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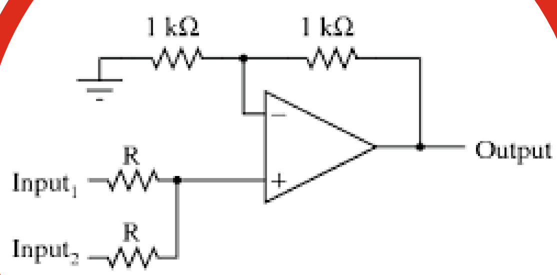


ELECTRICAL ENGINEERING

ANALOG ELECTRONICS

Text Book : Theory with worked out Examples and Practice Questions

Chapter 5

Analog Electronics

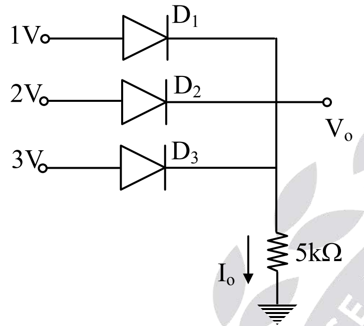
(Solutions for Text Book Practice Questions)

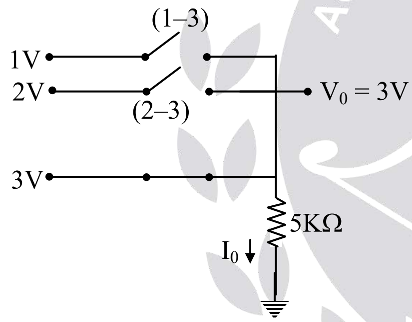
1. Diode Circuits

Solutions for Objective Practice Questions

01. Ans: (d)

Sol:





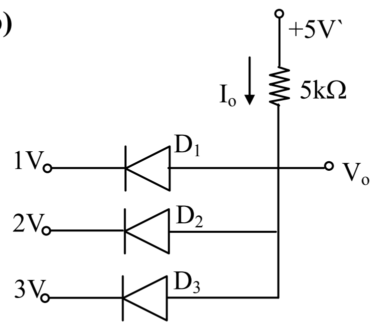
$\Rightarrow$ D_1, D_2 are reverse biased and D_3 is forward biased.

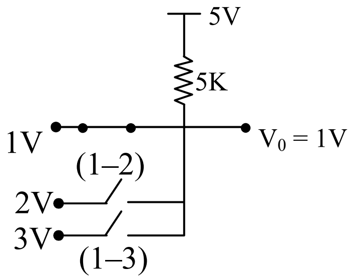
i.e., D_3 only conducts.

$\therefore$ $I_0 = 3/5K = 0.6mA$

02. Ans: (b)

Sol:





$\Rightarrow$ D_2 & D_3 are reverse biased and 'D_1' is forward biased.

i.e., D_1 only conduct

$$\therefore I_0 = \frac{5-1}{5K} = 0.8mA$$

03. Ans: (d)

Sol: Let diodes D_1 & D_2 are forward biased.

$\Rightarrow V_0 = 0$ volt

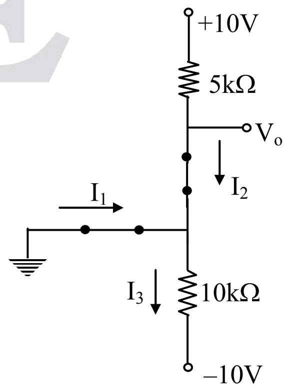
$$I_2 = \frac{10-0}{5K} = 2mA$$

$$I_3 = \frac{0-(-10)}{10K} = 1mA$$

Apply KVL at nodes 'V_0':

$-I_1 + I_3 - I_2 = 0$

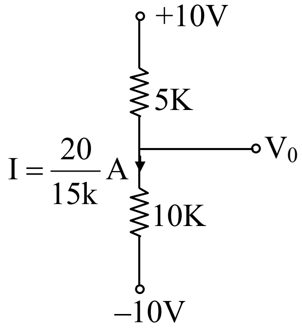
$\Rightarrow I_1 = -(I_2 - I_3) = -1mA$



So, D_1 is reverse biased & D_2 is forward biased.

⇒ 'D_1' act as an open circuit & D_2 is act as short circuit.

Then circuit becomes

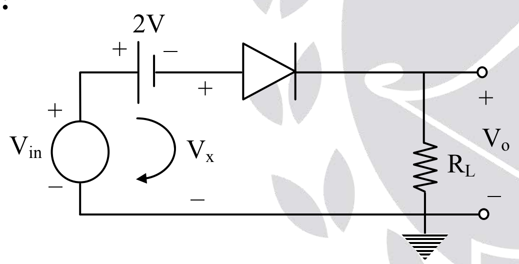


$$\Rightarrow V_0 = 10k \times \left(\frac{20}{15k}\right) - 10$$

$\therefore$ $V_0 = 3.33V$

04. Ans: (c)

Sol:



Apply KVL to the loop:

$V_{in} - 2 - V_x = 0$

$\Rightarrow V_x = V_{in} - 2$ ----- (1)

Given, V_{in} range = –5V to 5V

$\Rightarrow V_x$ range = –7V to 3V [∵ from eq (1)]

Diode ON for $V_x > 0V$

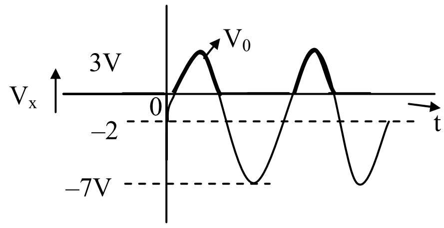
$\Rightarrow V_0 = V_x$

Diode OFF for $V_x < 0V$

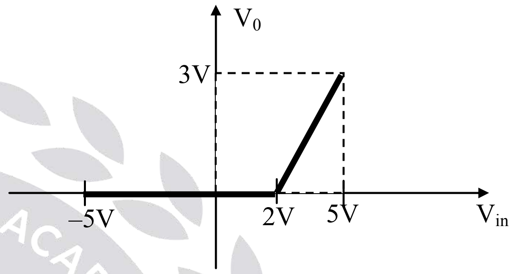
$\Rightarrow V_0 = 0$ V

$\therefore V_0$ range = 0 to 3V

Output wave form:

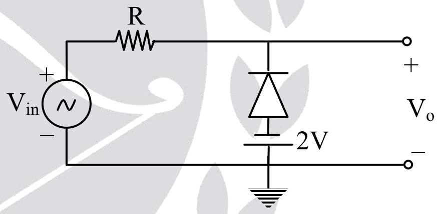


Transfer characteristics:



05. Ans: (b)

Sol:

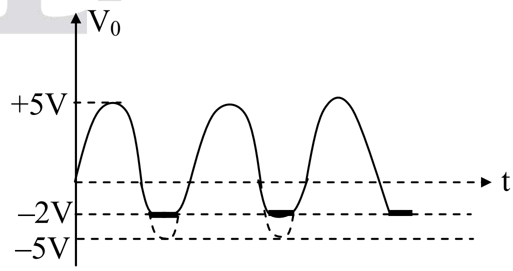


For $V_i < -2$Volt, Diode ON

$\Rightarrow V_0 = -2$Volt

For $V_i > -2$Volt, Diode OFF

$\Rightarrow V_0 = V_i$



06. Ans: (c)

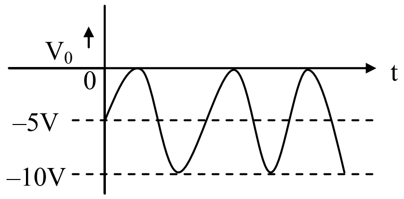
Sol: For positive half cycle diode Forward biased and Capacitor start charging towards peak value.

$\Rightarrow V_C = V_m = 5V$

$\Rightarrow V_0 = V_{in} - V_C = V_{in} - 5$

V_{in} range = – 5V to +5V

$\therefore$ V_0 range = – 10V to 0V



07. Ans: (d)

Sol: For +ve cycle, diode 'ON', then capacitor starts charging

$\Rightarrow V_C = V_m - 7$

$= 10 - 7$

$= 3V$

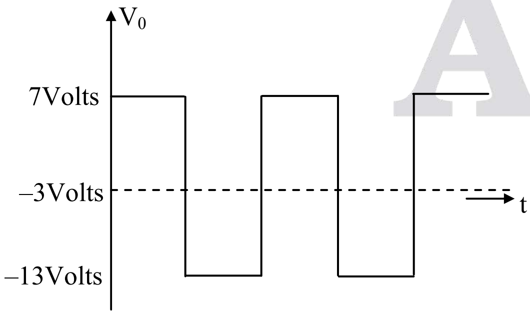
Now diode OFF for rest of cycle

$\Rightarrow V_0 = -V_C + V_{in}$

$= V_{in} - 3$

V_{in} range : –10V to +10V

$\therefore$ V_0 range: –13V to 7V



08. Ans: (a)

Sol: Always start the analysis of clamping circuit with that part of the cycle that will forward bias the diodes this diode is forward bias during negative cycle.

For negative cycle diode ON, then capacitor starts charging

$\Rightarrow V_C = V_P + 9$

$= 12 + 9$

$= 21V$

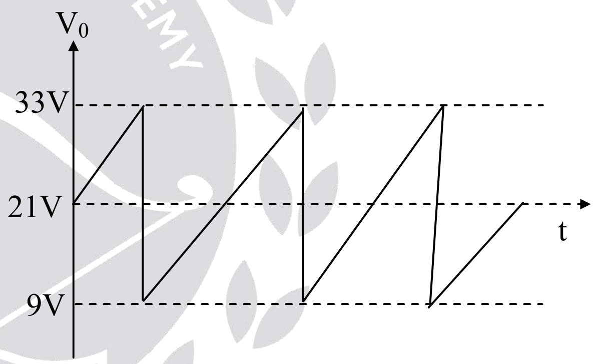
Now diode OFF for rest of cycle.

$\Rightarrow V_0 = V_C + V_{in}$

$= 21 + V_{in}$

V_{in} range: –12 to +12V

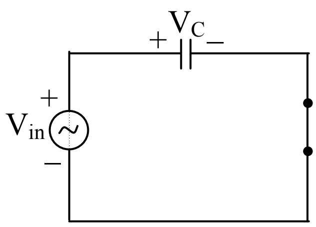
V_0 range: 9V to 33V



09. Ans: (b)

Sol: During positive cycle,

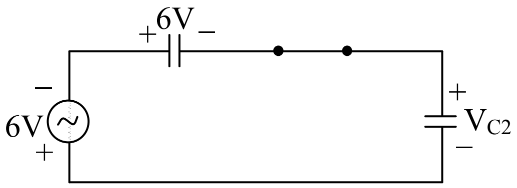
D_1 forward biased & D_2 Reverse biased.



$V_{C_1} = V_{in} = 6$volt

During negative cycle,

D_1 reverse biased & D_2 forward biased.



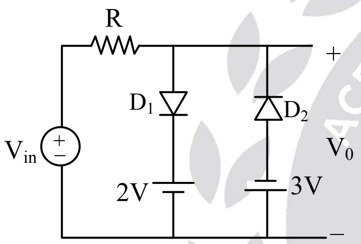
$V_{C2} = -6-6 = -12V$

Capacitor C_2 will charge to negative voltage of magnitude 12V.

Solutions for Conventional Practice Questions

01.

Sol:



For positive cycle:

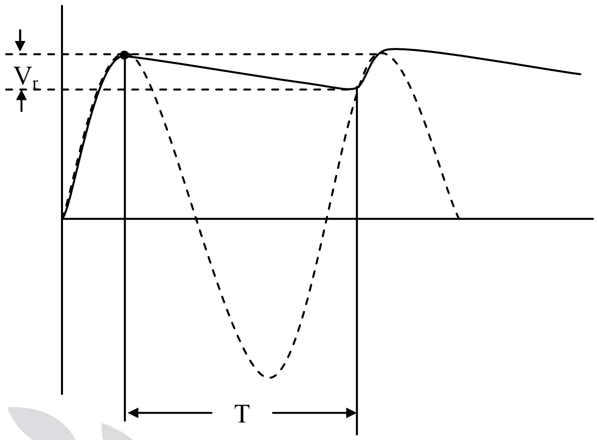
- If V_{in} is lie between 0 and 2V i.e $0 < V_{in} < 2V$, D_1 and D_2 are off, so $V_0 = V_{in}$
- If V_{in} is greater than 2V D_1 is short circuit and D_2 is open circuit, then $V_0 = 2V$

For negative cycle:

- If V_{in} is lie between 0 and –3V i.e. $-3V < V_{in} < 0V$ both D_1 and D_2 are off. Both are acts as open circuit, so output $V_0 = V_{in}$
- If V_{in} is less than –3V i.e $V_{in} < -3V$ diode D_1 is open circuit and diode D_2 is short circuit, so output $V_0 = -3V$.

02.

Sol:



$$\left[T << RC \Rightarrow \frac{T}{RC} << 1\right]$$

Ripple amplitude = $V_r = \left[V_m - V_m e^{-T/RC}\right]$

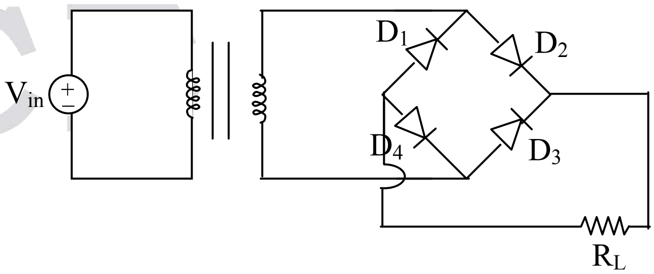
$$= \left[V_m - V_m\left(1-\frac{T}{RC}\right)\right] \quad \left[\because e^{-x} = 1-x \text{ if } x << 1\right]$$

$$= \left[\frac{V_m T}{RC}\right]$$

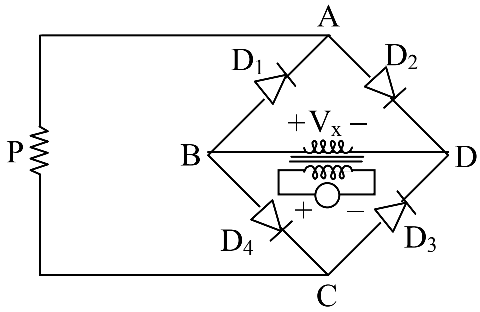
$$V_r = \frac{I}{fC}$$

03.

Sol:



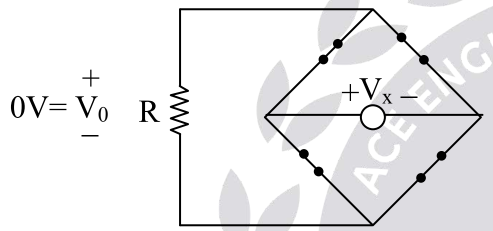
If we interchange the given circuit as the load at transform and transform at load nodes.



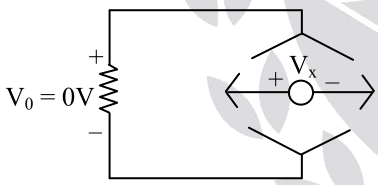
During positive cycle of V_x in the circuit all diodes [D_1, D_2, D_3, & D_4] are ON

But, when we check in negative cycle of V_x all diodes are OFF.

Positive cycle of V_x [D_1, D_2, D_3 & D_4 are ON]



Negative cycle of V_x [All diodes are OFF]



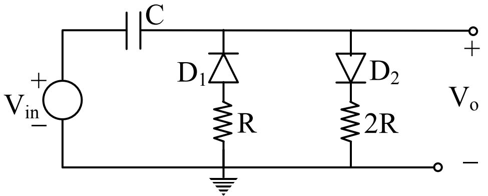
$\therefore\ V_0 = 0V$

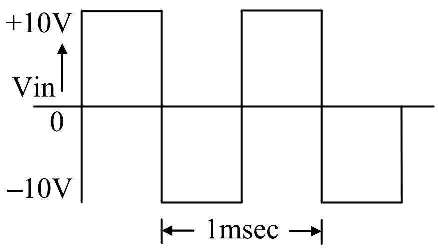
Conclusion:

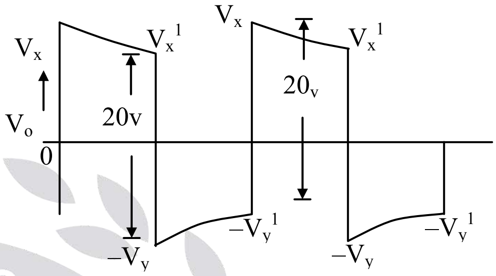
We should not interchange the positions of the transformer and the load positions.

04

Sol:







$V_x^1 - (-V_y) = V_x - (-V_y^1) = 20V$ -----(1)

$$V_x^1 = V_x e^{\frac{-t}{RC_{eq}}} \qquad t = \frac{T}{2} = 0.5\,\text{m sec}$$

$$= V_x e^{\frac{-T}{RC_{eq}}} \qquad \frac{t}{RC} = \frac{T}{2RC}$$

Req = 2RC [FB]

$$V_x^1 = V_x\left[1 - \frac{T}{4RC}\right]\ [RC >> T]$$

$$V_y^1 = -V_y e^{\frac{-t}{RC_{eq}}}$$

$$V_y^1 = V_y e^{\frac{-T}{2RC_{eq}}} \qquad [R_{eq} = RC\ (D_1FB)]$$

$$= V_y e^{\frac{-T}{2RC}}$$

$$= V_y\left[1 - \frac{T}{2RC}\right]$$

Let $\frac{T}{4RC} = \alpha$

$$\therefore V_x^1 = V_x[1 - \alpha]$$

$V_y^1 = V_y[1-2\alpha]$

Sub in (1)

$V_x^1 + V_y = V_y^1 + V_x$

$\rightarrow V_x - V_x\alpha + V_y = V_y - V_y(2\alpha) + V_x$

$\therefore V_x = 2V_y$ -----(3)

Sub in (1)

$V_x^1 + V_y = 20$

$\rightarrow V_x - V_x\alpha + V_y = 20$

$\rightarrow V_x + V_y = 20$ ----(4)

$[V_x - V_x\alpha = V_x$ as $RC >> T$ $\alpha << 1]$

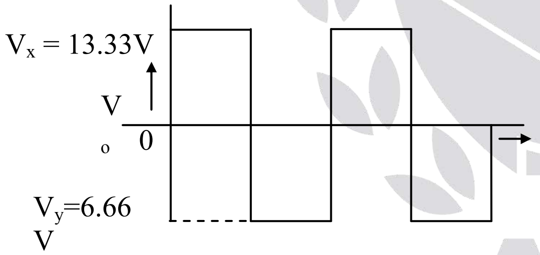
From (3) and (4)

$2V_y + V_y = 20 \rightarrow 3V_y = 20$

$\rightarrow V_y = 6.66V$

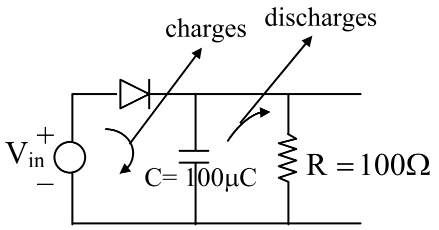
$\rightarrow V_x = 20 - V_y = 13.33V$

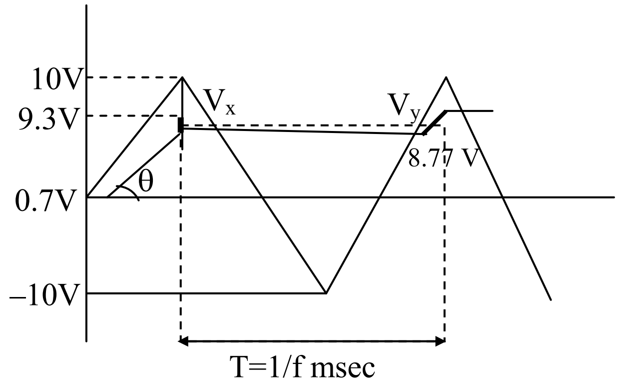
For RC >> T, the output wave form is as shown below



05.

Sol: Consider a half wave peak detector the calculate average value for triangular waveform





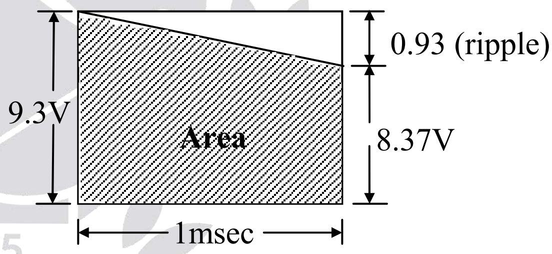
When diode is OFF, the capacitor discharges through the resistor

$V_y = V_x e^{-t/RC}\Big|_{t=T}$

$V_y = 9.3\left[1 - \dfrac{1m}{100\mu \times 100}\right] = 8.37\text{ V}$

Ripple amplitude, $V_r = V_x - V_y = 9.3 - 8.77$

$= 0.93$ V



(a) $V_{Avg} = \dfrac{\text{Area}}{\text{Base}} = \dfrac{9.3(1m) - \frac{1}{2}(0.93)(1m)}{1m}$

$= 9.3 - \dfrac{0.93}{2} = 8.84V$

(b) $\tan\theta = \dfrac{10}{(T/4)}\left[\dfrac{V_r}{\Delta t}\right]$

$= \dfrac{10}{0.25m} = \dfrac{0.93}{\Delta t}$

$\Delta t = 0.023$ msec

(c) $I_{C_{(avg)}} = C\dfrac{\Delta V}{\Delta t}$

$$= 100\mu\frac{0.93}{0.023m}$$

$$I_{C_{(avg)}} = 4A$$

(d) $I_R = \dfrac{V_P}{R} = \dfrac{9.3}{100}$

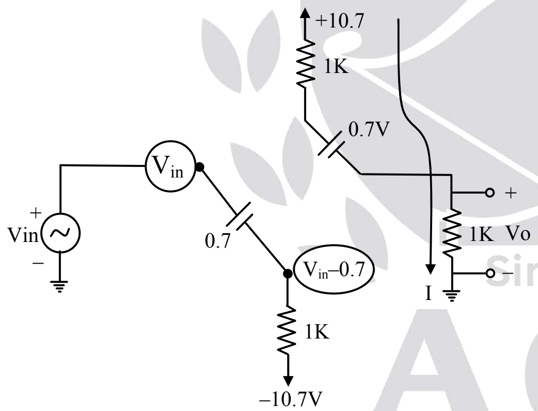
Total $I_D(max) = I_C + I_R$

$$= 4 + \frac{9.3}{100}$$

$$= 4.093\ A$$

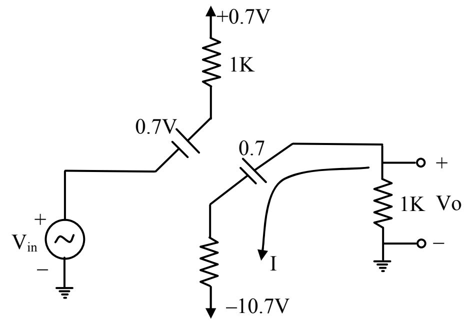
06.

Sol: Case 1: $V_{in} > 5V$ $\begin{bmatrix} D_1D_3 \to FB \\ D_2D_4 \to RB \end{bmatrix}$



$$V_o = I(1k) = \left(\frac{10.7-0.7}{2k}\right)1k = 5V$$

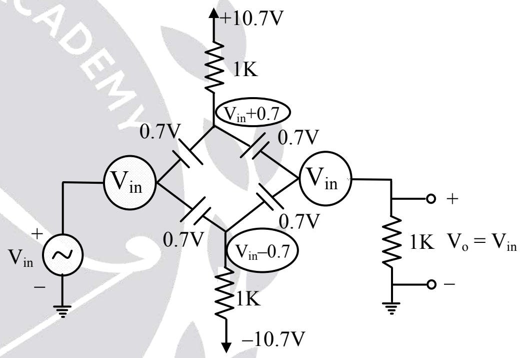
Case 2: $V_{in} < -5V$ $\begin{bmatrix} D_2D_4 \to FB \\ D_1D_3 \to RB \end{bmatrix}$

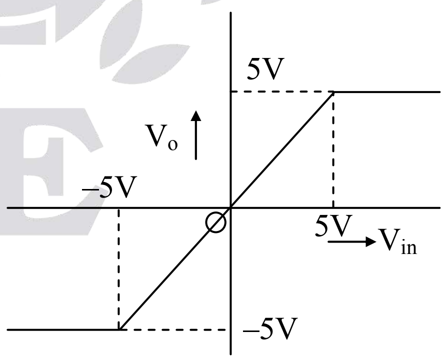


$$V_o = -I(1K) = -\left[\frac{10.7-0.7}{2K}\right]1K = -5V$$

Case 3: $-5V \le V_{in} \le 5V$ $[D_1D_2D_3D_4 \to FB]$

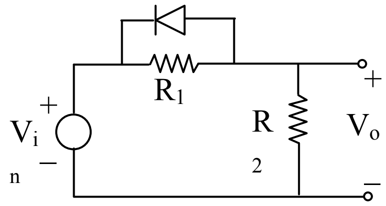
$\to V_o = V_{in}$





07.

Sol:



Case 1:

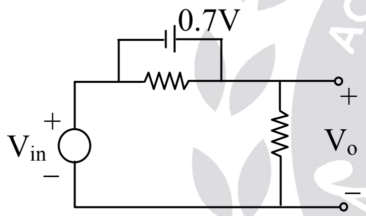
$$\frac{V_{in}R_1}{R_1+R_2} < -0.7$$

$$\rightarrow V_{in} < -\left[1+\frac{R_2}{R_1}\right]0.7 \qquad \text{[Diode FB]}$$

$\rightarrow V_o = 0.7 + V_{in}$

$y = mx + C$

Slope(m) = 1

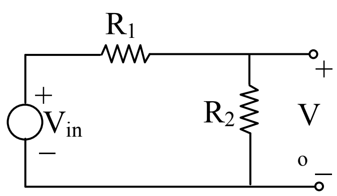


Case 2:

$$\frac{V_{in}R_1}{R_1+R_2} > -0.7$$

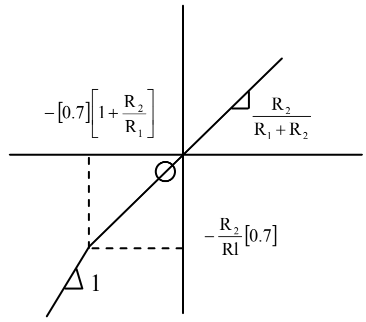
$$\rightarrow V_{in} > -\left[1+\frac{R_2}{R_1}\right]0.7 \qquad \text{[Diode RB]}$$

$$V_o = \frac{V_{in}R_2}{R_1+R_2}$$



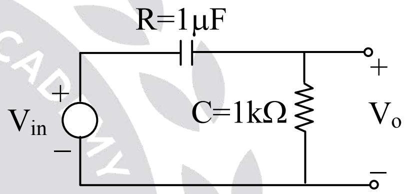
$y = mx$

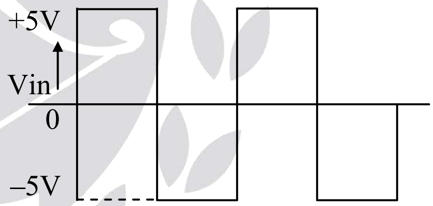
$$\text{Slope(m)} = \frac{R_2}{R_1+R_2}$$

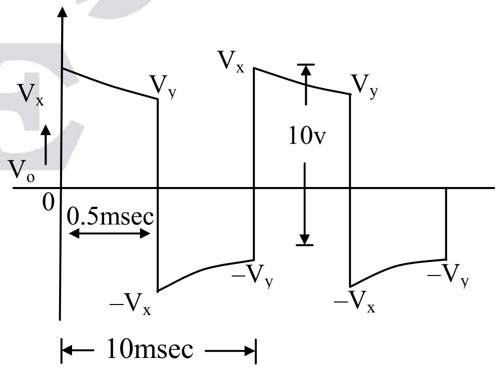


08.

