
ELECTRICAL AND ELECTRONIC MEASUREMENTS

Chapter 5 Measurement of Circuit Parameter, CRO and Other Meters

Complete Study Notes for Engineering Students

Topics 5.1 to 5.14, with diagrams, 15 MCQs with answer key and 10
broad questions

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5.1 Measurement of Resistance

Resistance is the opposition offered by a material to the flow of electric current. In engineering practice the resistances to be measured range from a few micro-ohms (busbar joints, shunts) to many thousands of mega-ohms (insulation of cables and machines). No single instrument or method can cover this complete range with good accuracy, so resistances are classified into three groups and a different method is used for each group.

Class	Range	Typical examples	Preferred method
Low resistance	Below 1 Ω	Winding resistance of transformers and motors, ammeter shunts, busbar and contact resistance, cable conductors	Kelvin's double bridge, potentiometer, micro-ohmmeter
Medium resistance	1 Ω to about 100 k Ω	Resistors, lamp filaments, heater elements, relay coils	Voltmeter-ammeter method, Wheatstone bridge, ohmmeter, substitution
High resistance	Above 100 k Ω	Insulation resistance of cables, windings, switchgear, bushings	Megger (insulation tester), loss-of-charge method, megohm bridge

Why a special method is needed for low resistance: when a low resistance is connected in an ordinary bridge or meter, the resistance of the connecting leads and of the contacts (a few milli-ohms) becomes comparable to the unknown value and causes a large error. The cure is to use four-terminal resistors (separate current and potential terminals) and a bridge arrangement that cancels the lead and contact resistance, as in Kelvin's double bridge.

5.1.1 Low Resistance: Kelvin's Double Bridge

Kelvin's double bridge is a modification of the Wheatstone bridge in which a second pair of ratio arms is added. It is used to measure resistances from about 0.1 $\mu\Omega$ up to 1 Ω with good accuracy (typically $\pm 0.05\%$ to $\pm 0.2\%$). The extra ratio arms eliminate the effect of the resistance of the connecting link between the standard and unknown resistances.

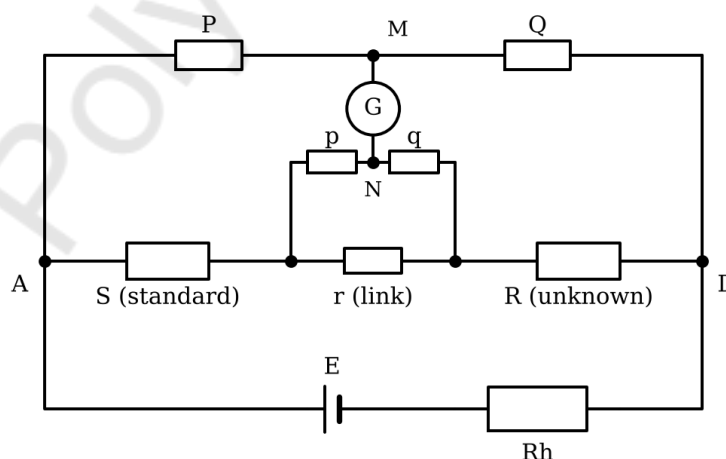


Fig. 5.1 Kelvin's double bridge

Circuit description

- R** is the unknown low resistance and **S** is a standard low resistance of the same order, both four-terminal types.

- **P and Q** are the outer (first) ratio arms; **p and q** are the inner (second) ratio arms that are connected across the link.
- **r** is the resistance of the heavy copper link joining S and R.
- **G** is a sensitive galvanometer connected between junctions M (of P and Q) and N (of p and q). A battery E with a rheostat Rh supplies a large current (a few amperes) through S, the link and R.

Working and balance equation

The ratio arms P, Q, p and q are made of high resistance (10 Ω to 1 k Ω) so that the current taken by them is small and the lead resistances in series with them are negligible. The standard resistor S is varied until the galvanometer shows no deflection. At balance the potential of M equals the potential of N, and analysis of the network gives

$$R = (P/Q) \cdot S + [q r / (p + q + r)] \cdot (P/Q - p/q)$$

If the ratio arms are made so that **P / Q = p / q** (usually by ganging the two pairs of arms on the same dial), the second term becomes zero and the result is independent of the link resistance r:

$$R = (P/Q) \cdot S$$

Points to remember

- Four-terminal connection is used for R and S: the current terminals are outside, the potential terminals are inside.
- The link should be as thick and as short as possible; its resistance is eliminated only when $P/Q = p/q$.
- Heavy current heats the resistors, so the current is switched on only for a short time while balancing.
- Thermal e.m.f.s at junctions are removed by reversing the battery and averaging the two readings.

Advantages	Limitations
Eliminates lead and contact resistance error; high accuracy for resistances below 1 Ω .	Needs a large current, which can cause heating and change the resistance being measured.
Direct reading from known ratio and standard; wide range using decade ratio arms.	Needs a sensitive galvanometer and careful shielding; not suitable for medium or high resistances.

Applications: measuring the resistance of copper conductors and cable cores, transformer and motor windings, ammeter shunts, bus-bar joints, welded and brazed joints, and the calibration of low-value standard resistors.

5.1.2 Medium Resistance: Voltmeter and Ammeter Method

This is the simplest method based on Ohm's law. A d.c. voltage is applied to the unknown resistance R; the voltmeter reads the voltage V across it and the ammeter reads the current I through it. The resistance is then **R = V / I**. Two connections are possible, and each introduces a small error because the instruments are not ideal (the ammeter has a small resistance R_a and the voltmeter has a large but finite resistance R_v).

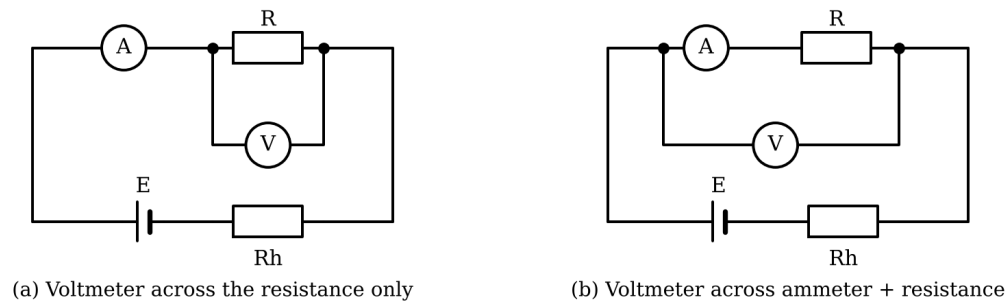


Fig. 5.2 Voltmeter-ammeter method: two possible connections

	Connection (a): voltmeter across R	Connection (b): voltmeter across ammeter + R
Ammeter reads	$I = I_R + I_V$ (load current plus voltmeter current)	True current through R
Voltmeter reads	True voltage across R	$V = V_R + V_a$ (includes drop in the ammeter)
Measured value R_m	$R_m = R R_V / (R + R_V)$, which is less than R	$R_m = R + R_a$, which is more than R
Error	$\approx -R / R_V$ (negative)	$\approx +R_a / R$ (positive)
Suitable for	Low resistance ($R \ll R_V$)	High resistance ($R \gg R_a$)

Choice of connection: both errors are equal when $R = \sqrt{(R_a R_V)}$. If the resistance to be measured is smaller than this value, connection (a) is preferred; if it is larger, connection (b) is preferred.

Example: with $R_a = 1 \Omega$ and $R_V = 10 \text{ k}\Omega$, the critical value is $\sqrt{(1 \times 10000)} = 100 \Omega$. For a 20Ω resistor use connection (a); for a $5 \text{ k}\Omega$ resistor use connection (b).

Other medium-resistance methods: Wheatstone bridge (null method, high accuracy), substitution method (unknown replaced by a decade box giving the same current) and the ohmmeter (quick, low accuracy).

5.1.3 High Resistance: Megger

The Megger is a portable insulation tester used to measure very high resistances, such as the insulation resistance between a conductor and earth or between two windings. It combines a hand-driven (or battery-powered) d.c. generator, which supplies a high test voltage, with a ratiometer-type moving-coil meter that is calibrated directly in mega-ohms. Because an insulation must be tested at a voltage close to its working stress, the Megger generates 250 V, 500 V, 1000 V, 2500 V or 5000 V d.c., depending on the model.

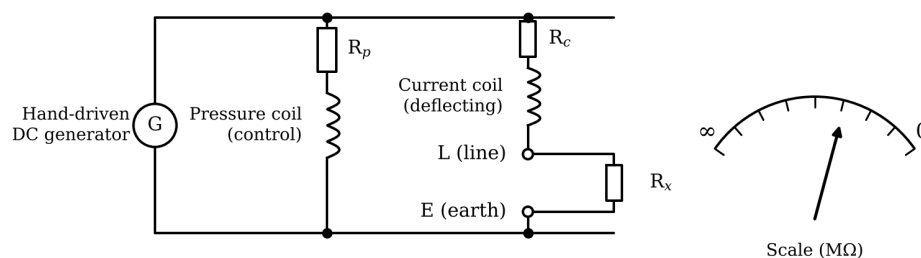


Fig. 5.3 Circuit of a Megger (insulation tester)

Construction

- **Generator:** a hand-cranked d.c. generator with a centrifugal clutch (or an electronic converter in modern types) giving a constant test voltage at the specified cranking speed.
- **Current coil (deflecting coil):** connected in series with a current-limiting resistance R_c and the unknown resistance R_x across the generator.
- **Pressure coil (control coil):** connected in series with a resistance R_p directly across the generator.
- **Moving system:** both coils are mounted on the same spindle at a fixed angle to each other and move in the field of a permanent magnet with shaped pole pieces. **There is no control spring.**
- **Terminals:** Line (L), Earth (E) and Guard (G). The guard terminal bypasses surface leakage currents so that only the volume resistance is measured.

Working

The two coils are wound so that the torques they produce act in opposite directions. The current coil current is $I_c = V / (R_c + R_x)$ and the pressure coil current is $I_p = V / R_p$. The moving system rotates until the two torques balance. At balance the deflection depends only on the ratio I_c / I_p , that is, on R_x , and not on the generator voltage. This is why a change of cranking speed does not affect the reading.

