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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

Name : VIBHA KHAIRWAL

Roll No : E E 1 9 M T D L A 6 1 2

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Student's Signature

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	
Q.3	46
Q.4	55
Section-B	
Q.5	40
Q.6	35
Q.7	
Q.8	
Total Marks Obtained	218

Signature of Evaluator: Sourabh 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) conductivity $\sigma = ne\mu_n + pe\mu_p$.
For n-doped si, concentration of free $e^- = n = N_D$
Concentration of holes $= p = \left(\frac{n_i^2}{n}\right)$.

$\therefore \sigma = e\left[\left(10^8 \times 1200\right) + \frac{(1.5)^2 \times 10^{20}}{10^8} \times \frac{1200}{2.5}\right]$

$= e\left[(12 \times 10^{12}) + 1080 \times 10^{12}\right] = e\left(1080.12 \times 10^{12}\right)$

$= 1.6 \times 10^{-19} \times 1080.12 \times 10^{12} = 1728.19 \times 10^{-7}$

$\sigma = 1.72819 \times 10^{-4}\ \frac{1}{\Omega m}$.

Resistance $= R = \frac{\rho l}{A} = \frac{l}{\sigma A}$

$= \frac{20 \times 10^{-6+2}}{1.72819 \times 10^{-4} \times 2 \times 10^{-4} \times 1 \times 10^{-4}}\ \Omega$

$= \frac{20 \times 10^{-4}}{3.456 \times 10^{-12}}\ \Omega = \frac{20}{3.456} \times 10^8\ \Omega$

$= 5.787 \times 10^8\ \Omega$

Use Rough space

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(ii) conductivity $= \sigma = ne\mu_n + pe\mu_p = e(n\mu_n + p\mu_p)$
Concentration of holes $= p = 10^{10}$ /cm³.
Concentration of free $e^- = n = \frac{n_i^2}{p} = \frac{(1.5)^2 \times 10^{20}}{10^{10}}$ /cm³

$n = 2.25 \times 10^{10}$ /cm³.

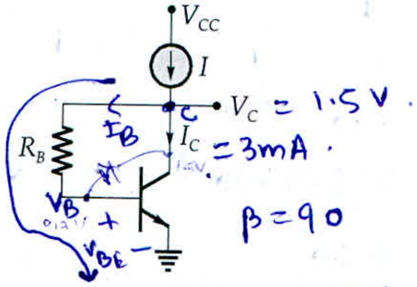
$\sigma = e\left[\left(2.25 \times 10^{10} \times 1200\right) + \left(10^{10} \times \frac{1200}{2.5}\right)\right]$

$= e\left[27 \times 10^{12} + 4.8 \times 10^{12}\right]$

$= 1.6 \times 10^{-19} \times [31.8] \times 10^{12} = 50.88 \times 10^{-7}\ \frac{1}{\Omega m}$

$R = \frac{20 \times 10^{-4}}{50.88 \times 10^{-7} \times 2 \times 10^{-8}} = \frac{20 \times 10^{-4+15}}{50.88 \times 2} = 0.393 \times 10^{11}\ \Omega$

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 $\beta = 90$.



[12 marks]

Active region operation. [Since: $V_C = 1.5$ V and $V_B = 0.7$V]

$$I_B = \left(\frac{I_C}{\beta}\right) = \frac{3}{90} \text{ mA} = 0.0333 \text{ mA}.$$

Apply KVL in L1 :

$$-V_C + I_B R_B + V_{BE} = 0.$$

$$I_B R_B = V_C - V_{BE}$$

$$R_B = \frac{V_C - V_{BE}}{I_B} = \frac{1.5 - 0.7}{0.0333} = 24 \text{ k}\Omega.$$

$$I = I_B + I_C = 3 + 0.0333 = 3.0333 \text{ mA}.$$

Objective approach

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

[12 marks]

$B = \mu_0(H+M)$ where $M = \chi_m H$

where B = magnetic flux density.
H = magnetic field intensity
M = magnetization.

Case 1: Given: $B_1 = 4$ Wb/m^2, $H_1 = 4800$ A/m.

$$H_1 + M_1 = \left[\frac{B_1}{\mu_0}\right] = \left(\frac{4}{4\pi \times 10^{-7}}\right)$$

$$M_1 = \left[\frac{10^7}{\pi}\right] - 4800$$

$$\boxed{M_1 = 3.1799 \times 10^6 \text{ A/m}}$$

Case 2: $H_2 = 640$ A/m, $B_2 = 1.8$ Wb/m^2.

$$H_2 + M_2 = \left(\frac{B_2}{\mu_0}\right) = \left(\frac{1.8 \times 10^7}{4\pi}\right)$$

$$M_2 = \frac{1.8 \times 10^7}{4\pi} - 640 = 1.43248 \times 10^6 \text{ A/m}$$

% change in magnetisation $= \frac{M_2 - M_1}{M_1}$

$$= \frac{1.43248 - 3.1799}{3.1799}$$

$$= -54.95\ \%$$

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1 (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]

Magnetization (M) = Magnetic dipole moment per unit volume

$$M = \frac{1}{\Delta v} \sum_{j=1}^{N} p_j$$

where p_j is the magnetic dipole moment of j th dipole, and N no. of such ~~atoms~~ dipoles are present in volume Δv.

~~M = Nm~~

magnetic dipole significance: on application of external magnetic field (B), the magnetic dipoles get aligned / oriented in direction of B and this results in magnetization of material,

~~M = Mol~~

$B = \mu_0 (H + M)$ ①

where
B = magnetic flux density
H = magnetic field intensity
M = magnetization

magnetic flux density is due to applied magnetic field H and due to magnetization of material

where $M = N \hat{p}_m$

N = No. of dipoles per unit volume with magnetic dipole moment p_m

$B = \mu_0 \mu_r H$ ②

from ① & ②

$\mu_0 H + \mu_0 M = \mu_0 \mu_r H$

$\mu_0 M = \mu_0 \mu_r H - \mu_0 H$

$\mu_0 M = \mu_0 H (\mu_r - 1)$

$M = H(\mu_r - 1)$

$\boxed{M = \chi_m H}$

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where $\chi_m = \mu_r - 1$

χ_m = magnetic susceptibility

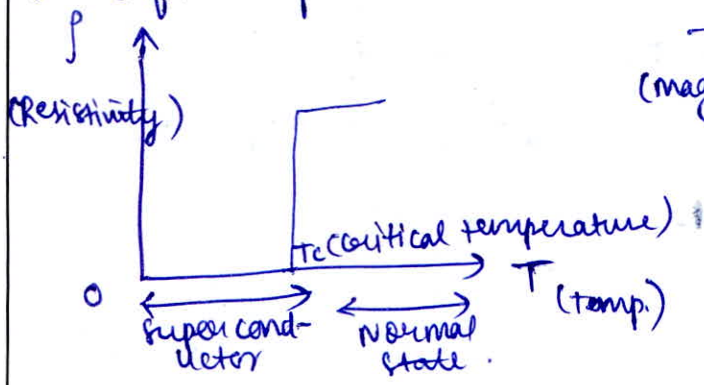
μ_r = relative permeability

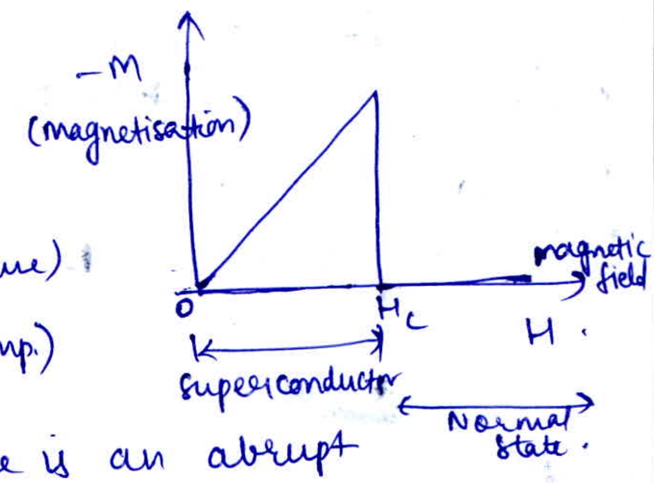
μ_0 = permeability of free space / vacuum.