Sol:







$$V_y = V_x e^{-t/Rc}$$

$$t = \frac{T}{2} = \frac{1\text{m sec}}{2} = 0.5\text{m sec}$$

$\rightarrow V_y = V_x e^{-0.5}$ ------(1)   RC = 1K(1μ) = 1m

t/RC = 0.5

from the fig

$V_x - (-V_y) = 10$

$\rightarrow V_x + V_y = 10$ -------(2)

Sub (1) in (2)

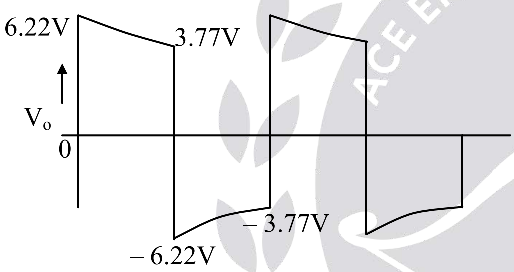
$V_x + V_x e^{-0.5} = 10$

$\rightarrow V_x[1+e^{-0.5}]=10$

$$\rightarrow V_x = \frac{10}{1+e^{-0.5}} = 6.22V$$

$\therefore V_y = 10 - V_x = 10 - 6.22$

= 3.77 V (from 2)

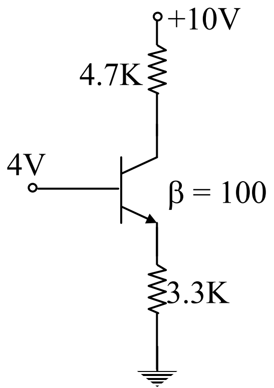


2. Bipolar Amplifiers

Solutions for Objective Practice Questions

01. Ans: (c)

Sol:



Given,

$V_B = 4V$

$V_{BE} = 0.7$

$V_B - V_E = 0.7$

$V_E = V_B - 7 = 3.3V$

$$\Rightarrow I_E = \frac{3.3}{3.3K\Omega} = 1mA$$

Let transisotr in active region

$\Rightarrow I_C = \beta/(\beta+1) \,.\, I_E = 0.99mA$

$I_B = I_C/\beta = 9.9\mu A$

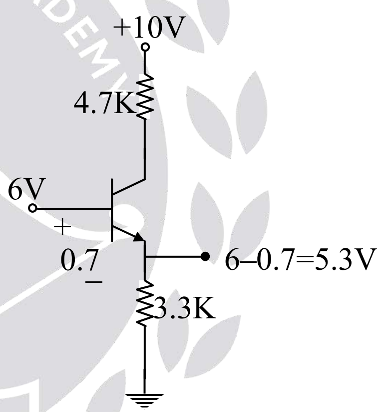
$V_C = 10 - 4.7\times10^3\times0.99\times10^{-3} = 5.347V$

$\Rightarrow V_C > V_B$

$\therefore$ Transistor in the active region.

02. Ans: (b)

Sol:



$V_E = V_B - V_{BE} = 6 - 0.7 = 5.3V$

$$I_E = \frac{5.3}{3.3K} = 1.6mA$$

Let transistor is active region

$$\Rightarrow I_C = \frac{\beta}{(1+\beta)} I_E$$

$I_C = 1.59mA$

$V_C = 2.55V$

$\Rightarrow V_C < V_B$

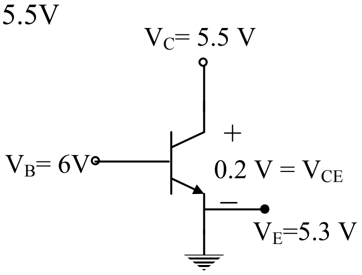
$\therefore$ Transistor in saturation region

$\Rightarrow V_{CE}(sat) = 0.2V$

$V_C - V_E = 0.2$

$V_C = 5.3 + 0.2$

$\Rightarrow V_C = 5.5V$



$$\Rightarrow I_C = \frac{10-5.5}{4.7K} = 0.957mA$$

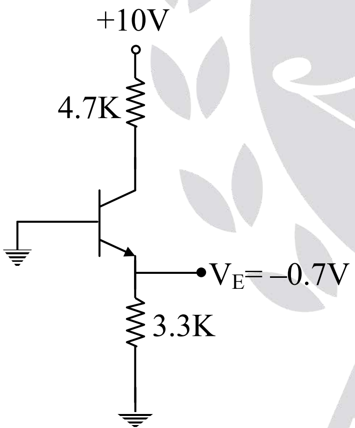
$I_B = 1.6 - 0.957 = 0.643mA$

$$\beta = \frac{I_C}{I_B} = \frac{0.957\ mA}{0.643\ mA} = 1.483$$

$\beta_{forced} < \beta_{active}$

03. Ans: (c)

Sol:



$V_E = -0.7V$

Transistor in cut off region

$I_C = I_B = I_E = 0A$

$V_{CE} = 10V$

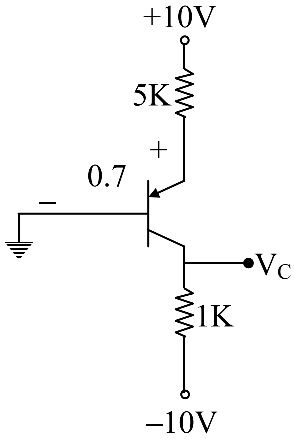
$V_E = 0V$

$V_C = 10V$

$V_B = 0V$

04. Ans: (c)

Sol:



$V_E = 0.7V$ [$\because V_B = 0V$]

$$\Rightarrow I_E = \frac{10-0.7}{5K} = 1.86mA$$

Let transistor in active region.

$$\Rightarrow I_C = \frac{\beta}{(\beta+1)} I_E = 1.84mA$$

$\Rightarrow V_C = -10 + 1K \times 1.84m$

$V_C = -8.16V$

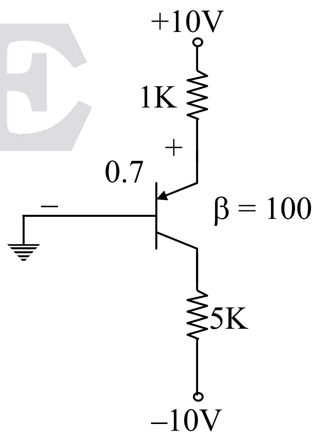
$V_{EC} = V_E - V_C = 8.86V$

$V_{EC} > V_{EB}$

$\therefore$ Transistor in active region

05. Ans: (d)

Sol:



Let transistor in active region

$V_E = 0.7V\ [\because V_B = 0V]$

$$I_E = \frac{10-0.7}{1k} = 9.3mA$$

$$I_C = \frac{\beta}{\beta+1}.I_E = 9.2mA$$

$\Rightarrow V_C = -10 + 5K \times 9.2m$

$V_C = 36V$

$V_{EC} < V_{EB}$

Transistor in saturation region

$\Rightarrow V_{EC} = 0.2$

$V_E - V_C = 0.2 \Rightarrow V_C = 0.5V$

$$\Rightarrow I_C = \frac{0.5+10}{5K} = 2.1mA$$

$I_B = I_E - I_C = 7.2mA$

$$\beta_{forced} = \frac{I_{c(sat)}}{I_B}$$

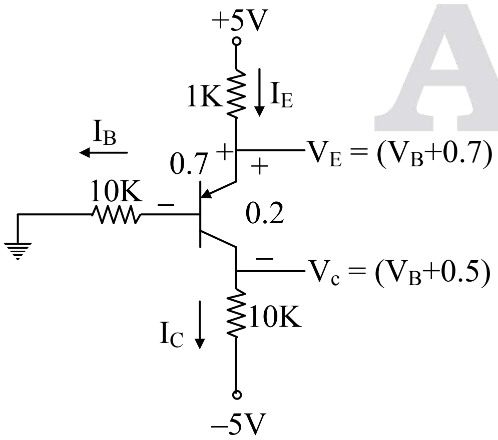
$$= \frac{2.1}{7.2}$$

$= 0.29$

$\beta_{forced} < \beta_{active}$ i.e., saturation region

06. Ans: (c)

Sol:



$I_E = I_C + I_B$

$$\Rightarrow \frac{5-(V_B+0.7)}{1k} = \frac{(V_B+0.5)+5}{10k} + \frac{V_B}{10k}$$

$10(5 - V_B - 0.7) = V_B + 0.5 + 5 + V_B$

$43 - 10V_B = 2V_B + 5.5$

$$V_B = \frac{43-5.5}{12} = 3.125V$$

$$I_B = \frac{3.125}{10K} = 0.3125mA$$

$V_C = V_B + 0.5 = 3.625V$

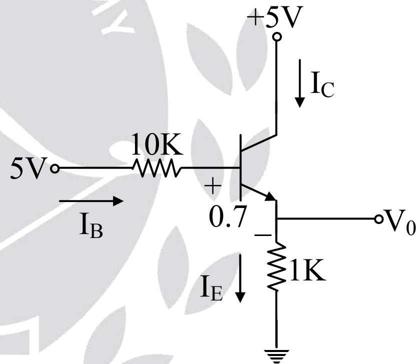
$V_E = 3.825V$

$\therefore I_E = 1.175mA$

$\therefore I_C = 0.862mA$

07. Ans: (b)

Sol: Here the lower transistor (PNP) is in cut off region.



Apply KVL to the base emitter loop:

$5 - 10K.\ I_B - 0.7 - 1K.\ (1+\beta)I_B = 0$

$$\Rightarrow I_B = \frac{4.3}{(101)K + 10K}$$

$= 38.73\mu A$

$I_C = 3.87mA$

$I_E = 3.91mA$

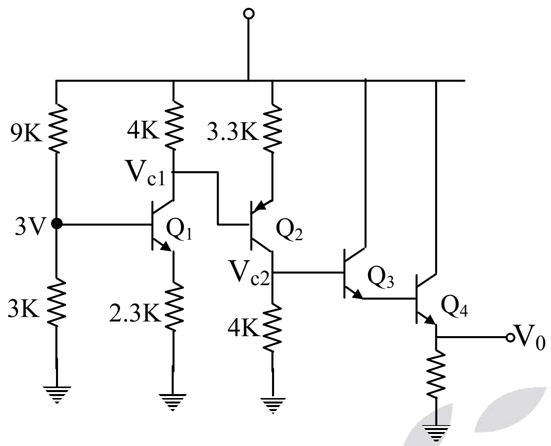
$\Rightarrow V_E = V_0 = I_E(1k) = 3.91\ V$

$V_C = 5V$

$V_B = 5 - 10\ k\ (I_B) = 4.61\ V$

08. Ans: (a)

Sol:



$$I_{C_1} = I_{\varepsilon_1} = \frac{2.3V}{2.3k} = 1m\,Amp$$

$$V_{C_1} = 12V - 4\times10^3 \times 1\times10^{-3}$$

$$= 8V$$

$$V_{\varepsilon_2} = 8 + 0.7V = 8.7V$$

$$I_{\varepsilon_2} = \frac{12V - V_{\varepsilon 2}}{3.3k}$$

$$= \frac{12V - 8.7}{3.3k}$$

$$= 1m\,Amp$$

$$V_{C_2} = 4k \times 1mA = 4V$$

$$V_{\varepsilon 3} = 4V - 0.7 = 3.3V$$

$$V_{\varepsilon_4} = 3.3 - 0.7 = 2.6V$$

$V_0 = 2.6$ V

Solutions for Conventional Practice Questions

01

Sol: (i) The variation of I_C with the variations in V_{BE} at a constant I_{CO} and β is considered as S^{11}.

$$S^{11} = \left(\frac{\partial I_C}{\partial V_{BE}}\right) \text{ with } I_{CO} \text{ and } \beta \text{ Constant.}$$

Derivation of Stability Factor (S):

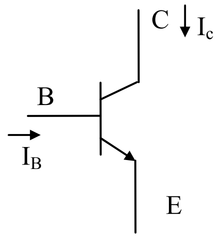
Consider the collector current equation of a BJT in CE configuration:

$I_c = \beta\, I_B + (1+\beta)\, I_{CO}$

Differentiating equation (1) w.r.t. I_C

$$1 = \beta\,\frac{\partial I_B}{\partial I_C} + (1+\beta)\frac{\partial I_{CO}}{\partial I_c}$$

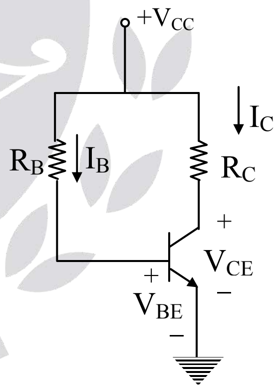
$$\frac{\partial I_{co}}{\partial I_c} = \frac{1-\beta\left(\dfrac{\partial I_B}{\partial I_c}\right)}{(1+\beta)}$$



$$\Rightarrow \frac{\partial I_C}{\partial I_{CO}} = \frac{1+\beta}{1-\beta\dfrac{\partial I_B}{\partial I_C}}$$

$$\therefore\ S = \frac{\partial I_C}{\partial I_{CO}} = \frac{1+\beta}{1-\beta\left[\dfrac{\partial I_B}{\partial I_C}\right]}$$

Fixed bias:



$$\text{Stability factor } S = \frac{\partial I_C}{\partial I_{CO}} = \frac{1+\beta}{1-\beta\left[\dfrac{\partial I_B}{\partial I_C}\right]}$$

KVL for the input section

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$$\Rightarrow \frac{\partial I_B}{\partial I_C} = 0$$

$\therefore$ S = 1+ β

Voltage-divider bias or self-bias:

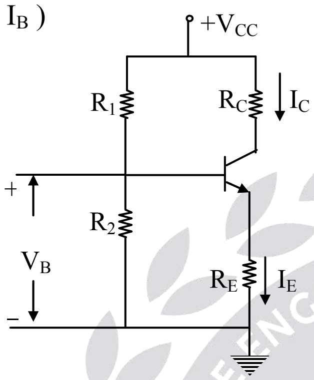
Stability Factor $S = \dfrac{\partial I_C}{\partial I_{CO}} = \dfrac{1+\beta}{1-\beta\left[\dfrac{\partial I_B}{\partial I_C}\right]}$

KVL for the input section of fig.10

$V_B - I_B R_B - V_{BE} - I_E R_E = 0$

$V_B - I_B R_B - V_{BE} - I_C R_E - I_B R_E = 0$

$(\because I_E = I_C + I_B)$



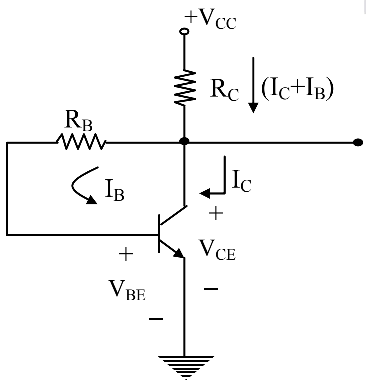
$I_B = \dfrac{V_B - V_{BE} - I_C R_E}{R_E + R_B}$

$\dfrac{\partial I_B}{\partial I_C} = \dfrac{-R_E}{R_E + R_B}$

$S = \dfrac{1+\beta}{1+\beta\left(\dfrac{R_E}{R_E + R_B}\right)}$

Collector-to- Base bias or Collector feedback bias:

Stability factor $S = \dfrac{\partial I_C}{\partial I_{CO}} = \dfrac{1+\beta}{1-\beta\left[\dfrac{\partial I_B}{\partial I_C}\right]}$



KVL for the input section of fig.8

$V_{CC} - (I_C + I_B)\, RC - I_B R_B - V_{BE} = 0$

$\Rightarrow V_{CC} - I_C R_C - I_B(R_C + R_B) - V_{BE} = 0$

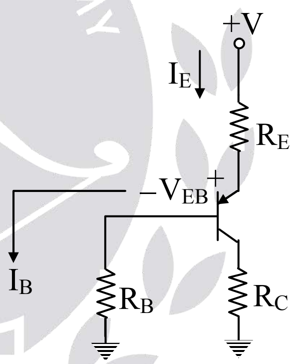
$\Rightarrow I_B = \dfrac{V_{CC} - V_{BE} - I_C R_C}{R_C + R_B}$

$\Rightarrow \dfrac{\partial I_B}{\partial I_C} = \dfrac{-R_C}{R_C + R_B}$

$\therefore S = \dfrac{1+\beta}{1+\beta\left(\dfrac{R_C}{R_C + R_B}\right)}$

(ii) $V_C = (I_C + I_B) R_E + V_{EB} + I_B R_B$

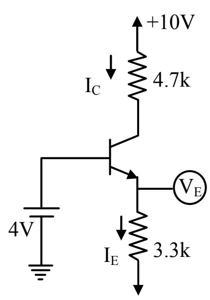
$S = \dfrac{1+\beta}{1-\beta\left[\dfrac{-R_E}{R_B + R_E}\right]}$



02.

Sol: DC Analysis:

Capacitor are replaced with open circuit and ac source V_{in} with short circuit]



Given β = 100

$V_E = 4 - 0.7 = 3.3V$

$$I_E = \frac{V_E}{3.3k} = \frac{3.3}{3.3k} = 1mA$$

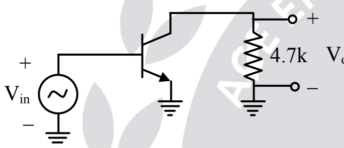
$$I_C = \left(\frac{\beta}{\beta+1}\right) I_E = \left(\frac{100}{101}\right) 1mA = 0.99mA$$

$$g_m = \frac{I_C}{V_t} = \frac{0.99m}{25m}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{\left(\frac{0.99}{25}\right)} \approx 2.5k\Omega$$

AC Analysis:

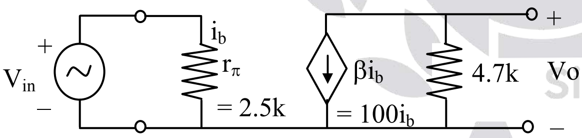
[Capacitors are replaced with short circuit and 10V, 4V DC source with short circuit]



$V_o = -100 i_b[4.7k]$

$V_{in} = i_b(2.5k)$

Voltage gain



$$A_v = \frac{V_o}{V_{in}}$$

$$= \frac{-100}{2.5k}[4.7k]$$

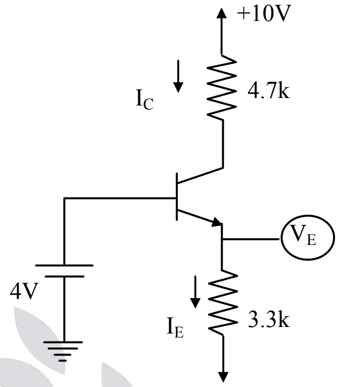
$$= -188$$

The negative sign in the voltage gain indicates that the output voltage V_o is 180 out of phase with V_{in}.

03.

Sol: DC Analysis:

[Capacitor are replaced with open circuit and ac source V_{in} with short circuit]



Given β = 100

$V_E = 4 - 0.7 = 3.3V$

$$I_E = \frac{V_E}{3.3k} = \frac{3.3}{3.3k} = 1mA$$

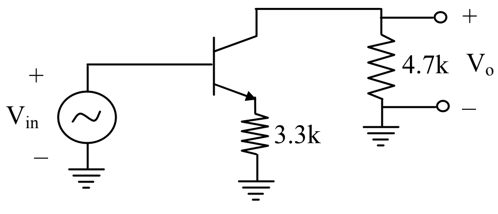
$$I_C = \left(\frac{\beta}{\beta+1}\right) I_E = \left(\frac{100}{101}\right) 1mA = 0.99\ mA$$

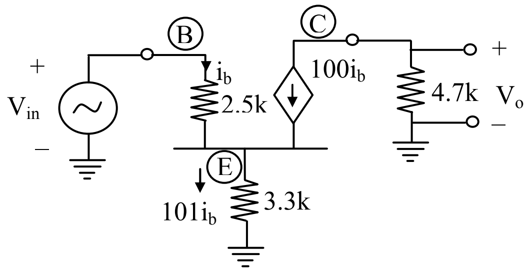
$$g_m = \frac{I_C}{V_t} = \frac{0.99m}{25m}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{\left(\frac{0.99}{25}\right)} \approx 2.5k\Omega$$

AC analysis:

Capacitors are replaced with short circuit DC sources are replaced with short circuit





$V_o = -100i_b[4.7k]$

$V_{in} = i_b\,(2.5k) + 101i_b[3.3k]$

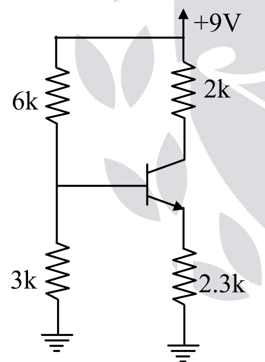
$$\text{Voltage gain } (A_v) = \frac{V_o}{V_{in}} = \frac{-100[4.7k]}{2.5k + 101(3.3k)}$$

$$= -1.4$$

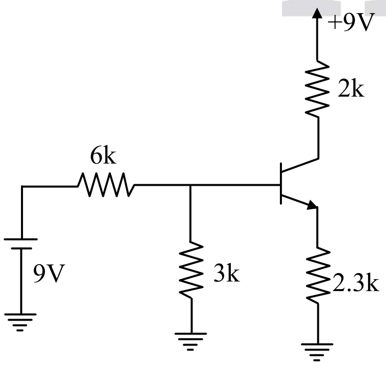
The negative sign indicates the output voltage V_o is 180 out of phase with input voltage V_{in}.

04.

Sol: **DC Analysis:** [capacitors are replaced with open circuits]



The circuit can be redrawn as shown below



$$V_{th} = \frac{9(3k)}{6k + 3k} = 3V$$

$$R_{th} = 6k \,||\, 3k = 2k$$

Apply KVL at input loop

$-V_{th} + I_B R_{th} + 0.7 + I_E(2.3k) = 0$ ---(1)

$$I_B = \frac{I_E}{\beta + 1} = \frac{I_E}{100 + 1} = \frac{I_E}{101} \text{ ---(2)}$$

Sub (2) in (1)

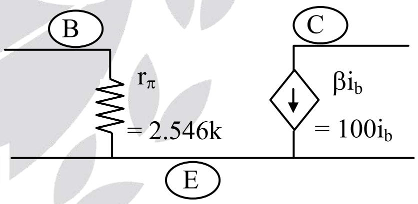
$$I_E = \frac{V_{th} - 0.7}{2.3k + \frac{R_{th}}{\beta + 1}} = \frac{3 - 0.7}{2.3k + \frac{2k}{101}} = 0.991\text{mA}$$

$$I_C = \left(\frac{\beta}{\beta + 1}\right) I_E$$

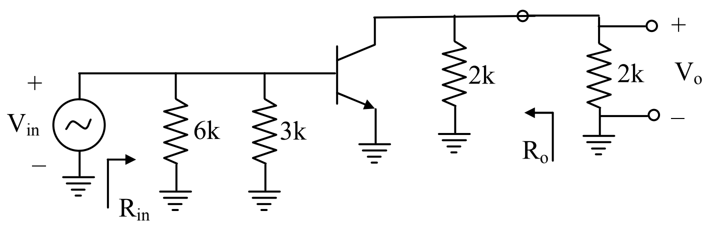
$$= \left(\frac{100}{101}\right)(0.991\text{m}) = 0.9816\text{mA}$$

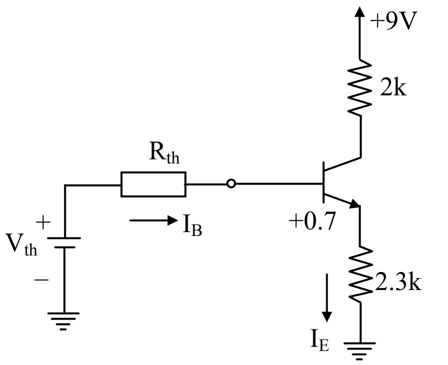
$$r_\pi = \frac{\beta}{g_m} = \frac{100}{\left[\frac{0.9816\text{m}}{25\text{m}}\right]} = 2.546\text{k}\Omega$$

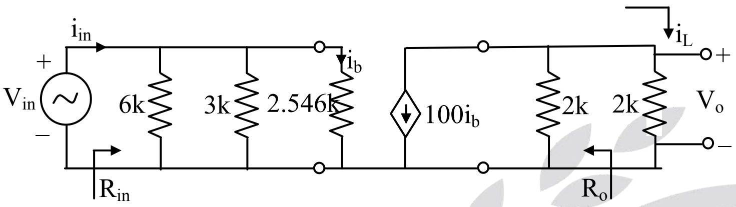
Small signal model of BJT ($V_A = \infty$)



$$\text{AC equivalent} \begin{bmatrix} \text{Cap} \rightarrow \text{SC} \\ \text{DCsources} \rightarrow \text{SC} \end{bmatrix}$$







Input resistance (R_{in}) = 6 k || 3k || 2.546k

= 1.12kΩ

$V_o = -100i_b[2k||2k]$

$V_{in} = i_b[2.546k]$

Voltage gain(A_v) $= \frac{V_o}{V_{in}}$

$= \frac{-100[2k \parallel 2k]}{2.546k} = -39.2$

Current gain (A_I) = $\frac{i_L}{i_{in}}$

$= \frac{(V_o/2k)}{(V_{in}/R_{in})} = \frac{A_v.R_{in}}{2k}$

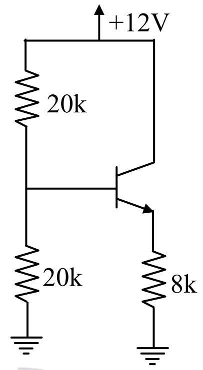
$\rightarrow A_I = \frac{-39.2[1.12k]}{2k} = -22$

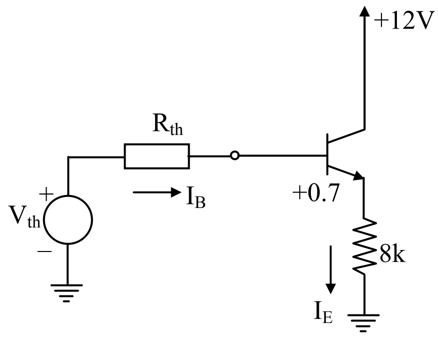
Output resistance (R_o) = 2k

if $V_{in} = 0$, $i_b = 0$

05.

Sol: DC Analysis: [Cap → OC]





$$V_{th} = \frac{12(20k)}{20k+20k} = 6V$$

$$R_{th} = 20k \parallel 20k = 10k$$

KVL at i/p loop: [Given β=100 V_{BE}(ON)= 0.7]

$-V_{th} + I_BR_{th} + 0.7 + I_E(8k) = 0$ ----(1)

$$I_B = \frac{I_E}{\beta+1} = \frac{I_E}{101} \text{ ---(2)}$$

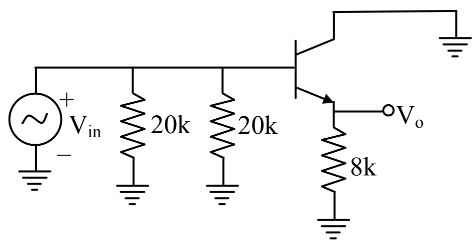
Sub (2) in (1)

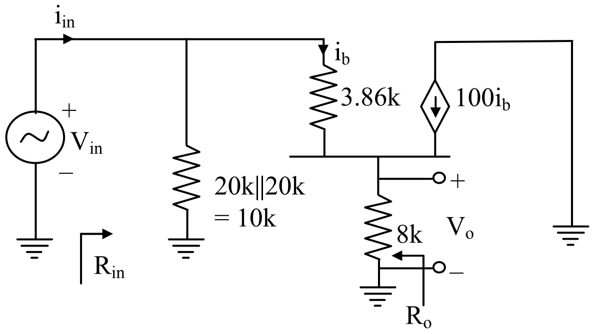
$$I_E = \frac{V_{th}-0.7}{8k+\frac{R_{th}}{\beta+1}} = \frac{6-0.7}{8k+\frac{10k}{101}} = 0.654mA$$

$$I_C = \left(\frac{\beta}{\beta+1}\right)I_E = \left(\frac{100}{101}\right)0.654m = 0.6479m$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{\left(\frac{I_C}{V_t}\right)} = \frac{100}{\left(\frac{0.6479m}{25m}\right)} = 3.858k\Omega$$

AC analysis: [capacitors are replaced with SC 12V DC source is also SC to ground]





$V_o = 101i_b(8k)$ ---- (1)

$V_{in} = i_b[3.86k] + 101i_b\,(8k)$ ----- (2)

Voltage gain $(A_v) = \frac{V_o}{V_{in}}$

$$= \frac{101(8k)}{3.86k + 101(8k)} = 0.995$$

[Note: CC Amplifier is a voltage buffer]

$$i_{in} = \frac{V_{in}}{10k} + i_b$$

$$= \frac{V_{in}}{10k} + \frac{V_{in}}{3.86k + (101)8k}$$

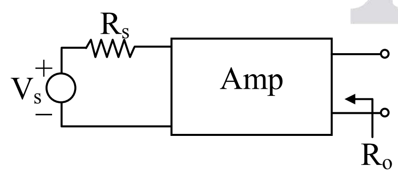
Input resistance $(R_{in}) = \frac{V_{in}}{i_{in}}$

$$\frac{V_{in}}{i_{in}} = \frac{1}{\frac{1}{10k} + \frac{1}{3.86k + (101)8k}}$$

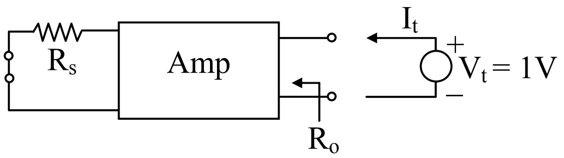
$$= 9878\Omega = 9.878k\Omega$$

[Note: R_{in} = 10K || $[r_\pi + (1+\beta)R_E]$]

For calculating R_o



Set $V_s = 0$

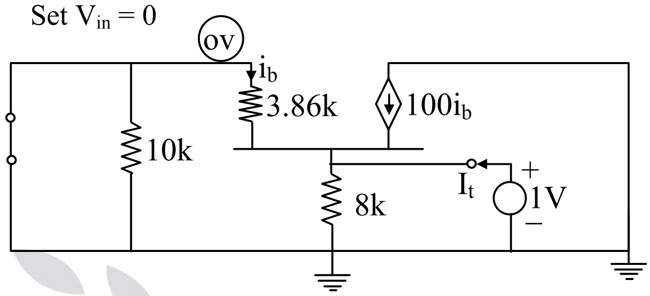


$$R_o = \frac{V_t}{I_t} = \frac{1V}{I_t}$$

Connect 1V source at the output terminals

Find I_t, $R_o = \frac{V_t}{I_t} = \frac{1V}{I_t}$

Set $V_{in} = 0$



$$i_b = \frac{0-1}{3.86k} = \frac{-1}{3.86k}$$

KCL $i_b + 100i_b + I_t = \frac{1}{8k}$

$$I_t = \frac{1}{8k} - [101]\left[\frac{-1}{3.86k}\right]$$

Output resistance $(R_o) = \frac{1}{I_t}$

$$= \frac{1}{\frac{1}{8k} + \frac{101}{3.86k}} = 38\Omega$$

$$\left[\text{Note } R_o = 8k \,||\, \frac{r_\pi}{1+\beta}\right]$$

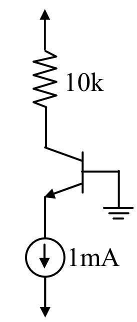
06.

