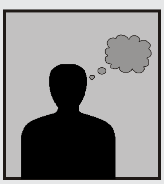
2020

RANK improvement WORKBOOK



Answer key and Hint of Objective & Conventional *Questions*

Electronics Engineering

Electrical & Electronic Measurements

MADE EASY Publications

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1 Basics of Measurement Systems, Error Analysis

LEVEL 1 Objective Questions

1. (d)
2. (a)
3. (c)
4. (a)
5. (b)
6. (a)
7. (c)
8. (b)
9. (d)

LEVEL 2 Objective Questions

10. (a)
11. (c)
12. (c)
13. (b)
14. (a)
15. (4.76)

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LEVEL 3 Conventional Questions

Solution : 1

% Uncertainty in loss = ±5.34%

% Uncertainty in efficiency = ±0.4030%

Solution : 2

On the 5 V range, the voltmeter reading is,

$$VR_b = 4.782\text{ V}$$

The % error on the 5 V range is

$$\%\text{Error} = -4.36\%$$

On 10 V range, the voltmeter reading is

$$VR_b = 4.88\text{ V}$$

The % error on the 10 V range= –2.4%

On 30 V range, the voltmeter reading on the 30 V range

$$VR_b = 4.95\text{ V}$$

The % error on the 30 V range = –1%

In the above example, the 30 V range introduces the least error due to loading. However, the voltage being measured causes only a 10% full scale deflection, whereas on the 10 V range the applied voltage causes approximately a one third of the full scale deflection.

Solution : 3

We have, $T \propto M^p E^q Z^t$

Therefore, we can write, $T = kM^p E^q Z^t$

where, K = a constant (a dimensionless quantity).

Writing the dimensions of various quantities:

$$\text{Torque} = \frac{\text{Power}}{\text{Angular velocity}}$$

$$\therefore \quad \text{Dimension of torque} = \frac{[ML^2T^{-3}]}{[T^{-1}]} = [ML^2T^{-2}]$$

$$[\text{Mutual inductance}] = [\mu L]$$

$$[\text{Emf}] = [E] = [\mu^{1/2} M^{1/2} L^{3/2} T^{-2}]$$

$$[\text{Impedance}] = [Z] = [\mu L T^{-1}]$$

Substituting the dimensions of various quantities in the expression for torque, we have:

$$[ML^2T^{-2}] = [\mu L]^p[\mu^{1/2} M^{1/2} L^{3/2} T^{-2}]^q [\mu L T^{-1}]^t$$

$$= \left[\mu^{p+q/2+t} + M^{q/2} + L^{p+(3/2)q+t} + T^{-2q-t}\right]$$

In order that the two sides should balance dimensionally,

$$p + \frac{q}{2} + t = 0, \qquad \frac{q}{2} = 1$$

$$p + \frac{3}{2}q + t = 2, \quad \text{and} \quad -2q - t = -2$$

From above, $p = 1$, $q = 2$ and $t = -2$

Therefore, the equation is $T \propto ME^2Z^{-2} \propto \dfrac{ME^2}{Z^2}$.

Solution : 4

$$\frac{P'}{P} \times 100 = 97.32\%$$

P' = True power and P = Power calculated by freshman

Solution : 5

(i) Arithmetic mean, $\bar{R}$ = 147.53 Ω

(ii) Average deviation, $\bar{D}$ = 0.216 Ω

(iii) Standard deviation, σ = 0.2983 Ω

Solution : 6

+ve limiting error = –0.07%
–ve limiting error = –0.3298%

Solution : 7

(a) Resonant frequency = 1 MHz

(b) Resonant frequency = 0.9 MHz
Relative error in f_r = –10%

(c) Resonant frequency = 1.1 MHz
Relative error in f_r = 10%

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2 Indicating Instrument, Power & Energy Measurement

LEVEL 1 Objective Questions

1.	(c)
2.	(d)
3.	(b)
4.	(d)
5.	(d)
6.	(b)
7.	(b)
8.	(b)
9.	(c)

LEVEL 2 Objective Questions

10.	(3.20)
11.	(c)
12.	(c)
13.	(d)
14.	(125.33)
15.	(1.20)
16.	(a)
17.	(71.2)
18.	(21.17)
19.	(224)
20.	(c)
21.	(c)
22.	(b)

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LEVEL 3 Conventional Questions

Solution : 1

(a) $R_{sh} = 31.26\ \Omega$

(b) $R_{sh} = 36.73\ \Omega$

Solution : 2

Reading of the wattmeter, $W = 2238.203$ W

Solution : 3

$$\text{Error registration} = \frac{1.104 - 0.958}{1.104} \times 100\% = 13.22\%$$

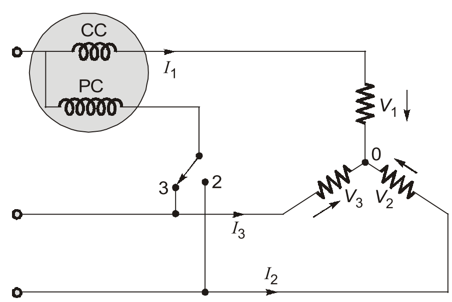
Error in rpm of energy meter, $$\%\ \text{error} = \frac{38.33 - 22.08}{22.08} \times 100 = 73.6\%\ \text{(fast)}$$

It can be rectified by bringing braking magnet near to the centre of disc.

Solution : 4

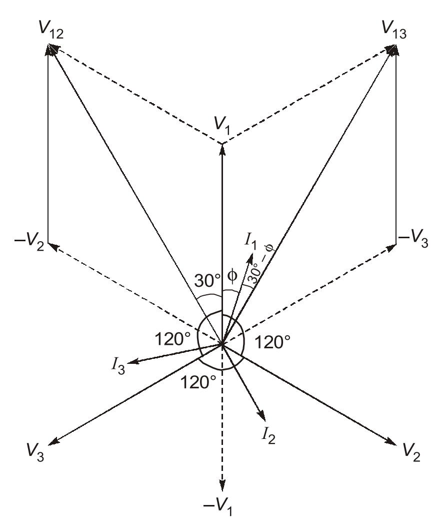
One wattmeter method can be used only when load is balanced. The connection are as under:

Measurement of active power:



One wattmeter method

The current coil is connected in one of the line and one end of pressure coil to the same line, other end being connected alternatively to other two lines. The phasor diagram is as under.



