

Electrical and Electronic Measurement (313334)

MSBTE K-Scheme · Electrical Engineering · Model Question Paper — Set A · 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) Define measurement; significance.

2 M

Measurement: Measurement is the process of comparing an unknown quantity with a predefined standard of the same kind, the result being expressed as a number with a unit (e.g. 230 V, 5 A).

Significance of measurement:

- It gives the exact numerical value of a quantity, which is needed to design, test and operate electrical equipment.
- Monitoring of processes and systems (voltage, current, power, energy, temperature) for safe operation.
- Control of processes — automatic control systems need measured values as feedback.
- Billing and commercial transactions (energy meters), quality control and testing, research and development.

(Definition 1 M, any two points of significance 1 M)

b) Define accuracy and sensitivity.

2 M

i) **Accuracy:** It is the closeness (degree of agreement) of the measured value to the true value of the quantity. Usually expressed as % of full scale, e.g. $\pm 1\%$.

ii) **Sensitivity:** It is the ratio of change in output (response) of the instrument to the change in input (measured quantity). Sensitivity = $\Delta \text{output} / \Delta \text{input}$, e.g. degrees per mA.

(1 M each)

c) Multiplying factor of wattmeter (250 V, 5 A, 500 W scale).

2 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 × Current coil range × rated pf) / Full scale reading of dial ; Actual power = Dial reading × MF.

$$\text{MF} = (\text{V} \times \text{I}) / \text{Full scale reading} = (250 \times 5) / 500 = 2.5$$

$$\text{Actual power} = \text{Dial reading} \times \text{MF} = 160 \times 2.5 = 400 \text{ W}$$

(Formula 1 M, answer 1 M)

d) Advantages of digital measuring instruments.

2 M

1. High accuracy and resolution; reading is shown directly in digits.
2. No parallax or human reading error.

3. High input impedance, so negligible loading of the circuit.
4. Automatic range selection, polarity indication and zero adjustment.

(Any four, $\frac{1}{2}$ M each)

e) Define sensor and transducer with examples.

2 M

Sensor: A device which detects (senses) a physical quantity such as temperature, pressure or displacement and gives a measurable response. Example: Bourdon tube, bimetallic strip.

Transducer: A device which converts one form of energy (physical quantity) into another form, generally into an electrical signal. Example: thermocouple, LVDT, strain gauge.

(Each definition with example 1 M)

f) Classification of level measurement methods.

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.

(Any four methods / groups 2 M)

g) Define temperature; units.

2 M

Temperature: Temperature is the degree of hotness or coldness of a body. It is the property which decides the direction of heat flow — heat flows from a body at higher temperature to a body at lower temperature (it is a measure of average kinetic energy of molecules).

Units: Kelvin (K) — SI unit; degree Celsius ($^{\circ}\text{C}$); degree Fahrenheit ($^{\circ}\text{F}$); degree Rankine ($^{\circ}\text{R}$).
 $T(\text{K}) = t(^{\circ}\text{C}) + 273.15$

(Definition 1 M, two units 1 M)

Q.2

a) Deflecting, controlling and damping torques.

4 M

For satisfactory working of an indicating instrument, three torques are needed:

1. **Deflecting torque (T_d):** Produced by the effect of the quantity being measured (magnetic, heating, electrostatic, induction effect). It moves the pointer from its zero position. In PMMC, $T_d = B A N I$.
2. **Controlling torque (T_c):** Opposes the deflecting torque and increases with deflection, so that the pointer stops at a definite position where $T_c = T_d$; it also brings the pointer back to zero when the quantity is removed. Methods: *spring control* ($T_c = K\theta$, uniform scale) and *gravity control* ($T_c = W l \sin \theta$).
3. **Damping torque:** Acts only while the moving system is moving and opposes the motion, so that the pointer comes to rest quickly at its final position without oscillations. Methods: air friction damping, eddy current damping, fluid friction damping. Instruments are normally made slightly under-damped (critically damped is ideal).

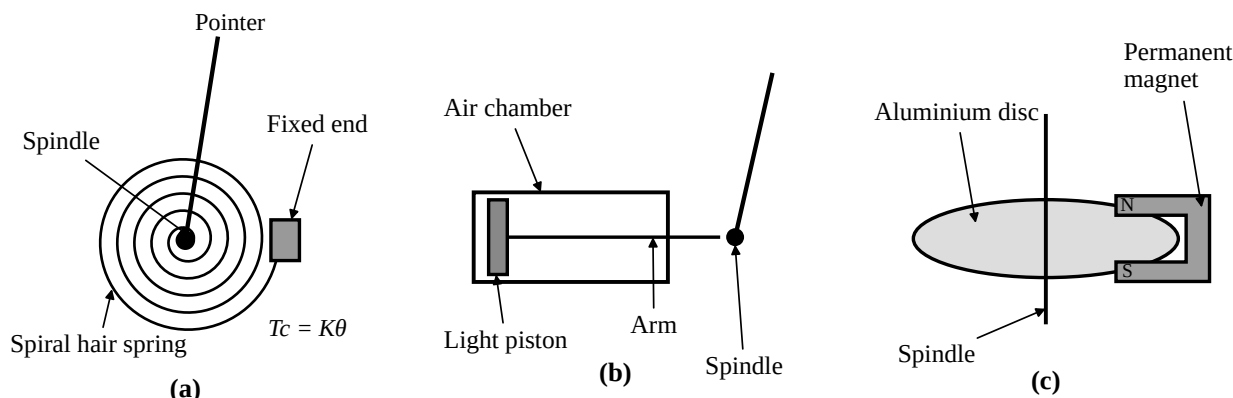


Fig.: (a) Spring control (b) Air friction damping (c) Eddy current damping

(Each torque 1 M, sketch 1 M)

b) Smart energy meter — block diagram and working.

