Transistor

1-Emitter-stabilized circuit

This circuit is also known as fixed bias circuit with an emitter resistance . Figure (1) shows the location of resistor, R_E. This circuit is more stable because I_B is not fixed as shown in previous example (fixed biased circuit). I_B will change if β change, which causes operating point to experience changes but not a much as fixed bias circuit.

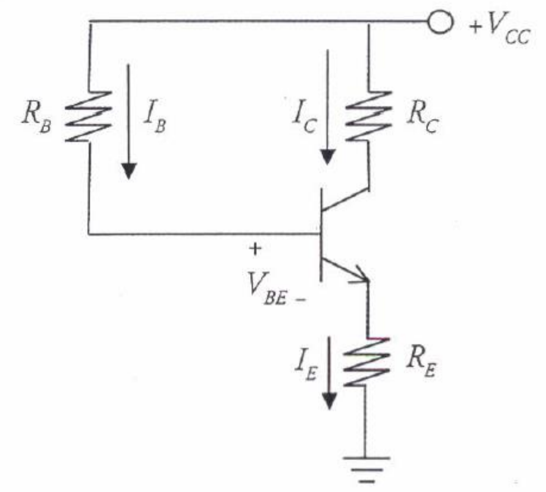


Figure (1)
An emitter-stabilized bias circuit

The DC analysis to determine the operating point of a circuit shown in figure (1) is as follows:-

Using KVL for the input loop (figure (1))

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

Substitute I_E= $(\beta + 1)$ I_B into above equation, it becomes

V_{cc}-$I_B R_B$-V_{BE}-$(\beta + 1)$ $I_B R_E$=0 and I_B=$\frac{V_{cc}-V_{BE}}{R_B+(\beta+1)\ R_E}$

Therefore I_c = β I_B and I_E= I_c + I_B= $(\beta + 1)$ I_B

Equation for the output loop in figure (1):-

V_{cc}-$I_c R_c$-V_{CE}- $I_E R_E$=0

Therefore V_{CE}= V_{cc}-$I_c R_c$- $I_E R_E$

Or V_{CE}= V_{cc}-$I_c(R_c + R_E)$ if an assumption $I_c \approx I_E$ is made.

The DC load-line of this circuit is shown in figure (2). It is difference as compared to a fixed bias circuit load-line is the $I_{c(sat)}$ value, where $I_{c(sat)}$= $\frac{V_{cc}}{R_c+R_E}$. The same effect as revealed as shown in previous lectures will happen if R_c and V_{cc} experience change.

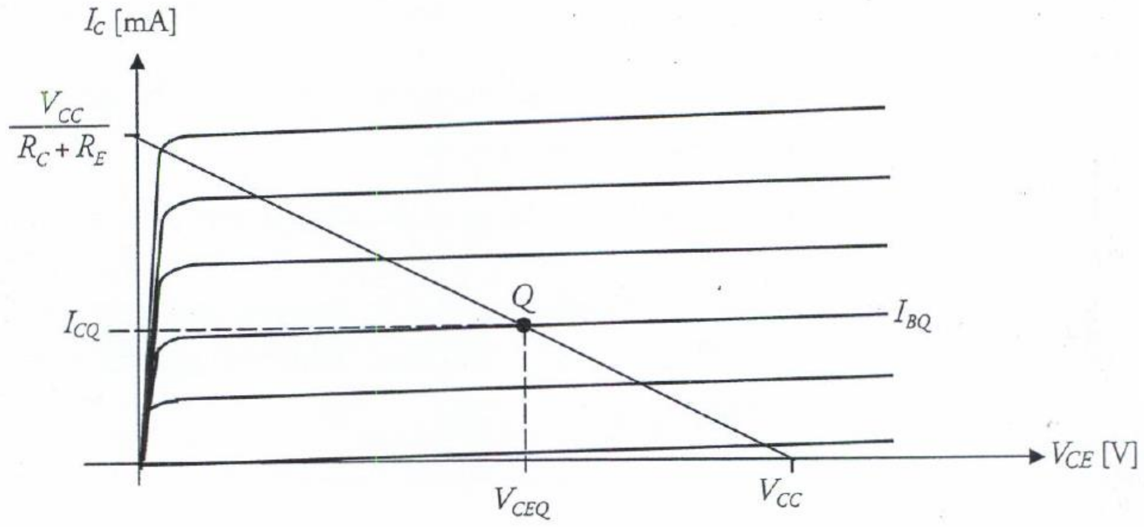
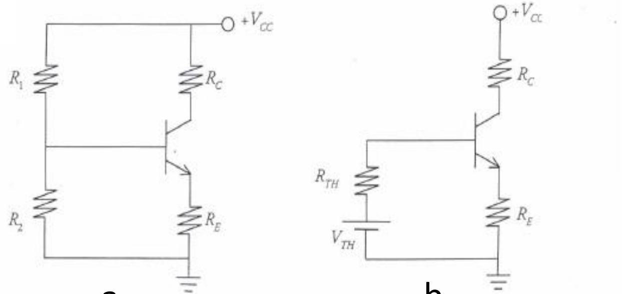


