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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 ☐	
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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	39
Q.2	/
Q.3	48
Q.4	/
Section-B	
Q.5	40
Q.6	/
Q.7	53
Q.8	53
Total Marks Obtained	233

Signature of Evaluator .... Cross Checked by ....

Good attempt.

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IMPORTANT INSTRUCTIONS

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

DONT'S

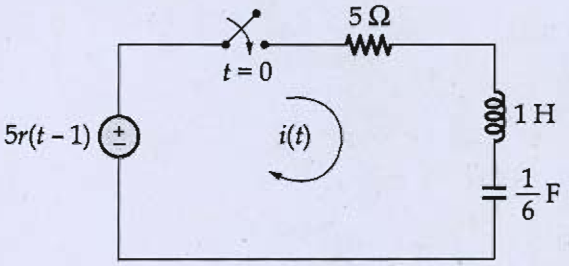
1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify 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

(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]

1. (a) from given circuit, initial conditions = 0.

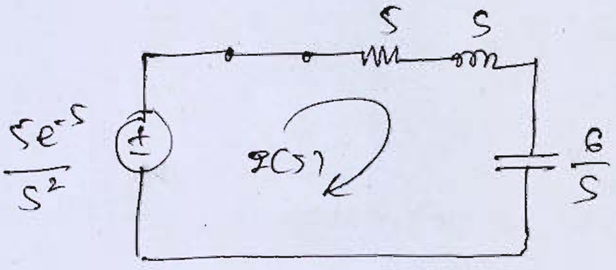
i.e $i_L(0^-)=0$ & $V_C(0^-) = 0$.

statement: we know, $r(t) = t\cdot u(t) \rightleftharpoons R(s) = \frac{1}{s^2}$

$\downarrow t \to t-1$

$r(t-1) = (t-1)u(t-1) \rightleftharpoons R(s) = \frac{e^{-s}}{s^2}$

∴ drawing the circuit by taking laplace transform after switch is closed,



∴ $I(s) = \frac{V(s)}{Z(s)}$

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

$I(s) = \frac{\frac{5e^{-s}}{s^2}}{\frac{s^2+5s+6}{s}}$ $\Rightarrow \boxed{I(s) = \frac{5e^{-s}}{s(s^2+5s+6)}}$ — ①

∴ ① is response in laplace domain.

Taking partial fractions:

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

$$I(S) = \frac{\overset{5/6}{A}}{S} + \frac{\overset{5e^3/3}{B}}{S+3} + \frac{\overset{-5/2\, e^2}{C}}{S+2}$$

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

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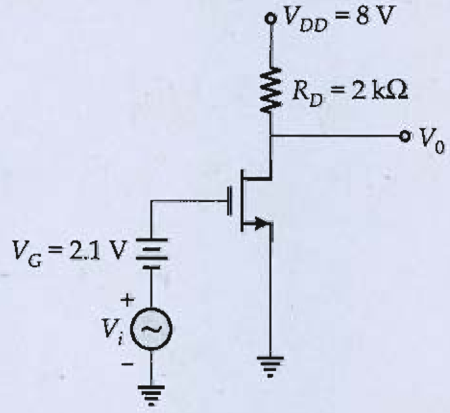
$$\therefore i(t) = \frac{5}{6}u(t) + \frac{5}{3}e^{-3t}\cdot e^{3}u(t) - \frac{5}{2}e^{-2t}e^{2}\cdot u(t)$$

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

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]

Q1 ⓑ Given: $V_{TN} = 1V$

$K = 0.9 \text{ mA}/V^2$

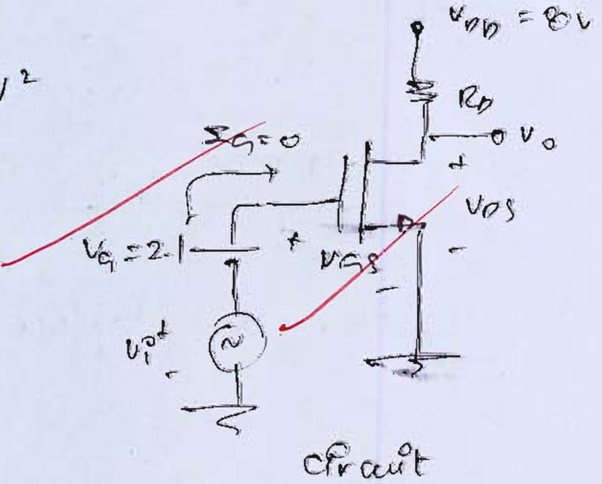
dc analysis,

$v_i \simeq 0$ v.

$V_{GS} = V_G - V_S$

$= 2.1 - 0$

$\boxed{V_{GS} = 2.1V}$



circuit

statement : we know for MOSFET in saturation,

$$I_{DS} = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS}-V_T)^2 \quad - ②$$

$$I_{DS} = K_n(V_{GS}-V_T)^2 \quad - ①$$

using ①, $I_{DS} = 0.9(2.1-1)^2$

$$\boxed{I_{DS} = 1.089 \text{ mA}}$$

from ② & ①,

$$\frac{\partial I_{DS}}{\partial V_{GS}} = g_m = 2K_N(V_{GS}-V_T) \quad - ③$$

$$\therefore \quad g_m = 2\times 0.9(2.1-1)$$

$$\boxed{g_m = 1.98 \text{ m℧}}$$

(iii) if $V_i = 10$ mV.

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

$$V_o = -g_m V_i \times R_D.$$

$$V_o = -1.98\times 2\times 10\times 10^{-3}(\sin\omega_o t)$$

$$\boxed{V_o = -39.6 \sin\omega_o t \text{ mV}.}$$

with DC input,

$$V_0 = -39.6\sin\omega_0 t + V_{DD} - I_D \times R_D$$

$$v_0 = -39.6\sin\omega_0 t + (8 - 2\times 1.089)$$

$$\boxed{v_0(t) = 5.822\text{v} - 39.6\sin\omega_0 t \text{ mV}}$$

ans.

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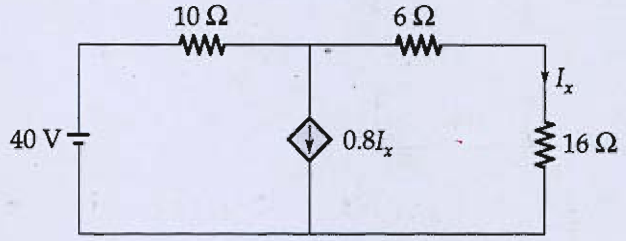
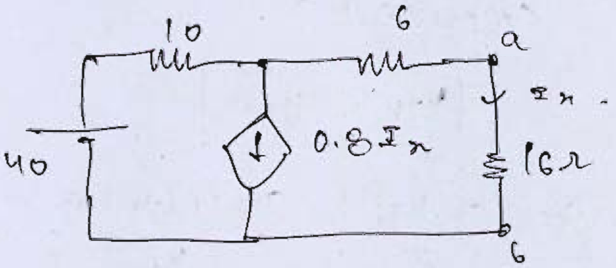
(c) For the network shown below, determine the current in the 16 Ω resistor using Thevenin's theorem.



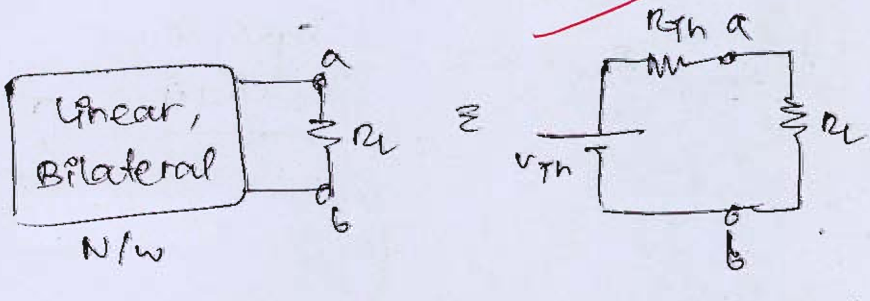
[12 marks]

(c)

Given: circuit



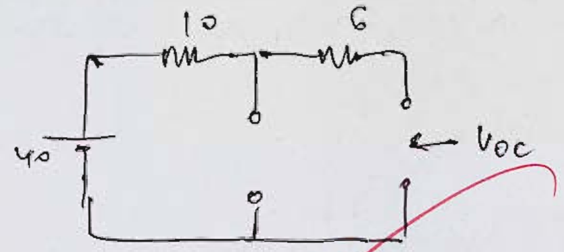
Statement: In a linear, bilateral network consisting of independent & dependent sources and elements, the entire network can be replaced by an equivalent circuit of voltage source & resistance.



where, V_{Th}: Thevenin voltage w.r.t. ab terminals, (open circuited)

R_{Th}: Thevenin resistance when all sources are replaced by their internal resistances.