Sol: **DC Analysis**: [Cap → OC]

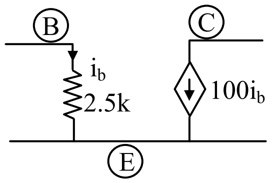
$$I_E = 1mA \rightarrow I_C = \left(\frac{\beta}{\beta+1}\right)I_E$$

$$= \left(\frac{100}{101}\right)1m$$

$= 0.99mA$

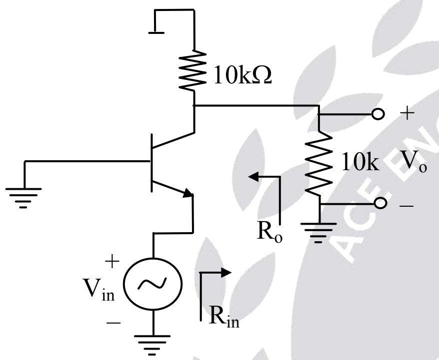


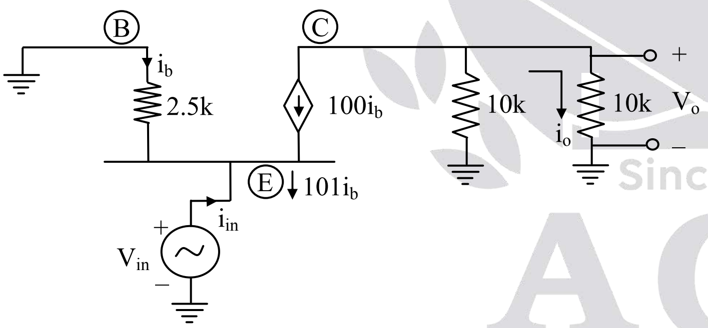
$$r_\pi = \frac{\beta}{g_m} = \frac{100}{\left[\frac{0.99m}{25m}\right]} = 2.5k\Omega$$



[small signal model of BJT]

AC equivalent: $\begin{bmatrix} Cap \to SC \\ DC\,sources \to SC \end{bmatrix}$





$V_o = -100i_b[10k \| 10k]$

KVL $\quad i_b(2.5k) + V_{in} = 0$

$V_{in} = -i_b[2.5k]$ ----(2)

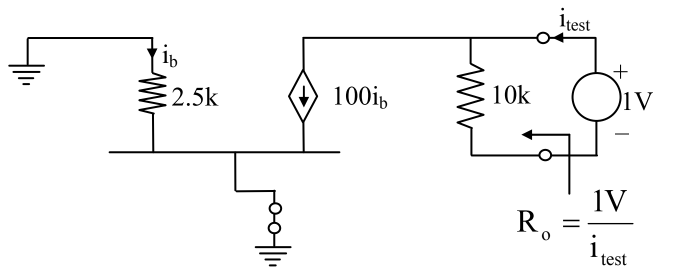
Voltage gain $(A_v) = \frac{V_o}{V_{in}}$

$$= \frac{-100[10k \| 10k]}{-2.5k} = +200$$

Input resistance $(R_{in}) = \frac{V_{in}}{i_{in}} = \frac{-i_b(2.5k)}{-101i_b}$

$= 24.7\Omega$

Output resistance (R_o)



$$R_o = \frac{1V}{i_{test}}$$

$i_b(2.5k) = 0 \to i_b = 0 \to 100i_b = 0$

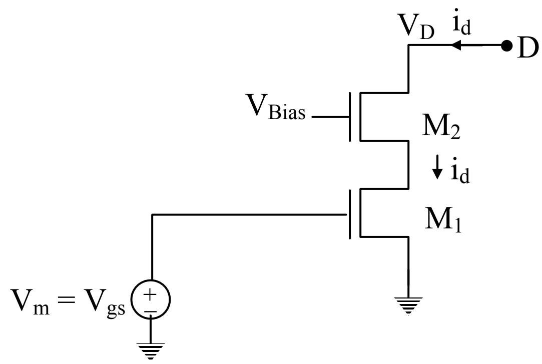
output resistance $R_o = \frac{1V}{i_t} = \frac{1V}{[1/10k]} = 10k\Omega$

3. MOSFET Amplifiers

Solutions for Objective Practice Questions

01. Ans: (c)

Sol: The circuit given is the MOS cascode amplifier, Transistor M_1 is connected in common source configuration and provides its output to the input terminals (i.e., source) of transistor M_2. Transistor M_2 has a constant dc voltage, V_{bias} applied at its gate. Thus the signal voltage at the gate of M_2 is zero and M_2 is operating as a CG amplifier. Which is current Buffer.

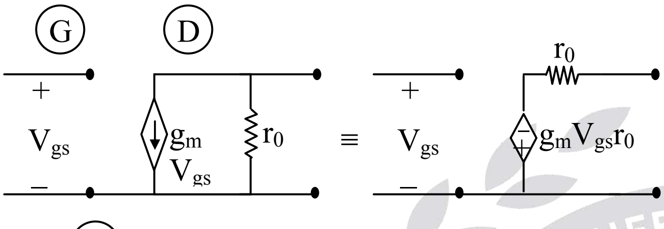


Overall transconductance

$$g_m = \frac{i_d}{V_{gs}} = \left[\frac{\partial i_D}{\partial V_{GS}}\right] = \frac{i_{d_1}}{V_{gs_1}} = g_{m_1}$$

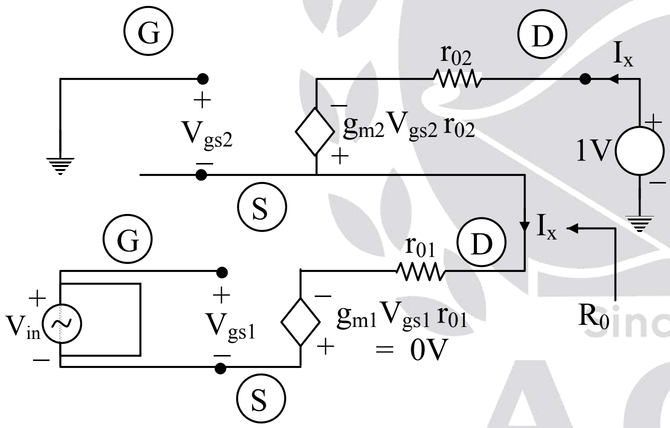
The overall (approximate) transconductance of the cascode amplifier is equal to the transconductance of common source amplifier g_{m_1}

AC model of MOSFET



Thevenin equivalent

Let us find the output resistance $R_0 = \dfrac{1V}{I_x}$



By KVL $V_{gs2} + I_x r_{01} = 0$

$V_{gs2} = -I_x r_{01}$ ------(1)

By KVL

$-1 + I_x r_{02} - g_m r_{02} V_{gs2} + I_x r_{01} = 0$

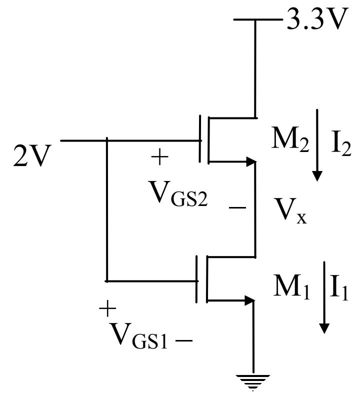
$-1 + I_x r_{02} + g_{m2} r_{02}\, I_x r_{01} + I_x\, r_{01} = 0$

$$\therefore I_x = \frac{1}{r_{01} + r_{02} + g_{m2} r_{02} r_{01}} \approx \frac{1}{g_{m2} r_{01} r_{02}}$$

$$R_0 = \frac{1}{I_x} = g_{m2} r_{01} r_{02}$$

02. Ans: (d)

Sol:



$$\left(\frac{W}{L}\right)_2 = 2\left(\frac{W}{L}\right)_1$$

$V_{TH} = 1V$ for both M_1 and M_2

For M_2 to be in saturation:

$V_D > V_G - V_{TH}$

$3.3 > 2 - 1$

$3.3 > 1$

So M_2 will be in saturation if it is ON.

For M_1 to be in saturation:

$V_D > V_G - V_{TH}$

$V_X > 2 - 1$

$V_X > 1V$ but if V_X is more than 1V, V_{GS2} becomes less than 1V, Which means M_2 will be off so M_1 can not be in saturation.

Now, we can conclude that M_1 is in triode and M_2 is in saturation

$V_{GS1} = 2V$

$V_{DS1} = V_X$

$V_{GS2} = 2 - V_X$

Now, $I_1 = I_2$

$$\mu_n C_{ox}\left(\frac{W}{L}\right)_1\left[(V_{GS1} - V_{TH})V_{DS1} - \frac{1}{2}V_{DS1}^{\;2}\right]$$

$$= \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{TH})^2$$

$$V_x - \frac{1}{2}V_x^2 = (1 - V_x)^2$$

$$3V_x^2 - 6V_x + 2 = 0$$

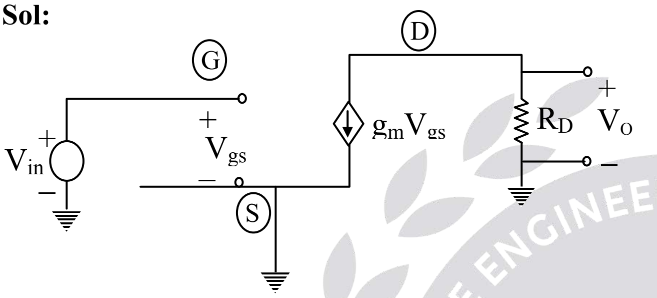
$V_x = 0.42\text{V}, \; -1.58\text{V}$

V_x cannot be more than 1V, since M_2 will become off

So, $V_x = 0.42$ V

03. Ans: (a)

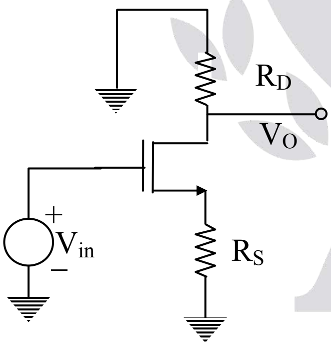
Sol:



$$\left.\begin{aligned} V_o &= -g_m V_{gs} R_D \\ V_{in} &= V_{gs} \end{aligned}\right\} \frac{V_o}{V_{in}} = -g_m R_D$$

04. Ans: (b)

Sol:

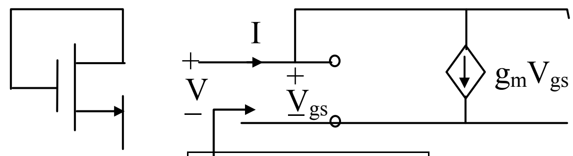


$$\frac{V_o}{V_{in}} = \frac{-\text{Drain resistance}}{\text{Source resistance}}$$

$$= \frac{-R_D}{R_S}$$

05. Ans: (c)

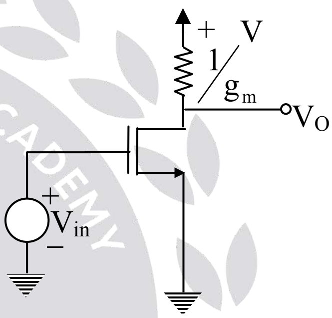
Sol:



$$R_{in} = \frac{V}{I} = \frac{1}{g_m}$$

$I = g_m V_{gs}$

$V = V_{gs}$



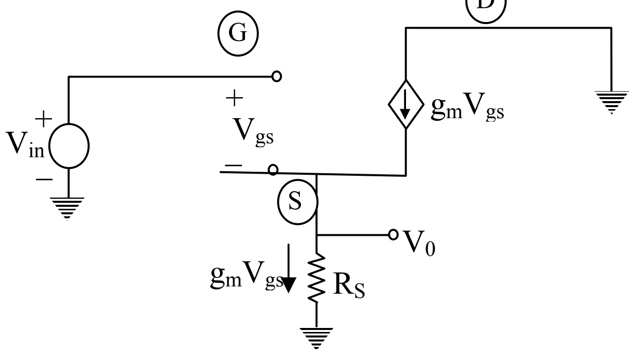
$$\frac{V_o}{V_{in}} = -g_m R_D$$

$= -g_m(1/g_m)$

$= -1$

06. Ans: (b)

Sol:



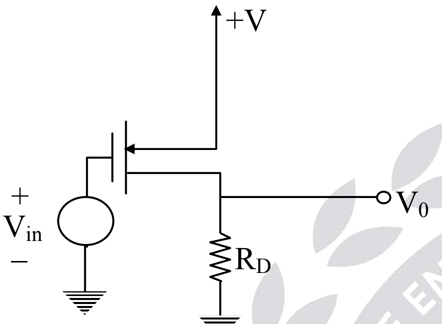
$V_o = g_m V_{gs} R_s$

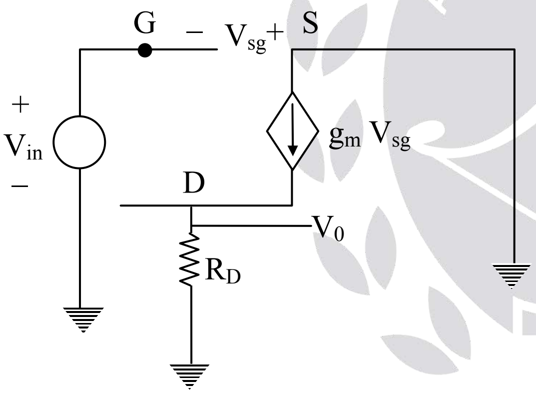
$V_{in} = V_{gs} + g_m V_{gs} R_s$

$$\frac{V_o}{V_{in}} = \frac{g_m R_S}{1 + g_m R_S} = \frac{R_S}{R_S + 1/g_m}$$

07. Ans: (c)

Sol: In volume-I book, the diagram is wrong. The correct circuit diagram is





Common source

$V_{sg} = -V_{in}$

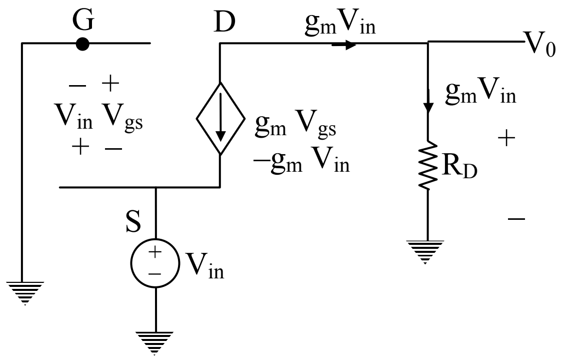
$V_0 = g_m V_{sg} R_D$

$= g_m(-V_{in})R_D$

$$\frac{V_0}{V_{in}} = -g_m R_D$$

08. Ans: (a)

Sol:



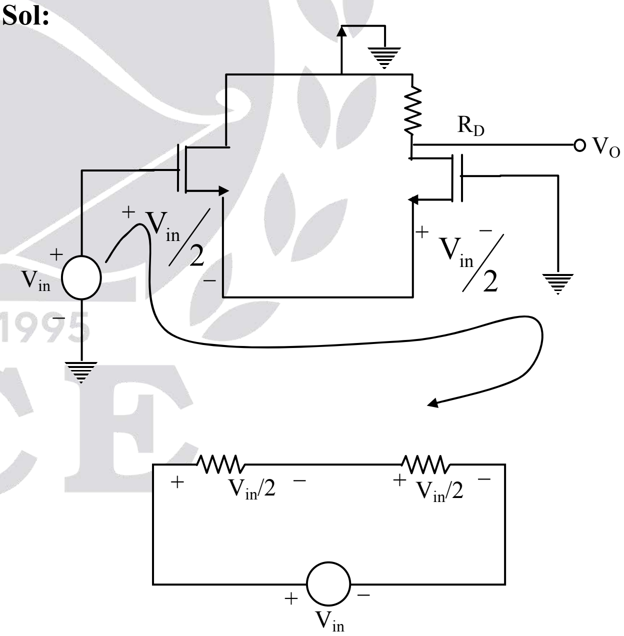
$V_{gs} = -V_{in}$

$V_0 = g_m V_{in} \times R_D$

$$\frac{V_0}{V_{in}} = g_m R_D$$

09. Ans: (d)

Sol:



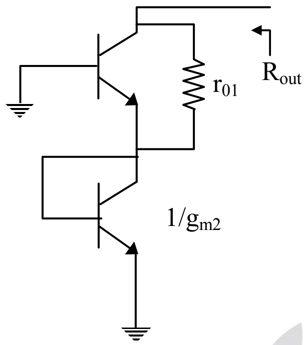
$V_o = -I_D R_D$

$$V_{GS} = V_{in}/2 \rightarrow V_{in} = 2V_{gs}$$

$$\frac{V_o}{V_{in}} = \frac{I_D R_D}{2V_{GS}} = \frac{R_D}{2\left(\frac{1}{g_m}\right)} = \frac{g_m R_D}{2}$$

10. Ans: (c)

Sol:



$R_{out} = r_{01} + (1+g_{m1}\, r_{01})\ \frac{1}{g_{m2}}$

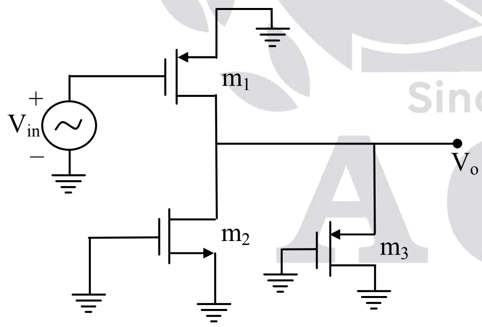
$= r_{01} + \frac{1}{g_{m2}} + r_{01}$

$= 2\, r_{01}$

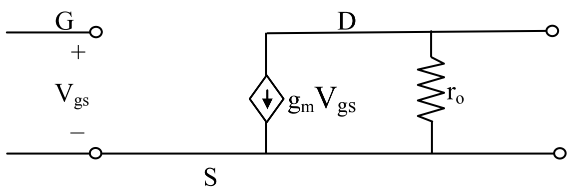
Solutions for Conventional Practice Questions

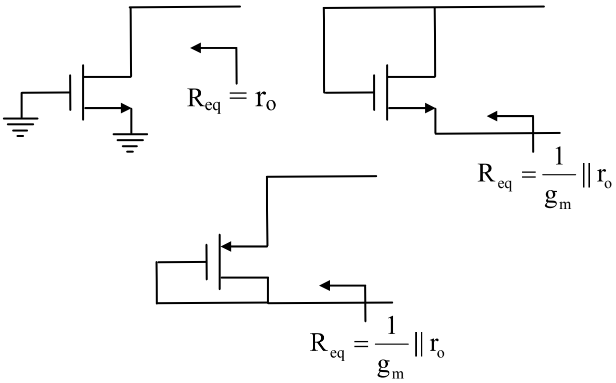
01.

Sol:

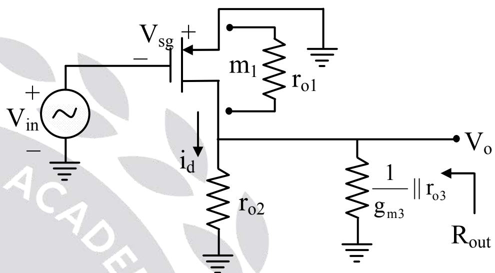


MOSFET ac equivalent is same both for NMOS and PMOS





The given circuit can be redrawn



$$R_{out} = r_{o2} \| \frac{1}{g_{m3}} \| r_{o3} \| r_{o1}$$

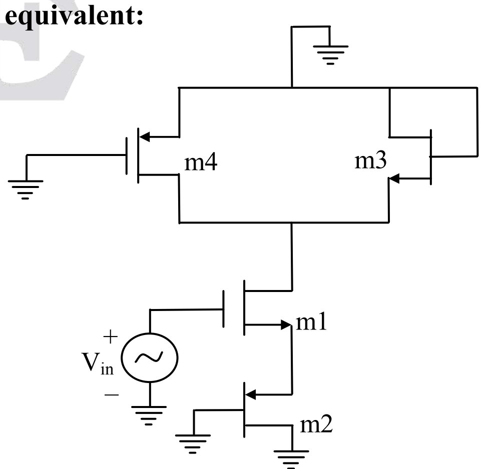
$$V_{in} = -V_{sg}$$

$$V_o = i_d\left[r_{o2} \| \frac{1}{g_{m3}} \| r_{o3}\right]$$

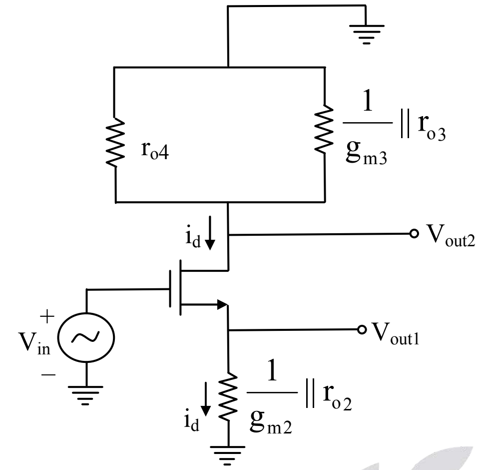
$$\Rightarrow \frac{V_o}{V_{in}} = -g_{m1}\left[r_{o2} \| \frac{1}{g_{m3}} \| r_{o3}\right]$$

02.

Sol: AC equivalent:



The circuit can be redrawn



$$V_{out1} = i_{d1}\left[\frac{1}{g_{m2}} \| r_{o2}\right]$$

$$V_{in} = V_{gs1}$$

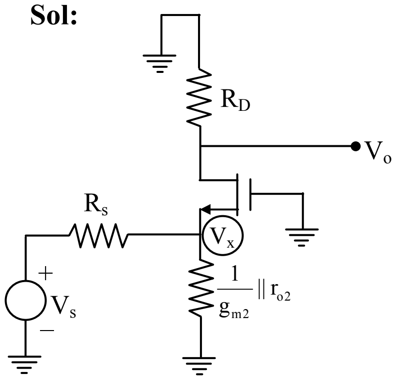
$$\frac{V_{out1}}{V_{in}} = g_{m1}\left[\frac{1}{g_{m2}} \| r_{o2}\right]$$

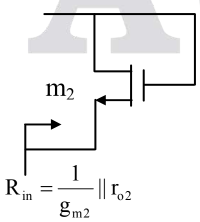
$$V_{out2} = -i_d\left[r_{o4} \| \frac{1}{g_{m3}} \| r_{o3}\right]$$

$$\frac{V_{out2}}{V_{in}} = -g_{m1}\left[r_{o4} \| \frac{1}{g_{m3}} \| r_{o3}\right]$$

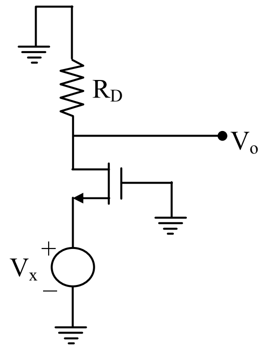
03.

Sol:

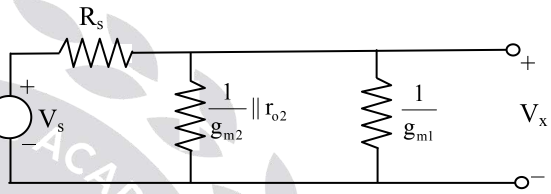




$$\frac{V_o}{V_s} = \frac{V_o}{V_x} = \frac{V_x}{V_s} \text{ ------ (1)}$$



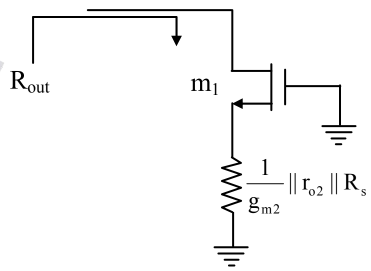
$$\frac{V_o}{V_x} = \frac{-i_d R_D}{-V_{gs}} = +g_m R_D$$



$$\frac{V_x}{V_s} = \frac{\frac{1}{gm_2} \| r_{o2} \| \frac{1}{g_{m1}}}{R_s + \frac{1}{g_{m2}} \| r_{o2} \| \frac{1}{g_{m1}}}$$

Sub in (1)

$$\therefore \frac{V_o}{V_s} = [g_m R_D]\left[\frac{\frac{1}{g_{m2}} \| r_{o2} \| \frac{1}{g_{m1}}}{R_s + \frac{1}{g_{m2}} \| r_{o2} \| \frac{1}{g_{m1}}}\right]$$



$$R_{out} = r_{o1} + (1 + g_{m1} r_{o1})\left[\frac{1}{g_{m2}} \| r_{o2} \| R_s\right]$$

04.

Sol: Given $I_{DSS} = 10mA$

$V_{GS} = -V_{GG} = -2V$

$V_P = -5V$

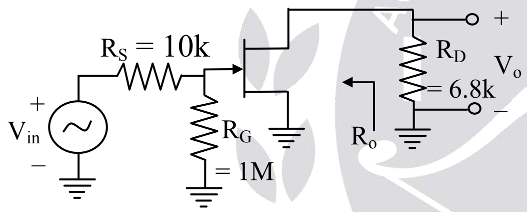
$$I_D = I_{DSS}\left[1-\frac{V_{GS}}{V_P}\right]^2$$

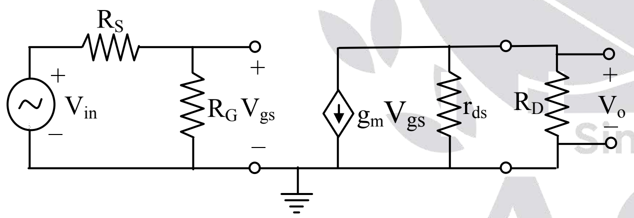
$$g_m = \frac{\partial I_D}{\partial V_{GS}} = 2I_{DSS}\left[1-\frac{V_{GS}}{V_P}\right]\left[-\frac{1}{V_P}\right]$$

$$= 2(10m)\left[1-\left(\frac{-2}{-5}\right)\right]\left[\frac{-1}{-5}\right]$$

$$= 2.4m\left(\frac{A}{V}\right)$$

AC equivalent $\begin{bmatrix}\text{Cap} \rightarrow \text{SC} \\ \text{DC sources} \rightarrow \text{SC}\end{bmatrix}$





$$V_o = -g_m V_{gs}[r_{ds}||R_D]$$

$$V_{gs} = \frac{V_{in}R_G}{R_S + R_G}$$

$$\frac{V_o}{V_{in}} = \frac{V_o}{V_{gs}} = \frac{V_{gs}}{V_{in}}$$

$$= -g_m[r_{ds} \,||\, R_D]\left[\frac{R_G}{R_G + R_S}\right]$$

$$= -2.4m[30k \,||\, 6.8k]\left[\frac{1M}{1M + 10k}\right]$$

$$= -13.17$$

05.

