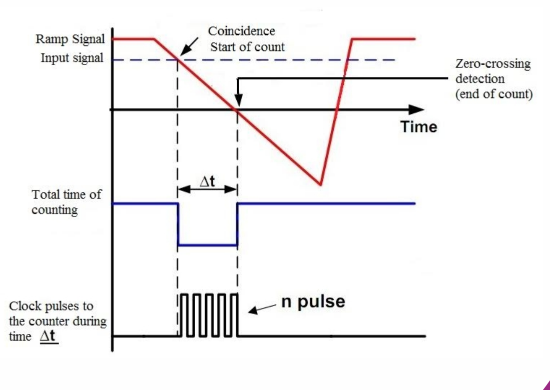
ACE
SINCE 2011

GATE | PSUs

INSTRUMENTATION ENGINEERING

Measurements

(Text Book: **Theory with worked out Examples and Practice Questions**)



Chapter 1 Error Analysis
(Solutions for Text Book Practice Questions)

01. Ans: (b)

Sol: $\% \text{ LE} = \dfrac{\text{FSV}}{\text{true value}} \times \%\text{GAE}$

$= \dfrac{200\,\text{V}}{100\,\text{V}} \times \pm 2\%$

$= \pm 4\%$

02. Ans: (d)

Sol: Variables are measured with accuracy

x = ± 0.5% of reading 80 (limiting error)

Y = ± 1% of full scale value 100 (Guaranteed error)

Z = ± 1.5 % reading 50 (limiting error)

The limiting error for Y is obtained as Guaranteed

Error = 100×(± 1/100)

= ± 1

Then % L.E in Y meter

$20 \times \dfrac{x}{100} = \pm 1$

x = 5%

Given $w = xy/z$, Add all %L.E s

Therefore = ± (0.5% + 5% + 1.5%)

= ± 7%

03. Ans: (d)

Sol: $W_T = W_1 + W_2$

$= 100 - 50$

$= 50\text{ W}$

$\dfrac{\partial W_T}{\partial W_1} = \dfrac{\partial W_T}{\partial W_2} = 1$

Error in meter 1 $= \pm \dfrac{1}{100} \times 100$

$= \pm 1\text{ W}$

Error in meter 2 $= \pm \dfrac{0.5}{100} \times 100$

$= \pm 0.5\text{ W}$

$W_T = W_1 + W_2$

$= 50 \pm 1.5\text{ W}$

$W_T = 50 \pm 3\%$

04. Ans: (a)

Sol: For 10V total input resistance

$R_v = \dfrac{V_{fsd}}{I_{m\,fsd}} = 10/100\mu\text{A} = 10^5\Omega$

Sensitivity $= R_v/V_{fsd} = 10^5/10$

$= 10\text{k}\Omega/\text{V}$

For 100V $\quad R_v = 100/100\mu\text{A}$

$= 10^6\Omega$

Sensitivity $= R_v/V_{fsd} = 10^6/100$

$= 10\text{ k}\Omega/\text{V}$

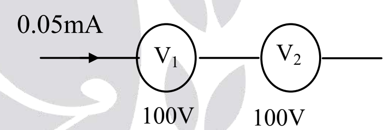
(or)

Sensitivity $= \dfrac{1}{I_{fsd}} = \dfrac{1}{100 \times 10^{-6}}$

$= 10\text{ k}\Omega/\text{V}$

05.

Sol:



V_1: $\quad S_{dc_1} = 10\,\text{k}\Omega/\text{V}$

$I_{fsd} = \dfrac{1}{S_{dc1}}$

$= 0.1\text{mA}$

V_2: $\quad S_{dc_2} = 20\,\text{k}\Omega/\text{V}$

$I_{fsd} = \dfrac{1}{S_{dc2}}$

$= 0.05\text{ mA}$

The maximum allowable current in this combination is 0.05mA, since both are connected in series.

Maximum D.C voltage can be measured as

$= 0.05\text{ mA }(10\text{ k}\Omega/\text{V} \times 100 + 20\text{ k}\Omega/\text{V} \times 100)$

$= 3000 \times 0.05 = 150\text{ V}$

06.

Sol: Internal impedance of 1st voltmeter

$= \dfrac{100\text{V}}{5\,\text{mA}} = 20\text{ k}\Omega$

Internal impedance of 2nd voltmeter

$= 100 \times 250\ \Omega/\text{V}$

$= 25\text{ k}\Omega$

Internal impedance of 3rd voltmeters,

$= 5\ k\Omega$

Total impedance across 120 V

$= 20 + 25 + 5$

$= 50\ k\Omega$

$$\text{Sensitivity} = \frac{50\,k\Omega}{120\,V}$$

$= 416.6\ \Omega/V$

$\Rightarrow$ Reading of 1st voltmeter

$$= \frac{20\,k\Omega}{416.6\,\Omega/V}$$

$= 48\ V$

Reading of 2nd voltmeter

$$= \frac{25\,k\Omega}{416.6\,\Omega/V}$$

$= 60\ V$

Reading of 3rd voltmeter

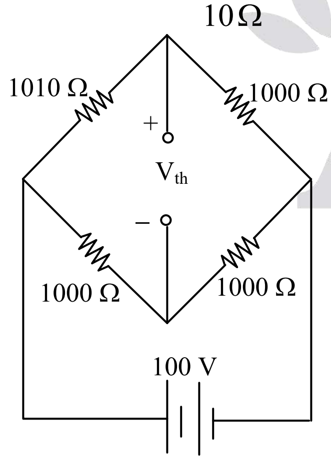
$$= \frac{5\,k\Omega}{4166\,\Omega/V}$$

$= 12\ V$

07. Ans: (b)

Sol: $$\text{Bridge sensitivity} = \frac{\text{Change in ouput}}{\text{Change in input}}$$

$$= \frac{V_{th}}{10\,\Omega}$$



$$V_{th} = \frac{1010\times 100}{2000} - \frac{1000\times 100}{2000}$$

$= 0.25V$

$$S_B = \frac{0.25\,V}{10\,\Omega}$$

$= 25\ mV/\Omega$

08. Ans: (b)

Sol: $$\text{Resolution} = \frac{200}{100}\times\frac{1}{10}$$

$= 0.2\ V$

09. Ans: (a & b)

Sol: $$RSE = LE = \frac{\text{Error}}{\text{True Value}}\times 100$$

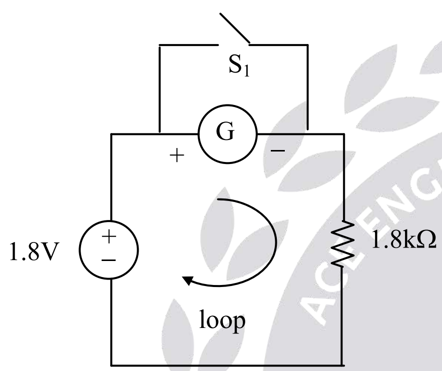
The Error which is expressed with respect to true value is called

- Relative static error
- % Limiting error

Chapter 2 Basics of Electrical Instruments

01. Ans: (d)

Sol: The pointer swings to 1 mA and returns, settles at 0.9 mA i.e, pointer has oscillations. Hence, the meter is under-damped. Now the current in the meter is 0.9 mA.



