

Electrical and Electronic Measurement (313334)

MSBTE K-Scheme · Electrical Engineering · Model Question Paper — Set B · 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) Importance of measurement.

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).

Importance 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 precision and resolution.

2 M

i) **Precision:** It is the closeness of repeated readings of the same quantity to one another, i.e. the degree of reproducibility of the instrument. A precise instrument need not be accurate.

ii) **Resolution:** It is the smallest change (increment) in the measured quantity that the instrument can detect and show, e.g. 0.01 V for a 3½-digit DVM on the 20 V range.

(1 M each)

c) Multiplying factor (10 A, 600 V, 1500 W dial).

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.

$$\text{MF} = (600 \times 10) / 1500 = 4$$

i.e. every watt shown on the dial represents 4 W of actual power.

(Definition 1 M, calculation 1 M)

d) Analog vs digital instruments.

2 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.

(Any two points, 1 M each)

e) Transducer; active and passive examples.

2 M

Transducer: A device that converts a physical (non-electrical) quantity into an electrical quantity (or one form of energy into another).

Active (self-generating) transducers: do not need external power — thermocouple, piezoelectric crystal, photovoltaic cell, tachogenerator.

Passive transducers: need external power supply — RTD / thermistor, strain gauge, LVDT, capacitive transducer, potentiometer.

(Definition 1 M, examples 1 M)

f) Four quadrants of energy meter.

2 M

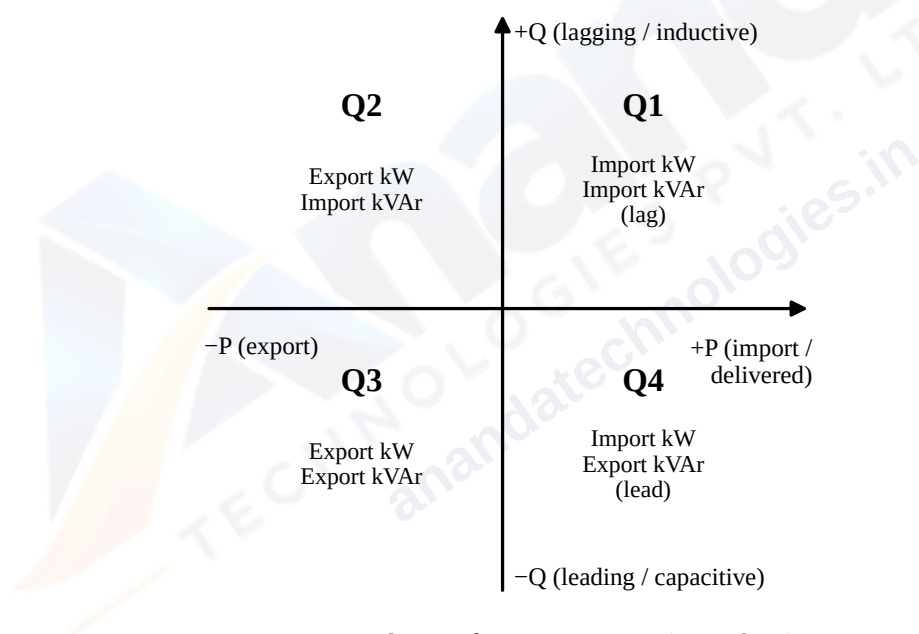


Fig.: Four quadrants of an energy meter (P–Q plane)

A four quadrant meter measures active (kWh) and reactive (kVArh) energy in both directions — import and export. Q1: import kW + lagging kVAr; Q2: export kW + import kVAr; Q3: export kW + export kVAr; Q4: import kW + leading kVAr. Used for net metering (rooftop solar), generator and grid interconnection points.

(Meaning of quadrants 2 M)

g) Advantages of RTD.

2 M

1. High accuracy and good long-term stability.
2. Nearly linear resistance–temperature characteristic.

3. Wide temperature range (platinum: -200°C to about 650°C).
4. Suitable for remote indication, recording and control; easy to calibrate (Pt-100 standard).

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

Q.2

a) Need of controlling torque; spring control.

4 M

Need of controlling torque: (i) to make the deflection definite for a particular value of the measured quantity (pointer stops where $T_c = T_d$), (ii) to bring the pointer back to zero when the quantity is removed. Without it the pointer would swing to full scale for any value of current.

Spring control method:

- Two phosphor-bronze hair springs of spiral shape are attached to the spindle, one at the front and one at the back, wound in opposite directions.
- The inner end of each spring is fixed to the spindle and the outer end to a fixed point (with zero adjuster).
- When the spindle rotates, the springs are twisted and produce a restoring torque proportional to the angle of twist: $T_c = K \theta$.
- At equilibrium $T_d = T_c$; for PMMC, $T_d \propto I$, so $\theta \propto I$ — the scale is **uniform**. The springs also carry current to the moving coil.
- Spring material must be non-magnetic, have low temperature coefficient, low resistance and must not fatigue.

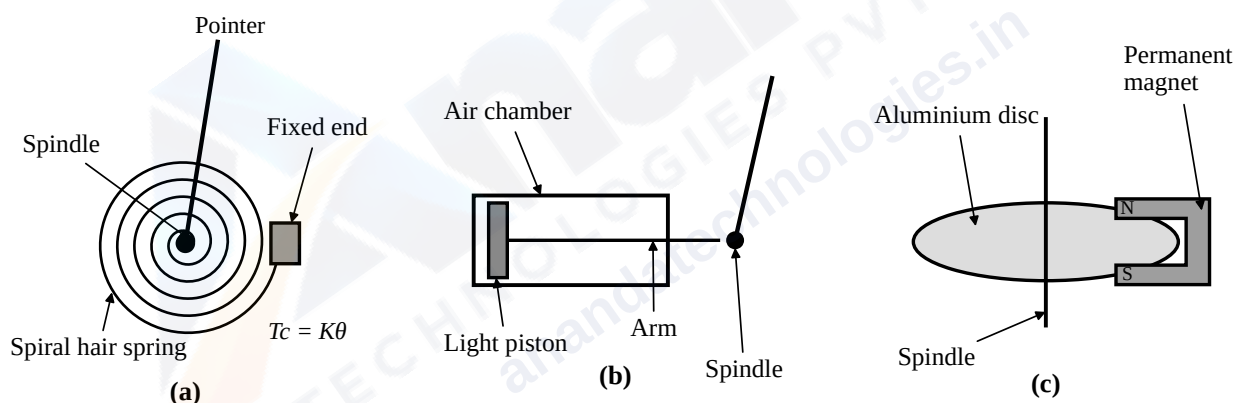


Fig.: (a) Spring control (also shown: air friction and eddy current damping)

Gravity control (alternative): a small adjustable weight on the moving system gives $T_c = W l \sin \theta$; the scale is non-uniform and the instrument must be kept vertical.

