MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-9 : Full Syllabus Test (Paper-I)

Name : ....

Roll No :

Test Centres	Student's Signature
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ Kolkata ☐ Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. 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.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	48
Q.2	45
Q.3	/
Q.4	/
Section-B	
Q.5	37
Q.6	/
Q.7	49
Q.8	59
Total Marks Obtained	238

Signature of Evaluator: Ch. [illegible signature] .... Cross Checked by: ....

Good attempt

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

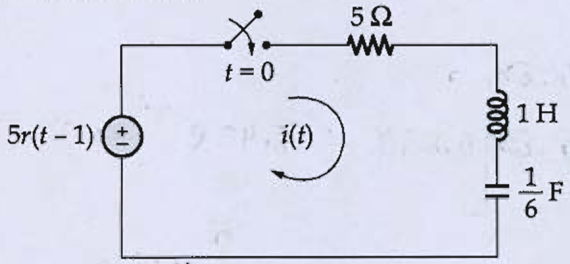
1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section A

.1 (a) For the network shown below, determine the current $i(t)$ when the switch is closed at $t = 0$ with zero initial conditions.

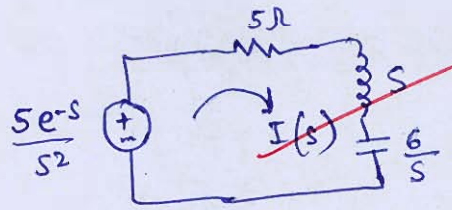


[12 marks]

Sol^n

Converting the circuit in Laplace Domain

$$5\,r(t-1) \rightarrow \frac{5e^{-s}}{s^2}$$



$$I(s) = \frac{\left(\frac{5e^{-s}}{s^2}\right)}{5 + s + \frac{6}{s}}$$

$$= \frac{5e^{-s}}{5s^2 + s^3 + 6s}$$

$$= \frac{5e^{-s}}{s(s^2+5s+6)}$$

$$I(s) = 5e^{-s}\left[\frac{1}{s(s+2)(s+3)}\right]$$

$$= 5e^{-s}\left[\frac{1}{6s} - \frac{1}{2(s+2)} + \frac{1}{3(s+3)}\right]$$

$$I(s) = \frac{5}{6}\frac{e^{-s}}{s} - \frac{5e^{-s}}{2(s+2)} + \frac{5e^{-s}}{3(s+3)}$$

Taking inverse Laplace

$$i(t) = \frac{5}{6}u(t-1) - \frac{5}{2}e^{-2(t-1)}u(t-1) + \frac{5}{3}e^{-3(t-1)}u(t-1)$$

$\therefore\ i(t) = \left[\frac{5}{6} - \frac{5}{2} e^{-2(t-1)} + \frac{5}{3} e^{-3(t-1)}\right] u(t-1)$

$i(t) = \left[0.833 - 18.47 e^{-2t} + 33.47 e^{-3t}\right] u(t-1)$

using
$e^{-at} u(t) \rightarrow \frac{1}{s+a}$
$f(t-t_0) \rightarrow e^{-st_0} F(s)$

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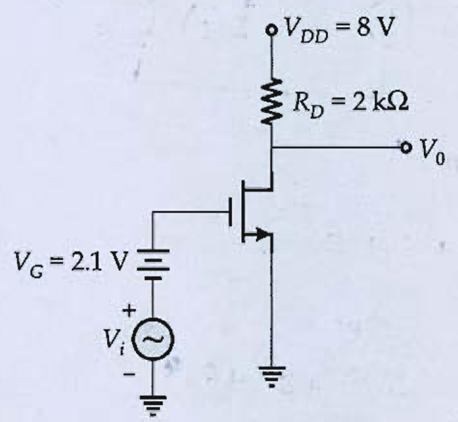
Q.1 (b) Consider the amplifier circuit given below. The *n*-channel MOSFET in the circuit has $V_{TN} = 1$ V and $K = 0.9$ mA/V^2.



(i) Assume that MOSFET is operating in the saturation region, determine the drain current.

(ii) Determine the transconductance, g_m.

(iii) If $V_i = 10$ mV, determine the drain current and voltages. Assume sinusoidal input.

[12 marks]

soln

(i) $I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TN})^2$ in saturation region.

$I_D = \frac{K}{\ } (V_{GS} - V_{TN})^2$

Here, $V_{GS} = 2.1V$

$\therefore I_D = 1 \times 0.9\,mA\,(2.1-1)^2$

~~$I_D = 0.545\,mA$~~ $\boxed{I_D = 1.089\,mA}$

(ii) $I_D = K(V_{GS} - V_T)^2$

$$\frac{\partial I_D}{\partial V_{GS}} = 2K(V_{GS} - V_T)$$

$$= 2K\sqrt{\frac{I_D}{K}}$$

$$g_m = 2\sqrt{K I_D}$$

$$= 2\sqrt{0.9 \times 1.089}$$

$$\boxed{g_m = 0.9801\,mA/V}$$

iii) For small signal input

$$\frac{\Delta V_o}{\Delta V_i} = -g_m R_D$$

$$\frac{\Delta V_o}{\Delta V_i} = -0.9801 \times 2$$

$$= -1.96$$

$$\boxed{\Delta V_o = -19.6\,mV}$$

DC drain voltage $= V_{DD} - I_D R_D$

$= 8 - 1.089 \times 2$

$= 5.822\,V$

$\therefore$ Total voltage (Drain) $= 5.82 - (0.196)\,V$

$= 5.624\,V$

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Do not write in this margin

$$\frac{\partial I_D}{\partial v_{GS}} = g_m$$

$\therefore$ ~~$\Delta I_D = 0.98 \times 10$~~

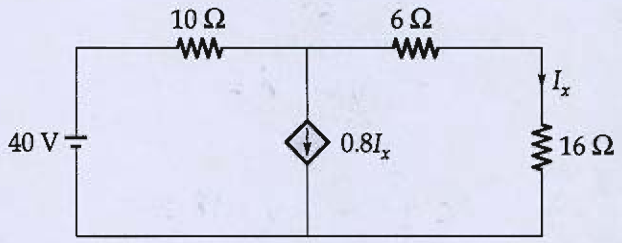
$$\Delta I_D = 0.9801 \times 10^{-3} \times 10^{-2} \text{ A}$$

$$= 0.009801 \text{ mA}$$

$$I_D = (1.089 + 0.009801) \text{ mA}$$

$$\boxed{I_D = 1.09888 \text{ mA}}$$

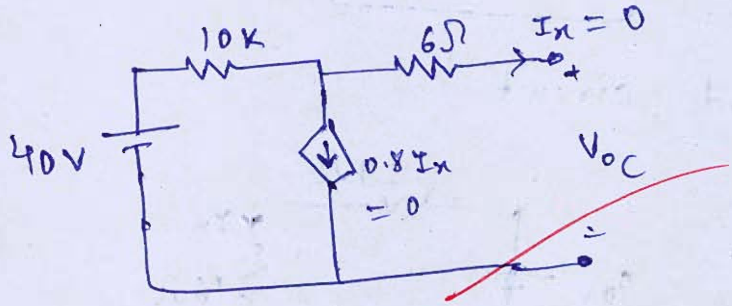
1 (c) For the network shown below, determine the current in the 16 Ω resistor using Thevenin's theorem.



