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UPSC ESE 2020

Main Exam Detailed Solutions

Electronics & Telecom. Engineering

PAPER-I

EXAM DATE : 19-10-2020 | 10:00 AM to 1:00 PM

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Electronics and Telecom. Engineering Paper Analysis ESE 2020 Main Examination

Sl.	Subjects	Marks
1.	Materials Science	84
2.	Electronic Devices and Circuits	40
3.	Analog Circuits	76
4.	Digital Circuits	52
5.	Network Theory	128
6.	Basic Electrical Engineering	40
7.	Electronic Measurements and Instrumentation	60
	Total	**480**

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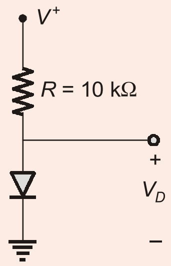
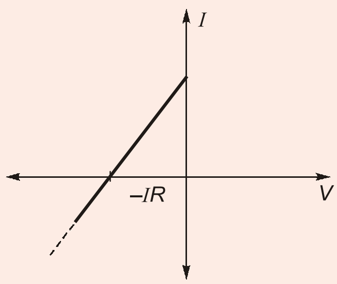
1. (a) (i) Consider the circuit shown below. The power supply V^+ has a dc value of 10 V on which is superimposed a 60 Hz sinusoid of 1 V peak amplitude, i.e., has a power supply ripple.

Calculate both the dc voltage of the diode and the amplitude of the sine-wave signal appearing across it, assuming a 0.7 V drop across it at 1 mA current.



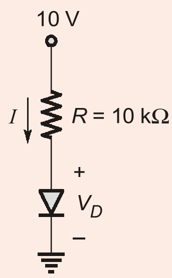
(ii) For the V-I characteristics as shown below, draw the circuit model using an ideal diode.



[6 + 6 Marks]

Solution:

(i) DC analysis :



$$I = \frac{10 - V_D}{10} = \frac{10 - 0.7}{10} = 0.93 \text{ mA}$$

Using diode equation,

$$V_2 - V_1 = \eta V_T \ln \frac{I_2}{I_1}$$

Let $\eta = 2$, $V_T = 0.026$ V

Put $V_2 = 0.7$ V, $I_2 = 1$ mA

$I_1 = 0.93$ mA

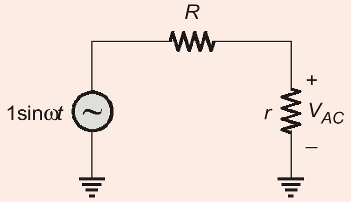
$$\Rightarrow \quad 0.7 - V_1 = 2 \times 0.026 \ln \frac{1}{0.93}$$

$\Rightarrow$ V_1 = 0.696 V which is nearest to 0.7 V. Hence, we can consider DC voltage across diode as approximately 0.7 V.

AC analysis :

$$r = \frac{\eta V_T}{I} = \frac{2\times 0.026}{0.93\times 10^{-3}} = 55.9\ \Omega$$

$r << R \Rightarrow$ voltage across diode will vary by small amount due to variation in V^+. Hence, we can apply small signal model to find V_{AC} across diode.

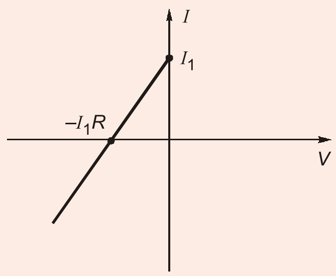


$$V_{AC} = \frac{1\sin\omega t\times r}{r+R} = \frac{1\sin\omega t + 55.9}{55.9+100\ \text{k}\Omega} = 5.56\ \sin\omega t\ \text{mV}$$

$\therefore$ $V_{DC} \simeq 0.7$ V, Amplitude of V_{AC} = 5.56 mV

(ii) For $V = 0^+$, $I \to \infty$

$\Rightarrow$ Thee should be a short circuit or an ON diode in parallel to V.

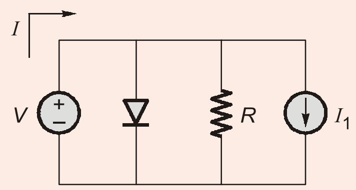


For V < 0 :

$$I - I_1 = \frac{0 - I_1}{-I_1 R - 0}(V - 0)$$

$$I = \frac{V}{R} + I_1$$

$\Rightarrow$ A resistor 'R' and a current source I_1 should be in parallel



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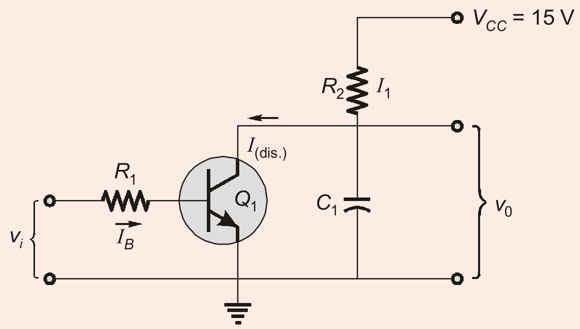
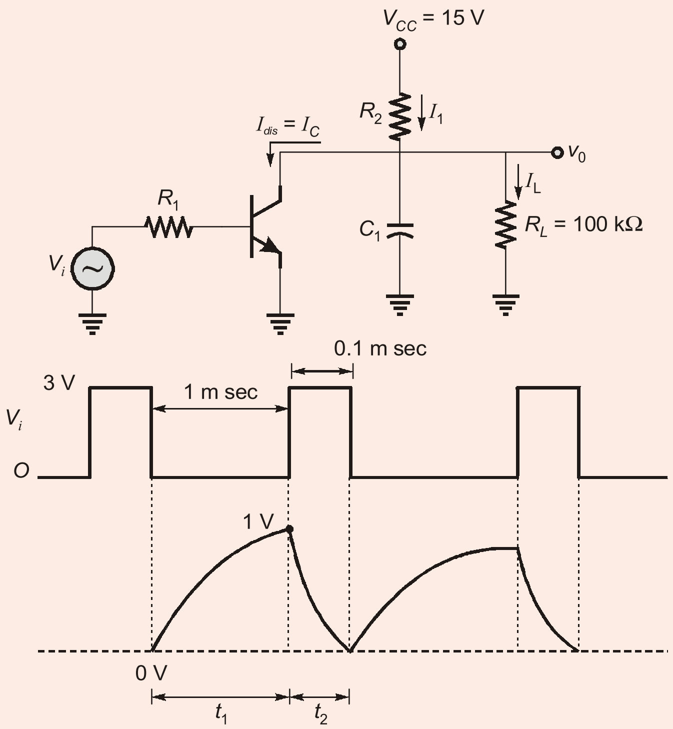
End of Solution

1. (b) The circuit shown below is to be used as ramp generator to produce a 1 V ramp output when the output is 3 V, 0.1 ms pulse with a 1 ms interval between pulses. The supply voltage is 15 V and a load resistance of 100 kΩ is connected at the output terminals. Assume Q_1 has $h_{FE(min)}$ = 50. Determine values of R_1, R_2 and C_1.



[12 Marks]

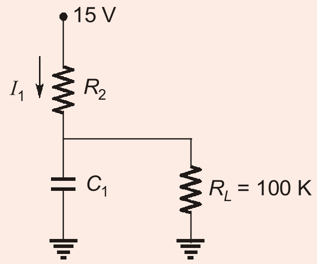
Solution:



During t_1 interval: $V_i = 0 \Rightarrow$ Transistor is OFF

$\therefore$ C_1 charges through R_2 and capacitor voltage increases upto 1 V.

Maximum load current is $I_{Lmax} = \dfrac{1\text{ V}}{100\text{ k}} = 10\ \mu\text{A}$



Assume minimum charging current as much greater than $I_{L,max}$.

i.e., Minimum $I_1 >> I_{L,max}$

Let Minimum $I_1 = 100\ I_{L,max} = 1$ mA

Now,
$$R_2 = \frac{V_{CC} - V_{C,max}}{I_{1,min}} = \frac{15-1}{1\times 10^{-3}}$$
$$R_2 = 14\ \text{k}\Omega$$
$$V_C = V_{Final} + (V_{Initial} - V_{Final})\, e^{-t/R_2C_1}$$
$$V_C = 15 + (0-15)e^{-t/R_2C_1}$$

$\Rightarrow$
$$C_1 = \frac{t}{R_2 \ln\left(\frac{15}{15-V_C}\right)}$$

Put t = 1 ms, V_C = 1 V, R_2 = 14 kΩ

$\Rightarrow$ $C_1 = 1.035\ \mu$F

During t_2 interval: $V_i = 3$ V $\Rightarrow$ Transistor becomes ON.

Now C discharges rapidly through transistor.

Discharging current should be much greater than charging current because capacitor has to discharge fully in a smaller time interval 0.1 ms.

Let
$$I_{discharge} = 100 \times I_{1,\ min} = 100 \text{ mA}$$

Collector current,
$$I_C = I_{discharge} + I_1 \cong 100 + 1 = 101 \text{ mA}$$
$$I_B = \frac{I_C}{\beta} = \frac{101}{50} = 2.02 \text{ mA}$$
$$R_1 = \frac{V_i - V_{BE}}{I_B} = \frac{3-0.7}{2.02\times 10^{-3}}$$
$$R_1 \cong 1.14\ \text{k}\Omega$$

End of Solution

1. (c) A 40 μF capacitance is charged to store 0.2 J of energy. An uncharged, 60 μF capacitance is then connected in parallel with the first one through perfectly conducting leads. What is the final energy of the system?

[12 Marks]

Solution:

Given, Capacitance, $C = 40\ \mu\text{F}$

Energy stored, $E = 0.2\ \text{J}$

but $E = \frac{1}{2}CV^2$

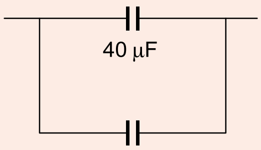
$$0.2 = \frac{1}{2}\times 40\times 10^{-6}\times V^2$$

∴ $v = 100\ \text{V}$

∴ The charge stored in 40 μF capacitor

$$Q = VC = 100 \times 40 \times 10^{-6} = 4 \times 10^{-3}\ \text{C}$$

Now, 60 μF capacitance is connected in parallel with 40 μF capacitor.



The energy stored in the above combination is

$$E' = \frac{1}{2}C_{eq}v_0^2$$

where, $v_0 = \frac{Q}{C_{eq}}$

$$E' = \frac{1}{2}C_{eq}\times\frac{Q^2}{C_{eq}^2} = \frac{1}{2}\frac{Q^2}{C_{eq}}$$

$$= \frac{1}{2}\times\frac{(4\times 10^{-3})^2}{40\,\mu\text{F} \parallel 60\,\mu\text{F}} = \frac{1}{2}\times\frac{(4\times 10^{-3})^2}{100\,\mu\text{F}}$$

$$= \frac{1}{2}\times\frac{(4\times 10^{-3})^2}{10^{-4}}$$

$$E' = 0.08\ \text{J}$$

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End of Solution

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1. (d) Identify magnitude of the Burgers vector for a material having cubic crystal structure, if the density, atomic weight and lattice constant are 7870 kg/m^3, 55.85 g/mol and 2.86 Å, respectively.

[12 Marks]

Solution:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Density} = \frac{N \times \dfrac{\text{Atomic weight}}{\text{Avagadro's } N_o}}{a^3}$$

$$7870 \times 10^3 = \frac{N \times 55.85}{(2.86 \times 10^{-10})^3 \times 6.023 \times 10^{23}}$$

$$\therefore \quad N \approx 2$$

Thus, atoms per unit cube is equal to 2. Hence the structure is BCC structure.

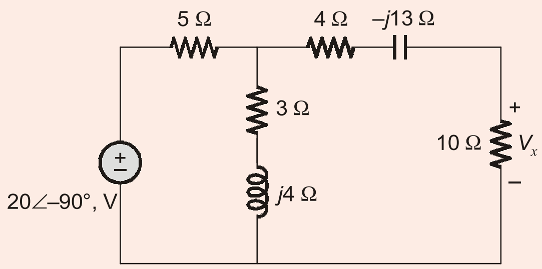
$$\therefore \quad |b| = 2R = 2 \times \frac{\sqrt{3}}{4} \times a$$

$$|b| = \frac{\sqrt{3}}{2} \times 2.86 \times 10^{-10} = 2.476\ \text{Å}$$

Thus, magnitude of Burger vector = 2.476 Å

End of Solution

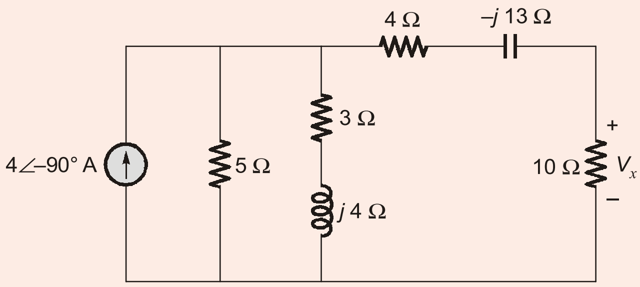
1. (e) Calculate V_x in the circuit shown in the figure using the method of source transformation.