(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]

Type I superconductors: These are ideal or soft superconductors.





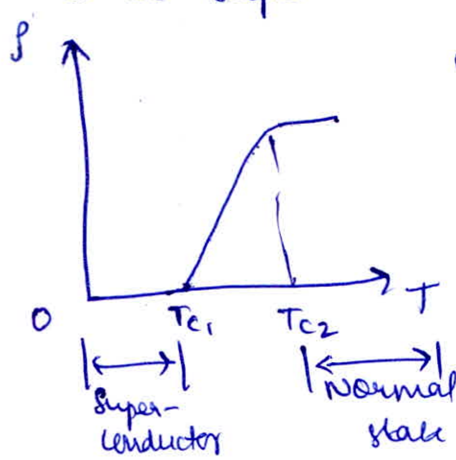
For these materials there is an abrupt or sudden change in magnetisation as material makes a transition from superconducting to normal state.

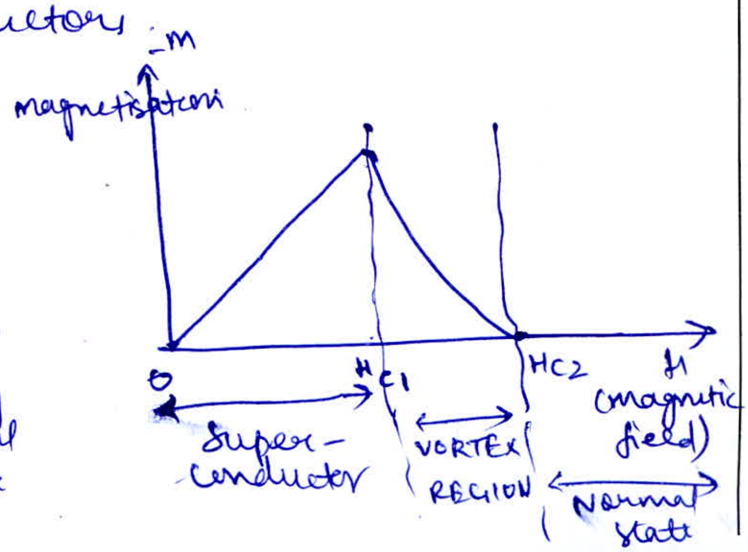
They exhibit complete Meissner's effect, i.e, the magnetic lines of forces or magnetic flux density inside these superconductors is 0, and they exhibit perfect diamagnetism.

They exhibit complete Silsbee Rule.

They have high value of critical magnetic field (Hc) and critical transition temperature Tc.

Type 2 superconductors: They are non-ideal or hard superconductors.





there is a gradual change in magnetisation as material makes a transition from superconducting to normal state.

They exhibit incomplete Meissner effect and silsbee rule in vortex region.

They have 2 values of critical magnetic field H_{C1} and H_{C2} between which lies the vortex region which is a region in which gradual change in state from superconducting to normal is observed.

$\rho = 0$

As frequency increases, the resistance of material increases due to skin effect, i.e, superconductivity is destroyed at high frequencies. ~~since~~ ~~resis~~ ρ ∴ superconductivity is observed upto radio frequencies where skin effect is less pronounced.

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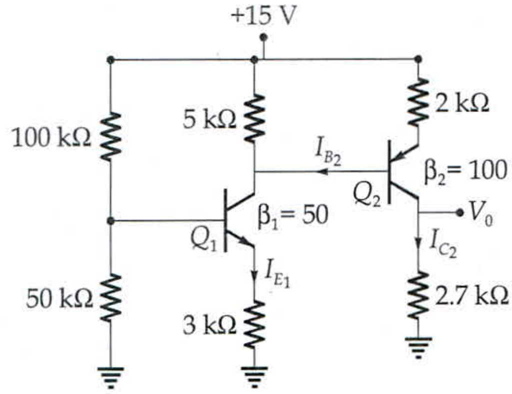
(a) The copper crystal has FCC unit cell configuration. If radius of Cu atom is 0.148 nm and atomic mass of Cu is 63.5 gm mol^{-1} then calculate atomic packing fraction (APF), the atomic concentration in a unit cell and density of Cu atom in gcm^{-3}.
(Take Avogadro number : 6.023×10^{23} mol^{-1})

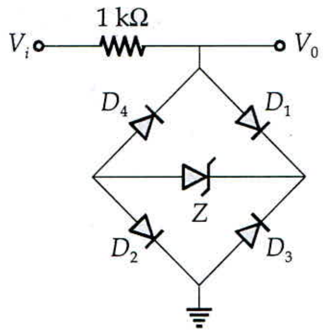
[20 marks]

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



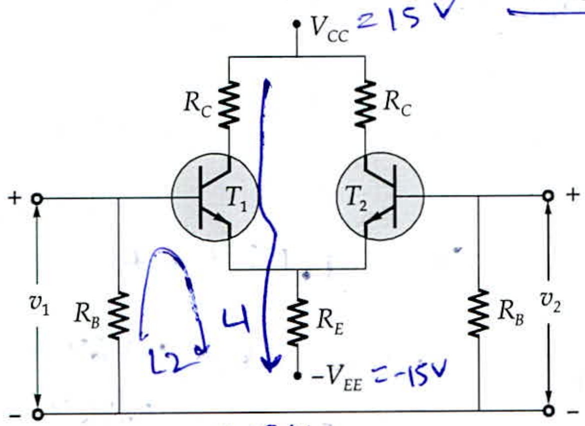
[20 marks]

c) Sketch the transfer characteristics of the circuit given below for $-20\text{ V} \leq V_i \leq 20\text{ V}$. 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.

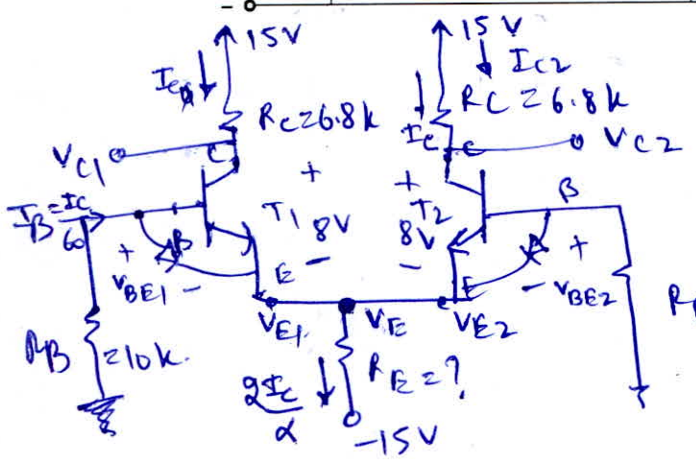


[20 marks]

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]



$\beta = 60$

$\alpha = 0.9836$

$R_B = 10$ k.

$I_C = \alpha I_E$

$I_E = \frac{I_C}{\alpha}$

$I_B = \left(\frac{I_C}{60}\right)$

for T1 : $V_{E1} = V_{C1} + V_{CE1}$ & for T2 $V_{E2} = V_{C2} + V_{CE2}$.

since $V_{E1} = V_{E2} = V_E$ & $V_{CE1} = V_{CE2} = 8$ V

$\therefore V_{C1} = V_{C2}$

$\therefore I_{C1} = I_{C2} = 2I_C$

Applying KVL in L1 : $-15 + I_C(6.8) + 8 + \frac{2I_C}{\alpha} R_E = +15$

$6.8\, I_C + \frac{2I_C}{\alpha} R_E = 30 - 8 = 22$

$6.8\, I_C + 2.03\, I_C R_E = 22$ ①.