[12 marks]

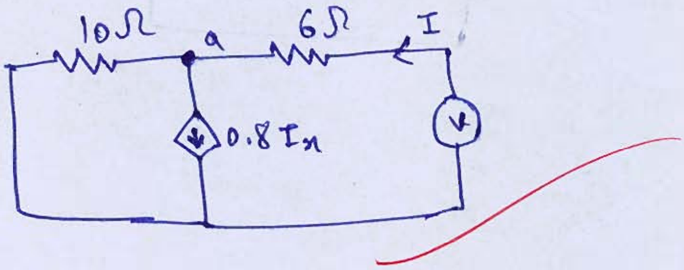
sol^n

Thevenin voltage:



$\therefore \quad V_{oc}$ = Thevenin voltage = 40 V

Thevenin Resistance:



$I = -I_x$

KCL at node a: $\frac{V_a}{10} + 0.8\, I_x = I$

$\frac{V_a}{10} + 0.8(-I) = I$

$\frac{V_a}{10} = 1.8\, I$

$\Rightarrow \boxed{V_a = 18\, I}$

Also, $I = \frac{V - V_a}{6}$

$= \frac{V - 18I}{6}$

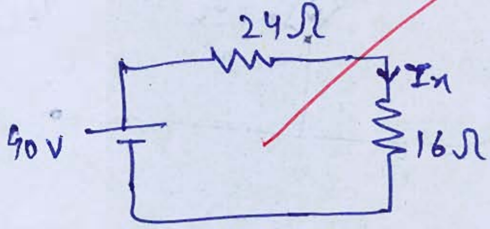
$\Rightarrow \quad 6I = V - 18I$

$24I = V$

Or $\frac{V}{I} = 24\Omega$

$\therefore \quad R_{Th} = 24\Omega$

Equivalent circuit :



$I_x = \frac{40}{24+16}$

$I_x = 1A$

12

Q.1 (d) The magnetization within a bar of some metal alloy is 3.2×10^5 A/m at an H field of 50 A/m. Compute the following:

(i) the magnetic susceptibility,

(ii) the permeability, and

(iii) the magnetic flux density within this material.

(iv) What type(s) of magnetism would you suggest as being displayed by this material? Why?

[12 marks]

Sol^n

Given : $M = 3.2 \times 10^5$ A/m

$H = 50$ A/m

(i) Magnetic susceptibility (χ_m)

$$M = \chi_m H$$

$$\Rightarrow \left[\chi_m = \frac{3.2 \times 10^5}{50} = 6400\right]$$

ii) $\chi_m = \mu_r - 1$

$\therefore \mu_r = 1 + \chi_m$

$= 6401$

$\therefore$ Permeability $(\mu) = \mu_r \mu_0$

$= 6401 \times 4\pi \times 10^{-7}$

$= 8.0437 \times 10^{-3}$

(iii) Magnetic Flux Density

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

or $B = \mu H$

$= 8.0437 \times 10^{-3} \times 50$

$$\boxed{B = 0.402 \text{ T}}$$

Do not write in this margin

(iv) $X_m = 6400$

As X_m is large and positive

∴ The material is Ferromagnetic or Ferrimagnetic.

12

Q.1 (e) A 4 MVA, 10 kV, 3-phase, 50 Hz, 10 pole low speed hydrogenerator has 144 slots containing a two-layer diamond winding with 5 conductors per coil side in each slot. The coil span is 12 slot pitches. The flux per pole is 0.2 Wb. Calculate the phase emf.

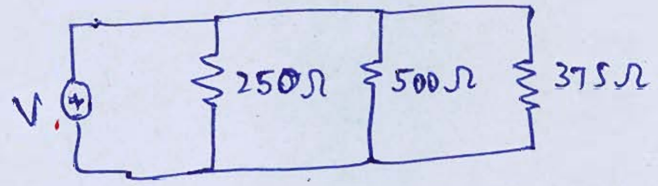
[12 marks]

Q.2 (a) **(i)** Three resistors having resistances of 250 Ω, 500 Ω and 375 Ω are connected in parallel. The 250 Ω resistor has a +0.025 fractional error, the 500 Ω resistor has a –0.036 fractional error, and the 375 Ω resistor has a +0.014 fractional error. Determine the fractional error of the total resistance based upon rated values.

(ii) Distinguish between Zener and Avalanche breakdown phenomenon.

[12 + 8 marks]

Sol^n



In Parallel combination

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{— (i)}$$

$$= \frac{1}{250} + \frac{1}{500} + \frac{1}{375}$$

$$= \frac{13}{1500}$$

$$\left[R_{eq} = \frac{1500}{13} = 115.384\,\Omega \right]$$

Differentiating equation (i)

$$-\frac{dR_{eq}}{R_{eq}^2} = -\frac{dR_1}{R_1^2} - \frac{dR_2}{R_2^2} - \frac{dR_3}{R_3^2}$$

or $$\frac{\Delta R_{eq}}{R_{eq}^2} = \frac{\Delta R_1}{R_1^2} + \frac{\Delta R_2}{R_2^2} + \frac{\Delta R_3}{R_3^2}$$

$$\therefore \frac{1}{R_{eq}}\left(\frac{\Delta R_{eq}}{R_{eq}}\right) = \frac{1}{R_1}\left(\frac{\Delta R_1}{R_1}\right) + \frac{1}{R_2}\left(\frac{\Delta R_2}{R_2}\right) + \frac{1}{R_3}\left(\frac{\Delta R_3}{R_3}\right)$$

$$\therefore \frac{13}{1500} \frac{\Delta R_{eq}}{R} = \left(\frac{1}{250} \times 0.025\right) + \left(\frac{1}{500} \times (-0.036)\right) + \left(\frac{1}{375} \times 0.014\right)$$

$$= 10^{-4} - 0.72 \times 10^{-4} + 0.373 \times 10^{-4}$$

$$= (1 - 0.72 + 0.373) \times 10^{-4}$$

$$= 0.653 \times 10^{-4}$$

$$\boxed{\frac{\Delta R_{eq}}{R} = 7.53 \times 10^{-3}}$$

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ii)

Zener Breakdown	Avalanche Breakdown
(a) Zener breakdown occurs when Electric field is more than critical field such that covalent bond breaks which causes large amount of current to flow .i.e., It is due to field ionisation	(a) Avalanche break down occurs when electron occupies sufficient velocity to knockout the outermost electron of another atom creating more charge carrier (carrier multiplication .i.e., It is due to impact ionisation.
b) The Diode is heavily doped	(b) The Diode is Lightly doped.
c) $V_{BR} < 6\,V$	(c) $V_{BR} > 6\,V$

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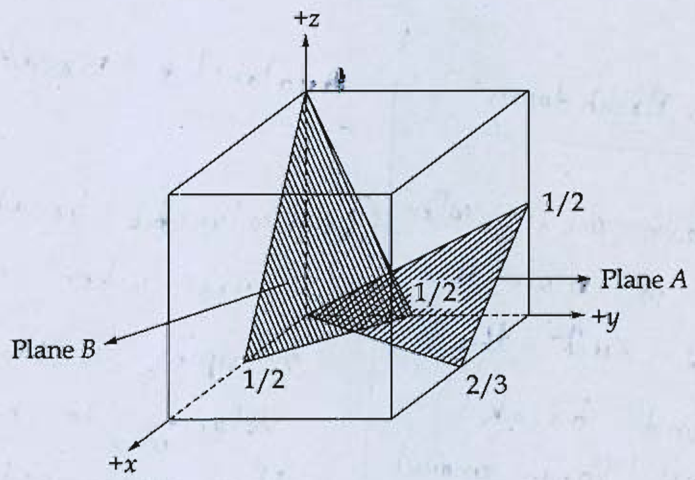
Zener Breakdown	Avalanche Breakdown
(d) The temperature coefficient for zener breakdown is negative	(d) The temperature coefficient for avalanche breakdown is positive.

