

Electrical and Electronic Measurement (313334)

MSBTE K-Scheme · Electrical Engineering · Model Question Paper — Set C · Model Answers

Answers are written point-wise as expected in MSBTE model answers. Marks scheme lines in blue italics are indicative. All numerical values were calculated by program.

Q.1

a) Measurement; methods of measurement.

2 M

Measurement: the process of comparing an unknown quantity with a standard of the same kind and expressing the result as a number and unit.

Methods: (i) **Direct method** — the unknown quantity is directly compared with a standard or read on a calibrated instrument (e.g. ammeter, voltmeter, measuring length by scale). (ii) **Indirect method** — the quantity is found by measuring other related quantities and using a relation (e.g. power $P = V I \cos \phi$, resistance $R = V/I$). (Comparison methods such as null / bridge methods are also used.)

(Definition 1 M, two methods 1 M)

b) Define dead zone and static error.

2 M

i) **Dead zone:** It is the largest change of input quantity for which there is no output (response) of the instrument. It is caused by friction, backlash or hysteresis.

ii) **Static error:** It is the difference between the measured value and the true value of a quantity which does not vary with time. Static error $\delta A = A_m - A_t$ (measured – true). Static correction $\delta C = A_t - A_m = -\delta A$.

(1 M each)

c) Function of deflecting and damping torque.

2 M

Deflecting torque: produced by the quantity being measured; it deflects (moves) the pointer from its zero position in proportion to the measured quantity.

Damping torque: opposes the motion of the moving system only while it moves, so that the pointer settles quickly at its final position without oscillating (air friction / eddy current / fluid friction damping).

(1 M each)

d) Applications of function generator and CRO.

2 M

Function generator: (i) signal source for testing frequency response of amplifiers and filters; (ii) square wave source for testing digital circuits / pulse circuits.

CRO: (i) observation of waveforms and measurement of voltage (amplitude); (ii) measurement of frequency, time period and phase difference.

(½ M each)

e) Sensor vs transducer.

2 M

Sensor	Transducer
A sensor senses (detects) a physical quantity and gives a response.	A transducer converts energy from one form into another (usually into an electrical signal).
Its output may be non-electrical (e.g. displacement of Bourdon tube).	Its output is normally an electrical quantity (voltage, current, resistance).
Sensor is a part (first element) of the transducer.	Transducer = sensing element + conversion element.

(Any two points, 1 M each)

f) Classification of level measurement transducers.

2 M

- **Direct methods:** sight glass (gauge glass), float type, dip stick / hook type.
- **Indirect (hydrostatic) methods:** pressure gauge, differential pressure, bubbler (purge) method.
- **Electrical methods:** resistive (conductivity probe), inductive, capacitive.
- **Non-contact methods:** ultrasonic, radar (microwave), radiation (gamma ray), laser.

(2 M)

g) Classification of flow meters with examples.

2 M

- **Variable head (differential pressure) meters:** orifice meter, venturi meter, flow nozzle, pitot tube.
- **Variable area meters:** rotameter.
- **Positive displacement / mechanical:** nutating disc, turbine flow meter.
- **Electrical flow meters:** electromagnetic flow meter, ultrasonic flow meter, hot-wire anemometer.
- **Mass flow meters:** Coriolis and thermal flow meters.

(Any four types with example, ½ M each)

Q.2

a) CT and PT for range extension.

4 M

For AC circuits carrying large current or high voltage, low-range meters are used along with instrument transformers:

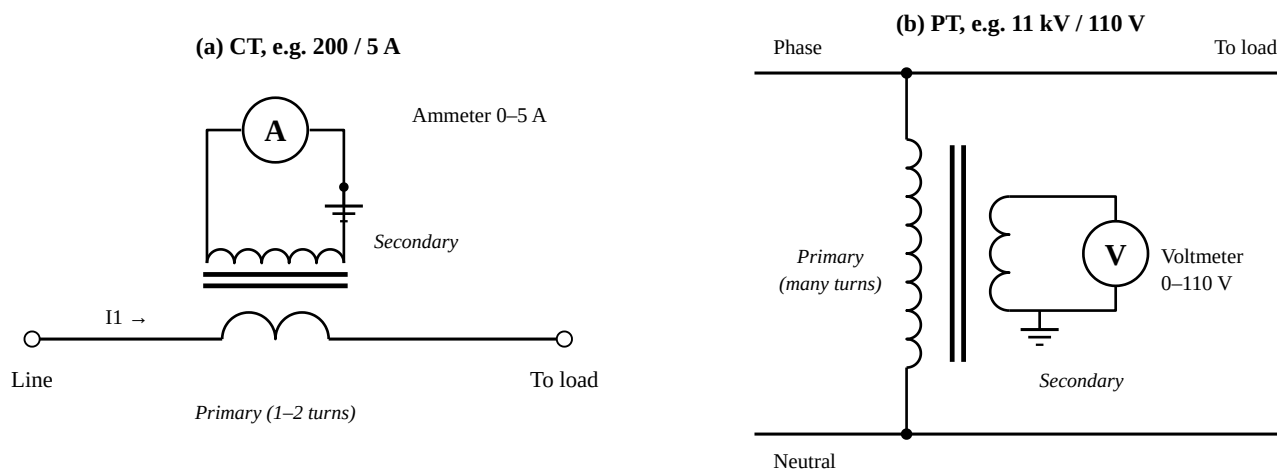


Fig.: Range extension of AC meters — (a) CT with ammeter (b) PT with voltmeter

(a) Current transformer (CT):

- Primary has one or a few turns and is connected in **series** with the line; secondary has many turns and is connected to a low-range ammeter (normally 5 A or 1 A).
- Line current = ammeter reading $\times$ CT ratio (e.g. 200/5 A: 3 A on the ammeter means 120 A in the line).
- Secondary of CT must **never be open-circuited** when primary is energised (dangerous high voltage and core saturation); it is short-circuited before removing the ammeter. One secondary terminal is earthed.

(b) Potential transformer (PT):

- Primary has many turns and is connected **across** (in parallel with) the high-voltage line; secondary (few turns) is connected to a voltmeter of normally 110 V range.
- Line voltage = voltmeter reading $\times$ PT ratio (e.g. 11 kV/110 V: 105 V reading means 10.5 kV).
- Secondary is earthed for safety; it works almost like a step-down transformer on no load.

Advantages: meters of standard low ranges can be used, the meter is isolated from the high-voltage line (safety), and power consumption is small.

(CT with diagram 2 M, PT with diagram 2 M)

b) Three phase digital energy meter.

4 M

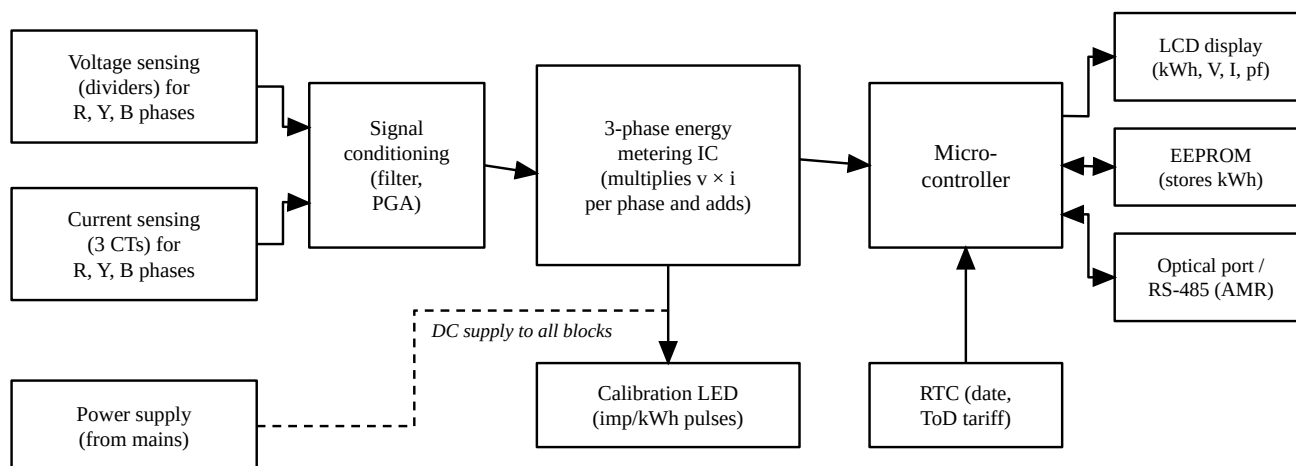


Fig.: Block diagram of three phase digital (static) energy meter

- **Voltage and current sensing:** Potential dividers sense the three phase voltages and three CTs (or shunts) sense the line currents of R, Y and B phases.
- **Signal conditioning:** Filters and programmable-gain amplifiers bring the signals to the input range of the ADCs.
- **3-phase energy metering IC:** Samples the voltage and current of each phase with ADCs, multiplies them ($p = v \times i$), adds the three phase powers and integrates to give kWh (also kVArh, kVAh, pf, maximum demand). It gives pulses proportional to energy to the calibration LED.
- **Microcontroller:** Reads the energy registers, stores data in EEPROM (non-volatile), controls the LCD (kWh, V, I, pf of each phase), RTC for ToD tariff, and optical port / RS-485 for automatic meter reading.
- No moving parts — accurate (class 0.5 / 1.0), tamper detection, low power consumption.