Phasor diagram

$$V_1 = V_2 = V_3 = V \quad (V \rightarrow \text{phase voltage})$$
$$I_1 = I_2 = I_3 = 1 \quad (I \rightarrow \text{phase current})$$
$$V_{13} = V_{12} = \sqrt{3}V$$

Reading of wattmeter switch at 3:

$$P_1 = V_{13} I_1 \cos(30 - \phi)$$
$$= \sqrt{3} VI \cos(30 - \phi)$$

Reading when switch at 2:

$$P_2 = V_{12} I_1 \cos(30 + \phi)$$
$$= \sqrt{3} VI \cos(30 + \phi)$$

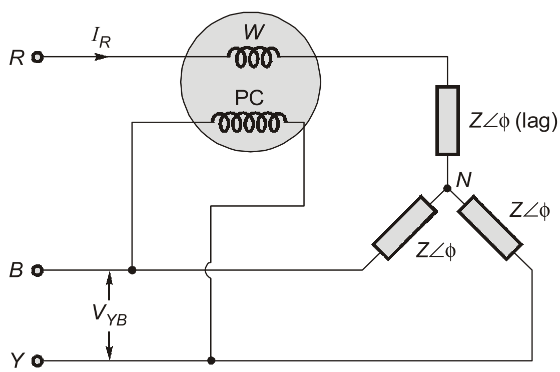
Sum of 2 reading, $P_1 + P_2 = \sqrt{3} VI (\cos(30 - \phi) + \cos(30 + \phi))$

We know, $\cos(A + B) + \cos(A - B) = 2 \cos A \cdot \cos B$

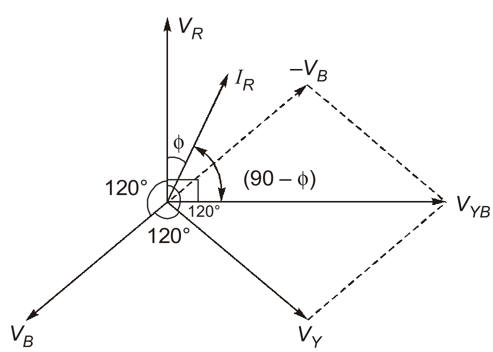
$$= 3\,VI \cos\phi$$
$$= \text{Power consumed by load}$$

However an drawback/limitation of this method is that it is suitable for balanced load only.

Measurement of reactive power:



Current coil is connected to one phase and potential coil connected between remaining two phases.



Wattmeter reading, $W = V_{YB} I_R \cos(\text{Angle between } V_{YB} \text{ and } I_R)$

$$= V_L I_L \cos(90 - \phi)$$
$$= V_L I_L \sin\phi \; (1\text{-}\phi \text{ reactive power})$$

$\therefore$ Three phase reactive power is

$$Q = \sqrt{3} W = \sqrt{3} V_L I_L \sin\phi$$
$$= \text{Reactive power consumed by 3-}\phi \text{ load}$$

Solution : 5

The value of R_s which will limit current to full scale deflection current can be calculated as

$$R_s = \frac{E}{I_m} - R_m = \frac{3}{1\,\text{mA}} - 100\Omega = 3\,\text{k}\Omega - 100\,\Omega = 2.9\,\text{k}\Omega$$

The value of R_x with a 20% deflection is

$$R_x = \frac{(R_s + R_m)}{P} - (R_s + R_m)$$

where $$P = \frac{I}{I_m} = 20\% = \frac{20}{100} = 0.2$$

$$R_x = \frac{(2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)}{0.2} - (2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)$$

$$R_x = \frac{3\,\text{k}\Omega}{0.2} - 3\,\text{k}\Omega = 15\,\text{k}\Omega - 3\,\text{k}\Omega = 12\,\text{k}\Omega$$

The value of R_x with a 40% deflection is

$$R_x = \frac{(R_s + R_m)}{P} - (R_s + R_m)$$

where $$P = \frac{I}{I_m} = 40\% = \frac{40}{100} = 0.4$$

$$R_x = \frac{(2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)}{0.4} - (2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)$$

$$R_x = \frac{3\,\text{k}\Omega}{0.4} - 3\,\text{k}\Omega = 7.5\,\text{k}\Omega - 3\,\text{k}\Omega = 4.5\,\text{k}\Omega$$

The value of R_x with a 50% deflection is

$$R_x = \frac{(R_s + R_m)}{P} - (R_s + R_m)$$

where $$P = \frac{I}{I_m} = 50\% = \frac{50}{100} = 0.5$$

$$R_x = \frac{(2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)}{0.5} - (2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)$$

$$R_x = \frac{3\,\text{k}\Omega}{0.5} - 3\,\text{k}\Omega = 6\,\text{k}\Omega - 3\,\text{k}\Omega = 3\,\text{k}\Omega$$

The value of R_x with a 75% deflection is

$$R_x = \frac{(R_s + R_m)}{P} - (R_s + R_m)$$

where $$P = \frac{I}{I_m} = 75\% = \frac{75}{100} = 0.75$$

$$R_x = \frac{(2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)}{0.75} - (2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)$$

$$R_x = \frac{3\,\text{k}\Omega}{0.75} - 3\,\text{k}\Omega = 4\,\text{k}\Omega - 3\,\text{k}\Omega = 1\,\text{k}\Omega$$

The value of R_x with a 90% deflection is

$$R_x = \frac{(R_s + R_m)}{P} - (R_s + R_m)$$

where $$P = \frac{I}{I_m} = 90\% = \frac{90}{100} = 0.90$$

$$R_x = \frac{(2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)}{0.90} - (2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)$$

$$R_x = \frac{3\,\text{k}\Omega}{0.90} - 3\,\text{k}\Omega = 3.333\,\text{k}\Omega - 3\,\text{k}\Omega = 0.333\,\text{k}\Omega$$

The value of R_x with a 100% deflection is

$$R_x = \frac{(R_s + R_m)}{P} - (R_s + R_m)$$

where, $$P = \frac{I}{I_m} = 100\% = \frac{100}{100} = 1$$

$$R_x = \frac{(2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)}{1} - (2.9\,\text{k}\Omega + 0.1\,\text{k}\Omega)$$

$$R_x = \frac{3\,\text{k}\Omega}{1} - 3\,\text{k}\Omega = 3\,\text{k}\Omega - 3\,\text{k}\Omega = 0$$