$I_C R_E = \frac{22 - 6.8\, I_C}{2.03}$ ③

3

KVL in L2 : $0 + \frac{I_C \times 10}{60} + 0.7 + \frac{2I_C}{\alpha} R_E = +15$

$$\frac{I_C}{6} + 2.033\, I_C R_E = 14.3 \quad (2)$$

from eqn (3)

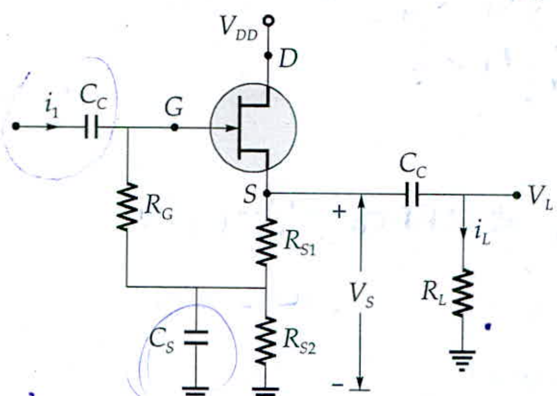
$$\frac{I_C}{6} + 2.033\left(\frac{22 - 6.8\, I_C}{2.03}\right) = 14.3$$

On solving, $I_C = 1.164$ mA

$$R_E = \frac{22 - (6.8)(1.164)}{2.03 \times 1.164}$$

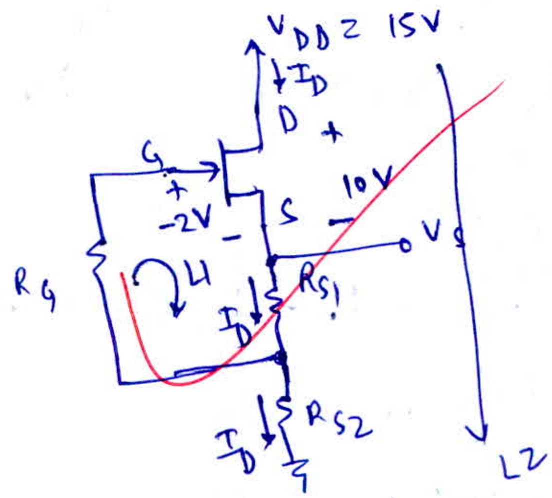
$$R_E = 5.96\ k\Omega$$

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.



for dc conditions

[10 marks]



$I_{DSS} = 10$ mA

$V_P = 4$ V

$R_G >> R_{S1}, R_{S2}$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 10\left(1 + \frac{2}{-4}\right)^2 = 10\left(1 - \frac{1}{2}\right)^2 = \frac{10}{2 \times 2}$$

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

KVL in L1

$$0 + V_{GS} + I_D R_{S1} = 0.$$

$$I_D R_{S1} = -V_{GS} \Rightarrow R_{S1} = \frac{-V_{GS}}{I_D}$$

$$R_{S1} = \frac{-(-2)}{2.5}\,k\Omega = 0.8\,k\Omega$$

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

KVL in L2

$$-15 + 10 + I_D(R_{S1} + R_{S2}) = 0$$

$$I_D(R_{S1} + R_{S2}) = 5$$

$$R_{S1} + R_{S2} = \frac{5}{2.5} = 2\,k\Omega$$

$$\Rightarrow \boxed{R_{S2} = 1.2\,k\Omega}$$

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

$$= 2 \times 2.5 = 5\,V$$

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

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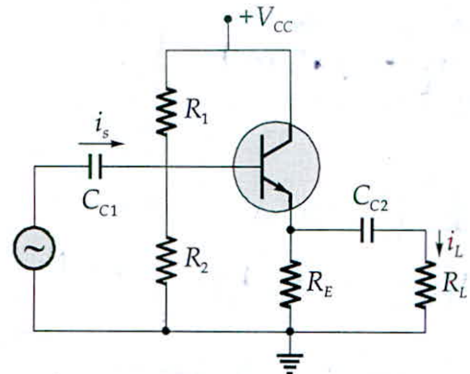
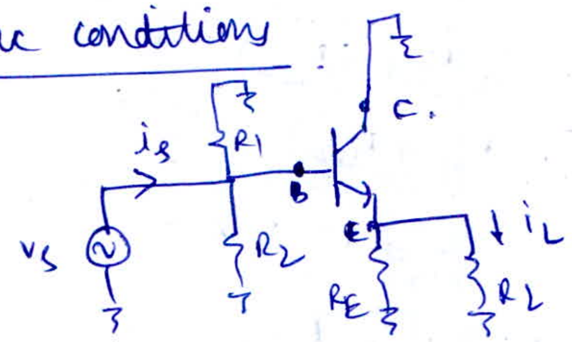
Q.3 (b) Consider the amplifier circuit shown below:



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.

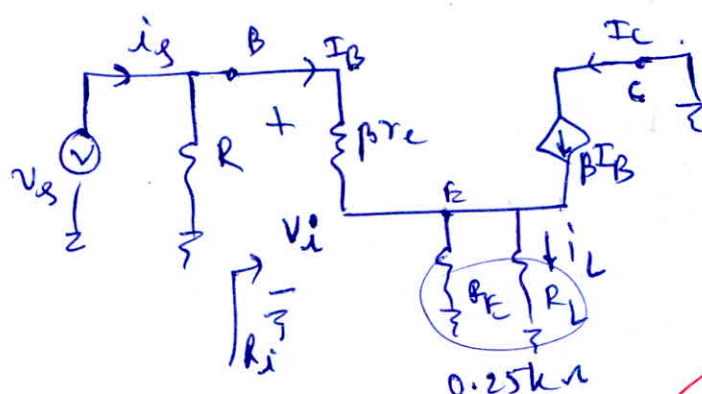
[20 marks]

for ac conditions



Let $R = R_1 \| R_2$

$R_E = R_L = 0.5\,k\Omega$



$$i_L = \frac{(\beta+1) I_B R_E}{R_E + R_L}$$

$$i_L = \frac{(81) I_B \times 0.5}{1}$$

$$\boxed{i_L = 40.5 I_B} \quad ①$$

$$R_i = \left(\frac{V_i}{I_B}\right)$$

$$V_i = I_B \beta r_e + (0.25)(1+\beta) I_B$$

$$\frac{V_i}{I_B} = \beta r_e + (0.25 \times 81)$$

$$\boxed{R_i = \beta r_e + 20.25}$$

$$I_B = (i_s)\left(\frac{R}{R + \beta r_e + 20.25}\right) \quad ②$$

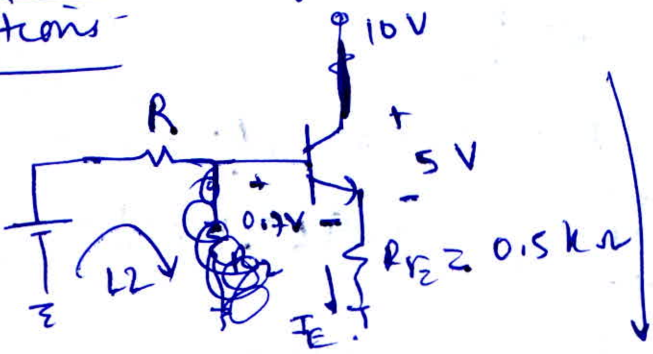
Put ② in ①

$$i_L = (40.5)\, i_s \left(\frac{R}{R + \beta r_e + 20.25} \right)$$

$$\boxed{\frac{i_L}{i_s} = \left(\frac{40.5 R}{R + \beta r_e + 20.25} \right) = 8}$$ ③

for dc conditions -

$R = (R_1 \| R_2)$



$V_{BB} = \left(\frac{10 \times R_2}{R_1 + R_2} \right)$

KVL in L1 : $-10 + 5 + I_E R_E = 0$

$I_E R_E = 5 \Rightarrow I_E = \frac{5}{0.5}\,mA$

$\boxed{I_E = 10\,mA}$ $\boxed{I_B = 0.123456\,mA}$ $\boxed{I_E = 10\,mA}$

$I_C = 10 \times \frac{80}{81} = 9.8765\,mA.$

$\beta r_e = 80 \times \frac{26}{9.8765} = 0.2106\,k\Omega$

Put $\beta r_e = 0.2106\,k\Omega$ in eq^n ③

$$\boxed{\left(\frac{40.5 R}{R + 20.4606} \right) = \frac{8}{1}}$$ ④.

$8R + 163.685 = 40.5R.$

$32.5R = 163.685 \Rightarrow \boxed{R = 5.0365\,k\Omega}$

$$\boxed{\left(\frac{R_1 R_2}{R_1 + R_2} \right) = 5.0365\,k\Omega}$$ ⑤.