(Need 1 M, explanation 2 M, sketch 1 M)

b) Dynamometer type wattmeter.

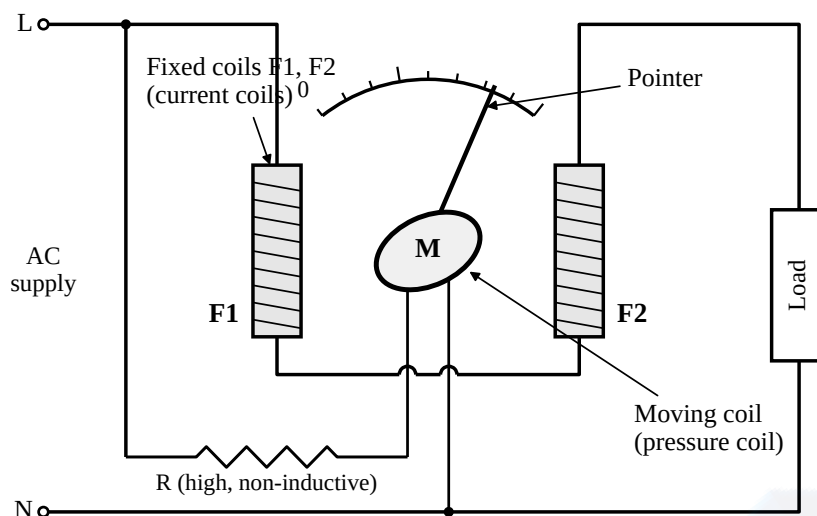


Fig.: Electro-dynamometer (dynamometer) type wattmeter — construction and connections

Construction:

- **Fixed coils (F1, F2):** Two air-cored fixed coils connected in series with the load; they carry load current and are called *current coils*. They are made of thick wire.
- **Moving coil (M):** A light coil pivoted between the fixed coils, connected across the supply in series with a high non-inductive resistance R; it carries current proportional to voltage and is called the *pressure coil*.
- Spring control (springs also lead current to moving coil), air friction damping (field is weak, so eddy current damping is not used), pointer moving over a uniform scale. No iron is used (air-cored) to avoid hysteresis and eddy current errors.

Working: The field of fixed coils is proportional to load current I and the current in the moving coil is proportional to supply voltage V . The interaction of the two fields produces a deflecting torque proportional to the product of the instantaneous values: $T_i \propto v \cdot i$. Due to inertia, the moving system responds to the average torque: $T_d \propto V I \cos \phi = \text{true power}$. With spring control $\theta \propto T_d$, so $\theta \propto \text{power}$ and the scale is uniform. It can be used on both AC and DC.

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

c) Procedure — earth resistance by digital earth tester.

4 M

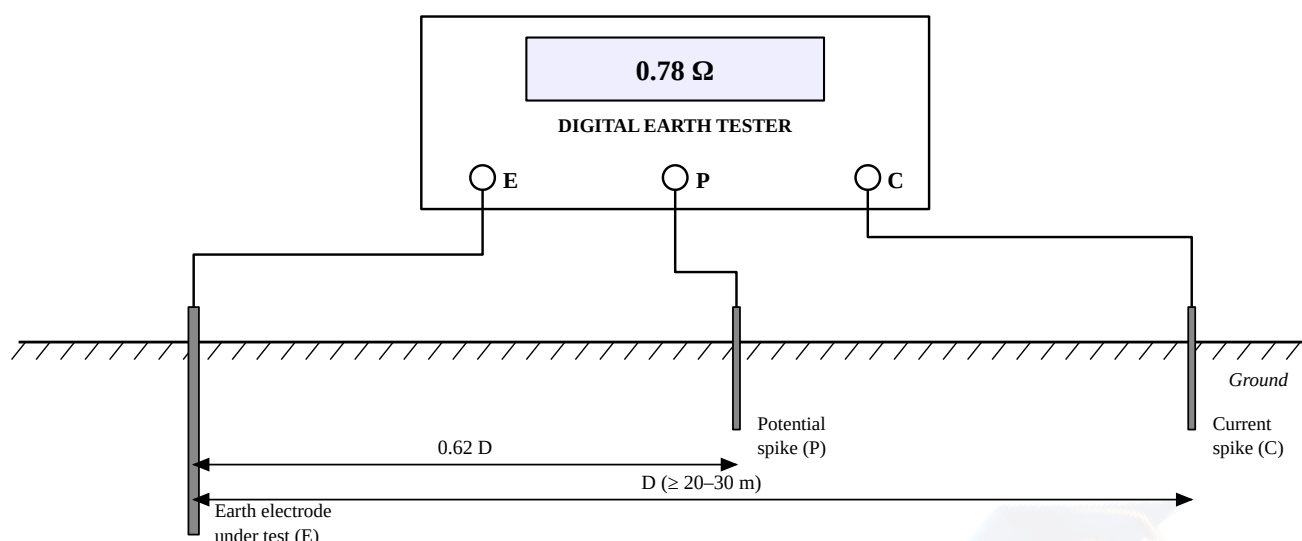


Fig.: Measurement of earth resistance by digital earth tester (three-terminal, fall of potential method)

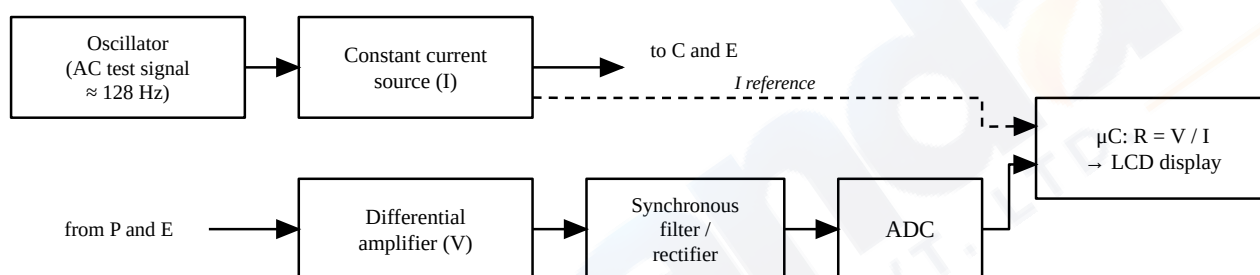


Fig.: Internal block diagram of digital earth tester

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) Piezoelectric transducer — working, classification, examples.

