Describe the types of voltmeters, ammeters, ohmmeters and Dynamic characteristics of measuring systems

.

ELECTRONIC MEASUREMENT AND INSTRUMENTATION(AEC014)

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CO's	Course outcomes
CO1	Describe the types of voltmeters, ammeters, ohmmeters and Dynamic characteristics of measuring systems
CO2	Understand the different types of Oscilloscopes and their working principles.

COs	Course Outcomes
CO3	Understand the Different types of signal generators and signal analyzers and their working principles
CO4	Explore the different types of A.C. and DC Bridges and their operations
CO5	Demonstrate the different types of transducers and their principles and operations

UNIT I

INTRODUCTION TO MEASURING INSTRUMENTS

INTRODUCTION

- Measurement is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.

- Instrumentation is a technology of measurement which serves sciences, engineering, medicine and etc.

- Instrument is a device for determining the value or magnitude of a quantity or variable.

- Electronic instrument is based on electrical or electronic principles for its measurement functions.

PERFORMANCE CHARACTERISTICS

- Accuracy
- Resolution
- Precision
- Sensitivity
- Expected value
- Error

Measurement Error

Errors are classified as,

(1) Gross Error
(2) Systematic Error
(3) Random Error

1.Gross Error:- These error occurs due to the human mistakes in reading or using the instruments.

(a) It can be avoided by taking care while reading and recording the measurement data.

(b) Taking more than one reading of same quantity, at least three or more reading must be taken by different persons.

Systematic Errors

2.Systematic Errors:-

Systematic errors are divided into 3 categories those are instrumental errors, environmental errors and observational errors.

(a) Instrumental Errors:-

-> Instrumental Errors may be avoided by

(i) Selecting a suitable instrument for the particular measurement application.

(ii) Applying correction factors after determining the amount of instrumental errors.

(iii) Calibrating the instruments against a standard.

Systematic Errors

b) Environmental Errors:-

-> These errors may be avoided by

(i) Using the proper correction factor & information supplied by the manufacturer of the instrument.

(ii) Using the arrangement which will keep the surrounding condition constant like use of air condition, temperature controlled enclosures etc

(iii) Making the new calibration under the local conditions.

c). Observational Errors:-

-> These errors occur due to carelessness of operator while taking the reading. There are many sources of observational errors such as parallax error while reading a meter, wrong scale selection, the habit of individual observer etc.

3. Random Errors:- Some errors are still result, though the systematic and instrumental errors are reduced. The causes of such errors are unknown and hence, the errors are called random errors.

-> The random errors follow the laws of probability and hence, these errors can be analyzed statically and treated mathematically.

4. Absolute Error **5.Relative Error**

PRECISION

- The precision of a measurement is a quantitative or numerical indication of the closeness with which a repeated set of measurement of the same variable agree with the average set of measurements.

DC AND AC METER

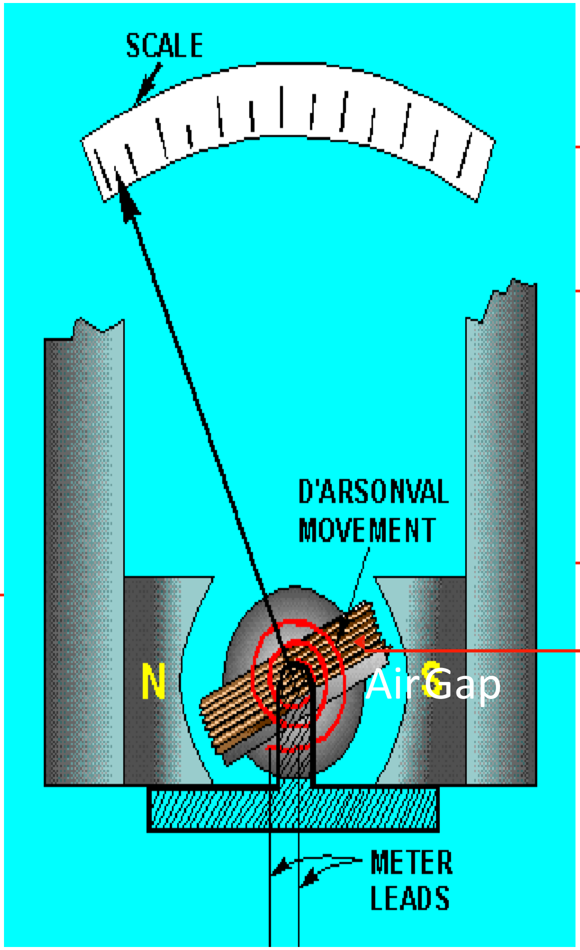
D’ARSORVAL METER MOVEMENT

- Also called Permanent-Magnet Moving Coil (PMMC).
- Based on the moving-coil galvanometer constructed by Jacques d’ Arsonval in 1881.

- Can be used to indicate the value of DC and AC quantity.
- Basic construction of modern PMMC can be seen in Figure .

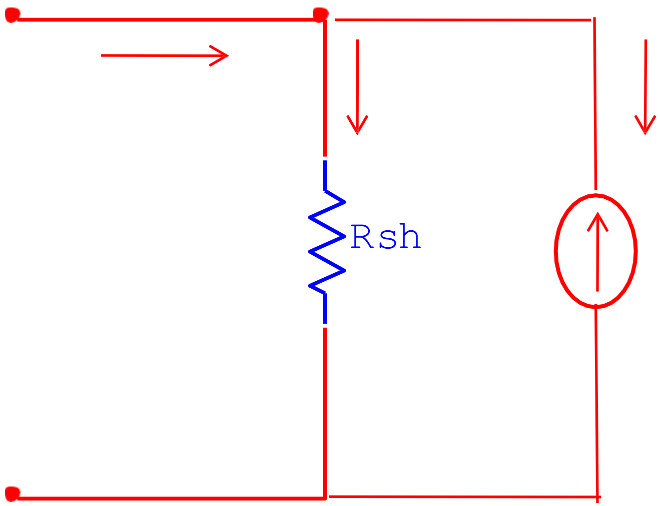
Operation of D„Arsonval Meter

- When current flows through the coil, the core will rotate.
- Amount of rotation is proportional to the amount of current flows through the coil.
- The meter requires low current (~50uA) for a full scale deflection, thus consumes very low power (25-200 uw).
- Its accuracy is about 2% -5% of full scale deflection


SCALE
D'ARSONVAL MOVEMENT
N
S
Air Gap
METER LEADS

DC AMMETER

- The PMMC galvanometer constitutes the basic movement of a dc ammeter.
- The coil winding of a basic movement is small and light, so it can carry only very small currents.
- A low value resistor (shunt resistor) is used in DC ammeter to measure large current.
- Basic DC ammeter:


Rsh

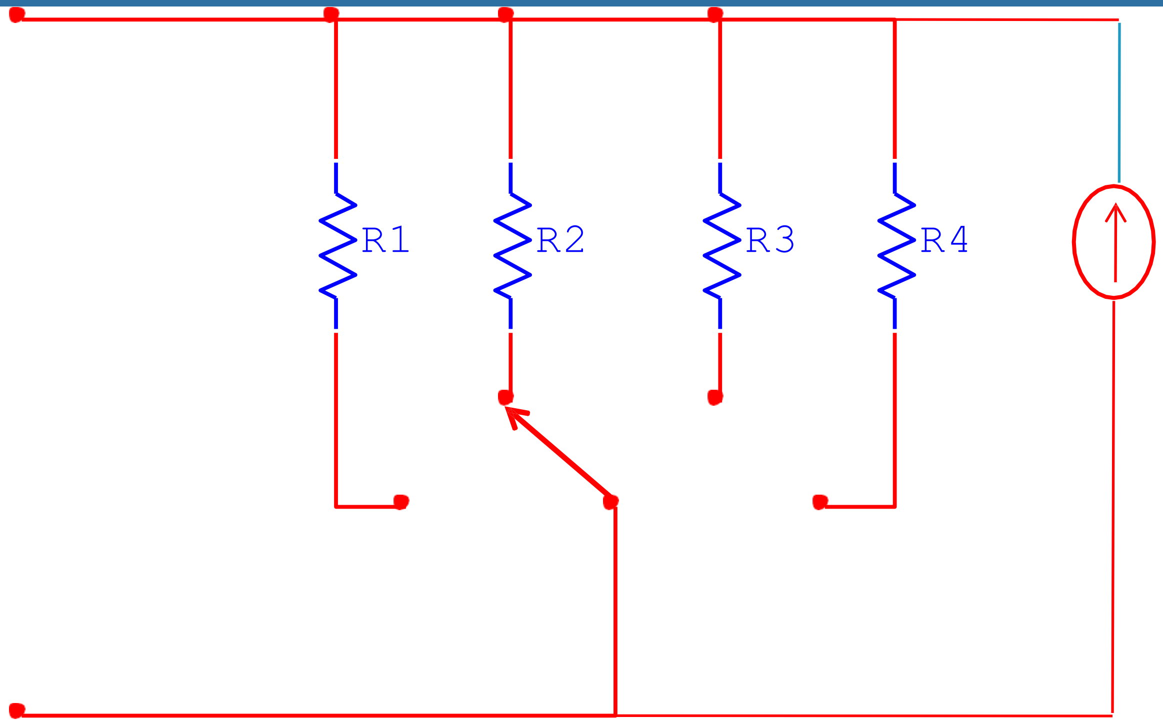
MULTIRANGE AMMETER

The range of the dc ammeter is extended by a number of shunts, selected by a range switch.

The resistors is placed in parallel to give different current ranges.

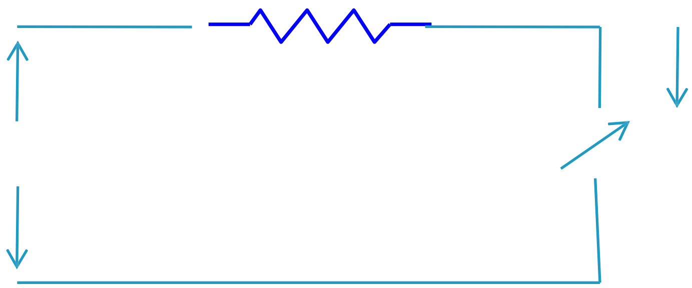
Switch S (multiposition switch) protects the meter movement from being damage during range changing.

Increase cost of the meter.


R1
R2
R3
R4

DC VOLTMETER

voltmeter by adding a series resistor (multiplier) as shown in Figure.



Im =full scale deflection current of the movement (Ifsd)

Rm=internal resistance of the movement

Rs =multiplier resistance

V =full range voltage of the instrument

- The PMMC galvanometer constitutes the basic movement of a dc ammeter.
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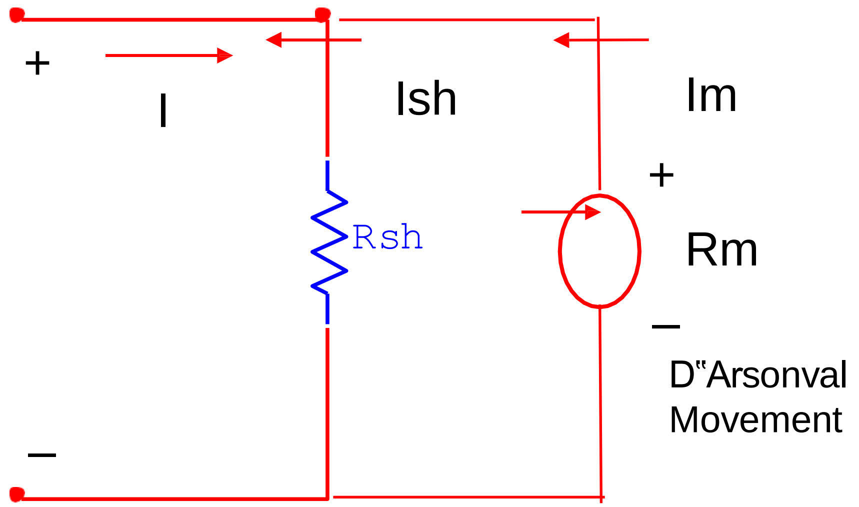


Figure 2.2: Basic DC Ammeter

$$I_{sh} R_{sh} = I_m R_m$$

$$I_{sh} = I - I_m$$

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

Rm = internal resistance of the movement

Rsh = shunt resistance

Ish =shunt current

Im = full scale deflection current of the movement

I = full scale current of the ammeter + shunt (i.e. total current)

MULTIRANGE AMMETER

- The range of the dc ammeter is extended by a number of shunts, selected by a range switch.
- The resistors is placed in parallel to give different current ranges.
- Switch S (multiposition switch) protects the meter movement from being damage during range changing.
- Increase cost of the meter.

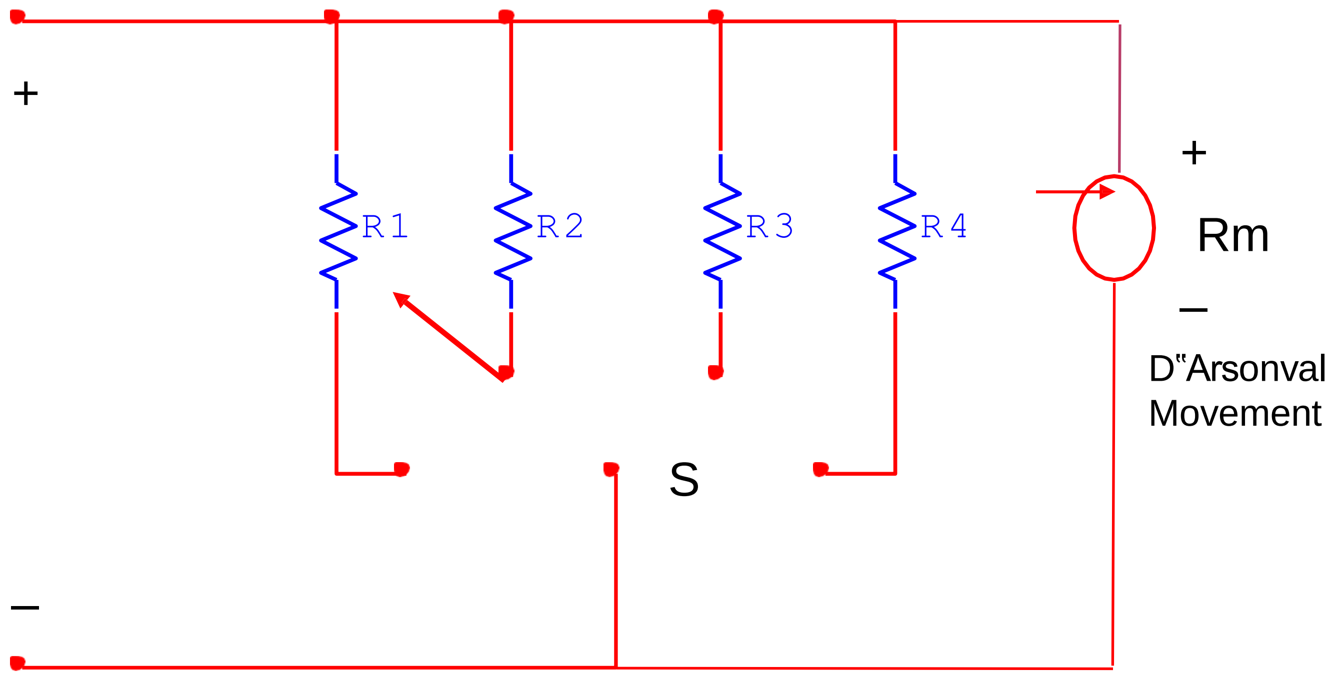


Figure 2.3: Multirange Ammeter

ARYTON SHUNT OR UNIVERSAL SHUNT

- Aryton shunt eliminates the possibility of having the meter in the circuit without a shunt.

- Reduce cost

- Position of the switch:

„1‟: Ra parallel with series combination of Rb, Rc and the meter movement. Current through the shunt is more than the current through the meter movement, thereby protecting the meter movement and reducing its sensitivity.

„2‟: Ra and Rb in parallel with the series combination of Rc and the meter movement. The current through the meter is more than the current through the shunt resistance.

„3‟: Ra, Rb and Rc in parallel with the meter. Maximum current flows through the meter movement and very little through the shunt. This will increase the sensitivity.

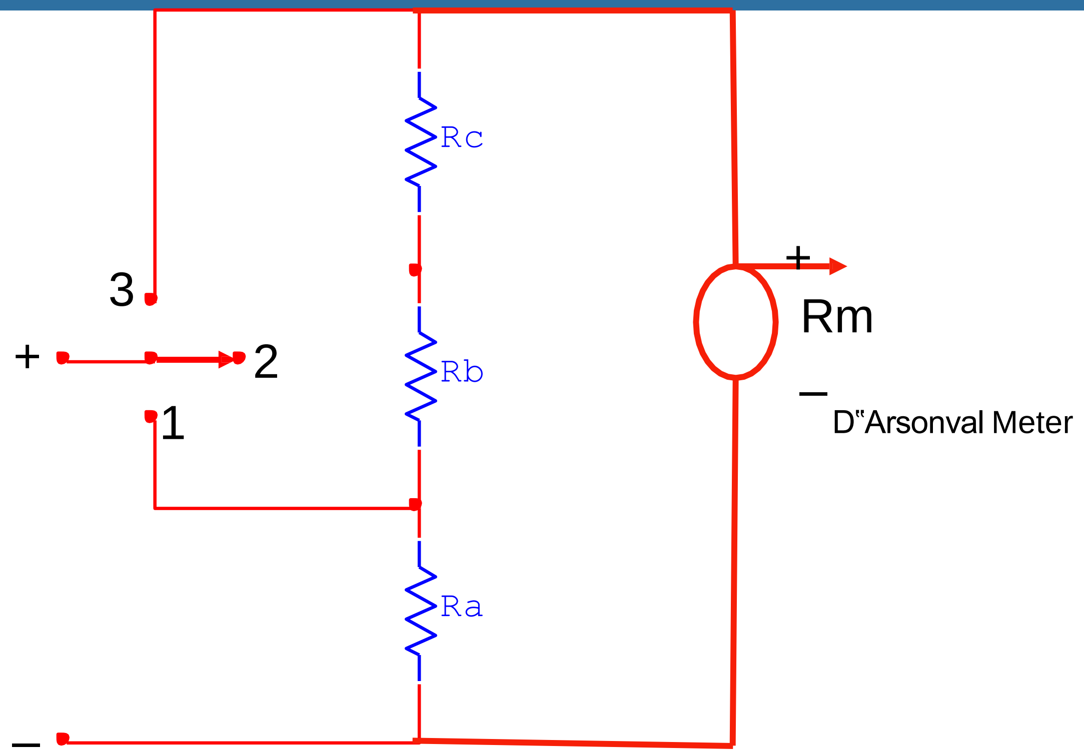
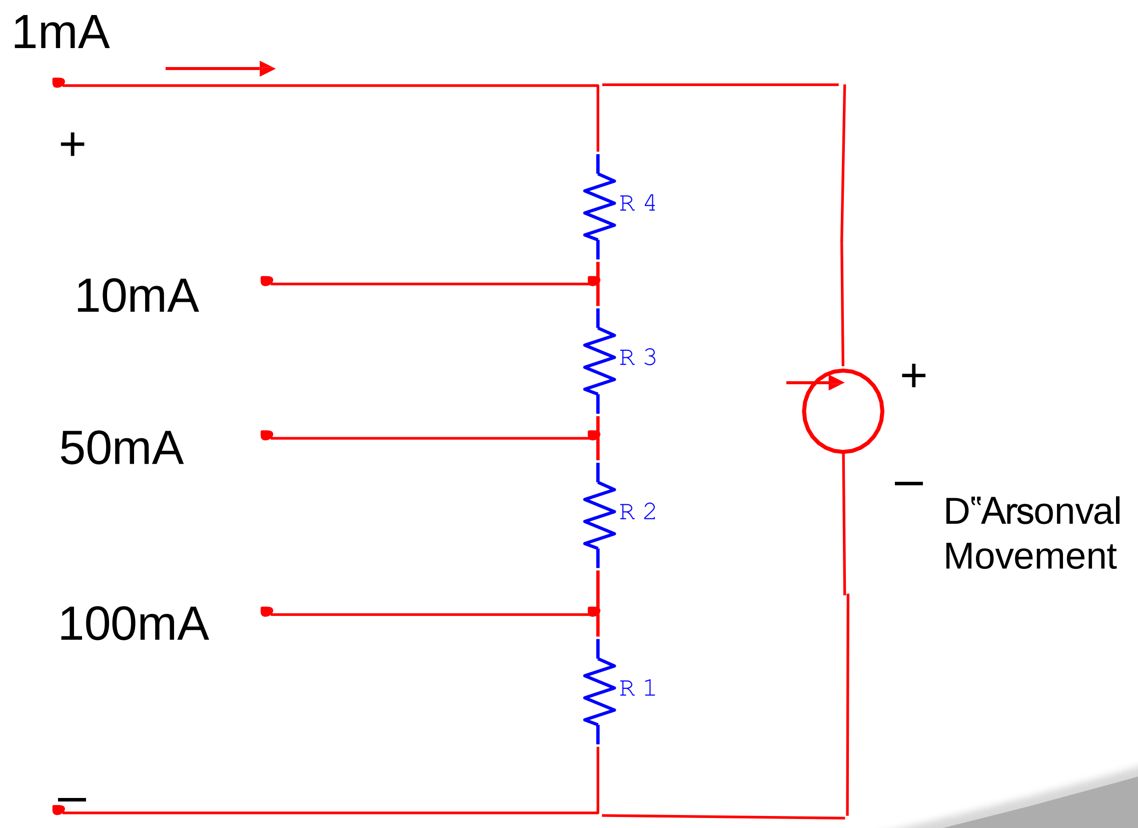


Figure 2.4: Aryton Shunt

EXAMPLE

- **Design an Aryton shunt to provide an ammeter with a current range of 0-1 mA, 10 mA, 50 mA and 100 mA. A D' Arsonval movement with an internal resistance of 100Ω and full scale current of 50 uA is used.**



REQUIREMENT OF A SHUNT

1) **Minimum Thermo Dielectric Voltage Drop**

Soldering of joint should not cause a voltage drop.

2) **Solderability**

-never connect an ammeter across a source of e.m.f

- observe the correct polarity

- when using the multirange meter, first use the highest current range.

BASIC METER AS A DC VOLTMETER

- To use the basic meter as a dc voltmeter, must know the amount of current (I_{fsd}) required to deflect the basic meter to full scale.

- The sensitivity is based on the fact that the full scale current should results whenever a certain amount of resistance is present in the meter circuit for each voltage applied.

$$S = \frac{1}{I_{fsd}}$$

EXAMPLE

Calculate the sensitivity of a 200 uA meter movement which is to be used as a dc voltmeter.

Solution:

$$S = \frac{1}{I_{fsd}} = \frac{1}{200uA} = 5k\Omega/V$$

DC VOLTMETER

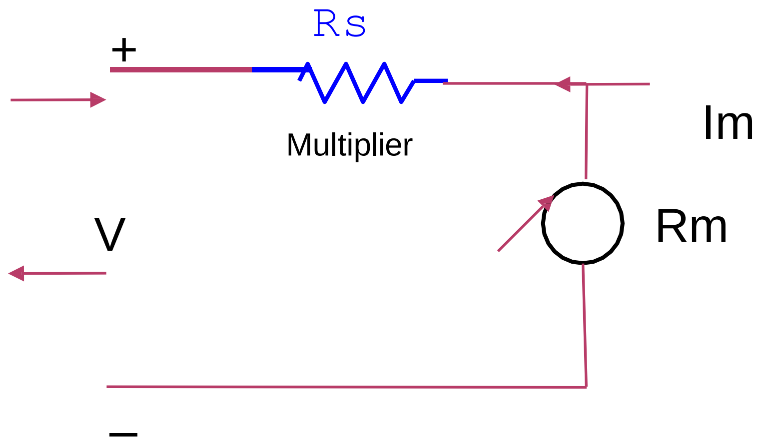


Figure : Basic DC Voltmeter

- From the circuit of Figure 2.5:

$$V = I_m (R_s + R_m)$$

$$R_s = \frac{V - I_m R_m}{I_m} = \frac{V}{I_m} - R_m$$

$$R_s = \frac{V}{I_m} - R_m$$

EXAMPLE

A basic D' Arsonval movement with a full-scale deflection of 50 uA and internal resistance of 500Ω is used as a DC voltmeter. Determine the value of the multiplier resistance needed to measure a voltage range of 0-10V.

Solution:

$$R_s = \frac{V}{I_m} - R_m = \frac{10V}{50uA} - 500\Omega = 199.5k\Omega$$

- Sensitivity and voltmeter range can be used to calculate the multiplier resistance, Rs of a DC voltmeter.

$$Rs=(S \times Range) - Rm$$

- From example 2.4:

Im= 50uA, Rm=500Ω, Range=10V

Sensitivity,

$$S = \frac{1}{I_m} = \frac{1}{50uA} = 20k\Omega / V$$

So, Rs = (20kΩ/V x 10V) – 500 Ω

= 199.5 kΩ

MULTI-RANGE VOLTMETER

- A DC voltmeter can be converted into a multirange voltmeter by connecting a number of resistors (multipliers) in series with the meter movement.
- A practical multi-range DC voltmeter is shown in Figure .

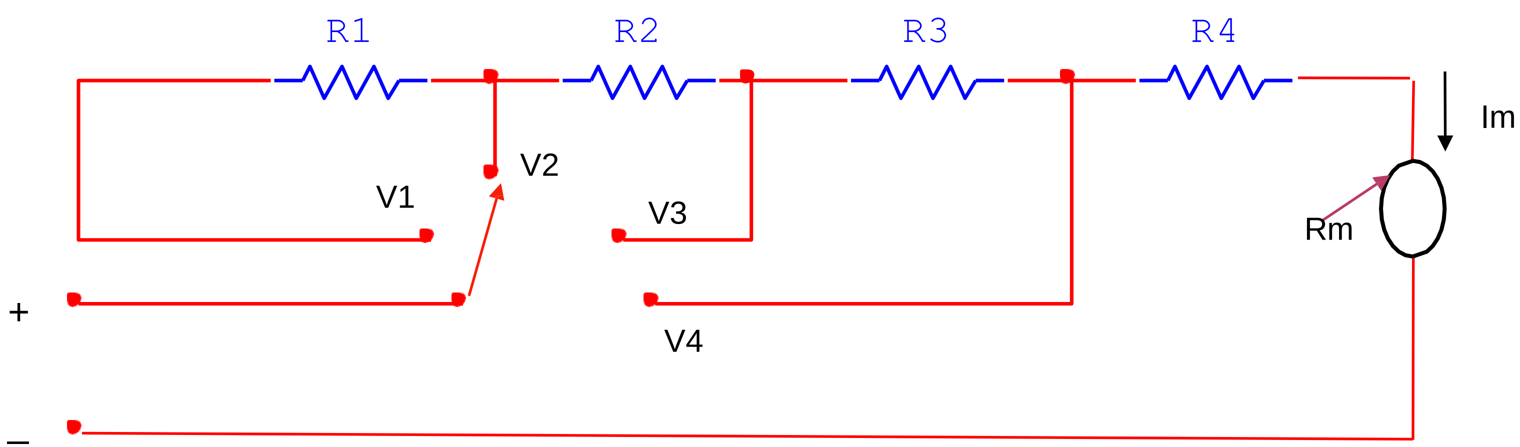


Figure : Multirange voltmeter

VOLTMETER LOADING EFFECTS

- When a voltmeter is used to measure the voltage across a circuit component, the voltmeter circuit itself is in parallel with the circuit component.
- Total resistance will decrease, so the voltage across component will also decrease. This is called voltmeter loading.
- The resulting error is called a loading error.
- The voltmeter loading can be reduced by using a high sensitivity voltmeter.

AMMETER INSERTION EFFECTS

- Inserting Ammeter in a circuit always increases the resistance of the circuit and, thus always reduces the current in the circuit. The expected current:

$$I_e = \frac{E}{R_1} \qquad (2\text{-}4)$$

- Placing the meter in series with R1 causes the current to reduce to a value equal to:

$$I_m = \frac{E}{R_1 + R_m} \qquad (2\text{-}5)$$

AMMETER INSERTION EFFECTS

- Dividing equation (2-5) by (2-4) yields:

$$\frac{I_m}{I_e} = \frac{R_1}{R_1 + R_m} \qquad (2\text{-}6)$$

- The Ammeter insertion error is given by :

$$\text{Insertion Error} = \left(1 - \frac{I_m}{I_e}\right) X\,100 \qquad (2\text{-}7)$$

OHMMETER (Series Type)

- Current flowing through meter movements depends on the magnitude of the unknown resistance
- The meter deflection is non-linearly related to the value of the unknown Resistance, R_x.
- A major drawback – as the internal voltage decreases, reduces the current and meter will not get zero Ohm.
- R_2 counteracts the voltage drop to achieve zero ohm. How do you get zero Ohm?

$$R_h = R_1 + (R_2 // R_m) = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

- R_1 and R_2 are determined by the value of $R_x = R_h$ where R_h = half of full scale deflection resistance.
- The total current of the circuit, $It=V/R_h$
- The shunt current through R2 is $I_2=I_t-I_{fsd}$

OHMMETER (Series Type)

- The voltage across the shunt, Vsh= Vm

So, $I_2 R_2 = I_{fsd} R_m$

Since $I_2 = I_t - I_{fsd}$

Then,

$$R_2 = \frac{I_{fsd} R_m}{I_t - I_{fsd}}$$

Since $I_t = V/R_h$

So,

$$R_2 = \frac{I_{fsd} R_m R_h}{V - I_{fsd} R_h}$$

$$R_1 = R_h - \frac{I_{fsd} R_m R_h}{V}$$

MULTI-RANGE OHMMETER

- Another method of achieving flexibility of a measuring instrument is by designing it to be in multi-range.
- Let us analyse the following examples. (figure 4.29 of your textbook)

MULTIMETER

- Multimeter consists of an ammeter, voltmeter and ohmmeter in one unit.
- It has a function switch to connect the appropriate circuit to the D'Arsonval movement.
- Fig.4.33 (in text book) shows DC miliammeter, DC voltmeter, AC voltmeter, microammeter and ohmmeter.

Digital Voltmeters

- The magnitude of voltage signals can be measured by various electrical indicating and test instruments, such as meters (both analogue and digital), the cathode ray oscilloscope and the digital storage oscilloscope.

- As well as signal-level voltages, many of these instruments can also measure higher-magnitude voltages, and this is indicated where appropriate.

•All types of digital meter are basically modified forms of the digital voltmeter (DVM), irrespective of the quantity that they are designed to measure.

•Digital meters designed to measure quantities other than voltage are in fact digital voltmeters that contain appropriate electrical circuits to convert current or resistance measurement signals into voltage signals.

•The binary nature of the output reading from a digital instrument can be readily applied to a display that is in the form of discrete numerals

ADVANTAGES

- Higher accuracy and resolution
- Greater speed
- No parallax
- Reduced human error
- Compatibility with other digital equipment for further processing and recording

VARIETIES OF DVM

•Digital voltmeters differ mainly in the technique used to effect the analogue-to-digital conversion between the measured analogue voltage and the output digital reading.

•As a general rule, the more expensive and complicated conversion methods achieve a faster conversion speed

DVM differ in the following ways

- Number of digits
- Number of measurements
- Accuracy
- Speed of reading
- Digital output of several types

CHARACTERISTICS FEATURES OF DVMs

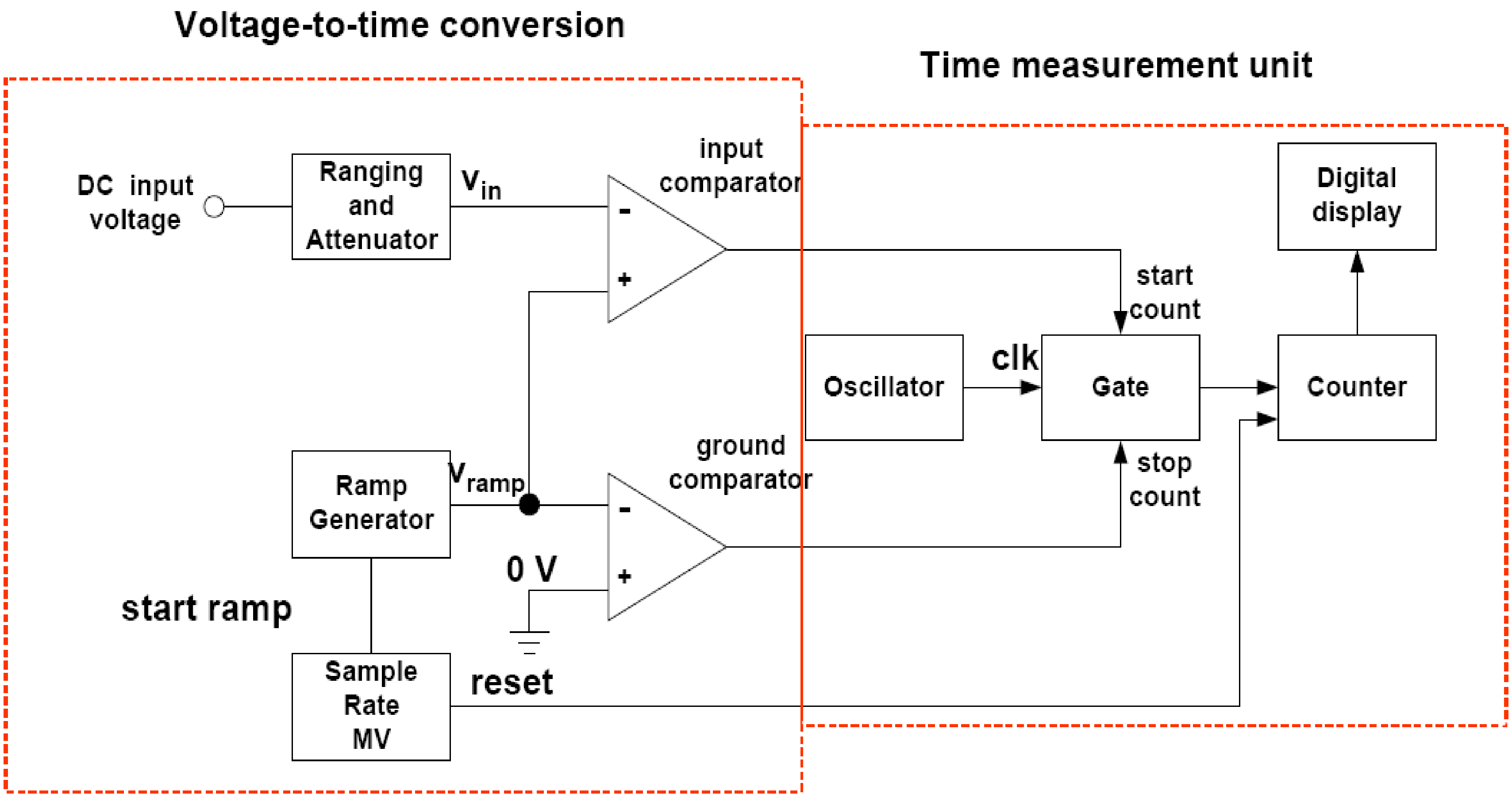
- Input Range: From ±1.000 to ±1000V with automatic range selection and overload indication
- Absolute accuracy: As high as ±0.005% of the reading
- Resolution: 1 part in 10^6
- Stability: Short term – 0.002% of the reading for a 24-hr period

  Long term – 0.008% of the reading for a 6 month period
- Input resistance: Typically 10 MΩ
- Input capacitance: 40 pF
- Output signals: BCD form

CLASSIFICATION OF DVMs

- Voltage to Time - Ramp type DVM
- Voltage to Frequency - Integrating type DVM
  - Dual slope integrating type DVM
- Direct - Successive approximation DVM
  - Staircase ramp DVM

Ramp-type Digital Voltmeter

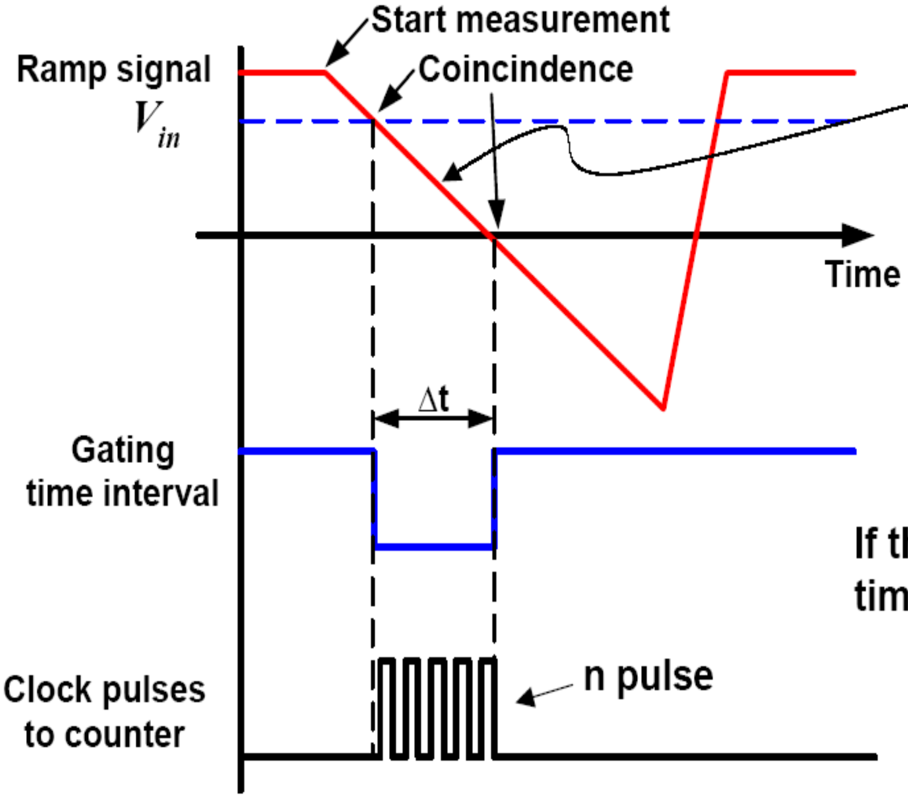


Block diagram of a ramp-type digital voltmeter.

Ramp-type Digital Voltmeter

(also called single slope)

Operation principle: The measurement of the time it takes for a linear ramp voltage to rise from O V to the level of the input voltage, or to decrease from the level of the input voltage to zero. This time interval is measured with an electronic time-interval counter.



$V_{ramp}(t) = V_o - m\,t$

Where m is the ramp rate

$V_{ramp}(t_1) = V_{in} = V_o - m\,t_1$

$V_{ramp}(t_2) = 0 = V_o - m\,t_2$

$\Delta t = t_2 - t_1 = V_{in}/m$

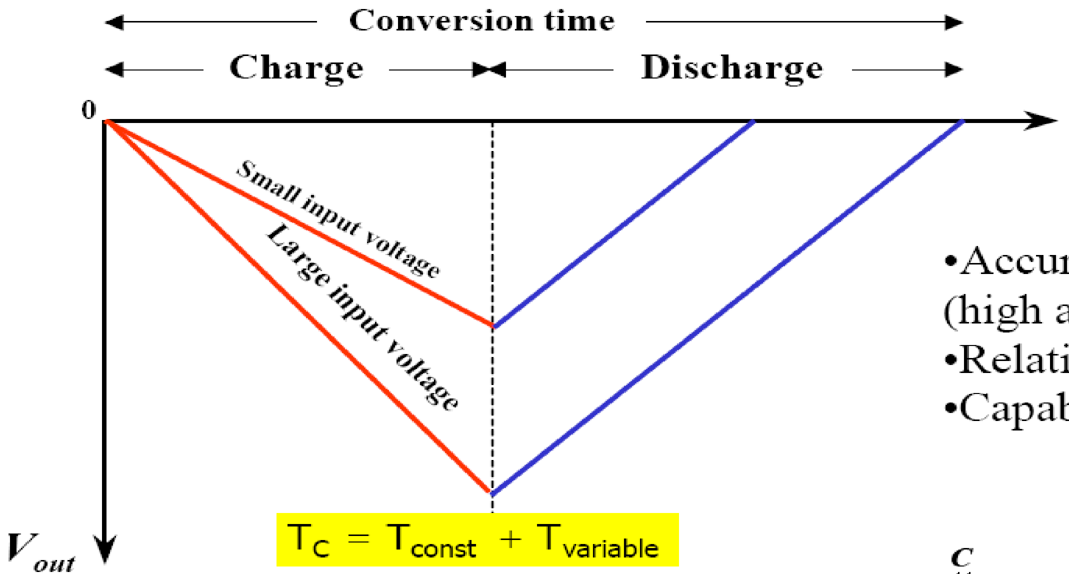
If the period of the clock is T, then during the time interval Δt_1, the number of pulses is

$\Delta t \approx nT$ or $V_{in} \approx nmT$

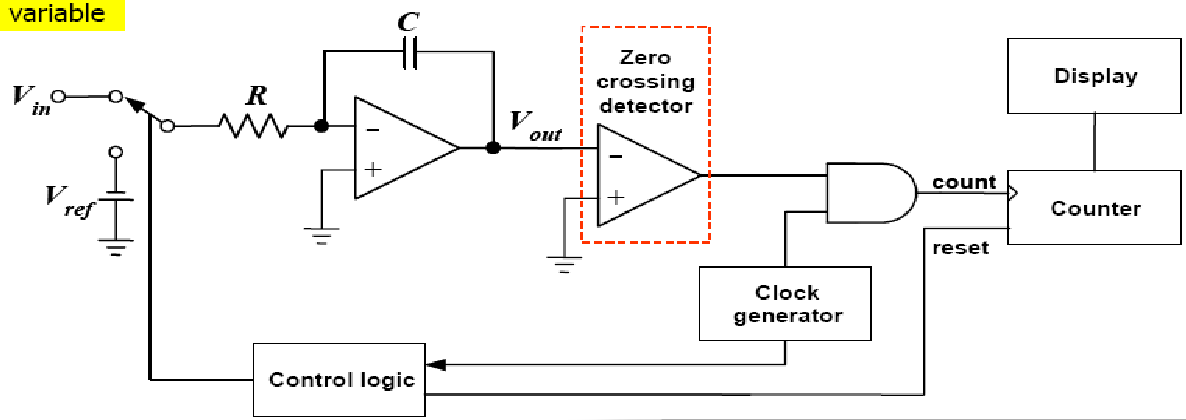
- Accuracy depends on both the ramp rate and clock period.

Voltage-to-time conversion using gated clock pulses.

Dual-slope Digital Voltmeter

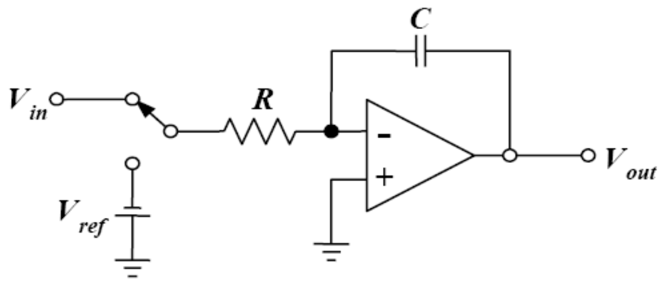


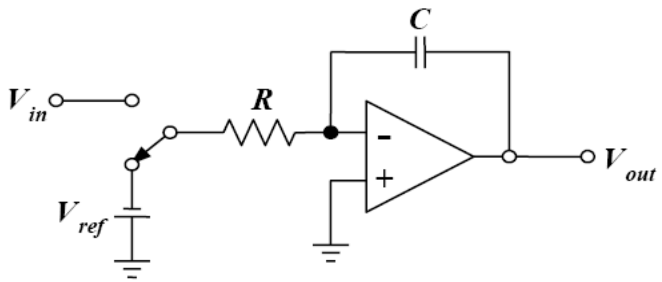
- Accuracy does not depend on ***R C*** and Clock (high accuracy)
- Relatively slow
- Capable to reject noise



Vi = Vref (T1 /T2)

Dual-slope Digital Voltmeter





Phase 1: charging C with the unknown input for a given time.

Phase 2: discharging *C* with the reference voltage until the output voltage goes to zero.

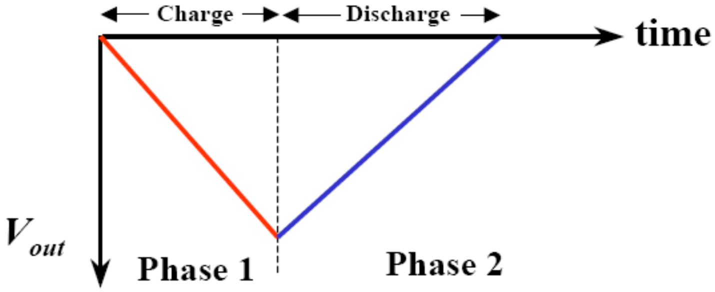
Assume $V_c(0) = 0$

$$V_{out1} = -\frac{V_{in}T}{RC}$$

where *T* is the charging time

$$V_{out} = \frac{V_{ref}T_x}{RC} + V_{out1}$$

find T_x at which V_{out} becomes zero

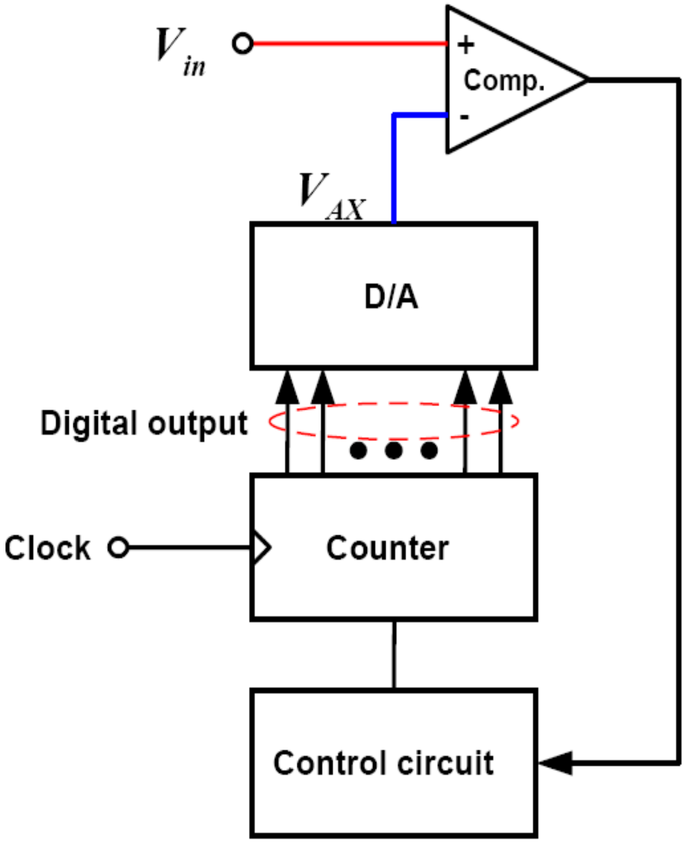


$$T_x = \frac{V_{in}T}{V_{ref}}$$

Staircase Ramp Digital Voltmeter

(also called digital ramp)

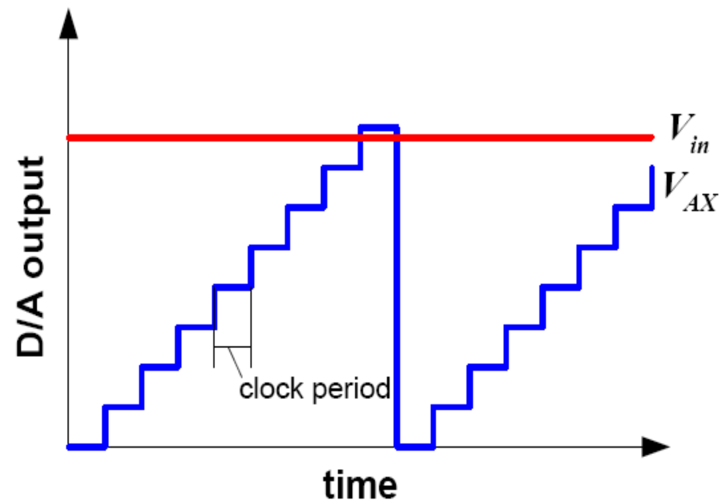
Compare the input voltage to the internally generated stair case ramp.