Sol: Given $V_P = -2V$

$I_{DSS} = 1.65mA$

$I_D = 0.8mA$

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

$$\rightarrow 0.8m = 1.65m\left[1+\frac{V_{GS}}{2}\right]^2 \rightarrow V_{GS} = -0.607$$

(ii) $$g_m = \frac{\partial I_D}{\partial V_{gs}} = 2I_{DSS}\left[1-\frac{V_{GS}}{V_P}\right]\left[\frac{-1}{V_P}\right]$$

$$= 2(1.65m)\left[1+\frac{0.607}{2}\right]\left[\frac{-1}{-2}\right]$$

$= 1.149m(A/V)$

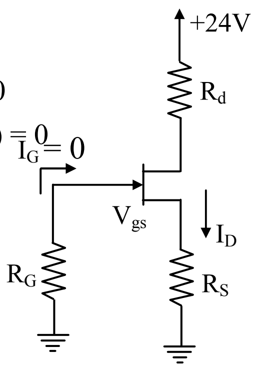
(iii) DC equivalent

KVL

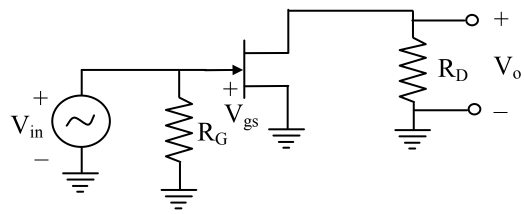
$I_G[R_G] + V_{gs} + I_D R_S = 0$

$0 - 0.607 + 0.8m(R_S) = 0$

$R_S = 758.75\Omega$



(iv) AC equivalent



$$\frac{V_o}{V_{in}} = -g_m R_D$$

$$\left[\text{Given}\left(\frac{V_o}{V_{in}}\right)_{dB} = 20 \rightarrow \frac{V_o}{V_{in}} = 10\right]$$

$10 = -\ 1.149m\ [R_D]$

$\rightarrow R_D = 8.7k\Omega$

4. Cascode Amplifiers, Current Mirrors & Differential Amplifiers

Solutions for Objective Practice Questions

01. Ans: (d)

Sol: For the given differential amplifier,

$I_E = 1mA$

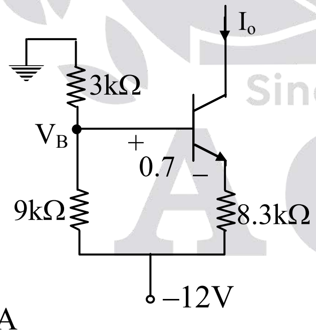
$$r_e = \frac{V_T}{I_E} = 25\Omega$$

$$A_d = \frac{V_0}{V_i} = \frac{-R_c}{r_e} = \frac{-3000}{25} \text{ (or) } -g_m R_c$$

$A_d = -120$

02. Ans: (a)

Sol:



$$I_1 = \frac{0-(-12)}{12k} = 1mA$$

$$I_1 = \frac{0-V_B}{3K}$$

$V_B = -3V$

$V_B - V_E = 0.7$

$V_E = V_B - 0.7$

$V_E = -3.7$ Volt

$$I_0 = \frac{-3.7+12}{8.3k} = 1mA$$

$I_E = 0.5mA$

$$r_e = \frac{25mV}{0.5mA} = 50\Omega$$

$$A_d = \frac{-R_C}{r_e} = \frac{-2000}{50}$$

$A_d = -40$

03. Ans: (a)

Sol: Since,

$$V_B = V_{BE_1} + I_1R_1 = V_{BE_2} + I_2R_2$$

Since in current mirror,

Transistor default must be perfectly matched

$\therefore\ I_{B_1} = I_{B_2}$

$\&\ \ I_{BE_1} = V_{BE_2}$

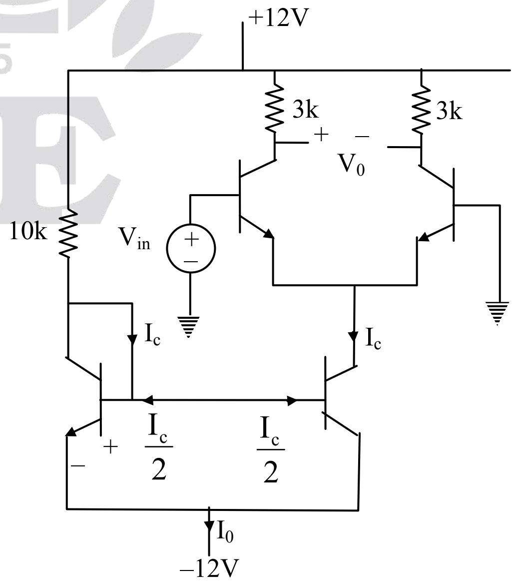
$\therefore\ I_1R_1 = I_2R_2$

$\therefore I_{ref}\ R_1 = I_{copy}\ R_2$

$$\therefore I_{copy} = I_{ref}\frac{R_1}{R_2}$$

04. Ans: (c)

Sol:



$$\frac{V_0}{V_i} = -g_m RC$$

$$= -g_m(3k)$$

$$g_m = \frac{I_c}{V_T}$$

$$I_0 = \frac{12 - 0.7 + 12}{10k}$$

$$= \frac{23.3}{10k} = 2.33\text{mA}$$

$$I_{c(Dc)} = \frac{I_0}{2}$$

$$= \frac{2.33}{2}\text{mA} = 1.16\text{mA}$$

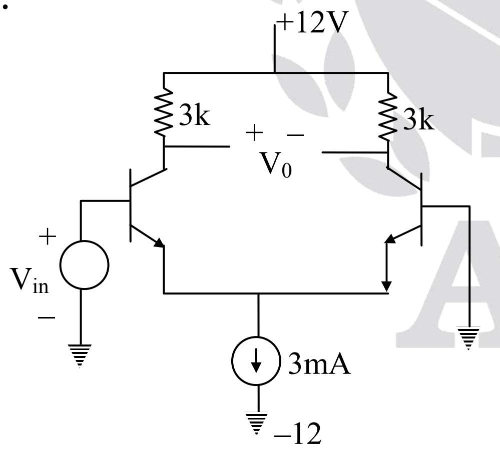
$$Ad = -\frac{1.16\mu A}{25\mu V} \times (3A)$$

$$= -\frac{1.16}{25} \times 3(k)$$

$$= -139.5$$

05. Ans: (d)

Sol:



$$I_{c(DC)} = \frac{3mA}{2} = 1.5\text{mA}$$

$$g_m = \frac{I_{c(DC)}}{V_T} = \frac{1.5}{25}$$

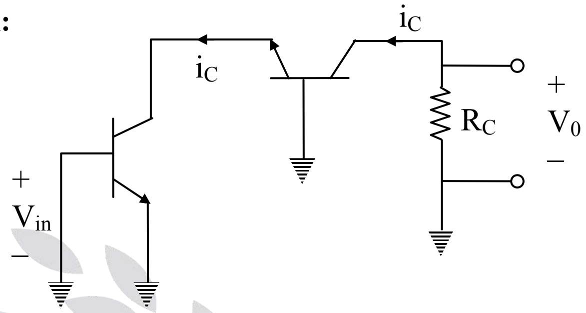
$$Ad = -g_m R_c$$

$$= -\frac{1.5}{25} \times 3k$$

$$= -180$$

06. Ans: (a)

Sol:



$$V_0 = i_c R_C$$

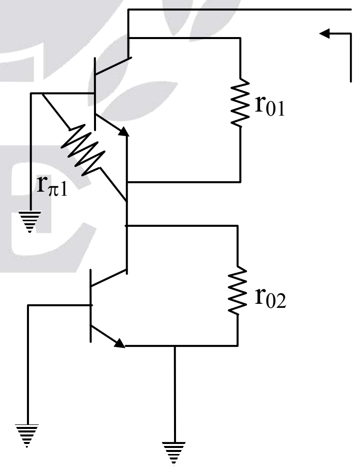
$$g_m = \frac{i_C}{V_{be}} = \frac{i_C}{V_{in}}$$

$$\frac{V_0}{V_{in}} = \frac{-I_c R_c}{V_{in}}$$

$$= -g_m R_c$$

07. Ans: (b)

Sol:



$$R_{out} = r_{01} + (+g_{m1} r_{01})$$

$$(r_{02} // r_{\pi 2})$$

$$= r_{01} + r_{\pi 2} + g_{m1} r_{01} r_{\pi 2}$$

$= r_{01} + \beta r_{01}$

$= (\beta+1) r_{01}$

$\approx \beta r_{01}$

08. Ans: (a)

Sol: $Q_1 \rightarrow 1(V_{01}\text{ gain})$

$$Q_2 \rightarrow \frac{-R_c}{re_2} = -g_{m2}R_c$$

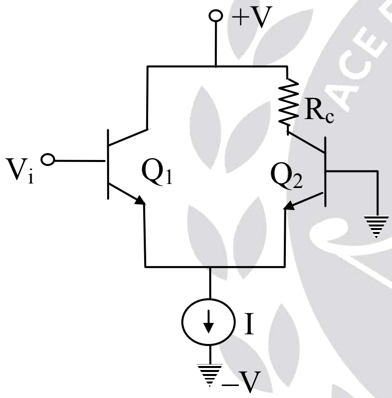
$$\therefore A_{V_T} = 1\times(-g_{m_2}R_c) = -g_{m_2}R_c$$

$$\therefore A_{V_T} = -g_{m_2}R_c$$

09. Ans: (d)

Sol: $Q_1 \rightarrow$ Act as CC [Ac circuit $\rightarrow$ I$\rightarrow$open]

$Q_1 \rightarrow$ Act as CB



Since for CC $\rightarrow$V01.gain = 1

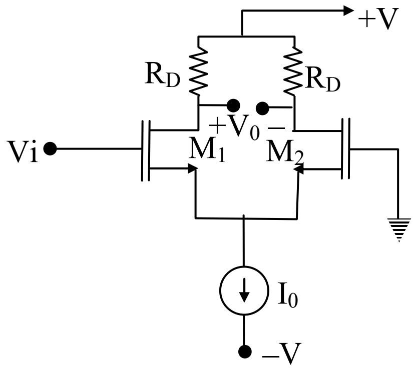
$$\text{For CB} \rightarrow \text{V01.gain} = \frac{R_c}{r_e}$$

$$\therefore Av = 1\frac{R_c}{r_e} = \frac{R_c}{\frac{V_T}{\frac{I_E}{2}}} = \frac{R_c}{2y_e} = \frac{g_mR_c}{2}$$

$$\therefore Av = \frac{g_mR_c}{2}$$

10. Ans: (b)

Sol:



$$\text{For } M_1 \rightarrow V_{01}.\text{gain} = -g_{m_1}\frac{R_0}{2} \Rightarrow g_{m_1}\frac{R_0}{2}V_i$$

$$\text{For } M_1\text{–}M_2 \rightarrow V_{01}.\text{gain} = +1\times+\frac{g_mR_0}{2}$$

$$= +\frac{g_mR_D}{2}$$

$$\Rightarrow V_{D_2} = \frac{g_mR_D}{2}V_i$$

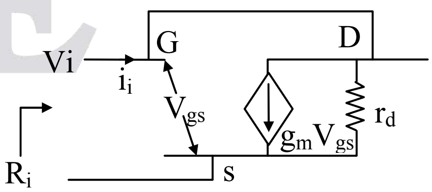
$$\therefore V_0 = V_{D_1} - V_{D_2} = \left[-g_{m_1}\frac{R_D}{2} - g_{m_2}\frac{R_D}{2}\right]V_i$$

$$\Rightarrow \frac{V_0}{V_i} = -g_mR_D$$

$\therefore V_{01}.\text{gain} = -g_mR_D$

11. Ans: (d)

Sol:



$$R_i = \frac{V_i}{i_i}, \text{ where } i_i = g_mV_{gs} + \frac{V_i}{r_d}$$

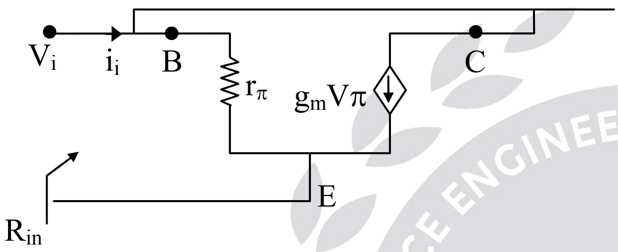
$$i_i = g_m V_i + \frac{V_i}{r_d}$$

$$\therefore R_i = \frac{V_i}{i_i} = \frac{1}{\frac{g_m r_d + 1}{r_d}} = \frac{r_d}{g_m r_d + 1} = \frac{1}{g_m}$$

$$\therefore R_i \frac{r_d}{g_m r_d + 1} = \frac{1}{g_m}$$

12. Ans: (b)

Sol:



$$R_{in} = \frac{V_i}{i_i}$$

Where,

$$i_i = g_m V_\pi + \frac{V_\pi}{r_\pi}$$

$$\therefore R_{in} = \frac{V_i}{i_i} = \frac{V_i}{V_i\left[g_m + \frac{1}{r\pi}\right]}$$

$$\therefore R_{in} = \frac{1}{g_m + \frac{1}{r_\pi}}$$

$$\therefore R_{in} = r_\pi // \frac{1}{g_m}$$

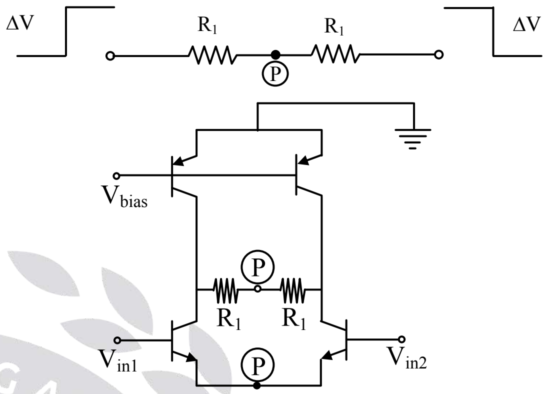
Solutions for Conventional Practice Questions

01.

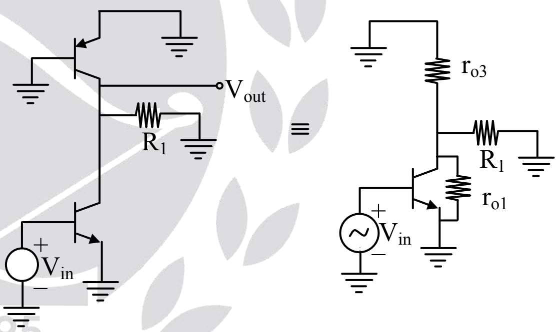
Sol: The differential gain is defined as the difference between the outputs divided by the difference between the input. As such, this gain is equal to the single-ended gain of each half circuit.

The symmetry of the circuits establishes a virtual ground at point "P".

Let us check the axis of symmetry



Single ended stage

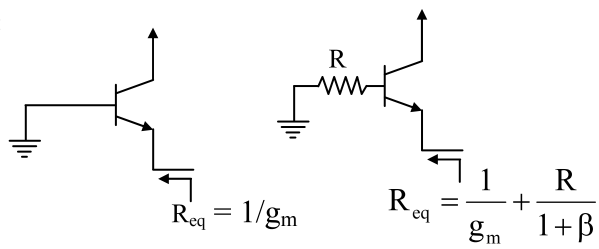


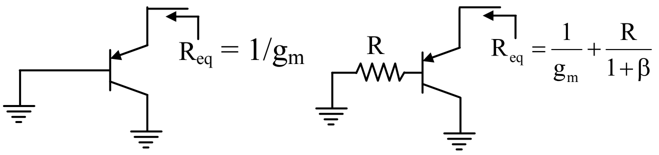
Voltage gain (A_v) = $-g_{m1}R_{out}$

$\rightarrow A_v = -g_{m1}[r_{o1}||r_{o3}||R_1]$

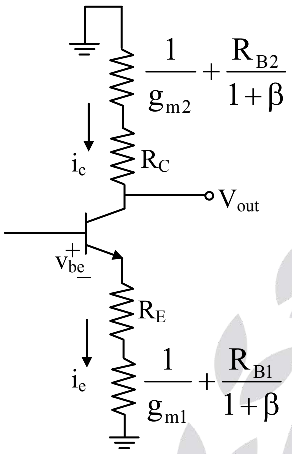
02.

Sol:





The given circuit can be redrawn



$$V_{out} = -i_c\left[R_C + \frac{1}{g_{m2}} + \frac{R_{B2}}{1+\beta}\right]$$

$$V_{in} = V_{be} + i_e\left[R_E + \frac{1}{g_{m1}} + \frac{R_{B1}}{1+\beta}\right]$$

$$A_V = \frac{V_{out}}{V_{in}}$$

$$= \frac{-i_c\left[R_C + \frac{1}{g_{m2}} + \frac{R_{B2}}{1+\beta}\right]}{V_{be} + i_e\left[R_E + \frac{1}{g_{m1}} + \frac{R_{B1}}{1+\beta}\right]}$$

Divide N_r and D_r by i_c

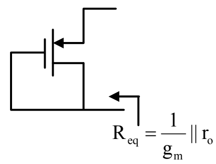
$$A_v = \frac{-\left[R_C + \frac{1}{g_{m2}} + \frac{R_{B2}}{1+\beta}\right]}{g_{m1} + \left(\frac{\beta+1}{\beta}\right)\left[R_E + \frac{1}{g_{m1}} + \frac{R_{B1}}{1+\beta}\right]}$$

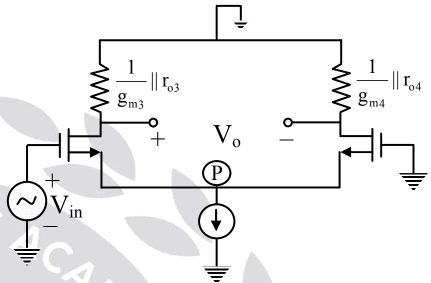
R_{out} = collector resistance

$$= R_C + \frac{1}{g_{m2}} + \frac{R_{B2}}{1+\beta}$$

03.

Sol:





Differential gain (A_d) for full circuit

= Voltage gain (A_v) of single ended circuit

[Assuming symmetry]

$$V_o = -i_d\left[\frac{1}{g_{m3}} \| r_{o3}\right]$$

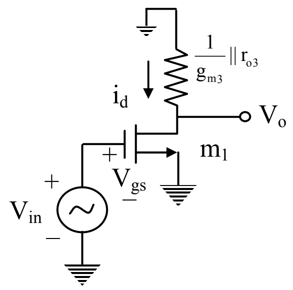
$$V_{in} = V_{gs}$$

$$\frac{V_o}{V_{in}} = A_v = A_d = -\frac{i_d\left[\frac{1}{g_{m3}} \| r_{o3}\right]}{V_{gs}}$$

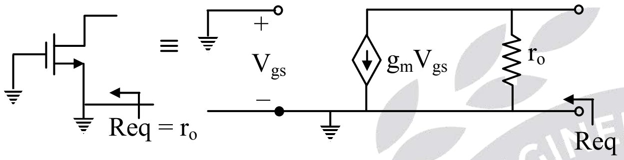
$$A_d = \frac{-\left[\frac{1}{g_{m3}} \| r_{o3}\right]}{\frac{1}{g_{m1}}} = -g_{m1}\left[\frac{1}{g_{m3}} \| r_{o3}\right]$$

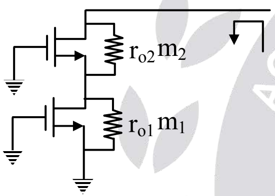
If m_1 transistor also has early effect

Then $A_d = -g_{m1}\left[\frac{1}{g_{m3}} \| r_{o3} \| r_{o1}\right]$



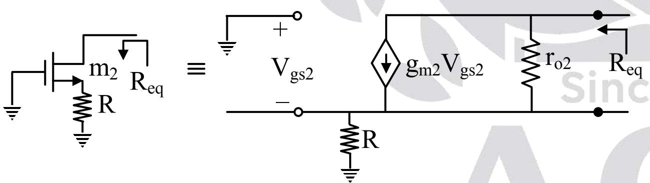
04.
Sol:



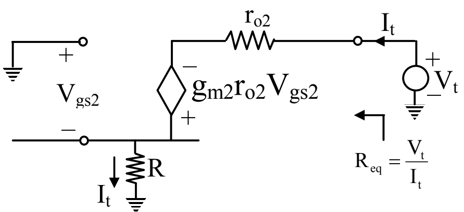


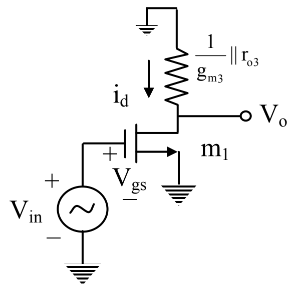
$R_{eq} = r_{o2} + (1 + g_{m2}r_{o2})r_{o1}$

Proof:



The above circuit can be redrawn





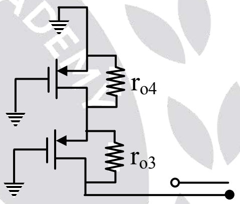
$V_{gs2} + I_tR = 0 \rightarrow V_{gs2} = -I_tR$ ------ (1)

KVL

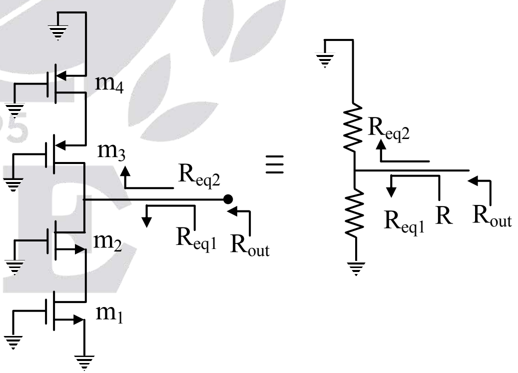
$-V_t + I_t(r_{o2}) - g_{m2}r_{o2}V_{gs2} + I_tR = 0$

$V_t = I_t[r_{o2} + (1 + g_{m2}r_{o2})R]$

$$\frac{V_t}{I_t} = R_{eq} = r_{o2} + (1 + g_{m2}r_{o2})R$$



$R_{eq} = r_{o3} + (1 + g_{m3}r_{o3})r_{o4}$



$R_{out} = R_{eq1} \| R_{eq2}$

Where $R_{eq1} = r_{o2} + (1 + g_{m2}r_{o2})r_{o1}$

$= r_{o2} + r_{o1} + g_{m2}r_{o2}r_{o1}$

$\approx g_{m2}r_{o2}r_{o1}$

$R_{eq2} = r_{o3} + (1+g_{m3}r_{o3})r_{o4}$

$= r_{o3} + r_{o4} + g_{m3}r_{o3}r_{o4}$

$$\approx g_{m3}r_{o3}r_{o4}$$

$R_{out} = R_{eq1}||R_{eq2}$

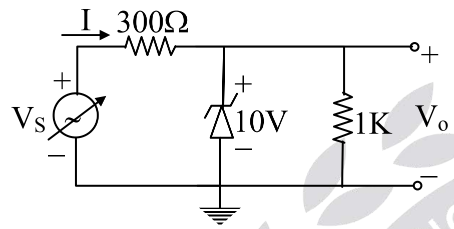
$R_{out} = g_{m2}r_{o2}r_{o1}||g_{m3}r_{o3}r_{o4}$

5. Operational Amplifiers

Solutions for Objective Practice Questions

01. Ans: (d)

Sol:



I_z = 1mA to 60mA

$$I = \frac{V_s - V_z}{300}$$

$$I_{min} = \frac{V_{s\,min} - 10}{300} \quad \text{\_\_\_\_\_\_(I)}$$

$$I_{max} = \frac{V_{smax} - 10}{300} \quad \text{\_\_\_\_\_(II)}$$

$$I_{min} = I_{zmin} + I_L \left[\because I_L + \frac{V_z}{1k} = 10mA\right]$$

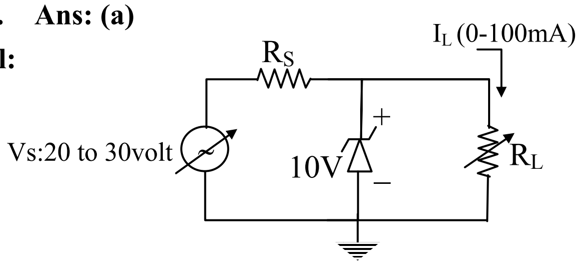
I_{min} = 1mA + 10mA = 11mA

I_{max} = 60mA + 10mA = 70mA

From equation (1) and (2) required range of V_S is 13.3 to 31 volt.

02. Ans: (a)

Sol:



The current in the diode is minimum when the load current is maximum and v_s is minimum.

$$R_s = \frac{V_{s\,min} - V_z}{I_{z\,min} + I_{L\,max}}$$

$$R_s = \frac{20-10}{(10+100)mA}$$

$R_s = 90.9\Omega$

$$I_{z\,max} = \frac{30-10}{90.9} = 0.22A\left[\because I_{L\,min} = 0A\right]$$

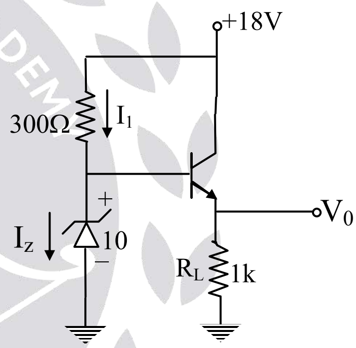
$P_z = V_z\, I_{zmax}$

$P_z = 10 \times 0.22$

$P_z = 2.2W$

03. Ans: (d)

Sol:



V_B = 10volt

V_E = 10 – 0.7 = 9.3volt

I_E = 9.3mA

$$I_B = \frac{I_E}{1+\beta}$$

$$= \frac{9.3mA}{101} = 92.07\mu A$$

$$I_1 = \frac{18-10}{300}$$

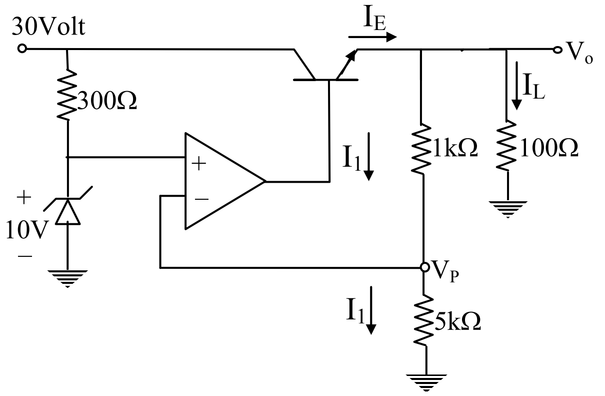
$$= 26.67mA$$

$$I_z = I_1 - I_B = 26.57mA$$

= 26.57

04. Ans: (b)

Sol:



V_p = 10volt

$$I_1 = \frac{10}{5k} = 2mA$$

$\Rightarrow V_0 = (6k)\ I_1 = 12V = V_E$

V_C = 30volt

$\Rightarrow V_{CE} = V_C - V_E = 18$ volt.