Applying KVL to circuit,

$1.8 \text{ V} - 0.9 \text{ mA} \times R_m - 0.9 \text{ mA} \times 1.8 \text{ k}\Omega = 0$

$1.8 \text{ V} - 0.9\times10^{-3} R_m - 1.62 = 0$

$$R_m = \frac{0.18}{0.9\times10^{-3}} = 200\ \Omega$$

02. Ans: 32.4° and 21.1°

Sol: $I_1 = 5$ A, $\theta_1 = 90°$; $I_2 = 3$ A, $\theta_2 = ?$

$\theta \propto I^2$ (as given in Question)

(i) Spring controlled

$\theta \propto I^2$

$$\frac{\theta_2}{\theta_1} = \left(\frac{I_2}{I_1}\right)^2$$

$$\Rightarrow \frac{\theta_2}{90} = \left(\frac{3}{5}\right)^2$$

$\theta_2 = 32.4°$

(ii) Gravity controlled

$\sin\theta \propto I^2$

$$\frac{\sin\theta_2}{\sin\theta_1} = \left(\frac{I_2}{I_1}\right)^2$$

$$\frac{\sin\theta_2}{\sin 90} = \left(\frac{3}{5}\right)^2$$

$$\Rightarrow \frac{\sin\theta_2}{1} = 0.36$$

$\theta_2 = \sin^{-1}(0.36) = 21.1°$

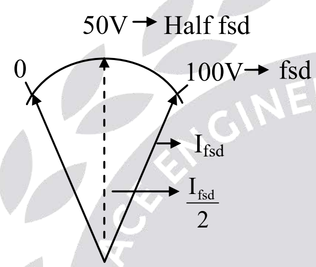
Chapter 3 Electromechanical Indicating Instruments

01. Ans: (c)

Sol: $S = \frac{1}{1000}\ \Omega/\text{volt}$

$S = \frac{1}{I_{fsd}}\ \Omega/V$

$I_{fsd} = \frac{1}{S} = \frac{1}{1000} = 1\text{ mA}$



100 V → 1 mA

50 V → ?

= 0.5 mA

02. Ans: (a)

Sol:

	1°C↑	10°C	T_c	θ
Spring stiffness(K_c)	0.04%↓	0.4%↓	0.4%↓	0.4%↑
			T_d	θ
Strength of magnet (B)	0.02%↓	0.2%↓	0.2%↓	0.2%↓

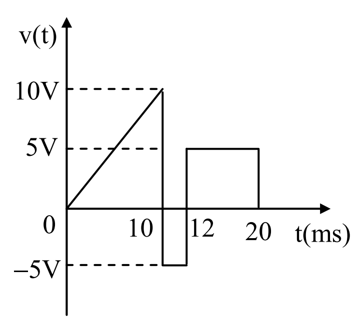
Net deflection (θ_{net}) = 0.4%↑ – 0.2%↓

= 0.2% ↑

Increases by 0.2%

03. Ans: (a)

Sol:



PMMC meter reads Average value

$$V_{avg} = \frac{\left(\frac{1}{2}\times 10\times 10\text{ms}\right)+(-5V\times 2\text{ms})+(5V\times 8\text{ms})}{20\text{ms}}$$

$$= \frac{50-10+40}{20} = 4V$$

(or)

$$\text{Avg. value} = \frac{1}{20}\left[\int_0^{10}(1)\,t\,dt - \int_{10}^{12}5\,dt + \int_{12}^{20}5\,dt\right]$$

$$= \frac{1}{20}\left[\left[\frac{t^2}{2}\right]_0^{10} - 5[t]_{10}^{12} + 5[t]_{12}^{20}\right]$$

$= 4$ V

04. Ans: 3.6 MΩ

Sol: V_m = (0 – 200) V ; S = 2000 Ω/V

V = (0 – 2000) V

$R_m = s \times V_m$

= 2000 Ω/V × 200 V

= 400000 Ω

$$R_{se} = R_m\left(\frac{V}{V_m} - 1\right)$$

$$= 400000\left(\frac{2000}{200} - 1\right)$$

= 3.6 MΩ

05. Ans: (c)

Sol: $T_d = \frac{1}{2}I^2\frac{dL}{d\theta}$

$$K_c\theta = \frac{I^2}{2}\frac{dL}{d\theta}$$

$$25\times 10^{-6}\times\theta = \frac{25}{2}\times\left(3-\frac{\theta}{2}\right)\times 10^{-6}$$

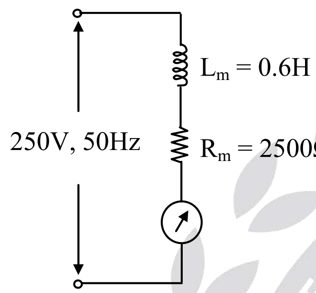
$$2\theta = 3 - \frac{\theta}{2}$$

$$\frac{5}{2}\theta = 3$$

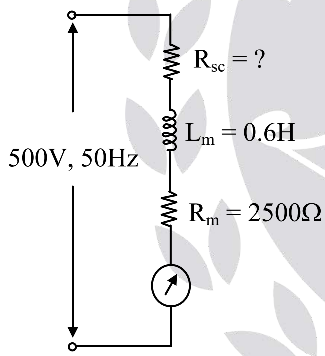
$$\theta = 1.2 \text{ rad}$$

06. Ans: 2511.5 Ω

Sol:



(i)



(ii)

Current is same in case (i) & (ii)

In case (i),

$$I_m = \frac{250\,V}{\sqrt{R_m^2 + (\omega L_m)^2}}$$

$$= \frac{250\,V}{\sqrt{(2500)^2 + (2\pi \times 50 \times 0.6)^2}}$$

$$= 0.0997 \text{ A}$$

In case (ii),

$$I_m = \frac{250\,V}{\sqrt{(R_m + R_{se})^2 + (\omega L_m)^2}}$$

$$0.0997\,A = \frac{500\,V}{\sqrt{(2500 + R_{se})^2 + (2\pi \times 50 \times 0.6)^2}}$$

$$\sqrt{(2500 + R_{se})^2 + 35.53 \times 10^3} = \frac{500}{0.0997}$$

$$\sqrt{(2500 + R_{se})^2 + 35.53 \times 10^3} = 5.015 \times 10^3$$

$$R_{se} = 2511.5\ \Omega$$

07. Ans: 0.1025 μF

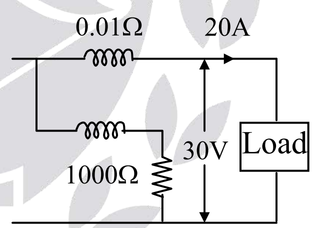
Sol: $C = \dfrac{0.41\, L_m}{R_{se}^2}$

$$C = \frac{0.41 \times 1}{(2\,k\Omega)^2}$$

$$= 0.1025\,\mu F$$

08. Ans: (c)

Sol: MC - connection

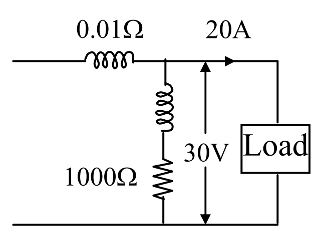


Error due to current coil

$$= \frac{20^2 \times 0.01}{(30 \times 20)} \times 100$$

$$= 0.667\%$$

LC - connection



Error due to potential coil

$$= \frac{(30^2/1000)}{(30\times 20)}\times 100$$

$= 0.15\%$

As per given options, 0.15% high

09. Ans: (c)

Sol: $R_{load} = \frac{V}{I} = \frac{200}{20} = 10\,\Omega$

For same error $R_L = \sqrt{R_C \times R_V}$

$\therefore\ 100 = 10\times 10^3 \times R_C$

$\Rightarrow\ R_C = 0.01\ \Omega$

10. Ans: (d)

Sol: $R_p = 1000\ \Omega$, $L_p = 0.5$ H, f = 50 Hz,

$\cos\phi = 0.7$,

$X_{Lp} = 2\times\pi\times f\times L$, $\tan\phi = 1$

$= 2\times\pi\times 50\times 0.5$

$= 157\ \Omega$

$$\tan\beta = \frac{X_{LP}}{R_P}$$

% Error $= \pm(\tan\phi\tan\beta)\times 100$

$$= \pm\left(1\times\frac{157}{1000}\right)\times 100$$

$= 15.7\% \simeq 16\%$

11. Ans: (a, b & c)

Sol: Sensitivities related to galvanometer is/are:

- Current sensitivity
- Voltage sensitivity
- Megohm sensitivity

12. Ans: (a, b & c)

Sol: In moving iron ammeter, the errors associated with dc current measurement is,

- Temperature error
- Hysteresis error
- Stray magnetic field error

13. Ans: (a & c)

Sol: In electrodynamometer type instruments,

- Fixed coil is air core
- Moving coil is air core

14. Ans: (a, b & d)

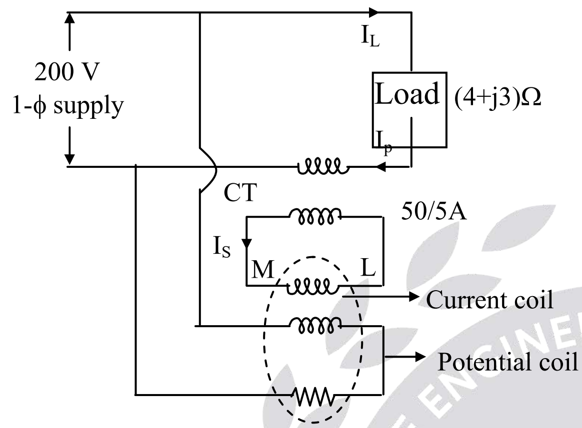
Sol: The hysteresis error in moving iron type instruments can be minimized by,

- Using small iron piece,
- Using iron parts at low flux density,
- Using iron alloy with narrow hysteresis loop.

Chapter 4 Measurement of Power

01. Ans: (b)

Sol:



Potential coil voltage = 200 V

C.T. primary current (I_p)

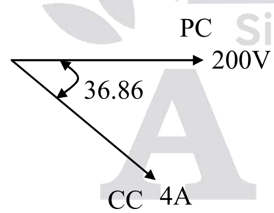
$$I_P = I_L = \frac{200\,V}{\sqrt{4^2+3^2}\ \tan^{-1}\left(\frac{3}{4}\right)}$$

$$I_p = I_L = \frac{200\,V}{5\angle 36.86}$$

$$I_p = 40\angle -36.86$$

$$\frac{I_p}{I_S} = \frac{50}{5}$$

$$\frac{40}{I_S} = \frac{50}{5}$$



$$I_S = \frac{5}{50}\times 40 = 4\,A$$

C.T secondary (I_S) = $4\angle -36.86°$

Wattmeter current coil = I_C

$= 4\angle -36.86°$

Wattmeter reading

$= 200\ V \times 4 \times \cos(36.86)$

$= 640.08$ W

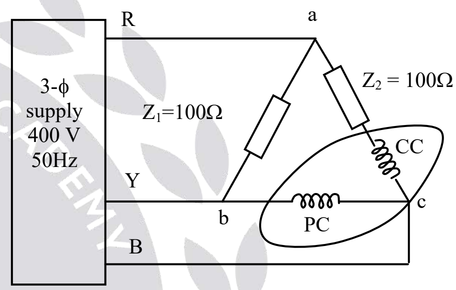
02. Ans: (c)

Sol: $W = \frac{E_1}{\sqrt{2}}\times\frac{I_1}{\sqrt{2}}\cos\phi_1 + \frac{E_3}{\sqrt{2}}\times\frac{I_3}{\sqrt{2}}\cos\phi_3$

$$W = \frac{1}{2}[E_1 I_1 \cos\phi_1 + E_3 I_3 \cos\phi_3]$$

03. Ans: (c)

Sol:



Based on R-Y-B

Assume abc phase sequence

$V_{ab} = 400\angle 0°$;

$V_{bc} = 400\angle -120°$

$V_{ca} = 400\angle -240°$ or $400\angle 120°$

Current coil current (I_c) = $\frac{V_{ca}}{Z_2}$

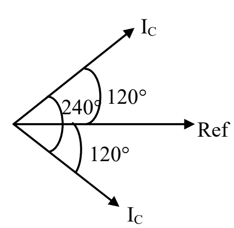
$= \frac{400\angle 120^\circ}{100\Omega}$

$= 4\angle 120^\circ$

Potential coil voltage (V_{bc}) = $400\angle -120°$

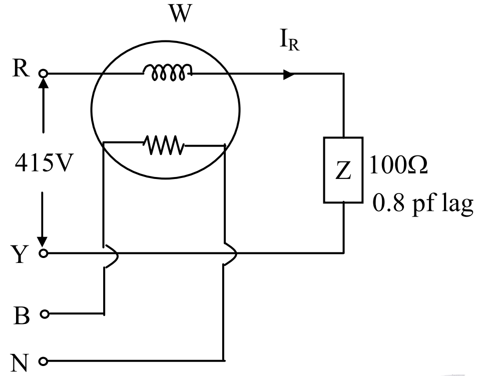
$W = 400 \times 4 \times \cos(240)$

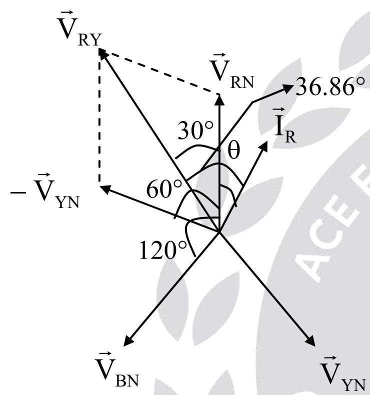
$= -800$ W



04. Ans: –596.46 W

Sol:





Current coil is connected in 'R_{phase}', it reads '$\vec{I}_R$' current.

Potential coil reads phase voltage i.e., $\vec{V}_{BN}$

$$W = \vec{V}_{BN} \times \vec{I}_R \times \cos(\vec{V}_{BN} \cdot \vec{I}_R)$$

$$V_L = 415 \text{ V},\ V_{BN} = \frac{415}{\sqrt{3}} \text{ V}$$

$$I_R = \frac{V_{RY}}{Z} = \frac{415}{100} = 4.15 \text{ A}$$

$\cos\phi = 0.8$

$\Rightarrow \phi = 36.86$ between $\vec{V}_{RY}$ & $\vec{I}_R$

$\theta = 36.86° - 30° = 6.86°$

Now angle between $\vec{V}_{BN}$ and $\vec{I}_R$

$= 120 + 6.86 = 126.86°$

$$W = \frac{415}{\sqrt{3}} \times 4.15 \times \cos(126.86)$$

$= -596.467$ W

05. Ans: (d)

Sol: $V_L = 400$ V, $I_L = 10$ A

$\cos\phi = 0.866$ lag, $\phi = 30°$

$W_1 = V_L I_L \cos(30 - \phi)$

$W_2 = V_L I_L \cos(30 + \phi)$

$W_1 = 400\times10\times\cos(30 - 30) = 4000$W

$W_2 = 400\times10\times\cos(30 + 30) = 2000$W

06. Ans: (b)

Sol: $\phi = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right]$

Power factor = $\cos\phi$

= 0.917 lag (since load is inductive)

07. Ans: W = 519.61 VAR

Sol:

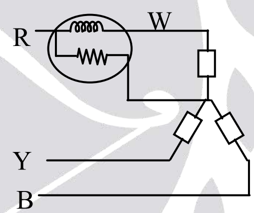


Fig. (a)

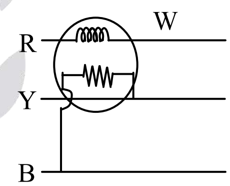


Fig. (b)

