MADE EASY

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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-3 : Analog Circuits + Electromagnetics

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	26
Q.2	49
Q.3	41
Q.4	
Section-B	
Q.5	26
Q.6	30
Q.7	/
Q.8	/
Total Marks Obtained	172

Signature of Evaluator: Ch. Rauf... Cross Checked by ....

• Can do better.

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.

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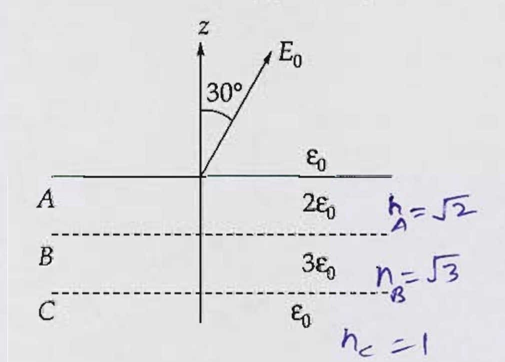
Section A : Analog Circuits + Electromagnetics

(a) A two element array consists of collinear hertz dipoles. The element spacing is $\frac{\lambda}{2}$. Find the directivity of the array when the elements are excited in phase.

[16 marks]

1 (b) Two planar slabs of equal thickness but with different dielectric constants are shown in below figure. E_0 in air makes an angle of 30° with the z-axis. Calculate the angle that E makes with z-axis in each of the three regions A, B and C.



[12 marks]

From snell's Law, in A to air

$n_A \sin\theta_A = \sin 30$

$\sin\theta_A = \frac{1}{2\sqrt{2}} \Rightarrow \boxed{\theta_A = 20.7°}$

Use Boundary conditions.

Snell's Law in B to A

$n_B \sin\theta_B = n_A \sin\theta_A = \frac{1}{2}$

$\sqrt{3}\sin\theta_B = \frac{1}{2}$

$\boxed{\theta_B = 16.778°}$

$\theta_c = 30°$ → Bcz it's air

1 (c) A line of 300 Ω characteristic impedance is terminated in an admittance of $0.01 + j\,0.02$ ℧. Find:

(i) The reflection coefficient at the load-end.

(ii) Reflection coefficient at a distance of 0.2λ from the load-end.

(iii) Impedance at a distance of 0.2λ from the load-end.

[12 marks]

∵ $Z_0 = 300\,\Omega$, $Y_L = (0.01 + j0.02)$ ℧

$\Rightarrow Z_L = \frac{1}{Y_L} = \frac{1}{(0.01 + j\,0.02)} = (20 - j40)\,\Omega$

Reflection coefficient, $\Gamma = \frac{Z_L - Z_0}{Z_L + Z_L}$

(i) $\Gamma = \left(\frac{20 - j40 - 300}{20 - j40 + 300}\right) = 0.877 \angle -164.74^\circ$ at Load

(ii) $l = 0.2\lambda$

$\beta l = \frac{2\pi}{\lambda} \times 0.2\lambda = 0.4\pi$ rad $= 72^\circ$

∴ $\Gamma(l) = \Gamma e^{-j2\beta l} = \left(0.877 \angle -164.74^\circ\right) e^{-j2\beta l}$

$\Gamma(l) = 0.877 \angle -164.74 - 2\times 72^\circ$

$\left[\Gamma(l) = 0.877 \angle 51.26^\circ\right]$ at 0.2λ from Load.

(iii) Impedence, at $l = 0.2\lambda \Rightarrow \beta l = 72°$

$$Z(l) = Z_0 \left[\frac{Z_L + jZ_0 \tan(\beta l)}{Z_0 + jZ_L \tan(\beta l)} \right]$$

$$= 300 \left[\frac{(20 - j40) + j300 \tan 72°}{300 + j(20 - j40) \tan 72°} \right]$$

$$Z(l) = 619.9 \angle 80.43° \ \Omega$$

at 0.2λ from Load.

12

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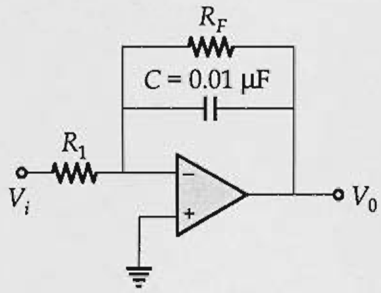
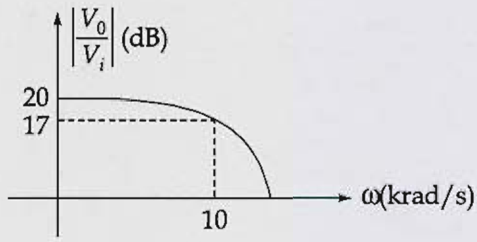
(d) Consider the circuit and the gain-frequency characteristics given below. Find the value of R_1 and R_F.





[8 marks]

$\because \frac{V_o}{V_i} = -\left[\frac{R_F \| \frac{1}{C_F s}}{R_1}\right] = \frac{-R_F}{R_1(1+R_F C_F s)} = -\frac{R_F}{R_1}\frac{1}{(1+R_F C_F s)}$

put $s = j\omega$ $\quad \frac{V_o}{V_i} = -\frac{R_F/R_1}{1+j\omega R_F C_F}$

$\left|\frac{V_o}{V_i}\right| = \frac{R_F/R_1}{(1+\omega^2 R_F^2 C_F^2)}$

$\because \omega_{3dB} = \frac{1}{R_F C_F} = 10 \times 10^3$

$R_F = \frac{1}{C_F \times 10^4} = \frac{1}{0.01 \times 10^{-6} \times 10^4} = 10 k\Omega$

$R_F = 10 k\Omega$

Also DC gain = 20 dB

$\Rightarrow 20 \log \frac{R_F}{R_1} = 20$

$\frac{R_F}{R_1} = 10 \Rightarrow R_1 = \frac{R_F}{10} = 1 k\Omega$

$R_1 = 1 k\Omega$, $R_F = 10 k\Omega$

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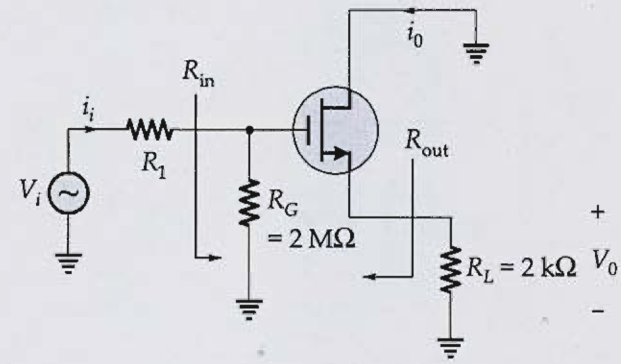
Q.1 (e) In the following amplifier circuit, assume that $R_G = 2\ M\Omega$, $R_1 = 100\ k\Omega$, $R_L = 2\ k\Omega$, $g_m = 10\ mS$, $\lambda = 0$ and $r_0 = \infty$.

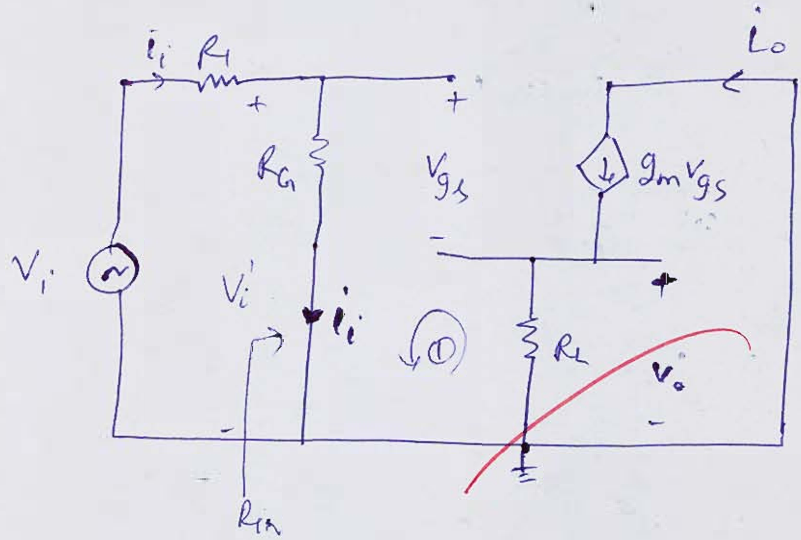
Find A_v, R_{in}, R_{out} and $A_i = \frac{i_0}{i_i}$



[12 marks]

Soln

Drawing small signal model.



