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ESE 2023

Main Exam Detailed Solutions

Electronics & Telecom. Engineering

PAPER-I

EXAM DATE : 25-06-2023 | 9:00 AM to 12:00 PM

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ANALYSIS

Electronics and Telecom. Engineering Paper-I
ESE 2023 Main Examination

Sl.	Subjects	Marks
1.	Basic Electronics Engineering (EDC)	77
2.	Materials Science	62
3.	Electronic Measurements and Instrumentation	42
4.	Network Theory	128
5.	Analog Circuits	99
6.	Digital Circuits	22
7.	Basic Electrical Engineering	50
	Total	**480**

Scroll down for detailed solutions

Section-A

Q.1 (a) (i) An InGaAs photodiode operating at 1.3 μm is limited by background radiation giving $I_B = 10^{-7}$ A. The responsivity of the diode is 0.74 A/W at 1.3 μm. Find the minimum detectable power of this photodiode if the bandwidth of the device is 10 MHz and load resistance is $R_L = 10^7\ \Omega$.

[6 marks : 2023]

(ii) An nMOS transistor has a threshold voltage (V_t) of 0.4 V and a supply voltage V_{DD} = 1.2 V. A circuit designer is evaluating a proposal to reduce V_t by 100 mV to obtain faster transistor. By what factor would the subthreshold leakage current increase at room temperature at V_{gs} = 0? Assume n = 1.4.

[6 marks : 2023]

Solution:

(i) Given responsivity, $R = 0.74$ A/W

background current $I_B = 10^{-7}$ A

$$\text{Responsivity } R = \frac{I_{out}}{P_{in}}$$

In the environment of noise $I_{out} = I_B$

$$R = \frac{I_B}{P_{in}}$$

and this P_{in} is the minimum detectable power at typical 1 HZ of Bandwidth.

$$\therefore \quad P_{in} = \frac{I_B}{R} \text{ W}/\sqrt{\text{HZ}} \quad \text{(at B.W. = 1 HZ)}$$

$$P_{in} = \frac{10^{-7}\text{ A}}{0.74\text{ A/W}} = 1.35135 \times 10^{-7}\text{ W}$$

Hence, at typical 1 HZ of B.W., minimum detectable power

$$= \frac{1.35135 \times 10^{-7}}{\sqrt{1}} \text{W}/\sqrt{\text{HZ}} \cong 1.35 \times 10^{-7}\text{ W}/\sqrt{\text{HZ}}$$

at 10 MHZ of B.W, minimum detectable power–

$$= \frac{1.35 \times 10^{-7}}{\sqrt{10 \times 10^6}} = \frac{1.35}{\sqrt{10}} \times 10^{-10}$$

$$= 0.426 \times 10^{-10}\text{ W}/\sqrt{\text{HZ}}$$

(ii) Drain to source leakage current at V_{gs} = 0 is

$$I_{ds} = I_{dso} e^{-V_t / n V_{thermal}}$$

where $V_t \rightarrow$ Threshold Voltage

$V_{thermal}$ = Thermal Voltage

$I_{dso} \rightarrow$ A constant factor

Given: V_{t_1} = 0.4 Volt

V_{t_2} = 0.4 V – 0.1 V = 0.3 Volt

$$\frac{I_{ds1}}{I_{ds2}} = \frac{e^{-V_{t_1}/nV_{\text{thermal}}}}{e^{-V_{t_2}/nV_{\text{thermal}}}} = e^{(V_{t_2}-V_{t_1})/nV_{\text{thermal}}}$$

$$= e^{(0.3-0.4)/1.4\times 0.0259}$$

$$\frac{I_{ds1}}{I_{ds2}} = 0.0634.$$

$$I_{ds_2} = 15.77\, I_{ds_1}$$

∴ Subthreshold leakage current will be increased by a factor of 15.77

End of Solution

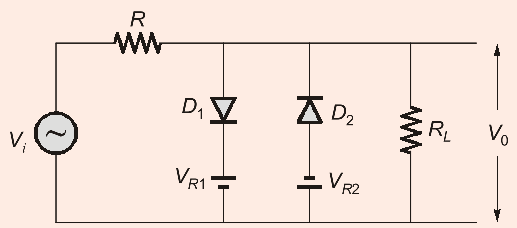
Q.1 (b) Design a two-sided limiting circuit using a resistor, two diodes and two power supplies to feed a 1 kΩ load with nominal limiting levels of ±3 V. Use voltage drop of 0.7 V for each diode when conducting. In the non-limiting region, the circuit voltage gain should be at least 0.95 V/V.

[12 marks : 2023]

Solution:

Two sided limiter is a two level clipper.

If D_1 becomes ON



then $V_0 = V_{R1} + 0.7 = 3$

⇒ $V_{R1} = 2.3$ V

If D_2 becomes ON then

$V_0 = -0.7 - V_{R2} = -3$

⇒ $V_{R2} = -2.3$ V

If both D_1 and D_2 are OFF then

$$V_0 = \frac{V_i \times R_L}{R + R_L} \Rightarrow \frac{V_0}{V_i} = \frac{R_L}{R + R_L}$$

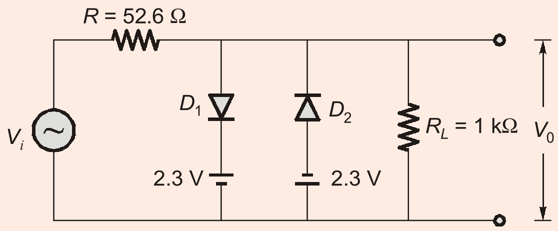
Given $\frac{V_0}{V_i} \geq 0.95$ and $R_L = 1$ kΩ

∴ $\frac{1}{R+1} \geq 0.95$

⇒ $R \leq 0.0526$ kΩ

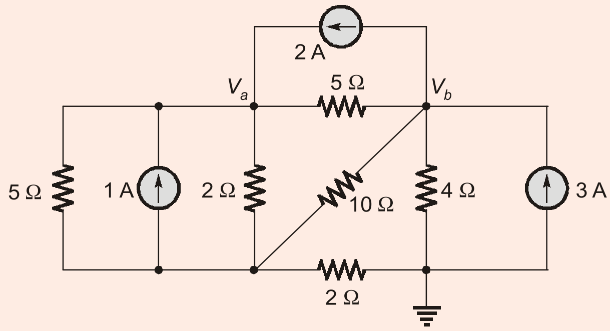
or $R \leq 52.6\ \Omega$

Hence, the final circuit for two sided limiter is as shown below:



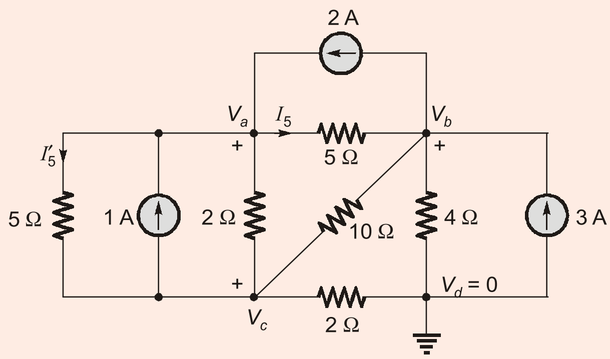
End of Solution

Q.1 (c) Find the node voltages V_a and V_b for the circuit shown in the figure using node voltage analysis. Also, find the current through 5 Ω resistor.



[12 marks : 2023]

Solution:



Node *a*,

$$\frac{V_a - V_c}{5} + \frac{V_a - V_c}{2} + \frac{V_a - V_b}{5} = 1 + 2$$

$$V_a\left[\frac{1}{5} + \frac{1}{2} + \frac{1}{5}\right] + V_b\left[\frac{-1}{5}\right] + V_c\left[\frac{-1}{5} - \frac{1}{2}\right] = 3$$

$$\frac{9}{10}V_a + V_b\left[\frac{-1}{5}\right] + V_c\left[\frac{-7}{10}\right] = 3 \quad \text{...(i)}$$

Node *b*,

$$\frac{V_b}{4} + \frac{V_b - V_a}{5} + \frac{V_b - V_c}{10} = 3 - 2$$

$$V_a\left[\frac{-1}{5}\right]+V_b\left[\frac{1}{4}+\frac{1}{5}+\frac{1}{10}\right]+V_c\left[\frac{-1}{10}\right] = 1$$

$$V_a\left[\frac{-1}{5}\right]+V_b\left[\frac{11}{20}\right]+V_c\left[\frac{-1}{10}\right] = 1 \quad ...(2)$$

Node c,

$$\frac{V_c}{2}+\frac{V_c-V_a}{2}+\frac{V_c-V_b}{10}+\frac{V_c-V_a}{5} = -1$$

$$V_a\left[\frac{-1}{2}-\frac{1}{5}\right]+V_b\left[\frac{-1}{10}\right]+V_c\left[\frac{1}{2}+\frac{1}{2}+\frac{1}{10}+\frac{1}{5}\right] = -1$$

$$\frac{-7}{10}V_a+V_b\left[\frac{-1}{10}\right]+\frac{13}{10}V_c = -1 \quad ...(3)$$

$$\begin{bmatrix} \frac{9}{10} & \frac{-1}{5} & \frac{-7}{10} \\ \frac{-1}{5} & \frac{11}{20} & \frac{-1}{10} \\ \frac{-7}{10} & \frac{-1}{10} & \frac{13}{10} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 3 \\ 1 \\ -1 \end{bmatrix}$$

$$V_a = \frac{136}{19} = 7.157 \text{ V}$$

$$V_b = \frac{96}{19} = 5.05 \text{ V}$$

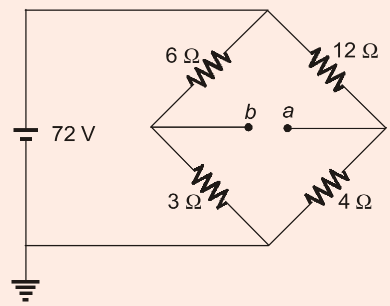
$$V_c = \frac{66}{19} = 3.473 \text{ V}$$

$\rightarrow$ $$I_5 = \frac{V_a-V_b}{5} = 0.4214 \text{ A}$$

$\rightarrow$ $$I_5' = \frac{V_a-V_c}{5} = 0.736 \text{ A}$$

End of Solution

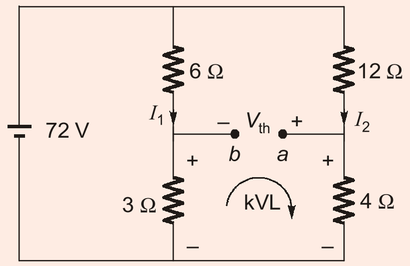
Q.1 (d) Find the Thevenin equivalent circuit for the network shown below. Also, find the current through the load resistor of 10 ohms, if connected across the terminal *a-b* of the Thevenin equivalent circuit.



[12 marks : 2023]

Solution:

Case 1: $[V_{th}]$



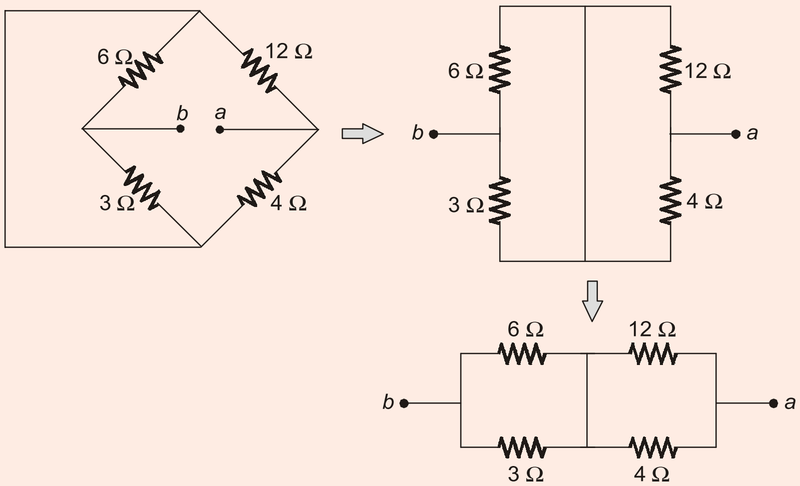
$$I_1 = \frac{72}{6+3},\ I_2 = \frac{72}{12+4}$$

$$-3I_1 - V_{th} + 4I_2 = 0$$

$$-3\left(\frac{72}{9}\right) - V_{th} + 4\left(\frac{72}{10}\right) = 0$$

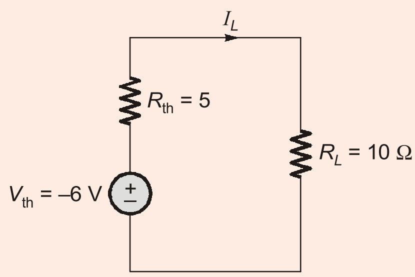
$$V_{th} = -6\text{ V}$$

Case 2: $[R_{th}]$



$$R_{th} = \left(\frac{12\times 4}{12+4}\right) + \left(\frac{6\times 3}{6+3}\right) = 5\ \Omega$$

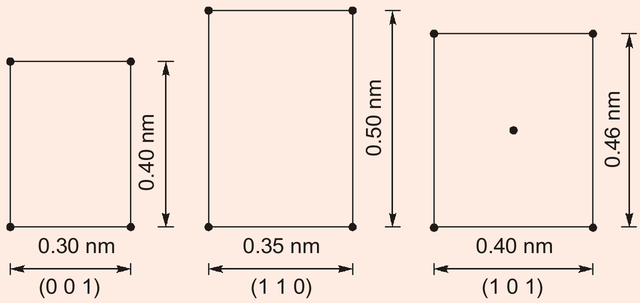
Case 3:



$$I_L = \frac{V_{th}}{R_{th} + R_L} = -0.4\text{ A}$$

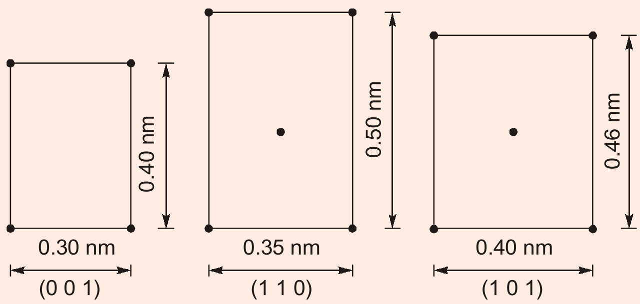
End of Solution

Q.1 (e) The following figure shows three different crystallographic planes for a unit cell of a hypothertical material. For each plane, the circles represents only those atoms contained within the unit cell, where circles are reduced from their actual diameter/size. Identity the unit cell and the crystal system it belong to:



[12 marks : 2023]

Solution:



$$(1\ 0\ 1), (0\ 1\ 1), (\bar{1}\ 0\ 1) \rightarrow \text{Same plane}$$

$$(1\ 0\ 0), (0\ \bar{1}\ 0) \rightarrow \text{Same plane}$$

End of Solution

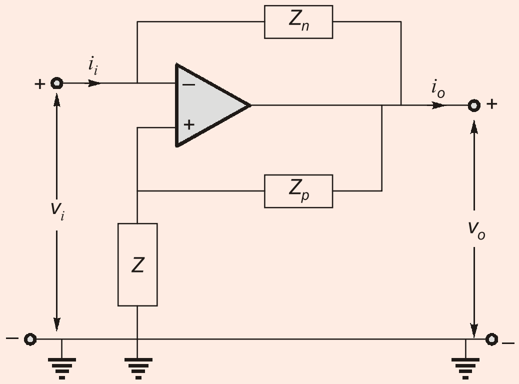
Q.2 (a) (i) Why are boron and phosphorus almost universally employed for *p*-type and *n*-type impurities in silicon?