Block diagram

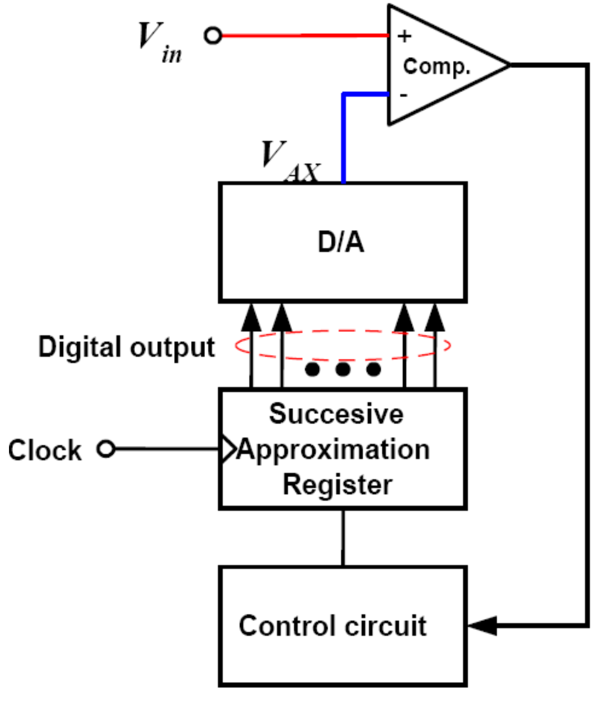
- The most simple A/D
- Slow conversion and conversion time depends on the magnitude of input signal.

$$T_{C,max} = (2^N - 1) \times \text{Clock period}$$



Successive Approximation Digital Voltmeter

Compare the input voltage to the internally generated voltage

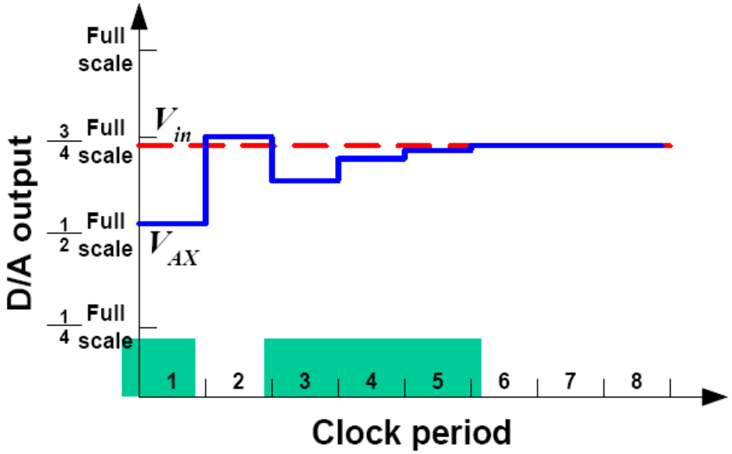


Block diagram

- The most common A/D for general applications
- Conversion time is fixed (not depend on the signal magnitude) and relatively fast

$$T_C = N \times \text{Clock period}$$

where N is the number of bits



Successive Approximation Digital Voltmeter

Ex. To determine a number between 0 – 511 (9 bit binary), given, the number to be determined is 301

No.	Estimate		Results
1	256	1 0000 0000	$V_{in} > V_{AX}$
2	256+128 = 384	1 1000 0000	<
3	256+64 = 320	1 0100 0000	<
4	256+32 = 288	1 0010 0000	>
5	288+16 = 304	1 0011 0000	<
6	288+8 = 296	1 0010 1000	>
7	296+4 = 300	1 0010 1100	>
8	300+2 = 302	1 0010 1110	<
9	300+1 = 301	1 0010 1101	Finished

UNIT II

OSCILLOSCOPES

INTRODUCTION:

- The cathode-ray oscilloscope (CRO) is a multipurpose display instrument used for the observation, measurement , and analysis of waveforms by plotting amplitude along y-axis and time along x-axis.
- CRO is generally an x-y plotter; on a single screen it can display different signals applied to different channels. It can measure amplitude, frequencies and phase shift of various signals.
- A moving luminous spot over the screen displays the signal. CROs are used to study waveforms, and other time-varying phenomena from very low to very high frequencies.
- The central unit of the oscilloscope is the cathode-ray tube (CRT), and the remaining part of the CRO consists

BLOCK DIAGRAM OF A CRO

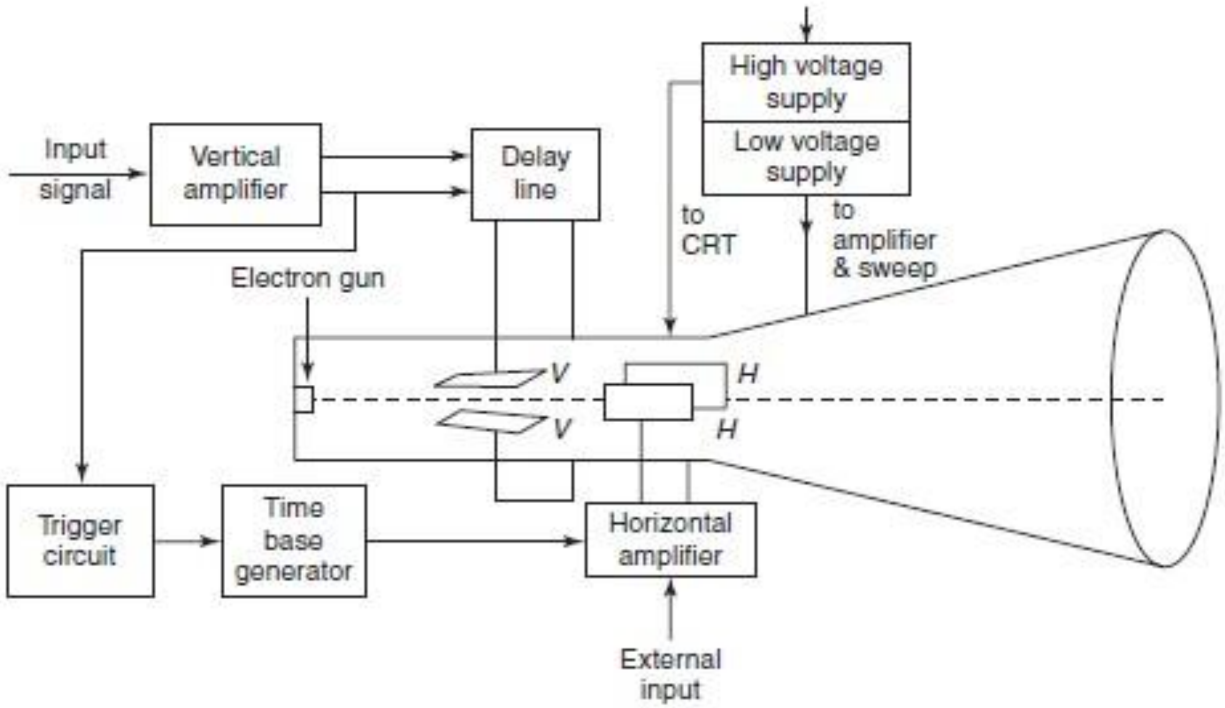


Figure 14-1 Block diagram of a cathode-ray oscilloscope

BLOCK DIAGRAM OF A CRO

COMPONENTS OF THE CATHODE-RAY OSCILLOSCOPE

The CRO consists of the following:

(i) CRT

(ii) Vertical amplifier

(iii) Delay line

(iv) Horizontal amplifier

(v) Time-base generator

(vi) Triggering circuit

(vii) Power supply

CATHODE-RAY TUBE

- **The electron gun or electron emitter, the deflecting system and the fluorescent screen are the three major components of a general purpose CRT.**

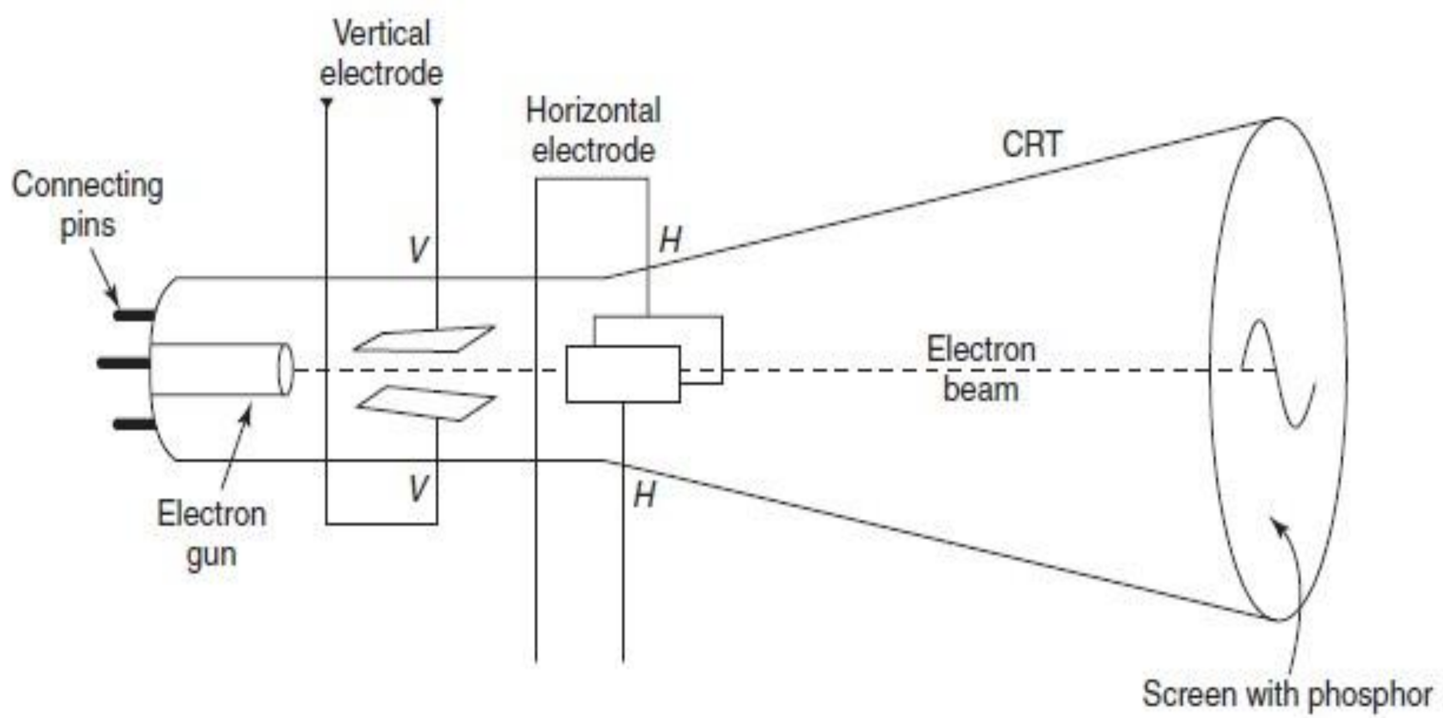


Figure 14-2 Components of a cathode-ray oscilloscope

ELECTRON GUN

- In the electron gun of the CRT, electrons are emitted, converted into a sharp beam and focused upon the fluorescent screen.
- The electron beam consists of an indirectly heated cathode, a control grid, an accelerating electrode and a focusing anode.
- The electrodes are connected to the base pins. The cathode emitting the electrons is surrounded by a control grid with a fine hole at its centre.
- The accelerated electron beam passes through the fine hole.
- The negative voltage at the control grid controls the flow of electrons in the electron beam, and consequently, the brightness of the spot on the CRO screen is controlled..

DEFLECTION SYSTEMS

- **Electrostatic deflection of an electron beam is used in a general purpose oscilloscope. The deflecting system consists of a pair of horizontal and vertical deflecting plates.**

- **Let us consider two parallel vertical deflecting plates P1 and P2. The beam is focused at point O on the screen in the absence of a deflecting plate voltage.**

- **If a positive voltage is applied to plate P1 with respect to plate P2, the negatively charged electrons are attracted towards the positive plate P1, and these electrons will come to focus at point Y1 on the fluorescent screen.**

DEFLECTION SYSTEMS

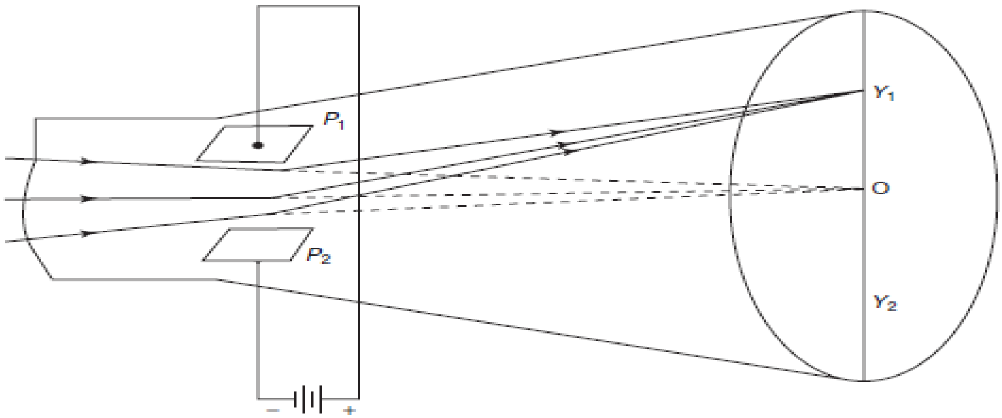


Figure 14-3(a) Deflecting system using parallel vertical plates

DEFLECTION SYSTEMS

- To deflect the beam horizontally, an alternating voltage is applied to the horizontal deflecting plates and the spot on the screen horizontally, as shown in Fig. 14-3(b).
- The electrons will focus at point X2. By changing the polarity of voltage, the beam will focus at point X1. T al
X1

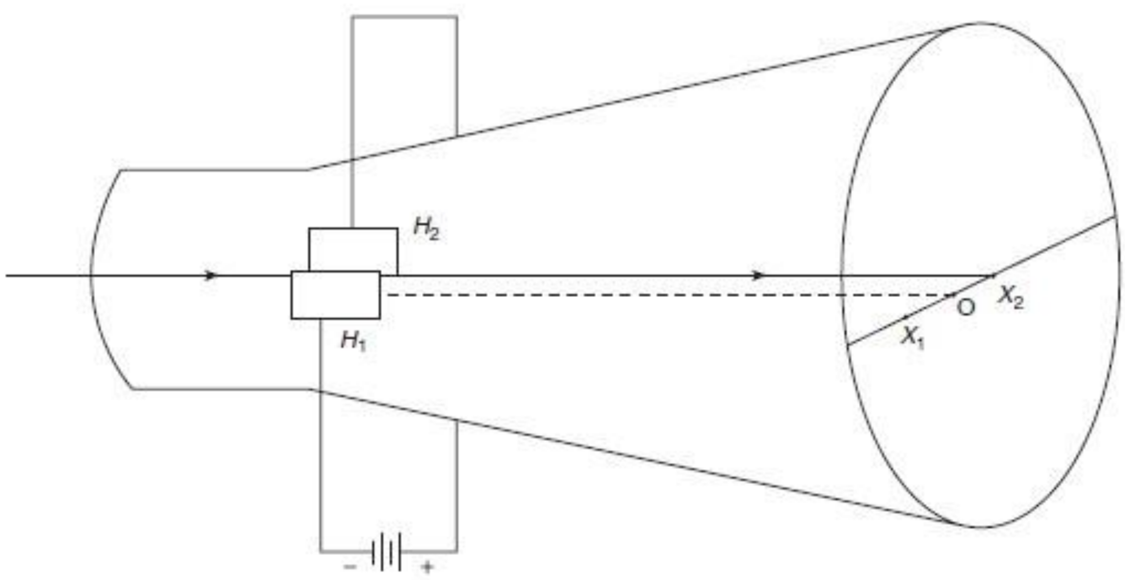


Figure 14-3(b) Deflecting system using parallel horizontal plate

SPOT BEAM DEFLECTION SENSITIVITY

The deflection sensitivity of a CRT is defined as the distance of the spot-beam deflection on the screen per unit voltage. If l_{total} is the total amount of deflection of the spot beam on the screen for the deflecting voltage V_d, as shown in Fig.14-4, the sensitivity can be expressed as:

$$S = \frac{l_{total}}{V_d} \quad (14\text{-}1)$$

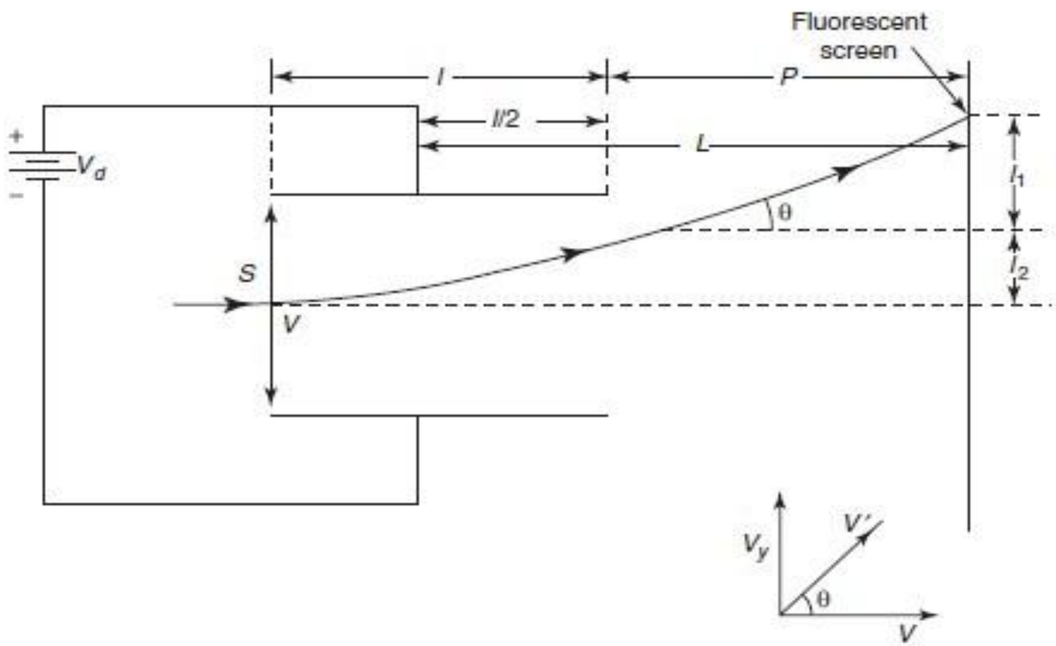


Figure 14-4 Schematic diagram of electrostatic deflection systems

ELECTROSTATIC DEFLECTION

Electrostatic Deflection

s = separation between deflecting plates

P = distance between the plate and screen S

l = length of each deflecting plate

V_d = deflecting voltage applied across the plates

m = mass of the electron

e = charge of the electron

v = velocity of the entering electron

V_a = accelerating anode voltage

Thus:

$$\frac{1}{2} mv^2 = eV_a \qquad (14\text{-}2)$$

$$v^2 = \frac{2eV_a}{m} \qquad (14\text{-}3)$$

Force exerted on the electron towards the positive deflecting plate is:

$$F.s = eV_d$$

$$F = \frac{eV_d}{s} \qquad (14\text{-}4)$$

ELECTROSTATIC DEFLECTION

$$mf = \frac{eV_d}{s}$$

Hence, acceleration is:

$$f = \frac{eV_d}{ms} \qquad (14\text{-}5)$$

Time taken by the electron to move through the deflecting plates is:

$$t = \frac{l}{v}$$

Therefore, the upward velocity acquired by the emerging electron is:

$$v_y = ft$$

$$v_y = \frac{fl}{v}$$

$$v_y = \frac{fl}{v} = \frac{eV_d}{sm}\frac{l}{v} \qquad (14\text{-}6)$$

ELECTROSTATIC DEFLECTION

where, D is the distance traversed by an electron, u is the initial velocity, f is the acceleration of an electron, and t is the time taken.

As the electron is starting from rest, the initial velocity is zero, i.e., $u = 0$ and the distance travelled by the electron $D = l_2$.

Substituting this value of D in the expression for D, from the formula of mechanics, we get:

$$l_2 = \frac{1}{2} ft^2 \tag{14-7}$$

Substituting the value of t in Eq. (14-7) we get:

$$l_2 = \frac{1}{2} f(\frac{l}{v})^2 = \frac{eV_d}{2\,sm} (\frac{l}{v})^2 \tag{14-8}$$

$$\tan\theta = \frac{v_y}{v} = \frac{l_1}{P} \tag{14-9}$$

$$l_{\text{total}} = l_1 + l_2 = \frac{eV_d l}{smv^2} (\frac{l}{2} + P) \tag{14-10}$$

Here:

$$L = \left(\frac{l}{2} + P\right) \tag{14-11}$$

ELECTROSTATIC DEFLECTION

Substituting v^2 from Eq. (14-3) and L from Eq. (14-11) in Eq. (14-10) we have:

$$l_{\text{total}} = \frac{lLV_d}{2sV_a} \tag{14-12}$$

The deflection sensitivity of the CRT is, by definition:

$$S = \frac{l_{\text{total}}}{V_d} = \frac{lL}{2sV_a} \text{ m/V} \tag{14-13}$$

The deflection factor of the CRT is:

$$G = \frac{1}{S} = \frac{2sV_a}{lL} \text{ V/m} \tag{14-14}$$

FLUORESCENT SCREEN

- **Phosphor is used as screen material on the inner surface of a CRT. Phosphor absorbs the energy of the incident electrons. The spot of light is produced on the screen where the electron beam hits.**
- **The bombarding electrons striking the screen, release secondary emission electrons. These electrons are collected or trapped by an aqueous solution of graphite called —Aquadag‖ which is connected to the second anode.**
- **Collection of the secondary electrons is necessary to keep the screen in a state of electrical equilibrium.**
- **The type of phosphor used, determines the color of the light spot. The brightest available phosphor isotope, P31, produces yellow–green light with relative luminance of 99.99%.**

DISPLAY WAVEFORM ON THE SCREEN

Figure 14-5(a) shows a sine wave applied to vertical deflecting plates and a repetitive ramp or saw-tooth applied to the horizontal plates. The ramp waveform at the horizontal plates causes the electron beam to be deflected horizontally across the screen.

If the waveforms are perfectly synchronized then the e

x … rs on

th…

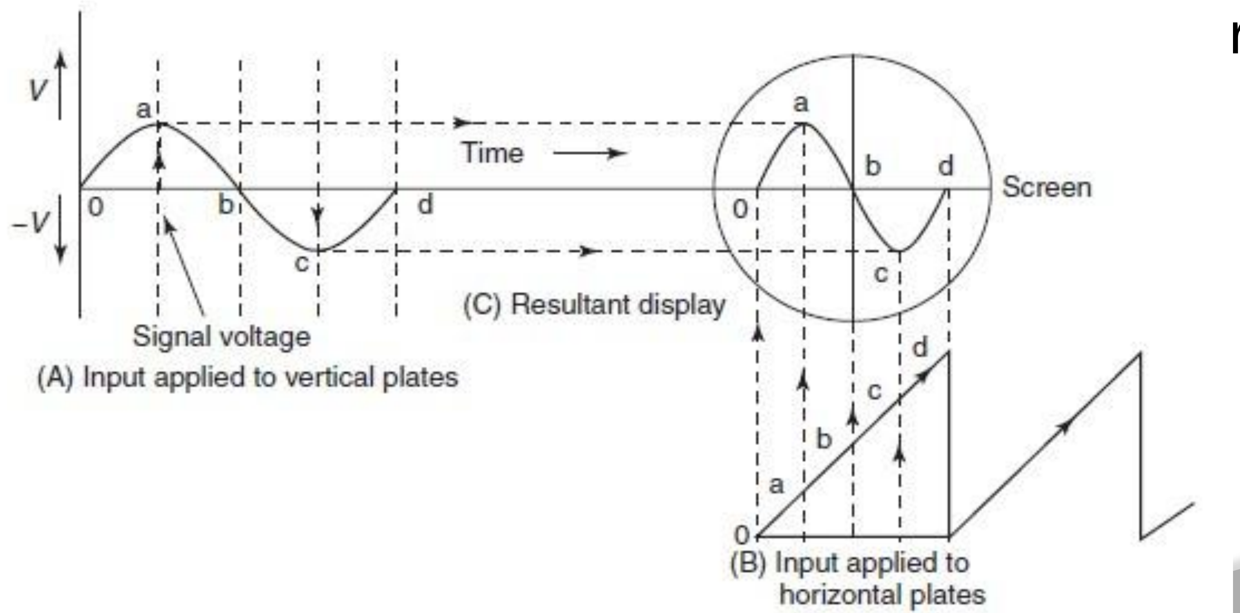


Figure 14-5(a) A typical display waveform on the screen

Triangular waveform

- **Similarly the display of the triangular waveform.**

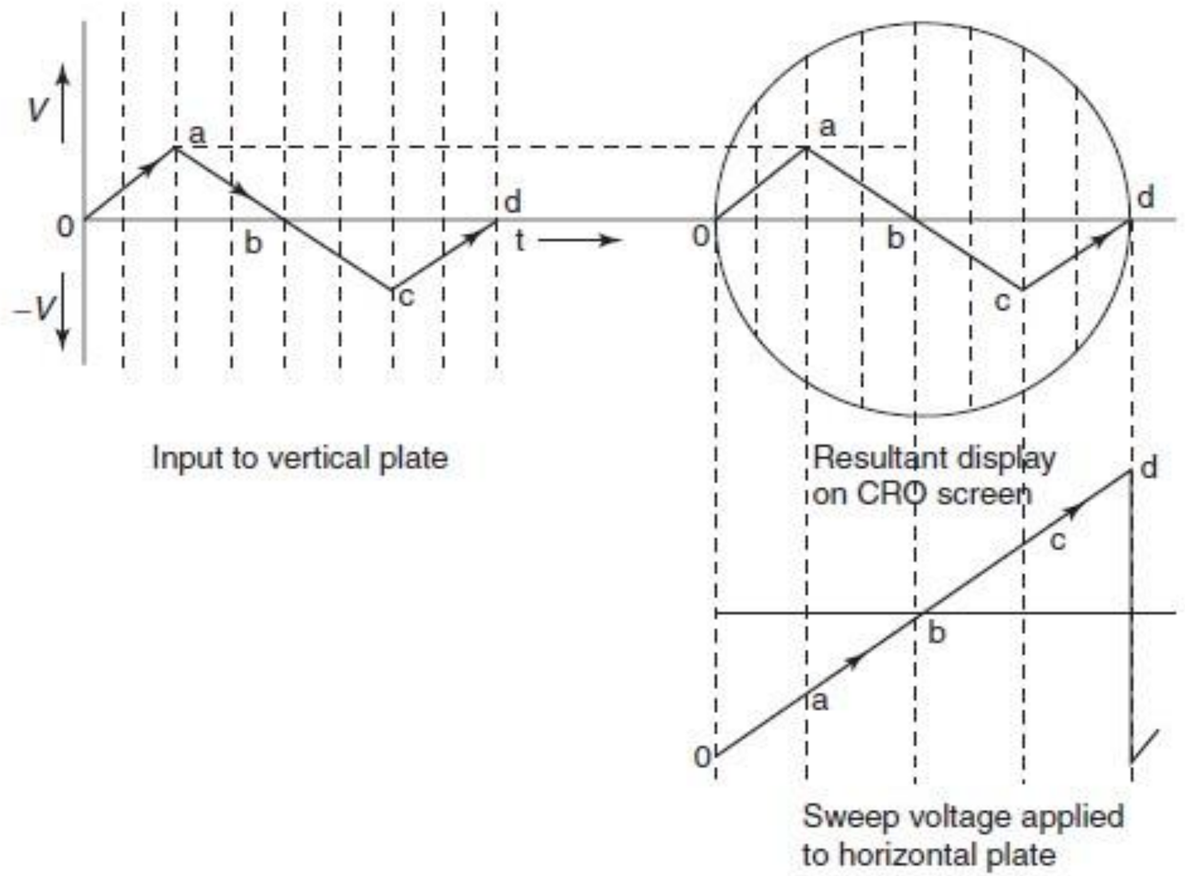


Figure 14-5(b) Triangular waveform input applied to the vertical deflecting plates of CRO

TIME-BASE GENERATORS

- The CRO is used to display a waveform that varies as a function of time. If the wave form is to be accurately reproduced, the beam should have a constant horizontal velocity.
- As the beam velocity is a function of the deflecting voltage, the deflecting voltage must increase linearly with time.
- A voltage with such characteristics is called a ramp voltage. If the voltage decreases rapidly to zero—with the waveform repeatedly produced, as shown in Fig. 14-6— ... ed a saw-too ...

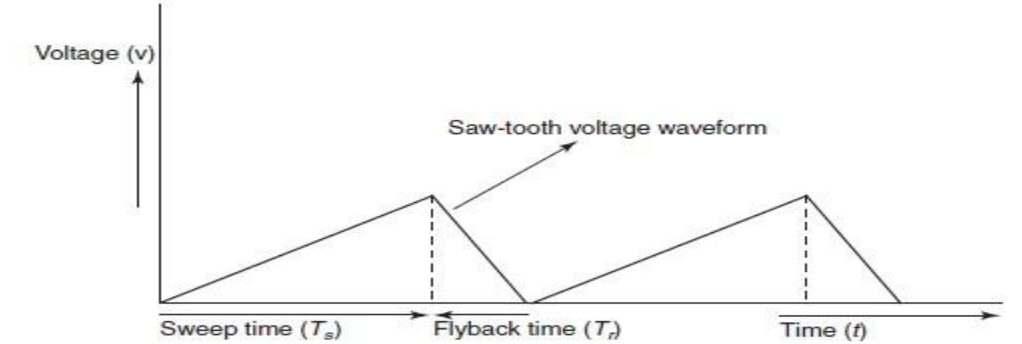


Figure 14-6 Typical saw-tooth waveform applied to the horizontal deflection plates

SIMPLE SAW-TOOTH GENERATOR

- **The circuit shown in Fig. 14-7(a) is a simple sweep circuit, in which the capacitor C charges through the resistor R.**
- **The capacitor discharges periodically through the transistor T1, which causes the waveform shown in Fig. 14-7(b) to appear across the capacitor.**
- **The signal voltage, Vi which must be applied to the base ervals.**

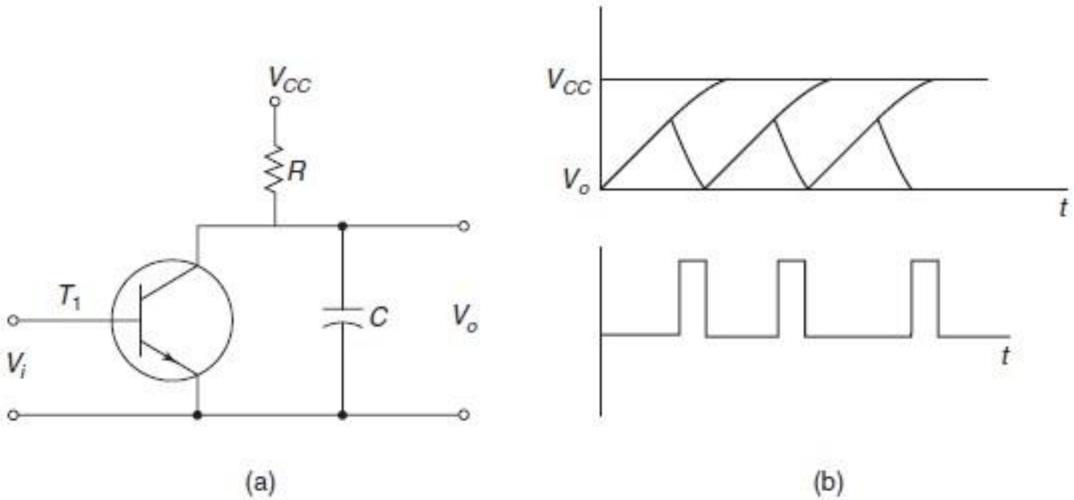


Figure 14-7: (a) simple saw-tooth generator (b) associated waveforms.

TIME-BASE GENERATOR USING UJT

- The continuous sweep CRO uses the UJT as a time-base generator. When power is first applied to the UJT, it is in the OFF state and CT changes exponentially through RT .
- The UJT emitter voltage VE rises towards VBB and VE reaches the plate voltage VP.
- The emitter-to-base diode becomes forward biased and the UJT triggers ON. This provides a low resistance discharge path and the capacitor discharg
- When the emitter voltage VE reaches the rapidly, the UJT goes OFF.
- The capacitor recharges and the RT is us continuous control of frequency within a r varied or changed in steps. They are some timing resistor and timing capacitor cycles

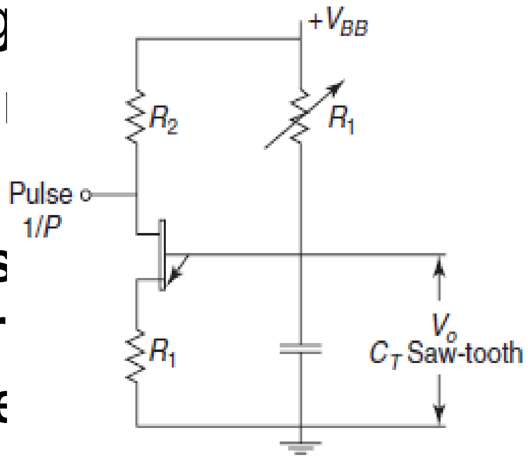


Figure 14-7 (c) Time-base generator using UJT

OSCILLOSCOPE AMPLIFIERS

- The purpose of an oscilloscope is to produce a faithful representation of the signals applied to its input terminals.
- Considerable attention has to be paid to the design of these amplifiers for this purpose. The oscillographic amplifiers can be classified into two major categories.

  (i) AC-coupled amplifiers

  (ii) DC-coupled amplifiers
- The low-cost oscilloscopes generally use ac-coupled amplifiers. The ac amplifiers, used in oscilloscopes, are required for laboratory purposes. The dc-coupled amplifiers are quite expensive. They offer the advantage of responding to dc voltages, so it is possible to measure dc voltages as pure signals and ac signals superimposed upon the dc signals.
- DC-coupled amplifiers have another advantage. They eliminate the problems of low-frequency phase shift and waveform distortion while observing low-frequency pulse train.
- The amplifiers can be classified according to bandwidth use also:

  (i) Narrow-bandwidth amplifiers (ii) Broad-bandwidth

VERTICAL AMPLIFIERS

- Vertical amplifiers determines the sensitivity and bandwidth of an oscilloscope. Sensitivity, which is expressed in terms of V/cm of vertical deflection at the mid-band frequency.
- The gain of the vertical amplifier determines the smallest signal that the oscilloscope can satisfactorily measure by reproducing it on the CRT screen.
- The sensitivity of an oscilloscope is directly proportional to the gain of the vertical amplifier. So, as the gain increases the sensitivity also increases.
- The vertical sensitivity measures how much the electron beam will be deflected for a specified input signal. The CRT screen is covered with a plastic grid pattern called a graticule.
- The spacing between the grids lines is typically 10 mm. Vertical sensitivity is generally expressed in volts per division.

FREQUENCY RESPONSE

- **The bandwidth of an oscilloscope detects the range of frequencies that can be accurately reproduced on the CRT screen. The greater the bandwidth, the wider is the range of observed frequencies.**
- **The bandwidth of an oscilloscope is the range of frequencies over which the gain of the vertical amplifier stays within 3 db of the mid-band frequency gain, as shown in Fig. 14-8.**
- **Rise time is defined as the time required for the edge to rise from 10–90% of its maximum amplitude. An approximate relation is given as follows:**

$$t_r \times BW = 0.35$$

where, t_r is the rise time in seconds and BW is the band width in Hertz.

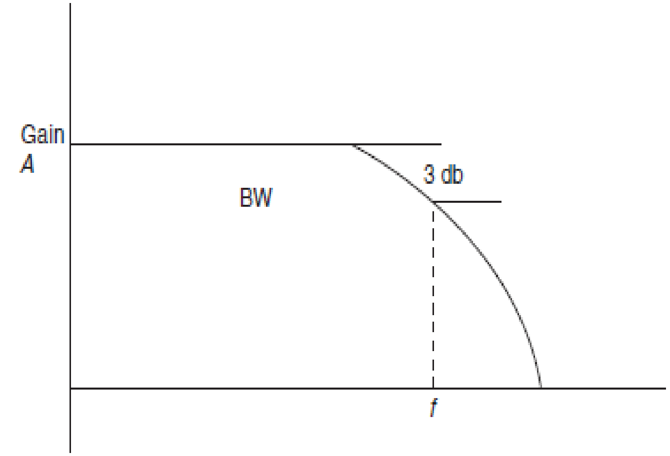


Figure 14-8 Frequency response graphs

MEASUREMENTS USING THE CRO

1) Measurement of Frequency:

Time-base Measurement

Time-base measurement helps to determine the frequency of a time-varying signal displayed on the CRT screen. If a time interval t has x complete cycles, then the time period of the signal is:

$$T = \frac{t}{x}$$

or,

$$f = \frac{1}{T} = \frac{x}{t}$$

Hence, the frequency is determind.

Measurement Using Lissajous Figures

The application of sinusoidal waves at the same time to the deflection plates produces various patterns. These patterns, are generated on the basis of the relative amplitudes, frequencies and phases of the different waveforms and are known as Lissajous figures.

Figure 14-9 shows the Lissajous figure as a form of ellipse.

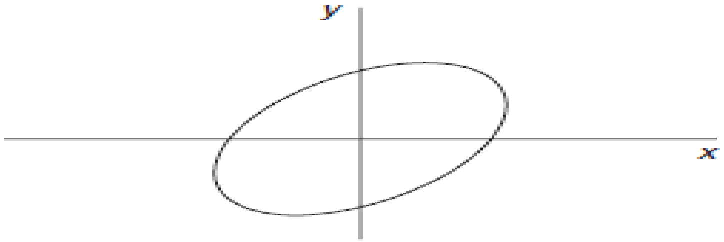


Figure 14-9 Lissajous figure as a form of ellipse

Frequency can be determined from:

$$\frac{f_v}{f_h} = \frac{\text{Number of horizontal tangencies}}{\text{Number of vertical tangencies}}$$

where, f_v and f_h are the frequencies of the vertical and the horizontal signals, respectively.

MEASUREMENTS USING THE CRO

2) Measurement of Phase:

The phase difference of two different waveforms displayed on the CRT screen can be found from the time axis. Two sinusoidal signals of time period T are in the same phase at time t_1 and t_2 respectively, and the phase difference between them is expressed as:

$$\varphi = \frac{2\pi}{T}(t_1 - t_2) \quad (14\text{-}16)$$

Figure 14-10 shows the phase difference of two different waveforms.

3) Measurement of Phase Using Lissajous Figures:

Lissajous figures are used to measure the phase difference between two sinusoidal voltages of the same amplitude and frequency. The signals are applied simultaneously to the horizontal and vertical deflection plates. The values of the deflection voltages are given by:

$$v_y = A \sin(\omega t + \varphi) \quad (14\text{-}17)$$

and

$$v_x = A \sin \omega t \quad (14\text{-}18)$$

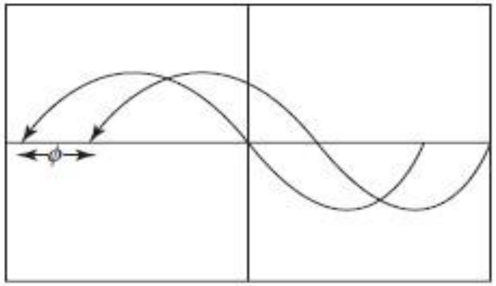


Figure 14-10 Measurement of phase difference

MEASUREMENT OF PHASE USING LISSAJOUS FIGURES:

The values of the deflection voltages are given by:

$$v_y = \mathrm{A} \sin(\omega t + \varphi)$$

$$v_x = \mathrm{A} \sin \omega t$$

Here A is the amplitude, ω is the angular frequency and φ is the phase angle by which v_y leads v_x. Eq. (14-17) can be expanded as:

$$v_y = A \sin \omega t \cos \varphi + A \cos \omega t \sin \varphi \qquad (14\text{-}19)$$

Equation (14-18) yields:

$$A \cos \omega t = \sqrt{A^2 - v_x^2} \qquad (14\text{- }20)$$

Substituting the sine and cosine terms from Eqs. (14-17) and (14-18) in Eq. (14-19), we get:

$$v_y = A \sin \omega t \cos \varphi + \sqrt{A^2 - v_x^2} \sin \varphi$$

$$v_y = v_x \cos \varphi + \sqrt{A^2 - v_x^2} \sin \varphi$$

$$v_y - v_x \cos \varphi = \sqrt{A^2 - v_x^2} \sin \varphi$$

$$(v_y - v_x \cos \varphi)^2 = (A^2 - v_x^2)\sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi\, v_y + v_x^2 \cos^2 \varphi = A^2 \sin^2 \varphi - v_x^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi\, v_y + v_x^2 \cos^2 \varphi\, v_x^2 \sin^2 \varphi = A^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi\, v_y + v_x^2 (\cos^2 \varphi + \sin^2 \varphi) = A^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi\, v_y + v_x^2 = A^2 \sin^2 \varphi$$

$$v_x^2 + v_y^2 - 2v_x v_y \cos\varphi = A^2 \sin^2 \varphi. \qquad (14.21)$$

The Lissajous figure is thus, an ellipse represented by Eq. (14-21). The ellipse is depicted in Fig. 14-9.

MEASUREMENT OF PHASE USING LISSAJOUS FIGURES

Case I: When $\varphi = 0°$, $\cos\varphi = 1$, $\sin\varphi = 0$

Then, Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 - 2v_x v_y = 0$$

$$(v_x - v_y)^2 = 0$$

$$v_x = v_y \qquad (14\text{-}22)$$

Equation (14-22) represents a straight line with slope 45°, i.e., $m = 1$. The straight line diagram is shown in Fig. 14-11(a).

Case II: When $0 < \varphi < 90$, $\varphi = 45°$, $\cos\varphi = \frac{1}{\sqrt{2}}$, $\sin\varphi = \frac{1}{\sqrt{2}}$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 - \sqrt{2}v_x v_y = \frac{A^2}{2} \qquad (14\text{-}23)$$

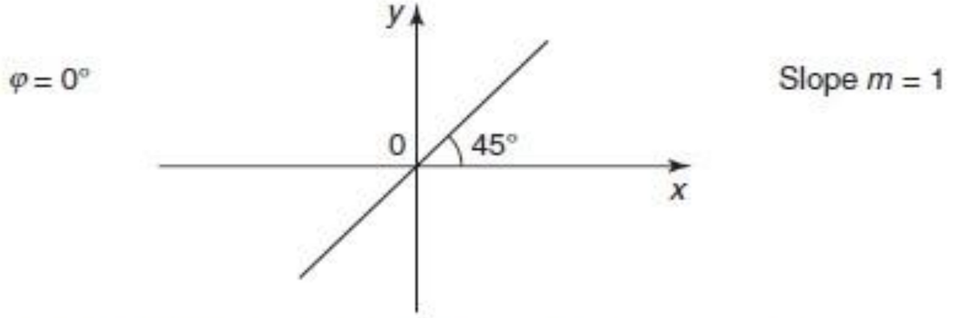


Figure 14-11(a) Lissajous figure at $\varphi = 0°$ is a straight line with slope $m = 1$

MEASUREMENT OF PHASE USING LISSAJOUS FIGURES

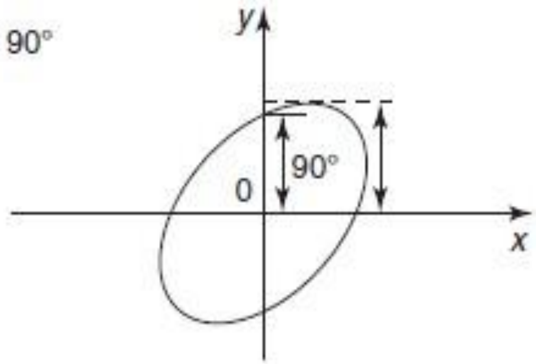


Figure 14-11(b) Lissajous figure at $0° < \varphi < 90$ takes the shape of an ellipse

Equation (14-11) represents an ellipse, as shown in Fig. 14-11(b).

Case III: When $\varphi = 90°$, $\cos\varphi = 0$, $\sin\varphi = 1$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 = A^2 \qquad (14\text{-}24)$$

Equation (14-24) represents a circle shown in Fig. 14-12.

Case IV: When $90 < \varphi < 180$; say $\varphi = 135°$,

$\cos\varphi = -\frac{1}{\sqrt{2}}$, $\sin\varphi = \frac{1}{\sqrt{2}}$

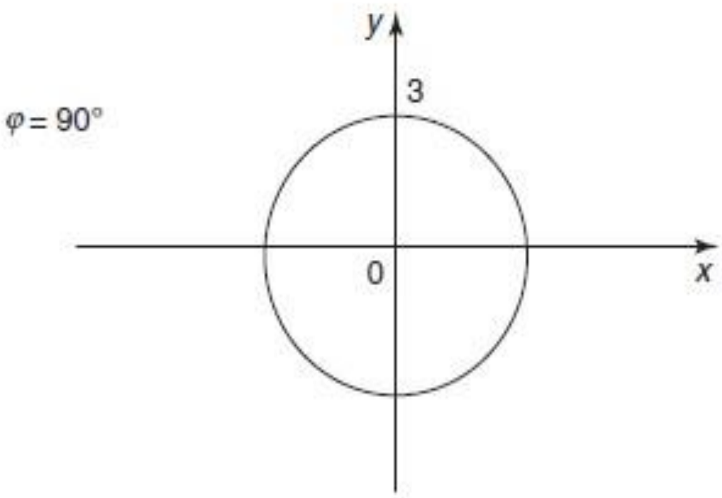


Figure 14-12 Lissajous figure at $\varphi = 90°$: it forms a circle

MEASUREMENT OF PHASE USING LISSAJOUS FIGURES

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 + \sqrt{2}v_x y_y = \frac{A^2}{2} \qquad (14\text{-}25)$$

Equation (14-25) represents an ellipse shown in Fig. 14-13.

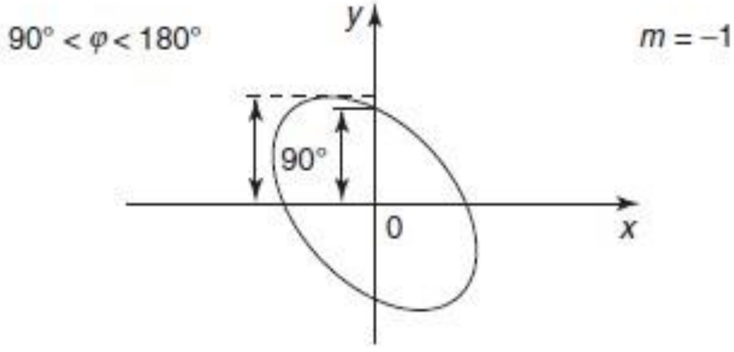


Figure 14-13 Lissajous figure when $90 < \varphi < 180$

Case V: $\varphi = 180°$, $\cos\varphi = -1$, $\sin\varphi = 0$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 + 2v_x v_y = 0$$

$$(v_x + v_y)^2 = 0$$

$$v_x = -v_y \qquad (14\text{-}26)$$

Equation (14-26) represents a straight line with slope $m = -1$; a slope of 45° in the negative direction of the x-axis, as shown in Fig. (14-14).

The maximum y-displacement, A, and the vertical displacement, V_y, at time $t = 0$ can be measured from the vertical scale of the CRO. Putting $t = 0$ in Eq. (14-17), we get:

$$v_{y0} = A\sin\varphi \qquad (14\text{-}27)$$

$$\sin\varphi = \frac{v_{y0}}{A} \qquad (14\text{-}28)$$

Thus, the phase angle can be found from Eq. (14-28) using any form of the Lissajous figure.

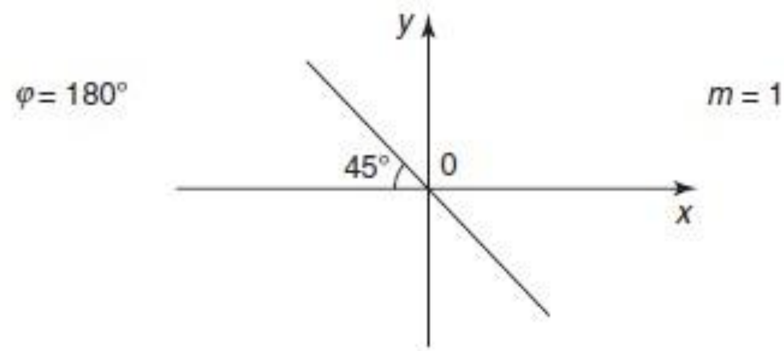


Figure 14-14 Lissajous figure at $\varphi = 180°$ with negative slope $m = -1$

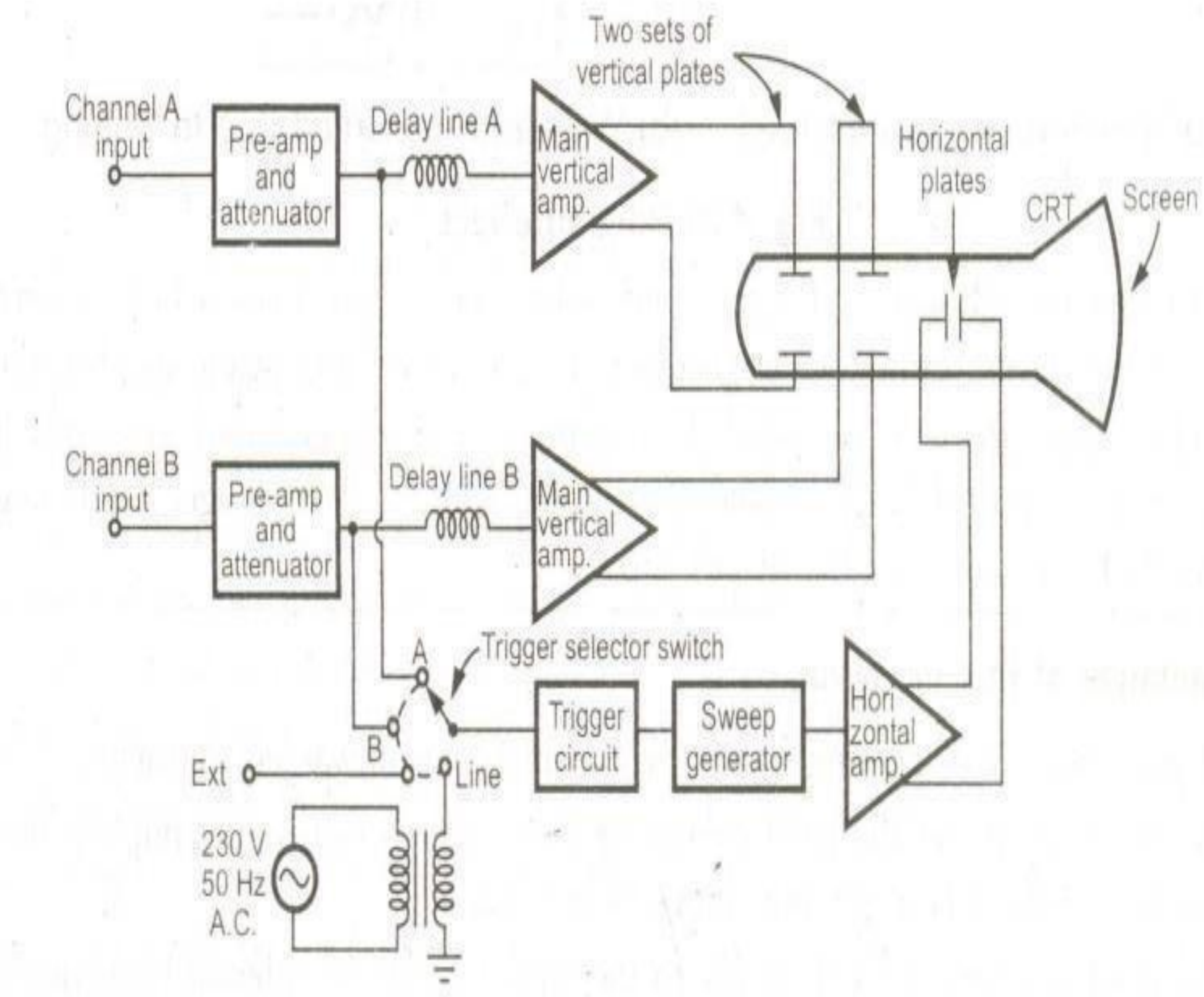
TYPES OF THE CATHODE-RAY OSCILLOSCOPES

The categorization of CROs is done on the basis of whether they are digital or analog. Digital CROs can be further classified as storage oscilloscopes.

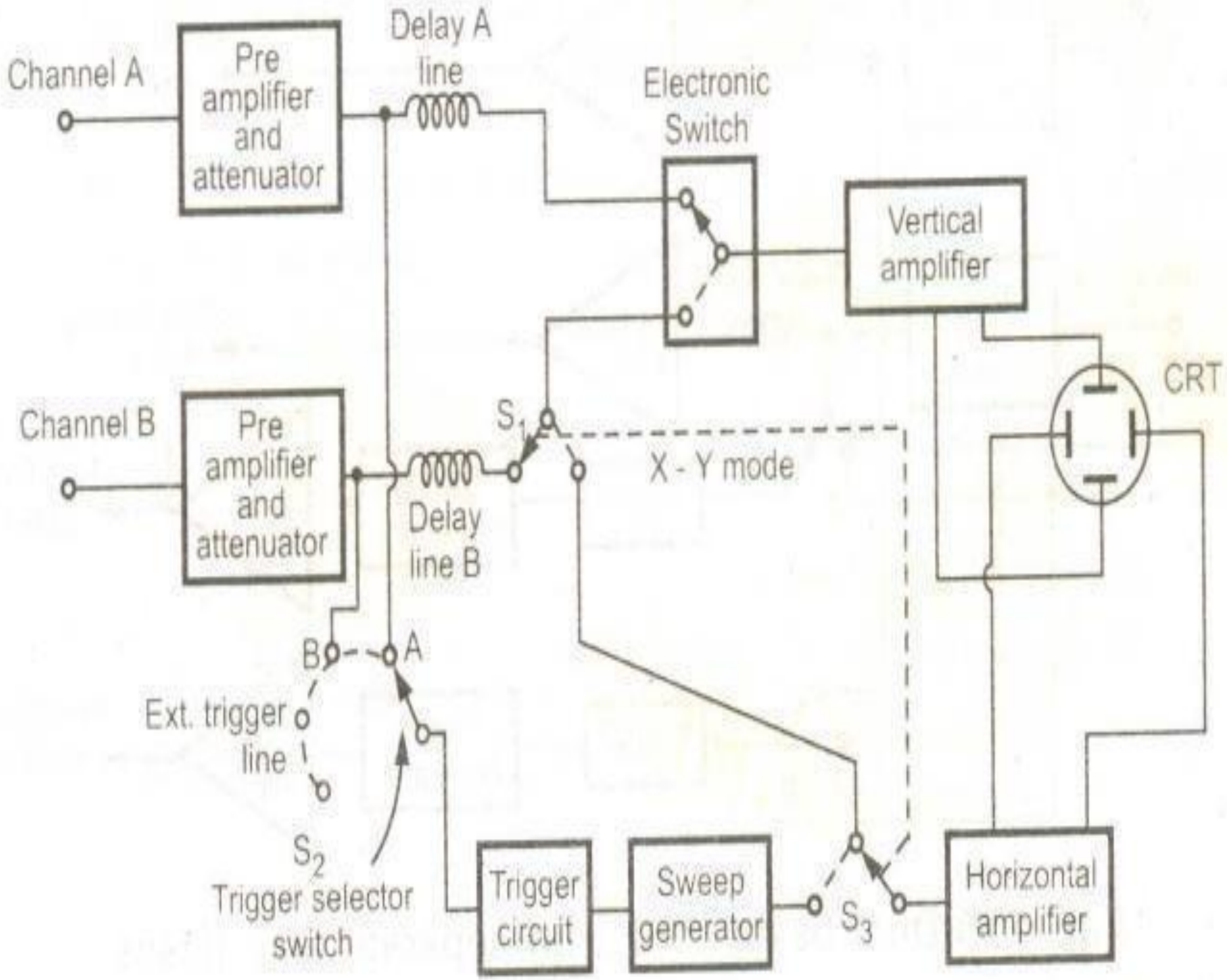
1. **Analog CRO:** In an analog CRO, the amplitude, phase and frequency are measured from the displayed waveform, through direct manual reading.
2. **Digital CRO:** A digital CRO offers digital read-out of signal information, i.e., the time, voltage or frequency along with signal display. It consists of an electronic counter along with the main body of the CRO.
3. **Storage CRO:** A storage CRO retains the display up to a substantial amount of time after the first trace has appeared on the screen. The storage CRO is also useful for the display of waveforms of low-frequency signals.
4. **Dual-Beam CRO:** In the dual-beam CRO two electron beams fall on a single CRT. The dual-gun CRT generates two different beams.

