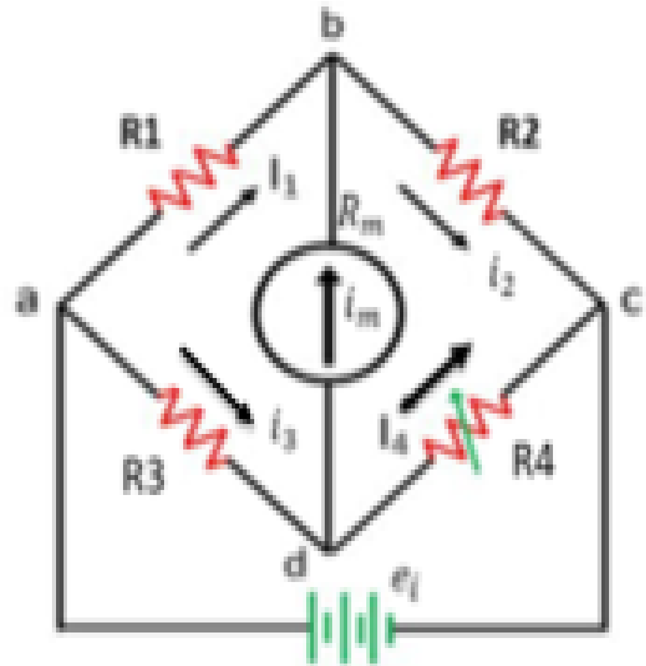
$= i_1 R_1 - i_3 R_3$.

But $i_1 = \frac{e_i}{R_1 + R_2}$ and $i_3 = \frac{e_i}{R_3 + R_4}$

So $e_o = \left[\frac{R_1}{R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right] e_i$

$= \left[\frac{R_1 R_4 - R_2 R_3}{(R_1 + R_2)(R_3 + R_4)}\right] e_i$

Suppose now $R_1$ changes by an amount $\Delta R_1$. This causes a change $\Delta e_o$ in the output voltage Thus :




Reference fig 1: Basic Wheatstone Bridge

# Voltage Sensitive Bridge

$$e_o + \Delta e_o = \left[\frac{(R_1 + \Delta R_1)R_4 \ - R_2 R_3}{(R_1 + \Delta R_1 + \ R_2)(R_3 + R_4)}\right] e_i$$

$$= \left[\frac{1 + \left(\frac{\Delta R_1}{R_1}\right) - \left(\frac{R_2 R_3}{R_1 R_4}\right)}{\left\{1 + \left(\frac{\Delta R_1}{R_1}\right) + (R_2/R_1)\right\} \{1 + (R_3/R_1)\}}\right] e_i$$

In order to simplify the relationship, let us assume that initially all the resistances comprising the bridge are equal *i e.,* $R_1 = R_2 = R_3 = R_4 = R$.

*Under these conditions:* $e_o$ *= 0 and* $\Delta e_o = \left[\frac{\left(\frac{\Delta R_1}{R_1}\right)}{4+2(\Delta R_1/R)}\right] e_i$

# Voltage Sensitive Bridge

It is clear from above equation that the input-output relationship *i.e.,* relationship between $\Delta R$ and $\Delta e_o$ is non-linear. However, if the change in resistance is very small as compared to initial resistance then we have: $2(\Delta R_1/R) \ll 4$.

$$\Delta e_o = \frac{\left(\frac{\Delta R_1}{R}\right)}{4} e_i \text{ so } \Delta e_o = e_i$$

- For such cases, the input-output relationship is linear. The major disadvantage of a voltage sensitive deflection bridge as compared to voltage sensitive null bridge is that the calibration of the former is dependent upon the value of supply voltage $e_i$.

- Therefore for constancy of calibration., the input voltage should be absolutely constant.