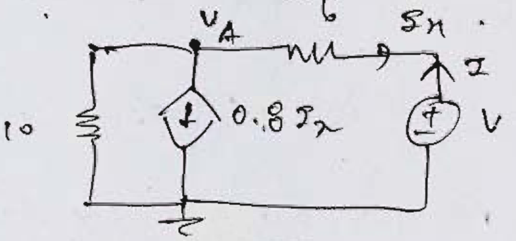
V_{Th} :



∵ $i_x = 0$. ∴ current source is open circuited (dependent).

$$\boxed{V_{Th} = 40V}$$

Calculation of R_{Th} : Considering a source V.



$$\boxed{I_x = -I}$$

By KCL,

$$\frac{V_A}{10} + 0.8 I_x + I_x = 0 \quad \text{①}$$

$$\frac{V_A - V}{6} = I_x \quad \text{②}$$

$$\frac{V_A}{10} = -1.8 I_x$$

$$V_A = -18 I_x \quad \text{③}$$

Put ③ in ②.

$$-18 I_x - V = 6 I_x$$

$$-V = 24 I_x$$

but

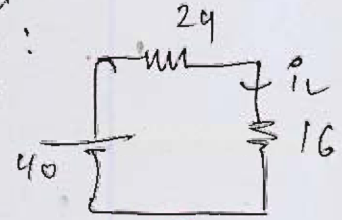
$I_x = -I$.

$V = 24 I$

∴ $\frac{V}{I} = R_{Th} = 24$

$$\boxed{R_{Th} = 24\Omega}$$

Equivalent circuit :



∴ $i_L = \frac{40}{24+16}$

∴ $\boxed{i_L = 1A}$

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(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]

(d) Given: $M = 3.2 \times 10^5$ A/m.

$H = 50$ A/m.

(i) magnetic susceptibility (χ_m)

we know $\chi_m = \frac{M}{H} = \frac{3.2 \times 10^5}{50}$.

$$\boxed{\chi_m = 6400}$$

(ii) permeability (μ_r).

$$\chi_m = \mu_r - 1.$$

$$\therefore \boxed{\mu_r = 6401}.$$

(iii) $B = \mu_0 (1 + \chi_m) H$.

$$\therefore B = 4\pi \times 10^{-7} (6401) \times 50.$$

$$\boxed{B = 0.40 \ A/m^2}$$

Since $\chi_m = 6400$ (+ive)

it represents a material which has a strong ability to get magnetized.

as χ_m represents ability to get magnetized.

The material can be ferro magnetic in nature.

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.

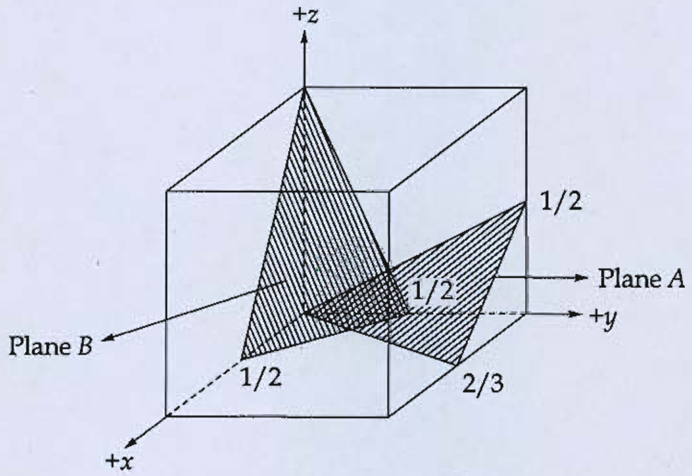
[12 marks]

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]

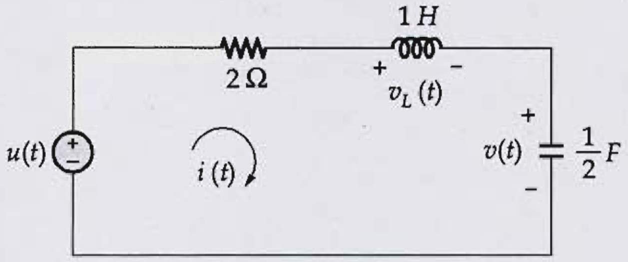
Q.2 (b) **(i)** Determine the Miller indices for the planes *A* and *B* shown in the following unit cell:



(ii) Explain briefly about Carbon Nanotubes.

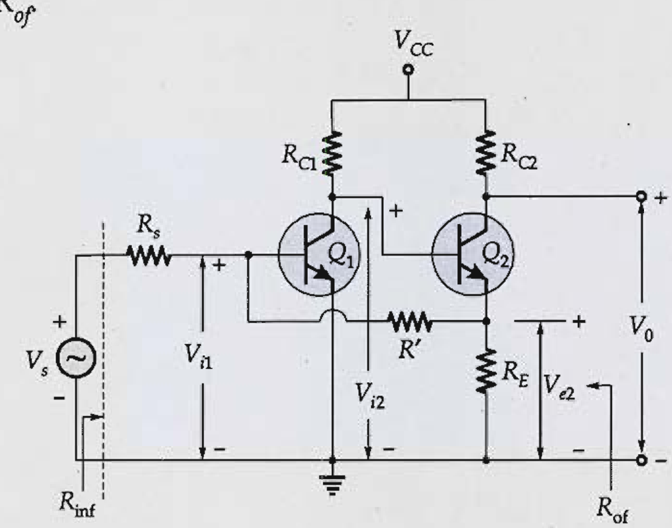
[14 + 6 marks]

(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]

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]

Q3) (a) ① Given circuit has current - shunt feedback.

∵ feed back not directly connected to output node → current sampling.

feedback directly connected to input node → shunt mixing.

② Calculation of feed back factor (β).

$$v_{e2} = v_{i1} \times \frac{R_E}{R'+R_E}$$

$$\beta = \frac{R_E}{R'+R_E} = \frac{0.5}{1.2+0.5}$$

$$\boxed{\beta = 0.294}$$

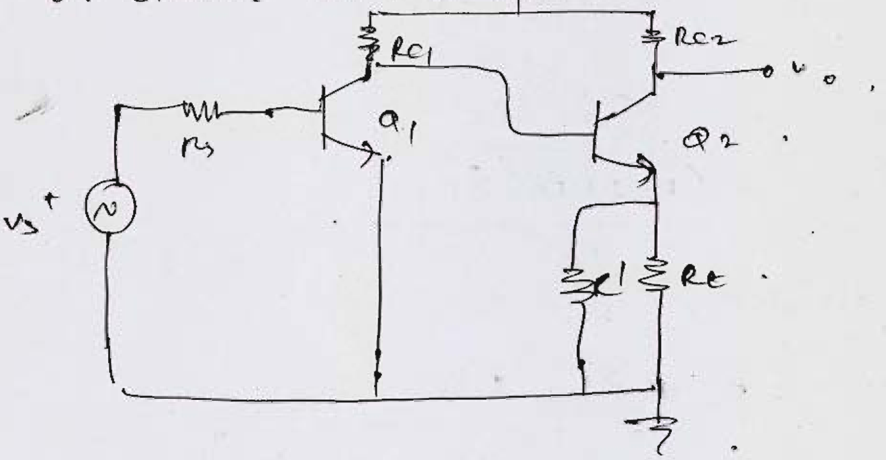
③ Considering circuit without feedback.

output side → input → shunt mixing

(R' appears in parallel with R_E.)

Input side → output → current sampling, breaking the output node.

