Electronics Measurement and Instrumentation

Dr. Rahul Meshram
Assistant Prof.
ECE Dept.
IIIT Allahabad
Email: rhmeshram@iiita.ac.in

5 Aug. 2021

Warning: These slides are not complete study material, many details are not provided in slides. To good understanding of topics, students are expect to read reference texts mention in the class.

- Why do we want to study Electronics measurement and instrumentation?

References

- H. S. Kalsi, “Electronic Instrumentation,” 2nd Edition, The McGrow-Hill
- David A Bell, “Electronic Instrument and Measurement,” 2nd Edition.
- A.K. Sawhney, Puneet Sawhney, “A Course In Electrical And Electronic Measurements and Instrumentation,” Dhanpat Rai Publications,

Course Content

Component 1:

- Unit 1: Theory Of Errors: Accuracy & precision, Systematic & random errors, Modeling of errors, Combination of errors.
- Unit 2: Electronic Instruments For Measuring Basic Parameters: Electronic Voltmeters, Shielding & grounding, CTPT. Oscilloscopes: Basic construction, working and use of it. Kinds of Oscilloscope.

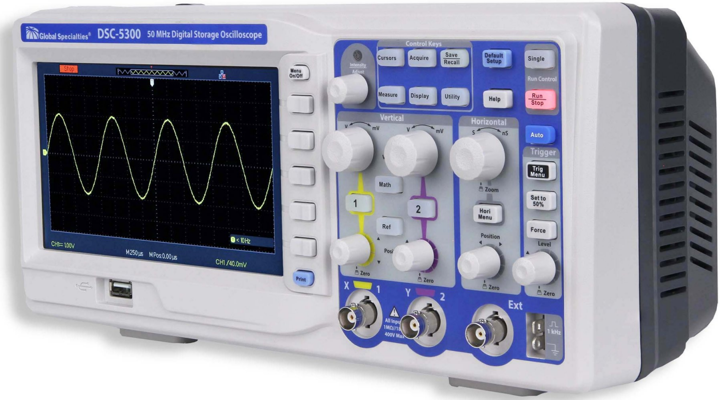
Component 2:

- Unit 3: Signal Generation and measurement techniques: Sine wave generators, Harmonic distortion analyzer, Spectrum analyzer.
- Unit 4: Transducers Classification, Selection Criteria, Characteristics, Construction, Application of following of different transducers.

- Lecture Timing:
  Monday 9 — 10 am
  Wednesday 1200 —1300
- Practical: Tuesday 1100—1300

Voltmeter: What is working principle?

Oscilloscope: How it works?



Signal generator: How it works?

Spectrum analyzer: How it works?

Hormonic-distortion-analyzer: How it works?

Pressure transducer: How it works?

Transducer in Medical: How it works?

Any Questions?

Topic this lecture

- Theory of Errors: Accuracy & precision, Systematic & random errors, Modeling of errors, Combination of errors

Characteristics of instrument

- What is an instrument?
- What is measurement?
- What is accuracy?
- What is resolution?
- What is precision?
- What is error?
- What is sensitivity?

Characteristics

- Instrument: A device or mechanism used to determine the present value of the quantity or measurement
- Measurement: The process of determining the amount, degree or capacity of comparison with acceptable standards of the systems
- Accuracy: The degree of closeness of measurement compared to the expected value.
- Resolution: A smallest change in the measured variable to which instrument will respond

Characteristics cont.

- Precision: A measure of consistency or repeatability of measurements
- Expected value: The design value, i.e., most probable value that calculations indicate one should expect to measure
- Error: The deviation of true value from desired value
- Sensitivity: The ratio of change in output of the instrument to a change in the input or measured variable

- Absolute Error: This is a difference between expected value of the variable and the measured value of variable, it is denoted by e

$$e = Y_n - X_n \tag{1}$$

Y_n is the expected value, X_n is the measured value

- Percentage Error:

$$\begin{aligned} \%\text{Error} &= \frac{\text{Absolutevalue}}{\text{Expectedvalue}} \times 100 \\ &= \frac{Y_n - X_n}{Y_n} \times 100 \end{aligned} \tag{2}$$

Error cont.

