

GATE

MADE EASY **WORKBOOK** 2024



**Detailed Explanations of
Try Yourself Questions**

Instrumentation Engineering Analog Electronics



MADE EASY
Publications

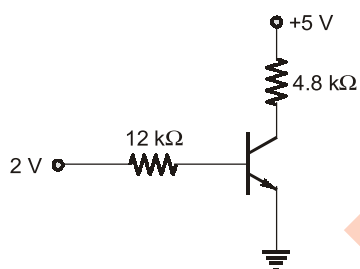
2

Testing of BJT in Different Operating Regions



Detailed Explanation of Try Yourself Questions

T1. (0.902)



$$I_B = \frac{2 - 0.7}{12} = 0.10833 \text{ mA}$$

$$I_{C(\text{sat})} = \frac{5 - 0.2}{4.8} = 1 \text{ mA}$$

$$I_B \geq I_{B(\text{min})}$$

$$= \frac{I_{C(\text{sat})}}{\beta}$$

$$I_B \geq \frac{1 \text{ mA}}{\beta}$$

$$\beta \geq \frac{1}{0.10833} \text{ and } \beta_{\text{min}} = 9.23$$

$$\alpha_{\text{min}} = \frac{\beta_{\text{min}}}{1 + \beta_{\text{min}}} = 0.902$$

T2. (c)

In active region

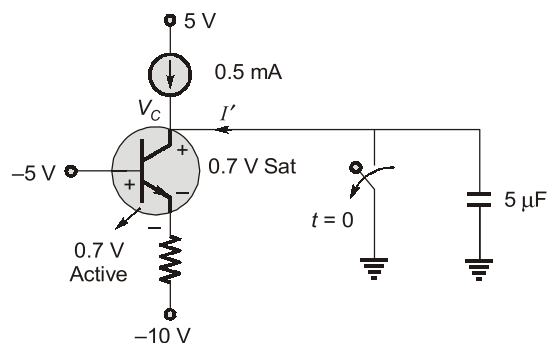
$$-5 - 0.7 - 4.3 I_E = -10$$

$$I_E = \frac{10 - 5.7}{4.3} = \frac{4.3}{4.3} = 1 \text{ mA}$$

$$I_C = I_E = I' + 0.5 \text{ mA} = 1 \text{ mA}$$

$$I' = 0.5 \text{ mA}$$

⇒



In saturation region ⇒

$$V_C - 0.7 - 4.3 \times 1 = -10$$

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

$$q = CV_C = -5 \times 10^{-6} \times 5 \text{ V} = -25 \times 10^{-6}$$

and $q = it$

$$I'(0 - t) = -25 \times 10^{-6}$$

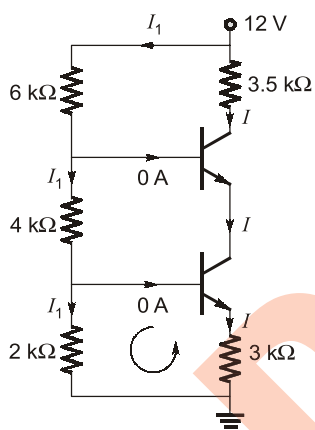
$$t = \frac{25 \times 10^{-6}}{0.5 \times 10^{-3}} = 50 \text{ m sec}$$

■■■■



Detailed Explanation of Try Yourself Questions

T1. Sol.



$$I_1 = \frac{12}{6 + 4 + 2} \text{ mA}$$

$$I_1 = 1 \text{ mA}$$

Applying KVL in loop L

$$I_1 \times 2 \text{ k}\Omega - I \times 3 \text{ k}\Omega = V_{BE}$$

$$2 - I \times 3 \text{ k} = 0.5$$

$$-I \times 3 \text{ k} = -1.5$$

$$I = \frac{-1.5}{-3} \times 10^{-3} = 0.5 \text{ mA}$$

■■■■

4

BJT Current Mirrors



Detailed Explanation of Try Yourself Questions

T1. (a)

$$I_{\text{ref}} = \frac{9 - 0.7}{30 \times 10^3} = 0.277 \text{ mA}$$

at node 'a' $I_{\text{ref}} = I_C + 3I_B$
(I_{B3} is assumed negligible)

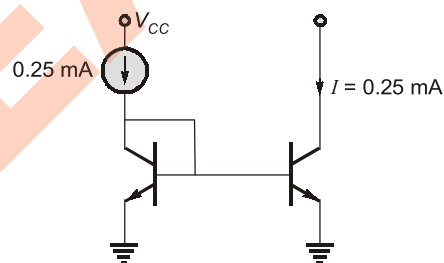
$$= I_C \left(1 + \frac{3}{\beta} \right)$$

$$I_C = I_{\text{ref}} \left(\frac{\beta}{3 + \beta} \right)$$

$$= 0.277 \times 10^{-3} \left(\frac{125}{128} \right)$$

$$I_{C1} = 0.27 \text{ mA}$$

T2. (c)



