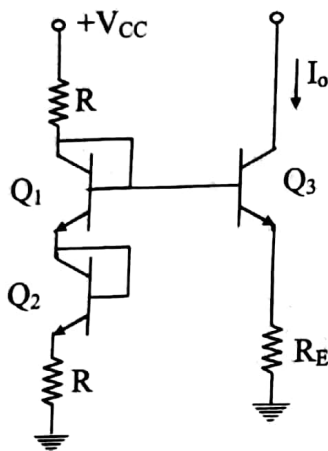


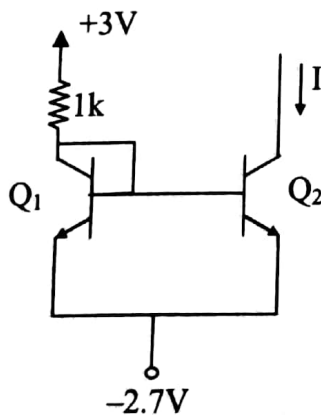
Practice Questions

01. Consider all transistors conduct same current and same V_{BE} show that

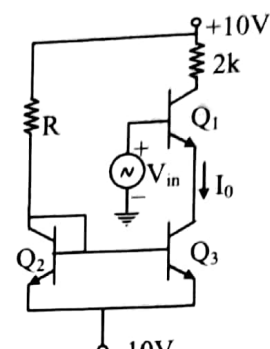
$$I_o = \frac{V_{CC}}{2R_E} \quad (\text{Consider } \beta \text{ large})$$



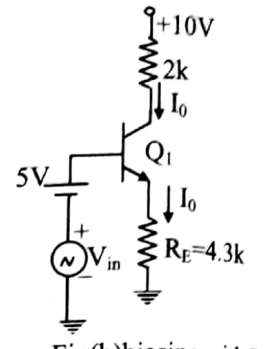
02. If Q_1 and Q_2 have same high β , find I



03. The transistor Q_1 is biased at a DC collector current I_o . Biasing is possible with resistor R_E . In the absence of R_E , we can use a current mirror to bias the BJT. If Q_1 is biased at same I_o , find resistance R ?

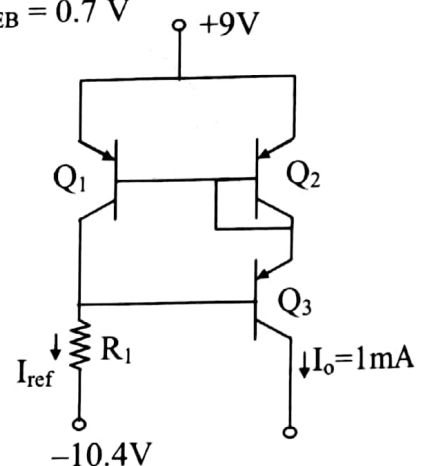


Fig(a) biasing with current mirror

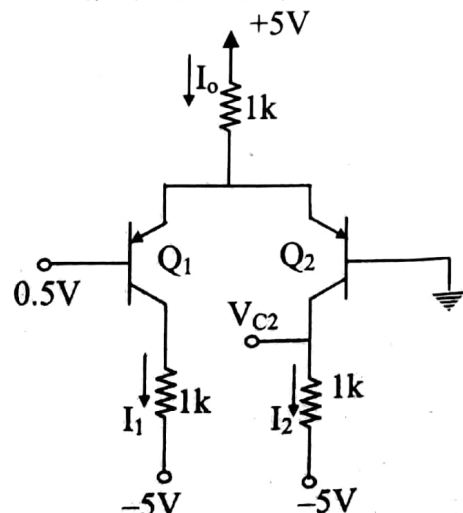


Fig(b) biasing with R_E

04. The circuit is a PNP version of Wilson current source to establish I_{ref} . If load current $I_o = 1\text{mA}$, find R_1 if β is very large and $V_{EB} = 0.7\text{V}$

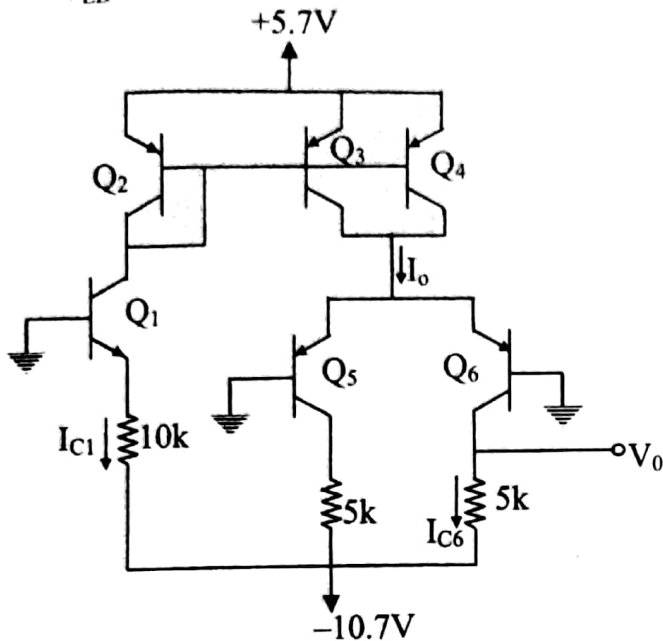


05. Find I_o , I_1 , I_2 , V_{C2} if β is large $V_{EB} = 0.7\text{V}$





06. Find I_o , V_o , I_{C1} and I_{C6} if β is large
 $V_{EB} = 0.7V$



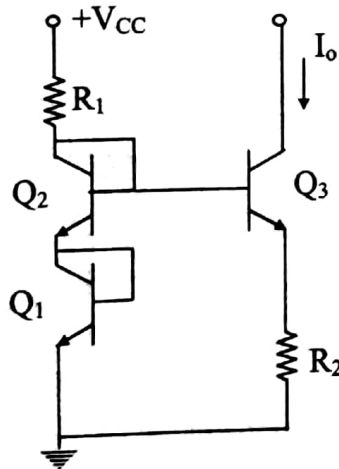
07. The current I_o for the given circuit shown is