$I_E = I_1 + I_L$

$$I_E = 2m + \frac{12}{100} = 122mA$$

$$\Rightarrow I_C = \frac{\beta}{1+\beta} I_E$$

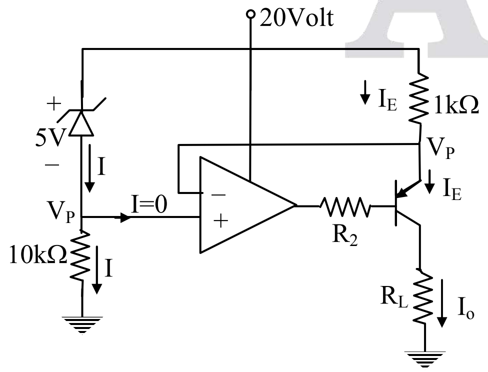
$\Rightarrow I_C = 0.120$Amp

$\Rightarrow P_T = I_C \times V_{CE}$

$\therefore P_T = 2.17W$

05. Ans: (c)

Sol:



$$I = \frac{20-5}{10k} = \frac{15}{10} mA$$

$V_P = 10k \times I = 15$volt

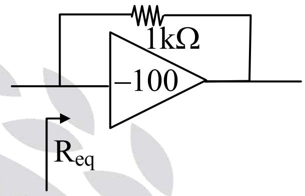
$$I_C = \frac{20 - V_P}{1k} = \frac{20-15}{1k} = 5mA$$

β large $\Rightarrow I_B \approx 0A$

$\therefore I_C = I_0 = 5$Ma

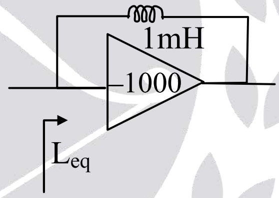
06. Ans: (b)

Sol:



Using millers effect,

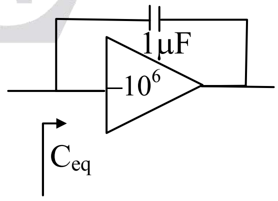
$$R_{eq} = \frac{1k}{1+100} = 9.9\Omega$$



$$L_{eq} = \frac{1mH}{1+1000} \approx 1\mu H$$

07. Ans: (b)

Sol:



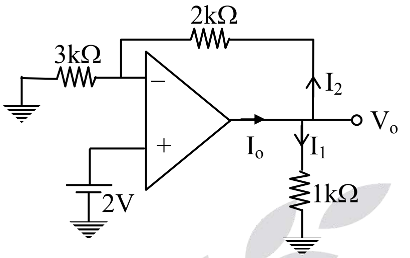
$$C_{eq} = 1\mu F(1+10^6) \approx 1F$$

08. Ans: (d)

Sol: $V_0 = \left(1+\frac{R_f}{R_1}\right)V_i$

$$V_0 = \left(1+\frac{2k}{3k}\right)2$$

$$V_0 = \frac{10}{3}\text{volt}$$



$$I_1 = \frac{V_0}{1k} = \frac{10}{3}\text{mA} \;\&$$

$$I_2 = \frac{V_0 - 2}{2k} = \frac{\frac{10}{3}-2}{2k} = \frac{2}{3}\text{mA}$$

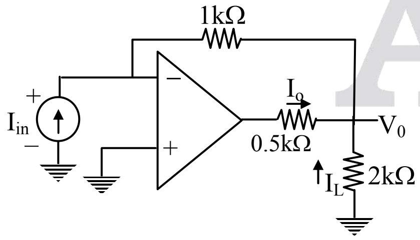
$$\therefore I_0 = I_1 + I_2 = 4\text{mA}$$

09. Ans: (c)

Sol: $V_0 = \frac{-R_2}{R_1}V_{in}$

10. Ans: (c)

Sol:



$V_0 = -I_{in} \times 1K$

$$I_L = \frac{I_i \times 1K}{2K} = \frac{I_{in}}{2}$$

$I_0 + I_{in} + I_L = 0$

$$I_0 + I_{in} + \frac{I_{in}}{2} = 0$$

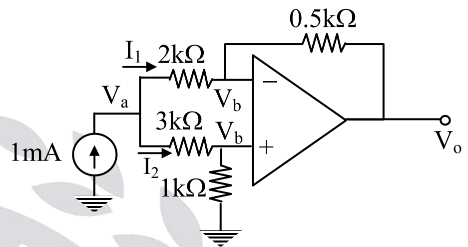
$$2I_0 + 2I_{in} + I_{in} = 0$$

$2I_0 = -3I_{in}$

$$\frac{I_0}{I_{in}} = \frac{-3}{2} = -1.5$$

11. Ans: (a)

Sol:



Apply KCL at V_a:

$$1m = \frac{V_a - V_b}{2k} + \frac{V_a - V_b}{3K}$$

$$1m = \frac{3V_a - 3V_b + 2V_a - 2V_b}{6k}$$

$6 = 5V_a - 5V_b$

$$V_a - V_b = \frac{6}{5}$$

$$V_a - V_b = 1.2\text{Volt}$$

$$I_1 = \frac{V_a - V_b}{2k} = \frac{1.2}{2k} = 0.6\text{mA}$$

$$I_2 = \frac{1.2}{3k} = 0.4\text{mA}$$

$V_b = 0.4m \times 1k = 0.4$ Volt

$$I_1 = \frac{V_b - V_0}{0.5k}$$

$$0.6m = \frac{0.4 - V_0}{0.5k}$$

$0.3 = 0.4 - V_0$

$\therefore V_0 = 0.1$ Volt

12. Ans: (c)

Sol: $V_C = \dfrac{-I}{C}.t = \dfrac{-10\times10^{-3}}{10^{-6}}\times 0.5\times10^{-3}$

$V_C = -5\text{Volt}$

13. Ans: (d)

Sol: Given open loop gain = 10

$$\frac{V_0}{V_i} = \frac{\left(1+\frac{R_f}{R_1}\right)}{1+\left(1+\frac{R_f}{R_1}\right)\times\frac{1}{A_{0L}}}$$

$$\frac{V_0}{V_i} = \frac{(1+3)}{1+\frac{4}{10}}$$

$$V_0 = V_i \times \frac{4}{1+\frac{4}{10}}$$

$$V_0 = \frac{2\times 4}{1+\frac{4}{10}} = 5.715\text{Volt}$$

14. Ans: (c)

Sol:
$$\frac{V_0}{V_i} = \frac{-R_f/R_1}{1+\frac{(1+R_f/R_1)}{A_{OL}}}$$

$$\frac{V_0}{V_i} = \frac{-9}{1+\frac{10}{10}}$$

$$\frac{V_0}{V_i} = \frac{-9}{2}$$

$V_0 = -4.5\text{Volt}$

15. Ans: (c)

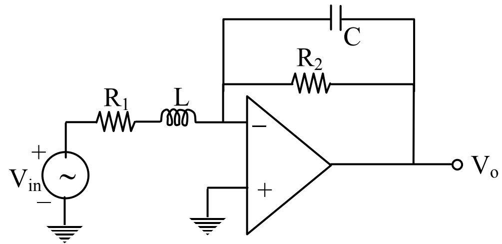
Sol: $SR = 2\pi f_{max} V_{0max}$

$$V_{0\,max} = \frac{SR}{2\pi f_{max}} = \frac{10^6}{2\pi\times 20\times10^3} = 7.95\text{Volt}$$

$$V_0 = A\times V_i \Rightarrow V_i = \frac{V_0}{A} = 79.5\text{mV}$$

16. Ans: (d)

Sol:



$$z_2 = R_2 \| \frac{1}{sC} = \frac{R_2}{sCR_2+1}$$

$z_1 = R_1 + sL$

$$\left|\frac{V_0}{V_i}\right| = \frac{\frac{R_2}{sCR_2+1}}{R_1+sL}$$

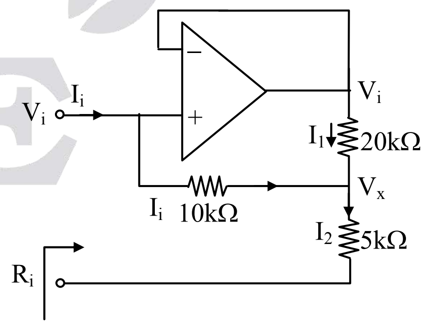
$$\left|\frac{V_0}{V_i}\right| = \frac{R_2}{(sCR_2+1)(R_1+sL)}$$

It represent low pass filter with

D.C gain $= \dfrac{R_2}{R_1}$

17. Ans: (b)

Sol:



Apply KCL at V_x :

$$\frac{V_x}{5k} = I_i + I_1$$

$$\frac{V_x}{5k} = \frac{V_i - V_x}{10k} + \frac{V_i - V_x}{20k}$$

$$\frac{V_x}{5} = \frac{3V_i - 3V_x}{20}$$

$$V_x = \frac{3}{7}V_i$$

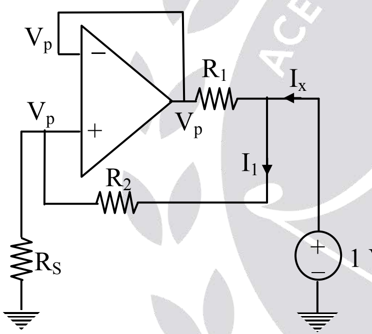
$$I_i = \frac{V_i - V_x}{10k}$$

$$I_i = \frac{V_i - \frac{3}{7}V_i}{10k}$$

$$\frac{V_i}{I_i} = 17.5\,k\Omega$$

18. Ans: (d)

Sol:



$$R_0 = \frac{1}{I_x}$$

$$V_p = \frac{R_s}{R_2 + R_s}$$

$$I_x = \frac{1 - V_p}{R_2} + \frac{1 - V_p}{R_1}$$

$$I_x = (1 - V_p)\left(\frac{1}{R_2} + \frac{1}{R_1}\right)$$

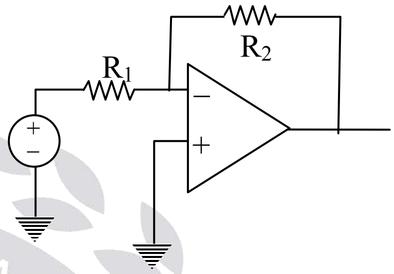
$$I_x = \left(1 - \frac{R_s}{R_2 + R_s}\right)\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

$$I_x = \frac{R_2}{R_2 + R_s}\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

$$\therefore R_0 = \frac{1}{I_x} = \left(\frac{R_s + R_2}{R_1 + R_2}\right)R_1$$

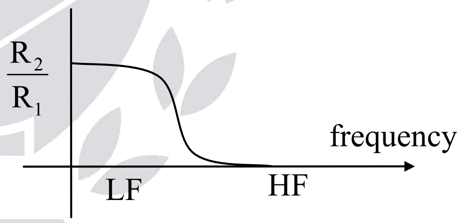
19. Ans: (b)

Sol: At Low frequency capacitor is open



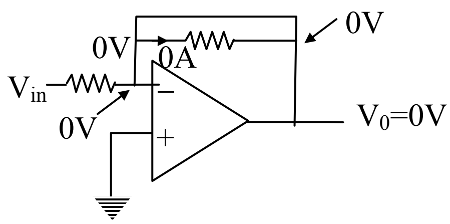
$$V_0 = -\frac{R_2}{R_1} \times V_{in}$$

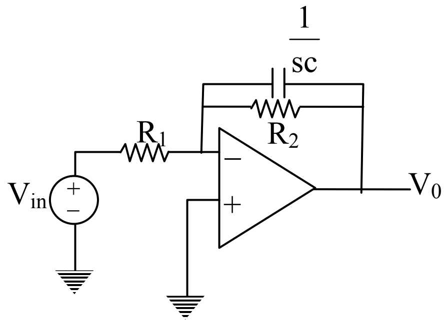
$$\left|\frac{V_0}{V_{in}}\right| = \frac{R_2}{R_1}$$



Low pass filter

At high frequency capacitor is short





$$\frac{R_2 \times \frac{1}{sc}}{R_2 + \frac{1}{sc}} = \frac{R_2}{1+scR_2} = Z_2 \ldots\ldots(1)$$

$$V_0 = -\frac{Z_2}{Z_1} \times V_{in} \ldots\ldots(2)$$

$$V_0 = -\frac{\frac{R_2}{1+sCR_2}}{R_1} \times V_{in} \ldots\ldots(3)$$

$$\left|\frac{V_0}{V_{in}}\right| = \frac{R_2}{R_1} \times \frac{1}{1+sCR_2} \ldots..(4)$$

$$\left|\frac{V_0}{V_{in}}\right| = \frac{\frac{R_2}{R_1}}{\sqrt{1+\omega^2C^2R_2^2}} = \frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+1}} \ldots..(5)$$

$\omega CR_2 = 1$

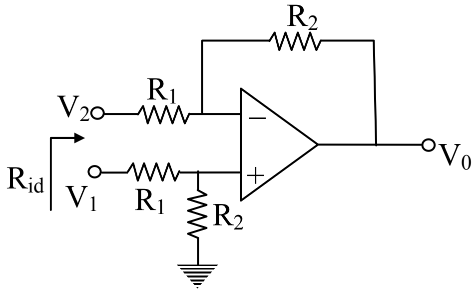
$$\omega = \frac{1}{CR_2}$$

$$\left|\frac{V_0}{V_{in}}\right| = \frac{1}{1+\frac{s}{\omega_{3dB}}}$$

$$\omega_{3dB} = \frac{1}{R_2C}$$

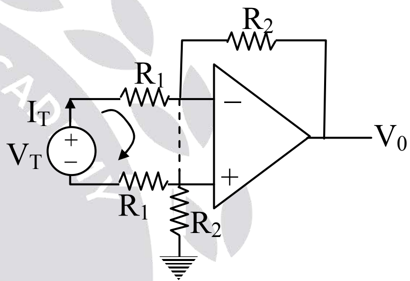
20. Ans: (c)

Sol:



To find input resistance R_{id} (differential input resistance) look from input port.

Connect a voltage source V_T &indicate current I_T from positive terminal of V_T as shown.



Op amp in negative feedback virtual short valid.

Writing KVL $\Rightarrow V_T = I_T R_1 + I_T R_1$

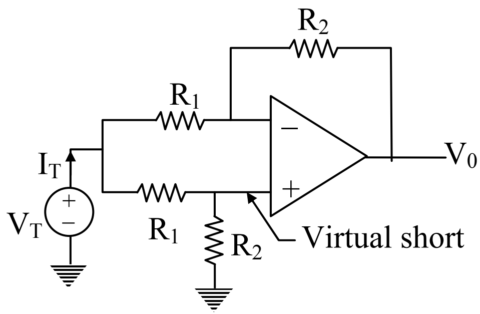
in loop $= 2I_T R_1$

$$\frac{V_T}{I_T} = 2R_1$$

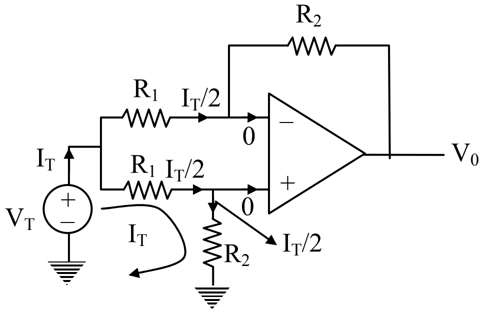
$R_{id} = 2R_1$

21. Ans: (d)

Sol: To find common input resistance (R_{cm}) connect a know voltage source V_T as shown.



Due to virtual short Two R_1 resistors are looking as in parallel



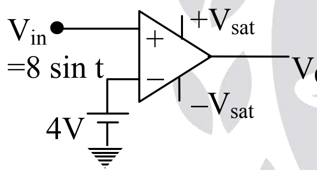
Writing KVL; $V_T = \frac{I_T}{2} \times R_1 + \frac{I_T}{2} \times R_2$

$= \frac{I_T}{2}(R_1 + R_2)$

$\frac{V_T}{I_T} = \frac{R_1 + R_2}{2}$

22. Ans: (c)

Sol:



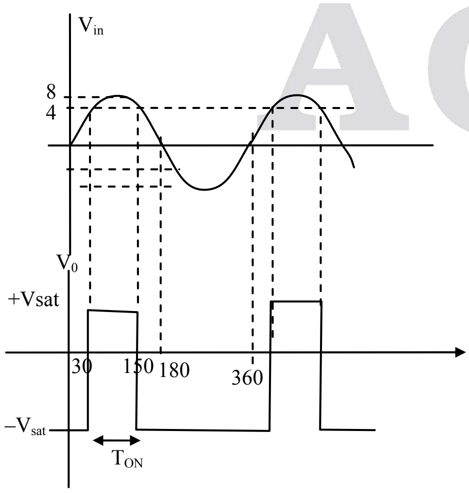
$V_{in} > 4 \Rightarrow V_0 = +V_{sat}$

$V_{in} < 4 \Rightarrow V_0 = -V_{sat}$

$V_{in} = 4 \Rightarrow 4 = 8$ sint

sin t =1/2

t = 30

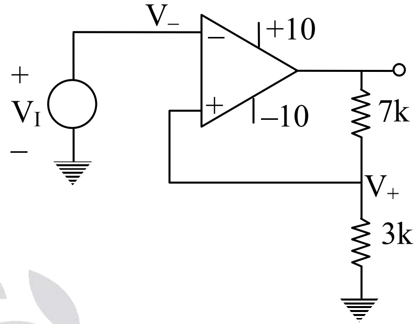


$T_{ON} = 120°$, $T = 360°$

Duty cycle $\frac{T_{ON}}{T} = \frac{120}{360} = \frac{1}{3}$

23. Ans: (c)

Sol:



Case (i) $V_0 = +10$

$V_- = V_I$

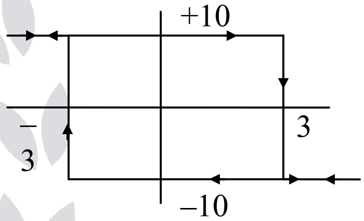
$V_+ = 10 \times \frac{3}{10}$

$= 3$

$V_+ > V_-$

$V_I < 3$

Upper trip point



Case (ii) $V_0 = -10$

$V_- = V_I$

$V_+ = -10 \times \frac{3}{10}$

$= -3$

$V_- > V_+$

$V_I > -3$

Lower Trip point

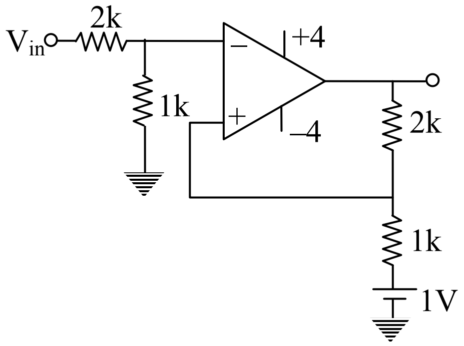
Hysterias is width = UTP – LTP

= 3 – (–3)

= 6V

24. Ans: (d)

Sol:



$$V_- = \frac{V_{in} \times 1}{1+2} = \frac{V_{in}}{3}$$

Case(i) $V_0 = +4$

$$V_- = \frac{V_{in}}{3}$$

$$V_+ = \frac{4\times 1}{1+2} + \frac{1\times 2}{1+2} = \frac{6}{3} = 2$$

(super position)

$V_+ > V_-$

$$2 > \frac{V_{in}}{3}$$

$V_{in} < 6$

Case (ii) $V_0 = -4$

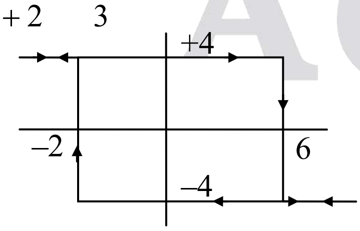
$$V_- = \frac{V_{in}}{3}$$

$$V_+ = \frac{-4\times 1}{1+2} + \frac{1\times 2}{1+2} = \frac{-2}{3}$$

$V_- > V_+$

$$\frac{V_{in}}{3} > \frac{-2}{3}$$

$V_{in} > -2$



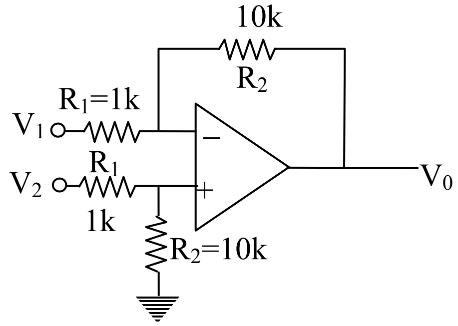
Hysteresis width = UTP – LTP

= 6 – (–2) = 8V

25. Ans: (d)

Sol: $V_1 = 10\sin(2\pi\times 60t) - 0.1\sin(2\pi\times 1000t)$

$V_2 = 10\sin(2\pi\times 60t) + 0.1\sin(2\pi\times 1000t)$



Given circuit is a difference amplifier

$$V_0 = \frac{R_2}{R_1}(V_2 - V_1)$$

$= 10(V_2 - V_1)$

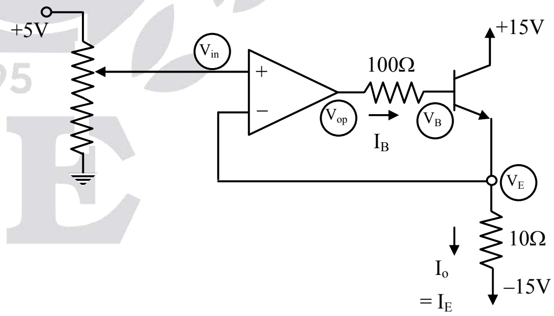
$= 10 \times[2\times 0.1\sin(2\pi \times 1000t)]$

$V_0 = 2\sin(2\pi\times 1000t)$

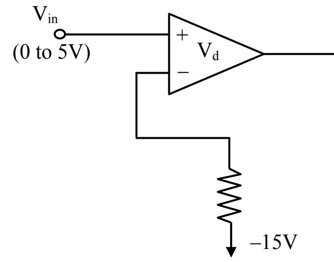
Solutions for Conventional Practice Questions

01.

Sol:



Virtual short is valid only when the base to emitter function is forward biased. It is true only when V_{op} is positive. Let us check.



V_{op} is positive and B-E function is FB

$\therefore$ By virtual short $V_E = V_{in}$

$V_{CE} = V_C - V_E$

$= 15 - V_{in}$

V_{in} range = 0 to 5 V

V_{CE} large = 10V to 15V

As V_{CE} is positive. It means the collector to base function is RB and the transistor is in Active region.

$$I_o = I_E = \left.\frac{V_{in} - (-15)}{10}\right|_{V_{in}=2V} = \frac{2+15}{10}$$

= 1.7 A

$$I_B = \frac{I_E}{\beta+1} = \frac{1.7}{100}$$

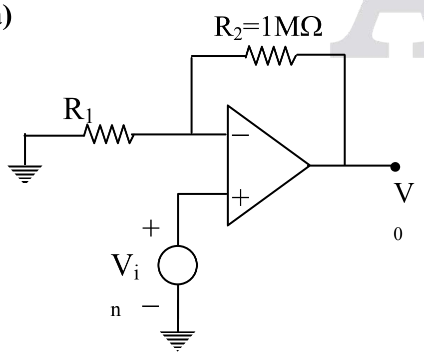
$\rightarrow V_B = V_{in} + 0.7 = 2 + 0.7 = 2.7$ V

$$I_B = \frac{V_{op} - V_B}{100} = \frac{1.7}{100}$$

$$\rightarrow \frac{V_{op} - 2.7}{100} = \frac{1.7}{100} \rightarrow V_{op} = 4.4V$$

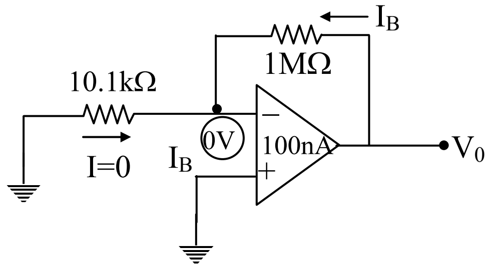
02.

Sol: (a)



$$\text{Gain} = \frac{V_0}{V_{in}} = 1 + \frac{1M}{R_1} = 100$$

$\Rightarrow R_1 = 10.1k\Omega$

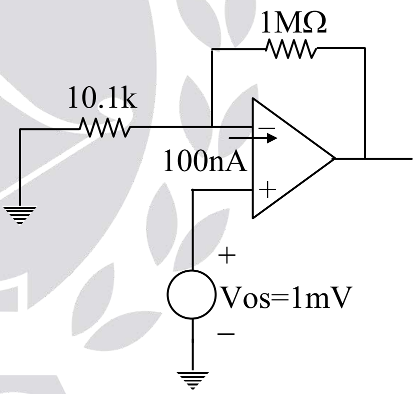


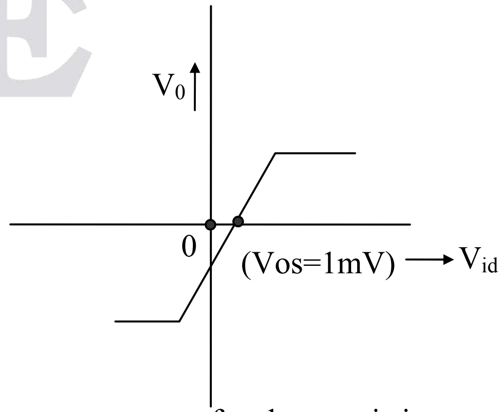
$I_{M\Omega} + I_{K\Omega} = 100nA$

$I_M + 0 = 100nA = I_B$

$V_0 = I_B\,(1M) = 100n(1M) = 0.1V$

(b) $\rightarrow$ op-amp CKT the curve doesn't go through '0' in transfer characteristics





transfer characteristics

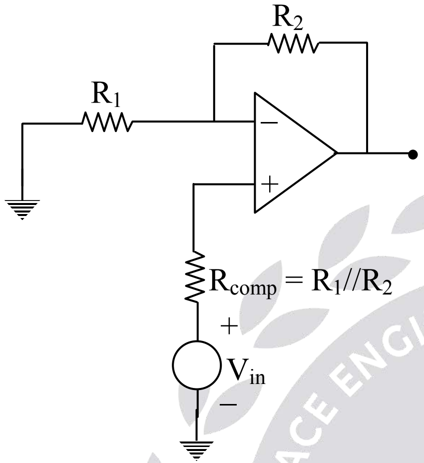
$$V_0 = \left|V_{0_{\text{Bias current}}}\right| + \left|V_{0_{\text{Offset Voltage}}}\right|$$

$$= 1M(I_B) + \left(1 + \frac{R_2}{R_1}\right)V_{os}$$

$= 1M\ (100nA) + 100(1mV)$

$= 0.2V$

(c)



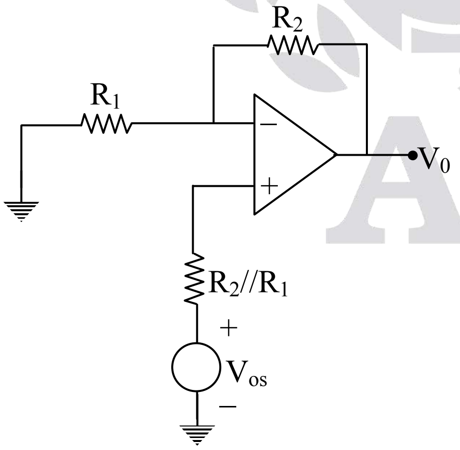
$\rightarrow R_{comp} = R_1//R_2$, then $V_0 = (I_{B1} - I_{B2})\ R_2 = I_{os}\ R_2$

$V_0 = (I_{B1} - I_{B2})\ R_2 = I_{os}$

$R_2 = 1/10\ (I_B R_2) = \frac{1}{10} 100nA(1M)$

$= 0.01V$

(d)

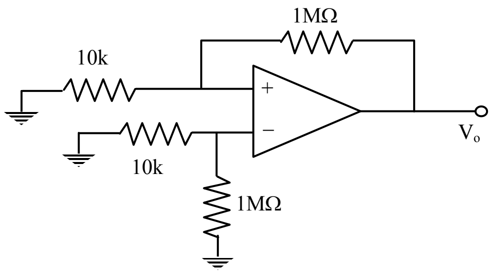


$$V_0 = \left|V_{0_{\text{Offset Voltage}}}\right| + \left|V_{0_{\text{Bias current}}}\right| = 0.1 + 0.01$$

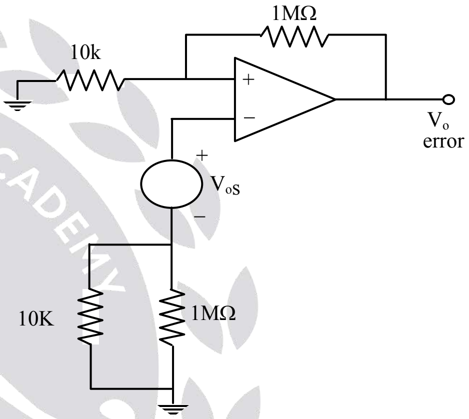
$= 0.11$

03.

Sol:



Calculation of $V_{o_{\text{error}}}$ due to V_{os} and I_{os}



$$V_{o_{\text{error}}} = \left[1 + \frac{1M}{10k}\right]V_{os} + I_{os}[1M\Omega]$$

$$= \left[1 + \frac{10^6}{10^4}\right]4m + 50nA(1M\Omega) = 0.454V$$

04.

Sol: **(i)** If the circuit has to oscillate and generate a sine wave, it should simulate a 2nd order differential equation(two pole system). This is possible by a minimum of two RC networks or one LC Network if op-amp open loop gain is real. In the problem given, op-amp is a single pole system. So with a single capacitor externally connected, it should sustain a sine wave when the loop gain is equal to one [Barkhausen's criterion]

If a circuit has to oscillate, loop gain = 1

$$\frac{V_f}{V_0}\cdot\frac{V_x}{V_f}\cdot\frac{V_0}{V_x}=1$$

$$V_f=\frac{V_0R_1}{R_1+R_2}$$

$$\frac{V_f}{V_0}=\frac{R_1}{R_1+R_2}$$

$$V_x=\frac{V_0\left(\frac{1}{sC_0}\right)}{R_0+\frac{1}{sC_0}}=\frac{V_0}{1+sC_0R_0}$$

$$\frac{V_0}{V_x}=1+sC_0R_0$$

$$V_f-V_x=V_d=\frac{V_0}{A},$$

$$\frac{V_f}{V_f}-\frac{V_x}{V_f}=\frac{V_0}{V_f\times A}$$

$$1-\frac{V_x}{V_f}=\frac{\left(1+\frac{R_2}{R_1}\right)}{A}$$

$$\frac{V_x}{V_f}=1-\frac{\left(1+\frac{R_2}{R_1}\right)}{A}$$

$$\frac{V_x}{V_f}=1-\frac{\left(1+\frac{R_2}{R_1}\right)s}{\omega_1}$$

$$\frac{V_f}{V_0}\cdot\frac{V_x}{V_f}\cdot\frac{V_0}{V_x}=1$$

$$\left(\frac{R_1}{R_1+R_2}\right)\left[1-\frac{s(R_1+R_2)}{R_1\omega_1}\right][1+sC_0R_0]=1$$

$$\frac{R_1}{R_1+R_2}\left[1+sC_0R_0-\frac{s(R_1+R_2)}{R_1\omega_1}-\frac{s^2C_0R_0(R_1+R_2)}{R_1\omega_1}\right]=1$$

Put s = jω and equate real and imaginary parts on both sides Equate imaginary parts

$$s\left[C_0R_0-\frac{R_1+R_2}{R_1\omega_1}\right]=0$$

$$\left[\frac{R_1+R_2}{R_1\omega_1}\right]=C_0R_0$$

$$\omega_1=\frac{\left(1+\frac{R_2}{R_1}\right)}{C_0R_0}$$

Equate real parts

$$\left(\frac{R_1}{R_1+R_2}\right)\left[1+\frac{\omega^2C_0R_0(R_1+R_2)}{R_1\omega_1}\right]=1$$

$$\omega^2=\frac{\omega_1}{C_0R_0\left(1+\frac{R_2}{R_1}\right)}\cdot\frac{R_2}{R_1}=\frac{\frac{\left(1+\frac{R_2}{R_1}\right)}{C_0R_0}}{C_0R_0\left[1+\frac{R_2}{R_1}\right]}\cdot\frac{R_2}{R_1}$$

$$\omega^2C_0^2R_0^2=1+\frac{R_2}{R_1}-1$$

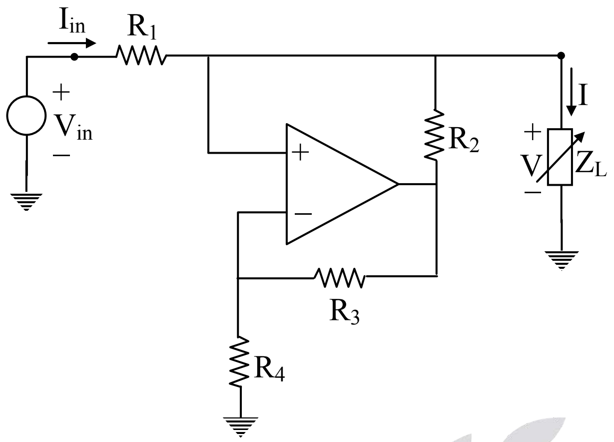
$$\omega_0=\frac{\sqrt{\frac{R_2}{R_1}}}{C_0R_0}$$

(ii) $$\omega_1=\frac{\left(1+\frac{R_2}{R_1}\right)}{C_0R_0}=\frac{\left(1+\frac{9K}{1K}\right)}{0.1\mu F(10K)}=10K\text{ rad/sec}$$

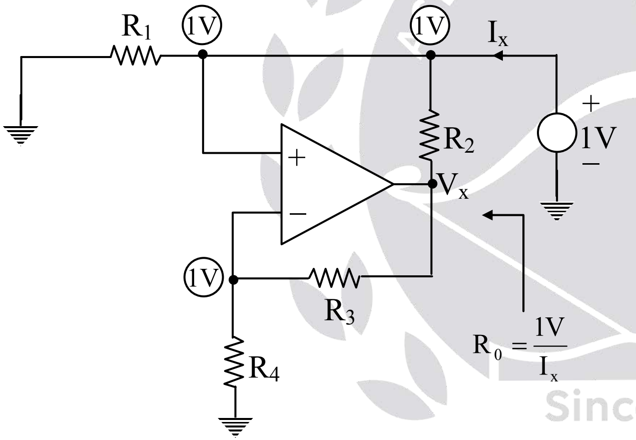
$$\omega_0=\frac{\sqrt{\frac{R_2}{R_1}}}{C_0R_0}=\frac{\sqrt{\frac{9K}{1K}}}{0.1\mu F.10K}=3K\text{ rad/sec}$$

05.

