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ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-5 : Basic Electronics Engineering + Analog Electronics + Electrical Materials + Electrical Machines - 1 + Power Systems - 2

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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	42
Q.2	56
Q.3	42
Q.4	
Section-B	
Q.5	38
Q.6	34
Q.7	
Q.8	
Total Marks Obtained	212

Signature of Evaluator: Saurabh kumar

Cross Checked by

Section A : Basic Electronics Engg. + Analog Electronics + Electrical Materials

(a) A conducting bar of 20 μm length, 2 μm wide and 1 μm thick is taken. Find the resistance of the bar if it is

(i) n-doped Silicon with $N_D = 10^8/\text{cm}^3$.

(ii) p-doped Silicon with $N_A = 10^{10}/\text{cm}^3$.

take $\mu_n = 2.5\,\mu_p = 1200\ \text{cm}^2/\text{Vs}$ and n_i for Silicon is $1.5 \times 10^{10}/\text{cm}^3$.

[12 marks]

→ (i) n-doped silicon $N_D = 10^8/\text{cm}^3$

$n_i = 1.5 \times 10^{10}/\text{cm}^3$

~~as $N_D >> n_i$~~

~~no.of $e^- \simeq N_D$~~

~~$n = N_D = 10^8$~~

~~$p = \frac{n_i^2}{n} = 1.5 \times 10$~~

$$n = \frac{(N_D - N_A) + \sqrt{(N_D - N_A)^2 + 4n_i^2}}{2}$$

$$= \frac{10^8 + \sqrt{(10^8)^2 + 4(1.5 \times 10^{10})^2}}{2}$$

$n = 1.505 \times 10^{10}$

$p = \frac{n_i^2}{n} = \frac{(1.5 \times 10^{10})^2}{(1.505 \times 10^{10})} = 1.495 \times 10^{10} \simeq n$

$\rho = \frac{1}{(ne\mu_n + pe\mu_p)} = \frac{1}{ne\,[\mu_n + \mu_p]}$

$\rho = 2.46 \times 10^5\ \Omega\text{-cm}$

$R = \frac{\rho l}{A} = \frac{2.46 \times 10^5 \times 20 \times 10^{-4}}{2 \times 1 \times 10^{-8}}$

$$\boxed{R = 2.46 \times 10^{10}\ \Omega}$$

→ ii) p-doped silicon, $N_A = 10^{10}$

$$p = \frac{(N_A - N_D) + \sqrt{(N_A - N_D)^2 + 4N_i^2}}{2}$$

$p = 2.08 \times 10^{10}/\text{cm}^2$

$n = \frac{n_i^2}{p} = \frac{(1.5 \times 10^{10})^2}{(2.08 \times 10^{10})} = 1.08 \times 10^{10}/\text{cm}^3$

Resistivity $\rho = \dfrac{1}{ne\mu_n + pe\mu_p e}$

$$\rho = \frac{1}{1.602\times10^{-19}[1.08\times10^{10}\times1200 + 2.08\times10^{10}\times\frac{1200}{2.5}]}$$

$\rho = 2.72\times10^{5}\,\Omega cm$

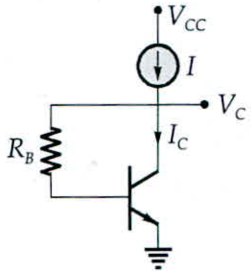
$$R = \frac{\rho l}{A} = \frac{2.72\times10^{5}\times20\times10^{-4}}{(2\times1\times10^{-8})}$$

$$\boxed{R = 2.72\times10^{10}\ \Omega}$$

Good

11

Q.1 (b) A circuit that can provide a very large voltage gain for a high resistance load is shown in figure below. Find the value of current *I* and R_B to bias the BJT at I_C = 3 mA and V_C = 1.5 V for β = 90.



[12 marks]

→ Given data - $\beta = 90$, I_c = 3~~0~~ mA, $V_c = 1.5$

as $I_c = 3mA$

$I = I_c + I_{RB}$ — KCL at V_c

$= I_c + \dfrac{I_c}{\beta}$

$= 3 + \dfrac{3}{90}$

$$\boxed{I = 3.033\ mA}$$

$V_c = R_B I_B + 0.7$ → KVL at R_B loop

$1.5V = R_B\left(\dfrac{I_c}{90}\right) + 0.7$ -- Assume $V_{BE} = 0.7$.

$1.5 = R_B\left(\frac{3}{90}\right) + 0.7$

$\boxed{R_B = 24\,k\Omega}$

11

Good

Do n
write
this r

Q.1 (c) A material with magnetic property such that when it was placed in a magnetic field, $B = 4\ \text{Wb/m}^2$, magnetic field intensity was found to be 4800 A/m. If $\vec{H}$ is reduced to 640 A/m and $B = 1.8\ \text{Wb/m}^2$, then calculate the percentage change in magnetization M of the material.

[12 marks]

Given data- $\left.\begin{array}{l} B = 4\ \text{wb/m}^2 \\ H = 4800\ \text{A/m} \end{array}\right\}$ — ①

now if $\vec{H} = 640\ \text{A/m}$ $B = 1.8\ \text{wb/m}^2$ ← ②

% change in $m = ?$

$B = \mu_0 [H + m]$

$B = \mu_0 [H + \chi H]$ $m = \chi H$

$B = \mu_0 (1+\chi) H$ $\boxed{\chi = \mu_r - 1}$

$B = \mu_0 \mu_r H$

Case ①

$\mu_0 \mu_{r_1} = \frac{B_1}{H_1} = \frac{4}{4800} = 8.33 \times 10^{-4}$

$\mu_{r_1} = \frac{8.33 \times 10^{-4}}{\mu_0} = 663.145$

$\chi_1 = \mu_{r_1} - 1 = 662.145$

$m_1 = \chi_1 H_1 = 662.145 \times 4800 = 3.17 \times 10^6\ \text{A/m}$

Case ②

$\mu_0 \mu_{r_2} = \frac{B_2}{H_2} = \frac{1.8}{640} = 2.8125 \times 10^{-3}$

$\mu_{r_2} = 2238.11$

$\chi_2 = \mu_{r_2} - 1 = 2237.116$

$m_2 = \chi_2 H_2 = 2237.116 \times 640 = 1.43 \times 10^6\ \text{A/m}$

% change in $m = \frac{m_2 - m_1}{m_1} \times 100$

$= \frac{1.43 \times 10^6 - 3.17 \times 10^6}{3.17 \times 10^6}$

$\boxed{\%\ \text{change in } m = -54.88\ \%}$

magnetisation of a material is reduced by 54.88 %

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Good

(d) What is the significance of 'Magnetic dipole' and 'Magnetization' phenomena in magnetic materials? Explain clearly with the help of definition and mathematical derivation. How are above two phenomena related to each other?

[12 marks]

(e) What are type-I and type-II superconductors? Draw the magnetization versus magnetic field characteristic for type-I and type-II superconductors. Why superconductivity is observed for signals upto radio frequencies?

[4 + 4 + 4 marks]

(a) → Type-① superconductors -
superconductors which have only two states i.e superconducting state and normal conducting state

Below certain critical magnetic field it is in superconducting state

Above certain H_c, it is in normal conducting states

eg. lead, strontium,

Type-② superconductors -
These conductors exist in three different states

① below critical magnetic field H_{c_1} it is in superconducting state

② Above certain critical magnetic field H_{c_2} it is in normal conducting state

③ between H_{c_1} & H_{c_2} it is in mixed state i.e it is superconductor but starts allowing magnetic field through it

eg. Indium doped lead.