Using current mirror concept,
For large ' β ',

$$I = I_{\text{ref}}$$

so,

$$I_y = (0.25 + 0.25 + 0.25) \text{ mA}$$

$$I_x = (0.25 + 0.25) \text{ mA}$$

$$I_x + I_y = (0.25) 5 \text{ mA} \\ = 1.25 \text{ mA}$$

■■■■

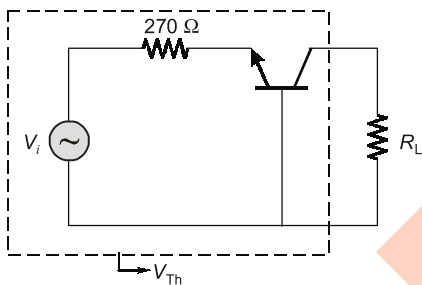
5

Small Signal Analysis of BJT Amplifiers



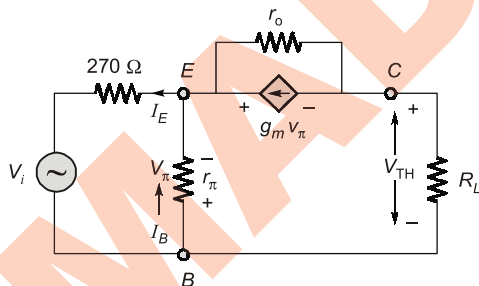
Detailed Explanation of Try Yourself Questions

T1. (d)



$$g_m = 2 \text{ mS} ; r_o = 250 \text{ k}\Omega$$

$$r_\pi = \beta r_e = \frac{\beta}{g_m} = \frac{100}{2 \text{ mS}} = 50 \text{ k}\Omega$$



$$V_\pi = -V_i \times \frac{r_\pi}{r_\pi + 270}$$

$$= \frac{-50 \text{ k}}{50 \text{ k} + 270} V_i = -0.994 V_i$$

$$V_{Th} + r_o g_m V_\pi - V_\pi = 0$$

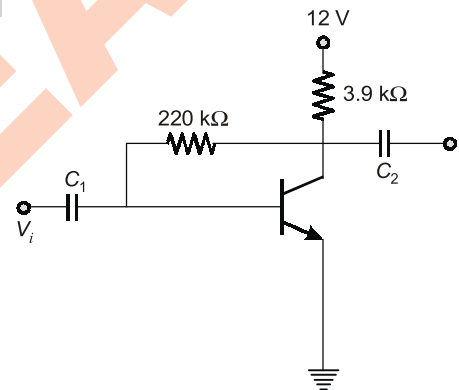
$$V_{Th} = -r_o g_m V_\pi - V_\pi$$

$$= -(1 + g_m r_o) (-0.994 V_i)$$

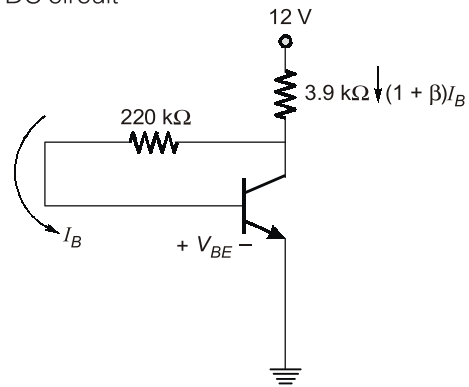
$$= -(1 + 2 \text{ mS} \times 250 \text{ k}\Omega) \times 0.994 V_i$$

$$V_{Th} = 497.9 V_i$$

T2. (d)



DC circuit

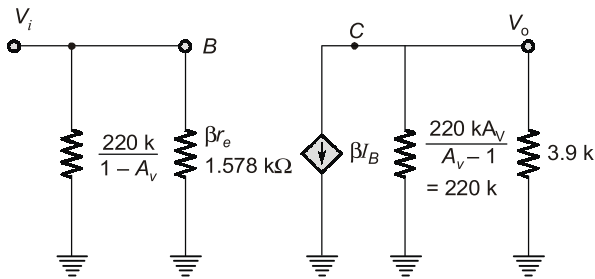


$$I_B = \frac{12 - 0.7}{(1 + \beta) 3.9 \text{ k} + 220 \text{ k}}$$

$$= 0.0163 \text{ mA}$$

$$I_E = (1 + \beta) I_B = 1.97 \text{ mA}$$

$$r_e = \frac{V_T}{I_E} = \frac{26 \text{ mV}}{1.97 \text{ mA}} = 13.15 \Omega$$



$$V_o = -(220 \text{ k} \parallel 3.9 \text{ k}) \beta I_B$$

$$A_v = \frac{-R_C \parallel R_L}{r_e} = \frac{-3.83 \text{ k}}{13.15} = -291.41$$

$$Z_i = \frac{V_i}{I_i} = \frac{220 \text{ k}}{1 - A_v} \parallel \beta r_e = 0.752 \text{ k} \parallel 1.578 \text{ k} = 0.509 \text{ k}\Omega = 509.4 \Omega$$