[10 marks : 2023]

(ii) The diffusion coefficients for copper in aluminium at 500°C and 600°C are 4.8×10^{-14} m^2/s and 5.3×10^{-13} m^2/s, respectively. Determine the approximate time at 500°C that will produce the same diffusion result as a 10-hour heat treatment at 600°C.

[5 marks : 2023]

(iii) Find the driving-point impedance to the right of the input terminals of the given circuit. Comment on the result:



[5 marks : 2023]

Solution:

(i) **Boron:** Boron has an intrinsic diffusivity of about 10^{-12} cm^2 s^{-1} at 1200°C.

- It has a high solid solubility and can be diffused with a surface concentration as large as 4×10^{20} atoms cm^{-3}.
- It's misfit factor $\xi = 0.254$ with silicon which is small.
- In practical case upper limit of electronically active boron doping limit is $\sim 5 \times 10^{19}$ atoms/cm^3.

Phosphorus

- Phosphorus has diffusivity which is comparable to that of boron.
- It's misfit factor is comparatively lower $\xi = 0.068$.
- It's solid solubility limit is close to 10^{21} cm^{-3}.
- Practically upper limit of electronically active phosphorus doping is $\sim 3 \times 10^{20}$ atoms/cm^3.

(ii) As per Fick's second law, diffusion equation is given as

$$\frac{x^2}{Dt} = \text{Constant}$$

$x \rightarrow$ Depth of diffusion; $D \rightarrow$ Diffusion of coefficient; $t \rightarrow$ time

For same diffusion depth

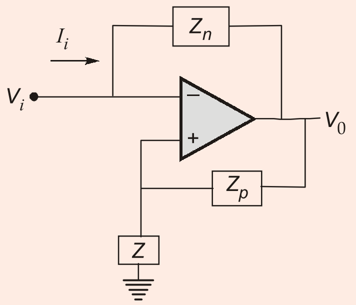
$$Dt = \text{Constant}$$

$$\therefore \qquad D_{500}\, t_{500} = D_{600}\, t_{600}$$

$$t_{500} = \frac{D_{600}\, t_{600}}{D_{500}} = \frac{(5.3 \times 10^{-13})(10)}{4.8 \times 10^{-14}}$$

$$t_{500} = 110.42 \text{ h}$$

(iii)
$$Z_i = \frac{V_i}{i_i}$$



Using virtual short circuit property,

$$V^- = V^+$$

$$\Rightarrow \quad V_i = \frac{V_o Z}{Z + Z_p}$$

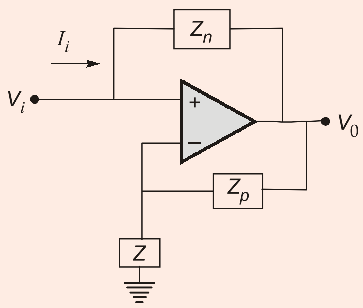
$$\Rightarrow \quad V_o = \frac{Z + Z_p}{Z} \times V_i = \left(1 + \frac{Z_p}{Z}\right) V_i$$

$$i_i = \frac{V_i - V_o}{Z_n} = \frac{1}{Z_n}\left[V_i - \left(1 + \frac{Z_p}{Z}\right) V_i\right]$$

$$i_i = -\frac{V_i \times Z_p}{Z Z_n}$$

$$i_i = \frac{-Z Z_n}{Z_p} \quad \Rightarrow Z_i = -\frac{Z Z_n}{Z_p}$$

Note: Above circuit has technical error. It should be as shown below:

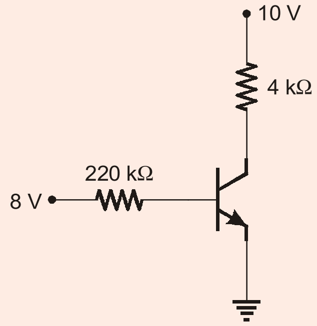


End of Solution

Q.2 (b) (i) Derive the Fermi level position in an intrinsic semiconductor in terms of E_c, E_v and effective masses of electron (m_n^*) and hole (m_p^*). Hence, calculate the position of the intrinsic Fermi level with respect to the centre of the band gap in silicon at T = 300 K. Given that m_n^* = 1.08 m_0 and m_p^* = 0.56 m_0. Here, m_0 is rest mass of the electron.

[10 marks : 2023]

(ii) Calculate the currents and voltages in the circuit given below. Also, calculate the power dissipated in the transistor. The transistor parameters are $\beta = 100$, $V_{BE(ON)} = 0.7$ V, $V_{CE(sat)} = 0.2$ V:



[10 marks : 2023]

Solution:

(i) Free electrons and holes concentration is given as

$$n = N_C\, e^{-(E_C - E_F)/kT} \text{ and } P = N_V\, e^{-(E_F - E_V)/kT}$$

For intrinsic semiconductor $n = p = n_i$ and $E_F \to E_{Fi}$

$$\therefore \quad N_C\, e^{-(E_c - E_{Fi})/kT} = N_V\, e^{-(E_{Fi} - E_V)/kT}$$

$$\frac{N_C}{N_V} = e^{-(E_{Fi} - E_V)/kT} \times e^{(E_C - E_{Fi})/kT}$$

$$\frac{N_C}{N_V} = e^{-[E_{Fi} - E_V - E_C + E_{Fi}]/kT}$$

$$\frac{N_C}{N_V} = e^{-(2E_{Fi} - E_C - E_V)/kT}$$

Taking ln both sides,

$$\ln\left(\frac{N_C}{N_V}\right) = -2(2E_{Fi} - E_C - E_V)/kT$$

$$-(2E_{Fi} - E_C + E_V) = kT \ln\left(\frac{N_C}{N_V}\right)$$

$$2E_{Fi} = E_C + E_V - kT \ln\left(\frac{N_C}{N_V}\right)$$

$$E_{Fi} = \frac{E_C + E_V}{2} - \frac{kT}{2} \ln\left(\frac{N_C}{N_V}\right)$$

where, $$\frac{E_C + E_V}{2} = E_{\text{mid}} \text{ and } \left(\frac{N_C}{N_V}\right) = \left(\frac{m_n^*}{m_p^*}\right)^{3/2}$$

$$\therefore \quad E_{Fi} = E_{\text{mid}} - \frac{kT}{2} \ln\left(\frac{m_n^*}{m_p^*}\right)^{3/2}$$

$\Rightarrow$ Given $\quad m_n^* = 1.08\, m_o$

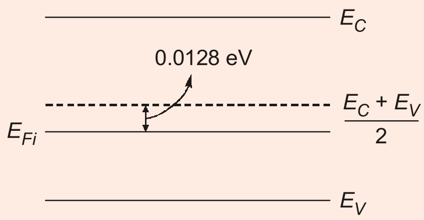
$m_p^* = 0.56\, m_o$

$T = 300 \quad \Rightarrow kT = 0.026$ eV

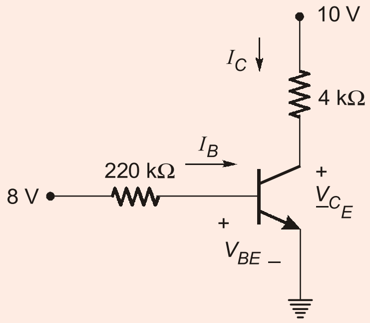
$$\therefore \quad E_{Fi} = E_{\text{mid}} - \frac{0.026}{2}\ln\left(\frac{1.08}{0.56}\right)^{3/2}$$

$$E_{Fi} = E_{\text{mid}} - 0.0128 \text{ eV}$$

i.e. intrinsic Fermi-level is 0.0128 eV below the centre of the band gap.



(ii) $I_B = \frac{8 - V_{BE}}{220\text{ k}\Omega} = 0.03318$ mA



Assume BJT in active region.

$$\therefore \quad I_C = \beta I_B = 3.318 \text{ mA}$$

$$V_{CE} = 10 - 4 \times I_C = 10 - 4 \times 3.318 = -3.272 \text{ V}$$

$V_{CE} < V_{BE} \Rightarrow$ BJT is in saturation region.

Hence, $\quad V_{CE} = V_{CE\,\text{sat}} = 0.2$ V

$$I_C = I_{C\,\text{sat}} = \frac{10 - V_{CE}}{4\text{ k}\Omega} = \frac{10 - 0.2}{4\text{ k}\Omega} = 2.45 \text{ mA}$$

$$I_E = I_B + I_C = 0.03318 + 2.45 = 2.483 \text{ mA}$$

Thus, $\quad I_B = 0.03318$ mA

$I_C = I_{C\,\text{sat}} = 2.45$ mA

$I_E = 2.483$ mA

$V_{CE} = V_{CE\,\text{sat}} = 0.2$ V

Power dissipation in BJT is,

$$P_D = V_{CE} \times I_C = 0.2 \times 2.245 = 0.49 \text{ mW}$$

End of Solution

Q.2 (c) (i) Predict the crystal structure and compute the theoretical density for FeO. Given—

Ionic radius of Fe^{++} = 0.77 nm

Ionic radius of O^{--} = 0.140 nm

Atomic weight of Fe = 55.845 g/mole

Atomic weight of O = 16 g/mole

Avogadro's number = 6.022×10^{23}/mole

[10 marks : 2023]

(ii) How are ceramic products fabricated? Explain the role of powder pressing and sintering in the fabrication of ceramic products.

[10 marks : 2023]

Solution:

(i)

$$\text{Ionic radius of } Fe^{++} = r_c = 0.077 \text{ nm}$$

$$\text{Ionic radius of } 0^{-} = r_A = 0.140 \text{ nm}$$

$$\text{Atomic weight of Fe} = 55.845 \text{ g/mole}$$

$$\text{Atomic weight of 0} = 16 \text{ g/mole}$$

$$\text{Avogadro's number } N_A = 6.022 \times 10^{23} \text{ atoms/mol}$$

⇒ Cation to anion radius ratio

$$\frac{r_C}{r_A} = \frac{0.077 \text{ nm}}{0.140 \text{ nm}} = 0.550$$

For ionic materials, we have,

r_C / r_A	Coordination No.
<0.155	2
0.155 – 0.225	3
0.225 – 0.414	4
0.414 – 0.732	6
0.732 – 1	8

From this table

$$0.414 < \frac{r_C}{r_A} = 0.55 < 0.732$$

So coordination No. = 6

⇒ The coordinate number for Fe^{2+} ion is 6 ; this is also coordination number for O^{2-}, since there are equal number of cations and anions. The predicted crystal structure will be rock salt, which is the *AX* crystal structure having a coordination number of 6.

⇒ Theoretical density of FeO is given as

$$\rho = \frac{n'(\Sigma A_c + \Sigma A_A)}{V_C N_A}$$

where, n' → Number of formula units within the unit cell
ΣA_C → The sum of the atomic weights of all cations in the formula unit
ΣA_A → The sum of atomic weights of all anions in the formula unit
V_C → The unit cell volume

$$\Rightarrow \quad V_C = a^3 = [2r_C + 2r_A]^3 = [(2\times 0.077 + 2\times 0.140)]^3$$

$$\Rightarrow \quad V_C = (0.434)^3 \text{ nm}^3 = (0.434\times 10^{-7})^3 \text{ cm}^3$$

$$V_C = 8.17\times 10^{-23} \text{ cm}^3$$

⇒ *AX* structure is result of penetration of FCC structure of *A* and *X*, hence Fe and O both form FCC here,

So, $n' = 4$

$$\Sigma A_C = A_{Fe} = 55.845 \text{ g/mol}$$

$$\Sigma A_A = A_o = 16 \text{ g/mol}$$

$$\rho = \frac{4\times(55.845+16)}{8.17\times 10^{-23}\times 6.023\times 10^{23}} \text{ g/cm}^3$$

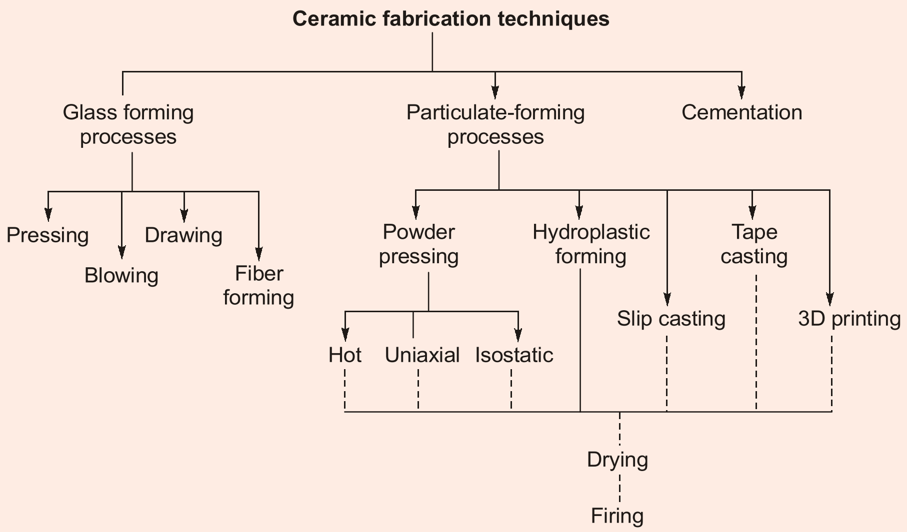
$$\rho = 5.843 \text{ g/cm}^3 = \text{Density of FeD}$$

(ii) **Fabrication of Ceramics:**

The ceramics materials have relatively high melting temperature casting them is normally impractical.

Furthermore, in most instances the brittleness of these materials precludes deformations. Some ceramic pieces are formed from powders (or particulate collections) that must ultimately be dried and fired. Glass shapes are formed at elevated temperatures from a fluid mass that becomes very viscous upon cooling. Cements are shaped by placing into forms a fluid paste that hardens and assume a permanent set by virtue of chemical reactions.

A taxonomical scheme for the several types of ceramic forming techniques is presented in below figure.



Powder Pressing:

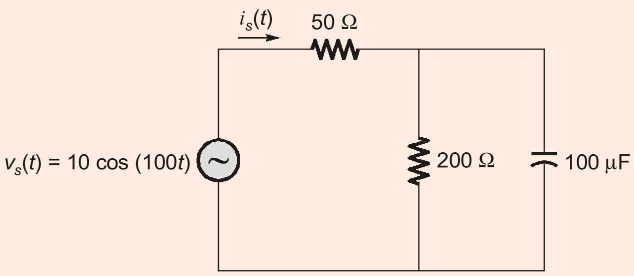
The important and commonly used method that warrants brief treatment is powder pressing. Powder pressing – the ceramic analogue to powder metallurgy is used to fabricate both clay and non clay composition, including electronic and magnetic ceramics as well as some refractory brick products. In essence, a powdered mass, usually containing a small amount of water or other binder, is compacted into the desired shape by pressure. The degree of compaction is maximized and the fraction of void space is minimized by using coarse and fine particles mixed in appropriate proportions. There is no plastic deformation of the particles during compaction, as there may be with metal powders. One function of the binder is to lubricate the power particles as they move past one another in the compaction process.