(Block diagram 2 M, working 2 M)

c) Working of CRO; need of delay line.

4 M

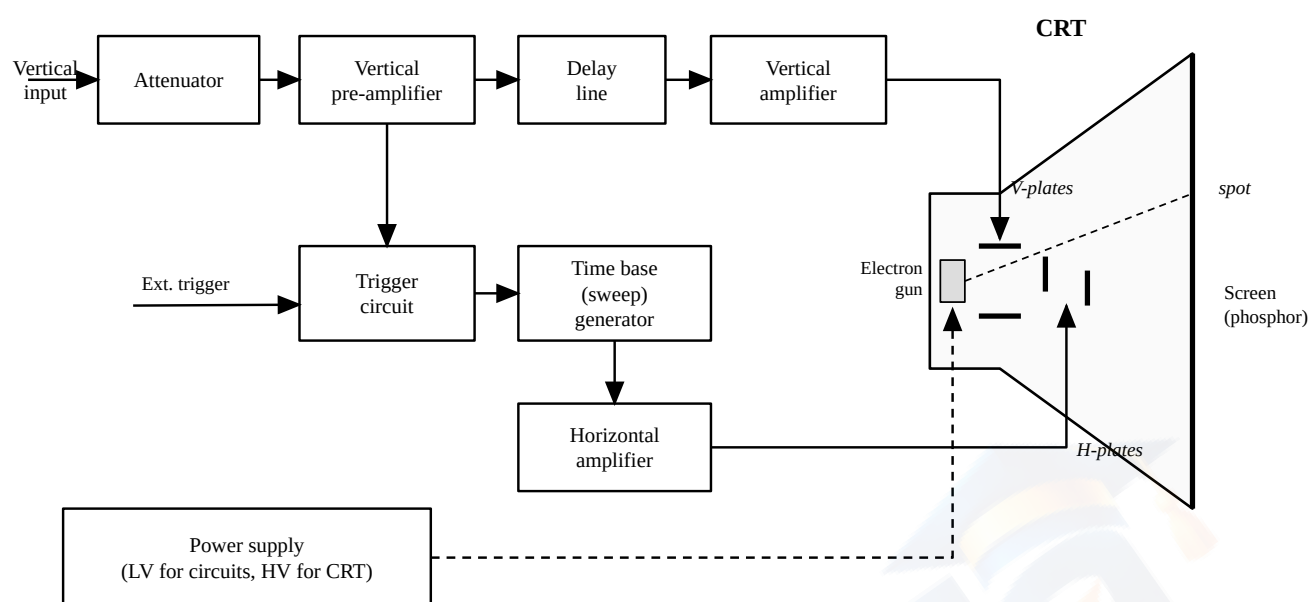


Fig.: Basic block diagram of CRO

Function of each block:

- 1. CRT (cathode ray tube):** Electron gun produces a focused beam of electrons; deflection plates deflect it; the beam strikes the phosphor-coated screen and produces a bright spot.
- 2. Attenuator:** Reduces the amplitude of large input signals (volts/div selector) so that the trace fits on the screen.
- 3. Vertical pre-amplifier and vertical amplifier:** Amplify weak input signals to a level sufficient to drive the vertical (Y) deflection plates.
- 4. Delay line:** Delays the signal ($\approx 0.2 \mu\text{s}$) reaching the vertical plates, so that the time base starts before the signal arrives and the leading edge of the waveform is displayed.
- 5. Trigger circuit:** Produces a trigger pulse from the input signal (or external / line source) to start the sweep at the same point of the waveform each time — gives a stable display.
- 6. Time base (sweep) generator:** Generates a sawtooth voltage that moves the spot from left to right at constant speed (time/div control) and quickly returns it (retrace).
- 7. Horizontal amplifier:** Amplifies the sweep voltage before applying it to the horizontal (X) deflection plates.
- 8. Power supply:** Gives high voltage (a few kV) for the CRT and low voltage for the amplifiers and other circuits.

(Block diagram 2 M, working 1 M, delay line 1 M)

Why delay line? The trigger circuit and time base take a short time ($\approx 80 \text{ ns}$) to start the sweep after receiving the signal. If the signal reached the vertical plates immediately, its leading edge would be lost. The delay line delays the signal ($\approx 200 \text{ ns}$) so that the sweep starts first and the complete waveform including its leading edge is displayed.

d) Piezoelectric transducer — classification with examples.

4 M

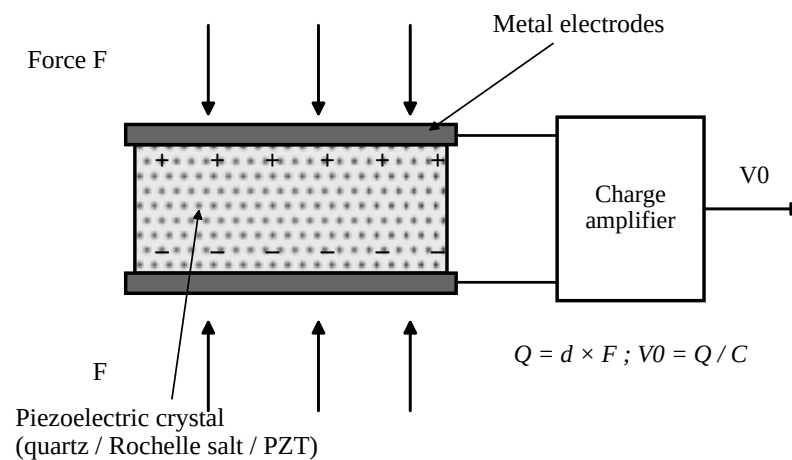


Fig.: Piezoelectric transducer — force applied on crystal produces charge on electrodes

Principle (piezoelectric effect): When mechanical stress or force is applied on certain crystals in a particular direction, an electric charge (and voltage) is produced across their faces. The charge $Q = d \times F$, where d is the charge sensitivity (e.g. quartz $\approx 2.3 \text{ pC/N}$). The effect is reversible.

Working:

- The crystal is placed between two metal electrodes. Force / pressure / acceleration to be measured is applied on the crystal.
- Due to deformation, positive and negative charges appear on opposite faces; the output voltage $V_0 = Q / C = d F / C$ (C = crystal capacitance).
- The output is very small and has high impedance, so a charge amplifier is used. Since charge leaks away, it is suitable for **dynamic** (changing) quantities, not for static measurement.

Classification and examples:

- **Natural crystals:** quartz, Rochelle salt, tourmaline.
- **Synthetic crystals:** lithium sulphate, ammonium dihydrogen phosphate (ADP).
- **Polarised ceramics:** barium titanate, lead zirconate titanate (PZT).

Applications: measurement of dynamic force, pressure and vibration (accelerometers), engine knock sensor, ultrasonic transducers, gas lighters, microphones and buzzers.

(Diagram and working 2 M, classification with examples 2 M)

Q.3

a) Classification of resistances; Wheatstone bridge numerical.

