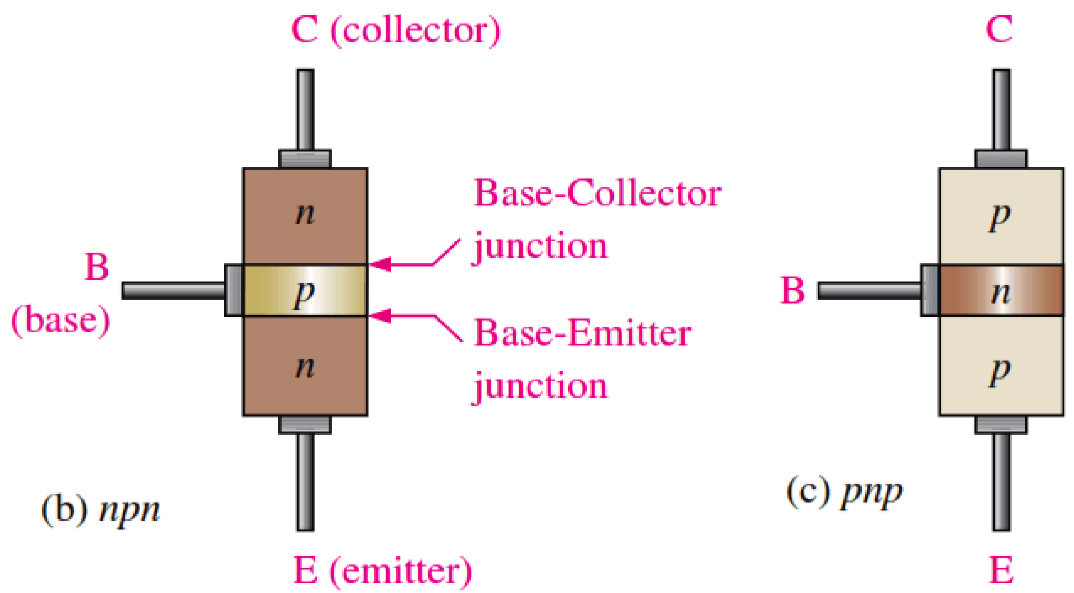
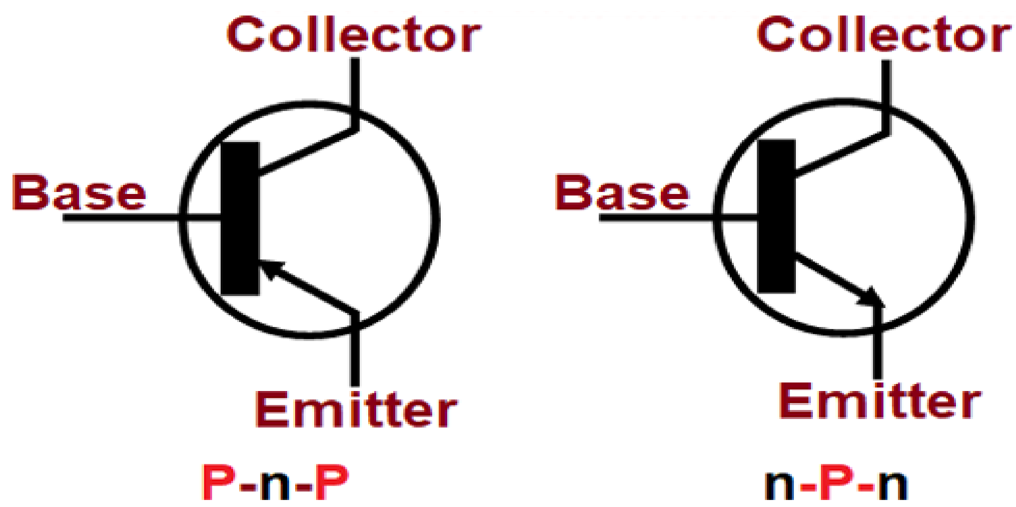
Bipolar Junction Transistor (BJT)

B**ipolar Junction Transistor (BJT)** uses both free electrons and holes. The word bipolar is an abbreviation for “two polarities.” It also consists two junctions. BJTs are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. BJTs are current regulating devices that control the amount of current flowing through them from the Emitter to the Collector terminals in proportion to the amount of biasing voltage applied to their base terminal, thus acting like a current-controlled switch. The transistor’s ability to change between these two states enables it to have two basic functions: “switching” (digital electronics) or “amplification” (analogue electronics). The bipolar junction transistor (BJT) is manufactured with three semiconductor regions that are doped differently.


