INSTRUMENTATION (II/II)

Course Code: ENEX - 252
(Module#2)

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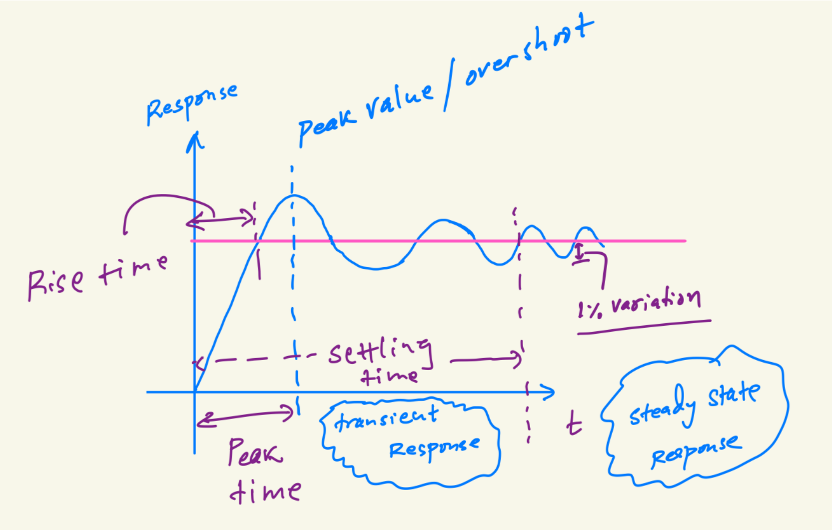
✓ Class Outline

Introduction

Theory of measurement

- The theory of measurement refers to the scientific principles and methodologies used to obtain quantitative information about physical variables using instruments.
- It is a crucial part of electrical, electronics, and mechanical engineering making measured value less erroneous.
- making error less measurement requires knowledge of characteristics and operations of instrument, basic laws to handle instrument, and cause of error.
- Therefore, study of characteristics of instruments includes
  - ✔ Error and its analysis,
  - ✔ Statistical analysis and
  - ✔ Error minimization

Static and Dynamic Performance



Static and Dynamic Performance

- Immediately after input is applied, the response does not take its expected value.
- Response passes through a period where it changes its value with time – transient period/response.
- The behavior during the period is – **Dynamic Characteristics**.
- After transient period, the response takes its value either fluctuation with acceptable variation or constant value – steady state period
- The behavior during the period is – **Static Characteristics**.

Statistical Performance Parameters

Static Characteristics

- Statistical parameters are studied during the steady-state of a system, not the transient phase.
- The system output is stable, so variations are due to **measurement noise**, **repeatability**, or **bias** — ideal for assessing accuracy and precision.
    1. Accuracy
    2. Precision or Repeatability
    3. Resolution
    4. Sensitivity
    5. Linearity

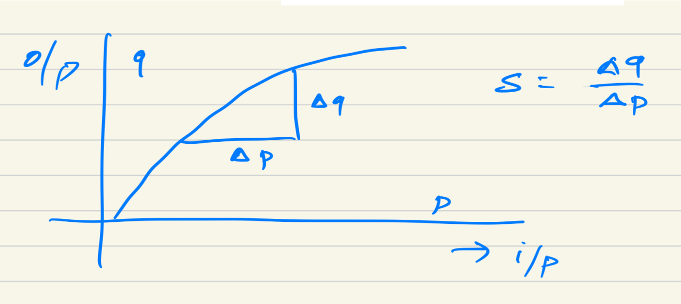
Statistical Performance Parameters

1. Accuracy: | Static Characteristics
   - Closeness of a measurement to the true or accepted value.
2. Precision or repeatability: | Static Characteristics
   - it is measure of consistency, how consistently a measurement system gives the same output for the same input under unchanged conditions.
3. Resolution: | Static Characteristics
   - maximum change in input for which there is no output changed
   - the minimum change in input for which there is detectable changes occur in output.

Statistical Performance Parameters

❹ Sensitivity: | Static Characteristics

- ratio of change in output to a change in input; it measures how responsive the system is.
- when the curve is linear than sensitivity is constant.



Statistical Performance Parameters

❺ Linearity: | Static Characteristics

- linear system means constant sensitivity; it defines the reproduceable characteristics. $y = mx + c$
- That is, how well the output follows a straight-line relationship with the input across the entire range.

Dynamic Performance Parameters

Dynamic Characteristics

- it describes how the system behaves when the measured quantity (input) changes with time.
- they are important when the system is subjected to time-varying signals and response is not instantaneous.