4 M

Class	Range	Methods of measurement
Low resistance	Below 1 Ω (armature windings, ammeter shunts, cables)	Kelvin double bridge, ammeter–voltmeter method, potentiometer method, micro-ohmmeter
Medium resistance	1 Ω to 100 k Ω (most apparatus)	Wheatstone bridge, ammeter–voltmeter method, substitution method, ohmmeter
High resistance	Above 100 k Ω (insulation resistance)	Megger (insulation tester) / digital megger, loss of charge method

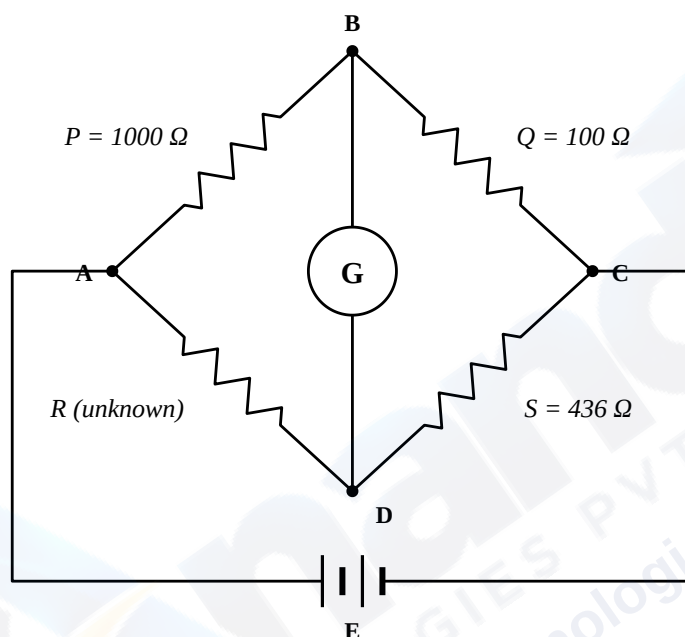


Fig.: Wheatstone bridge (balanced when galvanometer G shows zero)

At balance, no current flows through G: $P / Q = R / S$

$$R = (P / Q) \times S = (1000 / 100) \times 436 = \mathbf{4,360 \Omega}$$

(Classification 2 M, numerical 2 M)

b) Smart energy meter — working and advantages.

4 M

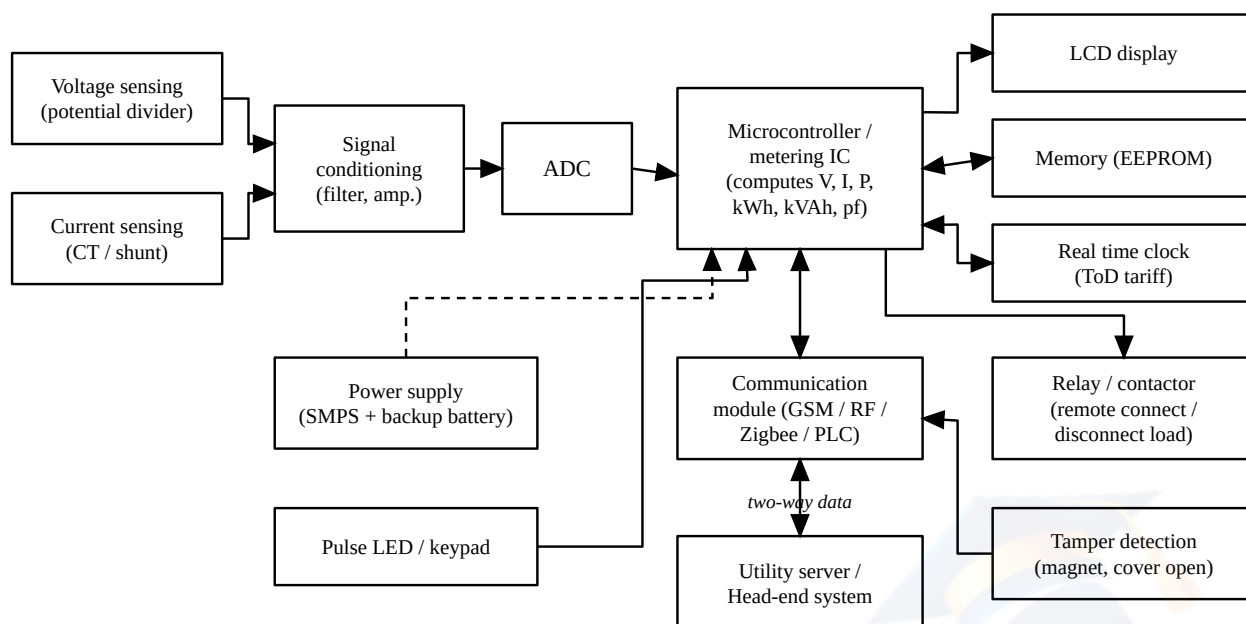


Fig.: Block diagram of smart energy meter

Working:

- Sensing:** A potential divider senses the supply voltage and a CT / shunt senses the load current; these give low-level signals proportional to v and i .
- Signal conditioning and ADC:** The signals are filtered and amplified and converted into digital samples by the ADC (in the metering IC).
- Microcontroller / metering IC:** Multiplies the samples of v and i and integrates them to compute kW, kWh, kVAh, kVArh, pf, maximum demand and load profile. Data is stored in EEPROM with date-time from the RTC (for time-of-day tariff).
- Display:** LCD shows cumulative energy, instantaneous parameters and tariff details.
- Two-way communication:** GSM / GPRS, RF mesh, Zigbee or PLC module sends readings to the utility server (AMI / head-end system) and receives commands such as tariff change, prepaid recharge, remote connect / disconnect (through the built-in relay).
- Tamper detection:** Detects magnet tamper, cover open, neutral missing, reverse current, and reports it to the utility.

Advantages / features:

- Automatic remote meter reading — no manual reading and billing errors.
- Prepaid and time-of-day (ToD) tariff possible; consumer can monitor usage on mobile app.
- Remote connection / disconnection, load limiting and outage detection.
- Tamper and theft detection; supports net metering for rooftop solar.

(Block diagram 2 M, working 2 M)

c) Procedure — earth resistance by digital earth tester.

4 M

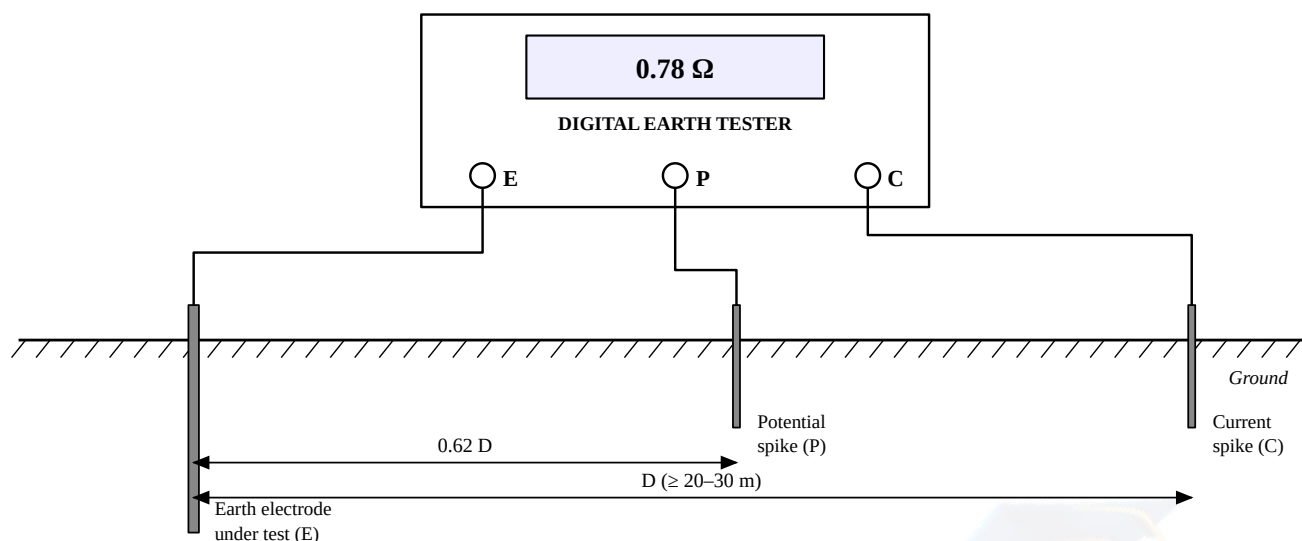


Fig.: Measurement of earth resistance by digital earth tester (three-terminal, fall of potential method)

