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ANALOG CIRCUITS

Volume - I : Study Material with Classroom Practice Questions

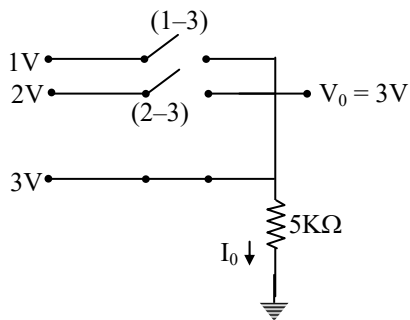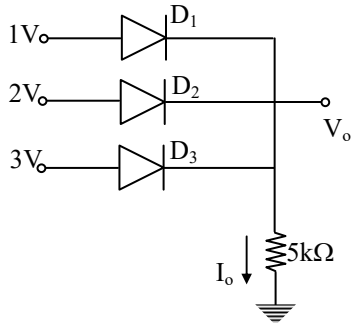*Study Material with Classroom Practice solutions*
To
Analog Circuits
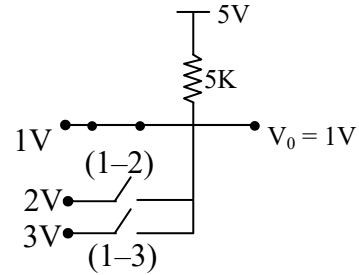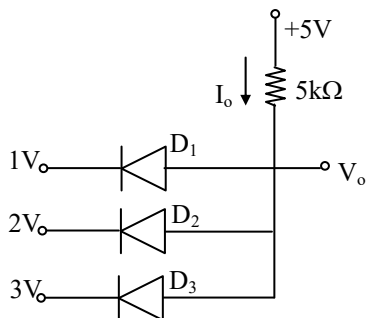
CONTENTS

Analog Circuits

01.
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.
Sol:

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

i.e., D_1 only conduct

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

03.
Sol: Let diodes D_1 & D_2 are forward biased.

$\Rightarrow$ $V_0 = 0$ volt
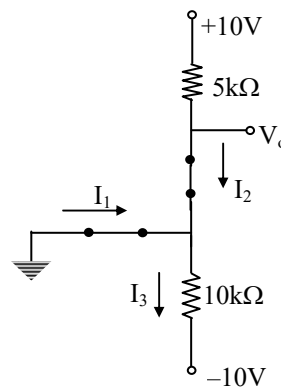
$I_2 = \dfrac{10-0}{5K} = 2mA$

$I_3 = \dfrac{0-(-10)}{10K} = 1mA$
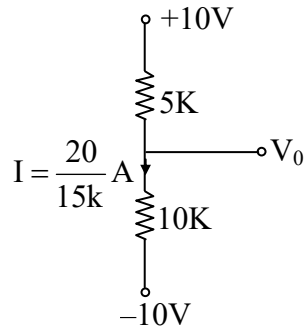
Apply KVL at nodes 'V_0':

$-I_1 + I_3 - I_2 = 0$

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

So, D_1 is reverse biased & D_2 is forward biased

$\Rightarrow$ 'D_1' act as an open circuit & D_2 is act as short circuit.
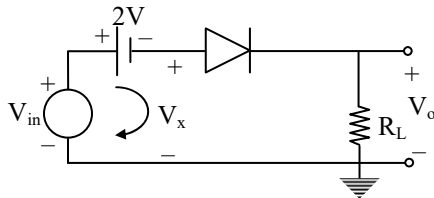
Then circuit becomes

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

$$\therefore V_0 = 3.33V$$

04.
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 $3V$ [$\because$ from eq (1)]
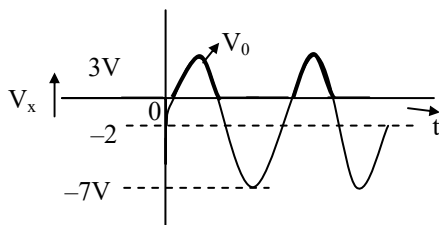
Diode ON for $V_x > 0V$

$\Rightarrow V_0 = V_x$

Diode OFF for $V_x < 0V$

$\Rightarrow V_0 = 0 V$

$\therefore V_0$ range $= 0$ to $3V$

Output wave form:

Transfer characteristics:
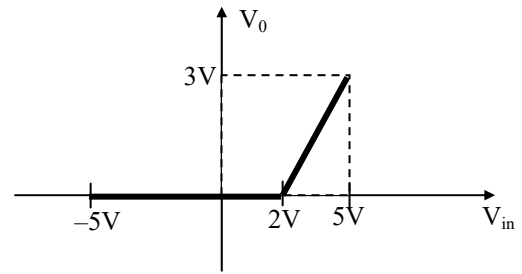
05.
Sol:
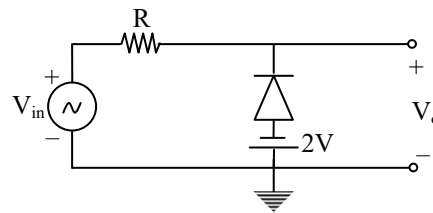
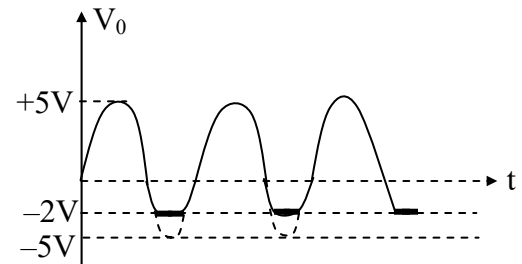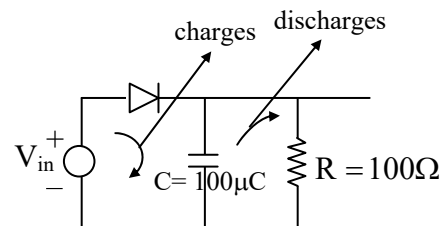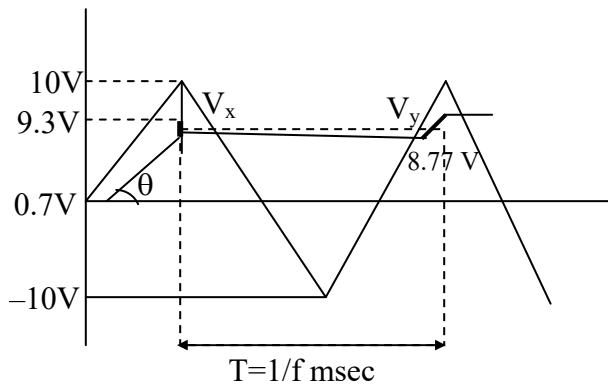For $V_i < -2$Volt, Diode ON

$\Rightarrow V_0 = -2$Volt

For $V_i > -2$Volt, Diode OFF

$\Rightarrow V_0 = V_i$

06.
Sol: Consider a half wave peak detector   the calculate average value for triangular waveform
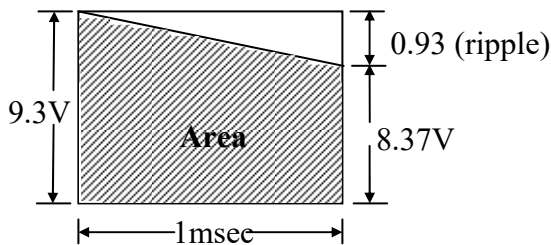
T=1/f msec

When diode is OFF, the capacitor discharges through the resistor

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

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

Ripple amplitude, $V_r = V_x - V_y$
$$= 9.3 - 8.77 = 0.93\ V$$

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

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

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

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

$$\Delta t = 0.023\ msec$$

(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 $I_D(max) = I_C + I_R$

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

$$= 4.093\ A$$

07.