(a) $\frac{V_{CC} - V_{BE}}{R_1 + R_2}$

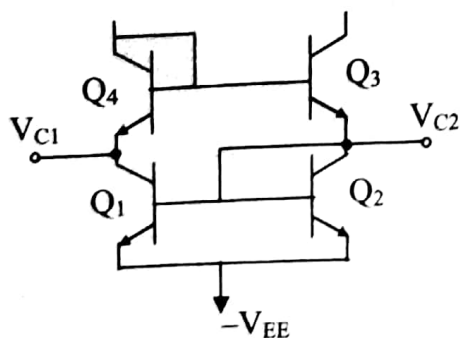
(b) $\frac{V_{CC}}{R_2}$

(c) $\frac{2V_{BE}}{R_1 + R_2}$

(d) $\frac{V_{BE}}{R_2}$

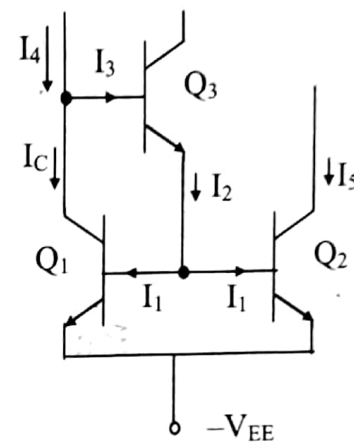


08. In the four transistor current mirror, which statement is correct

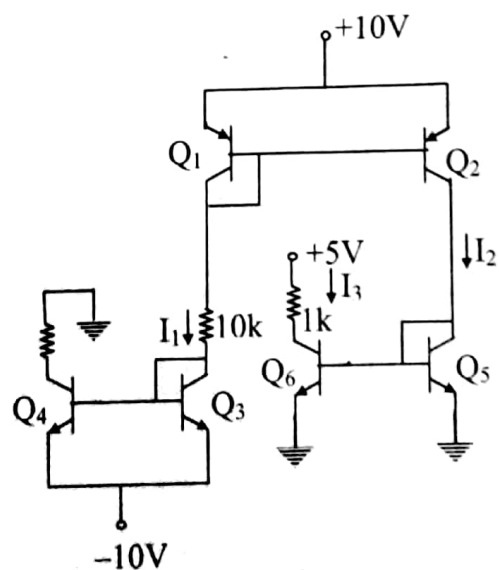


- (a) $V_{C1} = V_{C2}$
(b) $V_{C1} = 2V_{C2}$
(c) $V_{C1} = V_{BE} + V_{C2}$
(d) $V_{C2} = V_{BE} + V_{C1}$

09. A bipolar current mirror with base current compensation is shown. Transistor Q_1 and Q_2 are perfectly matched. Find I_1 , I_2 , I_3 , I_4 , I_5 in terms of I_C .

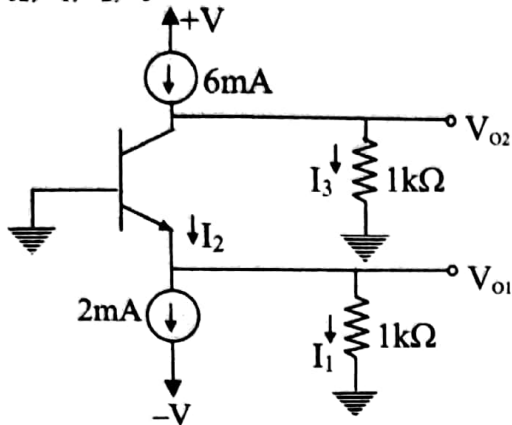


10. Find I_1 , I_2 & I_3 if $|V_{BE}| = 0.7V$ and β is very large.

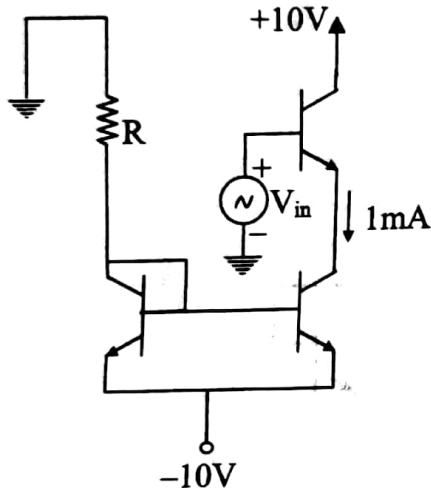




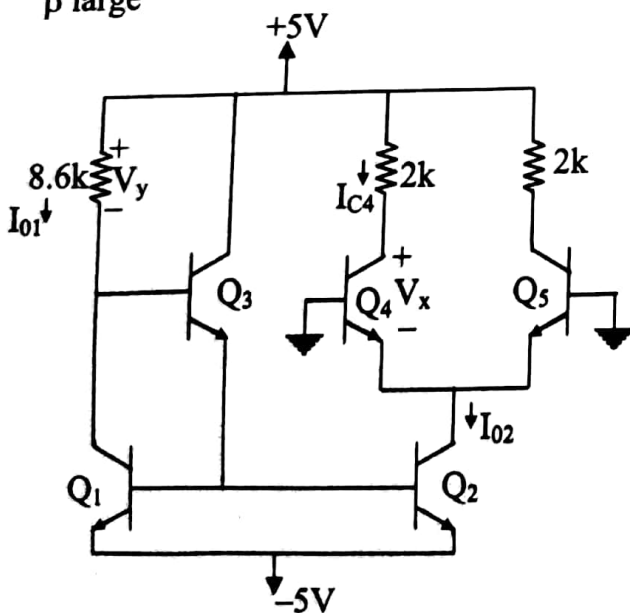
11. Given $V_{BE} = 0.7 \text{ V}$ and β large, find V_{O1} , V_{O2} , I_1 , I_2 , I_3