4 M

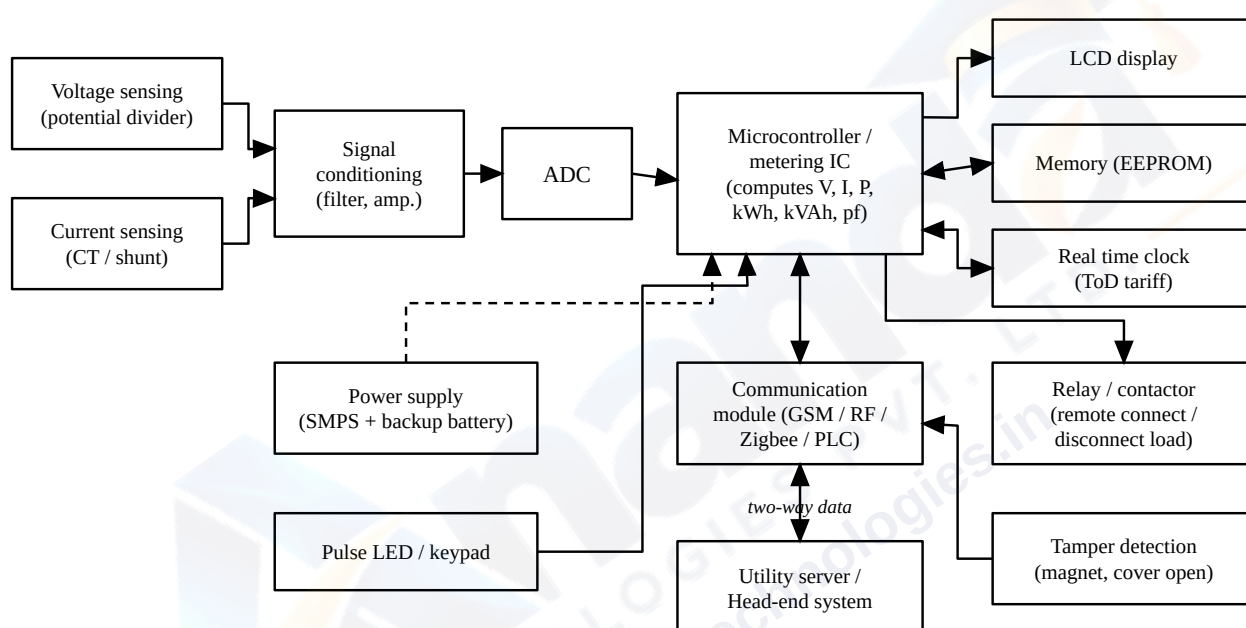


Fig.: Block diagram of smart energy meter

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).

6. **Tamper detection:** Detects magnet tamper, cover open, neutral missing, reverse current, and reports it to the utility.

(Block diagram 2 M, working 2 M)

c) **Basic block diagram of CRO with function of each block.**

4 M

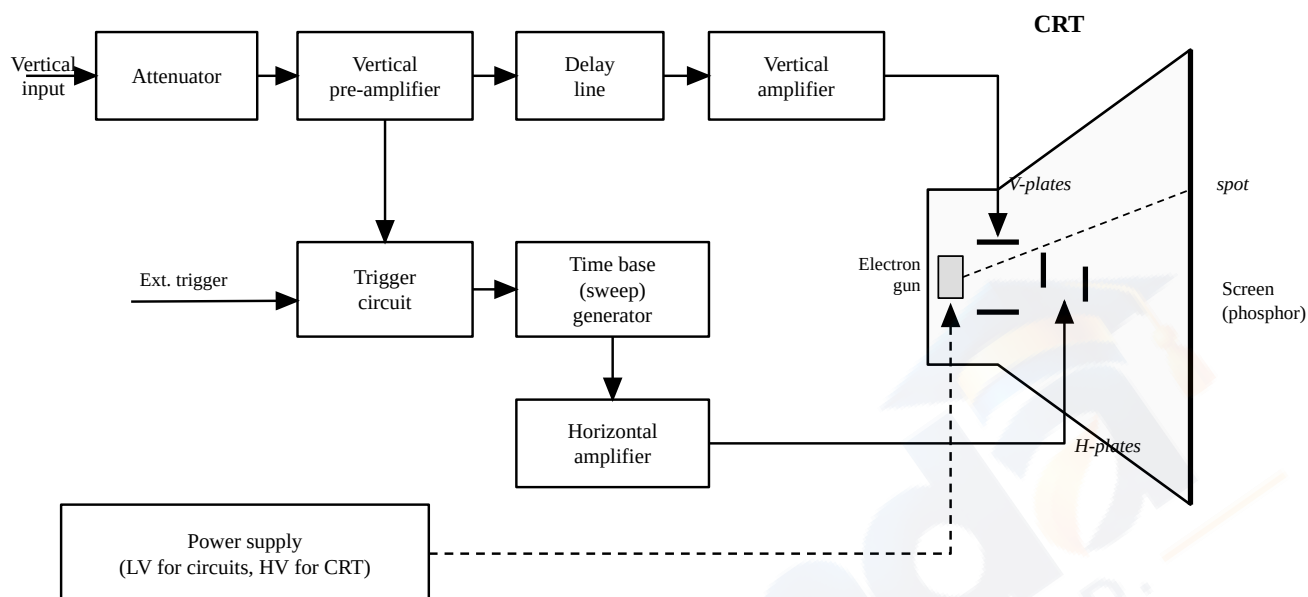


Fig.: Basic block diagram of CRO

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 2–3 M, functions 2–3 M)

d) Construction and working of LVDT.

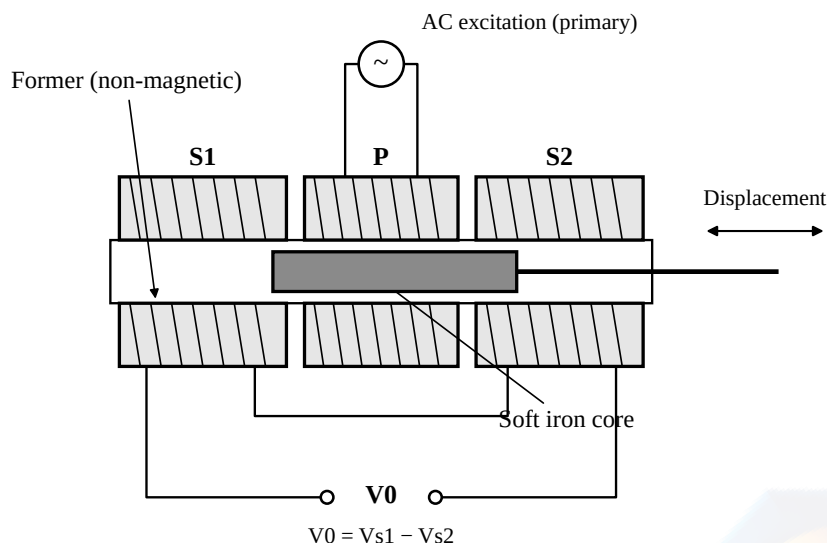


Fig.: Construction and circuit of LVDT (S1, S2 in series opposition: $V_0 = V_{s1} - V_{s2}$)

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.

Advantages: frictionless (no contact), high resolution and sensitivity, linear, rugged, low hysteresis. **Applications:** displacement measurement, secondary transducer with Bourdon tube / diaphragm for pressure, load cell, thickness gauges.