Figure (2)
DC load-line for an emitter stabilized bias circuit

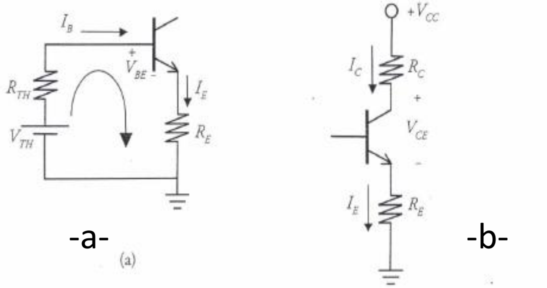
2- Voltage-divider Bias

Another bias circuit is voltage divider circuit (figure (3-a)). This circuit can be simplified further as shown in (figure (3-b)) using Thevenin's theorem for the DC analysis to determine the transistor operating point. For this, an equivalent of R_{TH} or R_{BB} and V_{TH} or V_{BB} that can be seen at the base terminal should be found.



-a- -b-

Figure (3)
a- Voltage divider circuit b- simplified circuit



-a- -b-

Figure (4) Voltage divider circuit
(a) Input loop (b) output loop

Using Thevenin's theorem, the following obtained:

$R_{th} = R_1 \,||\, R_2$ and $V_{th} = V_{cc} \frac{R_2}{R_1+R_2}$

Using KVL for the input loop (figure(4-a)):-

$V_{TH} - I_B\ R_{th}$- V_{BE}- $I_E\ R_E$=0 but I_E= $(\beta + 1)\ I_B$

Hence:-

$V_{TH} - I_B\ R_{th}$- V_{BE}- $(\beta + 1) I_E\ R_E$=0

$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta + 1)\ R_E}$

So that

$I_c = \beta\ I_B$ and $I_E = I_c + I_B = (\beta + 1)\ I_B$

Equation for the output loop figure (figure (4-b)):-

$V_{cc} - I_c R_c - V_{CE} - I_E R_E = 0$

$V_{CE} = V_{cc} - I_c R_c - I_E R_E$

Or $V_{CE} = V_{cc} - I_c (R_c + R_E)$ with an assumption $I_c \approx I_E$.

The DC load line for this circuit is same as figure (2).

The voltage divider bias circuit is very stable circuit. It does not depend on the value β if circuit parameters, i.e., resistance values are chosen correctly. This is shown as follows:

For voltage divider circuit, it is known that: $I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta+1)\ R_E}$

Normally $\beta \gg 1$, an assumption of $(\beta + 1)$ = β can be made.

For a good amplifier, $(\beta + 1)\ \ R_E \gg R_{th}$, therefore R_{th} value can be ignored.

Then

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + \beta\ R_E} = \frac{V_{TH} - V_{BE}}{\beta\ R_E}$$

$I_c = \beta\ I_B = \beta\left(\frac{V_{TH}-V_{BE}}{\beta\ R_E}\right) \rightarrow I_c = \frac{V_{TH}-V_{BE}}{R_E}$

The equation of I_c clearly shows that it does not depend on β. But condition $(\beta + 1)\ \ R_E \gg R_{th}$ must be complied. Since I_c does not depend on β value, therefore V_{CE} is also not depended on β.

3- DC Bias with Voltage feedback

This circuit is also known as collector feedback bias circuit. A bias circuit is shown in figure (5).