T3. (b)

$$A_I = \frac{-h_{fe}}{1 + h_{oe} R_L} = \frac{-50}{1 + \frac{1}{40} \times 10}$$

$$\Rightarrow A_I = \frac{-50}{1.25}$$

$$A_v = \frac{A_I \cdot Z_L}{Z_{in}} = \frac{A_I R_L}{h_{ie}}$$

$$A_v = \frac{-50}{1.25} \times \frac{10}{1}$$

$$\Rightarrow A_v = -400$$

T4. (c)

$$R_E = 0.5 \text{ k}\Omega ; \beta = 100$$

$$R_C = 5 \text{ k}\Omega$$

The voltage gain

$$= A_v = \frac{g_m R_C}{1 + g_m R_E} \left(\because R_E \gg \frac{1}{g_m} \right)$$

$$\text{Thus, } |A_v| \simeq \frac{R_C}{R_E} \simeq \frac{5}{0.5} \simeq 10$$

T5. (b)

$$g_m = \frac{I_c}{V_T} = \frac{100 \mu\text{A}}{25 \times 10^{-3} \text{ V}} = 4 \text{ mA/V}$$

Input resistance

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{4 \times 10^{-3}}$$

$$\Rightarrow R_i = r_\pi = 25 \text{ k}\Omega$$

T6. (c)

$$h_{oe} \times R_L < 0.1$$

 $\Rightarrow$ Approximate analysis can be used

$$A_I \approx -h_{fe} = -30$$

$$A_v \approx \frac{-h_{fe} R_L}{h_{ie}} = \frac{-30 \times 2.5}{1} = 75$$

$$A_p = A_v \times A_I = 2250$$

■■■■

6

Testing of MOSFET in Different Operating Regions



Detailed Explanation of Try Yourself Questions

T1. (d)

Given : $V_{Th} = 0.4 \text{ V}$

$$V_{GS} = V_G - V_S = 0.5 - 1.5 \\ = -1 \text{ V}$$

If $V_{GS} < V_{Th}$ in PMOS, M_1 will be ON

$$V_{DS} = V_D - V_S = 0 - 1.5 = -1.5 \text{ V} \\ V_{GS} - V_t = -1 - 0.4 \\ = -1.4 \text{ V}$$

If $V_{DS} \leq V_{GS} - V_t$, M_1 is in current saturation.

T2. (b)

Given : $V_{Th} = 0.4 \text{ V}$

$$V_{GS} = V_G - V_S \\ = 0 - 0.9 = -0.9 \text{ V}$$

If $V_{GS} < V_{Th}$ PMOS M_2 will be ON.

$$V_{DS} = V_D - V_S = 0.9 - 0.9 = 0$$

If $V_{DS} = 0 \text{ V}$ or mV, M_2 will be in ohmic.

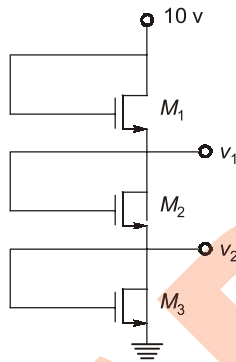
■■■■



Detailed Explanation of Try Yourself Questions

T1. (a)

If $V_D = V_G \therefore$ we conclude that each MOSFET is in saturation.



MOSFET M_1

$$I_D = k_{n1} (V_{GS} - V_T)^2$$

$$I_D = k_{n1} (V_{GS1} - V_T)^2$$

$$V_{GS1} = 10 - 5 = 5 \text{ V}$$

$$0.5 \text{ mA} = 36\mu \times \frac{1}{2} \cdot \left(\frac{W}{L}\right) \times (5 - 1)^2$$

$$\left(\frac{W}{L}\right)_1 = 1.73$$

MOSFET M_2

$$I_D = k_{n2} (V_{GS2} - V_T)^2$$

$$0.5 \text{ mA} = 36\mu \times \frac{1}{2} \left(\frac{W}{L}\right)_2 (3 - 1)^2$$

$$\left(\frac{W}{L}\right)_2 = 6.94$$

MOSFET M_3

$$I_D = k_{n3} (V_{GS3} - V_T)^2$$

$$0.5 \text{ mA} = 36\mu \times \frac{1}{2} \left(\frac{W}{L}\right)_3 (2 - 1)^2$$

$$\left(\frac{W}{L}\right)_3 = 27.8$$

T2. (a)

To calculate the value of V_{DS} , we require the voltage of both drain and source terminal. Now, assuming the transistor to be in saturation region, the value of V_{GS} can be calculated as

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

$$1 \times 10^{-3} = 0.5 \times 10^{-3} \times (V_{GS} - V_T)^2$$

$$\sqrt{2} + 1.2 = V_{GS}$$

$$V_{GS} = 1.414 + 1.2$$

$$V_{GS} = 2.614 \text{ V}$$

Now, $V_{GS} = V_G - V_S$

$\therefore V_G = 0$

Thus $V_S = -2.614 \text{ V}$

And $V_D = 5 \text{ V}$

Thus, $V_{DS} = V_D - V_S = 5 - (-2.614)$

$$V_{DS} = 7.614 \text{ V}$$

$V_{DS} > V_{GS} - V_T$, so our assumption is correct.