8

Q.2 (b) (i) Determine the Miller indices for the planes *A* and *B* shown in the following unit cell:



(ii) Explain briefly about Carbon Nanotubes.

[14 + 6 marks]

Sol^n

(i) For Plane 'B'.

Intercept on x-axis $= \frac{1}{2}$

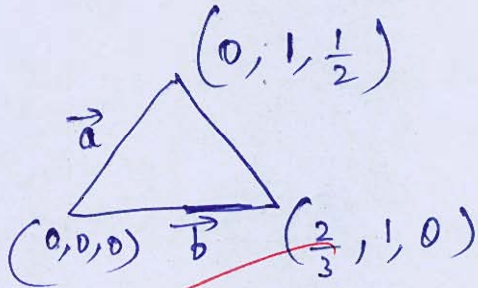
Intercept on y-axis $= \frac{1}{2}$

Intercept on z-axis $= 1$

∴ Miller indices for plane B

$= (2\ 2\ 1)$

For Plane A :



$\vec{a} = \hat{j} + \frac{1}{2}\hat{k}$

$\vec{b} = \frac{2}{3}\hat{i} + \hat{j}$

$\vec{a} \times \vec{b} = \left(\hat{j} + \frac{\hat{k}}{2}\right) \times \left(\frac{2}{3}\hat{i} + \hat{j}\right)$

$= -\frac{2}{3}\hat{k} + \frac{1}{3}\hat{j}$

$= 0\hat{i} + \frac{1}{3}\hat{j} - \frac{2}{3}\hat{k}$

Direction of plane → $0 : 1 : -2$

∴ Miller indices for plane A

$= (0\ 1\ \bar{2})$

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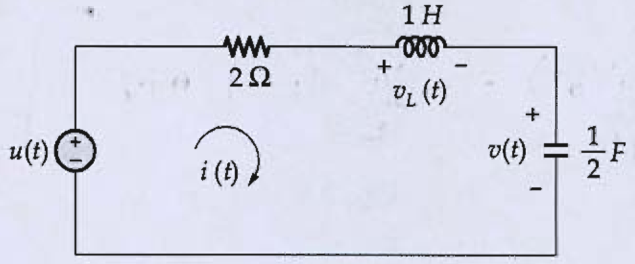
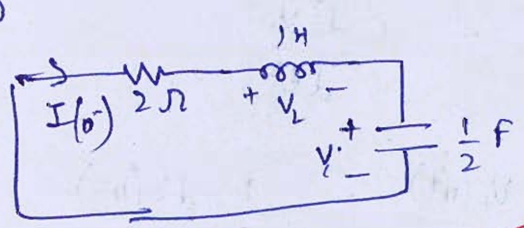
2 (c) For the given series RLC circuit, find the values of $v_L(0^+)$, $\frac{di(0^+)}{dt}$, $\frac{d^2v(0^+)}{dt}$ and determine whether the circuit is underdamped, overdamped or critically damped.



[20 marks]

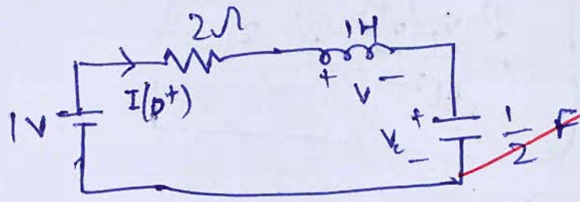
Sol^n

At $t = 0^-$



$I(0^-) = 0$, $V_c(0^-) = 0$

At $t = 0$



As current in the inductor will not change suddenly.

$\therefore \; I(0^+) = I(0^-) = 0$

Voltage across capacitor will not change suddenly

$\therefore \; V_c(0^+) = V_c(0^-) = 0$

Applying KVL, $1 - 0 \times 2 - V_L - 0 = 0$

$$\therefore \; \boxed{V_L(0^+) = 1\,V}$$

$V_L = L \frac{di}{dt}$

$\therefore \boxed{\frac{di(0^+)}{dt} = \frac{V_L}{L} = 1 \text{ A/V}}$

$I = C \frac{dV_c}{dt}$

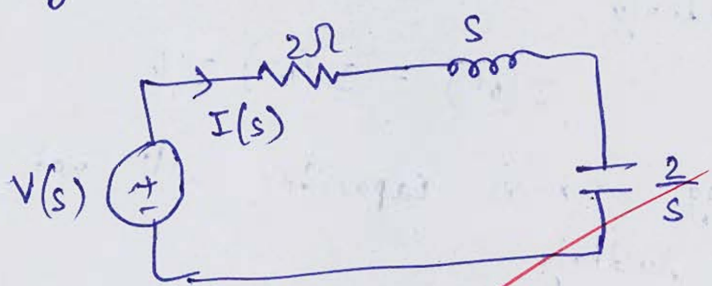
$\frac{dI}{dt} = C \frac{d^2 V_c}{dt^2}$

$\therefore \frac{d^2 V_t(0^+)}{dt^2} = \frac{1}{C} \frac{dI(0^+)}{dt}$

$= \frac{1}{0.5} \times 1$

$\boxed{\frac{d^2 V_t(0^+)}{dt^2} = 2}$

Converting the circuit in Laplace domain



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

$= \frac{s\,V(s)}{s^2 + 2s + 2}$

Characteristic Equation: $s^2 + 2s + 2 = 0$

Comparing with $s^2 + 2\xi\omega_n s + \omega_n^2 = 0$

$$\omega_n = \sqrt{2}$$

$$2\xi \times \sqrt{2} = 2$$

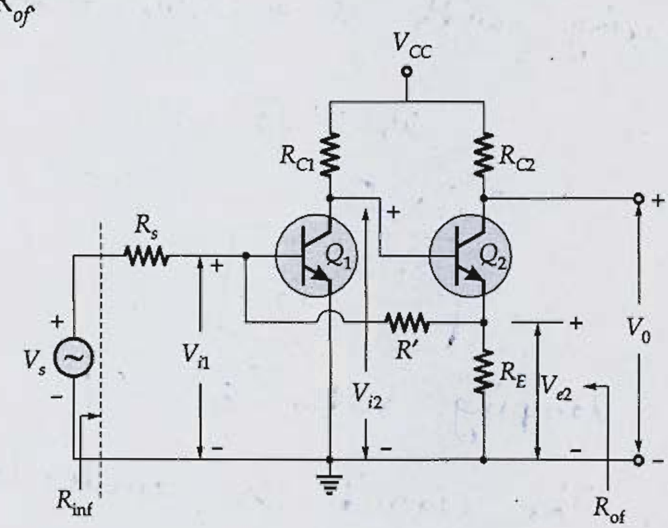
$$\boxed{\xi = \frac{1}{\sqrt{2}}}$$

As damping ratio $(\xi) < 1$

$\therefore$ The circuit is underdamped.

18

Q.3 (a) The feedback amplifier circuit shown below has the following parameters:
$R_{C1} = 3\ \text{k}\Omega$, $R_{C2} = 500\ \Omega$, $R_E = 50\ \Omega$, $R' = R_S = 1.2\ \text{k}\Omega$, $h_{fe} = 50$, $h_{ie} = 1.1\ \text{k}\Omega$, and $h_{re} = h_{ce} = 0$.
Calculate the voltage gain, current gain, input and output resistances with feedback:
A_{Vf}, A_{If}, R_{inf}, R_{of}



[20 marks]

.3 (b) A transformer is rated at 100 kVA. At full load, its copper loss is 1200 W and its iron loss is 960 W. Calculate:

(i) the efficiency at full load, unity power factor,

(ii) the efficiency at half load, 0.8 power factor,

(iii) the efficiency at 75% of full load, 0.7 power factor,

(iv) the load kVA at which maximum efficiency will occur, and

(v) the maximum efficiency at 0.85 power factor.