(Diagram 2 M, construction and working 2 M)

Q.3

a) Construction and working of PMMC instrument.

4 M

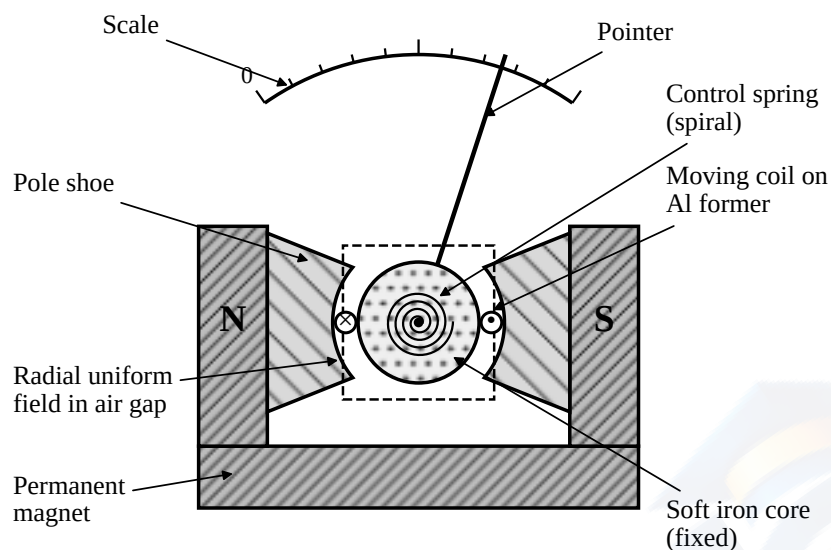


Fig.: Construction of permanent magnet moving coil (PMMC) instrument

Construction:

- **Permanent magnet:** A strong horse-shoe magnet (Alnico / Alcomax) with soft iron pole shoes having concave faces.
- **Soft iron core:** A cylindrical core is fixed between the pole shoes, so that the air gap is small and the magnetic field in the gap is *radial and uniform*.
- **Moving coil:** A rectangular coil of fine copper wire wound on a light aluminium former, pivoted on jewel bearings so that it can rotate in the air gap.
- **Control:** Two phosphor-bronze spiral springs give controlling torque and also lead current into the coil.
- **Damping:** Eddy current damping — eddy currents induced in the aluminium former oppose its motion.
- **Pointer and scale:** A light pointer attached to the spindle moves over a uniformly graduated scale.

Working: When current I flows through the coil placed in the magnetic field, a force acts on each side of the coil (motor principle, $F = B I L N$). The two forces form a couple which produces the deflecting torque $T_d = B A N I$. The spring produces controlling torque $T_c = K\theta$. At equilibrium, $K\theta = BAN I$, so $\theta = (BAN/K) I \propto I$. Hence the scale is uniform. If current is reversed the deflection reverses, so PMMC is used only for **DC**.

Advantages: uniform scale, high accuracy and sensitivity, low power consumption, efficient eddy current damping, not affected by stray fields. **Disadvantages:** DC only, costlier, ageing of magnet and springs.

(Diagram 2 M, construction and working 2 M)

b) Two wattmeter method — balanced star load.

4 M

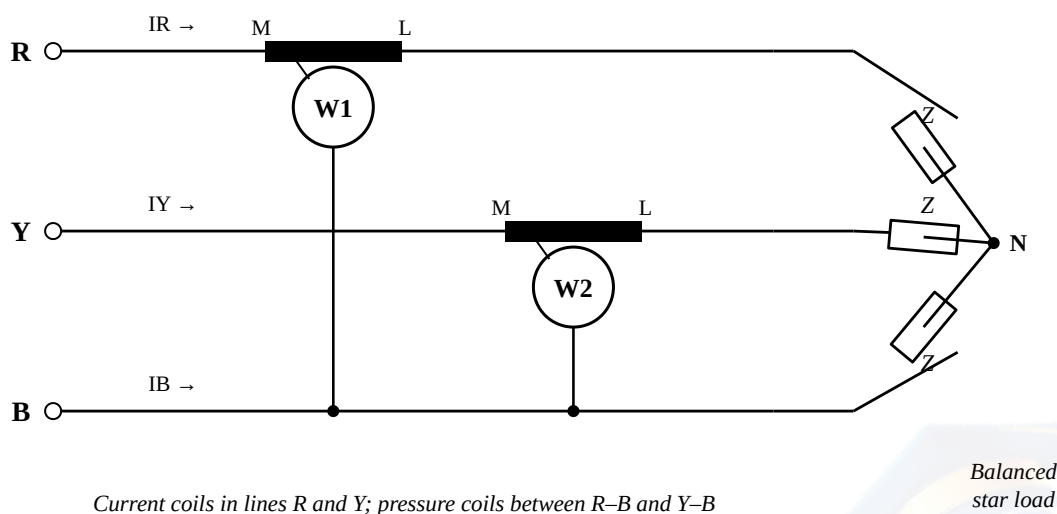


Fig.: Two wattmeter method — connection diagram for 3-phase, 3-wire balanced star connected load

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.

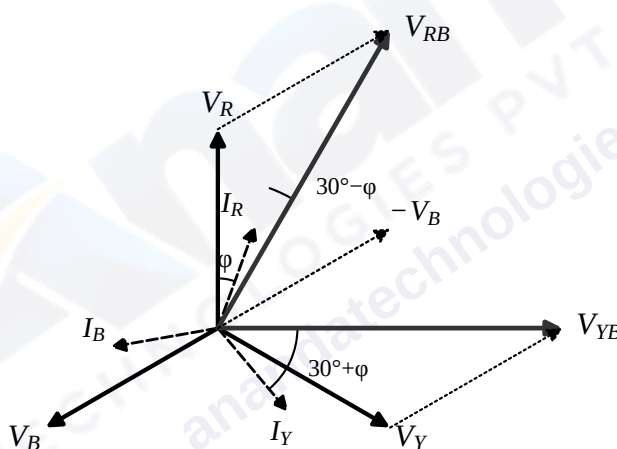


Fig.: Phasor diagram for two wattmeter method (balanced lagging load, $\phi = 20^\circ$ drawn)

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)

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

(Connection diagram 1 M, phasor diagram 1 M, proof 2 M)

c) Working of digital earth tester.