C (collector)
Base-Collector
junction
B
(base)
n
p
n
Base-Emitter
junction
(b) npn
E (emitter)
C
B
p
n
p
(c) pnp
E

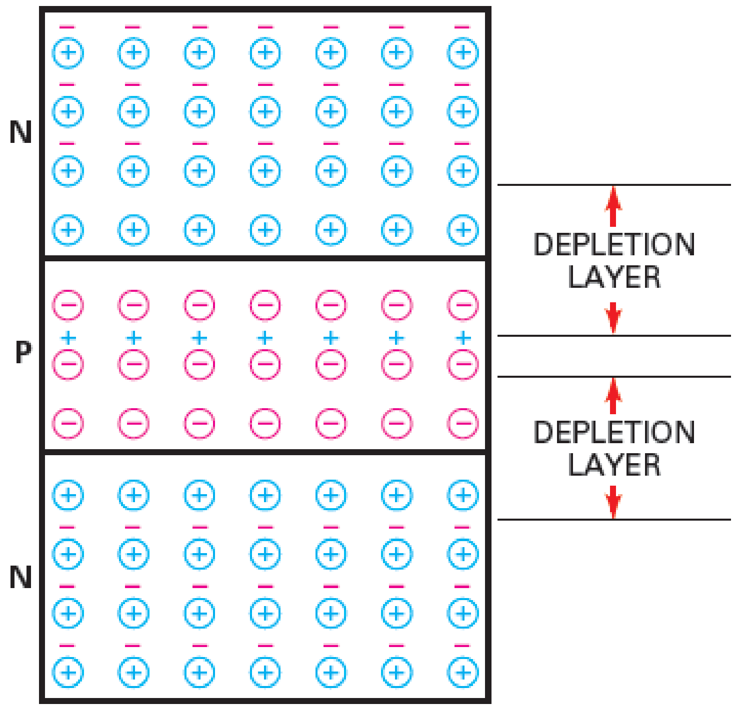

Collector
Base
Emitter
P-n-P
Collector
Base
Emitter
n-P-n

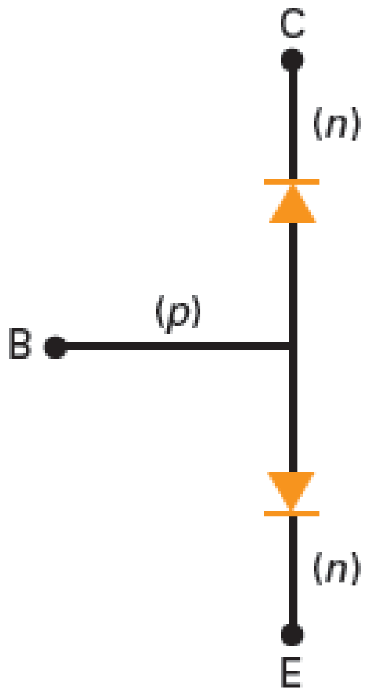
Doping levels:

Emitter is heavily doped, base is lightly doped and the doping level of the collector is intermediate. In an actual transistor, the base region is much thinner as compared to the collector and emitter regions.

Can we get a transistor by connecting to PN junction diodes?