[20 marks]

Q.3 (c) Design a 3-bit binary counter that goes through the states 0, 2, 4, 6, 0, 2 ... using *D*-flip flops. Assume the unused states as don't cares. Check whether the designed counter is self starting or not and thereby give the complete sequence diagram for the designed counter.

[20 marks]

4 (a) A 3-phase, Y-connected synchronous generator rated at 10 kVA and 230 V has a synchronous reactance of 1.2 ohms per phase and an armature resistance of 0.5 ohms per phase. Calculate the following:

(i) The % voltage regulation at full load with 0.8 lagging power factor.

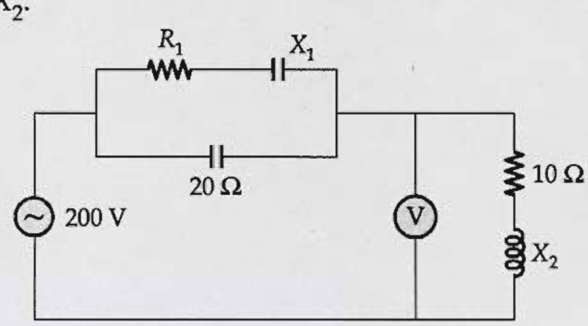
(ii) The power factor of the load such that the voltage regulation is zero on full load.

[20 marks]

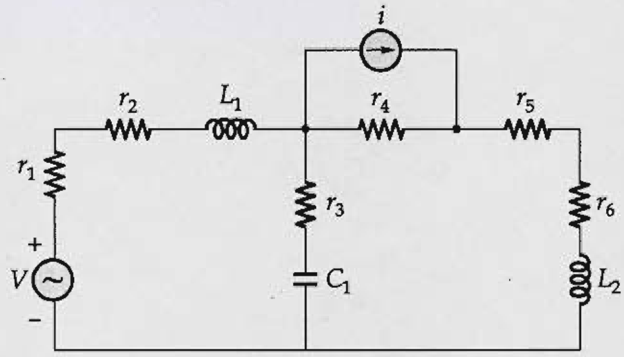
.4 (b) What are the differences between Carbon Dots and Quantum Dots?

[10 marks]

.4 (c) (i) The circuit shown in figure below takes a current of $12\angle 0°$A at a lagging power factor and dissipates 1800 W. The reading of the voltmeter is 200 V. Find R_1, X_1 and X_2.



(ii) For the circuit shown in figure below,



Draw the oriented graph and write:

1. incidence matrix,
2. tieset matrix, and
3. f-cutset matrix

[15 + 15 marks]

Section B

5 (a) Derive the conditions for Reciprocity for short-circuit admittance parameters (Y-parameters) of a two-port network.

[12 marks]

Solⁿ

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

Reciprocity condition in Z-parameter

$$Z_{12} = Z_{21}$$

$$[Y] = [Z]^{-1}$$

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}^{-1}$$

Cofactor Matrix of Z : $\begin{bmatrix} Z_{22} & -Z_{21} \\ -Z_{12} & Z_{11} \end{bmatrix}$

$$\text{Adj}(Z) = \begin{bmatrix} Z_{22} & -Z_{12} \\ -Z_{21} & Z_{11} \end{bmatrix}$$

$$\Delta Z = |Z| = Z_{22}Z_{11} - Z_{12} \cdot Z_{21}$$

$$Z^{-1} = \frac{1}{|Z|}\begin{bmatrix} Z_{22} & -Z_{12} \\ -Z_{21} & Z_{11} \end{bmatrix}$$

$$\therefore \quad Y_{12} = \frac{-Z_{12}}{\Delta Z}$$

$$Y_{21} = \frac{-Z_{21}}{\Delta Z}$$

$$Z_{12} = Z_{21}$$

$$\Rightarrow \quad -Y_{12}\,\Delta Z = -Y_{21}\,\Delta Z$$

$$\therefore \quad \boxed{Y_{12} = Y_{21}}$$

6

.5 (b) A voltage has a true value of 1.50 V. An analog indicating instrument with a scale range of 0-2.50 V shows a voltage of 1.46 V. What are the values of absolute error and correction? Express the error as a fraction of the true value and the full scale deflection (f.s.d).

[12 marks]

Soln

Absolute Error = 1.5 − 1.46

= 0.04 V

Correction = + 0.04 V

Fractional error = $\frac{0.04}{1.5}$

= 0.0267

Fraction of f.s.d = $\frac{0.04}{2.5}$

= 0.016

11

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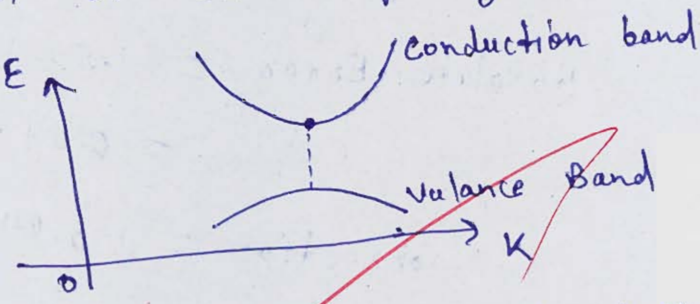
Q.5 (c) Differentiate between Direct and Indirect band gap semiconductors using E-K diagram.

[12 marks]

Sol^n

E-K diagram of Direct ~~bag~~ bandgap semiconductor:

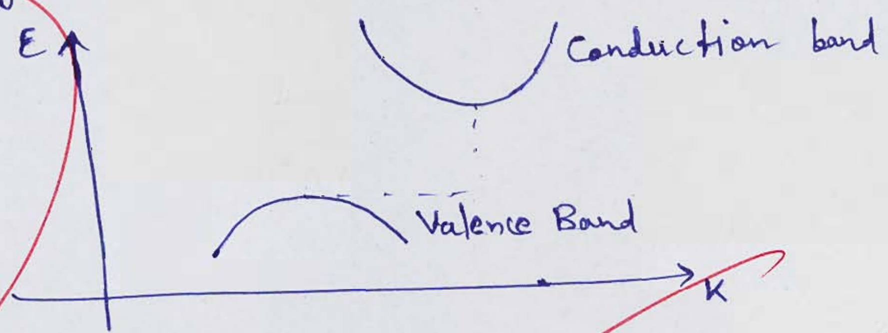


The top of the valence band and bottom of the conduction band occurs at the same value of K (momentum).

Energy radiated is in the form of light.

Ex- GaAs

E-K diagram of Indirect band gap semiconductor.



8

The top of the valence band and bottom of the conduction band occurs at different K (momenta).

Energy radiated is in the form of heat.

Ex- Si, Ge, InP

5 (d) An asynchronous sequential circuit is described by the following excitation and output functions:

$$Y = X_2X_1 + (X_2 + X_1)Y$$

and $Z = Y$

where Z is the output of the circuit.

(i) Draw the logic diagram of the circuit.

(ii) Derive the transition table of the circuit.

[12 marks]

Sol^n

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5 (e) Calculate the dielectric relaxation time constant for a particular 'Si' semiconductor with $\varepsilon_{r_{si}} = 11.7$.
(Assume an n-type semiconductor with a donor impurity concentration of $N_d = 10^{16}$ cm^{-3} and $\mu_n = 1200$ cm^2/V-s.)