4 M

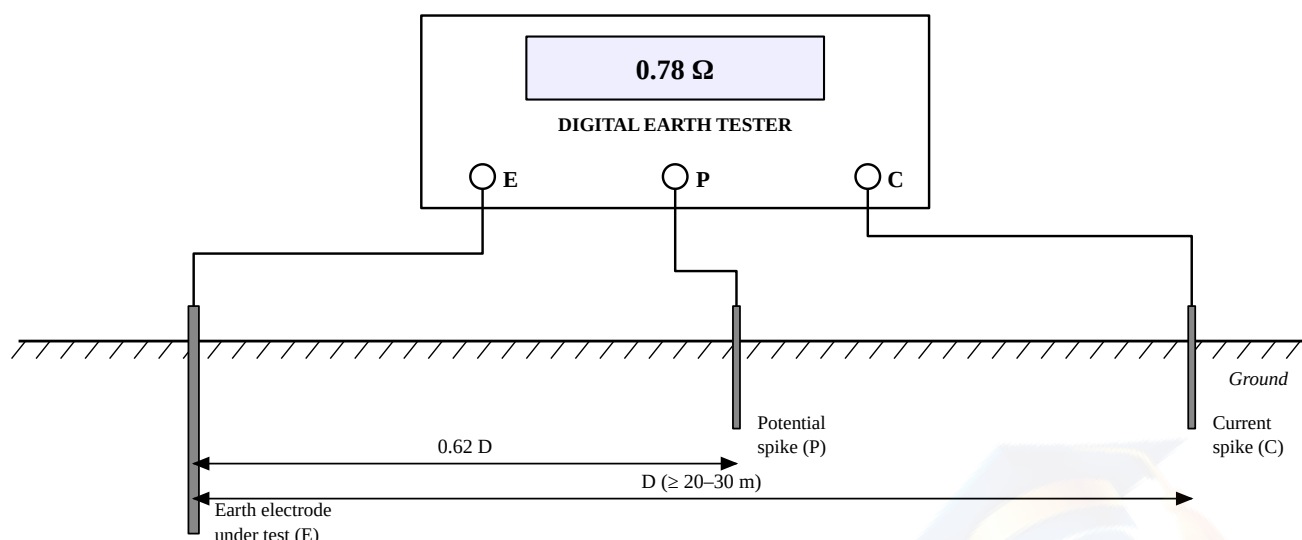


Fig.: Measurement of earth resistance by digital earth tester (three-terminal, fall of potential method)

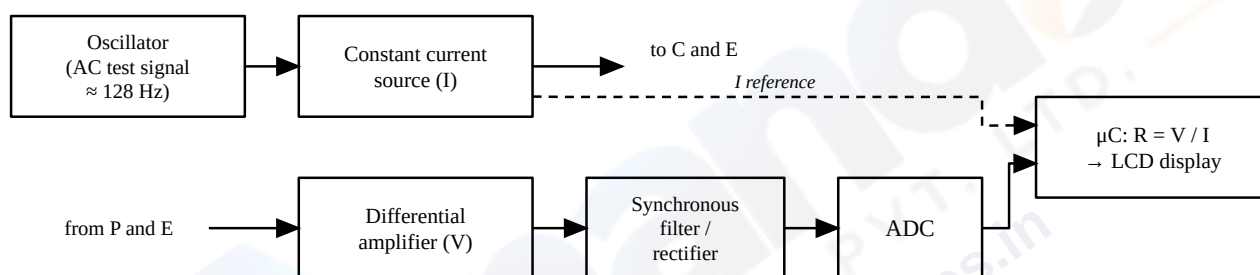


Fig.: Internal block diagram of digital earth tester

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.

- The C spike is driven at about 20–30 m and the P spike at 62 % of this distance from E , in a straight line.
- The internal oscillator and constant-current source pass current I through E and C ; the voltage V between P and E is amplified, filtered (to reject 50 Hz and stray currents), converted by ADC and the microcontroller displays $R = V/I$ directly in ohms.
- Readings are repeated with P shifted ± 10 %; nearly equal readings confirm the correct value.

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

d) Capacitive type level measurement.

4 M

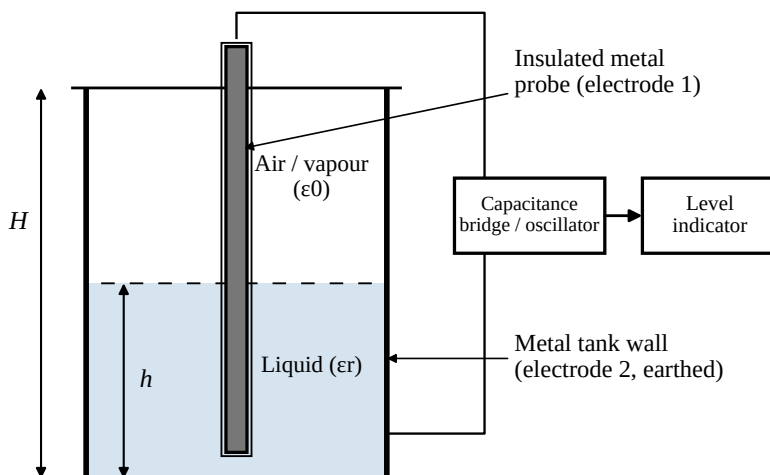


Fig.: Capacitive level measurement (insulated probe and metal tank wall form a cylindrical capacitor)

- **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.

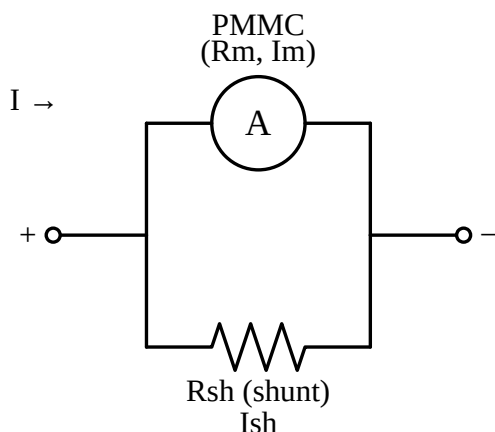
Limitation: affected by change in dielectric constant (temperature / composition) and coating on probe.

(Diagram 2 M, explanation 2 M)

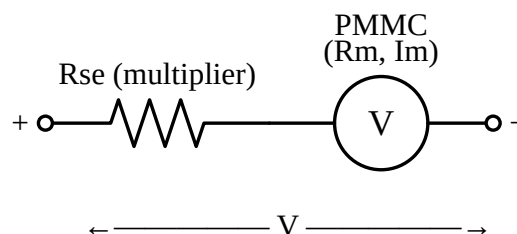
Q.4

a) Shunt and multiplier for PMMC ($R_m = 5 \Omega$, $I_m = 15 \text{ mA}$).