These two beams produce two spots of light on the CRT screen

DUAL BEAM OSCILLOSCOPE

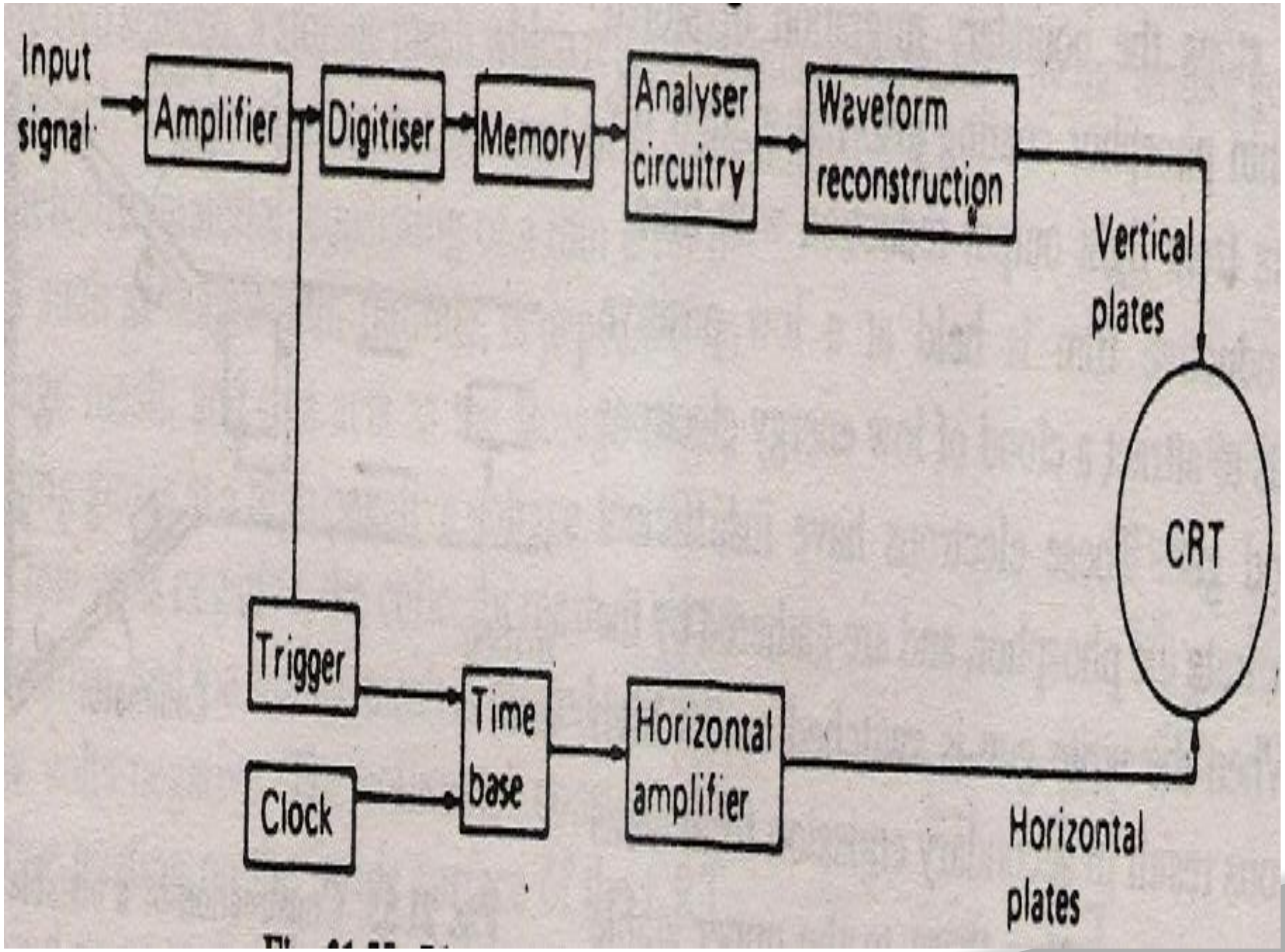


DUAL TRACEOSCILLOSCOPE

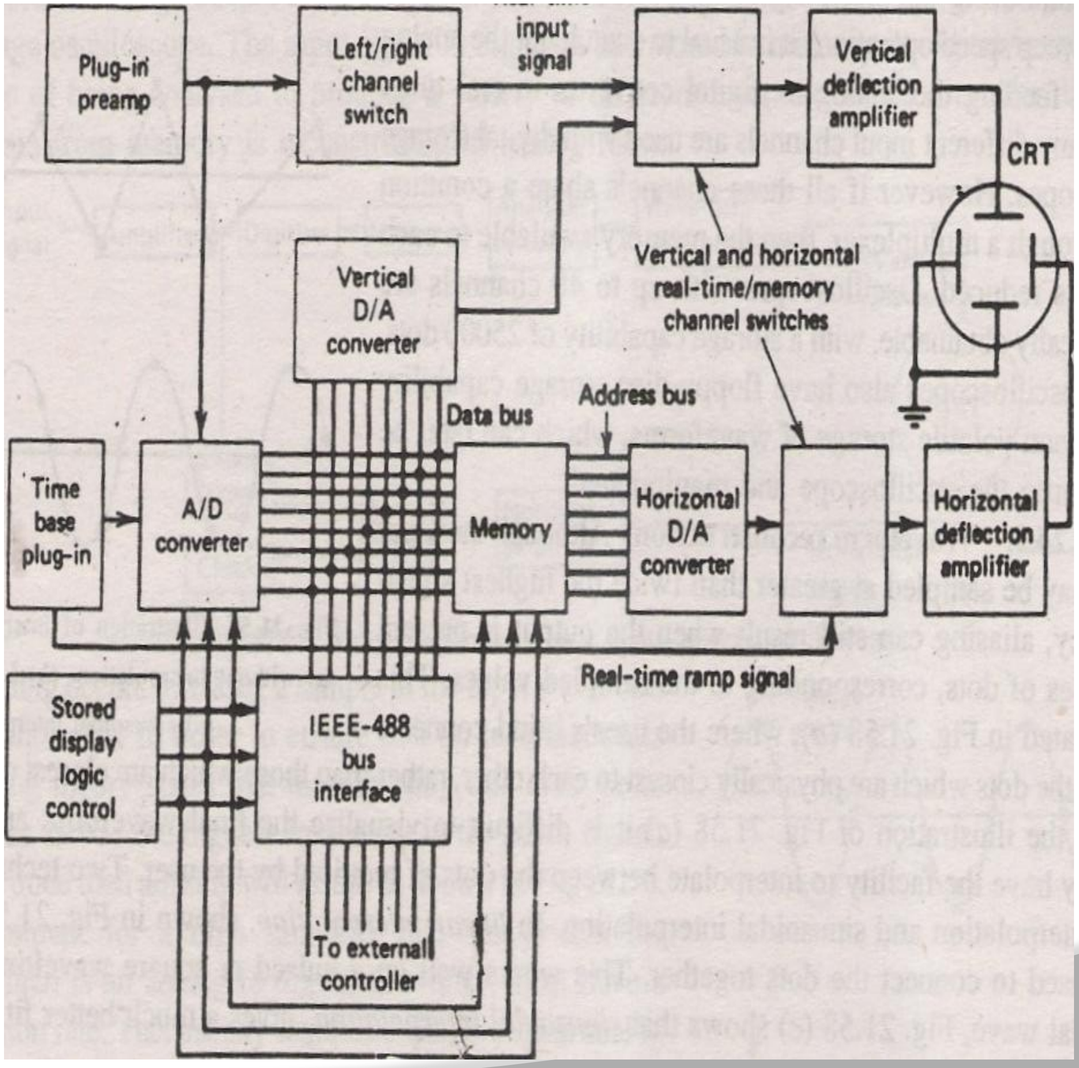


SPECIAL PURPOSE OSCILLOSCOPES

DIGITAL STORAGEOSCILLOSCOPE



COMPLETE BLOCK DIAGRAM OF DIGITAL STORAGE OSCILLOSCOPE



SPECIAL PURPOSE OSCILLOSCOPES

SAMPLING OSCILLOSCOPE

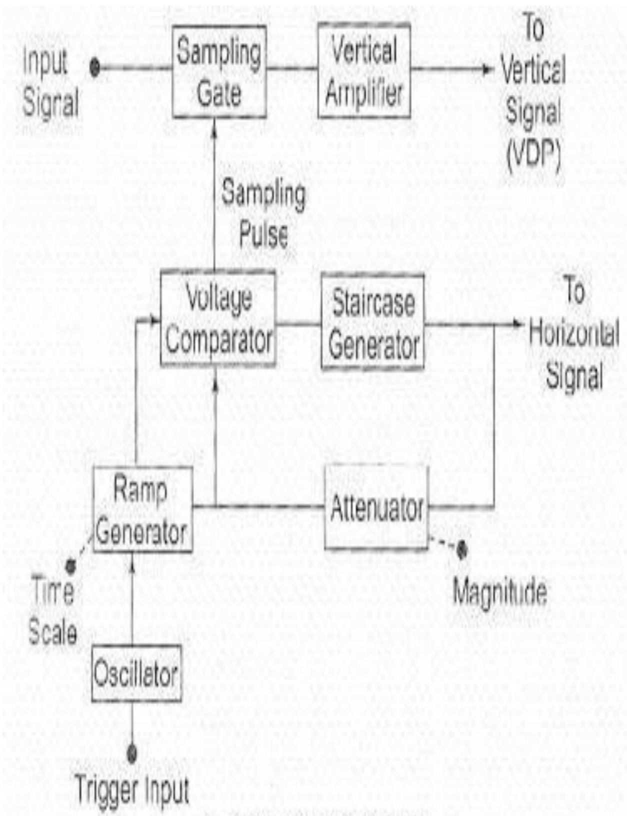


fig 4.1 Sampling Oscilloscope

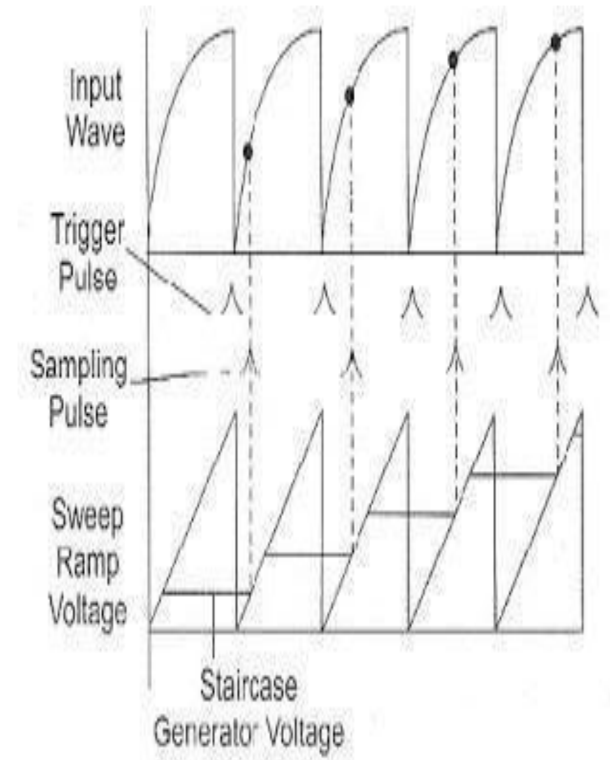
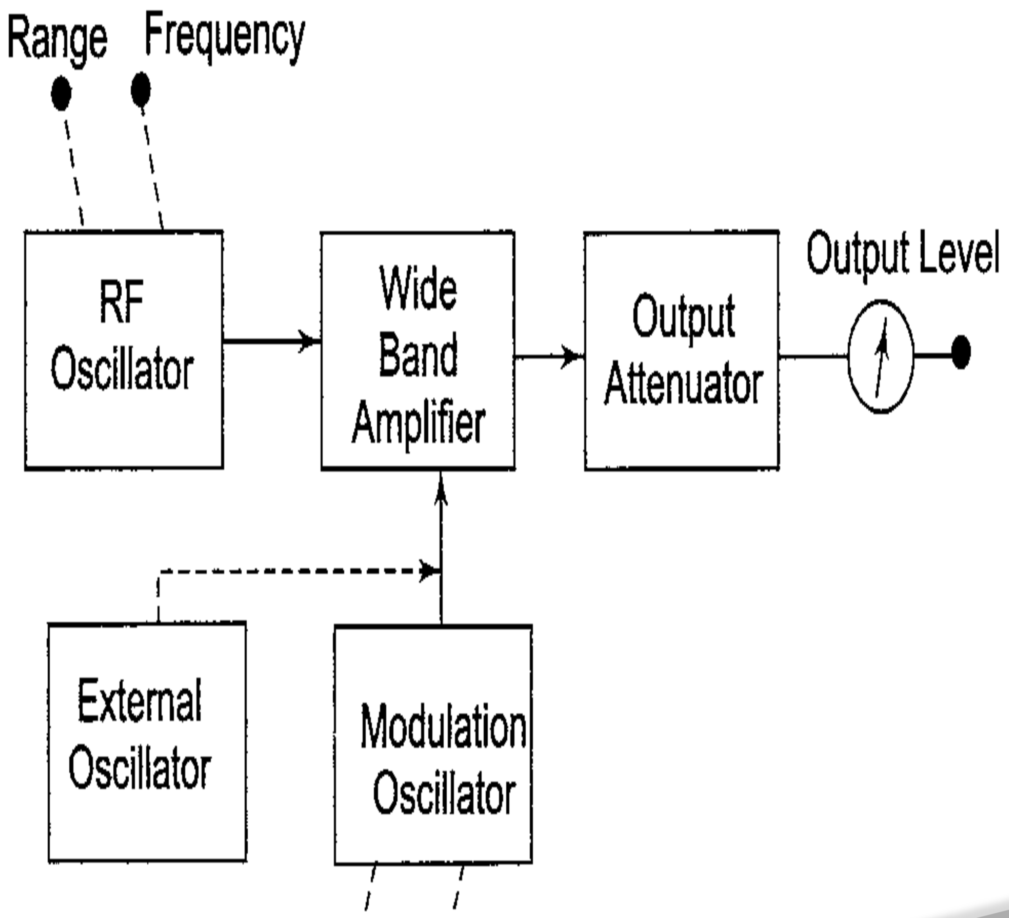
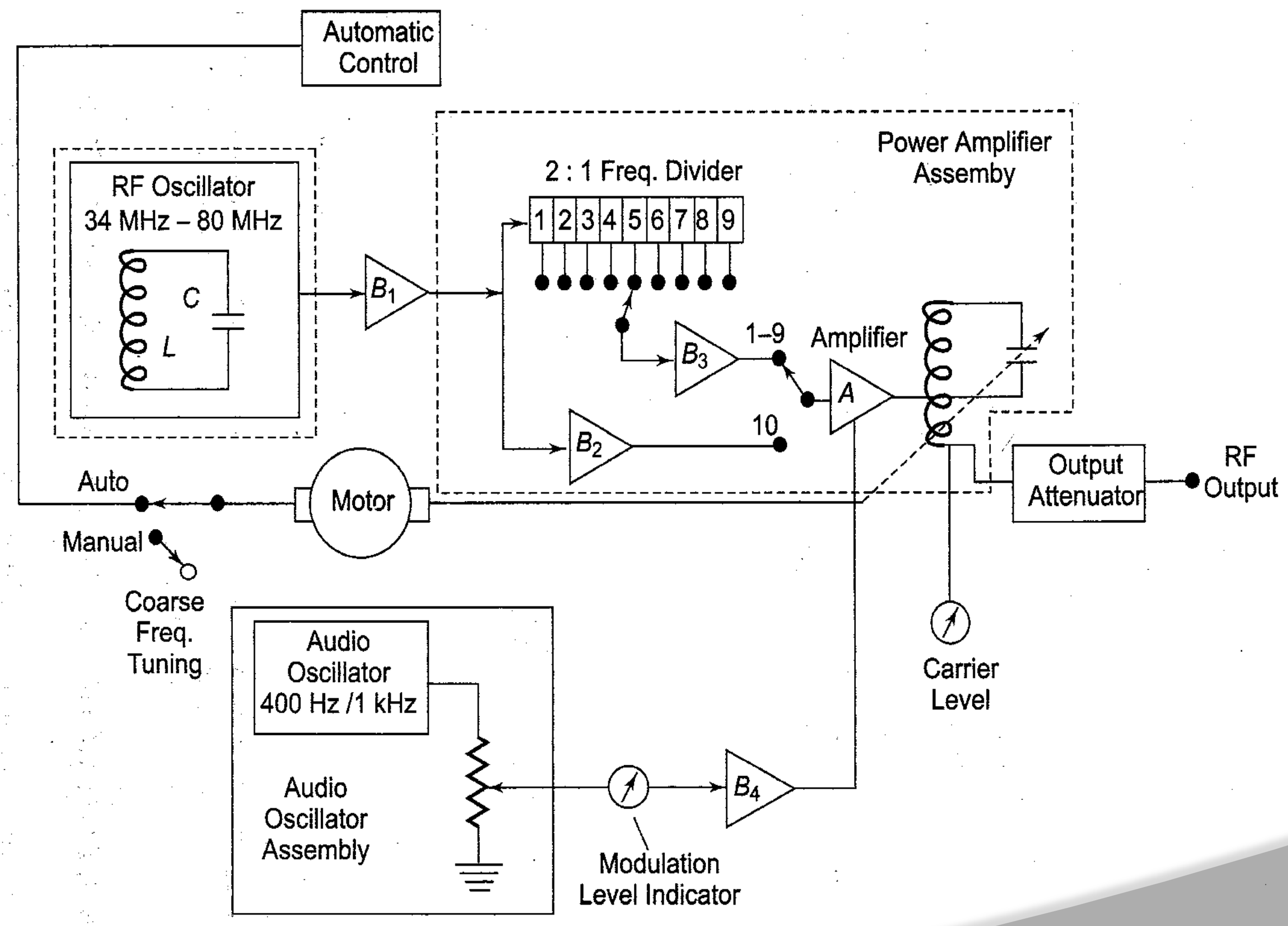


fig 4.2 Various Wave Forms at each block of oscilloscope

UNIT III
SIGNAL GENERATORS
(CIE-I)

CONVENTIONAL SIGNAL GENERATOR





Automatic Control
RF Oscillator
34 MHz – 80 MHz
C
L
B1
2 : 1 Freq. Divider
1 2 3 4 5 6 7 8 9
Power Amplifier Assemby
B3
1–9
Amplifier
A
B2
10
Auto
Motor
Manual
Coarse Freq. Tuning
Output Attenuator
RF Output
Audio Oscillator 400 Hz /1 kHz
Audio Oscillator Assembly
B4
Carrier Level
Modulation Level Indicator

- Compared to conventional std. signal gen, modern signal generator uses same oscillator on all bands. Eliminates range switching effects. Master oscillator is tuned by a capacitor. Motor driven variable Coarse freq. tuning – 7% frequency changes per second.
- Fine tuning – at 0.01% of the main dial.
- Modulation process is done at the power amplifier stage.
- Two internally generated signal are used (400Hz &1kHz) for modulation.

FUNCTION GENERATOR

function generator produces different waveforms of adjustable frequency.

The common output waveforms are the sine, square, triangular.

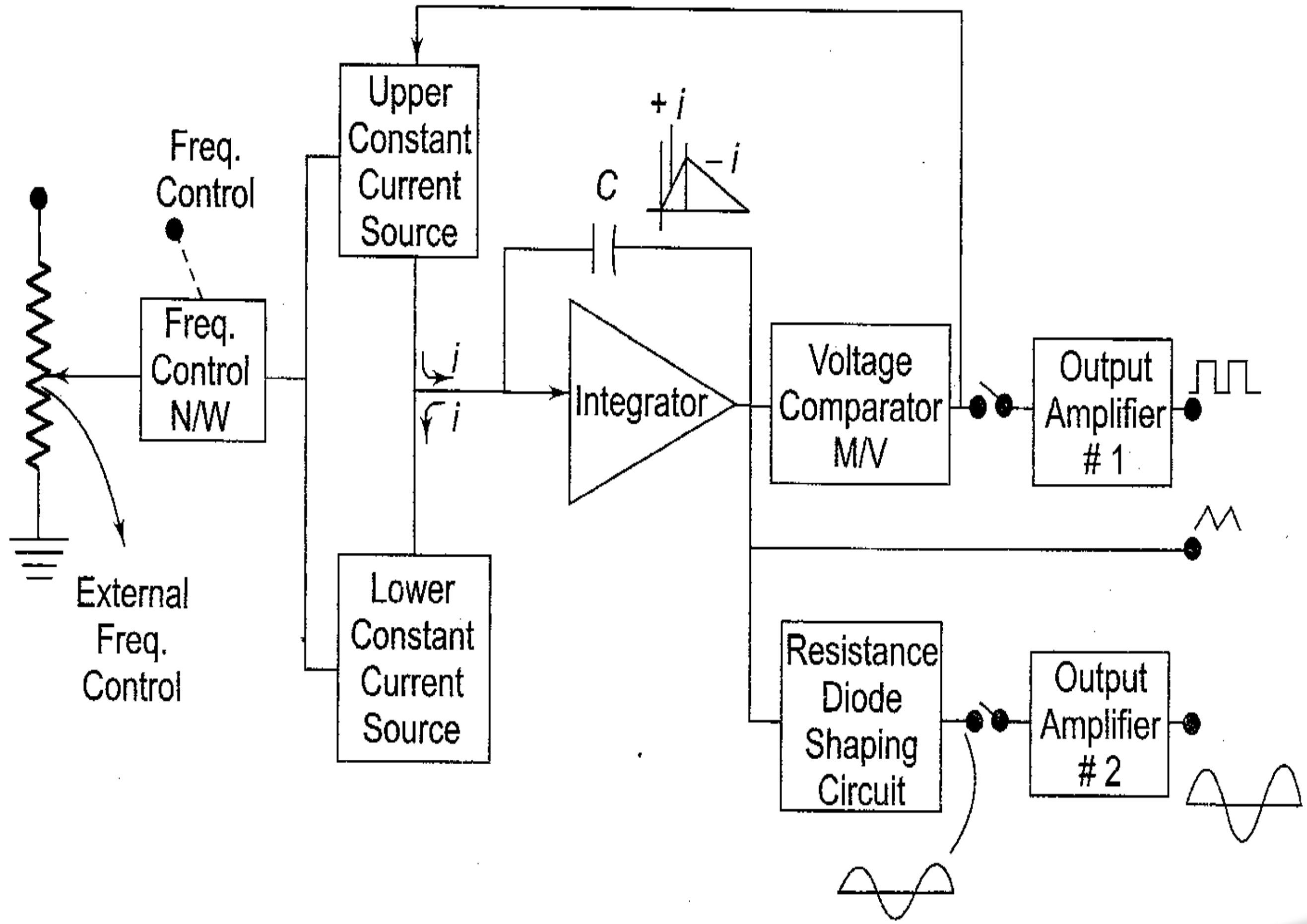
Theblock diagram of a function generator is shown in Figure 3.

Freq. Control – regulates two currents sources (control the freq).

Upper current source –supplies constant current to the integrator, produces an output voltage .

Lower current source – supplies a reverse current to the integrator so that its output decreases linearly with time.

FUNCTION GENERATOR



- Frequency is controlled by varying upper and lower currents. An increase or decrease in the current will increase or decrease the slope of the output voltage, hence controls the frequency.
- The voltage comparator – changes states at a pre-determined maximum and minimum level of the integrator output voltage.
- When t he pre-determined level is reached, it changes the state and switches the current source.

- The integrator output is a triangular waveform whose frequency is determined by the magnitude of the constant current sources.
- The comparator output delivers a square wave of the same frequency.
- The resistance diode network produces a sine wave from the triangular wave with less than 1% distortion.

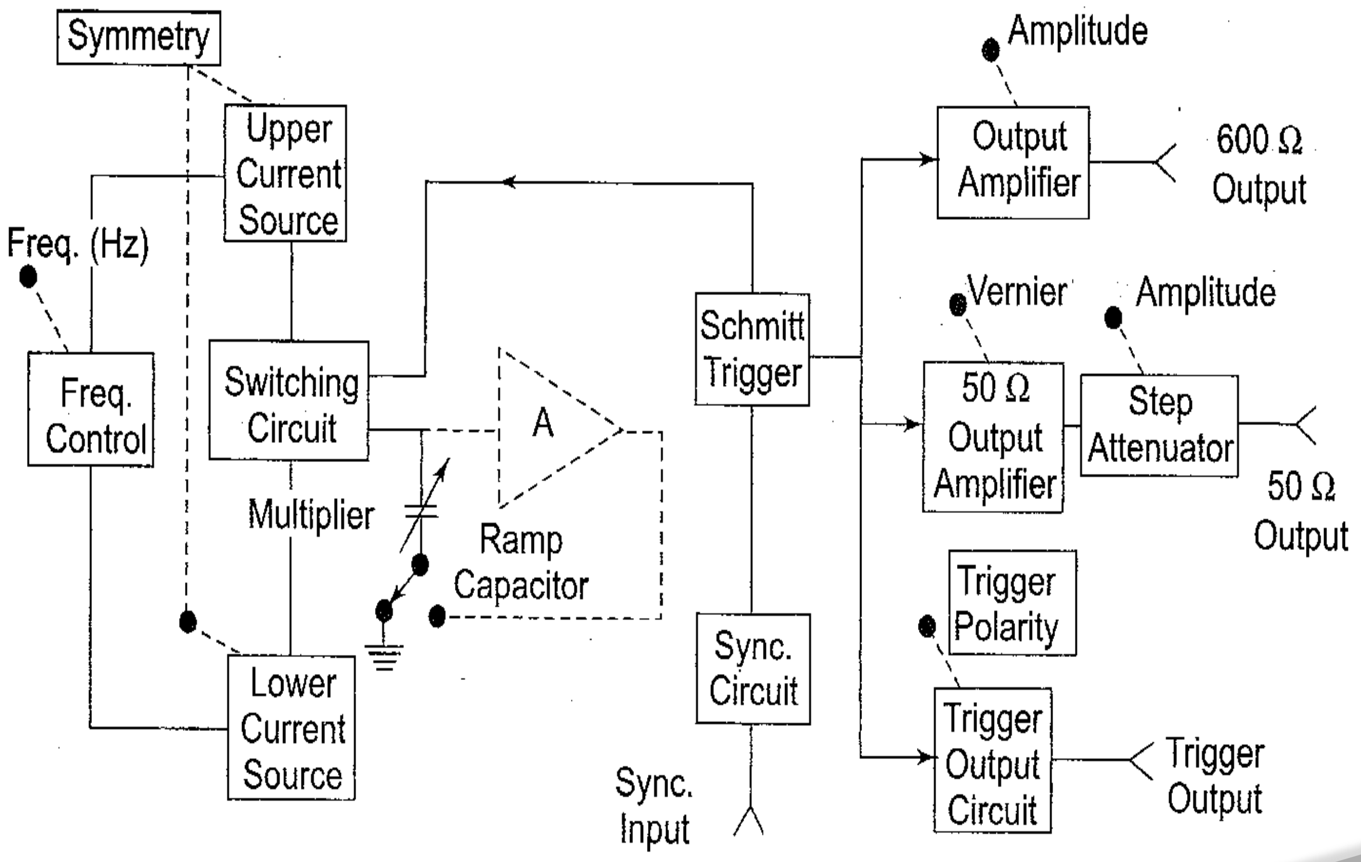
PULSE GENERATOR

- Pulse generators are instruments that produce a rectangular waveform similar to a square wave but with a different duty cycle.
- Duty cycle = pulse width/pulse period„
- A square wave generator has a 50% duty cycle.

•The basic circuit for pulse generation is the asymmetrical multi-vibrator.

- Figure . shows block diagram of a pulse generator.

PULSE GENERATOR



PULSE GENERATOR

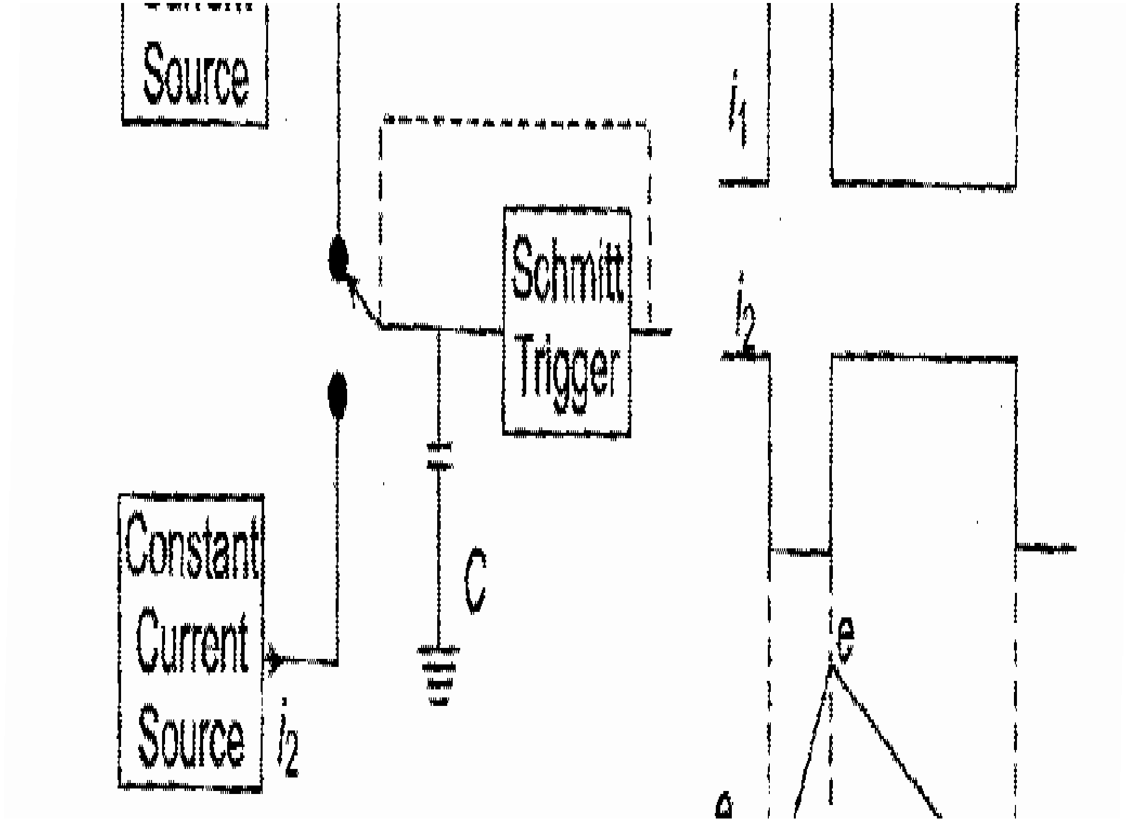
Theduty cycle can be varied from 25 to 75%

Two independent outputs:

- 50Ω - supplies pulses with a rise and fall time of 5ns at 5Vp.
- 600Ω-supplies pulses with a rise and fall time of 70ns at 30Vp.
- The instrument can operate as a free-running or can be

Basic generating loop consists of the current sources, the ramp capacitor, the Schmitt trigger, and the current switching circuit

PULSE GENERATOR



PULSE GENERATOR

- Upper current source – supplies a constant current to the ramp capacitor and the capacitor voltage increases linearly.
- When the positive slope of the ramp reaches the upper limit
- Schmitt trigger will change a state
- Reverses the condition of the current switch.
- Capacitor discharges linearly. (lower current source takes part)

•When the negative slope of the ramp reaches the lower limit, upper current will control the circuit.

- The process is repeated.

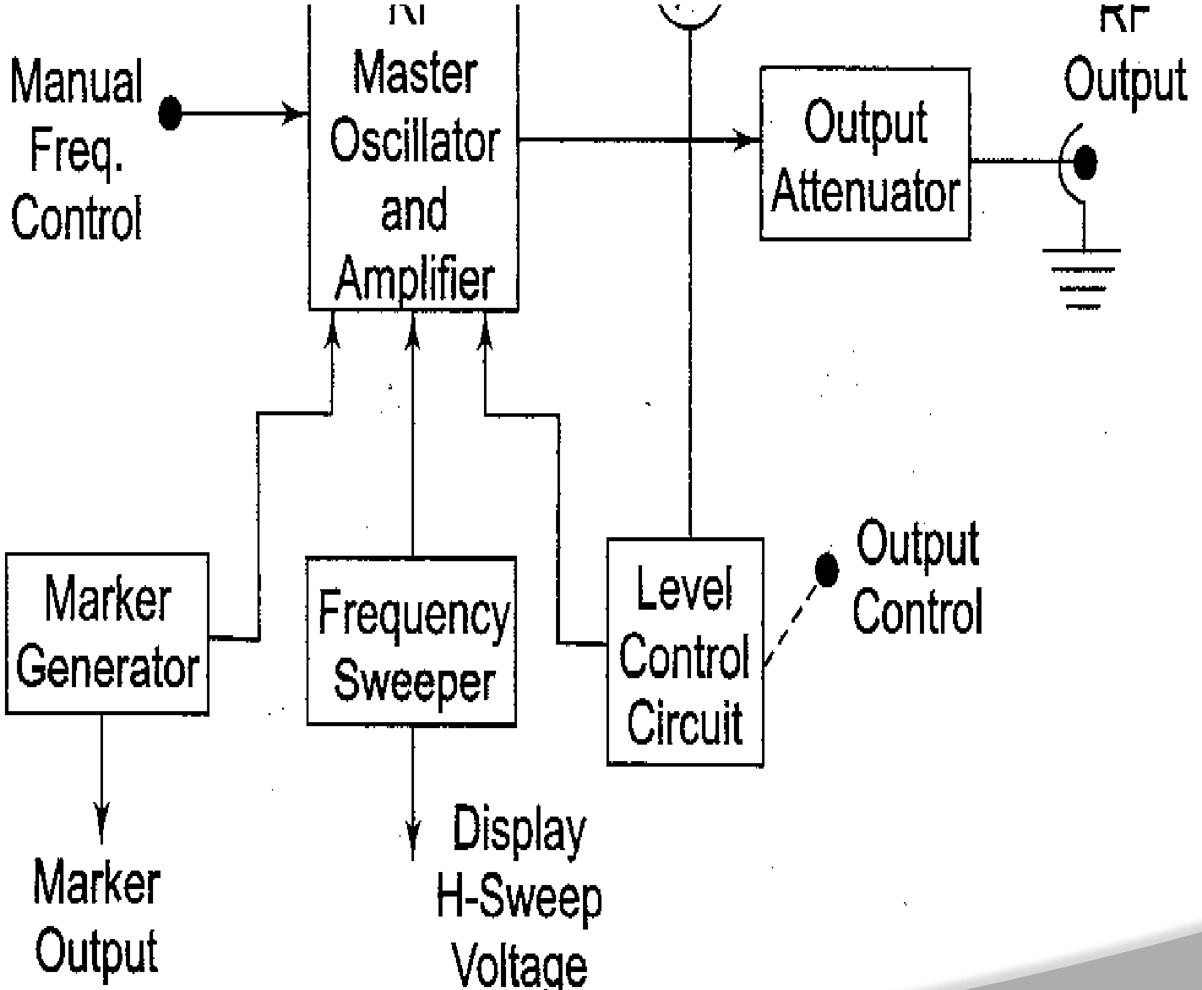
•The ratio i_1/i_2 determines the duty cycle, and is controlled by symmetry control.The sum of i_1 and i_2 determines the frequency.

- The size of the capacitor is selected by the multiplier switch.

SWEEP GENERATOR

- Sweep frequency generators are instruments that provide a sine wave in the RF range.
- Its frequency can be varied smoothly and continuously over an entire frequency band.
- Figure 8 shows the block diagram of the sweep generator.
- The frequency sweeper provides a varying sweep voltage for synchronization to drive the horizontal deflection plates of the CRO.
- A sweep rate can be of the order of 20 sweeps/sec.
- Figure 9 shows the modulated sinewave by a voltage- controlled oscillator (VCO).

SWEEP GENERATOR



SWEEP FREQUENCY GENERATOR

- A sweep frequency generator is a signal generator which can automatically vary its frequency smoothly and continuously over an entire frequency range. Figure 14-15 shows the basic block diagram of a sweep frequency generator.
- The sweep frequency generator has the ramp generator and the voltage-tuned oscillator as its basic components.

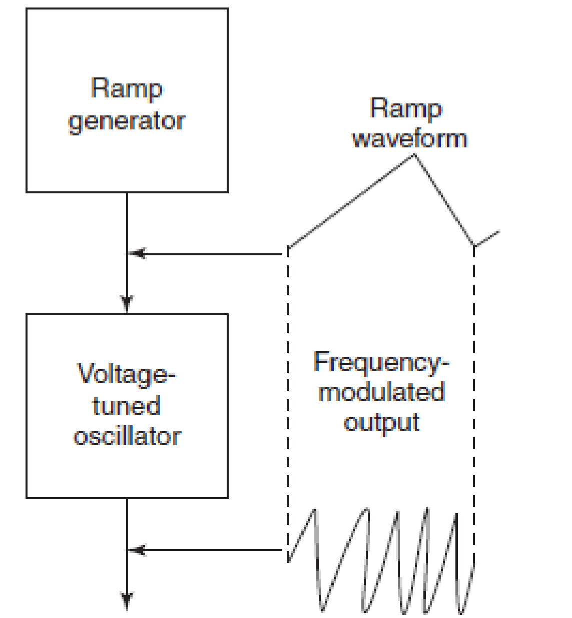


Figure 14-15 Block diagram of a sweep frequency generator

The output of the ramp generator is a linear ramp voltage which serves as the input to the voltage-tuned oscillator. The basic circuit of a voltage-tuned oscillator is similar to that of a frequency modulator circuit.

The resonant frequency of the tank circuit is given by:

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad (14\text{-}29)$$

Applications of the Sweep Frequency Generator

1. Sweep frequency generators are used to display the response curve of the various stages of frequency of television or radio receivers.
2. Sweep frequency generators can be used to determine the characteristics of a device over a wide continuous range of frequencies.

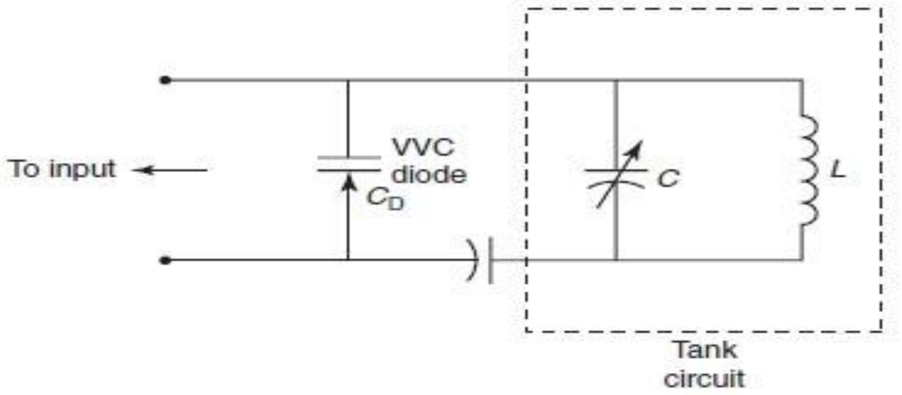


Figure 14-16 Oscillator tank circuit

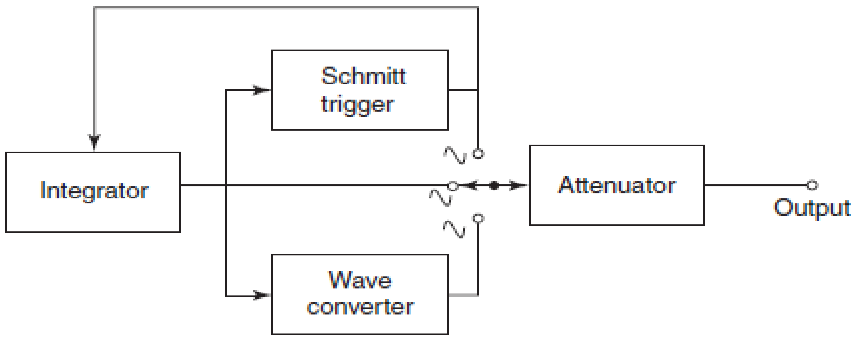


Figure 14-17 Block diagram of a function generator

FUNCTION GENERATOR

- The basic components of a function generator are:
- (i) Integrator
- (ii) Schmitt trigger circuit
- (iii) Sine wave converter
- (iv) Attenuator

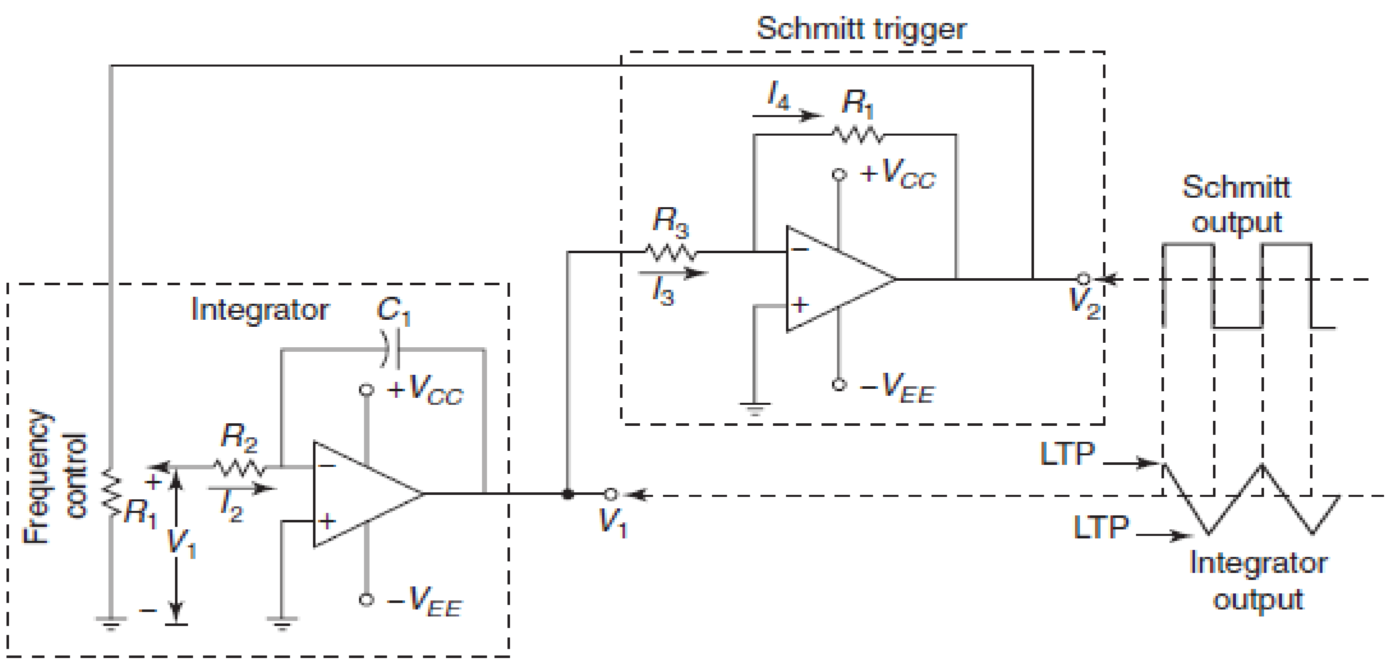


Figure 14-18 Circuit diagram of a function generator

SINE WAVE GENERATOR

- A sine wave is produced by converting a triangular wave, applying proper circuits. The triangular wave is produced by employing an integrator and a Schmitt trigger circuit.
- This triangular wave is then converted to a sine wave using the diode loading circuit ,as shown in Fig. 14-19. Resistors *R1 and R2 behave as the voltage divider. When VR2 exceeds V1, the diode D1 becomes forward*-biased.
- There is more attenuation of the output voltage levels above *V1 than levels below V1. With* the presence of the diode *D1 and resistor R3 in the circuit, the output voltage rises less steeply.*
- *The output voltage* falls below *V1 and the diode stops conducting, as it is in reverse-bias. The circuit behaves as a simple* voltage-divider circuit. This is also true for the negative half-cycle of the input *Vi . If R3 is carefully chosen to* be the same as *R4 , the negative and the positive cycles of the output voltage will be the same. The output is* an approximate sine wave.

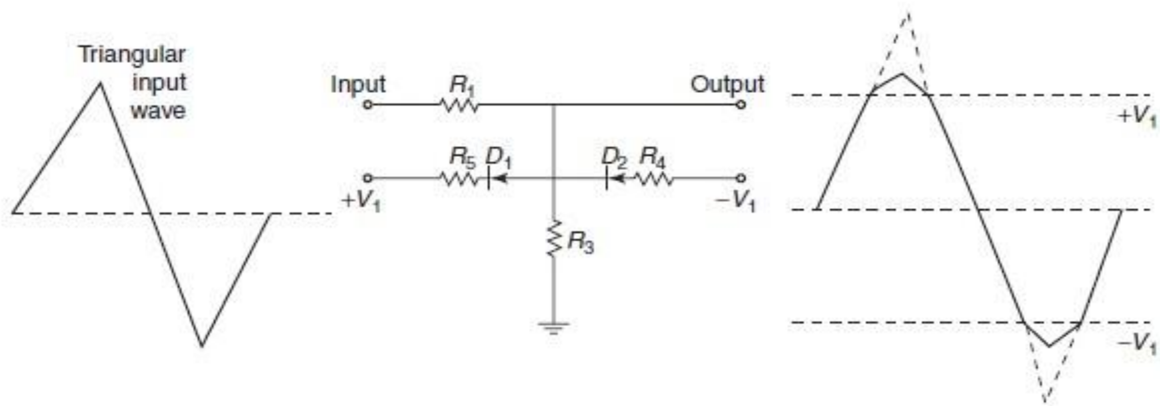


Figure 14-19 Two-level diode loading circuit

SINE WAVE GENERATOR

- The approximation may be further improved by employing a six-level diode loading circuit, as shown in Fig. 14-20(a).