[12 marks]

Soln

For n-type semiconductor

Conductivity $(\sigma) \simeq N_d q \mu_n$

$= 10^{16} \times 1.6 \times 10^{-19} \times 1200$

$= 1.92\ \Omega^{-1}\text{cm}^{-1}$

$\varepsilon_{r_{Si}} = 11.7$

$\therefore\ \varepsilon = \varepsilon_0 \varepsilon_{r_{si}}$

$= 8.854 \times 10^{-14} \times 11.7$ F/cm

$= 1.0359 \times 10^{-12}$ F/cm

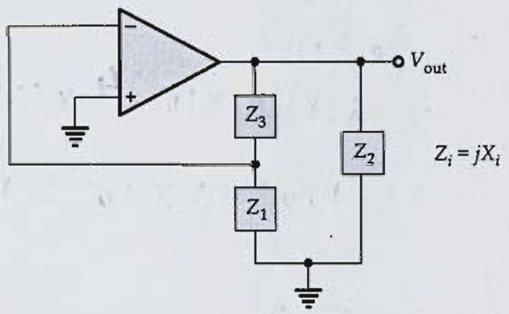
Relaxation time $(\tau_r) = \dfrac{\varepsilon}{\sigma}$

$= \dfrac{1.0359 \times 10^{-12}}{1.92}$ sec.

$= 5.395 \times 10^{-13}$ sec

12

Q.6 (a) Consider the circuit shown in the figure below:

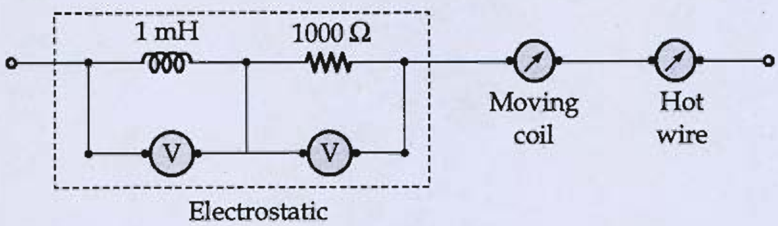


The op-amp in the circuit has a finite open loop gain (A_v), finite output resistance ($R_0 > 0$) and it is ideal in all other aspects. Z_1, Z_2 and Z_3 are purely reactive elements with magnitudes $|X_1|$, $|X_2|$ and $|X_3|$.

Prove that X_1 and X_2 must be of the same type (i.e., both must be either capacitive or inductive) to produce sustained oscillations.

[20 marks]

5 (b) A current of $(0.5 + 0.3 \sin \omega t - 0.2 \sin 2\omega t)$A is passed through the circuit shown in figure below. Determine the reading of each instrument if $\omega = 10^6$ rad/s.



[20 marks]

(c) (i) A 40 kW dc motor has a full load speed of 1150 rpm. The armature current at full load is 80 A and the friction, windage and core-losses are 8500 W. If the flux in each pole of the motor is reduced to 70% of its rated value and armature current is 80 A, what is the electromagnetic torque developed by the motor?

(ii) The metal rubidium has a BCC crystal structure. If the angle of diffraction for the (3 2 1) set of planes occurs at 27° (first-order reflection) when monochromatic X-radiation having a wavelength of 0.0711 nm is used, compute:

1. the interplanar spacing for this set of planes, and
2. the atomic radius for the rubidium atom.

[10 + 10 marks]

7 (a) An abrupt Si *p-n* junction has $N_A = 10^{18}$ cm^{-3} on one side and $N_D = 5 \times 10^{15}$ cm^{-3} on the other. The junction described has a circular cross-section with a diameter of 10 μm. Calculate:

(i) Depletion width on the *n*-side x_{no}.

(ii) Depletion width on the *p*-side x_{po}.

(iii) Accumulated space charge on either side of the junction.

[Assume $n_i = 1.5 \times 10^{10}$ cm^{-3}, $V_T = 25.9$ mV and $\varepsilon_{Si} = 11.8\varepsilon_0$]

[20 marks]

Sol^n

Area $= \frac{\pi d^2}{4} = 78.539\ \mu m^2$

(i) Total width $(W) = \sqrt{\frac{2\varepsilon}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right) V_0}$

$V_0 = V_T \ln \frac{N_a N_D}{n_i^2}$

$= (25.9\ mV) \times \ln\left(\frac{5 \times 10^{15} \times 10^{18}}{2.25 \times 10^{20}}\right)$

$= (25.9\ mv) \times \ln\left(\frac{20}{9} \times 10^{13}\right)$

$= 795.96$ mV

$V_0 \approx 0.796$ V

$$\therefore \quad W = \sqrt{\frac{2 \times 11.8 \times 8.854 \times 10^{-14}}{1.6 \times 10^{-19}} \left(\frac{1}{10^{18}} + \frac{1}{5 \times 10^{15}}\right)(0.796)}$$

$$= \sqrt{130.5965 \times 10^{5} \left(10^{-18} + 0.2 \times 10^{-15}\right) \times 0.796}$$

$$= 4.571 \times 10^{-5} \text{ cm}$$

~~W = 45.71 um~~

$$\boxed{W = 0.457\ \mu m}$$

$$x_{n_0} = \left(\frac{N_A}{N_A + N_D}\right) W$$

$$= \left(\frac{10^{18}}{10^{18} + 5 \times 10^{15}}\right) \times 0.457 \ \mu m$$

$$\boxed{x_{n_0} \simeq 0.4547\ \mu m}$$

ii) $$x_{p_0} = \left(\frac{N_D}{N_A + N_D}\right) W$$

$$\simeq \frac{N_D}{N_A} x_{n_0}$$

$$\simeq \frac{5 \times 10^{15}}{10^{18}} \times 0.4547\ \mu m$$

$$\simeq 2.3 \times 10^{-3}\ \mu m$$

$$\boxed{x_{p_0} \simeq 2.3\ nm}$$

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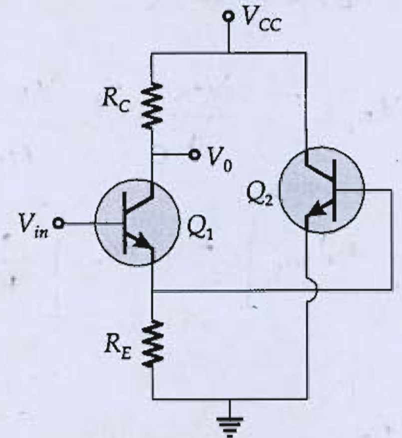
iii) Q (on N-side) $= q N_D x_n \times \text{Area} = 285.6 \times 10^{-16}$ C

Q (on P-side) $= Q$ (on N-side) $= 285.6 \times 10^{-16}$ C

7 (b) Consider the circuit shown in the figure below:

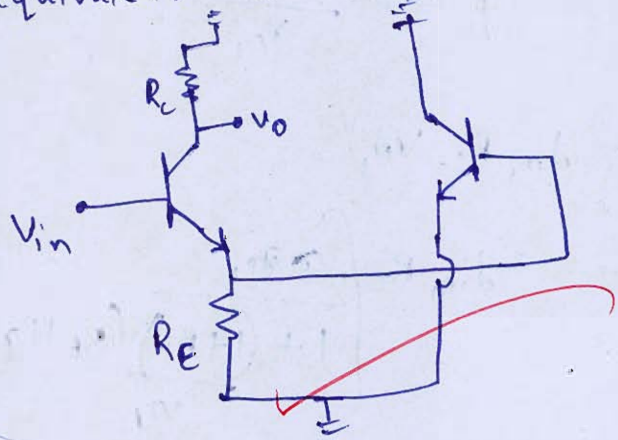


Assume both the transistors are in active region with $V_A = \infty$. Calculate the value of small signal voltage gain $A_V = V_0/V_{in}$.