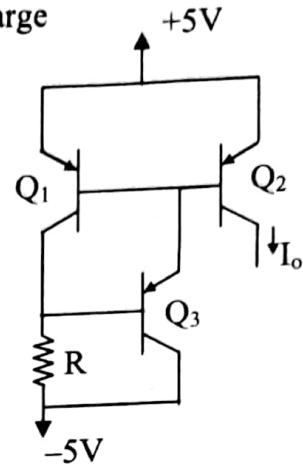
12. Find the value of R if $I = 1 \text{ mA}$ and β large



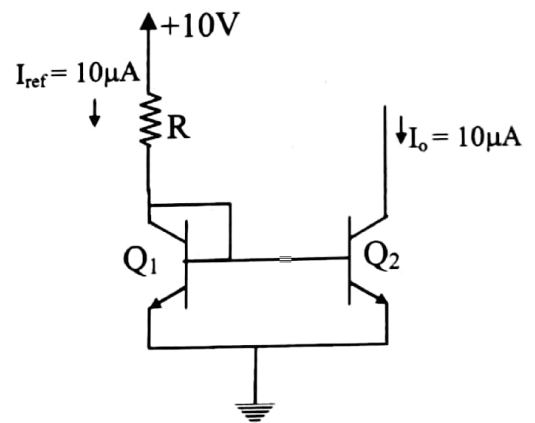
13. Find V_x , V_y , I_{O1} and I_{O2} , if $V_{BE} = 0.7 \text{ V}$, β large



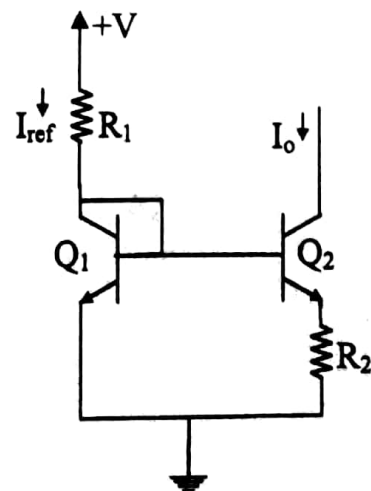
14. Given $I_0 = 0.5 \text{ mA}$, find R if $V_{BE} = 0.7 \text{ V}$ and β large



15. Given $V_{BE} = 0.7$ at $I_C = 1 \text{ mA}$ neglect the effect of finite β . Find R when $I_{ref} = I_0$ also find V_{BE1} (Consider $V_t = 25 \text{ mV}$)

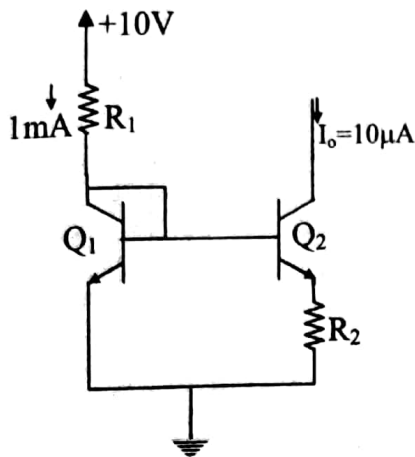


16. Show that $R_2 = \frac{V_t \ln \frac{I_{ref}}{I_0}}{I_0}$

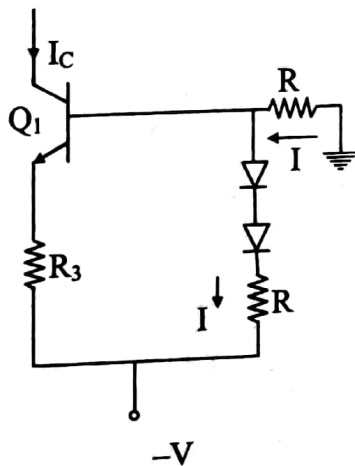




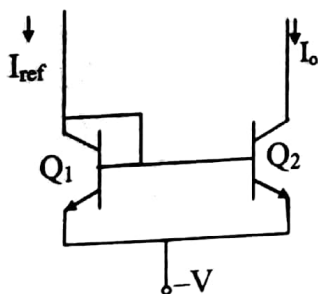
17. Given $V_{BE1} = 0.7V$ and $I_{ref} = 1mA$ find R_2 ?



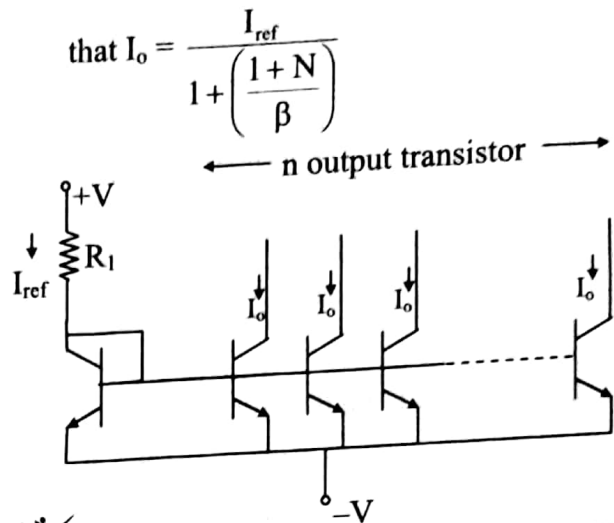
18. Neglecting base current and $V_{D(ON)} = V_{BE} = 0.7V$ show that $I_C = \frac{V}{2R_3}$