9

Small Signal Analysis of MOSFET Amplifiers



Detailed Explanation of Try Yourself Questions

T1. (b)

It is common drain amplifier.

$$A_v = \frac{g_m R_s}{1 + g_m R_s} = \frac{g_m 4 \text{ k}\Omega}{1 + g_m 4 \text{ k}\Omega} = 0.95$$

$$g_m = 4.75 \text{ mS}$$

$$g_m = 2 k_n (V_{GS} - V_T)$$

$$= 2 k_n \left(\sqrt{\frac{I_D}{k_n}} + V_T - V_T \right)$$

$$g_m = 2\sqrt{I_D k_n}$$

$$g_m = 2 \sqrt{I_D \times \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right)}$$

$$\frac{W}{L} = 47$$

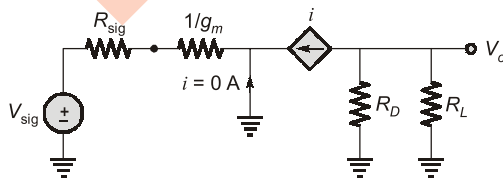
T2. (c)

$$g_m = 2\sqrt{k_n I_D}$$

$$= 2\sqrt{10 \times 10^{-3} \times 10 \times 10^{-3}}$$

$$g_m = 20 \text{ mA/V}$$

now, drawing the T equivalent model, we have



$$i = - \frac{V_{sig}}{\frac{1}{g_m} + R_{sig}}$$

and

$$V_{out} = \frac{(R_D \parallel R_L) \cdot V_{sig}}{\frac{1}{g_m} + R_{sig}}$$

$$V_{out} = \frac{g_m (R_D \parallel R_L)}{1 + g_m R_{sig}} \cdot V_{sig}$$

$$\therefore V_{out} = \frac{20 \times 10^{-3} (2 \times 10^3 \parallel 2 \times 10^3) \times 1 \times 10^{-3}}{1 + 20 \times 10^{-3} \times 50}$$

$$V_{out} = 10 \text{ mV}$$

T3. (b)

$$g_m = 2 \left[\frac{\mu_n C_{ox} W}{2L} \right] (V_{GS} - V_{TN})$$

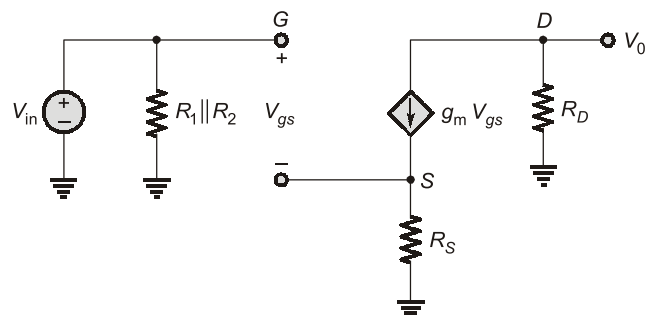
or

$$g_m = 2 \sqrt{\frac{\mu_n C_{ox} W}{2L} \times I_{DQ}}$$

$$= 2 \sqrt{1 \times 10^{-3} \times 0.5 \times 10^{-3}}$$

$$= 1.414 \text{ mA/V}$$

Thus, considering small signal model, we get,



Thus,

$$V_0 = -g_m V_{gs} R_D$$

$$V_{in} = V_{gs} + (g_m V_{gs}) R_S$$

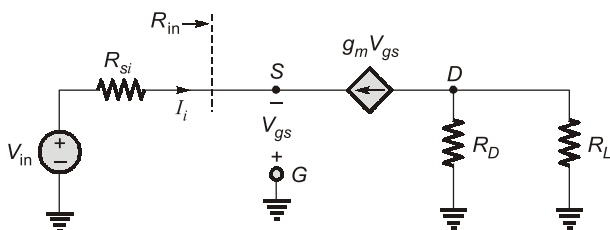
$$V_{in} = V_{gs} (1 + g_m R_S)$$

$$A_v = \frac{V_0}{V_{in}} = \frac{-g_m R_D}{1 + g_m R_S}$$

$$A_v = \frac{-(1.414)(7)}{1 + (1.414)(0.5)} = -5.80$$

T4. (b)

By drawing the small signal equivalent circuit by deactivating all the D.C. supplies, we get,



Now, from the figure,

$$R_{in} = \frac{-V_{gs}}{I_i}$$

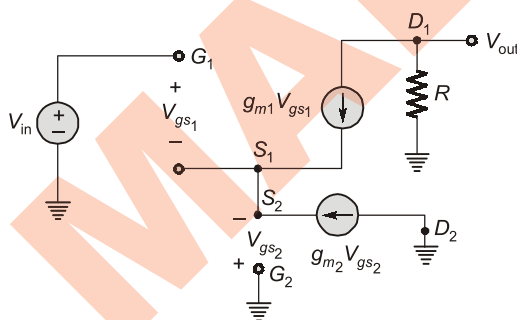
and

$$I_i = -g_m V_{gs}$$

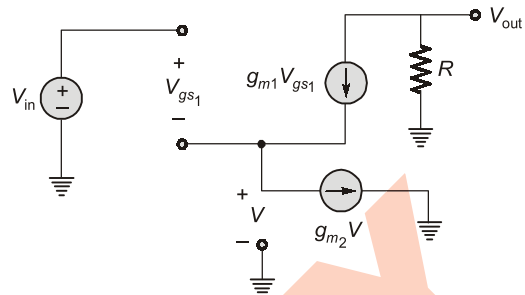
$$\therefore R_{in} = \frac{-V_{gs}}{-g_m V_{gs}} = \frac{1}{g_m}$$