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 $0V$
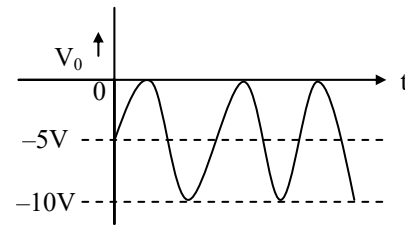
08.

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 $7V$

09.

Sol: For +ve cycle, diode ON, then capacitor starts charging $\Rightarrow V_C = V_P + 9$
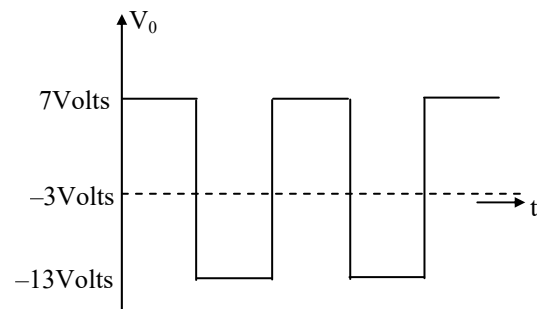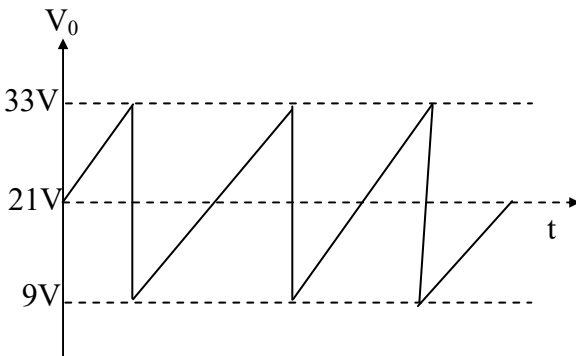$$= 12 + 9 = 21V$$

Now diode OFF for rest of cycle.

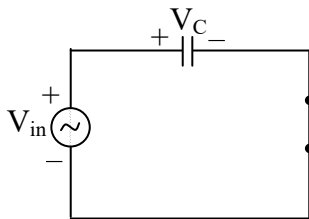$\Rightarrow V_0 = V_C + V_{in}$
$$= 21 + V_{in}$$

V_{in} range: –12 to +12V

V_0 range: 9V to 33V

10.

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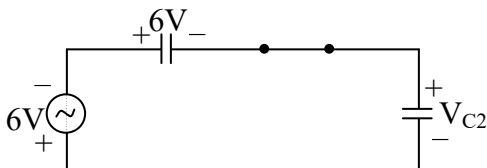
$V_{C2} = -6 - 6 = -12V$

Capacitor C_2 will charge to negative voltage of magnitude 12V

11.

Sol:
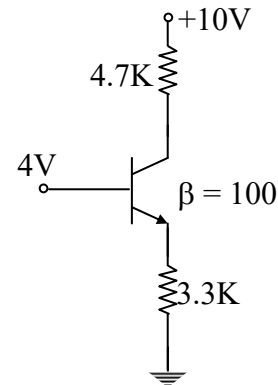
Given,

$V_B = 4V$

$V_{BE} = 0.7$

$V_B - V_E = 0.7$

$V_E = V_B - 7 = 3.3V$

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

Let transisotr in active region

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

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

$V_C = 10 - 4.7 \times 10^3 \times 0.99 \times 10^{-3} = 5.347V$

$\Rightarrow V_C > V_B$

$\therefore$ Transistor in the active region.

12.

Sol:

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

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

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

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

$V_C - V_E = 0.2$

$V_C = 5.3 + 0.2$
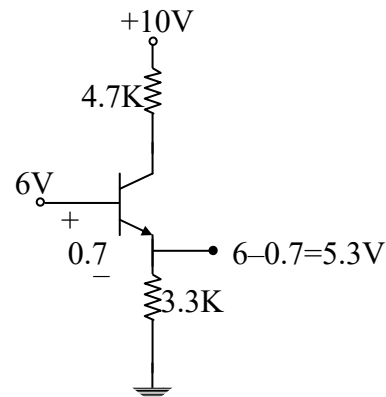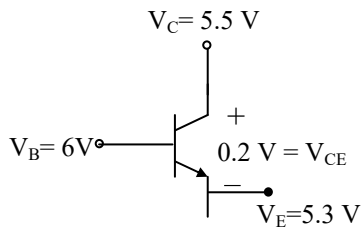
$\Rightarrow V_C = 5.5V$

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

$I_B = 1.6 - 0.957 = 0.643mA$

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

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

13.
Sol:
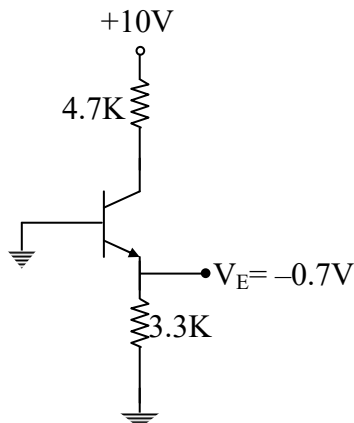
$V_E = -0.7V$

Transistor in cut off region

$I_C = I_B = I_E = 0A$

$V_{CE} = 10V$

$V_E = 0V$

$V_C = 10V$

$V_B = 0V$

14.
Sol:
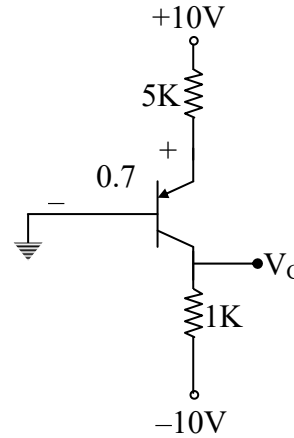
$V_E = 0.7V \ [\because V_B = 0V]$

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

Let transistor in active region.

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

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

$\quad V_C = -8.16V$

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

$V_{EC} > V_{EB}$

$\therefore$ Transistor in active region

15.
Sol:

Let transistor in active region

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

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

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

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

$V_C = 36V$

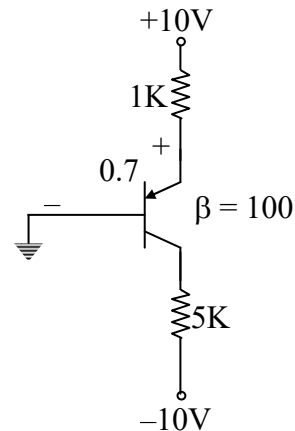$V_{EC} < V_{EB}$

Transistor in saturation region

$\Rightarrow V_{EC} = 0.2$

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

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

$I_B = I_E - I_C = 7.2mA$

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

$\qquad = \dfrac{2.1}{7.2}$

$\qquad = 0.29$

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

16.
Sol:
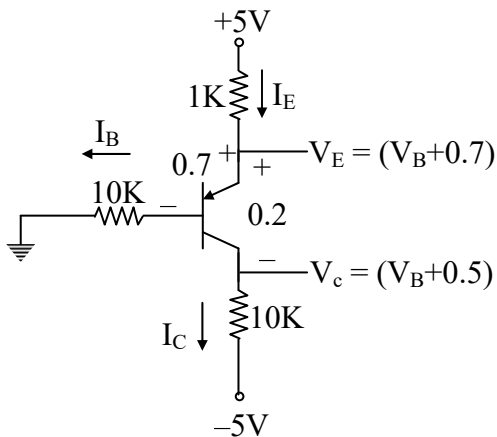
$I_E = I_C + I_B$

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

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

$43-10V_B = 2V_B+5.5$

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

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

$V_C = V_B+0.5 = 3.625V$

$V_E = 3.825V$

$\therefore I_E = 1.175mA$

$\therefore I_C = 0.862mA$

17.
Sol: Here the lower transistor (PNP) is in cut off region.

Apply KVL to the base emitter loop:

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

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

$\qquad = 38.73\mu A$

$I_C = 3.87mA$

$I_E = 3.91mA$

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

$V_C = 5V$

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

18.
Sol:

$$I_{C_1} = I_{\varepsilon_1} = \frac{2.3V}{2.3k} = 1m\,Amp$$
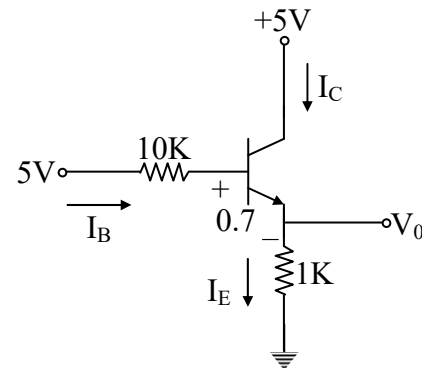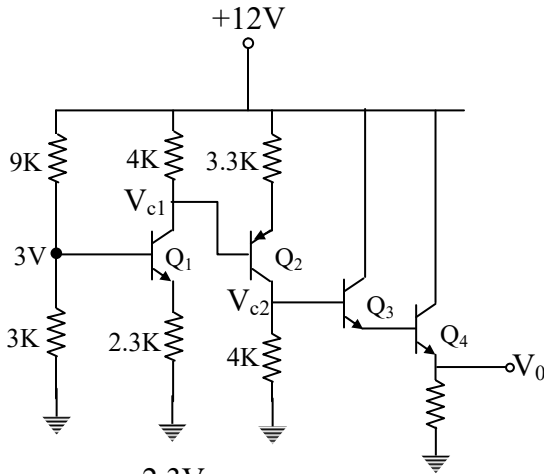
$$V_{C_1} = 12V - 4 \times 10^3 \times 1 \times 10^{-3} = 8V$$

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

$$I_{\varepsilon_2} = \frac{12V - V_{\varepsilon_2}}{3.3k} = \frac{12V - 8.7}{3.3k} = 1m\,Amp$$

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

$$V_{\varepsilon_3} = 4V - 0.7 = 3.3V$$

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

$$V_0 = 2.6\ V$$

19.
Sol:
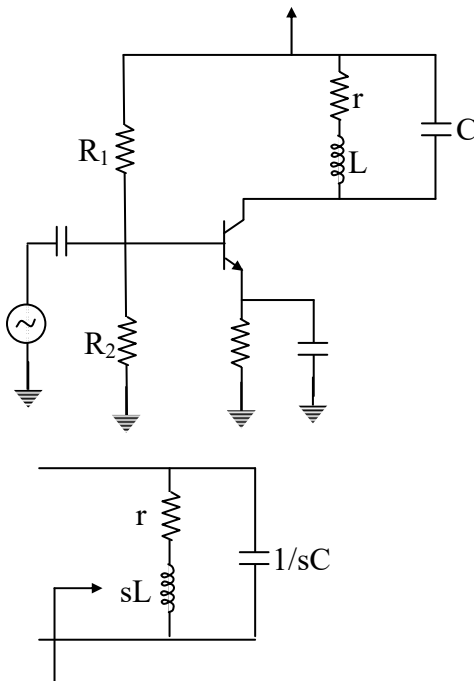
$$Z_{eq} = \frac{1}{sC + \dfrac{1}{r + sL}}$$

$$= \frac{r + sL}{srC + s^2LC + 1}$$

$$= \frac{r + j\omega L}{(1 - \omega^2 LC) + j\omega rC}$$

$$Z_{eq} = \frac{(r + j\omega L)\left[1 - \omega^2 LC - j\omega rC\right]}{\left(1 - \omega^2 LC\right)^2 + \left(\omega rC\right)^2}$$

$$= \frac{\omega^2 rLC + r - \omega^2 rLC + j\omega L[1 - \omega^2 LC] - j\omega r^2 C}{\left(1 - \omega^2 LC\right)^2 + \left(\omega rC\right)^2}$$

Equate Imaginary terms:

$$\omega L - \omega^3 L^2 C - \omega r^2 C = 0$$

$$L - \omega^2 L^2 C - r^2 C = 0$$

$$\omega^2 L^2 C = L - r^2 C$$

$$\omega = \sqrt{\frac{1}{LC} - \frac{r^2 C}{L^2 C}}$$

$$\omega = \sqrt{\frac{1}{LC} - \left(\frac{r}{L}\right)^2}$$

Equate real:

$$Z_{eq} = \frac{r - \omega^2 LCr + \omega^2 LCr}{(1 - \omega^2 LC)^2 + \omega^2 r^2 C^2}$$

$$= \frac{r}{\left(\dfrac{r^2 C}{L}\right)^2 + \left[\dfrac{1}{LC} - \dfrac{r^2}{L^2}\right]r^2 C^2}$$

$$= \frac{r}{\dfrac{r^4 C^2}{L^2} + \dfrac{r^2 C^2}{LC} - \dfrac{r^4 C^2}{L^2}}$$
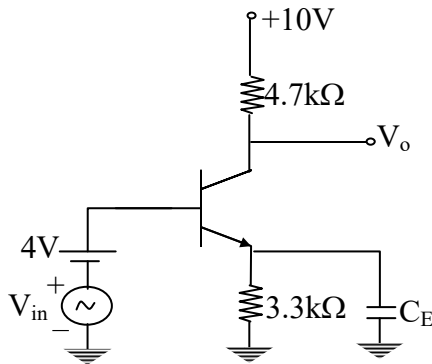
$$Z = \frac{L}{rC}$$

(ii) $\quad A_V = -g_m Z$

$$= -g_m \left[\frac{L}{rC}\right]$$
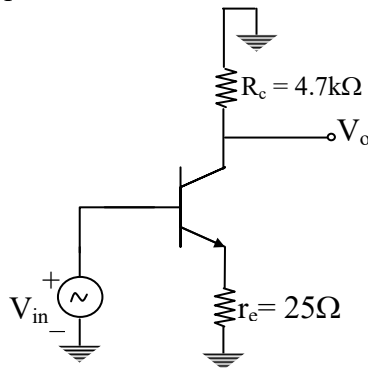
20.

Sol:

For D.C Analysis:

$V_B = 4$ V

$V_B - V_E = 0.7 \Rightarrow V_E = 4 - 0.7 = 3.3$ V

$I_E = \dfrac{3.3}{3.3k} = 1mA$

$r_e = \dfrac{V_T}{I_E} = \dfrac{25\,mV}{1mA} = 25\ \Omega$

To apply small signal analysis set D.C source equal to zero.

