Electronic Measurements (1)

DC and AC Bridges

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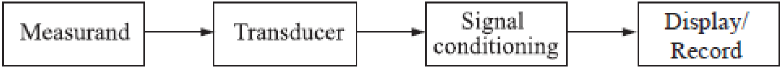
Measurements and Measurement Systems - Part 2
(A) Block Schematics of Measuring Systems

1- Block schematic of a general-purpose measuring system.

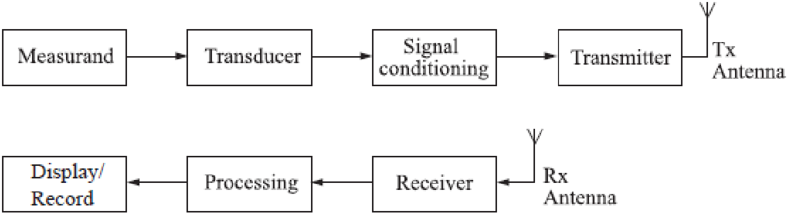


- **Measurand:** The quantity to be measured is called measurand.
- **Transducer:** A device that converts a physical quantity into an electrical quantity or vice-versa.
- **Signal conditioner:** Amplification, Filtering, Modulation, Demodulation, A/D conversion, etc.
- **Display/Record:** The quantity is recorded using X–Y or strip-chart recorders or displayed on monitors,etc.

Measurements and Measurement Systems - Part 2

(A) Block Schematics of Measuring Systems

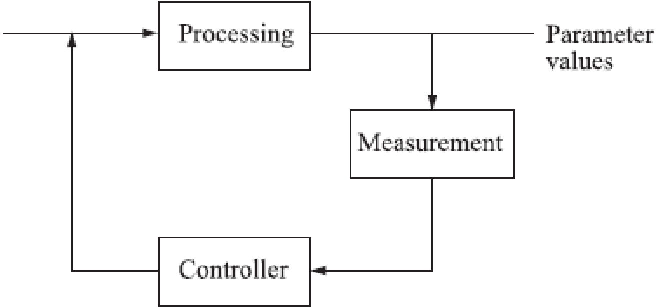
2- Block schematic of telemetry system.



- Telemetry stands for measurement of a parameter from a distance. The parameter is measured in one place and recorded at a remote point.

(A) Block Schematics of Measuring Systems

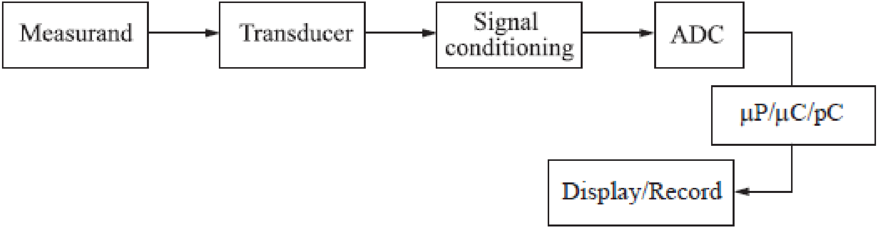
3- Block schematic of control instrumentation.



- A feedback loop exists between the input and the output to control the parameter to be measured.

(A) Block Schematics of Measuring Systems

4- Data Process System.



- Digital control techniques are employed using μP or μC on a PC.
- The analog signal is converted to a digital signal by ADC and is processed by microprocessor (μP) or microcontroller (μC) or PC.

(B) Types of Errors

The origination of error may be in a variety of ways. They are categorised in three main types:

1. Gross error
2. Systematic error
3. Random error

(B) Types of Errors - (1) Gross Error

- The errors occur because of mistakes in observed readings, or using instruments and in recording and calculating measurement results.
- These errors usually occur because of human mistakes and these may be of any magnitude and cannot be subjected to mathematical treatment.
- One common gross error is frequently committed during improper use of the measuring instrument.
- Any indicating instrument changes conditions to some extent when connected in a complete circuit so that the reading of measurand quantity is altered by the method used.

(B) Types of Errors - (1) Gross Error

- Another example of this type of error is in the use of a well-calibrated voltmeter for measurement of voltage across a resistance of very high value.
- The same voltmeter, when connected in a low resistance circuit, may give a more dependable reading because of very high resistance of the voltmeter itself.
- This shows that the voltmeter has a loading effect on the circuit, which alters the original situation during the measurement.

(B) Types of Errors - (1) Gross Error

- For another example, a multi-range instrument has a different scale for each range. During measurements, the operator may use a scale which does not correspond to the setting of the range selector of the instrument.
- Gross error may also be there because of improper setting of zero before the measurement and this will affect all the readings taken during measurements.
- The gross error cannot be treated mathematically, so great care should be taken during measurement to avoid this error.
- In general, to avoid gross error, at least two, three or more readings of the measurand quantity should be taken by different observers.