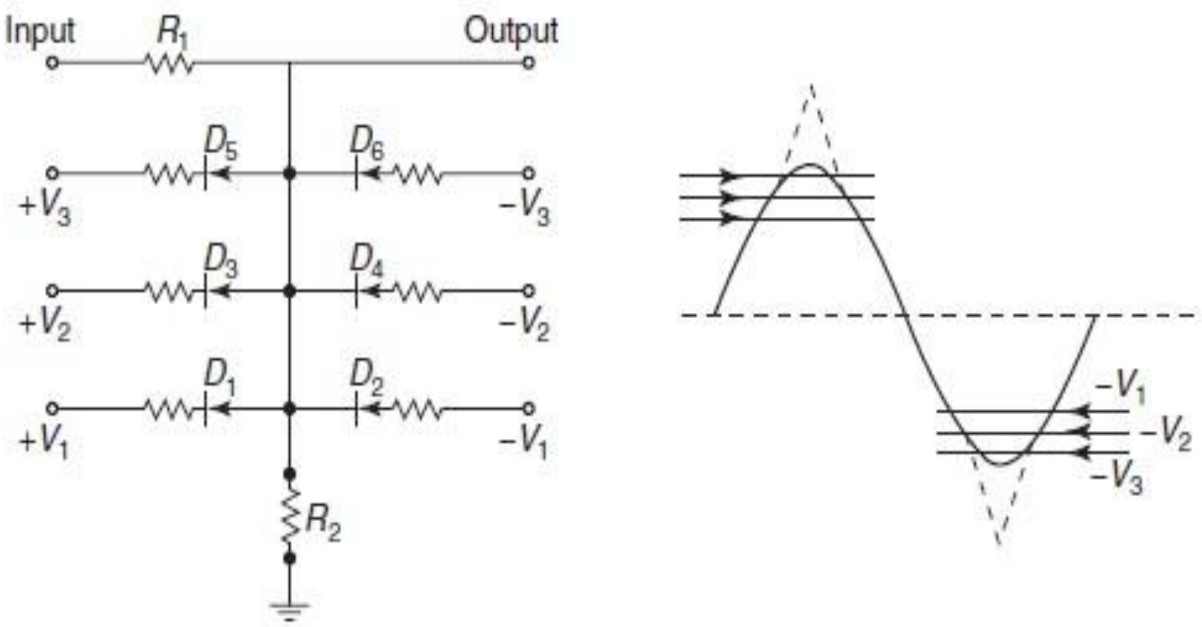


Figure 14-20(a) Diagram for the six-level diode loading circuit

SINE WAVE GENERATOR

- The circuit is adjusted by comparing a 1 kHz sine wave and the output of the triangular/sine wave converter on a dual-track CRO. *R1, R2, R3 and the peak amplitude of Ei are adjusted in*

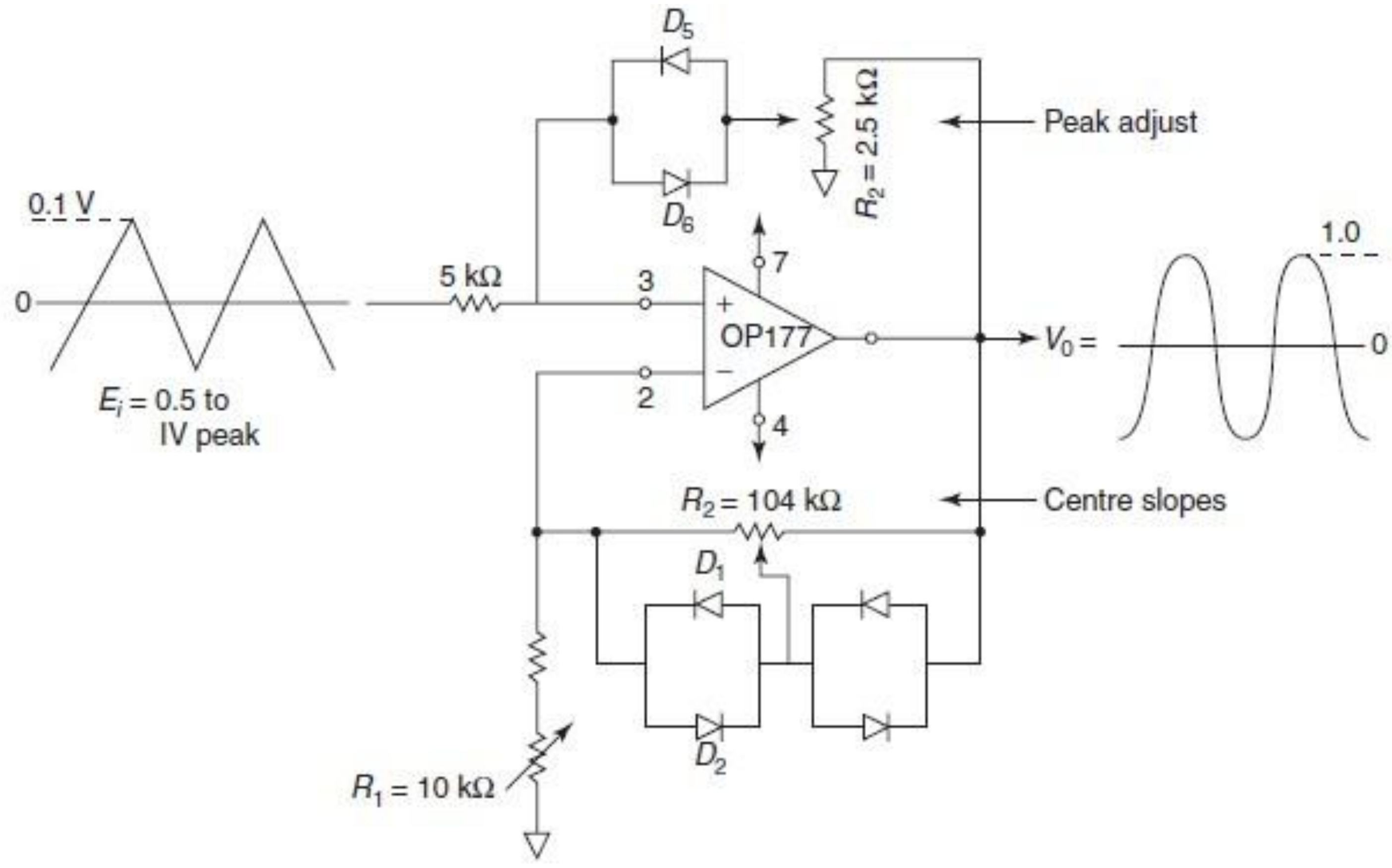


Figure 14-20(b) Triangular to sinewave generator using op-amp

CIRCUIT DIAGRAM OF SINE WAVE GENERATOR

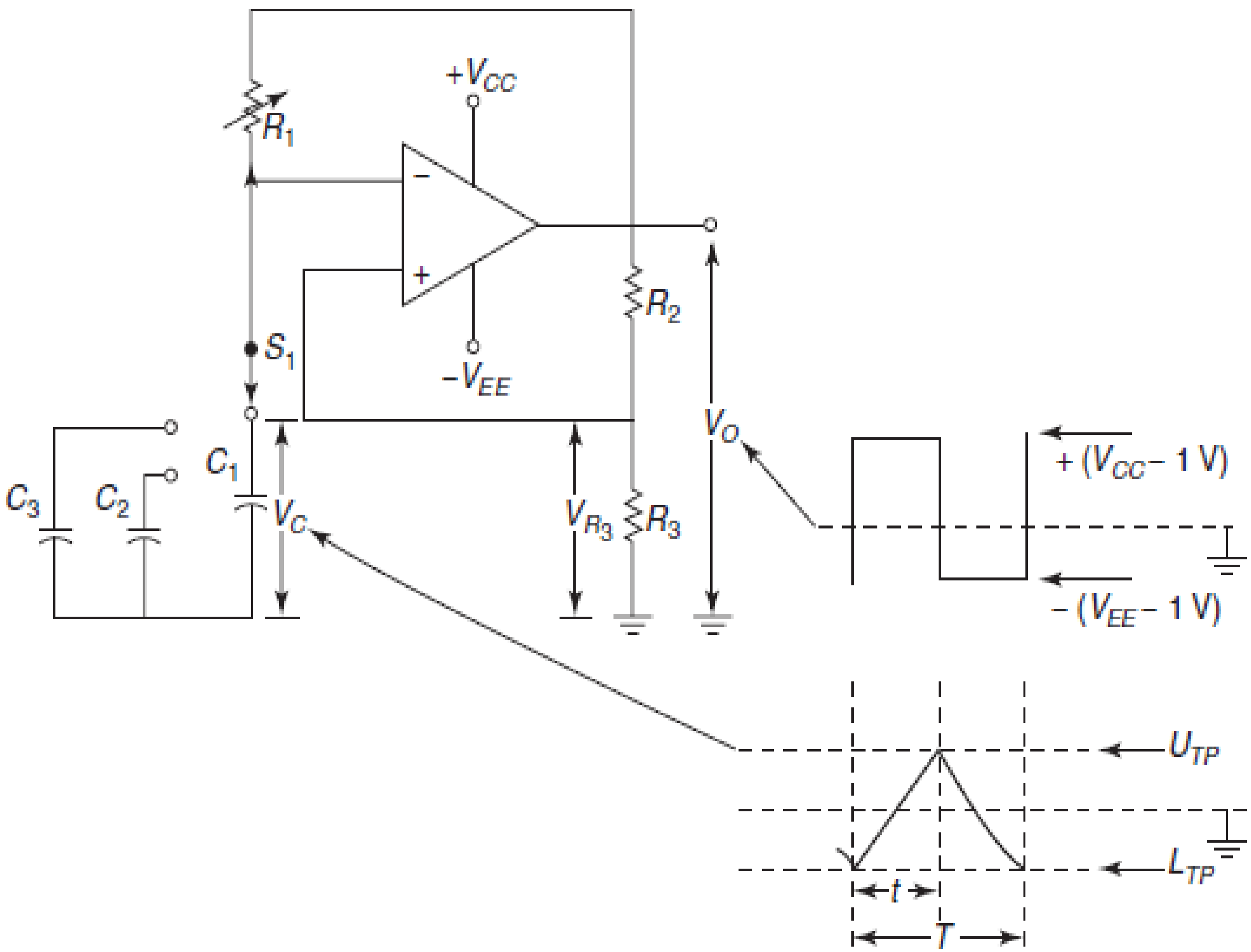


Figure 14-21 Sine wave generator

SQUARE WAVE GENERATOR

- A square wave can be most easily obtained from an operational amplifier astable multi-vibrator. An astable multi-vibrator has no stable state—the output oscillates continuously between high and low states.
- In Fig. 14-21, the block comprising the op-amp, resistors *R2 and R3 constitutes a Schmitt trigger circuit. The* capacitor *C1 gets charged through the resistor R1. When the voltage of the capacitor reaches the upper trigger* point of the Schmitt trigger circuit, the output of the op-amp switches to output low. This is because the Schmitt trigger is a non-inverting type. Now, when the op-amp output is low, the capacitor *C1 starts getting discharged.*

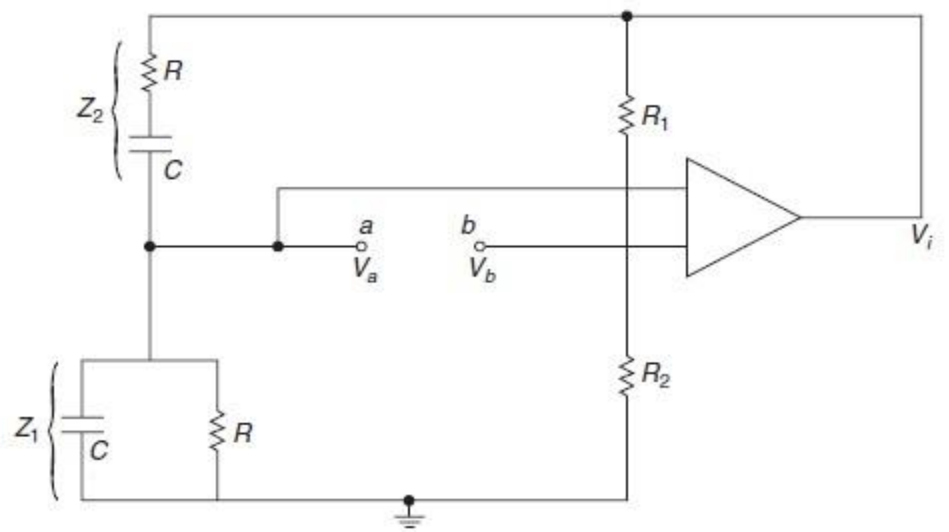


Figure 14-22 Wien-bridge feedback network with an amplifier

SQUARE WAVE GENERATOR

- As the capacitor discharges and the capacitor voltage reaches the lower trigger point of the Schmitt trigger, the output of the op-amp switches back to the output high state.
- The capacitor charges through the resistor again and the next cycle begins. The process is repetitive and produces a square wave at the output.
- The frequency of the output square wave depends on the time taken by the capacitor to get charged and discharged when the capacitor voltage varies from UTP (upper trigger point) and LTP (lower trigger point).

The frequency of the output square wave is given by:

$$f = \frac{1}{T} = \frac{1}{2t} \quad (14\text{-}30)$$

where, t is the time taken by the capacitor to get charged or discharged. The UTP and LTP values for the Schmitt trigger can be fixed by choosing appropriate values of R_2 and R_3.

$$|\mathrm{UTP}| = |\mathrm{LTP}| = V_0 \frac{R_3}{R_2 + R_3} \quad (14\text{-}31)$$

AF SIGNAL GENERATOR

An AF signal generator generally uses an oscillator which is regulated by a controlled phase shift through a resistor and capacitor network. The Wien-bridge oscillator produces sine waves using an RC network as a feedback.

The amplifier is connected as an oscillator in order to determine at what frequency the Wien-bridge provides the required criterion for oscillation. With respect to ground, the voltage at A is given by:

$$V_a = \frac{Z_1}{Z_1 + Z_2} V_i \qquad (14\text{-}32)$$

and

$$V_b = \frac{R_1}{R_1 + R_2} V_i \qquad (14\text{-}33)$$

Since V_a and V_b are the same, from Eqs. (14-32) and (14-33) we can write:

$$\frac{R_1}{R_1 + R_2} = \frac{Z_1}{Z_1 + Z_2} \qquad (14\text{-}34)$$

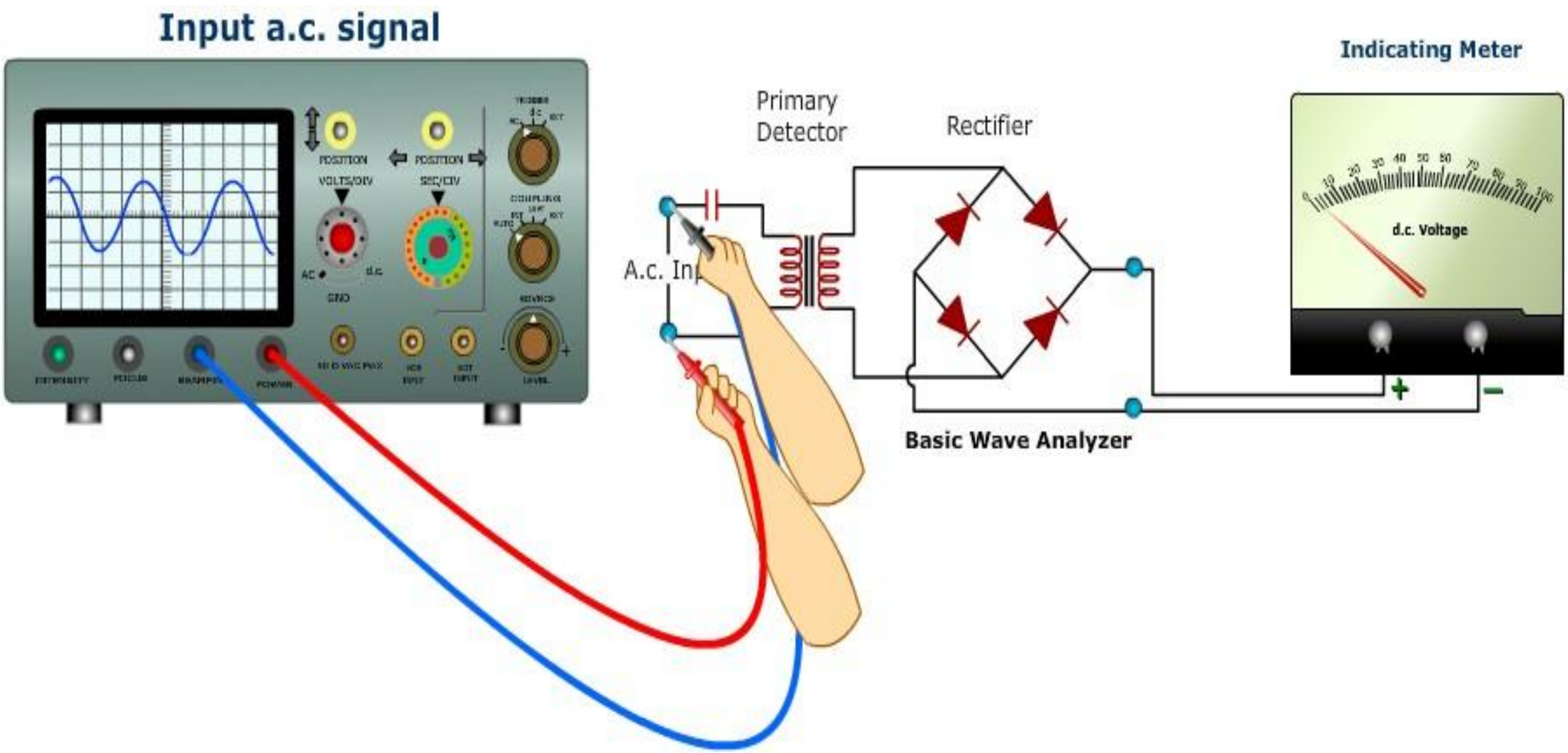
At a frequency $f_0 = 1/2\pi RC$, the phase angle between V_a and the output is zero. The Wien-bridge oscillator is tuned with a variable capacitance and the oscillator is band-switched using the resistance. The Wien-bridge oscillator is usually the heart of a general purpose AF signal generator. Harmonic distortion is then less than a few tenths of a percent.

UNIT III

SIGNAL ANALYZERS

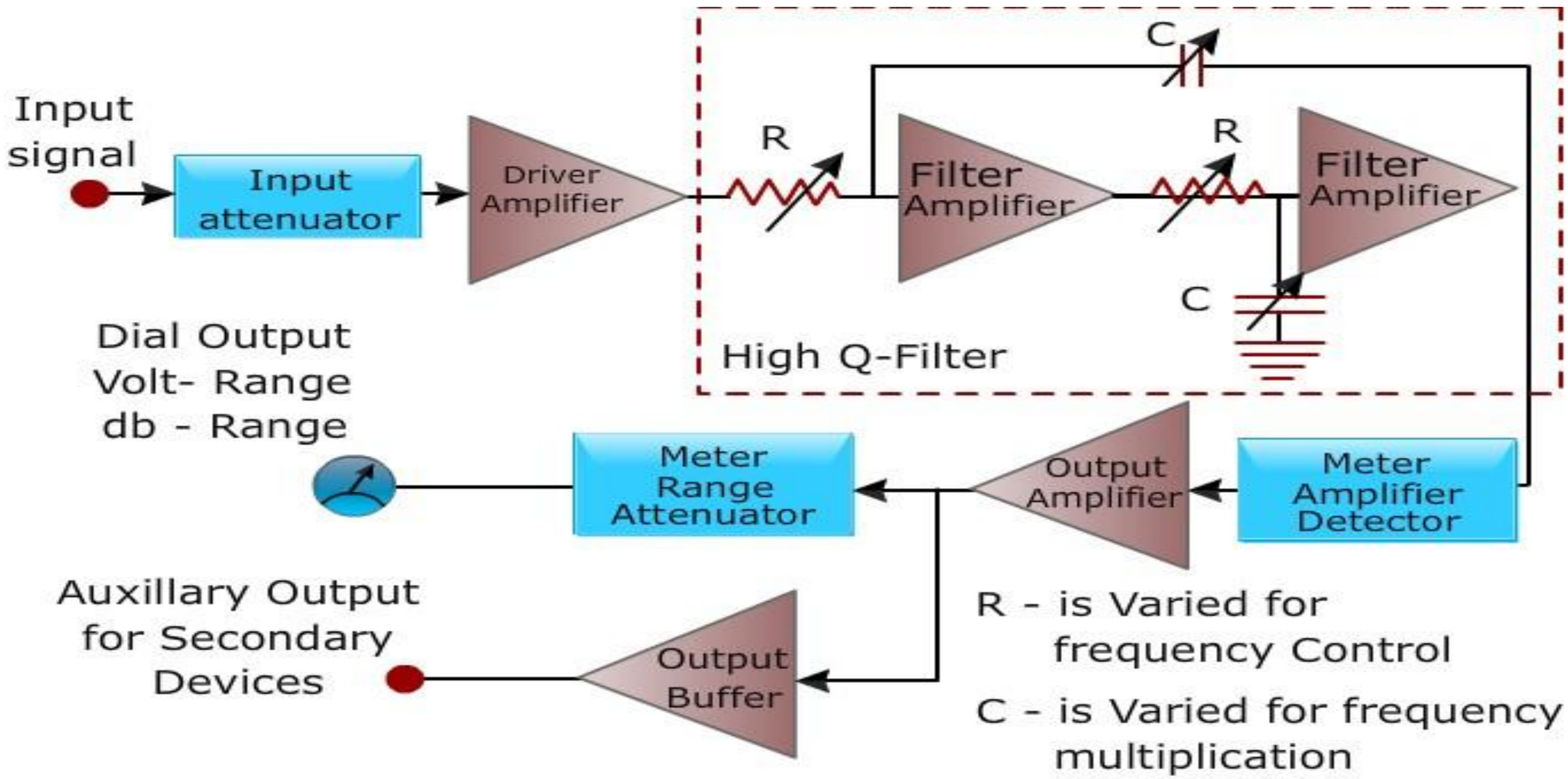
(CIE-II)

Basic Wave Analyzer



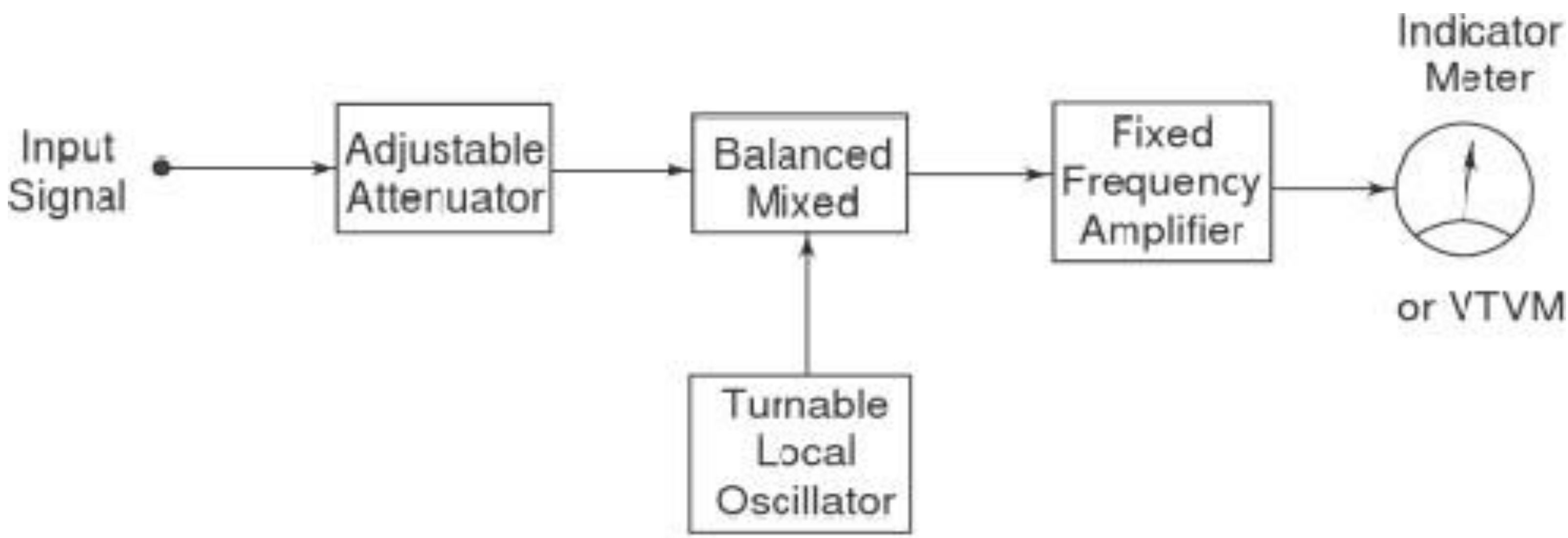
Basic Wave Analyzer

Frequency Selective Wave Analyzer

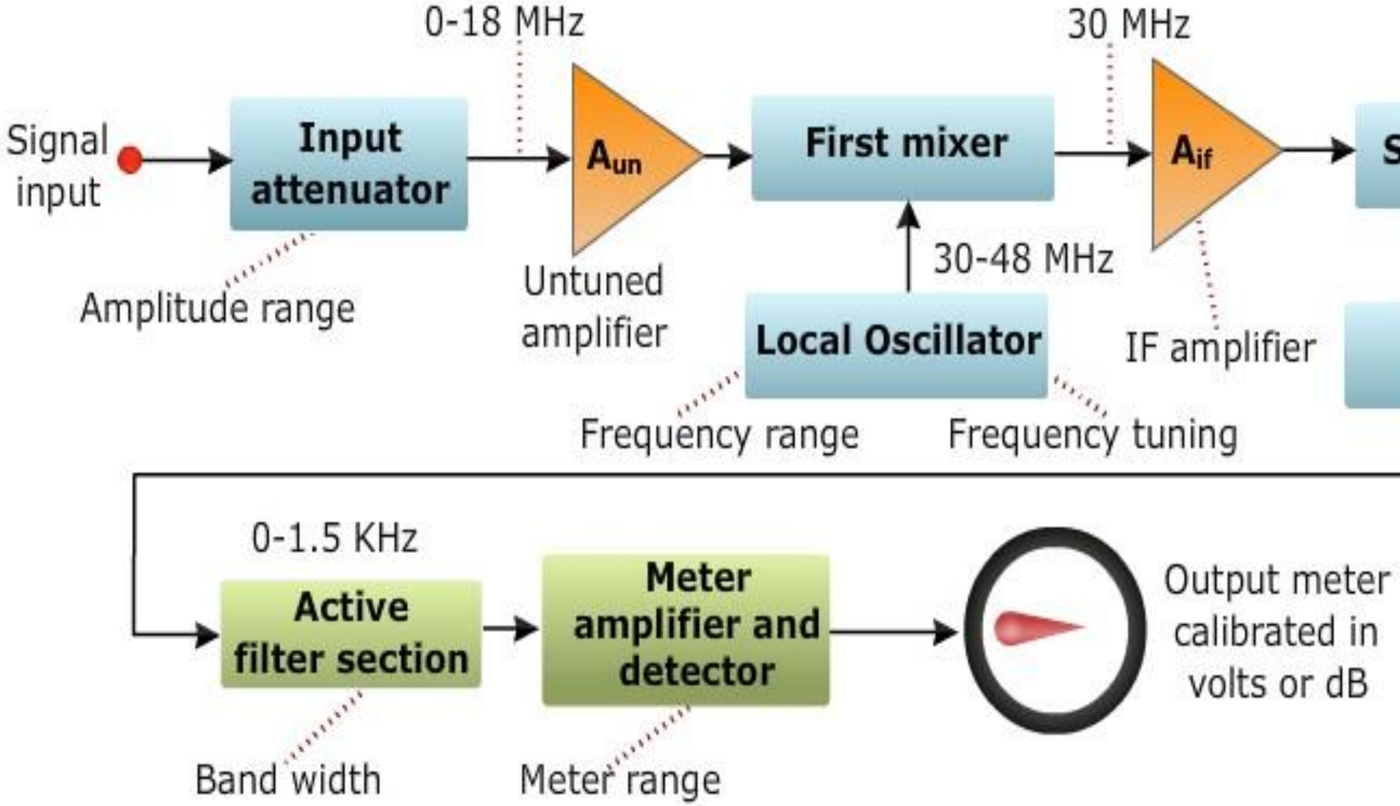


Frequency Selective Wave Analyzer

Heterodyne Wave Analyzer



Heterodyne wave analyzer



Block Diagram of Heterodyne Wave Analyzer

$$D_2 = \frac{B_2}{B_1},\ D_3 = \frac{B_3}{B_1},\ D_4 = \frac{B_4}{B_1}$$

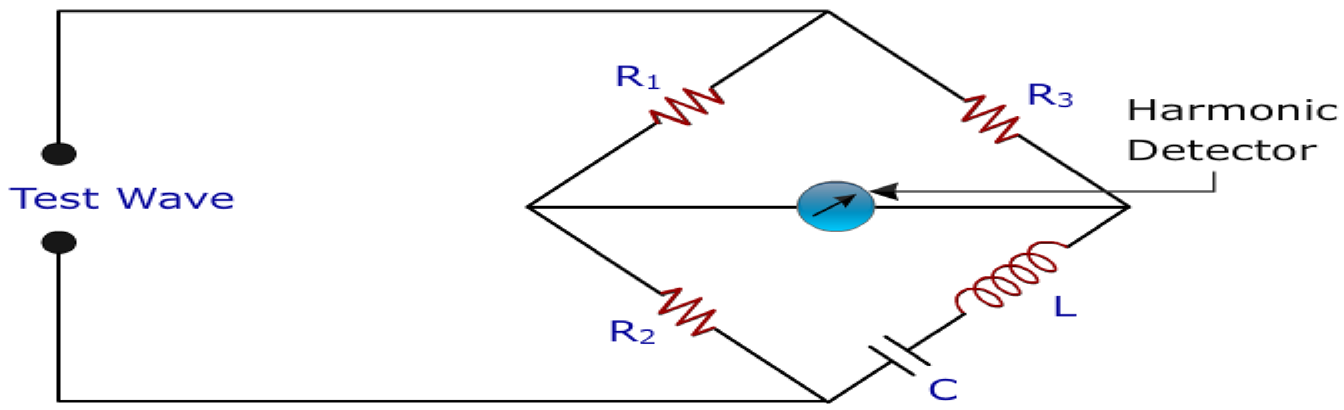
$$THD = \frac{\left[\Sigma(Harmonics)^2\right]^{\frac{1}{2}}}{Fundamental} = \frac{\sqrt{B^2{}_2 + B_3^2 + B_4^2 + ---}}{B_1}$$

$$THD = \sqrt{D_2^2 + D_3^2 + D_4^2 + ---}$$

are there, in that

Fundamental Suppression type.

(a) Employing Resonance Bridge

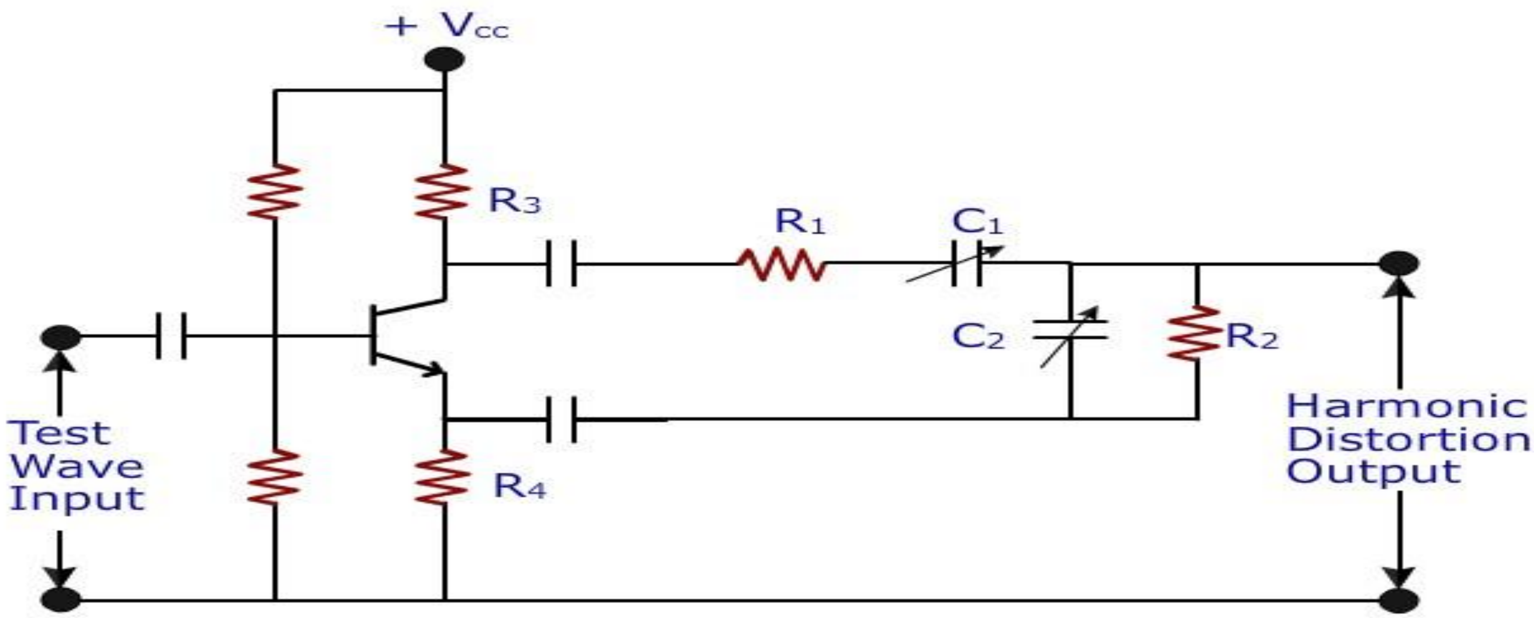


Resonance Bridge

frequency is

ed.

(b) Wien"s Bridge Method

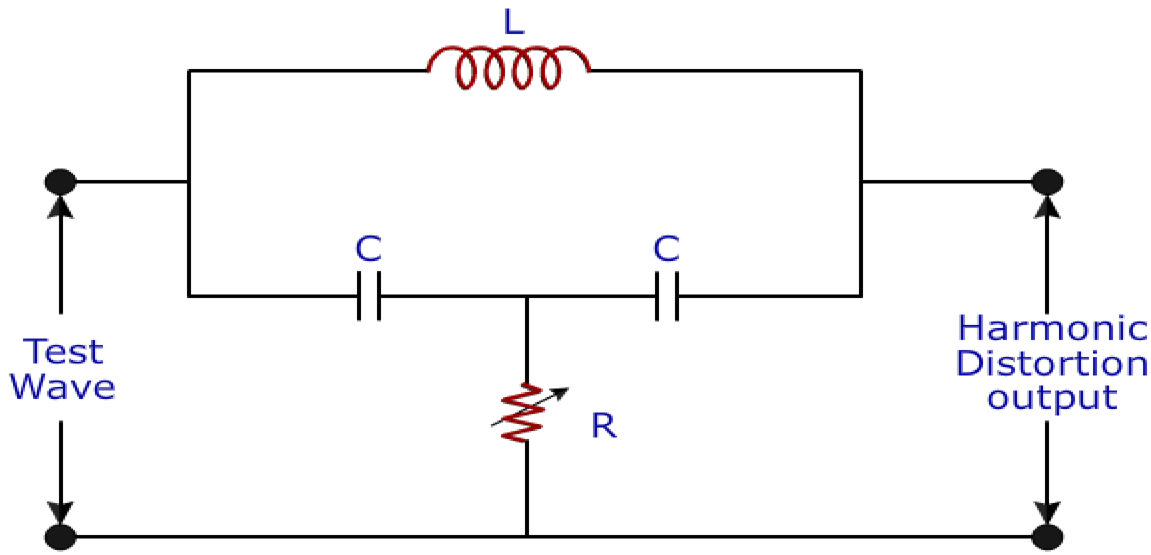


Wien's Bridge Method

- The bridge is balanced for the fundamental frequency. The fundamental energy is dissipated in the bridge circuit elements. Only the harmonic components reach the output terminals.
- The harmonic distortion output can then be measured with a meter. For balance at the fundamental frequency

$C_1=C_2=C$, $R_1=R_2=R$, $R_3=2R_4$.

(C) Bridged T-Network Method

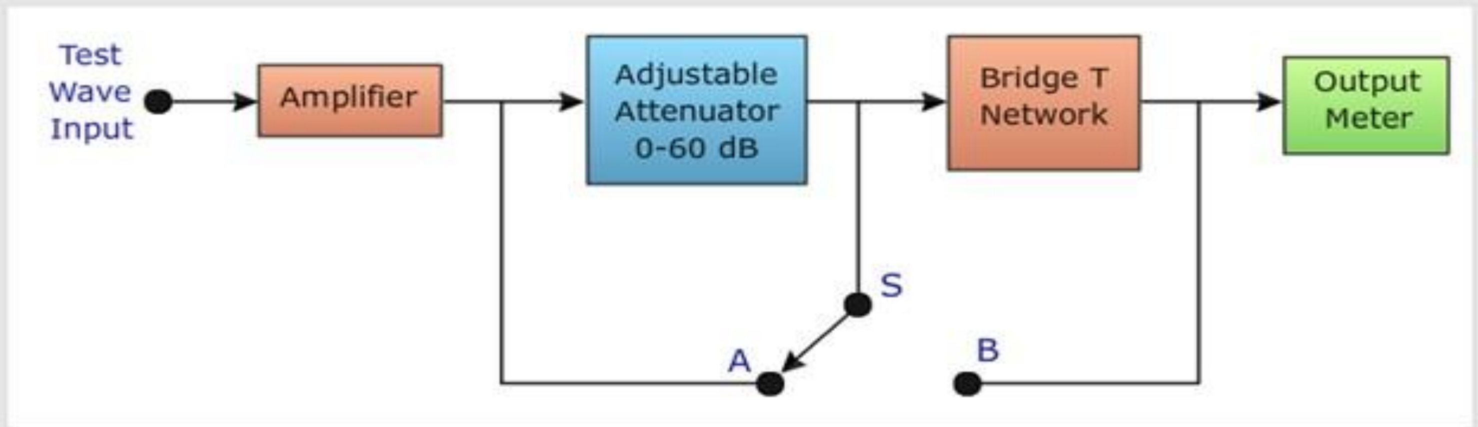


Bridged T-Network Method

and R is adjusted to bypass fundamental frequency.

➢The tank circuit being tuned to the fundamental frequency, the fundamental energy will circulate in the tank and is bypassed by the resistance. Only harmonic components will reach the output terminals and the distorted output can be measured by the meter.

HDA Using Bridged T-Network



Harmonic Distortion Analyzer Using Bridged T-Network

attenuator is excluded and the bridge T-network is adjusted for full suppression of the fundamental frequency, i.e. Minimum output indicates that the bridged T network is tuned to the fundamental frequency and that fundamental frequencies is fully suppressed.

➢The switch is next connected to terminal B, i.e. the bridge T- network is excluded. Attenuation is adjusted until the same reading is obtained on the meter. The attenuator reading indicates the total rams distortion.

analyzer, knowing the amplitude and the frequency of each component, the harmonic distortion can be calculated. However, distortion meters based on fundamental suppression are simpler to design and less expensive than wave analyzers.

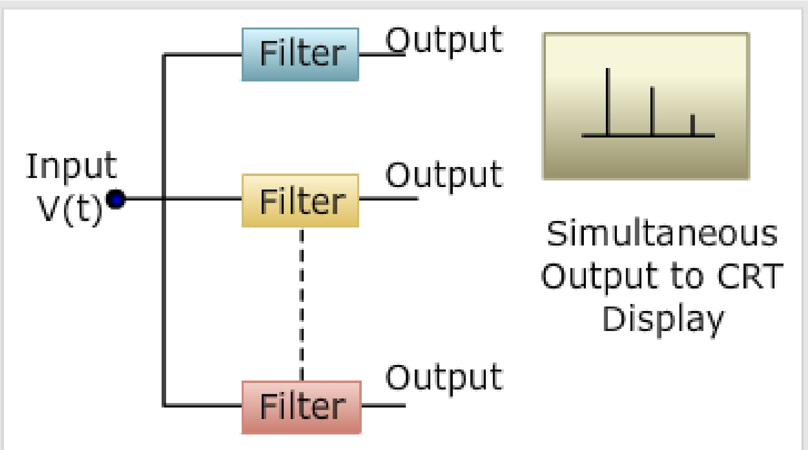
- The disadvantage is that they give only the total distortion and not the amplitude of individual distortion components.

Spectrum Analyzer

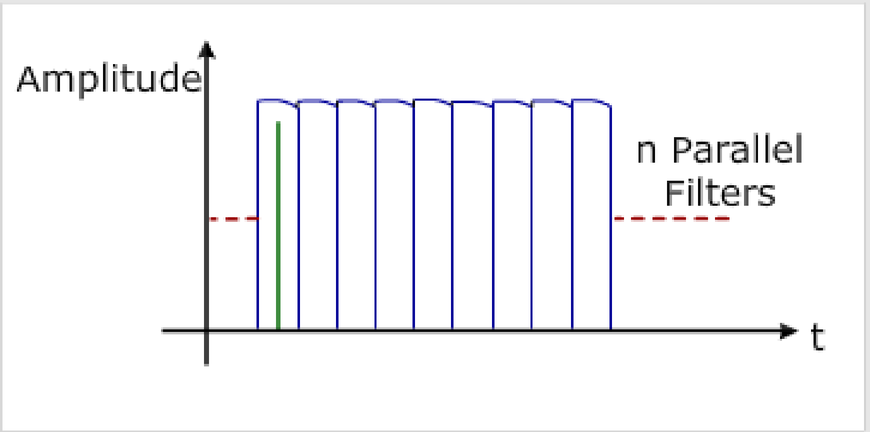
Generally in observation of signal we use the time domain, In this with time as the X-axis(Amplitude of signal Vs time). Another way of observing signals i.e. frequency domain, in x-axis frequency and y-axis amplitude. The instrument providing this frequency domain view is the spectrum analyzer.

- Spectrum analyzers provide a display of the frequency spectrum over a given frequency band. Spectrum analyzers use either a parallel filter bank or a swept frequency technique.

Spectrum Analyzer

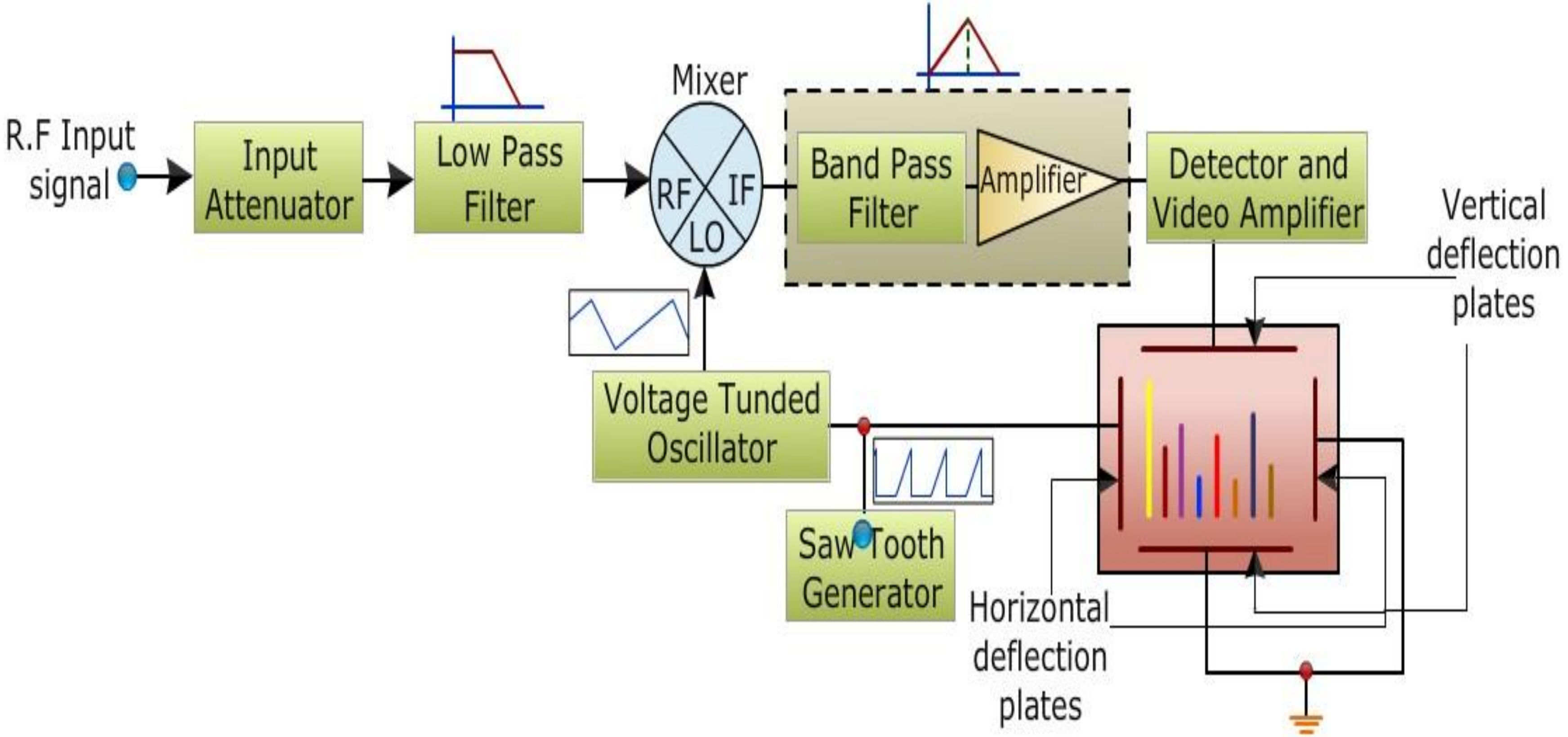


Parallel Filter Bank Analyzer



Overlapping Filter Bank

Spectrum Analyzer Using Swept Receiver Design



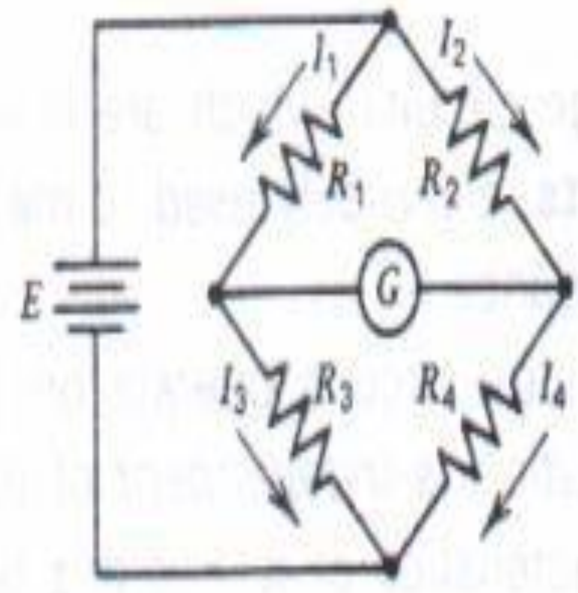
Block Diagram of Spectrum Analyzer

UNIT IV
AC and DC Bridges

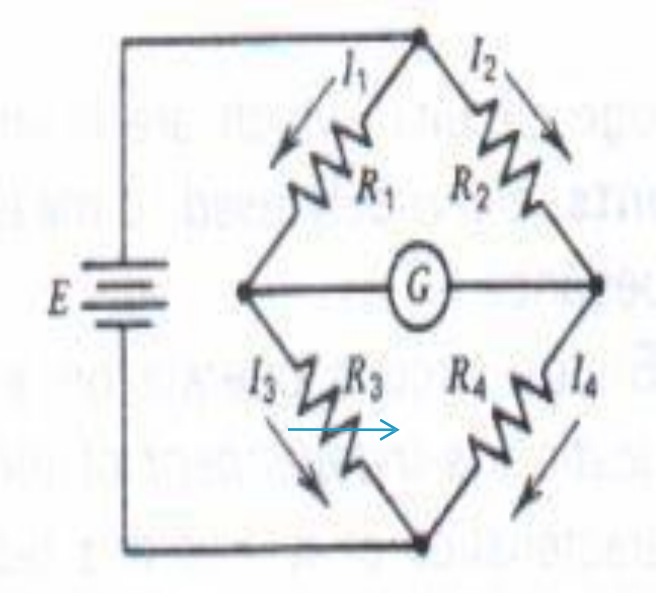
DC bridge

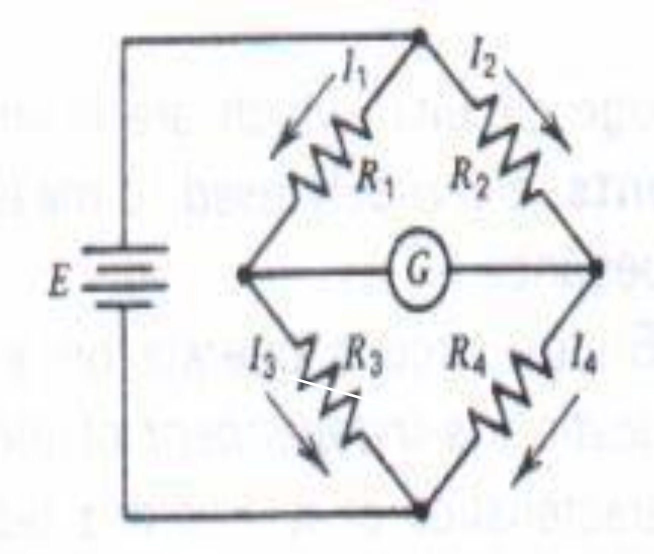
AC bridge

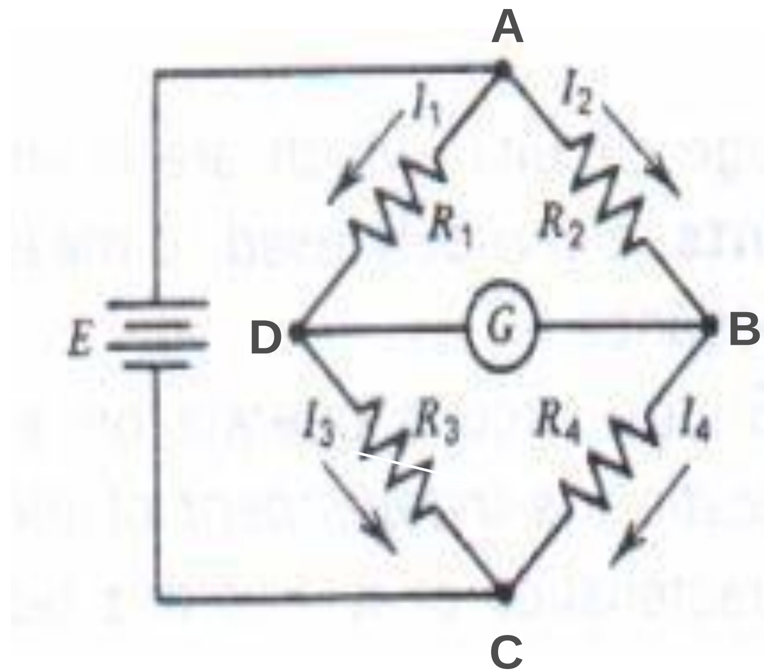
Wheatstone Bridge



Finding resistance of unknown resistor

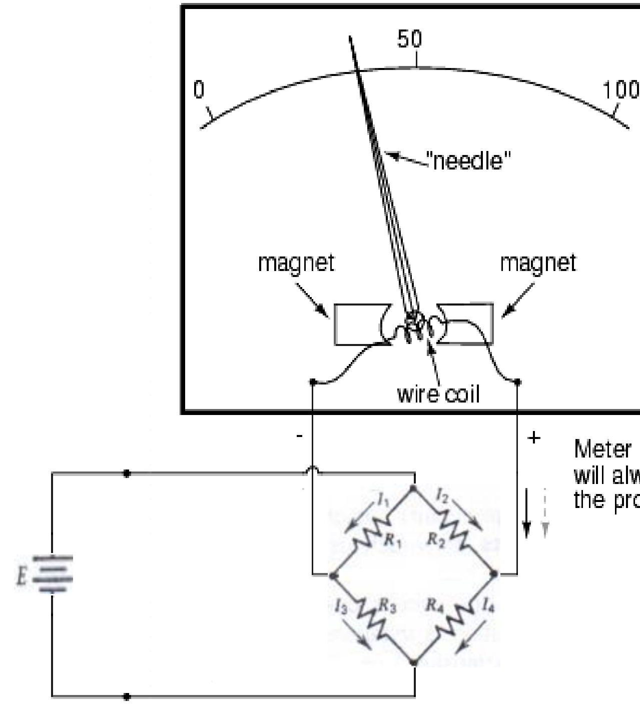



I_1
I_2
R_1
R_2
E
G
I_3
R_3
R_4
I_4



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

[redacted]



Meter movement needle will always be driven in the proper direction.