Solution : 6

∴ Control constant, $K = = 10 \times 10^{-9}$ Nm/rad

Inertia constant, $J = 9.12 \times 10^{-9}$ kgm^2

Total circuit resistance for critical damping or dead beat

$R = 1309\ \Omega$

Solution : 7

(a) Resistance temperature coefficient of instrument = 0.00066/°C

(b) Error = 1.2% low

(c) Capacitance, $C = 0.0455\ \mu$F

Solution : 8

Resistance of potential coil, $R_p = \frac{250}{0.05} = 5000\ \Omega$

Wattmeter reading, $P = 1768$ W

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3 Power Factor Meter, Potentiometer, Bridge Measurement & Instrument Transformer

LEVEL 1 Objective Questions

1.	(b)
2.	(c)
3.	(b)
4.	(a)
5.	(c)
6.	(b)
7.	(a)
8.	(d)

LEVEL 2 Objective Questions

9.	(b)
10.	(b)
11.	(a)
12.	(0)
13.	(d)
14.	(0.004)
15.	(1.68)
16.	(0.08275)
17.	(0.00734)
18.	(c)

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LEVEL 3 Conventional Questions

Solution : 1

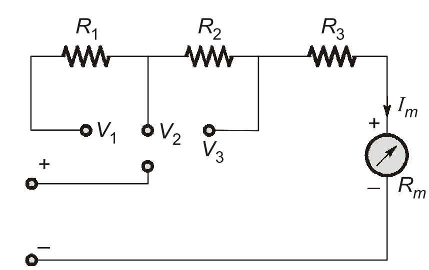
The value of shunts are,

$$R_1 = 0.05263\ \Omega;$$
$$R_2 = 0.05263\ \Omega$$
$$R_3 = 0.4147\ \Omega;$$
$$R_4 = 4.74\ \Omega$$

Solution : 2

$$R_a = 9.09\ \Omega,\ R_b = 0.909\ \Omega \text{ and } R_c = 0.101\ \Omega$$

Solution : 3



Step-1 : For a 5 V (V_3) the total circuit resistance is

$$R_t = 0.5\ \Omega$$
$$R_3 = R_t - R_m = 400\ \Omega$$

Step-2: For a 50 V (V_3) position,

$$R_f = 5\ \Omega$$
$$R_2 = R_t - (R_3 + R_m) = 4.5\ \text{k}\Omega$$

Step-3: For a 100 V range (V_1) position

$$R_f = 10\ \Omega$$
$$R_1 = R_t - (R_2 + R_3 + R_m) = 5\ \text{k}\Omega$$

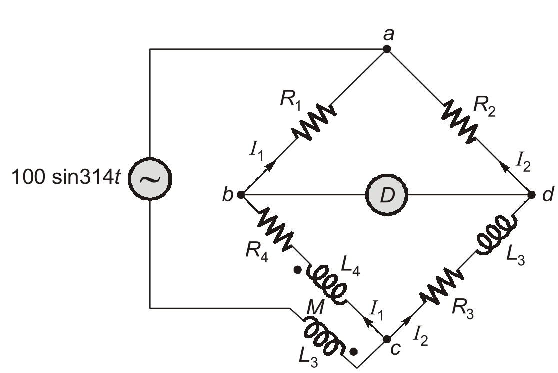
Hence it can be seen that R_3 has a non-standard value.

Solution : 4

(a) Sensitivity = 4 V/cm

(b) Loading error = 46.4%

Solution : 5



Let, M = Unknown mutual inductance

L_4 = Self inductance of secondary of mutual inductance

L_3 = Known self inductance

R_1, R_2, R_3 and R_4 = Non-inductive resistors

At balance condition voltage drop between *c* and *d* must be equal to the voltage drop between *a* and *d*. Also voltage drop across *c*-*b*-*a* must be equal to the voltage drop across *c*-*d*-*a*.

Thus, $$I_1R_1 = I_2R_2 \quad ...(i)$$

and $$(I_1 + I_2)(j\omega M) + I_1(R_1 + R_4 + j\omega L_4) = I_2(R_2 + R_3 + j\omega L_3) \quad ...(ii)$$

From equation (i) and (ii), we get

$$I_2\left(\frac{R_2}{R_1}+1\right)(j\omega M)+I_2\left(\frac{R_2}{R_1}\right)(R_1+R_4+j\omega L_4) = I_2(R_2 + R_3 + j\omega L_3)$$

or, $$(j\omega M)\left(1+\frac{R_2}{R_1}\right)+R_2+\frac{R_2R_4}{R_1}+j\omega L_4\cdot\frac{R_2}{R_1} = R_3 + R_2 + j\omega L_3$$

Equating real and imaginary part, we get.

Thus, $$R_4 = \frac{R_3R_1}{R_2}$$

and $$M = \frac{L_3 - L_4R_2/R_1}{\left(1+\dfrac{R_2}{R_1}\right)} = \frac{R_1L_3 - R_2L_4}{R_1+R_2}$$

If $R_1 = R_2$, $$M = \frac{L_3 - L_4}{2}$$

and $$R_3 = R_4$$

Solution : 6

(i) $$R_x = \frac{R_2}{R_1}\left(R_4+\frac{R_1C_1}{C_4}\right)$$

(ii) $$\omega = \frac{1}{\sqrt{R_1C_1R_4C_4}}$$

(iii) $$\omega = 2500 \text{ rad/sec}$$

Solution : 7

$$R_x = 4.86 \text{ k}\Omega \text{ and } L_x = 270 \text{ mH}$$

Solution : 8

(a) At balance, the value of unknown resistance,

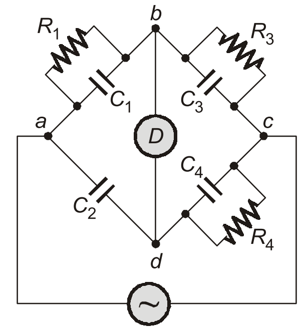
$$R = 0.001\ \Omega$$

(b) $$I \approx 20 \text{ A}$$

(c) Deflection of galvanometer, $\theta = S_iI_g = 1.34$ mm.