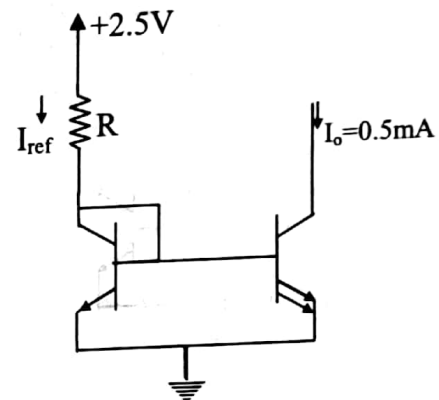
19. Given B-E area of Q_2 is n -times of Q_1 show that $I_o = \frac{n I_{ref}}{1 + \frac{1+n}{\beta}}$



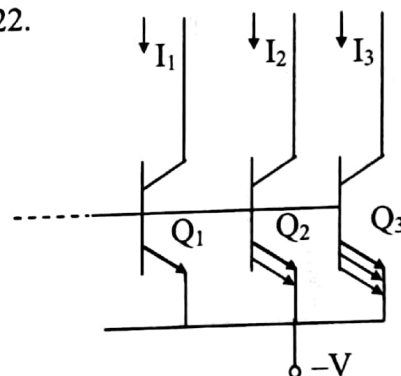
20. Assume all transistors are matched show that $I_o = \frac{I_{ref}}{1 + \left(\frac{1+N}{\beta} \right)}$



21. Find I_{ref} and R_1 if $\beta = 60$ and $V_{BE} = 0.7V$



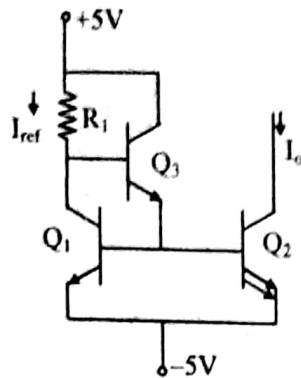
- 22.



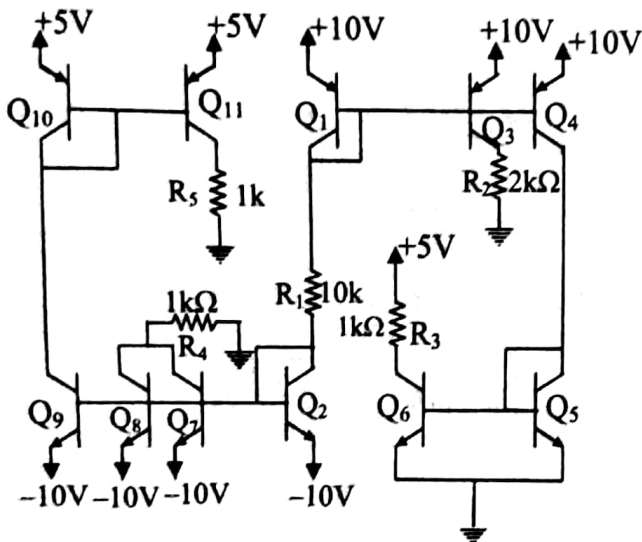
- (a) If Q_1 is diode connected and $I_1 = 0.5mA$, find I_2 and I_3
 (b) If Q_2 is diode connected and $I_2 = 0.5mA$, find I_1 and I_3
 (c) If Q_3 is diode connected and $I_3 = 0.5mA$, find I_1 and I_2



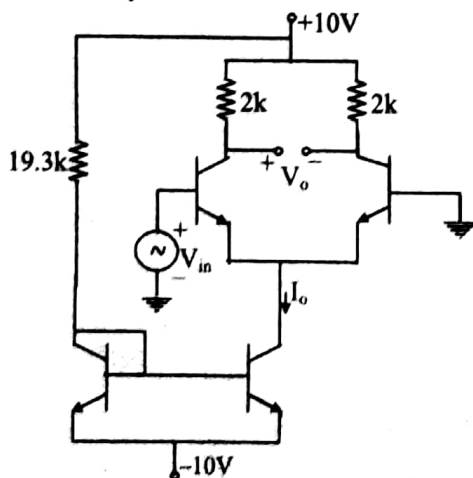
23. Given β very large, $V_{BE} = 0.7 \text{ V}$, $I_o = 2 \text{ mA}$
find I_{ref} and R_1



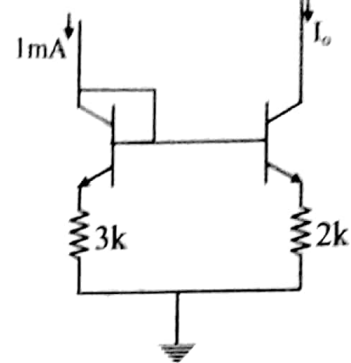
24. Calculate all node voltages and branch currents if $|V_{BE}| = 0.7 \text{ V}$ and $\beta = \infty$



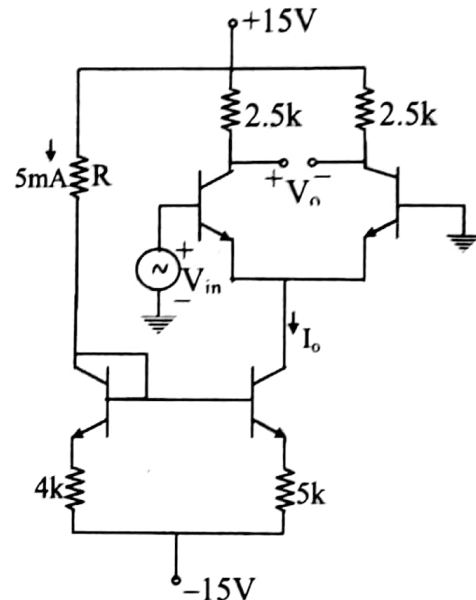
25. Find the differential gain $\frac{V_o}{V_{in}}$, if $V_{BE(ON)} = 0.7 \text{ V}$ and $V_t = 25 \text{ mV}$