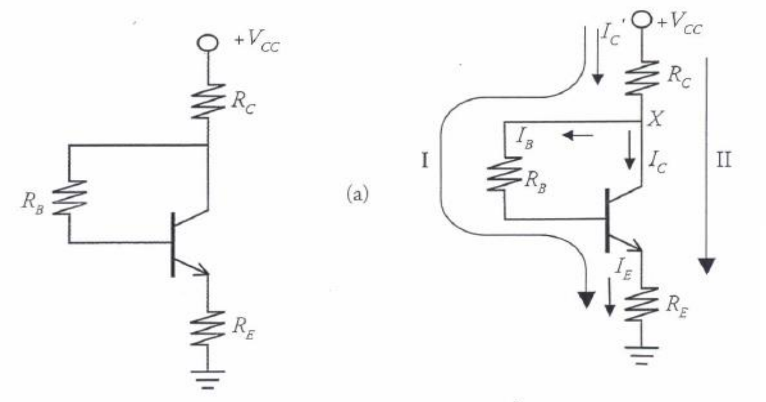


Figure (5)
Bias circuit with a voltage feedback

At node X, using KCL :$I_c' = I_B + I_{c'}$

$I_E = I_B + I_{c'}$

Then current that flows through R_c is emitter current, I_E, so $I_c' = I_E$

Using Loop I:

$V_{cc} - I_c' R_c - I_B R_B - V_{BE} - I_E R_E = 0$

Known that $I_E = (\beta + 1) I_B$

Then, $V_{cc} - (\beta + 1) I_B R_c - I_B R_B - V_{BE} - (\beta + 1) I_B R_E = 0$

$I_B = \frac{V_{cc} - V_{BE}}{R_B + (\beta + 1)(R_E + R_c)}$

Hence, I_c= β I_B and I_E= I_c + I_B= $(\beta + 1)$ I_B

Equation for loop II:

V_{cc}-$I_E R_c$-V_{CE}- $I_E R_E$=0

V_{CE}= V_{cc}- $I_E(R_E$+ $R_c)$

Or V_{CE}= V_{cc}- $I_C(R_E$+ $R_c)$

With as assumption $I_c \approx I_E$

Q1- For a given BJT:I_B = 50 μA and I_c = 3.65 mA . Find the dc current gain β_{dc} , I_E, α_{dc}?

Solution:-

$$\beta_{dc}=\frac{I_c}{I_B}=\frac{3.65\ mA}{50\ \mu A}=\frac{3.65\times10^{-3}}{50\times10^{-6}}=73$$

$$I_E= I_c + I_B= 50 \times 10^{-6}+ 3.65 \times 10^{-3}=3.7 \times 10^{-3}\ mA$$

$$\alpha_{dc}=\frac{I_c}{I_E}=\frac{3.65\ mA}{3.7mA}=\frac{3.65\times10^{-3}}{3.7\times10^{-3}}=0.986$$

Q2- For given NPN BJT circuit shown in figure(6) ,if β_{dc}=150. Find I_B , I_c, I_E, V_{BE}, V_{CE}, and V_{CB}?

Solution:-

$V_{BE} \cong 0.7\ Volt$

$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{5V - 0.7V}{10\ K\boldsymbol{\Omega}}$ = 430 μA

I_c= β_{dc} I_B= (150)(430 μA) = 64.5 mA

I_E= I_c + I_B= 64.5 mA+ 430 μA =64.9 mA

V_{CE} = V_{CC}- I_c R_c = 10V –(64.5 mA)(100$\boldsymbol{\Omega}$)=3.55 V

V_{CB} = V_{CE} - V_{BE} =3.55 V – 0.7 V= 2.85 V

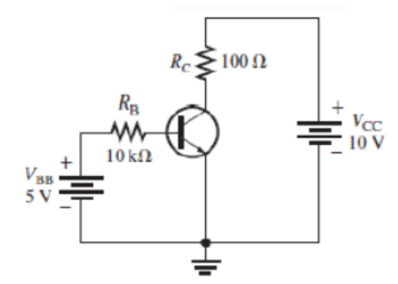


Figure (6)

Q3- Using ideal BJT switch of β_{dc}=200 , V_{CC}=10V and I_B=20 μA.

1) Find the value of base resistor R_B required to switch the load "ON" when the input terminal voltage exceeds 2.5 V and V_{BE}= 0.7V.
2) Calculate the R_c of point (1).
3) Find the minimum base current I_B required to turn the transistor " Fully -ON " (saturated) for a load that requires 200 mA when the input voltage increased to 5.0 V. Also calculate the new value of R_B.