$\Rightarrow V_0 = -i_c R_c$

$V_i = i_c r_e$

$\therefore A_V = \dfrac{V_0}{V_i}$

$= \dfrac{-i_c R_c}{i_c r_e} = \dfrac{-R_c}{r_e} = \dfrac{-4.7\,k}{25}$

$= -188$

21.
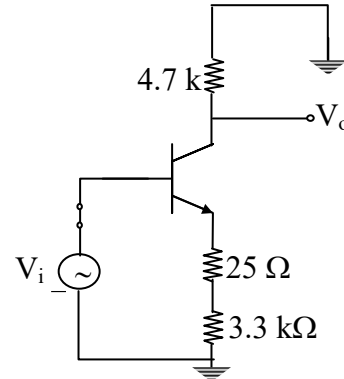
Sol: D.C calculation is same as previous question

$I_E = 1$ mA

$r_e = 25\ \Omega$

Apply small signal analysis:

$\dfrac{V_0}{V_i} = \dfrac{-R_c}{r_e + R_E} = \dfrac{-4700}{25 + 3300}$

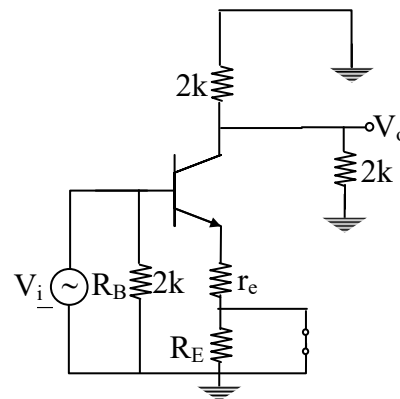$\therefore A_V = \dfrac{V_0}{V_i} = -1.413$

22.

Sol: To calculate r_e value apply D.C analysis

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

$= \dfrac{3 - 0.7}{2.3k + \dfrac{2k}{101}} = 0.991 mA$

$r_e = \dfrac{V_T}{I_E} = \dfrac{25}{0.991} = 25.22\Omega$

Now apply small signal analysis.:

$A_V = \dfrac{v_0}{v_i} = \dfrac{-R_C}{re} = \dfrac{-(2k\,\|\,2k)}{25.22} = -39.65$
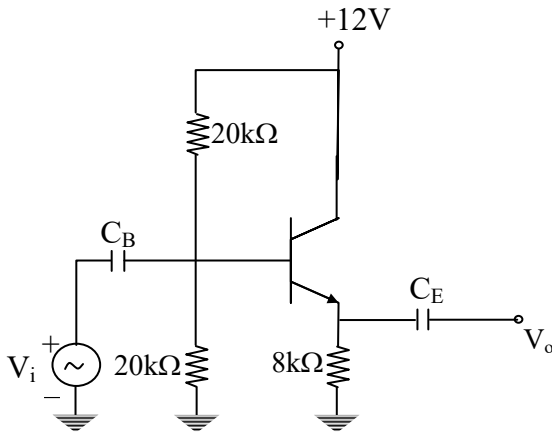
$R_i = R_B \parallel \beta r_e$

$R_i = 1.116 k\Omega$

$A_I = \dfrac{i_0}{i_i} = \dfrac{v_0}{R_L} \times \dfrac{R_i}{v_i} = A_V \times \dfrac{R_i}{R_L}$

$= \dfrac{-39.5 \times 1.116 \times 10^3}{2 \times 10^3} = -22.322$

$R_o = R_C = 2 k\Omega$

23.
Sol:

Apply KVL at input Loop:

$6 - 10k\,(I_B) - 0.7 - 8\,k(1+\beta)I_B = 0$

$I_B = \dfrac{6 - 0.7}{10k + 8k \times 101} = 6.47\,\mu A$

$I_E = 0.65\ mA$

$r_e = \dfrac{V_T}{I_E} = \dfrac{25}{0.65} = 38.5\,\Omega$

Apply small signal analysis

$A_v = \dfrac{V_0}{V_i} = \dfrac{R_E}{r_e + R_E} = 0.995$

$R_i = R_B \parallel \beta R_{E_{Total}}$

$R_{E_{Total}} = (R_E + r_e)$

$R_i = 10\ k \parallel 803.85k = 9.87\ k\Omega$

$R_0 = R_E \parallel r_e = 38.3\ \Omega$

24.
Sol: $V_0 = -i_c R_C$

$i_e \approx i_c = \dfrac{-V_i}{r_e}$

$V_0 = \left(\dfrac{V_i}{r_e}\right) R_C$

$\dfrac{V_0}{V_i} = \dfrac{R_C}{r_e}$

Given $I_E = 1mA$

$\Rightarrow r_e = \dfrac{25mV}{1mA} = 25\Omega$

$A_V = \dfrac{R_C}{re}$

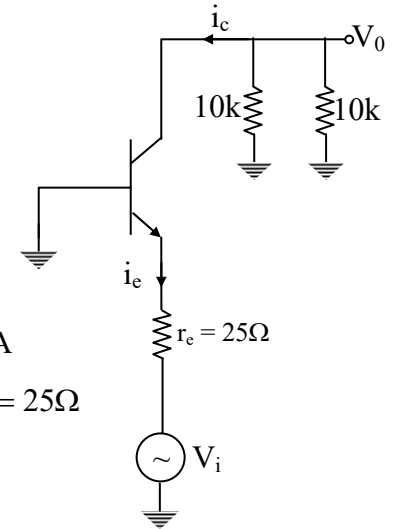$A_V = \dfrac{10k\,//10k}{25} = \dfrac{5000}{25} = 200$

$R_0 = R_C = 10k\Omega$

$R_i = r_e = 25\Omega$

$A_I = \dfrac{i_0}{i_i} = \dfrac{v_0}{R_L} \times \dfrac{R_i}{v_i}$

$= A_V \times \dfrac{R_i}{R_L} = \dfrac{200 \times 25}{10^4} = 0.5$

25.
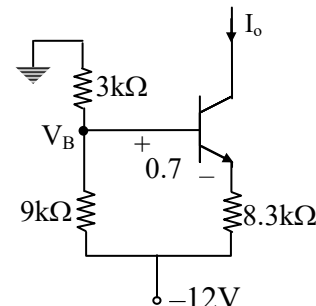**Sol:** For the given differential amplifier,

$I_E = 1mA$

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

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

$A_d = -120$

26.
Sol:

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

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

$$V_B = -3V$$

$$V_B - V_E = 0.7$$

$$V_E = V_B - 0.7$$

$$V_E = -3.7 \text{ Volt}$$

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

$$I_o = 1mA$$

$$I_E = 0.5mA$$

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

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

$$A_d = -40$$

27.
Sol: Voltage shunt feedback amplifier and

$$\frac{V_0}{V_{in}} = \frac{-R_f}{R_S} = \frac{-10k}{1k} \approx -10$$
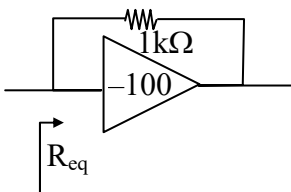
28.
Sol: Current – series feedback amplifier and
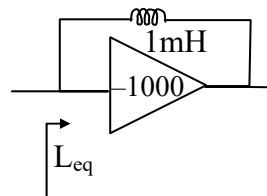
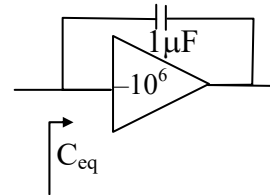$$A_V \approx \frac{-R_C}{R_E} = \frac{-4.7k}{3.3k} = 1.4242$$