KVL in L2 :

$\left(\frac{10 R_2}{R_1 + R_2} \right) - (0.123456) R = 0.7 + 5$

$\left(\frac{10 R_2}{R_1 + R_2} \right) - (0.123456) \times (5.0365) = 5.7$

$\frac{R_2}{R_1 + R_2} = \frac{6.32178}{10}$

$\frac{R_1}{R_2} + 1 = 1.58183 \Rightarrow \frac{R_1}{R_2} = 0.58183$

[redacted]

$$\frac{R_1 R_2}{R_1 + R_2} = 5.0365$$

$$\frac{R_1 R_2}{R_2\left(\frac{R_1}{R_2}+1\right)} = 5.0365$$

$$\frac{R_1}{R_2} = 0.58183$$

$$R_1 = (5.0365)(1.58183)$$

$$\boxed{R_1 = 7.967\ k\Omega}$$

$$\boxed{R_2 = 13.693\ k\Omega}$$

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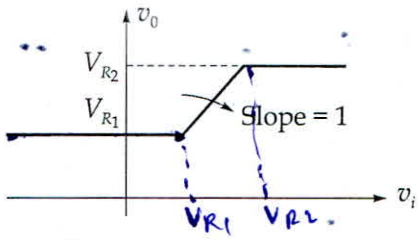
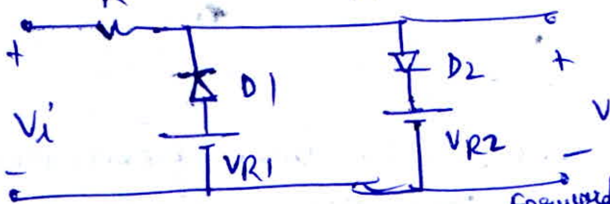
[redacted] (c) (i) Design a clipper circuit for the characteristics curve given below:



[10 marks]

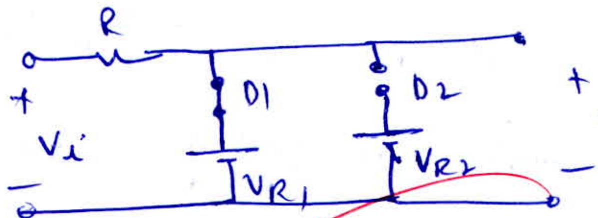
Circuit :



ANALYSIS:

when $v_i < V_{R1}$: $D_1 \rightarrow$ ~~Reverse~~ forward biased
$D_2 \rightarrow$ Reverse biased

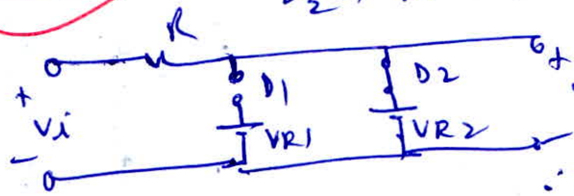
Equivalent ckt :



$\therefore$ $V_0 = V_{R1}$

when $v_i > V_{R2}$: $D_1 \rightarrow$ Reverse biased
$D_2 \rightarrow$ forward biased.

ckt is :

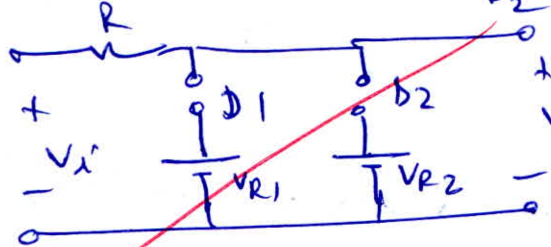


$\therefore$ $V_0 = V_{R2}$

when $V_{R1} < V_i < V_{R2}$.

$D_1 \rightarrow$ Reverse biased
$D_2 \rightarrow$ Reverse biased.

Ckt is :



$V_0 = V_i$.

9

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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]

$\sigma = ne\mu$, $\mu = \left(\frac{\tau e}{m}\right)$

τ

(ii) Mobility of e^- is the ease with which free electrons can move within conduction material when an external electric field is applied. It is denoted as μ.

(iii) conductivity $= \sigma = ne\mu$. $\sigma = ne\mu$

No. of atoms in 63.5 g $= N_A = 6.023 \times 10^{23}$ atoms.

Density $= 9.4 \frac{g}{cm^3}$

$\therefore$ No. of atoms in $\frac{63.5}{9.4}$ cm³ volume $= 6.023 \times 10^{23}$

$= \left[\frac{6.023 \times 10^{23} \times 9.4}{63.5}\right]$

$= 0.891594 \times 10^{23}$ atoms

Since 1 atom contributes 1 free e^-.

$\therefore n = 0.891594 \times 10^{23} \frac{\text{atoms}}{cm^3}$.

$\mu = \frac{\sigma}{ne} = \frac{1}{\rho n e}$

$= \frac{1}{1.72 \times 10^{-8} \times 10^{2} \times 0.891594 \times 10^{23} \times 1.6 \times 10^{-19}}$

$= \frac{1}{2.454 \times 10^{-2}}$

$\mu = \frac{100}{2.454} = 40.7497 \frac{cm^2}{Vs}$.

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$$\mu = 40.7497 \text{ cm}^2/\text{Vs}$$

$$\mu = \left(\frac{\tau e}{m}\right)$$

where m = mass of e^-

τ = avg. time of collision.

$$\Rightarrow \tau = \left(\frac{\mu m}{e}\right)$$

$$\tau = \left[\frac{40.7497 \times 10^{-4} \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19}}\right] \text{sec}$$

(constant)

$$\tau = 231.764 \times 10^{-16} \text{ sec}$$

8

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]

Diffusion capacitance $C_D = \left[\frac{\tau_T I_D}{V_T}\right]$

where τ_T = Mean lifetime of holes $= 10 \times 10^{-9}$ sec

I_D = forward current $= 0.1 \times 10^{-3}$ A

V_T = Thermal voltage

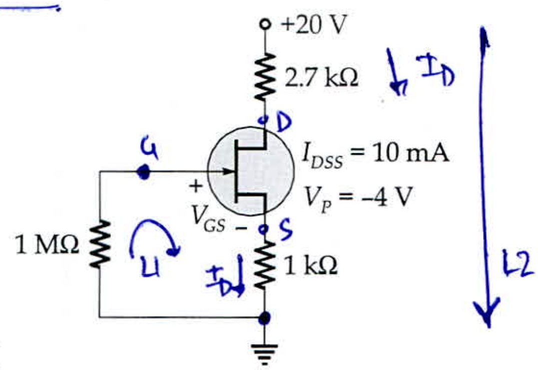
$V_T = \frac{T}{11600} = \frac{300}{11600} = 0.02586$ V

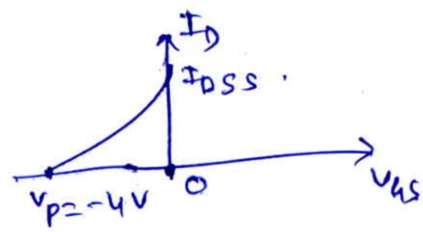
$$\therefore C_D = \frac{10 \times 10^{-9} \times 0.1 \times 10^{-3}}{0.02586}$$

$$C_D = \frac{10^{-12}}{0.02586} F = 38.67 \times 10^{-12} F.$$

(5)

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





[15 marks]

KVL in L1: $0 + V_{GS} + I_D = 0$

$$V_{GS} = -I_D$$

using: $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

$$I_D = (10)\left[1 + \frac{I_D}{(-4)}\right]^2 = (10)\left(1 + \frac{I_D^2}{16} - \frac{I_D}{2}\right)$$

$$0.1 I_D = 1 + \frac{I_D^2}{16} - \frac{I_D}{2}$$

$$0.0625 I_D^2 - 0.6 I_D + 1 = 0$$

$$I_D = \frac{0.6 \pm \sqrt{(0.6)^2 - (4 \times 0.0625)}}{2 \times 0.0625} = \frac{0.6 \pm 0.332}{0.125}$$

$I_D = 7.456$ mA, 2.144 mA

$V_{GS} = -7.456$ V, -2.144 V.