Sintering:

For both uniaxial and isostatic procedures, a firing operation is required after the pressing operation. During firing the formed piece shrinks and experience a reduction of porosity and an improvement in mechanical integrity. These changes occur by the coalescence of the powder particles into a denser mass in a process turned sintering. During initial sintering stage, necks form along the contact regions between adjacent particles, in addition, a grain boundary forms within each neck and every interstice between particles becomes a pore. As sintering progresses, the pores become smaller and more spherical. Sintering is carried out below the melting temperature, so that a liquid phase is normally not present.

End of Solution

Q.3 (a) (i) Determine the source current $i_s(t)$ for the circuit shown in the figure using phasor analysis method:



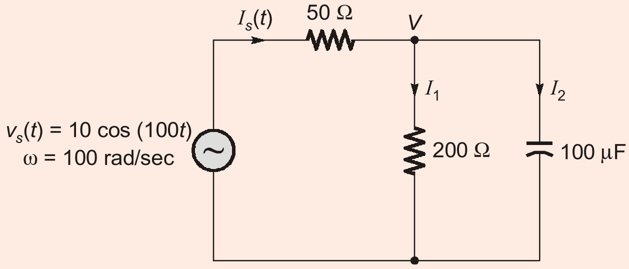
[10 marks : 2023]

(ii) A customer's plant has two parallel loads connected to the power utility's distribution lines. The first load consists of 50 kW of heating and is resistive. The second load is a set of motors that operate at 0.86 lagging power factor. The motors' load is 100 kVA. Power is supplied to the plant at 10000 volts r.m.s. Determine the total current flowing from the utility's lines into the plant and the plant's overall power factor.

[10 marks : 2023]

Solution:

(i)



$$X_C = \frac{1}{\omega C} = 100\ \Omega$$

By KCL,

$$\frac{V - 10\angle 0}{50} + \frac{V}{200} + \frac{V}{-j100} = 0$$

$$V\left[\frac{1}{50} + \frac{1}{200} + \frac{1}{-j\,100}\right] = \frac{10}{50}$$

$$V = 7.427\angle -21.80^\circ\ \text{V}$$

$$I_1 = \frac{V}{200} = 0.0371\angle -21.80^\circ\ \text{A}$$

$$I_2 = \frac{V}{-j \times c} = 0.0742\angle 68.2^\circ\ \text{A}$$

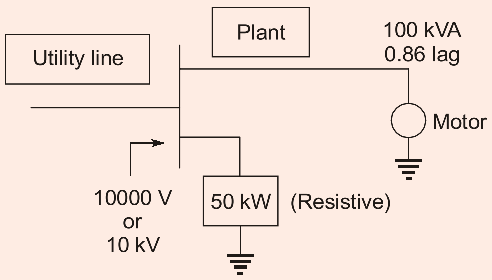
$$I_s = I_1 + I_2$$

$$= 0.0371\angle -21.80^\circ + 0.0742\angle 68.2^\circ$$

$$I_s = 0.083\angle 41.656^\circ$$

$$\therefore \quad I_s(t) = 0.083\cos[100t + 41.656^\circ]\ \text{A}$$

(ii)



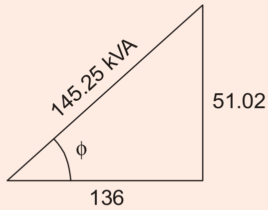
Overall active power of plant

$$= 50\ \text{kW} + (100 \times 0.86)\ \text{kW}$$

$$= 136\ \text{kW}$$

Overall reactive power of plant $= 0$ VAR $+ 100 \sin[\cos{-1}(0.86)]$ kVAR

$$= 51.02\ \text{kVAR}$$



$$\text{Overall power of plant} = \sqrt{(136)^2 + (51.02)^2} = 145.25 \text{ kVA}$$

$$\text{Power factor plant} = \cos\phi = \frac{136}{145.25}$$

Assumption 3-ϕ input, $\cos\phi = 0.9363$ lag

Total current flowing into plant is I, then

$$145.25 = \sqrt{3} \times 10 \times I$$

$$I = 8.386 \text{ A}$$

Assumption 1-ϕ input,

$$145.25 \times 10^3 = 10^4 I$$

$$I = 14.525 \text{ A}$$

End of Solution

Q.3 (b) (i) Draw the power flow diagrams of a DC generator and a DC motor.

[10 marks : 2023]

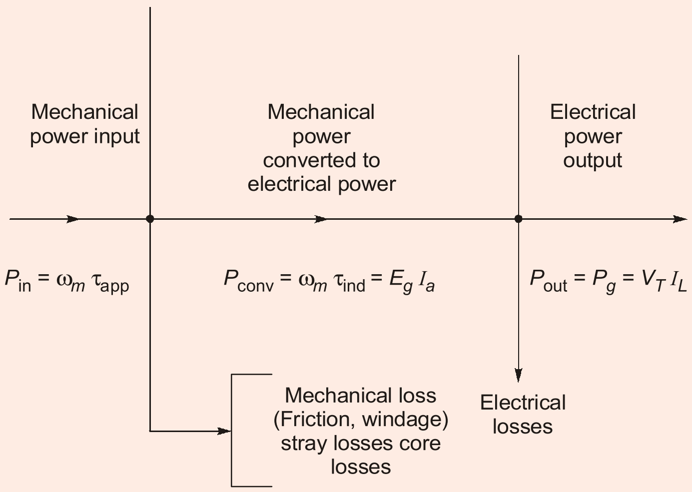
(ii) A 250 V shunt motor on no load runs at 1000 r.p.m. and takes 5 A. The total armature and shunt field resistances are respectively 0.2 Ω and 250 Ω. Calculate the speed when loaded and taking a current of 50 A, if the armature reaction weakens the field by 3%.

[10 marks : 2023]

Solution:

(i) The Power Flow Diagram is used to determine the efficiency of a generator or motor. In the below figure of power flow diagram of DC Generator, it is shown that initially the mechanical power is given as an input which is converted into electrical power, and the output is obtained in the form of electrical power. There are various losses such as friction, windage, stray losses and core losses

The power flow diagram of DC Generator is shown below:



Power Flow Diagram of a DC Generator

In a DC Generator, the input is the mechanical power. The power input is given by the equation shown below.

$$P_{in} = \omega_m \tau_{app} \quad \text{...(i)}$$

where,

ω_m is the angular speed of the armature in radian per second.

τ_{app} is the applied torque in Newton-meter.

The sum of stray losses, mechanical losses and core losses are subtracted from the input power, i.e. P_{in} to get the net mechanical power converted to electrical power by Electro-Mechanical conversion.

$$P_{conv} = P_i - \text{Stray loss} - \text{Mechanical Loss} - \text{Core Losses}$$

$$P_{conv} = \omega_m \tau_{app} = \omega_m \tau_e \quad \text{...(ii)}$$

Where τ_e is the electromagnetic torque. The resulting electric power produced is given by the equation:

$$P_{conv} = E_g I_a \quad \text{...(iii)}$$

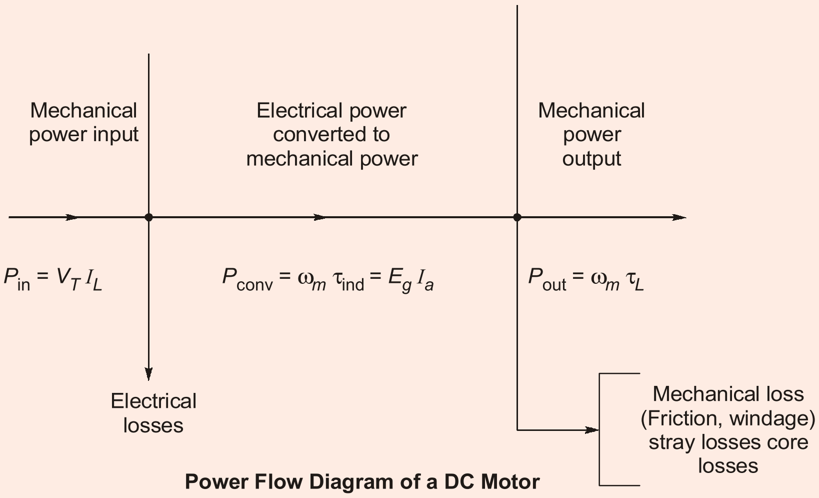
The net electrical power output is obtained by subtracting electrical power I_2R losses and brush losses from P_{conv}.

$$P_{out} = P_{conv} - \text{Electrical } I_R^2 - \text{Brush losses} \quad \text{...(iv)}$$

$$P_{out} = V_T I_L \quad \text{...(v)}$$

V_T is the terminal voltage, and IL is the current delivered to the load.

The power flow diagram of DC Motor is shown below:



Power Flow Diagram of a DC Motor

From the power flow diagram of DC Motor, it is clear that the input which is given to the motor is in the electrical form which is converted into mechanical power in the second stage. The output is in the form of mechanical power.

In a DC motor, the input electrical power Pin is given by the equation shown below:

$$P_{in} = V_T I_L \quad \text{...(vi)}$$

$$P_{conv} = P_i - \text{Copper Losses} \quad \text{...(vii)}$$

Power output is given by the equation shown below:

$$P_{out} = \omega_m \tau_L \quad \text{...(viii)}$$

Also, $P_{out} = P_{conv} - \text{Core losses} - \text{Mechanical losses} - \text{Stray losses}$

τ_L is the load torque in Newton-meter

Thus, the power flow diagram gives an overview, that how one form of energy is converted into another form.

(ii) 250 V shunt motor on No load.

runs at 1000 rpm and takes 5 A.

$$R_a = 0.2\ \Omega \text{ and } R_{sh} = 250\ \Omega$$

Speed = ?, when load current taken from supply = 50 A and armature reaction weakens the field by 3%.

Case-I: No load.

$$\text{Shunt current} = \frac{250}{250} = 1\text{ A}$$

armature current at no load

$$I_{a1} = (5-1)\text{ A}$$
$$= 4\text{ A}$$
$$\in_{b1} \propto \phi_1 N_1$$
$$(250 - 4 \times 0.2) \propto \phi_1(1000) \quad \text{...(1)}$$

Case-II: Loaded

$$\text{armature current} = (50-1)$$
$$I_{a2} = 49\text{ A}$$
$$\in_{b2} \propto \phi_2 N_2$$
$$(250 - 49 \times 0.2) \propto \phi_2(N_2) \quad \text{...(2)}$$

and $$\phi_2 = 0.97\,\phi_1 \quad \text{...(3) (given)}$$

using (1), (2) and (3),

$$\frac{(250-4\times 0.2)}{(250-49\times 0.2)} \propto \frac{1}{0.97}\times\frac{1000}{N_2}$$
$$N_2 = 993.69 \text{ rpm at load}$$

End of Solution

Q.3 (c) (i) Derive an expression for electrical conductivity of an intrinsic semiconductor and compute the room temperature intrinsic carrier concentration for gallium arsenide. [Given, the room temperature electrical conductivity for gallium arsenide is 3×10^{-7} $(\Omega\text{m})^{-1}$. The electron and hole mobilities are 0.80 m^2/V-s and 0.04 m^2/V-s, respectively]

[10 marks : 2023]

(ii) Discuss Matthiessen's rule and explain the influence of the factors affecting resistivity of metals.

[10 marks : 2023]

Solution:

(i) We know, electrical conductivity of a semiconductor is given as

$$\sigma = ne\mu_n + pe\mu_p \quad \text{...(1)}$$

where $\sigma \rightarrow$ Electrical conductivity

$n \rightarrow$ Concentration of electrons

$p \rightarrow$ Concentration of holes

$\mu_n \rightarrow$ Mobility of electrons

$\mu_p \rightarrow$ Mobility of holes
$e \rightarrow$ Charge of electrons (1.6×10^{-19}C)

For intrinsic semiconductor,

$$n = p = n_i \rightarrow \text{intrinsic concentration}$$
$$\sigma_i = n_i \cdot e[\mu_n + \mu_p]$$

Given:
$$\sigma_i = 3 \times 10^{-7}\ (\Omega\ \text{m})^{-1}$$
$$\mu_n = 0.8\ \text{m}^2/\text{V-sec}$$
$$\mu_p = 0.04\ \text{m}^2/\text{V-sec}$$

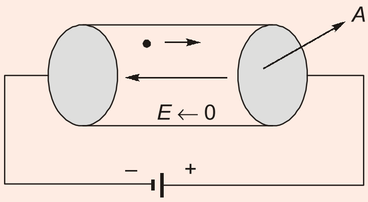
$\therefore$
$$\sigma_i = 3 \times 10^{-7} = n_i \times 1.6 \times 10^{-19}\ [0.8 + 0.04]$$

Intrinsic concentration of GaAs

$$n_i = 2.232 \times 10^{12}/\text{m}^3$$

Alternate solution:

Let us take a piece of intrinsic semiconductor of cross-sectional area A, is subjected to an external electric field E across it



Hence force applied on electron by electric field

$$F = qE$$

From Newton's law

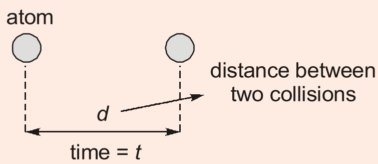
$$F = ma$$

where $m \rightarrow$ mass of electron
$q \rightarrow$ charge
$a \rightarrow$ acceleration

$$a = \frac{v - u}{t}$$

$u \rightarrow$ Final velocity $\Rightarrow u = 0$; $u \rightarrow$ initial velocity; $t \rightarrow$ scattering time

$$a = \frac{v}{t} = \frac{v_d}{t}$$



$$v_d \rightarrow \text{drift velocity} = \frac{d}{t}$$

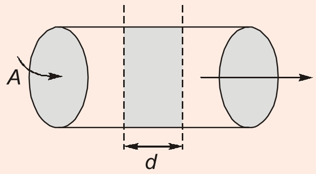
Hence,
$$F = ma = qE$$
$$m\frac{v_d}{t} = qE$$

$$v_d = \frac{qEt}{m} = \mu_n E \quad ...(1)$$

where $\mu_n \rightarrow$ mobility of electrons

$$\mu_n = \frac{qt}{m}$$

$\Rightarrow$



$$\text{electron density} = n$$
$$\text{charge density} = ne$$
$$\therefore \quad \text{charge} = ne\,(\text{Ad})$$
$$Q = neA\,(t\,v_d)$$
$$\frac{dQ}{dt} = neAv_d$$
$$\text{current } I_n = neAv_d$$
$$\text{Current density } J_n = \frac{I}{A} = nev_d = ne\mu_n E$$

Similarly for holes $J_p = pe\mu_p E$

Hence total current density, $J = nq\mu_n E + pq\mu_p E$

$$J = (nq\mu_n + pq\mu_p)E$$

Since $J = \sigma E$ (from point form of Ohm's law)

$\therefore$ $\sigma = nq\mu_n + pq\mu_p$

For intrinsic semiconductor $n = p = n_i$

$\Rightarrow$ $\sigma = n_i q\mu_n + n_i q\mu_p$

$\Rightarrow$ $$n_i = \frac{\sigma}{q(\mu_n + \mu_p)}$$

Given $\sigma = 3 \times 10^{-7}\ (\Omega\text{m})^{-1}$

$\mu_n = 0.80\ \text{m}^2/\text{V-sec}$

$\mu_p = 0.04\ \text{m}^2/\text{V-sec}$

$$n_i = \frac{3 \times 10^{-7}}{1.6 \times 10^{-19}(0.80 + 0.04)} = 2.232 \times 10^{12}\text{m}^{-3}$$

(ii) **Matthiessen's Rule:** An empirical rule which states that the total resistivity of a crystalline metallic specimen is the sum of the resistivity due to thermal agitation of the metal ions of the lattice and the resistivity due to the presence of imperfections in the crystal.

$$\rho_{total} = \rho_{thermal} + \rho_{impurity} + \rho_{deformation}$$

The above equation is called Matthiessen's rule.