29.
Sol:

using millers effect,

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

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

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

30.
Sol: Maximum power across the Transistor will be at the middle of active region

Ideally at $V_{CE} = \dfrac{V_{CC}}{2}$

$$V_{CE} = 12V$$

$$I_C = \frac{24-12}{8k} = 1.5mA$$

$$P_{Tmax} = V_{CE} \times I_C$$
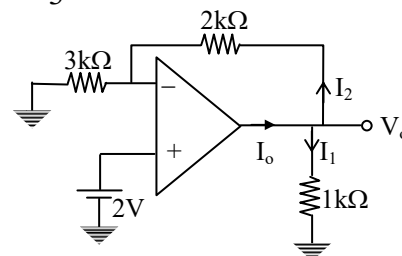$$= 12 \times 1.5$$
$$= 18mW$$

31.
Sol: $V_0 = \left(1 + \dfrac{R_f}{R_1}\right) V_i$

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

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

$I_1 = \dfrac{V_0}{1k} = \dfrac{10}{3}\,mA$ &

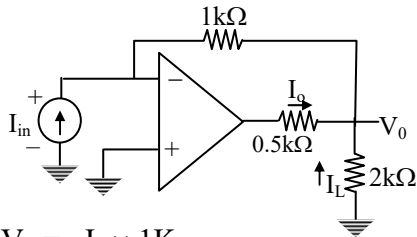$I_2 = \dfrac{V_0 - 2}{2k} = \dfrac{\dfrac{10}{3} - 2}{2k} = \dfrac{2}{3}\,mA$

$\therefore I_0 = I_1 + I_2 = 4mA$

32.

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

33.

Sol:

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

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

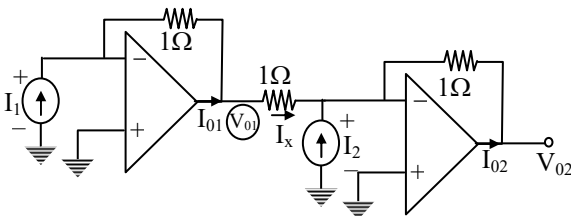$I_0 + I_{in} + I_L = 0$

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

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

$2I_0 = -3I_{in}$

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

34.

Sol:

$V_{01} = -I_1$

Apply KCL:

$I_x + I_2 = \dfrac{0 - V_{0_2}}{1}$

$\dfrac{V_{01}}{1} + I_2 = -V_{02}$

$V_{01} + I_2 = -V_{02}$

$-I_1 + I_2 = -V_{02}$

$V_{02} = (I_1 - I_2)volt$

$I_{01} + I_1 = I_x$

$I_{01} + I_1 = V_{01} \qquad \left[\because I_x = \dfrac{V_{01}}{1} \right]$

$I_{01} = V_{01} - I_1$

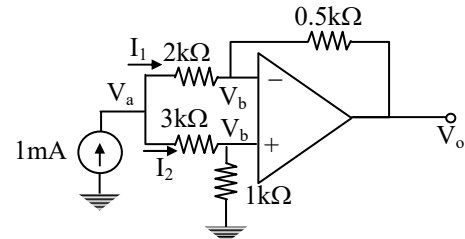$I_{01} = -2I_1 \qquad \left[\because V_{01} = -I_1 \right]$

$I_{02} = -(I_2 + I_x)$

$I_{02} = -(I_2 + V_{01})$

$I_{02} = (I_1 - I_2)A$

35.

Sol:

Apply KCL at V_a:

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

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

$6 = 5V_a - 5V_b$

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

$V_a - V_b = 1.2Volt$

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

$I_2 = \dfrac{1.2}{3k} = 0.4mA$

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

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

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

$$0.3 = 0.4 - V_0$$

$$\therefore V_0 = 0.1 \text{ Volt}$$

36.

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

$$V_C = -5 \text{Volt}$$

37.

Sol: Given open loop gain = 10

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

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

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

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

38.

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

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

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

$$V_0 = -4.5 \text{Volt}$$
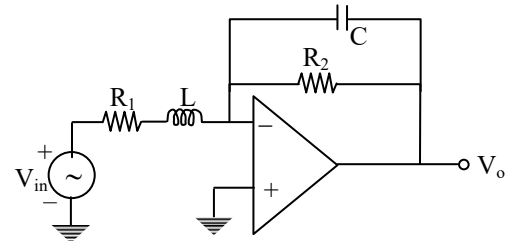
39.

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

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

$$= \frac{10^6}{2\pi \times 20 \times 10^3} = 7.95 \text{Volt}$$

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

40.

Sol:

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

$$z_1 = R_1 + sL$$

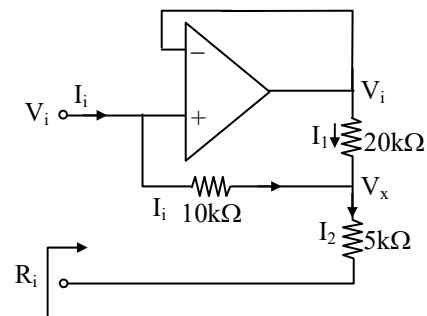$$\left| \frac{V_0}{V_i} \right| = \frac{\frac{R_2}{sCR_2 + 1}}{R_1 + sL}$$

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

It represent low pass filter with

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

41.

Sol: (i)

Apply KCL at V_x :

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

$$\frac{V_x}{5k} = \frac{V_i - V_x}{10k} + \frac{V_i - V_x}{20k}$$
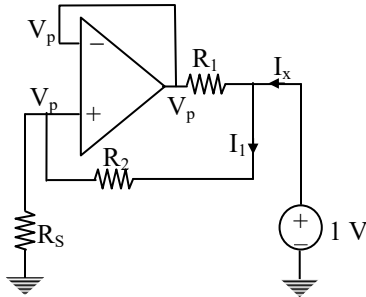
$$\frac{V_x}{5} = \frac{3V_i - 3V_x}{20}$$

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

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

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

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

(ii)

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

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

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

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

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

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

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

42.

Sol: $V_E = V_{in}$

$V_{CE} = V_C - V_E$

$V_{CE} = 15 - V_{in}$

given V_{in} 0 to 5 Volt

$\Rightarrow$ Transistor is in active region

$$I_E = I_0 = \frac{V_{in} + 15}{10} = \frac{17}{10} = 1.7\,A \quad [\therefore V_{in} = 2V]$$

$$I_B = \frac{I_0}{1 + \beta} = \frac{1.7}{100}\,A$$

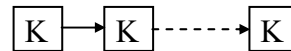$$V_B = V_{in} + 0.7 = 2.7V$$

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

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

$$V_{op} = 4.4\,Volt$$

43

Sol:

(a) n-stage
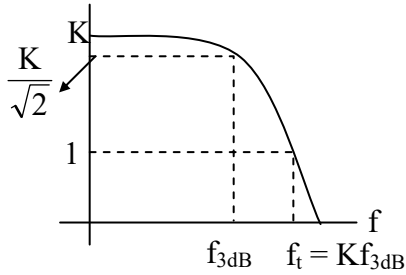

LPF single stage gain $= \dfrac{K}{1 + j\dfrac{f}{f_c}}$

For n stages gain $= \left[\dfrac{K}{1 + j\dfrac{f}{f_c}}\right]^n$
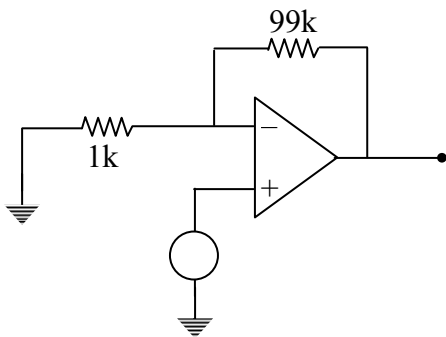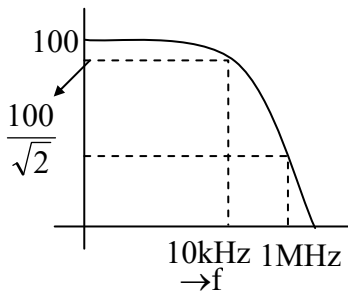
3dB cut-off frequency (f_{3dB}) is given by

$$\frac{K^n}{\sqrt{2}} = \left[\frac{K}{\sqrt{1+\left(\frac{f_{3dB}}{f_c}\right)^2}}\right]^n$$

$$\Rightarrow f_{3dB} = f_c\sqrt{2^{1/n}-1}$$
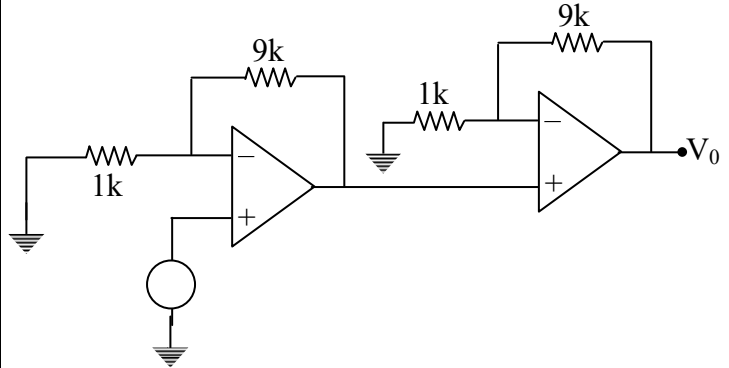

(b) Gain = 40dB = 100, f_t = 1MHz = Gain BW

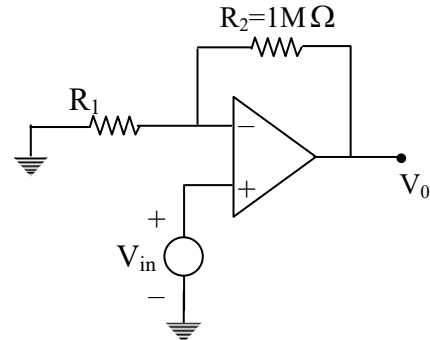$$BW \rightarrow f_{3dB} = \frac{f_t}{Gain} = \frac{10^6}{100} = 10kHz$$

(c)

$$f_{3dB} = \frac{1M}{10} = 100kHz, \quad f_{3dB} = 100kHz(\text{for}$$
single stage)

Overall BW = $f_{3dB}\sqrt{2^{1/2}-1}$
= 100k (0.04)
= 64 kHz

44
Sol:
   (a)

Gain = $\frac{V_0}{V_{in}} = 1 + \frac{1M}{R_1} = 100 \Rightarrow R_1 = 10.1k\Omega$
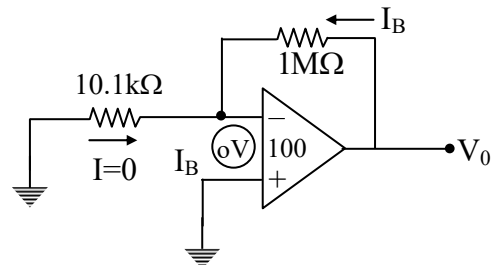
$V_0 = I_B(1M)$

$\quad = 100nA(1M)$

$\quad = 0.1V$
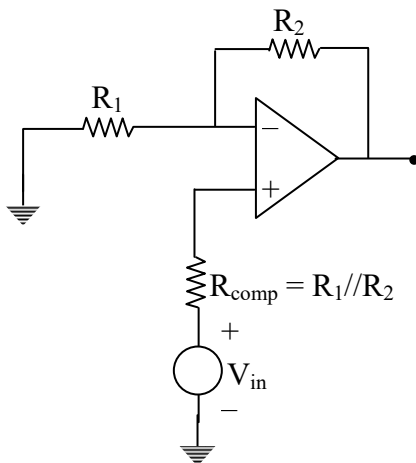
(b)

→ op-amp draws current

→ op-amp CKT the curve doesn't pass through '0' (transfer characteristics)
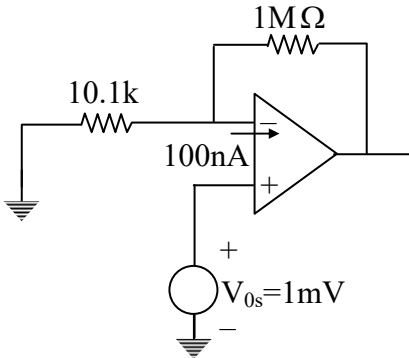
$V_0 = \left|V_{0_{Bios\,current}}\right| + \left|V_{0_{Offset\,Voltage}}\right|$

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

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

$\quad = 0.2V$

(c)

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

$\quad\quad\quad\quad = I_{os}\,R_2$

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

$\quad = I_{os}\,R_2$

$\quad = 1/10\,(I_B R_2)$

$= \dfrac{1}{10}100nA(1M)$

$\quad = 0.01V$
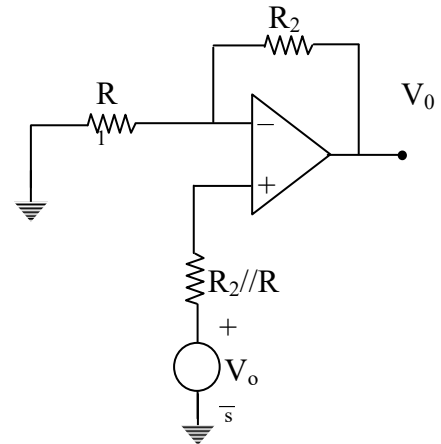
(d)

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

$\quad = 0.1 + 0.01$

$\quad = 0.11$

45.