W = 400 watt ; $W = V_{ph} I_{ph} \cos\phi$

$V_{ph} I_{ph} = 400/0.8$

This type of connection gives reactive power

$W = \sqrt{3} V_p I_p \sin\phi$

$= \sqrt{3} \times \frac{400}{0.8} \times 0.6$

$= 519.6$VAR

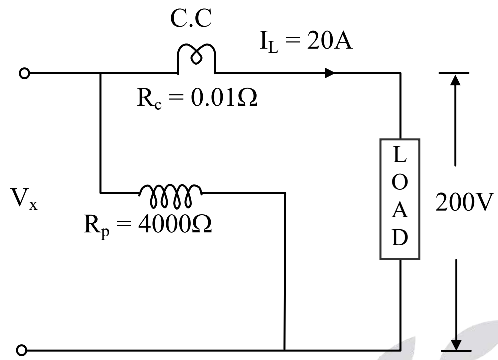
08. Ans: (a & d)

Sol: The errors in power measurement because of eddy currents in wattmeters are such that measured power in comparison to true power is,

- Higher for lagging power factor
- Higher for leading power factor

09. Ans: (a & d)

Sol: Case (i):



I_L = 20 A, P.F = 0.8 (lag)

$P_{true} = VI\cos\phi = 200 \times 20 \times 0.8$

P_{true} = 3200 W

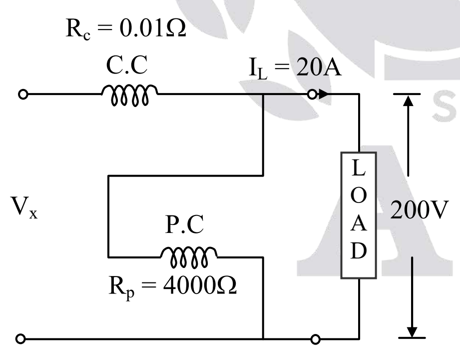
Error due to C.C = $R_c = (20)^2 \times 0.01$

$= 4W$

Measured error due to C.C on load side

$= \dfrac{4}{3200} \times 100 = 0.125\%$

Case (ii):



Error due to P.C = $\dfrac{V^2}{R_p} = \dfrac{(200)^2}{4000}$ = 10 W

Measured error due to C.C on source side or P.C on load side

$= \dfrac{10}{3200} \times 100$

$= 0.3125\%$

So both options a & d are correct.

10. Ans: (a & c)

Sol: W = 1200 W & W_2 = 600 W (given)

Note: $W_1 = 2W_2$

for $W_1 = 2W_2$ or $W_2 = 2W_1 \rightarrow \cos\phi = 0.866$

So option (c) is correct.

total measured power = $W_1 + W_2$

= 1200 + 600

= 1800 W

So option (a) is also correct.

Chapter 5 Measurement of Energy

01. Ans: (a)

Sol: Energy consumed in 1 minute

$$= \frac{240\times10\times0.8}{1000}\times\frac{1}{60} = 0.032\,\text{kWh}$$

Speed of meter disc

= Meter constant in rev/kWhr × Energy consumed in kWh/minute

= 400 × 0.032

= 12.8 rpm (revolutions per minute)

02. Ans: (a)

Sol: Energy consumed (True value)

$$= \frac{230\times5\times1}{1000}\times\frac{3}{60} = 0.0575\text{ kWhr}$$

Energy recorded (Measured value)

$$= \frac{\text{No. of rev (N)}}{\text{meter constant (k)}}$$

$$= \frac{90\text{ rev}}{1800\text{ rev/kWh}} = 0.05\text{ kWhr}$$

$$\%\text{Error} = \frac{0.05-0.0575}{0.0575}\times100$$

= – 13.04% = 13.04% (slow)

03. Ans: (c)

Sol: V = 220 V, Δ = 85°, I = 5A

Error = VI [sin(Δ – ϕ) – cos ϕ]

(1) cos ϕ = UPF, ϕ = 0°

Error = 220×5[sin(85 – 0) – cos 0]

= – 4.185 W

≃ – 4.12 W

(2) cos ϕ = 0.5 lag, ϕ = 60°

Error = 220×5 [sin(85 – 60) – cos 60]

= – 85.12 W

04. Ans: (c)

Sol: Meter constant = 14.4 A-sec/rev

= 14.4 × 250W-sec/rev

$$= \frac{14.4\times250}{1000}\text{ kW-sec/rev}$$

$$= \frac{14.4\times250}{1000\times3600}\text{ kWhr/rev}$$

$$\text{Meter constant} = \frac{1}{1000}\text{ kWhr/rev}$$

Meter constant in terms of rev/kWhr = 1000

05. Ans: (a & b)

Sol: In energy meters,

$$\text{Speed of disc} \propto \frac{T_B Z}{k_3\phi_m^2 R}$$

$N \propto Z$

$$N \propto \frac{1}{\phi_m^2}$$

So both options a & b are correct.

06. Ans: (a & d)

Sol: K = 0.4 (rev/kwhr)

$$\text{Recorded energy} = \frac{40}{0.4} = 100\text{ (kwhr)}$$

So option (a) is correct

Measured energy

$$= 20\times10^3\times400\times0.8\times\frac{60}{3600}\times10^{-3}$$

= 106. 67 (kwhr)

Error = –6.67 (kwhr)

% error measured as % of measured value

$$= \frac{-6.67}{100} \times 100 = -6.67\%$$

07. Ans: (a & c)

Sol: Average monthly load factor

$$= \frac{\text{total kwhr through month}}{\text{peak load in kw} \times 720}$$

$$= \frac{288000 \times 10^3}{1600 \times 10^3 \times 720}$$

$$= \frac{1}{4} = 0.25$$

$$\text{Power factor} = \frac{P}{S} = \frac{288000 \times 10^3}{400000 \times 10^3}$$

Power factor = 0.72

Chapter 6 Bridge Measurement of R, L & C

01. Ans: (a)

Sol: The deflection of galvanometer is directly proportional to current passing through circuit, hence inversely proportional to the total resistance of the circuit.

Let S = standard resistance

R = Unknown resistance

G = Galvanometer resistance

θ_1 = Deflection with S

θ_2 = Deflection with R

$$\therefore \frac{\theta_1}{\theta_2} = \frac{R+G}{S+G}$$

$$\Rightarrow R = (S+G)\frac{\theta_1}{\theta_2} - G$$

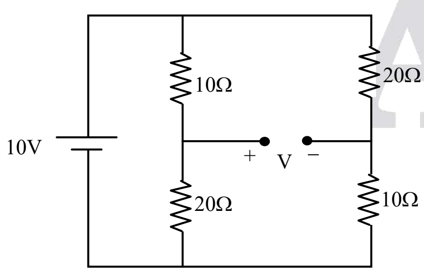
$$= (0.5\times10^6 + 10\times10^3)\left(\frac{41}{51}\right) - 10\times10^3$$

$$= 0.4 \times 10^6\ \Omega$$

$$= 0.4\ \text{M}\Omega$$

02. Ans: (d)

Sol:



$$V = V_+ - V_-$$

$$= 10\times\frac{20}{30} - 10\times\frac{10}{30}$$

$$= 6.66 - 3.33$$

$$= 3.33\ \text{V}$$

03. Ans: (c)

Sol: The voltage across R_2 is

$$= E\frac{R_2}{R_1+R_2} = \frac{E}{2}$$

The voltage across R_1 is

$$= E\frac{R_1}{R_1+R_2} = \frac{E}{2}$$

Now, $\frac{E}{2} = IR_3 + V$

$$I = \frac{E-2V}{2R_3} \Rightarrow I = \frac{E-2V}{2R}$$

and $\frac{E}{2} = IR_4$

$$\frac{E}{2} = \left(\frac{E-2V}{2R}\right)(R+\Delta R)$$

$$ER = (E-2V)(R+\Delta R)$$

$$R+\Delta R = \frac{ER}{(E-2V)}$$

$$\Delta R = \frac{ER}{(E-2V)} - R$$

$$= \frac{ER - ER + 2VR}{(E-2V)}$$

$$\Delta R = \frac{2VR}{(E-2V)}$$

04. Ans: (c)

Sol: $$R = \frac{0.4343\ T}{C\log_{10}\left(\frac{E}{V}\right)}$$

$$= \frac{0.4343\times60}{600\times10^{-2}\times\log_{10}\left(\frac{250}{92}\right)}$$

$$= \frac{26.058}{260.49\times10^{-12}}$$

$$R = 100.03\times10^9\ \Omega$$

05. Ans: 0.118 μF, 4.26kΩ

Sol: Given: $R_3 = 1000\ \Omega$

$$C_1 = \frac{\varepsilon_0\varepsilon_r A}{d}$$

$$= \frac{2.3\times 4\pi\times 10^{-7}\times 314\times 10^{-4}}{0.3\times 10^{-2}}$$