- **Terminals open ($R_x = \infty$):** no current in the current coil, the pressure coil torque turns the pointer to the ∞ end of the scale.
- **Terminals shorted ($R_x = 0$):** the current coil carries the maximum current and turns the pointer to the zero end.
- Because there is no control spring, the pointer floats and rests at any position when the instrument is not in use.

Equipment under test	Suggested Megger voltage	Remarks
Up to 440 V machines, wiring	500 V	Common value for low-voltage installations
660 V to 1.1 kV equipment	1000 V	Motors, cables up to 1.1 kV
3.3 kV to 11 kV equipment	2500 V	HV motors, transformers, cables
Above 11 kV	5000 V	HV cables, switchgear, bushings

Applications and precautions: insulation resistance of cables, motor and transformer windings, switchgear, wiring and earth leakage. Before testing, the equipment must be isolated from the supply and discharged; after testing, the capacitance of the object should be discharged by earthing the terminals. A common rule of thumb for minimum insulation resistance is 1 M Ω per kV of operating voltage, with a minimum of 1 M Ω .

5.1.4 Ohmmeter: Series and Shunt Type

An ohmmeter is a direct-reading instrument for measuring resistance. It consists of a permanent magnet moving-coil (PMMC) meter, a dry cell and adjustable resistors. The scale is marked directly in ohms. Two basic circuits are used: the series type for medium and high resistances and the shunt type for low resistances.

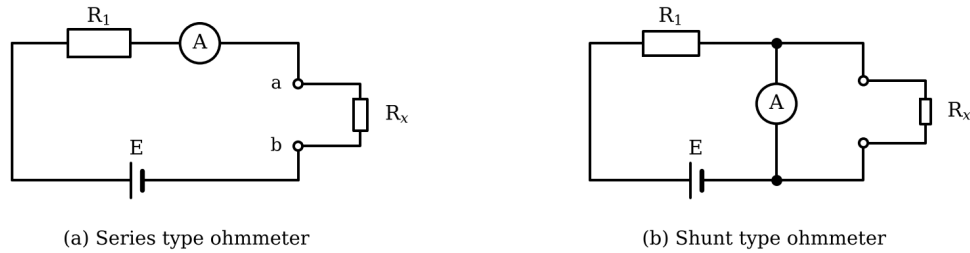


Fig. 5.4 Basic circuits of series and shunt type ohmmeters

Series type ohmmeter

The unknown resistance R_x is connected in series with the meter and the battery. The current is $I = E / (R_1 + R_m + R_x)$. Resistor R_1 limits the current to the full-scale value when the terminals a and b are shorted; it is adjusted (zero adjust) to compensate for the fall of battery voltage with age.

- $R_x = 0$ (terminals shorted): maximum current, full-scale deflection, so **zero ohms is marked at the right-hand end**.
- $R_x = \infty$ (terminals open): no current, so **infinity is marked at the left-hand end**.
- If $R_h = R_1 + R_m$ is the total internal (half-scale) resistance, then $I / I_{fs} = R_h / (R_h + R_x)$; the pointer reads half-scale when $R_x = R_h$.
- The scale is **non-linear and crowded** at the high-resistance end, so readings are most accurate near the middle of the scale.

Shunt type ohmmeter

The unknown resistance R_x is connected in parallel (shunt) with the meter. When $R_x = \infty$ the full battery current flows through the meter, which is adjusted to full-scale; when $R_x = 0$ the meter is short-circuited and the deflection is zero. Hence in this type **zero is at the left-hand end and infinity is at the right-hand end**, the reverse of the series type. It is suitable for low resistances. A switch is provided to disconnect the battery when the instrument is not in use, because the battery would otherwise discharge continuously.

Feature	Series type	Shunt type
Position of R_x	In series with meter	In parallel with meter
Zero of scale	Right (full scale)	Left (no deflection)
Infinity of scale	Left	Right (full scale)
Used for	Medium and high resistance	Low resistance
Battery switch	Not needed (no current with open terminals)	Needed (current flows when open)
Zero adjustment	Short terminals, adjust R_1	Open terminals, adjust for full scale

5.2 Measurement of Inductance Using Anderson Bridge

Anderson's bridge is an a.c. bridge used for the accurate measurement of the self-inductance of a coil in terms of a known standard capacitor and resistors. It is a development of the Maxwell-Wien bridge. Its main advantage is that balance is obtained with a **fixed capacitor** and variable resistors, whereas the Maxwell bridge needs a variable capacitor.

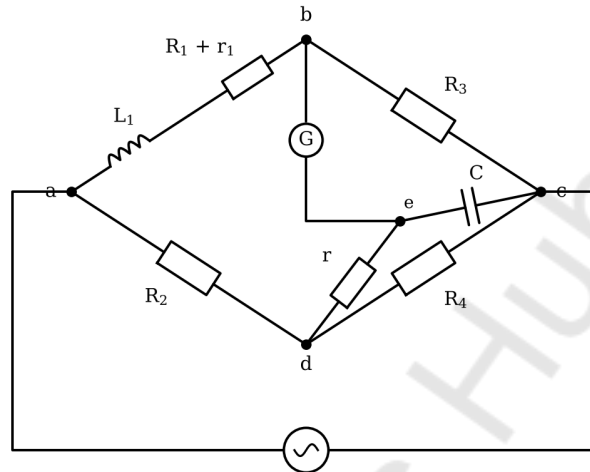


Fig. 5.5 Anderson's bridge

Arms of the bridge

- Arm ab: the unknown inductor L_1 with its own resistance R_1 , plus a variable series resistance r_1 (used when R_1 is small).
- Arm bc: known non-inductive resistance R_3 ; arm ad: R_2 ; arm dc: R_4 .
- A standard capacitor C in series with a variable resistance r forms a branch from point d to point c through the junction e.
- An a.c. source (audio-frequency oscillator) is connected across a and c; a detector (headphone or null amplifier) is connected between b and e.

Balance conditions

At balance the detector current is zero, so the potential of b equals the potential of e. Writing the loop equations and separating the real and imaginary parts gives the two balance equations:

$$R_1 = (R_2 R_3 / R_4) - r_1$$

$$L_1 = C R_3 [r (R_4 + R_2) + R_2 R_4] / R_4$$

The second equation can also be written as $L_1 = C R_3 [R_2 + r (1 + R_2 / R_4)]$. The first equation (resistance balance) is controlled by r_1 , and the second (inductance balance) is controlled by r . The two adjustments are made alternately and converge quickly, which is a practical advantage.

Advantages	Disadvantages
A fixed standard capacitor is enough; no variable capacitor needed.	Balance equations are more complicated than for Maxwell's bridge.
Easy and quick balance because r and r_1 are independent controls; accurate over a wide range (about 1 μ H to 100 H).	The bridge has an extra junction (e), so it is harder to shield and an earthing (Wagner) arrangement is needed for high accuracy.
Can also measure capacitance in terms of an inductance.	Calculation of L_1 requires all of C , R_2 , R_3 , R_4 and r .

Application: accurate measurement of self-inductance of coils, chokes and transformer windings at audio frequency; also used in laboratories to calibrate standard inductors.

5.3 Measurement of Capacitance Using Schering Bridge

Schering's bridge is an a.c. bridge used to measure the capacitance and the **dielectric loss (dissipation factor, $\tan \delta$)** of capacitors, cables, insulators and insulating oils. A real capacitor is represented by an ideal capacitance C_1 in series with a small resistance r_1 that represents its losses.

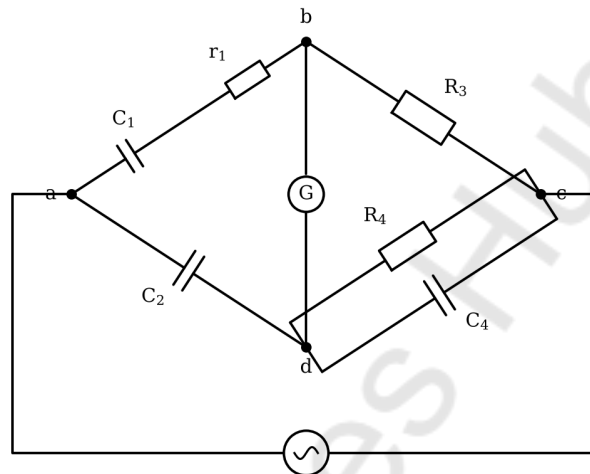


Fig. 5.6 Schering bridge

Arms of the bridge

- Arm ab: the capacitor under test, C_1 with equivalent series resistance r_1 .
- Arm ad: a standard loss-free capacitor C_2 (air or gas-filled for high-voltage work).
- Arm bc: a non-inductive resistance R_3 .
- Arm cd: a non-inductive resistance R_4 in parallel with a variable capacitor C_4 .
- The source is applied across a and c; the detector is connected between b and d.

Balance equations

At balance $Z_{ab} Z_{cd} = Z_{ad} Z_{bc}$, that is

$$(r_1 + 1/j\omega C_1) \cdot R_4 / (1 + j\omega C_4 R_4) = R_3 / j\omega C_2$$

Equating the real parts and the imaginary parts gives:

$$C_1 = C_2 R_4 / R_3 \quad r_1 = R_3 C_4 / C_2$$

The dissipation factor of the capacitor is

$$\tan \delta = D = \omega C_1 r_1 = \omega C_4 R_4$$

If R_4 is kept at a fixed value (for example $10^4/\pi \Omega$) and the supply frequency is 50 Hz, the dial of capacitor C_4 can be calibrated directly in dissipation factor. The quality factor of the capacitor is $Q = 1 / D$.

High-voltage Schering bridge

For testing cables, bushings and insulators at high voltage (up to about 100 kV) the standard capacitor C_2 is a gas-filled (compressed air or nitrogen) capacitor with very low loss and very small change of capacitance with voltage. The high-voltage arms (C_1 and C_2) are separated from the low-voltage arms (R_3 , R_4 , C_4) which the operator handles; spark gaps protect the low-voltage arms from flash-over, and a Wagner earth device removes stray capacitance effects.