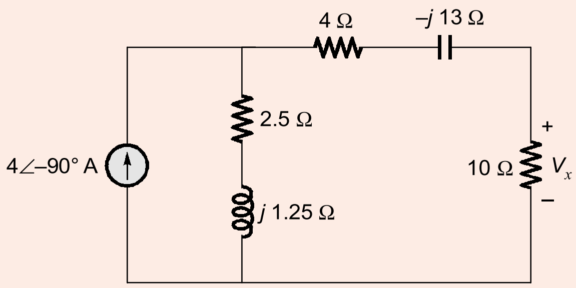


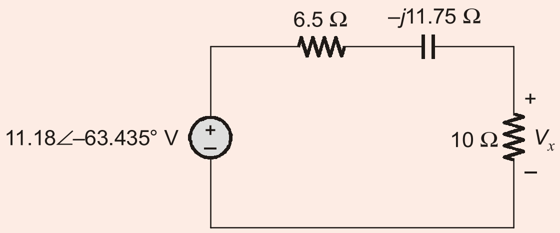
[12 Marks]

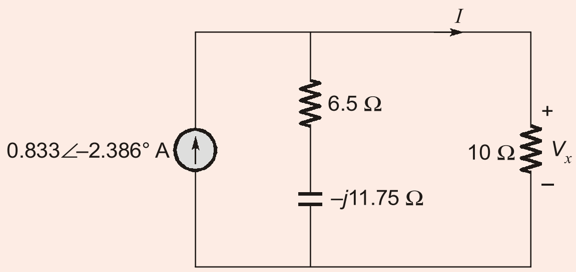
Solution:

By using source transformation,









$$V_x = 10\,I$$

where,
$$I = \frac{0.833\angle-2.386^\circ \times (6.5 - j11.75)}{16.5 - j11.75}$$

$$I = 0.552\angle-27.97^\circ \text{ A}$$

$\therefore$
$$V_x = 5.52\angle-27.97^\circ \text{ V}$$

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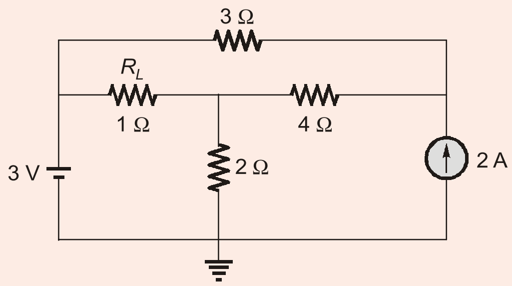
- **MADE EASY Classnotes : (Click here for reference)**

End of Solution

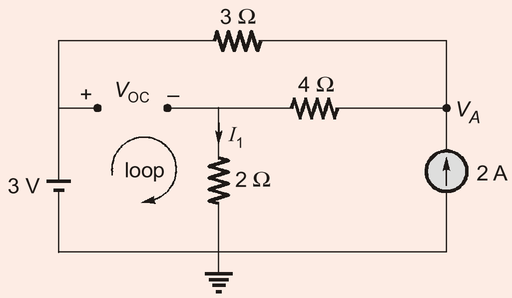
2. (a) Find the current through the load resistance 'R_L' using Thevenin's theorem and hence calculate the voltage across the current source for the circuit shown in figure.



[20 Marks]

Solution:

By using Thevenin's theorem,



By applying nodal analysis at node V_A,

$$-2+\frac{V_A-3}{3}+\frac{V_A}{6} = 0$$

$$-12+2V_A-6+V_A = 0$$

$$3V_A = 18$$

$$\therefore \quad V_A = 6\text{ V}$$

Let I_1 is the current through 2 Ω resistor

$$\therefore \quad I_1 = \frac{V_A}{6}=\frac{6}{6} = 1\text{ A}$$

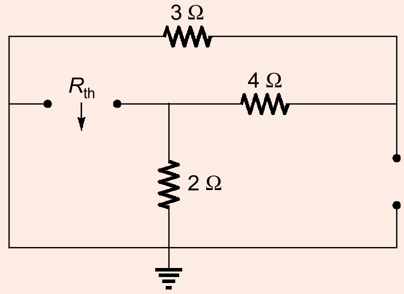
Voltage across 2 Ω resistor $V_{2\Omega} = 2 \times 1 = 2$ V

By applying kVL in loop

$$3-V_{OC}-V_{2\Omega} = 0$$

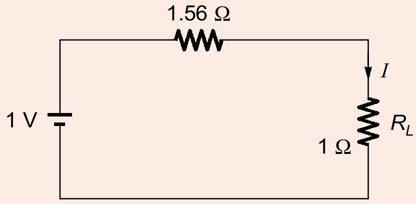
$$V_{OC} = 3-2 = 1\text{ V}$$

For thevenin's resistance R_{th} :

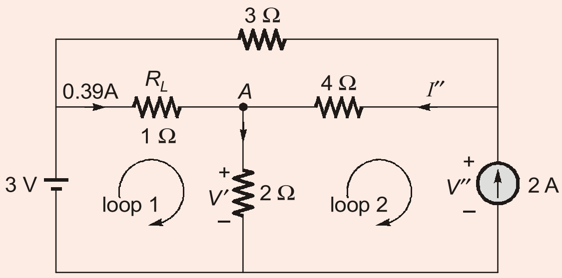


$$\therefore \quad R_{th} = 7 \parallel 2 = \frac{7\times 2}{7+2} = 1.56$$

∴ Current through the load resistance, is I



$$I = \frac{1}{1+1.56} = 0.39 \text{ A}$$



by kVL in loop 1 :

$$3 - 0.39 - V' = 0$$

$$\therefore \quad V' = 2.61 \text{ V}$$

$$I' = \frac{2.61}{2} = 1.305 \text{ A}$$

At node A, $\quad -0.39 + 1.305 - I'' = 0$

By kVL in loop 2 :

$$V' + 4 \times I'' - V' = 0$$

$$2.61 + 4 \times 0.915 = V''$$

∴ Voltage across the current source of 2 A

$$V'' = 6.27 \text{ V}$$

End of Solution

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2. (b) An abrupt Si p-n junction (A = 10^{-4} cm^2) has the following properties at 300 K:

p-side	n-side
$N_a = 10^{17}$ cm^{-3}	$N_d = 10^{15}$ cm^{-3}
$\tau_n = 0.1$ μs	$\tau_p = 10$ μs
$\mu_p = 200$ cm^2/V-s	$\mu_n = 300$ cm^2/V-s
$\mu_n = 700$ cm^2/V-s	$\mu_p = 450$ cm^2/V-s

Take n_i = 1.5 × 10^{10} cm^{-3}.

The junction is forward biased by 0.5 V. Find

(i) forward current

(ii) current at a reverse bias of –0.5 V.

[20 Marks]

Solution:

(i) The forward current equation of a P-N function diode is given as;

$$I_f = I_s\left[e^{\frac{VD}{\eta V_T}} - 1\right]$$

where
$$I_s = Aq\left[\frac{(D_p(P_{n0})}{L_p} + \frac{(D_n)\cdot(n_{p0})}{L_n}\right]$$

$$P_{n0} = \frac{n_i^2}{N_D} = \frac{(1.5\times10^{10})^2}{10^{15}} = 2.25\times10^5\text{cm}^{-3}$$

$$n_{p0} = \frac{n_i^2}{N_A} = \frac{(1.5\times10^{10})^2}{10^{17}} = 2.25\times10^3\text{cm}^{-3}$$

$$D_p = V_T\cdot\mu_P = \frac{KT}{q}\mu_p = 26\times10^{-3}\times450$$

$= 11.7$ cm^2/sec on n-side.

$D_n = V_T \cdot \mu_n = 26 \times 10^{-3} \times 700$

$= 18.2$ cm^2/sec, on p-side

$$L_p = \sqrt{D_p\cdot\tau_p} = \sqrt{11.7\times10\times10^{-6}}$$

$= 10.8 \times 10^{-3}$ cm

$$L_n = \sqrt{D_n\cdot\tau_n} = \sqrt{18.2\times0.1\times10^{-6}}$$

$= 1.34 \times 10^{-3}$ cm

$$I_s = 1.6\times10^{-19}\times10^{-4}\left[\frac{11.7\times2.25\times10^5}{10.8\times10^{-3}} + \frac{18.2\times2.25\times10^3}{1.34\times10^{-3}}\right]$$

$I_s = 4.38 \times 10^{-15}$ A

∴
$$I_f = I_s\left[e^{\frac{VD}{\eta V_T}} - 1\right] = 4.38\times10^{-15}\left[e^{\frac{0.5}{1\times26\times10^{-3}}} - 1\right]$$

$I_f = 9.8 \times 10^{-7}$ A

(ii) The forward current equation can be extended for reverse bias as:

$$I = -I_s\left[e^{\frac{-V_r}{\eta V_T}} - 1\right]$$

$$= -4.38\times10^{-15}\left[e^{\frac{-0.5}{1\times 26\times10^{-3}}} - 1\right]$$

$$I = 4.37 \times 10^{-15}\text{ A}$$

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- **Conventional Practice Question Book:** Basic Electronics Engineering (Page No. 24 (Q.20)) **(Click here for reference)**

End of Solution

2. (c) An InGaAs pin photodiode has the following parameters at a wavelength of 1300 nm:
I_D = 4 nA; η = 0.90; R_L = 1 kΩ; P_{in} = 300 nW
where P_{in} is incident optical power. The receiver bandwidth is 20 MHz. Assume surface leakage current is negligible.
Determine
(i) mean-square shot noise current,
(ii) mean-square dark current and
(iii) mean-square thermal noise current.
Which noise is more severe and why?

[20 Marks]

Solution:

The primary photocurrent can be calculated as

$$I_p = RP_{in} = \frac{\eta q}{h\nu}\cdot P_{in} = \frac{\eta q\lambda}{hc}\cdot P_{in}$$

$$= \frac{(0.9)(1.6\times10^{-19})(1.3\times10^{-6})}{(6.625\times10^{-34})(3\times10^{8})}\times 3\times10^{-7} = 0.282\,\mu\text{A}$$

(i) The mean-square shot noise current for a PIN photodiode is

$$< i^2_{shot} > = 2qI_pB_e$$

$$= 2(1.6\times10^{-19})(0.282\times10^{-6})(20\times10^{6}) = 1.8\times10^{-18}\text{ A}^2$$

(ii) The mean-square dark current is given as

$$< i^2_{DB} > = 2qI_DB_e$$

$$= 2(1.6\times10^{-19})(4\times10^{-9})(20\times10^{6}) = 2.56\times10^{-20}\text{ A}^2$$

(iii) The mean-square thermal noise current for the receiver is found from

$$< i^2_T > = \frac{4K_BT}{R_L}\cdot B_e = \frac{4(1.38\times10^{-23})(300)}{1\times10^{3}}\cdot 20\times10^{6} \quad (\text{Assuming } T = 300°\text{K})$$

$$= 331\times10^{-18}\text{ A}^2$$

Thus the total mean square short noise is equal to

$$< i^2_{TSh} > = 2.56 \times 10^{-20} + 1.8 \times 10^{-18}$$
$$= 1.8256 \times 10^{-18}\ A^2$$

From this we can see that the thermal noise is much greater than the short noise by nearly a factor of 181.

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- **ESE 2020 Mains Test Series:** Test-9 (Q.3(a)) **(Click here for reference)**

End of Solution

3. (a) The entry point and exit point of X-rays on a power pattern taken from a cubic crystal material could not be distinguished. Assuming one of the points to be the exit point, the following S values were obtained:

S values : 311.95 mm, 319.10 mm and 335.05 mm.

The camera radius is 57.3 mm and Molybdenum K_α radiation of wavelength 0.7 Å was used.

Determine the structure and the lattice parameter of the material.

[20 Marks]

Solution:

Given, Wavelength, $\lambda = 0.7$ Å

Radius of camera = 57.3 mm

s values : 31.95 mm, 319.10 mm, 335.05 mm

The Bragg's angle of reflection are calculated as $\frac{s}{4}$,

So, $$\frac{31.95}{4} = 77.987°,\ \frac{319.10}{4} = 79.75°,\ \frac{335.04}{4} = 83.762°$$

The Bragg's diffraction law is

$$2d\sin\theta = n\lambda$$

where, n = 1, 2, 3, ... is an integer

Here,
$$2d\sin\theta_1 = \lambda \quad \text{when } n = 1 \text{ (first order)}$$
$$2d\sin\theta_2 = 2\lambda \quad \text{when } n = 2 \text{ (second order)}$$
$$2d\sin\theta_3 = 3\lambda \quad \text{when } n = 3 \text{ (third order)}$$

Now, $$d = \frac{n\lambda}{2\sin\theta}$$

Here, the values of θ are experimentally found out as 77.987°, 79.775° and 83.762°.

As per Bragg's equation

$$\frac{1}{d} = \frac{2\sin\theta}{\lambda}$$

$$\therefore \quad \frac{1}{d_1} : \frac{1}{d_2} : \frac{1}{d_3} = \sin 77.987° : \sin 79.775° : \sin 83.762°$$

$$= 0.978 : 0.9841 : 0.994$$

$$\Rightarrow \quad \frac{1}{d_1} : \frac{1}{d_2} : \frac{1}{d_3} = 1 : 1 : 1$$

Hence, it is the interplanar spacing in <111> plane, so structure is FCC.