T5. (a)

By drawing the small signal equivalent circuit, we get



the above circuit can be redrawn as



$$\text{Substituting } V = -V_{gs2} \text{ now, } V_{in} = V_{gs1} + V \quad \dots(i)$$

$$\text{and } g_{m1} V_{gs1} = g_{m2} V \quad (\because \text{from KCL at node } S_1) \quad \dots(ii)$$

$$\text{thus } V_{out} = -[g_{m1} V_{gs1} R] \quad \dots(iii)$$

$$V_{out} = -g_{m1} R (V_{in} - V) \quad (\text{from (i)})$$

$$= -g_{m1} R V_{in} + g_{m1} R V$$

$$\text{now, } V = \frac{g_{m1} V_{gs1}}{g_{m2}} \quad (\text{from equation (ii)})$$

$$V_{out} = -g_{m1} R V_{in} + \frac{g_{m1} R V_{gs1}}{g_{m2}} \cdot g_{m1}$$

now from (3), we get

$$V_{out} = -g_{m1} R V_{in} - \frac{g_{m1}}{g_{m2}} V_{out}$$

$$\left(1 + \frac{g_{m1}}{g_{m2}}\right) V_{out} = -g_{m1} R V_{in}$$

$$V_{out} = \frac{-g_{m1} R}{1 + \frac{g_{m1}}{g_{m2}}} V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{-R}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}}$$

Hence, option (a) is correct.

■■■■

10

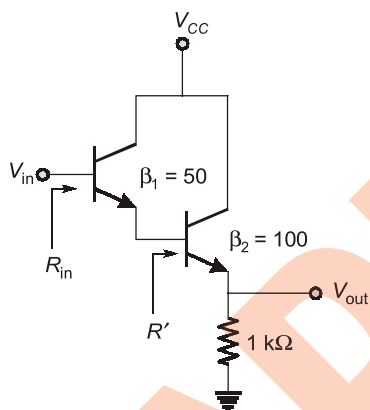
Multistage Amplifiers



Detailed Explanation of Try Yourself Questions

T1. (b)

The input resistance will be



$$R' = r_{\pi} + (\beta_2 + 1)R_E$$

$$= 1\text{ k} + (101)(1\text{ k}) = 102\text{ k}\Omega$$

$$R_{in} = r_{\pi} + (\beta_1 + 1)R'$$

$$= 1\text{ k} + (51)(102\text{ k}) = 5.203\text{ M}\Omega$$

■■■■

11

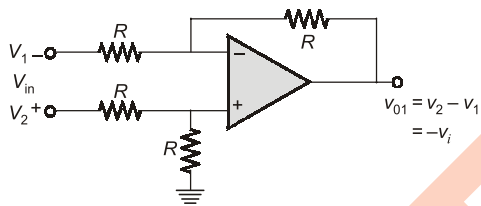
Differential Amplifiers & Operational Amplifiers



Detailed Explanation of Try Yourself Questions

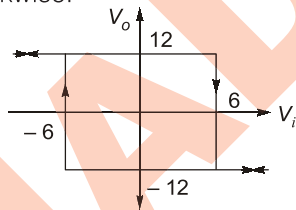
T1. (b)

Output of op-amp 1

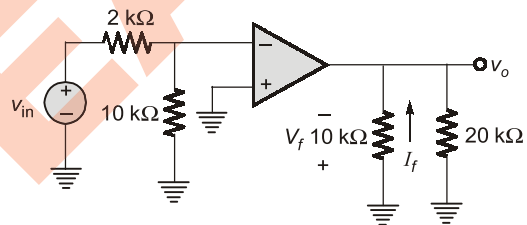


It is connected to schmitt trigger (inverting mode) → clockwise.

But inverting amplifier + inverting schmitt trigger → anticlockwise.



voltage shunt



$$\beta = \frac{V_f}{V_o} = -1$$

$$\beta = \frac{I_f}{V_o} = -\frac{1}{10k}$$

$$|\beta| = \frac{1}{10k}$$

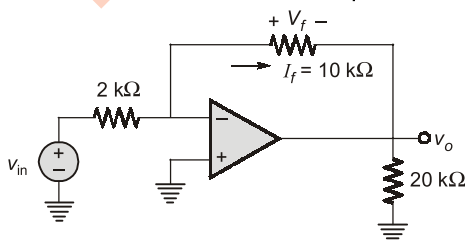
$$R_{if} = \frac{R_i}{A\beta} = \frac{10k}{10^5 \times \frac{1}{10k}}$$

$$= \frac{10 \times 10 \times 10^6}{10^5}$$

$$R_{if} = 1 k\Omega$$

T2. (b)

$$R_{if} = \frac{R_i}{1 + A\beta} = \frac{R_i}{A\beta} \quad A\beta \gg 1$$



T3. (0.5)