X

$\therefore$ $I_{DQ} = 2.144$ mA, $(V_{GS})_Q = -2.144$ V

KVL in L2:

$$20 - 2.7 I_D - V_{DS} - I_D = 0$$

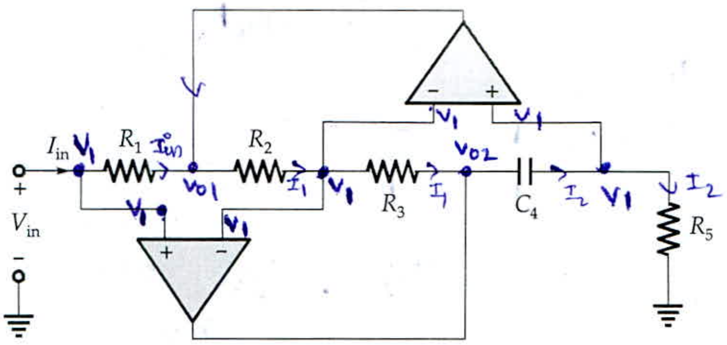
$$20 - 2.7(2.144) - V_{DS} - 2.144 = 0$$

$$-V_{DS} = -12.0672$$

$$(V_{DS})_Q = 12.0672 \text{ V}$$

14

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



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

[20 marks]

The voltages have been marked in the above diagram (using virtual ground concept of op-amp in negative feedback from output).
The currents I_{in}, I_1, I_2 have also been marked.

$V_1 = I_2 R_5 \Rightarrow \boxed{I_2 = \frac{V_1}{R_5}}$ ①

Also, $\boxed{I_2 = (V_{o2} - V_1) s C_4}$ ②

$\boxed{I_1 = \frac{V_1 - V_{o2}}{R_3}}$ ③ $\boxed{I_1 = \frac{V_{o1} - V_1}{R_2}}$ ④.

$\boxed{\frac{V_1 - V_{o1}}{R_1} = R_1 I_{in}}$ ⑤.

from ① & ②: $\frac{V_1}{sC_4R_5} = V_{o2} - V_1$

$\Rightarrow V_{o2} = \frac{V_1}{sC_4R_5} + V_1 = V_1\left[1 + \frac{1}{sC_4R_5}\right]$.

from ③ & ④ $\rightarrow R_2\left(\frac{V_1 - V_{o2}}{R_3}\right) = V_{o1} - V_1$

$V_{o1} = V_1 + \frac{R_2}{R_3}(V_1 - V_{o2}) = V_1\left[1 + \frac{R_2}{R_3}\right] - \frac{R_2}{R_3}(V_{o2})$

$V_{o1} = V_1\left(1 + \frac{R_2}{R_3}\right) - \frac{R_2 V_1}{R_3}\left[1 + \frac{1}{sC_4R_5}\right]$

$V_{o1} = V_1\left[1 + \frac{R_2}{R_3} - \frac{R_2}{R_3}\left(1 + \frac{1}{sC_4R_5}\right)\right] = V_1\left[1 + \frac{R_2}{R_3} - \frac{R_2}{R_3} - \frac{R_2}{R_3 sC_4R_5}\right]$

$V_{o1} = V_1\left[1 - \frac{R_2}{R_3 s C_4 R_5}\right)$

$$V_{01} = V_1\left[1 - \frac{R_2}{R_3 sC_4 R_5}\right]$$

$V_1 = V_{in}$.

$$\therefore V_{01} = V_{in}\left(1 - \frac{R_2}{R_3 sC_4 R_5}\right)$$

using eq^n (5):

$$R_1 I_{in} = \frac{V_{in} - V_{01}}{\cancel{R_1}}$$

$$I_{in} R_1 = V_{in} + V_{in}\left[-1 + \frac{R_2}{sC_4 R_3 R_5}\right]$$

$$I_{in} R_1 = \cancel{V_{in}} - \cancel{V_{in}} + V_{in}\left(\frac{R_2}{sC_4 R_3 R_5}\right)$$

$$\frac{V_{in}}{I_{in}} = \left(\frac{R_1(sC_4 R_3 R_5)}{R_2}\right).$$

$$\frac{V_{in}(s)}{I_{in}(s)} = Z_{in}(s) = s\left[\frac{R_1 C_4 R_3 R_5}{R_2}\right]$$

[Simulated an inductance using the circuit].

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(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 $\epsilon_r = 2.4$ with applied external electric field $\vec{E} = 10^4 \vec{a_x}$ V/m, then calculate the value of polarization and dipole moment in each molecule. (Consider all molecules have same dipole moment).

[20 marks]

~~Dielectric materials have charges which are not free to move. Some dielectrics have permanent~~

Dielectrics have charges which are not free to move. When an external electric field $\vec{E}$ is applied, the centres of positive and negative charges get displaced wrt each other. Thus, the dipoles are induced which tend to align along / parallel to the applied electric field. This phenomenon is called polarization in dielectrics and electric dipoles are induced in the dielectric due to which it becomes polarized. If the electric dipole moment of each dipole is p and if there are N no. of such atoms (per unit volume) which are subjected to the electric field then Polarization $P = Np$.
i.e polarization is electric dipole moment per unit volume.

$$P = \frac{1}{\Delta v} \sum_{j=1}^{N} p_j$$

where Δv is small volume which has 'N' no. of dipoles with dipole moment of jth dipole = p_j.

Types :

1. Electronic polarization (occurs in materials in which there is no interaction between atoms)
2. Ionic Polarization (occurs in materials which have polar covalent bond).
3. Orientational polarization (occurs in materials which have permanent dipole moments)
4. Space charge / interfacial polarization. (occurs in multiphase materials.)

$P = Np$.

Given → $N = 3.2 \times 10^{19}$ /m³.

$\epsilon_r = 2.4$.

$E = 10^4$ V/m.

Polarisation $P = \epsilon_0 (\epsilon_r - 1) E$

$P = 8.854 \times 10^{-12} \times 1.4 \times 10^4$

$P = 12.3956 \times 10^{-8}$ V/m.

~~$P = N\alpha E_i$~~

~~$P = \epsilon_0 \chi_e E$~~

~~$1 + \chi_e = \epsilon_r$~~

~~$\chi_e = (\epsilon_r - 1)$~~

Dipole moment in each molecule $= p$

$\therefore p = \left(\frac{P}{N}\right) = \frac{12.3956 \times 10^{-8-19}}{3.2}$ Cm.

$= 3.8736 \times 10^{-27}$ Cm.

18

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

[redacted]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.

$$Y_{bus} = j\begin{bmatrix} -3.78 & 1.25 & 2.5 & 0 \\ 1.25 & -3.42 & 1.11 & 1.0 \\ 2.5 & 1.11 & -4.89 & 1.25 \\ 0 & 1.0 & 1.25 & -2.31 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix}$$

[12 marks]

Admittance connected b/w :

Bus 1 and 2 $= -j1.25$

Bus 1 and 3 $= -j2.5$

Bus 1 and 4 $= 0$

Bus 2 and 3 $= -j1.11$

Bus 2 and 4 $= -j1$

Bus 3 and 4 $= -j1.25$

Admittance connected only at :

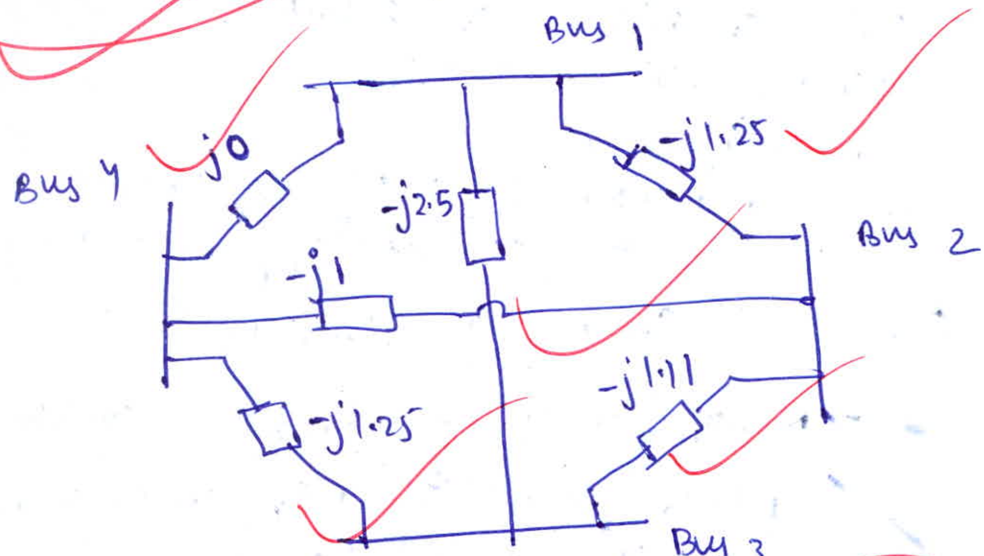
Bus1 $= j(-3.78 + 1.25 + 2.5)$
$= -j0.03$