Solution : 9

The voltage circuit is shown in figure.



For balance, $Y_1Y_4 = Y_2Y_3$

or
$$\left(\frac{1}{R_1} + j\omega C_1\right)\left(\frac{1}{R_4} + j\omega C_4\right) = (j\omega C_2)\left(\frac{1}{R_3} + j\omega C_3\right)$$

or
$$\left(\frac{1}{R_1R_4} - \omega^2 C_1C_4\right) + j\omega\left(\frac{C_4}{R_1} + \frac{C_1}{R_4}\right) = j\omega\frac{C_2}{R_3} - \omega^2 C_2C_3$$

Equating the real and imaginary parts, we have

$$\frac{1}{R_1R_4} - \omega^2 C_1C_4 = -\omega^2 C_2C_3 \quad \text{... (i)}$$

and
$$\frac{C_4}{R_1} + \frac{C_1}{R_4} = \frac{C_2}{R_3} \quad \text{... (ii)}$$

From (i) and (ii), we have

$$C_1 = \frac{\dfrac{C_2R_4}{R_3} + \omega^2 C_2C_3C_4R_4^2}{1+\omega^2 C_4^2R_4^2}$$

Now, $\omega^2 C_2C_3C_4R_4^2 << \dfrac{C_2R_4}{R_3}$ and $\omega^2 C_4{}^2R_4{}^2 << 1$

Hence we can write $C_1 = C_2\dfrac{R_4}{R_3}$

When the capacitor C_1 is without specimen dielectric, let its capacitance be C_0.

$$\therefore \quad C_0 = C_2\frac{R_4}{R_3} = 150 \times \frac{5000}{5000} = 150 \text{ pF}$$

When the specimen is inserted as dielectric, let the capacitance be C_s.

$$\therefore \quad C_s = C_2\frac{R_4}{R_3} = 900 \times \frac{5000}{5000} = 900 \text{ pF.}$$

Now, $C_0 = \dfrac{\varepsilon_0 A}{d}$ and $C_s = \dfrac{\varepsilon_r\varepsilon_0 A}{d}$

Relative permittivity of specimen, $\varepsilon_r = 6$

Solution : 10

(a) Value of resistance for which the errors are equal for the two types of connections

$$R = \sqrt{R_AR_V} = \sqrt{2\times 5000} = 100\ \Omega$$

Since the resistance to be measured has a value less than 100 Ω, the method should be used as it results in smaller error. Use (ii) method to reduce error.

(b) Since the error correspond to standard deviations, error due to ammeter and voltmeter

$$= \pm 1.38\%$$

Absolute error due to ammeter and voltmeter

$$\approx \pm 1.2\ \Omega$$

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4 CRO, Q-meter, Frequency Measurement Data Acquistion System

LEVEL 1 Objective Questions

1.	(a)
2.	(b)
3.	(d)
4.	(a)
5.	(d)
6.	(b)
7.	(b)

LEVEL 2 Objective Questions

8.	(a)
9.	(a)
10	(a)
11.	(100)
12.	(a)
13.	(48.71)
14.	(c)
15.	(d)
16.	(a)

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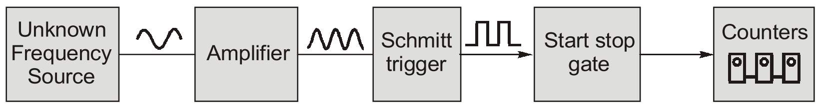
LEVEL 3 Conventional Questions

Solution : 1

Functional Block diagram of Digital Frequency Meter:



Principle of Operation:

1. The unknown frequency signal is fed to the schmitt trigger. The signal may be amplified before being applied to schmitt trigger.
2. In a schmitt trigger, the signal is converted into a square wave with very fast rise and fall times, then differentiated and clipped.
3. As a result, the output from a schmitt trigger is a train of pulses, one pulse, for each cycle of the signal.
4. The output pulses from the schmitt trigger are fed to start stop gate when this gate opens (start), the input pulses pass through this gate and are fed to an electronic counter which starts registering the input pulses.
5. When the gate is closed (stop), the input of pulses to counter ceases and it stops counting.
6. The counter displays the number of pulses that have passed through it in the time interval between start and stop. If this interval is known, the pulse rate and hence the frequency of the input signal can be known. Frequency of unknown signal,

$$f = \frac{N}{t}$$

where, f = frequency of unknown signal, N = number of counts displayed by counter
t = time interval between start and stop of gate and f = frequency of the signal = 3.5 kHz = 3500 Hz
Assuming 5 digit display

(i) t = 0.1 second

Display = 00350

(ii) t = 1 second,

Display = 03500

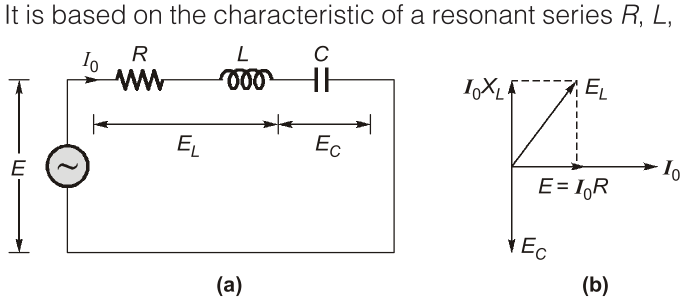
(iii) t = 10 second,

Display = 35000

Solution : 2

Q-meter is an instrument which is designed to measure the value of Q directly and as such is very useful in measuring characteristic of coils.