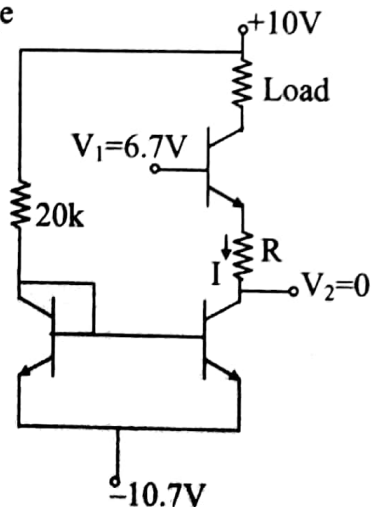
26. Find I_o (approximate), if β is large



27. Find the differential gain (A_d) if $V_{BE(ON)} = 0.7 \text{ V}$ and $V_t = 25 \text{ mV}$

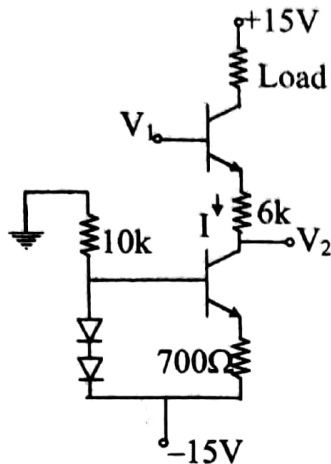


28. Find R in the level shifter circuit if β is large

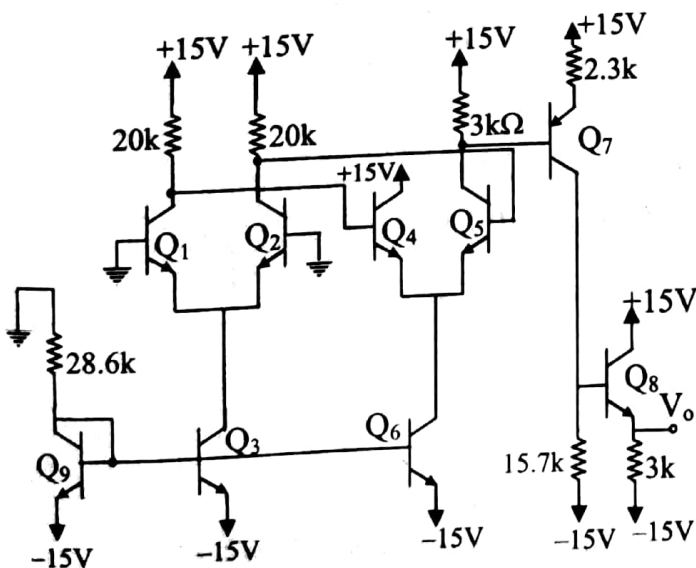




29. Find $(V_1 - V_2)$ for the level shifter circuit given if $V_{BE} = 0.7 = V_{D(ON)}$ and β is large



30. (a) Calculate all the DC currents and voltages in the circuit if Q6 has 4 times the area of each of Q9 and Q3. (Consider β large and $|V_{BE(ON)}| = 0.7$ V)
- (b) Calculate the power dissipation in this circuit
- (c) If transistors Q1 and Q2 have $\beta = 100$, calculate the input bias current of the op-amp.



Solutions

01.

Sol: $V_{B1} = V_{B3}$

$$V_{BE} + V_{BE} + I_o R = V_{BE} + I_o R_E$$

$$I_o = \frac{I_o R_E - V_{BE}}{R} \quad \text{----- (1)}$$

$$\text{But } I_o = \frac{V_{CC} - 2V_{BE}}{2R} \quad \text{----- (2)}$$

$$(1) = (2)$$

$$\frac{I_o R_E - V_{BE}}{R} = \frac{V_{CC} - 2V_{BE}}{2R}$$

$$(I_o R_E) 2 - V_{BE} = V_{CC} - 2V_{BE}$$

$$I_o = \frac{V_{CC}}{2R_E}$$

02.

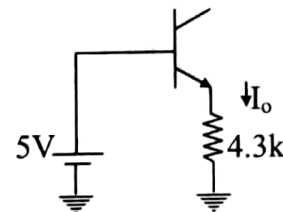
Sol: $V_{B1} = 0.7 - 2.7 = -2V$

$$I = I_{1k\Omega} = \frac{3 - V_{B1}}{1k} = \frac{3 - (-2)}{1k} = 5 \text{ mA}$$

$$\therefore I = 5 \text{ mA}$$

03.

Sol:



$$I_o = \frac{5 - 0.7}{4.3k} = 1 \text{ mA} \quad \text{----- (1)}$$

$$V_{B2} = V_{C2} = 0.7 - 10 = -9.3 \text{ V}$$

$$I_o = \frac{10 - V_{C2}}{R} = \frac{10 - (-9.3)}{R} \quad \text{----- (2)}$$

$$(1) = (2)$$

$$1 \text{ mA} = \frac{19.3}{R}$$

$$\Rightarrow R = 19.3 \text{ k}\Omega$$



04.

Sol: $V_{B1} = V_{B2} = 9 - 0.7 = 8.3 \text{ V}$

$$V_{B3} = V_{B2} - 0.7 = 8.3 - 0.7 = 7.6 \text{ V}$$

$$I_{\text{ref}} = \frac{V_{B3} - (-10.4)}{R_1}$$

$$\Rightarrow I_{\text{ref}} = \frac{7.6 - (-10.4)}{R_1} = \frac{18}{R_1}$$

But $I_o = I_{\text{ref}}$

$$\Rightarrow 1 \text{ mA} = \frac{18}{R_1}$$

$$\Rightarrow R_1 = 18 \text{ k}\Omega$$

05.