Sol: Given

$R_1 = R_3 = 10k\Omega$

$R_2 = R_4 = 1M\Omega$
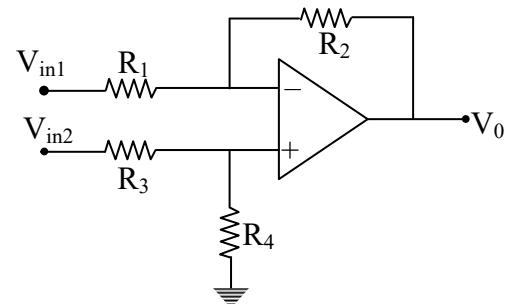
$V_0 = \dfrac{R_2}{R_1}\left(V_{in2} - V_{in1}\right)$

$\quad = \dfrac{1M}{10k}\left(V_{in2} - V_{in1}\right)$

Given $V_{os} = 4mV$

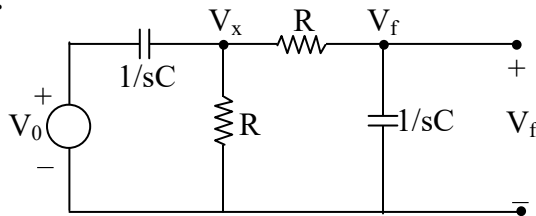$I_B = 0.3\ \mu A$

$I_{os} = 50\ nA$
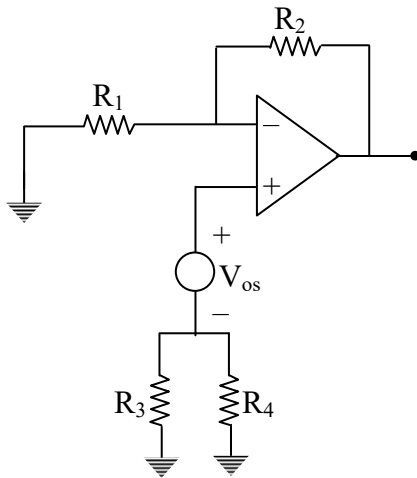
$$V_0 = \left[1 + \frac{R_2}{R_1}\right]V_{os} + I_{os}R_2$$

$$= \left[1 + \frac{1M}{10k}\right]4mV + 50nA[1M]$$

$$= 454mV$$

46.
Sol:

KCL

$$\frac{V_x - V_0}{(1/SC)} + \frac{V_x}{R} + \frac{V_x - V_f}{R} = 0 \text{ -------(1)}$$
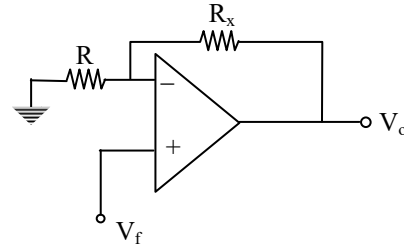
$$\frac{V_f - V_x}{R} + \frac{V_f}{(1/SC)} = 0 \text{ -------(2)}$$

From (1) and (2) eliminate V_x

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

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

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

$$A = \frac{V_0}{V_f} = 1 + \frac{R_x}{R}$$

Loop gain $=1 \rightarrow A = 1/\beta$

$A\beta = 1$

$$1 + \frac{R_x}{R} = 3 + j\left(\omega RC - \frac{1}{\omega RC}\right)$$
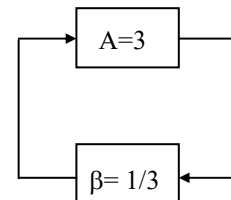
Equate img. parts

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

$$\omega^2 = \frac{1}{R^2C^2}$$

$$f = \frac{1}{2\pi RC} \text{ frequency of oscillation}$$

Equate

$$1 + \frac{R_x}{R} = 3$$

$$R_x = 2R$$

47.

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

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

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

$A\beta = 1$ for sustained oscillations

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

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

48.

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

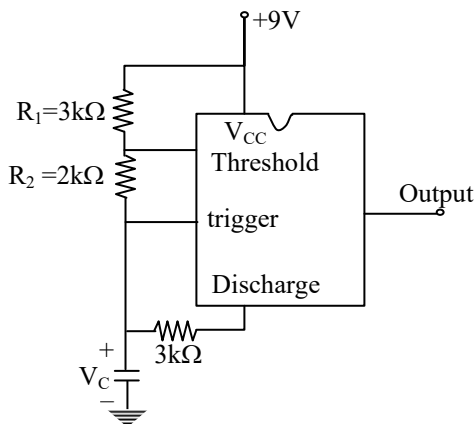$A = 1 + \dfrac{R_2}{R_1}$

$A\beta = 1$ for sustained oscillations

$\left(1 + \dfrac{R_2}{R_1}\right) \cdot \dfrac{1}{6} = 1$

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

$R_2 = 5 R_1$

49.

Sol:

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

$V_{th} - V_C = 2 \times 10^3 \times I \qquad \left(I = \dfrac{9-6}{3k}\right)$
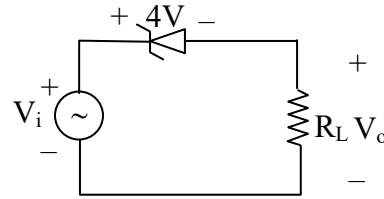
$V_{th} - V_C = 2 \text{ V}$

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

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

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

50.

Sol:

$V_i = 8 \sin t \text{ V}$

During $-\text{Ve}$ cycle, Zener is Forward biased and act as short circuit.
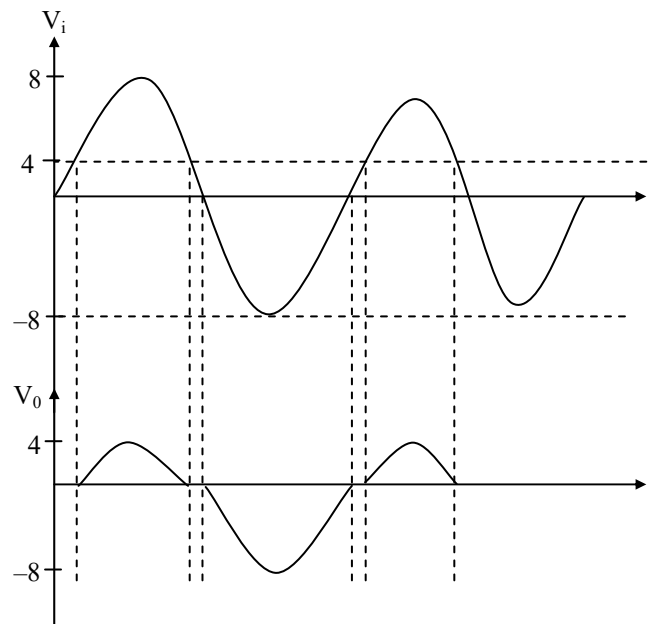
$\Rightarrow V_0 = V_i$

During $+\text{Ve}$ cycle,

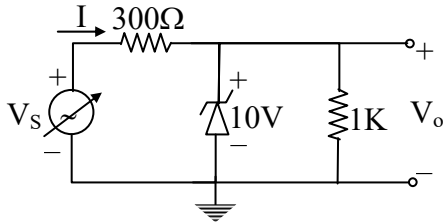For $0 < V_i < 4$, Zener OFF Since Zener is not in break down

$\Rightarrow V_0 = 0$

For $V_i > 4$, Zener is in break down.

$\Rightarrow V_0 = V_i - 4$

51.
Sol:

I_z = 1mA to 60mA

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

$$I_{min} = \frac{V_{smin} - 10}{300} \underline{\hspace{2cm}}(I)$$

$$I_{max} = \frac{V_{smax} - 10}{300} \underline{\hspace{2cm}}(II)$$

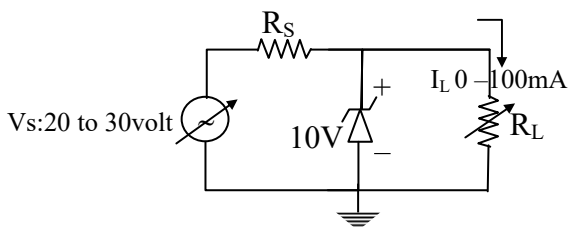$$I_{min} = I_{zmin} + I_L \left[\because I_L + \frac{V_z}{1k} = 10mA \right]$$

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.