Working principle: It is based on the characteristic of a resonant series R, L, C circuit



At resonant frequency f_0, we have

$$X_C = X_L$$

$$X_C = \frac{1}{2\pi f_0 C} = \frac{1}{\omega_0 C}$$

$$X_L = 2\pi f_0 L = \omega_0 L$$

So,
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

At resonance,
$$I_0 = \frac{E}{R}$$

$$E_C = |I_0 X_C| = |I_0 X_L| = I_0 \omega L = E_L$$

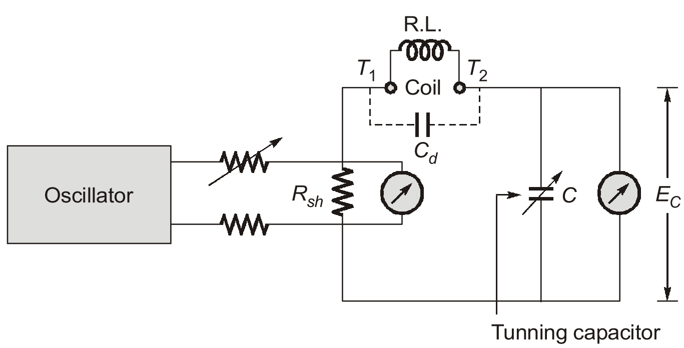
$$E = I_0 R$$

$$\frac{E_C}{E} = \frac{I_0 \omega_0 L}{I_0 R} = \frac{\omega_0 L}{R} = Q$$

So Q is measured by measuring supply voltage and voltage across capacitor.

Error:

- $Q = \frac{E_C}{E}$ and if supply voltage is kept constant, voltmeter across the capacitor may be calibrated to read value of Q of the coil. However there is an error. Measured value of Q is the Q of whole circuit and not the coil.
- **Circuit of a Q-meter:**



- Oscillator deliver current to R_{sh}. Further there is a distributed capacitance of the coil. There is an error on account of R_{sh} and distributed capacitance (C_d).

  Correction for R_{sh} gives $Q_{true} = Q_{measured}\left(1 + \frac{R_{sh}}{R}\right)$. If $R >> R_{sh}$ error will be lesser. If measurement is carried out for high Q coil i.e. R is smaller then large error may occur due to R_{sh}.
- $C_d = 14.29$ pF
- $L = 13.57$ μH

Solution : 3

Let, $X \rightarrow$ Horizontal plate deflection

$Y \rightarrow$ Vertical plate deflection

$X = V_1 \sin(\omega t + \theta_1)$

$X = V_1 (\sin \omega t \cos \theta_1 + \cos \omega t \sin \theta_1)$

Similarly, $Y = V_2(\sin \omega t \cos \theta_2 + \cos \omega t \sin \theta_2)$

$$\frac{X}{V_1} = \sin \omega t \cos \theta_1 + \cos \omega t \sin \theta_1 \quad ...(1)$$

$$\frac{Y}{V_2} = \sin \omega t \cos \theta_2 + \cos \omega t \sin \theta_2 \quad ...(2)$$

From (1) and (2), $\frac{X}{V_1} + \frac{Y}{V_2} = \sin \omega t (\cos \theta_1 + \cos \theta_2) + \cos \omega t (\sin \theta_1 + \sin \theta_2)$

Let, $\cos \theta_1 + \cos \theta_2 = K_1;\ \sin \theta_1 + \sin \theta_2 = K_2$

$$\frac{X}{V_1} + \frac{Y}{V_2} = K_1 \sin \omega t + K_2 \cos \omega t \quad ...(3)$$

Similarly, $\frac{X}{V_1} - \frac{Y}{V_2} = K_1 \sin \omega t - K_2 \cos \omega t \quad ...(4)$

Adding (3) and (4) gives, $\frac{X}{V_1} = K_1 \sin \omega t \quad ...(5)$

Substracting (3) and (4) gives,

$$\frac{Y}{V_2} = K_2 \cos \omega t \quad ...(6)$$

From (5) and (6) we gets, $\frac{X}{K_1 V_1} = \sin \omega t \quad ...(7)$

$$\frac{Y}{K_2 V_2} = \cos \omega t \quad ...(8)$$

Squaring and adding (7) and (8),

$$\frac{X^2}{(K_1 V_1)^2} + \frac{Y^2}{(K_2 V_2)^2} = 1$$

Let, $K_1 V_1 = a,\ K_2 V_2 = b$ (Constants)

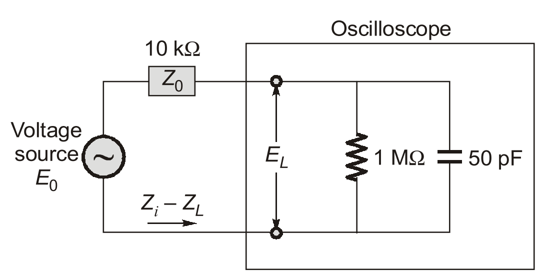
$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$$

Its an equation of ellipse with

$$a = V_1(\cos \theta_1 + \cos \theta_2)$$
$$b = V_2(\sin \theta_1 + \sin \theta_2)$$

Solution : 4

The equivalent circuit for the measurement system is shown in below figure.



When, Frequency = 100 kHz;

The voltage across the load, $E_L = 0.954\angle{-17.4°}$ V(peak)

When Frequency = 1 MHz

The voltage across the load is $E_L = 0.304\angle{-72.3°}$ V (Peak)

In this case the measured value is only 0.304 of its original value and the phase shift is 72.3°. Thus the output is considerably attenuated and is less than one third of its original value. The value of phase angle between voltages under no load and load conditions is 72.3°.

This indicates the effect of distortion of signal on account of increased shunting effect due to increase in frequency.

■■■■

5 Electronic Measuring Instrument and Transducer

LEVEL 1 Objective Questions

1.	(b)
2.	(c)
3.	(a)
4.	(a)
5.	(a)
6.	(b)
7.	(c)
8.	(c)
9.	(b)

LEVEL 2 Objective Questions

10.	(c)
11.	(b)
12.	(d)
13.	(2.5)
14.	(0.2)
15.	(d)
16.	(677.4)
17.	(c)
18.	(c)