$i_o = g_m V_{gs}$ — ①

KVL in loop ①

$g_m V_{gs} R_L + V_{gs} - R_G i_i = 0$

$i_i R_G = (g_m R_L + 1) V_{gs}$ — ②

from eqn ① and ②

$i_i R_G = (g_m R_L + 1) \frac{i_o}{g_m}$

$$\therefore \frac{i_o}{i_i} = A_i = \frac{g_m R_G}{1 + g_m R_L}$$ $\Rightarrow$ ~~$A_i = 19.98$~~

$$\because V_i' = \left(\frac{R_G}{R_G + R_1}\right) V_i \quad — (3)$$

Also, $V_i' = R_G i_i$

$$\therefore R_{in} = \frac{V_i'}{i_i} = R_G \Rightarrow R_{in} = R_G$$

$R_{in} = 20 M\Omega$

6

$$\because V_o = g_m V_{gs} R_L = i_o R_L \quad — (4)$$

$$\therefore A_v = \frac{V_o}{V_i} = \frac{V_o}{V_i'} \times \frac{V_i'}{V_i}$$

$$A_v = \frac{i_o R_L}{R_G i_i} \times \frac{R_G}{R_G + R_1} \quad \text{from (3) \& (4)}$$

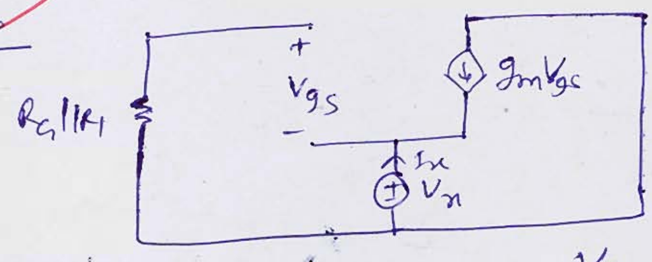
$$= \frac{i_o}{i_i} \times \frac{R_L}{R_G + R_1}$$

$$= A_i \frac{R_L}{R_G + R_1}$$

6

$$A_v = \left(\frac{g_m R_G}{1 + g_m R_L}\right) \cdot \frac{R_L}{R_G + R_1}$$ $\Rightarrow$ ~~$A_v = 0.019$~~

Ckt For R_o



$I_x = -g_m V_{gs}$, also $V_x + V_{gs} = 0 \Rightarrow V_{gs} = -V_x$

$$\Rightarrow R_o = \frac{V_x}{I_x} = \frac{-V_{gs}}{-g_m V_{gs}} \Rightarrow R_o = \frac{1}{g_m} = 100 \Omega$$

Q.2 (a) In a certain region for which $\sigma = 0$, $\mu = 2\mu_0$ and $\varepsilon = 10\varepsilon_0$, the displacement current density is, $\vec{J_d} = 60\sin(10^9 t - \beta z)\hat{a}_x$ mA/m^2.

(i) Find $\vec{D}$ and $\vec{H}$.

(ii) Determine β.

[20 marks]

Soln (i) $\sigma = 0, \quad \mu = 2\mu_0, \quad \epsilon = 10\epsilon_0$

$$\vec{J_d} = 60\sin(10^9 t - \beta z)\,\hat{a}_x \ \text{mA/m}^2$$

$$\because \nabla \times \vec{H} = \sigma \vec{E} + \frac{\partial \vec{D}}{\partial t} \quad (\sigma E = 0,\ \frac{\partial \vec{D}}{\partial t} \to \vec{J_d})$$

$$\vec{J_d} = \epsilon \frac{\partial \vec{D}}{\partial t}$$

$$\vec{D} = \frac{-1}{\epsilon}\int \vec{J_d}\,dt = \frac{+1}{10\epsilon_0 \times 10^9} 60\cos(10^9 t - \beta z)a_x$$

$$\vec{D} = +\frac{60}{10\times 8.854\times 10^{-12}\times 10^9}\cos(10^9 t - 14.9z)a_x$$

$$\boxed{\vec{D} = +677.66\cos(10^9 t - 14.9z)\,\hat{a}_x} \quad [\because \beta = 14.9\ \text{rad/m}]$$

$$\frac{\partial \vec{H}}{\partial z} = \vec{J_d} \Rightarrow \vec{H} = \int \vec{J_d}\,dz$$

$$\vec{H} = \frac{60}{\beta}(-\cos(10^9 t - \beta z))\hat{a}_y$$

$$\boxed{\vec{H} = 4.02\cos(10^9 t - 14.9z)\,\hat{a}_y \ \text{A/m}}$$

(ii) $$\because v_p = \frac{1}{\sqrt{\mu\epsilon}} = \frac{1}{\sqrt{2\mu_0\times 10\epsilon_0}} = \frac{c}{\sqrt{20}}$$

$$\therefore \beta = \frac{\omega}{v_p} = \frac{\omega}{c}\sqrt{20}$$

$$\beta = \frac{10^9}{3\times 10^8}\sqrt{20} \Rightarrow \boxed{\beta = 14.9\ \text{rad/m}}$$

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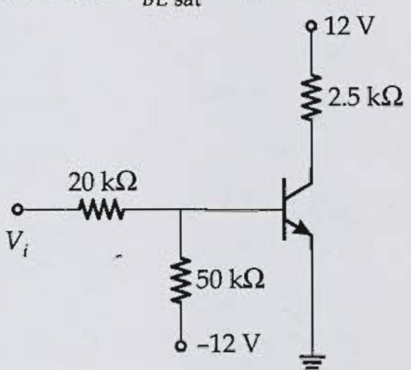
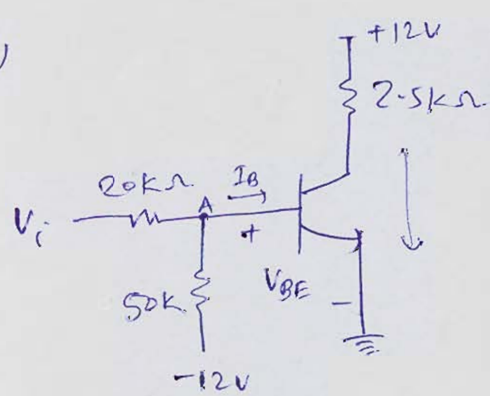
Q.2 (b) **(i)** A silicon transistor with $\beta = h_{fE} = 100$ is used in the circuit shown below. Find the maximum input supply voltage 'V_i' for which transistor remains in saturation region. Assume $V_{CE\,sat} = 0.2$ V and $V_{BE\,sat} = 0.8$ V.



(ii) For input voltage of 2 volt, it is noted that the above circuit is in cut-off region upto 100°C. Calculate the reverse saturation current (I_{CO}) of the circuit at room temperature. (Assume room temperature as 37°C)

[12 + 8 marks]

Soln (i)



Applying KCL at A

$$\frac{V_{BE} - V_i}{20k} + \frac{V_{BE} + 12}{50k} + I_B = 0$$

$$V_{BE}\left(\frac{1}{20k} + \frac{1}{50k}\right) - \frac{V_i}{20k} + \frac{12}{50k} + I_B = 0$$

—— (1)

Applying KVL

$$12 - 2.5K\, I_c = V_{CE}$$

For $V_{CE} = V_{CEsat} = 0.2V$

$$\boxed{I_{csat} = 4.72\, mA}$$

Also for saturation $I_B \geq I_{Bmin}$

$$I_B \geq \frac{I_{csat}}{h_{FE}}$$

$$I_B \geq 0.0472\, mA.$$

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from eq^n ①

$$\frac{V_i}{20K} - V_{BE}\left(\frac{1}{20K} + \frac{1}{50K}\right) - \frac{12}{50K} \geq 0.047\, mA.$$

$$\frac{V_i}{20K} \geq \left(0.8\left(\frac{1}{20K} + \frac{1}{50K}\right) + \frac{12}{50K} + 0.047\right) mA$$

$$\boxed{V_i \geq 6.86V}$$ → To keep transistor

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i) I_{co} doubles every 10°c temp.