4 M

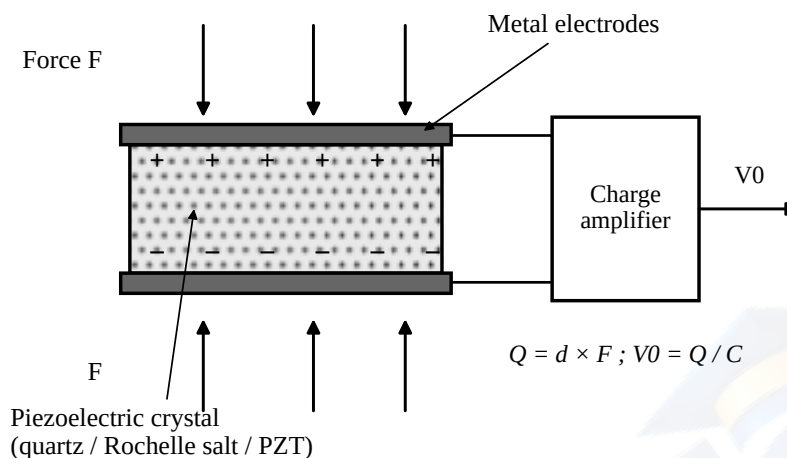


Fig.: Piezoelectric transducer — force applied on crystal produces charge on electrodes

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 1 M, working 2 M, classification 1 M)

Q.3

a) Moving iron instruments (attraction and repulsion).

4 M

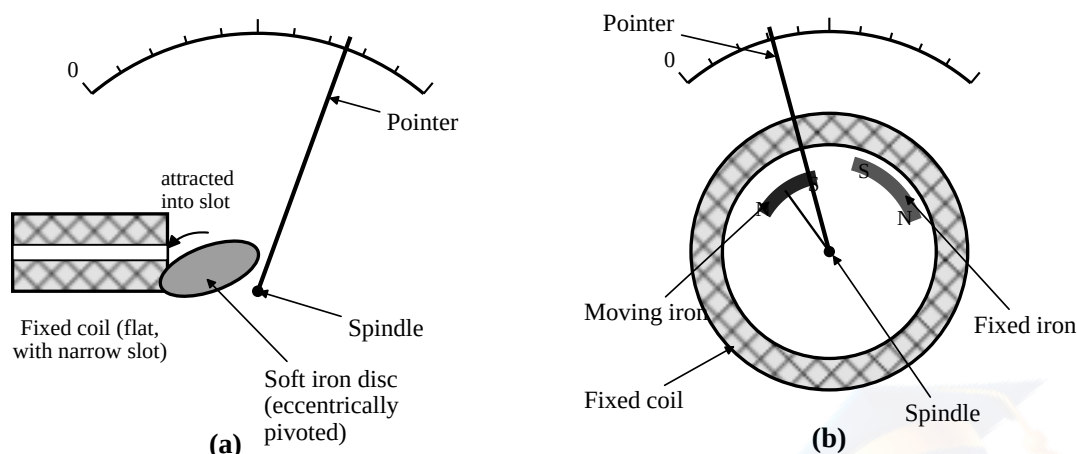


Fig.: Moving iron instruments — (a) attraction type (b) repulsion type

Principle: When a piece of soft iron is placed in the magnetic field of a current-carrying coil, it is magnetised and (a) is attracted into the field (attraction type) or (b) two similarly magnetised irons repel each other (repulsion type). The deflecting torque $T_d = \frac{1}{2} I^2 \frac{dL}{d\theta} \propto I^2$, so the instrument works on both AC and DC.

(a) Attraction type: A flat coil has a narrow slot. An oval soft iron disc is mounted eccentrically on the spindle. When current flows, the disc is attracted into the slot (towards the strong field), the spindle rotates and the pointer moves over the scale.

(b) Repulsion type: Two soft iron pieces (vaness/rods) are placed inside a cylindrical fixed coil — one fixed to the coil and the other attached to the spindle. Current magnetises both pieces with the same polarity (N–N, S–S), so they repel each other; the moving iron rotates and the pointer deflects. On AC both irons reverse polarity together, so the force is always repulsive.

- Control: spring control; Damping: air friction damping (eddy current damping is not used because the field is weak and the magnet would distort it).
- Scale is non-uniform (cramped at the beginning) as $\theta \propto I^2$.
- Advantages: cheap, robust, AC and DC use; Disadvantages: hysteresis and frequency errors, more power consumption.

(Diagram 2 M, construction and working 2 M)

b) Smart energy meter — block diagram and features.