Applying the concept of virtual ground, we get,

$$V_o = -\frac{R_2}{R_1} \cdot V_{in}$$

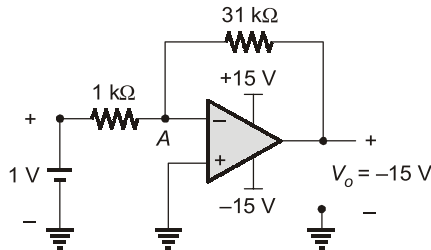
[∵ non-inverting amplifier]

$$\therefore V_o = -\frac{31\text{k}\Omega}{1\text{k}\Omega} \times 1\text{V}$$

$$V_o = -31\text{V} < -15\text{V}$$

which is not possible

Hence, the output voltage of the op-amp is equal to -15V .



Now applying KCL of node 'A', we get,

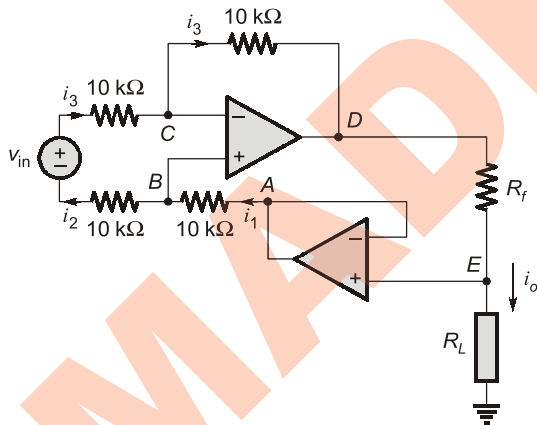
$$\frac{V_A - (-15)}{31\text{k}\Omega} + \frac{V_A - 1}{1\text{k}\Omega} = 0$$

$$\frac{V_A}{31\text{k}\Omega} + \frac{V_A}{1\text{k}\Omega} = \frac{-15}{31\text{k}\Omega} + \frac{1}{1\text{k}\Omega}$$

$$V_A \left[\frac{1}{31} + \frac{1}{1} \right] = \frac{-15}{31} + 1$$

$$V_A = 0.5\text{V}$$

T4. (b)



From the circuit,

$$V_E = i_o R_L$$

$$V_E = V_A \text{ (Virtual short concept)}$$

$$i_1 = i_2 = i_3$$

If we apply KVL between node B and C,

$$\therefore V_B = V_C \text{ (Virtual short concept)}$$

$$i_1 = i_2 = i_3 = \frac{V_{in}}{20\text{k}\Omega}$$

$$V_C - V_D = i_3 \times 10\text{k}\Omega = \frac{V_{in}}{2}$$

$$\text{and } V_A - V_B = i_1 \times 10\text{k}\Omega = \frac{V_{in}}{2}$$

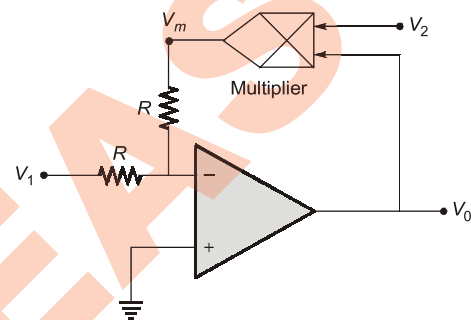
$$\therefore V_B = V_C$$

$$\Rightarrow V_D - V_E = -V_{in}$$

$$\therefore i_o = \frac{-V_{in}}{R_f}$$

T5. (b)

From the given figure



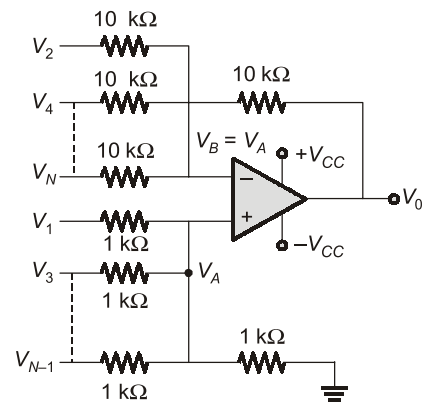
$$V_m = V_2 \times V_0$$

$$\text{and } V_m = -V_1 \left(\frac{R}{R} \right) = -V_1$$

$$\text{Thus, } -V_1 = V_2 \times V_0$$

$$V_0 = -\frac{V_1}{V_2} = \frac{-15}{3} = -5\text{ Volts}$$

T6. (15)