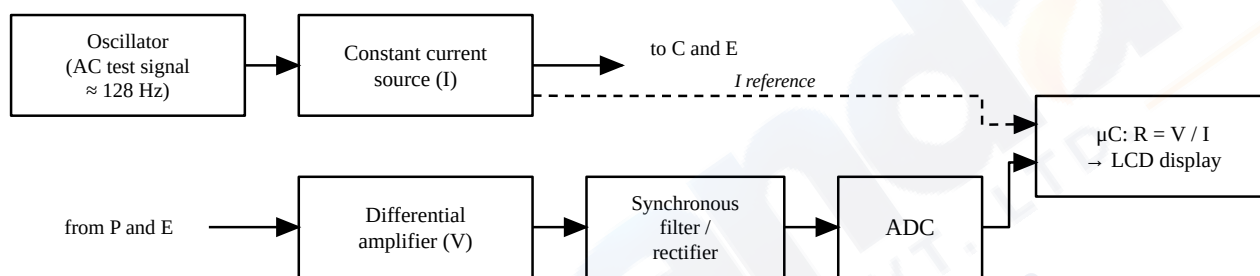


Fig.: Internal block diagram of digital earth tester

Principle (fall of potential method): The tester passes a known AC test current I between the earth electrode E and a current spike C , and measures the voltage V between E and a potential spike P . Earth resistance $R = V / I$ is displayed directly. AC of a frequency other than 50 Hz (e.g. ≈ 128 Hz) is used to avoid errors due to electrolytic polarisation, stray earth currents and supply-frequency interference.

Procedure:

1. Disconnect the earth electrode under test from the installation earthing conductor.
2. Drive the current spike C into the ground in a straight line at a distance D of about 20–30 m (more for large earth grids) from the electrode E .
3. Drive the potential spike P in the same line at 62 % of D from E (outside the resistance areas of E and C).
4. Connect terminal E (and $P1/C1$ shorted in 4-terminal testers) to the earth electrode, P to the potential spike and C to the current spike using test leads.
5. Select the range and press TEST; note the earth resistance shown on the display.
6. Shift P by about ± 10 % of D (≈ 52 % and 72 %) and repeat; if the readings are nearly the same, take their average as the earth resistance. Otherwise increase D .

7. Compare with permissible value (e.g. about $1\ \Omega$ or less for substations, a few ohms for domestic installations); reconnect the electrode.

(Diagram 2 M, procedure / working 2–4 M)

d) Capacitive level measurement; expression for capacitance.

4 M

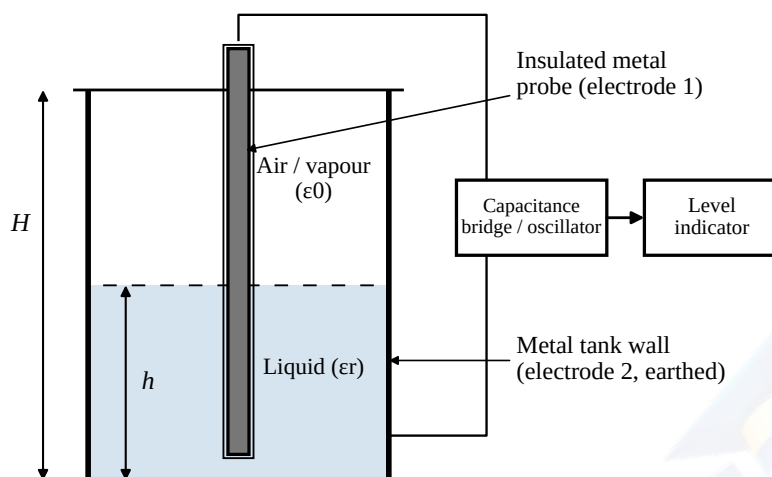


Fig.: Capacitive level measurement (insulated probe and metal tank wall form a cylindrical capacitor)

- **Principle:** Capacitance between two electrodes $C = \epsilon A / d$ depends on the dielectric between them. A liquid has a higher dielectric constant (ϵ_r) than air, so capacitance increases as level rises.
- **Construction:** An insulated metal rod (probe) is fixed vertically in the tank; the metal tank wall (or a concentric outer tube) forms the second electrode. Both are connected to a capacitance measuring circuit (AC bridge or oscillator).
- **Working:** The lower part of the probe is surrounded by liquid (ϵ_r) and the upper part by air / vapour. As level h rises, the total capacitance increases linearly. The bridge output is calibrated in level.
- For **conducting liquids** (water) the probe is insulated (PTFE coating); the insulation is the dielectric and the liquid acts as the other plate. For **non-conducting liquids** (oil) a bare probe can be used and the liquid itself is the dielectric.

For a probe of radius a in a cylindrical tank of radius b and height H : $C = 2\pi \epsilon_0 [\epsilon_r h + (H - h)] / \ln(b/a)$, i.e. C increases linearly with level h .

Advantages: no moving parts, suitable for liquids, slurries and powders, continuous measurement.

Limitation: affected by change in dielectric constant (temperature / composition) and coating on probe.

(Diagram 1 M, working 2 M, expression 1 M)

Q.4

a) Analog vs digital instruments.

4 M

Analog instrument	Digital instrument
Output is shown by deflection of a pointer on a graduated scale.	Output is shown directly in numerical digits (LCD / LED).
Accuracy is lower (± 1 to ± 3 % of full scale).	Accuracy is higher (± 0.05 to ± 0.5 % of reading).
Parallax and reading errors are possible.	No parallax / human reading error.
Input impedance is low — more loading effect.	Input impedance is high ($\approx 10 \text{ M}\Omega$) — negligible loading.
Usually no external power supply needed (PMMC, MI).	Needs battery / power supply.

(Any four points, 1 M each)

b) Multiplying factor numerical (10 A, 300 V, 150 div, 750 W).

4 M

Multiplying factor (MF) of wattmeter: When a wattmeter is used on ranges different from those for which its dial is calibrated, the reading on the dial must be multiplied by a constant to get the actual power. This constant is called the multiplying factor.

MF = (Pressure coil range $\times$ Current coil range $\times$ rated pf) / Full scale reading of dial ; Actual power = Dial reading $\times$ MF.

$$(i) \text{ MF} = (\text{PC range} \times \text{CC range}) / \text{Full scale reading} = (300 \times 10) / 750 = 4$$

$$\text{Dial constant} = 750 \text{ W} / 150 \text{ div} = 5 \text{ W per division}$$

$$(ii) \text{ Dial reading for 96 divisions} = 96 \times 5 = 480 \text{ W}$$

$$\text{Actual power} = \text{Dial reading} \times \text{MF} = 480 \times 4 = \mathbf{1,920 \text{ W}} \quad (\text{i.e. } 20 \text{ W per division})$$

(MF 2 M, actual power 2 M)

c) Instrument for synchronisation — synchroscope.

4 M

The instrument used to check the synchronisation of an incoming alternator with the bus-bars is the **synchroscope**. It shows whether the incoming machine is running fast or slow and the instant when it is in phase with the bus-bars.