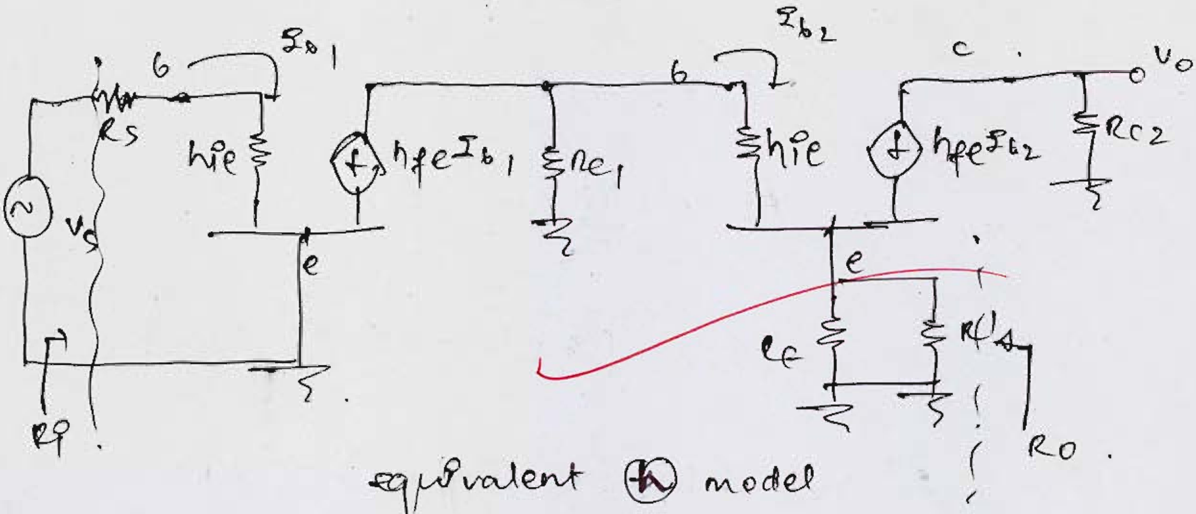
∴ circuit without feed back.



(AC equivalent circuit)

(here, voltage Vcc is grounded).

respective h-parameter model:



equivalent (h) model

without feedback

$R_i = R_s + h_{ie} = 1.2 + 101 = 2.3$ kΩ

$R_o = R_E || R' = 50 || 62 = 1.718$ kΩ.

Voltage gain: ~~Av ⇒~~ $-h_{fe} I_{b2} R_{C2} = V_o$

$A_V = \frac{V_o}{V_S}$.

V_s ⇒ By KVL @ input side

$-V_s + (R_s + h_{ie}) I_{b1} = 0$.

$V_s = (R_s + h_{ie}) I_{b1}$ - ① .

$$\therefore \boxed{\frac{V_o}{V_s} = \frac{-h_{fe} I_{b2} R_{c2}}{(R_s + h_{ie}) I_{b1}}}$$

By current division,

$$I_{b2} = \frac{-h_{fe} I_{b1} \times R_{c1}}{R_{c1} + [h_{ie} + R_E || R']}$$

on solving,

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$$I_{b2} = \frac{-50 \times I_{b1} \times 3}{3 + [101 + 1.718]}$$

$I_{b2} = -25.78 I_{b1}$.

$$A_I = \frac{I_L}{I_S} = \frac{I_{b2}}{I_{b1}}$$

$$\boxed{A_I = -25.78 \text{ A/A}}$$

$$\therefore A_V = \frac{-h_{fe} \times -25.78 \times \cancel{I_{b1}} \times R_{c2}}{(R_s + h_{ie}) \cancel{I_{b1}}}$$

$$A_V = \frac{-50 \times -25.78 \times 0.5}{(1.2 + 101)}$$

$$\boxed{A_V = 280.21 \text{ V/V}}$$

Desensitivity factor (D) = $1+\beta A$

$D = 1 + 0.294 \times 280.21$

$\boxed{D = 83.41}$ 6

$A_{vf} = \frac{A}{1+\beta A}$

$R_{if} = R_i/(1+\beta A) = \frac{2.3}{83.41}$

$A_{vf} = \frac{280.21}{83.41}$

$R_{of} = R_o \times (1+\beta A)$

$\boxed{R_{if} = 27.57\,\Omega}$ $\boxed{A_{vf} = 3.35\,V/V}$ 6

$\boxed{R_{of} = 143.29\,k\Omega}$ 6 $\boxed{A_{If} = -2150.30\,A/A}$

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]

3 ⑥ Given! $S = 100\ kVA$.

$P_{cufl} = 1200$

$P_i = 960w$.

Statement: efficiency for a transformer is calculated

as, ① $\eta_{fl} = \frac{(kVA)_R \cos\phi}{(kVA)_R \cos\phi + \underset{(kW)}{P_{cu\,fl}} + \underset{(kW)}{P_{ir\,fl}}}$

or

② $\eta_{x\text{-}fl} = \frac{(kVA)_R \times x \times \cos\phi}{(kVA)_R \times x \times \cos\phi + x^2 \underset{(kW)}{P_{cufl}} + \underset{(kW)}{P_i}}$

$$\therefore \quad \eta_{Fl} = \frac{100 \times \cancel{10^3} \times 1}{100 \times \cancel{10^3} \times 1 + 1.2 + 0.96}.$$

$$\eta_{Fl} = 0.9788$$

$$\boxed{\% \eta_{Fl} = 97.88 \%}.$$

(ii) $\eta_{\frac{1}{2}Fl}$, $\cos\phi = 0.8$.

$$\eta_{\frac{1}{2}Fl} = \frac{100 \times \frac{1}{2} \times 0.8}{100 \times \frac{1}{2} \times 0.8 + \frac{1}{4} \times 1.2 + 0.96}.$$

$$\boxed{\eta_{\frac{1}{2}Fl} = 96.94 \%}$$

(iii) $\eta_{\frac{3}{4}Fl}$, $\cos\phi = 0.7$.

$$\eta_{\frac{3}{8}Fl} = \frac{100 \times \frac{3}{8} \times 0.7}{100 \times \frac{3}{8} \times 0.7 + \left(\frac{3}{8}\right)^2 \times 1.2 + 0.96}.$$

$$= \frac{26.25}{26.25 + 0.16875 + 0.96}$$

$$\eta_{\frac{3}{8}Fl} = 0.9587$$

$$\boxed{\% \eta_{\frac{3}{8}Fl} = 95.87 \%}$$

(iv) for maximum efficiency,

$$\boxed{\text{variable losses} = \text{constant losses}}.$$

$$y^2 I_{Fl}^2 \times R = P_{iron}$$

$$y = \sqrt{\frac{P_{iron}}{I_{Fl}^2 \times R}}$$

$$y = \sqrt{\frac{960}{1200}} = 0.8944.$$

$$\text{load KVA} = 0.8944 \times 100$$

$$= \boxed{89.44 \text{ KVA}}$$

(v) maximum efficiency @ 0.85 pF.

$$\eta_{max} = \frac{(KVA)_{max} \times 0.85}{(KVA)_{max} \times 0.85 + 2P_i}.$$

$$= \frac{89.44 \times 0.85}{89.44 \times 0.85 + 2 \times 0.96}.$$

$$\boxed{\eta_{max} = 97.53\%}.$$

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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]**

Q3 ⓒ desired sequence : $⓪ \to ② \to ④ \to ⑥ \to ⓪$

Table :

Q_2	Q_1	Q_0	Q_2^+	Q_1^+	Q_0^+	D_2	D_1	D_0
0	0	0	0	1	0	0	1	0
0	0	1	x	x	X	X	X	X
0	1	0	1	0	0	1	0	0
0	1	1	x	x	X	X	X	X
1	0	0	1	1	0	1	1	0
1	0	1	x	x	x	X	X	X
1	1	0	0	0	0	0	0	0
1	1	1	x	x	x	X	X	X

statement : we know, $\boxed{Q^+ = D}$

property of D - flip flop.