Advantages	Limitations
Balance equations are simple and the capacitance balance is independent of frequency.	Needs a very low-loss standard capacitor.
Directly gives $\tan \delta$; suitable for both low and high voltage use.	Stray capacitances affect accuracy, so shielding and Wagner earth are required.

Applications: measurement of capacitance and dielectric loss of capacitors, power cables, bushings and transformer oil; insulation condition monitoring in power apparatus.

5.4 Earth Tester

An earth tester (earth resistance tester) measures the resistance between an earthing electrode (rod, plate, pipe or mat) and the general mass of the earth. A low earth resistance is essential for the safety of persons and equipment, because it ensures that a fault current flows to earth easily and that the protective devices operate quickly.

Working principle

The instrument is basically an ohmmeter of the megger type. It uses the **fall-of-potential (three-point) method**. A current is passed through the earth electrode under test (E) and a remote auxiliary current spike (C); the potential between E and an intermediate potential spike (P) is measured. The earth resistance is then $R_E = V_P / I$. To prevent electrolytic polarisation of the soil, the test current is alternating (obtained from a hand generator with a current reverser or from an electronic oscillator), and the potential reading is rectified in step with the current by a commutator or rectifier.

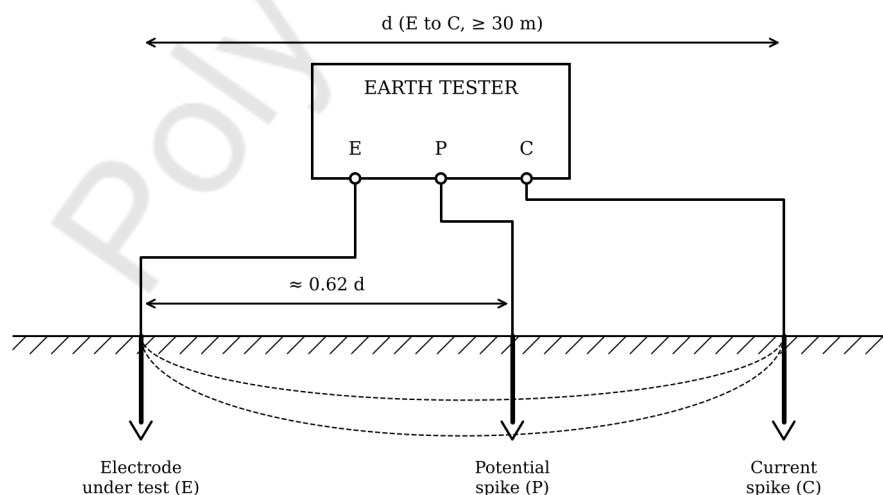


Fig. 5.7 Connection diagram of an earth tester (fall-of-potential method)

Connection and procedure

- 1 Disconnect the electrode under test from the installation so that other earth paths do not affect the reading.

- 2 Drive the current spike C into the soil in a straight line from E at a distance of 30 m or more (at least about 5 times the electrode depth or length).
- 3 Drive the potential spike P in the same line at about 62 % of the E-C distance (the 62 % rule).
- 4 Connect terminals E, P and C of the tester to the electrode and spikes with insulated leads. In a four-terminal tester the terminals C_1 , P_1 are shorted to E when measuring earth resistance.
- 5 Rotate the generator handle (or press the test key) and read the earth resistance directly from the dial.
- 6 Repeat after moving P a few metres closer to and farther from E; the three readings should agree, and their average is taken.

Installation	Typical earth resistance recommended
Large power stations	0.5 Ω or less
Major substations	1 Ω or less
Small substations	2 Ω or less
Neutral and general equipment earthing	About 5 Ω or less (as per IS 3043 guidance; check the applicable code)

Applications: testing the earth electrodes of substations, transformers, generators and buildings, lightning-protection earthing and telecom sites; with a four-terminal instrument and the Wenner method (four equally spaced spikes at distance a) the soil resistivity can also be found from $\rho = 2\pi a R$.

5.5 Digital Multimeter (DMM)

A digital multimeter is a multi-purpose electronic instrument that measures voltage, current and resistance (and often capacitance, frequency, temperature and diode or transistor parameters) and shows the result as a number on a digital display. It replaces the pointer and scale of an analog multimeter by an analog-to-digital converter (ADC) and a decoder, so there is no parallax error and the reading is easy to take.

Working principle

Whatever the quantity being measured, the input is first converted into a proportional **d.c. voltage** of suitable size. This voltage is then converted to a digital number by the ADC, counted, decoded and displayed. The conversions used are:

Quantity	Conversion before the ADC
D.C. voltage	Input attenuator (potential divider) brings the voltage within the ADC range; range is selected manually or by auto-ranging.
A.C. voltage	AC-DC converter (precision rectifier, average-responding, or a true-RMS converter) gives a d.c. voltage proportional to the r.m.s. value.
Current (d.c./a.c.)	Current flows through a precision shunt resistor; the voltage drop across the shunt is measured.
Resistance	A constant current from an internal source flows through the unknown resistance; the voltage drop $V = I R$ is measured.

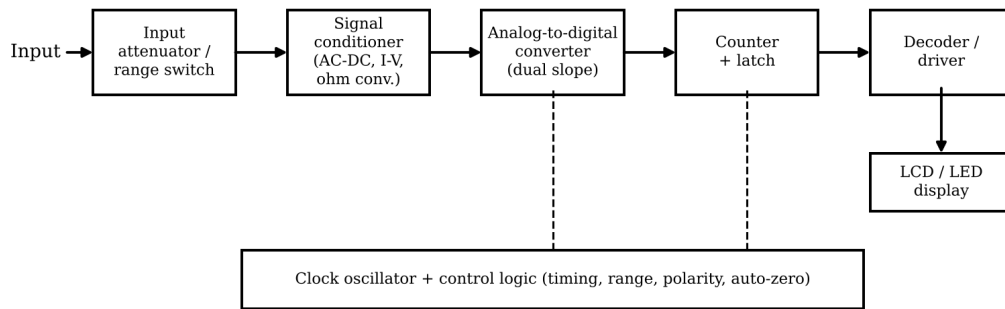


Fig. 5.8 Basic block diagram of a digital multimeter

Block diagram explanation

- **Input attenuator / range switch:** a high-impedance divider (typically 10 MΩ input resistance) that selects the range.
- **Signal conditioner:** contains the AC-DC converter, the current-to-voltage shunts and the constant-current source for resistance measurement.
- **ADC:** most DMMs use the **dual-slope integrating ADC**. The capacitor of an integrator is charged by the unknown voltage V_{in} for a fixed time T_1 , and is then discharged by a reference voltage V_{ref} of opposite polarity. The discharge time is $T_2 = T_1 V_{in} / V_{ref}$, so the number of clock pulses counted during T_2 is proportional to V_{in} . If T_1 is a multiple of the mains period (20 ms), the 50 Hz hum is averaged out.
- **Counter and latch:** count the clock pulses and hold the result steady.
- **Decoder / driver and display:** convert the binary code into seven-segment signals for the LCD or LED display.
- **Clock and control logic:** control the timing, polarity, auto-zero and range.

Specifications and digits

A “3½ digit” display has three full digits (0 to 9) and one half digit that can only be 0 or 1, so the maximum display is 1999. A 4½ digit meter reads up to 19999. Typical accuracy is $\pm(0.5\% \text{ of reading} + 1 \text{ digit})$ for a hand-held meter and better than $\pm 0.01\%$ for a bench instrument. Input impedance is usually 10 MΩ for voltage ranges.

Digital multimeter	Analog multimeter
Numerical display, no parallax error	Pointer and scale, parallax and reading error
High input impedance (about 10 MΩ) so loading error is small	Lower input impedance (sensitivity in Ω/V), loading effect is larger
Automatic polarity, auto-ranging and over-range indication	Polarity and range selected by the user
Higher accuracy and resolution	Lower accuracy
Needs battery or supply for the electronics	Voltage and current ranges work without a battery

Applications: measurement of voltage, current and resistance in electrical and electronic circuits, continuity and diode testing, fault finding in domestic and industrial wiring, battery checking, and, with extra functions, measurement of capacitance, frequency, temperature and transistor gain.

5.6 L-C-R Meter

An L-C-R meter is a digital instrument that directly measures the inductance (L), capacitance (C) and resistance (R) of a component, together with related quantities such as the quality factor Q, dissipation factor D, equivalent series resistance (ESR) and impedance Z. Modern instruments use an automatic balancing technique and a microprocessor, so no manual bridge balancing is needed.

Working principle

A sinusoidal test signal of fixed frequency (for example 100 Hz, 120 Hz, 1 kHz, 10 kHz or 100 kHz) and fixed level is applied to the component under test. The voltage across the component and the current through it (converted to a voltage by a range resistor and I-V converter) are measured. A **phase-sensitive detector**, driven by the reference signal from the oscillator, splits the response into an in-phase part and a quadrature part, which are converted by the ADC and used by the microprocessor to compute the following.

$$|Z| = V / I \quad R = |Z| \cos \theta \quad X = |Z| \sin \theta$$

$$L = X / \omega \quad C = 1 / (\omega X) \quad Q = X / R \quad D = 1 / Q$$

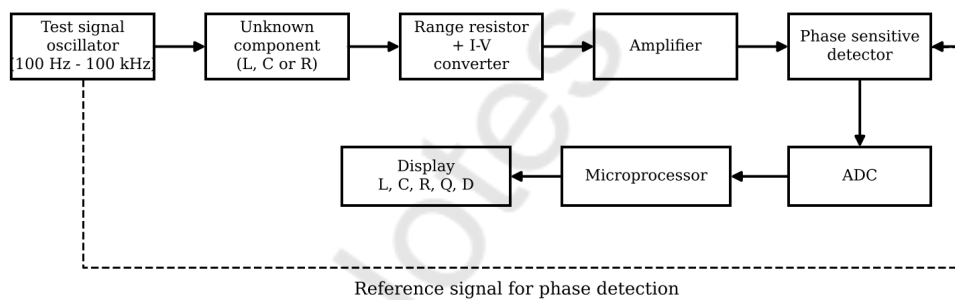


Fig. 5.9 Basic block diagram of an L-C-R meter

Block diagram explanation

- **Test signal oscillator:** supplies the a.c. test signal and the reference signal.
- **Range resistor and I-V converter:** sense the current in the unknown component; the range resistor is switched to suit the size of the impedance.
- **Amplifier and phase-sensitive detector:** amplify the signals and separate the resistive and reactive components.
- **ADC and microprocessor:** digitise the results, apply the formulas, select the series or parallel equivalent circuit and correct the errors.
- **Display:** shows L, C, R, Q, D or ESR with the units and range.