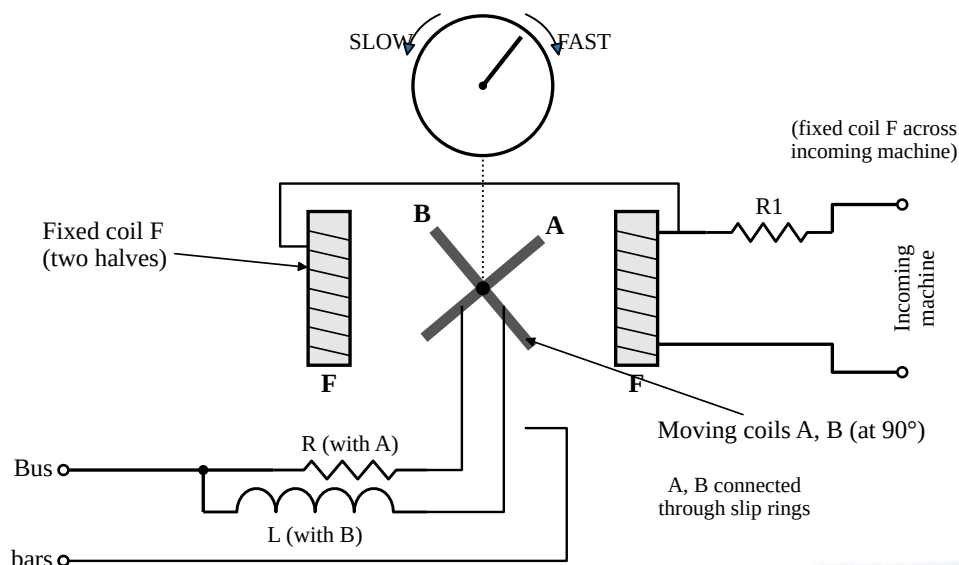


Fig.: Electro-dynamometer type synchroscope — coil arrangement and connections

Construction (electro-dynamometer type):

- A fixed coil F (in two halves) is connected across two lines of the incoming machine through a resistance.
- The moving system has two coils A and B fixed at 90° to each other on the same spindle; A is in series with a resistance R and B in series with an inductance L, both connected across the corresponding bus-bars. Thus currents in A and B are nearly 90° out of phase and produce a rotating field.
- The moving coils are fed through slip rings so that the pointer can rotate continuously; there is no controlling spring. The dial is marked FAST (clockwise) and SLOW (anticlockwise).

Working: The pointer takes up the position where the phase angle between the bus-bar voltage and incoming voltage is reflected. If the frequencies are different, the phase angle continuously changes and the pointer rotates at the **slip (difference) frequency**: clockwise (FAST) if the incoming frequency is higher, anticlockwise (SLOW) if lower. When frequencies are equal and the voltages are in phase, the pointer stands still at the vertical (zero / in-phase) mark — at this instant the synchronising switch is closed.

(Diagram 2–3 M, working 2–3 M)

d) LVDT for displacement with output characteristic.

4 M

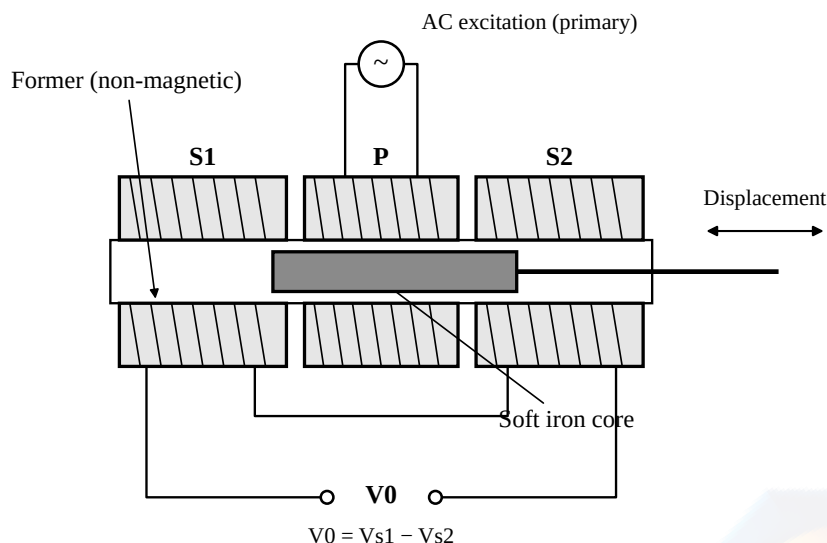


Fig.: Construction and circuit of LVDT (S1, S2 in series opposition: $V_0 = V_{s1} - V_{s2}$)

Construction:

- LVDT (Linear Variable Differential Transformer) has one **primary winding P** at the centre and two identical **secondary windings S1 and S2** on either side, wound on a hollow non-magnetic former.
- A movable **soft iron core** slides inside the former and is attached through a non-magnetic rod to the object whose displacement is to be measured.
- S1 and S2 are connected in **series opposition**, so the output $V_0 = V_{s1} - V_{s2}$.

Working:

- Primary is excited by AC (typically 1–10 kHz). EMFs V_{s1} and V_{s2} are induced in the secondaries by mutual induction.
- **Null position:** core at centre, flux linking S1 = flux linking S2, $V_{s1} = V_{s2}$, so $V_0 = 0$.
- Core moved towards S1: $V_{s1} > V_{s2}$, $V_0 = V_{s1} - V_{s2}$ is positive (in phase with primary).
- Core moved towards S2: $V_{s2} > V_{s1}$, V_0 is negative (180° out of phase).
- Magnitude of V_0 is proportional to displacement (in the linear range) and its phase shows the direction.

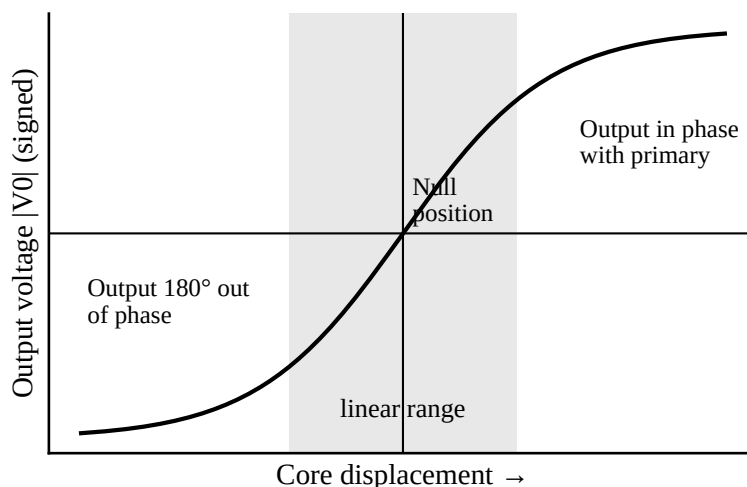


Fig.: Output characteristic of LVDT (computed ideal model: linear range with saturation at ends)

(Diagram 1 M, working 2 M, characteristic 1 M)

e) Radiation type level measurement.

4 M

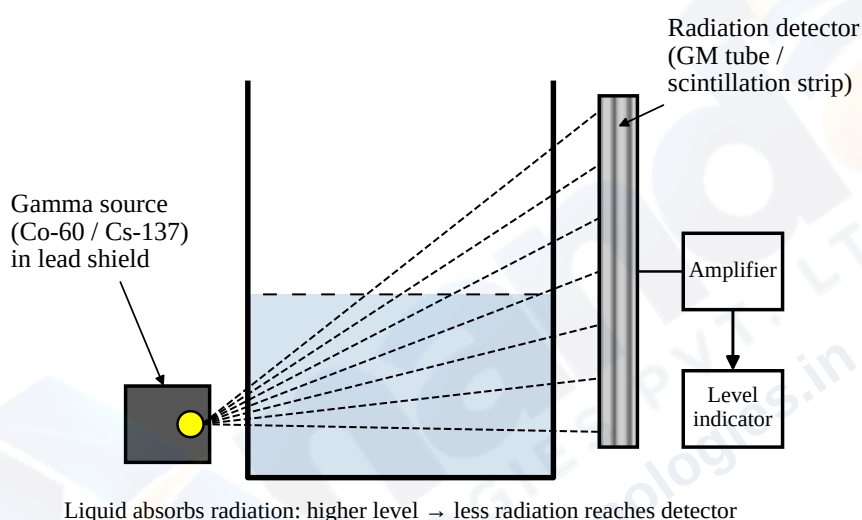


Fig.: Radiation (gamma ray) type level measurement — continuous method

- **Principle:** Gamma rays are absorbed when they pass through a material; the intensity reaching the detector is $I = I_0 e^{-\mu x}$, where x is the thickness of material in the path.
- **Construction:** A radioactive gamma source (Cobalt-60 or Caesium-137) in a lead-shielded container is fixed outside the tank on one side; a detector (GM tube, ionisation chamber or scintillation counter) is fixed on the opposite side.
- **Working:** When the level is low, most radiation reaches the detector; as level rises, more radiation is absorbed by the liquid and detector output falls. The detector output is amplified and the indicator is calibrated in level. A point source with a point detector gives on/off (point level) control; a strip detector gives continuous level.
- **Advantages:** fully non-contact — mounted outside the vessel, so used for corrosive, toxic, very hot, high-pressure liquids and solids. **Disadvantages:** radiation hazard, costly, licence / safety regulations needed.