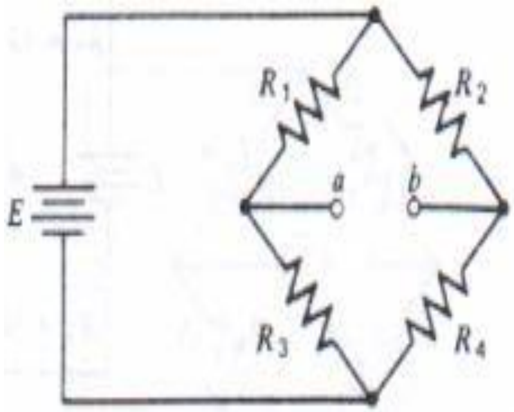
$$S = \frac{Deflection}{Current} = \frac{D}{I}$$

$$S = \frac{mil\lim eters}{\mu A} or;$$

$$S = \frac{\deg rees}{\mu A} or;$$

$$S = \frac{radians}{\mu A}$$

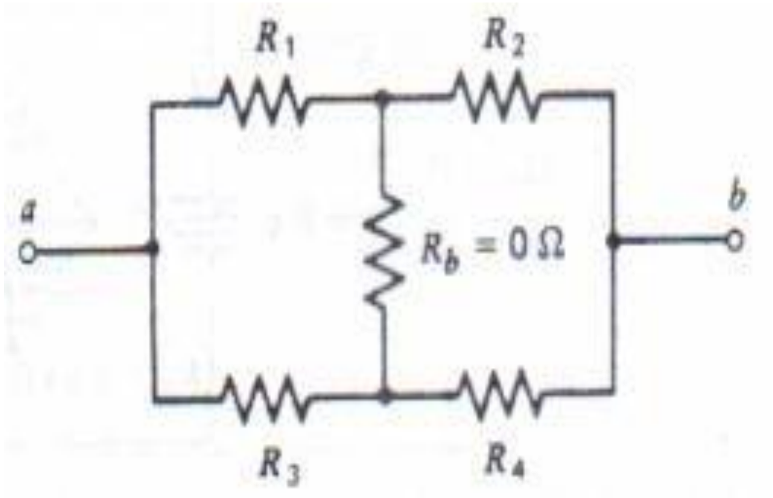
Thevinin's Theorem:



[redacted] [redacted]

Wheatstone Bridge

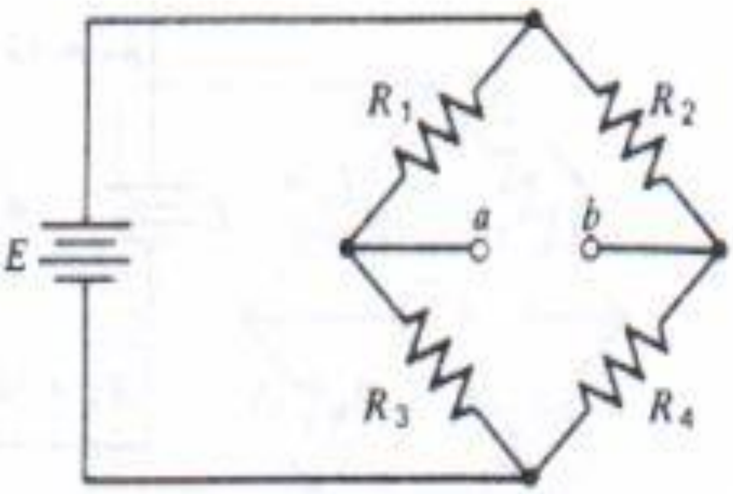
[redacted]

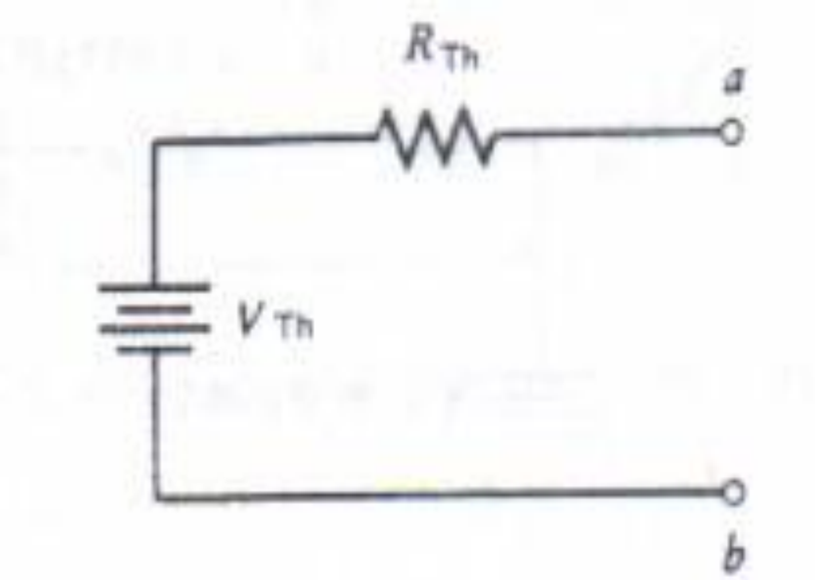


$$R_{Th} = R_1 // R_3 + R_2 // R_4$$

[redacted]

Wheatstone Bridge





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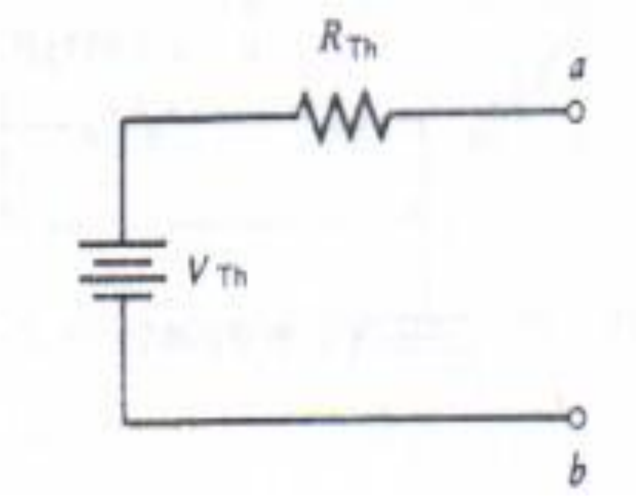
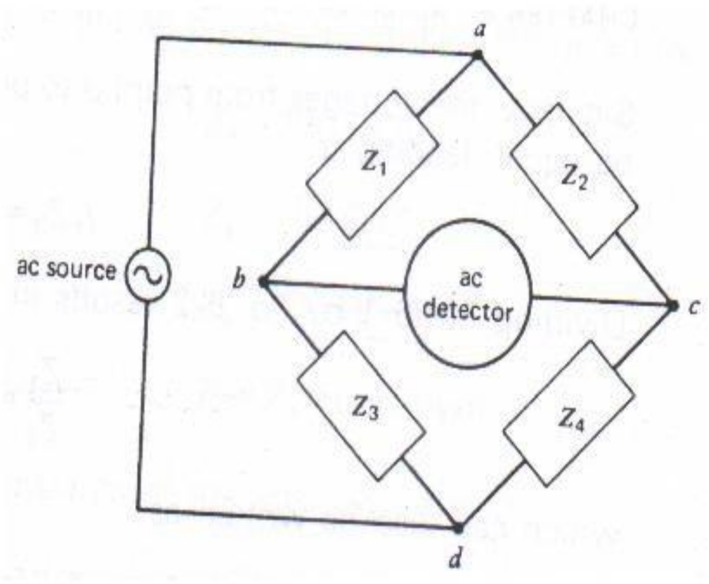
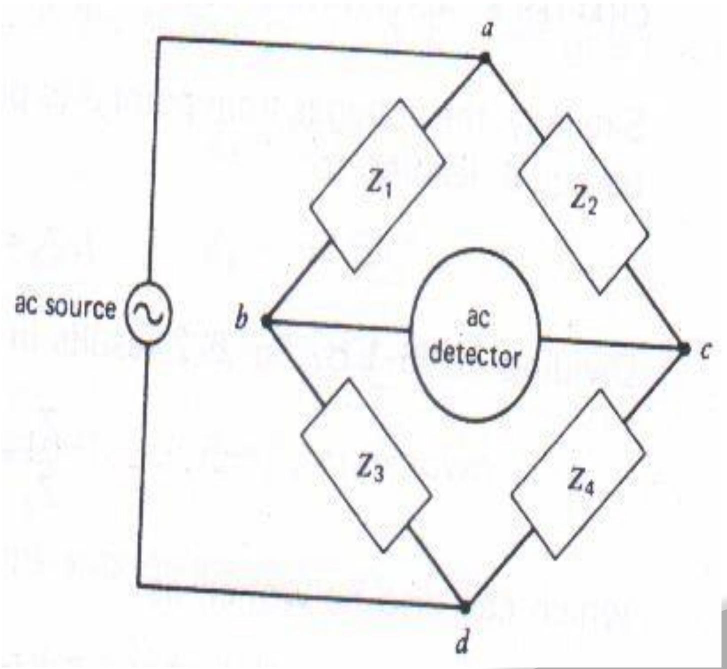


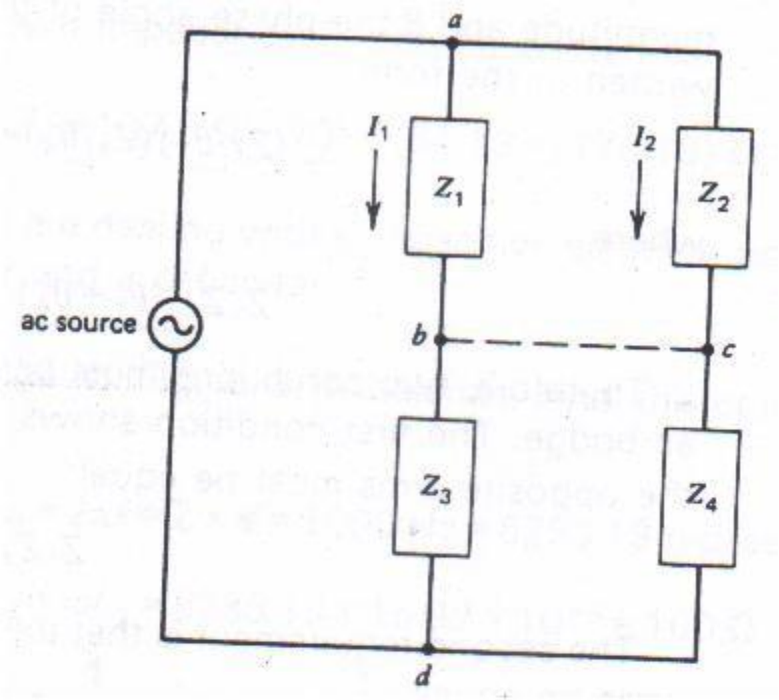
AC Bridges




a
Z1
Z2
ac source
b
ac
detector
c
Z3
Z4
d

the detector current

becomes zero there is no voltage difference across the detector

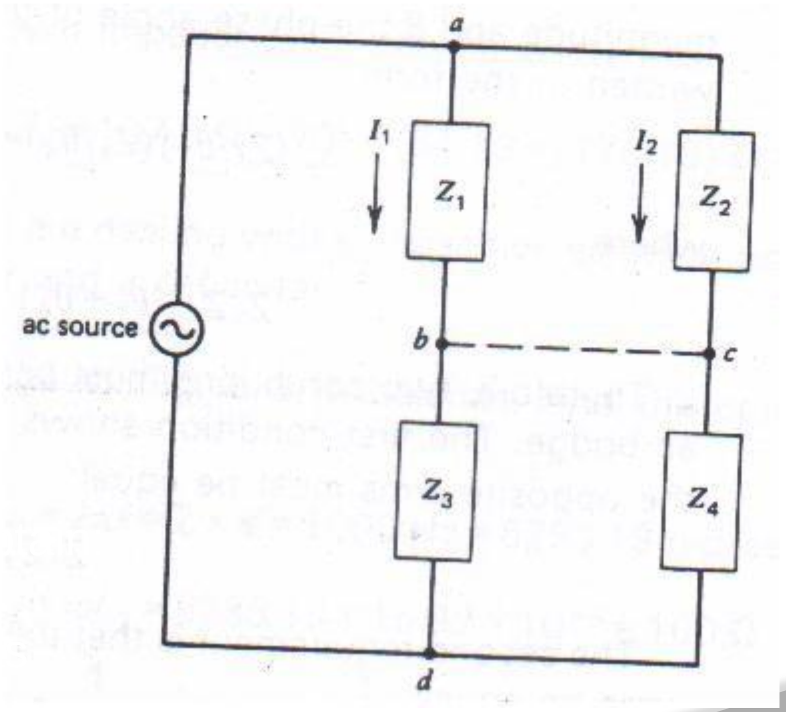


[redacted] -------(1)

[redacted]

$$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4}$$

[redacted]

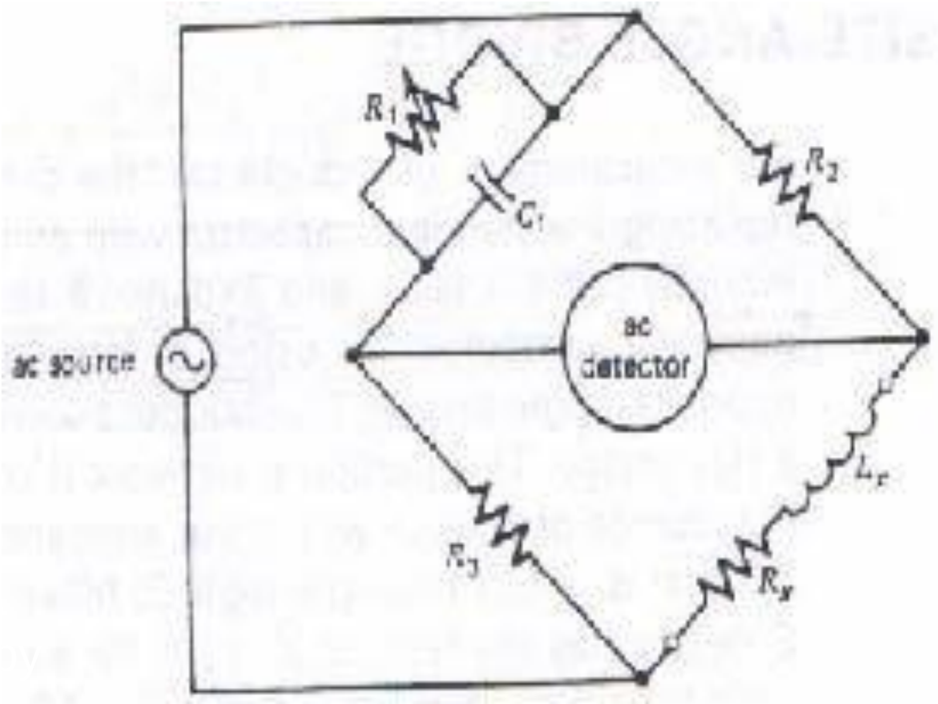


$$\left(Z_1\angle\theta_1\right)\left(Z_4\angle\theta_4\right)=\left(Z_2\angle\theta_2\right)\left(Z_3\angle\theta_3\right) \quad \text{-----}(3)$$

[redacted]

Maxwell Bridge

Maxwell Bridge:



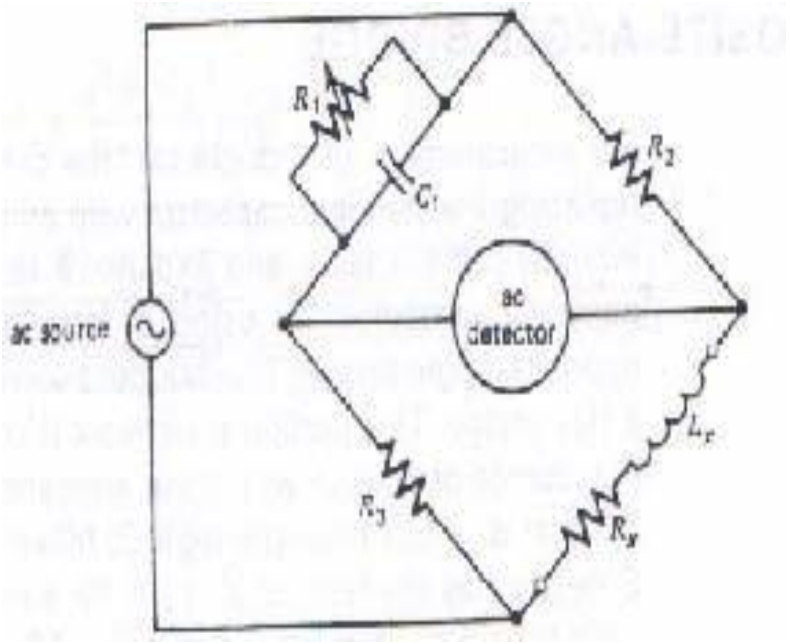
Maxwell Bridge

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

$$Z_2 = R_2$$

$$Z_3 = R_3$$

$$Z_4 = R_x + j X_{Lx}$$



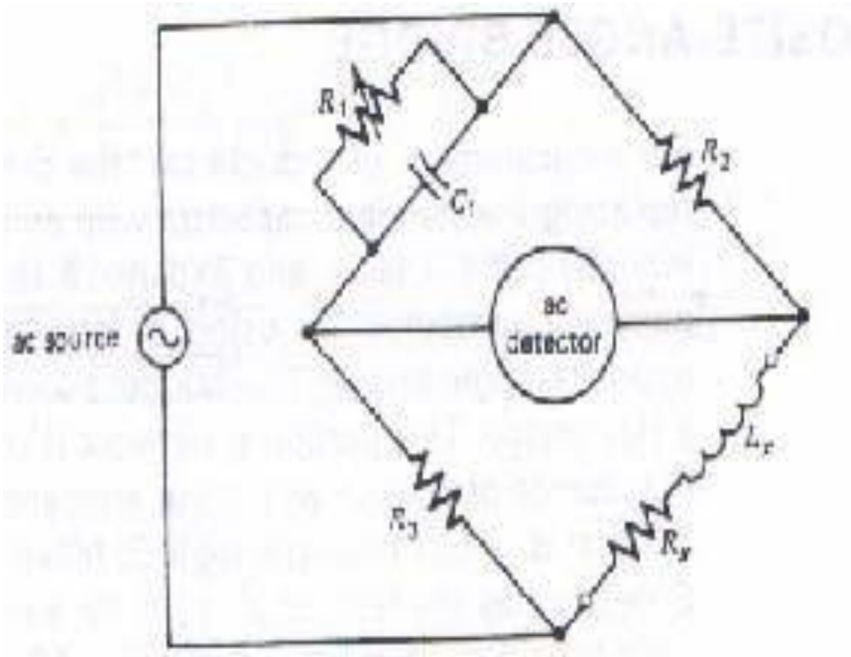
$$Z_1 Z_x = Z_2 Z_3$$

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

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

$$\frac{R_x + jX_{Lx}}{1 + j\omega C_1} = \frac{R_2 R_3}{R_1}$$

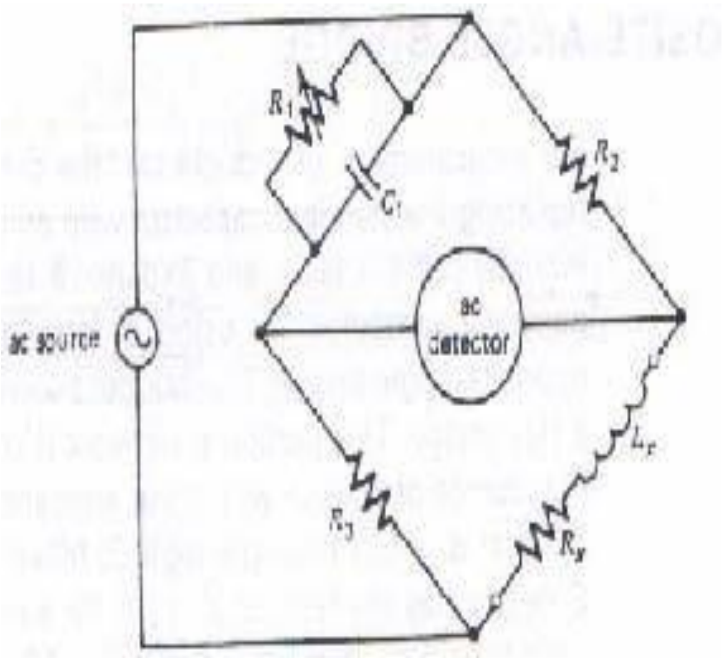
$$R_x + jX_{Lx} = \frac{R_2 R_3}{R_1} + j\omega R_2 R_3 C_1$$



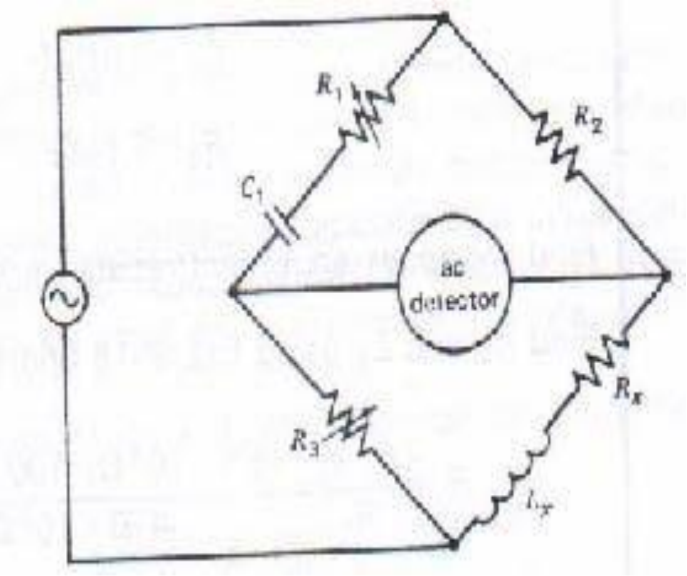
[redacted]

$$j\omega L_x = j\omega R_2 R_3 C_1$$

[redacted]



Hay‟s Bridge(Opposite Angle Bridge)



$$Z_1 = R_1 - \frac{j}{\omega C_1} \qquad Z_2 = R_2$$

$$Z_3 = R_3 \qquad Z_x = R_x + j\omega L_x$$

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

$$R_1 R_x + \frac{L_x}{C_1} - \frac{jR_x}{\omega C_1} + j\omega L_x R_1 = R_2 R_3$$

$$R_1 R_x + \frac{L_x}{C_1} = R_2 R_3 \quad \text{--------(1)}$$

$$\frac{R_x}{\omega C_1} = \omega L_x R_1$$

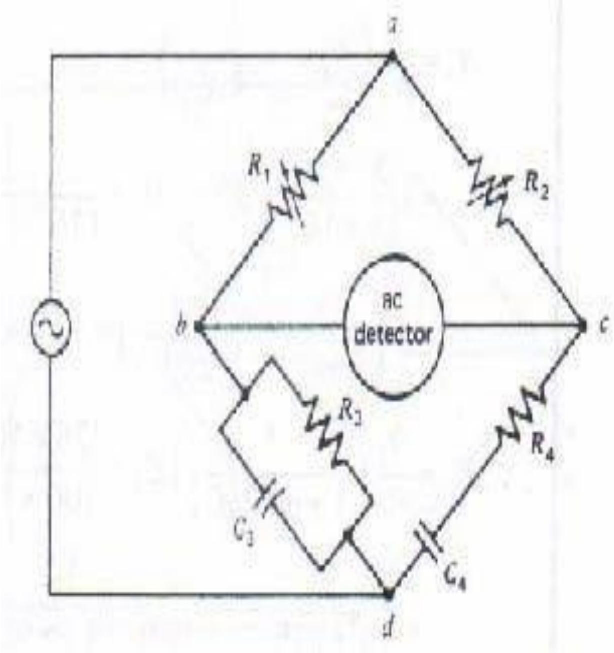
$$R_1(\omega^2 R_1 C_1 L_x) + \frac{L_x}{C_1} = R_2 R_3$$

$$\omega^2 R_1^2 C_1 L_x + \frac{L_x}{C_1} = R_2 R_3$$

[redacted]

$$\omega^2 R_1^2 C_1^2 L_x + L_x = R_2 R_3 C_1$$

[redacted]



a
R_1
R_2
b
AC detector
c
R_3
R_4
C_3
C_4
d

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

$$Z_4 = R_4 - \frac{j}{\omega C_4}$$

[redacted]

[redacted]

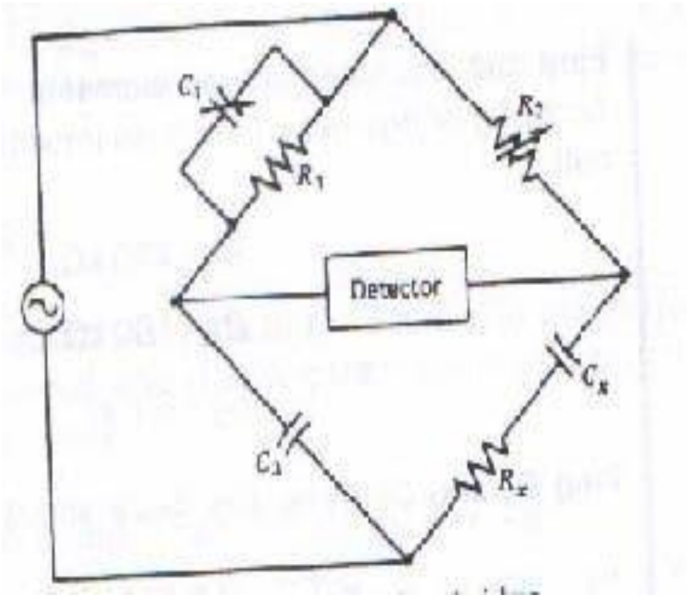
[redacted]

[redacted]

frequency

[redacted]

Schering Bridge



$$Z_1 = \frac{1}{\frac{1}{R_1} + \frac{1}{-jX_{C1}}}$$

$$Z_2 = R_2$$

$$Z_3 = -jX_{C3}$$

$$Z_4 = R_x - jX_x$$

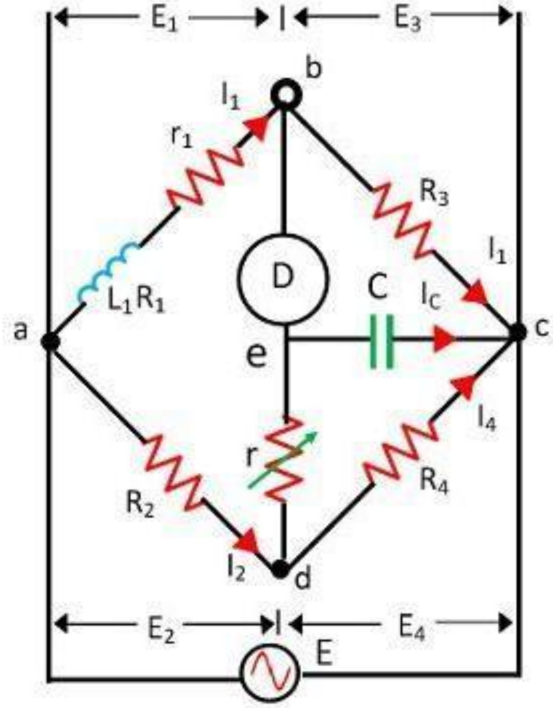
$$Z_4 = \frac{Z_2 Z_3}{Z_1}$$

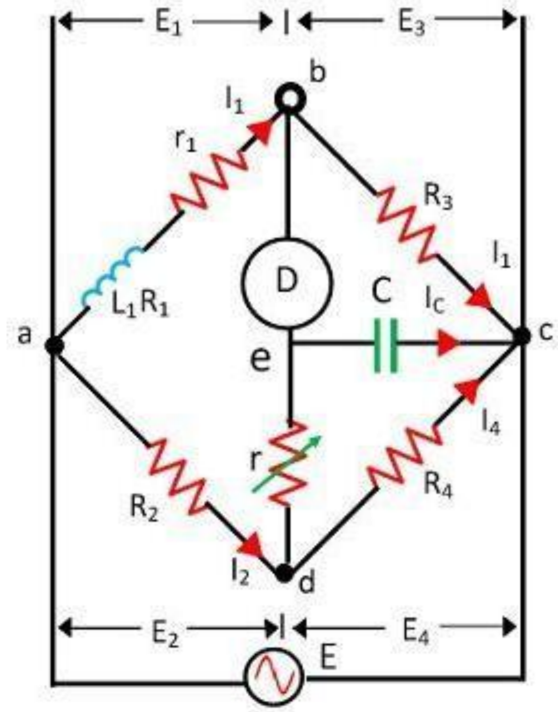
$$R_x - jX_x = \frac{R_2(-jX_{C3})}{\dfrac{1}{\dfrac{1}{R_1} + \dfrac{1}{-jX_{C1}}}}$$

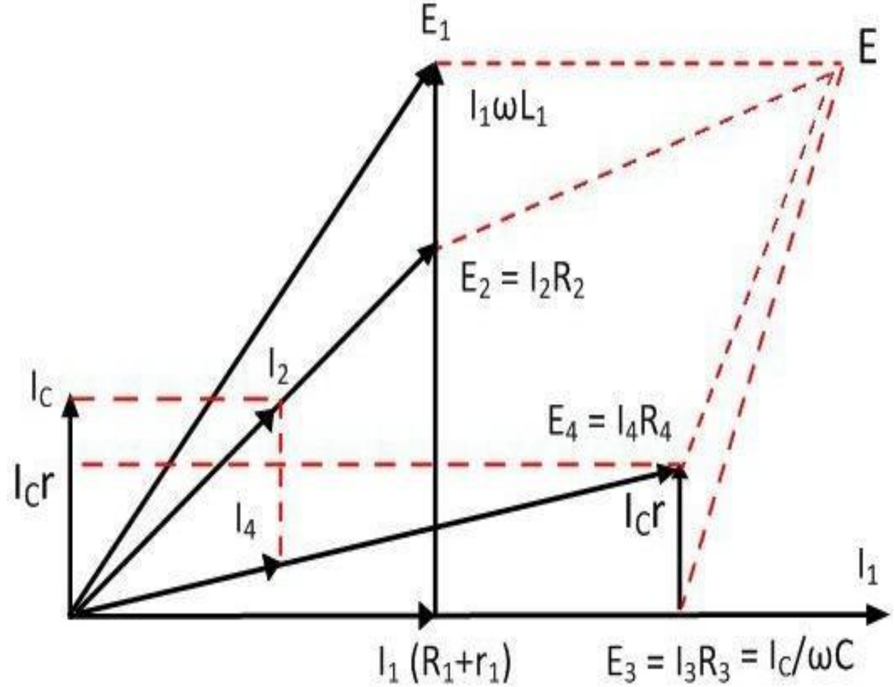
$$R_x \frac{j}{-\omega C_x} = R_2(-jX_{C3})\left(\frac{1}{R_1} + \frac{1}{-jX_{C1}}\right)$$

$$R_x - \frac{j}{\omega C_x} = \frac{R_2 C_1}{C_3} - \frac{jR_2}{\omega C_3 R_1}$$

Anderson’s Bridge




E1
E3
b
I1
r1
R3
I1
D
C
Ic
L1R1
a
c
e
I4
r
R4
R2
I2
d
E2
E4
E



E1
E
I1ωL1
E2 = I2R2
I2
IC
ICr
E4 = I4R4
I4
ICr
I1
I1 (R1+r1)
E3 = I3R3 = IC/ωC

Maxwell‟s bridge

) In this bridge a fixed standard capacitor is used therefore there is no need of costly variable capacitor.

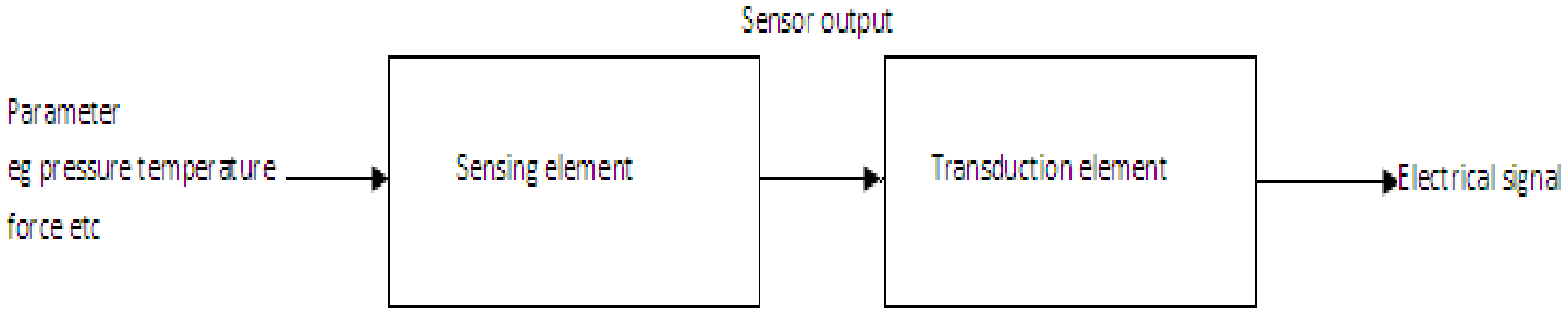
3) This method is very accurate for measurement of capacitance in terms of inductance.

UNIT V
TRANSDUCERS

INTRODUCTION OF TRANSDUCERS

- A transducer is a device that convert one form of energy to other form. It converts the measurand to a usable electrical signal.
- In other word it is a device that is capable of converting the physical quantity into a proportional electrical quantity such as voltage or current.

BLOCK DIAGRAM OF TRANSDUCERS



7. **Transient and frequency response : The transducer should meet the desired time domain specification like peak overshoot, rise time, setting time and small dynamic error.**
8. **Loading Effects: The transducer should have a high input impedance and low output impedance to avoid loading effects.**
9. **Environmental Compatibility: It should be assured that the transducer selected to work under specified environmental conditions maintains its input- output relationship and does not break down.**
10. **Insensitivity to unwanted signals: The transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signals.**

CLASSIFICATION OF TRANSDUCERS

The transducers can be classified as:

I. Active and passive transducers.
II. Analog and digital transducers.
III. On the basis of transduction principle used.
IV. Primary and secondary transducer
V. Transducers and inverse transducers.

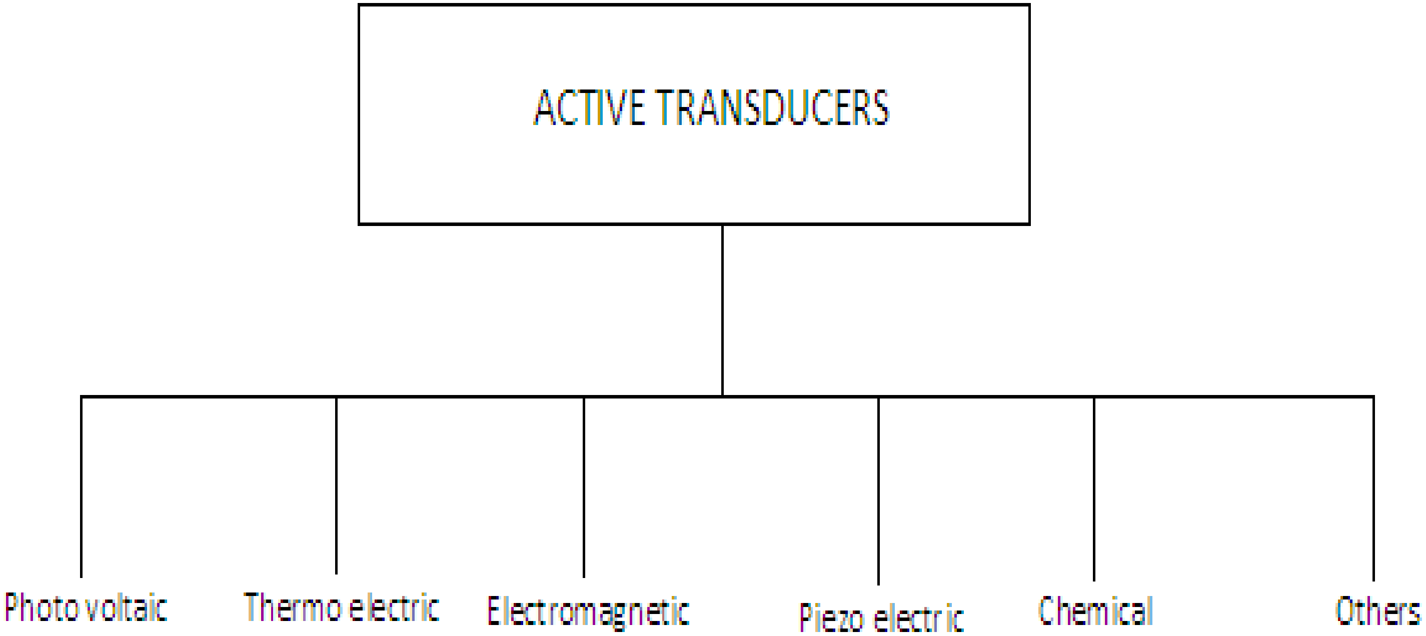
ACTIVE AND PASSIVE TRANSDUCERS

- **Active transducers :**
- These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.

I. The active transducer are self generating devices which operate under the energy conversion principle.

II. As the output of active transducers we get an equivalent electrical output signal e.g. temperature or strain to electric potential, without any external source of energy being used.

CLASSIFICATION OF ACTIVE TRANSDUCERS



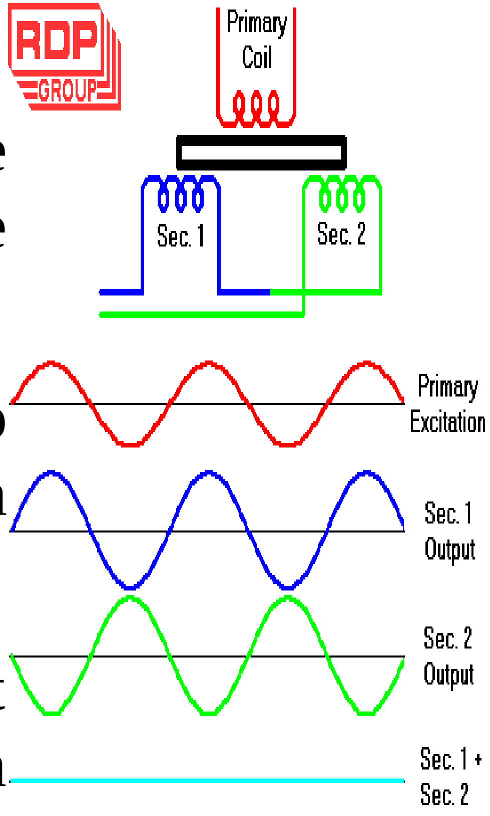
ACTIVE AND PASSIVE TRANSDUCERS

- **Passive Transducers :**

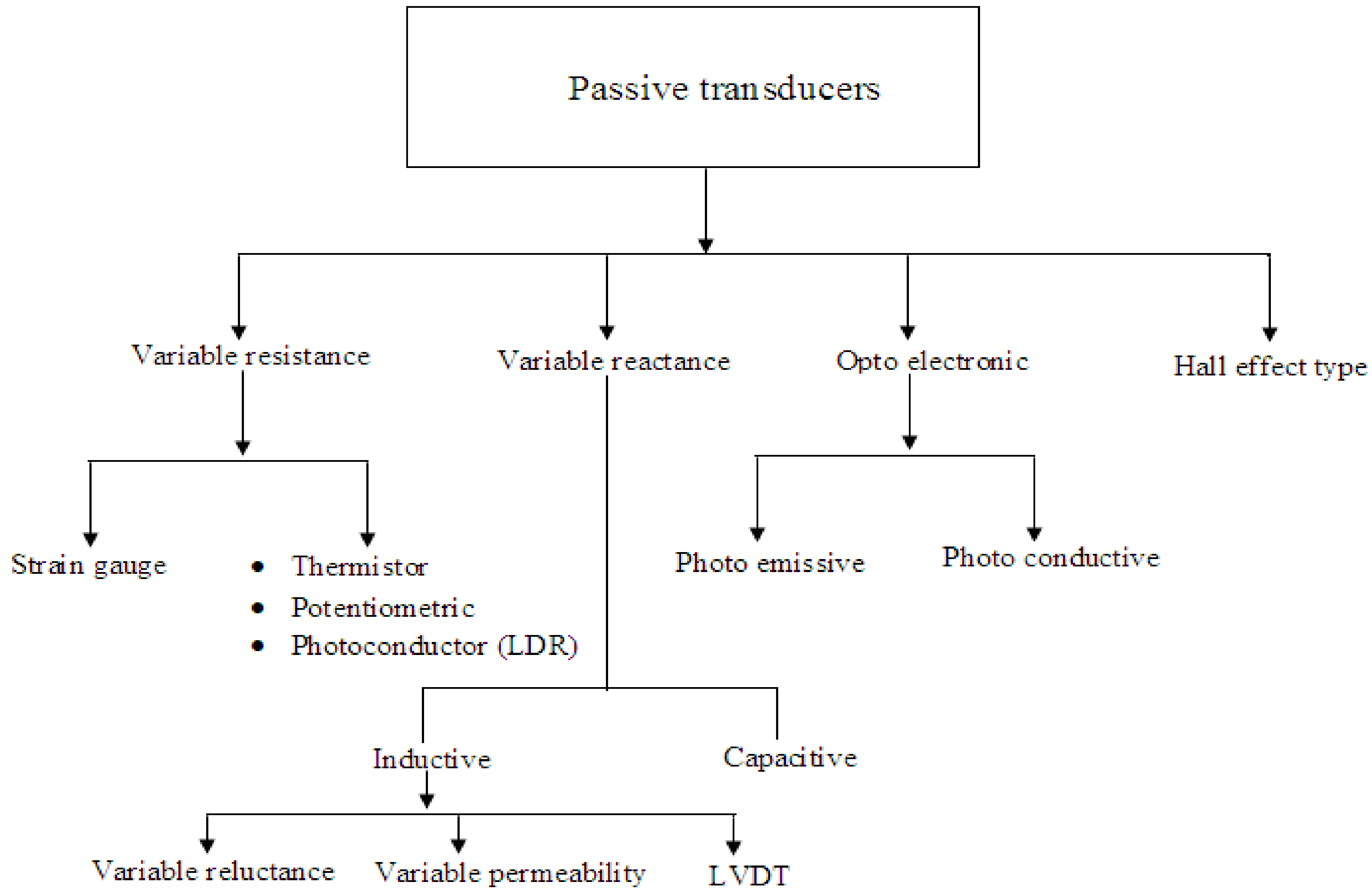
I. These transducers need external source of power for their operation. So they are not self generating type transducers.

II. A DC power supply or an audio frequency generator is used as an external power source.

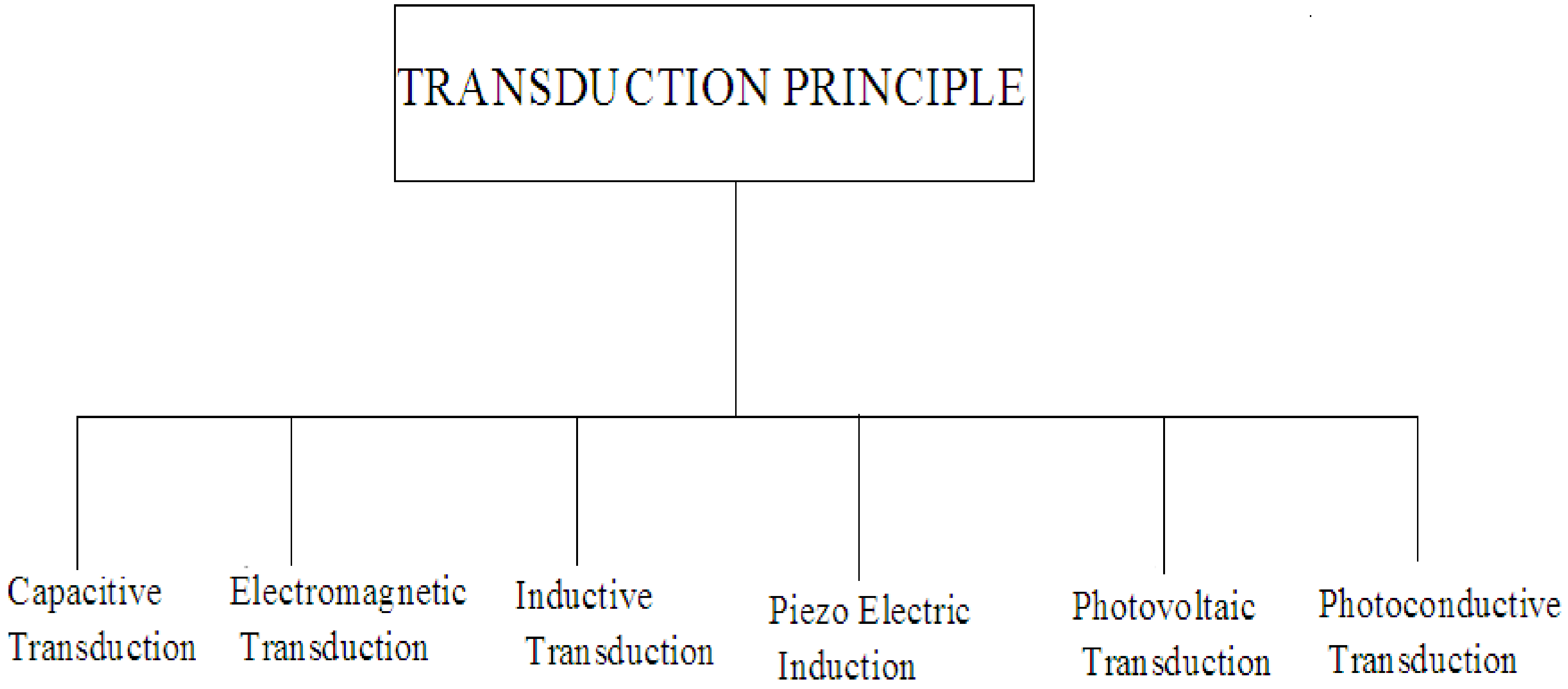
III. These transducers produce the output signal in the form of variation in resistance, capacitance, inductance or some other electrical parameter in response to the quantity to be measured.

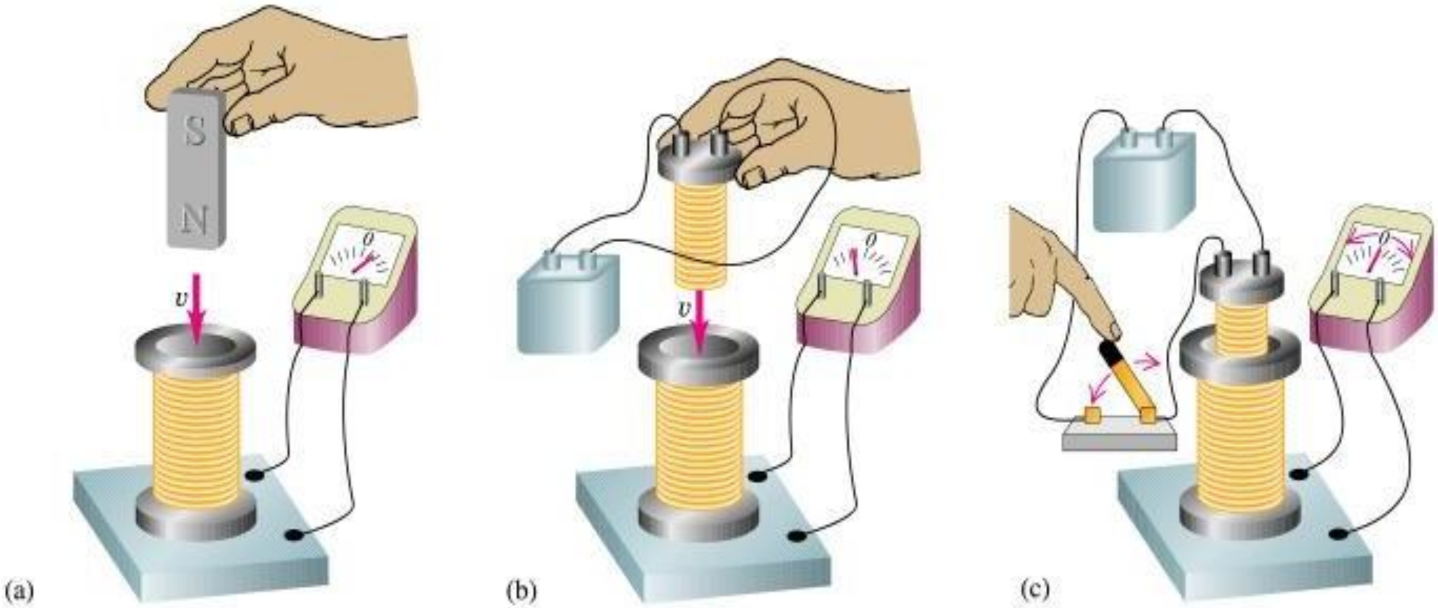


CLASSIFICATION OF PASSIVE TRANSDUCERS



CLASSIFICATION OF TRANSDUCERS ACCORDING TO TRANSDUCTION PRINCIPLE




S
N
v
0
v
0
0
(a)
(b)
(c)

STRAIN GAUGE

- The strain gauge is a passive, resistive transducer which converts the mechanical elongation and compression into a resistance change.
- This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.

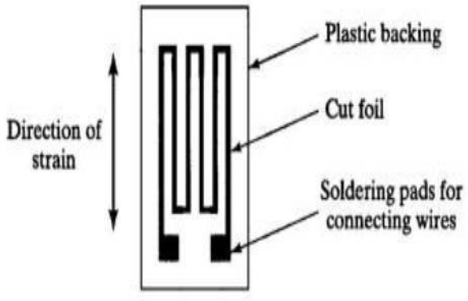
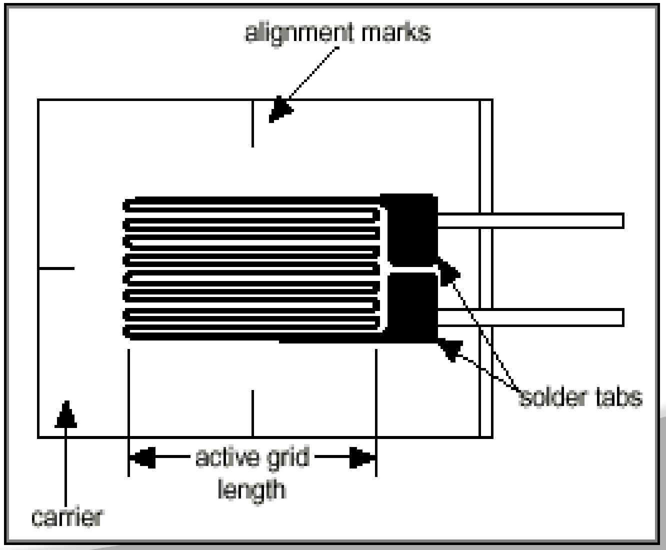


FIGURE 8.2
Foil strain gage.



TYPES OF STRAIN GAUGE

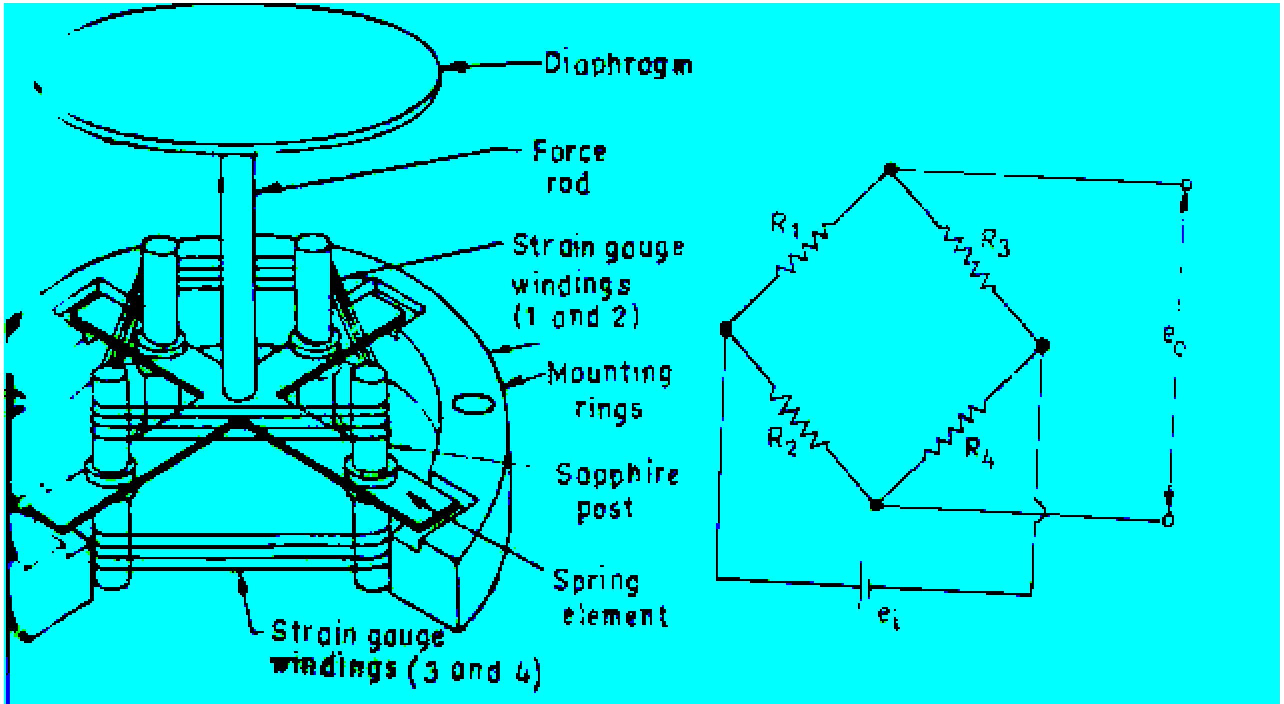
- **The type of strain gauge are as**

1. **Wire gauge**
   a) **Unbonded**
   b) **Bonded**
   c) **Foil type**
2. **Semiconductor gauge**

UNBONDED STRAIN GAUGE

- **An unbonded meter strain gauge is shown in fig**
- **This gauge consist of a wire stretched between two point in an insulating medium such as air. The wires may be made of various copper, nickel, crome nickle or nickle iron alloys.**
- **In fig the element is connected via a rod to diaphragm which is used for sensing the pressure. The wire are tensioned to avoid buckling when they experience the compressive force.**

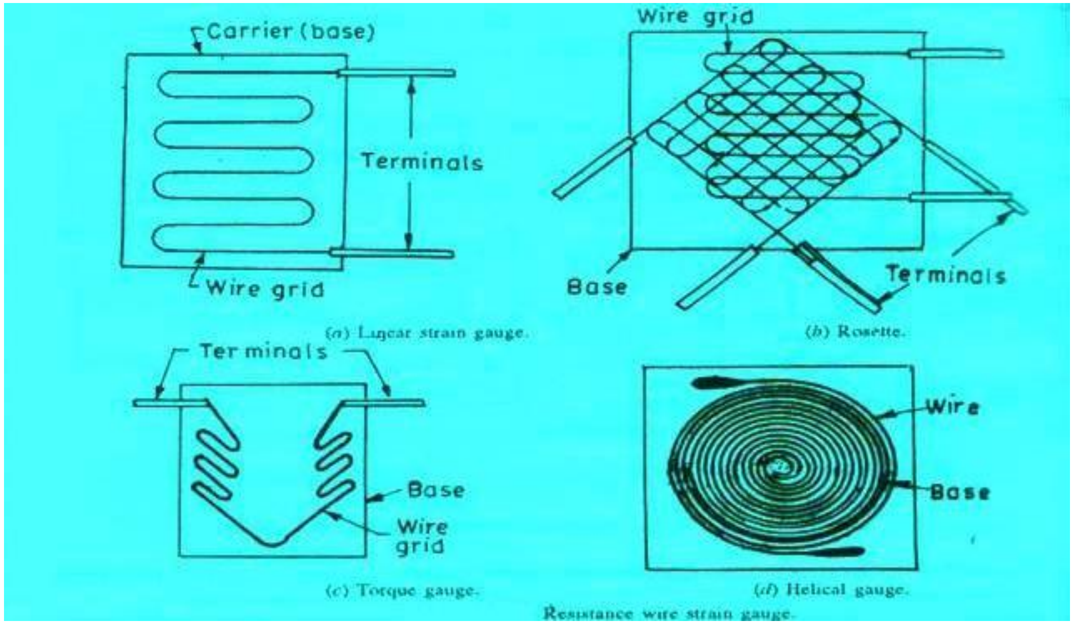
- **The unbounded meter wire gauges used almost exclusively in transducer application employ preloaded resistance wire connected in Wheatstone bridge as shown in fig.**
- **At initial preload the strain and resistance of the four arms are nominally equal with the result the output voltage of the bridge is equal to zero.**
- **Application of pressure produces a small displacement , the displacement increases a tension in two wire and decreases it in the other two thereby increase the resistance of two wire which are in tension and decreasing the resistance of the remaining two wire .**
- **This causes an unbalance of the bridge producing an output voltage which is proportional to the input displacement and hence to the applied pressure .**


Diaphragm
Force rod
Strain gauge windings (1 and 2)
Mounting rings
Sapphire post
Spring element
Strain gauge windings (3 and 4)
R_1
R_3
R_2
R_4
e_o
e_i

BONDED STRAIN GAUGE

- **The bonded metal wire strain gauge are used for both stress analysis and for construction of transducer.**
- **A resistance wire strain gauge consist of a grid of fine resistance wire. The grid is cemented to carrier which may be a thin sheet of paper bakelite or teflon.**
- **The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical demage.**
- **The carrier is bonded with an adhesive material to the specimen which permit a good transfer of strain from carrier to grid of wires.**

BONDED STRAIN GAUGE



BONDED METAL FOIL STRAIN GAUGE

- It consist of following parts:

1. Base (carrier) Materials: several types of base material are used to support the wires. Impregnated paper is used for room temp. applications.
2. Adhesive: The adhesive acts as bonding materials. Like other bonding operation, successful starain gauge bonding depends upon careful surface preparation and use of the correct bonding agent.