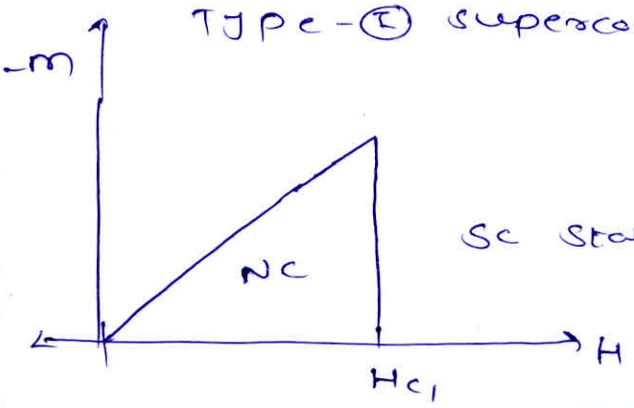
(b) magnetization Vs magnetic field -

$m = \chi_m H$ as $\chi_m = -1$

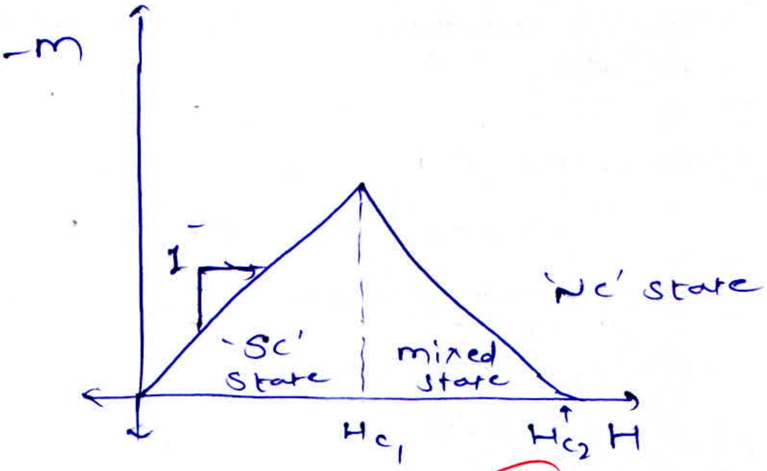
$m = -H.$

$\boxed{-m = H}$

Type-Ⓘ superconductor



Type-② superconductor



After H_{c_1} it starts allowing magnetic flux lines through it so it is non-linear.

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(a) The copper crystal has FCC unit cell configuration. If radius of Cu atom is 0.148 nm and atomic mass of Cu is 63.5 gm mol^{-1} then calculate atomic packing fraction (APF), the atomic concentration in a unit cell and density of Cu atom in gcm^{-3}.
(Take Avogadro number : 6.023×10^{23} mol^{-1})

[20 marks]

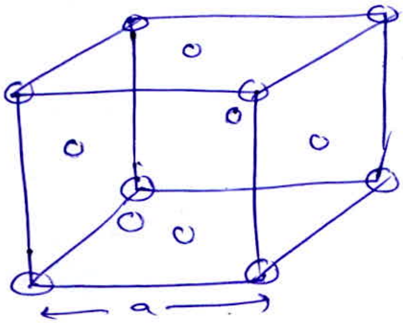
→ copper with FCC crystal

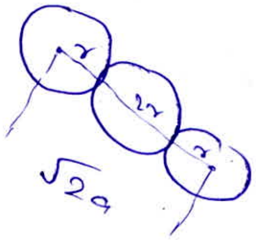
$r_{cu} = 0.148$ nm

$(Aw)_{cu} = 63.5$ gm / mole

APF = ?   Atomic concentrn in cell, density.

diagonal Face structure





From the figure   a = lattice parameter

$\sqrt{2}a = 4r$

$r = \frac{\sqrt{2}}{4}a$ $\boxed{a = \frac{4r}{\sqrt{2}}}$

Atomic concentration in unit cell

8 atoms at 8 corners → shared by 8 cell

6 atoms at Face centre → shared by 2 cell

$\frac{\text{no. of atoms}}{\text{cell}} = 8 \times \frac{1}{8} + 6 \times \frac{1}{2}$

$\boxed{n = 4 \text{ atoms / cell}}$

5

no. of atoms / m³

$= \frac{\text{no. of atoms in cell}}{\text{Volm of unit cell}}$

$= \frac{4}{a^3}$

no. of atoms / m³ $= \frac{4}{(4r/\sqrt{2})^3} = 5.48 \times 10^{28}$ atoms / m³

Do no write this m

$$APF = \frac{\text{volume occupied by atoms}}{\text{volm of unit cell}}$$

$$= \frac{4 \times \frac{4}{3} \pi r^3}{a^3}$$

$$= \frac{4 \times \frac{4}{3} \times \pi (0.148 \times 10^{-9})^3}{(4 \times 0.148 \times 10^{-9} / \sqrt{2})^3}$$

$$\boxed{APF = 0.740}$$

theorotical density

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{\text{no. of atoms in cell} \times \text{Atomic wt}}{\text{Avogadro Number} \times \text{volm of cell}}$$

$$= \frac{4 \times 63.5}{6.023 \times 10^{23} \times \left(\frac{4 \times 0.148 \times 10^{-7}}{\sqrt{2}}\right)^3}$$

$$\boxed{\text{density} = 5.749 \text{ gm/cm}^3}$$

Good

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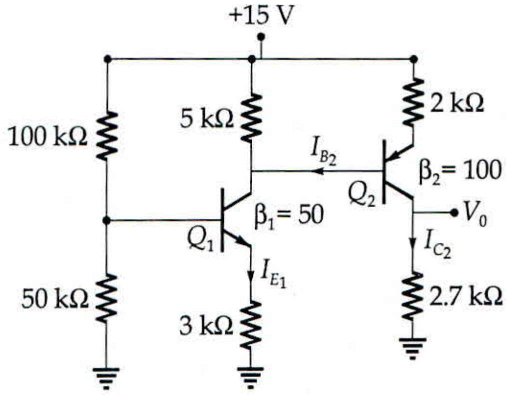
2 (b) In the below configuration, calculate the values of $I_{B_2}, I_{C_2}, I_{E_1}$ and V_0.

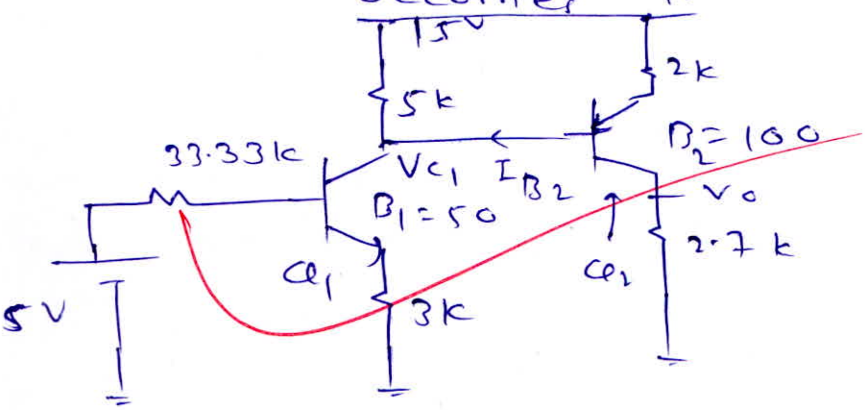


[20 marks]

Applying thevenins at the base terminal of Q_1, we get

$$V_{th} = \left(\frac{50k}{50k+100k}\right) \times 15 = 5$$

$R_{th} = 50k \,||\, 100k = 33.33k$ the circuit becomes



Assuming transistor in Active region

$$I_C = \beta I_B$$

KVL in B-E loop Q_1,

$$5 = 33.33k(I_B) + (1+\beta)3k\,I_B + 0.7$$

$$I_B = \frac{5-0.7}{33.33k + (1+50)\,3k}$$

$$I_{B_1} = 0.0230 \text{ mA}$$

$$I_{C_1} = \beta I_B = 50 \times 0.0230 = 1.15 \text{ mA}$$

$$V_{C_1} = 15 - 5k(1.15\text{ mA}) = 9.230 \text{ V}.$$

$$I_{E_1} = (1+\beta)I_B = 51 \times 0.0230 = 1.173 \text{ mA}$$

$$\boxed{I_{E_1} = 1.173\ mA}$$

now KVL in E-B loop of Q_2

$V_{C_1} = V_{B_2}$

$$15 - (1+B_2)\underset{(2k)}{I_{B_2}} - 0.7 - V_{B_2} = 0$$

$$I_{B_2} = \frac{15 - 0.7 - 9.230}{(1+100)2k}$$

$$\boxed{I_{B_2} = 0.0250\ mA}$$

Assuming Q_2 in Active region

$I_{C_2} = B_2 I_{B_2} = 100 \times 0.0250$

$$\boxed{I_{C_2} = 2.509\ mA}$$

$V_0 = I_{C_2} \times 2.7\,k\Omega$

$= 2.509m \times 2.7\,k$

$$\boxed{V_0 = 6.776\ V}$$

For confirming Q_2 in Active

$V_{E2} = V_{B2} + 0.7 = 9.230 + 0.7 = 9.93$

$V_{C2} = 6.776$

$V_{EC_2} = 9.93 - 6.776 = 3.154\ V$

$V_{EC_2} = 3.154\ V > 0.2$

it is in active region only

$$\boxed{V_0 = 6.776\ V}$$

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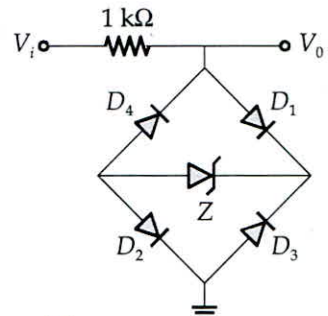
2 (c) Sketch the transfer characteristics of the circuit given below for $-20\text{ V} \le V_i \le 20\text{ V}$. Assume that diodes can be represented by a piece-wise linear model with $V_{D0} = 0.65$ V and $r_D = 20\ \Omega$. Assuming that the specified zener voltage at a current of 10 mA is 8.2 V and $r_Z = 20\ \Omega$. Represent the Zener by a piece-wise linear model.