4 M



$$(a) I = I_m + I_{sh}$$



$$(b) V = I_m (R_{se} + R_m)$$

Fig.: (a) Extension of ammeter range by shunt (b) Extension of voltmeter range by series multiplier

Given: $R_m = 5 \Omega$, $I_m = 15 \text{ mA} = 0.015 \text{ A}$

(i) Ammeter 0–10 A (shunt in parallel):

Voltage across meter at FSD, $V_m = I_m R_m = 0.015 \times 5 = 0.075 \text{ V}$

Shunt current $I_{sh} = I - I_m = 10 - 0.015 = 9.985 \text{ A}$

$R_{sh} = I_m R_m / (I - I_m) = 0.075 / 9.985 = 0.00751 \Omega \approx 7.511 \text{ m}\Omega$ (multiplying power $m = I/I_m = 666.67$)

(ii) Voltmeter 0–150 V (multiplier in series):

Total resistance $= V / I_m = 150 / 0.015 = 10,000 \Omega$

$R_{se} = V/I_m - R_m = 10,000 - 5 = 9,995 \Omega$ (voltage multiplying factor $m = V/V_m = 2,000$)

(Each part with circuit 2 M)

b) Maximum demand indicator (Merz-Price).

4 M

Maximum demand indicator (MDI) records the **maximum average power (kW / kVA) demanded** by a consumer over a fixed demand interval (usually 30 minutes) during the billing period. It is used in two-part tariff for industrial consumers.

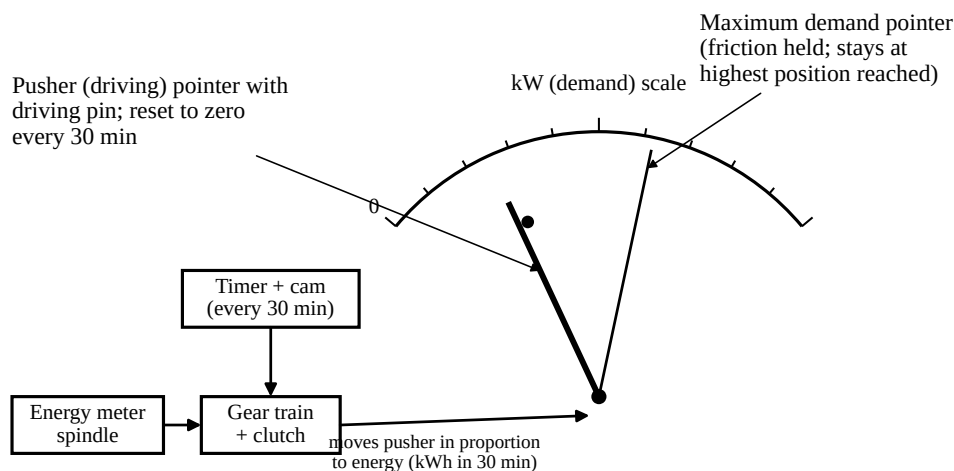


Fig.: Merz-Price maximum demand indicator (schematic)

- **Construction:** It is fitted in the energy meter. The meter spindle drives a *pusher pointer* (with driving pin) through a gear train and clutch. A separate *maximum demand pointer* is mounted on the same axis and is held in any position by light friction; it moves over a scale calibrated in kW.
- A timing device (synchronous motor / clock with cam) disengages the clutch every 30 minutes, and a reset spring brings the pusher pointer back to zero.
- **Working:** During each 30-minute interval the pusher pointer advances in proportion to the energy consumed (i.e. the average demand) and pushes the maximum demand pointer ahead of it.
- At the end of the interval the pusher returns to zero, but the MD pointer stays at the highest position reached. It moves further only if a later interval has a higher demand.
- Thus it shows the highest 30-minute average demand of the month; it is reset by the meter reader (sealed reset) after noting the reading.

(Diagram 2 M, construction and working 2 M)

c) Two wattmeter readings 4.8 kW and 1.6 kW.

4 M

For a balanced load: $P = W_1 + W_2$ and $\tan \phi = \sqrt{3} (W_1 - W_2) / (W_1 + W_2)$

Case 1: $W_1 = 4.8 \text{ kW}$, $W_2 = 1.6 \text{ kW}$

Total power $P = 4.8 + 1.6 = 6.4 \text{ kW}$

$\tan \phi = \sqrt{3} (4.8 - 1.6) / 6.4 = \sqrt{3} \times 3.2 / 6.4 = 0.8660$

$\phi = 40.89^\circ \Rightarrow$ power factor = $\cos \phi = 0.756$ (lagging)

Case 2: W_2 read after reversing current coil, i.e. $W_2 = -1.6 \text{ kW}$

Total power $P = 4.8 + (-1.6) = 3.2 \text{ kW}$

$\tan \phi = \sqrt{3} (4.8 + 1.6) / 3.2 = \sqrt{3} \times 6.4 / 3.2 = 3.4641$

$\phi = 73.90^\circ \Rightarrow$ power factor = 0.277 (lagging) (pf < 0.5, so one reading is negative)

(Each case 2 M)

d) Electrodynamometer type 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.

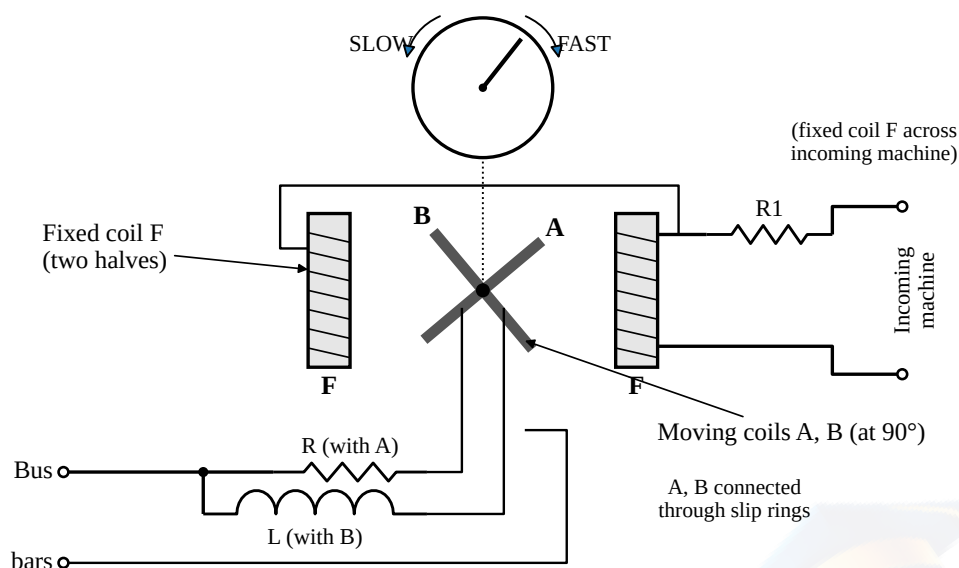


Fig.: Electro-dynamometer type synchroscope — coil arrangement and connections

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)

e) Piezoelectric transducer with applications.