   In order that the strain be faithfully transferred on to the strain gauge, the bond has to be formed between the surface to be strained and the plastic backing material on which the gauge is mounted .

•

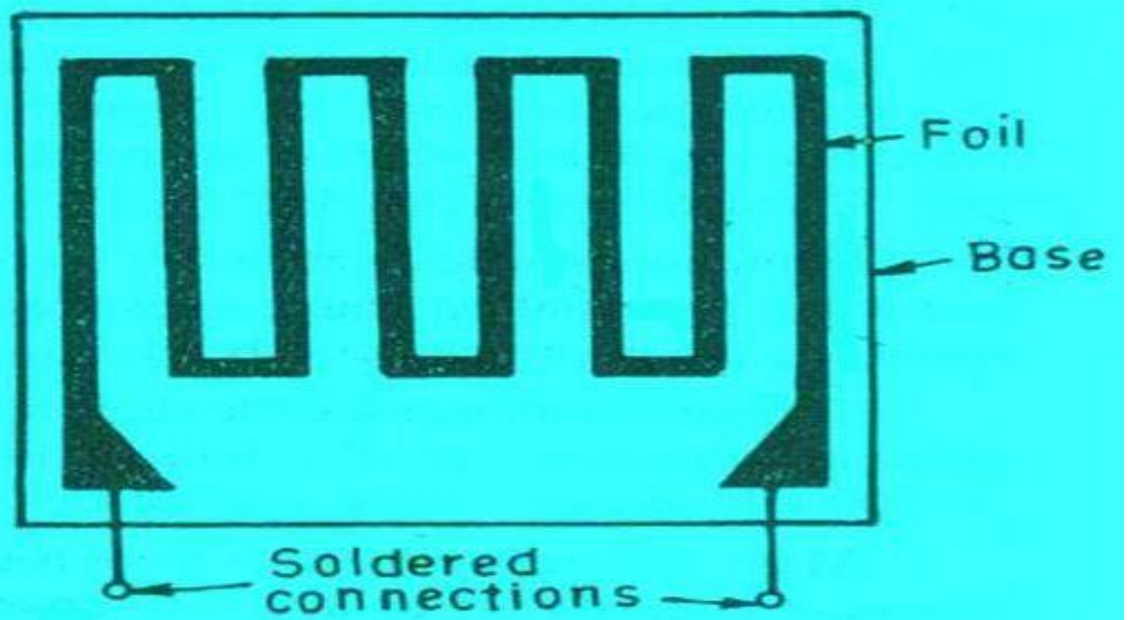
It is important that the adhesive should be suited to this backing and adhesive material should be quick drying type and also insensitive to moisture.

3. **Leads: The leads should be of such materials which have low and stable resistivity and also a low resistance temperature coefficent**

It is important that the adhesive should be suited to this backing and adhesive material should be quick drying type and also insensitive to moisture.

3. **Leads: The leads should be of such materials which have low and stable resistivity and also a low resistance temperature coefficent**

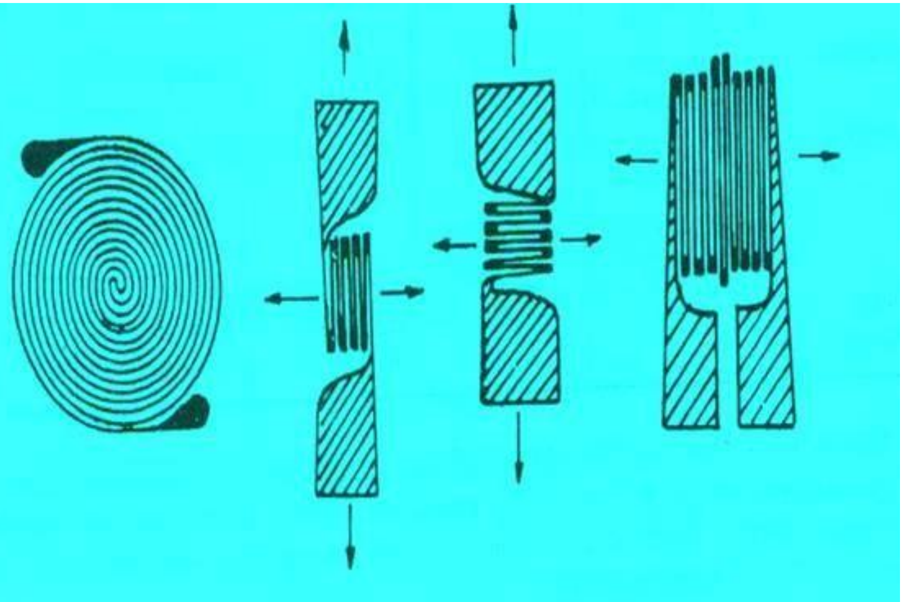
BONDED METAL FOIL STRAIN GAUGE



Bonded metal foil gauge.

- **This class of strain gauge is only an extension of the bonded metal wire strain gauges.**
- **The bonded metal wire starin gauge have been completely superseded by bonded metal foil strain gauges.**
- **Metal foil strain gauge use identical material to wire strain gauge and are used for most general purpose stress analysis application and for many transducers.**

METAL FOIL STRAIN GAUGE



Metal foil strain gauges.

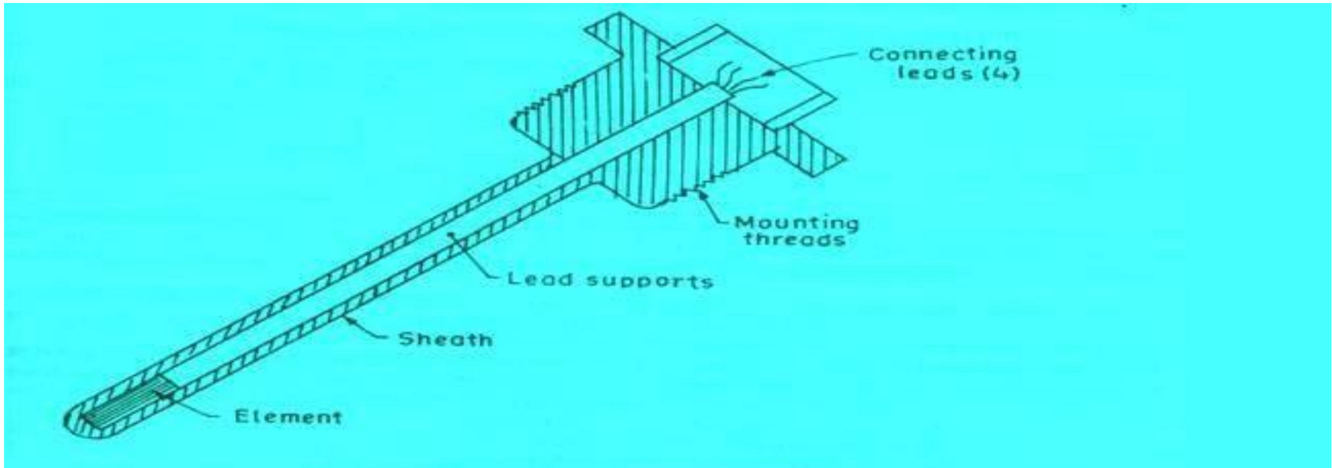
RESISTANCE THERMOMETER

- **Resistance of metal increase with increases in temperature. Therefore metals are said to have a positive temperature coefficient of resistivity.**

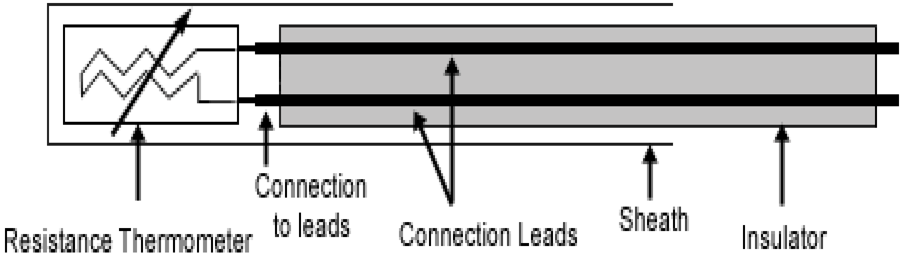
- **Fig shows the simplest type of open wire construction of platinum résistance thermometer. The platinum wire is wound in the form of spirals on an insulating material such as mica or ceramic.**

- **This assembly is then placed at the tip of probe**

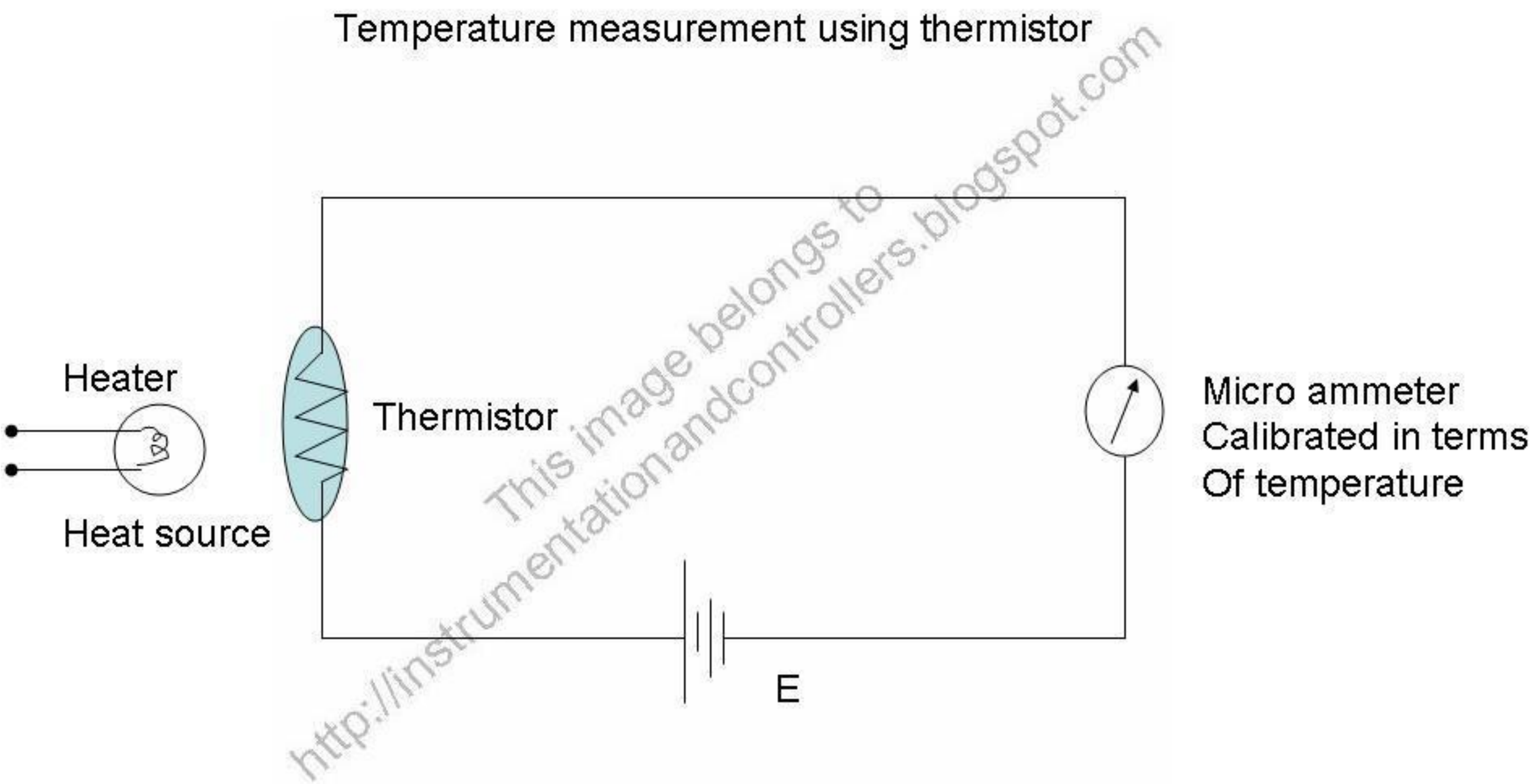
- **This wire is in direct contact with the gas or liquid whose temperature is to be measured.**



Industrial platinum resistance thermometer



- The resistance of the platinum wire changes with the change in temperature of the gas or liquid
- This type of sensor have a positive temperature coefficient of resistivity as they are made from metals they are also known as resistance temperature detector
- Resistance thermometer are generally of probe type for immersion in medium whose temperature is to be measured or controlled.


Temperature measurement using thermistor
Heater
Heat source
Thermistor
Micro ammeter
Calibrated in terms
Of temperature
E
This image belongs to
http://instrumentationandcontrollers.blogspot.com

What is an Anemometer?

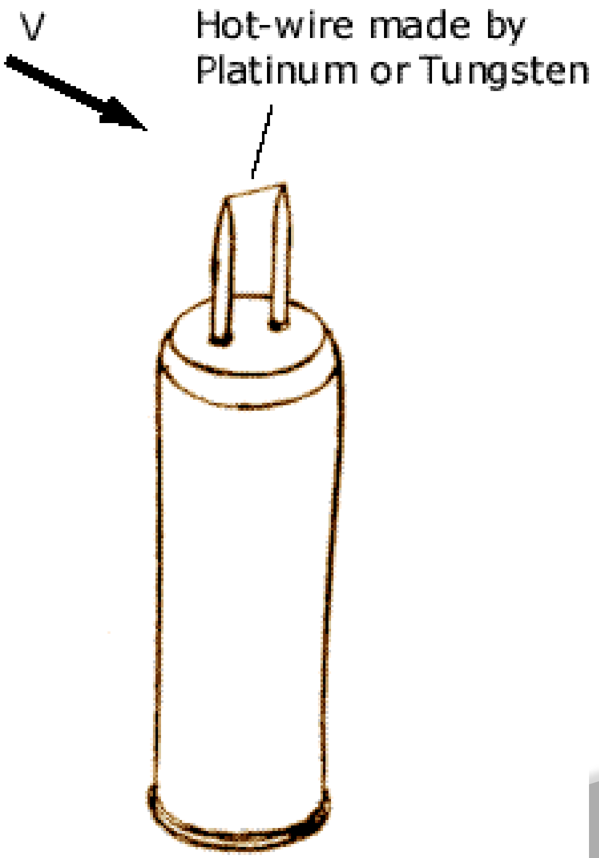
- **Anemometer – measures gas speed**
- **Types**
  - **rotating cup**
  - **pitot static tube**
  - **thermal (hot wire)**
    - **also performs temperature measurement**

Theory of Operation

- **Energy Balance**
- **Constant temperature or constant current operation**
- **Measure change in current or change in temperature**
- **Correlate I or T_{wire} to gas velocity based on convective H.T. and fluid dynamics**

Probe

- Tungsten or Platinum filament
  - ~1 mm long
  - 4-10 μm diameter
- Benefits
  - Good spatial resolution
  - Flat frequency response
- Limitations
  - Fragile
  - Requires clean flow
  - Cost (start at $300-400)

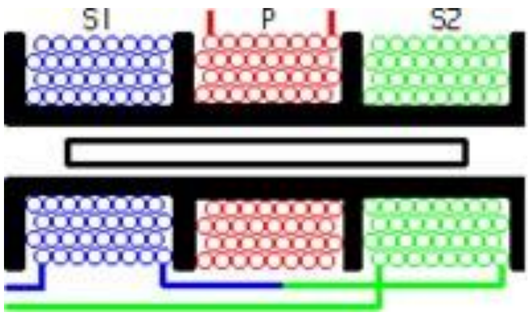


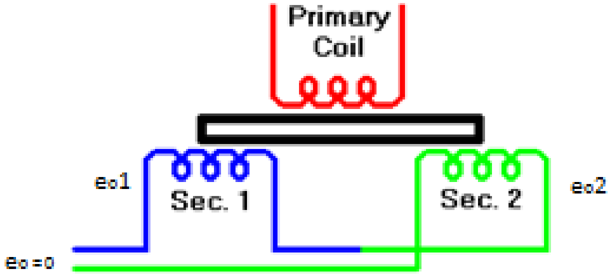
Interfacing

- Wide variety of options
  - Devices typically come with some sort of μ-controller
  - Depends on application
  - Handheld vs. in-situ
- Most common
  - Serial RS232 – for sampled data collection and control
- Larger selection for industrial sensors
  - Serial RS232, RS485
  - Analog 4-20 mA, 0-10V
  - Profibus, Modbus, etc.

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER(LVDT)

- AN LVDT transducer comprises a coil former on to which three coils are wound.
- The primary coil is excited with an AC current, the secondary coils are wound such that when a ferrite core is in the central linear position, an equal voltage is induced in to each coil.
- The secondary are connect in opposite so that in th central position the outputs o the secondary cancels ea other out.



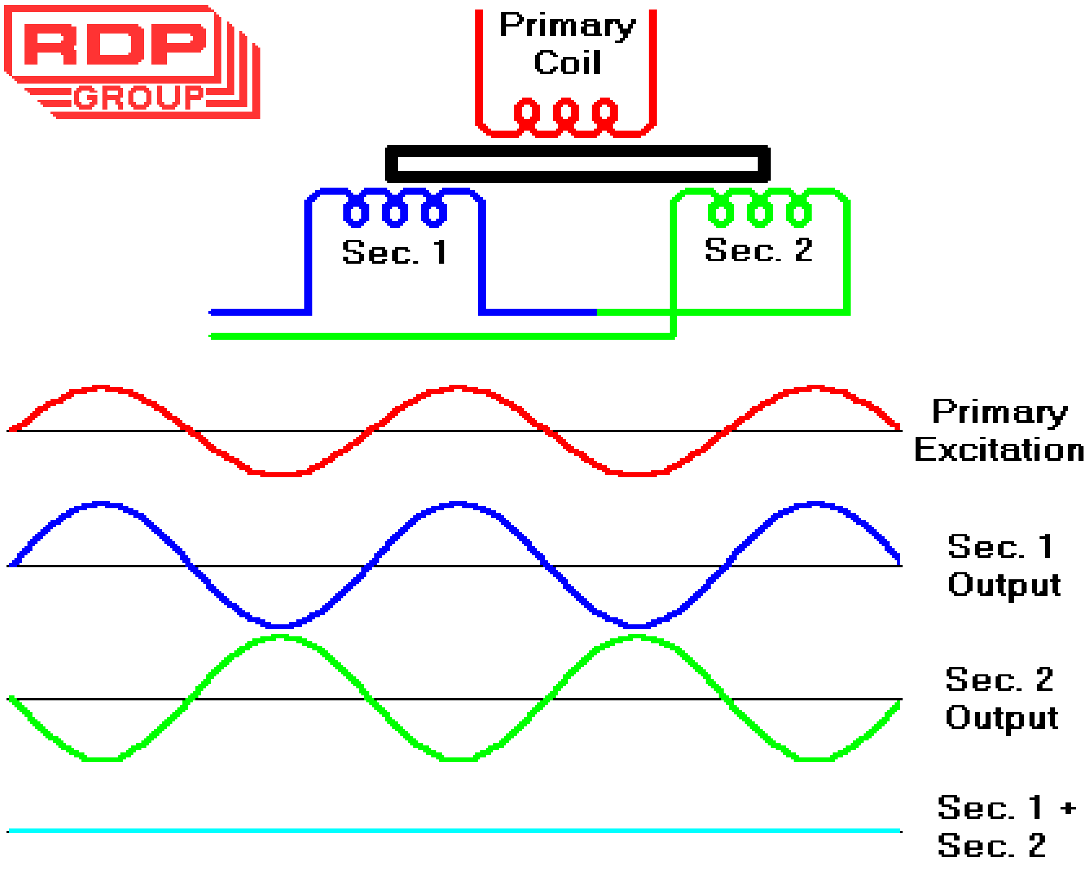


equal coupling with both secondaries therefore eo2 equal eo1

- The excitation is applied to the primary winding and the armature assists the induction of current in to secondary coils.

- When the core is exactly at the center of the coil then the flux linked to both the secondary winding will be equal. Due to equal flux linkage the secondary induced voltages (eo1 & eo2) are equal but they have opposite polarities. Output voltage eo is therefore zero. This position is called “null position”

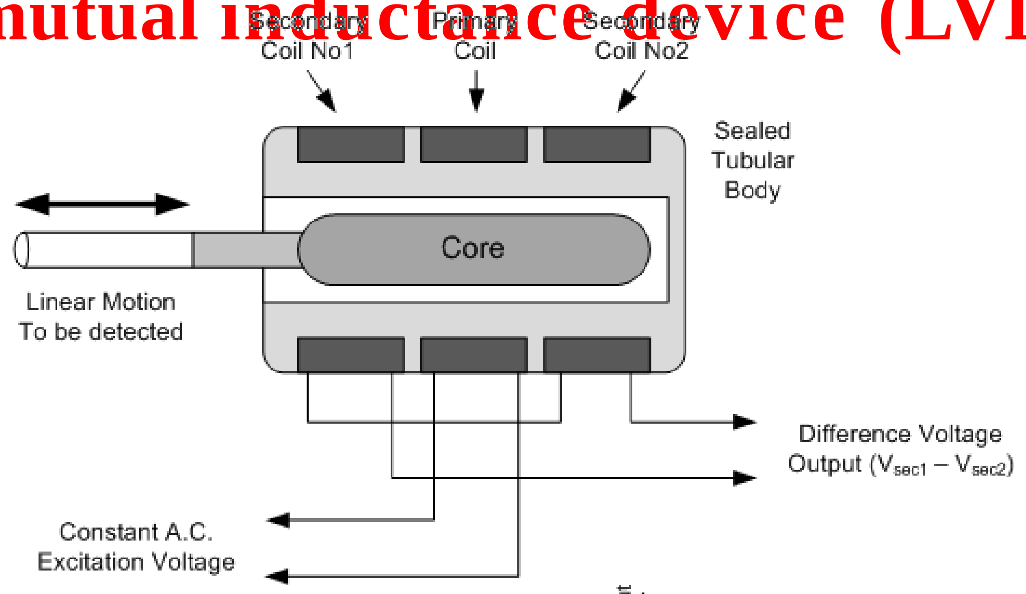
LVDT

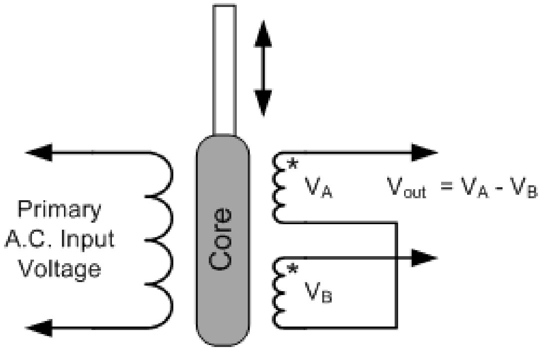


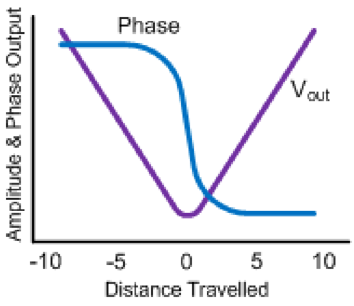
RDP GROUP
Primary Coil
Sec. 1
Sec. 2
Primary Excitation
Sec. 1 Output
Sec. 2 Output
Sec. 1 + Sec. 2

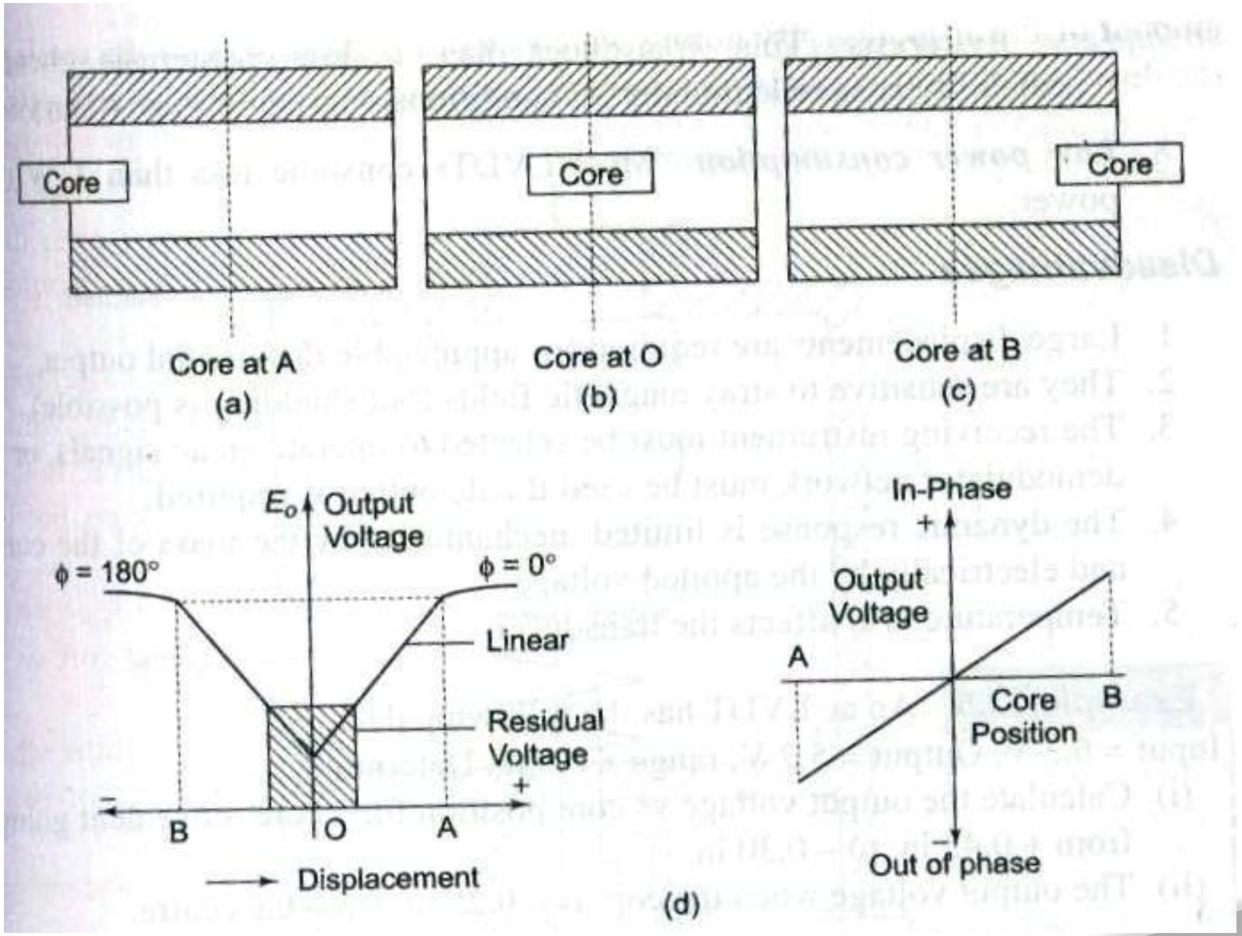
Linear Variable Differential Transformer

Three Coil mutual inductance device (LVDT)



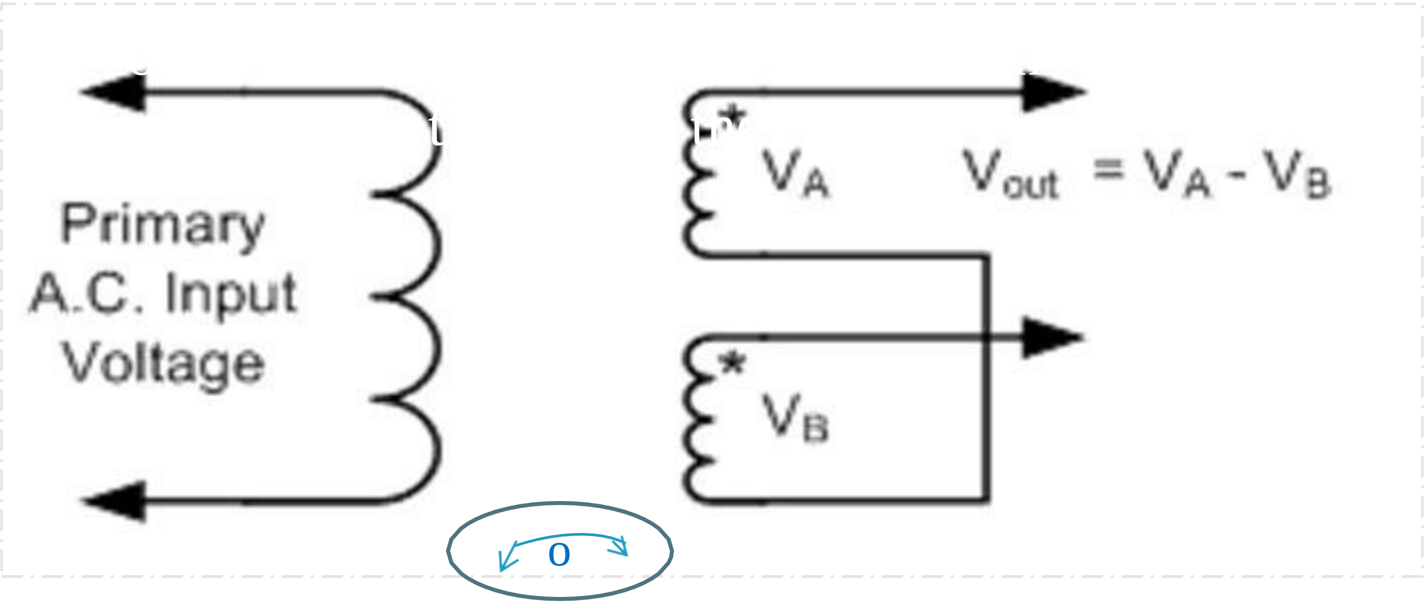





Core
Core at A
(a)
Core
Core at O
(b)
Core
Core at B
(c)
E_o Output Voltage
ϕ = 180°
ϕ = 0°
Linear
Residual Voltage
B
O
A
Displacement
In-Phase
Output Voltage
A
Core Position
B
Out of phase
(d)

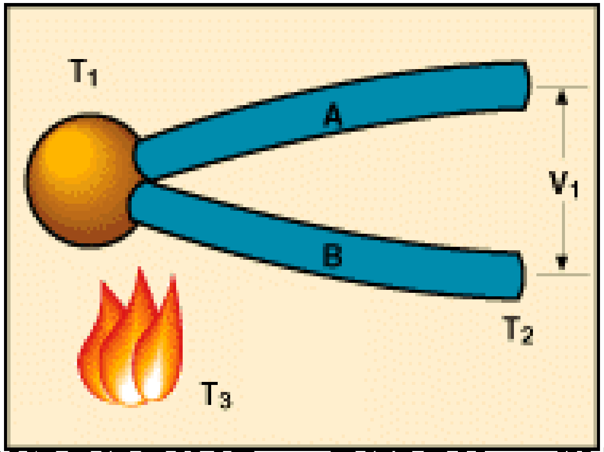
Rotary Variable Differential Transformer

RVDT



What are thermocouples?

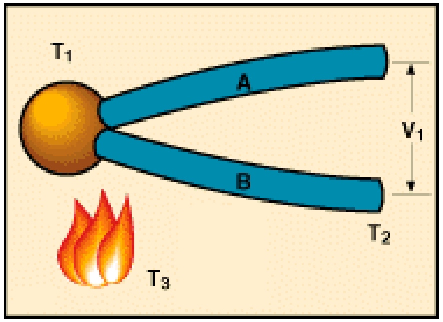
- Thermocouples operate under the principle that a circuit made by connecting two dissimilar metals produces a measurable voltage (emf-electromotive force) when a temperature gradient is imposed between one end and the other.

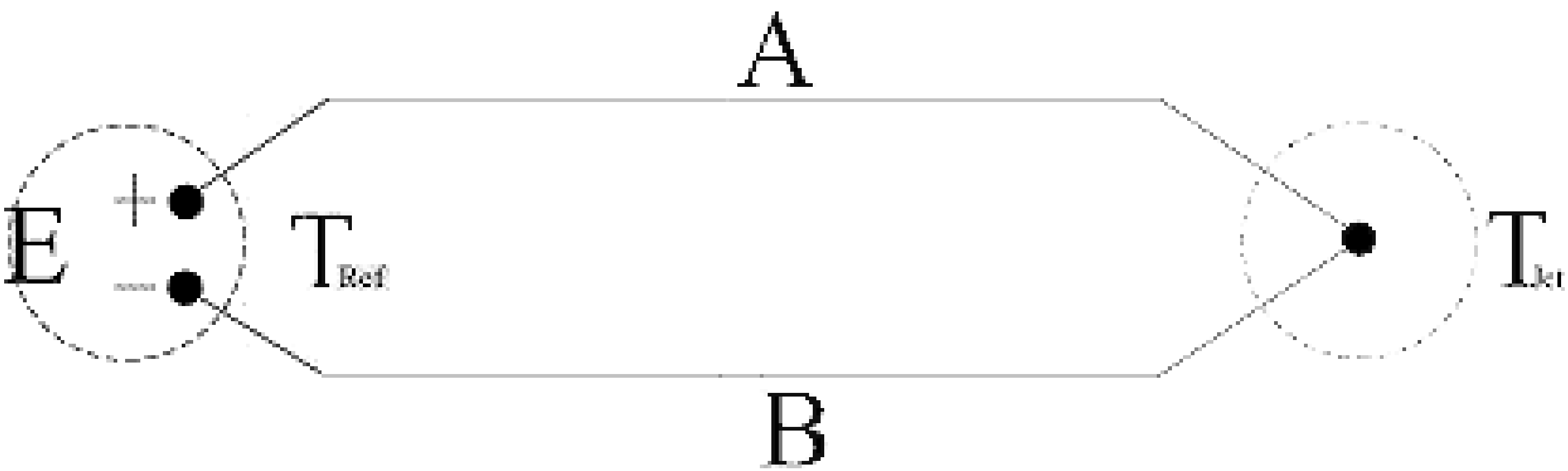


- They are inexpensive, small, rugged and accurate when used with an understanding of their peculiarities.

Thermocouples Principle of Operation

- In, 1821 T. J. Seebeck observed the existence of an electromotive force (EMF) at the junction formed between two dissimilar metals (Seebeck effect).
  - Seebeck effect is actually the combined result of two other phenomena, Thomson and Peltier effects.
    - Thomson observed the existence of an EMF due to the contact of two dissimilar metals at the junction temperature.
    - Peltier discovered that temperature gradients along conductors in a circuit generate an EMF.
    - The Thomson effect is normally much smaller than the Peltier effect.




A
E
+
−
T Ref
T
B

How thermocouples work

- It is generally reasonable to assume that the emf is generated in the wires, not in the junction. The signal is generated when dT/dx is not zero.
- When the materials are homogeneous, ε, the thermoelectric power, is a function of temperature only.
- Two wires begin and end at the

$$E = \int_{0}^{L} \varepsilon_A \frac{dT}{dx}dx + \int_{L}^{0} \varepsilon_B \frac{dT}{dx}dx \qquad \text{Equation 1}$$

If the wires are both homogeneous, then

$$E = \int_{T_{Ref}}^{T_{J1}} \varepsilon_A \, dT + \int_{T_{J1}}^{T_{Ref}} \varepsilon_B \, dT \qquad \text{Equation 2}$$

If both wires begin at T_{Ref} and end at T_{J1}, then

$$E = \int_{T_{Ref}}^{T_{J1}} (\varepsilon_A - \varepsilon_B)\, dT \qquad \text{Equation 3}$$

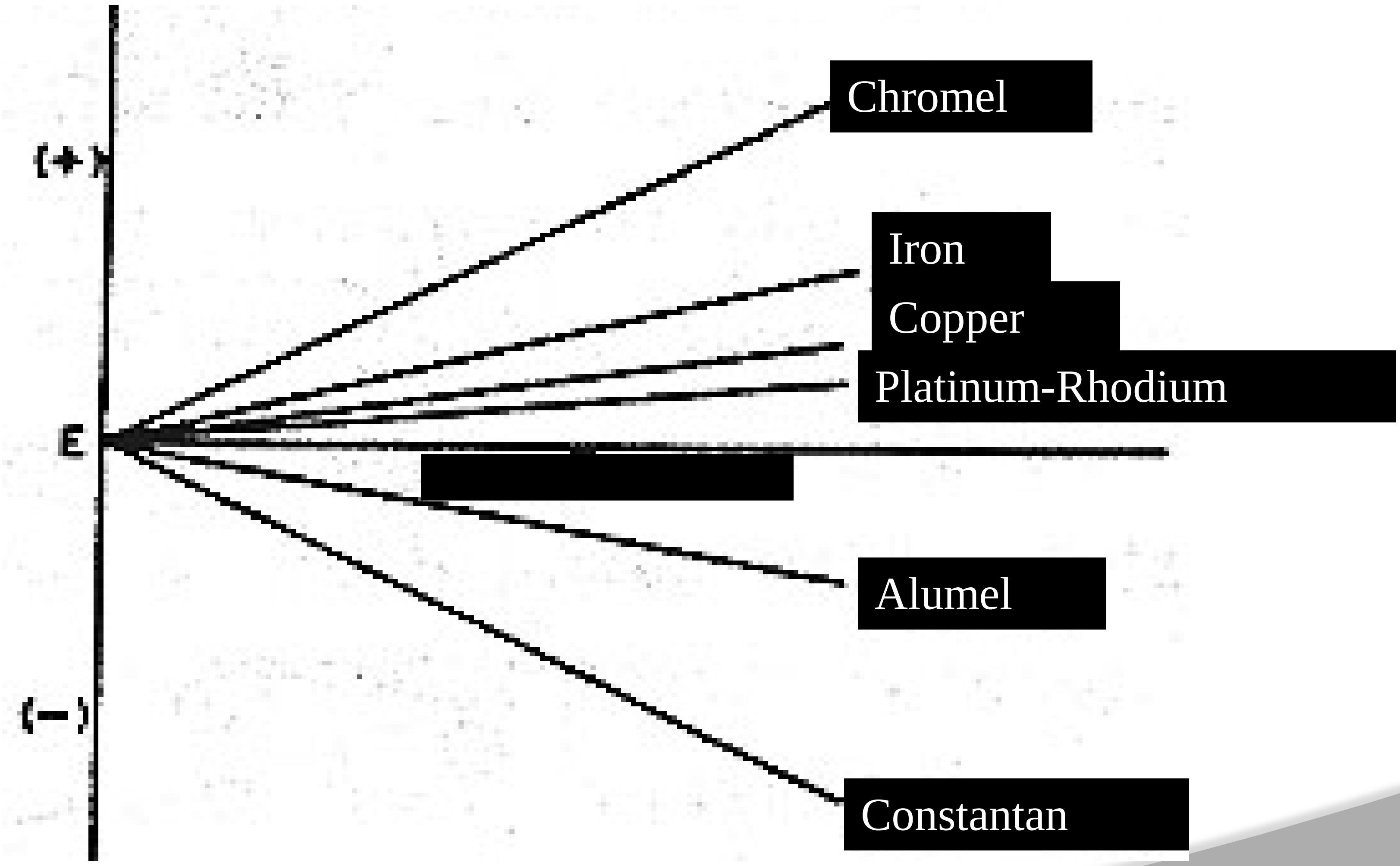
For small temperature differences, we can use the average calibrations:

$$E = (\varepsilon_A - \varepsilon_B)(T_{J1} - T_{Ref}) = \varepsilon_{AB}(T_{J1} - T_{Ref}) \qquad \text{Equation 4}$$

qn. is

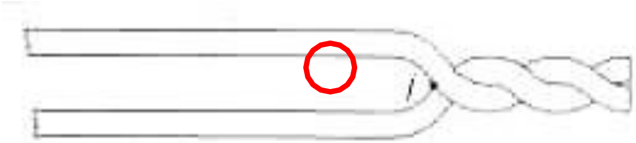
$$E = \alpha(T - T_o) + \beta(T - T_o)^2$$

Material EMF vs Temperature

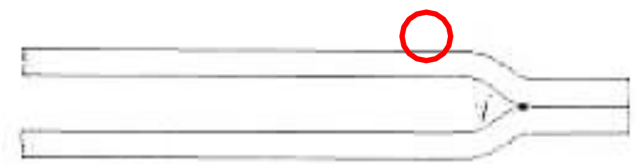


Thermocouple Effect

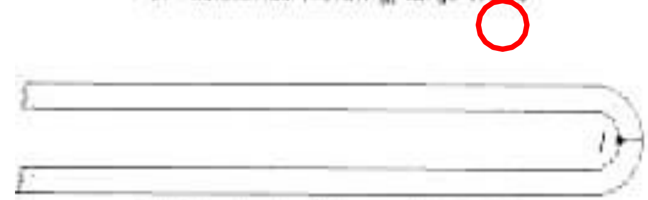
- Any time a pair of dissimilar wires is joined to make a circuit and a thermal gradient is imposed, an emf voltage will be generated.
  - Twisted, soldered or welded junctions are acceptable. Welding is most common.
  - Keep weld bead or solder bead diameter within 10-15% of wire diameter
  - Welding is generally quicker than soldering but both are equally acceptable
  - Voltage or EMF produced depends on:
    - Types of materials used
    - Temperature difference between the measuring junction and the reference junction



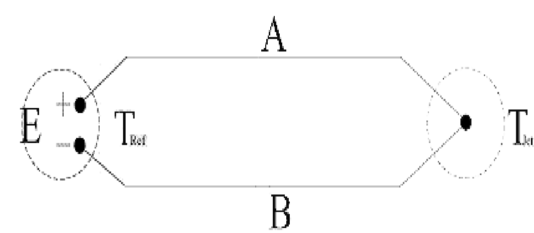
For gas, electric, and arc welding



For resistance welding, large wires



For forming noble metal wires for electric arc welding



- **Thermocouple tables correlate temperature to emf voltage.**
  - **Need to keep in mind that the thermocouple tables provide a voltage value with respect to a reference temperature. Usually the reference temperature is 0°C. If your reference junction is not at 0°C, a correction must be applied using the law of intermediate temperatures.**

The piezoelectric effect

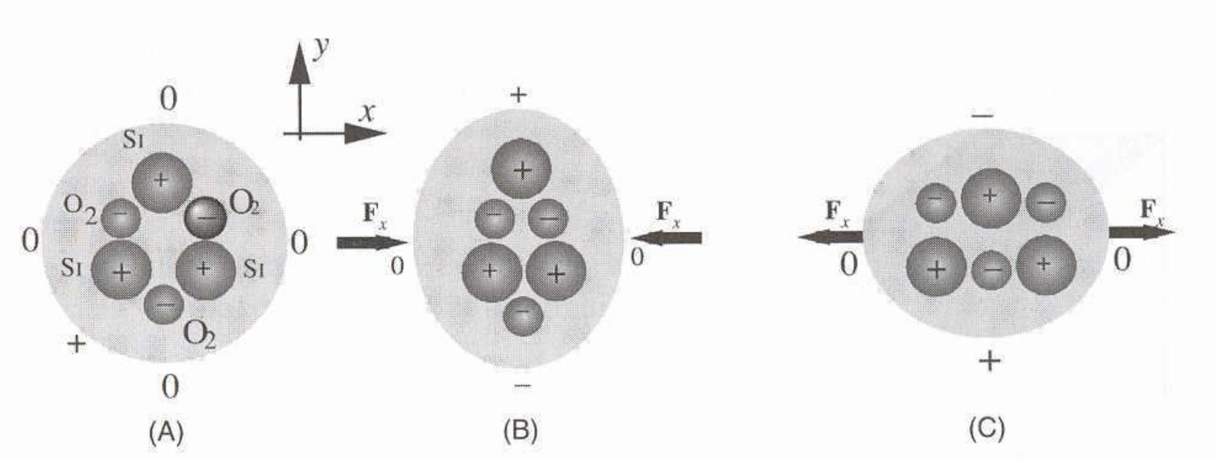
- **Piezoelectric effect is the generation of electric charge in crystalline materials upon application of mechanical stress.**
- **The opposite effect is equally useful: application of charge across the crystal causes mechanical deformation in the material.**
- **The piezoelectric effect occurs naturally in materials such as quartz (SiO_2 - a silicon oxide)**
- **Has been used for many decades in so called crystal oscillators.**

The piezoelectric effect

- It is also a property of some ceramics and polymers
- We have already met the piezoresistive materials of chapter 5 (PZT is the best known) and the polymer piezoresistive materials PVF and PVDF.
- The piezoelectric effect has been known since 1880
- First used in 1917 to detect and generate sound waves in water for the purpose of detecting submarines (sonar).
- The piezoelectric effect can be explained in a simple model by deformation of crystals:

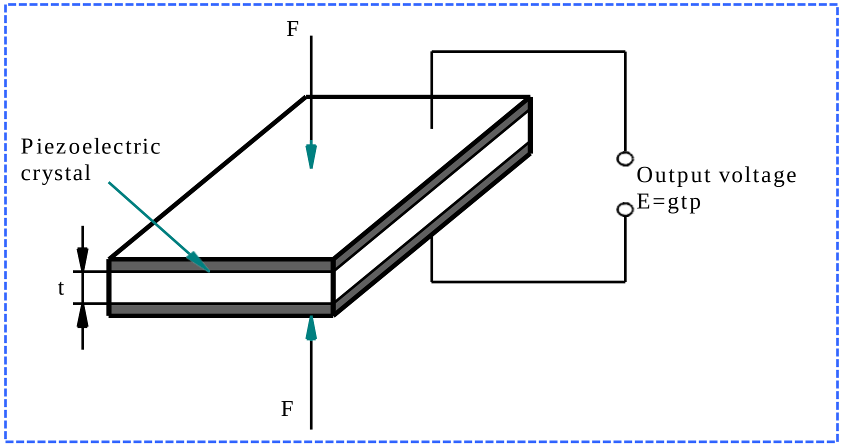
The piezoelectric effect

- **Deformation in one direction (B) displaces the molecular structure so that a net charge occurs as shown (in Quartz crystal - SiO_2)**
- **Deformation in a perpendicular axis (B) forms an opposite polarity charge**



Piezo-Electric Transducers

'Piezoelectric effect'.



„p" is the
given by g=(d/e), e being

Piezo-Electric Materials

The common piezoelectric materials are quartz, Rochelle salt (Potassium sodium tartrate), ammonium dihydrogen phosphate and ordinary sugar. The desirable properties are stability, high output, insensitivity to temperature and humidity and ability to be formed into desired shape.

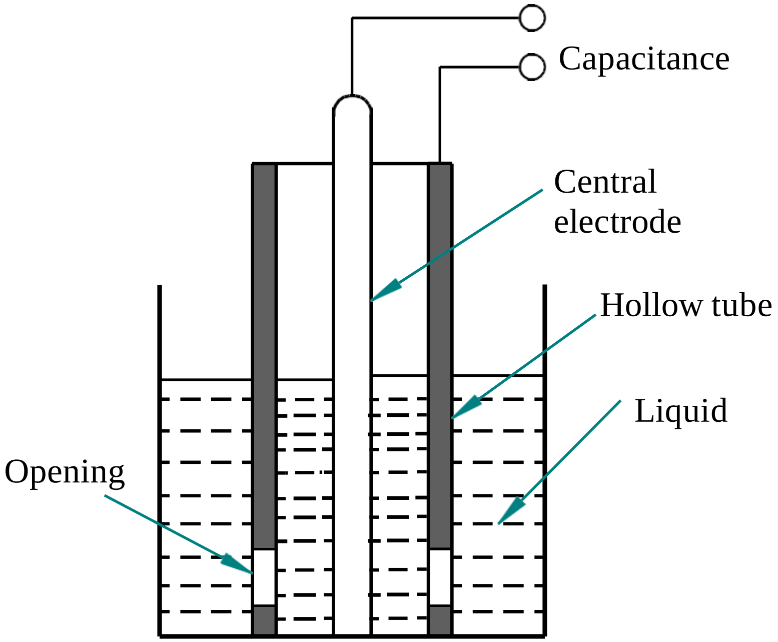
Quartz is most suitable and is used in electronic oscillators. Its output is low but stable.

Rochelle salt provides highest output, but requires protection from moisture in air & cannot be used above 45^oC.

Barium titanate is polycrystalline, thus it can be formed into a variety of sizes & shapes.

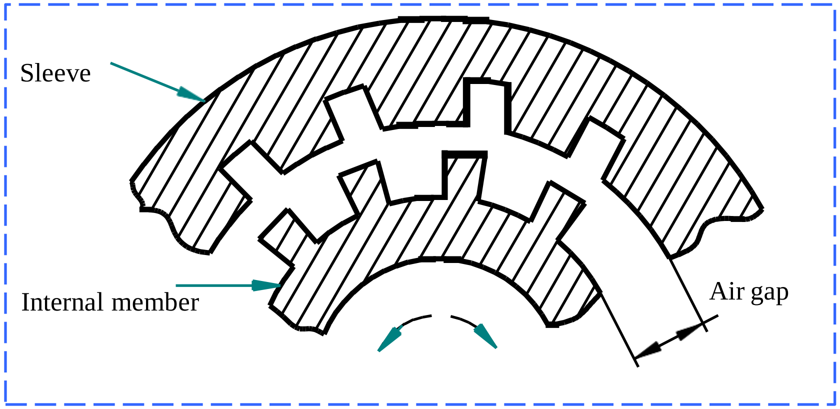
Piezoelectric transducers are used to measure surface roughness, strain, force & torque, Pressure, motion & noise.

Capacitive Transducer



ndication
lso be utilized for

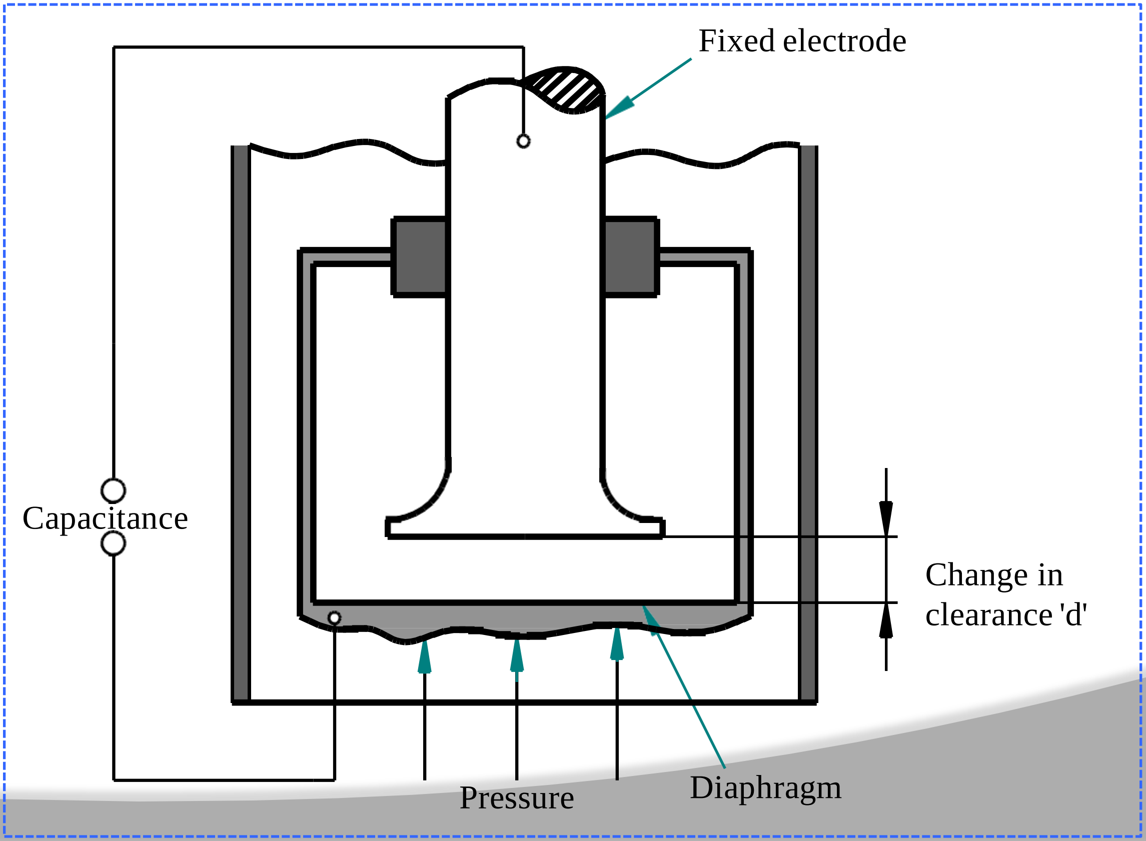
Capacitive Transducer
(Torque meter)



Torque meter.

s of
g capacitance

Capacitive Transducer
(Capacitive Type Pressure Transducer)



Advantages of Capacitive Transducers

(1) Requires extremely small forces to operate and are highly sensitive

(2) They have good frequency response and hence useful for dynamic measurements.