$C_1 = 30.25\ \mu F$

$\delta = 9°$ for 50 Hz

$\tan\delta = \omega C_1\ r_1$

$= \omega L_4 R_4$

$\Rightarrow r_1 = 16.67\ \Omega$

Variable resistor $(R_4) = R_3\left(\frac{C_1}{C_2}\right)$

$R_4 = 4.26k\ \Omega$

$C_4 = 0.118\ \mu F$

06. Ans: (a)

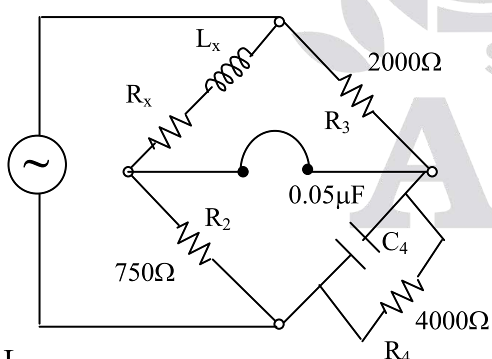
Sol: It is Maxwell Inductance Capacitance bridge

$R_x R_4 = R_2 R_3$

$$R_x = \frac{R_2 R_3}{R_4}$$

$$R_x = \frac{750\times 2000}{4000}$$

$R_x = 375\ \Omega$



$$\frac{L_x}{C_4} = R_2 R_3$$

$L_x = C_4 R_2 R_3$

$L_x = 0.05\times 10^{-6}\times 750\times 2000$

$L_x = 75$ mH

07. Ans: (a & d)

Sol: At balance

$$\left(R_1 + \frac{1}{j\omega C_1}\right)R_4 = R_2\left(\frac{R_3}{1+j\omega C_3 R_3}\right)$$

$$R_4\ (j\omega C_1 R_1 + 1)R_4 = \frac{j\omega C_1 R_2 R_3}{1+j\omega C_3 R_3}$$

$R_4\ (j\omega C_1R_1 - \omega^2 C_1R_1C_3R_3 + 1 + j\omega C_3R_3) = j\omega\ C_1R_1C_3R_3$

$j\omega(R_1C_1R_4 + C_3R_3R_4 - C_1R_2R_3) = \omega^2 C_1\ R_1C_3R_3R_4 - R_4$ .... (i)

Equate imaginary terry to zero

$R_1C_1R_4 + C_3\ R_3R_4 = C_1R_2R_3$

$$\frac{R_1}{R_3}+\frac{C_3}{C_1}=\frac{R_2}{R_4}$$

So option (a) is correct

So equate real terms to zero in equation (i)

$$\omega = \frac{1}{\sqrt{R_1R_3C_1C_3}}$$

So both options a & d are correct.

08. Ans: (a, c & d)

Sol:

- Direct deflection method is commonly used for cable resistance measurement
- Kelvin double bridge eliminates error due to contact and lead wire resistance
- Earth electrode resistance must be of low value due to safety reasons.

09. Ans: (a, b, c & d)

Sol: The value of earthing electrode resistance depends upon:

- Specific resistance of soil
- Depth of electrode
- Shape of electrode
- Electrode material

Chapter 7 Potentiometers & Instrument Transformers

01. Ans: (d)

Sol: Under null balanced condition the current flow in through unknown source is zero. Therefore the power consumed in the circuit is ideally zero.

02. Ans: (d)

Sol: Potentiometer is used for measurement of low resistance, current and calibration of ammeter.

03. Ans: (a)

Sol: Since the instrument is a standardized with an emf of 1.018 V with sliding contact at 101.8 cm, it is obvious that a length 101.8 cm represents a voltage of 1.018.

Resistance of 101.8 cm length of wire

$= (101.8/200) \times 400$

$= 203.6\ \Omega$

$\therefore$ Working current

$I_m = 1.018/203.6$

$= 0.005\text{ A} = 5\text{ mA}$

Total resistance of the battery circuit

= resistance of rheostat + resistance of slide wire

$\therefore$ Resistance of rheostat

R_h = total resistance – resistance of slide wire

$$= \frac{3}{5\times10^{-3}} - 400$$

$= 600 - 400$

$= 200\ \Omega$

04. Ans: (b)

Sol: Voltage drop per unit length

$$= \frac{1.45\text{ V}}{50\text{ cm}} = 0.029\text{ V/cm}$$

Voltage drop across 75 cm length

$= 0.029 \times 75 = 2.175\text{ V}$

Current through resistor (I)

$$= \frac{2.175\text{ V}}{0.1\ \Omega}$$

$= 21.75$ A (or)

75 cm $\rightarrow$ 0.1 Ω

50 cm $\rightarrow$?

Slide wire resistance with standard cell

$$= \frac{50}{70} \times 0.1$$

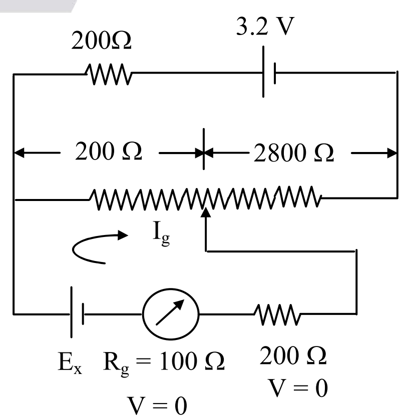
$= 0.067\ \Omega$

Then $0.067 \times I_w = 1.45$ V

$$I_w = \frac{1.45}{0.067} = 21.75\text{ A}$$

05. Ans: (a)

Sol:



Under balanced, $I_g = 0$

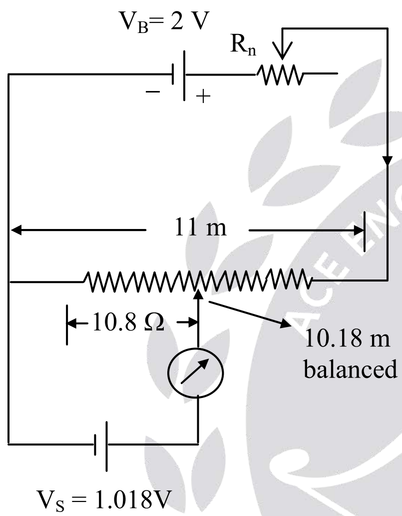
$$E_x = 3.2\,V \times \frac{200}{(200+200+2800)}$$

$$= 0.2\ V$$

$E_x = 200$ mV

06. Ans: (a)

Sol:



Resistance 1 Ω/cm

For 11 m → 11 Ω

For 10m + 18cm → 10.8Ω

$I_w \times 10.8\Omega = 1.018$ V

$$I_w = \frac{V_B}{R_n + 1_r}$$

$$\Rightarrow \quad 0.1 = \frac{2}{R_n + 11\Omega}$$

$$R_n = \frac{2}{0.1} - 11$$

$$= 9\ \Omega$$

07. Ans: $R_1 = 19$ MΩ & $R_2 = 1$ MΩ

Sol: By using voltage division rule we can write

$$V_2 = \frac{R_2}{R_1 + R_2} V_x$$

$V_x = 100$ V (given)

$R_1 + R_2 = 20$ MΩ (given)

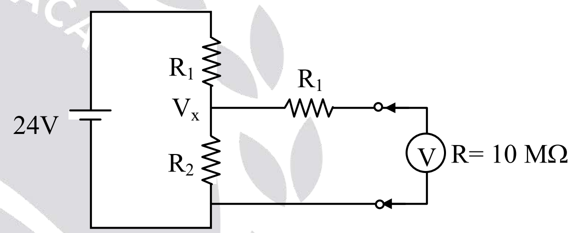
$V_2 = 5$V (given)

$$5 = \frac{R_2}{20M\Omega} \times 100$$

$R_2 = 1$ MΩ & $R_1 = 19$MΩ

08. Ans: (a & c)

Sol:



Case (i): True value of voltage measured without considering the voltmeter internal resistance

$$V_x = \frac{250}{250+250} \times 24 = 12V$$

So option (a) is correct

Case (ii):

Now we consider voltmeter internal resistance (r)

$$\frac{24 - V_x}{250} = \frac{V_x}{250} + \frac{V_x}{10}$$

$24 - V_x = V_x + 25\ V_x$

$27\ V_x = 24$

$$V_x = \frac{24}{27} = \frac{8}{9} = 0.89V$$

So option (b) is incorrect.

Case (iii): Considering additional resistance R_1 then V_x must be 90% of accuracy

$V_x = 0.9 \times 12\text{ V} = 10.8\text{V}$

$$\frac{24-10.8}{250} = \frac{10.8}{250} + \frac{10.8}{10+R_1}$$

$$13.2 = 10.8 + \left(\frac{10.8 \times 250}{10+R_1}\right)$$

$R_1 = 1115\text{ M}\Omega$

So option (c) is true.

So we can say that option a & c are correct.

09. Ans: (a & c)

Sol: Unknown resistance = $\dfrac{0.2(\Omega)}{1.75(\text{V})} \times 0.525\text{ (V)}$

$R_x = 0.06\ (\Omega)$

Power lost in unknown resistance

$= I^2R_x$

$= \left(\dfrac{1.75}{0.2}\right)^2 \times 0.06$

$= 4.6\text{ W}$

10. Ans: (a, c & d)

Sol: The following statements related to instrumentation transformers are:

- CTs and PTs are used for measurement of current and voltage measurement of high power circuits.
- Circular cores are used for CTs to eliminate joints and hence to decrease the reluctance of flux path.
- Standard burden rating for CTs are 2.5, 5, 7.5, 15 etc.

11. Ans: (a, c & d)

Sol:

Parameter	Power transformer	Potential transformer
• Efficiency	Low	High
• Core size	High	Low
• Core type	Rectangular	Rectangular

12. Ans: (a, b, c & d)

Sol:

- A CT (current transformer) is equivalent to series transformer
- A PT (Potential transformer) is equivalent to parallel transformer.
- The marked ratio on instrumentation transformer (CT or PT) is nominal ratio.
- Errors in current and potential transformers are due to no-load current.

Chapter 8 Cathode Ray Oscilloscope

01. Ans: (b)

Sol: Time period of one cycle = $\frac{8.8}{2}\times 0.5$

= 2.2 msec

Therefore frequency = $\frac{1}{T}=\frac{1}{2.2\times 10^{-3}}$

= 454.5 Hz

The peak to peak Voltage = 4.6×100

= 460 mV

Therefore the peak voltage V_m = 230 mV

R.M.S voltage = $\frac{230}{\sqrt{2}}$ = 162.6 mV

02. Ans: (c)

Sol: In channel 1

The peak to peak voltage is 5V and peak to peak divisions of upper trace voltage = 2

Therefore for one division voltage is 2.5V

In channel 2, the no. of divisions for unknown voltage = 3

Divisions = 3, voltage/division = 2.5

$\therefore$ voltage = 2.5 × 3 = 7.5 V

Similarly frequency of upper trace is 1kHz

So the time period T

(for four divisions) = $\frac{1}{f}$

$T = {}^{1}\!/_{10^3}$ = 1 msec

i.e., for four divisions time period = 1m sec

In channel 2, for eight divisions of unknown waveform time period = 2m sec.

03. Ans: (c)

Sol: No. of cycles of signal displayed

$= f_{signal} \times T_{sweep}$

$= 200\text{Hz} \times \left(10\,\text{cm}\times\frac{0.5\text{ms}}{\text{cm}}\right) = 1$

i.e, one cycle of sine wave will be displayed.

We know $V_{rms} = \frac{V_{p-p}}{2\sqrt{2}}$

$V_{rms} = \frac{N_v \times \text{Volt}/\text{div}}{2\sqrt{2}}$

$\Rightarrow N_v = \frac{2\sqrt{2}\times V_{rms}}{\text{Volt}/\text{div}}$

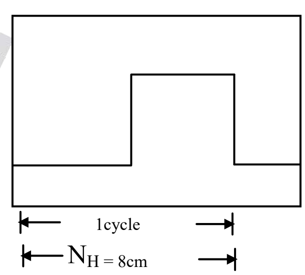
$\Rightarrow N_v = \frac{2\sqrt{2}\times 300\text{mV}}{100\text{mv}/\text{cm}}$

$\Rightarrow N_v = 8.485\text{cm}$

i.e., 8.485cm required to display peak to peak of signal. But screen has only 8cm (vertical) As such, peak points will be clipped.

04. Ans: (b)

Sol:



→ Given data: Y input signal is a symmetrical square wave

$f_{signal} = 25\text{kHz}, \quad V_{pp} = 10\text{V}$

→ Screen has 10 Horizontal divisions & 8 vertical divisions which displays 1.25 cycles of Y-input signal.

$\rightarrow V_{PP} = N_V \times \dfrac{VOLT}{div}$

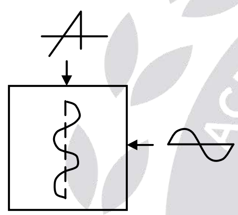
$\Rightarrow \dfrac{VOLT}{div} = \dfrac{V_{PP}}{N_V} = \dfrac{10V}{5cm} = 2$ volt/ c.m

$\rightarrow T_{signal} = N_H \text{per cycle} \times \dfrac{TIME}{div}$

$\Rightarrow \dfrac{TIME}{div} = \dfrac{T_{signal}}{N_H \text{per cycle}} = \dfrac{1}{25kHz \times 8cm} = 5\ \dfrac{\mu s}{cm}$

05. Ans: (a)

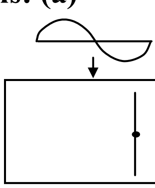
Sol: Frequency ratio is 2



$\therefore$ Two cycles of sine wave displayed on vertical time base.