Applications: incoming inspection and sorting of inductors, capacitors and resistors; checking the ESR of electrolytic capacitors; measuring winding inductance of chokes and transformers; production testing and design verification in electronics laboratories. A four-terminal (Kelvin) test fixture is used to avoid lead errors for small impedances.

5.7 Digital Frequency Meter

A digital frequency meter (frequency counter) measures the frequency of a periodic signal by counting the number of cycles that occur in an accurately known interval of time, and displays the result directly in Hz, kHz or MHz.

Working principle

If N pulses are counted during a gate time T , the frequency is

$$f = N / T$$

The unknown signal is amplified and shaped into a train of square pulses by a Schmitt trigger so that one pulse is produced per cycle. A crystal oscillator and a chain of decade dividers produce a very accurate gate time (for example 1 s, 0.1 s or 10 ms). A gate (AND gate) is opened by the gate-control flip-flop for exactly this time, and the decade counter counts the pulses that pass. At the end of the gate time the count is stored in the latch, decoded and displayed. The counter is then reset and the cycle repeats.

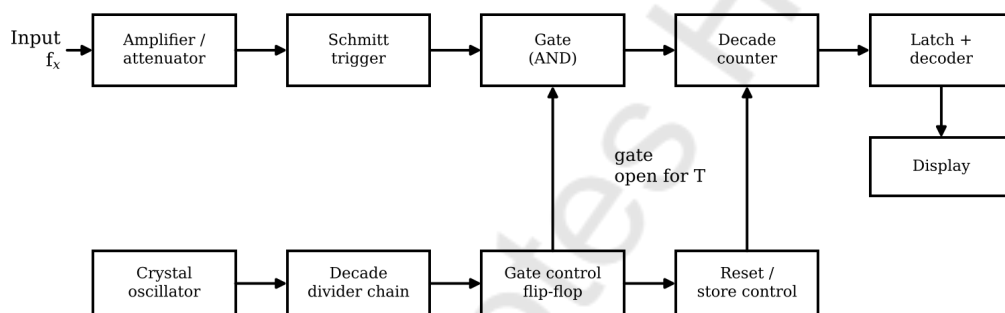


Fig. 5.10 Basic block diagram of a digital frequency meter

Gate time T	Display for 1 MHz input	Resolution
10 ms	1000.00 kHz	100 Hz
0.1 s	1000.0 kHz	10 Hz
1 s	1000.000 kHz	1 Hz
10 s	1000.0000 kHz	0.1 Hz

A longer gate time gives better resolution but a slower reading. The main errors are the ± 1 count error (gate not synchronised with the signal) and the crystal oscillator error. For low frequencies the meter can be used in **period mode**: the input signal opens the gate for one period and the counter counts clock pulses; the frequency is then found from $f = 1 / T_{\text{measured}}$.

Applications: measurement of the frequency of oscillators, signal generators, power supply (50 Hz) and radio transmitters; calibration of equipment; counting of events and pulses; measurement of speed of rotation using a pickup.

5.8 Phase Sequence Indicator

The phase sequence of a three-phase supply is the order in which the phase voltages reach their positive peaks (for example R-Y-B). A phase sequence indicator is used to find this order. It is important because:

- the direction of rotation of a three-phase induction motor depends on the phase sequence;
- before connecting an alternator in parallel with a bus-bar (synchronising), the phase sequence of both must be the same;
- three-phase meters, transformers in parallel and phase-sensitive protection relays need the correct sequence.

Two types of indicator are used: the **static type** (lamp and capacitor) and the **rotating type** (small induction motor).

Static (lamp) type

Two identical lamps and a capacitor are connected in star to the three lines R, Y and B. The capacitor is connected in the R line and the lamps in the Y and B lines, as in the figure. The star point is floating. The capacitor reactance is chosen equal to the resistance of each lamp. Because of the phase shift produced by the capacitor, the voltage across the two lamps is unequal and one lamp glows brighter than the other.

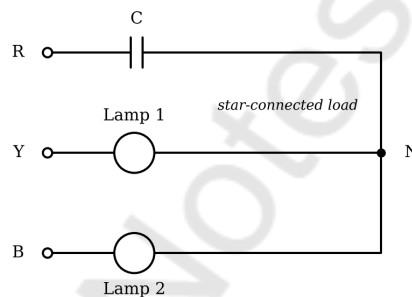


Fig. 5.11 Lamp type phase sequence indicator (basic circuit)

Analysis for the sequence R-Y-B with the capacitor in the R phase shows that the voltage across the lamp in the Y line is about 1.5 times the phase voltage, while the voltage across the lamp in the B line is only about 0.4 times the phase voltage. Hence the **lamp connected to the phase that follows the capacitor phase in the sequence glows brighter**. If the sequence is reversed (R-B-Y) the brighter lamp is the one in the B line. The terminals are therefore marked so that the brighter lamp tells whether the sequence is R-Y-B.

Rotating type

The rotating type has three coils mounted at 120° to each other around a light aluminium disc (or drum). When the coils are connected to the three-phase supply they produce a rotating magnetic field, which drives the disc by eddy-current torque. The disc rotates in the direction marked by an arrow if the terminals R, Y, B are connected in the correct sequence R-Y-B, and in the opposite direction for the reverse sequence.

Application: checking the connection of motors, alternators and synchronising panels, installation and testing of three-phase supplies, and ensuring correct rotation of pumps, fans and lifts.

5.9 Power Factor Meter

A power factor meter indicates the power factor ($\cos \phi$) of a circuit directly on its scale. The scale is marked with the power factor from zero lagging through unity to zero leading. The meters used for power frequency circuits are of the electrodynamicmeter (dynamometer) type.

Single phase dynamometer type power factor meter

Construction

- **Fixed coils:** two coils connected in series that carry the load current I . They produce a magnetic field proportional to I and in phase with I .
- **Moving coils:** two identical coils M_1 and M_2 mounted on the same spindle at 90° to each other. M_1 is connected in series with a non-inductive resistor R across the supply, so its current is in phase with the voltage V . M_2 is connected in series with an inductor L across the supply, so its current lags V by about 90° .
- **No controlling spring:** the moving system takes up the position where the two torques balance; current is led in by ligaments that exert no controlling torque.

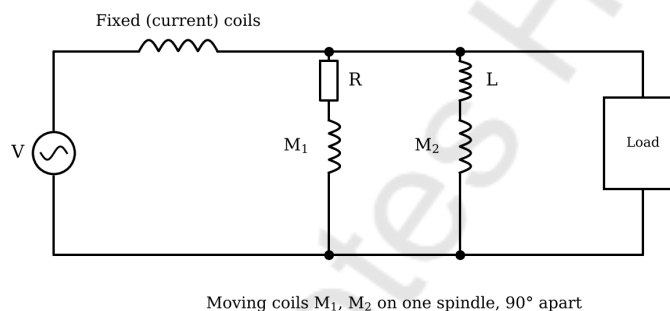


Fig. 5.12 Single phase dynamometer type power factor meter

Working principle

Let the load current I lag the voltage by the angle ϕ , and let θ be the angular position of the moving system. The torques on the two moving coils act in opposite directions and are

$$T_1 = K I I_1 \cos \phi \cdot \sin \theta \quad T_2 = K I I_2 \sin \phi \cdot \cos \theta$$

Since the moving coil currents are equal in magnitude ($I_1 = I_2$, the resistor R and the reactance of L are made equal), the torques balance when $\cos \phi \sin \theta = \sin \phi \cos \theta$, that is $\tan \theta = \tan \phi$, or $\theta = \phi$. The pointer deflection is therefore equal to the phase angle of the load, and the scale can be marked directly in power factor $\cos \phi$.

Three phase dynamometer type power factor meter

The construction is similar to the single-phase type, but the two moving coils are mounted **120° apart** on the spindle. The fixed (current) coil is connected in one line of the three-phase supply. The two moving (pressure) coils are connected, through equal non-inductive resistors, across different pairs of lines so that their currents differ in phase by 120° , as in the figure. No inductor is needed because the 120° phase difference is obtained from the supply itself. For a balanced load the moving system again takes up a position where the torques balance, and the deflection indicates the load power factor directly.

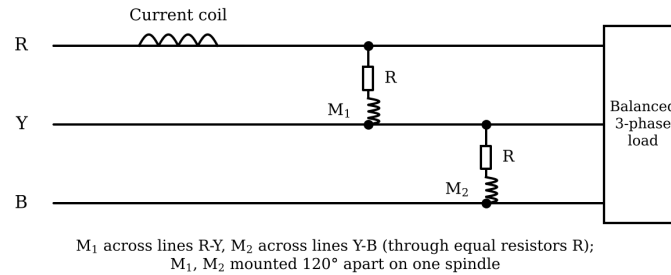


Fig. 5.13 Three phase dynamometer type power factor meter (schematic)

Features and limitations

- Direct indication of power factor, useful for monitoring power factor improvement equipment.
- Readings are affected by frequency and waveform changes because the circuits use R and L.
- The meter needs a minimum load current (about 10 % of rating) to give a reliable reading; with no current the pointer rests anywhere.
- In the three-phase type the load must be balanced for the reading to be correct.

5.10 Synchroscope

A synchroscope is an instrument that indicates whether an incoming alternator (or supply) is ready to be connected in parallel with the live bus-bars, and whether the incoming machine is running faster or slower than the bus. Before closing the circuit breaker, these conditions must be met: equal voltages, equal frequencies, same phase (zero phase difference), same phase sequence and similar waveform. The synchroscope checks frequency and phase.