Now, $d_{hkl} = \dfrac{a}{\sqrt{h^2 + K^2 + l^2}}$ where a is the parameter

Now to calculate lattice parameter, we will consider highest sine angle i.e. $n = 3$ (third order).

$$\therefore \quad 2d_{hkl}\sin\theta_3 = 3\lambda$$

$$\Rightarrow \quad 2 \times \frac{a}{\sqrt{3}} \times \sin 83.762 = 3 \times 0.7 \text{ Å}$$

$$\Rightarrow \quad a = \frac{3 \times 0.7 \text{ Å} \times \sqrt{3}}{2 \times \sin 83.762} = 1.829 \text{ Å} = \frac{1.81865 \text{ Å}}{0.994}$$

$$a = 1.829 \text{ Å}$$

So, structure is FCC with lattice parameter a = 1.829 Å

End of Solution

3. (b) (i) Obtain the exact equivalent circuit (per phase) of three-phase induction motor.

(ii) A 6-pole, 3-phase, 50 Hz induction motor takes 50 kW power at 940 rpm. The stator copper loss is 1.4 kW, stator core loss is 1.6 kW, and rotor mechanical losses are 1 kW. Find the motor efficiency.

[10 + 10 Marks]

Solution:

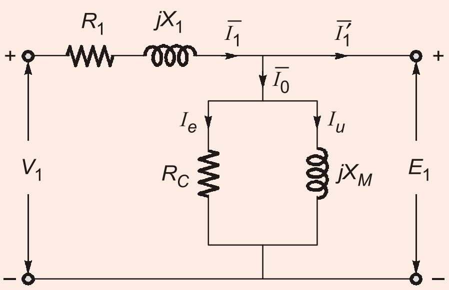
(i) Induced EMF in induction motor

$$E_1 = 4.44\, f \cdot N_2 \cdot \phi_M \times Kw_1 \rightarrow \text{in stator winding}$$

$$E_2 = 4.44\, f \cdot N_2 \cdot \phi_M \times Kw_2 \rightarrow \text{in rotor winding}$$

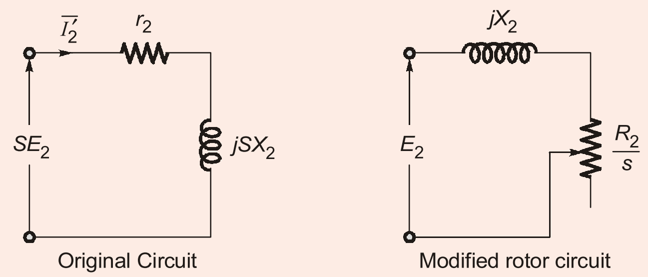
$$\frac{E_1}{E_2} = \frac{N_1 \cdot K\omega_1}{N_2 \cdot K\omega_2} = \frac{N_1'}{N_2'} = \text{Ratio of effective turns}$$

Circuit diagram of induction motor on stator side :



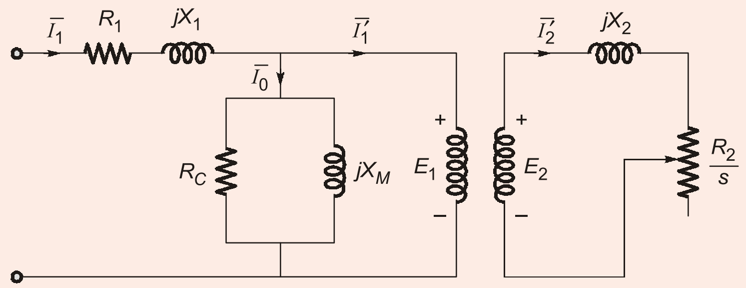
MMF balance, $N_1' \bar{I}_1 = N_2' \bar{I}_2 + N_1' \bar{I}_0$

Rotor circuit:

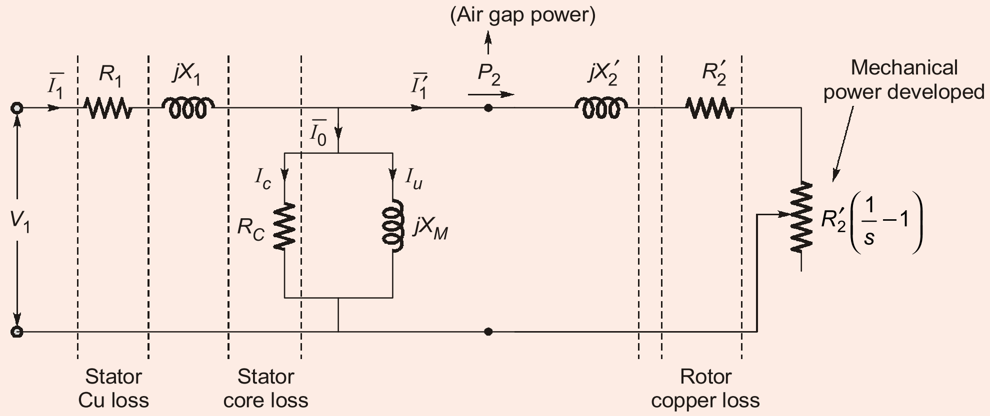


- The original rotor circuit is drawn at a frequency 'sf_s' due to which a factor of 's' appears in EMF and reactance so power drawn by rotor is equal to the rotor copper losses because frame of reference is rotor and we cannot observe rotor rotation.
- The modified circuit is drawn at a frequency 'f_s' due to which there is no factor of 's' in EMF and reactance and the frame of reference is stator. Hence, we can observe rotor rotation. So, rotor draws a power to drive the mechanical load and supply its losses as well.

Exact circuit of induction motor is :



Exact equivalent circuit of induction motor refer to stator side is



$$X_2' = X_2\left(\frac{N_1}{N_2}\right)^2$$

$$R_2' = R_2\left(\frac{N_1}{N_2}\right)^2$$

S = Slip of induction motor

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(ii) Given that, $P = 6$ pole, $f = 50$ Hz, $P_{in} = 50$ kW

$$N_r = 940 \text{ rpm}, \; N_s = \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

Stator copper losses $P_{st}(\text{Cu}) = 1.4$ kW

Stator core losses $P_{st}(\text{core}) = 1.6$ kW

Rotational losses $P_{rot} = 1$ kW

⇒ Air gap power, $P_g = P_{in} - P_{st(core)} - P_{st(core)} - P_{st(cu)}$

$P_g = 50 - 1.6 - 1.4 = 47$ kW

⇒ Rotor copper losses, $P_{cr} = s \cdot p_g$

$$\text{Slip} = \frac{N_s - N_r}{N_s} \times 100 = \frac{1000 - 940}{1000} = 0.06$$

$P_{cr} = 0.06 \times 47 \text{ kW} = 2.82$ kW

⇒ Mechanical power developed

$P_{md} = P_g - P_{cr} = 47 - 2.82 = 44.18$ kW

⇒ Shaft power, $P_{sh} = P_{md} - P_{rot} = 44.18 - 1 = 43.18$ kW

Percentage efficiency of induction motor = $\%\eta$

$$\%\eta = \frac{P_{sh}}{P_{in}} \times 100 = \frac{43.18}{50} \times 100 = 86.36\%$$

MADE EASY Source

- **ESE 2020 Mains Test Series:** Test-10, Q.8 (c) **(Click here for reference)**
- **MADE EASY Classnotes**

End of Solution

3. (c) An industrial consumer is operating a 50 kW induction motor at a lagging p.f. of 0.8. The source voltage is 230 V rms. In order to obtain lower electrical rates, the customer wishes to raise the p.f. to 0.95 lagging. Specify a suitable solution. [20 Marks]

Solution:

kW rating of induction motor = 50 kW

Operating power factor = $\cos\phi = 0.8$ lag

Supply voltage = 230 V(rms)

Complex power input to the motor is

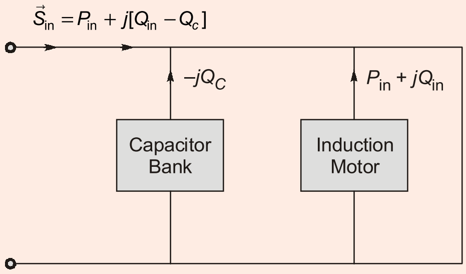
$$\vec{S}_{in} = P + jQ = P + j\tan\phi$$

$$\vec{S}_{in} = [50 + j50 \times 0.75] \text{ kVA}$$

$$\vec{S}_{in} = (50 + j37.5) \text{ kVA}$$

Now consumer wants to obtain lower electrical rates by raising the power factor to 0.95 lagging, this can be done by reducing the kVA input to the motor. Since, input active power is fix, it cannot be reduced without any additional active power source, but input reactive power can be reduced using either by static capacitor bank or over excited synchronous motor installed. Near the induction motor and in this way we can raised the input power factor of supply.

Suitable arrangement and location of capacitor bank



Now complex power input flow supply is

$$\vec{S}_{in} = P_{in} + j(Q_{in} - Q_c)$$

$$= [50 + jP_{in}\tan\phi_{new}] \text{ kVA} \quad \left\{\begin{matrix}\phi_{new} = \cos^{-1}0.95 = 18.19 \\ \tan\phi_{new} = 0.3285\end{matrix}\right\}$$

$$= 50 + j50 \times 0.3285$$

$$\vec{S}_{in} = (50 + j16.425) \text{ kVA}$$

kVAR rating of capacitor bank :

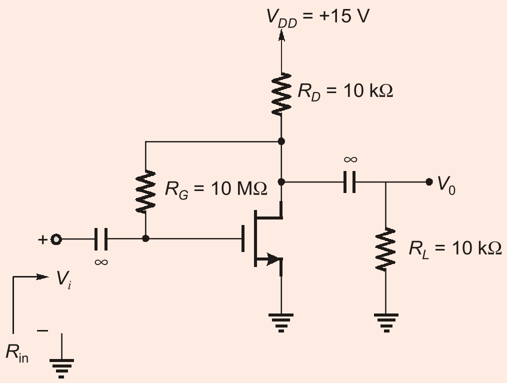
$$Q_c = 37.50 - 16.425 = 21.075 \text{ kVAR}$$

MADE EASY Source

- **MADE EASY Mains Workbook :** Basic Electrical Engg. Page No. 64, Q.14
  (Click here for reference)

End of Solution

4. (a) Figure below shows a discrete MOSFET amplifier utilizing a drain-to-gate resistance R_G. The input signal V_i is coupled to the gate via a large capacitor, and the output signal at the drain is coupled to load resistance R_L via another large capacitor. Analyze this amplifier circuit to determine its small signal voltage gain, its input resistance, and the largest allowable input signal. Assume V_t = 1.5 V, K_n' (W/L) process transconductance parameter) = 0.25 mA/V^2, and V_A = 50 V, where V_A is the intercept on the V_{DS} axis of the $i_D - V_{DS}$ characteristics when extrapolated. Assume that coupling capacitors are sufficiently large so as to act as short circuit at the frequencies of interest.

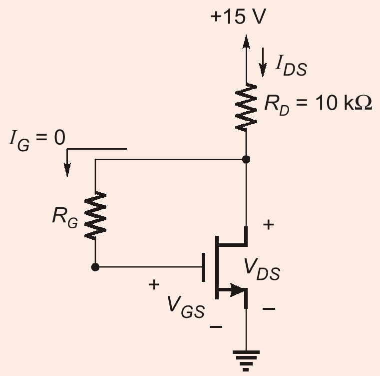


The effect of channel length modulation on the dc operating point can be neglected.

[20 Marks]

Solution:

DC analysis :



Since, $I_G = 0$

$\Rightarrow$ Voltage drop across R_G is 0.

$\Rightarrow$ $$V_{DS} = V_{GS} = 15 - 10I_{DS}$$

$\Rightarrow$ $$I_{DS} = \frac{15 - V_{GS}}{10} \qquad \text{...(i)}$$

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

$$\frac{15 - V_{GS}}{10} = \frac{0.25}{2}(V_{GS} - 1.5)^2$$

$$30 - 2V_{GS} = 2.5(V_{GS}^2 + 2.25 - 3V_{GS})$$

After solving, $V_{GS} = 4.41\ ,\ -2.21\ \text{V}$

V_{GS} should be greater than V_T.

$\therefore$ $$V_{GS} = 4.41\ \text{V}$$

$\Rightarrow$ $$I_{DS} = \frac{15 - 4.41}{10} = 1.059\ \text{mA}$$

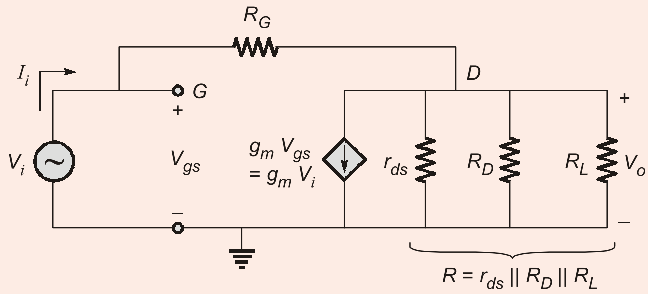
$$V_{DS} = 15 - 10I_{DS} = 4.41\ \text{V}$$

Now, $$g_m = \mu_N C_{ox}\frac{W}{L}(V_{GS} - V_T)$$

$$g_m = 0.25\ (4.41 - 1.5) = 0.7275\ \text{m℧}$$

$$r_{ds} = \frac{V_A + V_{DS}}{I_{DS}} = \frac{50 + 4.41}{1.059 \times 10^{-3}} = 51.38\ \text{k}\Omega$$

Replace MOSFET with small signal model.