Bus 2 $= j(1.25 - 3.42 + 1.11 + 1)$
$= -j0.06$

Bus 3 $= j(2.5 + 1.11 - 4.89 + 1.25)$
$= -j(0.03)$

Bus 4 $= j(1 + 1.25 - 2.31)$
$= -j0.06.$

Admittance diagram :



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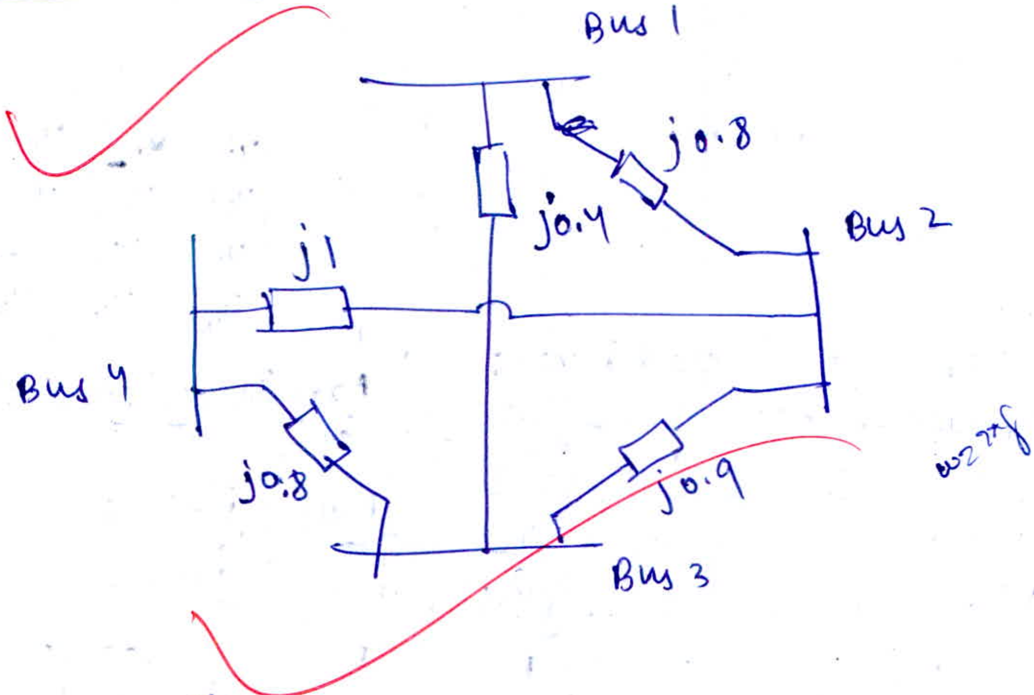
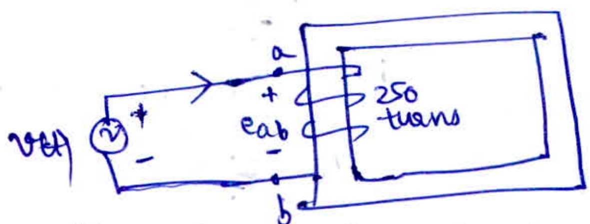
Reactance diagram:



Q.5 (b) A voltage of (200 sinω*t* – 50 sin 3ω*t*), 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 ω*t*?

[12 marks]



$v(t) = 200 \sin \omega t - 50 \sin 3\omega t$

$= v_{m1} \sin \omega t - v_{m2} \sin 3\omega t$

$v(t) = v_1(t) - v_2(t)$

Let flux $\phi(t) = \phi_{m1} \sin \omega t - \phi_{m2} \sin 3\omega t$

$\phi(t) = \phi_1(t) - \phi_2(t)$

According to Faraday's law:

$e_{ab} = + N \frac{d\phi(t)}{dt}$ [+ sign is taken to satisfy Lenz law]

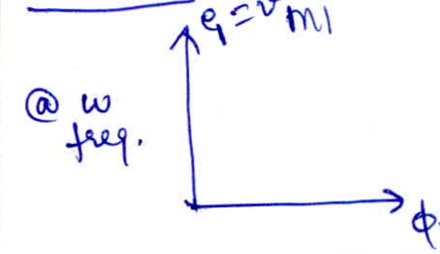
$e_{ab} = N \frac{d}{dt} [\phi_{m1} \sin \omega t - \phi_{m2} \sin 3\omega t]$

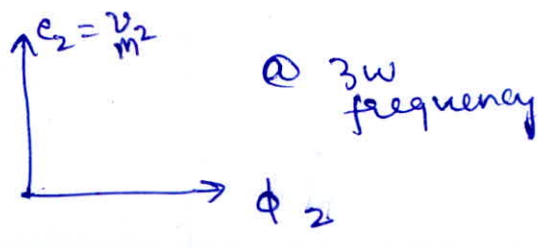
$= N (\omega \phi_{m1} \cos \omega t - \phi_{m2} (3\omega) \cos 3\omega t)$

$= N\omega \phi_{m1} \cos \omega t - 3N\phi_{m2} \omega \cos 3\omega t$

$= e_1(t) - e_2(t)$

Phasor:





$e_1 = N\omega\,\phi_{m1} = 200$ & $e_2 = 3N\,\phi_{m2}\,\omega = 50$

$\phi_{m1} = \frac{200}{250 \times 2\pi \times 50}$, $\phi_{m2} = \frac{50}{3 \times 250 \times 2\pi \times 50}$

$\phi_{m1} = 2.548 \times 10^{-3}\,wb$, $\phi_{m2} = 0.21231 \times 10^{-3}\,wb$

$\therefore \phi(t) = \phi_{m1} \sin\omega t - \phi_{m2} \sin 3\omega t$.

Eddy current loss $= P_e \propto f^2 B_m^2 \propto V^2$

$\boxed{P_e \propto V^2}$

$\phi_{max} = ?$

Case 1: $V_1 = \sqrt{\left(\frac{200}{\sqrt{2}}\right)^2 + \left(\frac{50}{\sqrt{2}}\right)^2}$

$= \sqrt{\frac{(200)^2}{2} + \frac{(50)^2}{2}} = \sqrt{20000 + 1250}$

$\boxed{V_1 = 145.77\ V}$

Case 2: $V_2 = \frac{200}{\sqrt{2}} =$

Case 1: $P_{e1} \propto (f)^2(\phi_{m1})^2 + 9f^2(\phi_{m2})^2$

Case 2: $P_{e2} \propto (f)^2(\phi_{m1})^2$

% change $= \frac{f^2\left[(\phi_{m1})^2 - [(\phi_{m1})^2 + 9(\phi_{m2})^2]\right]}{f^2\left((\phi_{m1})^2 + 9(\phi_{m2})^2\right)}$

$= \frac{(2.548)^2 - \left[(2.548)^2 + (9 \times (0.21231)^2)\right]}{(2.548)^2 + 9(0.21231)^2}$

$= \frac{(6.4923) - \left[(6.4923) + 0.4056\right]}{6.8979}$

$= -5.88\%$

10

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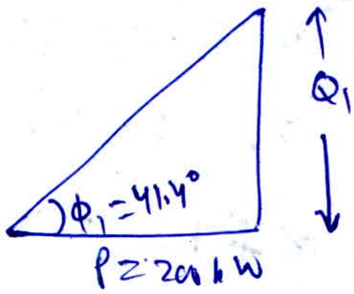
Q.5 (c) An industry load of 200 kW at 0.75 p.f. lagging is fed from the 3-ϕ, 11 kV distribution feeders. It is required to maintain the 0.9 p.f. lag at the drawl point. Find the rating of capacitor installed at industrial drawl point.