Sol: $Q_1 \text{ (OFF)}, Q_2 \text{ (ON)}$

$$\therefore V_{B2} = 0 \text{ V}$$

$$V_{E2} = 0.7 \text{ V}$$

$$I_o = \frac{5 - V_{E2}}{1 \text{ k}\Omega} = 4.3 \text{ mA}$$

$$I_1 = 0 \text{ A and } I_o = I_2 = 4.3 \text{ mA}$$

$$V_{C2} = I_2(1 \text{ k}) - 5 \text{ V} = 4.3 - 5 = -0.7 \text{ V}$$

06.

Sol: $V_{B1} = 0 \text{ V and } V_{E1} = -0.7 \text{ V,}$

$$I_{C1} = \frac{V_{E1} - (-10.7)}{10 \text{ k}} = 1 \text{ mA}$$

$$I_o = 2I_{C1} = 2 \text{ mA and } I_{C6} = \frac{I_o}{2} = 1 \text{ mA}$$

$$V_o = I_{C6}(5 \text{ k}) - 10.7 \text{ V} = 1 \text{ m}(5 \text{ k}) - 10.7 \\ = -5.7 \text{ V}$$

07. **Ans: (d)**

Sol: $V_{B2} = V_{B3}$

$$2 V_{BE} = V_{BE} + I_o R_2$$

$$\Rightarrow I_o = \frac{V_{BE}}{R_2}$$

08. **Ans: (a)**

Sol: $V_{B4} = V_{B3}$

$$V_{BE} + V_{C1} = V_{BE} + V_{C2}$$

$$V_{C1} = V_{C2}$$

09.

Sol: $I_1 = I_C/\beta, I_2 = 2I_C/\beta$

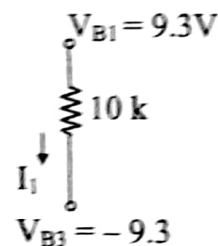
$$I_3 = \frac{2I_C/\beta}{\beta+1} = \frac{2I_C}{\beta(\beta+1)}$$

$$I_4 = I_C + I_3 = I_C \left[1 + \frac{2}{\beta(\beta+1)} \right]$$

$$I_5 = I_C$$

10.

Sol:



$$V_{E1} = 10 \text{ V and } V_{B1} = 10 - 0.7 = 9.3 \text{ V}$$

$$V_{E3} = -10 \text{ V and } V_{B3} = 0.7 - 10 = -9.3$$

$$I_1 = \frac{9.3 - (-9.3)}{10 \text{ k}} = 1.86 \text{ mA}$$

$$\therefore I_1 = I_2 = I_3 = 1.86 \text{ mA}$$

11.

Sol: $V_{o1} = -0.7 \text{ V}$

$$I_1 = \frac{V_{o1}}{1 \text{ k}} = -0.7 \text{ mA}$$

$$I_2 = 2 \text{ mA} + I_1 = 1.3 \text{ mA}$$

$$I_2 + I_3 = 6 \text{ mA}$$

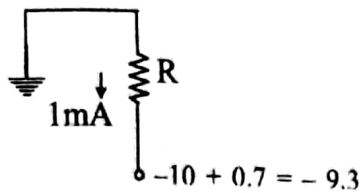
$$I_3 = 6 \text{ mA} - I_2 = 4.7 \text{ mA}$$

$$V_{o2} = I_3(1 \text{ k}) = 4.7 \text{ m}(1 \text{ k}) = 4.7 \text{ V}$$



12.

Sol:



$$R = \frac{0 - (-9.3)}{1\text{m}} = 9.3\text{k}$$

13.

Sol: $V_{B1} = 0.7 - 5 = -4.3\text{ V}$,

$$V_{B3} = 0.7 + V_{B1} = -3.6\text{ V}$$

$$I_{O1} = \frac{5 - V_{B3}}{8.6\text{k}} = 1\text{mA} = I_{O2}$$

$$I_{C4} = I_{O1}/2 = 0.5\text{ mA}$$

$$V_{C4} = 5 - I_{C4}(2\text{k}) = 5 - 0.5\text{ m}(2\text{k}) = 4\text{ V}$$

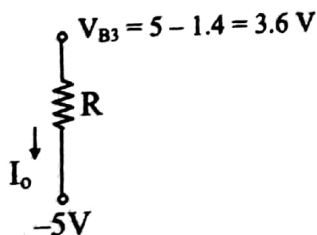
$$V_{E4} = -0.7\text{ V}$$

$$\therefore V_x = V_{C4} - V_{E4} = 4 - (-0.7) = 4.7\text{ V}$$

$$V_y = 5 - V_{B3} = 5 - (-3.6) = 8.6\text{ V}$$

14.

Sol:



$$R = \frac{V_{B3} - (-5)}{I_O} = \frac{3.6 - (-5)}{0.5\text{m}} = 17.2\text{ k}\Omega$$

15.

Sol: $I_C = I_S e^{\frac{V_{BE}}{V_t}}$

$$V_{BE} = V_t \ln \left[\frac{I_C}{I_S} \right]$$

$$V_{BE1} = V_t \ln \left[\frac{I_{C1}}{I_S} \right]$$

$$V_{BE2} = V_t \ln \left[\frac{I_{C2}}{I_S} \right]$$

$$V_{BE1} - V_{BE2} = V_t \ln \left[\frac{I_{C1}}{I_{C2}} \right]$$

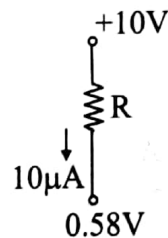
Given $V_{BE} = 0.7$ at $I_C = 1\text{mA}$,

Let us find V_{BE} at $I_C = 10\text{ }\mu\text{A}$

$$\therefore V_{BE1} - 0.7 = V_t \ln \left[\frac{10\mu}{1\text{m}} \right]$$

$$V_{BE1} = 0.7 + 25\text{m} \ln \left[\frac{10\mu}{1\text{m}} \right] = 0.58$$

In the Given Circuit



$$R = \frac{10 - 0.58}{10\mu} = 942\text{ k}\Omega$$

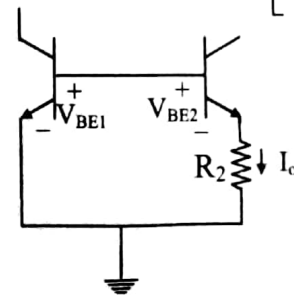
16.