KCL at drain :

$$\frac{V_i - V_o}{R_G} = g_m V_i + \frac{V_o}{R}$$

$$\Rightarrow \qquad \frac{V_o}{V_i} = \frac{\frac{1}{R_G} - g_m}{\frac{1}{R} + \frac{1}{R_G}}$$

$$\Rightarrow \qquad A_v = -3.313$$

KCL at Gate:

$$I_i = \frac{V_i - V_o}{R_G} = \frac{V_i - A_v V_i}{R_G}$$

$$\Rightarrow \qquad \frac{V_i}{I_i} = \frac{R_G}{1 - A_v} \Rightarrow R_i = \frac{10\text{ M}\Omega}{1 + 3.313}$$

$$R_i = 2.138\text{ M}\Omega$$

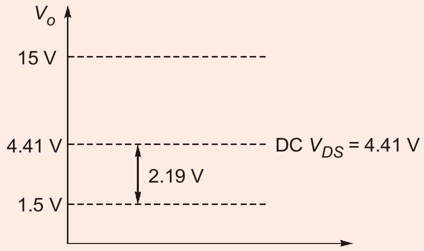
To find maximum allowable input :

In given circuit $V_{DS} = V_{GS}$

∴ V_{DS} or V_o can decrease upto V_T i.e., 1.5 V.

V_{DS} or V_o can increase upto V_{DD} = 15 V.

Maximum possible undistorted output is 2.91 V.



$$\therefore \text{ Maximum allowed peak input} = \frac{2.91}{|A_v|} = \frac{2.91}{3.313} = 0.878\text{ V}$$

MADE EASY Source

- **ESE 2020 Mains Test Series:** Mock Test-1 (Q.1(b))
- **MADE EASY Classnotes : (Click here for reference)**

End of Solution

4. (b) (i) Define nanomaterials and classify nanomaterials on the basis of number of dimensions. What are the different approaches for the preparation of nanomaterials? Discuss any one method of preparation of nanomaterials from each approach.

(ii) Explain how dislocation density increases on cold working.

[10 + 10 Marks]

Solution:

(i) **Nanomaterials :** Nanomaterials are the materials which have atleast one of the dimensions in nanometer range.

Classification of nanomaterials on basis of dimensions :

(a) **Zero dimensional :** All three dimensions are in nanorange e.g. quantum dots.

(b) **One dimensional :** Materials where two dimensions are in nanorange and third dimension is much larger e.g. nanowave, nanotubes, etc.

(c) **Two dimensional :** One of dimension in nanorange and other two are much larger e.g. nanofilms, nanosheets.

(d) **Three dimensional :** All three dimensions of particle are much larger than nanorange e.g. bulk nanomaterials.

Preparation approaches :

Top down approach	Bottom up approach
(i) Ball milling (ii) Dry etching (iii) Photolithography (iv) Electron beam lithography	(i) Bottom up appraoch (ii) Inert gas condensation (iii) Chemical vapour deposition (iv) Sputtering (v) Electro deposition

Ball milling : It is a high energy deformation process that progressively introduces defect structures, atomic scale chemical disorder, and elastic strain energy into initially crystalline starting powders through shearing actions of ball powder collisions. Milling can be used to produce wide variety of effects in intermetallic alloys due to complex dependence of nanostructures on milling intensity, temperature and other factors.

Sputtering :

- It is a physical vapour deposition process.
- High energy ions bombard a solid target material to eject its atoms into vapour phase. The ejected atoms can be deposited in the form of nanofilm on a cold substrate.
- Low deposition time and low temperature of the substrate help is preventing the growth of nanomaterials into larger ones.

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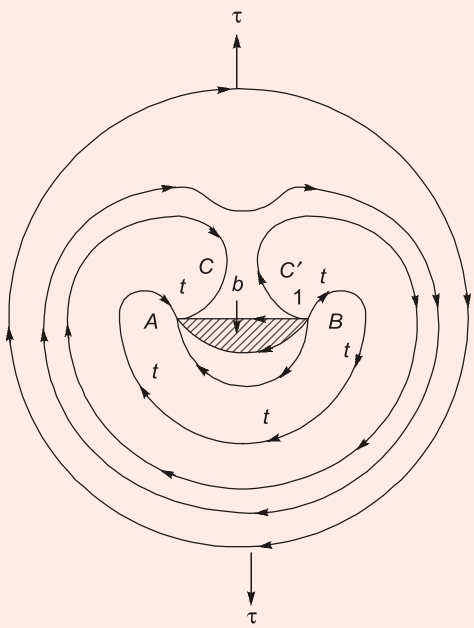
(ii) A lightly cold worked crystal may have a dislocation density of 10^{12} m^{-2}, while a very heavily cold worked crystal may have 10^{16} m^{-2} of dislocations. This indicates that there are sources within the crystal, which generate new dislocations during plastic deformation. One such source is called the Frank-Read source.

In below figure, a segment *AB* of a dislocation line lies on a slip plane that is the most common one for this crystal. *A* and *B* are dislocation nodes or points beyond which the dislocation line does not lie on the slip plane. Only the segment *AB* is capable of moving easily in response to an applied stress. Let a shear stress τ be applied parallel to the slip plane on which *AB* is lying. The segment cannot pull itself away from the anchoring points, because of the geometrical requirement that a dislocation cannot end abruptly within the crystal. It responds to the applied stress, by bending itself to position 2 about the fixed points *A* and *B* and thereby increasing its length. The total line energy of the segment increases in the process. The extra energy comes from the work done by the externally applied stress in bending the dislocation. Between positions 1 and 2, the slip displacement equal in magnitude to the Burgers vector **b** of the dislocation occurs over the shaded area of the slip plane.

As the stress is increased, the dislocation bends progressively to a semicircular shape as illustrated. The *t* vector indicated in figure below follows the bent dislocation line, going from *B* to *A*.



On further increase of the stress, the dislocation bends back on itself and the slip displacement spreads to regions on the other side of the line *AB*. In one of these configurations, the direction of the dislocation line at point *C* is opposite in sense to the direction at point *C*′. The *t* vectors are in opposite directions at these two points. As the Burgers vector is invariant, this means that the segment of the dislocation line near *C* is opposite in sign to that near *C*′. The two segments attract and annihilate each other. This produces a full dislocation loop and a left-over piece, which springs back to the initial position AB. Note that, during this entire cycle, the direction of dislocation motion at any point on the line is always perpendicular to the line at that point (except at A and B).

The cycle can now be repeated to produces another full loop and so on. A Frank-Read source can operate continuously and produce an indefinite number of loops, provided the loops produces move out and disappear at the surface of the crystal. If, however, the loops are piled up against an obstacle such as a grain boundary, back stress will begin to build up at the source, the operation of the source eventually coming to a halt.

MADE EASY Source

- **Conventional Practice Question Book:** Materials Science (Page No. 79-80 Q.35 & Q.36)
- **MADE EASY Classnotes : (Click here for reference)**

End of Solution

4. (c) (i) The Burgers vector of a mixed dislocation line is $\frac{1}{2}[1\ \ 1\ \ 0]$. The dislocation line lies along the $[1\ \ 1\ \ 2]$ direction. Find the slip plane on which this dislocation lies.

(ii) Explain, why end centered tetragonal geometry does not exist.

[10 + 10 Marks]

Solution:

(i) Burger vector $\quad$ 'b' $= \frac{1}{2}[1\ 1\ 0]$

Direction $\quad$ 't' $= [1\ \ 1\ \ 2]$

Given is the mixed dislocation, it can move only in a plane containing both b and t.

Let the indices of slip plane be $(h\ \ k\ \ l)$

Then, $\quad t_1 n + t_2 k + t_3 l = 0$

$\Rightarrow \quad n + k + 2l = 0 \quad$ ...(i)

and $\quad b_1 n + b_2 k + b_3 l = 0$

$\Rightarrow \quad \frac{1}{2}n + \frac{1}{2}k + 0l = 0 \quad$ ...(ii)

Solving equations (i) and (ii)

$$\frac{1}{2}n = -\frac{1}{2}k$$

$$h = -k$$

and, $\quad 2l = -n - k = -n + n = 0$

$\Rightarrow \quad l = 0$

Slip plane is $(h\ \ k\ \ l) = (1\ \ \bar{1}\ \ 0)$

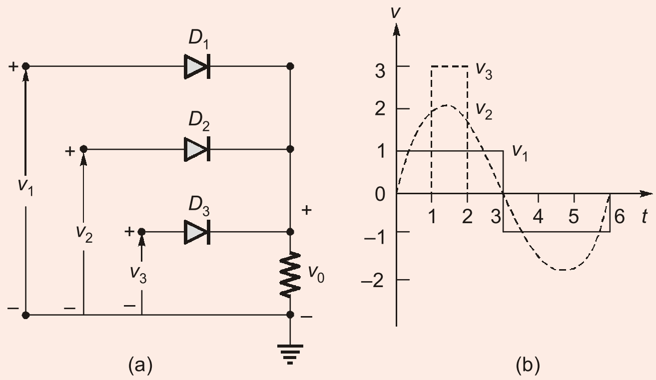
(ii) This is because if we join all four end centred lattice point to a common lattice points of unit cells (points joining two unit cells), a new unit cell is formed which is primitive tetragonal only which has single four fold axis symmetry.

Hence due to symmetry there is no end centred tetragonal unit cell.

End of Solution

5. (a) (i) Sketch the circuit of a one-shot using a 555 timer to provide one time period of 20 µs. If R_A = 7.5 kΩ, what value of C is needed? Also sketch the input and output waveforms, when triggered by a 10 kHz clock for R_A = 5.1 kΩ and C = 5 nF.

(ii) The logic OR gate can be used to fabricate composite waveforms. Sketch the output v_0 of the gate of figure (a) shown below if the three signals as shown below in (b) are impressed on the input terminals. Assume the diodes are ideal.



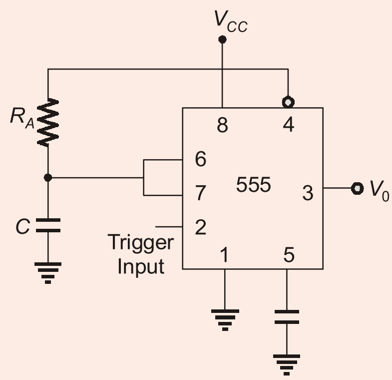
(a) (b)

[6 + 6 Marks]

Solution:

(i) One-shot is Monostable Multivibrator.

It provides pulse output of duration.



$$T_0 = 1.1\ R_AC$$

$$C = \frac{T_0}{1.1R_A}$$

$$C = \frac{20 \times 10^{-6}}{1.1 \times 7.5 \times 10^3}$$

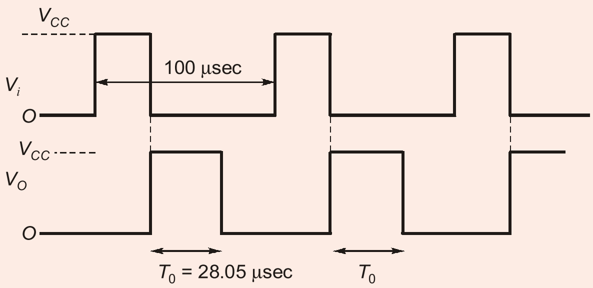
$$C = 2.424 \text{ nF}$$

If R_A = 5.1 kΩ and C = 5 nF

then, $T_0 = 1.1\ R_AC = 28.05$ µsec

$$\text{Time period of input clock} = \frac{1}{f_{clock}} = \frac{1}{10 \times 10^3} = 100\ \mu\text{sec}$$

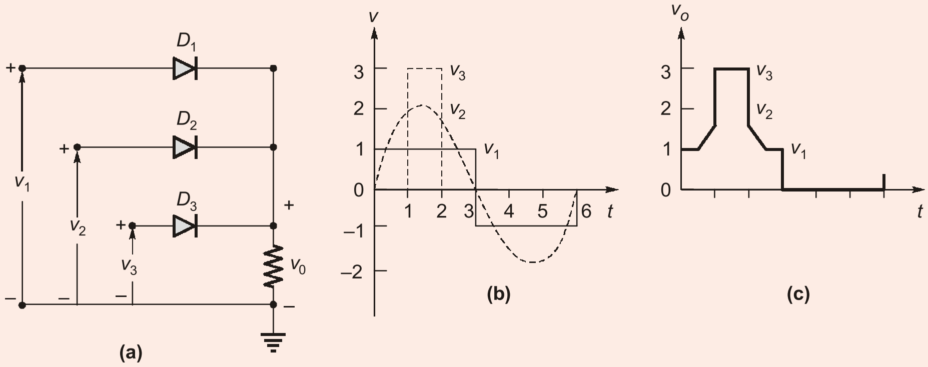
At the falling edge of clock, output enters quasi-stable state logic '1' or V_{CC}.