(B) Types of Errors - (2) Systematic Error

- These are the errors that remain constant or change according to a definite law on repeated measurement of the given quantity.
- These errors can be evaluated and their influence on the results of measurement can be eliminated by the introduction of proper correction.
- There are two types of systematic errors:
  - Instrumental error
  - Environmental error

(B) Types of Errors - (2) Systematic Error - Instrumental Errors.

- **Instrumental errors:** are inherent in the measuring instruments because of their mechanical structure and calibration or operation of the apparatus used.
- For example, in D'Arsonval movement, friction in bearings of various components may cause incorrect readings.
- Improper zero adjustment has a similar effect. Poor construction, irregular spring tensions, variations in the air gap may also cause instrumental errors.
- Calibration error may also result in the instrument reading either being too low or too high.
- Such instrumental errors may be avoided by :
  - Selecting a proper measuring device for the particular application.
  - Calibrating the measuring device or instrument against a standard.

(B) Types of Errors - (2) Systematic Error - Environmental Errors.

- **Environmental errors:** are much more troublesome as the errors change with time in an unpredictable manner.
- These errors are introduced due to using an instrument in different conditions than in which it was assembled and calibrated.
- Change in temperature is the major cause of such errors as temperature affects the properties of materials in different ways, including dimensions, resistivity, spring effect and many more.
- Other environmental changes also effect the results given by the instruments such as humidity, altitude, earth's magnetic field, gravity, stray electric and magnetic field, etc.

(B) Types of Errors - (2) Systematic Error - Environmental Errors

- These errors can be eliminated or reduced by taking the following precautions:

  • Use the measuring instrument in the same atmospheric conditions in which it was assembled and calibrated.

  • If the above precaution is not possible then deviation in local conditions must be determined and suitable compensations are applied in the instrumental reading.

  • Automatic compensation, employing sophisticated devices for such deviations, is also possible.

(B) Types of Errors - (3) Random Error.

- These errors are of variable magnitude and sign and do not maintain any known law.
- The presence of random errors become evident when different results are obtained on repeated measurements of one and the same quantity.
- The effect of random errors is minimised by:
  measuring the given quantity many times under the same conditions and calculating the arithmetical mean of the results obtained.
- The mean value can justly be considered as the most probable value of the measured quantity since random errors of equal magnitude but opposite sign are of approximately equal occurrence when making a great number of measurements.

(C) Loading Effects

- Under ideal conditions, an element used for signal sensing, conditioning, transmission and detection should not change/distort the original signal.
- The sensing element should not use any energy or take least energy from the process so as not to change the parameter being measured.
- However, under practical conditions, it has been observed that the introduction of any element in a system results invariably in extraction of the energy from the system, thereby distorting the original signal.
- This distortion may take the form of attenuation, waveform distortion, phase shift, etc., and consequently, the ideal measurements become impossible.

(C) Loading Effects

- The incapability of the system to faithfully measure the input signal in undistorted form is called loading effect. This results in loading error.
- **Examples:**
  - A voltmeter connected in parallel with a very high resistance.
  - An ammeter is connected in series with a very low resistance, the total resistance of the circuit changes, and in succession, the circuit current also changes.

Introduction to DC and AC Bridges

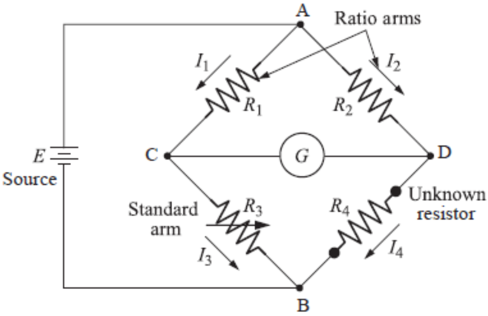
- To measure parameters R, L, C, f, Q (Quality factor of a coil) and 'D' (Dissipation factor of a capacitor) of electronic circuits, bridge circuits are employed.
- DC bridges can measure resistance R accurately over wide ranges.
- AC bridges can also be used for resistance measurements, but they are mainly used to determine inductance, capacitance, impedance, admittance, or the frequency of the AC input.
- **The advantages with bridge-measuring circuits is that:**
  1- Some errors which occur in measurements due to parasitic values, temperature effects, errors due to improper grounding and shielding can be eliminated.
  2- The measurement range of the parameters is large.
  3- Even parameters like quality factor of a coil Q, dissipation factor D of a capacitor can also be measured using AC bridges in addition to frequency.