(Diagram 2 M, explanation 2 M)

Q.5

a) Two wattmeter method — delta load; effect of pf; numerical.

6 M

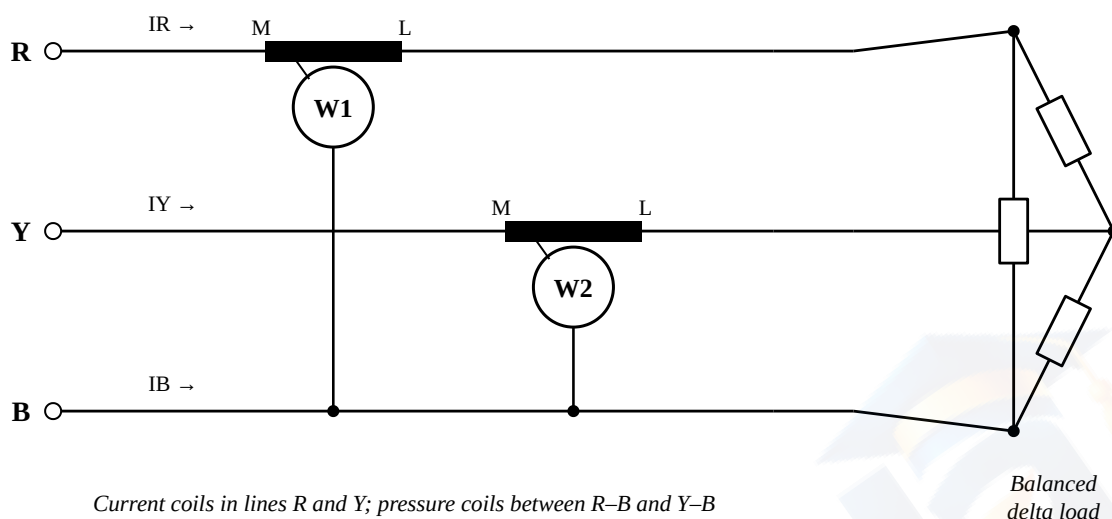


Fig.: Two wattmeter method — connection diagram for 3-phase, 3-wire balanced delta connected load

Connection: Current coils of W1 and W2 are connected in lines R and Y; pressure coil of W1 is connected between R and B and that of W2 between Y and B (the line without current coil). The sum of the two readings gives total 3-phase power for any balanced or unbalanced 3-wire load.

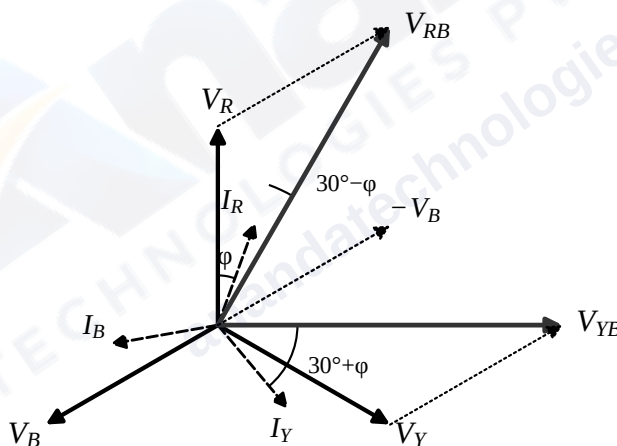


Fig.: Phasor diagram for two wattmeter method (balanced lagging load, $\phi = 20^\circ$ drawn)

For a delta load, the same phasor diagram applies using the equivalent star phase voltages and the line currents, so the result is identical.

Proof (balanced lagging load, phase angle ϕ): From the phasor diagram, the voltage across PC of W1 is $V_{RB} = V_R - V_B = V_L$, and the angle between V_{RB} and I_R is $(30^\circ - \phi)$. For W2, the angle between V_{YB} and I_Y is $(30^\circ + \phi)$.

$$W1 = V_L I_L \cos(30^\circ - \phi)$$

$$W2 = V_L I_L \cos(30^\circ + \phi)$$

$$W1 + W2 = V_L I_L [\cos(30^\circ - \phi) + \cos(30^\circ + \phi)] = V_L I_L (2 \cos 30^\circ \cos \phi) = \sqrt{3} V_L I_L \cos \phi = P$$

(total power)

$$\text{Also } W1 - W2 = V_L I_L \sin \phi \Rightarrow \tan \phi = \sqrt{3} (W1 - W2)/(W1 + W2)$$

Effect of power factor on the readings (values computed for $V_L I_L = 1$):

pf	ϕ	$W1 = \cos(30^\circ - \phi)$	$W2 = \cos(30^\circ + \phi)$	Remark
1	0.0°	0.866	0.866	Both readings equal and positive
0.866	30.0°	1	0.5	$W1 = 2 W2$
0.5	60.0°	0.866	0	$W2 = 0$; total power = $W1$
0.3	72.5°	0.737	-0.217	$W2$ negative — reverse its current coil (or PC) connection and subtract
0	90.0°	0.5	-0.5	$W1 = -W2$; total power = 0

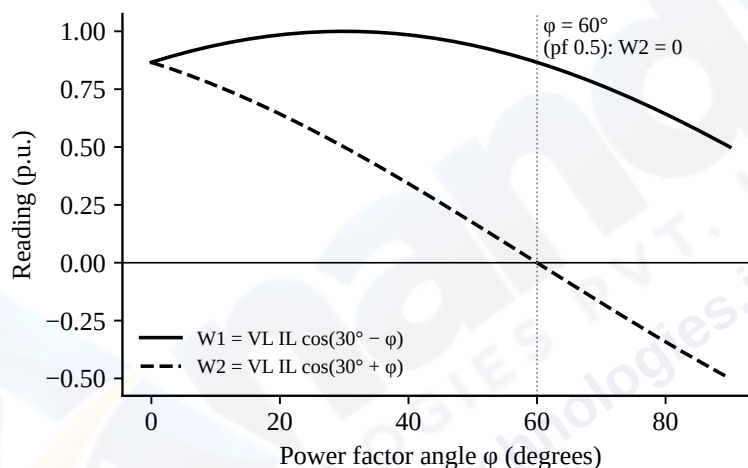


Fig.: Variation of wattmeter readings $W1$, $W2$ with power factor angle (computed for $V_L I_L = 1$)

Numerical: $W1 = 5 \text{ kW}$, $W2 = -1 \text{ kW}$

$$\text{Total power } P = W1 + W2 = 5 + (-1) = 4 \text{ kW}$$

$$\tan \phi = \sqrt{3} (W1 - W2)/(W1 + W2) = \sqrt{3} \times 6 / 4 = 2.5981 \Rightarrow \phi = 68.95^\circ$$

Power factor = $\cos \phi = 0.359$ (**lagging**) — less than 0.5, which is why one reading is negative.

(Diagram 2 M, effect of pf 2 M, numerical 2 M)

b) Digital storage oscilloscope — block diagram.