[12 marks]

$P = 200\,kW$ @ $\cos\phi_1 = 0.75$ (lag)

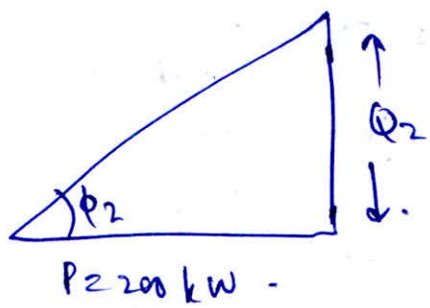


$Q_1 = P\tan\phi_1$

$= (200)\tan(41.4)$

$\boxed{Q_1 = 176.383\,kVAr}$

Required: $\cos\phi_2 = 0.9$ (lag) $\Rightarrow \phi_2 = 25.842°$



$Q_2 = P\tan\phi_2$

$\boxed{Q_2 = 96.86\,kVAr}$

lagging reactive VAR to be supplied by capacitor (Rating) $= (Q_c)_{3\phi} = 79.5185\,kVAr$.

Assuming: capacitor bank is connected in delta.

$V_{ph} = 11000\,V$.

$V_{ph}^2\,\omega C_{ph} = 26.506\times10^3$

$Q = V^2(\omega)C$

$C_{ph} = \dfrac{26.506\times10^3}{2\pi\times50\times(11000)^2}$

$= 6.976\times10^{-7}\,F$

~~$= 0.6976\,\mu F$~~

$= 0.6976\,\mu F$.

10

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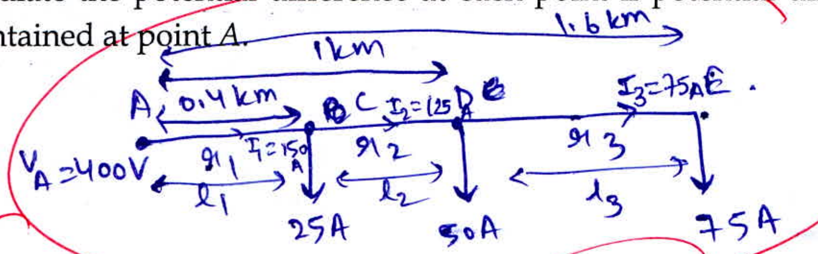
5 (d) A 2-wire DC distributor cable *AB* is 2.2 km long and supplies loads of 25 A, 50 A, 75 A at 0.4 km, 1 km and 1.6 km from the point *A*. Each conductor has a resistance of 0.05 Ω/km. Calculate the potential difference at each point if potential difference of 400 volts is maintained at point *A*.

[12 marks]



given: $r = 0.05 \Omega/km$

$r_1 = (2r) \times l_1 = 2 \times 0.05 \times 0.4 = 0.04 \ \Omega$

$r_2 = (2r) \times l_2 = 2 \times 0.05 \times 0.6 = 0.06 \ \Omega$

$r_3 = (2r) \times l_3 = 2 \times 0.05 \times 0.6 = 0.06 \ \Omega$.

$I_1 = 150$ A, $I_2 = 125$ A, $I_3 = 75$ A. [indicated in diagram.]

$V_C = V_A - I_1 r_1 = 400 - (150 \times 0.04) = 394$ V

$V_D = V_C - I_2 r_2 = 394 - (125 \times 0.06) = 386.5$ V

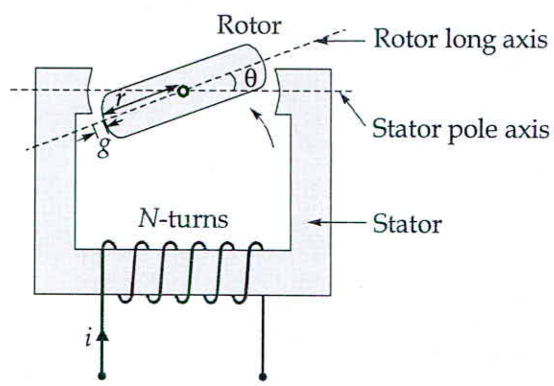
$V_E = V_D - I_3 r_3 = 386.5 - (75 \times 0.06) = 382$ V.

10

write clearly

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:

$$\text{Radius, } r = 50 \text{ mm,}$$
$$\text{Gap length, } g = 2 \text{ mm,}$$
$$\text{Length normal to radius is } l = 10 \text{ mm.}$$



[12 marks]

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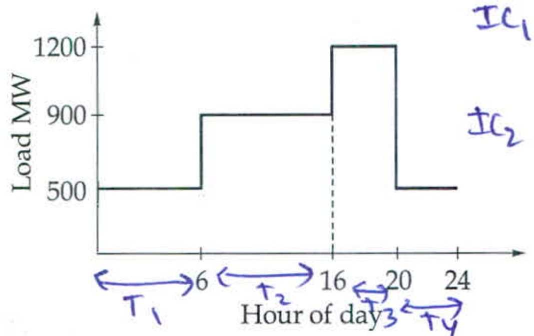
Q.6 (a) The fuel cost characteristics of two thermal plants are as under,

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

$IC = \frac{dC}{dP}$



$IC_1 = 52.8 + 11 \times 10^{-3} P_1$ Rs/MWh

$IC_2 = 15 + 0.1 P_2$ Rs/MWh.

[20 marks]

For time slot T_1: $P_D = P_1 + P_2 = 500$ MW

for economic load sharing: $IC_1 = IC_2$

$52.8 + 0.011P_1 = 15 + 0.1P_2$

$0.011P_1 - 0.1P_2 = -37.8$

$0.1P_1 + 0.1P_2 = 50$

$0.111 P_1 = 12.2$ $\Rightarrow P_1 = 109.9$ MW

$P_2 = 390$ MW.

Since $P_1 < 200$ MW, $\therefore P_1 = 200$ MW.

$P_2 = 300$ MW.

For time slot T_2: $P_D = P_1 + P_2 = 900$ MW.

$IC_1 = IC_2$

$0.011P_1 - 0.1P_2 = -37.8$

$0.1P_1 + 0.1P_2 = 90$.

$0.111P_1 = 52.2$ $\Rightarrow P_1 = 470.27$ MW

$P_2 = 429.72$ MW.

For time slot T_3: $P_D = P_1 + P_2 = 1200$ MW.

$IC_1 = IC_2$

$0.011P_1 - 0.1P_2 = -37.8$

$0.1P_1 + 0.1P_2 = 120$

$0.111P_1 = 82.2$

$P_1 = 740.54$ MW, $P_2 = 459.45$ MW

For slot T_4:

$P_D = P_1 + P_2 = 500$ MW.

$P_1 = 200$ MW, $P_2 = 300$ MW.

8

Incomplete answer

Do not write in this

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]

(i) $IC_1 = 0.012P_1 + 8$, $IC_2 = 0.008P_2 + 9.6$

$100\text{ MW} \le P \le 550\text{ MW}$

Load on plant varies from: 100 MW to 1100 MW

for load = 100 MW; calculate incremental cost of generation for each plant:

$IC_1 = 9.2$ Rs/MWh, $IC_2 = 10.4$ Rs/MWh.

Since $IC_1 < IC_2$, ∴ $P_1 = 100$ MW, $P_2 = 0$ MW

Economic Load dispatch starts when $IC_1 = 10.4$ Rs/MWh

to calculate P_1 for $IC_1 = 10.4$ Rs/MWh

$P_1 = \frac{10.4 - 8}{0.012} = 200$ MW

& $P_2 = 100$ MW

For load of 200 MW: $IC_1 = 10.4$ Rs/MWh

$IC_2 = 11.2$ Rs/MWh.

so $P_1 = 200$ MW & $P_2 = 0$ MW.

For $P_D = 500$ MW, $P_1 + P_2 = 500$.

& $IC_1 = IC_2$

$0.012P_1 - 0.008P_2 = 1.6$

$0.008P_1 + 0.008P_2 = 4.0$

$0.02P_1 = 5.6$

~~$P_1 = 452.17$ MW, $P_2 = 47.82$ MW~~

$P_1 = 280$ MW, $P_2 = 220$ MW

$P_D = P_1 + P_2$ (MW)	P_1 (MW)	P_2 (MW)	λ (Rs/MWh).
100	100	0	–
200	200	0	–
300	200	100	10.4
500	280	220	11.36
700			
900			
1050	500	550	14
1100	550	550	–

→ Load dispatch problem starts. (at 300)

→ Load dispatch ends (at 1050)

To calculate P_D when load dispatch ends:

for P_2 = 550 MW.