[20 marks]

$V_Z = 8.2\,V$

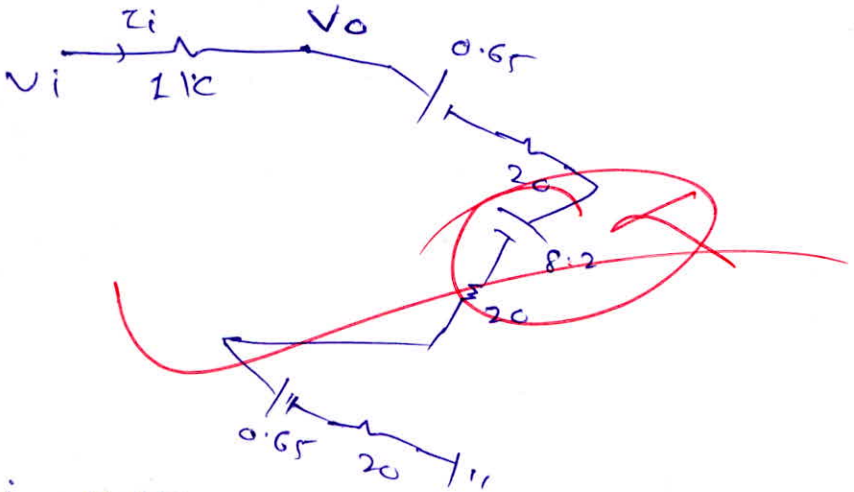
$V_d = 0.65\,V$

Case-①,

when $V_i > 0.65 + 8.2 + 0.65$ $V_i > 9.\cancel{80}5\,V$

diode D_1, Zener & d_2 on

ckt becomes



$$I_i = \frac{V_i - 9.5}{1060\,\Omega} = \frac{V_i - 9.5}{1.060\,k}$$

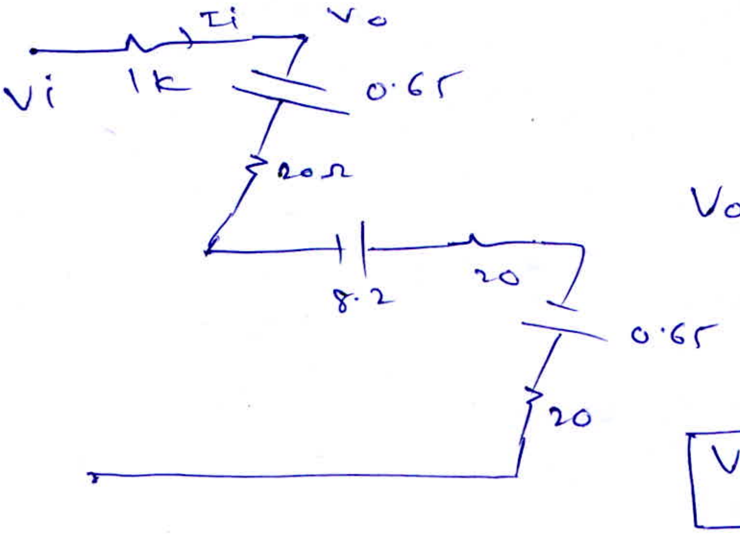
$$V_o = V_i - (1k)\,I_i$$

$$= V_i - \frac{(1\cancel{k})(V_i - 9.5)}{(1.060\cancel{k})}$$

$$= 0.056\,V_i + \frac{9.5}{1.060}$$

$$\boxed{V_o = 0.056\,V_i + \overset{\cancel{8.773}}{8.962}} \quad -①$$

when $V_i < -\cancel{9.80}$ -9.5, Diode D_3, Zener & D_4 becomes on so circuit is



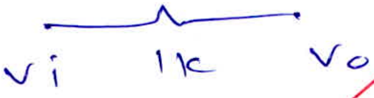
$$I_i = \frac{V_i + 9.5}{(1.060k)}$$

$$V_o = V_i - I_i (1k)$$

$$= V_i - 1\cancel{k}\frac{(V_i+9.5)}{1.060\cancel{k}}$$

$$\boxed{V_o = 0.056V_i - 8.962V} \quad — ②$$

when $-9.5 < V_i < 9.5$, diodes and zener is OFF, the circuit becomes



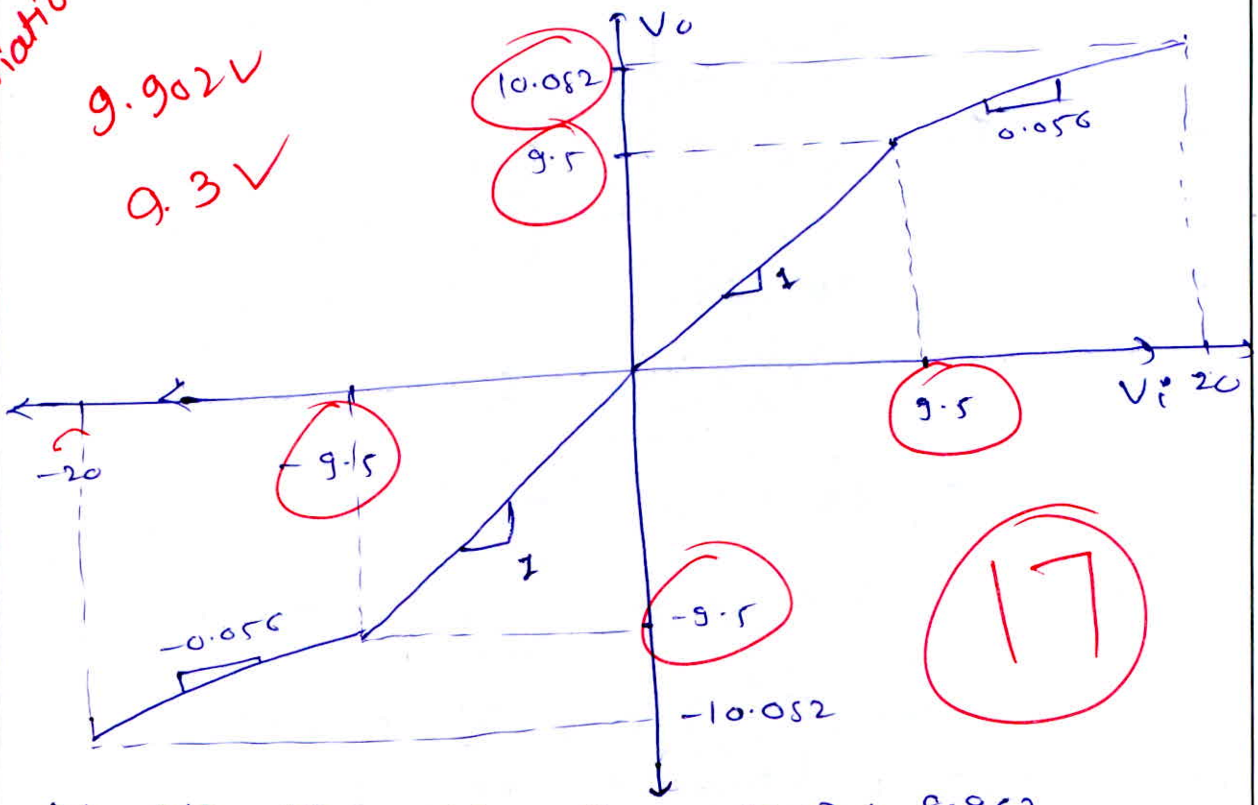
$$\boxed{V_o = V_i} \quad — ③$$

From ①, ② & ③ combining all the regions the graph for Vo Vs Vi is

little deviation

9.902V ✓

9.3V ✓



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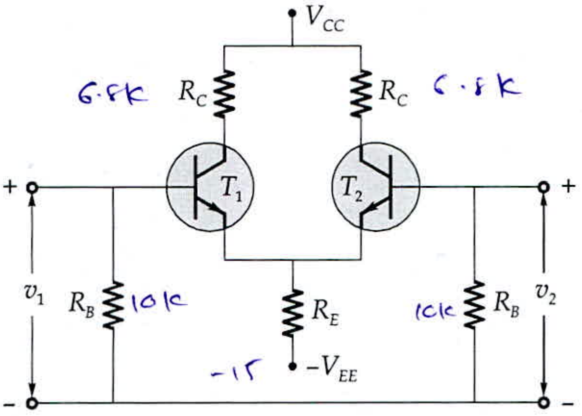
At $V_i = +20$, $V_o = 0.056(20) + 8.962$

3 (a) **(i)** The BJT in the differential amplifier circuit shown below have negligible leakage current and $\beta_1 = \beta_2 = 60$. Also $R_C = 6.8\ \text{k}\Omega$, $R_B = 10\ \text{k}\Omega$ and $V_{CC} = V_{EE} = 15$ V. Find the value of R_E needed to bias the amplifier such that $V_{CEQ_1} = V_{CEQ_2} = 8$ V.