K-map for respective D inputs :

for D_2 :

$Q_2 \backslash Q_1Q_0$	00	01	11	10
0	$_0$	X_1	X_3	1_2
1	1_4	X_5	X_7	$_6$

$D_2 = \bar{Q}_2 Q_1 + Q_2 \overline{Q_1}$

$\boxed{D_2 = Q_2 \oplus Q_1}$

for D_1 :

$Q_2 \backslash Q_1Q_0$	00	01	11	10
0	1_0	X_1	X_3	$_2$
1	1_4	X_5	X_7	$_6$

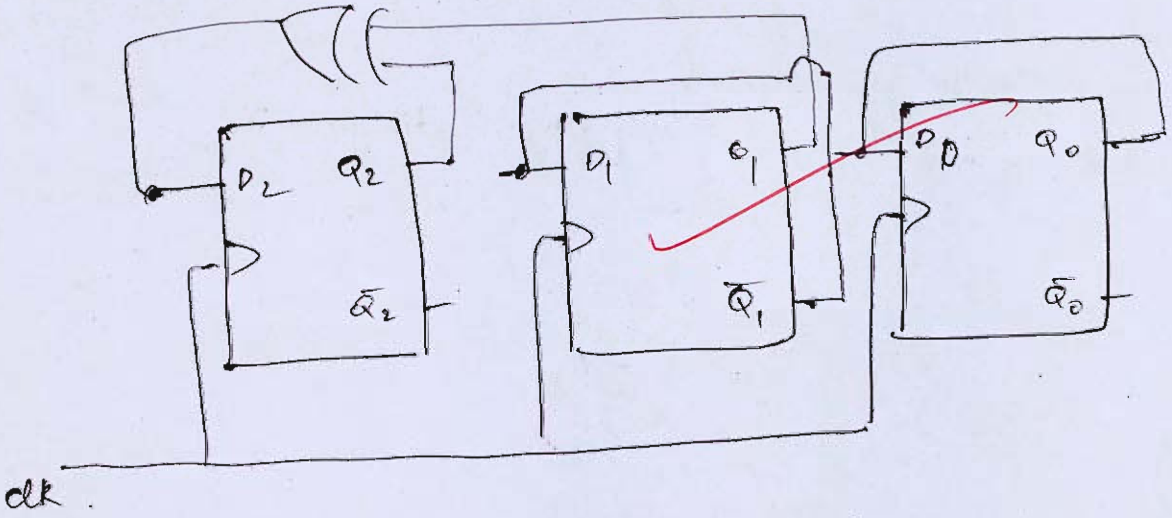
$$\boxed{D_1 = \overline{Q_1}}$$

for D_0 :

$Q_2 \backslash Q_1Q_0$	00	01	11	10
0	$_0$	X_1	X_3	$_2$
1	$_4$	X_5	X_7	$_6$

$$\boxed{D_0 = Q_0}$$

ⓒ Diagramatic representation



(3- bit binary counter)

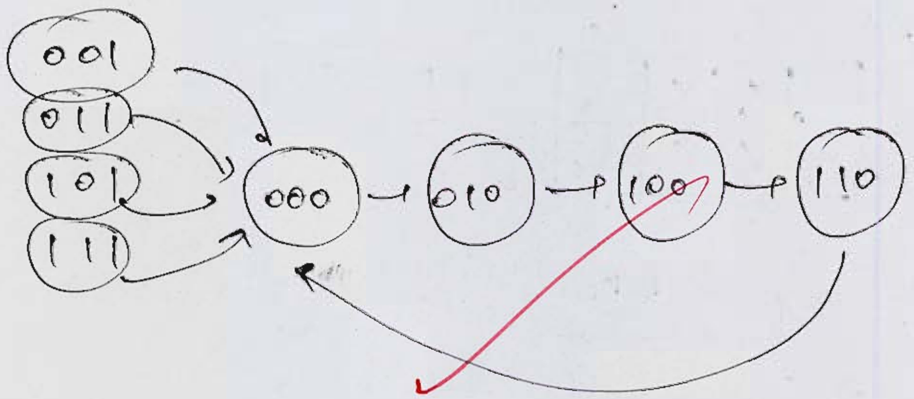
for self starting,

considering input $Q_2Q_1Q_0$ = 000.

since next state is 010.

Hence counter is self starting.

overall sequence diagram :-



(sequence diagram)

20

(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.

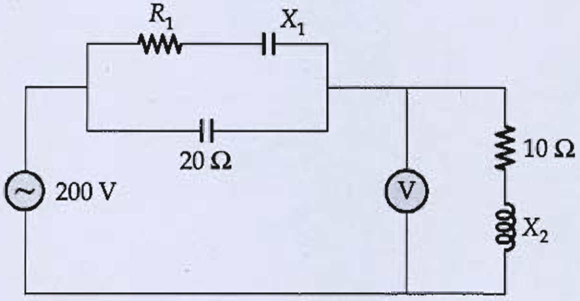
(ii) The power factor of the load such that the voltage regulation is zero on full load.

[20 marks]

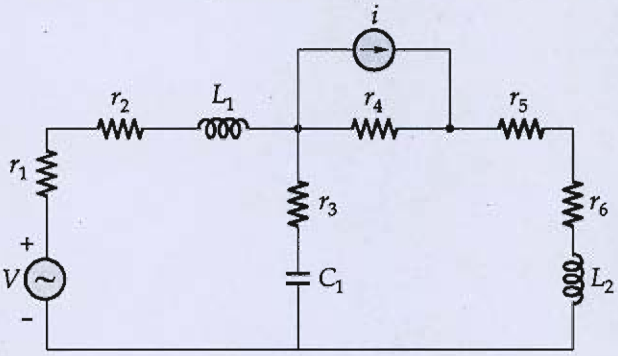
(b) What are the differences between Carbon Dots and Quantum Dots?

[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]

Q5) (a) To prove : $\boxed{Y_{12} = -Y_{21}}$ - ①

① Represents the condition for Reciprocity for Y parameters.

①

Q.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]

Q5 ① Given: $A_T = 1.50$ V.

Range: 0 - 2.5 V

$A_m = 1.46$.

Statement: we know,

$$\boxed{A_m = A_T \pm \delta A}.$$

δA : Absolute error.

∴ 1.50 − 1.46 = ± δA

$$\boxed{\delta A = -0.04} \quad ①$$

① represents absolute error.

$$\boxed{\text{Correction factor} = +0.04.}$$

$$E_{r_1} = \frac{\delta A}{A_T} = \frac{0.04}{1.50} = 0.0266$$

12

$$\boxed{\% E_{r_1} = -2.66\%}$$

where, E_{r_1} represents error as a fraction of true value + E_{r2} for F.S.D.

$$E_{r2} = \frac{\delta A}{A} = \frac{0.04}{2.5} = 0.016$$

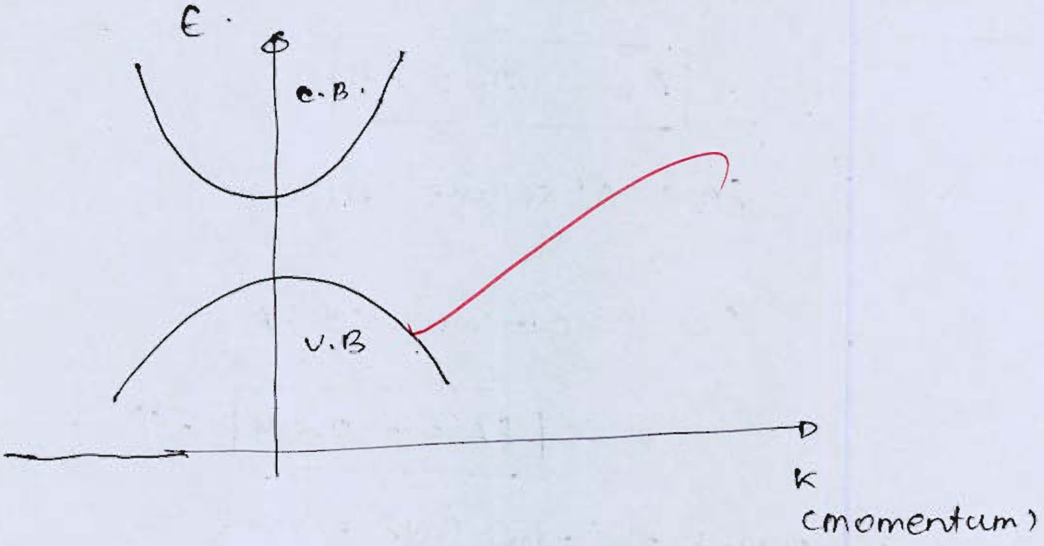
$$\boxed{E_{r_2} = 1.6\%}$$

Q.5 (c) Differentiate between Direct and Indirect band gap semiconductors using E-K diagram. **[12 marks]**

Q5) (c) Direct band gap semiconductors.

Eg : GaAs, InP.

- These type of semiconductors are used for manufacturing of LED and similar sources.