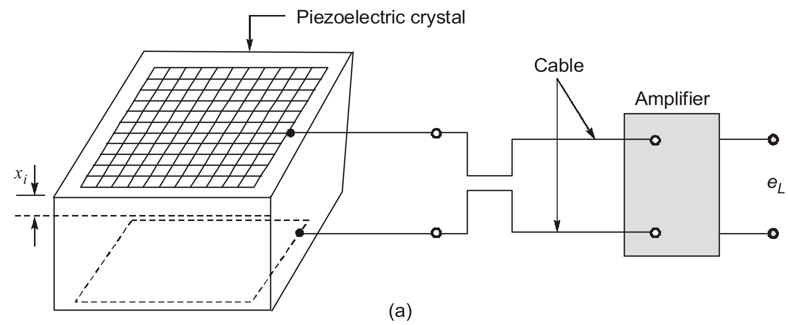
■■■■

LEVEL 3 Conventional Questions

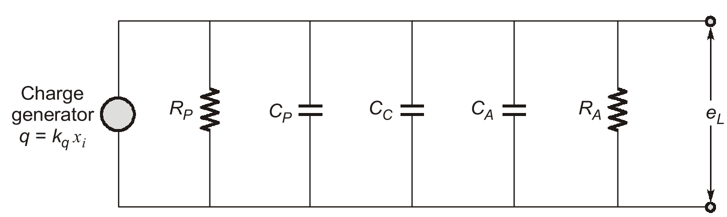
Solution : 1

A piezo-electric material is one in which an electric potential appears across certain surfaces of a crystal if the dimensions of the crystal are changed by the application of a mechanical force. This potential is produced by the displacement of charges. The effect is reversible, i.e. conversely, if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it. This effect is known as piezo-electric effect. Elements exhibiting piezo-electric quantities are called as electro-resistive elements. The materials that exhibit a significant and useful piezo-electric effect are divided into two categories: (a) Natural group and (b) Synthetic group.

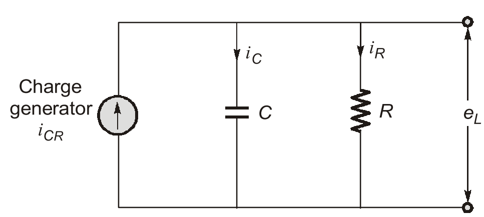
Quartz and Rochelle salt belong to natural group while materials like lithium sulphate, ethylene diamine tartarate belong to the synthetic group.



(a)



(b)



(c)

Consider the transducer, the connecting cable and the amplifier as a unit. The impedance of the transducer is very high and hence an amplifier with a high input impedance has to be used in order to avoid loading errors.

Charge produced, $q = K_q x_i$ coulomb

where, K_q = sensitivity; C/m

and x_i = displacement; m

Figure (b) shows the equivalent circuit:

R_P = Leakage resistance of transducer; Ω

C_P = Capacitance of transducer; F

C_C = Capacitance of cable; F

C_A = Capacitance of amplifier; F

R_A = Resistance of amplifier; Ω

The charge generator is converted into a constant current generator as shown in figure (c). The capacitance connected across the current generator is C where:

$$C = C_P + C_C + C_A$$

Resistance, $$R = \frac{R_A R_P}{R_A + R_P}$$

Since the leakage resistance of transducer is very large (of the order of 0.1×10^{12} Ω) and therefore,

$$R = R_A$$

Converting the charge generator into a current generator

$$i_{CR} = \frac{dq}{dt} = K_q\left(\frac{dx_i}{dt}\right)$$

where i_{CR} is the current of the constant current generator.

Now, $$i_{CR} = i_C + i_R$$

∴ Output voltage at load, $$e_L = e_C = \frac{1}{C}\int i_C\,dt = \frac{1}{C}\int (i_{CR} - i_R)dt$$

or $$\frac{d(e_L)}{dt} = \frac{1}{C}(i_{CR} - i_R)$$

or $$C\frac{d(e_L)}{dt} = i_{CR} - i_R = K_q\frac{d(x_i)}{dt} - \frac{e_L}{R}$$

or $$RC\frac{d(e_L)}{dt} + e_L = K_q R\frac{d(x_i)}{dt}$$

$$\tau\frac{d(e_L)}{dt} + e_L = K\tau\frac{d(x_i)}{dt}$$

where, $$K = \text{sensitivity} = \frac{K_q}{C}\ \text{V/m}$$

Taking Laplace transform:

$$(\tau s + 1)\,E_L(s) = K\tau s\,X_i(s)$$

∴ Transfer function:

$$\frac{E_L(s)}{X_i(s)} = \frac{K\tau s}{1 + \tau s}$$

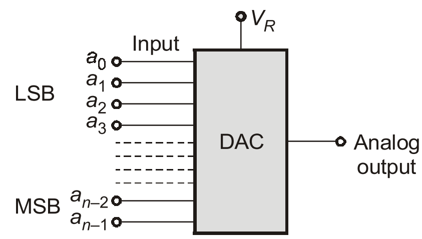
Sinusoidal transfer function:

$$\frac{E_L}{X_i}(j\omega) = \frac{j\omega K\tau}{1 + j\omega\tau}$$

Solution : 2

Digital to Analog Converter: In D/A conversion, the input to the converter is in the form of bits, 0 or 1 (binary digit) or as BCD and is converted to a voltage or current proportional to the digital value, A general block diagram is,

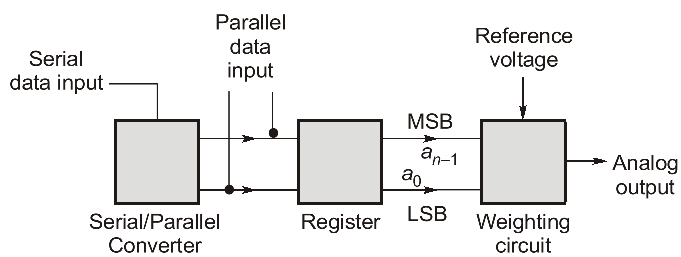
$a_0, a_1, a_2, \ldots, a_{n-2}, a_{n-1}$ is the word length for n bits. V_R is the reference voltage and it is the maximum voltage possible at the analog output.



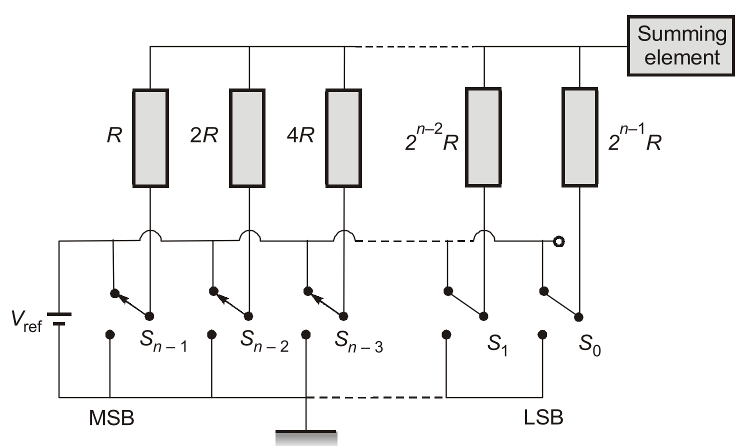
In general, analog output = $K \times$ digital input

where, K is the proportionality factor and a constant for given DAC.