(ii) For this circuit, KVL gives

$$v_1 - v_2 = v_{D1} - v_{D2}$$
$$v_1 - v_3 = v_{D1} - v_{D3}$$

i.e., the diode voltages have the same ordering as the input voltages. Suppose that v_1 is positive and exceeds v_2 and v_3. Then D_1 must be forward-biased, with v_{D1} = 0 and, consequently, $v_{D2} < 0$ and $v_{D3} < 0$. Hence, D_2 and D_3 block, while v_1 is passed as v_o. This is so in general. The logic of the OR gate is that the largest positive input signal is passed as v_o,



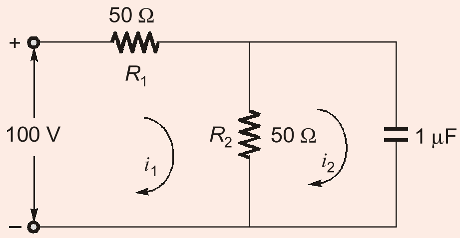
while the remainder of the input signals are blocked. If all input signals are negative, v_o = 0. Applications of this logic gives the sketch of v_o in figure (c).

MADE EASY Source

- **MADE EASY Classnotes : (Click here for reference)**

End of Solution

5. (b) A dc voltage of 100 V is suddenly applied in the network shown in the figure. Find the transient currents in both the loops and obtain the transient voltage across the capacitor.



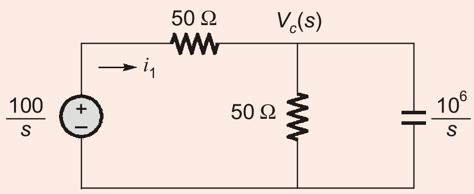
[12 Marks]

Solution:

Initial charge on the capacitor is 0 V

$$V_c(0^-) = 0 \text{ V}$$

Apply Laplace transform



$$\frac{\frac{100}{s} - V_c(s)}{50} = \frac{V_c(s)}{50} + \frac{V_c(s)}{10^6/s}$$

$$\frac{100}{50s} = V_c(s)\left[\frac{1}{50} + \frac{1}{50} + \frac{s}{10^6}\right]$$

$$\frac{100}{50s} = V_c(s)\left[\frac{10^6 + 10^6 + 50s}{50 \times 10^6}\right]$$

$$V_c(s) = \frac{100 \times 10^6}{s(50s + 2 \times 10^6)}$$

$$V_c(s) = \frac{2 \times 10^6}{s(s + 40 \times 10^3)}$$

$$V_c(s) = \frac{A}{s} + \frac{B}{s + 40 \times 10^3}$$

$$\Rightarrow \quad = \frac{50}{s} - \frac{50}{s + 40 \times 10^3}$$

$$V_c(s) = 50 - 50\, e^{-40000t} \qquad (t \geq 0)$$

$$I_1(s) = \left[\frac{100}{s} - \frac{2\times10^6}{s(s+40\times10^3)}\right]\frac{1}{50}$$

$$I_1(s) = \left[\frac{50}{s} + \frac{50}{s+40\times10^3}\right]\frac{1}{50}$$

$$i_1(t) = (1 + e^{-40,000t})\ \text{A} \qquad (t \geq 0)$$

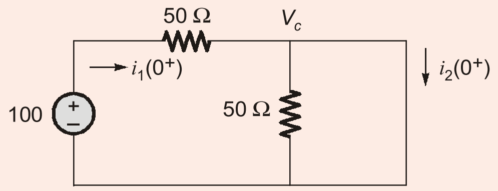
$$I_2(s) = \frac{\left[\frac{2}{s+40\times10^3}\right]\frac{s}{10^6}}{10^6/s}$$

$$I_2(s) = \frac{2}{s+40\times10^3}$$

$$i_2(t) = (2\,e^{-40,000t}) \qquad (t \geq 0)$$

or $\quad V_c(0^+) = 0\ \text{V}$

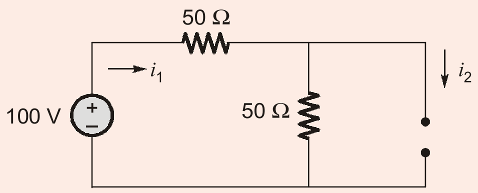
$t = 0^+$



$$i_1(0^+) = \frac{100}{50} = 2\ \text{A}$$

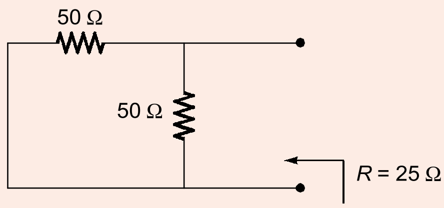
$$i_2(0^+) = 2\ \text{A}$$

$t \to \infty$ (Capacitor acts as open circuit)



$$i_1(\infty) = \frac{100}{100} = 1\ \text{A}; \qquad i_2(\infty) = 0\ \text{A}$$

Time constant



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Last 10 Years Results of ESE

Exam Year	Total Vacancies	Total Selections	Selection %	All India Rank-1 (Stream-wise)	Selections in Top 10 (out of 40)	Selections in Top 20 (out of 80)
ESE-2019	494	465	94%	All 4 Streams	40	78
ESE-2018	511	477	94%	All 4 Streams	38	78
ESE-2017	500	455	91%	All 4 Streams	40	78
ESE-2016	604	505	84%	All 4 Streams	39	76
ESE-2015	434	352	82%	All 4 Streams	38	73
ESE-2014	589	445	75%	All 4 Streams	32	64
ESE-2013	702	482	69%	All 4 Streams	34	62
ESE-2012	635	395	62%	All 4 Streams	32	60
ESE-2011	693	401	60%	CE, ME, EE	29	55
ESE-2010	584	295	51%	ME, EE, ET	26	51

Last 10 Years Results of GATE

Exam Year	Total AIR-1	All India Rank-1 (Stream-wise)	Ranks in Top 10	Ranks in Top 20	Ranks in Top 100
GATE-2020	9	CE, ME, EC, CS, IN, PI	61	109	441
GATE-2019	7	CE, ME, EE, EC, CS, IN, PI	60	118	426
GATE-2018	5	CE, ME, CS, IN, PI	57	103	406
GATE-2017	6	CE, ME, EE, CS, IN, PI	60	101	351
GATE-2016	6	ME, EE, EC, CS, IN, PI	53	96	368
GATE-2015	6	ME, EE, EC, CS, IN, PI	48	80	314
GATE-2014	5	CE, ME, EE, EC, IN	34	58	214
GATE-2013	3	CE, ME, PI	26	42	178
GATE-2012	3	CE, IN, PI	18	22	89
GATE-2011	2	ME, PI	06	11	57

Our result is published in national/regional newspapers every year and the detailed result alongwith names of candidates/rank/course(s) joined/marks obtained is available on our website.

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$$\tau = 25 \times 1\ \mu\text{sec} = 25\ \mu\text{sec}$$

$$i_1(t) = i_1(\infty) + (i_1(0^+) - i_1(\infty))\, e^{-t/\tau}$$

$$i_1(t) = 1 + (2-1)\, e^{-t/25\times10^{-6}}$$

$$= 1 + e^{-40,000t}$$

$$i_2(t) = 0 + (2-0)e^{-t/25\times10^{-6}}$$

$$= 2\, e^{-40,000\,t} \quad ; \quad t \geq 0$$

MADE EASY Source

- **MADE EASY Classnotes : (Click here for reference)**

End of Solution

5. (c) Predict and draw the crystal structure of MgO and compute its theoretical density. (Give Ionic radius of Mg^{++} ion, $r_{MG^{++}}$ = 0.72 Å and ionic radius of O^{--} ion, $r_{O^{--}}$ = 1.40 Å; atomic masses of 'Mg' and 'O' are 24.31 g/mol and 16.00 g/mol, respectively, Avogadro's Number = 6.023 × 10^{23} g/mol).

[12 Marks]

Solution:

Structure FCC union packing, cations in the octahedral voids.

Radius of Mg^{2-} ion, $r^{2+}_{Mg} = 0.72$ Å

Radius of O^{2-} ion, $r^{2-}_{O} = 1.40$ Å

Lattice parameter, $a = 2\left[r^{2+}_{Mg} + r^{2-}_{O}\right]$

$$= 2[0.72 + 1.40] = 4.24 \text{ Å}$$

Effective number of oxygen unions at FCC positions in the unit cell

$$= 8 \times \frac{1}{8}(\text{Corner ions}) + 6 \times \frac{1}{2}(\text{Face centred ions}) = 4$$

Effective number of magnesium cations in octahedral voids

$$= 1(\text{Body centre}) + 12 \times \frac{1}{2}(\text{midpoint of cube edges}) = 4$$

$$\text{Density} = \frac{\text{Mass of atoms in unit cell}}{\text{Volume of unit cell}} = \frac{n_{Mg}\, M_{mg} + n_O\, M_O}{\text{Volume of unit cell}}$$

$$= \frac{n_{Mg}\, M_{Mg} + n_O\, M_O}{a^3 \times N_A} = \frac{4(24.31 + 16)}{(4.24 \times 10^{-8})^3 \times 6.022 \times 10^{23}}\ \text{g/cm}^3$$

$$\text{Density} = 3.5126\ \text{g/cm}^3$$

End of Solution

5. (d) A digital ramp A/D converter has the following values:

Clock frequency, f_c = 1 MHz

Threshold voltage, V_T = 100 μV

D/A-V_{ref} = 10.24 V and Number of input bits = 10.

Determine:

(i) Digital/equivalent representation for V_{in} = 4.872 V.

(ii) Resolution of the A/D converter and

(iii) Conversion time required by this digital ramp A/D converter.

[12 Marks]

Solution:

(i) the DAC has a 10-bit input and a reference voltage of 10.24 V

$$\text{Step size} = \frac{V_{FS}}{2^n - 1} = \frac{V_r}{2^n - 1} = \frac{10.24}{2^{10} - 1} = 10 \text{ mV}$$

This means that V_A increase in steps of 10 mV as the counter counts up from 0. Because V_{in} = 4.872 V and V_T = 0.1 mV, V_{in} must reach 4.872 V on more before the comparator switches low.

$$\text{This will require, } \frac{4.872\text{ V}}{10\text{ mV}} = 487.2 \text{ V} = 487 \text{ steps.}$$

At the end of the conversion, the counter will hold the binary equivalent of 487, which is 111100111. This is the desired digital equivalent of V_{in} = 4.872 V, as produced by this ADC.

(ii) $$\text{Resolution} = \frac{V_{ref}}{2^n} = \frac{10.24}{2^{10}} = 0.01$$

(iii) 487 steps are required to complete the conversion. Thus, 487 clock pulses appeared at the rate of one per microsecond.

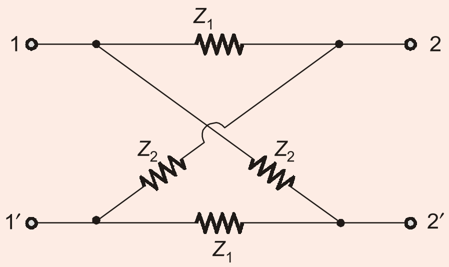
∴ Total conversion time = 487 μsec

MADE EASY Source

- **Theory Book:** Digital Circuits (Page. No. 315, Example-9.9) **(Click here for reference)**

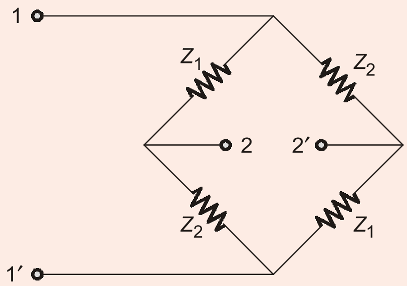
End of Solution

5. (e) For the lattice two port network of the figure shown, find the image impedance and the image transfer constant.



[12 Marks]

Solution:



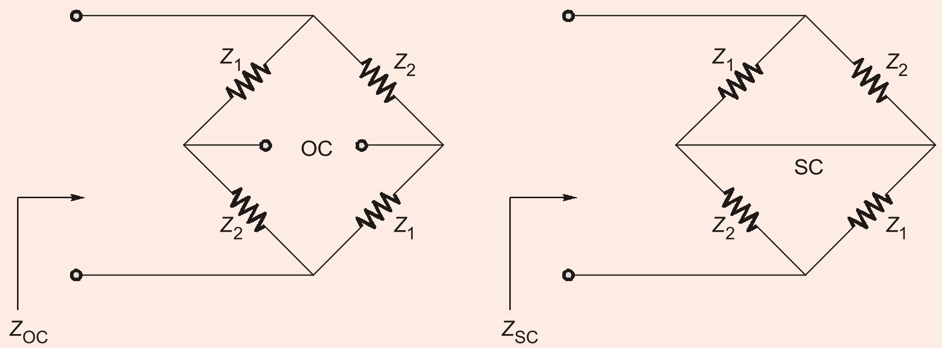
In a symmetrical network image impedance and iterative impedances are equal and also characteristic impedance.

$$Z_o = \sqrt{Z_{OC} \cdot Z_{SC}}$$

Z_o is characteristic impedance.

$$Z_{OC} = \frac{Z_1 + Z_2}{2}$$

$$Z_{SC} = 2\left(\frac{Z_1 Z_2}{Z_1 + Z_2}\right)$$



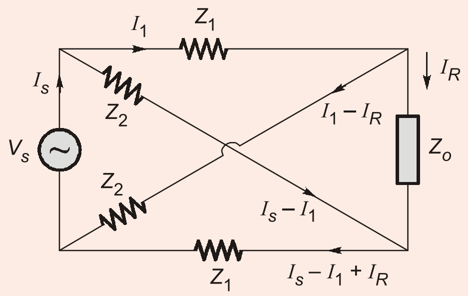
$$Z_0^2 = Z_1\, Z_2$$

$$Z_o = \sqrt{Z_1 Z_2}$$

Z_o is also equal to image impedance.