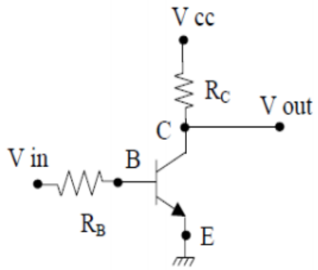


Figure (7)

Solution:-

1- R_B=$\frac{V_{in}-V_{BE}}{I_B}$=$\frac{2.5V\ -0.7V}{20\ \times 10^{-6}}$ = 90 $K\boldsymbol{\Omega}$.

2- For ideal BJT at saturation $V_{CE}\ = 0\ \text{Volt}$

I_c= $\beta_{dc}\ I_B$= 200 $\times\ 20\ \ \times\ 10^{-6}$= 4 mA

R_c= $\frac{V_{cc}-V_{CE}}{I_c}$=$\frac{10-0}{4\times 10^{-3}}$= 2.5 $K\boldsymbol{\Omega}$.

3- At ON state, the load current is equal to I_c

I_B=$\frac{I_c}{\beta_{dc}}$=$\frac{200\ mA}{200}$ =1 mA

R_B=$\frac{V_{in}-V_{BE}}{I_B}$=$\frac{5.V\ -0.7V}{1\ \times 10^{-3}}$ = 4.3 $K\boldsymbol{\Omega}$.

Q4- For fixed bias circuit shown in figure (8), if R_B= 240 $K\boldsymbol{\Omega}$, R_c=2.2 $K\boldsymbol{\Omega}$, β_{dc}=50. V_{cc}=12 V. Determine

1- I_B, I_c

2- V_{CE}

3- V_B, V_C

4- V_{BC}

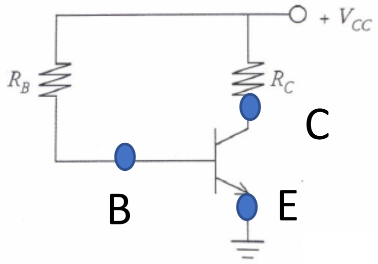


Figure (8)

Solution:-

$1 - I_B = \frac{V_{cc} - V_{BE}}{R_B} = \frac{12V - 0.7V}{240\ K\boldsymbol{\Omega}}$ = 47.08 μA

$I_c = \beta_{dc}\ I_B$ = 50 $\times$ 47.08 $\times 10^{-6}$ = 2.35 mA

2-V_{CE} = V_{CC}- $I_c\ R_c$ = 12V –(2.35 mA)(2.2 K$\boldsymbol{\Omega}$)$=$6.83 V

3- $V_B = V_{BE} =$0.7 V

4-$V_C = V_{CE} =$6.83 V

5-$V_{BC} = V_B$- $V_C =$0.7 V – 6.83V =-6.13 V

Q5- For figure (10) Determine:-

1- V_{CC}

2- R_C

3- R_B

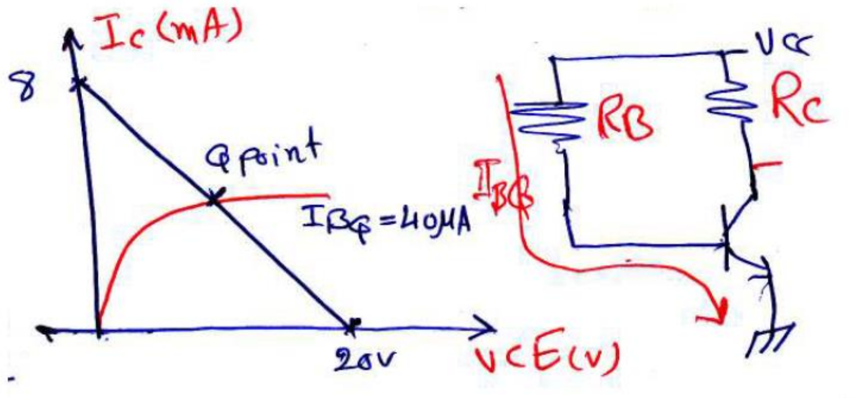


Figure (10)

Solution:-

1- V_{CC}=20 V

2- I_c =8 $mA \rightarrow R_c$=$\frac{V_{CC}}{I_c}$ =$\frac{20\ V}{8\ mA}$ = 2.5 K$\boldsymbol{\Omega}$