Sol: $I_{C1} = I_S e^{\frac{V_{BE1}}{V_t}}$

$$I_{C2} = I_S e^{\frac{V_{BE2}}{V_t}}$$

$$\frac{I_{C1}}{I_{C2}} = e^{\frac{V_{BE1} - V_{BE2}}{V_t}} = \frac{I_{\text{ref}}}{I_O}$$

$$\therefore V_{BE1} - V_{BE2} = V_t \ln \left[\frac{I_{\text{ref}}}{I_O} \right] \text{ ----- (1)}$$





KVL

$$-V_{BE1} + V_{BE2} + I_o R_2 = 0$$

$$I_o R_2 = V_{BE1} - V_{BE2} \text{ ----- (2)}$$

Sub (2) in (1)

$$I_o R_2 = V_t \ln \left[\frac{I_{ref}}{I_o} \right]$$

$$\therefore R_2 = \frac{V_t \ln \left[\frac{I_{ref}}{I_o} \right]}{I_o}$$

17.

$$\text{Sol: } R_2 = \frac{V_t \ln \left[\frac{I_{ref}}{I_o} \right]}{I_o} = \frac{25 \text{ mV} \ln \left[\frac{1 \text{ m}}{10 \mu} \right]}{10 \mu} = 11.5 \text{ k}\Omega$$

Conclusion:

In problem 15, for biasing a BJT at $10 \mu\text{A}$ we require a resistance of $942 \text{ k}\Omega$. This resistor is impractical to implement in I_C form. Hence we go for widlar current source in prob 17.

Here,

$$R_1 = \frac{10 - 0.7}{1 \text{ m}} = 9.3 \text{ k} \text{ and}$$

$$R_2 = 11.5 \text{ k}\Omega$$

For biasing Q_2 at $10 \mu\text{A}$. Therefore 11.5 k is low value of resistor that results in considerable saving in chip area.

18.

Sol: KVL

$$IR + 0.7 + 0.7 + IR - V = 0$$

$$\Rightarrow V = 2(IR + 0.7) \text{ (1)}$$

KVL

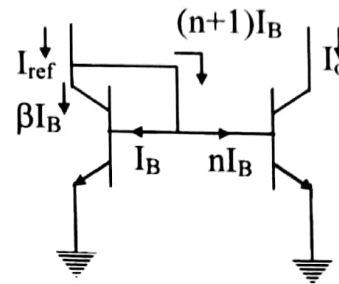
$$IR + 0.7 + I_C R_3 - V = 0$$

$$\Rightarrow \frac{V}{2} + I_C R_3 - V = 0 \text{ (}\because \text{equation(1))}$$

$$\Rightarrow I_C = \frac{V}{2R_3}$$

19.

Sol:



$$I_{ref} = I_{\beta} [n+1+\beta]$$

$$I_o = n\beta I_{\beta}$$

$$\frac{I_o}{I_{ref}} = \frac{\beta n}{\beta + 1 + n} = \frac{n}{1 + \left(\frac{1+n}{\beta} \right)}$$

$$\therefore I_o = \frac{n I_{ref}}{1 + \left(\frac{1+n}{\beta} \right)}$$

20.

Sol: For one output transistor

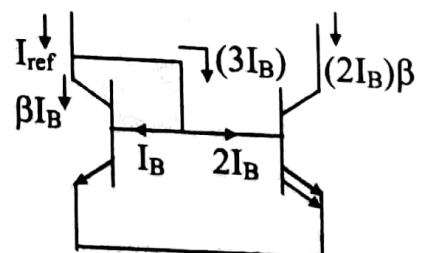
$$I_o = \frac{I_{ref}}{1 + \frac{2}{\beta}} = \frac{I_{ref}}{1 + \frac{(1+1)}{\beta}}$$

For N output transistor

$$I_o = \frac{I_{ref}}{1 + \frac{(1+N)}{\beta}}$$

21.

Sol:





$$I_{ref} = I_B [\beta + 3]$$

$$I_o = 2\beta I_B$$

$$\frac{I_{ref}}{I_o} = \frac{\beta + 3}{2\beta}$$

$$\therefore I_{ref} = \left(\frac{\beta + 3}{2\beta} \right) I_o = \frac{63}{120} (0.5)$$

$$= 0.2625 \text{ mA}$$

$$R_1 = \frac{2.5 - 0.7}{0.2625} = 6.86 \text{ k}\Omega$$

22.

Sol: $I_2 = 2I_1$

$$I_3 = 3I_1$$

(a) $I_1 = 0.5 \text{ mA}$, $I_2 = 1 \text{ mA}$, $I_3 = 1.5 \text{ mA}$

(b) $I_1 = 0.25 \text{ mA}$, $I_2 = 0.5 \text{ mA}$, $I_3 = 0.75 \text{ mA}$

(c) $I_1 = 0.167 \text{ mA}$, $I_2 = 0.333 \text{ mA}$,
 $I_3 = 0.5 \text{ mA}$

23.