06. Ans: (a)

Sol:



Vertical straight line

07. Ans: (a)

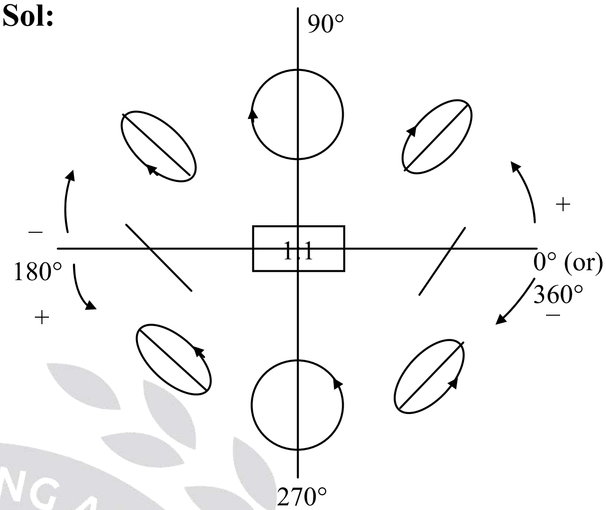
Sol: Since the coupling mode is set to DC the capacitance effect at the input side is zero. Therefore the waveform displayed on the screen is both DC and AC components.

08. Ans: (a)

Sol: In order to display correctly, a delay line of 150 ns has to be inserted in to the Y-channel between output of vertical amplifier and Y-input of CRT.

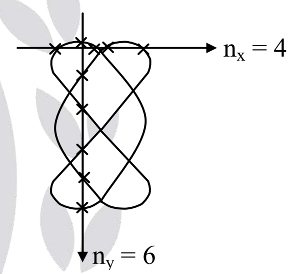
09. Ans: (d)

Sol:



10. Ans: (b)

Sol:



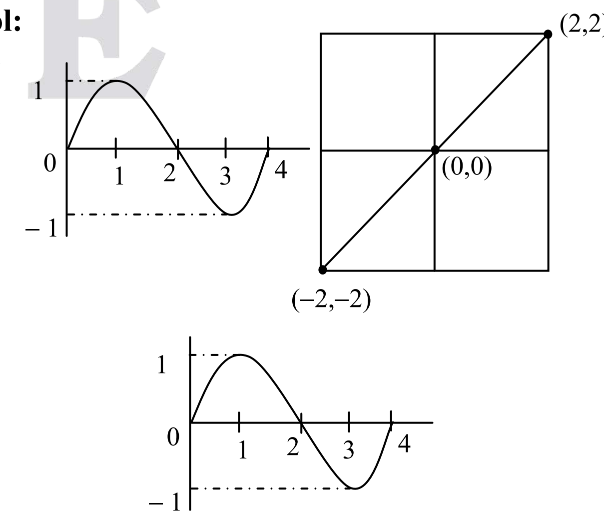
$f_y = \dfrac{n_x}{n_y} f_y$

$= \dfrac{4}{6} \times 600\text{Hz}$

$= 400$ Hz

11. Ans: (d)

Sol:



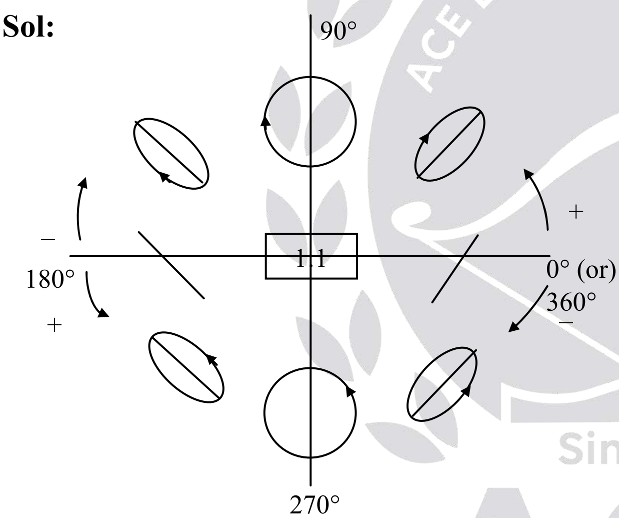
Let $K_y = K_x = 2\ ^{Volt}\!/_{div}$

t	V_y	V_x	$d_y = k_y V_y$	$d_x = k_x V_x$	points
0	0	0	0	0	(0,0)
1	1	1	2	2	(2,2)
2	0	0	0	0	(0,0)
3	–1	–1	–2	–2	(–2,–2)
4	0	0	0	0	(0,0)

By using these points draw the line which is a diagonal line inclined at 45° w.r.t the x-axis.

12. Ans: (a, b & c)

Sol:



- If the major axis of the ellipse lies in the first and third quadrants the phase angle is either between 0° to 90° or between 270° to 360°.
- when the major axis of ellipse lies in the second and fourth quadrants, the phase angle is either between 90° to 180° or between 180° to 270°.
- an aquadag is used in a CRO to collect secondary emission electrons.

13. Ans: (c & d)

Sol: $f_v = f_h \times \dfrac{\text{Horizontal cut}}{\text{Vertical cut}}$

$$f_v = f_h \times \frac{4}{2}$$

$$\frac{f_v}{f_h} = \frac{2}{1} \quad \text{(or)} \quad \frac{f_h}{h_v} = \frac{1}{2}$$

Chapter 9 Digital Voltmeters

01. Ans: (a)

Sol: The type of A/D converter normally used in a $3\frac{1}{2}$ digit multimeter is Dual-slope integrating type since it offers highest Accuracy, Highest Noise rejection and Highest Stability than other A/D converters.

02. Ans: (d)

Sol: DVM measures the average value of the input signal which is 1 V.

$\therefore$ DVM indicates as 1.000 V

03. Ans: (c)

Sol: 0.2% of reading +10 counts $\rightarrow$ (1)

$$= 0.2 \times \frac{100}{100} + 10\,(\text{sensitivity} \times \text{range})$$

$$= 0.2 \times \frac{100}{100} + 10\left(\frac{1}{2\times10^4} \times 200\right)$$

$$= 0.2 + 0.1 = \pm\, 0.3 \text{ V}$$

$$\%\text{error} = \pm\frac{0.3}{100}\times100 = 0.3\%$$

04. Ans: (d)

Sol: When $\frac{1}{2}$ digit is present voltage range becomes double. Therefore 1V can read upto 1.9999 V.

05. Ans: (d)

Sol: $\text{Resolution} = \dfrac{\text{full} - \text{scale reading}}{\text{maximum count}}$

$$= \frac{9.999\text{V}}{9999} = 1\text{mV}$$

06. Ans: (b)

Sol: Sensitivity = resolution × lowest voltage range

$$= \frac{1}{10^4}\times 100 \text{ mV}$$

$$= 0.01 \text{ mV}$$

07. Ans: (c)

Sol: The DVM has $3\frac{1}{2}$ digit display

Therefore, the count range is from 0 to 1999 i.e., 2000 counts. The scale resolution is 0.001. And, the resolutions in each selected voltage Ranges of 2V, 20V & 200V are 1mV, 10mV & 100mV.

08. Ans: (a)

Sol: $\text{Resolution} = \dfrac{\text{max. voltage}}{\text{max. count}} = \dfrac{3.999}{3999} = 1\text{mV}$

09. Ans: (b)

Sol: A and R are true, but R is not correct explanation for A.

10. Ans: (c)

Sol: When $\frac{1}{2}$ digit switched ON, then DVM will be able to read more than the selected range.

11. Ans: (a, b & d)

Sol: The below statements correct one(s) are

- Electronic voltmeter is more accurate than digital voltmeter.
- Electronic voltmeter employes op - amp.
- In ramp type DVM, voltage to time conversion takes place.

Chapter 10 Q-meter

01. Ans: (a)

Sol: $C_1 = 300\text{pF}$ $C_2 = 200$ pF

$Q = 1/(\omega C_1 R)$ $= 120 = 1/(C_2 + C_x)R$

$C_1 = C_2 + C_x$

$\therefore C_x = 100$ pF

02. Ans: (b)

Sol: $\%\text{error} = -\dfrac{r}{r+R}\times 100 = -\dfrac{0.02}{0.02+10}\times 100$

$= -0.2\%$

03. Ans: (c)

Sol: Q-meter consists of R, L, C connected in series.