Binary-Weighted resistance D/A Converter: A general structure of a digital to analog converter is



We will consider the weighting circuit only and is for a 4 bit as follows:



The major components of the binary weighted resistance DAC are

1. a weighted resistor network, R to $2^{n-1}R$.
2. n switches one for each bit applied to input.
3. reference voltage V_{ref}.
4. Summing element which sums up the currents flowing in the resistors to give an output proportional to input, usually an op-amp.

When a particular switch is closed, current flows through the connected resistor and the circuit is complete through the summing element. So is the LSB switch and when it is closed current is

$$I(\text{LSB}) = \frac{V_{ref}}{2^{n-1}R}$$

This current is the least.
When the MSB switch S_{n-1} is closed.

$$\text{Current } I\,(\text{MSB}) = \frac{V_{ref}}{R}$$

and is the highest. So the currents are in multiples of 2, 2^{n-1}. When the switch is connected to supply the bit $a_i = 1$ and when grounded $a_i = 0$. The resistors need not be in multiples of 2. It can be in submultiples of 2, $2^{-(n-1)}$. If all the switches are closed, all the resistors come in parallel. If, say, two switches are closed these two resistors are in parallel while the grounded resistors are in parallel with the load (input resistance of summing element). A binary number N of n-bits is

$$N = a_0\, 2^0 + a_1\, 2^1 + a_2\, 2^2 + \ldots + a_{n-2}\, 2^{n-2} + a_{n-1}\, 2^{n-1}$$

$$N = \sum_{i=0}^{n-1} a_i\, 2^i \qquad \ldots(v)$$

The current flowing into the summing element assuming to be shorted is

$$I_{SC} = S_{n-1}\frac{V_R}{R} + S_{n-2}\frac{V_R}{2R} + \ldots + \frac{S_1 V_R}{2^{n-2} R} + \frac{S_0 V_R}{2^{n-1} R} \qquad \ldots(vi)$$

If each switch position corresponds to one bit
$S_{n-1} = a_{n-1}$; $S_{n-2} = a_{n-2}$; ... $S_1 = a_1$; $S_0 = a_0$
then equation (vi) can be written as

$$I_{SC} = \frac{V_R}{2^{n-1} R}\left(a_{n-1}\, 2^{n-1} + a_{n-2}\, 2^{n-2} + \ldots + a_1\, 2^1 + a_0\, 2^0\right)$$

$$I_{SC} = \frac{V_R}{2^{n-1} R}\sum_{i=0}^{n-1} a_i\, 2^i \qquad \ldots(vii)$$

The output voltage $I_{SC}\, R$ of DAC is proportional to the bit corresponding to switches connected to V_R i.e., $a_i = 1$.
Maximum output current will flow when all switches are closed i.e., $a_i = 1$.

$$I_{max} = \frac{V_R}{R}\cdot\frac{2^n - 1}{2^{n-1}} \qquad \ldots(viii)$$

Similarly, when all switches are closed, all the resistors come in parallel so that total resistance

$$R_T = \frac{V_R}{I_{max}} = \frac{2^{n-1} R}{2^n - 1} \qquad \ldots(ix)$$

I_{min} will be only when one resistor is through,

$$I_{min} = \frac{V_R}{R}\cdot\frac{1}{2^{n-1}}$$

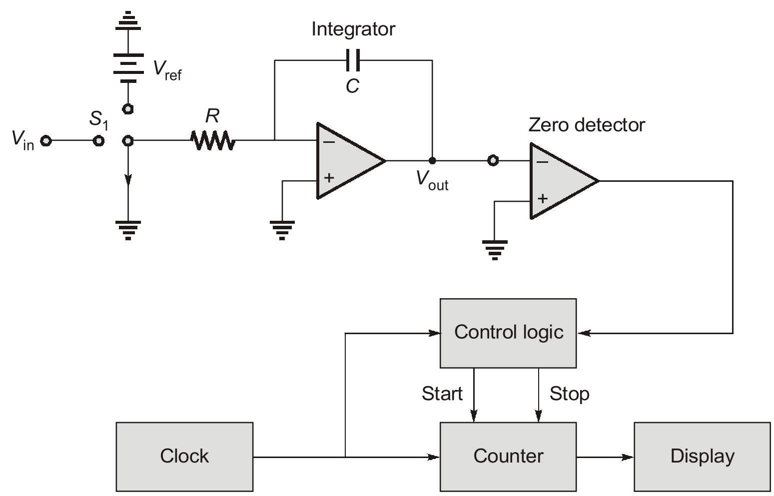
Solution : 3

DVM stands for Digital Voltmeter
Following are the type of DVM
1. Ramp type DVM
2. Integrating type DVM
3. Potentiometric type DVM
4. Successive approximation type DVM
5. Flash or parallel type DVM

Integrating type DVM: Integrating type DVM has following components:

- Integrator
- Electronically controlled switches
- Counter
- Clock
- Control logic
- Zero comparator

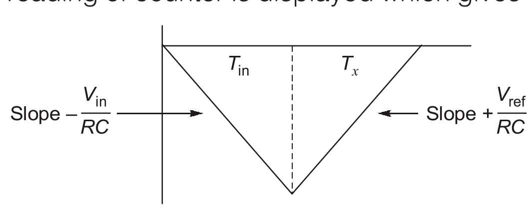
Working: Block diagram is given as:



Integrating type Digital Voltmeter

A dual slope integrator based DVM integrates an unknown input voltage V_{in} for fixed time T_{in} and then de-integrates in time T_x using a known reference voltage V_{ref}.