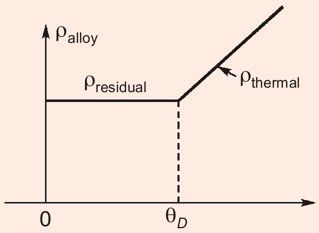
Factors affecting the resistivity of a conducting materials:

1. Any conductor has impurity atoms, because of impurity atom the regular structure of the pure conductor becomes irregular, collision are increased and gives residual resistivity.

Due of temperature, atoms vibrate and collision increases, which leads to thermal resistivity.

So, total resistivity is,

$$\rho_{alloy} = \rho_{residual} + \rho_{thermal}$$



(Debye temperature)

At low temperature, thermal resistivity is zero and above debye temperature $\rho_{thermal}$ increases linearly.

2. **Temperature effect:**

If temperature is increase resistivity of the material increases according to the following equation.

$$\rho = \rho_0[1 + \alpha(T - T_{RT})]$$
$$\rho = \rho_0(1 + \alpha \Delta T)$$

$T_{RT} \rightarrow$ Room temperature (or) Reference temperature.

$\Delta T = T - T_{RT}$ where T is operating temperature.

$T \rightarrow$ Temperature

$\alpha \rightarrow$ Temperature coefficient of resistivity [1/°C]

At $T = T_{RT} \rightarrow \rho = \rho_0 \quad \Rightarrow$ Resistivity at room temperature.

3. **Alloying effect:**

In case of pure metal the atomic structure is regular. Collision are less and resistivity is less. If any metal is added to pure metal (alloying) then structure becomes irregular, collision increase and resistivity of alloy is increased.

4. **Cold work:**

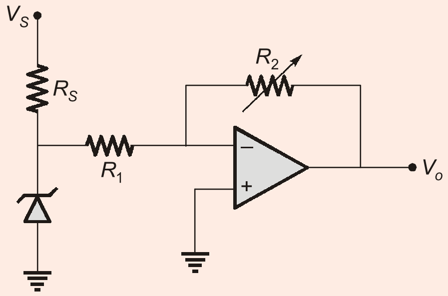
Cold working is also known as work hardening or strain hardening. Cold working used to increase the mechanical strength of the metal. Cold working distrubs the crystal structure of metals which interfere with the movement of electrons in metal, due to which the resistivity of metal increases.

End of Solution

Q.4 (a) (i) The recombination process in an LED at 300 K is dominated by bulk radiative, SRH and auger processes. The mean lifetimes of carriers due to radiative, SRh and auger processes are 5 ns, 10 ns and 25 ns, respectively. Estimate the quantum efficiency of the LED in absence of surface recombination. What is the bandwidth of this LED?

[10 marks : 2023]

(ii) Find the maximum allowed voltage of V_S in the given adjustable output voltage regulator circuit. The Zener diode specifications limit the maximum current through Zener diode to $I_{Z_{max}}$:



[10 marks : 2023]

Solution:

(i)

$$\tau_{radiative} = 5 \text{ ns (or) } \tau_r = 5 \text{ ns}$$

$$\tau_{SRH} = 10 \text{ ns} \quad \text{and} \quad \tau_{Auger} = 25 \text{ ns}$$

$$\frac{1}{\tau_{net}} = \frac{1}{\tau_1} + \frac{1}{\tau_2} + \frac{1}{\tau_3} + \ldots$$

$$\therefore \quad \frac{1}{\tau_{net}} = \frac{1}{5} + \frac{1}{10} + \frac{1}{25}$$

$$\frac{1}{\tau_{net}} = \frac{5 + 2.5 + 1}{25} = \frac{7.5}{25} = 3.33 \text{ ns}$$

Quantum efficiency of the LED (Q) = $\frac{\tau_{nr}}{\tau_{nr} + \tau_r}$

$\tau_{nr} \rightarrow$ non radiative recombination life ime

$$\frac{1}{\tau_{nr}} = \frac{1}{\tau_{SRH}} + \frac{1}{\tau_{Auger}} = \frac{1}{10} + \frac{1}{25} = \frac{2.5 + 1}{25}$$

$$\tau_{nr} = \frac{25}{3.5} = 7.1428 \text{ ns}$$

$$\therefore \quad Q = \frac{\tau_{nr}}{\tau_{nr} + \tau_r} = \frac{7.1428}{7.1428 + 5} = 0.588$$

$$Q = 58.8\%$$

Electric bandwidth of the LED $f_{electrical}^{3\text{ dB}} = \frac{1}{2\pi\tau_{net}}$

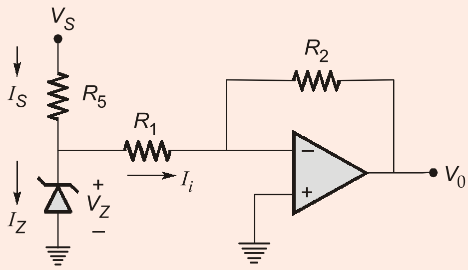
$$W_{electrical}^{3\text{ dB}} = \frac{1}{\tau_{net}}$$

$$\therefore \quad W_{electrical}^{3\text{ dB}} = \frac{1}{\tau_{net}} = \frac{1}{3.33 \text{ nsec}}$$

$$= \frac{10^9}{3.33} \frac{\text{rad}}{\text{sec}} \simeq 3 \times 10^8 \text{ rad/sec}$$

Optical bandwidth $f_{optical}^{3\text{ dB}} = \sqrt{3}\, f_{electrical}^{3\text{ dB}} = \sqrt{3} \times \frac{10^9}{3.33} \frac{\text{rad}}{\text{sec}} \simeq 5.2 \times 10^8 \text{ rad/sec}$

(ii)



$$V^- = V^+ = 0$$

$$I_1 = \frac{V_z - 0}{R_1} = \frac{V_z}{R_1}$$

KCL: $$I_s = I_z + I_1$$

To prevent damage to Zener diode,

$$I_s \le I_{z\,max} + I_1$$

$$\frac{V_s - V_z}{R_s} \le I_{z\,max} + \frac{V_z}{R_1}$$

$$V_s \le I_{z\,max} R_s + \frac{V_z R_s}{R_1} + V_z$$

Hence, Maximum allowed $V_s = I_{z\,max} R_s + \dfrac{V_z R_s}{R_1} + V_z$

End of Solution

Q.4 (b) (i) State the applications of synchronous motors. Compare synchronous motor with induction motor.

[10 marks : 2023]

(ii) Compare with neat sketches squirrel-cage and slip-ring three-phase induction motor with reference to construction, performance and applications.

[10 marks : 2023]

Solution:

(i) **Applications of Synchronous Motors:**

Synchronous motors are rarely used below 40 kW output in the medium speed range because of their much higher initial cost in comparison to that of induction motors. In addition they need a dc excitation source, and the starting and control devices are usually more expensive—especially where automatic operation is required. However, there is a kW output and speed range where the disadvantage of higher initial cost vanishes, even to the point of putting the synchronous motors to the advantage. Where low speeds and high kW outputs are involved the induction motors are no longer cheaper because they need large amounts of iron in order to restrict the air gap flux density to 0.7 T. In the synchronous machines, on the other hand, a value twice this figure is permissible because of the separate excitation.

The various classes of service for which synchronous motors are employed may be classified as (i) power factor correction (i) voltage regulation and (ii) constant speed, constant-load drives.

1. They are used in power houses and substations in parallel to the bus-bars to **improve the power factor**. For this purpose they are run **without mechanical load** on them and overexcited.
2. In factories having a large number of induction motors, or other power apparatus operating at lagging power, they are employed to improve the power factor.
3. Such motors are also used to regulate the voltage at the end of transmission lines.
4. Because of the higher efficiency possible with synchronous motors, they can be employed advantageously for the loads where constant speed is required. Typical applications of high-speed synchronous motors **(above 500 rpm)** are such drives as **fans, blowers, dc generators, line shafts, centrifugal pumps** and **compressors, reciprocating pumps** and **compressors**, **constant speed frequency changers, rubber** and **paper mills** etc.

The fields of applications of low speed synchronous motors **(below 500 rpm)** are drives such as reciprocating compressors when started unloaded, dc generators, centrifugal and screw type pumps, vacuum pumps, electroplating generators, line shafts, rubber and band mills, ball and tube mills, chippers, metal rolling mills etc. Flywheel is used for pulsating loads.

High power electronic convertors generating very low frequencies made the operation of synchronous motors at ultra low speeds. Synchronous motors in very large sizes (as high as 10 MW size) operating at ultra low speeds are employed to drive crushers, rotary kilns and variable speed ball mills.

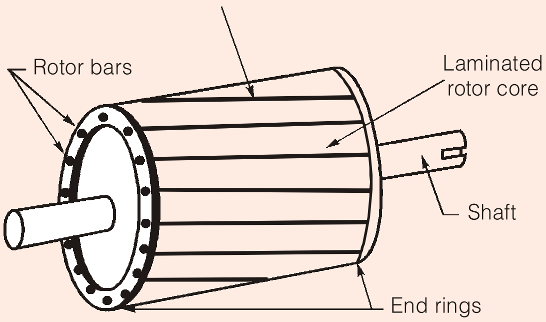
Basis of Difference	Synchronous motor	Induction Motor
Type of Excitation	A synchronous motor is a doubly excited machine.	An induction motor is a single excited machine.
Supply System	Its armature winding is energized from an AC source and its field winding from a DC source.	Its stator winding is energized from an AC source.
Speed	It always runs at synchronous speed. The speed is independent of load.	If the load increased the speed of the induction motor decreases. It is always less than the synchronous speed.
Starting	It is not self starting. It has to be run up to synchronous speed by any means before it can be synchronized to AC supply.	Induction motor has self starting torque.
Operation	A synchronous motor can be operated with lagging and leading power by changing its excitation.	An induction motor operates only at a lagging power factor. At high loads the power factor becomes very poor.
Usage	It can be used for power factor correction in addition to supplying torque to drive mechanical loads.	An induction motor is used for driving mechanical loads only.
Efficiency	It is more efficient than an induction motor of the same output and voltage rating.	Its efficiency is lesser than that of the synchronous motor of the same output and the voltage rating.
Cost	A synchronous motor is costlier than an induction motor of the same output and voltage rating	An induction motor is cheaper than the synchronous motor of the same output and voltage rating.

(ii) The rotors employed in 3-phase induction motors, according to the type of windings used, are of two types, viz; **squirrel cage rotor** and the **wound rotor**.

1. Squirrel Cage Rotor

Almost 90 per cent of induction motors are provided with squirrel cage rotor because of its very simple, robust and almost indestructible construction.

In cage construction, **copper**, **brass**, or **aluminium** bars are placed, as the rotor conductors, parallel or approximately parallel to the shaft (one bar in each slot) and close to the rotor surface. The conductors are not insulated from the core, since the rotor currents naturally follow the path of least resistance, i.e., the rotor conductors. At both ends of the rotor, the rotor conductors are all short circuited by the continuous end rings of similar material to that of the rotor conductors. The rotor conductors and their end rings form a complete closed circuit in itself, resembling a squirrel cage, thus explaining the name. In motors with ratings up to 100 kW, the squirrel cage structure is formed by aluminium cast (under pressure) into the slots of the rotor. In large motors the rotor bars, instead of being cast, are wedged into the rotor slots and are then welded securely to the end rings. The slots on rotor are either of semi-closed type or of totally closed type, because there is little difficulty in inserting the rotor bars in such slots.



The squirrel cage rotor windings are perfectly symmetrical and have the advantage of being adaptable to **any number of pole pairs**. The distribution of current due to electromagnetic induction in the rotor bars varies from bar to bar sinusoidally and depends upon the position and time, assuming sinusoidal distribution of radial flux density in space and also the applied voltage to be varying sinusoidally with time.

Since the rotor winding is permanently short circuited in cage construction, there is no possibility of adding any external resistance in the rotor circuit.

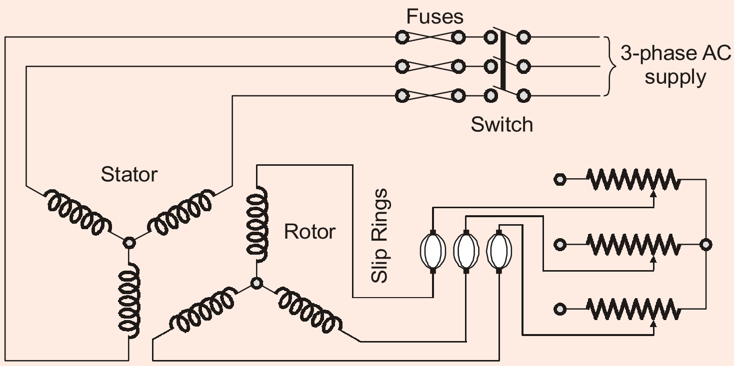
2. Wound Rotor or Slip ring rotor

As the name implies, such a rotor is wound with an insulated winding **similar** to that of the stator except that the number of slots is smaller and fewer turns per phase of a heavier conductor are used. **Bar**, **strap**, or **wire** is used for rotor windings, the last being used where many turns are desired. A large number of rotor turns increases the secondary voltage and reduces the current that flows through the slip rings. The secondary voltage determines the insulation that must be provided; furthermore, the voltage and current influence the value of the resistance to be employed across the slip rings. The motor operation is not influenced by the number of rotor turns, but the ratio of transformation is determined by consideration of secondary current, danger of high secondary emf at starting, and distance to secondary resistors. The standstill open-circuit slip-ring voltage is usually **100 to 400 V** for small machines using hand operated gear and maximum up to 1 kV for large machines.

The rotor is wound for the same number of poles as that of the stator. **The rotor winding is always 3-phase winding even when the stator is wound for two phases. The rotor winding may be star or delta connected but star-connection is usually preferred.**

The three finish terminals are connected together to form star point and the three start terminals are connected to three phosphor-bronze (or brass) slip rings mounted on but insulated from the rotor shaft. The brushes, which carry the current from and to the rotor windings are held in box type holders mounted on insulated steel rods, securely bolted to the end shield. Each brush is fed forward by a lever held in tension by an adjustable spring. These brushes are further externally connected to a 3-phase star-connected rheostat for the purpose of starting and speed control.

At the time of starting, the entire resistance is included in the rotor circuit and this resistance is gradually cut out as the rotor picks up the speed. For the normal running condition the entire external resistance is cut out and the rotor windings are short circuited automatically through the slip rings by means of a metal collar which is pushed along the shaft and connects all the rings together. The rotor is skewed in this case also. Since the connection of the wound secondary to the external terminals is made through slip rings and brushes, wound secondary motors often are called slip-ring induction motors. A sectional diagram of a **slip-ring induction motor** is shown in Fig. (b).