[10 marks]

as all the parameters of transistors

$\beta_1 = B_2$, $R_{C1} = R_{C2} = R_C$, are equal

$I_{E1} = I_{E2} = I_E$

Also, $V_{CEQ_1} = V_{CEQ_2} = 8$ V

Apply KVL in CE loop

$$V_{CC} - I_C(6.8k) - V_{CEQ_1} - 2 I_E R_E + 15 = 0$$

$$I_C = \beta I_B \quad , \quad I_E = (1+B) I_B$$

$$V_{CC} - 60 I_B (6.8k) - 8 - 2(1+60) R_E I_D + 15 = 0$$

$$I_B = \frac{30-8}{60 \times 6.8k + 122 R_E} \quad -①$$

$$I_B = \frac{20}{408k + 122 R_E} \quad -②$$

KVL in B-E loop

$$-I_B(10k) - 0.7 - 2(1+B) I_B R_E + 15 = 0$$

$$I_B(10k + 61 R_E) = 15 - 0.7$$

$$I_B = \frac{14.3}{10k + \overset{122}{\cancel{61}} R_E} \quad -③$$

3

Equating ② & ③

$$\frac{20}{408k + 122R_E} = \frac{14.3}{10k + 122R_E}$$

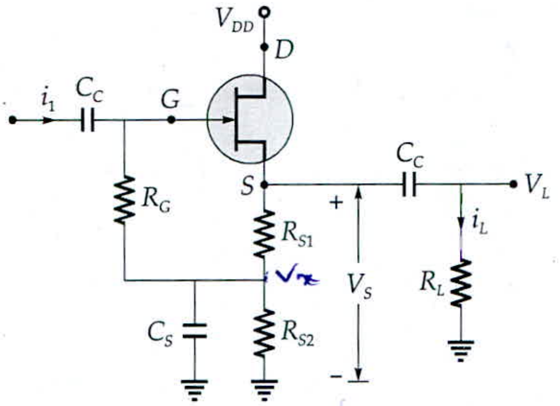
$$20(10k + 122R_E) = 14.3(408k + 122R_E)$$

$$200k + 2440R_E = 5834.4k + 1744.6R_E$$

$$(2440 - 1744.6)R_E = 5834.4 - 200$$

$$\boxed{R_E = 8.10\ k\Omega}$$

Q.3 (a) **(ii)** In the circuit shown below $R_G >> R_{S1}, R_{S2}$. The JFET is described by $I_{DSS} = 10$ mA, $V_P = 4$ V, $V_{DD} = 15$ V, $V_{DSQ} = 10$ V and $V_{GSQ} = -2$ V. Find the value of R_{S1} and R_{S2} to set amplifier at above Q-point and also find the value of V_S.



[10 marks]

Given JFET is N-channel JFET

$(V_{GS})_{OFF} = -4V.$, $i_G = 0$

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_{GS(OFF)}}\right]^2 \quad \text{—①}$$

$V_{DD} = 15V$, $V_{DSQ} = 10$

i.e $V_S = 15 - 10 = 5V$

$$\boxed{V_S = 5V}$$

$$I_D = 10mA\left[1 - \frac{(-2)}{(-4)}\right]^2$$

$$\boxed{I_D = 2.5\ mA}$$

$V_{GS} = -2$

$V_G = V_S + V_{GS}$

$= 5 - 2$

$V_G = 3V$

$V_x = 5 - I_D(R_{S1})$

as $R_G >> R_{S1}$ & R_{S2}

c/n through R_G can be neglected

$I_D(R_{S1} + R_{S2}) = V_S$

$2.5m(R_{S1} + R_{S2}) = 5$

$\boxed{R_{S1} + R_{S2} = 2k}$

so, $V_x = V_G$

$V_x = 3V.$

$3 = 5 - I_D(R_{S1.})$

$I_D R_{S1} = 2$

$\boxed{R_{S1} = 0.8k}$

$R_{S2} = 2k - 0.8k$

$\boxed{R_{S2} = 1.2k}$

so, $R_{S1} = 0.8k$, $R_{S2} = 1.2k.$

$\boxed{V_S = 5V}$

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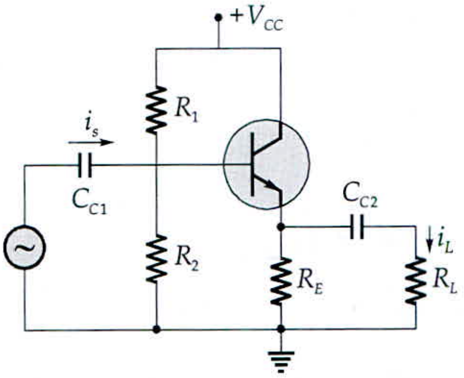
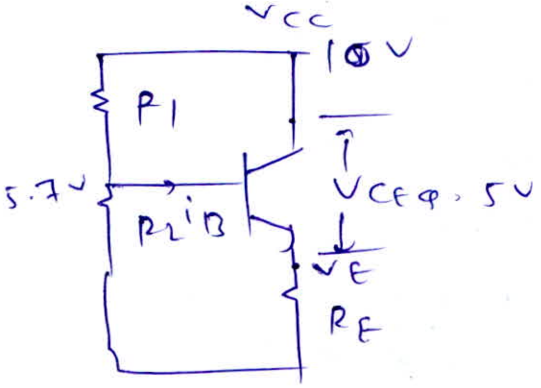
Q.3 (b) Consider the amplifier circuit shown below:



The parameters of BJT and the circuit are, $\beta = 80$, $V_{CC} = 10$ V, $V_{CEQ} = 5$ V, $V_{BE\,(on)} = 0.7$ V and $R_E = R_L = 500\ \Omega$. Design the values of R_1 and R_2 such that the mid-band current gain $A_i = \frac{i_L}{i_S} = 8$. Assume that $V_T = 26$ mV.

[20 marks]

From DC analysis,



$VE = 10 - 5 = 5V$

$IE = \frac{5}{RE} = \frac{5}{500\Omega} = 0.01A = 10mA$

$IB = \frac{IE}{1+\beta} = \frac{10mA}{81} = 0.123\ mA$

$Ic = \beta IB = 9.87\ mA$

$gm = \frac{Ic}{VT} = \frac{9.87}{26} = 0.379$

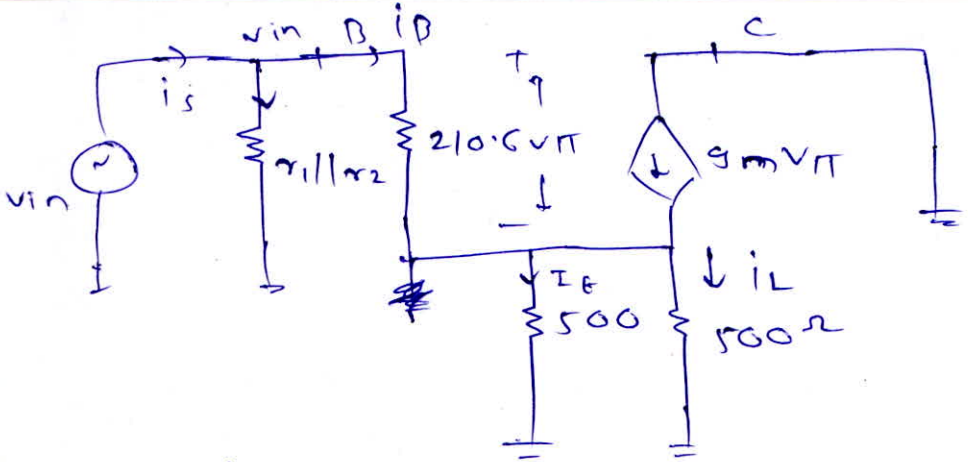
For AC equivalent model, r_π-model

All dc sources short,

All capacitors acts as short.

midband gain $\frac{iL}{is} = 8$

$r_\pi = \frac{\beta}{gm} = \frac{80}{0.379} = 210.6\ \Omega$



as $\frac{i_L}{i_s} = 8$ $\qquad i_L = 8 i_s$ — ①

$I_E = 8 I_s$ — ②

$g_m V_\pi = \beta I_\beta$

Assume $i_s = 1$ Amp

$i_L = i_E = 8 I_s = 8$ Amp

KCL at emmitter terminal,

$i_\beta + \beta i_\beta = 8 + 8$

$(1+\beta) i_\beta = 16$

$i_\beta = \frac{16}{81}$ $\qquad \boxed{i_\beta = 0.197 \text{ A}}$

From ~~current~~ vts division at,

Base terminal,

$I_{Req} = I_s - I_\beta$

$= 1 - 0.197 = 0.802$ Amp.