In a symmetrical network image transfer constant is equal to propagation constant.

To determine the propagation apply kVL in a loop



$$V_s = I_1Z_1 + I_RZ_o + (I_s - I_1 + I_R)Z_1$$

$$V_s = I_sZ_1 + I_R(Z_0 + Z_1)$$

When the network is terminated at its Z_o. Its input impedance is Z_o.

$\therefore$ $$Z_o = \frac{V_s}{I_C}$$

$\Rightarrow$ $$V_s = I_s\,Z_o \qquad \text{...(ii)}$$

Substract equation (ii) in equation (i)

$$I_1\,Z_o = I_s\,Z_1 + I_E(Z_o + Z_1)$$

$$I_s(Z_0 - Z_1) = I_R\,(Z_0 + Z_1)$$

$$\frac{I_s}{I_R} = \frac{Z_0 + Z_1}{Z_0 - Z_1}$$

By definition propagation constant

$$P = \log_e \frac{I_s}{I_R}$$

$$P = \log_e \frac{Z_0 + Z_1}{Z_0 - Z_1}$$

$$e^p = \frac{Z_0 + Z_1}{Z_0 - Z_1}$$

$$\frac{e^p - 1}{e^p + 1} = \frac{Z_1}{Z_0}$$

$$\frac{e^{p/2} - e^{-p/2}}{e^{p/2} + e^{-p/2}} = \frac{Z_1}{Z_0}$$

$$\tanh\frac{p}{2} = \frac{Z_1}{Z_0} = \sqrt{\frac{Z_1}{Z_2}}$$

MADE EASY Source

- **Theory Book:** Network Theory (Page No. 245-246) **(Click here for reference)**

End of Solution

6. (a) A first-order thermometer was dipped in a temperature-controlled water bath maintained at 100°C and the following time-temperature readings were obtained:

Time (s)	0	4	8	12	16	20
Temperature (°C)	15	50	70	85	90	95

Estimate the time constant of the thermometer. Determine the steady state error when the thermometer is required to measure the temperature of a liquid which is being heated at a constant rate of 0.1°C/s.

[20 Marks]

Solution:

For fist order system :

$$T(t) = T_f + (T_i - T_f)\, e^{-t/\tau}$$

$$T_f = 100°C \quad ; \quad T_i = 15°C$$

At $t = 4$ sec,
$$T(t) = 50°C$$

$$50 = 100 + (15 - 100)\, e^{-4/\tau}$$

$$50 = 100 - 85\, e^{-4/\tau}$$

$$\tau = 7.538 \text{ sec}$$

Transfer function of thermometer,

$$\frac{C(s)}{R(s)} = \frac{K}{1+Ts} = \frac{100}{1+Ts}$$

Input,
$$R(t) = 0.1t$$

$$R(s) = \frac{0.1}{s^2}$$

∴ Steady state error,
$$e_{ss} = \lim_{s\to 0} \frac{sR(s)}{1+G(s)} = \lim_{s\to 0} \frac{s\times\frac{0.1}{s^2}}{1+\frac{100}{1+Ts}}$$

$$e_{ss} = \infty$$

End of Solution

6. (b) A quartz Piezoelectric Transducer (PZT) has the following specifications: Area = 1 cm^2; Thickness = 2 mm; Young's modulus = 9×10^{10} Pa; Charge sensitivity = 2 pC/N; Relative permittivity = 5 and Resistivity = 10^{12} Ω-cm. A 10 pF capacitor and a 100 MΩ resistor are connected in parallel across the electrodes of the PZT. If a force $F = 0.02 \sin(10^3 t)$N is applied, determine

(i) the peak-to-peak voltage generated across the electrodes and

(ii) the maximum change in crystal thickness.

[20 Marks]

Solution:

(i) $A = 1\ cm^2$; Charge density, $d = 2$ pC/N ; Thickness, $t = 2$ mm
$y = 9 \times 10^9$ Pa

$$F = 0.02\sin(10^3 t) N$$

Under open circuit condition

$$V_o = gtp \quad ; \quad g = \text{voltage sensitivity}$$

$$g = \frac{d}{\epsilon_o \epsilon_r} = \frac{2\times 10^{-12}}{8.854\times 10^{-12}\times 5} = 0.045\left(\frac{V_m}{N}\right)$$

$$V_o = 0.045 \times 2 \times 10^{-3} \text{ F/A}$$

$$= \frac{0.045\times 2\times 10^{-3}\times 0.02\sin(10^3 t)}{1\times 10^{-4}}$$

$$V_o = 18 \times 10^{-3} \sin(10^3 t)$$

Open circuit peak to peak voltage = $2V_o = 36 \times 10^{-3}$ V = 36 mV

Under load conditions :

$$V_{L\text{ (peak to peak)}} = \frac{2d\, f_{max} t}{\epsilon_o \epsilon_r\, A}\left[\frac{\omega C_p R_L}{\sqrt{1+\omega^2 (C_p + C_L)^2 R_L^2}}\right]$$

$$\phi = \frac{\epsilon_o \epsilon_r\, A}{t} = \frac{5 \times 8.854 \times 10^{-12} \times 10^{-4}}{2 \times 10^{-3}} = 2.2135 \times 10^{-12}\text{ F}$$

$$R_L = 100\text{ M}\Omega$$

$$C_L = 10\text{ pF}$$

$$V_{L\text{ (peak to peak)}} = 36 \times 10^{-3}\left[\frac{10^3 \times 2.2135 \times 10^{-12} \times 100 \times 10^6}{\sqrt{1+(10^3)^2\,(2.2135+10)^2 \times 10^{-24} \times 10^{16}}}\right]$$

$$= 5.048 \times 10^{-3}\text{ V} = 5.048\text{ mV}$$

(ii)
$$Y = \frac{\text{Stress}}{\text{Strain}} = \frac{F}{A\left(\frac{\Delta t}{t}\right)}$$

where Δt is the change in thickness.

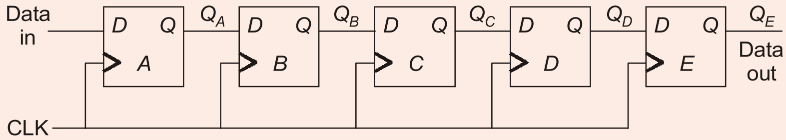
$$\Delta t_{max} = \frac{F_{max}}{Ay} \times t = \frac{0.02 \times 2 \times 10^{-3}}{10^{-4} \times 9 \times 10^9} = 4.44 \times 10^{-11}\text{ m}$$

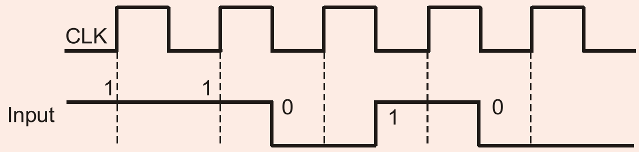
End of Solution

6. (c) (i) Generate the logic function given in the table below using IC74151 8-to-1 MUX.

Inputs			Output
C	B	A	Y
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

(ii) Show the states of the five-bit register shown below using waveforms, for the specified data input and clock signal. Assume the registers to be initially cleared (all 0s). How long will it take to shift an 8-bit number into a shift register if the clock is set to 10 MHz?





[10 + 10 Marks]

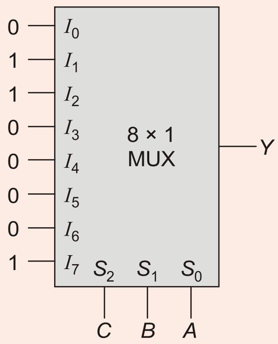
Solution:

(i) $Y = \Sigma m(1, 2, 7)$

C \ BA	00	01	11	10
0	0	1 (1)	3	2 (1)
1	4	5	7 (1)	6

$\therefore \quad Y = \bar{C}\bar{B}A + \bar{C}B\bar{A} + CAB$

$Y = \bar{C}(A \oplus B) + CAB$



(ii) Clock frequency = 10 MHz

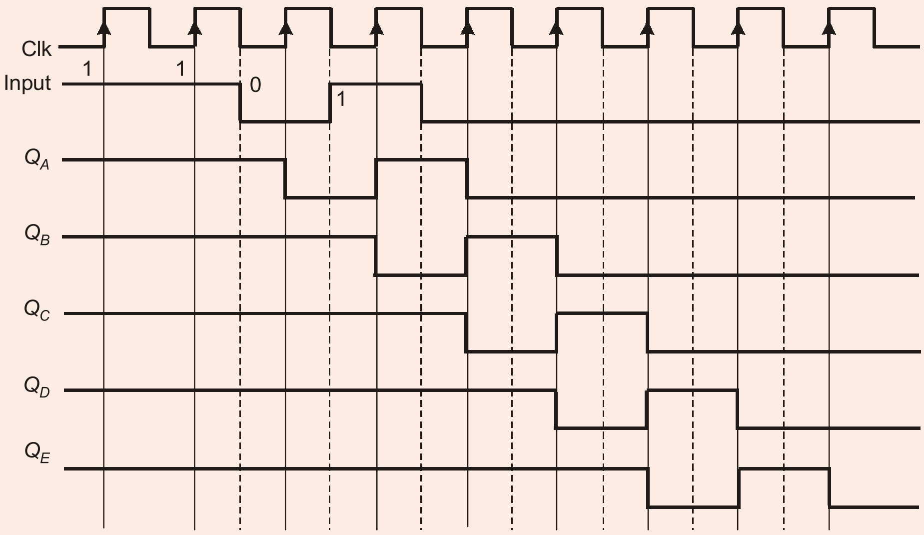
$$\therefore \quad T_{clk} = \frac{1}{10} \mu\text{sec} = 0.1 \mu\text{sec}$$

$\because$ The given register is SISO, therefore, the no. of clock pulses required to store a 'n-bit' data is 'nT_{clk}'.

$\therefore$ Time taken by the register to shift an 8-bit number $= 8 \times T_{clk}$

$= 8 \times 0.1 \mu\text{sec}$

$= 0.8 \mu\text{sec}$

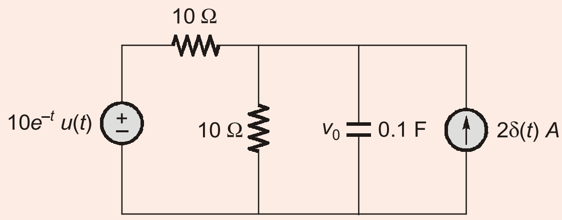


MADE EASY Source

- **MADE EASY Classnotes : (Click here for reference)**

End of Solution

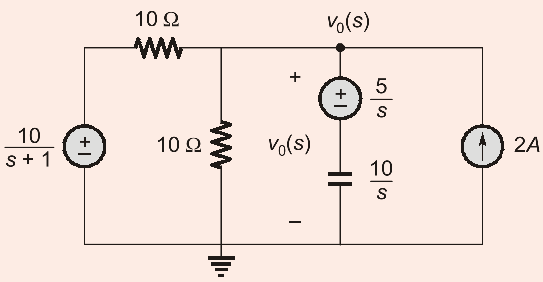
7\. (a) Find $v_0(t)$ in the circuit shown in the figure. Assume $v_0(0)$ = 5 V.



[20 Marks]

Solution:

Given, $V_0(0)$ = 5 V, by using Laplace transform approach,



by using nodal analysis at node $V_0(s)$

$$\frac{V_0(s) - \frac{10}{s+1}}{10} + \frac{V_0(s)}{10} + \frac{V_0(s) - \frac{5}{s}}{\frac{10}{s}} - 2 = 0$$

$$V_0(s)\left[\frac{1}{10}+\frac{1}{10}+\frac{s}{10}\right] = 2+\frac{1}{s+1}+\frac{1}{2}$$

$$V_0(s)\left[\frac{s+2}{10}\right] = 2.5+\frac{1}{s+1}$$

$$V_0(s) = \frac{25}{s+2}+\frac{10}{(s+1)(s+2)}$$

$$= \frac{25}{s+2}+\frac{10}{s+1}-\frac{10}{s+2}$$

$$\therefore \qquad V_0(s) = \frac{10}{s+1}+\frac{15}{s+2}$$

by using increase Laplace transform,

$$V_0(s) = (10\,e^{-t} + 15\,e^{-2t})\,u(t)$$

MADE EASY Source

- **ESE 2020 Mains Test Series:** Test-4 (Q.6(b))
- **MADE EASY Classnotes : (Click here for reference)**

End of Solution

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7. (b) (i) In a cathode-ray tube, the electron beam is displaced vertically by a magnetic field of flux density 2×10^{-4} Wb/m^2. The length of the magnetic field along the tube axis is same as that of electrostatic deflection plates. The final anode voltage is 1 kV. Determine the voltage which should be applied to the y-deflection plats 10 mm apart to return the spot back to the centre of the screen. Take

Mass of electron = 9.107×10^{-31} kg and

Charge on electron = 1.6×10^{-19} C.