Sol:



While calculating the output resistance short circuit the input voltage and apply 1V source at output.



$$1 = \frac{V_x R_y}{R_3 + R_4}$$

$$V_x = 1 + \frac{R_3}{R_4} \quad \text{------(1)}$$

$$I_x = \frac{1 - V_x}{R_2} + 1/R_1 \text{-----(2)}$$

Substitute eq(1) in eq(2)

$$= \frac{1 - \left[1 + \frac{R_3}{R_4}\right]}{R_2} + 1/R_1$$

For output current to be independent of output voltage, the circuit should be a current source(with grounded load) with $R_0 = \infty$ (ideal)

$\rightarrow I_x = 0$

$$\therefore 0 = \frac{-R_3}{R_4 R_2} + \frac{1}{R_1}$$

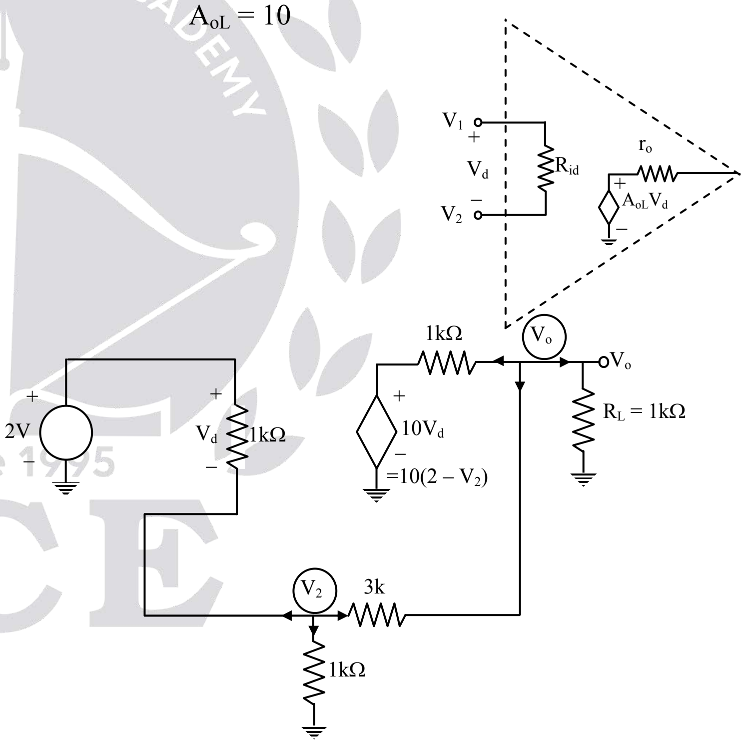
$$\rightarrow R_2 R_4 = R_1 R_3$$

06.

Sol: Given $R_{id} = 1k\Omega$

$r_o = 1k\Omega$

$A_{oL} = 10$



KCL

$$\frac{V_2 - 2}{1k} + \frac{V_2}{1k} + \frac{V_2 - V_o}{3k} = 0$$

$$\rightarrow V_2\left[\frac{1}{1k}+\frac{1}{1k}+\frac{1}{3k}\right]+V_o\left[\frac{-1}{3k}\right]=\frac{2}{1k}$$

$$\rightarrow V_2\left[\frac{3+3+1}{3k}\right]+V_o\left[\frac{-1}{3k}\right]=\frac{6}{3k}$$

$$\rightarrow V_2\,[7] + V_o[-1] = 6 \text{ ----(1)}$$

KCL

$$\frac{V_o-(20-10V_2)}{1k}+\frac{V_o-V_2}{3k}+\frac{V_o}{1k}=0$$

$$V_o\left[\frac{1}{1k}+\frac{1}{3k}+\frac{1}{1k}\right]+V_2\left[\frac{10}{1k}-\frac{1}{3k}\right]=\frac{20}{1k}$$

$$V_o\left[\frac{3+1+3}{3k}\right]+V_2\left[\frac{30-1}{3k}\right]=\frac{60}{3k}$$

$7V_o + 29V_2 = 60$ ----(2)

$-\ V_o\ +\ 7V_2\ =\ 6$ ----(1)

[multiply by 7]

$-7V_o + 49V_2 = 42$

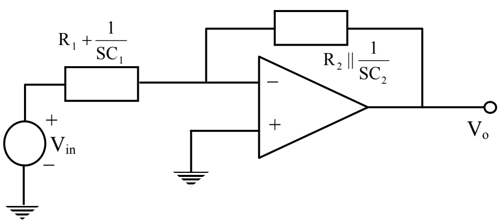
$78V_2 = 102 \rightarrow$

$$V_2=\frac{102}{78}=1.307$$

$$\rightarrow V_o=\frac{60-29V_2}{7}=3.15V$$

07.

Sol: The given filler is a bandpass filter with lower cutoff frequency (f_L) = 20 Hz and upper cutoff frequency (f_H) = 20 kHz with a gain = 20 dB = 10



$$\frac{V_o(S)}{V_{in}(S)}=\frac{-\left[\dfrac{R_2.\frac{1}{SC_2}}{R_2+\frac{1}{SC_2}}\right]}{R_1+\dfrac{1}{SC_1}}=\frac{-\left[\dfrac{R_2}{1+SC_2R_2}\right]}{\left(\dfrac{1+SC_1R_1}{SC_1}\right)}$$

$$\frac{V_o(S)}{V_{in}(S)}=\frac{-SC_1R_2}{(1+SC_2R_2)(1+SC_1R_1)}$$

$$=\frac{-R_2}{R_1}\frac{SC_1R_1}{(1+SC_2R_2)(1+SC_1R_1)}$$

$$=\frac{-R_2}{R_1}\frac{j\omega C_1R_1}{(1+j\omega C_2R_2)(1+j\omega C_1R_1)}$$

$$\frac{V_o}{V_{in}}=\frac{-R_2}{R_1}\frac{-\left(j\frac{\omega}{\omega_L}\right)}{\left(1+j\frac{\omega}{\omega_L}\right)\left(1+j\frac{\omega}{\omega_H}\right)}$$

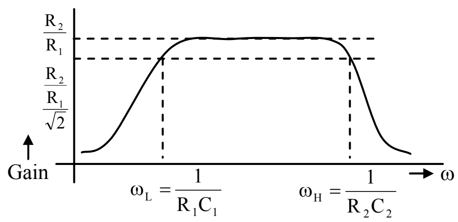
Given $\omega_H >> \omega_L$

At

$$\omega=\omega_L \rightarrow \left|\frac{V_o}{V_{in}}\right|=\frac{\frac{R_2}{R_1}\left(j\frac{\omega_L}{\omega_L}\right)}{\left(1+j\frac{\omega_L}{\omega_L}\right)\left(1+j\frac{\omega_L}{\omega_H}\right)}=\frac{\frac{R_2}{R_1}}{\sqrt{2}}$$

At

$$\omega=\omega_H \rightarrow \left|\frac{V_o}{V_{in}}\right|=\frac{\frac{R_2}{R_1}\left(j\frac{\omega_H}{\omega_L}\right)}{\left(1+j\frac{\omega_H}{\omega_L}\right)\left(1+j\frac{\omega_H}{\omega_H}\right)}=\frac{\frac{R_2}{R_1}}{\sqrt{2}}$$



08.

Sol: **O**p-amp gain is 60 dB = 1000 at

f = 10 kHz

$\therefore$ unity gain freq (f_t) = Gain .BW

= 1000. 10k

= 10^7 Hz

(a) DC gain = 120 dB = 10^6

$\therefore$ f_t = DC gain f_{3db}

$\rightarrow 10^7 = 10^6, f_{3db} \rightarrow f_{3db} = 10$ Hz

(b) unity gain freq (f_t) = 10^7 Hz

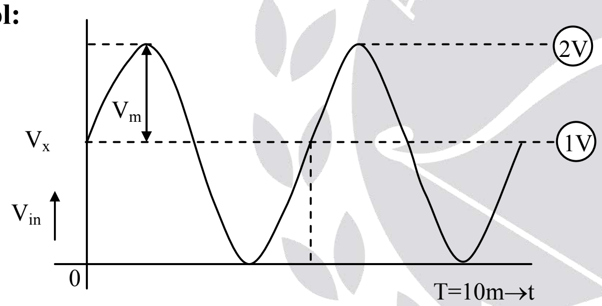
(c) f_t = Gain .(1KHz)

$\rightarrow 10^7 = \text{gain} .10^3 \rightarrow \text{Gain} = 10^4$

$\rightarrow$ Gain = 80 dB

09.

Sol:



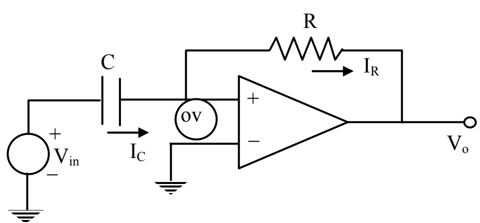
$V_{in} = V_m \sin\omega t + V_{DC}$

$= V_m \text{Sin} 2\pi f t + V_{DC}$

$$= V_m \sin\frac{2\pi}{T}t + V_{DC}$$

$$= 1\sin\frac{2\pi}{10m}t + 1$$

$= 1 + \sin 200\pi t$



$I_C = I_R$

$$\frac{CdV_c}{dt} = \frac{0 - V_o}{R}$$

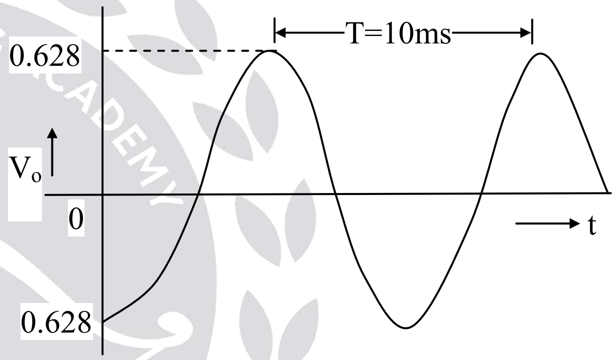
$$\frac{CdV_{in}}{dt} = \frac{-V_o}{R} \rightarrow V_o = -RC\frac{dV_{in}}{dt}$$

$$\left.\begin{matrix} R = 100k \\ C = 10nF \end{matrix}\right\} RC = 10^5.10^{-8} = 1m\sec$$

$$V_o = -1m\frac{d}{dt}(1 + \sin 200\pi t)$$

$= -1m\ 200\pi \cos 200\pi t$

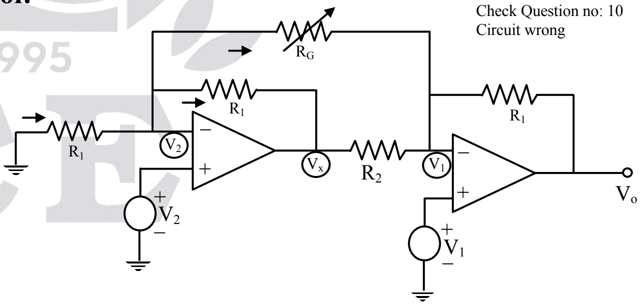
$V_o = -\ 0.628 \cos 200\pi t$ (V)



10.

Sol:

Check Question no: 10
Circuit wrong



KCL

$$\frac{0 - V_2}{R_1} = \frac{V_2 - V_x}{R_2} + \frac{V_2 - V_1}{R_G}$$

$$\rightarrow \frac{V_x}{R_2} = \frac{V_2 - V_1}{R_G} + V_2\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

$$\frac{V_x}{R_2} = V_2\left[\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_G}\right]+V_1\left[\frac{-1}{R_G}\right] \text{---(1)}$$

KCL

$$\frac{V_x - V_1}{R_2} = \frac{V_1 - V_2}{R_G} + \frac{V_1 - V_o}{R_1}$$

$$\frac{V_x}{R_2} = V_1\left[\frac{1}{R_G}+\frac{1}{R_1}+\frac{1}{R_2}\right]+V_2\left[\frac{-1}{R_G}\right]+V_o\left[\frac{-1}{R_1}\right] \text{---}$$

(2)

(1) = (2)

$$V_2\left[\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_G}\right]+V_1\left[\frac{-1}{R_G}\right]$$

$$= V_1\left[\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_G}\right]+V_2\left[\frac{-1}{R_G}\right]+V_o\left[\frac{-1}{R_1}\right] \text{---(2)}$$

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

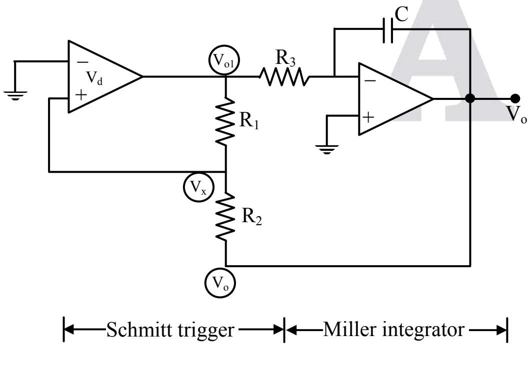
$$V_o = \left[1+\frac{R_1}{R_2}+\frac{2R_1}{R_G}\right][V_1 - V_2]$$

Differential gain

$$(A_d) = \frac{V_o}{V_d} = \frac{V_o}{V_1 - V_2} = 1+\frac{R_1}{R_2}+\frac{2R_1}{R_G}$$

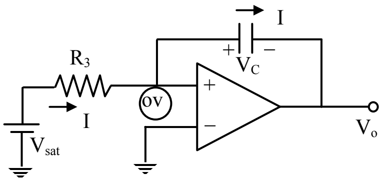
11.

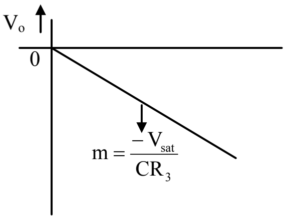
Sol:



A triangular wave generator is designed using a Schmitt trigger and miller integrator

Operation of miller integrator





$$I = \frac{V_{sat} - 0}{R_3} = \frac{V_{sat}}{R_3}$$

$$V_C = \frac{1}{C}\int I dt = \left(\frac{I}{C}\right)t = \left(\frac{V_{sat}}{CR_3}\right)t$$

$$V_o = -V_C$$

$$V_o = \left(\frac{V_{sat}}{CR_3}\right)t \rightarrow y = mx$$

Operation of Schmitt trigger

Case 1.

Let $V_{o1} = +V_{sat} \rightarrow V_o = \left(\frac{-V_{sat}}{CR_3}\right)t$

KCL $\quad \frac{V_{o1} - V_x}{R_1} = \frac{V_x - V_o}{R_2} \rightarrow \text{If } V_x = 0$

$$\rightarrow V_o = \frac{-R_2 V_{o1}}{R_1}$$

If $V_x < 0$ then $V_d < 0$

$\rightarrow$ If $V_o < \frac{-R_2 V_{o1}}{R_1}$ (or) If $V_o < \frac{-R_2 V_{sat}}{R_1}$ then

$V_d < 0$ so V_{o1} switches from $+V_{sat}$ to $-V_{sat}$

Case 2:

Let $V_{o1} = -V_{sat} \rightarrow V_o = \left(\frac{+V_{sat}}{CR_3}\right)t$

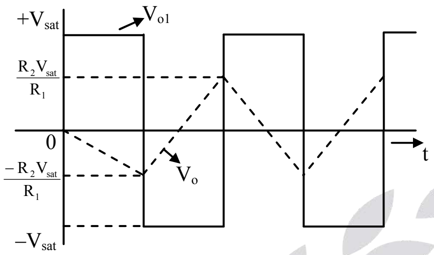
KCL $\quad \frac{V_{o1} - V_x}{R_1} = \frac{V_x - V_o}{R_2}$

$\rightarrow$ If $V_x = 0 \rightarrow V_o = \dfrac{-R_2V_{o1}}{R_2}$

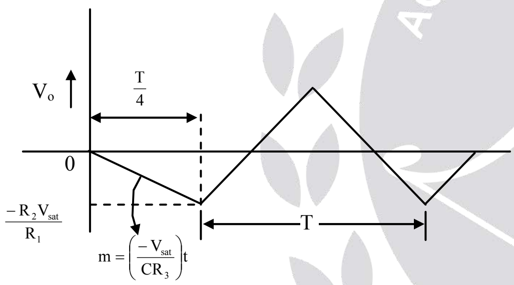
If $V_x > 0$ then V_{o1} switch from $-V_{sat}$ to $+V_{sat}$

$$\rightarrow V_o > \frac{-R_2V_{o1}}{R_2} \text{(or)} V_o > \frac{R_2V_{sat}}{R_1} \text{ for } V_{o1}$$

To switch from $-V_{sat}$ to $+V_{sat}$



Calculation of Time period and frequency of triangular wave



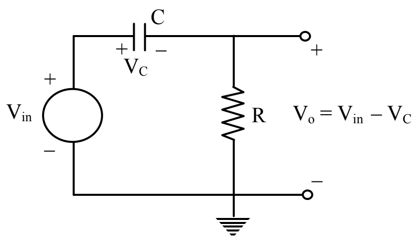
$$Y = mx$$

$$\frac{-R_2V_{sat}}{R_1} = \left[\frac{-V_{sat}}{CR_3}\right]\left[\frac{T}{4}\right]$$

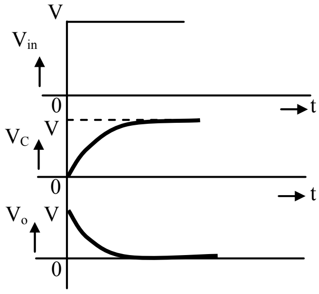
$$T = \frac{4R_2R_3C}{R_1} \rightarrow f = \frac{R_1}{4R_2R_3C}$$

12.

Sol:

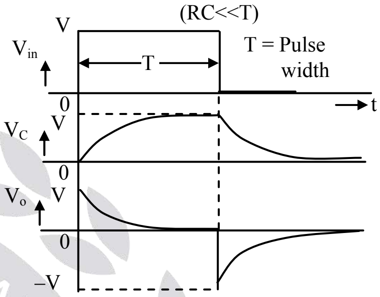


V_{in} is a step input



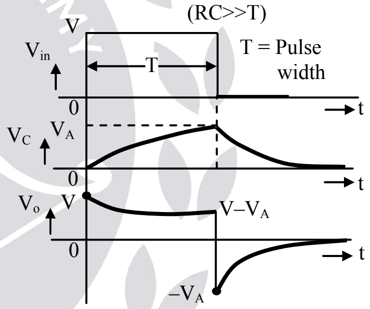
V_{in} is a pulse input

(RC<<T)

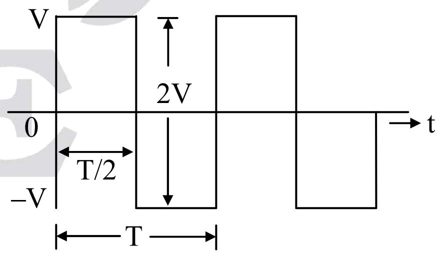


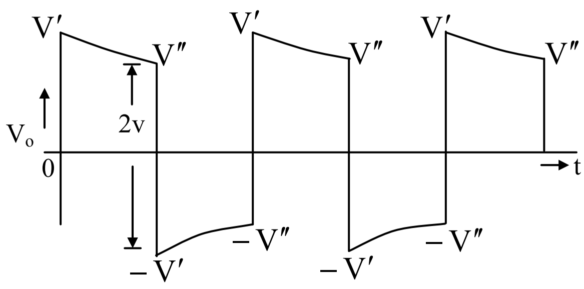
V_{in} is a pulse input

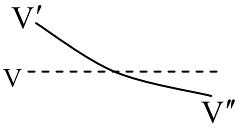
(RC>>T)



V_{in} is a square wave input (RC >> T)







$$\%\text{tilt} = \frac{V' - V''}{2V} \times 100\,\%$$

$$V'' = V' e^{-t/RC} \qquad t = T/2$$

$$\rightarrow V'' = V' e^{-T/2RC} \text{ ---(1)}$$

RC >> T

$$V'' - (-V') = 2V$$

$$\rightarrow V' + V'' = 2V \text{ ---(2)}$$

Sub (1) in (2)

$$V' + V' e^{-T/2RC} = 2V$$

$$V' = \frac{2V}{1 + e^{-T/2RC}} \text{ ----(4)}$$

From (1) $V' = \dfrac{V''}{e^{-T/2RC}} = V'' e^{T/2RC}$ ----(3)

Sub (3) in (2)

$$V'' e^{T/2RC} + V'' = 2V$$

$$V'' = \frac{2V}{1 + e^{T/2RC}} \text{ ---(5)}$$

$$1 + e^{-T/2RC} = 1 + 1 - \frac{T}{2RC}$$

$$= 2 - \frac{T}{2RC} = 2\left[1 - \frac{T}{2RC}\right]$$

$$\therefore \frac{2V}{1 + e^{-T/2RC}} = \frac{2V}{2\left[1 - \frac{T}{2RC}\right]}$$

$$= \frac{2V\left[1 + \frac{T}{4RC}\right]}{2} = V\left[1 + \frac{T}{4RC}\right]$$

$$\|_y \quad \frac{2V}{1 + e^{\frac{T}{2RC}}} = \frac{2V}{1 + 1 + \frac{T}{2RC}}$$

$$= \frac{2V}{2\left[1 + \frac{T}{4RC}\right]}$$

$$= V\left[1 - \frac{T}{4RC}\right]$$

$$\%\text{tilt} = \frac{V' - V''}{2V} \times 100\%$$

$$= \frac{V\left[1 + \frac{T}{4RC}\right] - V\left[1 - \frac{T}{4RC}\right]}{2V} \times 100\%$$

$$= \frac{T}{4RC} \times 100\%$$

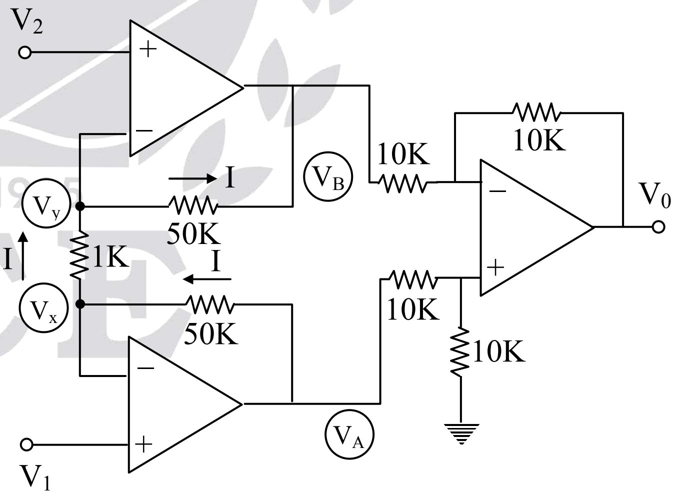
13.

Sol: Given $V_{cm} = 3V$

$V_d = 10\sin\omega t$ (mV)

$V_1 = V_{cm} + V_d / 2 = 3 + 5\sin\omega t$ (mV)

$V_2 = V_{cm} - V_d / 2 = 3 - 5\sin\omega t$ (mV)



$V_x = V_1 = 3 + 5\sin\omega t$

$V_y = V_2 = 3 - 5\sin\omega t$

$$I = \frac{V_x - V_y}{1k} = \frac{V_A - V_x}{50k}$$

$$\frac{10\sin\omega t}{1k} = \frac{V_A - [3 + 5\sin\omega t]}{50k}$$

$\rightarrow V_A = 3 + 505\ \sin\omega t$

$$I = \frac{V_y - V_B}{50k} = \frac{V_x - V_y}{1k}$$

$V_y - V_B = [10\ \sin\omega t]50$

$\rightarrow V_B = 3 - 505\ \sin\omega t$

$$V_0 = \frac{10K}{10K}(V_A - V_B)$$

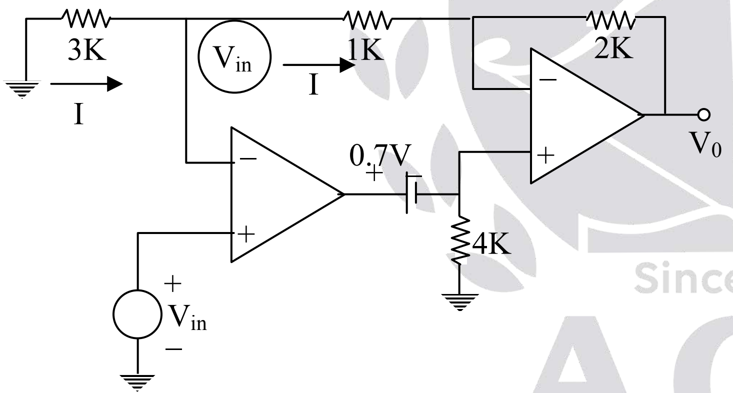
$= 1010\ \sin\omega t\ (mV)$

$= 1.01\ \sin\omega t\ (V)$

14.

Sol: Case 1:

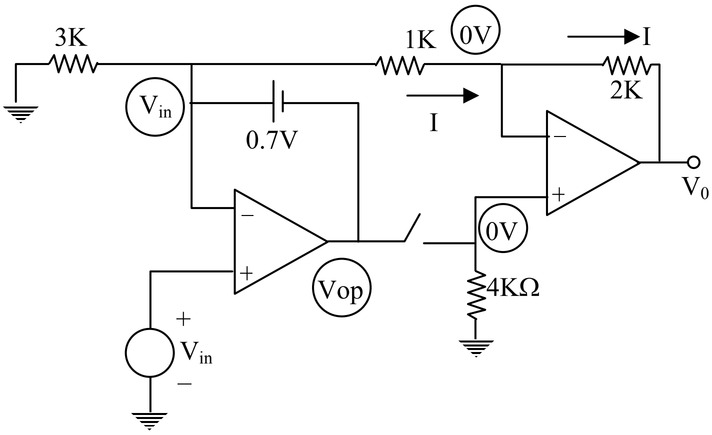
If V_{in} positive then output of first op-amp is positive. Therefore D_1 is RB and D_2 is FB



$$I = \frac{0 - V_{in}}{3K} = \frac{V_{in} - V_0}{1K + 2K}$$

$\Rightarrow\ V_0 = 2\ V_{in}$

Case 2: If V_{in} is negative then output of first op-amp is negative. Therefore D_1 is FB, D_2 is RB



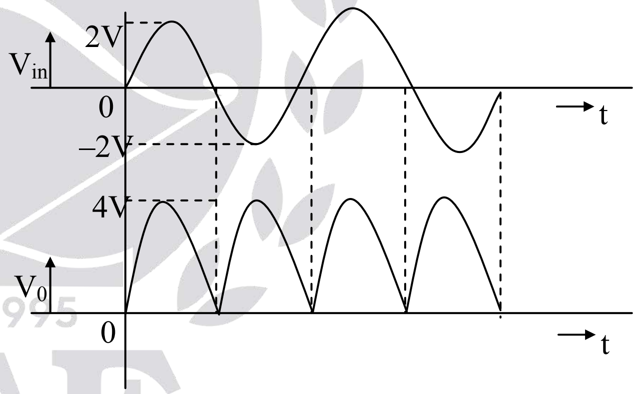
KCL at the inverting terminal of second op-amp:

$$\frac{V_{in} - 0}{1K} = \frac{0 - V_0}{2K}$$

$\Rightarrow\quad V_0 = -2\ V_{in}$

V_{in} Pos $\rightarrow V_0 = 2\ V_{in}$

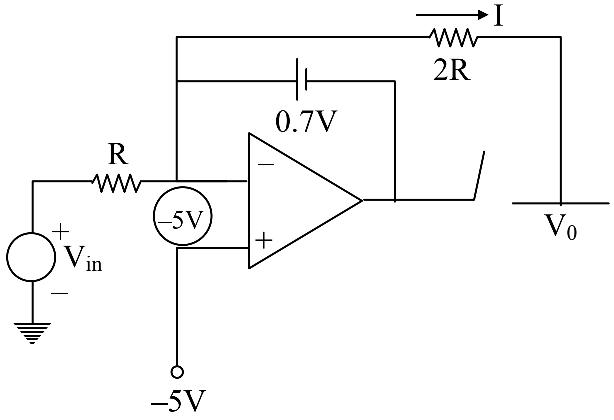
V_{in} Neg $\rightarrow V_0 = -2\ V_{in}$



15.