4 M

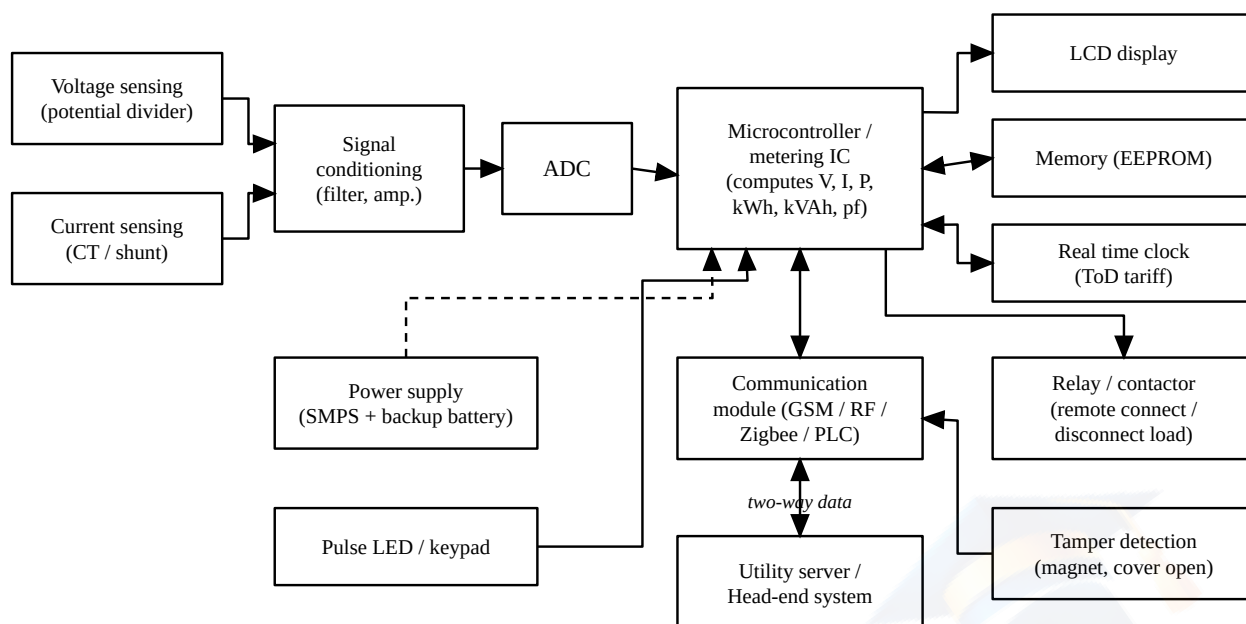


Fig.: Block diagram of smart energy meter

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, any four features 2 M)

c) Vertical and horizontal deflection systems of CRO.

4 M

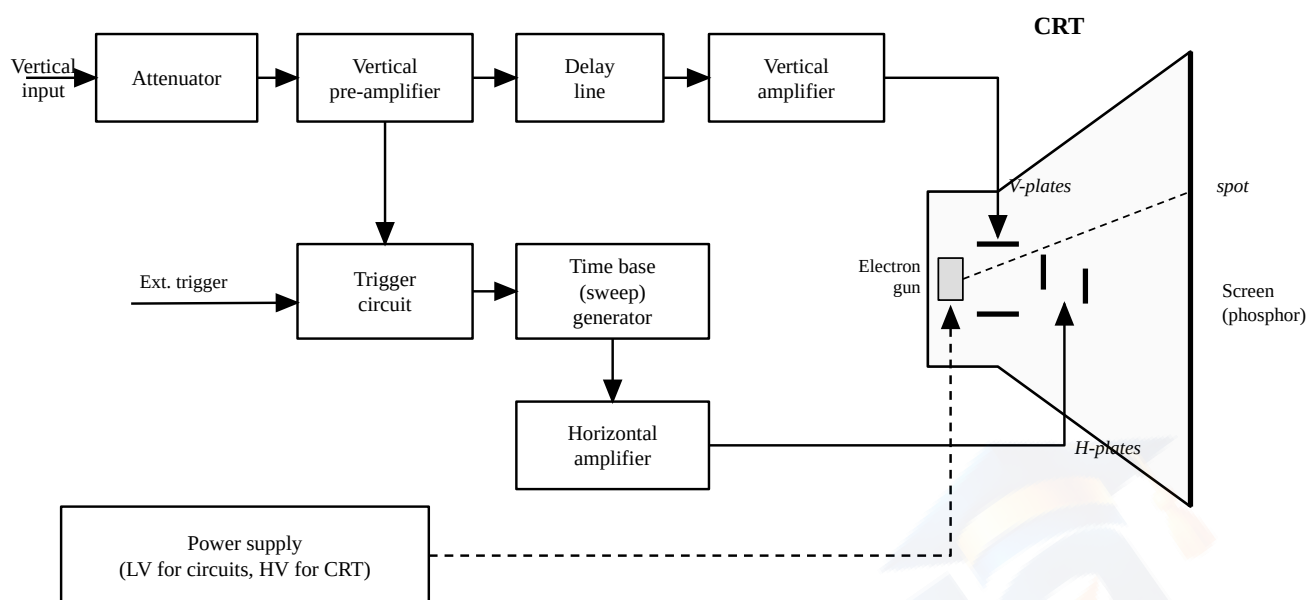


Fig.: Basic block diagram of CRO

Vertical deflection system (signal path):

- **Attenuator** (volts/div switch) reduces large signals to suitable level.
- **Vertical pre-amplifier and main amplifier** amplify the signal to drive the vertical (Y) plates; the deflection is proportional to the instantaneous signal voltage.
- **Delay line** delays the signal so that the leading edge is seen after the sweep has started.

Horizontal deflection system (time axis):

- **Trigger circuit** gives a pulse at a fixed point of the input signal so that each sweep starts at the same point — stable display.
- **Time base (sweep) generator** produces a sawtooth voltage; it moves the spot from left to right at uniform speed and returns it rapidly (retrace, blanked).
- **Horizontal amplifier** amplifies the sweep voltage applied to the horizontal (X) plates. Thus the screen shows signal voltage (Y) against time (X).

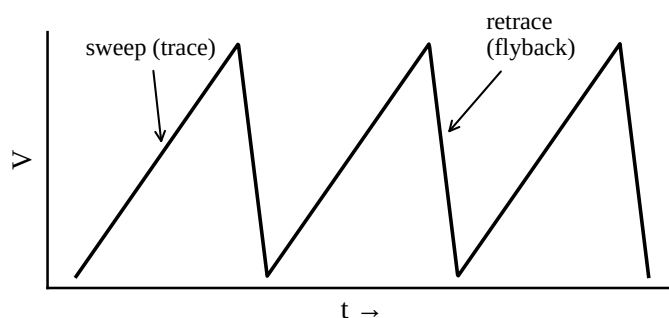


Fig.: Sweep (sawtooth) voltage applied to horizontal plates

(Block diagram 2 M, explanation 2 M)

d) Level measurement classification; ultrasonic method.

Classification:

- **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.

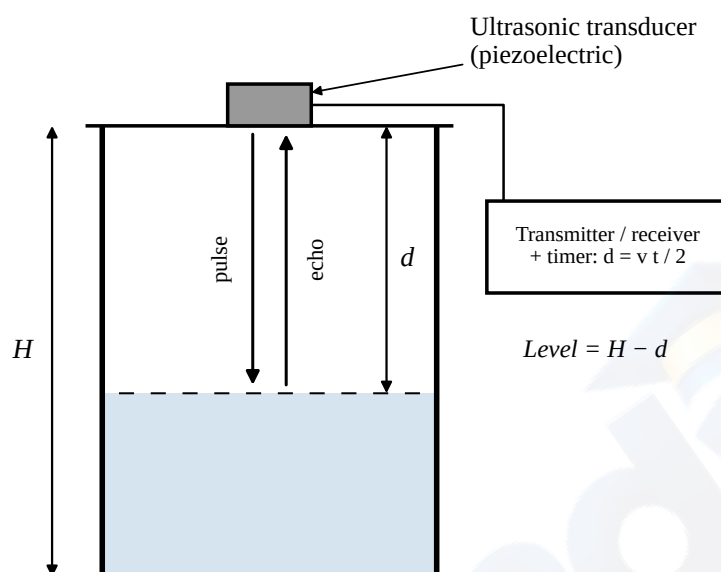


Fig.: Ultrasonic level measurement (pulse-echo, non-contact)

- An ultrasonic transducer (piezoelectric) mounted at the top of the tank sends short pulses of ultrasonic waves (20–200 kHz) downwards.
- The pulses are reflected from the liquid surface and the echo is received by the same transducer.
- The electronic unit measures the time t between transmission and echo. Distance $d = v t / 2$ (v = velocity of sound, ≈ 343 m/s in air at 20 °C).
- Level = $H - d$, where H is the distance from transducer to tank bottom. It is a non-contact method, suitable for corrosive and viscous liquids; affected by foam, vapour and temperature (compensated).