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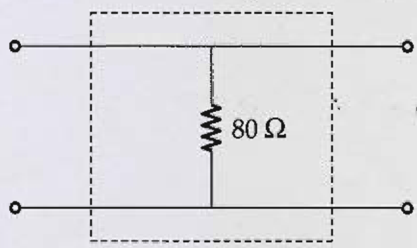
.2 (c) (i) Determine the *s*-parameters for the given two-port network:



$Z_o = 80\ \Omega$

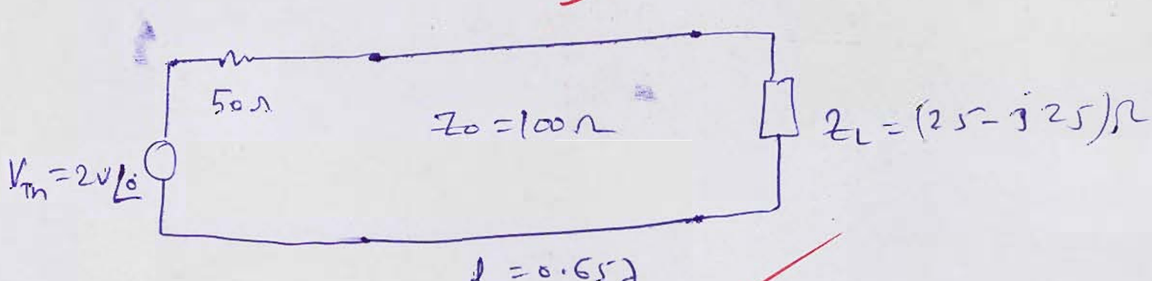
(ii) A uniform loss-less transmission line with a characteristic impedance $Z_o = 100\ \Omega$ has a length of 0.65λ. The line is driven by a time-harmonic source with a 2 V Thevenin voltage and a 50 Ω internal impedance. The line is terminated by a load $Z_L = (25 - j25)\Omega$.

1. Determine the input impedance of the line.
2. Determine amplitude of the forward wave, V_o^+.

[10 + 10 marks]

(ii) Lossless, $\alpha = 0$, $Z_o = 100\Omega$, $l = 0.65\lambda$

$V_{Th} = 2V$, $R_{Th} = 50\Omega$, $Z_L = (25 - j25)\Omega$



$\beta l = \frac{2\pi}{\lambda} \times 0.65\lambda = \frac{13\pi}{10}$ rad $= 234°$

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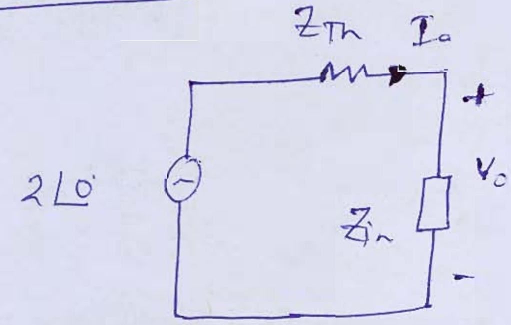
(1) $Z_{in} = Z_0 \left(\frac{Z_L + j Z_0 \tan \beta l}{Z_0 + j Z_L \tan \beta l} \right)$

$Z_{in} = 100 \left(\frac{(25 - j25) + j\,100 \tan 234^\circ}{100 + j(25 - j25) \tan 234^\circ} \right)$

$Z_{in} = 83.16 \angle 63.13^\circ \ \Omega$

(2)



$I_0 = \frac{2 \angle 0^\circ}{Z_{Th} + Z_{in}}$

$I_0 = 0.0174 \angle -40.26^\circ \ A$

$V_0 = I_0 Z_{in} = 1.45 \angle 22.87^\circ \ V$

$\therefore \ V^+ = \frac{1}{2} (V_0 + I_0 Z_0)$

$V^+ = 1.36 \angle -11.9^\circ \ V$

$|V^+| = 1.36 \ V$

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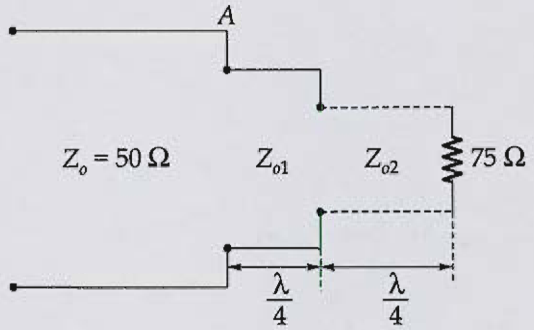
Q.3 (a) (i) In a one-dimensional device, the charge density is given by $\rho_v = \frac{\rho_o x}{a}$. If electric field, $E = 0$ at $x = 0$ and potential $V = 0$ at $x = a$, find V and E.

(ii) Two $\frac{\lambda}{4}$ transformers in tandem are to connect a 50 Ω line to a 75 Ω load as shown in below figure.



Determine the characteristic impedance Z_{o1} if $Z_{o2} = 30\ \Omega$ and there is no reflected wave to the left of A.

[12 + 8 marks]

Solⁿ (i) $\because \rho_v = \frac{\rho_o x}{a}$ From Poisson's Equation

$$\nabla^2 V = \frac{\rho_v}{\epsilon} \Rightarrow \frac{\partial^2 V}{\partial x^2} = \frac{\rho_o x}{\epsilon a}$$ [∵ Device is one dimentional] $\left[\frac{dV}{\partial y} = \frac{\partial V}{\partial z} = 0\right]$

$$\frac{\partial V}{\partial x} = \frac{\rho_o x^2}{2a\epsilon} + C_1$$

$$\because E = -\frac{\partial V}{\partial x} = 0 \text{ at } x = 0 \Rightarrow C_1 = 0$$

$$\therefore \frac{\partial V}{\partial x} = \frac{\rho_o x^2}{2a\epsilon} \Rightarrow E = -\frac{\partial V}{\partial x} \Rightarrow \boxed{E = \frac{-\rho_o x^2}{2a\epsilon}}$$

$$\Rightarrow V(x) = \frac{\rho_o x^3}{6a\epsilon} + C_2$$

But $V(a) = 0 \Rightarrow C_2 = \frac{-\rho_o a^3}{6a\epsilon}$

$$\Rightarrow \boxed{V(x) = \frac{\rho_o (x^3 - a^3)}{6a\epsilon}}$$

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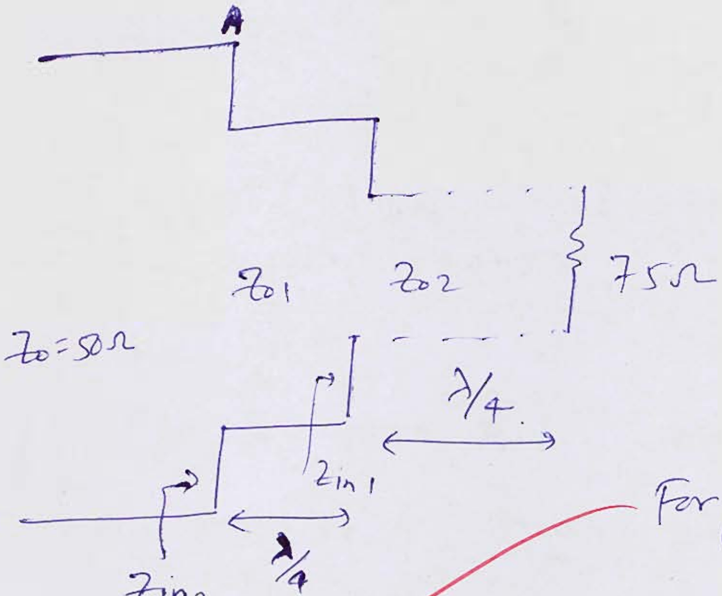
$$\boxed{v = \frac{\rho_0 (x^3 - a^3)}{6a\epsilon}}$$ and $$\boxed{E = \frac{-\rho_0 x^2}{2a\epsilon}}$$