3- R_B=$\frac{V_{CC}-V_{BE}}{I_B}$ = $\frac{20\ \ -0.7}{40 \times 10^{-6}}$

= 482.5 K$\boldsymbol{\Omega}$

Q6- For emitter-bias circuit shown in figure (11). Determine:-

$I_B, I_c, V_{CE}, V_C, V_E, V_B$ and V_{BC}

Where:-

V_{CC}=20 V, R_B=430 K$\boldsymbol{\Omega}$, R_E=1 K$\boldsymbol{\Omega}$, R_c=2 K$\boldsymbol{\Omega}$, β_{dc}=50

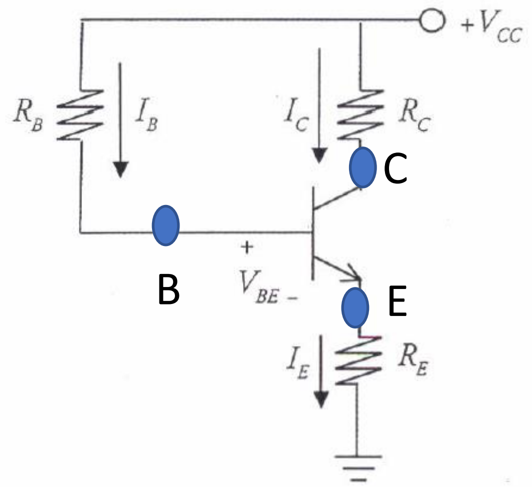


Figure (11)

Solution:-

$I_B = \frac{V_{cc} - V_{BE}}{R_B + (\beta+1)\ R_E} = \frac{20 - 0.7}{430\text{K}\boldsymbol{\Omega} + (50+1)(1\text{K}\boldsymbol{\Omega})} = 40.1\ \mu A$

$I_c = \beta_{dc}\ I_B = 50 \times 40.1 \times 10^{-6} = 2.01\ mA$

$I_E = I_c + I_B = 2.01\ mA + 40.1\ \mu A = 2.05\ mA$

$V_{CE} = V_{CC} - I_c\ R_c - I_E\ R_E = 20V - (2.01\ mA)(2.\ \text{K}\boldsymbol{\Omega}) - (2.05\ mA)(1.\ \text{K}\boldsymbol{\Omega})$
$= 13.93\ \text{V}$

$V_C = V_{CE} + I_E\ R_E = 13.93 + (2.05\ mA)(1.\ \text{K}\boldsymbol{\Omega}) = 15.98\ \text{V}$

$V_E = I_E\ R_E = (2.05\ mA)(1.\ \text{K}\boldsymbol{\Omega}) = 2.05\ \text{V}$

Or V_E = V_C - V_{CE}

V_E= 15.98- 13.93=2.05 V

V_B = V_E + V_{BE}

V_B =0.7+2.05 =2.75 V

V_{BC} = V_B- V_C

V_{BC} = 2.75- 15.98=-13.89

Q7- For circuit shown in figure (12), R_1 =39 K$\boldsymbol{\Omega}$, R_2 =3.9 K$\boldsymbol{\Omega}$, R_c =10 K$\boldsymbol{\Omega}$, R_E =1.5 K$\boldsymbol{\Omega}$, β_{dc}=100, V_{CC}=22 V_{CC}

determine:- V_{CE} , I_c

Solution:-

$$R_{th} = R_1 \,||\, R_2$$

$$R_{th} = \frac{(39)(3.9)}{(39+3.9)} = 3.55 \text{ K}\boldsymbol{\Omega}$$

$$V_{th} = \frac{V_{CC}R_2}{R_1+R_2} = \frac{(22)(3.9)}{(39+3.9)} = 2 \text{ V}$$

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta+1)\ R_E}$$

$$I_B = \frac{2-0.7}{3.5K+(101)(1.5K)} = 8.38\ \mu A$$

$I_c = \beta_{dc}\ I_B = 100 \times 8.38 \times 10^{-6} = 0.84\ mA$

$V_{CE} = V_{CC} - I_c(R_c + R_E)$

$V_{CE} = 22 - 0.84\ mA(10K\boldsymbol{\Omega} + 1.5K\boldsymbol{\Omega}) = 12.34$ V