(Classification 1 M, diagram 1 M, working 2 M)

Q.4

a) Types of errors and methods to minimise.

4 M

Type of error	Causes / examples	Methods to reduce (compensation)
Gross errors	Human mistakes in reading, recording or calculation; wrong connection; parallax.	Take care while reading and recording; take 3–4 readings, preferably by different persons; use mirror scale.
Systematic — instrumental	Friction in bearings, ageing of spring/magnet, wrong zero, loading effect.	Calibrate the instrument against a standard; zero adjustment; apply correction factors; choose instrument with high input resistance.
Systematic — environmental	Temperature, humidity, stray magnetic and electric fields, dust, vibration.	Air-conditioning, magnetic shielding, hermetic sealing; use of swamping resistance (manganin) for temperature compensation.
Systematic — observational	Parallax error, error due to the observer's habit.	Mirror-backed scale, knife-edge pointer, digital display.
Random (residual) errors	Unknown, small, varying causes even after removing other errors.	Take a large number of readings and use statistical analysis (mean, standard deviation).

(Types 2 M, methods 2 M)

b) Two wattmeter readings — star load 230 V, 15 A, pf 0.8.

4 M

Star connection: $V_L = \sqrt{3} \times V_{ph} = \sqrt{3} \times 230 = 398.37 \text{ V}$; $I_L = I_{ph} = 15 \text{ A}$

$\cos \phi = 0.8 \Rightarrow \phi = 36.87^\circ$

$W1 = V_L I_L \cos(30^\circ - \phi) = 398.37 \times 15 \times \cos(-6.87^\circ) = \mathbf{5,932.7 \text{ W}}$

$W2 = V_L I_L \cos(30^\circ + \phi) = 398.37 \times 15 \times \cos(66.87^\circ) = \mathbf{2,347.3 \text{ W}}$

Check: $W1 + W2 = 8,280 \text{ W} = 3 V_{ph} I_{ph} \cos \phi = 3 \times 230 \times 15 \times 0.8 = 8,280 \text{ W} \checkmark$

(Line values 1 M, W1 1.5 M, W2 1.5 M)

c) Energy meter error (K = 1200 rev/kWh).

4 M

True energy consumed = $V I \cos \phi \times t = 230 \times 12 \times 1 \times (10/60) \text{ h} = 460 \text{ Wh} = 0.4600 \text{ kWh}$

Energy recorded by meter = $\text{Revolutions} / K = 560 / 1200 = 0.4667 \text{ kWh}$

(Correct number of revolutions = $0.46 \times 1200 = 552 \text{ rev}$)

% error = $(\text{Recorded} - \text{True}) / \text{True} \times 100 = (0.4667 - 0.4600) / 0.4600 \times 100 = \mathbf{+1.45 \%}$

The error is positive, so the meter is running **fast** (it records more energy than actually consumed).

(True energy 1 M, meter energy 1 M, % error 1 M, fast/slow 1 M)

d) Weston type frequency meter.

4 M

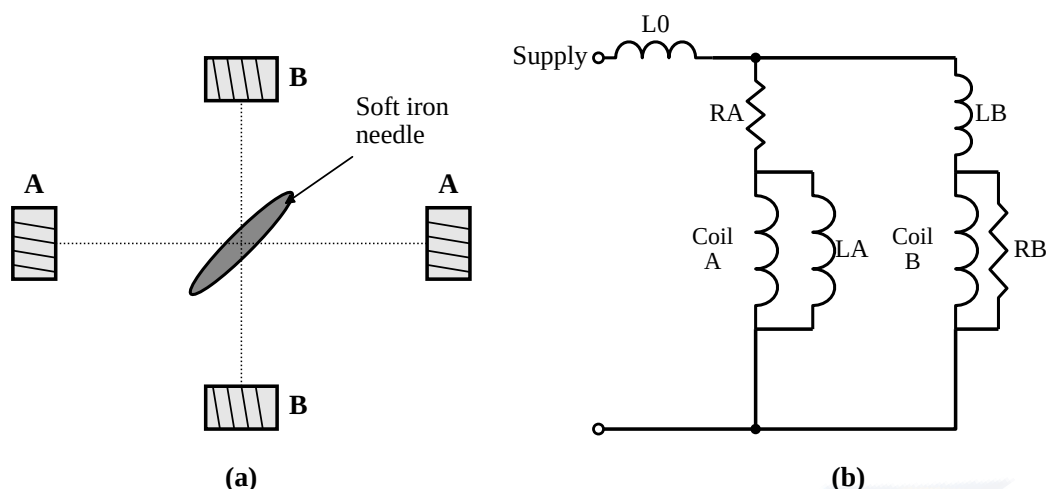


Fig.: Weston type frequency meter — (a) coil arrangement (b) circuit

- **Construction:** Two fixed coils A and B are mounted with their axes at 90° . Coil A has a series resistance R_A and a reactance coil L_A in parallel; coil B has a series inductance L_B and a resistance R_B in parallel. A series inductance L_0 suppresses harmonics. A soft iron needle carrying the pointer is pivoted at the centre; there is no controlling spring.
- **Working:** The needle sets itself along the resultant magnetic field of the two coils. At normal (rated) frequency the circuit is so designed that the currents in A and B are equal and the needle stays at 45° (centre of scale, e.g. 50 Hz).
- If frequency **increases**, reactance of L_A increases, so more current flows through coil A; reactance of L_B increases, so current in coil B decreases. The field of A becomes stronger and the needle turns towards the axis of coil A — the pointer moves to the higher-frequency side.
- If frequency **decreases**, the opposite happens and the needle moves towards coil B (lower-frequency side). Range is small, e.g. 45–55 Hz.