(ii) A moving coil milli-ammeter having a resistance of 20 Ω gives full scale deflection when a current of 10 mA is passed through it. Describe how this instrument can be used for measurement of

Current up to 1A and

Voltage up to 5 V.

[10 + 10 Marks]

Solution:

(i) Given, Flux density (B) = 2×10^{-4} Wb/m^2

Anode voltage (V_a) = 1 kV

Mass of electron = 9.107×10^{-31} kg

Charge of electron = 1.6×10^{-19} C

Distance between the plates (d) = 10×10^{-3} m.

We know that, the magnetostatic deflection is given as,

$$D = \frac{IBL}{\sqrt{V_a}}\sqrt{\frac{q}{2m}}$$

The electrostatic deflection is,

$$D = \frac{ILV_d}{2dV_a}$$

For returning the beam back to the centre, the electrostatic deflection and the magnetostatic deflection must be equal

i.e.,
$$\frac{ILV_d}{2dV_a} = \frac{IBL}{\sqrt{V_a}}\sqrt{\frac{q}{2m}}$$

Therefore,
$$V_d = dB\sqrt{\frac{2V_a q}{m}}$$

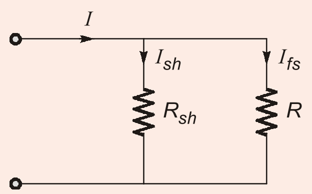
$$= 10\times10^{-3}\times2\times10^{-4}\sqrt{\frac{2\times10^{3}\times1.6\times10^{-19}}{9.107\times10^{-31}}}$$

$$V_d = 37.49 \text{ V}$$

$\therefore$ Deflection voltage, $V_d = 37.49$ V

(ii) $I_{fs} = 10$ mA

$R = 20\ \Omega$



$$I = 1 \text{ A}$$

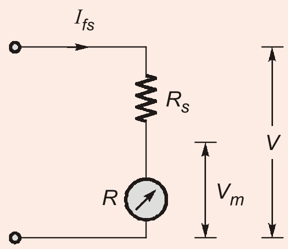
$$I = I_{sh} + I_{fs} \qquad \text{...(i)}$$

$$I_{sh}\times R_{sh} = I_{fs}\times R$$

$$(I - I_{fs})\times R_{sh} = I_{fs}\times R \qquad \text{(from equation (i))}$$

$$R_{Sh} = \frac{I_{fs}\times R}{I - I_{fs}} = \frac{R}{\left(\frac{I}{I_{fs}}\right) - 1}$$

$$R_{Sh} = \frac{20}{\frac{1}{10\times10^{-3}} - 1} = \frac{20}{99} = 0.2020\ \Omega$$



$$V = 5\text{ V}$$
$$V = I_{fs} \times R_s + I_{fs} \times R$$
$$R_s = \frac{V - I_{fs} \times R}{I_{fs}} = \frac{V}{I_{fs}} - R = \frac{5}{10 \times 10^{-3}} - 20 = 480\ \Omega$$

MADE EASY Source

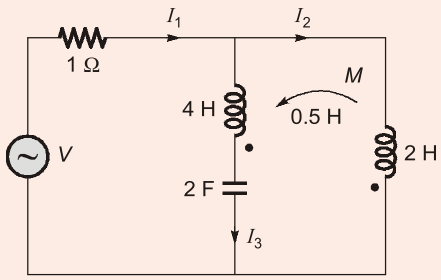
- **MADE EASY Mains Workbook :** Electronic Measurements and Instrumentation (Page No. 117, Q.8 and Q.9) **(Click here for reference)**

End of Solution

7. (c) (i) Draw the oriented graph of a network with fundamental cutset matrix as shown below:

Twigs				Links		
1	2	3	4	5	6	7
1	0	0	0	–1	0	0
0	1	0	0	1	0	1
0	0	1	0	0	1	1
0	0	0	1	0	1	0

(ii) For the network shown in the figure, draw the oriented graph, obtain the cutset-matrix and find the number of links.



[10 + 10 Marks]

Solution:

(i) Number of links, $l = b - n + 1$

Number of nodes, $n = b - l + 1 = 7 - 3 + 1 = 5$

f-cutsets are written as,

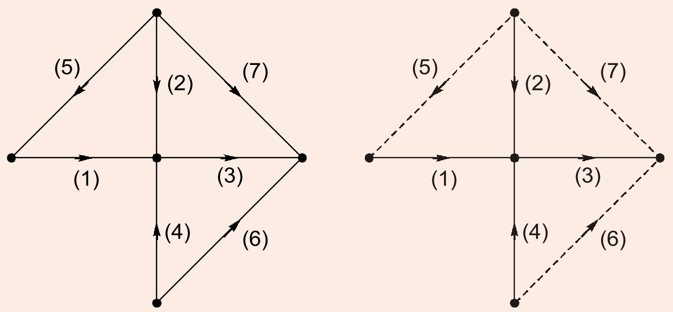
f - cutset 1 : {1, 5}

f - cutset 2 : {2, 5, 7}

f - cutset 3 : {3, 6, 7}

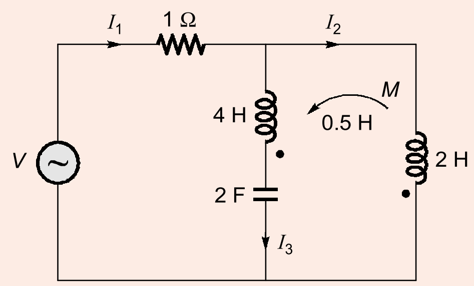
f - cutset 4 : {4, 6}

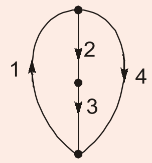
Then oriented graph can be written as,



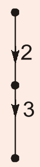
Twigs : {1, 2, 3, 4}
links : {5, 6, 7}

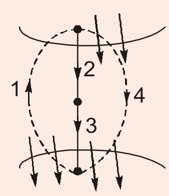
(ii) Given, Network





We select the tree as





Number of branches, $B = 4$
Number of nodes, $N = 3$

∴ Number of links,

$$B - N + 1 = 4 - 3 + 1 = 2$$

∴ The *f*-cutset matrix,

Twigs	1	2	3	4
2	–1	1	0	1
3	–1	0	1	1

MADE EASY Source

- **ESE 2020 Mains Test Series:** Test-4 (Q.5(d)) for Part (i) **(Click here for reference)**
- **ESE 2020 Mains Test Series:** Test-14 (Q.8(a)) for Part (ii) **(Click here for reference)**

End of Solution

8\. (a) (i) For the network in the figure shown below, determine

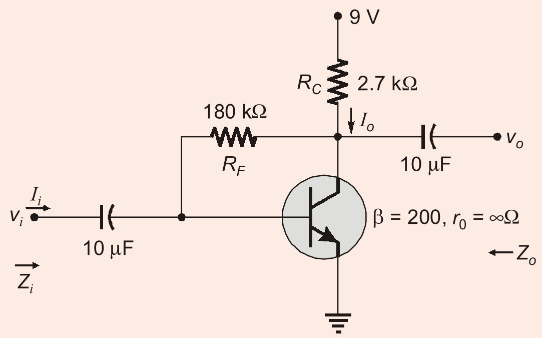
I. r_e

II. Z_i

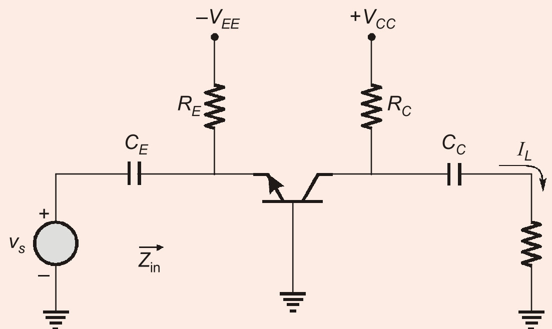
III. Z_0

IV A_v

Repeat parts II, III and IV with r0 = 20 kW and compare results.



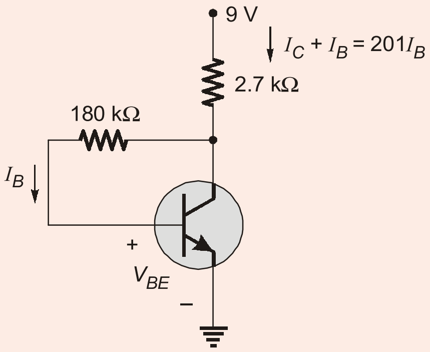
(ii) Draw the equivalent circuit (hybrid-π high frequency model) of the CB amplifier shown below. Find an expression for the high-frequency voltage-gain ratio. Also describe the high-frequency behaviour of this amplifier.



[10 + 10 Marks]

Solution:

(i) DC analysis :



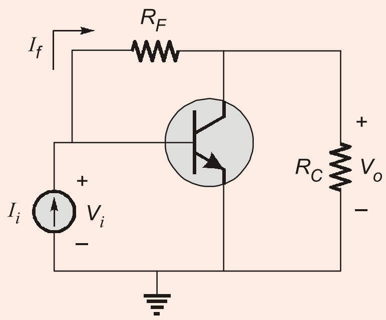
KVL : $9 = 2.7 \times 201 I_B + 180 I_B + V_{BE}$

$\Rightarrow$ $I_B = \dfrac{9 - V_{BE}}{722.7} = \dfrac{9 - 0.7}{722.7} = 11.48\ \mu A$

Now, $r_\pi = \dfrac{V_T}{I_B} = \dfrac{26\text{ mV}}{11.4\ \mu A} = 2.265\text{ k}\Omega$

Given, circuit can be analyzed by using feedback approach.

Given circuit has voltage shunt feedback. It can be shown as transresistance amplifier.

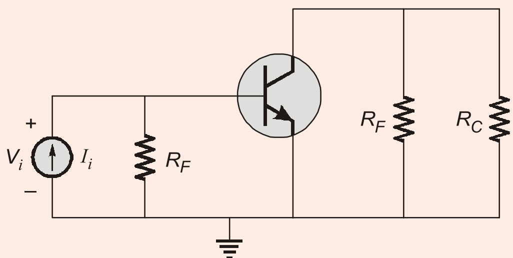


$$I_f = \frac{V_i - V_o}{R_F} = -\frac{V_o}{R_F} \quad (\because\ V_i \text{ is set to zero which finding } I_f)$$

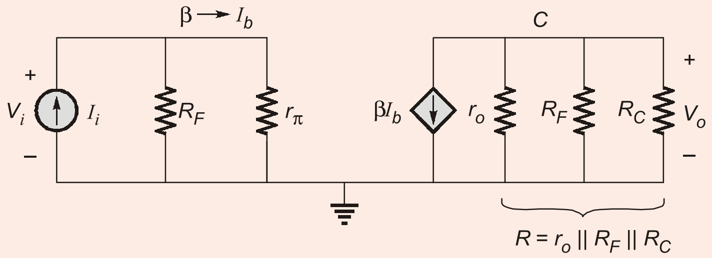
$$\frac{I_f}{V_o} = \beta = -\frac{1}{R_F}$$

$$\beta = -\frac{1}{180\text{ k}\Omega}$$

Draw circuit without feedback :



Replace transistor with π-model :



$$V_o = -\beta I_b R \Rightarrow \frac{V_o}{I_b} = -\beta R$$

$$I_b = \frac{I_i R_F}{R_F + r_\pi} \Rightarrow \frac{I_b}{I_i} = \frac{R_F}{R_F + r_\pi}$$

Transresistance gain is,

$$R_M = \frac{V_o}{I_i} = \frac{V_o}{I_b} \times \frac{I_b}{I_i} = -\frac{\beta R R_F}{R_F + r_\pi}$$

$$R_i' = R_F \| r_\pi$$

$$R_o' = r_o \| R_F \| R_C = R$$

Take $r_o = \infty$:

$$R = R_F \| R_C = 2.66 \text{ k}\Omega$$

$$R_M = -200 \times 2.66 \text{ k}\Omega \times \frac{180}{180 + 2.265}$$

$$R_M = -525.4 \text{ k}\Omega$$

$$R_i' = 180 \| 2.265 = 2.237 \text{ k}\Omega$$

$$R_o' = R = 2.66 \text{ k}\Omega$$

Desensitivity, $D = 1 + \beta R_M = 1 + \frac{525.4}{180} = 3.919$

$$R_{MF} = \frac{R_M}{1 + \beta R_M} = -\frac{525.4}{3.919} = -134 \text{ k}\Omega$$

$$Z_i = R_{i_f}' = \frac{R_i'}{D} = \frac{2.237 \text{ k}\Omega}{3.919} = 570.8\ \Omega$$

$$Z_o = R_{o_f}' = \frac{R_o'}{D} = \frac{2.66 \text{ k}\Omega}{3.919} = 678.7\ \Omega$$

$$A_{vf} = \frac{V_o}{V_i} = \frac{V_o}{I_i R_{i_f}'} = \frac{R_{Mf}}{R_{i_f}'} = -\frac{134 \times 10^3}{570.8} = -234.76$$