(3) High resolution can be obtained.

(4) They have high input impedance & hence loading effects are minimum.

(5) These transducers can be used for applications where stray magnetic fields render the inductive transducers useless.

Disadvantages of Capacitive Transducers

(1) Metallic parts must be properly insulated and the frames must be earthed.

(2) They show nonlinear behaviour due to edge effects and guard rings must be used to eliminate this effect.

(3) They are sensitive to temperature affecting their performance.

(4) The instrumentation circuitry used with these transducers are complex.

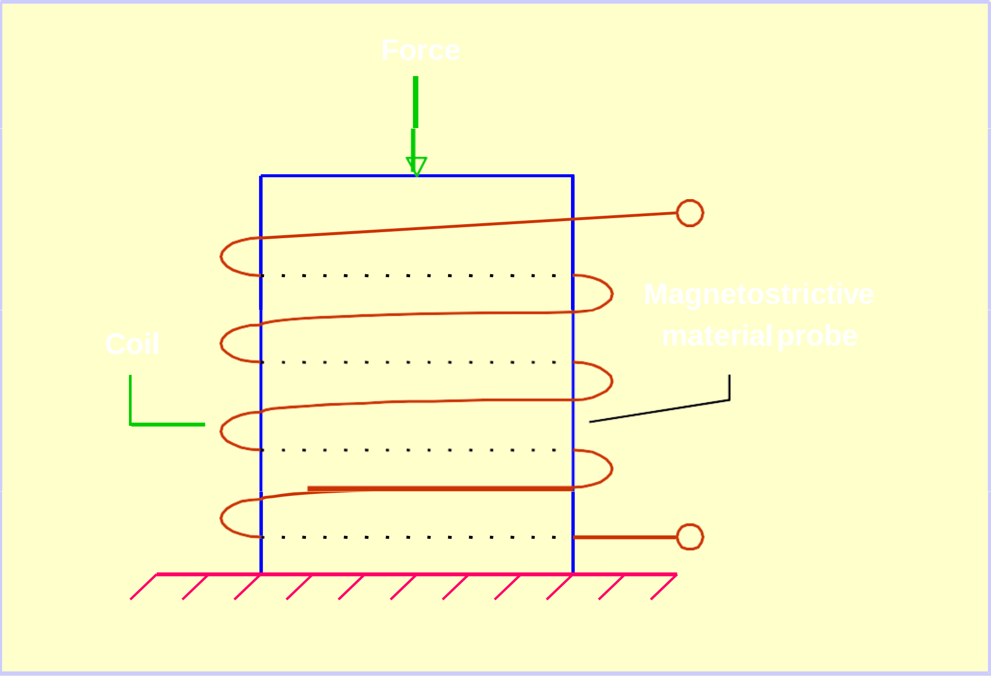
Capacitance of these transducers may change with presence of

Magnetostrictive Transducers

Characteristics:

- **Magnetostrictive materials transduce or convert magnetic energy Character istics: to mechanical energy and vice versa.**
- **If a magnetostrictive material is magnetized, it strains. Conversely, if an external force produce a strain in a magnetostrictive material the an external force produce a strain in a magnetostrictive material, the magnetic state of the material will change.**
- **Magnetostriction is an inherent material is an inherent material property that does not property that does not degrade with time.**
- **The pp p rinci ple of o peration of these transducers de pends on the chan ge of permeability of ferromagnetic materials, like Ni, when they are subjected to strain**

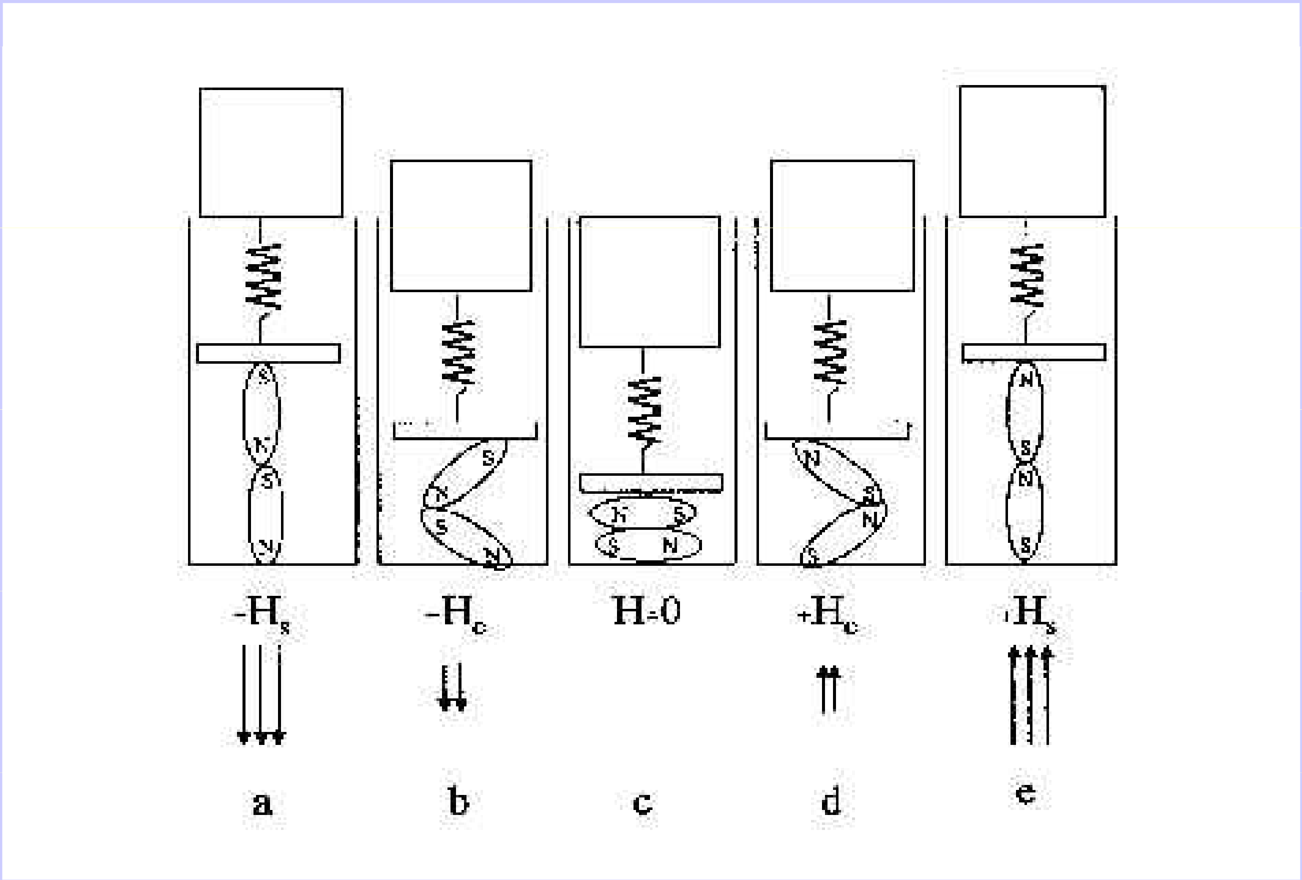
Magnetostrictive Transducers



The schematic representation of a magnetostrictive transducer

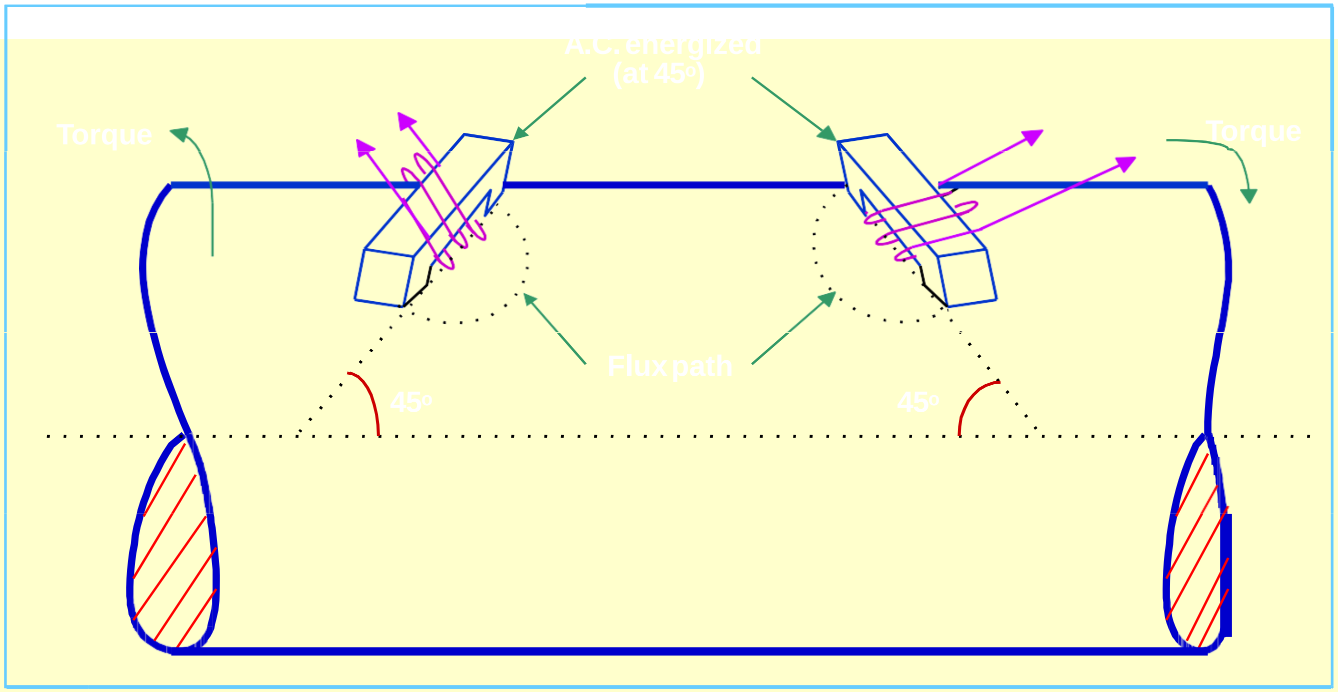
An actual magnetostrictive transducer

Magnetostrictive Transducers



A simplistic representation of the strain and magnetic induction observed in magnetostrictive materials

Measurement of Shaft Torque: A Popular Application



- ✓ An a.c. bridge circuit is employed, with two coils forming two arms.
- ✓ The voltage output of the a.c. bridge gives a measure of the torque applied.

Measurment of Physical Parameters

HUMIDITY MEASUREMENT

- Humidity is the amount of water vapour in the air and Humidity Measurement is a measure of relative amount of water vapour present in the air or a gas.

  The humidity can be expressed in different ways:
- Absolute Humidity
- Relative Humidity
- Dew Point

HUMIDITY MEASUREMENT

- Devices that indirectly measure humidity by sensing changes in physical or electrical properties in materials due to their moisture content are called hygrometers.
- The three major instruments used for measuring humidity in industry are:
- The Electrical Hygrometer
- The Psychrometer
- The Dew Point Meter

RESISTANCE HYGROMETER

- This is an electrical hygrometer.
- It is an active transducer.
- These instruments are suitable for measuring moisture levels between 15% and 95%.
- It has typical measurement uncertainty of 3%.
- Atmospheric contaminates and operation in saturation conditions both cause characteristics drift.

PRINCIPLE OF RESISTANCE HYGROMETER

- **Some Hygroscopic Salts exhibit a change in resistivity with humidity. Resistive hygrometer humidity sensors use the change in resistance of a hygroscopic material between two electrodes on an insulating substrate.**
- **The hygroscopic salt is deposited between two electrodes. The resistance of the element changes when it is exposed to variations in humidity.**

RESISTANCE HYGROMETER

- The Resistance Hygrometer should not be exposed to conditions of 100% humidity as the resulting condensation may damage the device.
- These are accurate to within ± 2.5 % or ± 1.5 % in some cases.
- Response times are typically of the order of a few seconds.

APPLICATIONS

- **Humidity sensors can be used not only to measure the humidity in an atmosphere but also to automatically control:**

  -> Humidifiers

  -> Dehumidifiers

  -> Air conditioners for adjustment.

VELOCITY MEASUREMENT

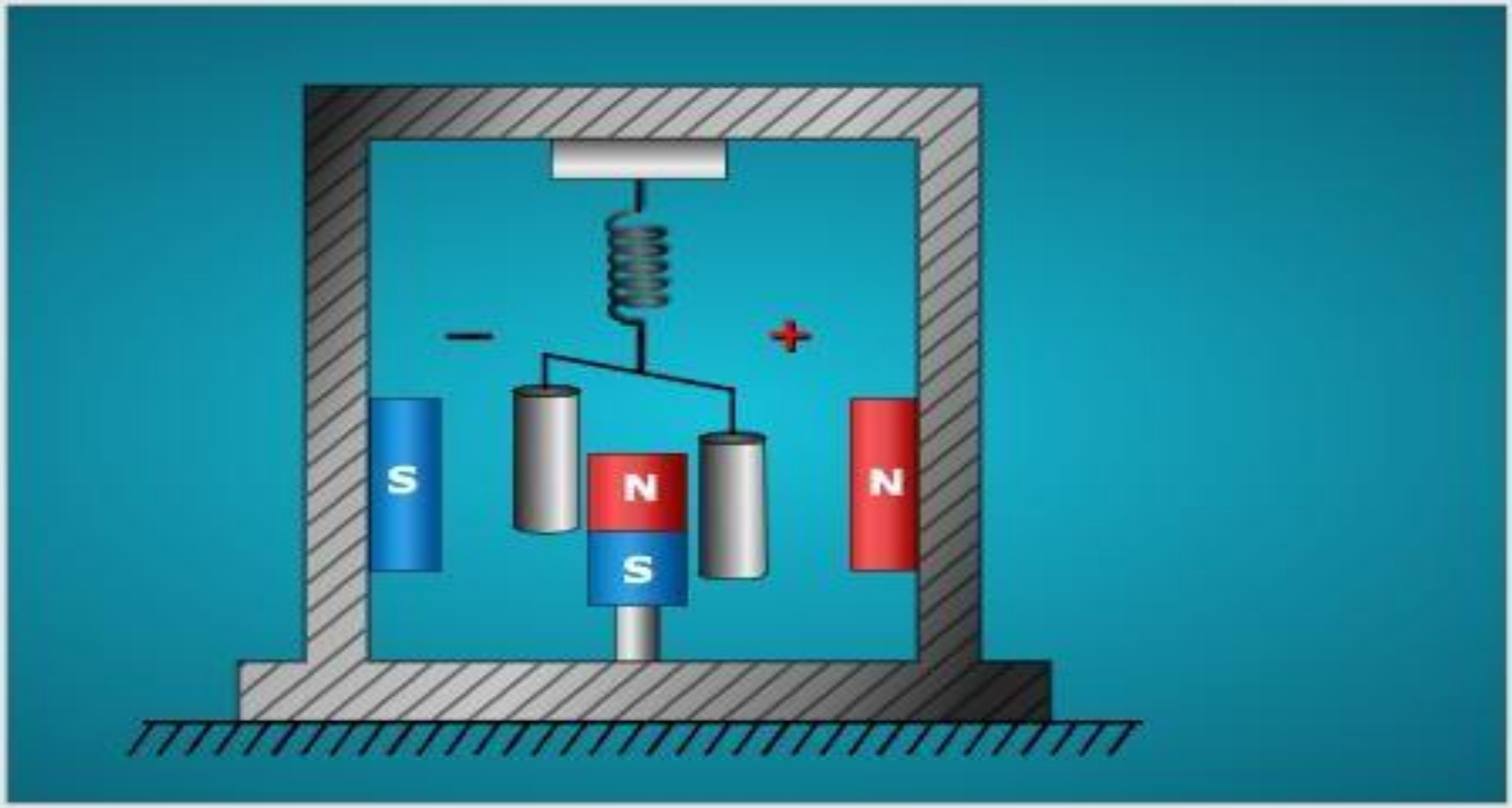
- Velocity is the rate of change of distance in a specific direction
- Velocity is a vector quantity having both magnitude and direction
- The average velocity of an object having a displacement (Δx) during a time interval (Δt) is given by

$$\bar{\upsilon} = \frac{\Delta x}{\Delta t}$$

- Velocity transducers are used to measure linear velocity and angular velocity
- To measure linear velocity, it must be converted into angular velocity, and then measured

Linear Velocity Transducers

- The linear velocity transducers use the principle of electromagnetic induction and converts mechanical vibrations into alternating voltages. So, they are referred to as electromagnetic transducers
- Electromagnetic transducers are of two types:



Moving Coil Type Velocity Transducer

- The moving coil type velocity transducer operates based on the action of moving coil in a magnetic field
- The construction of such transducer is given in image
- A coil is hung up between the pole pieces of the permanent magnet and the spring assembly acts as the support of the suspended coil
- The moving coil in the magnetic field produces voltage. The output is directly proportional to the velocity of the moving coil
- This system is also referred to as electrodynamic pick-up system and it is used for measuring linear, sinusoidal or random velocities

- The voltage induced in the coil at any instant of time is given by

$$e_0 = B.l.v$$

where e_0 – Output voltage,

B – Flux density

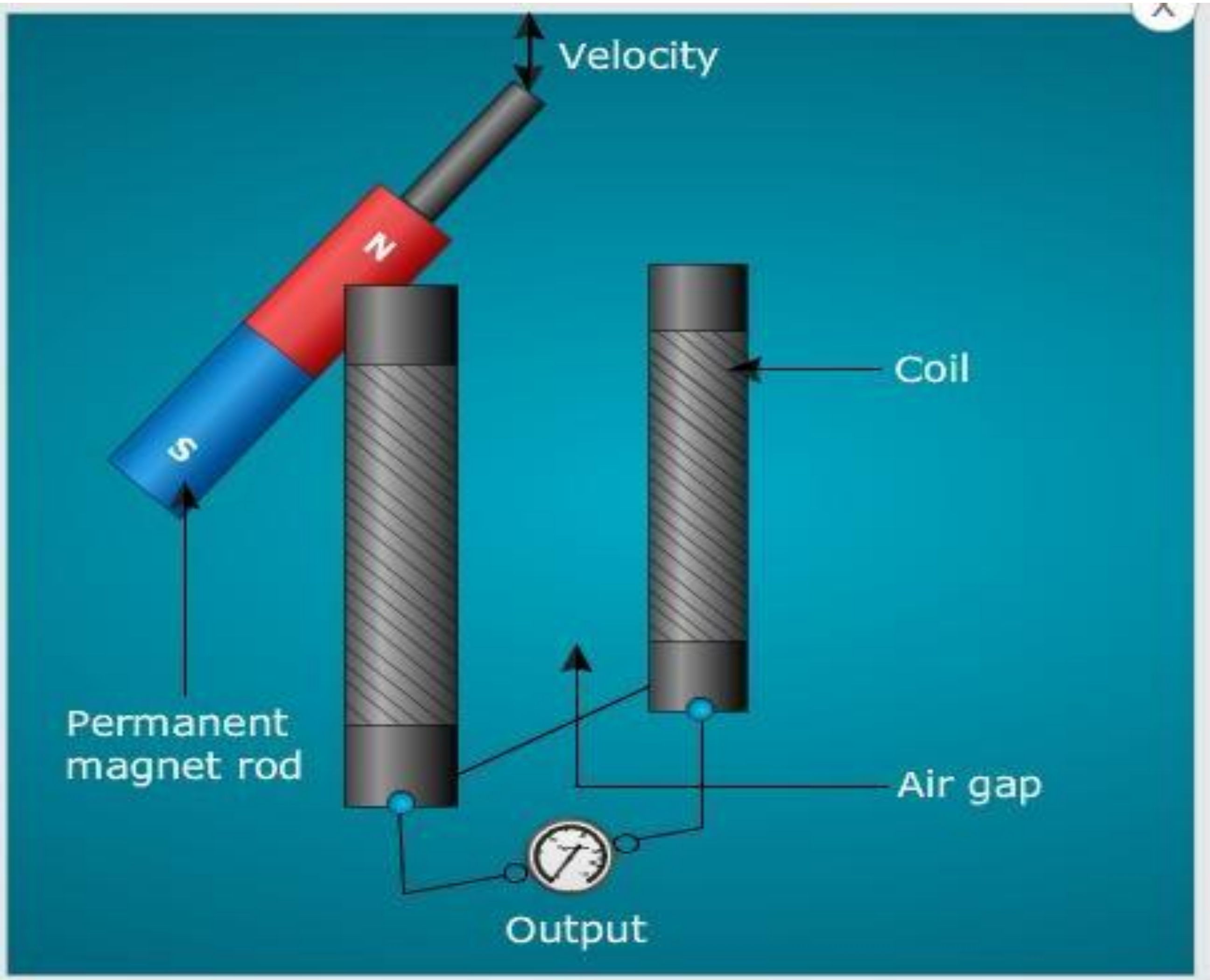
l – Length of coil

v – Relative velocity of the coil with respect to the permanent magnet which is fixed

Advantages

- The system forms closed magnetic circuit with constant air gap
- The entire unit is placed inside antimagnetic material case, hence the effects of stray magnetic fields are reduced
- Damping is achieved by an electrical means. Under varying temperature conditions, the system provides high stability

MOVING MAGNET TYPE VELOCITY TRANSDUCERS



Moving Magnet Type Velocity Transducers

- A constant polarized field is obtained with the help of permanent magnet
- Image shows the construction of transducer
- Permanent magnet rod, whose velocity is to be measured is surrounded by a coil
- Voltage gets induced in the coil due to the motion of rod and the amplitude of induced voltage is proportional to the velocity of the rod
- Direction of motion of the rod is determined by the polarity of the output voltage

Advantages

- There are no mechanical surfaces or contact, hence the maintenance required is negligible
- The output voltage is linearly proportional to the velocity
- Robust and less expensive

Limitations

- The stray magnetic field affects the performance of these transducers
- Limited frequency response

TEMPARATURE MEASUREMENT

- **Thermocouples**

  overview, reference junction, proper connections, types, special limits of error wire, time constants, sheathing, potential problems, DAQ setup

- **RTDs**

  overview, bridges, calibration, accuracy, response time, potentail problems

- **Thermistors**
- **Infrared Thermometry**

  fundamentals, emissivity determination, field of view

- **Other**

  Non-electronic measurement, thin-film heat flux gauge

- **Temperature Controllers**
- **How to Choose**

  Standards, cost, accuracy, stability, sensitivity, size, contact/non-contact, temperature range, fluid type

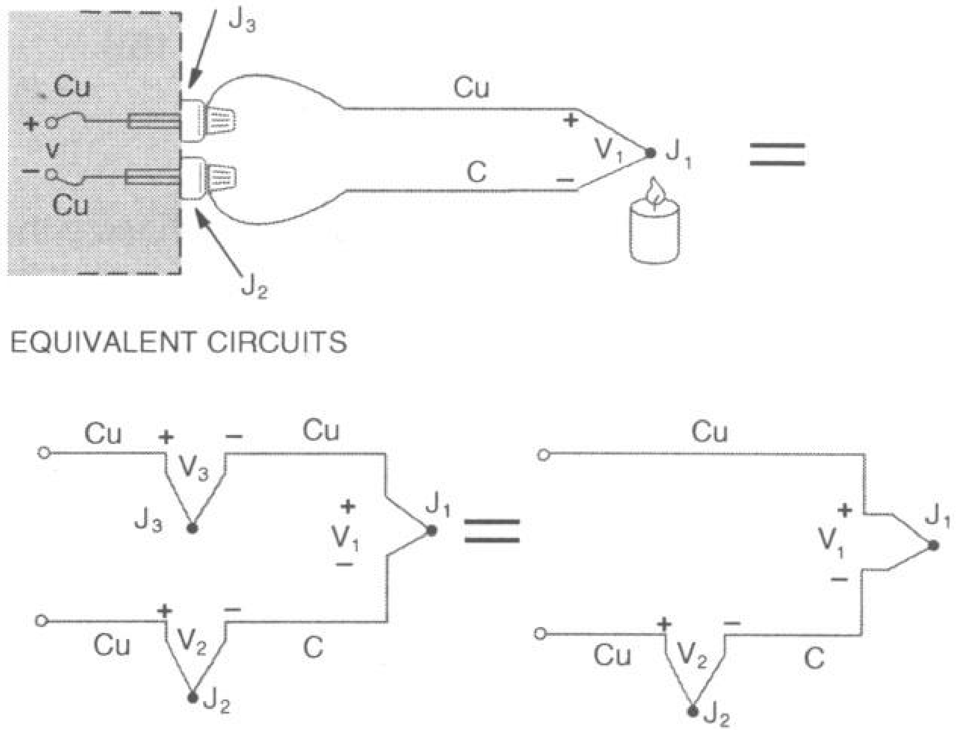
THERMOCOUPLES

- **Seebeck effect**
  - **If two wires of dissimilar metals are joined at both ends and one end is heated, current will flow.**
  - **If the circuit is broken, there will be an open circuit voltage across the wires.**
  - **Voltage is a function of temperature and metal types.**
  - **For small DT"s, the relationship with temperature is linear**

  - **For larger ΔT's, non-linearities may occur.**

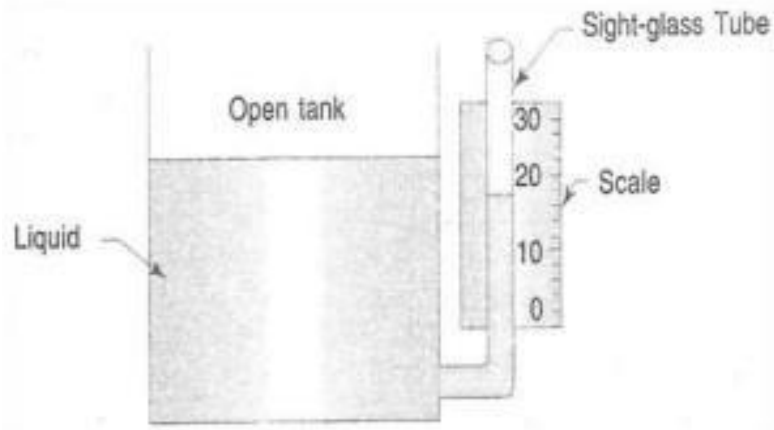
MEASURING THE THERMOCOUPLE VOLTAGE

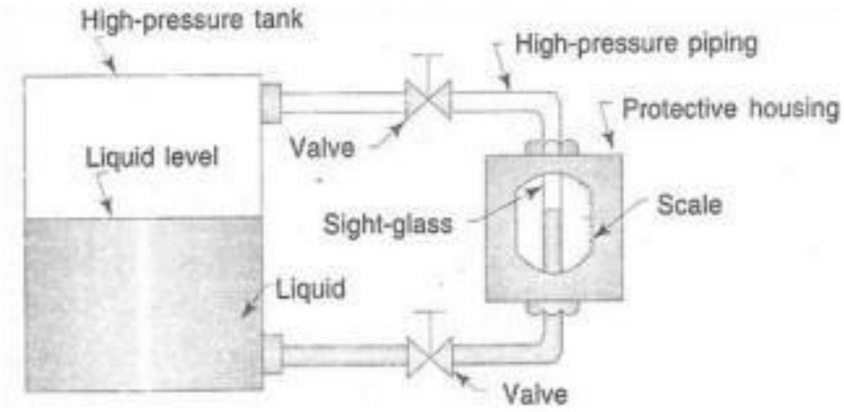
- If you attach the thermocouple directly to a voltmeter, you will have problems.



- You have just created another junction! Your displayed voltage will be proportional to the difference between J_1 and J_2 (and hence T_1 and T_2). Note that this is "Type T" thermocouple.

SIGHT GLASS / GAUGE GLASS





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EDUCATION FOR LIBERATION

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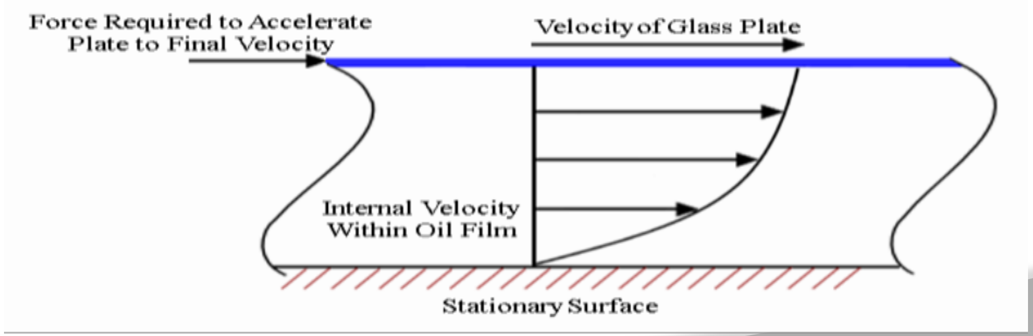
Advantages

Disadvantages

FLOW MEASUREMENT

DEFINITION OF FLOW & FLUID TYPES

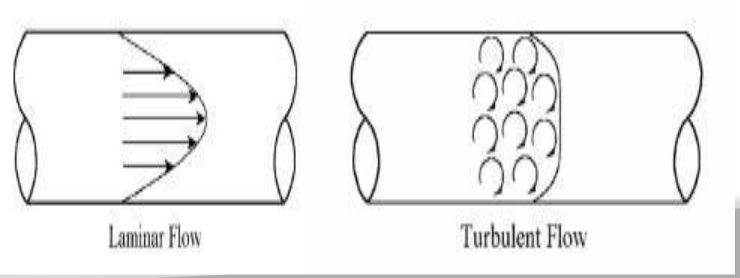


REYNOLDS NUMBER

$$R_D = \frac{V \cdot D}{\rho \;\; \mu}$$

UNITS OF FLOW

TYPES OF FLOW



Bernoulli's Equation

$$p + \frac{1}{2}\rho V^2 + \rho g h = constant$$

$$\frac{\partial}{\partial s}\left(\frac{v^2}{2} + \frac{p}{\rho} + g.h\right) = 0$$

$$\frac{v^2}{2} + \frac{p}{\rho} + g.h = constant$$

$$\frac{v^2}{2g} + \frac{p}{\gamma} + h = constant, where\ \gamma = \rho.g$$

$$\frac{\rho v^2}{2} + p = constant$$

$$\frac{\rho {v_1}^2}{2} + p_1 = \frac{\rho {v_2}^2}{2} + p_2 = constant$$

BASIC REQUIREMENTS FOR FLOW MEASUREMENT

FACTOR AFFECTING FLOW METER PERFORMANCE

Introduction

- **Pressure is define as force divided by area.** **(exerts on solid, gas, liquid)**

P = F/A

- **The unit of pressure is in Pa, psi, atm, bar, torr**

1 psi = 6895 pa

1 bar = 105 Pa

1 atm = 101325 Pa

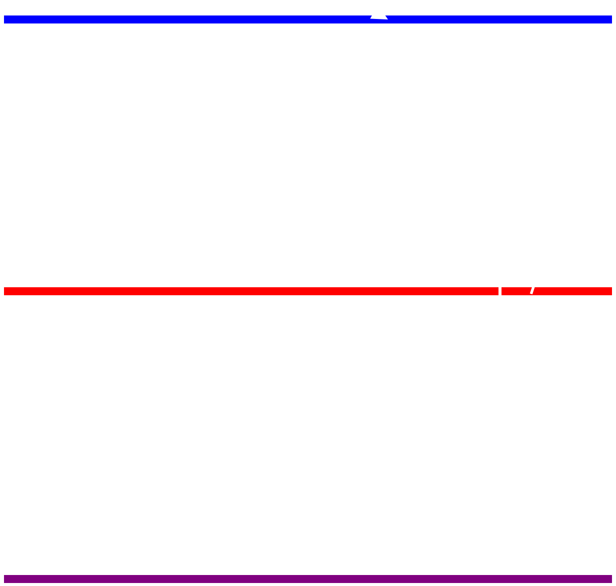
1 torr = 133.3 Pa

Static and Dynamic Pressure

- **Static pressure is the pressure of fluid or gases that are stationary or not in motion.**
- **Dynamic pressure is the pressure exerted by a fluid or gas when it impacts on a surface or an object due to its motion or flow.**

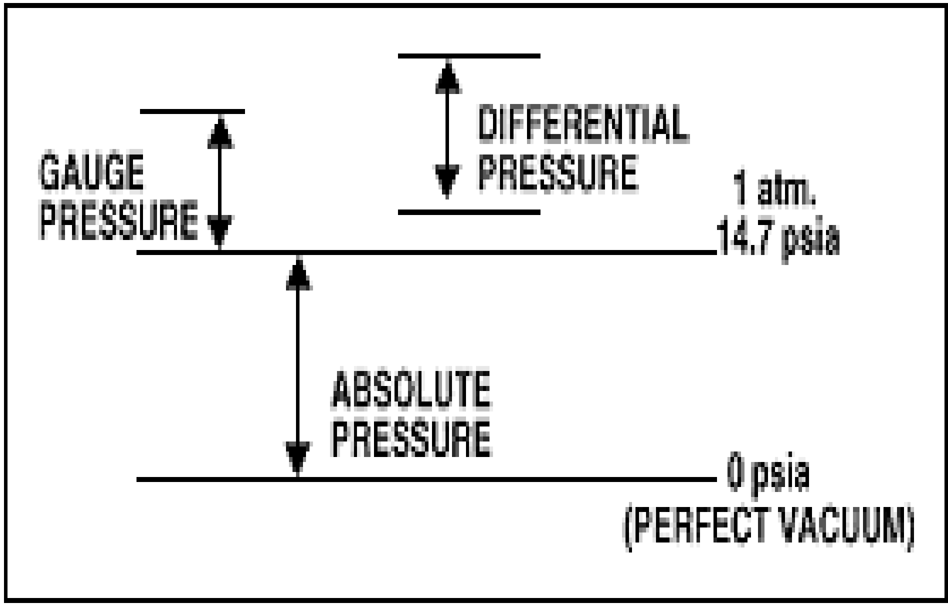
Pressure Measurement

- **Absolute pressure is the pressure measured wrt a vacuum (unit = psia)**
- **Gauge pressure is the pressure measured wrt atmospheric pressure (unit = psig)**
- **Atmospheric pressure is the pressure on the earth‟s surface due to the weight of gases in the earth‟s atmosphere (14.7psi)**



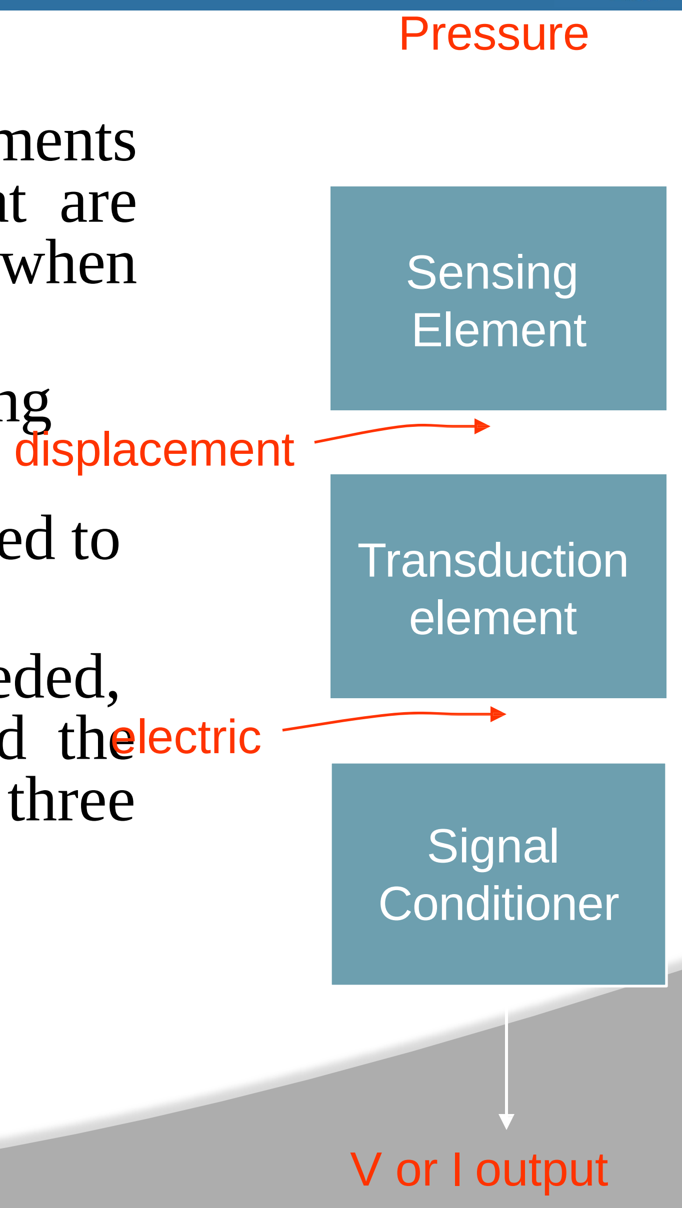
Types of Pressure measurements

- *Absolute pressure* is measured relative to a perfect vacuum (psia)
- *Gauge pressure* is measured relative to ambient pressure (psig)
- *Differential pressure* is the difference in pressure between two points of measurement. (psid).
- Note that the same sensor may be used for all three types; only the reference is different.



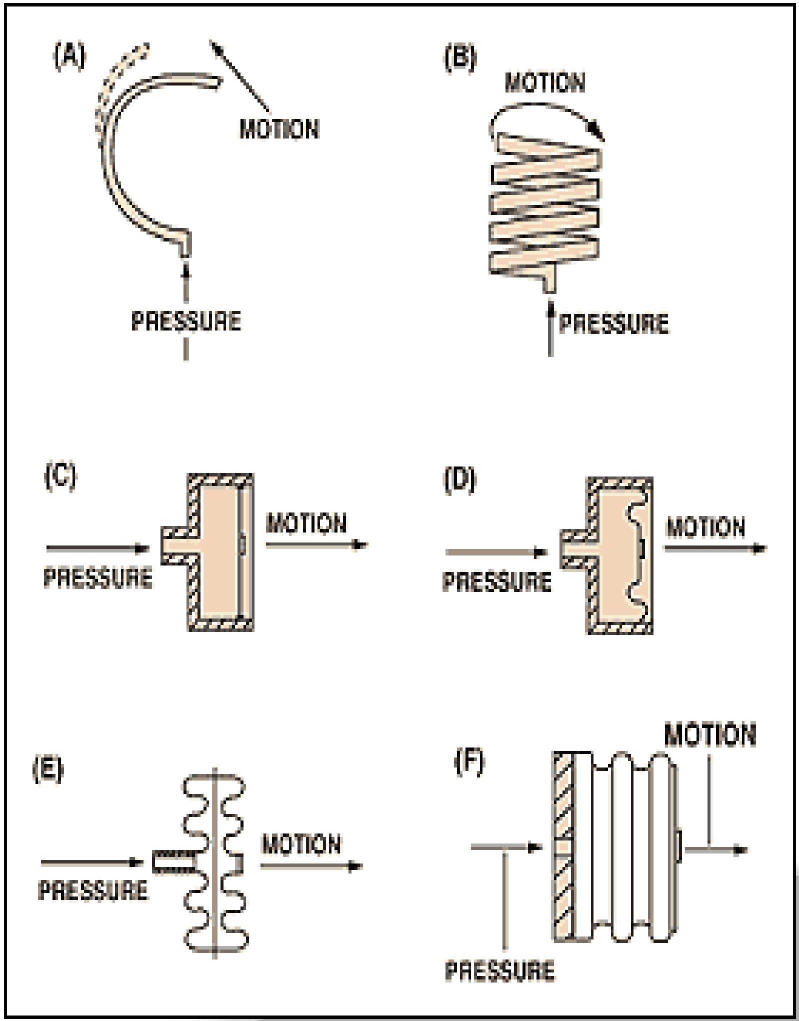
PRESSURE SENSING

- Pressure is sensed by mechanical elements such as plates, shells, and tubes that are designed and constructed to deflect when pressure is applied.
- This is the basic mechanism converting pressure to physical movement.
- Next, this movement must be transduced to obtain an electrical or other output.
- Finally, signal conditioning may be needed, depending on the type of sensor and the application. Figure 8 illustrates the three functional blocks.



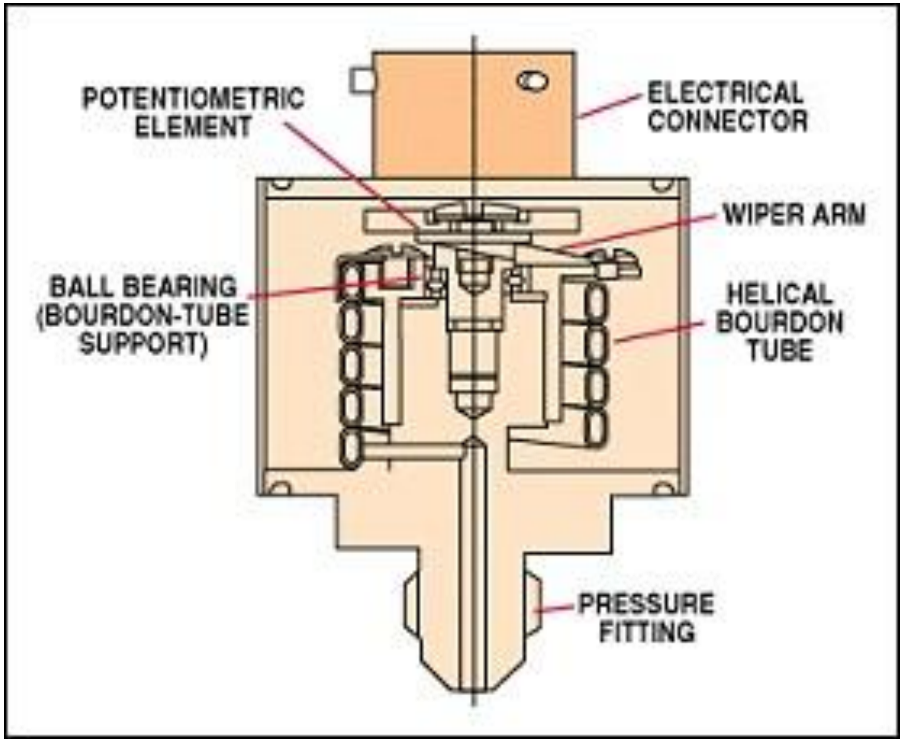
SENSING ELEMENTS

- The main types of sensing elements are Bourdon tubes, diaphragms, capsules, and bellows
- All except diaphragms provide a fairly large displacement that is useful in mechanical gauges and for electrical sensors that require a significant movement



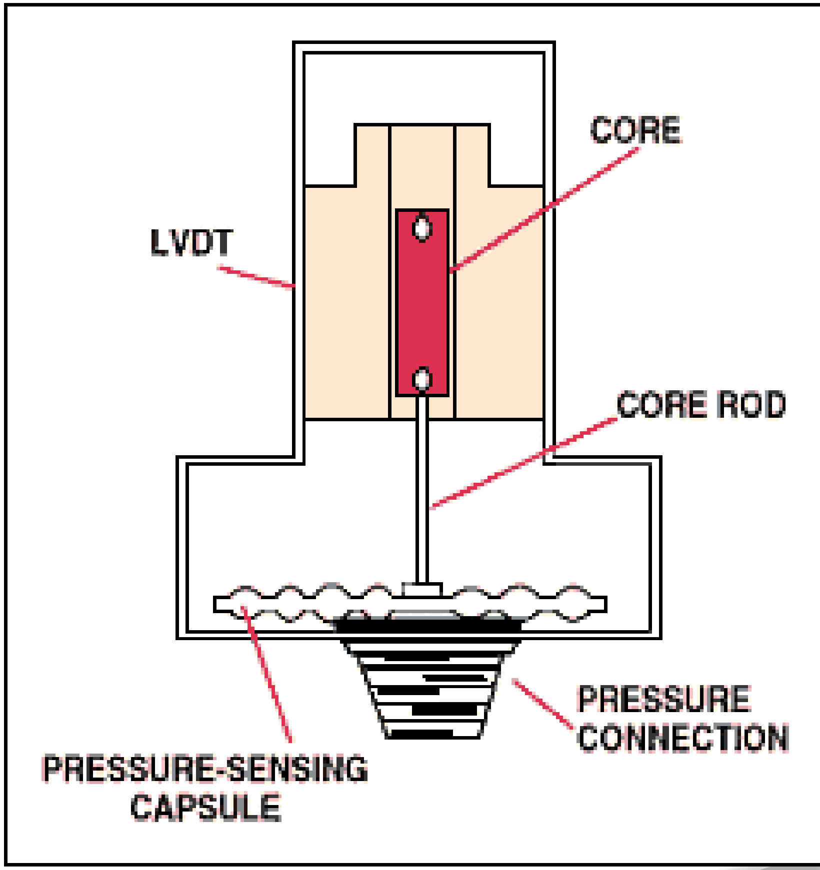
POTENTIOMETRIC PRESSURE SENSORS

- Potentiometric pressure sensors use a Bourdon tube, capsule, or bellows to drive a wiper arm on a resistive element.
- For reliable operation the wiper must bear on the element with some force, which leads to repeatability and hysteresis errors.
- These devices are very low cost, however, and are used in low-performance applications such as dashboard oil pressure gauges



Inductive Pressure Sensors

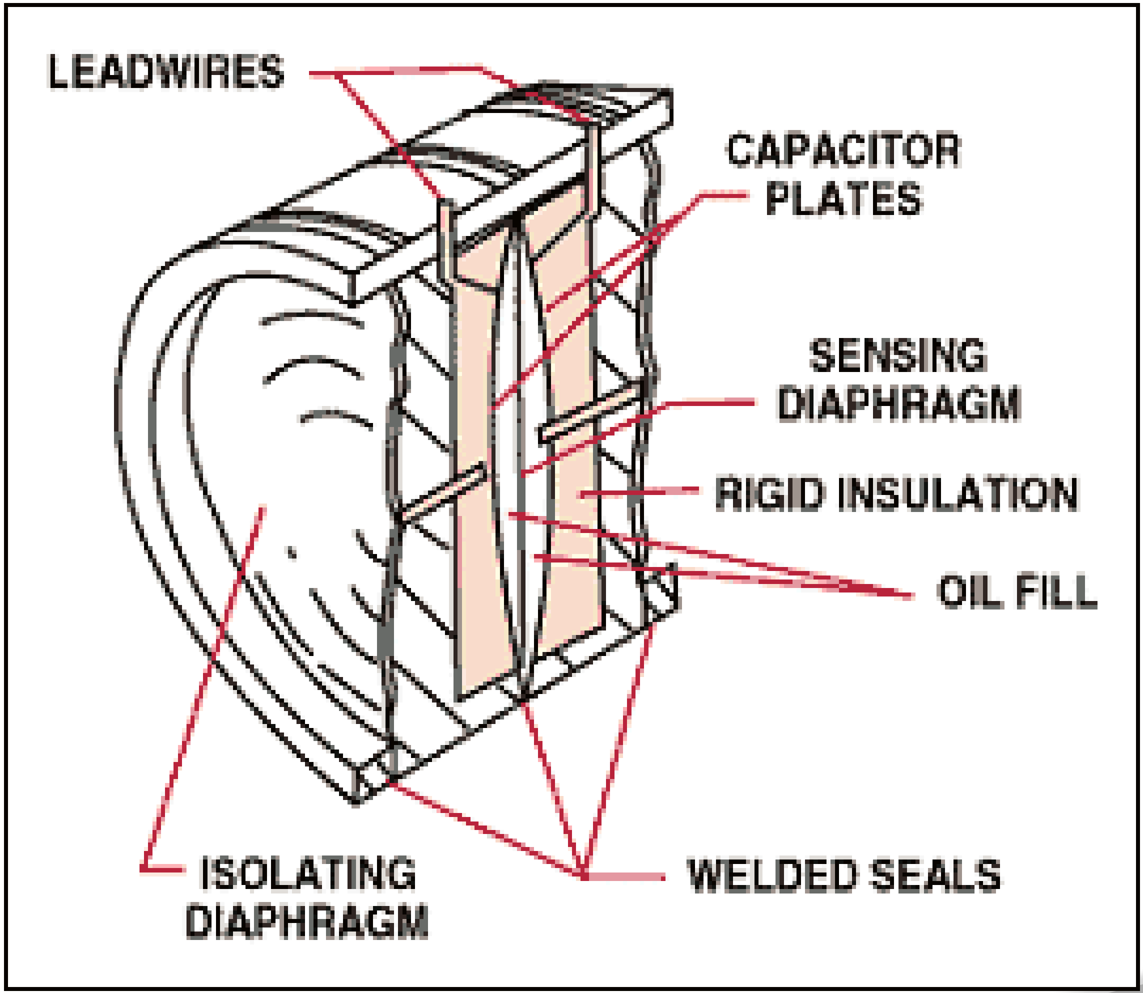
- Several configurations based on varying inductance or inductive coupling are used in pressure sensors. They all require AC excitation of the coil(s) and, if a DC output is desired, subsequent demodulation and filtering. The LVDT types have a fairly low frequency response due to the necessity of driving the moving core of the differential transformer
- The LVDT uses the moving core to vary the inductive coupling between the transformer primary and secondary.



CAPACITIVE PRESSURE SENSORS

- Capacitive pressure sensors typically use a thin diaphragm as one plate of a capacitor.
- Applied pressure causes the diaphragm to deflect and the capacitance to change.
- This change may or may not be linear and is typically on the order of several picofarads out of a total capacitance of 50-100 pF.
- The change in capacitance may be used to control the frequency of an oscillator or to vary the coupling of an AC signal through a network.
- The electronics for signal conditioning should be located close to the sensing element to prevent errors due to stray capacitance.

CAPACITIVE PRESSURE SENSORS

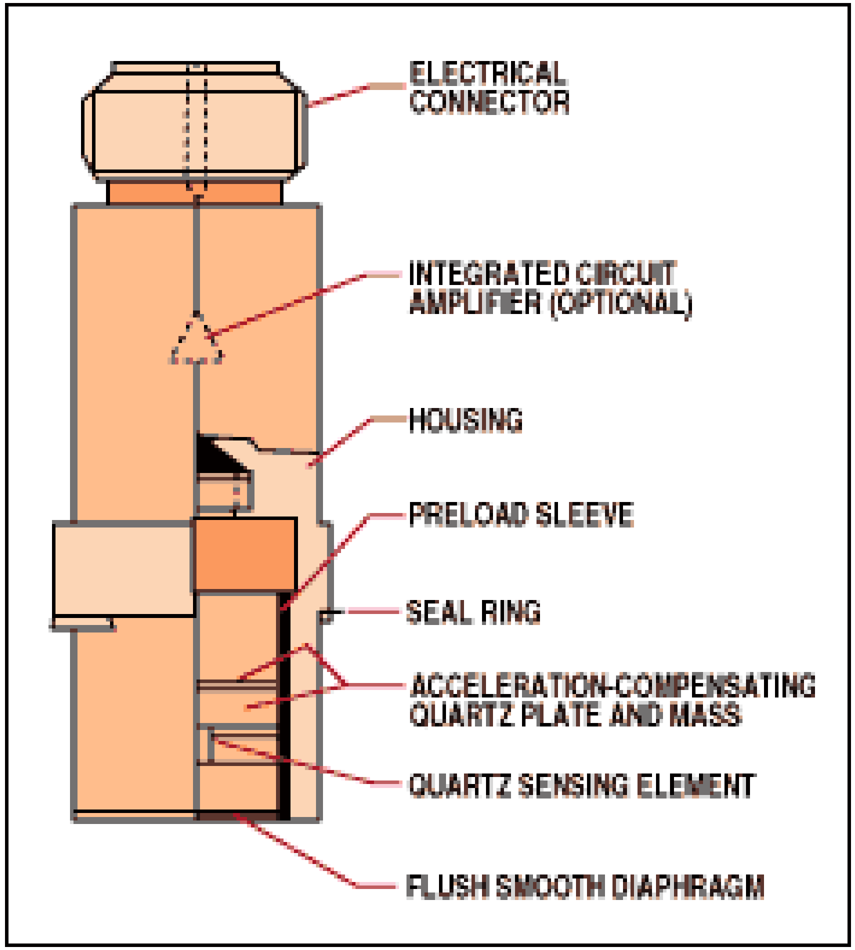


Capacitive Pressure Sensors

PIEZOELECTRIC PRESSURE SENSORS

- **Piezoelectric elements are bi-directional transducers capable of converting stress into an electric potential and vice versa.**
- **One important factor to remember is that this is a dynamic effect, providing an output only when the input is changing.**
- **This means that these sensors can be used only for varying pressures.**
- **The piezoelectric element has a high-impedance output and care must be taken to avoid loading the output by the interface electronics. Some piezoelectric pressure sensors include an internal amplifier to provide an easy electrical interface.**

Piezoelectric Pressure Sensors.



ce versa.

ying pressures.