IC_1 = 14.6 Rs/MWh, IC_2 = 14 Rs/MWh.

To calculate P_1 when IC_1 = 14 Rs/MWh

$$P_1 = \frac{14-8}{0.012} = 500 \text{ MW}.$$

So $P_D = P_1 + P_2 = 500 + 550 = 1050$ MW.

For $P_D = 1100$ MW, $P_2 = 550$, $P_1 = 550$ MW

λ = ?

(11) Given $P_D = 600$ MW

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$$0.012 P_1 - 0.008 P_2 = 1.6$$
$$0.008 P_1 + 0.008 P_2 = 4.8$$
$$0.02 P_1 = 6.4$$

Economic dispatch: $P_1 = 320$ MW $P_2 = 280$ MW

Equal sharing: $P_1 = 300$ MW $P_2 = 300$ MW

$$\text{Total profit} = \int_{280}^{300} (0.008 P_2 + 9.6)\, dP_2 - \int_{300}^{320} (0.012 P_1 + 8)\, dP_1$$

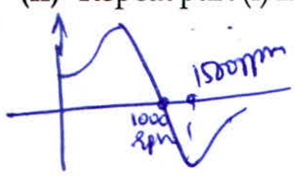
$$= \frac{0.008}{2} \left[P_2^2 \right]_{280}^{300} + 192 - \left[\frac{0.006}{2} \left(P_1^2 \right)_{300}^{320} + 160 \right]$$

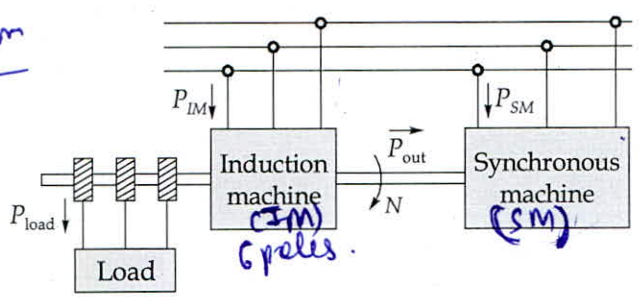
$$= 238.4 - 234.4 = \text{Rs. } 4/\text{hr}.$$

(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]

(i) Speed of synchronous machine = $N_s = \frac{120 \times 50}{4}$
= 1500 rpm.

Synchronous speed of induction m/c = $\frac{120 \times 50}{6}$
= 1000 rpm

Since both the m/cs are mechanically coupled, ∴
Speed of IM = 1500 rpm (acts as generator).
and SM acts as motor.

Slip of IM = $\frac{N_s - N_r}{N_s} = \frac{1000 - 1500}{1000} = -0.5$

Frequency of current = sf = 0.5 × 50 = 25 Hz

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(ii) When phase sequence is reversed:

Slip = s = $\frac{-N_s - N_r}{-N_s} = \frac{+1000 + 1500}{+1000}$

= 2.5 , Frequency = 125 Hz

Speed of synchronous machine = 1500 rpm

Speed of induction machine = 1500 rpm

Speed of stator flux of induction machine wrt stator of induction machine = 1000 rpm (opposite to rotor of IM)

7 (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]

Q.7 (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]**

Do [redacted]
wri[redacted]
this[redacted]

(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.

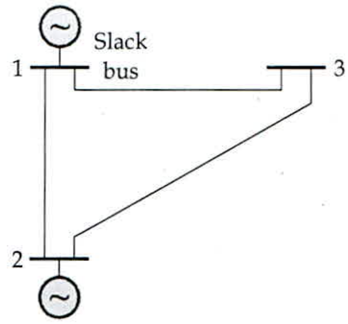


Table 1: Scheduled generation and loads and assumed bus voltage

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 not write in this margin

[redacted]

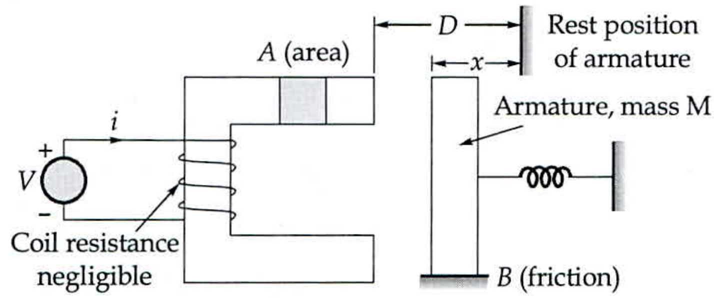
b) For the electromechanical system shown in figure, the area of cross-section of core is A and the air-gap flux density under steady operating condition is $B(t) = B_m \sin\omega t$.

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]

[redacted]

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]

OOOO

$\rightarrow \phi(t)$

$e_{ab} = \pm \frac{N\, d\phi(t)}{dt}$

using $\phi = \phi_m \sin \omega t$

~~$\phi_m \sin \omega t$~~.

$\phi(t) = \phi_{m1} \sin \omega t + \phi_{m2} \sin 3\omega t$

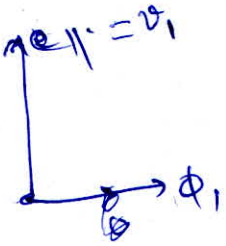
$= \phi_1 + \phi_2$

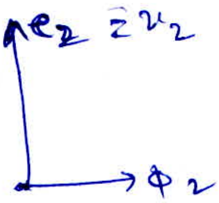
$= N\frac{d\phi(t)}{dt} = N\phi_{m1}\, \omega \cos \omega t + N\phi_{m2} \times 3\omega \cos 3\omega t$

$= e_1 + e_2$

$e_{ab} = v$

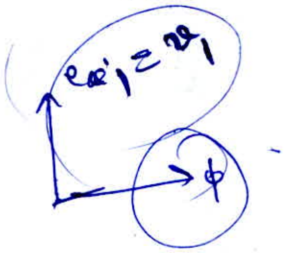
$200 \sin \omega t - 50 \sin 3\omega t = N\phi_{m1}\, \omega \cos \omega t$





$\phi_m \sin \omega t$

$e_{ab} = N\phi_m \omega \cos \omega t$



$B = \mu_0(H+M) = 0$

$\mu_0 (H+M) = 0$

$H = -M$

$M = \chi_m H$

$-M = (1) H$

$I = \frac{Q}{t}$

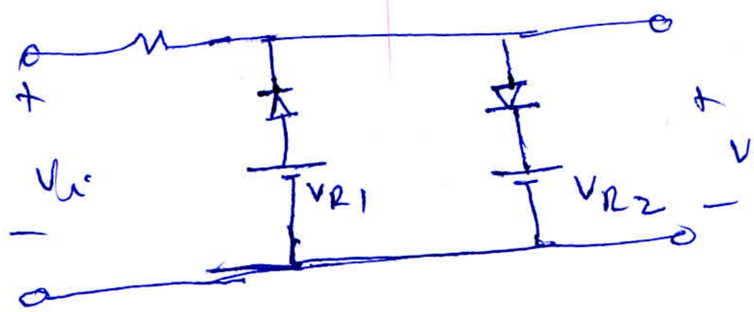
$Q = CV$

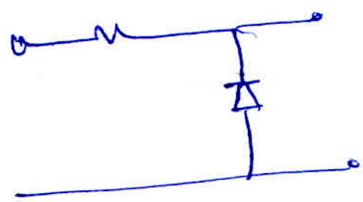
$C = \left(\frac{Q}{V_T}\right) = \left(\frac{tI}{V_T}\right)$

$9.4\,g \rightarrow 1\,cm^3$

$1\,g \rightarrow \frac{1}{9.4}\,cm^3$

$63.5\,g \rightarrow \frac{63.5}{9.4}\,cm^3$





$$\frac{I_c}{6} + 22.033 - 6.81\, I_c = 14.3$$

$$+6.6433\, I_c = 2.733$$

$$\boxed{I_c = 1.164}$$

$v = \mu E$

$$\mu = \frac{v_d}{E}$$

$$= \frac{m}{s\,V}\, m$$

$$= \frac{cm^2}{V s}$$