(b) Slip-Ring Induction Motor with Starting Rheostat

Squirrel cage Induction motor **Advantages**	Slip ring Induction motor **Advantages**
(i) Rugged in construction (ii) No slip rings, brush gears, etc. (iii) Minimum maintenance (iv) Trouble-free performance (v) Cheaper (vi) Comparatively higher efficiency (vii) Possible to obtain medium starting torque by using double cage rotor or deep bar rotor (viii) Relatively better cooling conditions (ix) Comparatively better pull out torque and overload capacity.	(i) Much higher starting torque (by inserting resistance in rotor circuit) (ii) Comparatively lesser starting current (2 to 3 times the full load current) (iii) Capable of starting with load demanding high starting torque (iv) speed control (by varying resistance in the rotor circuit) (v) Can be starting directly on lines, (resistance in the rotor circuit acts like a starter and reduces the starting current)
Disadvantages	**Disadvantages**
(i) Low starting torque (ii) Higher starting current (5 to 6 times the full load current) (iii) No speed control (iv) Needs a starter (v) Cannot be used for loads demanding high starting torque	(i) Higher cost (ii) Comparatively lower efficiency (iii) Higher degree of maintenance (iv) Extra losses in external resistance, specially when operated at reduced speed (v) Extra slip ring, brush gears, etc.

End of Solution

Q.4 (c) (i) What is magnetic anisotropy? Explain the importance of magnetic anisotropy in transformer cores.

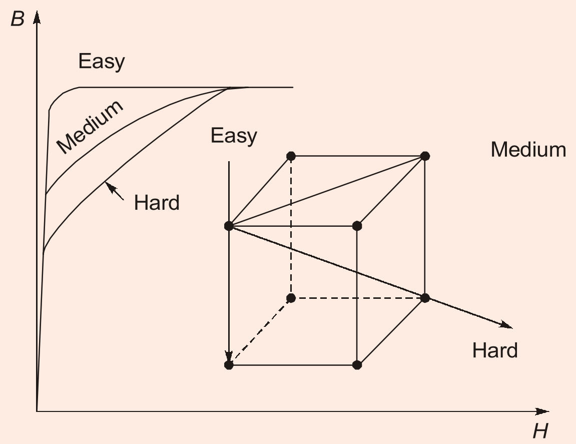
[10 marks : 2023]

(ii) What are the different synthesis strategies for producing nanoparticles? Classify them on the basis of physical methods, chemical synthesis and mechanical processes.

[10 marks : 2023]

Solution:

(i) **Magnetic Anisotropy:** In single crystal magnetic materials such as iron, the magnetic properties depend on the direction in which they are measured, i.e. iron exhibits preferred direction of magnetization. In the absence of an external field, the spontaneous, magnetization takes up a specific direction with respect to crystal axis. In iron there are six equivalent preferred easy directions, one of the cube edges. This phenomenon is called as magnetocryslalline anisotropy. The magnetization curves in different directions of an iron single crystal are shown in figure below.



In some polycrystalline materials, the various crystals are oriented more or less at random, and the properties in different direction are not greatly different. In many materials, which have been subjected to specific treatment, such as cold rolling, some regularity in the distribution of orientations, male the magnetic properties of the material markedly anisotropic. This is called induced anisotropy and is of considerable practical importance. Thin films o Ni-Fe alloy, deposited on to a substrate, by evaporation in vacuum with magnetic field applied in the plane of the substrate, have subsequently easy direction for spontaneous magnetization as the original field direction. This is another example of induced anisotropy, and thin magnetic films are used 3 storage elements in the computers. In bulk materials, there are three basic methods by which the uniaxial anisotropy can be induced : (i) cold working particularly cold rolling, uniaxial anisotropy is induced in the direction q rolling, (ii) magnetic annealing, heat treatment of a material in a magnetic field produces a uniaxial anisotropy, related to field direction, (iii) magnetic quench quenching, material is cooled in the presence of a magnetic field through the Curie temperature, leading a uniaxial anisotropy, either parallel or perpendicular to the field direction.

(ii) Top-down and Bottom-up methods are two approaches for synthesis of nano-materials and the fabrication of nano-structures.

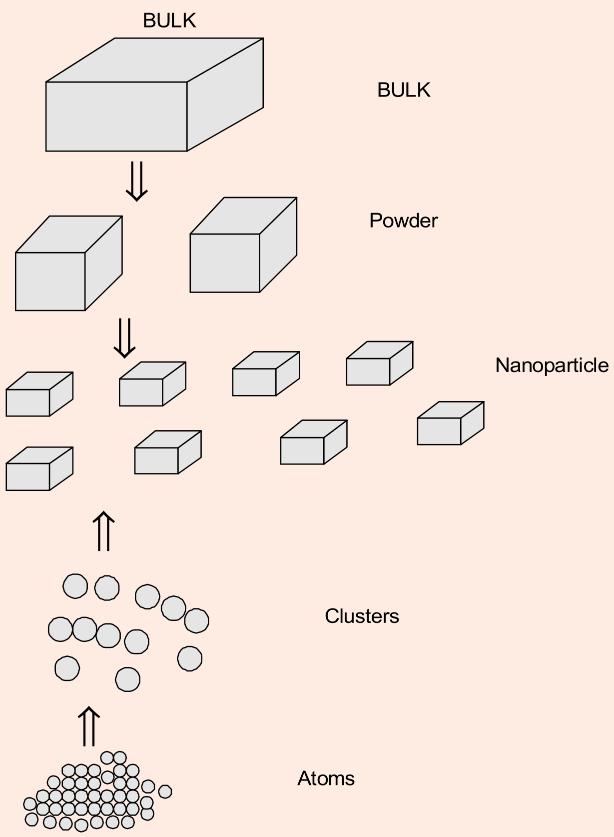
Top-down Approach

Top-down approach refers to slicing or successive cutting of a bulk material to get nano sized particle.

Bottom-up Approach

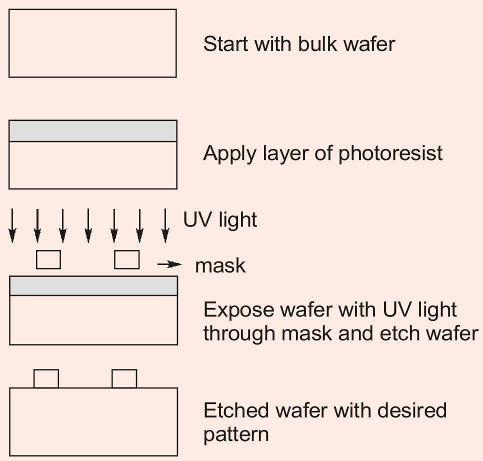
- Bottom-up approach refers to the build up of a material from the bottom : atom by atom molecule by molecule.
- Atom by atom deposition leads to formation of self-assembly of atom/molecules and clusters.
- These clusters come together to form self-assembled monolayers on the surface of substrate.

Figure shows the two approaches used for synthesis of nano-materials.



Top-Down Approach : It uses physical processing methods.

1. Mechanical Methods :
   Cutting, Etching, Grinding.
2. Lithographic Techniques :
   Photo lithography, Electron Beam lithography.



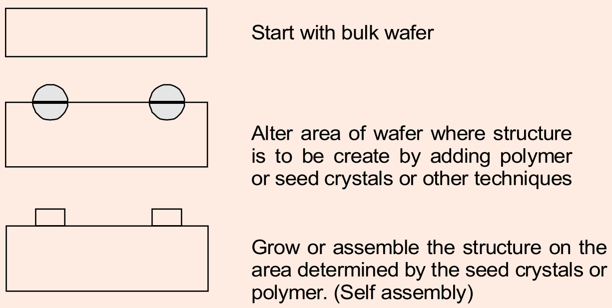
Advantages
1. Large-scale production.
2. Deposition over a large substrate is possible.
3. Chemical purification is not required.

Disadvantages
1. Varied particle shapes or geometry.
2. Control over deposition parameters is difficult to achieve.
3. Impurities : Stress, Defects and imperfections get introduced.
4. It is an expensive technique.

Bottom-Up Approach : In all the bottom-up techniques, the starting material is either gaseous state or liquid state of matter. This approach uses physical and chemical processing methods.

Physical Techniques :
- Physical vapor deposition (PVD), involves condensation of vapor phase species.
- Evaporation (Thermal, e-beam)
- Sputtering
- Plasma arcing

Chemical Techniques :
- CVD (Chemical vapor deposition) : Deposition of vapor phase of reaction species.
- Self-assembled monolayer : Electrolytic deposition, sol-gel method, Microemulsion route, pyrolysis.



Advantages
1. Ultra-fine nanoparticles, nanoshells, nanotubes can be prepared.
2. Deposition parameters can be controlled.
3. Narrow size distribution is possible (1 – 20 nm)
4. Cheaper Technique.

Disadvantages
1. Large scale production is difficult.
2. Chemical purification of nano-particles is required.

End of Solution

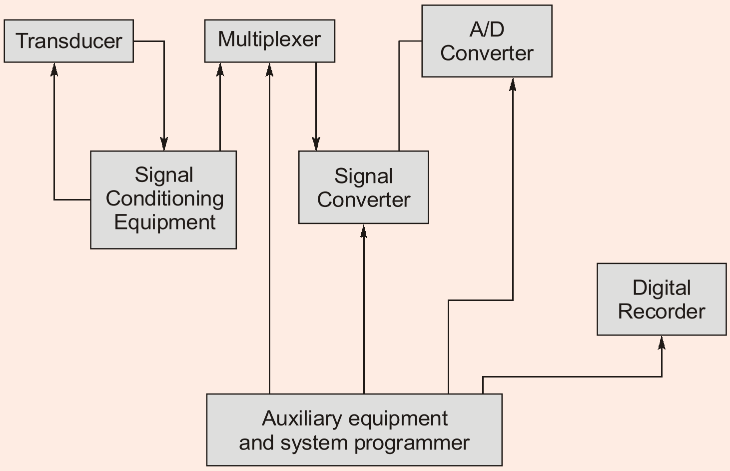
Section-B

Q.5 (a) Draw the block diagram of digital data acquisition system and explain the essential function of each block and component.

[12 marks : 2023]

Solution:

Generalized Data Acquisition System (Digital):



The essential functional operations of a digital data acquisition system are

(i) Handling of analog signals.

(ii) Making the measurement.

(iii) Converting the data to digital form and handling it, and

(iv) Internal programming and control.

The various components and their functions are described below.

Transducer: The convert a physical quantity into an electrical signal which is acceptable by the data acquisition system.

Signal Conditioning Equipment: Signal conditioning equipment includes any equipment that assists in transforming the output of transducer to the desired magnitude or form required by the next state of the data acquisition system.

Multiplexer: Multiplexing is the process of sharing a single channel with more than one input. Thus a multiplexer accepts multiple analog inputs and connects them sequentially to one measuring instrument. Another name for a multiplexer is "scanner".

Signal Converter: A signal converter translates the analog signal to a form acceptable by the analog to digital converter. An example of the signal converter la an amplifier for amplifying the low-level signal voltages produced by transducers.

Analog to Digital Converter (AD Converter): An A/D converter converts the analog voltage to its equivalent digital form. The output of the A/D converter may be fed to digital display devices for visual display or may be fed to digital recorders for recording. It may be fed to a digital computer for data reduction and further processing.

Auxiliary Equipment: This contains devices for system programming functions and digital data processing. Some of the typical functions done by auxiliary equipment are linearization and limit comparison of signals. These functions may be performed by individual devices or by a digital computer.

Signal Digital Recorders: Records of information in digital form may be stored on punched cards, perforated paper tapes, type written pages, floppy, discs, magnetic tape, or a combination of these systems.

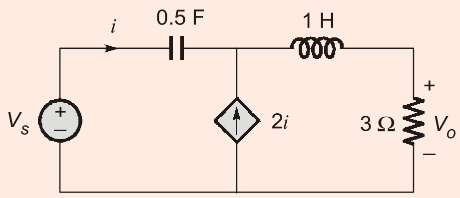
Digital Printers: After all the tests have been completed and the data is generated, it becomes necessary to record the numbers and in some cases reduce the data to a more meaningful form. A digital printer can be specified to interface with an electronic instrumentation system in order to perform this work, and thus provide a high quality hard copy for records and minimizing the labour of the operating staff.

Uses:

- Digital data acquisition systems are used when the physical quantity being monitored has a narrow bandwidth (i.e., when the quantity varies slowly).
- Digital data acquisition systems are in general, more complex than analog systems, both in terms of instrumentation involved and the volume and complexity of the data they can handle.

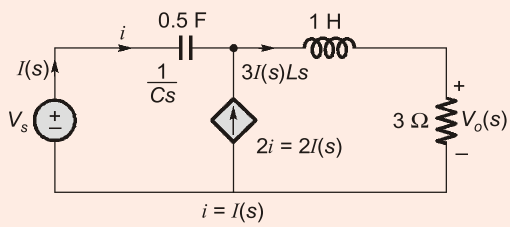
End of Solution

Q.5 (b) Obtain the transfer function $H(s) = \frac{V_o}{V_b}$ for the circuit given below:



[12 marks : 2023]

Solution:



By KVL

$$V_s(s) = \frac{2I}{s}(s) + 3[3 + s]I(s)$$

$$sV_s(s) = 2I(s) + (3sI(s) + s^2I(s))3$$

$$sV_s(s) = (3s^2 + 9s + 2)I(s)$$

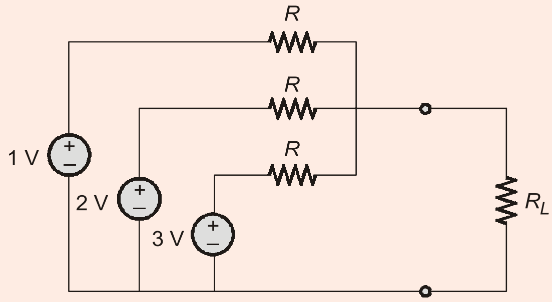
$$\frac{V_s(s)}{I(s)} = \frac{3s^2+9s+2}{s} \quad ...(1)$$

$$V_0(s) = 3[3I(s)] \quad ...(2)$$

$$H(s) = \frac{V_0}{V_s} = \frac{9s}{3s^2+9s+2}$$

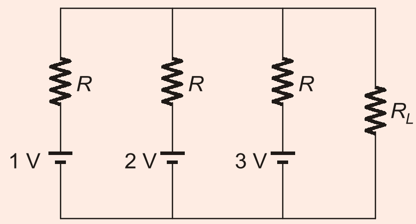
End of Solution

Q.5 (c) For the given circuit, find the value of R, if the maximum power delivered to the load is 3 mW :

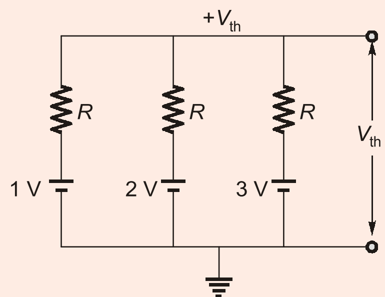


[12 marks : 2023]