Sol: $I_o = 2 \text{ mA}$

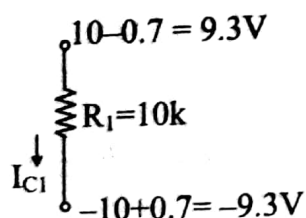
$$I_{ref} = 1 \text{ mA}$$

$$I_{ref} = \frac{5 - V_{B3}}{R_1} = \frac{5 - (-5 + 1.4)}{R_1}$$

$$R = 8.6 \text{ k}\Omega$$

24.

Sol:



$$I_{C1} = I_{C2} = I_{C3} = I_{C4} = I_{C5} = I_{C6}$$

$$= \frac{9.3 - (-9.3)}{10 \text{ k}} = 1.86 \text{ mA}$$

$$V_{B1} = V_{B3} = V_{B4} = 10 - 0.7 = 9.3 \text{ V}$$

$$V_{B2} = V_{B7} = V_{B8} = V_{B9} = -10 + 0.7$$

$$= -9.3 \text{ V}$$

$$V_{C3} = 1.86 \text{ m} (2 \text{ k}) = 3.72 \text{ V}$$

$$V_{C6} = 5 - 1.86 \text{ m} (1 \text{ k}) = 3.14 \text{ V}$$

$$V_{C5} = 0.7 \text{ V}$$

$$I_{R4} = 2(1.86 \text{ m}) = 3.72 \text{ mA}$$

$$V_{C11} = 1.86 \text{ m} (1 \text{ k}) = 1.86 \text{ V}$$

25.

Sol: $I_o = \frac{10 - (-10 + 0.7)}{19.3 \text{ k}} = 1 \text{ mA}$,

$$I_{C(DC)} = I_o / 2 = 0.5 \text{ mA}$$

$$A_d = -g_m R_c = -\frac{0.5 \text{ m}}{25 \text{ m}} (2 \text{ k}) = -40$$

$$\left[\because g_m = \frac{I_{C(DC)}}{25 \text{ mV}} = \frac{0.5}{25} \right]$$

26.

Sol: $\frac{I_o}{I_{ref}} = \frac{R_1}{R_2}$

$$I_o = \frac{3 \text{ k}}{2 \text{ k}} (1 \text{ m}) = 1.5 \text{ mA}$$

27.

Sol: $I_o = I_{ref} \left(\frac{R_1}{R_2} \right) = 5 \text{ m} \left(\frac{4 \text{ k}}{5 \text{ k}} \right) = 4 \text{ mA}$

$$I_{C(DC)} = I_o / 2 = 2 \text{ mA}$$

$$g_m = \frac{I_{C(DC)}}{V_t} = \frac{2 \text{ m}}{25 \text{ m}} = \frac{2}{25}$$

$$A_d = -g_m R_c = -\frac{2 \text{ m}}{25 \text{ m}} (2.5 \text{ k}) = -200$$



28.

Sol: $V_1 - V_2 = 6.7 - 0 = 0.7 + IR$

$$6 = IR$$

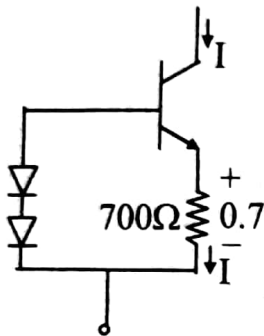
Where $I = \frac{10 - (-10.7 + 0.7)}{20k} = 1\text{mA}$

$$\therefore 6 = 1\text{m}(R)$$

$$R = 6\text{ k}\Omega$$

29.

Sol:



$$V_1 - V_2 = 0.7 + IR$$

Where $I = \frac{0.7}{700} = 1\text{mA}$

$$\therefore V_1 - V_2 = 0.7 + 1\text{m}(6k) = 6.7\text{ V}$$

30.

Sol: (a) $I_{C9} = \frac{0 - V_{C9}}{28.6k} = \frac{0 - (-15 + 0.7)}{28.6k}$

$$= 0.5\text{ mA}$$

$$I_{C3} = 0.5\text{ mA}$$

$$I_{C1} = I_{C2} = 0.25\text{ mA}$$

$$I_{C6} = 4(0.5\text{m}) = 2\text{ mA}$$

$$V_{C1} = 15 - I_{C1}(20\text{ k}) = 10\text{ V} = V_{C2}$$

$$I_{C4} = I_{C5} = \frac{I_{C6}}{2} = 1\text{mA}$$

$$V_{C5} = 15 - I_{C5}(3k) = 12\text{V}$$

$$V_{E7} = 0.7 + 12 = 12.7\text{ V}$$

$$I_{E7} = \frac{15 - V_{E7}}{2.3k} = \frac{15 - 12.7}{2.3k} = 1\text{mA}$$

$$V_{B8} = I_{C7}(15.7k) - 15 = 0.7\text{ V}$$

$$V_o = V_{B8} - 0.7 = 0.7 - 0.7 = 0\text{V}$$

(b) From 15 V supply, the total current
 $= 0.25 + 0.25 + 1 + 1 + 1 + 5 = 8.5\text{ mA}$

From -15 V supply, the total current
 $= 0.5 + 0.5 + 2 + 1 + 5 = 9\text{ mA}$

Total power = $|P_{15V}| + |P_{-15V}|$
 $= 15(8.5\text{ m}) + 15(9\text{ mA})$
 $= 262.5\text{ mW}$

(c) Input bias current,

$$|I_B| = \frac{I_{B1} + I_{B2}}{2}$$

$$I_{C3} = 0.5\text{ mA}$$

$$I_{C1} = 0.25\text{ mA}$$

$$I_{B1} = \frac{0.25\text{m}}{100} = 2.5\mu\text{A}$$

and $I_{B2} = 2.5\mu\text{A}$

$$\therefore |I_B| = \frac{2.5\mu + 2.5\mu}{2} = 2.5\mu\text{A}$$