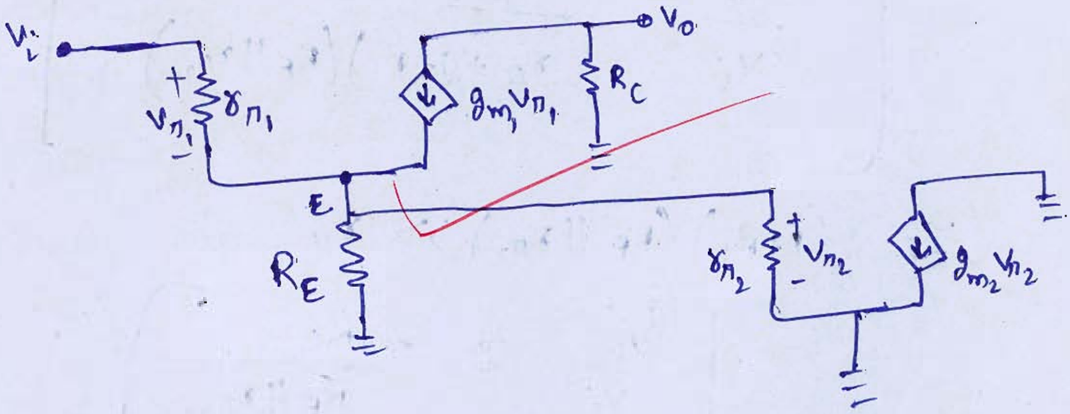
[20 marks]

Sol^n

AC equivalent circuit :-



Equivalent π - Model.



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Applying KCL at node E :

$$\frac{V_{\pi_1}}{r_{\pi_1}} + g_{m_1} V_{\pi_1} = \frac{V_{\pi_2}}{R_E} + \frac{V_{\pi_2}}{r_{\pi_2}}$$

$$V_{\pi_1}\left[\frac{1}{r_{\pi_1}} + g_{m_1}\right] = V_{\pi_2}\left[\frac{1}{R_E} + \frac{1}{r_{\pi_2}}\right] \quad \text{— (i)}$$

$$V_i = V_{\pi_1} + V_{\pi_2}$$

$$= V_{\pi_1} + V_{\pi_1}(R_E \| r_{\pi_2})\left(\frac{1 + g_{m_1} r_{\pi_1}}{r_{\pi_1}}\right)$$

$$= V_{\pi_1}\left[1 + \frac{(1+\beta_1)}{r_{\pi_1}}(R_E \| r_{\pi_2})\right]$$

$$V_o = -g_{m_1} R_C V_{\pi_1}$$

$$\therefore V_o = -g_{m_1} R_C \left[\frac{1}{1 + \frac{(1+\beta_1)}{r_{\pi_1}}(R_E \| r_{\pi_2})}\right] V_i$$

$$V_o = \frac{-g_{m_1} R_C \, r_{\pi_1} V_i}{r_{\pi_1} + (1+\beta_1)(R_E \| r_{\pi_2})}$$

$$\boxed{\frac{V_o}{V_i} = \frac{-\beta_1 R_C}{r_\pi + (1+\beta_1)(R_E \| r_{\pi_2})}}$$

If $(1+\beta_1)(R_E \| r_{\pi_2}) >> r_\pi$

$$\boxed{\frac{V_o}{V_i} \approx -\frac{R_C}{R_E \| r_{\pi_2}}}$$

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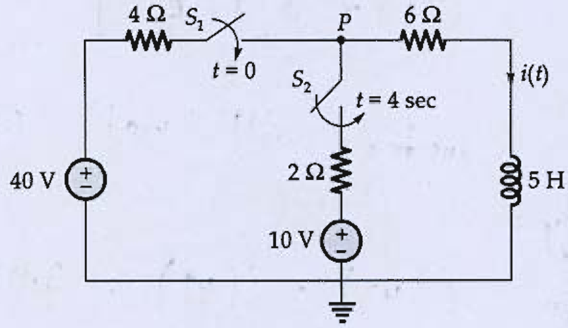
(c) In the circuit shown below, at $t = 0$, switch S_1 is closed, and switch S_2 is closed 4 seconds later. Find $i(t)$ for $t > 0$. Calculate $i(t)$ at $t = 2$ sec and $t = 5$ sec.



[20 marks]

Sol^n

For $0 < t < 4$:

At $t = 0^-$: $i(t) = 0$

$\therefore$ ~~i(a~~ $i(0^+) = 0$

~~$i(t) = \left(\frac{40}{4+6}\right)$~~

$$i(t) = i(\infty) + [i(0) - i(\infty)] e^{-\frac{Rt}{L}}$$

$R = 4\Omega + 6\Omega = 10\Omega$

$L = 5H$

$\therefore$ $i(\infty) = \frac{40}{4+6} = 4A$

$\therefore$ $i(t) = 4 + (0-4) e^{-2t}$

or $i(t) = 4[1 - e^{-2t}]$ for $0 \le t \le 4$

At $t = 2$ sec :

$i(2) = 4[1 - e^{-4}]$

$= 3.92 A$

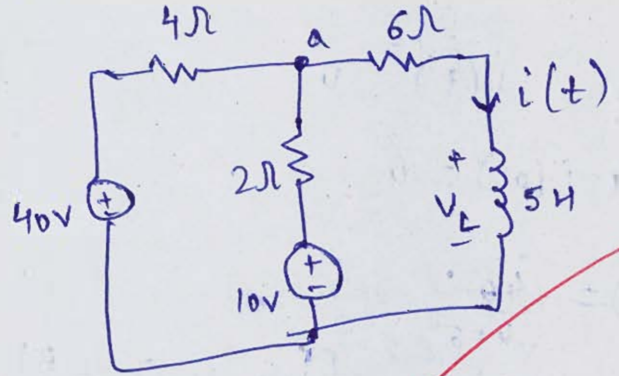
At $t = 4$ sec :

$$i(t) = 4\left[1 - e^{-8}\right] = 3.998 \text{ A}$$

Current in inductor will not change suddenly

So, $i(4^-) = i(4^+) = 3.998$ A

For $t > 4$



Applying ~~nodal~~ KCL at a :

$$\frac{V_a - 40}{4} + \frac{V_a - 10}{2} + i(t) = 0$$

$$\frac{3V_a}{4} - 15 + i(t) = 0 \quad \text{---(i)}$$

$$i(t) = \frac{V_a - V_L}{6} \Rightarrow V_a = V_L + 6\,i(t) \quad \text{---(ii)}$$

& $V_L = L\frac{di}{dt} = 5\frac{di}{dt}$

∴ From equation (i), (ii)

$$\frac{3}{4}(V_L + 6i) - 15 + i = 0$$

$$\frac{3}{4} \times 5\frac{di}{dt} + \frac{9}{2}i - 15 + i = 0$$

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$$\Rightarrow \frac{15}{4}\frac{di}{dt} = 15 - \frac{11}{2}i$$

$$\frac{di}{dt} = 4 - \frac{22}{15}i$$

$$\int_{3.998}^{i} \frac{di}{4-\frac{22}{15}i} = \int_{4}^{t} dt$$

$$-\frac{15}{22}\ln\left|4-\frac{22}{15}i\right| = t-4$$

$$\Rightarrow 4 - \frac{22i}{15} = e^{-\frac{22}{15}(t-4)}$$

$$\Rightarrow i(t) = \frac{15}{22}\left[4 - e^{-\frac{22}{15}(t-4)}\right]$$

$$i(t) = 1.467\left[4 - e^{-1.467(t-4)}\right] \quad t > 4$$

$$\left[\, i(5) = 5.529\,A \,\right]$$

6

(a) (i) In a particular semiconductor material, $\mu_n = 1000\ cm^2/V\text{-}s$, $\mu_p = 600\ cm^2/V\text{-}s$ and $N_C = N_V = 10^{19}\ cm^{-3}$. These parameters are independent of temperature. The measured conductivity of the intrinsic material is $\sigma = 10^{-6}\ (\Omega\text{-}cm)^{-1}$ at $T = 300$ K. Find the conductivity of the semiconductor at $T = 500$ K.