4 M

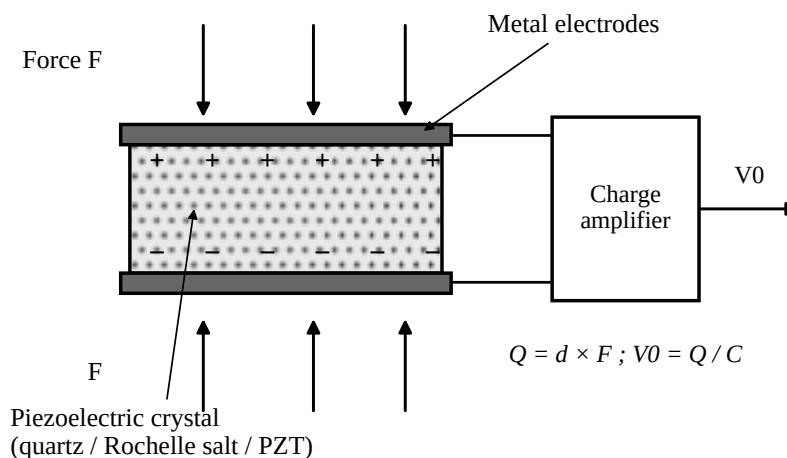


Fig.: Piezoelectric transducer — force applied on crystal produces charge on electrodes

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 ≈ 2.3 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 $V0 = Q / C = d F / C$ (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.

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

(Diagram 1 M, working 2 M, two applications 1 M)

Q.5

a) Function generator — block diagram, functions, applications.

6 M

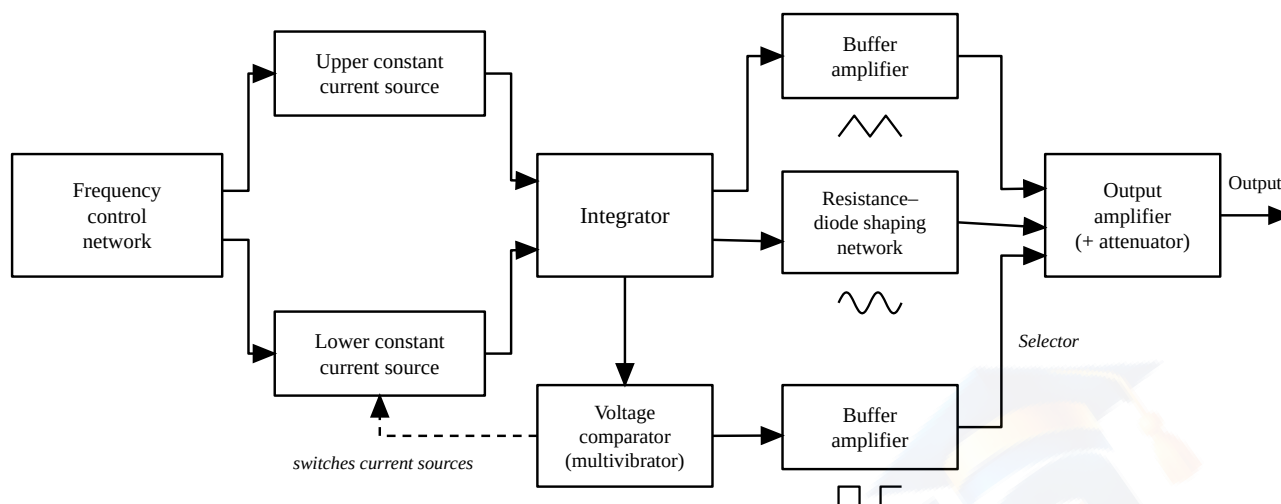


Fig.: Block diagram of function generator

Working / function of blocks:

- 1. Frequency control network:** Selects the frequency (range switch and fine dial) by controlling the magnitude of current of the two constant current sources.
- 2. Upper and lower constant current sources:** Supply constant charging and discharging current to the integrator capacitor.
- 3. Integrator:** A constant current charges the capacitor linearly, so the output rises linearly; when the lower source is switched on it falls linearly — this gives a **triangular wave**.
- 4. Voltage comparator (multivibrator):** Compares the integrator output with preset upper and lower levels and switches the current sources at these levels; its output is a **square wave** of the same frequency.
- 5. Resistance–diode shaping network:** Changes the slope of the triangular wave in steps (piecewise) to convert it into a **sine wave**.
- 6. Buffer and output amplifiers:** Isolate the generator from the load; the selected wave is amplified and taken out through an attenuator (amplitude control) at low output impedance (50 / 600 Ω).