6 M

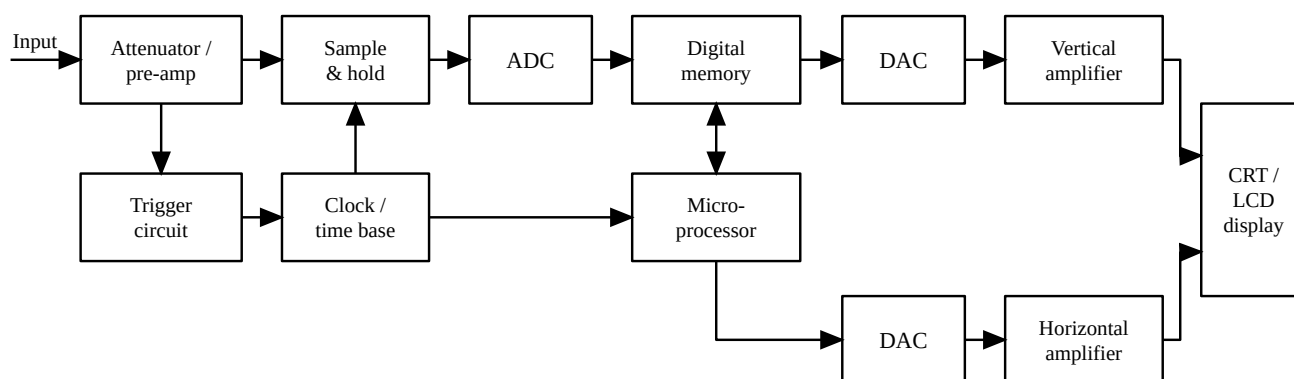


Fig.: Basic block diagram of digital storage oscilloscope (DSO)

1. **Attenuator / pre-amplifier:** scales the input signal to a suitable level.
2. **Sample and hold + ADC:** the analog signal is sampled at regular intervals (set by the clock) and each sample is converted into a digital word.
3. **Digital memory:** stores the digitised samples; the waveform can be stored for a long time, recalled, compared and transferred to a computer.
4. **Microprocessor (control):** controls acquisition, triggering, measurements (frequency, V_{pp} , rise time) and display.
5. **DAC and vertical amplifier:** stored data is converted back to analog and drives the vertical deflection / LCD display.
6. **Clock / time base and horizontal DAC + amplifier:** generate the time axis (horizontal sweep) in step with memory read-out.
7. **Trigger circuit:** starts acquisition at a selected point; pre-trigger viewing is possible.

Advantages: storage of single-shot / transient events, no flicker for slow signals, automatic measurements, interfacing with PC / printer.

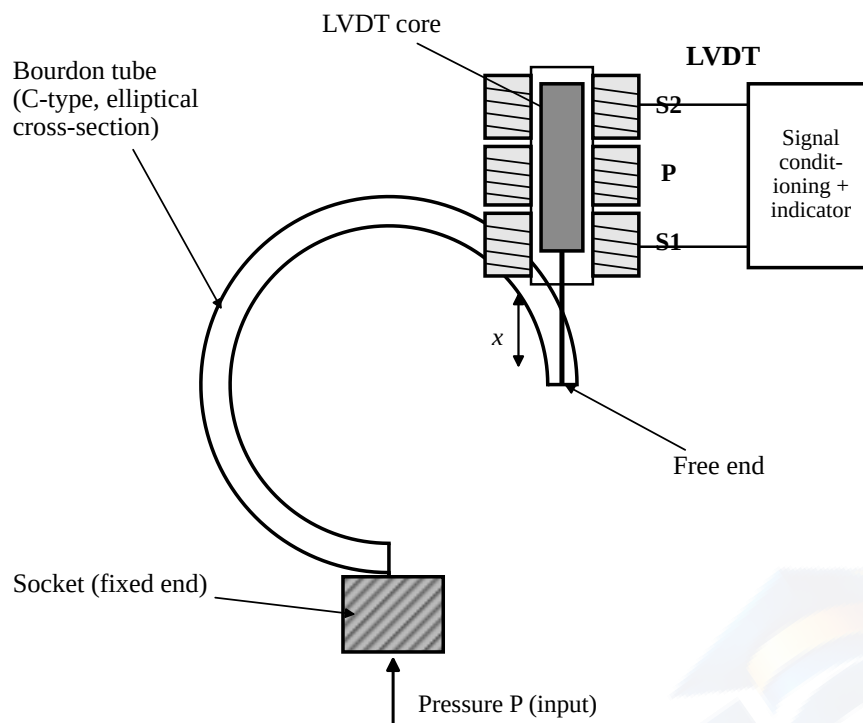
(Block diagram 3 M, functions 3 M)

c) Pressure and its types; Bourdon tube with LVDT.

6 M

Pressure: Force acting per unit area, $P = F/A$. Units: N/m^2 (pascal), bar (10^5 Pa), kg/cm^2 , psi, mm of Hg, atm.

- **Atmospheric pressure:** pressure exerted by air (≈ 1.013 bar).
- **Absolute pressure:** pressure measured with respect to perfect vacuum.
- **Gauge pressure:** pressure above atmospheric ($P_{abs} = P_{atm} + P_{gauge}$).
- **Vacuum:** pressure below atmospheric ($P_{vac} = P_{atm} - P_{abs}$).



$P \uparrow \rightarrow$ tube tends to straighten $\rightarrow$ free end and core move ($x \propto P$) $\rightarrow V_0 \propto P$

Fig.: Bourdon tube with LVDT as secondary transducer for pressure measurement

- **Primary transducer — Bourdon tube:** a C-shaped tube of elliptical cross-section made of phosphor bronze / brass / stainless steel; one end is fixed in the socket through which pressure is applied, the other end is closed and free.
- **Secondary transducer — LVDT:** the core of the LVDT is attached to the free end of the Bourdon tube; the primary is excited by AC and the secondaries are connected in series opposition.
- **Working:** when pressure is applied, the elliptical section tends to become circular and the tube tends to straighten; the free end moves by a distance x proportional to pressure.
- This moves the LVDT core from its null position, so the differential output voltage $V_0 = V_{s1} - V_{s2} \propto x \propto P$.
- The output is rectified (phase-sensitive) and amplified and displayed on a meter calibrated directly in pressure units (bar / kg/cm²); it can also be transmitted to a remote place.
- Advantages: electrical output for remote indication / recording, good linearity, no friction. Used up to several hundred bar.

(Definition and types 2 M, diagram 2 M, working 2 M)

Q.6

a) Reactive power by one wattmeter method — delta load; numerical.

6 M

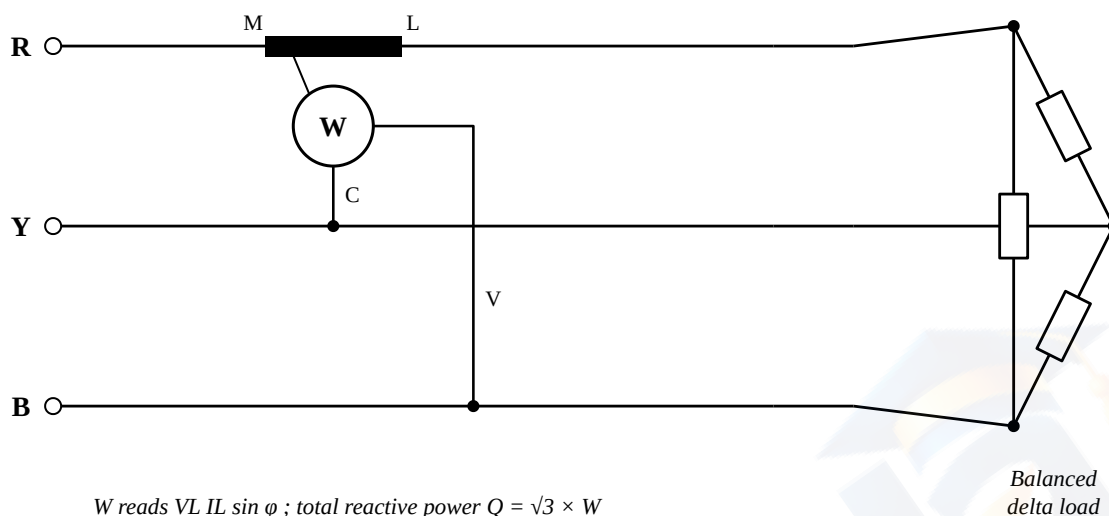


Fig.: Measurement of reactive power by one wattmeter method (current coil in R, pressure coil across Y-B), balanced delta load

- The current coil is connected in line R and the pressure coil across the other two lines Y and B.
- From the phasor diagram, the voltage across the pressure coil $V_{YB} = V_L$ and the angle between V_{YB} and I_R is $(90^\circ - \phi)$.
- Wattmeter reading $W = V_{YB} I_R \cos(90^\circ - \phi) = V_L I_L \sin \phi$.
- Total reactive power of a balanced load $Q = \sqrt{3} V_L I_L \sin \phi = \sqrt{3} \times W$ (VAr). The method is valid only for balanced loads.