Sol: Case 1: $V_{in} > -5V \rightarrow$ Output of op-amp is negative

Therefore D_1 FB, D_2 RB



By virtual short

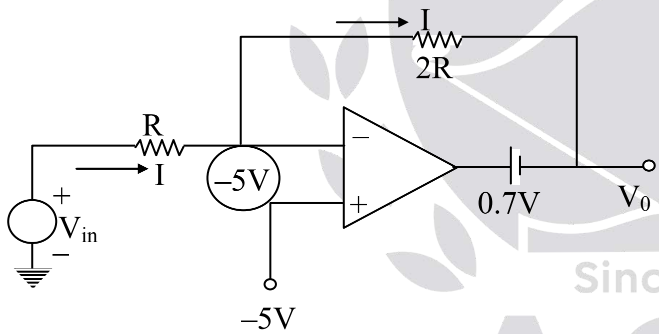
$V_+ = V_- = -5V$

$\therefore \quad V_0 = -5 - I(2R)$

$\rightarrow \quad V_0 = -5$ [As I = 0 in open circuit]

Case 2: $V_{in} < -5V \rightarrow$ Output of op-amp is positive

Therefore D_1 RB, D_2 FB

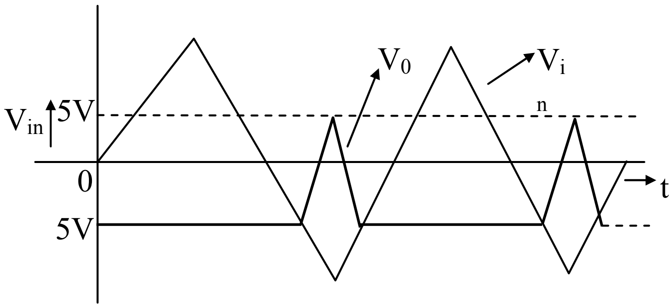


KCL

$$\frac{V_{in}-(-5)}{R} = \frac{-5-V_0}{2R}$$

$2V_{in} + 10 = -5 - V_0$

$V_0 = -(2\, V_{in} + 15)$



06. Feedback Amplifiers & Oscillators

Solutions for Objective Practice Questions

01. Ans: (b)

Sol: Given $\beta = \frac{1}{6}$

$A = 1 + \frac{R_2}{R_1}$

$A\beta = 1$ for sustained oscillations

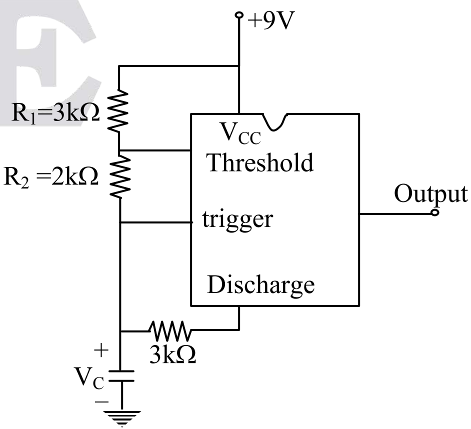
$\left(1+\frac{R_2}{R_1}\right).\frac{1}{6} = 1$

$\frac{R_2}{R_1} = 5$

$R_2 = 5\, R_1$

02. Ans: (c)

Sol:



$V_{th} = \frac{2}{3}V_{CC} = \frac{2}{3}\times 9 = 6\text{ V}$

$V_{th} - V_C = 2\times10^3\times I \qquad \left(I = \frac{9-6}{3k}\right)$

$V_{th} - V_C = 2\text{ V}$

$V_C = V_{th} - 2 = 4\text{ V}$

$V_{trigger} = \frac{1}{3}V_{CC} = 3\text{ V}$

$V_C = 3\text{ V to } 4\text{ V}$

03. Ans: (b)

Sol: $\omega_0 = \frac{1}{\sqrt{LC}}$

$\frac{V_F}{V_0} = \beta = \frac{0.5k}{R_x + 0.5}$

$A = 1 + \frac{9k}{1k} = 10$

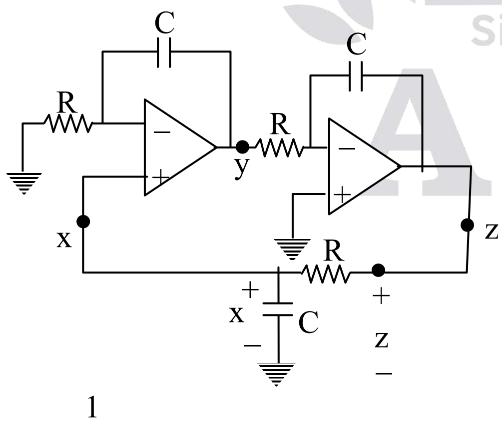
$A\beta = 1$ for sustained oscillations

$\frac{0.5k}{R_x + 0.5k}\times 10 = 1$

$\therefore R_x = 4.5\text{ k}\Omega$

04. Ans: (a)

Sol:



$$\frac{y}{x} = 1 + \frac{\frac{1}{sC}}{R} = 1 + \frac{1}{sCR} = \frac{sCR+1}{sCR} \quad \text{.......(1)}$$

$$\frac{z}{y} = \frac{-\frac{1}{sC}}{R} = \frac{-1}{sCR} \quad \text{.....(2)}$$

$$\frac{x}{z} = \frac{1}{1+sCR} \quad \text{......(3)}$$

For sustained oscillations

Loop Gain $=1 \Rightarrow \frac{y}{x}\times\frac{z}{y}\times\frac{x}{z} = 1$

$$\frac{sCR+1}{sCR}\times\left(\frac{-1}{sCR}\right)\times\frac{1}{1+sCR} = 1$$

$S^2C^2R^2 = -1$

$j^2\,\omega^2C^2R^2 = -1$

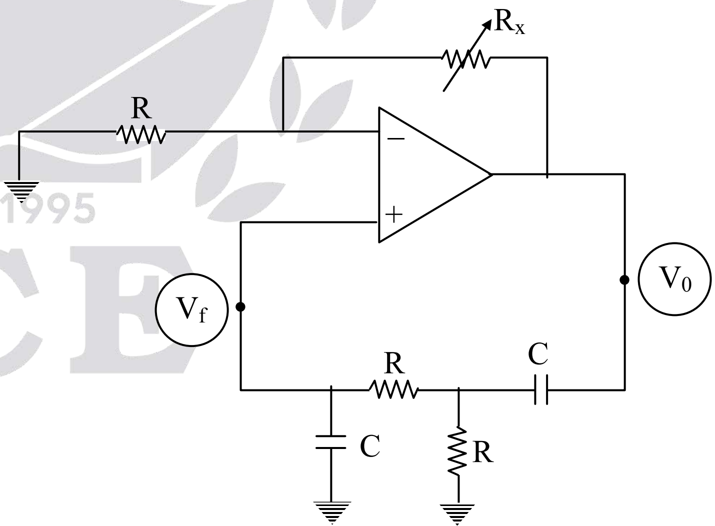
$\omega^2C^2R^2 = 1$

$\omega = \frac{1}{RC}$

Solutions for Conventional Practice Questions

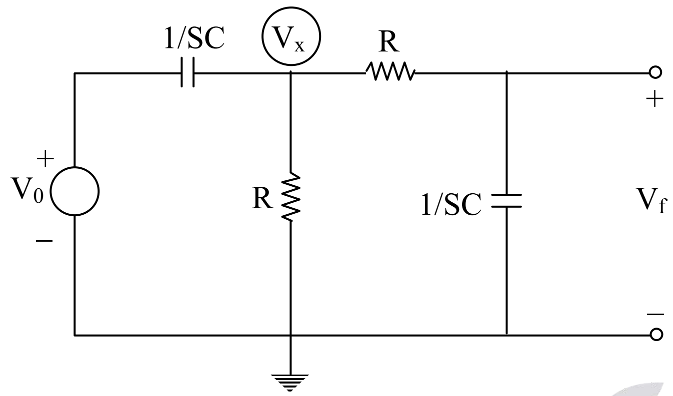
01.

Sol:



Gain of Amplifier (A) $= \frac{V_0}{V_f} = 1 + \frac{R_x}{R}$

Feedback factor (β) = $\dfrac{V_f}{V_0}$



KCL

$$\frac{V_x - V_0}{\left(\frac{1}{SC}\right)} + \frac{V_x}{R} + \frac{V_X - V_f}{R} = 0 \;\ldots\ldots\ldots(1)$$

KCL

$$\frac{V_x - V_f}{R} = \frac{V_f}{\left(\frac{1}{SC}\right)} \;\ldots\ldots\ldots(2)$$

From (1) and (2), eliminate V_x

$$\beta = \frac{V_f}{V_0} = \frac{SCR}{S^2C^2R^2 + 3SCR + 1}$$

$$\beta = \frac{1}{3 + SCR + \frac{1}{SCR}}$$

Put S = jω

$$\therefore\ \beta = \frac{1}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)}$$

To sustain sinusoidal oscillations the loop gain $A\beta = 1 \rightarrow A = 1/\beta$

$$\rightarrow 1 + \frac{Rx}{R} = 3 + j(\omega RC - 1/\omega RC)$$

Equate real terms:

$$1 + \frac{Rx}{R} = 3 \qquad \rightarrow \quad Rx = 2R$$

Equate imaginary terms:

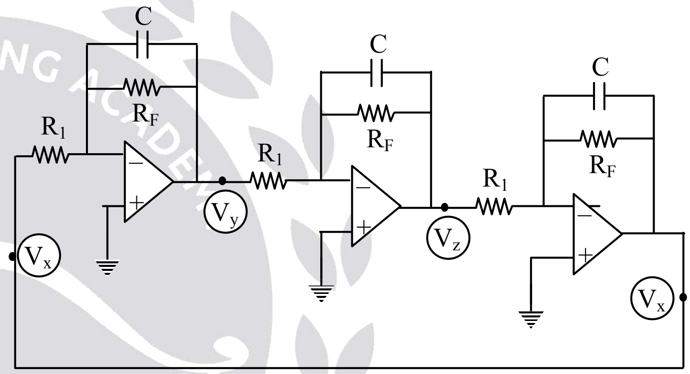
$$0 = \omega RC \frac{-1}{\omega RC} \;\rightarrow \omega = \frac{1}{RC}$$

This is the frequency of oscillations

$$f = \frac{1}{2\pi RC}$$

02.

Sol: Given



3-ϕ Oscillators

$$\Rightarrow \frac{V_y}{V_x} = \frac{-[R_F // (1/SC)]}{R_1} = \frac{-R_F/R_1}{1 + SCR_F}$$

Loop gain = 1

$$\frac{V_y}{V_x}\frac{V_z}{V_y}\frac{V_x}{V_z} = 1$$

$$\left[\frac{V_y}{V_x}\right]^3 = 1$$

$$\therefore \left[\frac{-R_F}{R_1}\right]^3 = (1 + SCR_F)^3$$

Equate real and imaginary

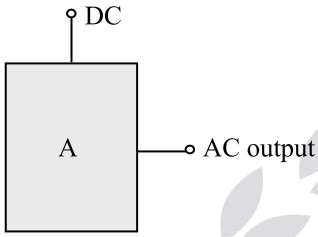
$R_F = 2R_1$

$\omega = \sqrt{3}/CR_F$

$$f = \frac{\sqrt{3}}{2\pi CR_F}$$

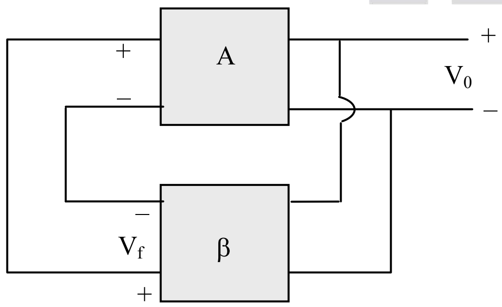
03.

Sol: (a) An electronic circuit which generates an AC output signal or an electronic circuit which provides AC output signal without any AC input signal is called an oscillator.



Oscillator

- An electronic circuit which converts DC signals into AC is called as an oscillator.
- An amplifier with sufficient gain or suitable gain is required
- For an oscillator, as there is no external AC input signal, positive feedback is required i.e feed back signal must be in phase with the input terminals of the amplifier (or) The phase difference between feedback signal and the input terminals of amplifier should be either zero or 360° so that oscillations are initiated.



- Barkhausen-criterion is to be implemented i.e the loop gain of the system should be equal to 1 (or) $|A\beta| = 1$, so that the oscillations are sustained.

Classification of oscillators:

1. Based on active device used

(a) BJT based oscillators

(b) FET/MOSFET based oscillators

(c) Operational Amplifier based oscillators

2. Based on the mechanism implemented

(a) Positive feedback based

(b) Negative feedback based

3. Based on frequency range

(a) Audio Frequency oscillators

(b) Radio frequency oscillators

(c) Ultra high frequency oscillators

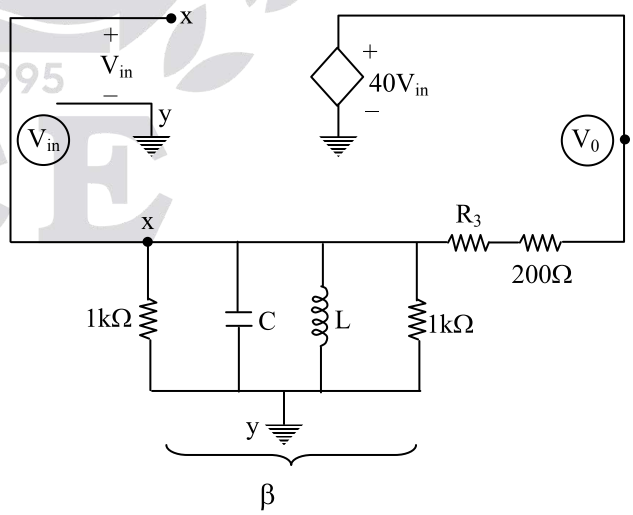
(d) Micro wave oscillators

4. Based on feedback network used

(a) RC oscillators

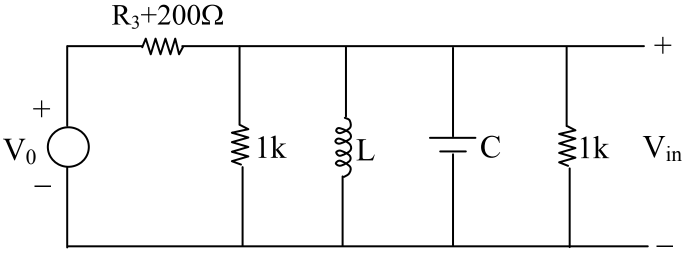
(b) LC oscillators

(b) To overcome loading. Effect, we will push the resistor in the below manner.



$$A = \frac{V_0}{V_{in}} = 40$$

$$\beta = \frac{V_{in}}{V_0}$$



KCL

$$\frac{V_{in} - V_0}{R_3 + 200} + \frac{V_{in}}{0.5k} + V_{in}\left[SC + 1/SL\right] = 0$$

Put S = jω

$$V_{in}\left[\frac{1}{R_3 + 200} + \frac{1}{0.5k} + j\left(\omega c - \frac{1}{\omega L}\right)\right] = \frac{V_0}{R_3 + 200}$$

Barkhavsens criterion for oscillation

$A\beta = 1\ \angle 0°$ (or) $1\angle 360°$

$$[40]\left[\frac{1/(R_3 + 200)}{1/(R_3 + 200) + 1/0.5k + j\left(\omega C - 1/\omega L\right)}\right] = 1$$

Equating imaginary parts

$$\omega C - \frac{1}{\omega L} = 0$$

$$\omega = \frac{1}{\sqrt{LC}},\ f = \frac{1}{2\pi\sqrt{LC}}$$

Equating real parts

$$\frac{40}{R_3 + 200} = \frac{1}{R_3 + 200} + \frac{1}{0.5k}$$

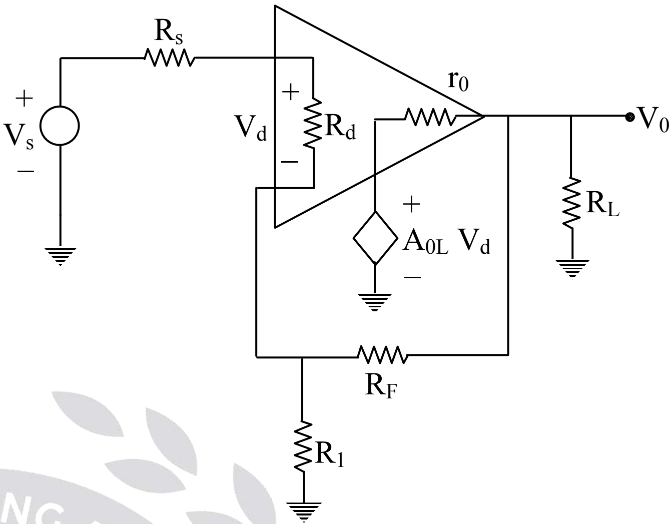
$$\frac{39}{R_3 + 200} = \frac{1}{0.5k}$$

$$39 \times 0.5k = R_3 + 200$$

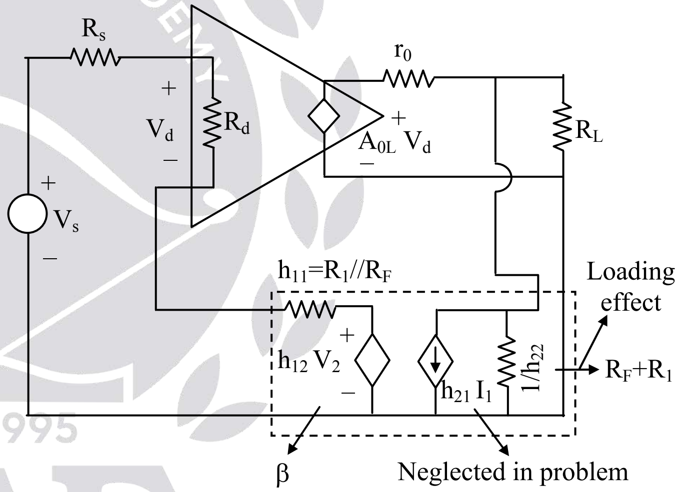
$$R_3 = 19.3k\Omega$$

04.

Sol: Given



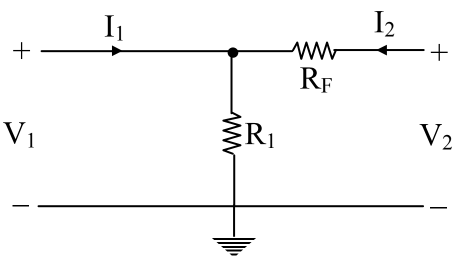
Here, we have to consider loading effect



$h_{11}\beta$ & $\dfrac{1}{h_{22}\beta}$ will load the basic Amp [op-amp]

$V_1 = h_{11}\, I_1 + h_{12}\, V_2$

$I_2 = h_{21}\, I_1 + h_{22}\, V_2$

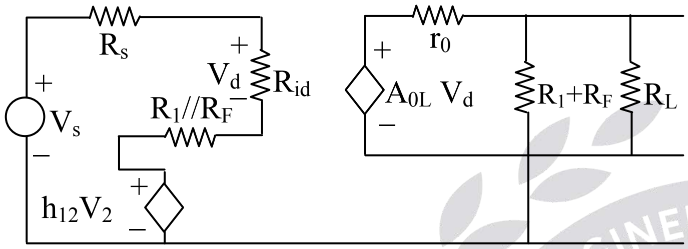


$$h_{11} = \left.\frac{V_1}{I_1}\right|_{V_2=0} = R_1 \parallel R_F$$

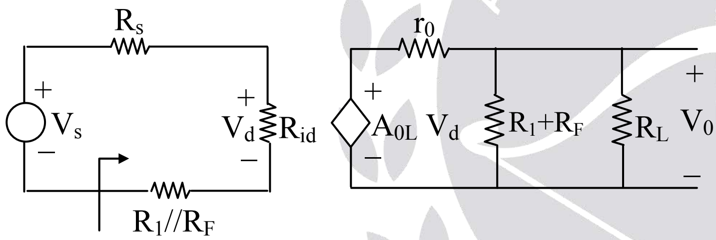
$$h_{12} = \beta = \left.\frac{V_1}{V_2}\right|_{I_1=0} = \frac{R_1}{R_F + R_1} = h_{21}$$

$$\frac{1}{h_{22}} = R_F + R_1$$

Calculation of A:



$$h_{12} = \frac{R_1}{R_F + R_1}$$



$$A = \frac{V_0}{V_s}$$

$$V_0 = \frac{A_{0L}V_d\left[(R_1 + R_F)//R_L\right]}{r_0 + \left[(R_1 + R_F)//R_L\right]}$$

$$= \frac{A_{0L}\left[(R_1 + R_F)//R_L\right]}{r_0 + \left[(R_1 + R_F)//R_L\right]}\,\frac{V_sR_{id}}{R_s + R_{id} + R_1//R_F}$$

$$\Rightarrow A = \frac{V_0}{V_s}$$

$$= \frac{A_{0L}\left[(R_1 + R_F)//R_L\right]R_{id}}{\left[r_0 + \left[(R_1 + R_F)//R_L\right]\right]\left[R_s + R_{id} + R_1//R_F\right]}$$

Desensitivity factor = 1 + Aβ

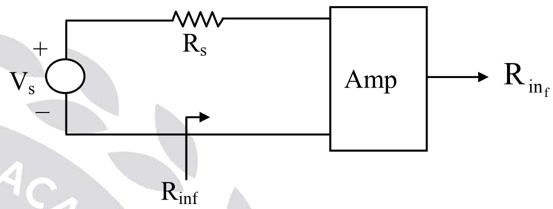
$$= 1 + \left[\frac{V_0}{V_s}\right]\frac{R_1}{R_F + R_1}$$

$$\left[\because \beta = \frac{R_1}{R_f + R_1}\right]$$

$$\text{Gain } (A_f) = \frac{A}{1 + A\beta}$$

$\Rightarrow R_{in_{\text{Basic AMP}}} = R_s + R_{id} + R_1 // R_F$

$\Rightarrow R_{in_{f_{\text{overall}}}} = (R_s + R_{id} + R_1 // R_F)\,[1 + A\beta]$



Excluding source resistance

Where, $R_{in_f} = [R_s + R_{id} + R_1//R_F][1+A\beta] - R_s$

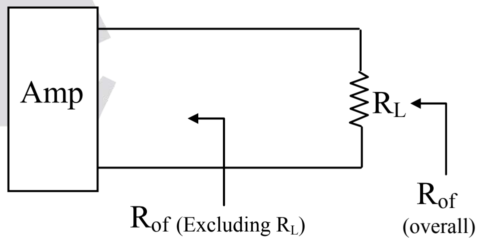
$R_{in_f} = [R_s + R_{id} + R_1//R_F][1+A\beta] - R_s$

$\rightarrow R_{0_{\text{Basic AMP}}} = r_0//(R_1+R_F)//R_L$

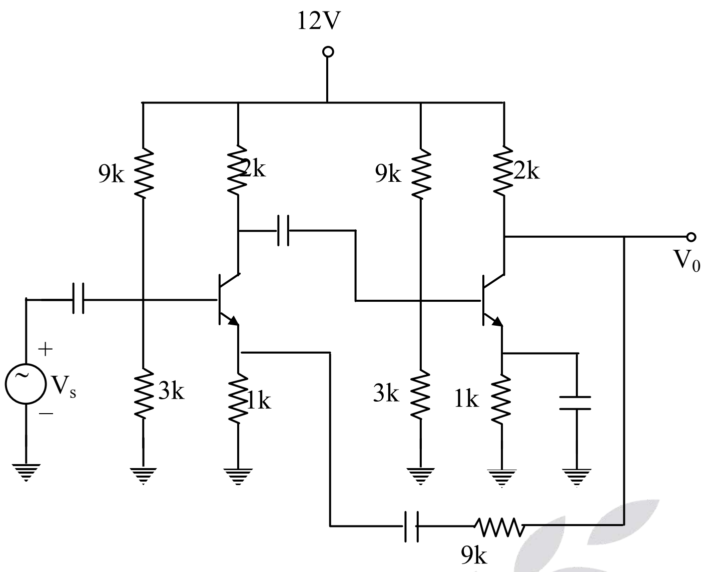
$$\rightarrow R_{of_{\text{overall}}} = \frac{r_0//(R_1 + R_F)//R_L}{1 + A\beta}$$

05.