Take $r_o = 20 \text{ k}\Omega$: $R = r_o \| R_F \| R_C = 2.348 \text{ k}\Omega$

$$R_M = -200 \times 2.348 \text{ k}\Omega \times \frac{180}{180 + 2.265} = -463.76 \text{ k}\Omega$$

$$R_i' = R_F \| r_\pi = 2.237\text{ k}\Omega$$

$$R_o' = R = 2.348\text{ k}\Omega$$

$$D = 1+\beta R_M = 1+\frac{463.76}{180} = 3.576$$

$$Z_i = R_{i_f}' = \frac{R_i'}{D} = \frac{2.237\text{ k}\Omega}{3.576} = 625.56\ \Omega$$

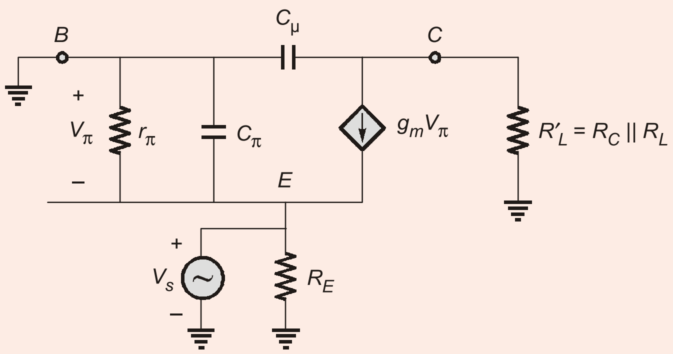
$$Z_o = R_{o_f}' = \frac{R_o'}{D} = \frac{2.348\text{ k}\Omega}{3.576} = 656.6\ \Omega$$

$$R_{MF} = \frac{R_M}{D} = -\frac{463.76\text{ k}\Omega}{3.576} = -129.69\text{ k}\Omega$$

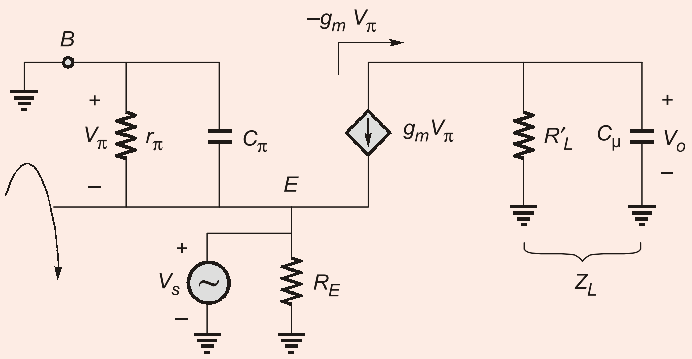
$$A_{vf} = \frac{R_{MF}}{R_{i_f}'} = -\frac{129.69\text{ k}\Omega}{625.56} = -207.3$$

(ii) Replace transistor with high frequency π-modal and assume $r_o = \infty$, $r_b \simeq 0$

r_b : Base spreading resistance



C_μ is seen between collector and ground.



KVL : $V_\pi + V_s = 0$

$\Rightarrow$ $V_s = -V_\pi$ ...(i)

$$V_o = -g_m V_\pi Z_L = -g_m V_\pi \frac{\left[R_L' \times \frac{1}{j\omega C_\mu}\right]}{R_L' + \frac{1}{j\omega C_\mu}}$$

$$V_o = -\frac{g_m V_\pi R_L'}{1 + j\omega R_L' C_\mu} \quad \text{...(ii)}$$

$$\frac{V_o}{V_s} = \frac{\dfrac{-g_m V_\pi R_L'}{1 + j\omega R_L' C_\mu}}{-V_\pi}$$

$$A_{VH} = \frac{g_m R_L'}{1 + j\omega R_L' C_\mu}$$

$$A_{VH} = \frac{A_{Vm}}{1 + \dfrac{j\omega}{\omega_H}} \qquad \left\{ A_{Vm} = g_m R_L', \quad \omega_H = \frac{1}{R_L' C_\mu} \right\}$$

$$A_{VH} = \frac{A_{Vm}}{1 + \dfrac{jf}{f_H}}$$

$$|A_{VH}| = \frac{A_{Vm}}{\sqrt{1 + \left(\dfrac{f}{f_H}\right)^2}}$$

If frequency f increases then voltage gain decreases due to C_μ.

At $f = f_H$, $\quad |A_{VH}| = \dfrac{A_{vm}}{\sqrt{2}}$

f_H is higher cut-off frequency

$$f_H = \frac{1}{2\pi R_L' C_\mu}$$

MADE EASY Source

- **MADE EASY Mains Workbook :** Analog Circuits (Page No. 49, Q.27)
  (Click here for reference)

End of Solution

8. (b) Find $[z]$ and $[g]$ of a two-port network if $[T] = \begin{bmatrix} 10 & 1.5\Omega \\ 2s & 4 \end{bmatrix}$.

[20 Marks]

Solution:

Given, $\quad [T] = \begin{bmatrix} 10 & 1.5\Omega \\ 2s & 4 \end{bmatrix}$

$$V_1 = 10\, V_2 - 1.5\, I_2 \quad \text{...(i)}$$
$$I_1 = 2\, V_2 - 4\, I_2 \quad \text{...(ii)}$$

From equation (ii), we can write

$$2V_2 = I_1 - 4 I_2$$

$$V_2 = \frac{1}{2}I_1 + 2I_2 \quad \text{...(iii)}$$

by substituting equation (iii) in equations (i)

$$V_1 = 5 I_1 + 20 I_2 - 1.5 I_2$$

$$V_1 = 5 I_1 + 18.5 I_2 \quad \text{...(iv)}$$

From equation (iv) and (iii), we write

$$[Z] = \begin{bmatrix} 5 & 18.5 \\ 0.5 & 2 \end{bmatrix}$$

From equation (i),

$$10 V_2 = V_1 + 1.5 I_2$$

$$\therefore \quad V_2 = 0.1 V_1 + 0.15 I_2 \quad \text{...(v)}$$

From equation (ii),

$$I_2 = 2 [0.1 V_1 + 0.15 I_2] - 4 I_2$$

$$= 0.2 V_1 + 0.3 I_2] - 4 I_2$$

$$\therefore \quad I_1 = 0.2 V_1 - 3.7 I_2 \quad \text{...(vi)}$$

From equation (vi) and (v), we can write,

$$[g] = \begin{bmatrix} 0.2 & -3.7 \\ 0.1 & 0.15 \end{bmatrix}$$

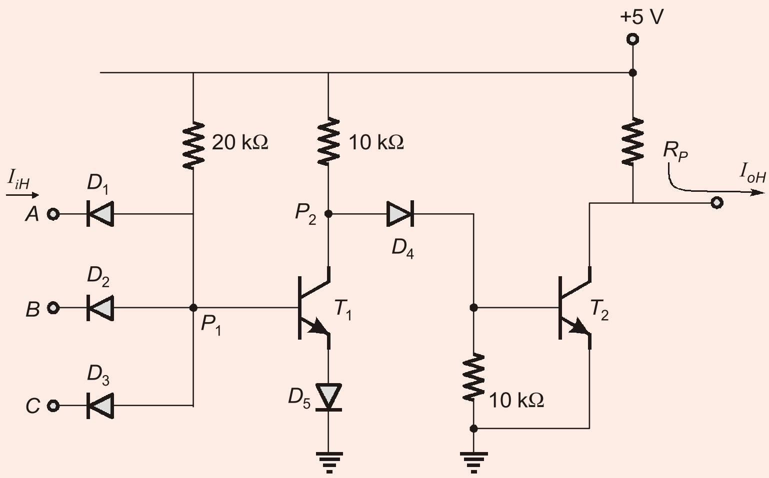
MADE EASY Source

- **Theory Book:** Network Theory (Page No. 240) **(Click here for reference)**

End of Solution

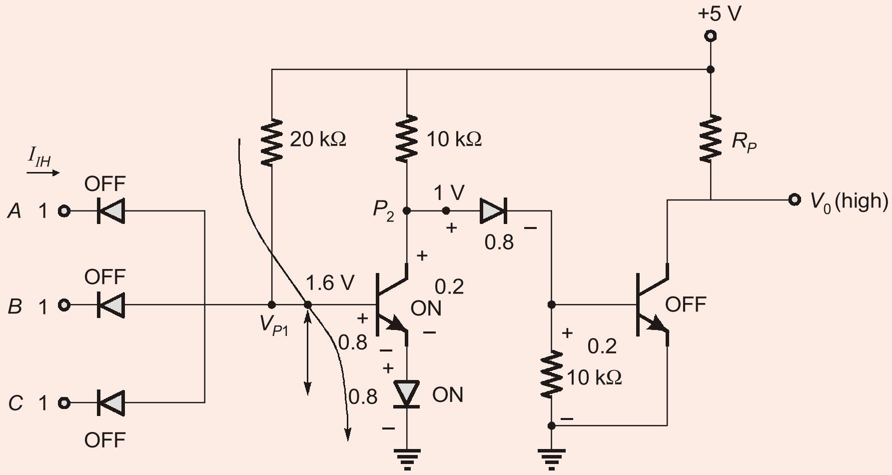
8. (c) For the circuit shown below, identify the logic function performed by it. Also determine the high level fan-out, if R_P (pull-up resistor) = 10 kΩ. Compute the maximum value of R_P for a fan-out of 5. Assume that input diode has a leakage current of 100 μA.

Given: V_T = 0.7 V, V_D (forward voltage drop) = 0.8 V, V_{BE}(cut-in) = 0.5 V. V_{CE}(sat) = 0.2 V. Transistor leakage current is negligible.



[20 Marks]

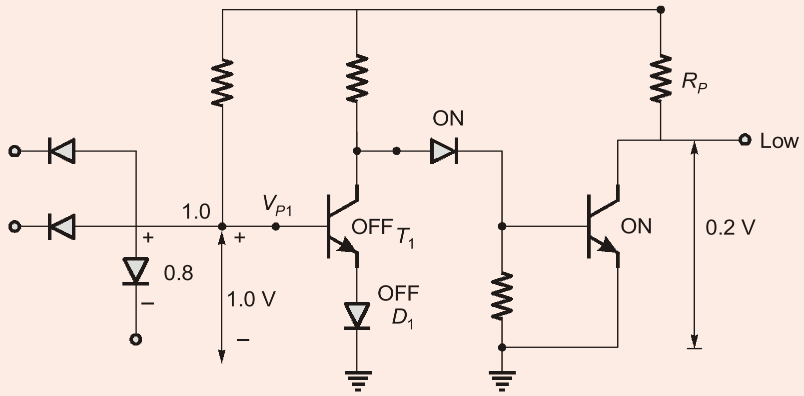
Solution:



If $A = 1,\ B = 1,\ C = 1 \quad V_0 \rightarrow$ high

For output to be high V_A can be as low as 1.5 V (belong diode will be OFF till 1.5 V).

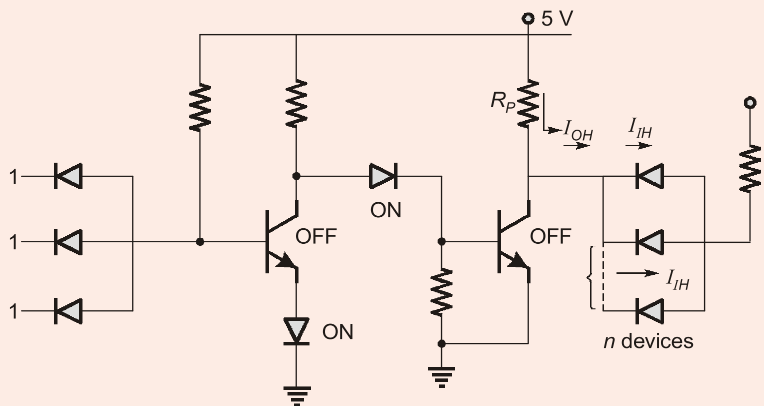
$$V_{IH} = 1.5\text{ V (for } V_A,\ V_B,\ V_C \quad V_{IH} = 1.5\text{ V)}$$



To turn ON T_1 and D_1 minimum V_{P1} should be (V_{BE} cut-in + V_T) = 0.5 + 0.7 = 1.2.

The above circuit is AND gate.

Fanout calculation in high condition.



$$I_{OH} = n * I_{IH} \Rightarrow I_{OH} = n * 100\ \mu A$$

$$5 - (n * 100\ \mu A) * R_P = 1.5\ V \text{ (minimum high value)}$$

$$R_P = 5\ k\Omega$$

$$5 - n * 0.5 = 1.5 \quad n = 7$$

$$(\text{fanout})_{high} = 7$$

Calculation of R_P if fanout = 5

$$5 - (n * 100\ \mu A) * R_P = 1.5$$

$$5 - 0.5\ mA * R_P = 1.5$$

$$R_P = 7\ k\Omega$$

End of Solution

■■■■