(ii)



For $\left(\frac{\lambda}{4}\right) \rightarrow \beta l = \frac{\pi}{2}$

$$Z_{in1} = \frac{Z_{02}^2}{Z_L} = \frac{(30)^2}{75} = 12\Omega$$

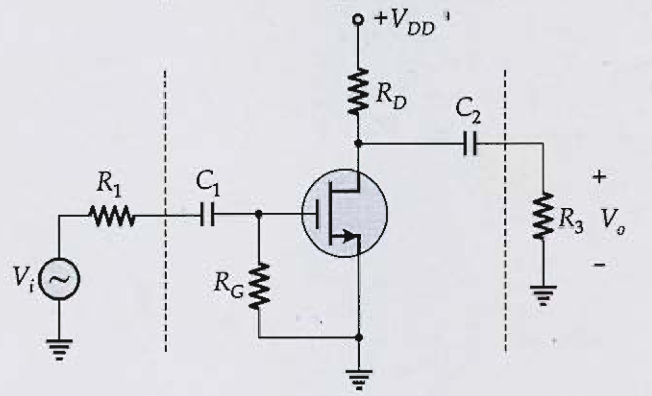
$$Z_{in2} = \frac{Z_{01}^2}{Z_{in1}} \Rightarrow Z_{01} = \sqrt{Z_{in1} Z_{in2}}$$

But it is given that there is no reflection at A $\Rightarrow Z_{in2} = Z_0 = 50\Omega$

$$\Rightarrow Z_{01} = \sqrt{12 \times 50}$$

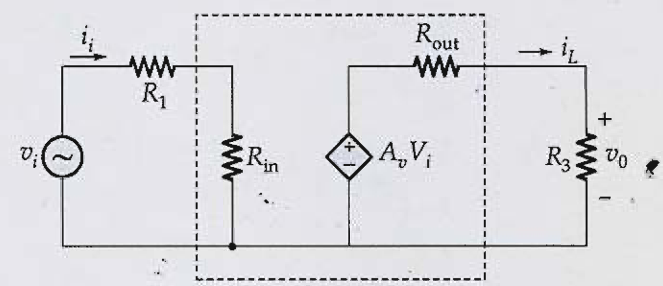
$$\boxed{Z_{01} = 24.5\Omega}$$

Q.3 (b) In the following amplifier circuit, assume that $V_{DD} = 15$ V, $\mu_N C_{ox} \frac{W}{L} = 225\,\mu A/V^2$, $V_{TN} = -3$ V, $R_G = 2.2$ MΩ, $R_D = 7.5$ kΩ, $R_1 = 10$ kΩ, $R_3 = 220$ kΩ, $\lambda = 0.015\ V^{-1}$.



(i) Draw the dc equivalent circuit and find the Q-point for the amplifier.

(ii) Draw the ac equivalent circuit of the amplifier. Assume all capacitors have infinite value. Obtain the values of R_{in}, R_{out} and A_v for the small-signal equivalent circuit of the amplifier as shown below:



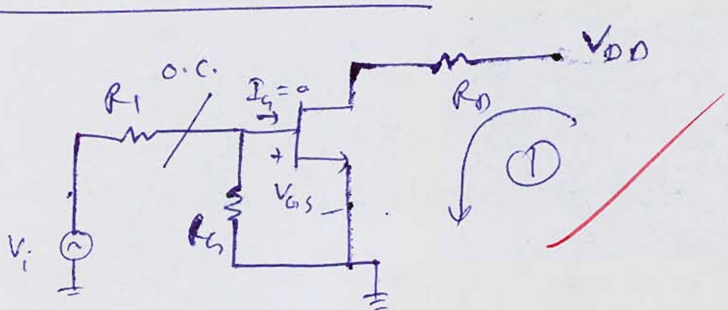
[20 marks]

Sol^n]

Since give MOSFET is N-channel hence

$V_{TN} = -3$ V ~~(It can't be negative)~~

For DC Analysis



$\because I_G = 0 \Rightarrow \boxed{V_{GS} = 0\,V}$

For saturation, $I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)\left[V_{GS} - V_{TN}\right]^2$

$$I_D = \frac{1}{2} \times 225 \times 10^{-6} (0+3)^2$$

$$\boxed{I_D = 1.0125 \text{ mA}}$$

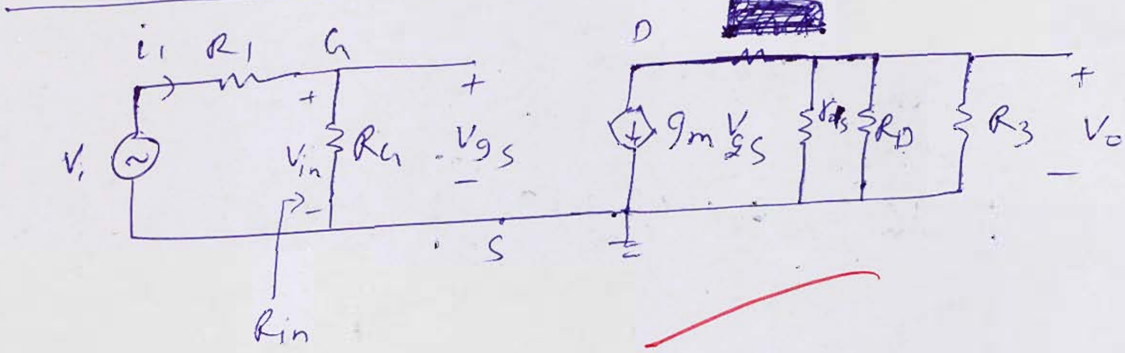
Applying KVL, $V_{DS} = V_{DD} - I_D R_D$

$$V_{DS} = 15 - 1.0125 \times 7.5$$

$$\boxed{V_{DS} = 7.4 \text{ V}}$$

Hence, $Q(V_{DS}, I_D) = (7.4\text{V}, 1.0125 \text{ mA})$

Now AC equivalent.



$\because$ $V_{in} = R_G i_i \Rightarrow R_{in} = \frac{V_{in}}{i_i} = R_G$

$$\boxed{R_{in} = 2.2 \text{ M}\Omega}$$

$\because$ $V_o = -g_m V_{gs} (R_D \| R_3 \| r_{ds})$ — ①

$V_{in} = V_{gs}$ — ②

and from voltage division rule

$$V_{in} = \left(\frac{R_G}{R_1 + R_G}\right) V_i \quad — ③$$

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$\therefore$ from eqn (1) (2) & (3)

$$A_v = \frac{V_o}{V_i} = \frac{V_o}{V_{in}} \times \frac{V_{in}}{V_i} = \left(\frac{V_o}{V_{gs}}\right) \times \left(\frac{V_{in}}{V_i}\right)$$

$$A_v = \frac{-g_m V_{gs} (R_3 || R_D || r_{ds})}{V_{gs}} \times \left(\frac{R_G}{R_G + R_1}\right)$$