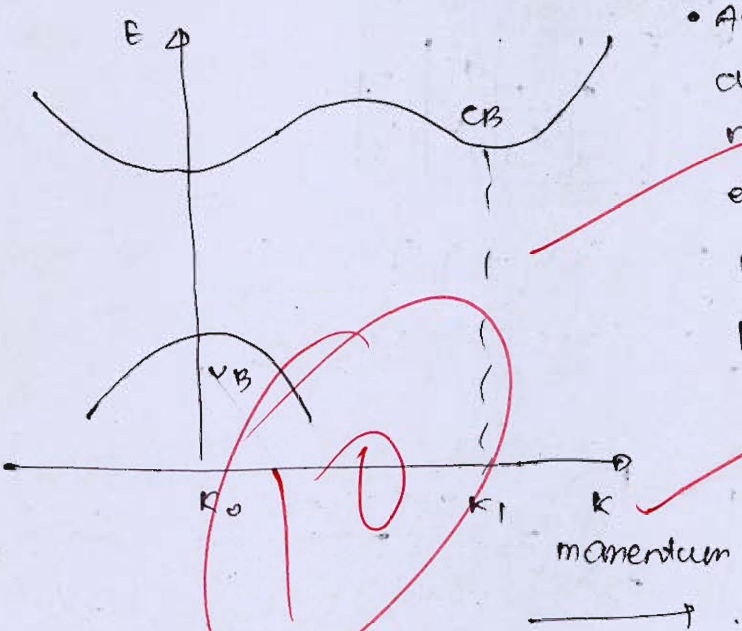


- As the C.B (conduction band) edge and V.B (valence band) edge occur for the same momentum, the energy is released in the form of light, hence used in application of LED's.

Indirect band gap semiconductors.

Eg: n-type Si.

- These semiconductors find their use in amplification and similar related application.



10

• As CB and VB edge are at different momentum, the energy releadsed is in the form of heat.

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]

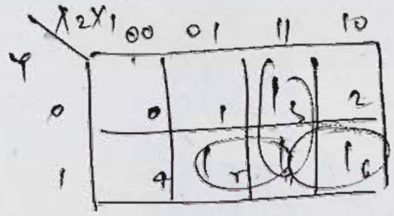
5 (d) Given: $Y = X_2 X_1 + (X_2 + X_1) Y$.

$Z = Y$.

truth table :

Y	X_2	X_1	Z = Y.
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

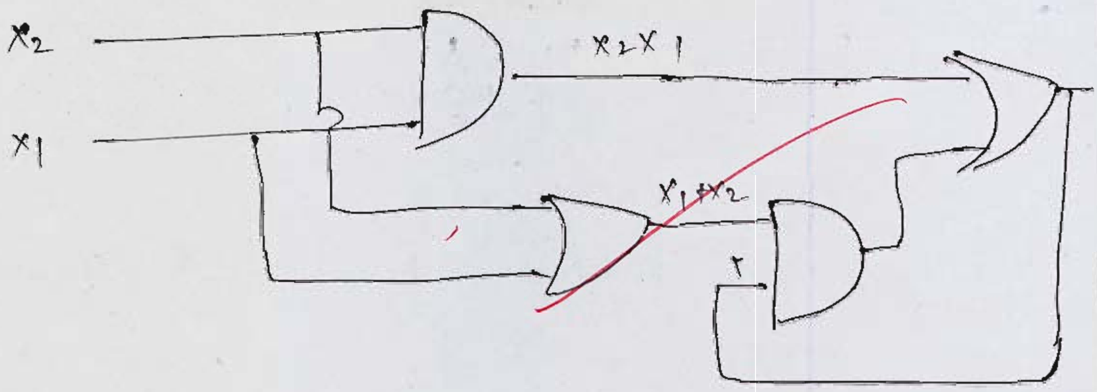
K-map for Z



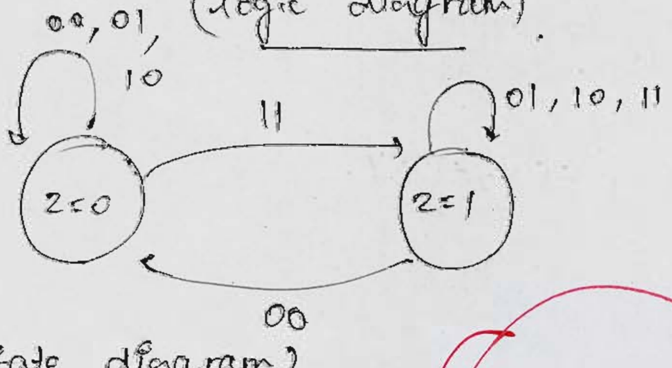
$$Z = X_2X_1 + YX_1 + YX_2$$

$$\boxed{Z = X_2X_1 + Y(X_1+X_2)}$$

(c)



(logic diagram)



(c)

(state diagram)

Z	Z^+	X_2X_1
0	0	X X
0	1	1 1
1	0	0 0
1	1	X X

Transition Table

11

.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]

(i) statement: Relaxation time constant is

(2) defined as,

$$\boxed{t_r = \frac{\epsilon_r}{\sigma}} \quad \cdots ①$$

σ : conductivity of material.

(II) conductivity (σ) ≃ nqμn . (for n-type)

$$\boxed{\sigma = N_D q \mu_n} \cdot ② \; (n \simeq N_D) .$$

using ②, $\sigma = 10^{16} \times 1.6 \times 10^{-19} \times 1200$.

$$\boxed{\sigma = 1.92 \; \mho/cm}$$

6

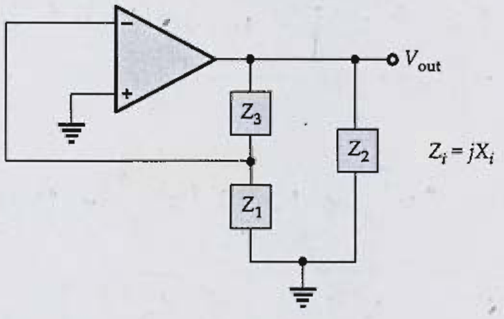
$$\therefore \quad t_r = \frac{11.7}{1.92}$$

t_r = 6.09 seconds

$$\boxed{t_r = 6.09 \, s}.$$

6

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

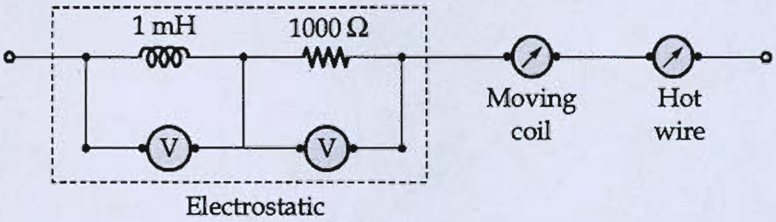


The op-amp in the circuit has a finite open loop gain (A_v), finite output resistance ($R_0 > 0$) and it is ideal in all other aspects. Z_1, Z_2 and Z_3 are purely reactive elements with magnitudes $|X_1|$, $|X_2|$ and $|X_3|$.

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]

.6 (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]

.6 (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]

(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]

7 ⓐ Given: abrupt pn junction.

$N_A = 10^{18}/cm^3 \qquad N_D = 5\times10^{15}/cm^3$.

Junction ; D = 10 μm.

$\therefore$ Area $= \frac{\pi D^2}{4} = 7.85 \times 10^{-11}\ m^2$.

Statement: we know, built in potential.

$$\phi_{bi} = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) \quad -①$$

$$\phi_{bi} = 0.0259 \ln\left(\frac{10^{18}\times 5\times 10^{15}}{2.25\times 10^{20}}\right) = 0.295V$$

$$\therefore \boxed{\phi_{bi} = 0.295V}$$

$\therefore$ (i) Depletion width on n-side.

$$x_n = \sqrt{\frac{2\epsilon_s}{q}\frac{N_A}{N_D}\times\frac{1}{(N_A+N_D)}\times\phi_{bi}}$$

$$x_n = \sqrt{\frac{2\times 11.8\times 8.854\times 10^{-14}\times 10^{18}}{1.6\times 10^{-19}\times 5\times 10^{15}}\times\frac{\cancel{\phi}\ 0.295}{(5\times 10^{15}+10^{18})}}$$

$$\boxed{x_n = 0.454\ \mu m}$$

(ii) Depletion width on p-side.

$$x_p = \sqrt{\frac{2\epsilon_s}{q}\left(\frac{N_D}{N_A}\right)\times\frac{1}{(N_A+N_D)}\times(\phi_{bi})}$$

on solving,

$$\boxed{x_p = 22.72\ \mu m}$$

(iii) Accumulated space charge.