  1. Response time,
  2. Time Constant
  3. Frequency Response
  4. bandwidth
  5. Rise time
  6. Delay time

Dynamic Performance Parameters

❶ <u>Response Time:</u> | Dynamic Characteristics

- In measurement systems, unless explicitly stated otherwise, response time is typically the total time required to reach the steady state (settling time), not just the time to begin responding.

❷ <u>Time Constat:</u> | Dynamic Characteristics

- Time it takes for the system's response to reach 63.2% of its final value after a step input

❸ <u>Bandwidth:</u> | Dynamic Characteristics

- Frequency range over which the system accurately responds

Dynamic Performance Parameters

❹ Frequence Response: | Dynamic Characteristics

- It describes how the system behaves when subjected to sinusoidal inputs of varying frequencies.

Amplitude Ratio (Gain)

- The ratio of the output signal amplitude to the input signal amplitude as a function of frequency.

Phase Shift

- The delay (in degrees or radians) between the input and output signals.

Dynamic Performance Parameters

❺ Rise Time: | Dynamic Characteristics

- Time taken to rise from 10% to 90% of the final value
- Short rise time means a faster system response to inputs.

❻ Delay Time: | Dynamic Characteristics

- Time between the application of input and the beginning of the output response
- Delays can lead to instability or lag in feedback systems.

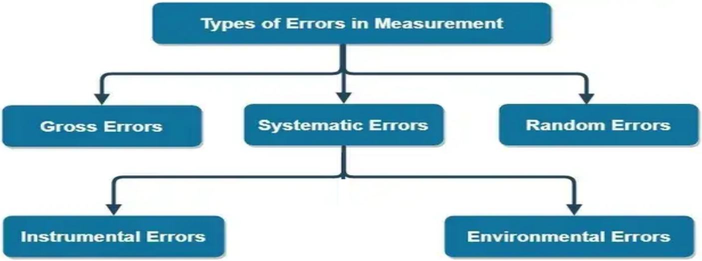
Error in Measurement

Error in Measurement

- it is the deviation of the measuredvalue (M.V) from the true value (T.V) of the quantity under measurement.
- so error estimate:

$$error = \frac{true\ value - measured\ value}{true\ value} x100\%$$

- Errors may come from different sources and usually classified to be three main types



Error in Measurement

Gross Error: | Error in Measurement

✔ is the error due to users:

error in calculation,

error in observation,

error in connections,

error in placement

Corrective Methods:

Careful measurement

At least three measurement fo the same quantity by different users.

Error in Measurement

Sytematic Error: | Error in Measurement

1. **Instrumental Error:**

    errors are due to

    short-coming of instruments,

    less accuracy in scale calibration

    errors due to defective parts

    improper tension in spring.

    Corrective Methods:

    use of standard instrument

    re-calibration or correct scaling

    use of correlation factors

Error in Measurement

Sytematic Error: | Error in Measurement

2. **Environmental Error:**

   variation in temperature, humidity

   error due to external electro-static/magnetic field.

   Corrective Methods:

   measurement in air-conditioned room

   casing for pressure and humidity effect

   use of shielding

Error in Measurement

Random Error: | Error in Measurement

✔ cause of error is unknown

this type of error can't be corrected

Corrective Methods:

use of statistical analysis – mean (arithmetic)

use the statistical analysis only after minimizing gross error and systematic error

Random Error: | Error in Measurement

✔ **Statistical Analysis:**

arithmetic mean

deviation

average deviation ($\sim$ zero)

standard deviation / RMS (σ)

variance (v)

Error in Measurement

Summary of Error: | Error in Measurement

Error Type	Crucial When	Why Critical
Gross	Due to human mistakes or negligence	Often large errors; easily preventable
Systematic	When left undetected in long-term measurements or automated systems	Leads to consistently wrong decisions
Random	In ultra-precise systems (e.g., quantum sensors, nanotech)	Affects resolution; can be minimized but not avoided

Errors in Measurement

What is next?

Explore more on:

- ✔ What are the different methods to measure low resistance? see detailed circuit diagram on ammeter-voltmeter method.
- ✔ What is AC/DC bridge? detailed of circuit diagram and mathematics.
- ✔ block diagram and basic relations of arm parameters.
  1. Wheat-stone bridge,
  2. maxwell's bridge,
  3. Schering's bridge

Measurement of Resistance

Low Resistance Measurement

- there are three types of methods to measure low resistance
    1. Ammeter - Voltmeter method
    2. Kelvin's double bridge method
    3. Potentio-meter method

Measurement of Resistance

Ammeter-Voltmeter method: | Low Resistance Measurement

- Consider the following circuit diagram:
- measure of Resistance

$$R_m = \frac{V}{I} \quad \rightarrow \quad R = R_m\left[1 + \frac{R_m}{R_v}\right]$$