Solution:



Case 1: $[V_{th}]$

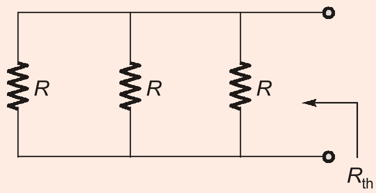


By KCL,

$$\frac{V_{th}-1}{R} + \frac{V_{th}-2}{R} + \frac{V_{th}+3}{R} = 0$$

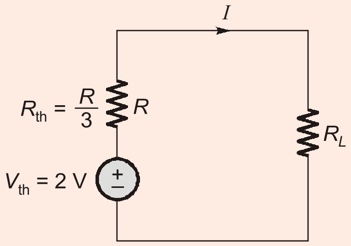
$$V_{th} = 2\text{ V}$$

Case 2: $[R_{th}]$



$$R_{th} = \frac{R}{3}$$

Case 3:



For Max. Power,

$$R_L = R_{th}$$

$$R_L = \frac{R}{3}$$

$$I = \frac{V_{th}}{R_{th} + R_L} = \frac{2}{\frac{R}{3} + \frac{R}{3}} = \frac{3}{R}$$

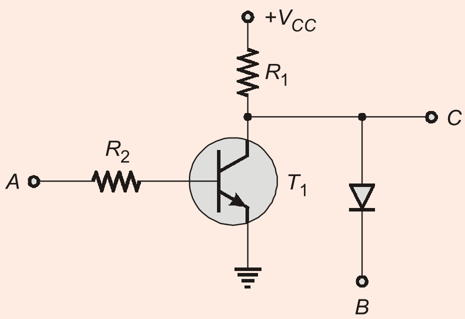
$$P_{max} = I^2 R_L$$

$$3 \times 10^{-3} = \left[\frac{3}{R}\right]^2 \times \frac{R}{3}$$

$$R = 1000\ \Omega$$

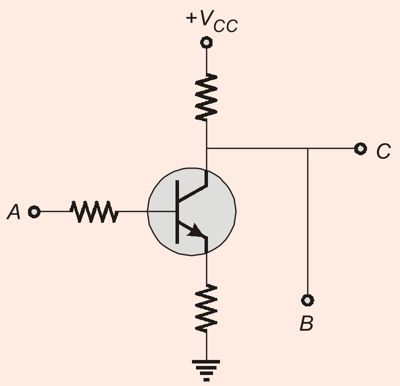
End of Solution

Q.5 (d) The transistor T_1 has negligible collector-to-emitter saturation voltage as shown in the figure below. Also, the diode drops negligible voltage when conducting. If the power supply is +5 V, A and B are digital signals with V_{CC} as logic 1 and 0 V as logic 0, find the Boolean expression for output C.



[12 marks : 2023]

Solution:

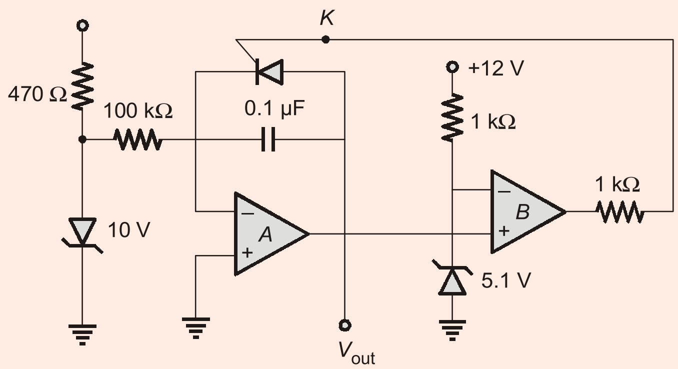


A	B	Q	C
0	0	OFF	0
0	+5 V	OFF	+5 V
+5 V	0	ON	0
+5 V	+5 V	ON	0

$$C = \bar{A}B$$

End of Solution

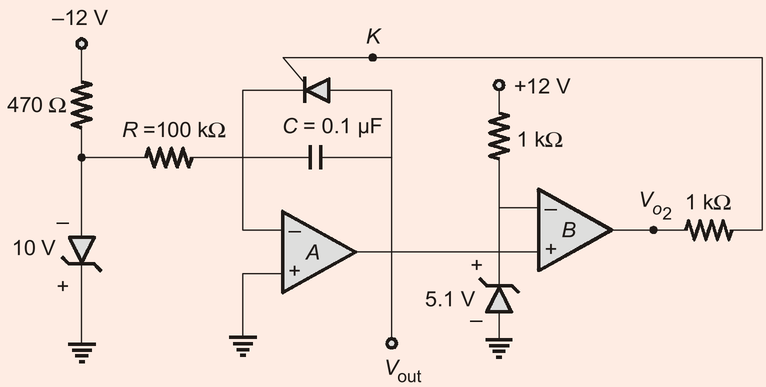
Q.5 (e) Explain the operation of the circuit shown below. Include a description of its output waveform, including its amplitude and period:



The device which is connected in parallel to the capacitor can be considered a controlled diode which conducts in one direction only, when triggered by a positive trigger at the control, input *K*, and stops conducting when a negative trigger is applied or if the forward bias to its removed, similar to an SCR. Assume that the capacitor is uncharged initially.

[12 marks : 2023]

Solution:



Op-amp-A acts as integrator.

KCL at INV mode of A:

$$\frac{-10-0}{R} + C \times \frac{d}{dt}(V_{out} - 0) = 0$$

$$\frac{dV_{out}}{dt} = \frac{10}{RC}$$

Integrate both sides, $$V_{out} = \int_0^t \frac{10}{RC} \times dt = \frac{10}{RC} \times t$$

$$V_{out} = \frac{10}{10^5 \times 10^{-7}} \times t = 1000t$$

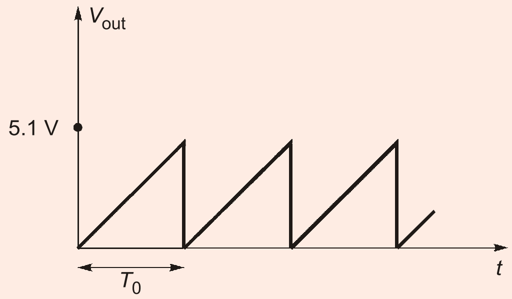
$$V_{out} = 1000t \Rightarrow V_{out} \text{ is a ramp.}$$

Op-amp B acts as comparator.

If V_{out} becomes slightly greater than 5.1 V then V_{o2} becomes $+V_{sat}$. Hence, SCR becomes ON. Then capacitor discharges rapidly through SCR and V_{out} becomes zero. Now SCR becomes OFF because $V_{out} < 5.1$ V or $V_{o2} = -V_{sat}$.

Then again capacitor starts charging through 100 kΩ and $V_{out} = 1000t$ i.e. another ramp is generated.

Above operation keeps repeating and V_{out} waveform is a train of ramps.



Amplitude of V_{out} = 5.1 V

T_o : Time period of output

$$V_{out} = 1000t$$

Put V_{out} = 5.1 V and $t = T_o$

$\Rightarrow$ $$5.1 = 1000 \times T_o$$

$$T_o = 5.1 \text{ msec}$$

End of Solution

Q.6 (a) (i) Define noise. Explain with examples the generated noise, conducted noise and radiated noise. Describe the techniques used for reducing the magnitude of the above-mentioned categories of noise.

[10 marks : 2023]

(ii) An amplifier whose bandwidth is 100 kHz has a noise power spectrum density input of 7×10^{-21} J. If the input resistance is 50 kΩ and the amplifier gain is 100, what is the noise output voltage?

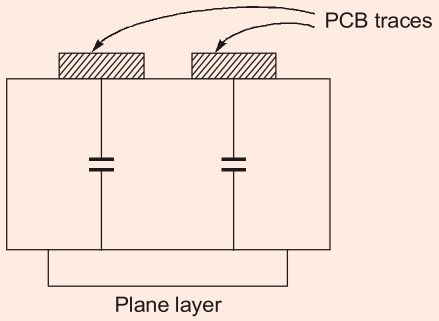
[10 marks : 2023]

Solution:

(i) Noise is an unwanted signal which interferes with the original message signal and corrupts the parameters of the message signal.

Conducted Noise: It is the noise that is transmitted along with signals through power supply lines, signal lines and trace patterns on printed circuit boards.

Unintended (parasitic) capacitors are everywhere and they will readily provide a path by which a high-frequency signal can couple from one conductor to another



- Switching power supply, DC/DC converter are a widespread source of conducted EMI and noise.
- To reduce conducted noise: **(i)** Proper insulation should be there between two conductors; **(ii)** Two conductors should be well separated if possible.

Radiated Noise: It is noise that travels through space and arrives as unwanted electromagnetic waves.

Every conductor is an antenna that is capable of both transmitting and receiving signals. Along with receiving/transmitting actual signals we also get received/transmitted noise. This noise is called radiated noise.

- Shielding, reflection, bypassing and absorption are the four basic methods to counter the noise. Sometimes twisted pair wire are used to eliminate this radiated noise in wired communication.

Generated Noise Reduction:

- Component Selection: Choosing components with lower noise characteristics, such as low-noise amplifiers or voltage regulators, can help minimize generated noise.
- Layout and Grounding: Proper circuit board layout and grounding techniques can reduce noise generated by high-speed digital circuits and minimize the coupling of noise between components.
- Power Supply Filtering: Using filtering techniques, such as ferrite beads or capacitors, in power supply lines can attenuate noise generated by switching regulators or other noisy power sources.

(ii) Given: B_n = 100 kHz ; $N_o = 7 \times 10^{-21}$ J ; R_L = 50 kΩ ; G = 100

Noise voltage,

$$V_n = \sqrt{4kTB_nR_L} \times G$$

$$N_o = kT = 7 \times 10^{-21} \text{ J}$$

∴

$$V_n = \sqrt{4 \times 7 \times 10^{-21} \times 100 \times 10^3 \times 50 \times 10^3} \times 100$$

$$V_n = 1.183 \times 10^{-3} \text{ Volt} = 1.183 \text{ mV}$$

End of Solution

Q.6 (b) Describe in brief the different methods used for measurement of medium resistance.

[20 marks : 2023]

Solution:

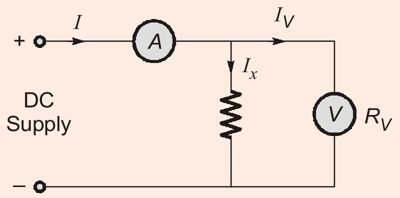
The resistances that range from about 1 Ω to about 100 kΩ are classified as medium resistances. The resistances of most of electrical apparatus are the examples of medium resistances.

Measurement of Medium Resistances: To measure the medium resistances following methods are used:

- Ammeter-Voltmeter Method
- Substitution Method
- Wheatstone Bridge
- Carey-Foster Slide-Wire Bridge Method.

Ammeter-Voltmeter Method: In this method, current through the unknown resistor (Rx) and the potential drop across it are simultaneously measured. The readings are obtained by ammeter and voltmeters respectively. There are two ways in ammeter and voltmeters may be connected for measurement as,

Case 1: When voltmeter is directly connected across the resistor, then the ammeter measures current flowing through the unknown resistance (Rx) and the voltmeter.



$$\text{Current through ammeter} = \text{Current through}(R_x) + \text{Current through voltmeter}$$

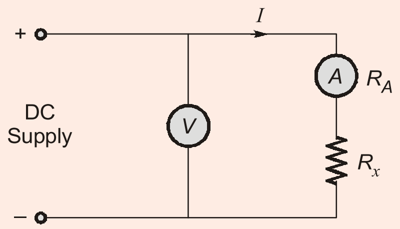
$$I = I_{R_x} + I_V$$

$$\Rightarrow \quad I_{R_x} = I - I_V$$

Therefore, the value of unknown resistance,

$$R_x = \frac{V}{I_x} = \frac{V}{I - I_V} = \frac{V}{I - (V/R_V)} \quad ...(i)$$

Case 1: When the ammeter is connected such that it measures only the current flowing through the unknown resistor (R_x), then the voltmeter measures voltage drop across the ammeter and R_x.

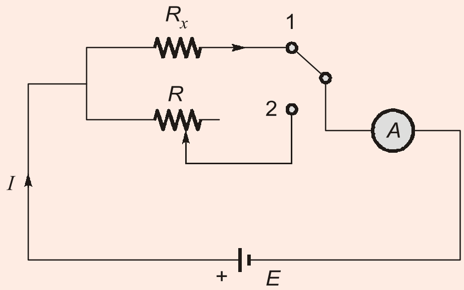


Therefore, $$V = IR_A + IR_x = I(R_A + R_x)$$

$\Rightarrow$ $$R_x = \frac{V}{I} - R_A \quad \text{...(ii)}$$

Substitution Method:

Step1 : In this method, first the unknown resistance (R_x) is put into the circuit and note the value of current.



Wheatstone Bridge: The Wheatstone bridge method is the most accurate method for the measurement of resistances.

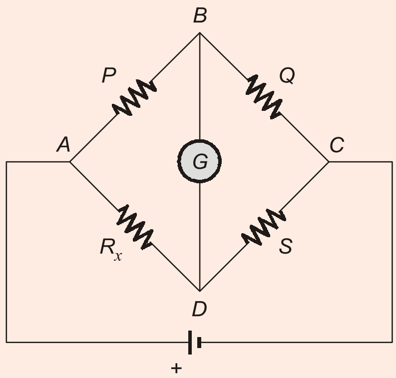
The bridge consists of four resistive arms, source of emf and a galvanometer (null detector). The current through the galvanometer depends upon the potential difference between the points *B* and *D*. The bridge is said to be balanced when the potential difference across the galvanometer is zero so that there is no current flows through the galvanometer.

For the balanced Wheatstone bridge,

$$PS = QR_x$$

$\Rightarrow$ $$R_x = \frac{PS}{Q} \quad \text{...(iii)}$$

Carey-Foster Slide-Wire Bridge Method: The circuit of this bridge is the elaborated form of Wheatstone bridge and is specially used for comparing two nearly equal resistances.



The circuit consists of four resistive arms, where R1 and R2 are the ratio arms, R3 is standard resistance and R_x is unknown resistance. A slide-wire (m-n) of length l and uniform cross-section is connected between R_3 and R_x . The slide wire has a resistance of $r\,\Omega$ per unit length.

The resistances R_1 and R_2 are adjusted so that the ratio $\left(\frac{R_1}{R_2}\right)$ is approximately equal to the ratio $\left(\frac{R_x}{R_3}\right)$. This balance is obtained by adjusting the sliding contact on the slide-wire. Then, For the first balance, let l_1 is the distance of the sliding contact from the point m of the slide wire. Thus,

$$\frac{R_1}{R_2} = \frac{R_x + l_1 r}{R_3 + (1 - l_1) r} \quad \text{...(iv)}$$

For the second balance, let l_2 is the distance from the point m of the slide wire and the resistances R_x and R_3 are interchanged, then

$$\frac{R_1}{R_2} = \frac{R_3 + l_2 r}{R_x + (l - l_2) r} \quad \text{...(v)}$$

From equations (iv) and (v), we get,

$$\frac{R_x + l_1 r}{R_3 + (l - l_1) r} = \frac{R_3 + l_2 r}{R_x + (l - l_2) r}$$

Hence, the difference $(R_3 - R_x)$ is obtained from resistance of the slide wire between the two balance points.