$V_{in} = 500(8) + (210.6)(0.197)$

$= 4041.48$ V

$I_{Req} = \frac{V}{R_{eq}} = \frac{4041.48}{R_{eq}} = 0.802$

$R_{eq} = 5.039$ k

$R_1 || R_2 = 5.039$ k

$$\frac{r_1 r_2}{r_1+r_2} = 5.039\,k$$

From DC ckt,

$$V_B = V_{BE} + V_E = \underline{5.7}\,V.$$

$$\frac{10-5.7}{R_1} - \frac{5.7}{R_2} = 0.123\,mA$$

$$\frac{4.3}{R_1} - \frac{5.7}{R_2} = 0.123\times10^{-3} \quad -①$$

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{5.039\times10^{3}} \quad -②$$

solving these ② eqns,

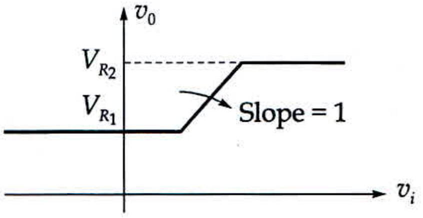
$$\frac{1}{R_1} = 1.254\times10^{-4} \qquad \frac{1}{R_2} = 7.303\times10^{-5}$$

$$\boxed{R_1 = 7.974\,k\Omega} \qquad \boxed{R_2 = 13.693\,k\Omega}$$

Good

19

3 (c) (i) Design a clipper circuit for the characteristics curve given below:



[10 marks]

Q.3 (c) **(ii)** Define the 'mobility' of electrons in conductive materials and derive relation showing components of random velocity and average drift velocity to deduce expression for electron mobility.

(iii) If a conductor material has following data as shown below:

Density : 9.40 gram/cc
Resistivity : 1.72×10^{-8} ohm-m
Atomic weight : 63.5

Compute the mobility and the average time of collision of electrons in the conductors if valance electron for each conductor material atom is 1.

[10 marks]

→ii) mobility -

mobility is defined as the ability of the electrons to flow through the conducting medium.

It express how the electrons drifts in the applied electric field

$$\boxed{V_d = \mu E}$$

when e- flows through medium,

$V_{drift} = accel^n \times time$

force experience on it = eE

$$eE = ma$$

$$a = \frac{eE}{m}$$

$$V_{drift} = \frac{eE}{m} t$$

$$V_{drift} = \frac{et}{m} E$$ as $V_d = \mu E$

$$V_{drift} = \mu E.$$

$$\boxed{\mu = \frac{eT}{m}}$$

iii) density = TD = 9.40 gm/cc

$\rho = 1.72\times10^{-8}$ ohm/m

$A_w = 63.5$

no. of atoms = no. of valence e^-

$$\text{no. of atoms}/cm^3 = \frac{TD \times A_v}{A_w}$$

$$= \frac{9.40\times 6.023\times10^{23}}{63.5}$$

$$n = 8.915\times10^{22}\ e^-/cm^3$$

$$\rho = 1.72\times10^{-6}\ \Omega\,cm$$

$$\rho = \frac{1}{ne\mu}$$

$$\mu = \frac{1}{ne\rho} = \frac{1}{8.915\times10^{22}\times1.602\times10^{-19}\times1.72\times10^{-6}}$$

$$\boxed{\mu = 40.72\ cm^2/V\text{-}sec}$$

arg. time of collision,

$$\mu = \frac{e\tau}{m}$$

$$\tau = \frac{\mu m}{e}$$

$$= \frac{40.72\times10^{-4}\ \frac{m^2}{V\text{-}sec}\times 9.1\times10^{-31}}{(1.602\times10^{-19})}$$

$$\boxed{\tau = 2.311\times10^{-14}\ sec}$$

10

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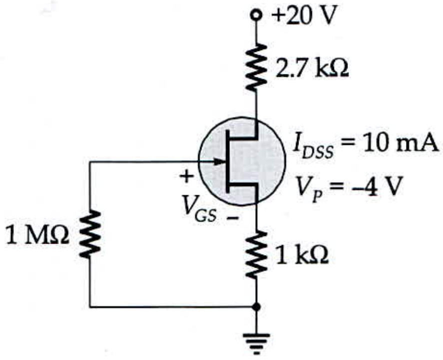
Q.4 (a) **(i)** Consider a diode with mean lifetime of holes to be 10 nsec and $\eta = 1$. If a forward current of 0.1 mA is flowing in diode then determine the diffusion capacitance. (Assume room temperature to be 300 K).

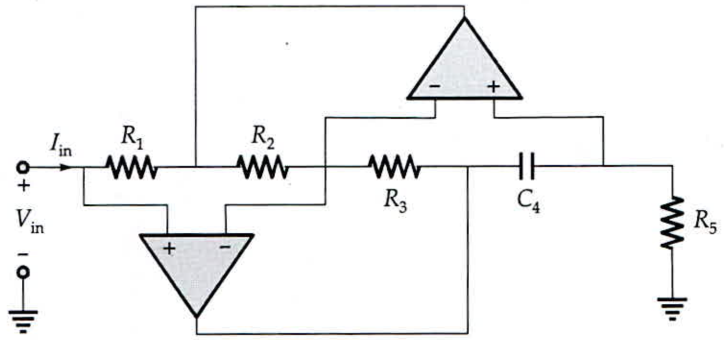
[5 marks]

.4 (a) **(ii)** Determine V_{GSQ}, I_{DQ} and V_{DS} for the self bias circuit shown in figure below.



[15 marks]

.4 (b) Consider the circuit with ideal op-amps, shown in the figure below:



Calculate the input impedance $Z_{in}(s) = \dfrac{V_{in}(s)}{I_{in}(s)}$ and comment on the result obtained.

[20 marks]

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.4 (c) Explain briefly the polarization occurring in dielectric materials. What are different types of polarization occurring in dielectric material?

If a dielectric material contains 3.2×10^{19} polar molecules/m^3 and the relative permittivity of material is $\in_r = 2.4$ with applied external electric field $\vec{E} = 10^4 \overrightarrow{a_x}$ V/m, then calculate the value of polarization and dipole moment in each molecule. (Consider all molecules have same dipole moment).

[20 marks]

Section B : Electrical Machines-1 + Power Systems-2

.5 (a) Draw the reactance diagram of the system whose bus admittance matrix is given below. First, second, third and fourth rows refer to buses 1, 2, 3 and 4 respectively.

$$Y_{bus} = j\begin{bmatrix} -3.78 & 1.25 & 2.5 & 0 \\ 1.25 & -3.42 & 1.11 & 1.0 \\ 2.5 & 1.11 & -4.89 & 1.25 \\ 0 & 1.0 & 1.25 & -2.31 \end{bmatrix}$$

[12 marks]

From Y_{bus}.

Shunt admittance at bus - ① $= Y_{11} + Y_{12} + Y_{13}$

$= -j0.03$

at bus -② $= Y_{22} + Y_{21} + Y_{23} + Y_{24}$

$-j0.06$

at bus -③ $= -j0.03$

at bus -④ $= -j0.06$

as all shunt admittances are negative there is inducter at bus.