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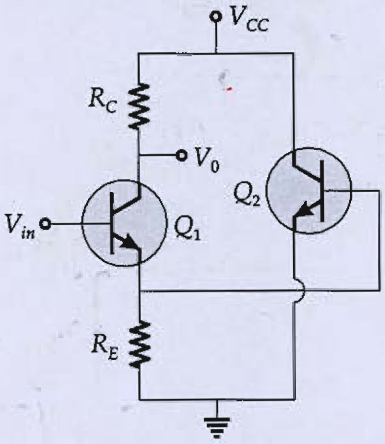
$$|Q| = q N_D \times x_n$$

$$= 1.6\times 10^{-19}\times 10^{18}\times 0.454\times 10^{-6}\times 100$$

$$\boxed{|Q| = 7.264\times 10^{-6}\ C/cm^2}$$

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

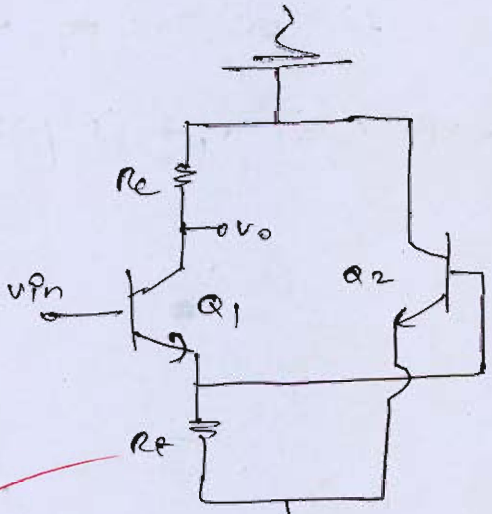


Assume both the transistors are in active region with $V_A = \infty$. Calculate the value of small signal voltage gain $A_V = V_0/V_{in}$.

[20 marks]

7) ⓑ from given circuit, drawing AC equivalent circuit.

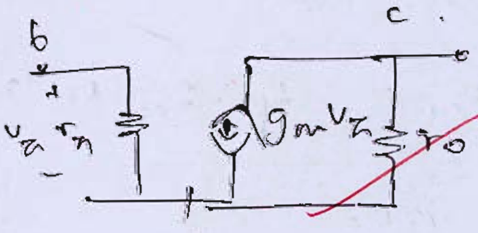
Here, Vcc → grounded.



(AC equivalent model)

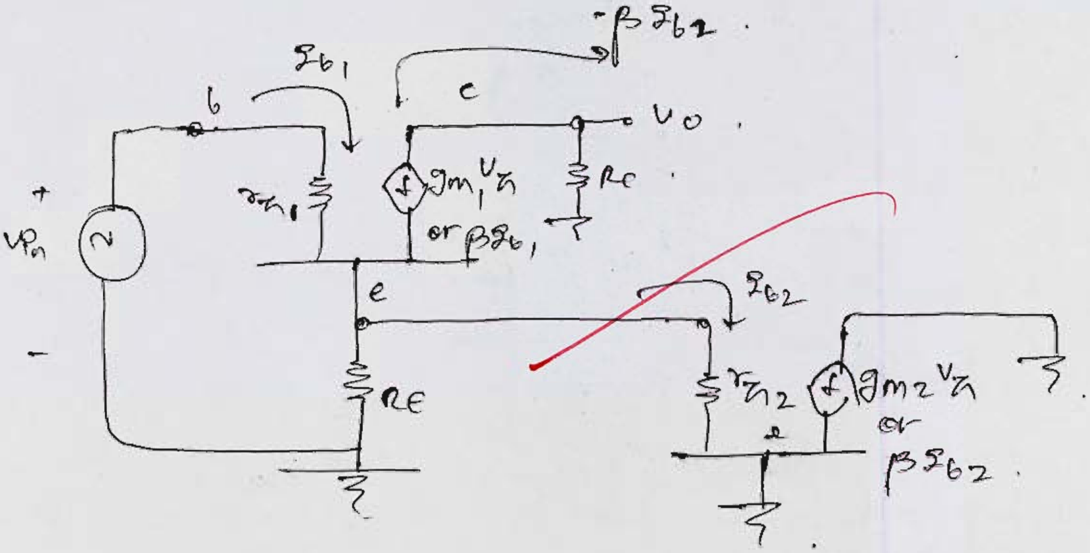
Taking (π) model of the circuit,

for a BJT, π model is



π- model

∴



from above, $v_o = -\beta I_{b_1} R_C$ — ①

~~I_{b_2} by current~~ .

for v_{in} taking KVL,

$$-v_{in} + I_{b_1} r_{\pi_1} + (1+\beta) I_{b_1} (R_E || r_{\pi_2}) = 0 .$$

$$v_{in} = I_{b_1} r_{\pi_1} + (1+\beta) I_{b_1} (R_E || r_{\pi_2}) .$$

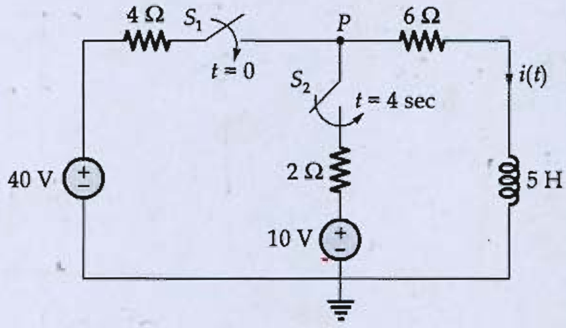
17

$$\therefore \frac{v_o}{v_{in}} = \frac{-\beta I_{b_1} R_C}{I_{b_1} r_{\pi_1} + (1+\beta) I_{b_1} (R_E || r_{\pi_2})}$$

$$\boxed{\frac{v_o}{v_{in}} = A_v = \frac{-\beta R_C}{r_{\pi_1} + (1+\beta)(R_E || r_{\pi_2})}} \quad - ②$$

conclusion: ② represents the voltage gain.

7 (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.

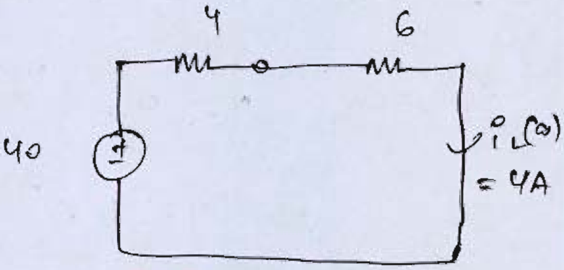


[20 marks]

(c) at $t=0^-$, $i_L(0^-) = 0A$.

considering time instance : $0<t<4$.

circuit :



$$i_L(t) = (i(0^+) - i(\infty))e^{-t/\tau} + i(\infty) \quad \text{①}$$

① represents the current response of an inductor.

$[i(\infty) = i(4)]$ in this case.

$$i_L(t) = (0 - 4)e^{-t/\tau} + 4.$$

$$i_L(t) = 4 - 4e^{-t/\tau}$$

$$\tau = \left(\frac{Req}{L}\right)^{-1} = \frac{L}{R}. \quad Req = 10\Omega.$$

$$\tau = \frac{10}{5} = (2)^{-1} = 0.5 \text{ sec}.$$

So at t = 2sec.

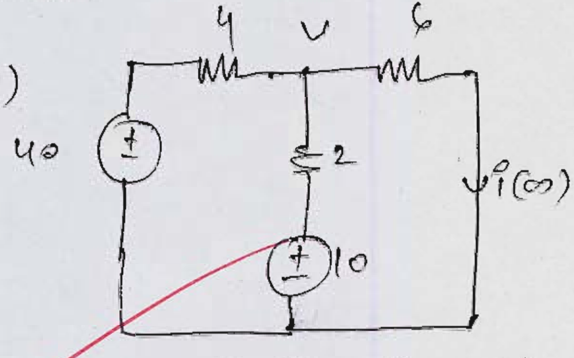
$$i(2) = 4 - 4e^{-2/0.5}.$$

$$i(2) = 4 - 4e^{-4}.$$

$$\boxed{i(2) = 3.926 A}$$

for t>4 : circuit becomes,

$$i_L(t) = [i(4^+) - i(\infty)]e^{-\frac{(t-4)}{\tau}} + i(\infty)$$



circuit after t>4

$i(4^+) = i(4^-)$ — ③

③ represents the property of inductor, as it does not allow sudden change.

$$i(4^+) = 4 - 4e^{-4/0.5}$$

$$= 4 - 4e^{-8}$$

$$\boxed{\therefore i(4^+) = 3.99\,A}$$

for $i(\infty)$:- By KCL,

$$\frac{V-40}{4} + \frac{V-10}{2} + \frac{V}{6} = 0$$

$$V\left(\frac{1}{4} + \frac{1}{2} + \frac{1}{6}\right) = 10 + 5$$

$$V \times \frac{11}{12} = 15 \qquad \boxed{V = 16.36\,V}$$

$$i(\infty) = \frac{16.36}{6} = 2.72\,A$$

$$\boxed{i(\infty) = 2.72\,A}$$

$$\therefore i(t) = [3.99 - 2.72]e^{-(t-4)/\tau'} + 2.72$$

τ' = New time constant = $\frac{L}{R_{eq}}$

$R_{eq} = (4 || 2 + 6)$

$R_{eq} = 7.33\Omega$.