Working principle (electrodynamometer type)

The fixed coils are connected, through an inductor, across the bus-bars (running supply), so that their current lags the bus voltage by almost 90° . The moving coil is connected, through a resistor, across the incoming machine, so its current is in phase with the incoming-machine voltage. The torque on the moving coil depends on the phase angle α between the bus voltage and the machine voltage; the moving coil and its pointer take up the position corresponding to α and turn through 360° as α changes through 360° .

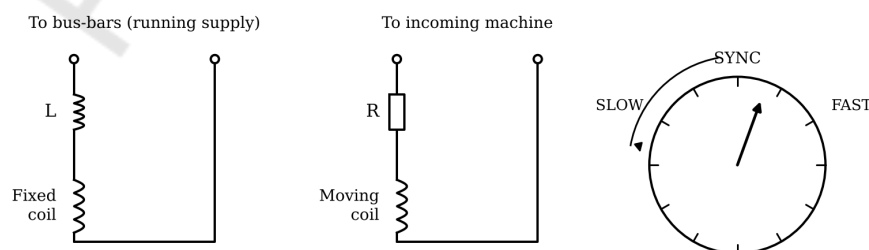


Fig. 5.14 Synchroscope (dynamometer type): coil connections and dial

- If the two frequencies differ, α changes continuously and the **pointer rotates steadily**, at a speed equal to the difference of the two frequencies (the slip frequency).

- **Clockwise rotation** (marked FAST) means the incoming machine is running faster than the bus; **anticlockwise rotation** (marked SLOW) means it is slower.
- When the frequencies are equal the pointer stops. If it stops at the top (vertical, marked SYNC) the phase difference is zero and the voltages are in phase.
- The speed of the incoming machine is adjusted by its governor until the pointer moves very slowly. The breaker is closed a little before the pointer reaches the vertical position, to allow for the closing time of the breaker.

Other forms: the moving-iron synchroscope uses a rotating-field principle; simple installations also use **synchronising lamps** (dark-lamp method, bright-lamp method and the two-bright one-dark method), which show the phase difference by the flickering of lamps.

Applications: parallel operation of alternators in power stations, connection of an alternator to the grid, and synchronising of a captive generator with the utility supply.

5.11 Tri-Vector Meter

A tri-vector meter is a three-phase energy meter which measures and records the **active energy (kWh)**, **reactive energy (kVARh)** and **apparent energy (kVAh)** together, and normally also the maximum demand in kVA. The three quantities form a power triangle and are related as vectors, hence the name “tri-vector”.

Working principle

The meter contains an active-energy measuring element, which responds to $V I \cos \phi$, and a reactive-energy measuring element, in which the voltage is shifted by 90° so that it responds to $V I \sin \phi$. The outputs of the two elements are combined by a **vector summation** to give the apparent energy. In older electromechanical meters this is done by a mechanical differential or a cross-coil arrangement; in modern static (electronic) meters, voltage and current are sampled by an ADC and a microcontroller computes all quantities digitally.

$$kVA = \sqrt{(kW^2 + kVAR^2)} \quad \text{power factor} = kW / kVA = \cos \phi$$

Quantity	Symbol and unit	Expression
Active power / energy	kW / kWh	$V I \cos \phi$
Reactive power / energy	kVAR / kVARh	$V I \sin \phi$
Apparent power / energy	kVA / kVAh	$V I = \sqrt{(kW^2 + kVAR^2)}$
Power factor	$\cos \phi$	kWh / kVAh

Applications: billing of high-tension (HT) industrial and commercial consumers on a kVAh and maximum demand basis; monitoring the power factor and reactive power; checking the effect of capacitor banks; energy audits and load studies in industries and substations.

5.12 Cathode Ray Oscilloscope (CRO)

The cathode ray oscilloscope is the most versatile instrument of electrical and electronic measurement. It displays a graph of an electrical signal (voltage) against time on the screen of a cathode ray tube, and so allows the shape, amplitude, period, frequency and phase of a signal to be seen and measured. It has a very high input impedance, a very wide frequency range and an almost instantaneous response, because the moving element is an electron beam which has negligible inertia.

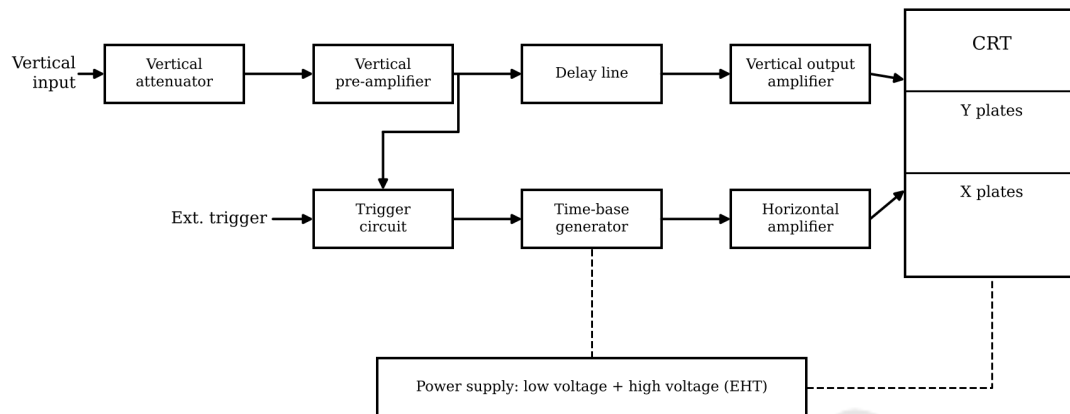


Fig. 5.15 Basic block diagram of a cathode ray oscilloscope

Block diagram explanation

- **Vertical attenuator and pre-amplifier:** the input signal passes through a compensated attenuator (volts/div switch) and a high-input-impedance pre-amplifier.
- **Delay line:** delays the signal by about $0.2 \mu\text{s}$ so that the beginning of a fast signal can be seen; the delay gives the trigger and time-base circuits time to start the sweep before the signal reaches the plates.
- **Vertical output amplifier:** a push-pull amplifier that drives the vertical (Y) deflection plates.
- **Trigger circuit:** takes a sample of the vertical signal (internal), the line frequency or an external signal and produces a pulse at the chosen level and slope to start the sweep.
- **Time-base generator:** produces the linear sawtooth voltage that moves the spot horizontally at a uniform speed.
- **Horizontal amplifier:** amplifies the sawtooth (or an external X signal in X-Y mode) and drives the X plates.
- **CRT and power supply:** the cathode ray tube and the low-voltage and extra-high-voltage supplies that it needs.

5.12.1 Single Beam / Single Trace and Dual Trace CRO

A **single beam, single trace** oscilloscope has one electron gun and one vertical input channel, so it can display only one waveform at a time. To compare two signals (for example input and output of an amplifier) the signals must be viewed one after the other, which makes it impossible to see the exact time relation between them.

A **dual trace** oscilloscope displays two waveforms at the same time on the screen of a single-gun CRT. It has two vertical channels (CH A and CH B), each with its own attenuator and pre-amplifier, and an **electronic switch** that connects the two channels alternately to the common vertical amplifier. The time base and the horizontal amplifier are common.

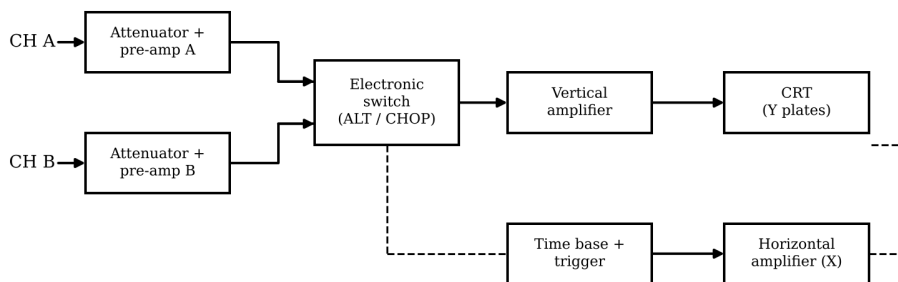


Fig. 5.16 Block diagram of a dual trace oscilloscope

Mode	Action of the electronic switch	Best used for
ALT (alternate)	Switches between CH A and CH B at the end of each sweep; one complete trace of A is drawn, then one of B.	High-frequency signals (short sweep times), when the sweep is faster than the flicker rate.
CHOP	Switches rapidly (typically 100 kHz to 1 MHz) between A and B during a single sweep, so each trace is made of tiny segments.	Low-frequency signals (slow sweep times); at fast sweeps the chopping dots become visible.

A **dual beam** oscilloscope, in contrast, has two separate electron guns and two sets of Y plates in one tube, but is more costly and is not as common as the dual trace type.

5.12.2 Digital Storage Oscilloscope (DSO): Basic Block Diagram and Working

A digital storage oscilloscope converts the input signal into digital form, stores it in memory, processes it with a microprocessor and then displays it on a raster-scan (LCD) screen. The waveform is therefore no longer limited by the persistence of a phosphor screen and can be kept as long as required.

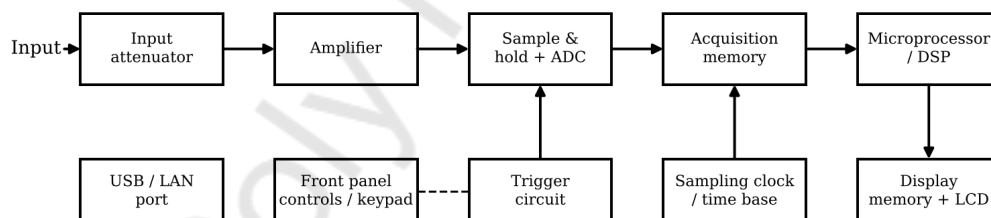


Fig. 5.17 Basic block diagram of a digital storage oscilloscope

Working

- 1 The input is attenuated and amplified by the vertical system to a suitable level.
- 2 A **sample-and-hold circuit** and an **analog-to-digital converter (ADC)** sample the signal at a rate fixed by the sampling clock (time base) and convert each sample into an 8-bit (or higher) number.
- 3 The **trigger circuit** decides which samples are kept: the memory is filled continuously and, after the trigger event, acquisition stops after a set number of points. Because of this, the signal **before** the trigger (pre-trigger information) can also be seen.