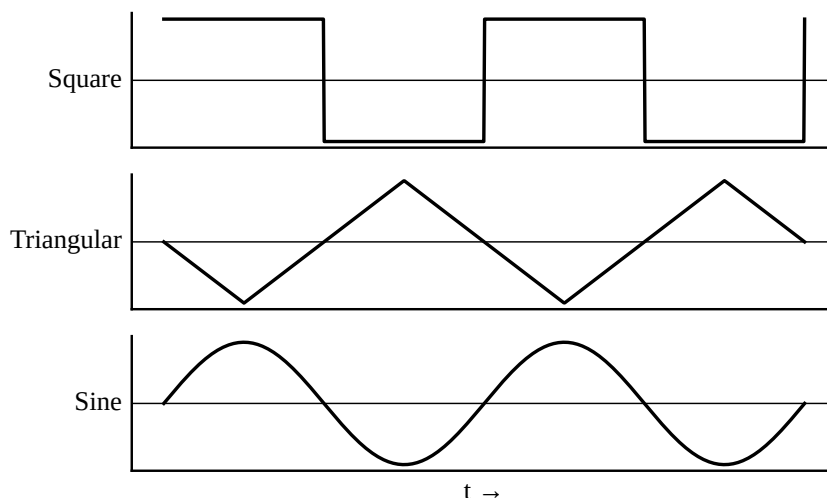


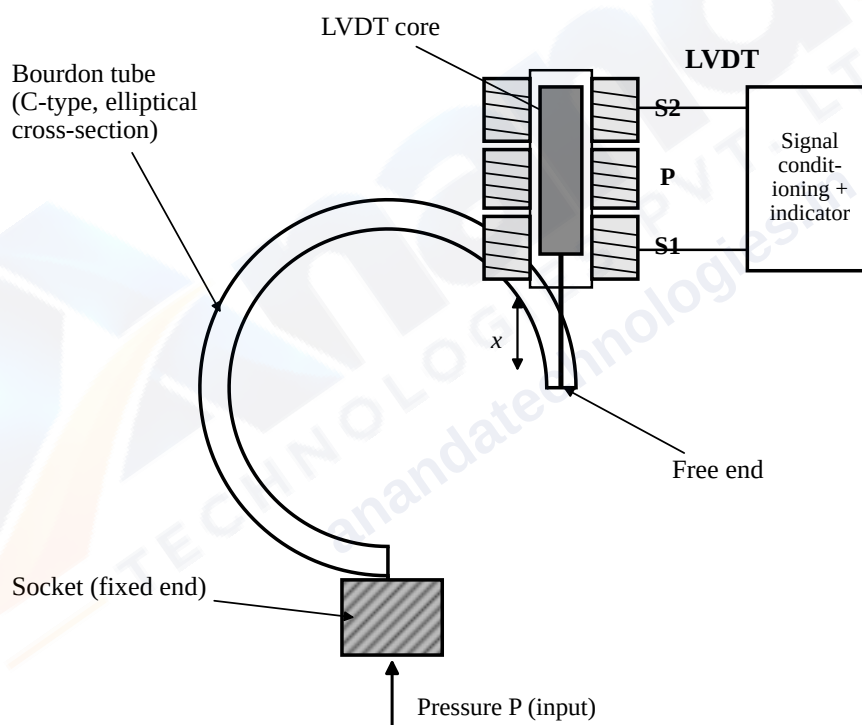
Fig.: Output waveforms of function generator — square (comparator), triangular (integrator) and sine (shaping network)

Applications: signal source for testing amplifiers and filters (frequency response), testing of digital circuits with square / pulse wave, calibration and repair of electronic equipment, laboratory experiments.

(Block diagram 3 M, explanation 2 M, applications 1 M)

b) Bourdon tube with LVDT as secondary transducer.

6 M



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

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.

(Diagram 3 M, explanation 3 M)

c) Classification of flow meters; electromagnetic flow meter.

6 M

Classification of flow meters:

- **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.

Electromagnetic flow meter:

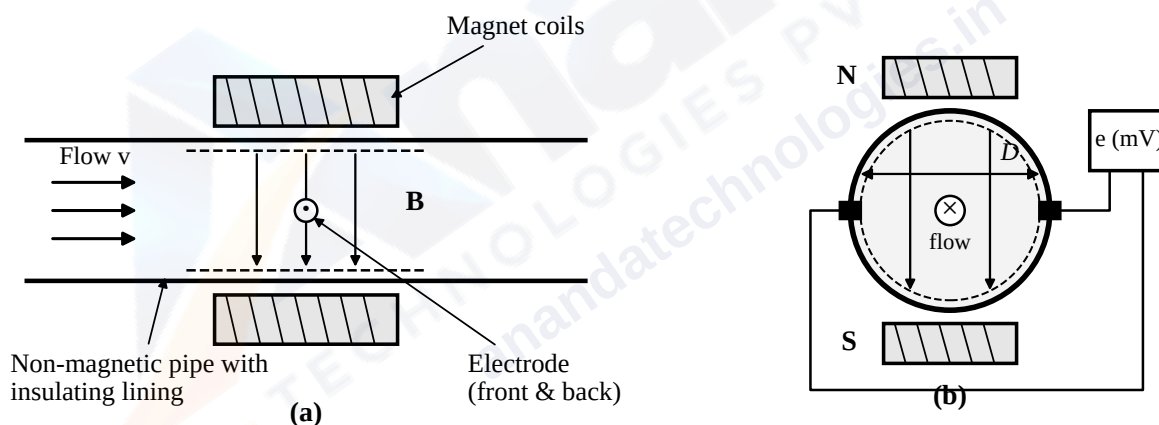


Fig.: Electromagnetic flow meter — (a) side view (b) cross-section; $e = B D v$

- **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.

(Classification 2 M, diagram 2 M, working 2 M)

Q.6

a) Single phase induction type energy meter.

6 M

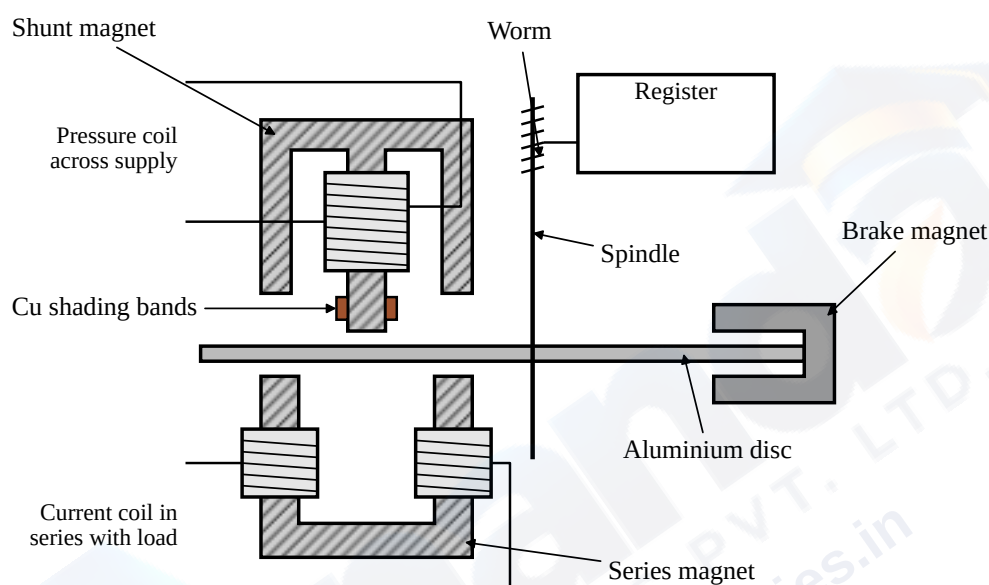


Fig.: Construction of single phase induction type energy meter

Construction:

- **Shunt magnet:** M-shaped laminated electromagnet with the *pressure coil* (many turns of fine wire, highly inductive) on the central limb, connected across the supply. Copper shading bands on the central limb are used for lag (power factor) adjustment.
- **Series magnet:** U-shaped laminated electromagnet with the *current coil* (few turns of thick wire) connected in series with the load.
- **Moving system:** A thin aluminium disc mounted on a vertical spindle, placed in the air gap between shunt and series magnets.
- **Braking system:** A permanent (brake) magnet near the edge of the disc; eddy currents induced in the moving disc produce a braking torque proportional to speed.
- **Registering (counting) mechanism:** The spindle drives a train of dials / cyclometer register through a worm and gear, which records energy in kWh.