$$\boxed{A_v = \frac{-g_m (R_D || R_3 || r_{ds}) R_G}{(R_G + R_1)}}$$

But $g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)$

$$g_m = 225 \times 10^{-6} (0 + 3)$$

$$\boxed{g_m = 0.675 \text{ m}\mho}$$

and $r_{ds} = \frac{1}{\lambda I_{DS}} = \frac{1}{0.015 \times 1.0125}$

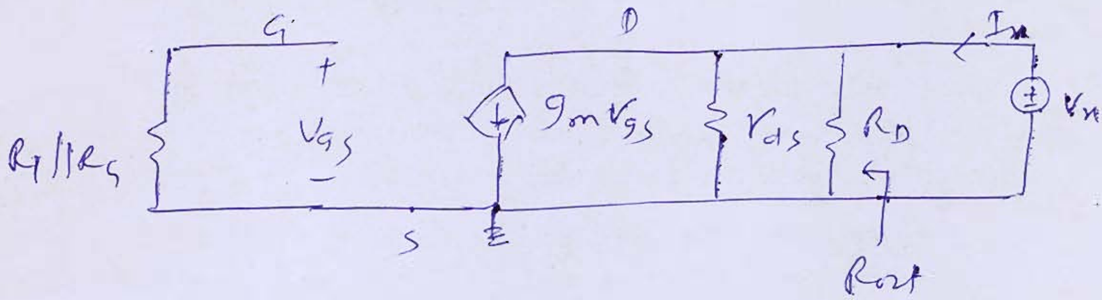
$$\boxed{r_{ds} = 65.84 \text{ k}\Omega}$$

$$A_v = \frac{-0.675 \times 10^{-3} \times (7.5k || 220k || 65.84k) \times 2.}{(2.2 \times 10^6 + 10k)}$$

$$A_v = -\frac{0.675 \times 10^{-3} \times 6.53 \times 10^3 \times 2.2 \times 10^6}{(2.2 \times 10^6 + 10^4)}$$

$$A_v = -4.39$$

For R_{out}



$\because V_{gs} = 0 \Rightarrow g_m V_{gs} = 0$

$$R_{out} = \frac{V_x}{I_x} = r_{ds} || R_D$$

$$R_{out} = 65.84k || 7.5k$$

$$R_{out} = 6.733\,k\Omega$$

20

Q.3 (c) **(i)** Consider a plane wave with an electric field intensity $\bar{E} = -E_0 \cos(\omega t - \beta z)\hat{y}$ V/m where $E_0 = 1200$ V/m and $f = 400$ MHz propagating is in free space. Assume lossless propagation.

1. What is the direction of propagation of wave?
2. Calculate the instantaneous and time averaged power densities in the wave.
3. Calculate the total instantaneous and time averaged power transmitted by the wave.
4. Suppose a receiving dish antenna is 2 m in diameter. How much power is received by the receiving antenna if the surface of dish is perpendicular to the direction of propagation of the wave?

(ii) Obtain a wave equation of the electric scalar potential V for a time varying field.

[15 + 5 marks]

Sol^n | (i) $\vec{E} = -E_0 \cos(\omega t - \beta z)\hat{y}$ V/m

$E_0 = 1200$ V/m, $f = 400$ MHz

(1) $\because \frac{\omega}{\beta} = V_p = +\frac{dz}{dt}$ → wave is propagating in +ve z direction

(2) $H_0 = \frac{E_0}{\eta}$ $\quad \because \hat{E} \times \hat{H} = \hat{a}_z$

$-\hat{a}_y \times \hat{H} = \hat{a}_z$

$\hat{H} \times \hat{a}_y = \hat{a}_z$

$\Rightarrow \boxed{\hat{H} = \hat{a}_x}$

Q.4 (a) **(i)** Design a voltage divider bias network using a depletion type MOSFET with I_{DSS} = 10 mA and V_p = –4 V to have a Q-point at I_{DQ} = 2.5 mA using a supply of 24 V. In addition, set gate voltage, V_G = 4 V and use R_D = 2.5 R_s with R_1 = 22 MΩ. (All the notations used are standard one)

(ii) Design a voltage regulator using zener diode that will maintain an output voltage of 20 V across 1 kΩ load with an input that will vary between 30 and 50 V. Specify the proper value of limiting resistor R_s and the maximum zener diode current I_{zm}.

[10 + 10 marks]

(b) (i) A 2 cm × 1 cm waveguide is made of copper ($\sigma_c = 5.8 \times 10^7$ S/m) and filled with a dielectric material for which $\varepsilon = 2.6\varepsilon_0$, $\mu = \mu_0$, $\sigma_d = 10^{-4}$ S/m. If the guide operates at 12 GHz, evaluate attenuation constant due to dielectric losses (α_d) for TE_{10} mode.

(ii) A lossless 60 Ω line is terminated by a load of $60 + j60$ Ω. If $Z_{in} = 120 - j60$ Ω, how far (in terms of wavelength) is the load from the generator?

[10 + 10 marks]

(c) (i) Design a monostable multivibrator using 555 IC which generate a pulse of 1 μs width when trigger input is applied. Use a capacitor of 325 pF. Explain the circuit operation with waveforms.

(ii) A full-wave rectifier uses a transformer with secondary voltage of 50 V_{rms} and diode having internal resistance of 20 Ω. A 6 H inductor of DC resistance 30 Ω is connected in series with load resistance of 650 Ω. If line frequency is 60 Hz and DC resistance of secondary winding is 45 Ω, calculate:

1. Ripple factor.
2. DC output voltage and AC output voltage.
3. Regulation factor.

[15 + 5 marks]

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Section B : Analog Circuits + Electromagnetics

Q.5 (a) An electric field strength of 10 μV/m is to be measured at an observation point $\theta = \frac{\pi}{2}$, 500 km from a $\frac{\lambda}{4}$ monopole operating in air at 50 MHz.

(i) What is the length of the dipole?

(ii) Calculate the current that must be fed to the antenna.

(iii) Find the power radiated by the antenna.

(iv) If a transmission line with $Z_0 = 75\ \Omega$ is connected to the antenna, determine the standing wave ratio.

[12 marks]

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5 (b) In a conducting medium, the magnetic field is given as

$\vec{H} = y^2 z \hat{a}_x + 2(x+1)yz\hat{a}_y - (x+1)z^2\hat{a}_z$ A/m.

Determine the conduction current density at point (2, 0, –1). Also find the current enclosed by the square loop $y = 1, 0 \le x \le 1, 0 \le z \le 1$.

[12 marks]

$\vec{H} = y^2 z\, a_x + 2(x+1)yz\, a_y - (x+1)z^2\, a_z$

∵ Conduction current density

$\vec{J}_c = \nabla \times \vec{H}$

$$\vec{J}_c = \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ y^2 z & 2(x+1)yz & -(x+1)z^2 \end{vmatrix}$$

$\vec{J} = \hat{a}_x(2y(x+1)) - \hat{a}_y[-z^2 - y^2] + \hat{a}_z[2yz - 2yz]$

$\vec{J}_c = 2y(x+1)\hat{a}_x + (y^2+z^2)\hat{a}_y$ A/m^2

Do not write in this margin

at (2, 0, -1)

$\vec{J}_c = \hat{a}_y$ A/m²

Now, $I_c = \vec{J}_c \times \vec{Area}$

$I_c = \hat{a}_y \times (1 \times 1)\hat{a}_y$

$I_c = 1$ Amp

↳ Enclosed by square loop.

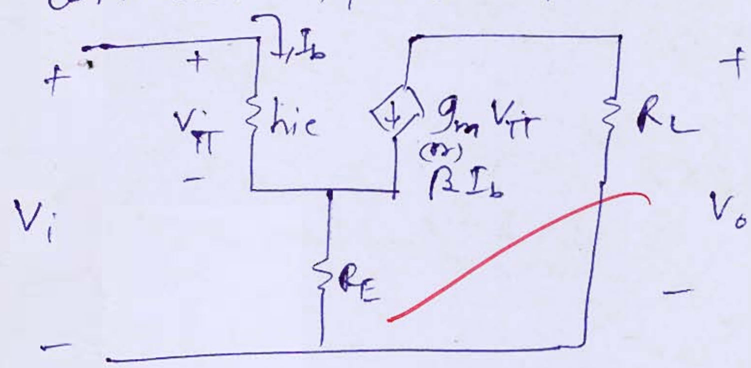
6

(c) Prove that Bypass capacitor in common emitter amplifier is used to enhance the voltage gain of the amplifier.