Introduction to DC and AC Bridges

- DC bridges are used to determine the unknown conducting value or sometimes to determine the conductance associated with conducting wires $\sigma = I/R\ A$.
- **Wheatstone bridge and Kelvin double bridge** are the two types in this category.
- Balancing AC bridges is more difficult than DC bridges , since reactive components are also involved in AC bridges.
- In bridge circuits, a small difference in the imbalance current can be detected by a sensitive galvanometer and hence measurement, accuracy, and precision improves.
- Bridge circuits are analogous to difference amplifiers, wherein a small change in the input compared to the reference signal is amplified.
- AC bridges are frequency dependent, wherein the variation in supply frequency in addition to the voltage can affect the measurement.

DC Bridges
(A) Wheatstone Bridge

- The Wheatstone bridge is the most commonly used circuit for measurement of medium range resistances. few Ω to hundred KΩ or several MΩ
- It consists of four resistance arms, together with a battery (voltage source) and a galvanometer or a sensitive current meter **(null detector)**.



DC Bridges
(A) Wheatstone Bridge

- Construction:

- Arms AC and AD are called ratio arm .
- The value of unknown Rx (R_4) depends on the ratio of the elements (R_1 and R_2) connected in these arms.
- Arm CD is called standard arm . A standard precision element is connected in this arm.
- The unknown element is connected in the arm BD.
- The bridge is said to be balanced when the potential difference between points C and D is zero.

DC Bridges
(A) Wheatstone Bridge

- Operation:

- When the bridge is at balance:

$$I_1 \ R_1 = I_2 \ R_2 \tag{1}$$

$$I_1 = I_3 = \frac{E}{R_1 + R_3} \tag{2}$$

$$I_2 = I_4 = \frac{E}{R_2 + R_4} \tag{3}$$

- Substituting (2) and (3) into (1) and simplifying the resulting expression. R_4, the unknown element (R_x) , is derived as:

$$R_4 = \left(\frac{R_2}{R_1}\right) \ R_3 \tag{4}$$

(A) Wheatstone Bridge

- Measurement Errors

Wheatstone bridge is a fairly convenient and accurate method for measuring resistance. However, it is not free from errors as listed below:

- Discrepancies between the true and marked values of resistances of the three known arms can introduce errors in measurement (tolerance).
- Inaccuracy of the balance point due to insufficient sensitivity of the galvanometer may result in false null points (instrumental error).
- Bridge resistances may change due to self-heating resulting in error in measurement calculations.
- Thermal electromotive forces (emfs) in the bridge circuit can also affect balancing of the bridge. This arises because of dissimilar metals in contact with one another in making connections. The effect is significant for low values of R_x.

- **Measurement Errors**

- Errors may creep into measurement due to resistances of leads and contacts (the wires used for connections in the circuit). This effect is however, negligible unless the unknown resistance is of very low value.
- There may also be personal errors in finding the proper null point, taking readings,or during calculations (gross error).

DC Bridges
(A) Wheatstone Bridge

- **Avoid/Reduce Measurement Errors**
  - Errors due to inaccuracies in values of standard resistors and insufficient sensitivity of galvanometer can be eliminated by using good quality resistors and galvanometer.
  - Temperature dependent change of resistance due to self-heating can be minimised by performing the measurement within as short time as possible.
  - To minimize thermal emf, some sensitive galvanometers employ all-copper systems (i.e., copper coils as well as copper suspensions), so that there is no junction of dissimilar metals to produce thermal emf.
  - The effect of thermal emf can be balanced out in practice by adding a reversing switch in the circuit between the battery and the bridge, then making the bridge balance for each polarity and averaging the two results.

DC Bridges
(A) Wheatstone Bridge

The idea of a thermocouple is based on three principles of effect discovered by Seebeck, Peltier, and Thomson.

Seebeck effect:

The Seebeck effect happens when two different or unlike metals are joined together at two junctions and an electromotive force (emf) is generated at the two junctions, which is different for different types of metals.

Peltier effect:

An emf is generated in a circuit when two dissimilar metals are joined to form two junctions due to the different temperatures of the two junctions of the circuit.

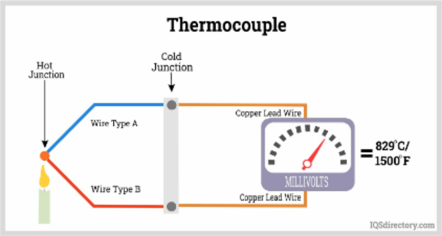
Thomson effect:

The Thomson effect is when heat is absorbed along the length of a rod whose ends are at different temperatures. The temperature of the heat is associated with the flow of current to the temperature along the rod.