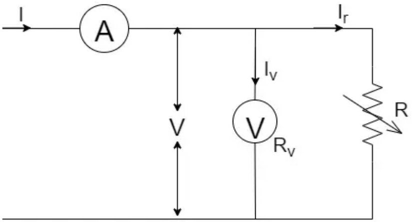


Fig. 1 Measurement of resistance by ammeter-voltmeter method

Measurement of Resistance

Ammeter-Voltmeter method: | Low Resistance Measurement

- Consider the following circuit diagram:

measure of Resistance

$$R_m = \frac{V}{I}$$

$$= \frac{V}{I_r + I_v}$$

$$= \frac{V}{\frac{V}{R} + \frac{V}{R_v}}$$

$$= \frac{R}{1 + \frac{R}{R_v}}$$

True of Resistance

$$R = \frac{V}{I_r}$$

$$= \frac{V}{I - I_v} = \frac{V}{I - \frac{V}{R_v}}$$

$$= \frac{V}{I\left(1 - \frac{V}{R_v x \ I}\right)}$$

$$R = \frac{R_m}{1 - \frac{R_m}{R_v}}$$

Measurement of Resistance

Wheatstone Bridge – DC Bridge

- A very important circuit used to measure medium resistance.

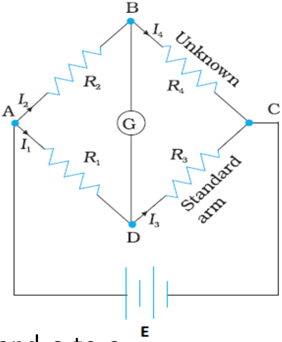
For balanced circuit,

galvanometer current is zero

$I_1 R_1 = I_2 R_2$ ....(a)

$I_1 = I_3 = \frac{E}{R_1 + R_3}$ ......(b)

$I_2 = I_4 = \frac{E}{R_2 + R_4}$ ......(c)



Substituting I_1 and I_2 from b and c to a

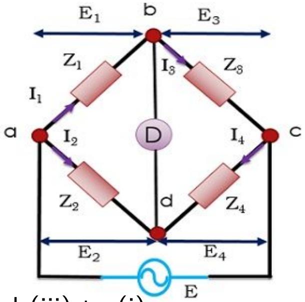
$R_1 R_4 = R_2 R_3 \rightarrow R_4 = \frac{R_2 R_3}{R_4}$

Measurement of Impedance Components

AC Bridge

- when excitation voltage or current to the bridge circuit is alternating, the bridge is ac bridge;
- the ac bridge circuit is used to measure impedance components such as inductance, capacitance, loss factor.

✔ For balanced circuit,
current through Detector is zero



$I_1 Z_1 = I_2 Z_2$ ....(i)

$I_1 = I_3 = \frac{E}{Z_1+Z_3}$ ......(ii)

$I_2 = I_4 = \frac{E}{Z_2+Z_4}$ ......(iii)

Substituting I_1 and I_2 from (ii) and (iii) to (i)

$Z_1 Z_4 = Z_2 Z_3$

Measurement of Impedance Components

AC Bridge

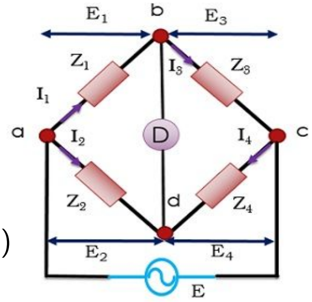
✔ When considered polar form of the impedance;

1. the product of magnitude of any two opposite arms impedance must be equal to the product of magnitude of other two arm's impedance.
2. the sum of phase angle of any two opposite arm impedance must be equal to that of other two.

✔ For balanced circuit,
current through Detector is zero

$Z_1 Z_4 = Z_2 Z_3$.......(iv)

$$|Z_1||Z_4|\angle(\theta_1 + \theta_4) = |Z_2||Z_3|\angle(\theta_2 + \theta_3)$$



Measurement of Impedance Components

Maxwell's Bridge – AC Bridge

- Inductance L_x is measured in terms of capacitance known.

From the circuit diagram:

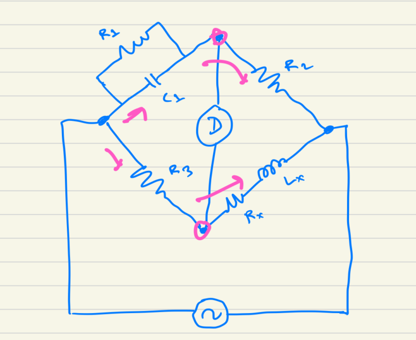
$$Z_2 = R_2\ \angle 0$$

$$Z_x = R_x + jX_L$$

$$Z_x = R_x + jwL_x$$

$$Z_3 = R_3\ \angle 0$$

$$Y_1 = \frac{1}{R_1} + jwc_1$$



Measurement of Impedance Components

Maxwell's Bridge – AC Bridge

- Inductance L_x is measured in terms of capacitance known.