$\tau' = \frac{5}{7.33}$

$\boxed{\tau' = 0.08\,sec}$.

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(ii) at $t = 5\,sec$.

$i(5) = [3.99 - 2.72]e^{-(5-4)/0.08} + 2.72$.

on calculation.

$\boxed{i(5) = 3.01\,A}$.

(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]

(a) (i) Given:

$\mu_n = 1000\ cm^2/V\text{-}sec$.

$\mu_p = 600\ cm^2/V\text{-}sec$.

$N_C = N_V = 10^{19}/cm^2$

$\sigma_i = 10^{-6}\ (\Omega\text{-}cm)^{-1}$ $T = 300\ K$.

Statement:

we know, $\sigma = nq\mu_n + pq\mu_p$.

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

~~$\sigma =$~~

Here n & p would be subject~~ed~~ to change with rise of temperature & $n = p = n_i$.

$n = N_c e^{-(E_c - E_F)/KT}$.

& $\sigma_P = n_i q(\mu_n + \mu_p)$.

$10^{-6} = n_i \times 1.6 \times 10^{-19} (1600)$

$$\boxed{n_i = 3.9 \times 10^{9} /cm^3}$$

we know,

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

$n_i = \sqrt{N_c N_v} \, e^{-E_{g0}/2KT}$.

$n_i = \sqrt{10^{19} \times 10^{19}} \, e^{-E_{g0}/2 \times 8.625 \times 10^{-5} \times 300}$.

$\frac{3.9 \times 10^{9}}{10^{19}} = e^{-E_{g0}/2 \times 8.625 \times 10^{-5} \times 300}$

$-21.66 = -\frac{E_{g0}}{2 \times 8.625 \times 10^{-5} \times 300}$

$$\boxed{E_{g0} = 1.12 \text{ eV}}$$

as T ↑,

$n_i = 10^{19} e^{-1.12/2 \times 8.625 \times 500 \times 10^{-5}}$

$n_i = 10^{19} \times 2.26 \times 10^{-6}$.

$$\boxed{n_i' = 2.26 \times 10^{13} /cm^3}$$

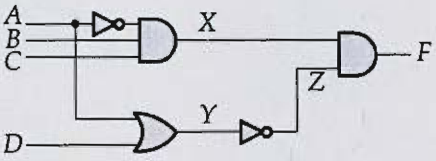
n_i' is new intrinsic concⁿ.

∴ $\sigma' = n_i' q(\mu_n + \mu_p)$

∴ $\boxed{\sigma' = 5.78 \times 10^{-3} (\Omega\text{-cm})^{-1}}$

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]

Q 8 ⓑ (i) Truth table

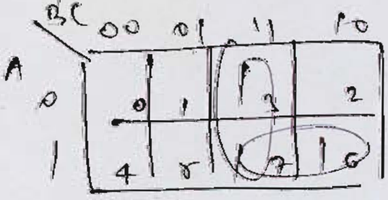
	A	B	C	X	Y	Z
(0)	0	0	0	0	0	1
(1)	0	0	1	0	1	0
(2)	0	1	0	0	1	1
(3)	0	1	1	1	0	0
(4)	1	0	0	0	1	0
(5)	1	0	1	0	1	1
(6)	1	1	0	1	0	0
(7)	1	1	1	1	0	1

(0)–(3): one greater condition

(4)–(7): Two less condition

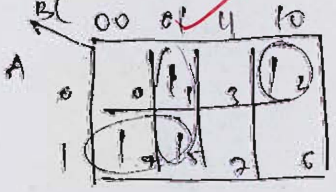
∴ By K-map.

for X →



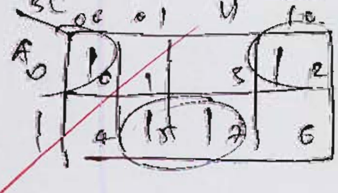
$\boxed{X = BC + AB}$

for Y →



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

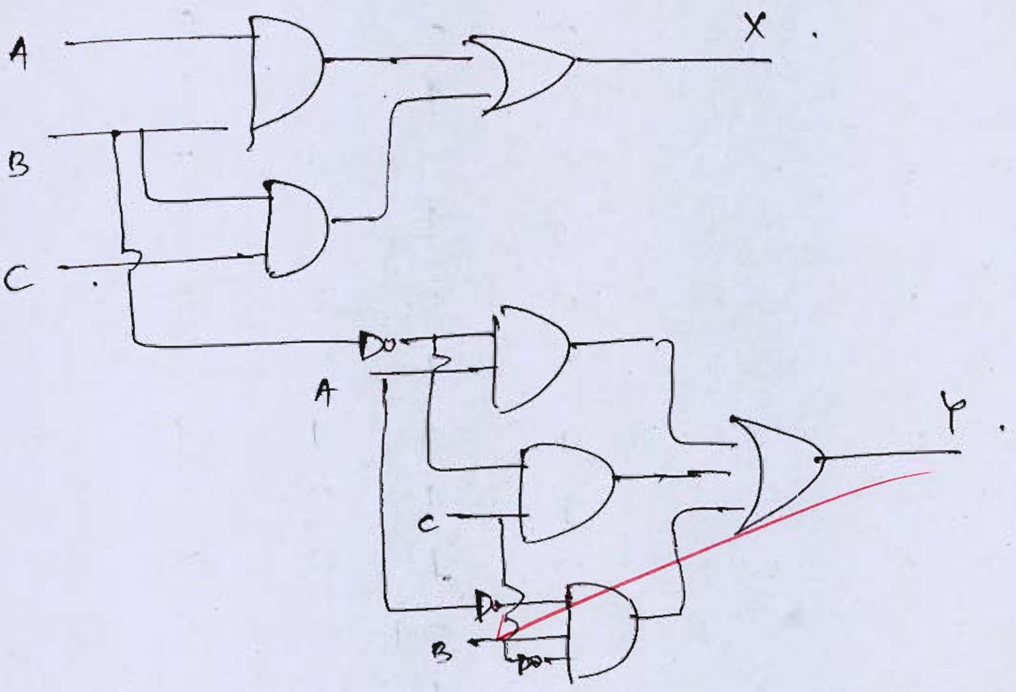
for Z →

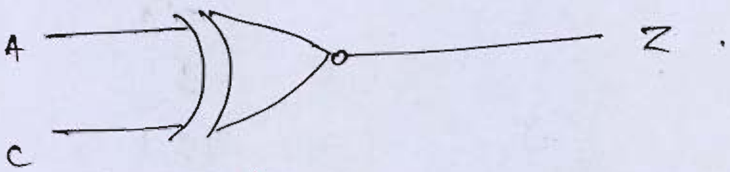


$Z = \bar{A}\bar{C} + AC$

$\boxed{Z = A \odot C}$

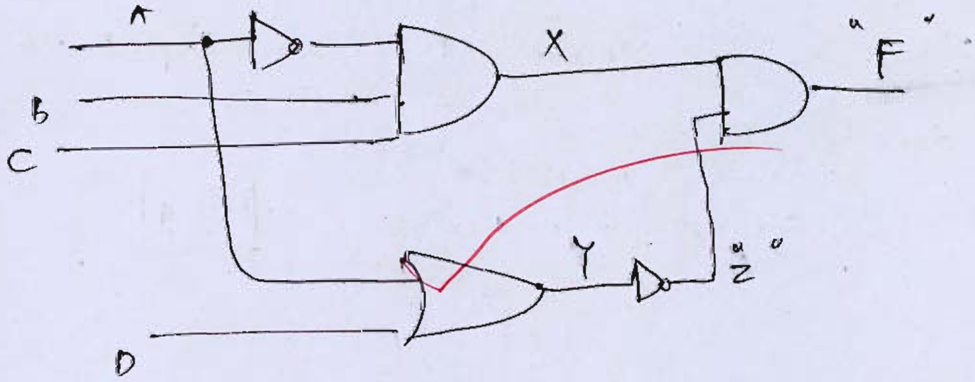
So circuit design :-





⑥ (ii)

Given circuit :-



from above, $X = \bar{A}BC$ $\quad Z = \bar{Y}$

$Y = A + D$ $\quad F = X.Z$

A	B	C	D	X	Y	Z	F
0	0	0	0	0	0	1	0
0	0	0	1	0	1	0	0
0	0	1	0	0	0	1	0
0	0	1	1	0	1	0	0
0	1	0	0	0	0	1	0
0	1	0	1	0	1	0	0
0	1	1	0	1	0	1	1
0	1	1	1	1	1	0	0
1	0	0	0	0	1	0	0
1	0	0	1	0	1	0	0
1	0	1	0	0	1	0	0
1	0	1	1	0	1	0	0
1	1	0	0	0	1	0	0
1	1	0	1	0	1	0	0
1	1	1	0	0	1	0	0
1	1	1	1	0	1	0	0

$\boxed{f \Rightarrow \; 0110 \; (6) = 1}$

The above circuit is a input - 6 detector,

A B CD

wherever 0 1 1 0 , $\boxed{F = 1}$.