[12 marks]

without bypass capacitor:

14



$$V_i = I_b(hie + (1+\beta)R_E)$$

$$V_o = -\beta I_b R_L$$

$$\therefore A_v = \frac{V_o}{V_i} = \frac{-\beta R_L}{hie + (1+\beta)R_E}$$

generally β is between 50 to 100

$hie << (1+\beta)R_E$ [$\because R_E$ and hie are same order]

8

$$\Rightarrow A_v = -\frac{\beta R_L}{R_E(1+\beta)} \simeq -\frac{R_L}{R_E}$$

$$\boxed{A_v \simeq -\frac{R_L}{R_E}}$$

But if we use emitter bypass capacitor then, R_E gets shorted.

$$\therefore \boxed{A_v' = -\frac{\beta R_L}{hie}} \Rightarrow |A_v'| >> |A_v|$$

Hence, if we use emitter bypass capacitor it enhances gain of the amplifier.

Proved

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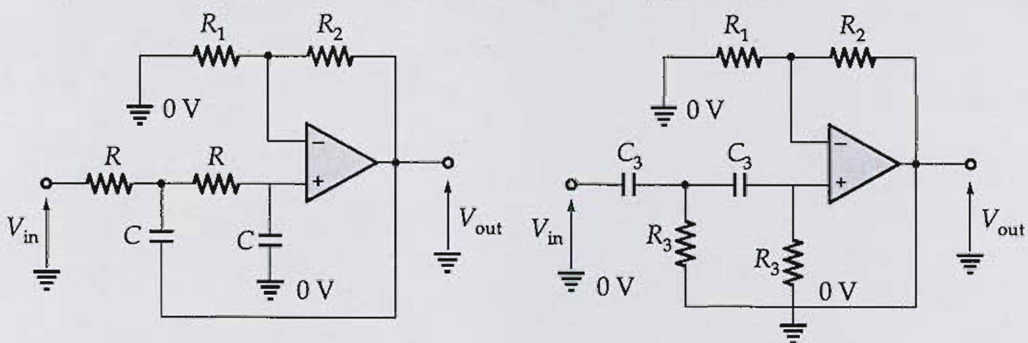
Q.5 (d) An application requires the use of a band pass filter having a roll-off rate of 40 dB/decade and cut-off frequencies f_1 = 2 kHz and f_2 = 4 kHz. Using the Sallen and Key sections, a band pass filter is designed to get maximally flat Butterworth frequency response. The low pass and high pass sections are shown in figure below.

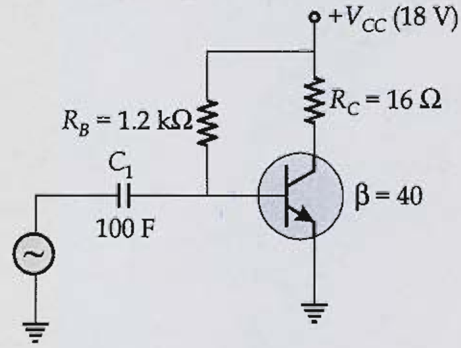


(a) 2nd order low pass section **(b) 2nd order high pass section**

(Assume R_1 = 1 kΩ, $C = 10^{-8}$ F and $C_3 = 10^{-7}$ F.)
Determine the numerical value of R_2, R_3 and R.

[12 marks]

Q.5 (e) Consider the circuit shown below:



Determine:

(i) Quiescent point

(ii) DC input power

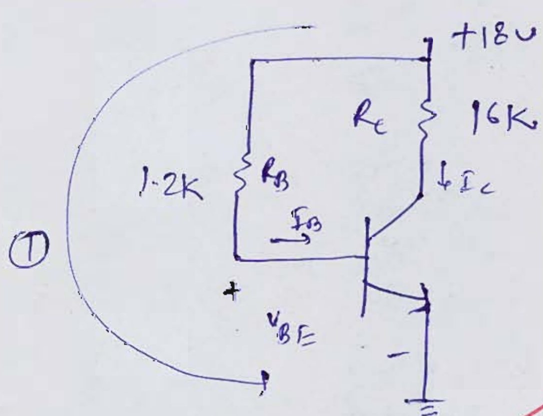
(iii) Output Power

(iv) Power Efficiency

(Assume base current due to ac source, I_B = 5 mA rms)

[12 marks]

Sol^n | DC Analysis



KVL in Loop ①

$$18 - I_B R_B = V_{BE}$$

$$I_B R_B = 18 - V_{BE} \Rightarrow I_B = \frac{18 - 0.7}{1.2K}$$

$$\boxed{I_B = 14.416 \text{ mA}}$$

$$\boxed{I_c = \beta I_B = 0.576 \text{ A}}$$

$$V_{CE} = V_{cc} - I_c R_c = 18 - 0.576 \times 16 = 8.773V$$

① $Q(V_{CE}, I_C) = (8.773\text{ V}, 0.576\text{ A})$

② DC Input Power $= V_{CC} \times (I_C + I_B) = 12(0.576 + 0.01446)$

$P_{DC} \approx 10.627$ Watts

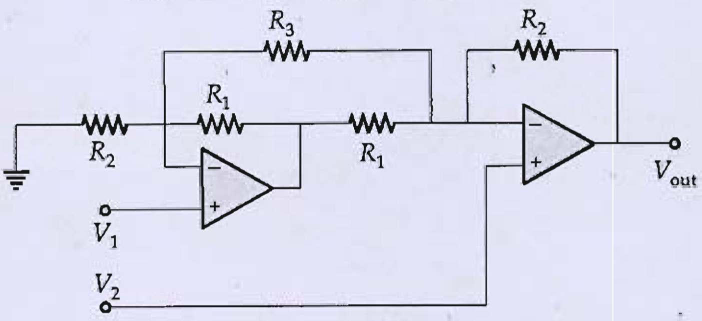
③ $P_{out} = I_{Crms}^2 R_C = \beta^2 I_{Brms}^2 R_C = (40)^2 \times (5\times10^{-3})^2 \times 16$

$P_{out} = 0.64\text{ W}$

④ Power Efficiency, $\eta = \dfrac{P_{out}}{P_{in}} \times 100 = \dfrac{0.64}{10.627} \times 100$

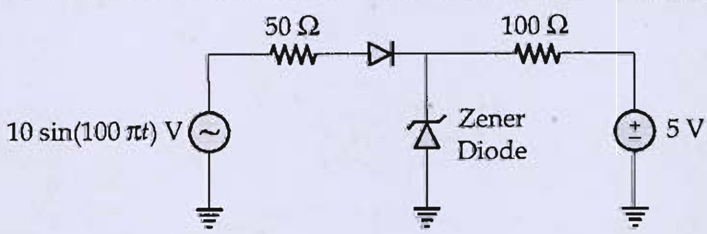
$\therefore \%\eta = 6.02\%$

(a) (i) Consider the circuit shown in figure below:



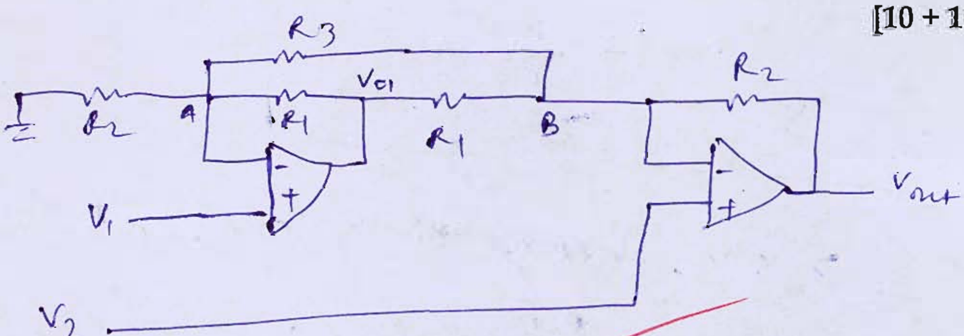
Assuming the two op-amps to be ideal, calculate the value of $\dfrac{V_{out}}{V_2 - V_1}$.