# Current Sensitive Bridge

- When using galvanometers at the output, terminals, the resistance of the meter cannot be neglected as galvanometers draw an appreciable current.
- Under such circumstances, wherein the measuring device has a low impedance, the deflection is on account of the meter current $i_m$, which cannot be assumed to be zero, the bridge is said to be a current sensitive bridge.
- In order to find the input-output relationship and the bridge sensitivity for this general case, it is necessary to convert the bridge circuit of Fig. 4, to a Thevenin generator looking into the output terminals B and *D.*

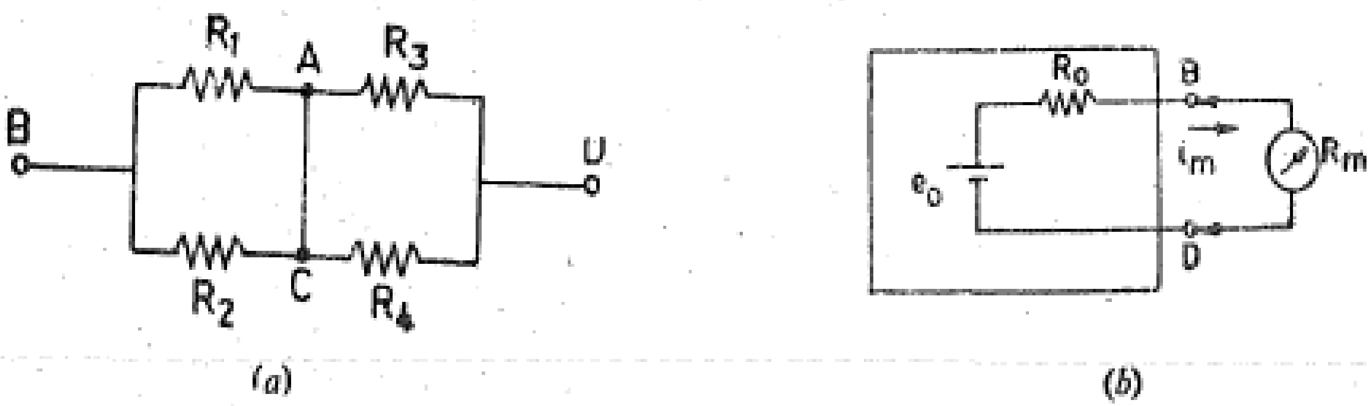


Fig. 4: Thevenin Equivalent circuit of Wheat stone bridge

# Current Sensitive Bridge

open circuit voltage of the Thevenin generator

$$e_o = \left[\frac{(R_1 R_4 - R_2 R_3)}{(R_1 + R_2)(R_3 + R_4)}\right] e_i$$

The internal resistance of the Thevenin generator is found from looking into terminals *B* and *D* and shorting terminals *A* and *C* as shown in Fig. 4 *(a).*

The internal resistance of the Thevenin generator looking into the terminals *B* and *D* and is :

$$R_o = \frac{R_1 R_2}{R_1 + R_2} + \frac{R_3 R_4}{R_3 + R_4} = \frac{(R_1 R_2)(R_3 + R_4) + (R_3 R_4)(R_1 + R_2)}{(R_1 + R_2)(R_3 + R_4)}$$

The current through the meter is given by :

$$i_m = \frac{e_o}{R_0 + R_m} = \frac{(R_1 R_4 - R_2 R_3) e_i}{(R_1 R_2)(R_3 + R_4) + (R_3 R_4)(R_1 + R_2) + R_m (R_1 + R_2)(R_3 + R_4)}$$

*Let* $R_1 = R_2 = R_3 = R_4 = R$ *and ΔR is the change in R.*

$$i_m = \frac{[(R + \Delta R) R - R^2] e_i}{(R + \Delta \mathrm{R})(R)(2R) + R^2 (R + \Delta \mathrm{R} + R) + R_m (R + \Delta \mathrm{R} + R)(2R)}$$

# Current Sensitive Bridge

When $\Delta R \ll R$

We have $i_m = \frac{[\Delta R/R^2]e_i}{4\,(1+ R_m/R)}$

Voltage output under load conditions is:

$$e_{ol} = i_m R_m = \left[\frac{[\Delta R/R^2]e_i}{(1+ R_m/R)}\right]\frac{R_m}{4} = \left[\frac{[\Delta R/R]e_i}{(R+ R_m)}\right]\frac{R_m}{4} = \left[\frac{[\Delta R/R]e_i}{4(1+R/R_m)}\right]$$

From Eqn. 26'55, it follows that open circuit voltage

$$e_o = \left[\frac{\Delta R}{4R}\right] e_i$$

The voltage under loaded conditions is :

$$e_{ol} = \frac{e_o\, R_m}{(R_0+ R_m)}$$

So Ratio of voltage under loaded and no load:

$$\frac{e_{ol}}{e_o} = \frac{1}{(1 + \, R_0/R_m)}$$