$y_{12} = -Y_{12} = -j1.25 \Rightarrow$ $z_{12} = \frac{1}{-j1.25} = j0.8$

$y_{13} = -Y_{13} = -j2.5$ $z_{13} = \frac{1}{-j2.5} = j0.4$

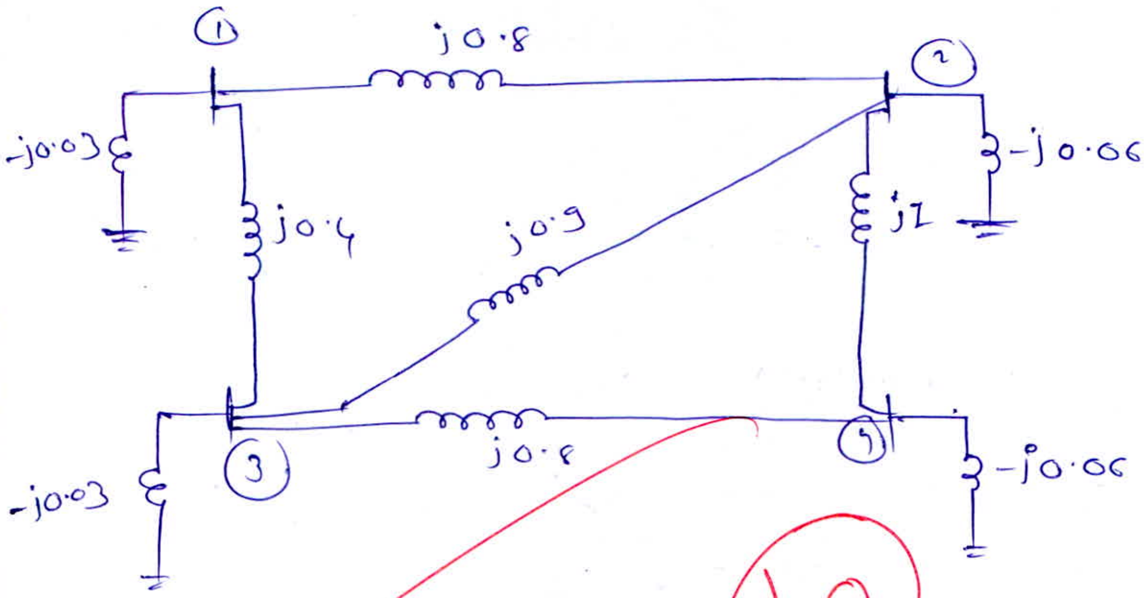
$y_{14} = -Y_{14} = 0$

$y_{23} = -Y_{23} = -j1.11 =$ $z_{23} = \frac{1}{-j1.11} = j0.9$

$y_{34} = -Y_{34} = -j1.25$ $z_{34} = \frac{1}{-j1.25} = j0.8$

$y_{24} = -Y_{24} = -j1$ $z_{24} = j1$

representing all the Tr. lines and shunt admittances the network diagram is



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Q.5 (b) A voltage of (200 sinωt – 50 sin 3ωt), 50 Hz is applied to a 250 turn transformer winding having negligible resistance and leakage reactance. Deduce an expression for flux and find its maximum value. By what percentage will eddy current loss in the iron core be reduced if the applied voltage is altered to 200 sin ωt?

[12 marks]

$$V = N\frac{d\phi}{dt} \quad \text{— Faraday's law}$$

$$\int d\phi = \frac{1}{N}\int V\cdot dt$$

$$\phi = \frac{1}{N}\int V\cdot dt$$

$$= \frac{1}{N}\int 200\sin\omega t - 50\sin 3\omega t \cdot dt$$

$$= \frac{1}{250}\left\{\frac{200[-\cos\omega t]}{\omega} + \frac{50\cos 3\omega t}{3\omega}\right]$$

$$\phi = \frac{1}{250\times 100\pi}\left[-200\cos\omega t + \frac{50}{3}\cos 3\omega t\right]$$

— — $\omega = 100\pi$

$$\phi = 1.273\times 10^{-5}\left[-200\cos\omega t + 16.66\cos 3\omega t\right]$$

Flux will be peak at $\omega t =$ [illegible]

i.e at $\frac{d\phi}{dt} = 0$ i.e $V = 0$

$$200 \sin\omega t = 50 \sin 3\omega t$$

$$\sin\omega t = \frac{1}{4} \sin 3\omega t$$

$$\omega t = \pi$$

$$(\phi)_{peak} = 1.273 \times 10^{-5} \left[-200 \times (-1) + 16.66 \cos 3\pi\right]$$

$$= 1.273 \times 10^{-5} \left[200 - 16.66\right]$$

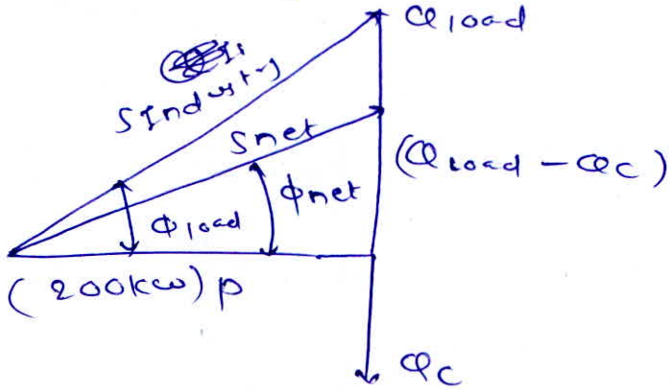
$$\boxed{\phi_{peak} = 2.333 \text{ mwb}}$$

⑥

Q.5 (c) An industry load of 200 kW at 0.75 p.f. lagging is fed from the 3-ϕ, 11 kV distribution feeders. It is required to maintain the 0.9 p.f. lag at the drawl point. Find the rating of capacitor installed at industrial drawl point.

[12 marks]

From phasor diagram



$Q_{capacitor} = -(Q_{net} - Q_{load})$

$Q = P \tan \phi,$

$Q_{net} = P \tan \phi_{net}$

$= 200kW \tan[\cos^{-1}[0.9)]$

$Q_{net} = 96.86$ KVAR

$Q_{load} = P \tan \phi_{load}$

$= 200 \tan[\cos^{-1}(0.75)]$

$= 176.38$ KVAR

$Q_{cap} = 176.38$ KVAR $- 96.86$

$$\boxed{Q_{cap} = 79.52 \text{ KVAR}}$$

11

Good

Assuming Δ-connected bank

$Q_{cap} = 3V_{ph}^2 \times 2\pi f C_{ph}$

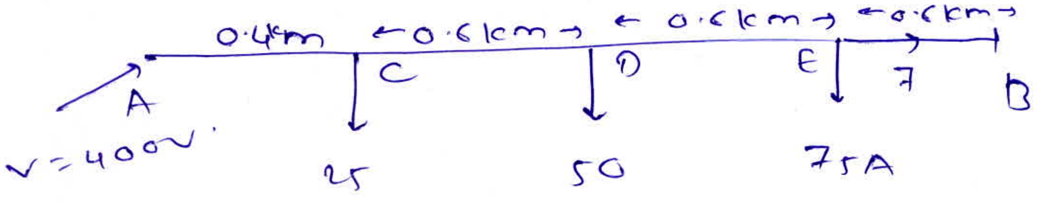
$$C_{ph} = \frac{79.52 \times 10^3}{3 \times (11 \times 10^3)^2 \times 100\pi}$$

$$\boxed{C_{ph} = 0.697 \text{ nF}}$$

(d) A 2-wire DC distributor cable *AB* is 2.2 km long and supplies loads of 25 A, 50 A, 75 A at 0.4 km, 1 km and 1.6 km from the point *A*. Each conductor has a resistance of 0.05 Ω/km. Calculate the potential difference at each point if potential difference of 400 volts is maintained at point *A*.

[12 marks]

Given data-



resistance of conducter = 0.05 Ω/km

Loop resistance = $0.05 \times 2 = 0.1\ \Omega/km$

$V_C = V_A - I_{AC}(0.4)(0.1)$

$= 400 - (25+50+75)(0.04)$

$= 400 - 150 \times 0.04$

$\boxed{V_C = 394\ V}$

$V_D = V_C - I_{CD}(0.6)(0.1)\ \Omega/km$

$= 394 - (50+75)(0.06)$ ~~km~~

$\boxed{V_D = 386.5\ V}$

potentialDifference at E

$V_E = V_D - I_{DE}(\underset{km}{0.6})(0.1)\ \Omega/km$

$= 386.5 - 75(0.06)$

$\boxed{V_E = 382\ V}$

Assuming no current in EB section

$\boxed{V_B = V_E = 382\ V}$

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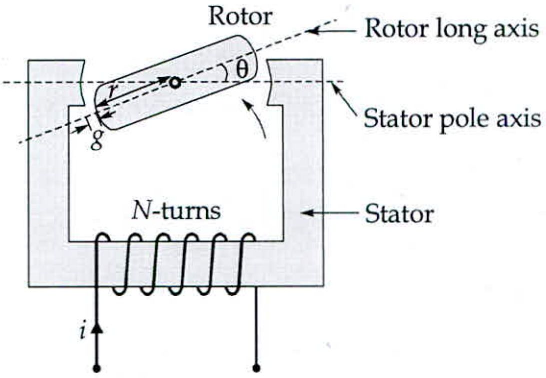
Q.5 (e) For the electro-mechanical configuration shown in figure, assume all the field energy is present in the overlapping regions. Radius is r and the airgap length is g. Calculate the magnitude of torque, when the maximum flux density in the airgap is limited to 2.2 T. The other data are as follows:

Radius, r = 50 mm,
Gap length, g = 2 mm,
Length normal to radius is l = 10 mm.