(Diagram 2 M, working 2 M)

e) Capacitive level measurement — conducting and non-conducting liquids.

4 M

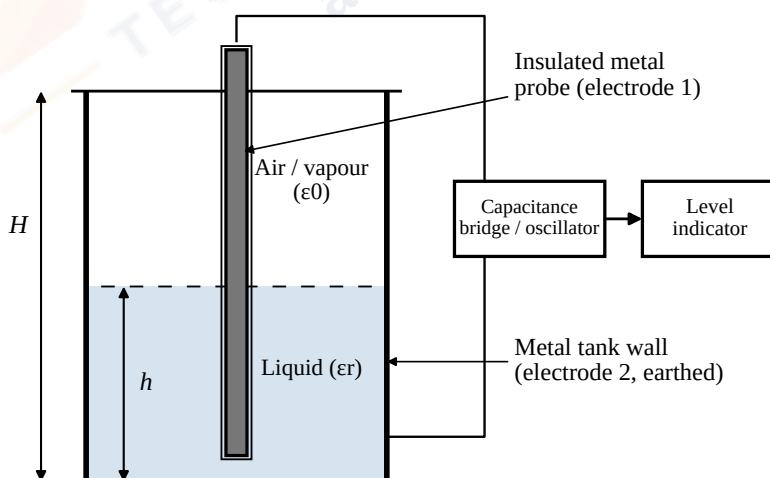


Fig.: Capacitive level measurement (insulated probe and metal tank wall form a cylindrical capacitor)

- **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.

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.5

a) Synchroscope — construction, working, conditions for synchronisation.

6 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.

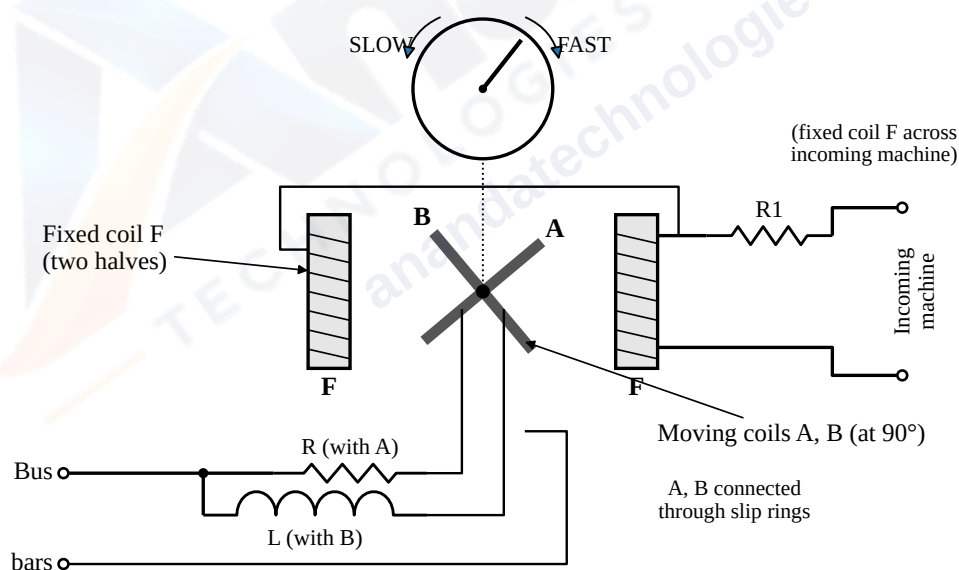


Fig.: Electro-dynamometer type synchroscope — coil arrangement and connections

Construction (electrodynamometer 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.

Conditions for synchronisation: equal voltages, equal frequencies, same phase sequence and the voltages in phase at the instant of closing the switch.

(Identification 1 M, diagram 2 M, working 2 M, conditions 1 M)

b) LVDT with output characteristic; LVDT vs RVDT.

6 M

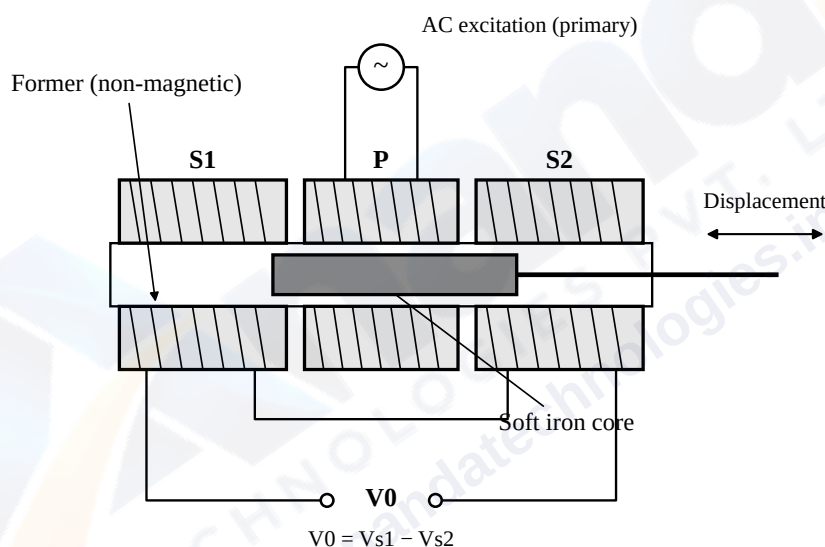


Fig.: Construction and circuit of LVDT (S1, S2 in series opposition: $V_0 = V_{s1} - V_{s2}$)

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 S_1 = flux linking S_2 , $V_{s1} = V_{s2}$, so $V_0 = 0$.
- Core moved towards S_1 : $V_{s1} > V_{s2}$, $V_0 = V_{s1} - V_{s2}$ is positive (in phase with primary).
- Core moved towards S_2 : $V_{s2} > V_{s1}$, 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.