Working: The shunt-magnet flux $\phi_{sh} (\propto V, \text{lagging } V \text{ by } 90^\circ \text{ after lag adjustment})$ and the series-magnet flux $\phi_{se} (\propto I, \text{in phase with } I)$ are alternating and displaced in space and time. They induce eddy currents in the disc; interaction of each flux with the eddy currents due to the other produces a driving torque $T_d \propto \phi_{sh} \phi_{se} \sin \beta \propto V I \cos \phi$ (power). The brake magnet produces braking

torque $T_b \propto \text{speed } N$. At steady speed $T_d = T_b$, so $N \propto \text{power}$ and the total number of revolutions in a given time $\propto \text{energy}$, which the register records. Meter constant $K = \text{revolutions per kWh}$.

(Diagram 2 M, construction 2 M, working 2 M)

b) Instrumentation system — block diagram and functions.

6 M

Instrumentation system: An instrumentation system is an arrangement of devices (elements) which measures a physical quantity (measurand), converts and processes it, and presents its value to the observer or uses it for control.

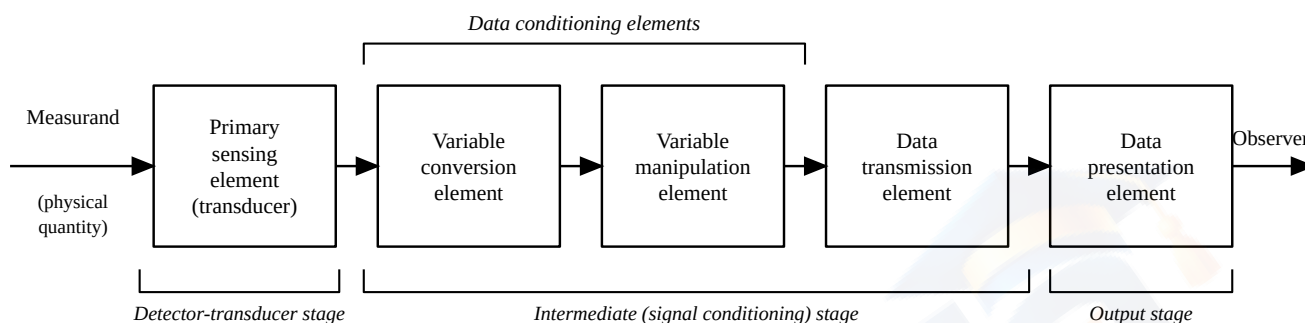


Fig.: Block diagram of generalised instrumentation system

- 1. Primary sensing element:** First comes in contact with the measurand and gives an output that depends on it (e.g. Bourdon tube, thermocouple). Often it is a transducer converting the quantity into an electrical signal.
- 2. Variable conversion element:** Converts the output of the primary element into a more suitable form (e.g. displacement into voltage, analog to digital) without changing the information.
- 3. Variable manipulation element:** Changes the magnitude (amplification, attenuation) of the signal while preserving its nature.
- 4. Data transmission element:** Transmits the signal from one element to another when they are physically separated (cables, telemetry, wireless).
- 5. Data presentation element:** Presents the information to the observer in a readable form — indicating meter, digital display, recorder, CRO, computer monitor.
- The conversion, manipulation and transmission elements together are called *signal (data) conditioning elements*.

(Block diagram 2–3 M, function of each block 3 M)

c) RTD — construction, working, advantages and applications.

6 M

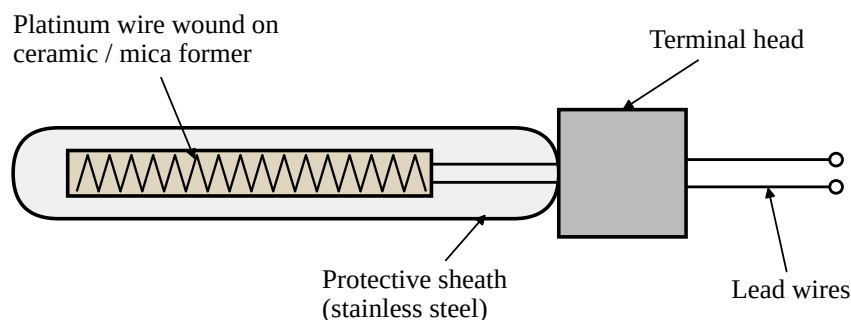


Fig.: Construction of platinum RTD (resistance temperature detector)

- **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.

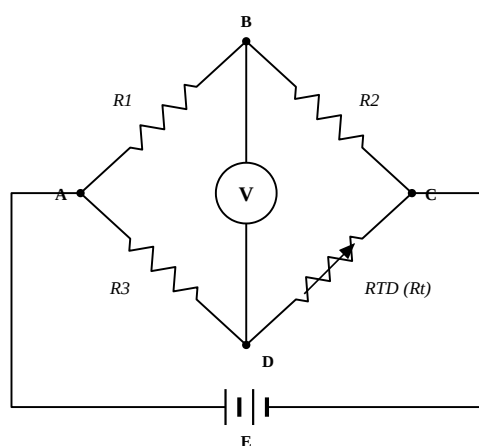


Fig.: RTD in bridge circuit (V calibrated in $^\circ\text{C}$)

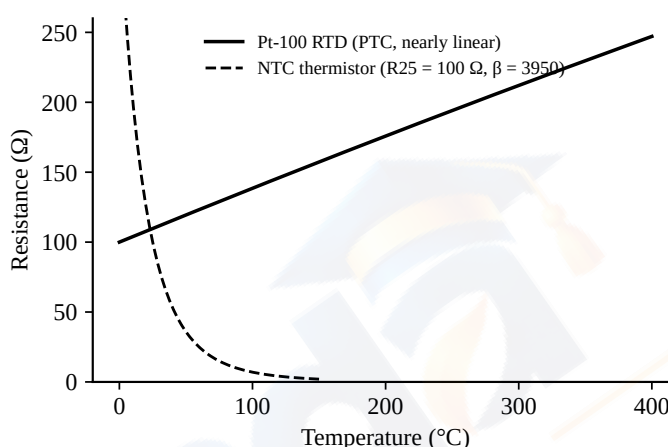


Fig.: R–T characteristic of Pt-100 (computed) vs NTC thermistor

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.

(Diagram 2 M, working 2 M, advantages and applications 2 M)

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