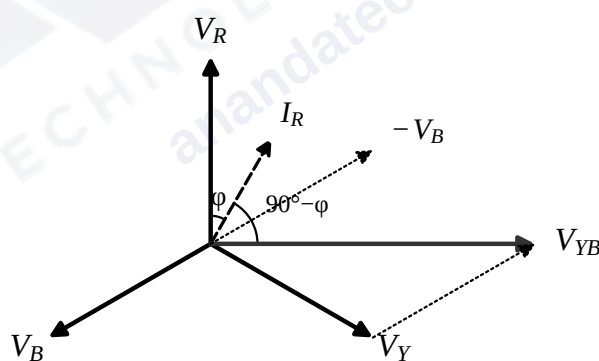


Fig.: Phasor diagram for one wattmeter method of reactive power ($\phi = 30^\circ$ shown)

Numerical: $V_L = 400$ V, $I_L = 10$ A, $\cos \phi = 0.6$ lag

$$\sin \phi = \sqrt{1 - 0.6^2} = 0.8$$

$$\text{Wattmeter reading } W = V_L I_L \sin \phi = 400 \times 10 \times 0.8 = \mathbf{3,200 \text{ W}}$$

$$\text{Total reactive power } Q = \sqrt{3} \times W = \sqrt{3} \times 3,200 = \mathbf{5,542.6 \text{ VAr} \approx 5.54 \text{ kVAr}}$$

(Circuit 1 M, phasor 1 M, explanation 2 M, numerical 2 M)

b) Electromagnetic flow meter; not for petroleum products.

6 M

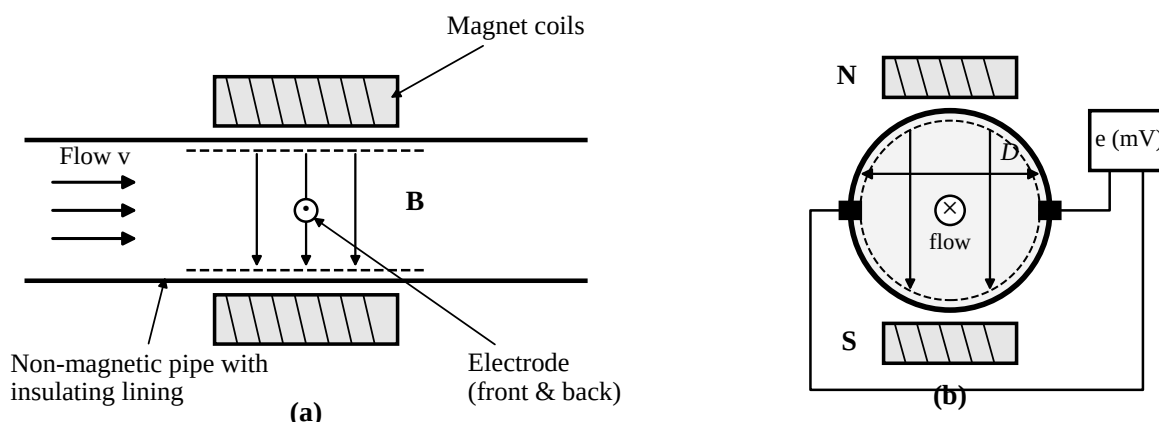


Fig.: Electromagnetic flow meter — (a) side view (b) cross-section; $e = B D v$

- **Principle:** Faraday's law — when a conductor moves through a magnetic field, an emf is induced in it. Here the conducting liquid flowing through the pipe acts as the moving conductor: $e = B D v$ (B = flux density, D = pipe diameter = length of conductor, v = average velocity).
- **Construction:** A non-magnetic pipe (stainless steel) lined with insulating material (rubber, PTFE) is placed between the poles of an electromagnet (coils fixed above and below the pipe). Two electrodes are fitted flush with the inner wall, diametrically opposite, at right angles to the magnetic field.
- **Working:** The liquid flowing across the field induces emf e between the electrodes. Since D and B are constant, $e \propto v$. Volume flow rate $Q = (\pi D^2/4) v$, so $Q = \pi D e / (4 B)$, i.e. $e \propto Q$. The emf (millivolts) is amplified by the signal converter and indicated as flow rate. AC or pulsed DC excitation is used to avoid polarisation of electrodes.
- **Advantages:** no obstruction and no pressure drop, linear output, bidirectional, unaffected by viscosity, density and temperature, suitable for slurries and corrosive liquids.

Applications: water supply and sewage treatment, slurries, paper pulp, acids and chemicals, milk and food industry, blood flow measurement.

Limitation: works only for liquids having some minimum electrical conductivity ($\approx 5 \mu\text{S/cm}$). It cannot be used for gases, petroleum products / oils and de-ionised water because they are non-conducting and no emf is developed. It is also costly and heavy for large sizes.

(Diagram 2 M, construction and working 3 M, reason 1 M)

c) Units of temperature; RTD; Pt-100 numerical.

6 M

Units of temperature: kelvin (K, SI unit), degree Celsius ($^{\circ}\text{C}$), degree Fahrenheit ($^{\circ}\text{F}$), degree Rankine ($^{\circ}\text{R}$).

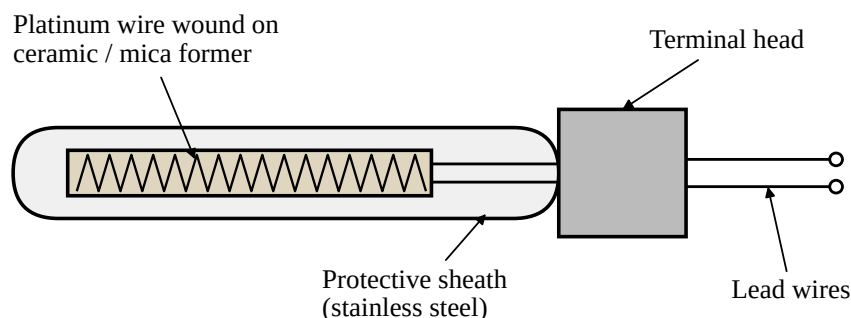


Fig.: Construction of platinum RTD (resistance temperature detector)

- **Principle:** Resistance of a metal increases with temperature: $R_t = R_0 (1 + \alpha t)$, where R_0 is resistance at 0°C and α is the temperature coefficient (platinum: $\alpha = 0.00385 / ^\circ\text{C}$).
- **Construction:** A fine platinum (or nickel / copper) wire is wound in non-inductive (bifilar) form on a ceramic or mica former and enclosed in a protective stainless steel sheath; lead wires are taken out to a terminal head. Pt-100 ($100\ \Omega$ at 0°C) is the most common.
- **Working:** The RTD is placed in the medium; its resistance changes with temperature. The RTD forms one arm of a Wheatstone bridge; the unbalance voltage is proportional to the change in resistance and the meter is calibrated in $^\circ\text{C}$. Three-wire connection compensates lead resistance.

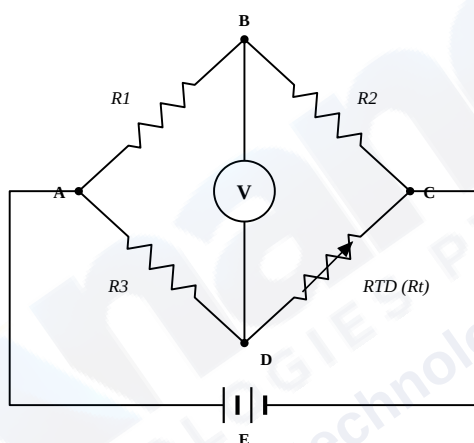


Fig.: RTD in bridge circuit (V calibrated in $^\circ\text{C}$)

Advantages: high accuracy and stability, nearly linear characteristic, wide range (platinum -200°C to about 650°C), suitable for remote indication. **Applications:** winding and bearing temperature of transformers, motors and generators, food processing, pharmaceutical and chemical plants, air-conditioning.

Numerical (linear approximation $R_t = R_0 (1 + \alpha t)$):

At 100°C : $R_t = 100 (1 + 0.00385 \times 100) = 138.5\ \Omega$

For $R_t = 119.25\ \Omega$: $t = (R_t/R_0 - 1)/\alpha = (1.1925 - 1)/0.00385 = 50^\circ\text{C}$

(Units 1 M, diagram and working 3 M, numerical 2 M)

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