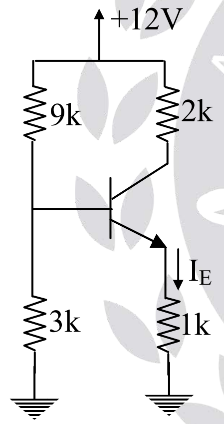
Sol:



$$\Rightarrow \frac{1}{R_{of(\text{excluding } R_L)}} + \frac{1}{R_L} = \frac{1}{R_{of(\text{overall})}}$$



DC circuit Analysis: [capacitor replaced by O.C]



$$I_E = \frac{V_{th} - V_{BE}}{R_E + \frac{R_{th}}{\beta + 1}}$$

$$= \frac{\frac{12(3k)}{9k + 3k} - 0.7}{1k + \frac{9k // 3k}{101}}$$

$$= 2.29\text{mA}$$

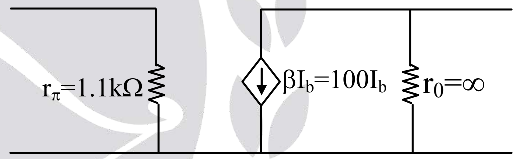
$$I_C = \left(\frac{\beta}{\beta + 1}\right) I_E = \frac{100}{101}(2.29\text{mA})$$

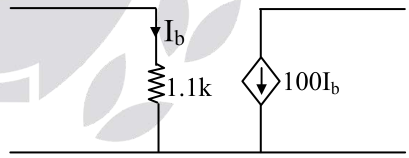
$$= 2.26\text{mA}$$

$$r_\pi = \beta / g_m = \frac{100}{\frac{2.26\text{m}}{25\text{m}}} = 1.1\text{k}\Omega$$

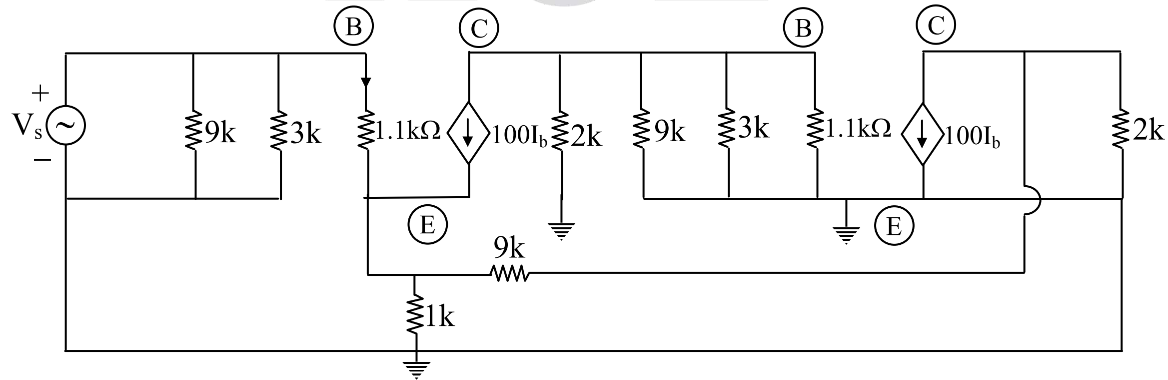
$$r_0 = \frac{|V_A|}{I_{C_{DC}}} = \frac{\infty}{I_{CC}} = \infty$$

Small Signal model Equivalent :

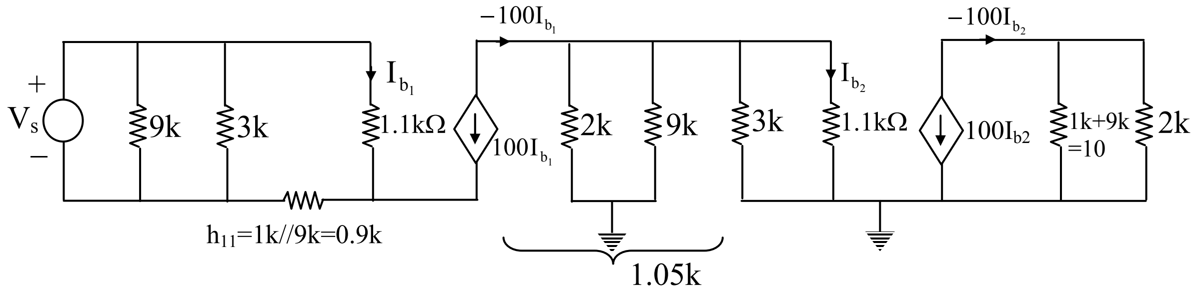




AC circuit analysis: [capacitor replaced by S.C]



Calculation of A



$V_0 = -100\ I_{b_2}$ [10k//2k]

$$I_{b_2} = \frac{-100I_{b1}[1.05k]}{1.05k + 1.11k}$$

$$I_{b_1} = \frac{V_s}{1.11k + 0.9k}$$

$$\Rightarrow A = \frac{V_0}{V_s} = \frac{V_0}{I_{b_2}}\frac{I_{b_2}}{I_{b_1}}\frac{I_{b_1}}{V_s} = 4030.77$$

$$\Rightarrow \beta = \frac{R_1}{R_F + R_1} = \frac{1}{10}$$

$\Rightarrow$ Desensitivity factor = 1 + Aβ

= 1+ 4030.77 (1/10)

= 404.077

$$\Rightarrow \text{Gain with feedback } A_F = \frac{A}{1 + A\beta}$$

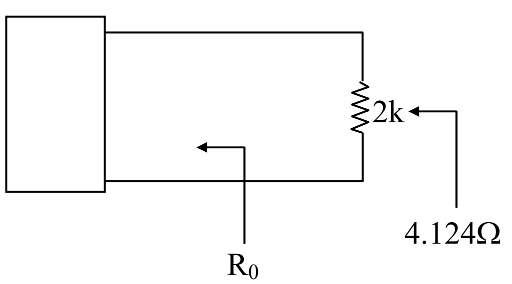
$$= \frac{4030.77}{404.077} = 9.97$$

$$\Rightarrow R_{in_f} = R_{in}[1 + A\beta]$$

= 9k//3k//[1.1k + 0.9k] [404.077]

= 427.8kΩ

$$\Rightarrow R_{of} = \frac{10k // 2k}{1 + A\beta} = \frac{10k // 2k}{404.077} = 4.124\Omega$$

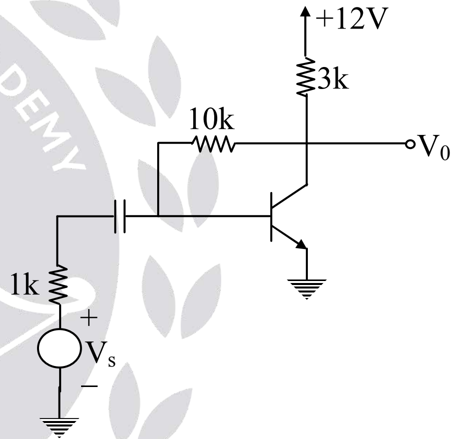


$$\Rightarrow \frac{1}{R_0} + \frac{1}{2k} = \frac{1}{4.124}\Omega$$

R_0 = 4.133Ω

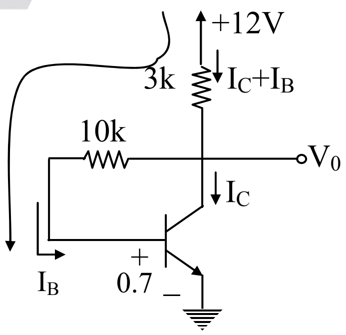
06.

Sol:



→ Here, given circuit is shunt-shunt. So, it is Transresistance amplifier.

DC Analysis: [capacitor replaced by O.C]



KVL

$12 = (I_C + I_B)\,3k + I_B\,(10k) + 0.7$ ______(1)

$$I_B = \frac{I_C}{\beta} = \frac{I_C}{100} \text{______(2)}$$

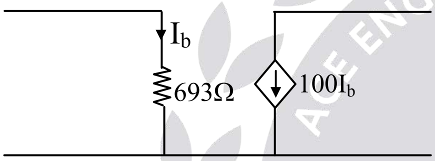
Sub (2) in (1)

$$I_C = \frac{12-0.7}{3k + \frac{13k}{100}} = 3.61\text{mA}$$

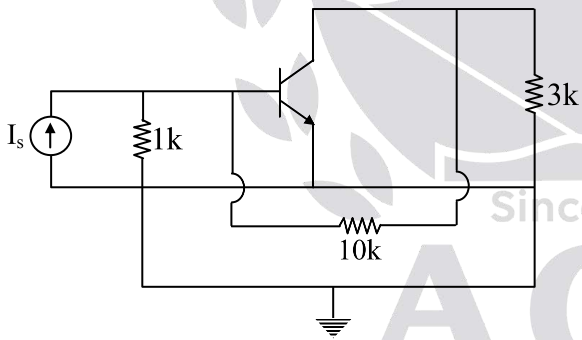
$$g_m = \frac{I_{C_{DC}}}{V_t} = \frac{3.61\text{mA}}{25\text{mV}};$$

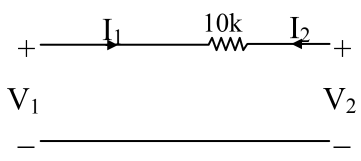
$$r_\pi = \frac{\beta}{g_m} = \frac{100}{\left(\frac{3.61}{25}\right)} = 693\Omega$$

Small signal equivalent



AC circuit analysis:





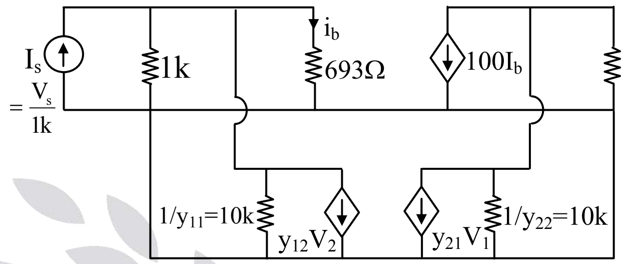
[y]

$I_1 = y_{11}\,V_1 + y_{12}\,V_2$

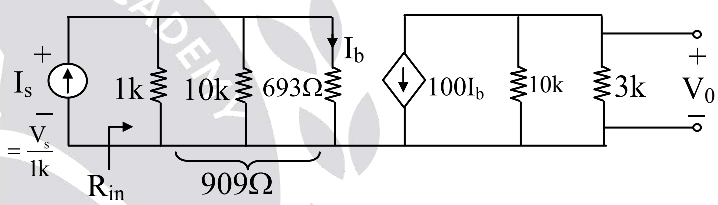
$$\Rightarrow I_1 = \frac{V_1 - V_2}{10k} = V_1\left(\frac{1}{10k}\right) + V_2\left(\frac{-1}{10k}\right)$$

$I_2 = y_{21}\,V_1 + y_{22}\,V_2$

$$\Rightarrow I_2 = \frac{V_2 - V_1}{10k} = V_1\left(\frac{-1}{10k}\right) + V_2\left(\frac{1}{10k}\right)$$



Calculation of A:



$V_0 = -100\,I_b\,[10k//3k]$

$$I_b = \frac{I_s[909]}{693+909}$$

$$A = \frac{V_0}{I_s}$$

$$= \frac{V_0}{I_b}\frac{I_b}{I_s} = -130.6\times10^3$$

$$\beta = y_{12} = \frac{-1}{10k}$$

Desensitivity factor = 1 + Aβ

= 1 + (–130.6k) (–1/10k)

= 14.06

$$\text{Gain } (V_0/I_s) = A_f = \frac{A}{1+A\beta}$$

$$= \frac{-130.6\times10^3}{14.06}$$

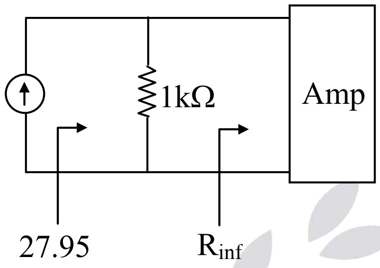
$= -9.288\times10^{3}$

$$\frac{V_0}{V_s} = \frac{V_0}{I_s}\frac{I_s}{V_s}$$

$= -9.288\times10^{3}\ (1/1k)$

$= -9.288$

$$\rightarrow R_{in_f} = \frac{909 // 693k}{1+A\beta} = 27.95\Omega$$

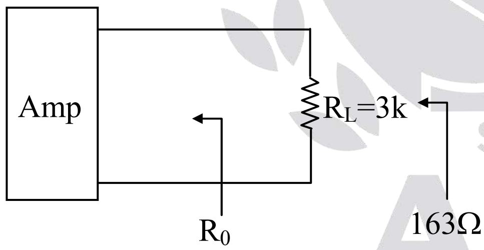


$$\frac{1}{27.95} = \frac{1}{R_{in_f\,(without\,1k)}} + \frac{1}{1k}$$

$R_{in_f\,(without\,1k)} = 28.75\Omega$

$$\rightarrow R_{of} = \frac{10k // 3k}{1+A\beta}\ \text{(including load)}$$

$= 163\Omega$

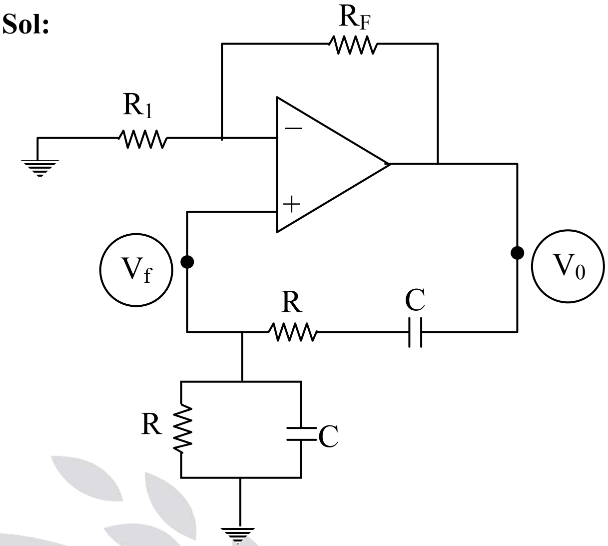


$$\frac{1}{R_{of\,(Excluding\ load)}} + \frac{1}{3k} = \frac{1}{163}$$

$R_{of(Excluding\ load)} = 172.36\Omega$

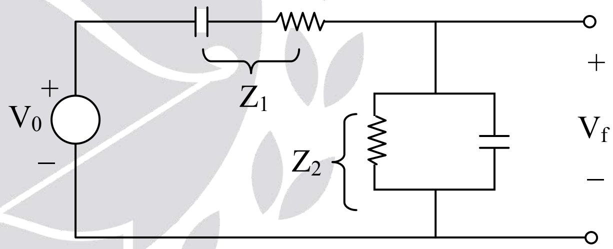
07.

Sol:



Gain of Amplifier $\left(\frac{V_0}{V_f}\right) = A = 1+\frac{R_F}{R_1}$

Feedback factor $(\beta) = \frac{V_f}{V_0}$



$$\frac{V_f}{V_0} = \frac{Z_2}{Z_1+Z_2} \quad \text{where } Z_1 = R+\frac{1}{SC}$$

$$Z_2 = R \,||\, \frac{1}{SC}$$

$$= \frac{R}{1+SCR}$$

By substitution

$$\beta = \frac{V_f}{V_0} = \frac{SCR}{S^2C^2R^2+3SCR+1}$$

$$= \frac{1}{3+SCR+\frac{1}{SCR}}$$

$$= \frac{1}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)}$$

To sustain oscillations $A\beta = 1 \rightarrow A = \frac{1}{\beta}$

$$\therefore\ 1 + \frac{R_F}{R_1} = 3 + j\left(\omega RC - \frac{1}{\omega RC}\right)$$

Equate real parts:

$$1 + \frac{R_F}{R_1} = 3 \ \rightarrow\ R_F = 2R_1$$

Equate Imaginary terms:

$$0 = \omega RC - \frac{1}{\omega RC} \rightarrow \omega^2 R^2 C^2 = 1$$

$$\omega = \frac{1}{RC}$$

$$f = \frac{1}{2\pi RC}$$

This is the frequency of oscillations.

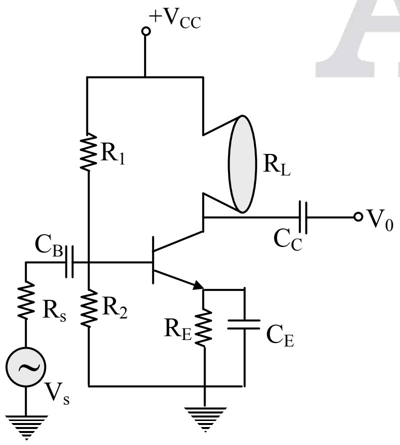
7. Power Amplifiers

Solutions for Conventional Practice Questions

01.

Sol: 2

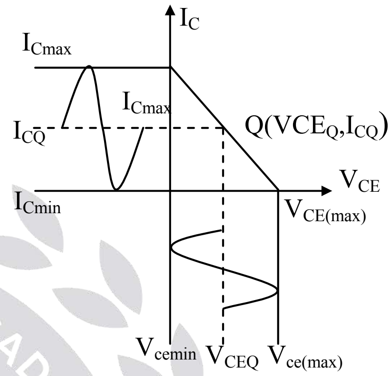
(i) Series - fed Class - A power amplifier:



Conduction angle

- The conduction angle of a transistor used in class A Power Amplifier is 360° i.e., the transistor is biased to conduct current for full cycle into the load over the entire full cycle of input signal.

Operating point [Q-point] analysis:



- In a class A Power Amplifier, the operating point is established at the middle of DC load line or at the centre of active region, so that amplifier can provide full cycle of output signal with negligible amount of distortion.

Over all conversion efficiency:

$$\eta = \frac{P_{ac\,max}}{P_{dc}} \text{ ------- (1)}$$

Step1: $P_{dc} = V_{dc}\ .\ I_{dc}$ ------ (2)

Where, $V_{dc} = V_{CC}$ & $I_{dc} = I_{CQ}$-----(3)

$\therefore\ P_{dc} = V_{CC}\, I_{CQ}$ ------- (4)

Step2: $P_{ac} = V_{rms}.\ I_{rms}$

Where,

$$V_{rms} = \frac{V_m}{\sqrt{2}} \qquad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$\therefore\ P_{ac} = \frac{V_m I_m}{2}$$

$$\therefore P_{ac(max)} = \frac{\left[\frac{V_{CC}}{2}\right]\left[I_{CQ}\right]}{2}\left[\because V_m = \frac{V_{CC}}{2} \;\&\; I_m = I_{CQ}\right]$$

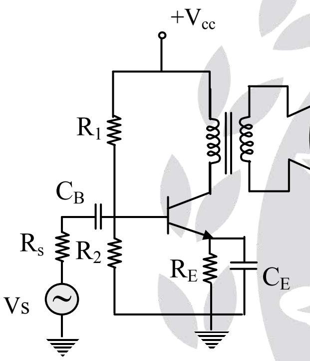
$$= \frac{V_{CC}.I_{CQ}}{4}$$

Step3:

$$\%\eta = \frac{P_{ac(max)}}{P_{dc}} \times 100 = \frac{V_{CC}I_{CQ}}{4 \times V_{CC}I_{CQ}} \times 100 = 25\%$$

$\therefore$ % η = 25 % [maximum]

(ii) Transformer coupled class-A Power Amplifier.



Conduction angle and operating point analysis is same as series - fed class A Power Amplifier.

Efficiency (η):

Step 1: $P_{dc} = V_{dc} \,.\, I_{dc}$

Where, $V_{dc} = V_{cc}$ & $I_{dc} = I_{cQ}$

$\Rightarrow P_{dc} = V_{cc}I_{cQ}$

Step 2: $P_{ac} = V_{rms}\, I_{rms}$

Where, $V_{rms} = \frac{V_m}{\sqrt{2}}$ & $I_{rms} = \frac{I_m}{\sqrt{2}}$

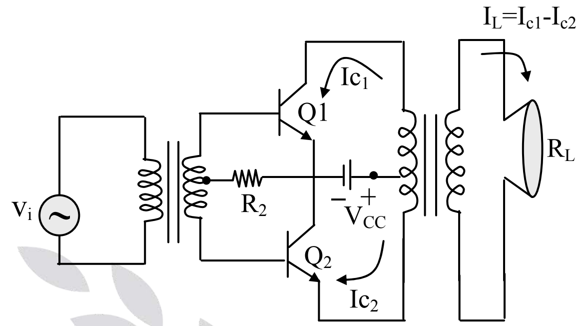
$$\Rightarrow P_{ac} = \frac{V_m I_m}{2}$$

$$\therefore P_{ac\,max} = \frac{V_{CC}I_{CQ}}{2} [\because V_m = V_{CC} \;\&\; I_m = I_{CQ}]$$

Step 3: $\%\eta = \frac{P_{ac\,max}}{P_{dc}} = \frac{V_{CC}I_{CQ}}{2V_{CC}.I_{CQ}} \times 100$

% η = 50 % [max]

(iii) Class - B push pull power amplifier [double - ended]:



Note: Conduction angle and operating point analysis for Class – B push pull power amplifier is same as that of Class - B power amplifier.

Overall conversion efficiency:

$$\%\eta = \frac{P_{ac(max)}}{P_{ac}} \times 100$$

Step1: $P_{dc} = V_{dc} \,.\, I_{dc}$

Where, $V_{dc} = V_{cc}$ & $I_{dc} = \frac{2I_m}{\pi}$

Step2: $P_{ac} = V_{rms}.\, I_{rms}$

Where, $V_{rms} = \frac{V_m}{\sqrt{2}}$ & $I_{rms} = \frac{I_m}{\sqrt{2}}$

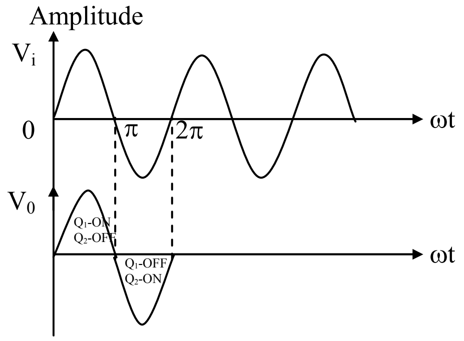
$$\Rightarrow P_{ac} = \frac{V_m I_m}{2}$$

$$P_{ac(max)} = \frac{V_{cc}.I_m}{2}$$

$$\therefore \%\eta = \frac{V_{cc}.I_m}{2 \times .\frac{V_{cc}.2I_m}{\pi}} \times 100 = \pi/4 \times 100$$

$\therefore$% η = 78.5 % (max)

Operation:



Case (i): 0 to π [+ve half cycle of input]

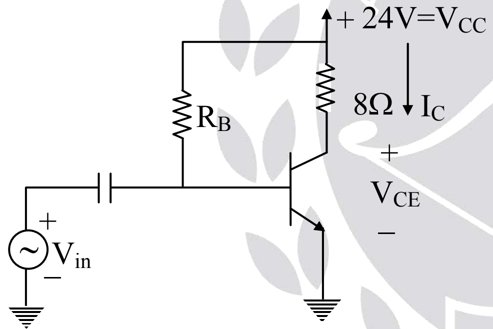
Q_1-ON & Q_2- OFF

Case (ii): π to 2π [-ve half cycle of input]

Q_1 – OFF, & Q_2 – ON

02.

Sol:



Power dissipation (P_D) = $V_{CE}\, I_C$

$= (V_{CC} - I_C R_C)\, I_C$

$= V_{CC}\, I_C - I_C^2 R_C$ ……..(1)

To find I_C at $P_{D_{max}}$:

Condition $\frac{dP_D}{dI_C} = 0$

$$\rightarrow \frac{d}{dI_C}\left[V_{CC} I_C - I_C{}^2 R_C\right] = 0$$

$\rightarrow V_{CC} - 2I_C R_C = 0$

$$\rightarrow I_C = \frac{V_{CC}}{2R_C}$$

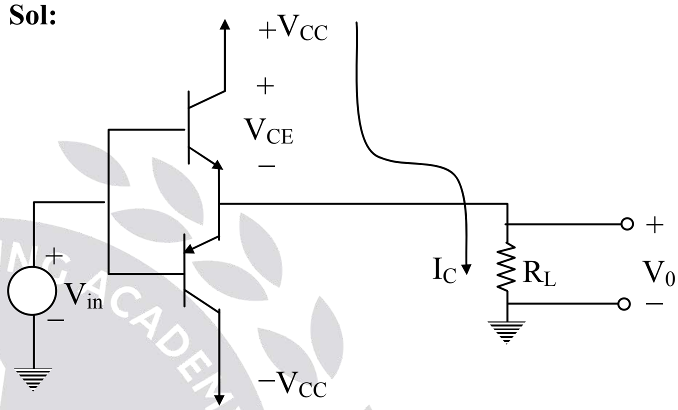
Sub in (1)

$$P_D = V_{CC}\left[\frac{V_{CC}}{2R_C}\right] - \left[\frac{V_{CC}}{2R_C}\right]^2 R_C = \frac{V_{CC}{}^2}{4R_C}$$

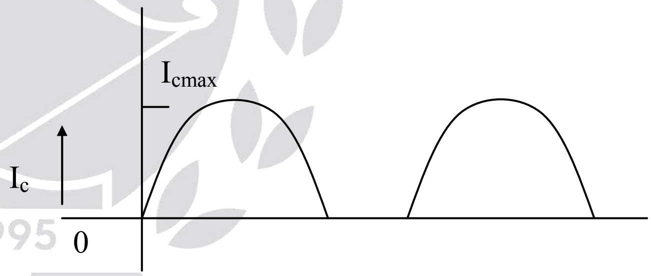
$$\therefore\ P_D = \frac{(24)^2}{4(8)} = 18\ \text{W}$$

03.

Sol:



Average power input $\left(P_{in(avg)}\right) = 2V_{CC} I_{C\ total(avg)}$



$$I_{C\,total(avg)} = \frac{I_{C\max}}{\pi}$$

$$\therefore\ P_{in} = 2V_{CC}\frac{I_{C\max}}{\pi}$$

$$P_{in(avg)} = 2V_{CC}\left[\frac{V_0}{R_L}\right]$$

For max power efficiency

$$P_{in(avg)} = 2V_{CC}\left[\frac{\frac{V_{CC}}{R_L}}{\pi}\right]$$

$$= \frac{2\,V_{CC}^{\ 2}}{\pi R_L}$$

Power output is the average of ac power dissipated in load R_L

$$P_{out(avg)} = \frac{1}{T}\int I_L^2 R_L\ d(\omega t)$$

$$= \frac{1}{T}\int_0^T (I_{LM}\sin\omega t)^2 R_L\ d(\omega t)$$

$$= \frac{I_{LM}^2}{T} R.(T/2)$$

$$= \frac{1}{2} I_{LM}^2 R_L$$

For max efficiency $I_{LM} = \frac{V_{CC}}{R_L}$

$$\therefore\ P_{o(avg)} = \frac{1}{2}\left[\frac{V_{CC}}{R_L}\right]^2 R_L$$

$$= \frac{1}{2}\frac{V_{CC}^{\ 2}}{R_L}$$

$$\text{Efficiency } (\eta) = \frac{P_0}{P_{in}} \times 100\%$$

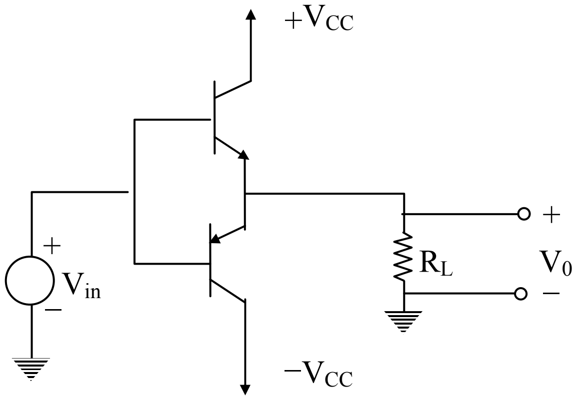
$$= \frac{1/2\ \frac{V_{CC}^{\ 2}}{R_L}}{\frac{2V_{CC}^{\ 2}}{\pi R_L}} \times 100\%$$

$$= \frac{\pi}{4} \times 100\%$$

$= 78.5\%$

04.

Sol:



$$P_{in} = 2V_{CC}\left[\frac{I_C}{\pi}\right]$$

$$P_0 = \frac{1}{2} I_C^2 R_L$$

$$P_D = P_{in} - P_0$$

$$= 2V_{CC}\left[\frac{I_C}{\pi}\right] - \frac{1}{2} I_C^2 R_L \quad \text{.............(1)}$$

To Find I_C at $P_{D_{max}}$ Let $\frac{dP_D}{dI_C} = 0$

$$\frac{dP_D}{dI_C} = \frac{2V_{CC}}{\pi} - I_C R_L = 0$$

$$2I_C R_L = \frac{V_{CC}}{\pi}$$

$$I_C = \frac{2V_{CC}}{\pi R_L}$$

sub in (1)

$$P_{D_{max}} = \frac{2V_{CC}}{\pi}\left[\frac{2V_{CC}}{\pi R_L}\right] - \frac{1}{2}\left[\frac{2V_{CC}}{\pi R_L}\right]^2 R_L$$

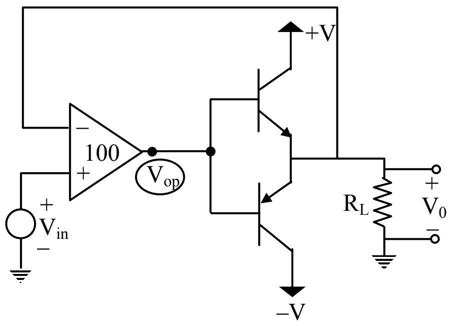
$$= \frac{4V_{CC}^2}{\pi^2 R_L} - \frac{2V_{CC}^2}{\pi^2 R_L} = \frac{2V_{CC}^2}{\pi^2 R_L}$$

Max power dissipation per BJT

$$= \frac{\left(\frac{2V_{CC}^2}{\pi^2 R_L}\right)}{2} = \frac{V_{CC}^2}{\pi^2 R_L}$$

05.

Sol:



$$V_{op} = 100[V_+ - V_-]$$

$V_{op} = 100\ [V_{in} - V_0]$

V_{in} POS:

$V_{op} - 0.7 = V_0$

$100\ V_{in} - 100\ V_0 - 0.7 = V_0$

$$V_0 = \frac{100V_{in}}{101} - 0.0069$$

$V_0 = 0.99V_{in} - 0.0069$

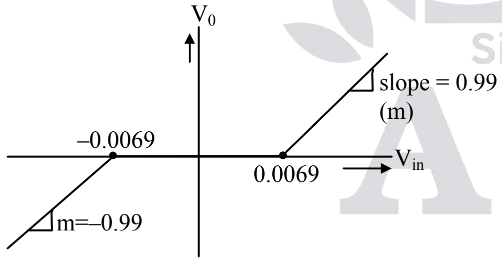
V_{in} Neg:

$V_0 - 0.7 = V_{op}$

$V_0 - 0.7 = 100\ [V_{in} - V_0]$

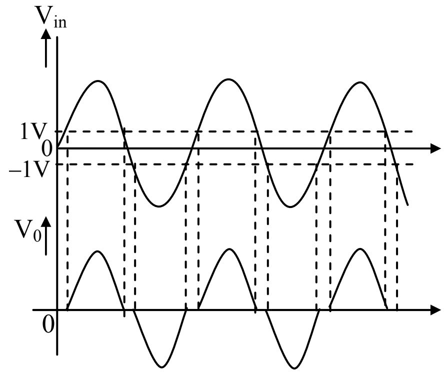
$101\ V_0 = 100\ V_{in} + 0.7$

$V_0 = 0.99V_{in} + 0.0069$

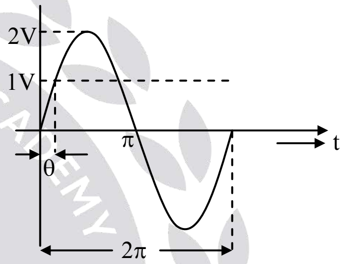


06.

Sol: (a)



(b) Given $V_{in} = 2\ \sin t$



$$2\sin t = 1 \rightarrow t = \frac{\pi}{6} = \theta$$

$$\%\text{ of output voltage } = \frac{4\theta}{2\pi} \times 100$$

$$= \frac{4\left(\frac{\pi}{6}\right)}{2\pi} \times 100\% = 33.33\%$$