- 4 The digital values are held in the **acquisition memory**. The **microprocessor / digital signal processor** performs scaling, averaging, interpolation, cursor measurements, FFT and similar operations and moves the result to the display memory.
- 5 The **display memory** is read repeatedly to refresh the LCD screen. Data can also be exported through USB or LAN.

Sampling: for a repetitive signal the scope can use *equivalent-time sampling* to build up the waveform from many cycles; for a single event, *real-time sampling* is required, with the sampling rate at least 2 times (preferably 5 to 10 times) the highest frequency in the signal, by the Nyquist criterion.

Analog CRO	Digital storage oscilloscope
Real-time display using CRT, no storage (except special storage tubes)	Signals are digitised, stored and displayed on LCD
Cannot capture a single, non-repetitive event	Captures single-shot events and transients; pre-trigger viewing
Bandwidth limited by the amplifiers and CRT	Bandwidth limited by the ADC and sampling rate
Measurements are read off the graticule	Automatic measurements, cursors, averaging, FFT and printing
Waveform is gone when the signal is removed	Waveform can be saved, recalled and transferred to a computer

5.12.3 Cathode Ray Tube, Electrostatic Deflection, Amplifiers and Time Base

Cathode ray tube (CRT)

The CRT is a highly evacuated glass tube containing an electron gun, a deflection system and a fluorescent screen.

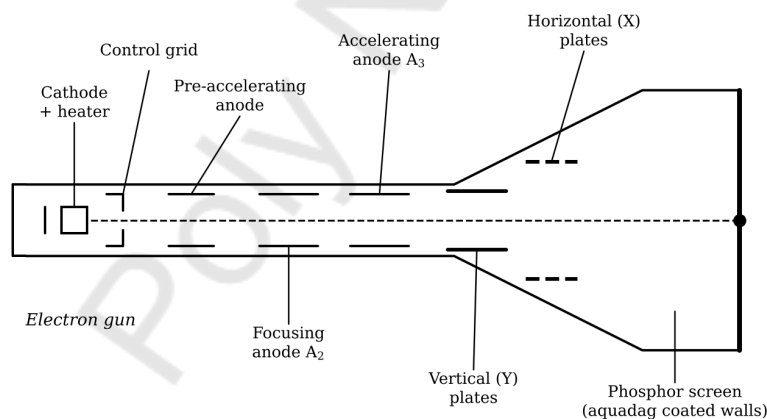


Fig. 5.18 Cathode ray tube with electrostatic deflection

- **Electron gun:** an indirectly heated *cathode* coated with oxide emits electrons. The *control grid* (a cylinder at a negative potential) controls the number of electrons in the beam and so the brightness (intensity control). The *pre-accelerating anode*, *focusing anode* and *accelerating anode* form an electrostatic lens that focuses the beam into a fine spot (focus control) and accelerate it to a high speed.
- **Deflection plates:** two pairs of parallel plates at right angles: the *vertical (Y) plates* move the spot up and down and the *horizontal (X) plates* move it left and right.

- **Fluorescent screen:** the inside of the screen is coated with a phosphor (for example P31, green, medium persistence) which emits light where the electron beam strikes it. An *aquadag* (graphite) coating on the inside walls collects the secondary electrons and returns them to the supply.
- The beam is accelerated by a high voltage (a few kV, and in some tubes an additional post-deflection accelerating voltage) to give a bright trace.

Electrostatic deflection

Let V_a be the accelerating voltage, V_d the voltage applied between a pair of plates of length l separated by distance d , and L the distance from the centre of the plates to the screen. An electron leaves the anode with velocity $v = \sqrt{2eV_a / m}$. Between the plates it experiences a transverse force eV_d / d , and so leaves the plates at an angle θ with $\tan \theta = V_d l / (2 d V_a)$. The deflection on the screen is therefore

$$D = L \tan \theta = l L V_d / (2 d V_a)$$

$$\text{Deflection sensitivity } S = D / V_d = l L / (2 d V_a) \text{ (metres per volt)}$$

The reciprocal $1/S$ is the *deflection factor* (volts per metre or volts per division). The deflection is directly proportional to the deflecting voltage and inversely proportional to the accelerating voltage; a higher V_a gives a brighter but less sensitive trace.

Vertical amplifier

A signal of a few millivolts cannot deflect the spot visibly, so the vertical channel contains an amplifier. It consists of an input **attenuator** (a compensated divider that presents about 1 M Ω in parallel with 20 pF), a **pre-amplifier** with FET input and gain control, the **delay line**, and a **push-pull output amplifier**. The bandwidth and rise time of this amplifier determine the bandwidth of the oscilloscope.

Horizontal amplifier

The horizontal amplifier amplifies the sawtooth voltage from the time-base generator (or an external signal in the X-Y mode) so that it can deflect the beam across the whole screen. It also contains the horizontal position control and a magnification switch ($\times 10$ sweep).

Time base generator

The time base produces a **sawtooth voltage** that rises linearly with time, moving the spot across the screen at constant speed (the sweep or trace), and then falls quickly to zero (the retrace or flyback) during which the beam is blanked. It is built with a relaxation oscillator (UJT or thyatron in older sets) or, in modern oscilloscopes, a Miller integrator. The sweep speed is set by the TIME/DIV switch, which changes the charging resistor and capacitor.

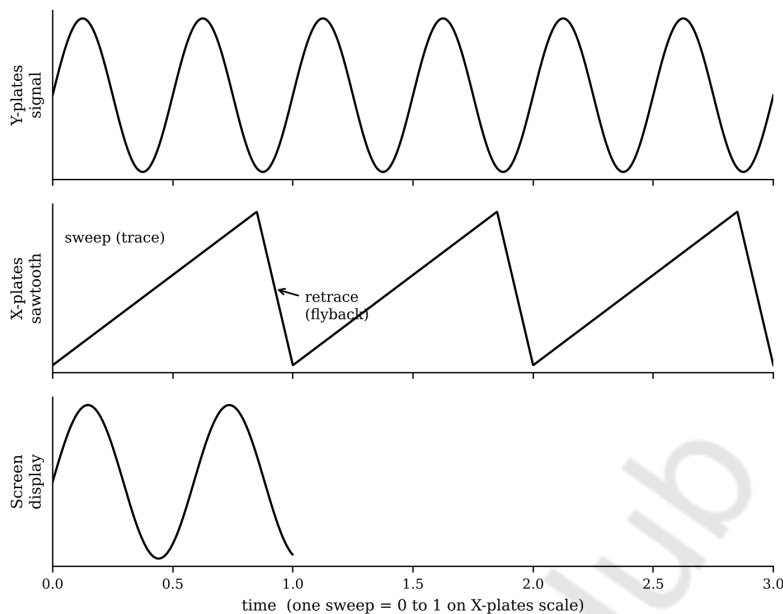


Fig. 5.19 Sawtooth sweep applied to the X plates produces a time-axis display of the Y signal

- **Stationary display:** a steady picture is obtained only if the sweep period is an exact multiple of the signal period ($T_{\text{sweep}} = n T_{\text{signal}}$). This is achieved by **synchronisation or triggering**.
- **Triggered sweep:** the sweep starts only when a trigger pulse arrives, so every trace starts at the same point of the signal. The trigger source (INT, EXT, LINE), level and slope (+ or -) are selectable; AUTO mode keeps a base line on the screen when there is no signal.

5.12.4 Measurements Using a CRO; Lissajous Figures

Voltage and amplitude

With the Y-input coupled to the signal, read the vertical height in divisions and multiply by the VOLTS/DIV setting (and by 10 if a $\times 10$ probe is used).

$$V_{pp} = (\text{number of vertical divisions peak to peak}) \times (\text{VOLTS/DIV})$$

$$V_m = V_{pp} / 2 \quad V_{rms} = V_m / \sqrt{2} \quad (\text{for a sine wave})$$

Time period and frequency

$$T = (\text{number of horizontal divisions for one cycle}) \times (\text{TIME/DIV}) \quad f = 1 / T$$

Example: a sine wave has 4 divisions peak to peak at 2 V/div and one cycle occupies 5 divisions at 0.2 ms/div. Then $V_{pp} = 8 \text{ V}$, $V_m = 4 \text{ V}$, $V_{rms} = 2.83 \text{ V}$, $T = 1 \text{ ms}$ and $f = 1 \text{ kHz}$.

Phase angle

(a) Dual-trace method: display both signals, with the same TIME/DIV, and measure the horizontal distance Δt between corresponding points (for example zero crossings) and the period T : $\phi = (\Delta t / T) \times 360^\circ$. **(b) Ellipse (X-Y) method:** apply one signal to the X input and the other to the Y input. An ellipse is obtained; if A is the length of the ellipse cut by the vertical axis and B is the maximum vertical height of the ellipse, then $\sin \phi = A / B$. A straight line indicates 0° or 180° and a circle indicates 90° (equal amplitudes).