- At $t = 0$, S_1 is set so as to integrates the input V_{in} for T_{in}. So at $t = T_{in}$, $V_{out} = -\frac{V_{in}T_{in}}{RC}$.
- When S_1 is set counter began to count clock pulse. The counter is reset to zero at $t = T_{in}$.
- At $t = T_{in}$, S_1 is set so $-V_{ref}$ is the input to the integrator with initial voltage $\frac{V_{in}T_{in}}{RC}$.
- The integrator voltage drops to zero with time T_x and slope $+\frac{V_{ref}}{RC}$.
- A comparator used to determine when the output voltage of integrator cross zero.
- When it is zero, the reading of counter is displayed which gives V_{in}.



Let N_1 = Number of pulses counted during T_{in}

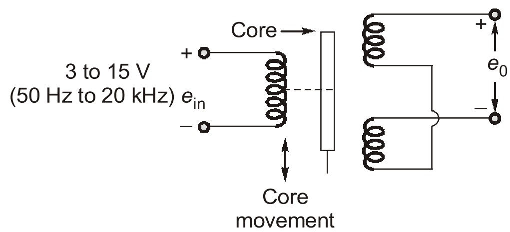
N_2 = Number of pulses counted during T_x

$$\frac{V_{in}}{V_{ref}} = \frac{N_1}{N_2} = \frac{T_{in}}{T_x}$$

Solution : 4

LVDT works on the principle of change of mutual inductance. For LVDT frequency limit is 50 Hz - 20 kHz. Voltage range of LVDT is 3 V to +15 V. Lower voltage is due to the fact that insulation requirement is reduced which reduces the size of LVDT. Also higher frequency implies more sensitivity and lesser power requirement. Range of frequency is limited by the eddy current loss.

In LVDT there are two secondaries identical in nature which are connected in opposition as shown below.

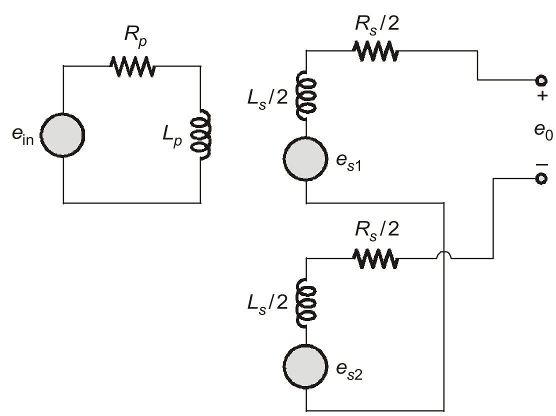


Advantage of using this connection is that when core is at geometric null position, the output voltage 'e_0' will be zero.

Let $i_p \rightarrow$ Current in primary

R_p, $L_p \rightarrow$ Resistance and inductance of primary

M_1 $M_2 \rightarrow$ Mutual inductance between primary and secondary winding.



Equivalent circuit

Applying KVL on primary side,

$$i_p R_p + L_p \frac{d_{ip}}{dt} - e_i = 0$$

$$\therefore \qquad i_p = \frac{e_i}{R_p + L_p D} \qquad ...(1)$$

$$D = \frac{d}{dt}$$

$$e_{s1} = M_1 \frac{di_p}{dt}$$

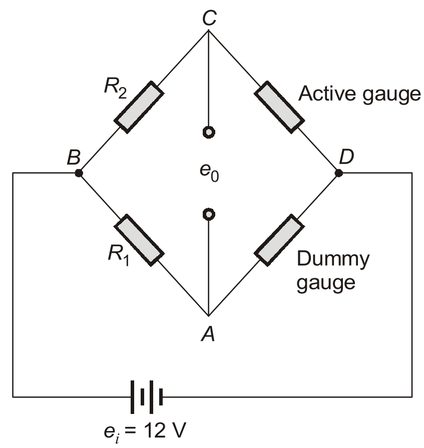
$$e_{s2} = M_2 \frac{di_p}{dt}$$

$$e_0 = e_{s1} - e_{s2} = (M_1 - M_2)\frac{di_p}{dt} \qquad ...(2)$$

$(M_1 - M_2)$ varies linearly with the core motion.

From equation (1) and (2), $$e_0 = \frac{[(M_1 - M_2)] \cdot D}{L_p D + R_p} \cdot e_i = \frac{\left[(M_1 - M_2)/R_p\right] D}{\tau_p D + 1} e_i$$

$$\tau_p = \frac{L_p}{R_p}$$



Bridge has equal arms when no strain. It has only one active gauge.

$$e_0 = \text{Offset voltage} = 15 \text{ mV}$$

Solution : 5

(a) Uses of capacitive transducer:

1. Capacitance transducer can be used for measurement of linear and angular displacement. They can measure extremely small displacements e.g. 0.1×10^{-6} mm. They can also be used for distance measurement like 30 m.
2. They can be used to measure force and pressure by converting them to displacement.
3. They can be used to measure pressure directly in cases where dielectric constant of a medium changes with pressure e.g. benzene.
4. They can be used to measure humidity in gases as dielectric constant of gas changes with humidity.

(b) Range of displacement for transducer = 0 to 2.53 cm

Solution : 6

Reading obtained with a DC voltmeter

$$ER_2 = 4.76 \text{ V}$$

Reading obtained with half wave recitifer AC voltmeter

$$E = 4.499 \text{ V}$$

The voltage read by the full wave rectifier AC voltmeter

$$E = 4.73 \text{ V}$$

As can be seen an AC voltmeter using half wave or full wave rectifier has more loading effect than DC voltmeter.

Solution : 7

(a) Therefore, we get, $(e_0)_{p-p} \simeq 2.8$ mV

(b) Maximum change in the cyrstal thickness = 4.4 pm

Solution : 8

(i) Ratio of signal voltage to noise voltage = 269

(ii) Ratio of signal voltage to noise voltage = $\dfrac{0.12 \times 10^{-6}}{0.446 \times 10^{-6}} = 0.27$

Solution : 9

(a) Strain, $s = 5.092 \times 10^6$ N/m^2

Force, $F = 2.037 \times 10^3$ N

(b) Difference mode gain, $A_d = 100$

Common mode gain, $A_c = 0.01$

∴ Common mode rejection ratio CMRR

= 80 dB

Solution : 10

(a) The reading is 05 00 000 μs or

Maximum error = ±251 μs

(b) The reading is 00 000 500 s or Reading = 500 s

Maximum error = ±1.025 s

(c) Maximum possible accuracy with which a reading of 500s can be read by this meter is

= ±26 ms

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