$\therefore$ Q-meter works on the principle of series resonance.

04. Ans: (b)

Sol: Given data: $C_d = 820$ pF,

$\omega = 10^6$rad/sec & C = 9.18nF

We know, $L = \dfrac{1}{\omega^2[C+C_d]}$

$= \dfrac{1}{(10^6)^2[9.18\text{nF}+820\text{pF}]}$

$= 100\mu$H

The inductance of coil tested with a Q-meter is 100μH.

05. Ans: (b)

Sol: A series RLC circuit exhibits voltage magnification property at resonance. i.e., the voltage across the capacitor will be equal to Q-times of applied voltage.

Given that V = applied voltage and

V_0 = Voltage across capacitor

There fore, $Q = \dfrac{V_{c\max}}{V_{in}}$

$\Rightarrow$ $Q = \dfrac{V_0}{V}$

06. Ans: (b)

Sol: $f_1 = 500$ kHz ; $f_2 = 250$kHz

$C_1 = 36$ pF ; $C_2 = 160$ pF

$n = \dfrac{250\,\text{kHz}}{500\,\text{kHz}} \Rightarrow n = 0.5$

$C_d = \dfrac{36\text{pF}-(0.5)^2 160\text{pF}}{(0.5)^2-1}$

$= 5.33$ pF

07. Ans: (c)

Sol: $Q = \dfrac{\text{capactor voltmeter reading}}{\text{Input voltage}}$

$= \dfrac{10}{500\times10^{-3}} = 20$

08. Ans: i $\rightarrow$ (c), ii $\rightarrow$ (a)

Sol: (i) $C_d = \dfrac{C_1 - n^2 C_2}{n^2-1}$

$= \dfrac{360-288}{3} = 24$ pF

(ii) $L = \dfrac{1}{\omega_1^2[C_1+C_d]}$

$= \dfrac{1}{\left[2\pi\times500\times10^3\right]^2[24+360]\times10^{-6}} = 264\mu\text{H}$

09. Ans: (b)

Sol: $Q_{true} = Q_{meas}\left(1+\frac{r}{R_{coil}}\right)$

$$Q_{actual} = Q_{observed}\left[1+\frac{R}{R_s}\right]$$

10. Ans: (c)

Sol: $1+\frac{C_d}{C} = \frac{Q_{true}}{Q_{measured}}$

$$\Rightarrow \frac{C_d}{C} = \frac{245}{244.5} - 1$$

$$= 2.044\times10^{-3}$$

$$\Rightarrow \frac{C}{C_d} = 489$$

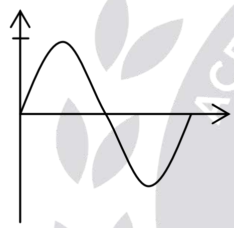
Chapter 11 Analog Electronic Voltmeter

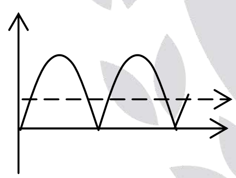
01. Ans: (a)

Sol: The full wave Rectifier type electronic AC voltmeter has a scale calibrated to read r.m.s value for square wave inputs. As such, the scale calibration factor used for deriving rms volt scale from DC volt scale is 1.

Reading = 1× V_{dc} Where V_{dc} is Average voltage of output of full wave Rectifier for given input.

This voltmeter is used to measure a sinusoidal voltage





DC. voltmeter measures V_{dc} of output of FWR

$$V_{dc} = \frac{2V}{\pi}$$

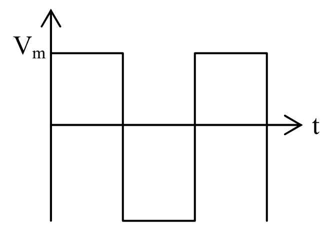
Therefore, reading = $1 \times V_{dc} = \frac{2}{\pi} V$

02. Ans: (b)

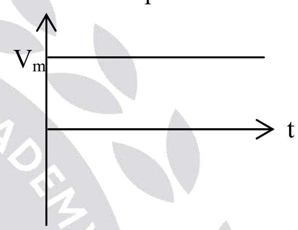
Sol: The scale of a full wave rectifier type voltmeter is calibrated to read r.m.s for ideal sine wave i.e, reading = $1.11V_{dc}$ where V_{dc} is average voltage of output of FWR for given input.

This voltmeter is used for square wave input

FWR input



FWR output



DC voltmeter measures V_{dc} of output of FWR

$V_{dc} = V_m$

reading = $1.11V_{dc}$

$= 1.11V_m$

i.e., indicated rms is $1.11V_m$ where true rms of square wave is V_m.

Therefore, the multiplying factor of the meter for correction is

$$\frac{1}{1.11}\left(\because 1.11V_m \times \frac{1}{1.11} \Rightarrow V_m\right)$$

03. Ans: (b)

Sol: Given data: Voltmeter sensitivity is 20kΩ/V Reading of 4.5V on its 5V full scale Reading of 6V on its 10V full scale *Say, voltage source is V_s and its internal resistance is R_s.

5V range:

$$R_V = 20\frac{k\Omega}{V} \times 5 = 100k\Omega$$

$$\text{Reading} = V_s \times \frac{100k\Omega}{R_s + 100k\Omega}$$

$$4.5V = V_s \times \frac{100k\Omega}{R_s + 100k\Omega}$$

$$\therefore V_s = \frac{4.5V}{100k\Omega}(R_s + 100k\Omega) \rightarrow (1)$$

10V Range:

$$R_V = 20\frac{K\Omega}{V} \times 10V$$

$$= 200k\Omega$$

$$\text{Reading} = V_S \times \frac{200k\Omega}{R_s + 200k\Omega}$$

$$6V = V_S \times \frac{200k\Omega}{R_s + 200k\Omega}$$

$$\therefore V_s = \frac{6V}{200k\Omega}(R_s + 200k\Omega) \rightarrow (2)$$

Solving equation (1) & (2)

$$\frac{6V}{200k\Omega}(R_s + 200k\Omega)$$

$$= \frac{4.5V}{100k\Omega}(R_s + 100k\Omega)$$

$$R_s + 200k\Omega = 1.5(R_s + 100k\Omega)$$

$$0.5R_s = 50k\Omega$$

$$R_s = 100k\Omega$$

Putting the value of R_s in equation (1)

$$V_s = \frac{4.5V}{100k\Omega}(100k\Omega + 100k\Omega)$$

$$= 4.5V \times 2$$

$$= 9V$$

Therefore, the voltage source is 9V and its internal resistance is 100kΩ

04. Ans: (c)

Sol: Given data: Full wave Bride Rectifier AC voltmeter's AC volt range is 0-100V. The PMMC ammeter used in the design has full scale current rating of 1mA and internal resistance of 100Ω & diodes are ideal

$$R_s = 0.9 \times \frac{V_{rmsFSD}}{I_{dcFSD}} - 2R_d - R_m$$

$$= 0.9 \times \frac{100V}{1mA} - 100\Omega$$

$$= 90k\Omega - 100\Omega$$

$$= 89.9k\Omega$$

05. Ans: (b)

Sol: **Given data:** PMMC ammeter full scale current range is 100μA, and internal resistance is 100Ω.

Required current range is 1A

$$R_{sh} = \frac{100\Omega}{\frac{1A}{100\mu A} - 1}$$

$$\Rightarrow R_{sh} = 10m\Omega$$

$\therefore$ 10mΩ in parallel with the meter

06. Ans: (c)

Sol: PMMC ammeter will read average value of current.

$$I_{dc} = 0.636\ I_m$$

($\because$ full wave rectified sinusoidal)

$$= 0.636 \times \frac{1V}{10k\Omega}$$

$$= 0.0636mA$$

$$= 63.6\mu A$$