- Relative accuracy

$$A = 1 - \left| \frac{Y_n - X_n}{Y_n} \right| \tag{3}$$

- Accuracy expressed as % accuracy

$$a = A \times 100\% \tag{4}$$

- The precision:

$$P = 1 - \left| \frac{X_n - \overline{X}_n}{\overline{X}_n} \right| \tag{5}$$

X_n is value of the nth measurement,
$\overline{X}_n$ is an average set of measurement
Repeated set of measurements of same variable

Types of static error

- Gross error (human errors)
- Systematic errors: Instrumental errors, Environmental errors, Observational errors
- Random errors: Statistically analyzed

- Arithmetic mean:

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{6}$$

where, $\bar{x}$ arithmetic mean, x_n nth reading, n total number of readings

- Deviation from the Mean :

$$\begin{aligned} d_1 &= x_1 - \bar{x}, \\ d_2 &= x_2 - \bar{x}, \\ &\vdots \\ d_n &= x_n - \bar{x} \end{aligned}$$

Average Deviations

- It is an indication of the precision of the instruments used in measurement

$$
\begin{aligned}
D_{avg} &= \frac{|d_1| + |d_2| + |d_3| + \cdots + |d_n|}{n} \\
&= \frac{\sum_i^n |d_i|}{n}
\end{aligned} \tag{7}
$$

$|d_i|$ absolute value of deviation

Standard deviation

- For large n observations (measurements)

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n}} \tag{8}$$

- Small n observations (measurements), $n < 30$,

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \cdots + d_n^2}{n-1}} \tag{9}$$

Limiting errors

- Most manufacturers of measuring instruments specify accuracy within a certain % of full scale reading
- Manufacturer of a certain voltmeter may specify the instrument to be accurate within 2% with full scale deflection
- This specification is called as limiting error
- Reading less than full scale, the limiting error increases

Dynamic Characteristics

- Speed of response
- Fidelity
- Lag
- Dynamic error

Today's lecture

- Dynamic characteristics
- Bridges

Bridge Circuit

- Why do we want to study bridges?
- What is bridge circuit?

What is bridge circuit?

- It is a simple circuit consists of a network for four resistance arms forming a closed circuit, with dc source of current applied to two opposite junctions and a current detector.
- It is used for measuring component values such as R, L, C.
- It uses idea of null indication at the bridge balance $\rightarrow$ null detector.

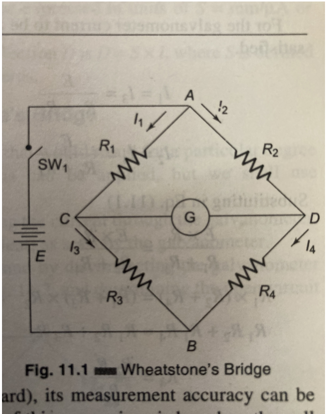


Fig. 11.1 Wheatstone's Bridge

Types of Bridges

- AC Bridge
  - Maxwell’s Bridge
  - Hay’s Bridge
  - Schering’s Bridge
  - Wein’s Bridge
  - Resonance Bridge
- DC Bridge
  - Wheatstone’s Bridge
  - Kelvin Bridge
  - Kelvin Double Bridge

DC Bridge: Wheatstone Bridge

- Measuring resistance and popular for laboratory use
- Balance condition: The bridge is balanced when there is no current through the galvanometer, or when the potential difference at points C and D is equal, i.e. the potential across the galvanometer is zero.

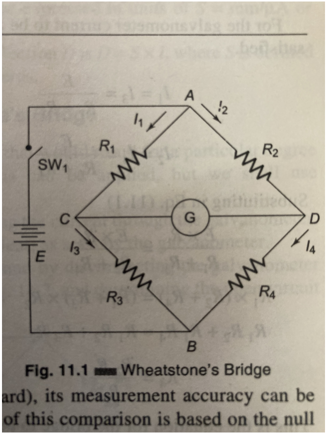


Fig. 11.1 Wheatstone's Bridge

Balance equation

- Balance equation:

$$I_1 R_1 = I_2 R_2 \tag{10}$$

- What is I_1, and I_2?

Balance equation

- Balance equation:

$$I_1 R_1 = I_2 R_2 \tag{10}$$

- What is I_1, and I_2?