(ii) Calculate the velocity of an electron beam in an oscilloscope if the voltage applied to its vertical deflection plates is 2000 V. Also, calculate the cutoff frequency if the maximum transit time is $\frac{1}{4}$ of a cycle. The length of horizontal plate is 50 mm.

[15 + 5 marks]

Sol^n

using,
$$n = N_c e^{-(E_c - E_{Fi})/KT}$$
$$p = N_v e^{-(E_{Fi} - E_v)/KT}$$

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

$$\sigma = n_i q(\mu_n + \mu_p) \quad \text{[Intrinsic semiconductor]}$$

$$n_i^2 = N_c N_v e^{-(E_c - E_v)/KT}$$

$$n_i^2 = N_c N_v e^{-E_g/KT}$$

$$n_i = \sqrt{N_c N_v}\, e^{-E_g/2KT}$$

$$\sigma = n_i q(\mu_n + \mu_p)$$

At $T = 300K$: $\sigma = 10^{-6}\ (\Omega\text{-cm})^{-1}$

$$\Rightarrow 10^{-6} = n_i \times 1.6\times10^{-19} \times 1600$$

$$n_i = \frac{10^{-6}}{1.6\times10^{-19}\times1600} = \frac{10^{13}}{1.6\times1600}$$

$$n_i = 390625\times10^{4}\ cm^{-3}$$

Also, $n_i = \sqrt{N_c N_v}\, e^{-E_g/2KT}$

$$\Rightarrow \frac{E_g}{2KT} = \ln\frac{\sqrt{N_c V_v}}{n_i}$$

$$E_g = 2KT \ln\frac{\sqrt{N_c N_v}}{n_i}$$

$$= 2\times1.38\times10^{-23}\times300 \ln\frac{10^{19}}{390625\times10^{4}}$$

$$E_g = 8.28\times10^{-21}\times21.66\ J$$

$$E_g = 179.37\times10^{-21}\ J$$

At $t = 500K$

$$n_i = 10^{19}\, e^{-\frac{179.37\times10^{-21}}{2\times1.38\times10^{-23}\times500}}$$

$$\simeq 10^{19}\, e^{-13}$$

$$n_i \approx 2.26\times10^{13}\ cm^{3}$$

$\therefore \sigma_{500} = 2.26 \times 10^{13} \times 1.6 \times 10^{-19} \times 1600$

$= 5.786 \times 10^{-3} \ (\Omega\text{-cm})^{-1}$

ii) $\frac{1}{2} m v^2 = qV$

$v = \sqrt{\frac{2qV}{m}}$

$= \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 2000}{9.1 \times 10^{-31}}}$ m/s

$v = 2.65 \times 10^{7}$ m/s

Transit Time

~~Cycle time =~~

Transit time $= \frac{50 \times 10^{-3}}{2.65 \times 10^{7}}$

$= 18.86 \times 10^{-10}$ sec

cycle time $= 4 \times 18.86 \times 10^{-10}$

$= 75.47 \times 10^{-10}$ sec

$\therefore$ Frequency = 132.5 MHZ

0

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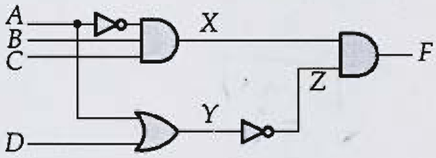
Q.8 (b) **(i)** A combinational circuit has three inputs *A*, *B* and *C*, and three outputs *X*, *Y* and *Z*. When the binary input is 0, 1, 2 or 3, the binary output is one greater than the input. When the binary input is 4, 5, 6 or 7, the binary output is two less than the input. Design this circuit using basic logic gates.

(ii) Analyze the operation of the logic circuit shown in the figure below by creating a table showing the logic state at each node of the circuit. Comment on the operation of the circuit.



[15 + 5 marks]

Sol^n

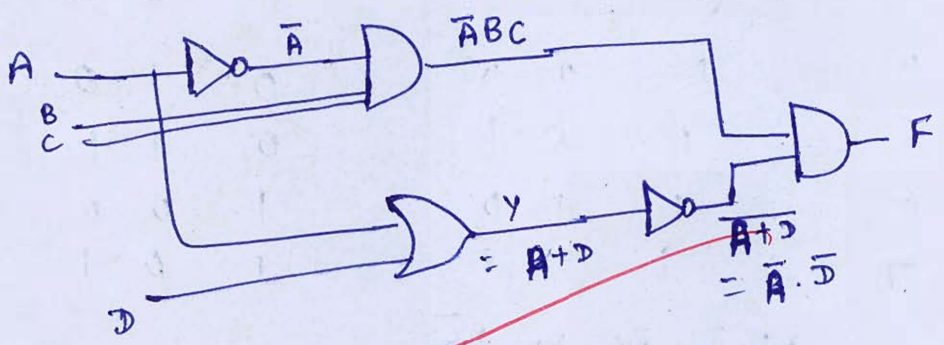
(i)

A	B	C	X
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	
1	0	1	
1	1	0	
1	1	1	

A_1	A_0	X_1	X_0
0	0	0	1
0	1	1	0
1	0	1	1
1	1	0	0

A			X		
a_2	a_1	a_0	x_2	x_1	x_0
0	0	0	0	0	1
0	0	1	0	1	0
0	1	0	0	1	1
0	1	1	1	0	0
1	0	0	0	1	0
1	0	1	0	1	1
1	1	0	1	0	0
1	1	1	1	0	1

ii)



$F = \bar{A}BC \cdot \bar{A} \cdot \bar{D}$

$$\boxed{F = \bar{A}BC\bar{D}}$$

A	B	C	D	F
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	0
0	1	1	0	1
0	1	1	1	0
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	0
1	1	0	0	0
1	1	0	1	0
1	1	1	0	0
1	1	1	1	0

(i)

	A	B	C	X	Y	Z
0	0	0	0	0	0	1
1	0	0	1	0	1	0
2	0	1	0	0	1	1
3	0	1	1	1	0	0
4	1	0	0	0	1	0
5	1	0	1	0	1	1
6	1	1	0	1	0	0
7	1	1	1	1	0	1

X :

A \ BC	$\bar{B}\bar{C}$	$\bar{B}C$	BC	$B\bar{C}$
$\bar{A}$			1	
A			1	1

$\Rightarrow X = BC + AB$

Y :