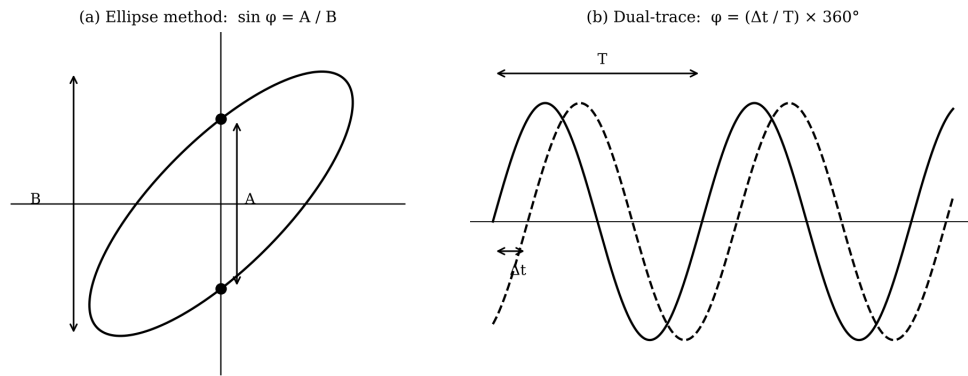


Fig. 5.20 Phase measurement by (a) ellipse method and (b) dual-trace method

Lissajous figures

When two sinusoidal voltages are applied to the X and Y plates at the same time (X-Y mode, time base off), the spot traces a closed pattern called a Lissajous figure. The shape depends on the frequency ratio and the phase difference. The unknown frequency is found by comparing the figure with a known frequency applied to the other plates.

$$f_y / f_x = (\text{number of points where the figure touches a horizontal line at the top}) / (\text{number of points where it touches a vertical line at the side})$$

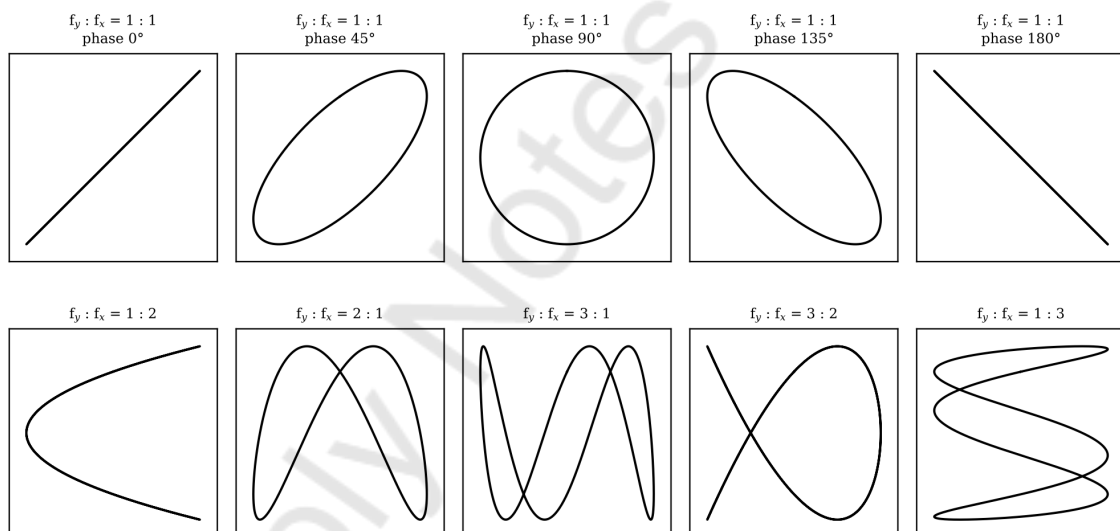


Fig. 5.21 Lissajous figures: (top) equal frequencies with different phase; (bottom) different frequency ratios

For equal frequencies the figure is a straight line (0° or 180°), an ellipse (other angles) or a circle (90° , equal amplitudes); a ratio such as $2 : 1$ gives a figure of eight, and the figure becomes more complex as the ratio increases. If the ratio is not exact, the figure appears to rotate slowly, the speed of rotation being the difference between the two frequencies.

5.12.5 Specifications of a CRO

Specification	Meaning	Typical value
Bandwidth	Frequency at which the response falls by 3 dB; determines the highest usable signal frequency	D.C. to 20 MHz, 100 MHz, 500 MHz and above
Rise time	Time of the response to a step input (10 % to 90 %); $t_r = 0.35 / \text{bandwidth}$	17.5 ns for 20 MHz
Vertical sensitivity	Smallest voltage per division that can be set	1 mV/div to 5 V/div or 10 V/div
Time base range	Range of sweep speeds	0.1 $\mu\text{s}/\text{div}$ to 0.5 s/div, $\times 10$ magnifier
Input impedance	Resistance and capacitance seen by the signal source	1 M Ω in parallel with 15-30 pF; with 10:1 probe 10 M Ω and about 10 pF
Accuracy	Error of the vertical and horizontal calibration	$\pm 3\%$ (analog)
Number of channels	Number of independent vertical inputs	1, 2 or 4
Maximum input voltage	Largest safe input (d.c. + peak a.c.)	300 V to 400 V (more with probe)
Screen size	Display area, usually 8×10 divisions	8×10 divisions (1 div = 1 cm)
Trigger	Source, mode and coupling facilities	INT/EXT/LINE, AUTO/NORMAL, level and slope
DSO only: sampling rate and memory depth	Samples per second and number of points stored	1 GS/s, 1 M points or more; 8-bit resolution

5.13 Signal Generator

A signal generator is a source of sinusoidal (and sometimes modulated) signals of accurately known frequency and adjustable amplitude, used for testing, aligning and measuring electronic circuits. The output frequency may be in the audio range (20 Hz to 20 kHz) or the radio-frequency range (100 kHz up to many MHz or GHz); a standard (RF) signal generator also provides amplitude or frequency modulation.

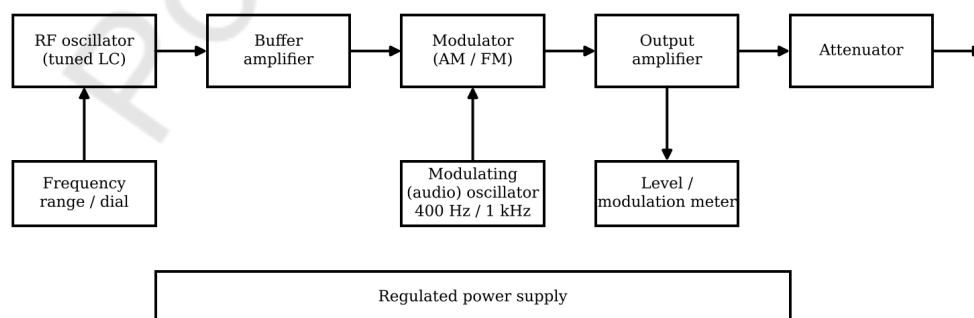


Fig. 5.22 Basic block diagram of a (standard) signal generator

Block diagram explanation

- **RF oscillator:** a tuned-circuit (LC) oscillator that generates the carrier frequency; its frequency is set by the range switch and tuning dial. Its stability decides the frequency accuracy.

- **Buffer amplifier:** isolates the oscillator from the load so that changes in the load or modulation do not pull the frequency.
- **Modulating (audio) oscillator:** produces a fixed audio signal (commonly 400 Hz or 1 kHz) that is used to modulate the carrier.
- **Modulator:** amplitude-modulates (or frequency-modulates) the carrier; the percentage modulation is shown on the modulation meter.
- **Output amplifier and attenuator:** adjust the output level from microvolts to about 1 V and keep the output impedance constant (often 50 Ω or 75 Ω); a level meter indicates the output voltage.
- **Power supply:** regulated supply for all stages.

Applications: testing and alignment of radio and television receivers (sensitivity, selectivity and image rejection); measuring the gain and frequency response of amplifiers; testing filters and bandwidth; calibration of other instruments; providing a test signal for transmission-line and antenna measurements.

5.14 Function Generator

A function generator produces several standard waveforms, mainly **sine, square and triangular waves** (and often ramp and pulse), over a wide frequency range, typically 0.01 Hz to a few MHz. It is a general-purpose laboratory source for testing circuits in the audio and low radio frequency range.

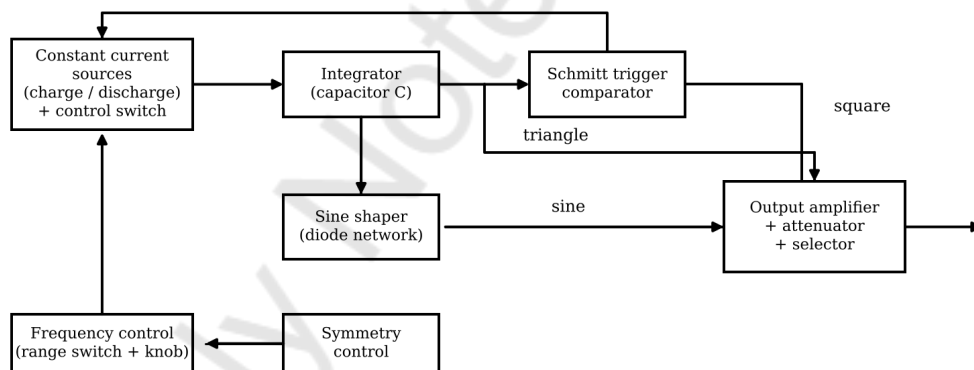


Fig. 5.23 Basic block diagram of a function generator

Working

- Two **constant-current sources** alternately charge and discharge a capacitor C through a switch. Because the current is constant, the voltage across C rises and falls **linearly**, producing a triangular wave at the output of the **integrator**.
- The triangular wave is applied to a **Schmitt trigger (comparator)**. When the triangle reaches the upper threshold, the Schmitt trigger changes state and reverses the current sources (discharging the capacitor); at the lower threshold it changes back. The Schmitt trigger output is a **square wave** of the same frequency.
- The triangular wave is passed through a **sine-wave shaping circuit** (diode network that progressively rounds the peaks) to produce an approximate **sine wave** (distortion about 1 %).

- A selector switch connects one of the three waveforms to the **output amplifier** with amplitude control, attenuator and d.c. offset control.
- The frequency is varied by changing the value of the charging current (frequency knob) and the capacitor (range switch).

Function of the symmetry control

The symmetry (duty cycle) control changes the ratio of the charging current to the discharging current of the capacitor. When both currents are equal, the rise time equals the fall time, so the triangle is symmetric and the square wave has a 50 % duty cycle. When the currents are unequal, the rise and fall times differ while the frequency can be kept constant:

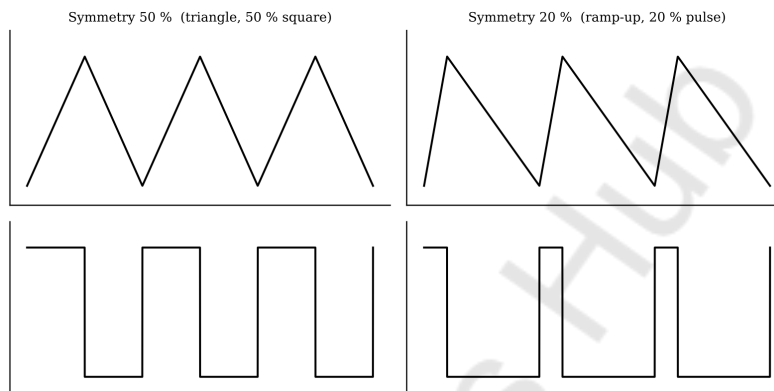


Fig. 5.24 Effect of the symmetry control on the triangular wave and the square wave

Symmetry setting	Triangular output	Square output
50 % (equal currents)	Symmetric triangle	Square wave, 50 % duty cycle
Less than 50 %	Ramp with fast fall (sawtooth)	Pulse train with narrow pulses
More than 50 %	Ramp with slow fall (reverse sawtooth)	Pulse train with wide pulses

With the symmetry control a function generator can therefore also deliver sawtooth (ramp) and rectangular pulse waveforms, which are needed for testing time-base circuits and digital logic.