(ii) If the diodes in the circuit shown below are ideal and the breakdown voltage V_z of the zener diode is 5 V, find the power dissipated in the 100 Ω resistor.



[10 + 10 marks]

(a) (i)



From virtual ground concept, $V_A = V_1$, $V_B = V_2$

Applying KCL at A

$$\frac{V_1}{R_2} + \frac{V_1 - V_{01}}{R_1} + \frac{V_1 - V_2}{R_3} = 0$$

$$V_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right) + \frac{V_1 - V_2}{R_3} = \frac{V_{01}}{R_1} \quad \text{—(1)}$$

Applying KCL at B

$$\frac{V_2 - V_1}{R_3} + \frac{V_2 - V_{01}}{R_1} + \frac{V_2 - V_{out}}{R_2} = 0$$

$$\frac{V_2}{R_1} + \frac{V_2 - V_{out}}{R_2} - \frac{(V_1 - V_2)}{R_3} = \frac{V_{01}}{R_1} \quad \text{—(2)}$$

From eq^n (1) − (2)

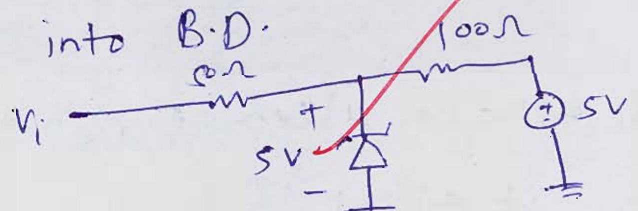
$$V_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{V_2}{R_1} - \left(\frac{V_2 - V_{out}}{R_2}\right) + \frac{2(V_1 - V_2)}{R_3} = 0$$

$$(V_1 - V_2)\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{2}{R_3}\right] = \frac{-V_{out}}{R_2}$$

$$\Rightarrow \frac{V_{out}}{V_2 - V_1} = R_2\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{2}{R_3}\right]$$

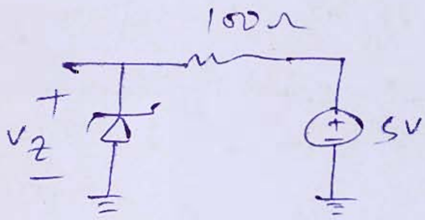
$$\boxed{\frac{V_{out}}{V_2 - V_1} = 1 + \frac{R_2}{R_1} + \frac{2R_2}{R_3}}$$

(ii) When $V_i \geq 5V$, Normal Diodes OFF, and Zener goes into B.D.



$$\boxed{I_{100\Omega} = 0\,A}$$

When $V_i < 5V$, Diode (Normal) is OFF



In this case also, if Zener is in B.D.

[illegible] $V_Z = 5V \rightarrow I_{100\Omega} = 0$

Hence $(I_{avg})_{100\Omega} = 0$

$\therefore (P_{dissipated})_{100\Omega} = 0\,W$

10

Q.6 (b) (i) An air-filled rectangular waveguide of dimensions $a = 2$ cm, $b = 4$ cm transports energy in the dominant mode at a rate of 2 mW. If the frequency of operation is 10 GHz, determine the peak value H_0 of the magnetic field in the waveguide.

(ii) In free space, $\vec{H} = 0.2\cos(\omega t - \beta x)\hat{a}_z$ A/m. Find the total power passing through a square plate of side 10 cm on plane $x + y = 1$.

[12 + 8 marks]

Sol^n] (i) $\because \frac{1}{2} H_o^2 \eta_o \times \text{Area} = 2\,\text{mW}$ [Area = $a \times b$]

$$\therefore H_o = \sqrt{\frac{2 \times 2 \times 10^{-3}}{(2 \times 10^{-2} \times 4 \times 10^{-2}) \times 120\pi}}$$

$$\boxed{H_o = 0.115 \text{ A/m}}$$

(ii) $\vec{H} = 0.2 \cos(\omega t - \beta x)\, \hat{a}_z$ A/m

$\vec{E} = E_o \cos(\omega t - \beta x)\, \hat{a}_y$ V/m

$E_o = \eta_o H_o = 120\pi \times 0.2 = 75.398$ V/m

$\vec{P}_{avg} = \frac{1}{2}(\vec{E} \times \vec{H}^*) = \frac{75.392 \times 0.2}{2}\, \hat{a}_z$

$$\boxed{\vec{P}_{avg} = 7.5398\, \hat{a}_z \text{ Watt/m}^2}$$

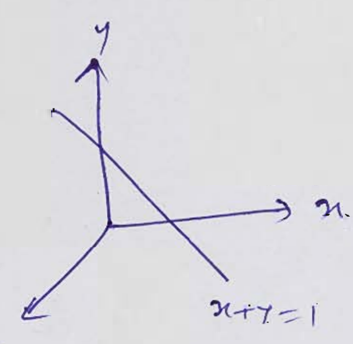


Plate $\vec{A} = \left(\frac{a_x + a_y}{\sqrt{2}}\right) ds$

$\Rightarrow P = \vec{P}_{avg} \cdot \vec{A} = 0$ watts

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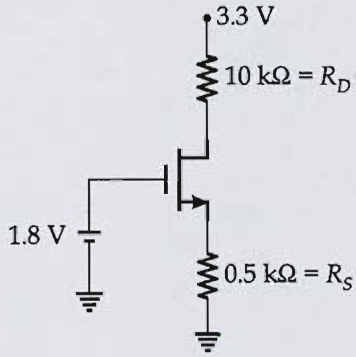
Hence No power will cross the square plate.

Q.6 (c) (i) The transistor shown in the figure below has $V_T = 1$ V, and $\mu_n C_{ox}\left(\frac{W}{L}\right) = 2$ mA/V^2.

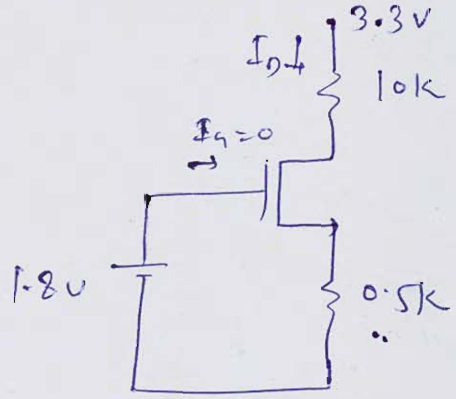
Determine the drain voltage.



(ii) Define transconductance, dynamic drain resistance and amplification factor of JFET.