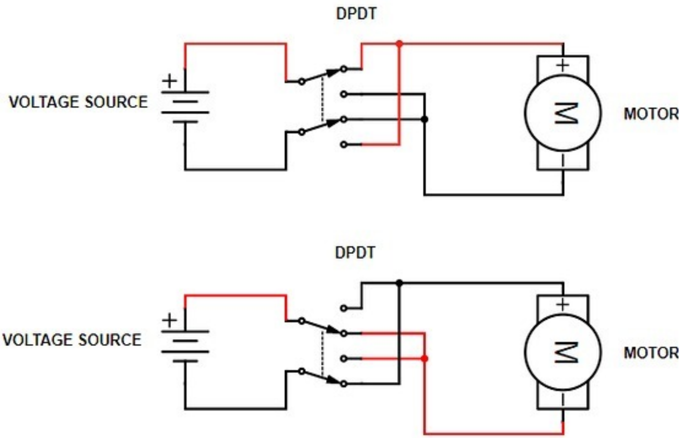
(A) Wheatstone Bridge

Describing How a Thermocouple Works

The circuit of a thermocouple is shown in the image below, where A and B are two dissimilar wires that are joined to form a junction. The two junctions are at different temperatures to generate the Peltier emf in the circuit, which is the function of the temperatures of two junctions.



DC Bridges
(A) Wheatstone Bridge



Reverse Switch

DC Bridges
(B) Kelvin double bridge

- Wheatstone Bridges used for measurement of medium resistances are not suitable for measurement of low resistances.
- This is due to the fact that resistances of leads and contacts, though small, are appreciable in comparison to the low resistances under measurement.
- For example, a contact resistance of 0.001 Ω causes a negligible error when a medium resistance of value say, 100 Ω is being measured, but the same contact resistance would cause an error of 10% while measuring a low resistance of value 0. 01 Ω.

DC Bridges
(B) Kelvin double bridge

- Kelvin's double-bridge bridge is a modification of the Wheatstone bridge circuit.
- This is used usually to measure very low values of resistance in the range 0.00001 Ω to 1 Ω.
- The effect of contact resistances, and the resistances of the wires are also taken into account in the analysis of the bridge circuit.
- Thus, Kelvin's bridge overcomes the limitations of Wheatstone's bridge in determining very low values of resistances.

DC Bridges
(B) Kelvin double bridge

How Kelvin's bridge outperforms the Wheatstone bridge.

- R_y represents the resistance of the connecting lead from R3 to Rx.
- The galvanometer can be connected to point m or point n.
- If it is connected to m, the resistance of the connecting lead Ry is added to the unknown Rx resulting in too high indication for Rx.
- If it is connected to point n, Ry is added to arm R_3, and the resulting resistance R_x will be lower than the correct value.

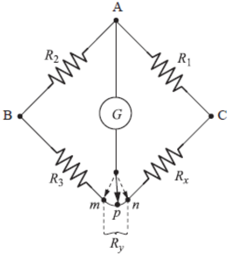


Figure: Wheatstone bridge with resistance R_y of the lead from m to n.

(B) Kelvin double bridge

If the galvanometer is connected to point p, in between m and n, in such a way that the ratio of resistances from n to p and from m to p equals the ratio of resistors R_1 and R_2.

$$\frac{R_{np}}{R_{mp}} = \frac{R_1}{R_2} \tag{5}$$

- The balance equation is:

$$\frac{R_x + R_{np}}{R_3 + R_{mp}} = \frac{R_1}{R_2}$$

$$R_x + R_{np} = \frac{R_1}{R_2}\left(R_3 + R_{mp}\right) \tag{6}$$

DC Bridges
(B) Kelvin double bridge

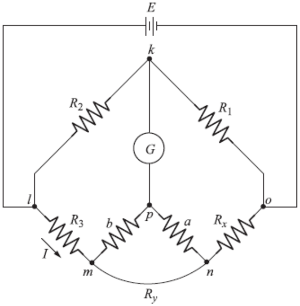
- Substitute (5) into (6), the simplified form is:

$$R_x = \left(\frac{R_1}{R_2}\right) R_3 \tag{7}$$

- Equation (7) is the same as the one obtained for the Wheatstone bridge.
- This shows that the effect of the resistance of the connecting lead from point m to point n has been eliminated by connecting the galvanometer to the intermediate position p.
- Based on this principle, Kelvin's double bridge, which is known as the Kelvin bridge is constructed.

DC Bridges
(B) Kelvin double bridge

- Kelvin's bridge circuit has two additional arms; hence, it is also known as **Kelvin double bridge**.
- The second set of arms *a* and *b* in the diagram connect the galvanometer points to *p* between *m* and *n*.
- It eliminates the effect of the yoke resistance *Ry*.



Lecture References

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