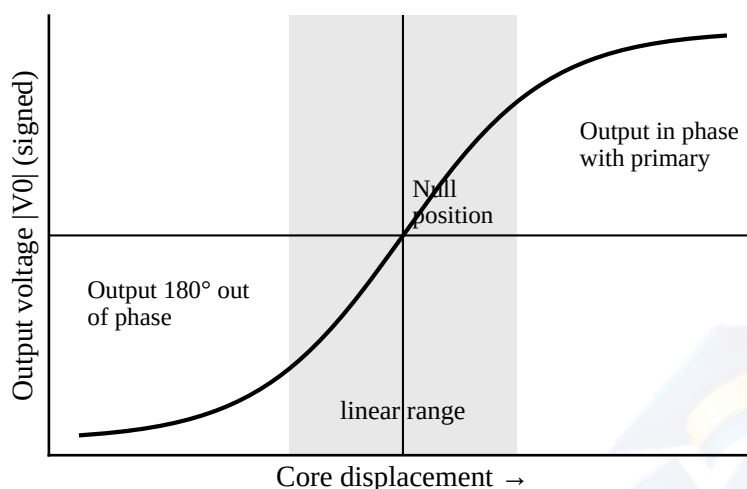


Fig.: Output characteristic of LVDT (computed ideal model: linear range with saturation at ends)

LVDT vs RVDT:

LVDT	RVDT
Measures linear displacement.	Measures angular (rotary) displacement.
Core is a straight cylindrical soft iron rod moving axially.	Core is a cam-shaped (cardioid) soft iron piece rotating on a shaft.
Linear range from about ± 0.25 mm to ± 250 mm.	Linear range about $\pm 40^\circ$ (up to $\pm 60^\circ$ with reduced linearity).
Output $\propto$ linear displacement x .	Output $\propto$ angle of rotation θ .

(Diagram 2 M, working with characteristic 2 M, comparison 2 M)

c) Classification of flow devices; electromagnetic flow meter.

6 M

Classification:

- **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.

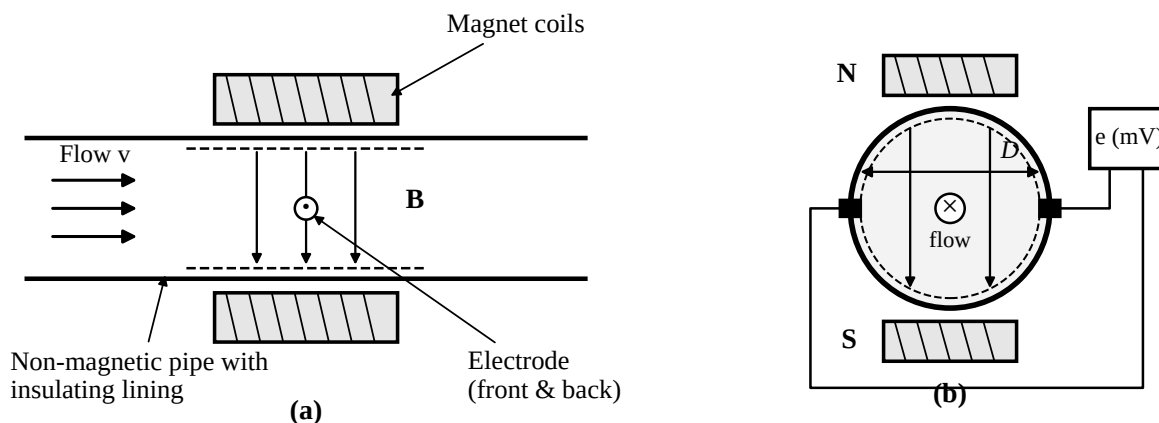


Fig.: Electromagnetic flow meter — (a) side view (b) cross-section; $e = B D v$

- **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, principle and working 3 M, applications 1 M)

Q.6

a) Function generator — generation of square, triangular and sine waves.

6 M

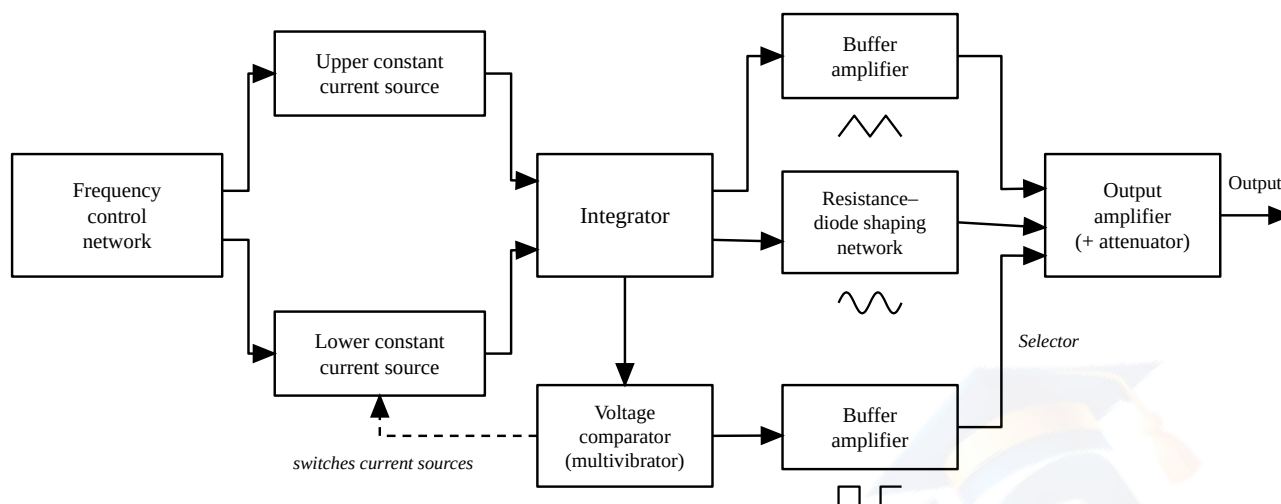


Fig.: Block diagram of function generator

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).

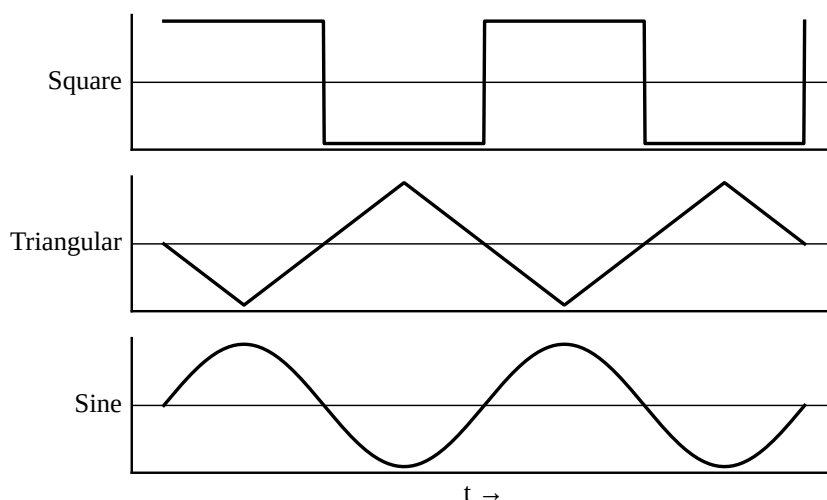


Fig.: Output waveforms of function generator — square (comparator), triangular (integrator) and sine (shaping network)

(Block diagram 3 M, generation of waves 3 M)

b) Bourdon tube with LVDT.