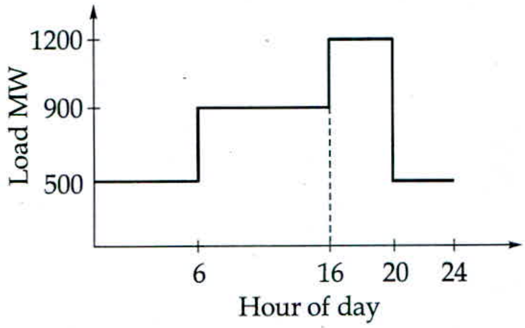
[12 marks]

Q.6 (a) The fuel cost characteristics of two thermal plants are as under,

$C_1 = 7700 + 52.8P_1 + 5.5 \times 10^{-3} P_1^2$ Rs/hour

$C_2 = 2500 + 15P_2 + 0.05 P_2^2$ Rs/hour

The limit of generation for the two units are $200 \le P \le 800$ MW. The load curve is shown in figure below. Find the daily operating schedule to minimize the operating costs. The cost of taking a unit off and then putting it on is Rs 1000.00.



[20 marks]

$C_1 = 7700 + 52.8 P_1 + 5.5 \times 10^{-3} P_1^2$

$IC_1 = \frac{dC_1}{\partial P_1} = 52.8 + 0.011 P_1$ — ①

$C_2 = 2500 + 15P_2 + 0.05 P_2^2$

$IC_2 = \frac{\partial C_2}{\partial P_2} = 15 + 0.1 P_2$ — ②

now for optimum generation

$IC_1 = IC_2$

$52.8 + 0.011 P_1 = 15 + 0.1 P_2$

$0.011 P_1 - 0.1 P_2 = 15 - 52.8$

$0.011 P_1 - 0.1 P_2 = -37.8$ — ①

For 0 to 6 hrs,

$P_1 + P_2 = 500$ — ②

solving ① & ②

$P_1 = 109.90$ $P_2 = 390.09$

as $P_1 = 109.90 < 200$

$\boxed{P_1 = 200}$ $\boxed{P_2 = 300 \text{ mw}}$ — ⓐ

For 6 to 16 hrs

$P_1 + P_2 = 900$ — ③

Solving ① & ③

$\boxed{P_1 = 470.27 \text{ mw}}$ $\boxed{P_2 = 429.72 \text{ mw}}$ — ⑥

when during 16 to 20 hrs,

$P_1 + P_2 = 1200$ —— ④

solving ① & ④

$\boxed{P_1 = 740.54 \text{mw}}$ $\boxed{P_2 = 459.45 \text{ mw}}$

For 20 to 24 hrs.

$P_1 + P_2 = 500$ —— ⑤

Solving ① & ⑤,

$P_1 = 109.90$ $P_2 = 390.09$.

$P_1 \leq 109.90$ it will be off as

$P_1 < 200$ mw

$\boxed{P_2 = 500 \text{mw}}$

time	operating P_1 (mw)	schedule P_2 (mw)
0 to 6 hrs	0	500
6 to 16 hrs	470.27 mw	429.72
16 to 20	740.54	459.45
20 to 24	0	500

500MW load is decided based upon costing

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Q.6 (b) **(i)** The incremental fuel costs for two units of a plant are $\lambda_1 = \frac{df_1}{dP_{g1}} = 0.012P_{g1} + 8.0$; $\lambda_2 = \frac{df_2}{dP_{g2}} = 0.008\,P_{g2} + 9.6$ where f is in (Rs/hour) and P_g is in megawatts (MW). If both units operate at all times and maximum and minimum loads on each unit are 550 and 100 MW respectively then find λ of the plant in Rs/MWh versus plant output in MW for economic dispatch as total load varies from 200 to 1100 MW.

(ii) Find the saving in Rs/hour for economic dispatch of load between the units of part (i) compared with their sharing the output equally when the total plant output is 600 MW.

[20 marks]

$\lambda_1 = 0.012\,P_1 + 8$

$\lambda_2 = 0.008\,P_2 + 9.6$

$100 < P_1, P_2 < 550$

when total load is 200 $\underline{\underline{mw}}$

$(P_D)_{min} = (P_1)_{min} + (P_2)_{min}$

$200 = P_{1min} + P_{2min}$

$P_1 = 100$ mw $\quad P_2 = 100$ mw

min load such that $I_{c_1} = I_{c_2}$

$(I_c)_1\, min = 0.012\,P_1 + 8$

$= 9.2$

$(I_c)_2\, min = 0.008\,P_2 + 9.6$

$= 10.4$

(I_c) is maxm of (I_c) min

$(I_c) = 10.4$ — for $P_D min = I_{c_1} = I_{c_2}$

~~$P_1 = 0.012(10.4) + 8 = 8.1248$ mw~~

maxm load such that $I_{c_1} = I_{c_2}$

$(I_c)max = 0.012\,P_1 + 8$

$= 0.012(550) + 8$

$(I_{c1})_{max} = 14.6$

$(I_{c_2})_{max} = 0.008 P_2 + 9.6$

$(I_{c_2})_{max} = 14$

$[I_c] \rightarrow$ for PDmax for $I_{c_1} = I_{c_2}$ is minimum of (I_c) max

$(I_c)_{max} = 14$

For maxm PD,

$I_c = 14$

$14 = 0.012 P_1 + 8$ $\quad$ $14 = 0.008 P_1 + 9.6$

$\boxed{P_1 = 500}$ $\quad$ $\boxed{P_2 = 550}$

$PD = 500 + 550 = 1050$ mw.