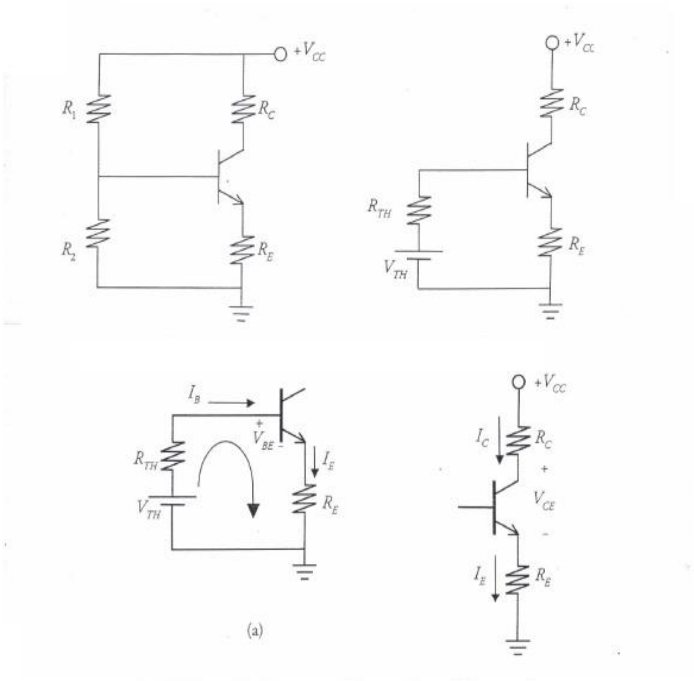

+V_{CC}
R_1
R_C
R_2
R_E
+V_{CC}
R_C
R_{TH}
V_{TH}
R_E
I_B
+
V_{BE}
-
I_E
R_{TH}
V_{TH}
R_E
(a)
+V_{CC}
I_C
R_C
+
V_{CE}
-
I_E
R_E

Figure (12)

Q7- For circuit shown in figure (13),R_c =4.7 K$\boldsymbol{\Omega}$, R_B =250 K$\boldsymbol{\Omega}$, R_E =1.2 K$\boldsymbol{\Omega}$, β_{dc}=90 , V_{CC} =10 V. Find I_c, V_{CE}. Repeat previous example if β_{dc}=150

Solution:-

I_B=$\frac{V_{cc}-V_{BE}}{R_B+(\beta+1)(\ R_E+\ R_c)}$

I_B=$\frac{10-0.7}{250\ +(90+1)(1.2+4.7)}$ =11.91 μA

I_c= β_{dc} I_B= 90 $\times$ 11.91×10^{-6}= 1.07 mA

V_{CE} = V_{CC}- I_c(R_c+ R_E)

V_{CE} =10- 1.07 mA(4.7K+1.2K)=3.69 V

If β_{dc}=150

$I_B = \frac{V_{cc} - V_{BE}}{R_B + (\beta+1)(\ R_E + \ R_c)}$

$I_B = \frac{10-0.7}{250\ +(150+1)(1.2+4.7)}$ =8.89 μA

I_c= $\beta_{dc}\ I_B$= $150 \times 8.89 \times 10^{-6}$= 1.2 mA

V_{CE} = V_{CC}- I_c(R_c+ R_E)

V_{CE} =10- 1.2 mA(4.7K+1.2K)=2.92 V

Level β_{dc} increase 50%

Level of I_c increased by 12%

Level of V_{CE} decreased by 20.9%

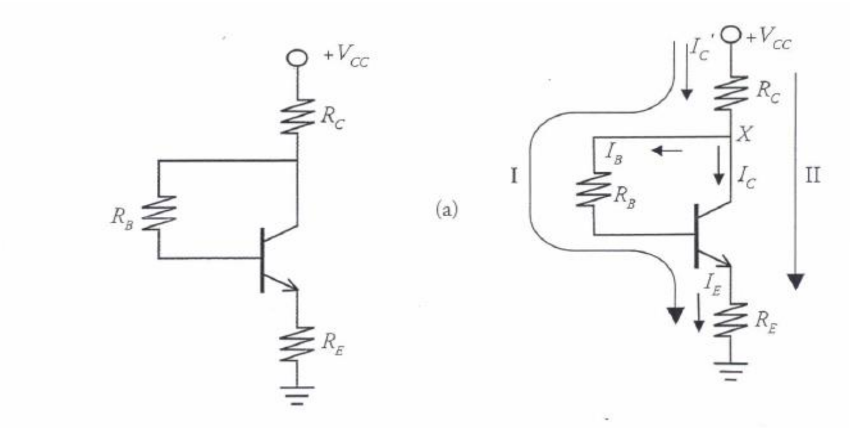


Figure (13)