Node A:

$$\frac{V_A - V_1}{1\text{K}} + \frac{V_A - V_3}{1\text{K}} + \dots + \frac{V_A - V_{N-1}}{1\text{K}} + \frac{V_A}{1\text{K}} = 0$$

$$V_A \left(\frac{N}{2} + 1 \right) = V_1 + V_3 + \dots + V_{N-1}$$

$$V_B = V_A \quad \therefore \text{Virtual short}$$

Node B:

$$\frac{V_A - V_2}{10K} + \frac{V_A - V_4}{10K} + \dots + \frac{V_A - V_N}{10K} + \frac{V_A - V_0}{10K} = 0$$

$$V_0 = V_A \left(\frac{N}{2} + 1 \right) - (V_2 + V_4 + V_6 + \dots + V_N)$$

$$= \left(\frac{N}{2} + 1 \right) \cdot \frac{(V_1 + V_3 + \dots + V_{N-1})}{\left(\frac{N}{2} + 1 \right)} - (V_2 + V_4 + \dots + V_N)$$

$$= V_1 - V_2 + V_3 - V_4 + \dots$$

$$= 1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} \dots$$

$$= \sum \frac{1}{N} = \infty$$

$\Rightarrow$ Output of op-amp goes to saturation

$$V_0 = V_{\text{sat}} = V_{CC} = 15 \text{ V}$$

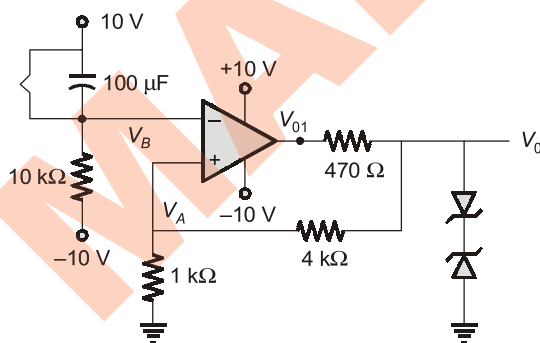
T7. (0.798)

Initially switch is closed and $V_B = 10 \text{ V}$

$$\Rightarrow V_{01} = -10 \text{ V}$$

$$\Rightarrow V_0 = -V_2 = -5 \text{ V}$$

$$\Rightarrow V_A = \frac{V_0}{4k + 1k} \times 1k = -1 \text{ V}$$



At $t = 0$;

The switch is opened and as $t \rightarrow \infty$, V_B approaches -10 V .

Let at $t = T_1$,

V_B exceeds V_A (-1 V) so that V_{01} changes from -10 V to 10 V

$\Rightarrow V_0$ charges from -5 V to 5 V

$$V_B = V_f + (V_i - V_f) e^{-t/\tau}$$

$$= -10 + [10 - (-10)] e^{-t/RC}$$

$$\text{At } t = T_1 \quad V_B = -1$$

$$-1 \text{ V} = -10 + 20 e^{-T_1/RC}$$

$$\Rightarrow T_1 = RC \ln \frac{20}{9}$$

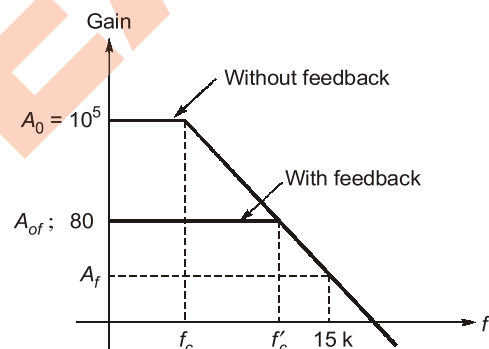
$$= 10 \times 10^3 \times 100 \times 10^{-6} \times 0.798$$

$$= 0.798 \text{ sec}$$

T8. (44.4)

• In the given circuit,

$$\text{Feedback factor, } \beta = \frac{R_1}{R_1 + R_2} = \frac{1}{80}$$



$$A_{of} = \frac{A_o}{1 + A_o \beta} \approx 80$$

$$f'_c = f_c (1 + A_o \beta) = 8 \left(1 + \frac{10^5}{80} \right) \text{ Hz} = 10,008 \text{ Hz}$$

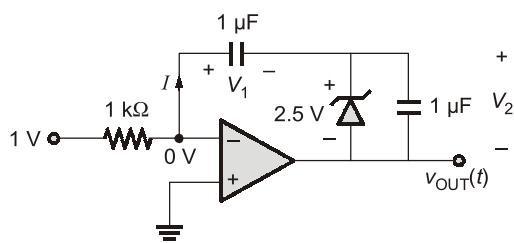
• Gain at $f = 15 \text{ kHz} = 15000 \text{ Hz}$ is,

$$A_f = \frac{A_{of}}{\sqrt{1 + \left(\frac{f}{f'_c} \right)^2}}$$

$$= \frac{80}{\sqrt{1 + \left(\frac{15000}{10008} \right)^2}} \approx 44.4$$

T9. (c)

For $t > 0$,



$$I = \frac{1V}{1k\Omega} = 1mA$$

The capacitor charges with constant current I and both V_1 and V_2 will increase till V_2 reaches 2.5 V. Thereafter, $V_2 = 2.5$ V and V_1 increases with time.