A \ BC	$\bar{B}\bar{C}$	$\bar{B}C$	BC	$B\bar{C}$
$\bar{A}$		1		1
A	1	1		

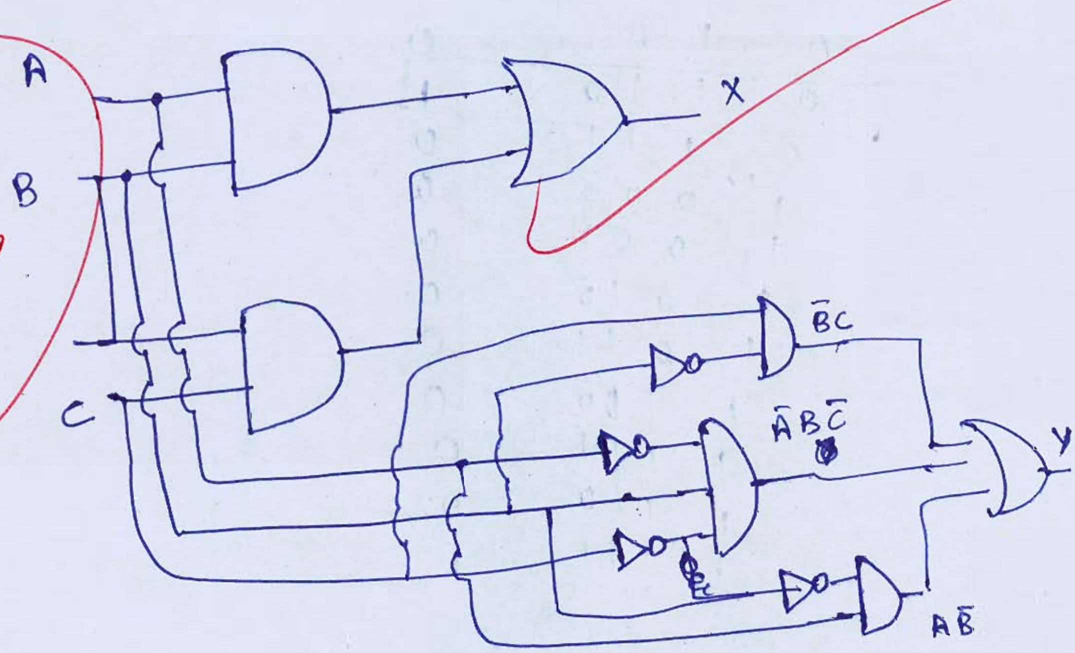
$Y = \bar{B}C + A\bar{B} + \bar{A}B\bar{C}$

Z :

A \ BC	$\bar{B}\bar{C}$	$\bar{B}C$	BC	$B\bar{C}$
$\bar{A}$	1			1
A		1	1	

$Z = \bar{A}\bar{C} + AC$

15



(c) A R-L-C series circuit with a resistance of 10 Ω, inductance of 0.2 H and a capacitance of 40 μF is supplied with a 100-V supply at variable frequency. Find the following with respect to series resonant circuit:

(i) the frequency at which resonance takes place.

(ii) the current at resonance.

(iii) power.

(iv) power factor.

(v) magnitude of voltage across *R*, *L*, *C* at resonance.

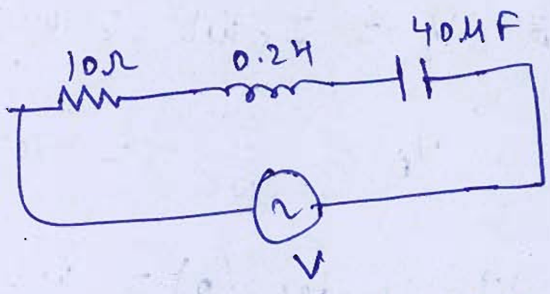
(vi) quality factor.

(vii) half-power frequencies.

(viii) phasor diagram and plot of current variation with frequency.

[20 marks]

Sol^n



(i) Resonant Frequency $(f_c) = \frac{1}{2\pi\sqrt{LC}}$

$$= \frac{1}{2\pi\sqrt{0.2 \times 40 \times 10^{-6}}}$$

$$\boxed{f_c = 56.269 \text{ Hz}}$$

(ii) Current at Resonance $(I) = \frac{V}{R}$

$= \frac{100}{10}$

$= 10A$

(iii) Power $= I^2 R$

$= (10)^2 \times 10$

$= 1000\ W$

(iv) Power factor $= \cos\phi = \frac{R}{Z}$

$Z = R$ (at Resonance)

$\therefore$ Power factor $= 1$

(v) Magnitude of voltage:

$V_R = 100V$

$V_L = I \times \omega L = 10 \times 2\pi \times 56.269 \times 0.2$

$= 707.1\ V$

$V_C = \frac{I}{\omega C} = 707.1\ V$

vi) Quality Factor $(Q) = \frac{\omega L}{R}$

$= \frac{V_L}{V_R}$

$= \frac{707.1}{100}$

$= 7.071$

(vii) At half power :

$$Z_{eq} = R \pm jR$$

$$\therefore \quad \omega_H L - \frac{1}{\omega_H C} = R$$

$$\omega_H^2 LC - 1 = R\omega_H C$$

$$\omega_H^2 - \frac{R}{L}\omega_H - \frac{1}{LC} = 0$$

$$\omega_H^2 - \frac{10}{0.2}\omega_H - 125000 = 0$$

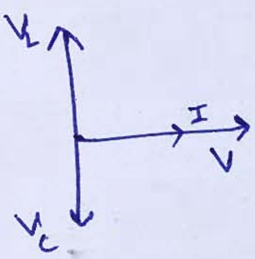
$$\omega_H^2 - 50\omega_H - 125000 = 0$$

$$\omega_H = 379.43$$

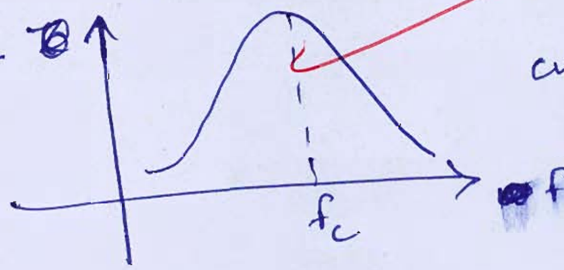
$$\boxed{f_H = 60.38 \text{ HZ}}$$

$$f_L f_H = f_c^2 \Rightarrow f_L = \frac{f_c^2}{f_H} = 52.434 \text{ HZ}$$

viii)



Phasor diagram



current vs frequency

19

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$$i = \frac{15}{22}\left[4 - e^{-\frac{22}{15}(t-4)}\right]$$

$$\ln\left(4 - \frac{22i}{15}\right) = -\frac{22}{15}(t-4)$$

$1.6\times10^{-19} \times \frac{5\times10^{15}}{10^{12}} \times 0.4547 \times 78.539$

$10^{-19} \times 10^{3}$

10^{-16}

$1\,cm = 10^{-4}\,\mu m$ $4.5\times10^{-6}\,m$

10^{-7}

4.5

$\frac{V}{I} = \frac{1}{\sigma}\frac{L}{A}$

4.5×10^{-7}

$\Omega - cm$

$4.5\times10^{-} \frac{\varepsilon}{\sigma}$ 10^{-1}

$N_A x_p = N_D x_n$

$\frac{\partial\rho}{\partial t} = -\partial\rho_v$

$1\,\mu m = 10^{-4}\,cm$

$\frac{1}{-2\times1}$ $\frac{1}{-3\times-1}$

ε/σ

$\nabla\cdot J = -\frac{\partial\rho_v}{\partial t}$

$\sigma(\nabla\cdot E) = -\frac{\partial\rho_v}{\partial t}$

$\frac{\sigma}{\varepsilon}\cdot\rho_v = -\frac{\partial\rho_v}{\partial t}$

Space for Rough Work