Signal generator	Function generator
Produces sine wave (AF or RF) with AM / FM modulation	Produces sine, square, triangular (and ramp, pulse) waveforms
Frequency range up to many MHz or GHz	Usually 0.01 Hz to a few MHz
Mainly for receiver and RF testing	General laboratory use, digital and analog circuit testing

Applications: testing and servicing of amplifiers, filters and oscillators; frequency response and transient-response measurements; generating clock and trigger pulses for digital circuits; driving a CRO time base or X-Y display; testing of audio equipment and control systems.

Quick Reference: Important Formulas

Topic	Formula / condition
Kelvin double bridge	$R = (P/Q) S$, when $P/Q = p/q$
V-A method, connection (a)	$R_m = R R_v / (R + R_v)$; error $\approx -R / R_v$
V-A method, connection (b)	$R_m = R + R_a$; error $\approx + R_a / R$; critical $R = \sqrt{(R_a R_v)}$
Series ohmmeter	$I = E / (R_1 + R_m + R_x)$; half scale at $R_x = R_h$
Anderson bridge	$R_1 = R_2 R_3 / R_4 - r_1$; $L_1 = C R_3 [r(R_4 + R_2) + R_2 R_4] / R_4$
Schering bridge	$C_1 = C_2 R_4 / R_3$; $r_1 = R_3 C_4 / C_2$; $\tan \delta = \omega C_4 R_4$
Earth resistance	$R_E = V_p / I$; P spike at 0.62 d; Wenner: $\rho = 2\pi a R$
Dual-slope ADC	$T_2 = T_1 V_{in} / V_{ref}$
L-C-R meter	$L = X/\omega$; $C = 1/(\omega X)$; $Q = X/R$; $D = 1/Q$
Frequency meter	$f = N / T$
PF meter	Deflection $\theta = \phi$
Tri-vector meter	$kVA = \sqrt{(kW^2 + kVAR^2)}$; $\cos \phi = kW / kVA$
CRT deflection	$D = l L V_d / (2 d V_a)$; $S = l L / (2 d V_a)$
CRO measurements	$V_{rms} = V_{pp} / (2\sqrt{2})$; $T = \text{div} \times \text{time/div}$; $\phi = (\Delta t/T) 360^\circ$; $\sin \phi = A/B$; $t_r = 0.35 / BW$
Lissajous figure	$f_y / f_x = (\text{touches on horizontal line}) / (\text{touches on vertical line})$

Practice Questions: 15 Multiple Choice Questions

Choose the correct option. The answer key with short explanations follows the questions.

1. Low resistances (below 1 Ω) are measured most accurately by
 - (A) Wheatstone bridge
 - (B) Kelvin's double bridge
 - (C) Megger
 - (D) Voltmeter-ammeter method with connection (b)
2. The deflection of a Megger pointer depends on
 - (A) The generator voltage only
 - (B) The speed of cranking
 - (C) The ratio of the currents in the current coil and the pressure coil
 - (D) The torque of a control spring
3. In a series type ohmmeter, the zero mark of the scale is at
 - (A) The left end
 - (B) The centre
 - (C) The right end (full-scale position)
 - (D) A position that depends on the battery
4. Anderson's bridge measures self-inductance in terms of
 - (A) A fixed standard capacitor and resistors
 - (B) A variable standard capacitor only
 - (C) A standard mutual inductor
 - (D) The supply frequency only
5. In the Schering bridge, the dissipation factor of the capacitor under test is
 - (A) $\omega C_2 R_3$
 - (B) C_1 / C_2
 - (C) R_4 / R_3
 - (D) $\omega C_4 R_4$
6. In the fall-of-potential method with an earth tester, the potential spike P is usually placed at about
 - (A) 20 % of the E-C distance
 - (B) 62 % of the E-C distance
 - (C) 90 % of the E-C distance
 - (D) Very close to the electrode under test
7. The maximum reading of a 3½ digit digital multimeter on a range is
 - (A) 1999
 - (B) 3999
 - (C) 9999
 - (D) 19999
8. A digital frequency meter counts 5000 pulses during a gate time of 0.1 s. The frequency of the input signal is
 - (A) 500 Hz
 - (B) 5 kHz
 - (C) 50 kHz
 - (D) 500 kHz

9. In a lamp type phase sequence indicator with the capacitor in the R line, for the sequence R-Y-B the brighter lamp is in the
(A) R line
(B) B line
(C) Both lamps are equally bright
(D) Y line
10. In a dynamometer type power factor meter, the angular deflection of the pointer is equal to
(A) The power in watts
(B) The phase angle ϕ of the load
(C) $\tan \phi$
(D) The load current
11. If the pointer of a synchroscope rotates slowly in the clockwise (FAST) direction, the incoming machine is
(A) Running faster than the bus-bar frequency
(B) Running slower than the bus-bar frequency
(C) At exactly the same frequency
(D) Connected with the wrong phase sequence
12. A tri-vector meter records 80 kWh and 60 kVARh. The apparent energy in kVAh is
(A) 140
(B) 20
(C) 100
(D) 70
13. A sine wave displayed on a CRO is 6 divisions peak to peak with the VOLTS/DIV switch at 2 V/div. Its r.m.s. voltage is nearly
(A) 12 V
(B) 6 V
(C) 8.48 V
(D) 4.24 V
14. A Lissajous figure touches the top horizontal tangent 3 times and the side vertical tangent 2 times. The ratio f_y / f_x is
(A) 2 / 3
(B) 3 / 2
(C) 5
(D) 1
15. In a function generator, the symmetry control changes
(A) The ratio of charging to discharging current, and hence the duty cycle
(B) Only the amplitude of the output
(C) The frequency range only
(D) Only the d.c. offset

Answer Key for the Multiple Choice Questions

Q. No.	Answer	Explanation
1	(B) Kelvin's double bridge	Kelvin's double bridge cancels lead and link resistance when $P/Q = p/q$.
2	(C) The ratio of the currents in the current coil and the pressure coil	It is a ratiometer type instrument with no control spring; voltage and speed cancel out.
3	(C) The right end (full-scale position)	With terminals shorted the current is maximum, so zero ohms is at full-scale deflection.
4	(A) A fixed standard capacitor and resistors	Its advantage over the Maxwell bridge is that a fixed capacitor is enough.
5	(D) $\omega C_4 R_4$	$\tan \delta = \omega C_1 r_1 = \omega C_4 R_4$.
6	(B) 62 % of the E-C distance	The 62 % rule gives the true earth resistance value on the flat part of the resistance curve.
7	(A) 1999	The half digit can only be 0 or 1, so the maximum is 1999.
8	(C) 50 kHz	$f = N / T = 5000 / 0.1 = 50\,000\text{ Hz}$.
9	(D) Y line	The lamp in the phase that follows the capacitor phase in the sequence glows brighter.
10	(B) The phase angle ϕ of the load	The torques balance when $\theta = \phi$, so the scale can be marked directly in $\cos \phi$.
11	(A) Running faster than the bus-bar frequency	The pointer rotates at the slip frequency; clockwise means the incoming machine is faster.
12	(C) 100	$\text{kVAh} = \sqrt{(80^2 + 60^2)} = 100$.
13	(D) 4.24 V	$V_{pp} = 12\text{ V}$, $V_m = 6\text{ V}$, $V_{rms} = 6 / \sqrt{2} = 4.24\text{ V}$.
14	(B) 3 / 2	$f_y / f_x = (\text{touches on the horizontal line}) / (\text{touches on the vertical line}) = 3 / 2$.
15	(A) The ratio of charging to discharging current, and hence the duty cycle	Unequal charge and discharge currents turn the triangle into a ramp and the square wave into a pulse train.

Practice Questions: 10 Broad (Long Answer) Questions

Answer each question with neat labelled diagrams, equations and examples wherever needed.

- Q1.** Explain the working of Kelvin's double bridge with a neat circuit diagram. Derive the expression for the unknown resistance and show how the effect of the link resistance is eliminated. State its applications.
- Q2.** Describe the voltmeter-ammeter method of measuring medium resistance with the two possible connections. Derive the percentage error in each case and state how you decide which connection to use.
- Q3.** With a neat sketch, explain the construction and working of a Megger. Why does the reading not depend on the generator voltage? What is the purpose of the guard terminal? State its applications and precautions.
- Q4.** Explain the working of the series type and the shunt type ohmmeters with circuit diagrams. Compare their scales and state the use of each.
- Q5.** Draw the circuit of Anderson's bridge and derive the balance equations for the unknown inductance and its resistance. State the advantages of this bridge.
- Q6.** Explain the Schering bridge for measurement of capacitance and dissipation factor. Derive the balance equations and state the applications of the high-voltage Schering bridge.
- Q7.** Explain the principle of an earth tester. Draw its connection diagram, describe the procedure of measuring earth resistance by the fall-of-potential method and state its applications.
- Q8.** With the help of block diagrams, explain the working of (a) a digital multimeter and (b) an L-C-R meter, and state the applications of each.
- Q9.** Explain the construction and working principle of a single phase dynamometer type power factor meter and of a synchroscope with circuit diagrams.
- Q10.** Explain with a neat block diagram the working of a cathode ray oscilloscope. Describe the cathode ray tube and derive the expression for electrostatic deflection sensitivity. Explain how the CRO is used to measure voltage, frequency and phase angle, and how Lissajous figures are used.