When $v_{out}(t) = -10$ V,

$$V_1 = 7.5 \text{ V}$$

So,

$$\frac{1}{1\mu F} \int_0^t (1mA) dt = 7.5 \text{ V}$$

$$10^3 t = 7.5$$

$$t = 7.5 \text{ msec}$$

■■■■

12

Negative Feedback Amplifiers & Oscillators



Detailed Explanation of Try Yourself Questions

T1. (a)

The overall forward gain is 1000 and close loop gain is 100. Thus, $\beta = 0.009$.

Now, when gain of each stage increase by 10% then overall forward gain will be 1331 and using the previous value of β the close loop will be 102.55.

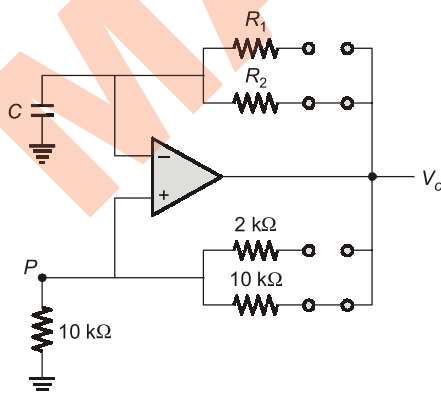
$\Rightarrow$ Close loop Voltage gain increase by 2.55%.

T2. (b)

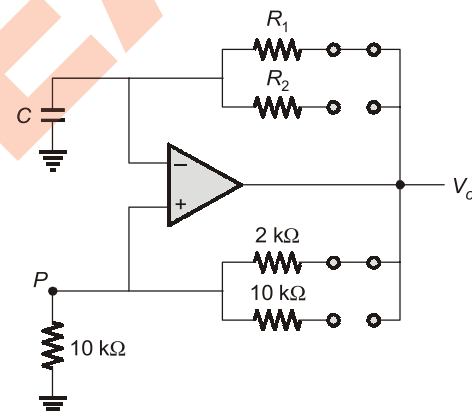
The feedback element is R_f it samples voltage and mix current so shunt-shunt feedback.

T3. (a)

The output can be ± 12 V only, when output is 12 V then



So, $V_p = 6$ V
when output is -12 V then



So, $V_p = -10$ V

T4. (d)

Since there are 3 capacitors the maximum phase shift that can be provided will be 270° but due to the presence of the RC circuit the phase shift is equal to 60° for the individual RC circuit, making the phase shift of the feedback network equal to 180° . Thus the amplifier should be an inverting amplifier so that it can be a positive feedback circuit and because the amplifier is a practical amplifier thus $|A\beta| > 1$ for the circuit to work.

■■■■

14

Bipolar Junction Transistor



Detailed Explanation of Try Yourself Questions

T1. (c)

$$\therefore (\beta + 1) = \frac{I_{CEO}}{I_{CBO}} = \frac{0.6 \times 10^{-3}}{3 \times 10^{-6}} = 200$$

$$\therefore \beta = 199$$

T2. (d)

$$\therefore I_B = 0$$

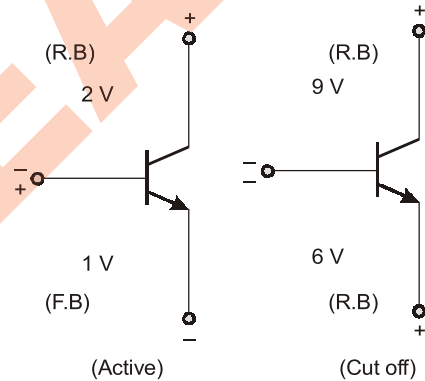
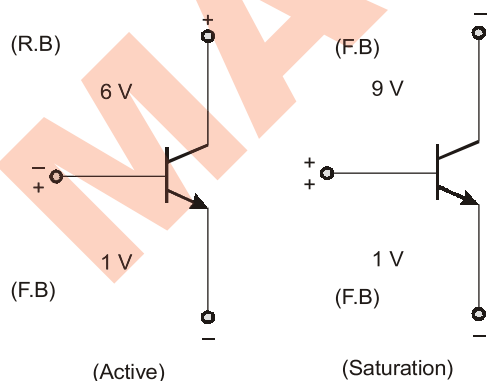
then only emitter to collector current will flow

$$\therefore I_{CEO} = (\beta + 1)I_{CBO}$$

$$= 101 \times 15 \times 10^{-6}$$

$$= 1515 \mu\text{A} = 1.515 \text{ mA}$$

T3. (c)



T4. (c)

If base length > length of diffusion then the carriers will not enter the collector.

T5. Sol.

$$I_C = \beta I_C + (\beta + 1)I_{CO}$$

$$\text{Now, } \beta + 1 = \frac{I_{CEO}}{I_{CBO}} = \frac{0.6 \times 10^{-3}}{3 \times 10^{-6}} = 200$$

$$\therefore \beta = 199$$

$$\therefore I_C = 199(10 \mu\text{A}) + (1 + 199) \times 3 \times 10^{-6}$$

$$= 2.59 \times 10^{-3} \text{ Amp}$$

■■■■