For balanced AC bridge:

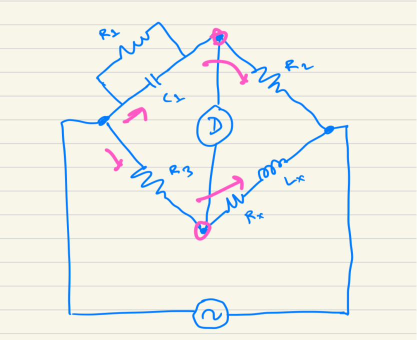
$$Z_1 Z_x = Z_2 Z_3$$

$$Z_x = \frac{Z_2 Z_3}{Z_1} \quad \left(Y_1 = \frac{1}{Z_1}\right)$$

$$Z_x = R_2 R_3 \left(\frac{1}{R_1} + jwc_1\right)$$

$$R_x + jwL_x = R_2 R_3 \left(\frac{1}{R_1} + jwc_1\right)$$

$$R_x + jwL_x = \frac{R_2}{R_1} R_3 + jwR_2 R_3 c_1$$



➜ Equating real and imaginary parts:

$$R_x = \frac{R2}{R_1} R_3 ....(i) \qquad L_x = R_2 R_3 c_1 ....(ii)$$

Schering's Bridge – AC Bridge

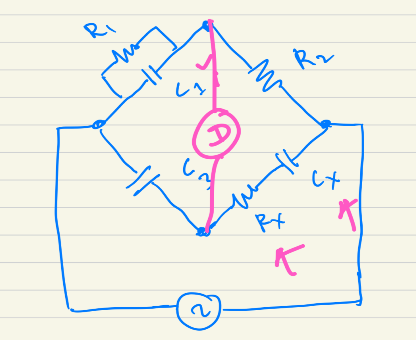
- A very important circuit used to measure Capacitance.

$$Y_1 = \frac{1}{R_1} + jwc_1$$

$$Z_2 = R_2$$

$$Z_x = R_x - j\frac{1}{wc_x}$$

$$Z_3 = -j\frac{1}{wc_3}$$



Measurement of Impedance Components

Schering's Bridge – AC Bridge

- A very important circuit used to measure Capacitance.

For balanced circuit,

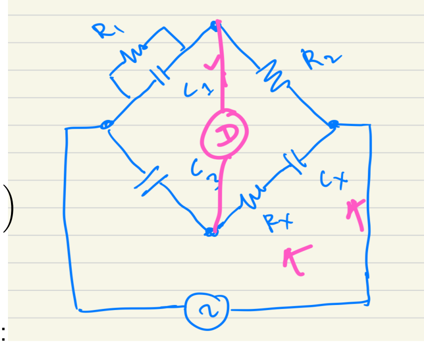
Detector current is zero

$$Z_1 Z_x = Z_2 Z_3$$

$$Z_x = Z_2 Z_3 Y_1$$

$$R_x - j\frac{1}{wc_x} = R_2\left(-\frac{j}{wc_3}\right)\left(\frac{1}{R_1} + jwc_1\right)$$

$$R_x - j\frac{1}{wc_x} = -j\frac{R_2}{wR_1 c_3} + R_2\frac{c_1}{c_3}$$



➜ Equating real and imaginary parts:

$$R_x = \frac{c_1}{c_3} R_2 ....(i) \qquad c_x = \frac{R_1}{R_2} c_3 ....(ii)$$

Maxwell's and Schering's Bridge

Comparative block Diagram

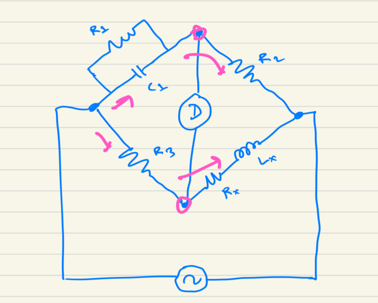


Fig. 2 Maxwell's Bridge

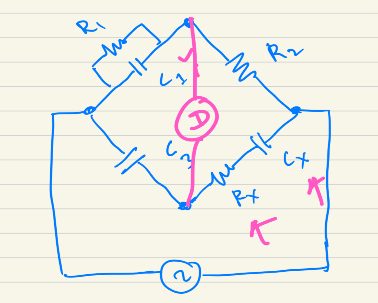


Fig. 3 Schering's Bridge

As you go Assignment

Assignment Module#2 is available at MS-Team.

Submission Deadline: 30th May 2025 (*Before 3:00 PM*)