Balance equation

- Balance equation:

$$I_1 R_1 = I_2 R_2 \tag{10}$$

- What is I_1, and I_2?
- For Galvanometer current to be zero,

$$I_1 = I_3 = \frac{E}{R_1 + R_3}$$
$$I_2 = I_4 = \frac{E}{R_2 + R_4}$$

Balance equation

- Balance equation:

$$I_1 R_1 = I_2 R_2 \tag{10}$$

- What is I_1, and I_2?
- For Galvanometer current to be zero,

$$I_1 = I_3 = \frac{E}{R_1 + R_3}$$
$$I_2 = I_4 = \frac{E}{R_2 + R_4}$$

- Substituting in balance equation

$$\frac{E \times R_1}{R_1 + R_3} = \frac{E \times R_2}{R_2 + R_4}$$
$$R_4 = \frac{R_2 R_3}{R_1}$$

Balance equation

- Balance equation:

$$I_1 R_1 = I_2 R_2 \tag{10}$$

- What is I_1, and I_2?
- For Galvanometer current to be zero,

$$I_1 = I_3 = \frac{E}{R_1 + R_3}$$
$$I_2 = I_4 = \frac{E}{R_2 + R_4}$$

- Substituting in balance equation

$$\frac{E \times R_1}{R_1 + R_3} = \frac{E \times R_2}{R_2 + R_4}$$
$$R_4 = \frac{R_2 R_3}{R_1}$$

- It is used to determine the unknown resistance.

Sensitivity of a Wheatstone Bridge

- Unbalanced condition: Current flows through galvanometer, causing deflection to its pointer
- The amount of deflection is a function of the sensitivity of the galvanometer. Sensitivity can be thought of as deflection per unit current.
- Can we analyze unbalanced Wheatstone Bridge? How?

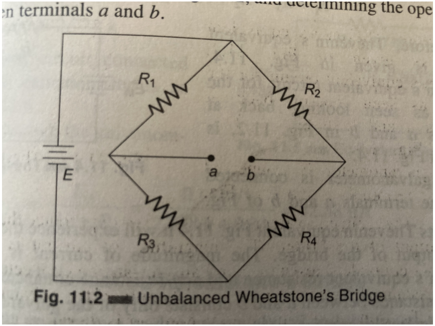


Fig. 11.2 Unbalanced Wheatstone's Bridge

looking into terminals *a* and *b*.
ry low, we treat it as 0 Ω. Thévenin's equiva
n Fig. 11.3.

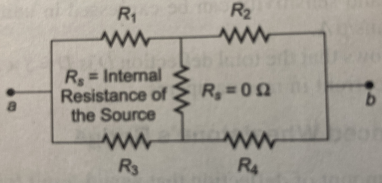
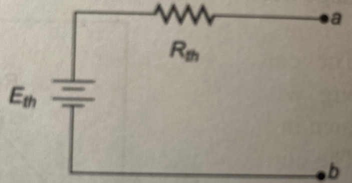


Fig. 11.3 — Thévenin's Resistance

e circuit is $R_1//R_3$ in series with $R_2//R_4$ i.e.

$$\frac{{}_2 R_4}{+ R_4}$$

ent
.4.
the
at
is



ed
ig.

Fig. 11.4 — Thévenin's Equivalent

11.4 it will experience the same deflection
magnitude of current is limited by both

Th
alon
shov
Th
eter

- Voltage at point a is $E_a = \frac{E \times R_3}{R_1 + R_3}$ and at point b is $E_b = \frac{E \times R_4}{R_2 + R_4}$.
- Difference between voltage at point a and b, this is also called as Thevenin's equaivalent voltage

$$\begin{aligned} E_{th} = E_{ab} &= E_a - E_b && (11) \\ &= E\left(\frac{R_3}{R_1 + R_3} - \frac{R_4}{R_2 + R_4}\right) && (12) \end{aligned}$$

- Thevenin's equivalent resistance

$$R_t h = \frac{R_1 R_3}{R_1 + R_3} + \frac{R_2 R_4}{R_2 + R_4} \tag{13}$$

- The deflection current in the galvanometer is $I_g = \frac{E_{th}}{R_{th} + R_g}$

Applications and Limitations of Wheatstone's Bridge

- Applications: Motor winding, transformer, to locate cable faults
- Limitations:
  - For low resistance measurement, the resistance of the leads and contacts becomes significant and introduces an error. This can be eliminated by Kelvin's Double bridge.
  - For high resistance measurements, the resistance presented by the bridge becomes so large that the galvanometer is insensitive to imbalance.
  - Another difficulty in Wheatstone's bridge is the change in resistance of the bridge arms due to the heating effect of current through the resistance.

Reading exercise

- Reading of Kelvin Bridge, page no. 356, Kelvin Double Bridge

Thank you