20

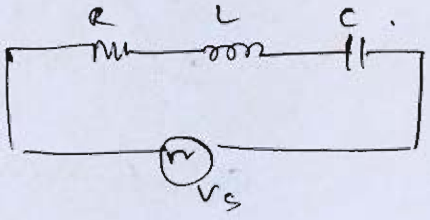
(c) A R-L-C series circuit with a resistance of 10 Ω, inductance of 0.2 H and a capacitance of 40 μF is supplied with a 100-V supply at variable frequency. Find the following with respect to series resonant circuit:

- **(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]

(c) Given: $R = 10\Omega$ $C = 40\ \mu F$.

$L = 0.2H$ $V_s = 100V$.



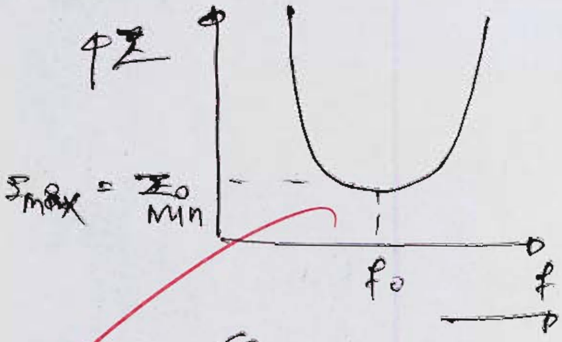
(i) f_0

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$\boxed{f_0 = 56.26\ Hz}$ or $\boxed{\omega_0 = 353.55\ rad/sec}$

ⓑ current @ resonance

$I_{max} = \frac{V}{Z}$



(Impedance v/s freq) graph.

@ Resonance

$Z_{min} = R$.

$I_{min} = \frac{V}{R} = \frac{100}{10} = \boxed{10A.}$

ⓒ power. @ Resonance

$P = V \times I$

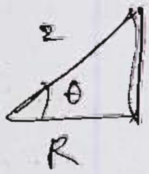
$= 100 \times 10$

$\boxed{P = 1 kW}$

ⓓ Power factor

$p.f = \cos\theta$.

$pf = \frac{R}{Z}$



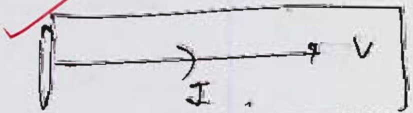
$Z = R + j(X_L - X_C)$.

@ Resonance $X_L = X_C$.

$\therefore Z = R$.

$\therefore pf = \frac{R}{R} = 1$.

$\therefore \boxed{\cos\theta = 1}$.



voltage and current (in-phase)

ⓔ $V_R = I \times R = 10 \times 10 = 100V$.

ⓕ $Q = \frac{X_L}{R} = \frac{\omega L}{R} = \frac{1}{R}\sqrt{\frac{L}{C}}$.

$$Q = \frac{1}{10}\sqrt{\frac{0.2}{40\times10^{-6}}}.$$

$$\boxed{Q = 7.07}$$

ⓖ Half power frequencies.

$$B.W = \frac{f_0}{Q}.$$

$$f_2 - f_1 = \frac{f_0}{Q} = \frac{56.26}{7.07}$$

$$\therefore \boxed{f_2 - f_1 = 7.95\,Hz}.$$

$$f_2 = f_1 + 7.95\,Hz.$$

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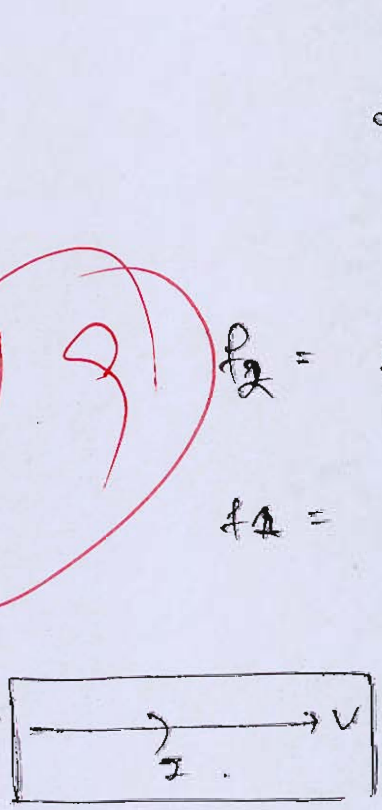
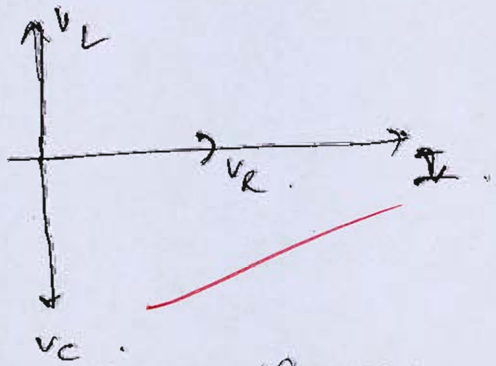
$$f_2 = f_0 + \left(\frac{f_2 - f_1}{2}\right) = 60.535\,Hz$$

$$f_1 = f_0 - \left(\frac{f_2 - f_1}{2}\right) = 52.58\,Hz.$$

ⓗ



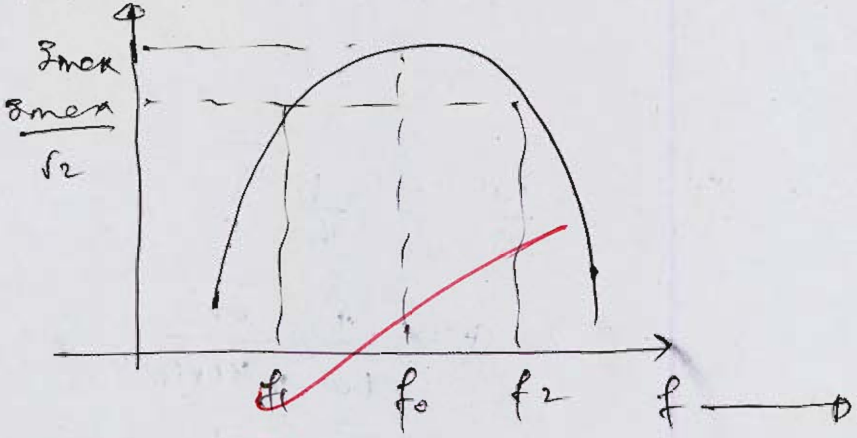
@ Resonance



Phasor diagram of RLC

(4) current variation. →

①



Space for Rough Work

$$f_v(t) = f_{v0}\, e^{-t/\tau_r} = f_{v0}\, e^{-\sigma t/\epsilon_r}.$$

$$\left\{ \tau_r = \frac{\epsilon_r}{\sigma} \right\}.$$

$$i(t) = [i(0^+) - i(\infty)]\, e^{-t/\tau} + i(\infty)$$

$$\tau = RL$$

$$e^{-Rt/L}.$$

$$\boxed{\tau = L/R} \checkmark.$$

$$V_{e2} = \frac{V_{i1} \times R_E}{R' + R_E}.$$

$$\frac{V_{e2}}{V_{i1}} = \boxed{\frac{R_E}{R' + R_E} = \beta}.$$

current - shunt.

$\boxed{R_o \uparrow}$. $\boxed{R_i}\downarrow$.

Vol: $R_o \downarrow$ Series $R_i \uparrow$.

Space for Rough Work