Strain Gauge Pressure Sensors

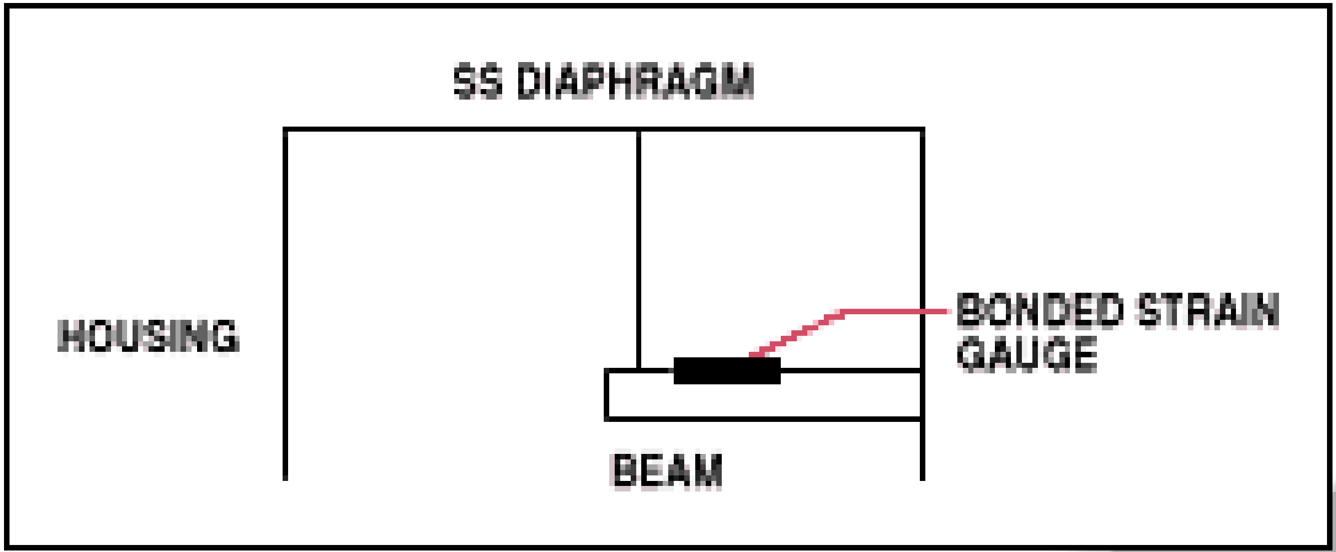
- Strain gauge sensors originally used a metal diaphragm with strain gauges bonded to it.
- the signal due to deformation of the material is small, on the order of 0.1% of the base resistance
- Semiconductor strain gauges are widely used, both bonded and integrated into a silicon diaphragm, because the response to applied stress is an order of magnitude larger than for a metallic strain gauge.

Strain Gauge Pressure Sensors

- When the crystal lattice structure of silicon is deformed by applied stress, the resistance changes. This is called the piezoresistive effect. Following are some of the types of strain gauges used in pressure sensors.
- *Deposited strain gauge*. Metallic strain gauges can be formed on a diaphragm by means of thin film deposition. This construction minimizes the effects of repeatability and hysteresis that bonded strain gauges exhibit. These sensors exhibit the relatively low output of metallic strain gauges.

Strain Gauge Pressure Sensors

- *Bonded semiconductor strain gauge*. A silicon bar may be bonded to a diaphragm to form a sensor with relatively high output. Making the diaphragm from a chemically inert material allows this sensor to interface with a wide variety of media



Displacement measurement

- There are a wide variety of devices used to measure displacement
- Potentiometer
- Linear and Rotary Variable Differential Transformers
- Capacitive Displacement Sensors
- Linear Velocity Transducers
- Angular Displacement and Velocity Devices

ELECTRONIC MEASUREMENT AND INSTRUMENTATION(AEC014)

ELECTRONICS AND COMMUNICATION ENGINEERING

B.Tech VI Semester-IARE R16

Prepared by

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UNIT I
INTRODUCTION TO MEASURING INSTRUMENTS

INTRODUCTION

- **Measurement** is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.

- **Instrumentation** is a technology of measurement which serves sciences, engineering, medicine and etc.

- **Instrument** is a device for determining the value or magnitude of a quantity or variable.

- **Electronic instrument** is based on electrical or electronic principles for its measurement functions.

ELECTRONIC INSTRUMENT

Transducer | Signal Modifier | Indicating Device

1) Transducer
   - convert a non electrical signal into an electrical signal
2) Signal modifier
   - convert input signal into a suitable signal for the indicating device (e.g amplifier)
3) Indicating device
   - indicates the value of quantity being measure (e.g ammeter)

FUNCTIONS

- The 3 basic functions of instrumentation
  - Indicating – visualize the process/operation
  - Recording – observe and save the measurement reading
  - Controlling – to control measurement and process

PERFORMANCE CHARACTERISTICS

- Performance Characteristics -

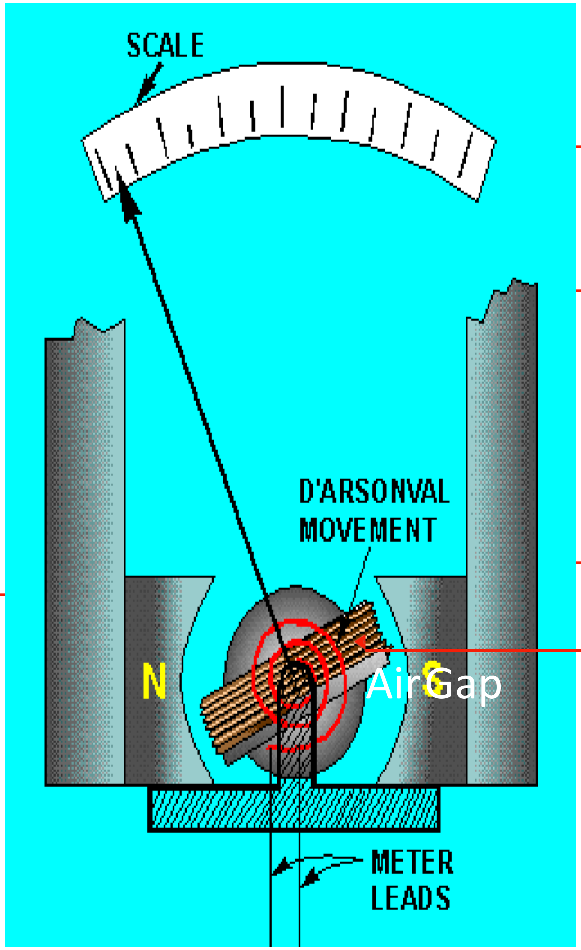
  instrument

- Two basic characteristics :

PERFORMANCE CHARACTERISTICS

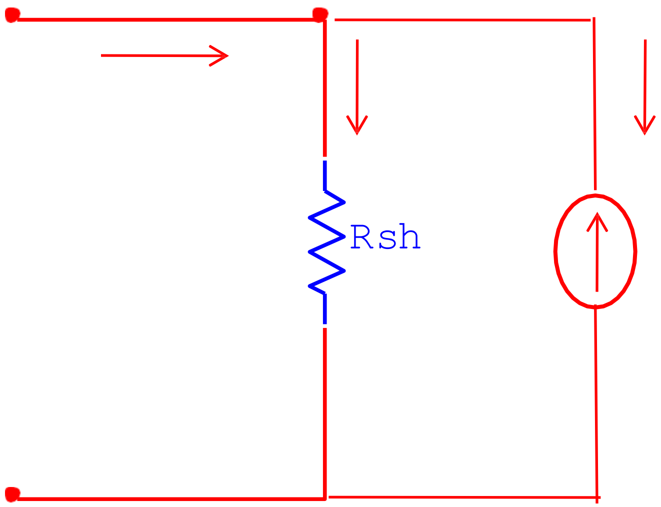
- Accuracy
- Resolution
- Precision
- Sensitivity
- Expected value
- Error

DC AND AC METER


SCALE
D'ARSONVAL
MOVEMENT
N
S
Air Gap
METER
LEADS

DC AMMETER

- **The PMMC galvanometer constitutes the basic movement of a dc ammeter.**
- **The coil winding of a basic movement is small and light, so it can carry only very small currents.**
- **A low value resistor (shunt resistor) is used in DC ammeter to measure large current.**
- **Basic DC ammeter:**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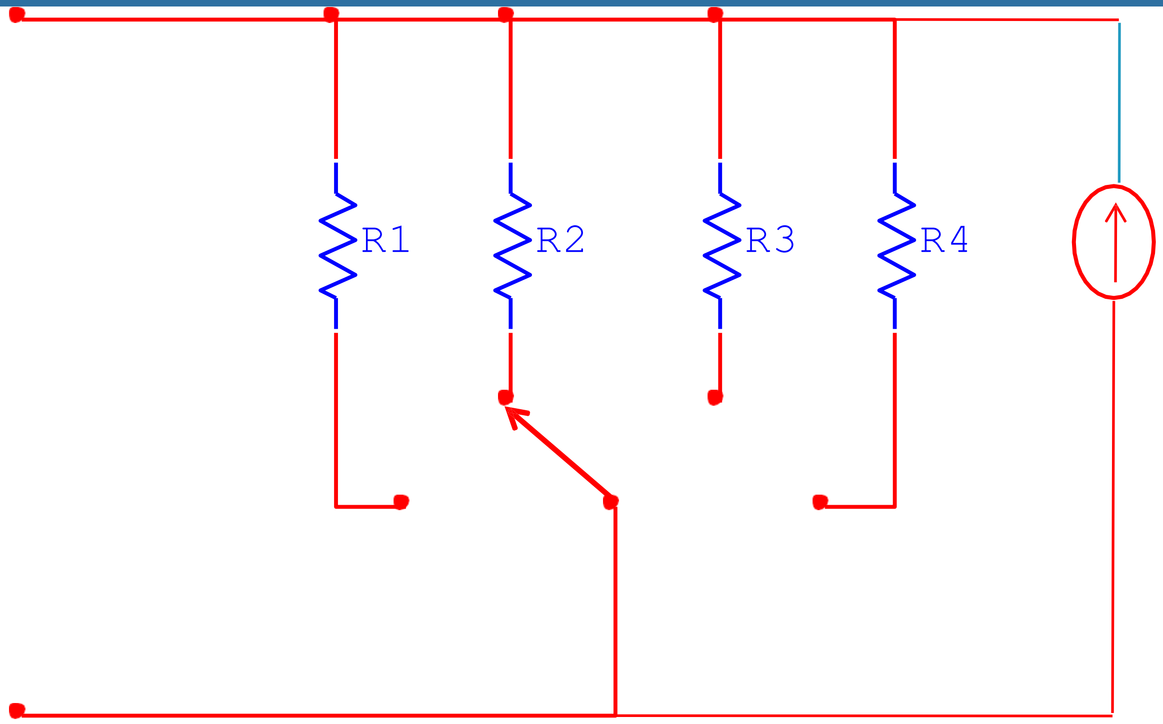
MULTIRANGE AMMETER


R1
R2
R3
R4

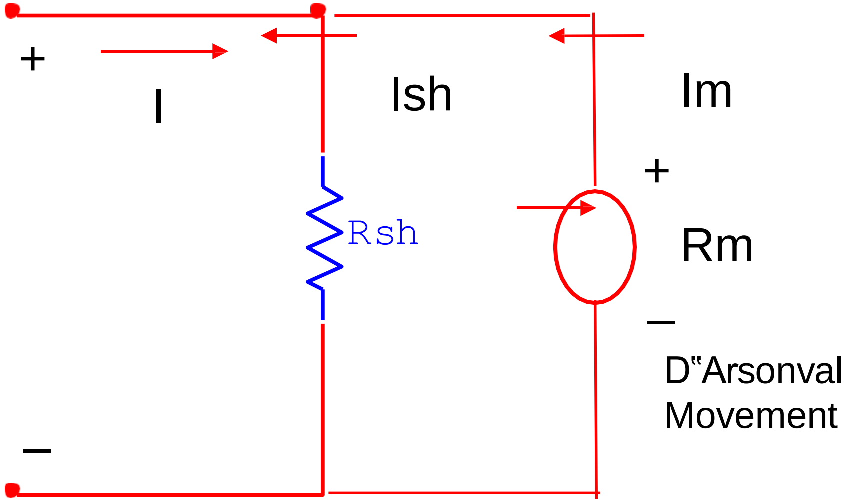


Figure 2.2: Basic DC Ammeter

$$I_{sh} R_{sh} = I_m R_m$$

$$I_{sh} = I - I_m$$

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

Rm = internal resistance of the movement

Rsh = shunt resistance

Ish =shunt current

Im = full scale deflection current of the movement

I = full scale current of the ammeter + shunt (i.e. total current)

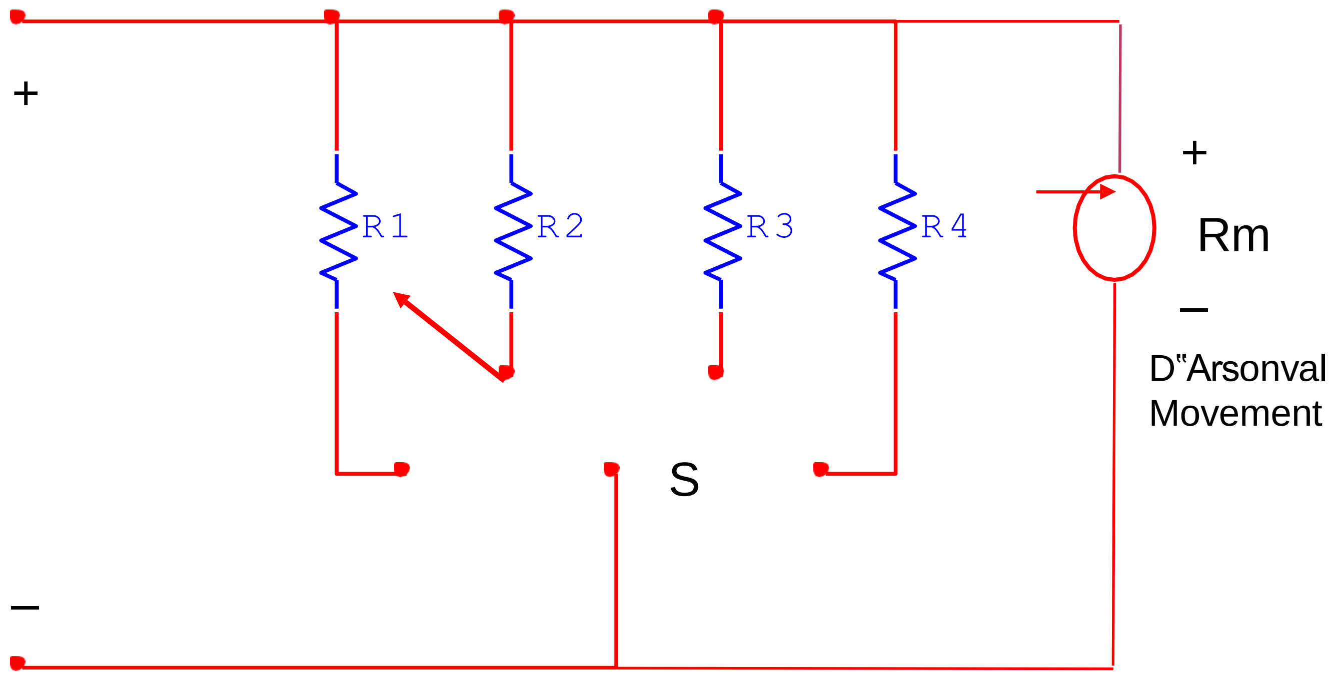


Figure 2.3: Multirange Ammeter

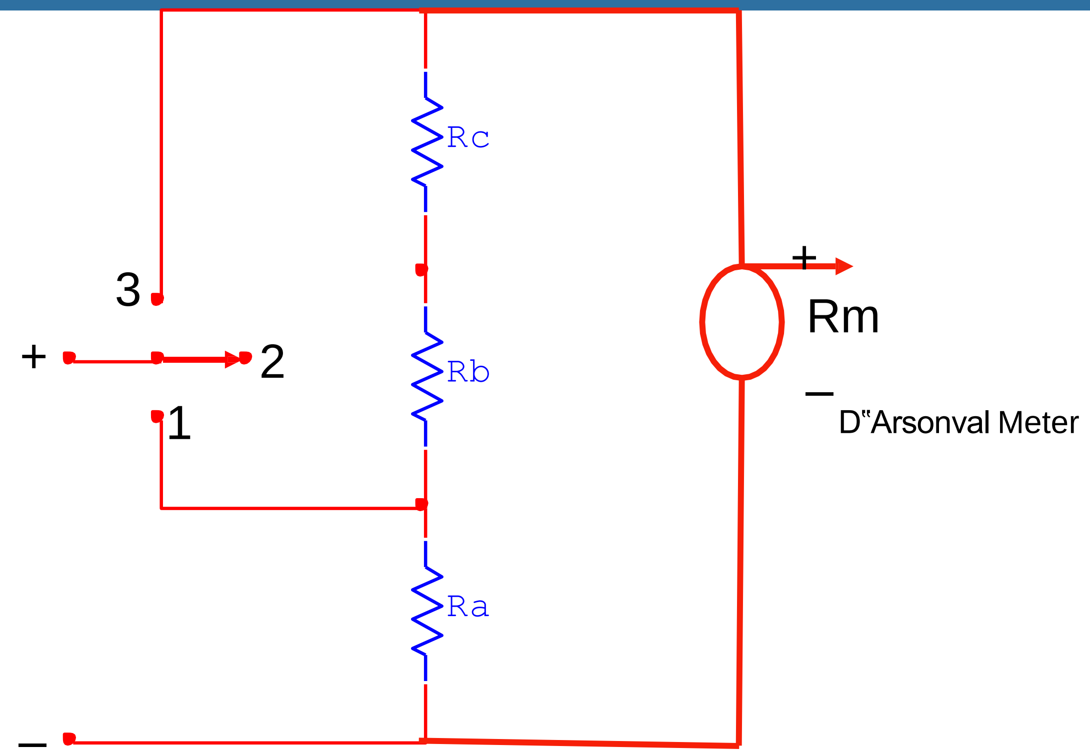
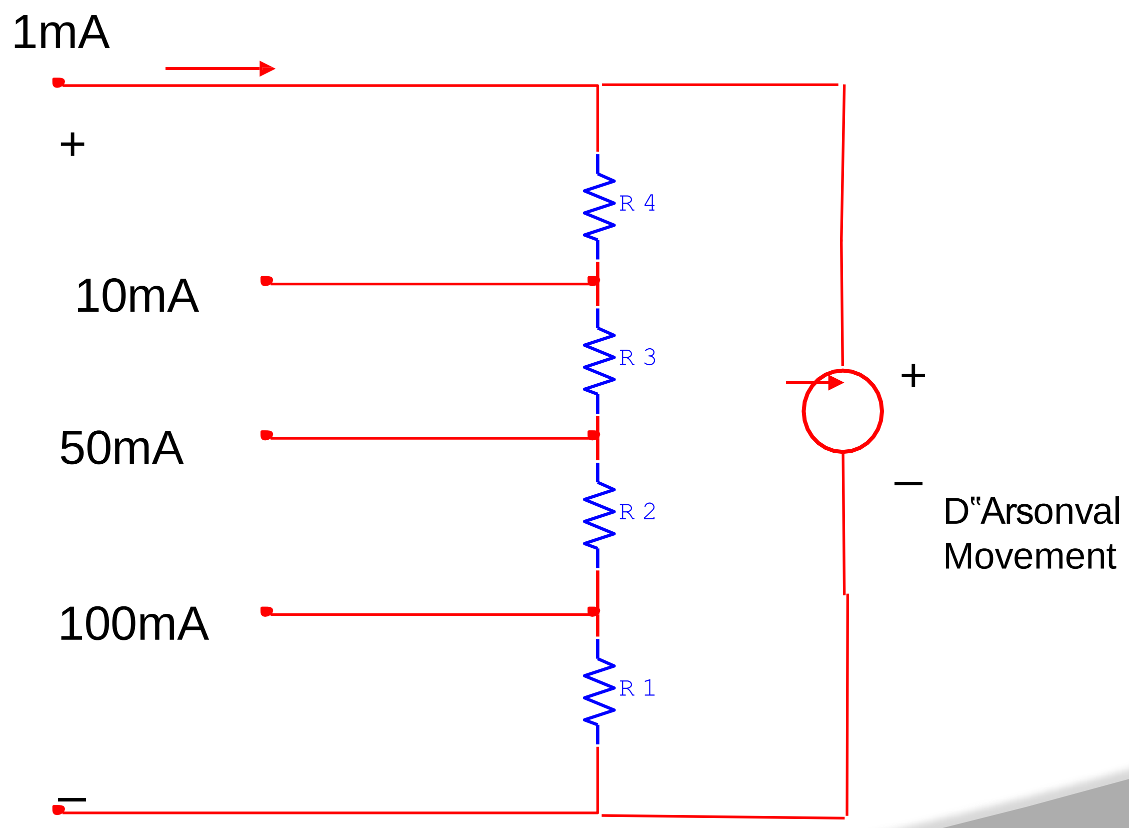


Figure 2.4: Aryton Shunt

EXAMPLE

- Design an Aryton shunt to provide an ammeter with a current range of 0-1 mA, 10 mA, 50 mA and 100 mA. A D' Arsonval movement with an internal resistance of 100Ω and full scale current of 50 uA is used.



REQUIREMENT OF A SHUNT

1) **Minimum Thermo Dielectric Voltage Drop**

Soldering of joint should not cause a voltage drop.

2) **Solderability**

-never connect an ammeter across a source of e.m.f

- observe the correct polarity

- when using the multirange meter, first use the highest current range.

BASIC METER AS A DC VOLTMETER

-

-

$$S = \frac{1}{I_{fsd}}$$

EXAMPLE

Calculate the sensitivity of a 200 uA meter movement which is to be used as a dc voltmeter.

Solution:

$$S = \frac{1}{I_{fsd}} = \frac{1}{200uA} = 5k\Omega/V$$

DC VOLTMETER

❑

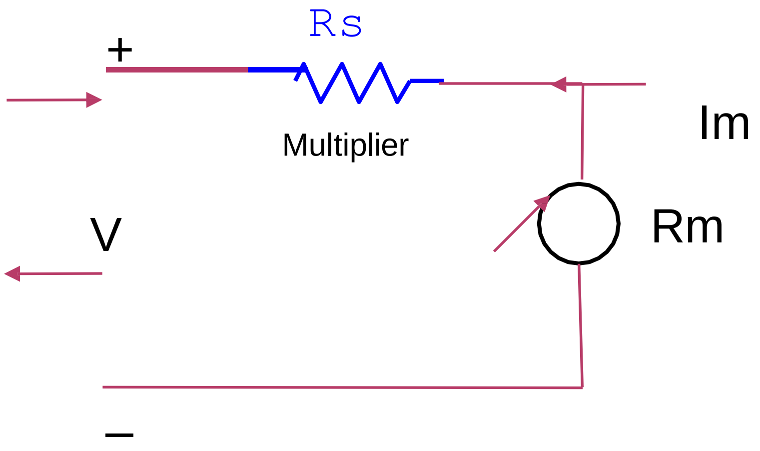


Figure : Basic DC Voltmeter

- From the circuit of Figure 2.5:

$$V = I_m (R_s + R_m)$$

$$R_s = \frac{V - I_m R_m}{I_m} = \frac{V}{I_m} - R_m$$

$$R_s = \frac{V}{I_m} - R_m$$

EXAMPLE

A basic D' Arsonval movement with a full-scale deflection of 50 uA and internal resistance of 500Ω is used as a DC voltmeter. Determine the value of the multiplier resistance needed to measure a voltage range of 0-10V.

Solution:

$$R_s = \frac{V}{I_m} - R_m = \frac{10V}{50uA} - 500\Omega = 199.5k\Omega$$

- Sensitivity and voltmeter range can be used to calculate the multiplier resistance, Rs of a DC voltmeter.

$$R_s = (S \times Range) - R_m$$

- From example 2.4:

Im= 50uA, Rm=500Ω, Range=10V

Sensitivity,

$$S = \frac{1}{I_m} = \frac{1}{50uA} = 20k\Omega / V$$

So, Rs = (20kΩ/V x 10V) – 500 Ω

= 199.5 kΩ

- A DC voltmeter can be converted into a multirange voltmeter by connecting a number of resistors (multipliers) in series with the meter movement.
- A practical multi-range DC voltmeter is shown in Figure .

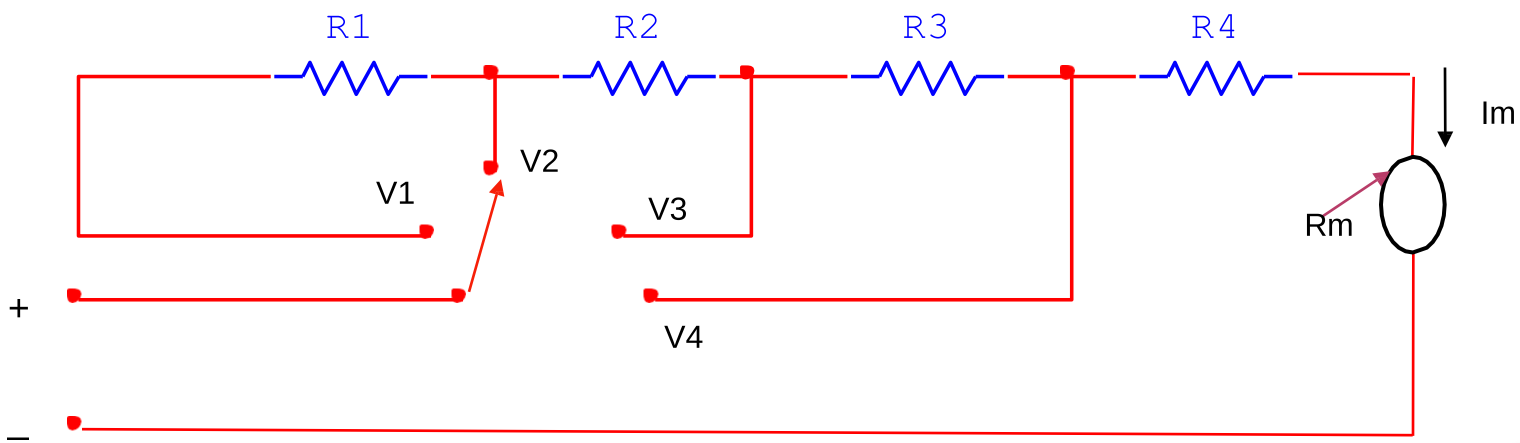


Figure : Multirange voltmeter

VOLTMETER LOADING EFFECTS

- When a voltmeter is used to measure the voltage across a circuit component, the voltmeter circuit itself is in parallel with the circuit component.
- Total resistance will decrease, so the voltage across component will also decrease. This is called voltmeter loading.
- The resulting error is called a loading error.
- The voltmeter loading can be reduced by using a high sensitivity voltmeter.

AMMETER INSERTION EFFECTS

- Inserting Ammeter in a circuit always increases the resistance of the circuit and, thus always reduces the current in the circuit. The expected current:

$$I_e = \frac{E}{R_1} \quad (2\text{-}4)$$

- Placing the meter in series with R1 causes the current to reduce to a value equal to:

$$I_m = \frac{E}{R_1 + R_m} \quad (2\text{-}5)$$

AMMETER INSERTION EFFECTS

- Dividing equation (2-5) by (2-4) yields:

$$\frac{I_m}{I_e} = \frac{R_1}{R_1 + R_m} \qquad (2\text{-}6)$$

- The Ammeter insertion error is given by :

$$\text{Insertion Error} = \left(1 - \frac{I_m}{I_e}\right) X\,100 \qquad (2\text{-}7)$$

OHMMETER (Series Type)

- Current flowing through meter movements depends on the magnitude of the unknown resistance
- The meter deflection is non-linearly related to the value of the unknown Resistance, R_x.
- A major drawback – as the internal voltage decreases, reduces the current and meter will not get zero Ohm.
- R_2 counteracts the voltage drop to achieve zero ohm. How do you get zero Ohm?

$$R_h = R_1 + (R_2 // R_m) = R_1 + \frac{R_2 R_m}{R_2 + R_m}$$

- R_1 and R_2 are determined by the value of $R_x = R_h$ where R_h = half of full scale deflection resistance.
- The total current of the circuit, $It = V/R_h$
- The shunt current through R2 is $I_2 = I_t - I_{fsd}$

OHMMETER (Series Type)

- The voltage across the shunt, Vsh= Vm

So, $I_2 R_2 = I_{fsd} R_m$

Since $I_2 = I_t - I_{fsd}$

Then,

$$R_2 = \frac{I_{fsd} R_m}{I_t - I_{fsd}}$$

Since $I_t = V/R_h$

So,

$$R_2 = \frac{I_{fsd} R_m R_h}{V - I_{fsd} R_h}$$

$$R_1 = R_h - \frac{I_{fsd} R_m R_h}{V}$$

MULTI-RANGE OHMMETER

- Another method of achieving flexibility of a measuring instrument is by designing it to be in multi-range.
- Let us analyse the following examples. (figure 4.29 of your textbook)

MULTIMETER

- Multimeter consists of an ammeter, voltmeter and ohmmeter in one unit.
- It has a function switch to connect the appropriate circuit to the D'Arsonval movement.
- Fig.4.33 (in text book) shows DC miliammeter, DC voltmeter, AC voltmeter, microammeter and ohmmeter.

Digital Voltmeters

- The magnitude of voltage signals can be measured by various electrical indicating and test instruments, such as meters (both analogue and digital), the cathode ray oscilloscope and the digital storage oscilloscope.

- As well as signal-level voltages, many of these instruments can also measure higher-magnitude voltages, and this is indicated where appropriate.

•All types of digital meter are basically modified forms of the digital voltmeter (DVM), irrespective of the quantity that they are designed to measure.

•Digital meters designed to measure quantities other than voltage are in fact digital voltmeters that contain appropriate electrical circuits to convert current or resistance measurement signals into voltage signals.

•The binary nature of the output reading from a digital instrument can be readily applied to a display that is in the form of discrete numerals

ADVANTAGES

- Higher accuracy and resolution
- Greater speed
- No parallax
- Reduced human error
- Compatibility with other digital equipment for further processing and recording

VARIETIES OF DVM

•Digital voltmeters differ mainly in the technique used to effect the analogue-to-digital conversion between the measured analogue voltage and the output digital reading.

•As a general rule, the more expensive and complicated conversion methods achieve a faster conversion speed

DVM differ in the following ways

- Number of digits
- Number of measurements
- Accuracy
- Speed of reading
- Digital output of several types

CHARACTERISTICS FEATURES OF DVMs

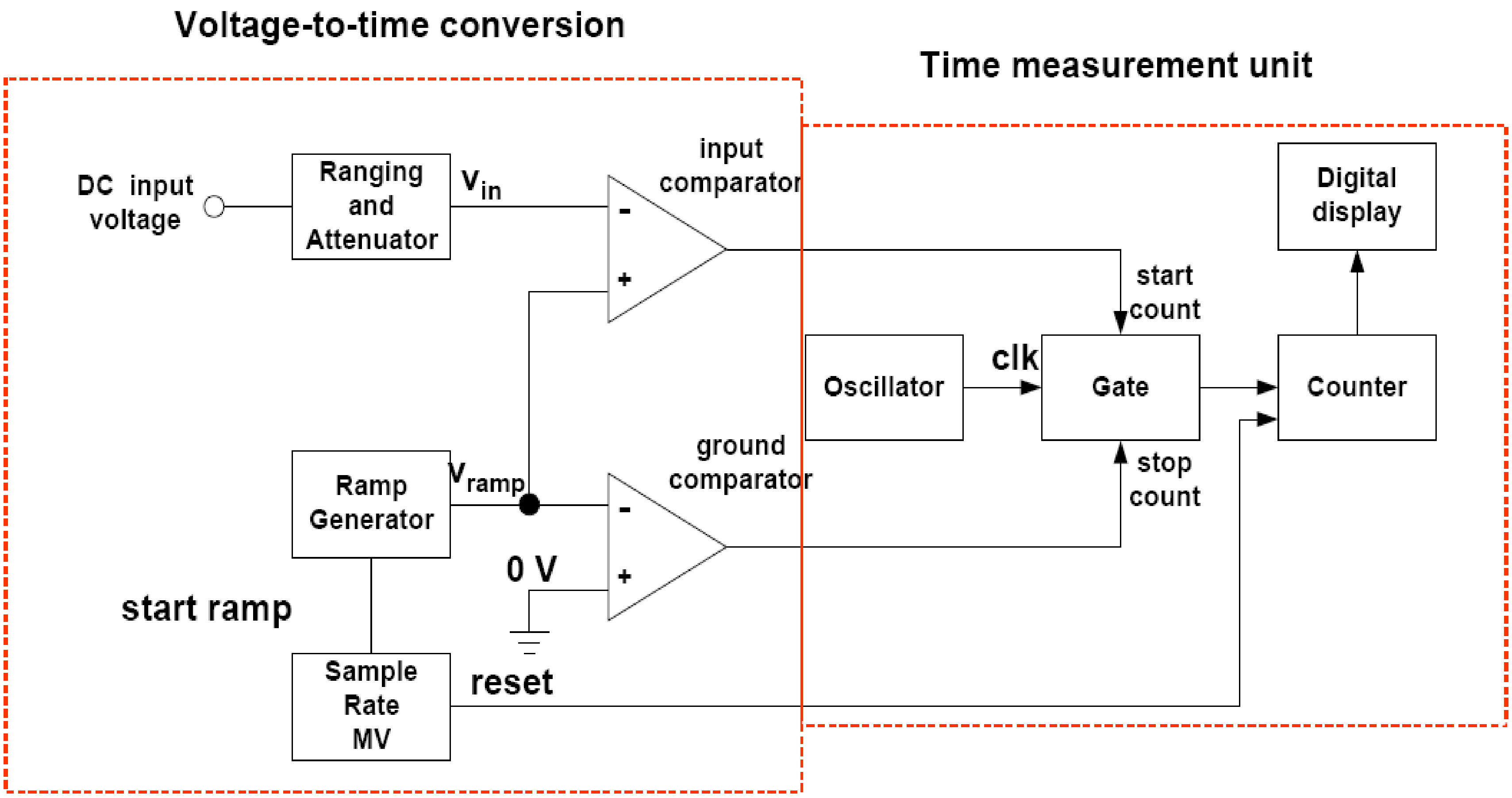
- Input Range: From ±1.000 to ±1000V with automatic range selection and overload indication
- Absolute accuracy: As high as ±0.005% of the reading
- Resolution: 1 part in 10^6
- Stability: Short term – 0.002% of the reading for a 24-hr period

  Long term – 0.008% of the reading for a 6 month period
- Input resistance: Typically 10 MΩ
- Input capacitance: 40 pF
- Output signals: BCD form

CLASSIFICATION OF DVMs

- <u>Voltage to Time</u> - Ramp type DVM
- <u>Voltage to Frequency</u> - Integrating type DVM
  - Dual slope integrating type DVM
- <u>Direct</u> - Successive approximation DVM
  - Staircase ramp DVM

Ramp-type Digital Voltmeter

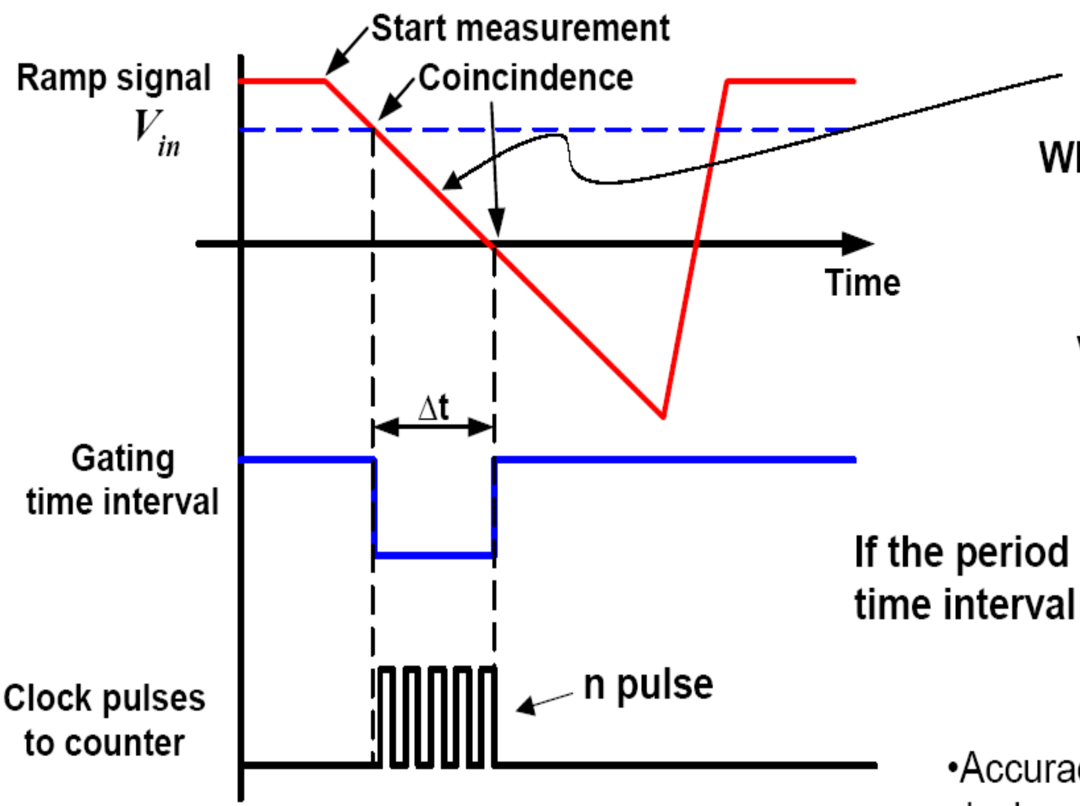


Block diagram of a ramp-type digital voltmeter.

Ramp-type Digital Voltmeter

(also called single slope)

Operation principle: The measurement of the time it takes for a linear ramp voltage to rise from 0 V to the level of the input voltage, or to decrease from the level of the input voltage to zero. This time interval is measured with an electronic time-interval counter.



Voltage-to-time conversion using gated clock pulses.

$$V_{ramp}(t) = V_o - m\,t$$

Where m is the ramp rate

$$V_{ramp}(t_1) = V_{in} = V_o - m\,t_1$$

$$V_{ramp}(t_2) = 0 = V_o - m\,t_2$$

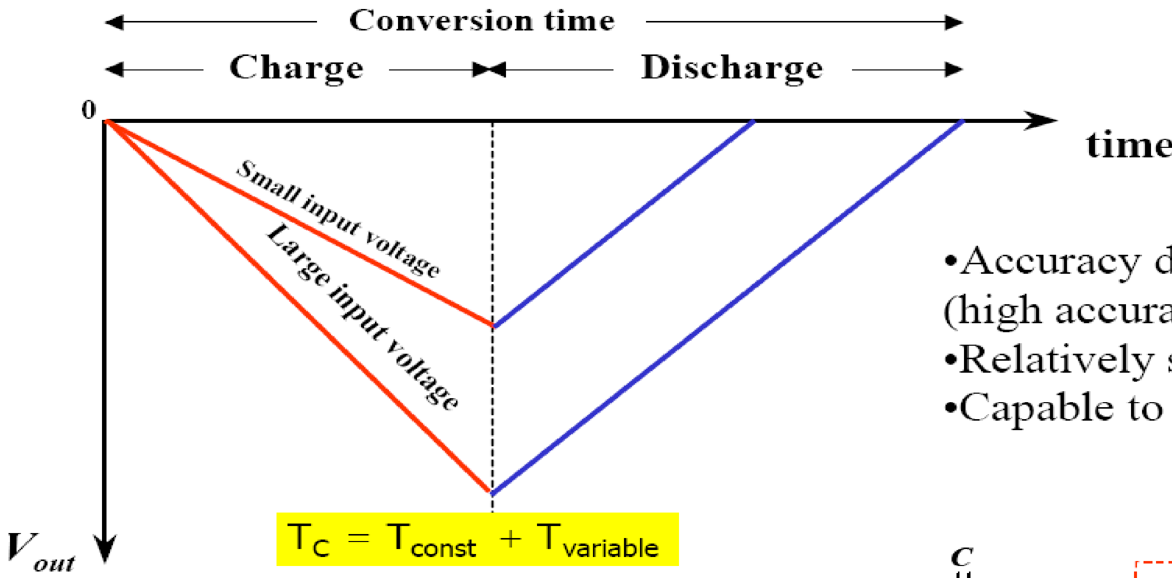
$$\Delta t = t_2 - t_1 = V_{in}/m$$

If the period of the clock is T, then during the time interval Δt_1, the number of pulses is

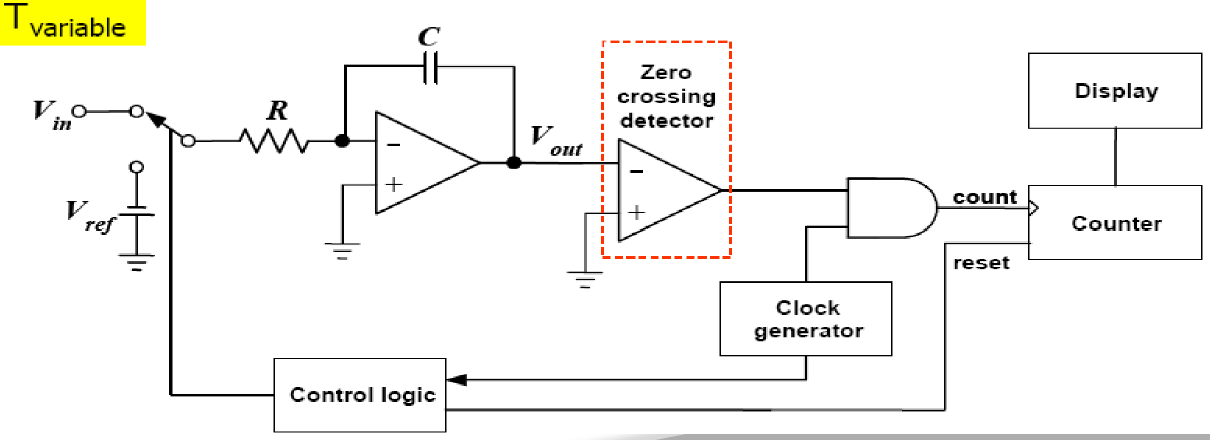
$$\Delta t \approx nT \text{ or } V_{in} \approx nmT$$

- Accuracy depends on both the ramp rate and clock period.

Dual-slope Digital Voltmeter

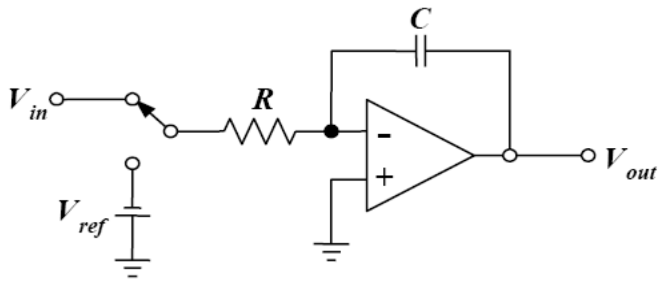


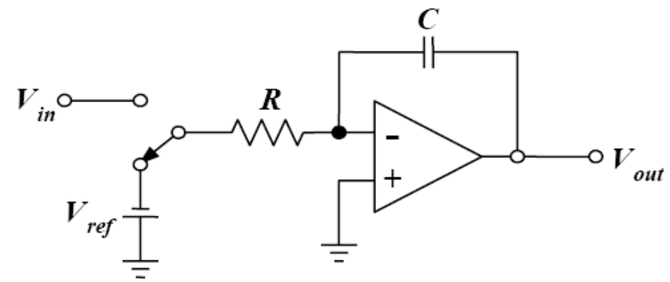
- Accuracy does not depend on ***R C*** and Clock (high accuracy)
- Relatively slow
- Capable to reject noise



$V_i = V_{ref} (T1 / T2)$

Dual-slope Digital Voltmeter





Phase 1: charging C with the unknown input for a given time.

Assume $V_c(0) = 0$

$$V_{out1} = -\frac{V_{in}T}{RC}$$

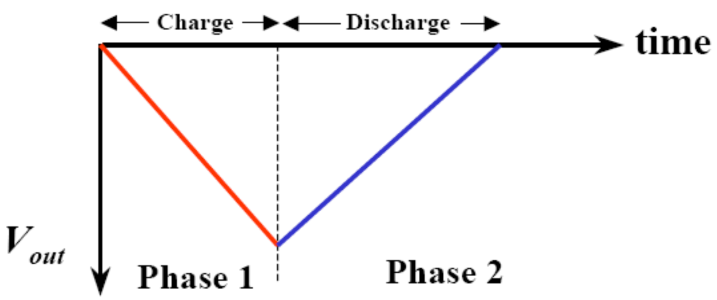
where T is the charging time

Phase 2: discharging C with the reference voltage until the output voltage goes to zero.

$$V_{out} = \frac{V_{ref}T_x}{RC} + V_{out1}$$

find T_x at which V_{out} becomes zero

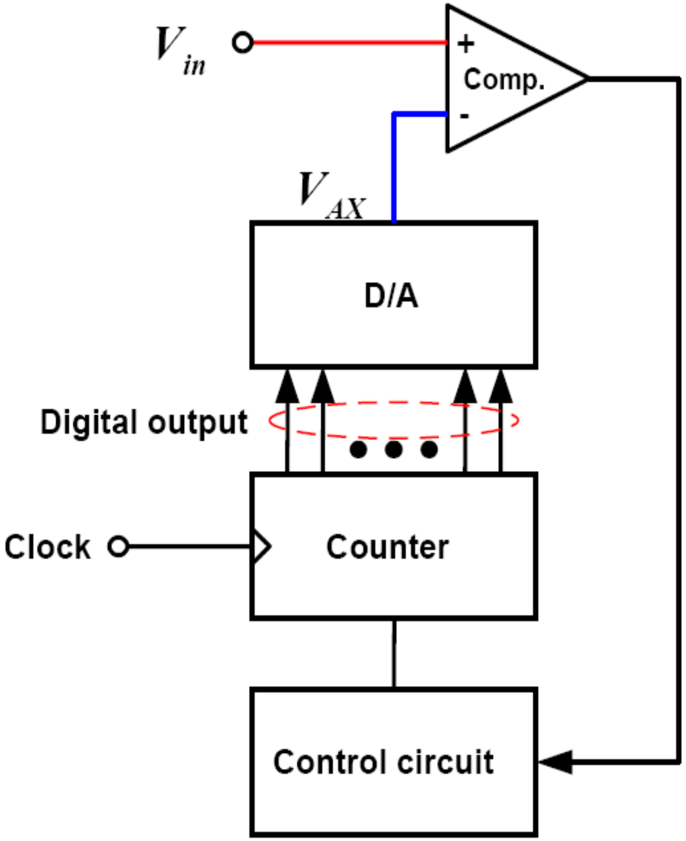
$$T_x = \frac{V_{in}T}{V_{ref}}$$



Staircase Ramp Digital Voltmeter

(also called digital ramp)

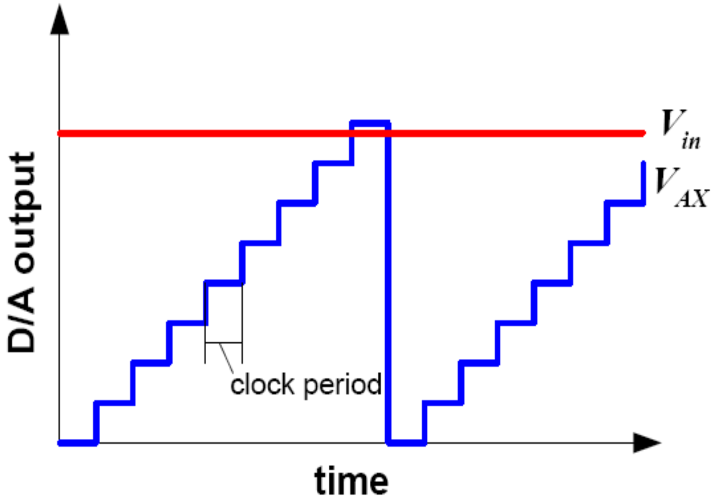
Compare the input voltage to the internally generated stair case ramp.



Block diagram

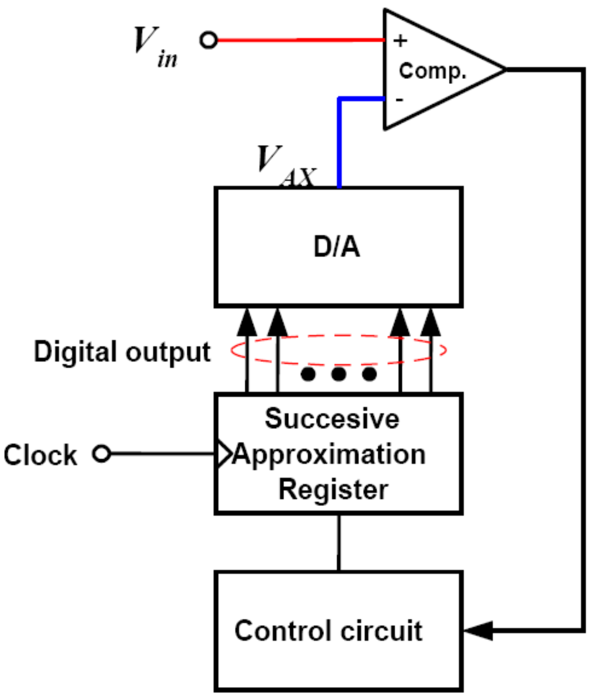
- The most simple A/D
- Slow conversion and conversion time depends on the magnitude of input signal.

$$T_{C,max} = (2^N - 1) \times \text{Clock period}$$



Successive Approximation Digital Voltmeter

Compare the input voltage to the internally generated voltage

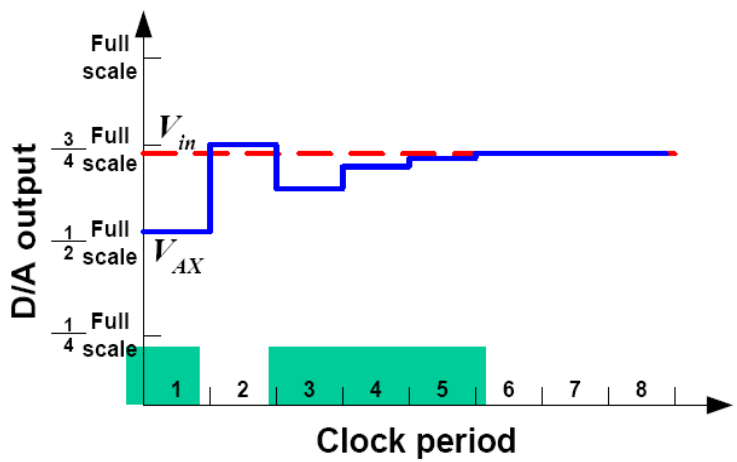


Block diagram

- The most common A/D for general applications
- Conversion time is fixed (not depend on the signal magnitude) and relatively fast

$$T_C = N \times \text{Clock period}$$

where N is the number of bits



Successive Approximation Digital Voltmeter

Ex. To determine a number between 0 – 511 (9 bit binary), given, the number to be determined is 301

No.	Estimate		Results
1	256	1 0000 0000	$V_{in} > V_{AX}$
2	256+128 = 384	1 1000 0000	<
3	256+64 = 320	1 0100 0000	<
4	256+32 = 288	1 0010 0000	>
5	288+16 = 304	1 0011 0000	<
6	288+8 = 296	1 0010 1000	>
7	296+4 = 300	1 0010 1100	>
8	300+2 = 302	1 0010 1110	<
9	300+1 = 301	1 0010 1101	Finished