[14 + 6 marks]

Sol^n/ (i)



$V_{GS} = V_G - V_S = (1.8V - 0.5K\,I_D)$ — ①

But, Assume MOSFET in saturations

$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$

$\left(\frac{1.8 - V_{GS}}{500}\right) = \frac{1}{2} \times 2 \times 10^{-3}(V_{GS} - 1)^2$

$3.6 - 2V_{GS} = V_{GS}^2 - 2V_{GS} + 1$

$V_{GS} = \pm\sqrt{2.6} = +1.612V$ ✓, $-1.612V$ ✗

$\because V_{GS} > V_T \Rightarrow$ $V_{GS} = 1.612V$

$$I_D = \frac{1.8 - V_{GS}}{500} = 3.75 \times 10^{-4} A.$$

$$V_D = 3.3 - I_D R_D = 3.3 - 3.75 \times 10^{-4} \times 10 \times 10^3$$

$$V_D = -0.46$$

and $V_S = 0.1875V \Rightarrow V_{DS} = -0.46 - 0.1875$

$$V_{DS} = -0.6475$$

$\Rightarrow V_{DS} < V_{GS} - V_T \Rightarrow$ MOSFET is in Linear region.

$$\therefore I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$[\because V_{DS} = 3.3 - (R_D + R_S)I_D = 3.3 - 10.5 I_D]$

$$\frac{1.8 - V_{GS}}{0.500} = 2 \times \left[(V_{GS} - 1)(3.3 - 10.5 I_D) - \frac{(3.3 - 10.5 I_D)^2}{2}\right]$$

$$\therefore 1.8 - V_{GS} = (V_{GS} - 1)\left[3.3 - 10.5\left(\frac{1.8 - V_{GS}}{0.5}\right)\right]$$

$$- \frac{1}{2}\left[3.3 - 10.5\frac{(1.8 - V_{GS})}{0.5}\right]^2$$

$$1.8 - V_{GS} = (V_{GS} - 1)\left[3.3 - 21(1.8 - V_{GS})\right]$$

$$- \frac{1}{2}\left[3.3 - 21(1.8 - V_S)\right]^2$$

$$1.8 - V_{GS} = \{0.8 - (1.8 - V_{GS})\}\{3.3 - 21(1.8 - V_{GS})\}$$

$$- \frac{1}{2}\left[3.3 - 21(1.8 - V_{GS})\right]^2$$

Take $1.8 - V_{GS} = x$

$$x = (0.8 - x)(3.3 - 21x) - 0.5(3.3 - 21x)^2$$

$x = 3.3\times 0.8 - 21\times 0.8x - 3.3x + 21x^2$

$+ 0.5\left[(3.3)^2 + (21x)^2 - 2\times 21\times 3.3x\right]$

4

$x = 8.085 - 89.4x + 241.5x^2$

$241.5x^2 - 90.4x + 8.085 = 0$

$x = 0.226\,V, 0.1477\,V$

$1.8 - V_{GS} = x$

$V_{GS} = 1.574\,V, 1.65\,V$

$I_{DS} = \frac{1.8 - V_{GS}}{500} = 3\times 10^{-4}\,A$

$V_{DS} = 3.3 - I_{DS}(R_D + R_S)$

$V_{DS} = 3.3 - 3\times 10^{-4}(10.5\times 10^3)$

$V_{DS} = 0.15\,V$, $I_{DS} = 3\times 10^{-4}\,A$

$V_D = 3.3 - I_D R_D = 3.3 - 3\times 10^{-4}\times 10\times 10^3$

$V_D = 0.3\,V$

(ii) $g_m = \frac{\partial I_d}{\partial V_{GS}}$, $r_{ds} = \frac{\partial V_{ds}}{\partial I_{ds}}$

2

Amplification Factor $= g_m r_d$

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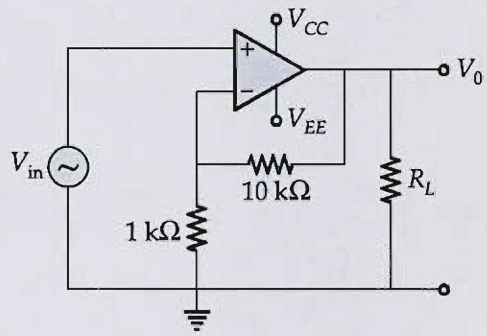
) (i) A section of a rectangular waveguide of cross-section 2 cm × 1.5 cm operating in the dominant mode is to be used as a delay line in a radar at 10 GHz. What should be the length of the section to realize a delay of 50 nsec?

(ii) Draw the voltage standing wave patterns for the following types of load impedances of the transmission line :

1. Complex Inductive load $(R + jX)$
2. Complex Capacitive load $(R - jX)$
3. Pure resistive load (R)
4. Pure Inductive load $(+jX)$
5. Pure Capacitive load $(-jX)$

[10 + 10 marks]

Q.7 (b) **(i)** The 741-IC Op-Amp having the following parameters is connected as shown in the figure.



Open loop voltage gain A = 20000, R_i = 2 MΩ, R_0 = 75 Ω, f_0 = 5 Hz, supply voltage = ±15 V and output voltage swing = ±13 V.

Find A_f, R_{if} and R_{0f} of the op-amp with feedback.

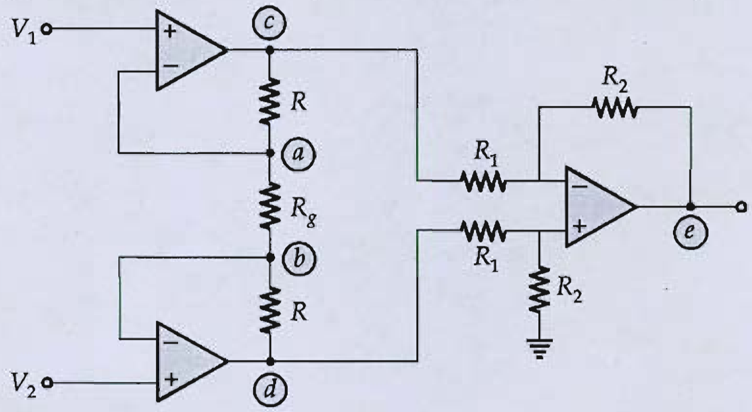
(ii) Draw the circuit diagram of voltage to current converter with floating load using op-amp. Derive the necessary equations that describes its operation.

[15 + 5 marks]

Q.7 (c) A uniform plane wave is normally incident on an infinitely thick dielectric slab, having dielectric constant 10 and loss tangent 10^{-2} at $\omega = 10^{10}$ rad/sec. If the power density of the incident wave is 100 W/m^2, find the power density of the wave in the dielectric at a distance of 10 m from the surface.

[20 marks]

Q.8 (a) The circuit given below is made by three ideal operational amplifiers (op-amp):



(i) Specify the type of circuit. Comment upon its CMRR in comparison to op-amp.

(ii) Find the expressions for voltages at points ⓐ, ⓑ, ⓒ, ⓓ and ⓔ.

(iii) If $V_1 = 5$ V and $V_2 = 5.05$ V and V_e (voltage at point ⓔ) is 5 V, find the ratio R/R_g and R_2/R_1, when overall gain is divided in the ratio of 10 : 1 between first and second stage of the circuit.

[20 marks]

(i) The radiation resistance of an antenna is 280 Ω and the efficiency factor is 0.8. Calculate the loss resistance R_{loss} if the magnitude of the current is $I_0 = 5$ A. Also, calculate the power radiated and the ohmic loss.

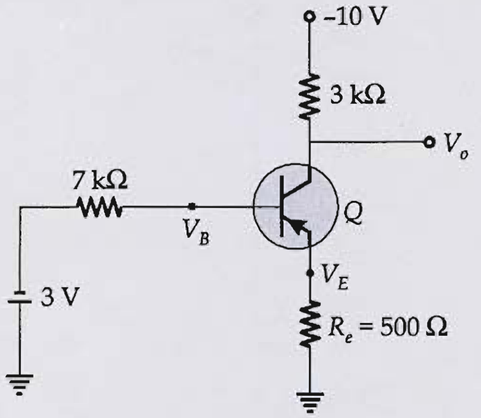
(ii) An antenna in air radiates a total power of 100 kW so that a maximum radiated electric field strength of 12 mV/m is measured 20 km from the antenna.

Find: 1. its directivity in decibels,

2. its maximum power gain if $\eta_r = 98\%$.

[12 + 8 marks]

(i) For the circuit shown in the figure, assume $\beta = h_{FE} = 100$.



1. Determine if the silicon transistor is in cut-off, saturation or in active region.

2. Find V_0, V_B, V_E.

Assume $V_{CE\,sat} = -0.2$ V and $V_{BE\,sat} = -0.8$ V.

(ii) With reference to a BJT, show that $\frac{\partial P_c}{\partial T_j} < \frac{1}{\theta_{JA}}$ must be satisfied in order to prevent thermal runaway. Here, P_C is the heat generated at the collector junction, T_j is the junction temperature and θ_{JA} is the thermal resistance between the junction and the air.

[12 + 8 marks]

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Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work