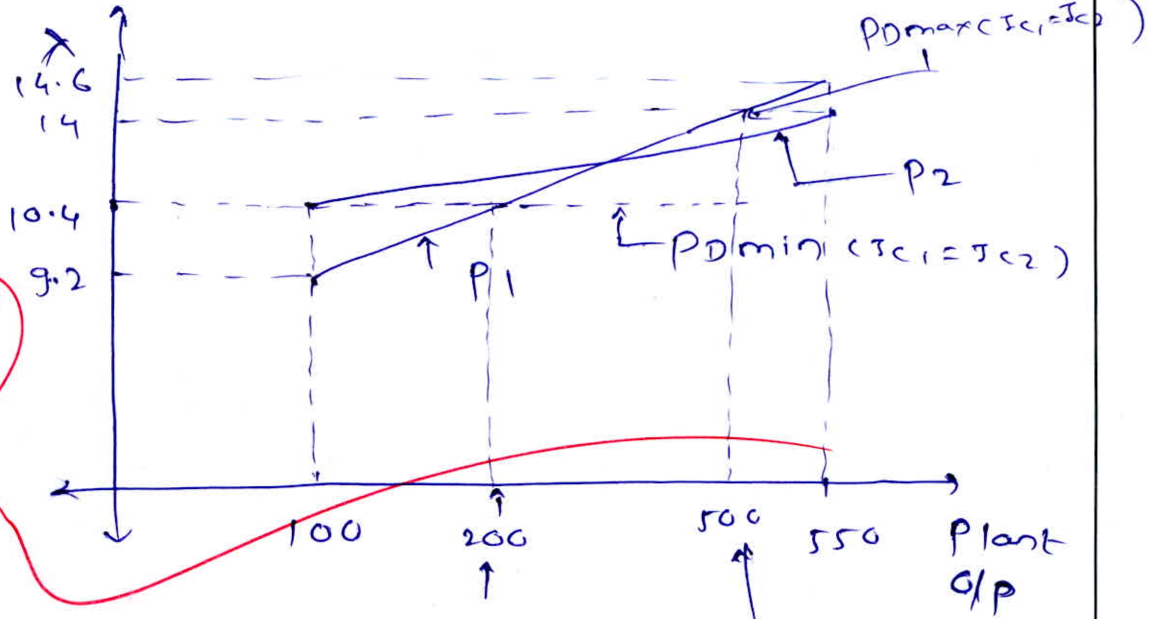
For min PD,

$I_c = 10.4$ $\quad$ $I_c = 10.4$

$10.4 = 0.012 P_1 + 8$ $\quad$ $10.4 = 0.008 P_2 + 9.6$

$P_1 = 200$ mw $\quad$ $\boxed{P_1 = 100 \text{ mw}}$

$\boxed{PD = P_1 + P_2 = 300 \text{ mw}}$



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$PD = P_1 + P_2$

$= 100 + 200$

$PD = 300$

$PD = 500 + 550$

$\boxed{PD = 1050}$

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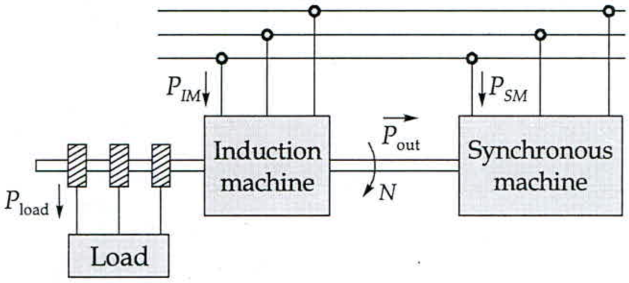
(c) A 3-ϕ wound-rotor induction machine is mechanically coupled to a 3-ϕ synchronous machine as shown in figure. The synchronous machine has 4-poles and the induction machine has 6-poles. The stator of the two machines are connected to a 3-ϕ, 50 Hz supply. The rotor of the induction machine is connected to a 3-ϕ resistive load. Neglect rotational losses and stator resistance losses. The load power is 1 p.u. The synchronous machine rotates at the synchronous speed.

(i) The rotor rotates in the direction of the stator rotating field of the induction machine. Determine the speed, frequency of the current in the resistive load, and power taken by the synchronous machine and by the induction machine from the source.

(ii) Repeat part (i) if the phase sequence of the stator of the induction machine is reversed.



[20 marks]

PIm = 4 poles   Psynchr = 6 poles

$N_s = \frac{120f}{p} = \frac{120 \times 50}{1000}$

N_s $\boxed{N_s = 1000 \text{ rpm}}$

As speed of SM is fixed, rotor will rotate at 1000 rpm.

(i) rotor rotates in dirn of field

PIm = 4 poles $(N_s)_{Im} = \frac{120 \times 50}{4}$

$\boxed{N_{s\,Im} = 1500 \text{ rpm}}$

Pload = 1 pu

From power eqns of Im.

Pload = S pag

$S = \frac{N_s - N_r}{N_s} = \frac{1500 - 1000}{1500} = \frac{1}{3}$

$1 = \frac{1}{3} P_{ag}$

$\boxed{P_{ag} = 3 \text{ pu}}$

frequency of ckt = SF = $\frac{1}{3}\times 50$ = 16.66 Hz

$\boxed{P_{IM} = 3\,pu}$

$P_{IM} = P_{ag} = 3\,pu$

$P_{ag} = P_{mech} + P_{load}$

$P_{mech} = 3 - 1 = 2$ pu.

$P_{synchr} = 2\,pu$

$\boxed{\text{power taken by sm} = +2\,pu}$

Case-② when ~~rotor~~ stator of IM phase sequence changes,

$$slip = \frac{N_s + N_r}{N_s} = \frac{1500+1000}{1500} = 5/3$$

$P_{load} = S\,P_{ag}$

$1 = \frac{5}{3} P_{ag}$

$P_{ag} = 3/5$ pu

$P_{ag} = P_{mech} + P_{load}$

$\frac{3}{5} = P_{mech} + 1$

$\boxed{P_{mech} = -\frac{2}{5}}$

②

So, $P_{mech} = -2/5$

$\boxed{\text{power Ind}^n\ m/c = 3/5\ pu}$

power taken by sm

$\boxed{P_{sm} = \frac{2}{5}\,pu}$

(a) The primary, secondary and tertiary winding of a three-winding transformer are rated as 11 kV, 6 MVA, star/3.3 kV, 3 MVA, star/400 V, 3 MVA, delta respectively. The short circuit tests on this transformer gave the following results:

Secondary shorted ; primary excited : 500 V, 100 A
Tertiary shorted ; primary excited : 600 V, 100 A and
Tertiary shorted ; secondary excited : 100 V, 200 A

(i) Find the per unit leakage reactances of the star equivalent circuit. Neglect resistance.

(ii) The primary is energized at rated voltage and the secondary is open circuited. For a three-phase balanced short circuit at the tertiary terminals, calculate the short circuit current and the secondary terminal voltage.

[20 marks]

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(b) A 4-pole, 50-Hz turbo-alternator is rated at 45 MW, 0.8 pf lag and has an inertia of 25000 kg-m^2. It is connected via a transmission system to another set whose corresponding data is 2-pole, 50 Hz, 60 MW, 0.75 lag, 9000 kg-m^2. Calculate the inertia constant of each set on its own rating and that of the single equivalent set connected to an infinite bus-bar and on a base rating of 100 MVA.

[20 marks]

Q.7 (c) The following test results are obtained for a 3-ϕ, 280 V, 60 Hz, 6.5 A induction machine.

Block-rotor test : 44 V, 60 Hz, 25 A, 1250 W

No load test : 208 V, 60 Hz, 6.5 A, 500 W

The average resistance measured between two stator terminals is 0.27 Ω.

Determine:

(i) the no load rotational loss.

(ii) the output power in horse power (hp) at $s = 0.1$.

(iii) the efficiency.

(Take 1 hp = 746 W) **[20 marks]**

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(a) Figure below shows the single line diagram of a sample 3-bus power system. Data for this system are given in table-1 and table-2.

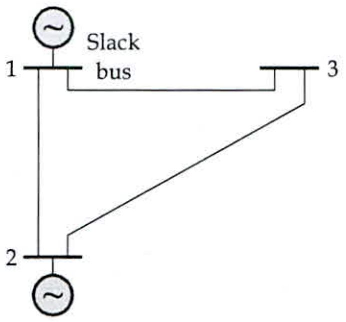

Table 1: Scheduled generation and loads and assumed bus voltage

Bus code i	**Assumed Bus voltage**	**Generation**		**Load**	
		MW	**MVAr**	**MW**	**MVAr**
1 (slack bus)	$1.05 + j0.0$	–	–	0	0
2	$1 + j0.0$	50	30	305.6	140.2
3	$1 + j0.0$	0	0	138.6	45.2

Base MVA = 100

Table 2: Line impedance

Bus code $i - k$	**Impedance** Z_{ik} **(p.u.)**
1 - 2	$0.02 + j0.04$
1 - 3	$0.01 + j0.03$
2 - 3	$0.0125 + j0.025$

Using the Gauss-Seidel method, determine the phasor values of voltages at buses 2 and 3. Perform one iteration only.

[20 marks]

Do
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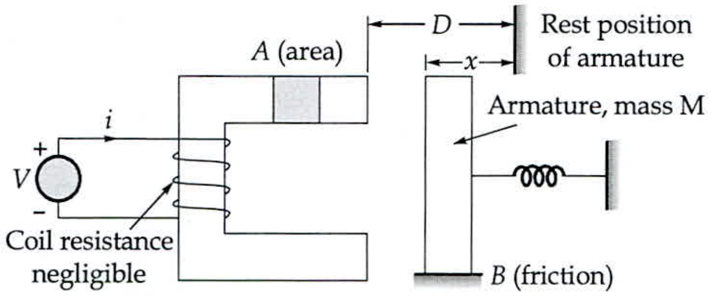
(b) For the electromechanical system shown in figure, the area of cross-section of core is A and the air-gap flux density under steady operating condition is $B(t) = B_m \sin\omega t$.

Find:

(i) the coil voltage.

(ii) the force of field origin as a function of time.

(iii) the displacement of armature as a function of time.



[20 marks]

Do writ this

Q.8 (c) A 1-ϕ 10 kVA, 2400/240 V, 50 Hz distribution transformer has the following characteristics.

Core loss at rated voltage = 100 W
Copper loss at half load = 60 W

(i) Determine the per unit rating at which the transformer efficiency is maximum. Also determine this efficiency if the load power factor is 0.9 (lag).

(ii) The transformer has the following load cycles

no load for 6 hours.
70% full load for 10 hours at 0.8 p.f.
90% full load for 8 hours at 0.9 p.f.

Determine the all-day efficiency of the transformer:

(iii) If the above transformer is connected as autotransformer then, determine the maximum kVA rating and for this rating determine the efficiency when delivering full load at 0.8 power factor lagging.

[20 marks]

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Space for Rough Work

Space for Rough Work