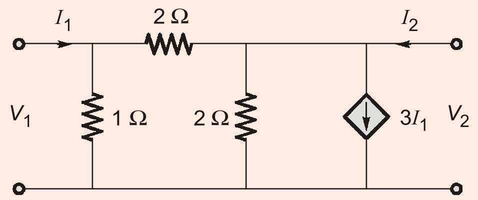
Now, the value of r i.e. resistance per unit length of the slide wire is obtained by connecting a known high resistance in parallel with R_3, that reduces the effective value to R_3', thus again repeat the above procedure to obtain new balance points l_1' and l_2', so that,

$$\frac{R_3 - R_x}{R_3' - R_x'} = \frac{r(l_1 - l_2)}{r(l_1' - l_2')}$$

$$\Rightarrow \quad R_x = \frac{R_3(l_1' - l_2') - R_3'(l_1 - l_2)}{(l_1' - l_2' - l_1 + l_2)} \quad \text{...(viii)}$$

End of Solution

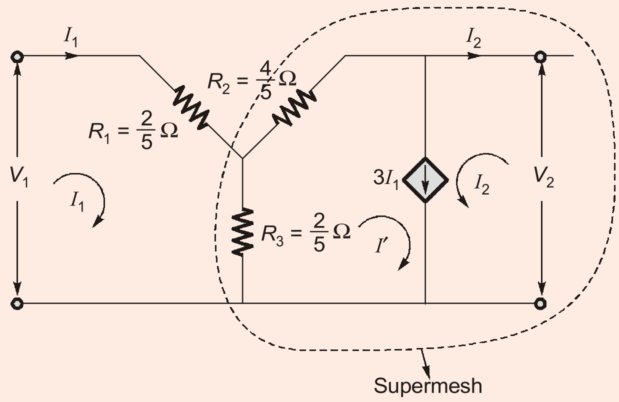
Q.6 (c) Find the Z-parameters of the network given below:



[20 marks : 2023]

Solution:

$$V_1 = Z_{11}I_1 + Z_{12}I_2$$
$$V_2 = Z_{21}I_1 + Z_{22}I_2$$



$$R_1 = \frac{2\times1}{2+1+2} = \frac{2}{5}$$
$$R_2 = \frac{2\times2}{2+1+2} = \frac{4}{5}$$
$$R_3 = \frac{2\times1}{2+1+2} = \frac{2}{5}$$

Applying KVL in loop,

$$V_1 = \left(\frac{2}{5}+\frac{2}{5}\right)I_1 - \frac{2}{5}I' \quad ...(1)$$

Supermesh,

$$\frac{2}{5}(I'-I_1) + \frac{4}{5}I' + V_2 = 0 \quad ...(2)$$
$$I' + I_2 = 3I_1$$
$$I' = 3I_1 - I_2 \quad ...(3)$$

Substitute equation (3) in (1),

$$V_1 = \frac{-2}{5}I_1 + \frac{2}{5}I_2$$

Substitute equation (3) in (2),

$$V_2 = \frac{-16}{5}I_1 + \frac{6}{5}I_2$$

By comparing,

$$Z_{11} = \frac{-2}{5}, Z_{12} = \frac{2}{5}$$

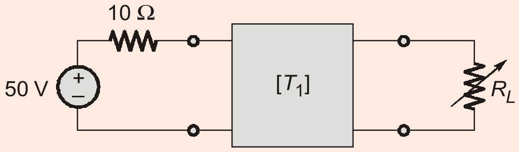
$$Z_{21} = \frac{-16}{5}, Z_{22} = \frac{6}{5}$$

End of Solution

Q.7 (a) (i) The *ABCD* parameters of the two-port network in the given figure are

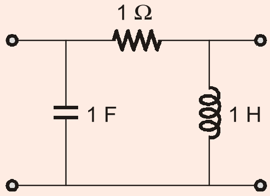
$$\begin{bmatrix} 4 & 20\ \Omega \\ 0.1S & 2 \end{bmatrix}$$

The output port is connected to a variable load for maximum power transfer. Find R_L and the maximum power transferred.



[10 marks : 2023]

(ii) Find the *T*-network equivalent to the π network given in the figure in *s*-domain using Laplace transform:

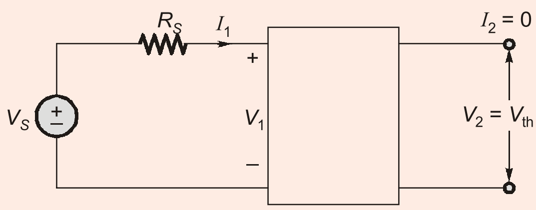


Find the element values for $s = j1$.

[10 marks : 2023]

Solution:

(i) Case I: (V_{th})



$$V_S = I_1R_S + V_1$$

$$V_1 = V_S - I_1R_S \quad ...(1)$$

$$I_1 = CV_2 - DI_2$$

$$I_1 = CV_{th} - D(0)$$

$$I_1 = CV_{th} \quad ...(2)$$

Now, we know,

$$V_1 = AV_2 - BI_2$$

$$= AV_{th} - B(0) \quad ...(3)$$

Substitute equation (1) in equation (3),

$$V_S - I_1R_S = V_{th} \quad ...(4)$$

Substitute equation (2) in equation (1)

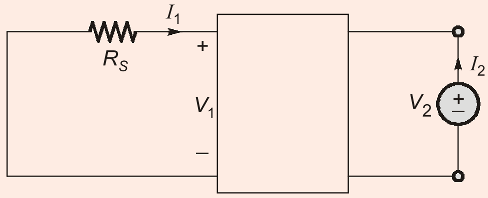
$$V_S - CV_{th}R_S = AV_{th}$$

$$V_{th}(A + CR_S) = V_S$$

$$V_{th} = \frac{V_S}{A + CR_S} = \frac{50}{4 + (0.1)10} = 10\text{ V}$$

Case 2:

$$R_{th} = \frac{V_2}{I_2}$$



$$V_1 = -I_1R_S$$

We know, $V_1 = AV_2 - BI_2$

$$-I_1R_S = AV_2 - BI_2 \quad ...(1)$$

We also know, $I_1 = CV_2 - DI_2 \quad ...(2)$

Substitute equation (2) in (1)

$$-R_S(CV_2 - DI2) = AV_2 - BI_2$$

After putting values,

$$-10(0.1V_2 - 2I_2) = 4V_2 - 20I_2$$

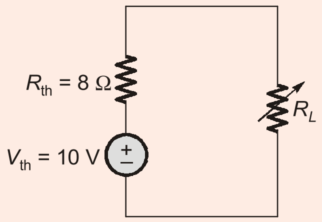
$$-V_2 + 20I_2 = 4V_2 - 20I_2$$

$$5V_2 = 40I_2$$

$$\Rightarrow \quad \frac{V_2}{I_2} = 8\ \Omega$$

$$R_{th} = 8$$

Case 3:



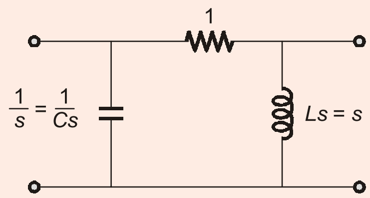
$$R_L = R_{th} = 8\ \Omega$$

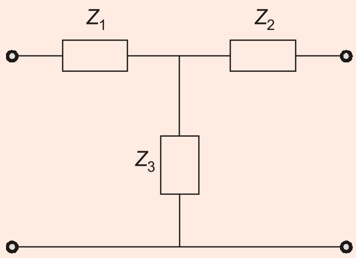
$$I = \frac{V_{th}}{R_{th} + R_L} = \frac{10}{8 + 8}$$

$$P_{max} = I^2R_L = \left(\frac{10}{16}\right)^2 8$$

$$= 3.125\text{ W}$$

(ii)

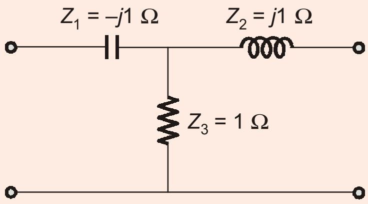




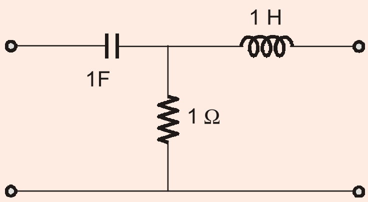
$$Z_1 = \frac{1 \times \frac{1}{s}}{1 + \frac{1}{s} + s} = \frac{1}{s^2 + s + 1} = \frac{1}{(j1)^2 + (j1) + 1} = -j1\,\Omega$$

$$Z_2 = \frac{s^2}{s^2 + s + 1} = \frac{(j1)^2}{(j1)^2 + j1 + 1} = j1\,\Omega$$

$$Z_3 = \frac{s^2}{s^2 + s + 1} = \frac{(j1)}{(j1)^2 + j1 + 1} = 1\,\Omega$$

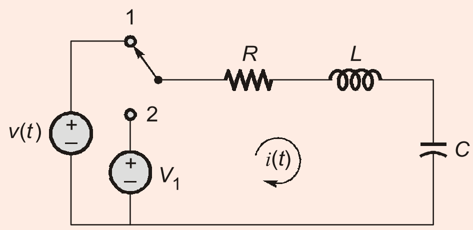


Here $\omega = 1$,



End of Solution

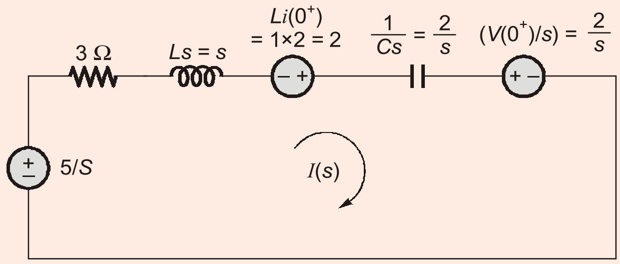
Q.7 (b) The switch is moved from position 1 to 2 at $t = 0$ in the following circuit. The initial conditions are specified as $i_L(0_+) = 2$ A, $v_C(0_+) = 2$V. Find the current $i(t)$ for $t > 0$, assuming $L = 1$ H, R = 3 Ω, C = 0.5 F and $V_1 = 5$ V. Use Laplace transform method:



[20 marks : 2023]

Solution:

After applying Laplace transform for given circuit (for $t > 0$), we get,



By KVL

$$\frac{-5}{s} + \left[3 + s + \frac{2}{s}\right] I(s) - 2 + \frac{2}{s} = 0$$

$$\frac{-5}{s} + \frac{3s + s^2 + 2}{s} I(s) - 2 + \frac{2}{s} = 0$$

$$-5 + (3s + s^2 + 2)I(s) - 2s + 2 = 0$$

$$I(s) = \frac{2s+3}{s^2 + 3s + 2}$$

$$I(s) = \frac{2s+3}{(s-1)(s-2)}$$

$$i(t) = L^{-1} I(s)$$

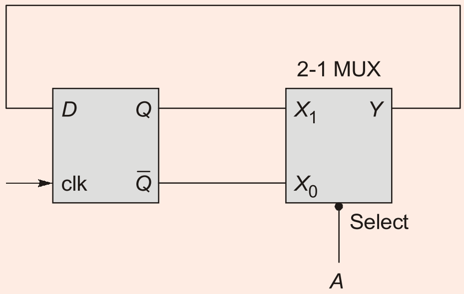
$$= [e^{-2t} + e^{-t}]u(t)$$

End of Solution

Q.7 (c) (i) Derive the expressions for the current gain g and the input impedance Z_{in} for a common-collector amplifier. Show the all necessary steps, starting with the circuit diagram (equivalent circuit model) for the derivation.

[10 marks : 2023]

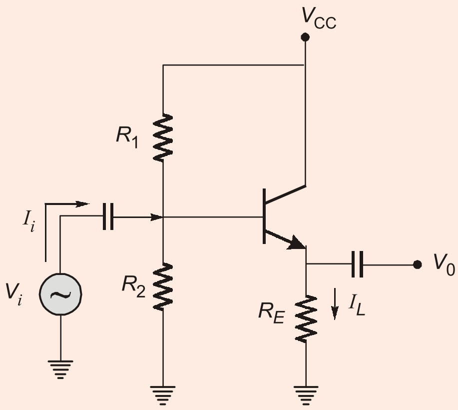
(ii) Draw the state transition diagram for the logic circuit shown below:



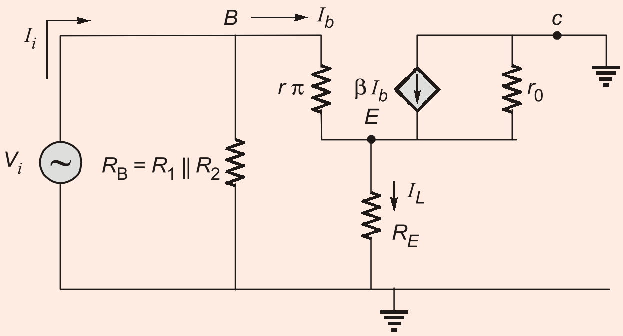
[10 marks : 2023]

Solution:

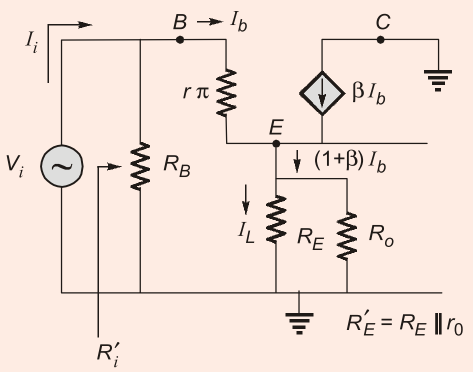
(i) Common collector amplifier



Replace transistor with π-model.



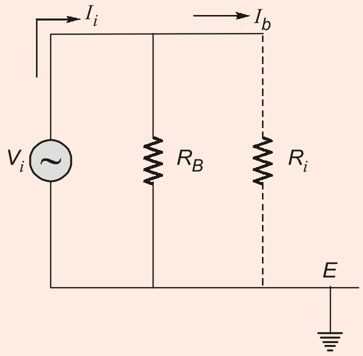
r_o is in parallel to R_E



KVL: $$V_i = I_b r_\pi + (1+\beta) I_b R_E'$$

$$\frac{V_i}{I_b} = R_i = r_\pi + (1+\beta) R_E'$$

Net input resistance $= R_i' = R_B \parallel R_i$



Current gain $= A_I = \dfrac{I_L}{I_b}$

Using current divider, $$I_C = \frac{(1+\beta) I_b r_o}{r_o + R_E}$$

$$A_I = \frac{I_L}{I_b} = \frac{(1+\beta) r_o}{r_o + R_E}$$

Overall current gain $= g = \dfrac{I_L}{I_i}$

$$g = \frac{I_L}{I_b} \times \frac{I_b}{I_i} = A_I \times \frac{R_B}{R_B + R_i}$$

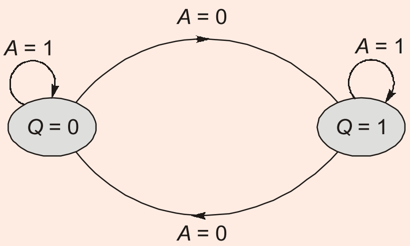
(ii) $$Y = \bar{A}\bar{Q} + AQ = A \odot Q$$

and $$D = Y = A \odot Q$$

State transition table:

A	Q	$Q^+ = D = A \odot Q$
0	0	1
0	1	0
1	0	0
1	1	1

State transition diagram:



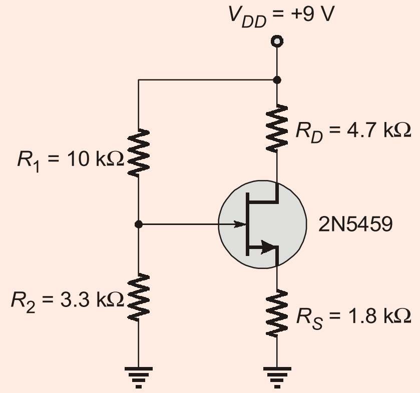
End of Solution

Q.8 (a) (i) An analog switch uses an *n*-channel MOSFET with $V_{GS(th)}$ = 4 V. A voltage of +8 V is applied to the gate. Determine the maximum peak-to-peak input signal that can be applied, if the drain-to-source voltage drop is neglected.