6 M

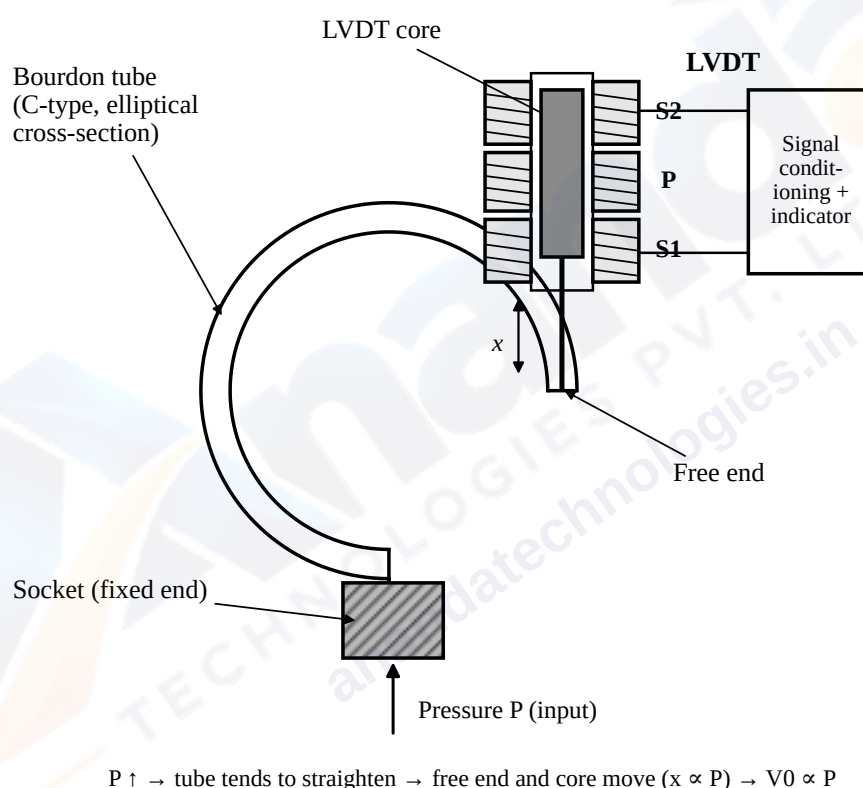


Fig.: Bourdon tube with LVDT as secondary transducer for pressure measurement

- **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, working 3 M)

c) Temperature measurement with thermocouple; J, K, R, S materials.

6 M

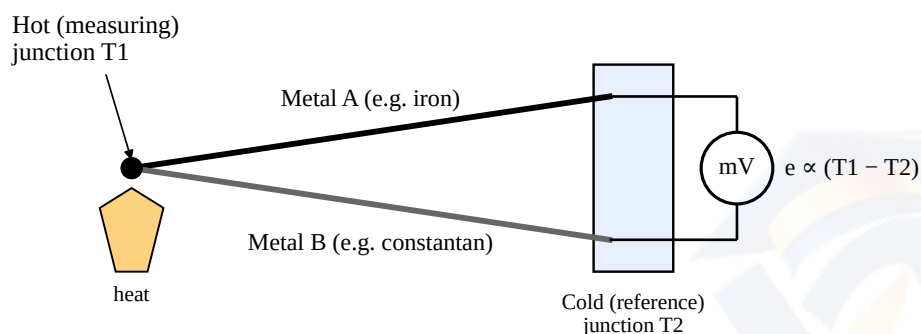


Fig.: Thermocouple temperature measurement (Seebeck effect)

- **Principle (Seebeck effect):** When two dissimilar metals are joined to form two junctions and the junctions are kept at different temperatures, an emf is produced in the circuit which is proportional to the temperature difference ($T_1 - T_2$).
- **Working:** The hot (measuring) junction is placed in the medium; the cold (reference) junction is kept at a constant known temperature (0 °C ice bath or room temperature with cold junction compensation). The millivoltmeter (or digital indicator) connected in the circuit is calibrated in °C.
- Compensating (extension) leads of similar thermo-electric properties are used to bring the cold junction to the instrument.

Type	Materials (+ / -)	Range (approx.)	Sensitivity (approx.)
J	Iron / Constantan	-40 to 750 °C	≈ 52 μV/°C
K	Chromel (Ni-Cr) / Alumel (Ni-Al)	-200 to 1250 °C	≈ 41 μV/°C
R	Platinum-13 % Rhodium / Platinum	0 to 1450 °C	≈ 10 μV/°C
S	Platinum-10 % Rhodium / Platinum	0 to 1450 °C	≈ 10 μV/°C

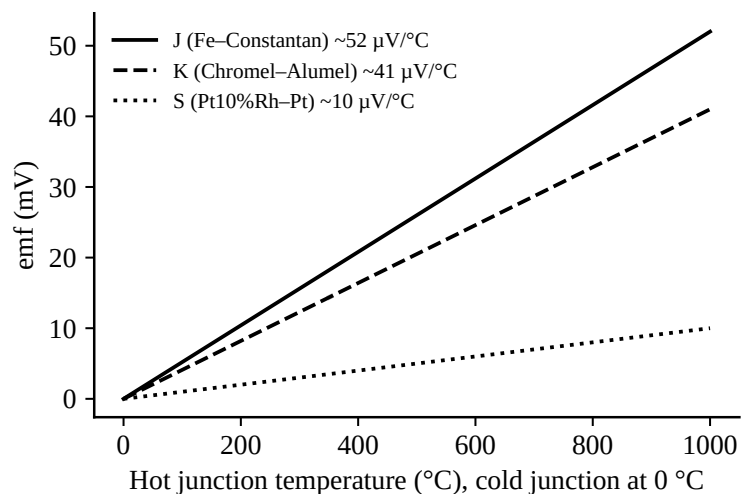


Fig.: Thermo-emf vs temperature for J, K and S type thermocouples (approx. average sensitivities)

(Diagram 2 M, working 2 M, materials 2 M)

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