52.
Sol:

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

$$R_s = \frac{V_{smin} - V_z}{I_{zmin} + I_{Lmax}}$$

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

R_s = 90.9Ω

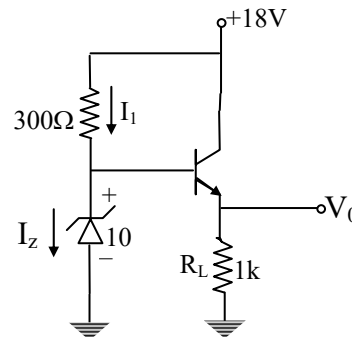$$I_{zmax} = \frac{30 - 10}{90.9} = 0.22A \left[\because I_{Lmin} = 0A \right]$$

$P_z = V_z I_{zmax}$

$P_z = 10 \times 0.22$

$P_z = 2.2W$

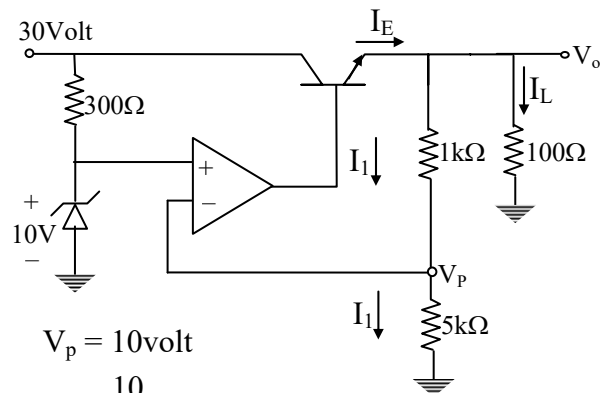**53.**
Sol:

V_B = 10volt

V_E = 10 − 0.7 = 9.3volt

I_E = 9.3mA

$$I_B = \frac{I_E}{1 + \beta} = \frac{9.3mA}{101} = 92.07\mu A$$

$$I_1 = \frac{18 - 10}{300} = 26.67mA$$

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

54.
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.

$I_E = I_1 + I_L$

$I_E = 2m + \dfrac{12}{100} = 122 mA$
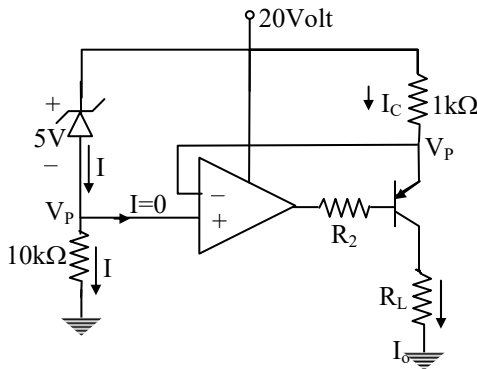
$\Rightarrow I_C = \dfrac{\beta}{1+\beta} I_E$

$\Rightarrow I_C = 0.120 Amp$

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

$\therefore P_T = 2.17W$

55.
Sol:

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

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

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

β large $\Rightarrow I_B \approx 0A$

$\therefore I_C = I_0 = 5mA$

56.
Sol: Given $I_{DSS} = 10$ mA, $V_P = -5V$,

$V_{GG} = -2V$ and $r_d = 30$ kΩ
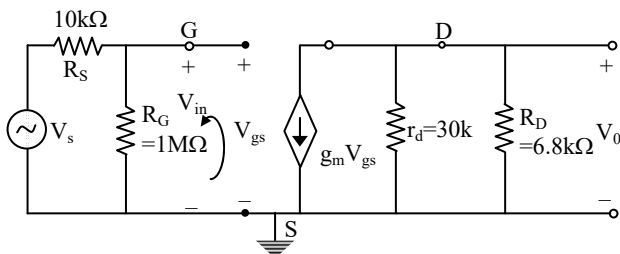
$V_0 = -g_m V_{gs} (r_d || R_D)$

$\therefore A_V = -g_m(r_d || R_D)$

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

$V_G = -2V$

$V_{GS} = -2 - 0 = -2V \ (\therefore V_S = 0V)$

$I_D = 10m\left[1 - \dfrac{-2}{-5}\right]^2$

$I_D = 3.6$ mA

$g_m = \dfrac{2\sqrt{I_D I_{DSS}}}{V_P}$

$= \dfrac{2\sqrt{(3.6m)(10m)}}{5} = \dfrac{2 \times 6m}{5} = 2.4ms$

$\therefore A_V = -(2.4 \times 10^{-3})[30 k || 6.8 k]$

$\dfrac{V_0}{V_{gs}} = A_V = -13.3$

$V_{gs} = \dfrac{10^6}{10^6 + 10^4} V_s$

$= 0.99 V_s$

$\dfrac{V_0}{V_s} = A_{Vs}$

$= -13.3 \times 0.99$

$= -13.16$

$V_G = -2V$

$V_{GS} = -2 - 0 = -2V \ (\therefore V_S = 0V)$

$I_D = 10m\left[1 - \dfrac{-2}{-5}\right]^2$

$I_D = 3.6$ mA

$g_m = \dfrac{2\sqrt{I_D I_{DSS}}}{V_P}$

$= \dfrac{2\sqrt{(3.6m)(10m)}}{5} = \dfrac{2 \times 6m}{5} = 2.4ms$

$\therefore A_V = -(2.4 \times 10^{-3})[30 k || 6.8 k]$
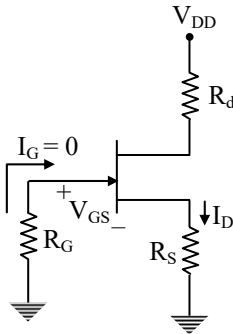
$\dfrac{V_0}{V_{gs}} = A_V = -13.3$

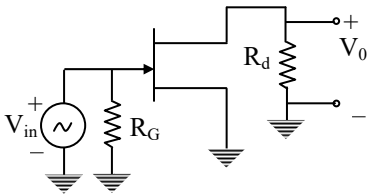$V_{gs} = \dfrac{10^6}{10^6 + 10^4} V_s$

57.
Sol: **DC Equivalent**

AC Equivalent

Device equation

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

$\Rightarrow 0.8 \text{ mA} = 1.65 \text{ mA}\left[1 - \dfrac{V_{GS}}{-2}\right]^2$

$\Rightarrow V_{GSQ} = -0.607 \text{ V}$

(ii) $g_m = \dfrac{\partial I_{DS}}{\partial V_{GS}} = 2I_{DSS}\left[1 - \dfrac{V_{GSQ}}{V_P}\right]\left[-\dfrac{1}{V_P}\right]$

$= 2(1.65 \text{ mA})\left[1 - \dfrac{0.607}{2}\right]\left[\dfrac{1}{2}\right]$

$= 1.149 \text{ ms}$

(iii) $V_G = V_{GS} + I_{DS}R_S = 0$

$\Rightarrow -0.607 + 0.8 \text{ mA}(R_S) = 0$

$R_S = \dfrac{-0.607}{-0.8 \text{ mA}} = 758.75\Omega$

(iv) Voltage gain $(A_V) = -g_mR_d$

Gain (db) $= 20 \log A_V$

$20 = 20 \log A_V$

$\Rightarrow A_V = 10$

$\Rightarrow 10 = g_mR_d$

$\Rightarrow 10 = (1.149 \text{ m})R_d$

$\therefore R_d = 8.7 \text{ k}\Omega$