Also determine the minimum frequency of the pulses applied to the MOSFET gate, if this switch is used to sample a signal with a maximum frequency of 15 kHz.

[10 marks : 2023]

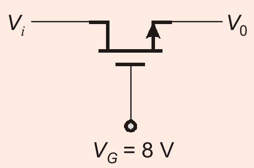
(ii) Determine the maximum I_D and V_{GS} for the circuit given below:



[10 marks : 2023]

Solution:

(i)



$$V_{GS(Th)} = 4 \text{ V}$$

To keep MOSFET switch ON,

$$V_{GS} \geq V_{Th}$$
$$V_G - V_0 \geq V_{Th}$$
$$8 - V_0 \geq 4$$
$$\Rightarrow \quad V_0 \leq 4 \text{ V}$$

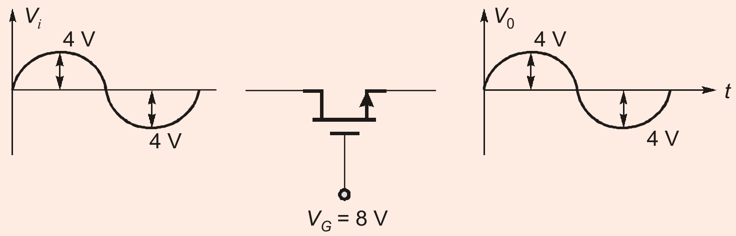
Hence Maximum peak output = 4 V

∴ Maximum peak-to-peak output = 2 × 4 = 8 V.

Drain to source voltage drop is negligible.

Hence, $V_0 = V_i$

∴ Maximum peak-to-pak input = 8 V



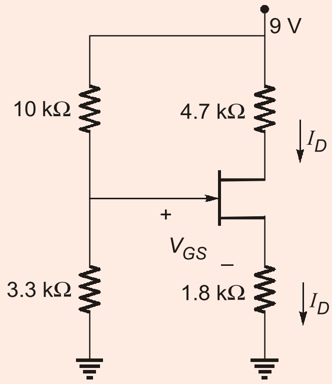
Given $f_{in,\ max}$ = 15 kHZ

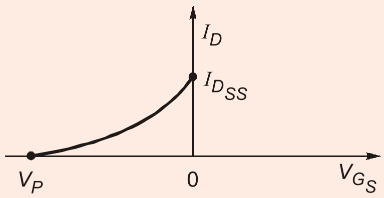
From sampling theorem,

$$f_{sampling} \geq 2 f_{in,max}$$
$$f_{sampling} \geq 2 \times 15 \text{ kHz} \geq 30 \text{ kHz}$$

$\therefore$ Minimum sampling frequency = 30 kHz

(ii)





For JFET, VGS lies between 0 and V_p.

Hence, maximum $V_{GS} = 0$, maximum $I_D = I_{DSS}$

$$V_{GS} = V_G - V_S$$

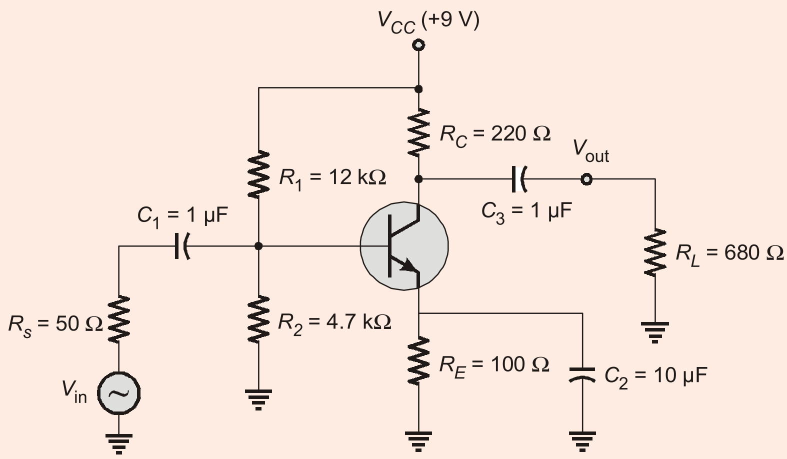
$$0 = \frac{9 \times 3.3}{10 + 3.3} - 1.8 \times I_D$$

$$\Rightarrow \quad I_D = \frac{2.233}{1.8} = 1.24 \text{ mA}$$

Maximum I_D = 1.24 mA

End of Solution

Q.8 (b) Determine the lower cut-off frequency of the amplifier shown in the figure:

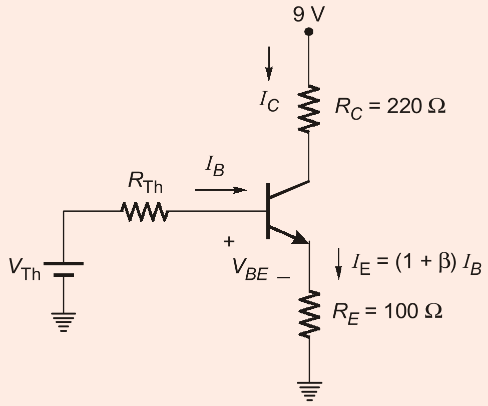


Given, $\beta_{DC} = \beta_{AC} = 125$, $C_{be} = 25$ pF and $C_{bc} = 10$ pF.

Thus, also calculate the voltage gain A_V at lower cut-off frequency.

[20 marks : 2023]

Solution:



DC analysis:

$$V_{Th} = \frac{9 \times 4.7}{12 + 4.7} = 2.5329 \text{ V}$$

$$R_{Th} = 12 \,||\, 4.7 = 3.377 \text{ k}\Omega$$

KVL:

$$-V_{Th} + I_B R_{Th} + V_{BE} + (1 + \beta) I_B R_E = 0$$

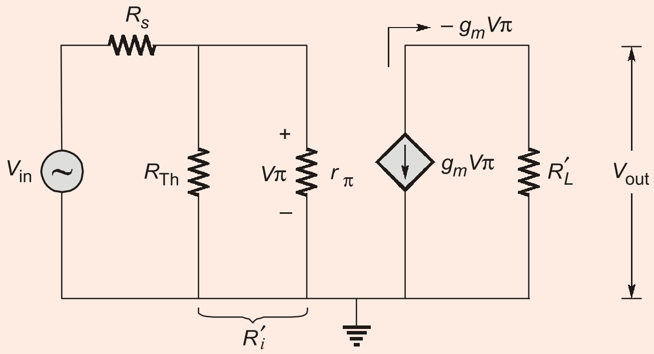
$$I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + (1+\beta)R_E} = 0.11472 \text{ mA}$$

$$I_C = \beta I_B = 14.34 \text{ mA}$$

$$g_m = \frac{I_C}{V_T} = \frac{14.34 \text{ mA}}{26 \text{ mV}} = 0.5515 \ \mho$$

$$r_\pi = \frac{\beta}{g_m} = \frac{125}{0.5515} = 226.6 \ \Omega$$

Assume that A_{Vm} is mid-frequency voltage gain.



$$R_L' = R_C \,||\, R_L = 166.22 \ \Omega$$

$$R_i' = R_{Th} \,||\, r_\pi = 212.35 \ \Omega$$

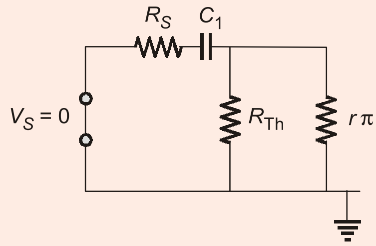
$$A_{Vm} = \frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_\pi} \times \frac{V_\pi}{V_{in}} = -g_m R_L' \times \frac{R_i'}{R_s + R_i'}$$

$$A_{Vm} = -0.5515 \times 166.22 \times \frac{212.35}{50 + 212.35}$$

$$A_{Vm} = -74.2 \quad \Rightarrow \quad |A_{Vm}| = 74.2$$

At $f = f_L$, Voltage gain $= \frac{|A_{Vm}|}{\sqrt{2}} = \frac{74.2}{\sqrt{2}} = 52.47$

If $C_1 = 1$ μF is considered: $f_{L1} = \frac{1}{2\pi R C_1}$

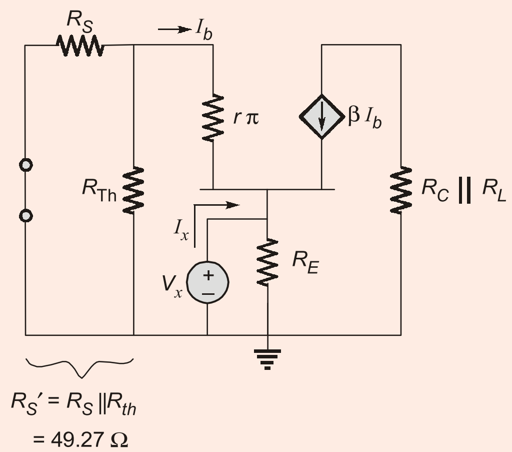


$$R = R_s + (R_{Th} \parallel r_\pi) = 50 + (3377 \parallel 226.6)$$

$$R = 262.35\ \Omega$$

$$f_{L1} = \frac{1}{2\pi \times 262.35 \times 1 \times 10^{-6}} \quad \Rightarrow \quad f_{L1} = 606.65\ \text{Hz}$$

If $C_2 = 10$ μF is considered: $f_{L2} = \frac{1}{2\pi R C_2}$

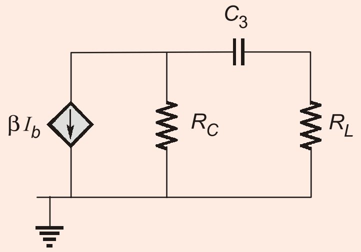


$$\frac{V_x}{I_x} = R = \left(\frac{R_s' + r_\pi}{1+\beta}\right) \Bigg\| R_E$$

$$R = 2.1425\ \Omega$$

$$f_{L2} = \frac{1}{2\pi \times 2.1425 \times 10 \times 10^{-6}} = 7428.46\ \text{Hz}$$

If $C_3 = 1$ μF is considered: $f_{L3} = \frac{1}{2\pi R C_3}$



$$R = R_C + R_L = 900\ \Omega$$

$$f_{L3} = \frac{1}{2\pi \times 900 \times 1 \times 10^{-6}} = 176.84\text{ Hz}$$

Net lower cut-off frequency is the highest of above three frequencies.

$f_{L2} > 4f_{L1}$ and $f_{L2} > f_{L3}$

Hence, net $f_L = f_{L2} = 7428.46$ Hz.

End of Solution

Q.8 (c) (i) Derive the expressions for stress in an element subjected to biaxial stress.

[10 marks : 2023]

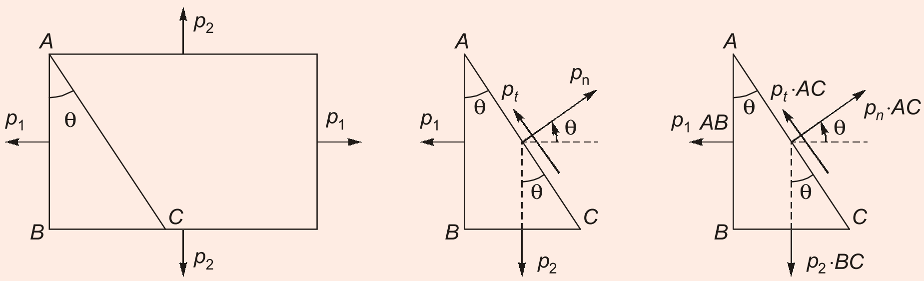
(ii) A simple tension member having an area of 100 mm^2 subjected to a load of 3000 kg. strain of 1520 and – 544 microstrain are measured in the axial and transverse directions, respectively. Determine the value of Young's modulus and Poisson's ratio.

[10 marks : 2023]

Solution:

(i) **Stresses due to state of biaxial stress:**

Figure (a) shows the state of biaxial stress, in which both p_1 and p_2 are tensile. Figure (b) shows the stresses on the wedge shaped stress element (both marked in the positive direction) whie Figure (c) shows forces on the stress element.



(a) **(b) Stresses** **(c) Forces**

Taking unit thickness of the stress element and resolving the forces perpendicular to AC, we have,

$$p_n \cdot AC = p_1 AB\cos\theta + p_2 BC\sin\theta$$

or

$$p_n = p_1 \frac{AB}{AC}\cos\theta + p_2 \frac{BC}{AC}\sin\theta = p_1 \cos^2\theta + p_2 \sin^2\theta$$

Similarly, resolving the forces along AC, we have,

$$p_t \cdot AC = -p_1 AB\sin\theta + p_2 BC\cos\theta$$

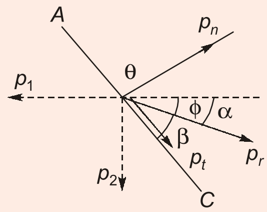
or $$p_t = -p_1\frac{AB}{AC}\sin\theta + p_2\frac{BC}{AC}\cos\theta = -p_1\cos\theta\sin\theta + p_2\sin\theta\cos\theta$$

or $$p_t = -\frac{p_1 - p_2}{2}\sin 2\theta$$

(The negative sign shows that it acts in reversed direction than shown in Figure (c))

Maximum shear stress occurs at $\theta = 45°$:

For this value of θ, normal stress is given by



$$p_n = p_1\cos^2 45° + p_2\sin^2 45° = \frac{p_1 + p_2}{2}$$

(ii) Given,
$$A = 100 \text{ mm}^2,\ P = 3000 \text{ kg}$$
$$E_x = 1520 \times 10^{-6},\quad E_g = -544 \times 10^{-6}$$

$$\text{Poisson ratio } (\mu) = \frac{-\text{Lateral strain } (E_g)}{\text{Longitudinal strain } (E_x)}$$

$$\mu = \frac{(-544)\times 10^{-6}}{1520\times 10^{-6}} = 0.3578$$

$$\text{Longitudinal stress} = \frac{3000\times 9.81}{100} = 294.3 \text{ MPa}$$

$$\text{Young's modulus} = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}} = \frac{294.3}{1520\times 10^{-6}}$$

$$= 193.681 \text{ GPa}$$

End of Solution

■■■■