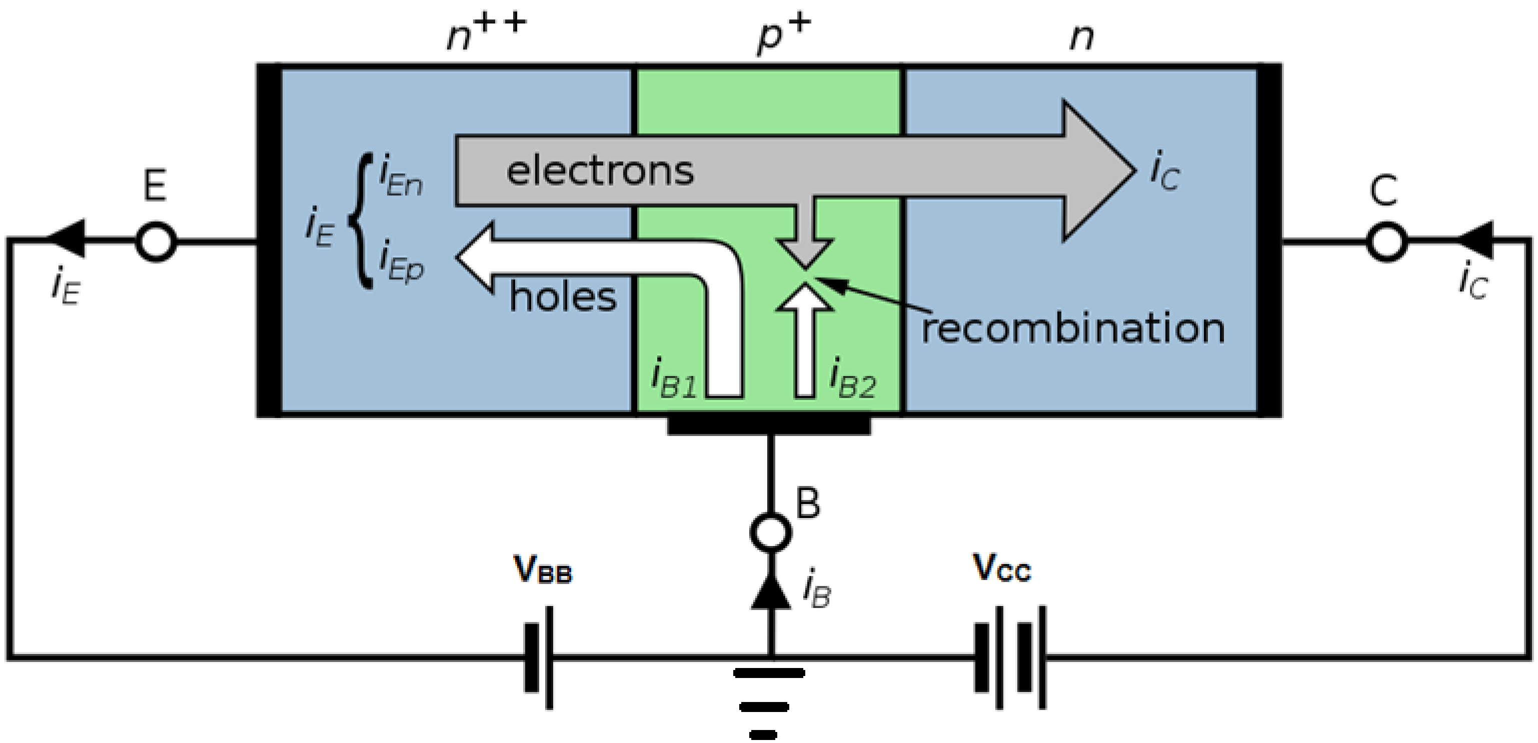
Unbiased Transistor





Here there are two junctions : Emitter-Base junction and Collector-Base junction. For biasing, emitter-base junction is forward biased and collector-base junction is reverse biased

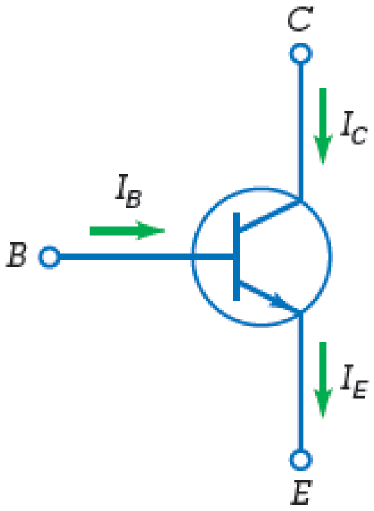
Biased Transistor



Forward biased E-B junction has a low resistance path whereas reverse biased C-B junction has high resistance path. Therefore a transistor transfers a signal from low resistance to high resistance path

Transistor Currents

$I_E = I_B + I_C,$ $I_B << I_C,$ $I_E \approx I_C$



I_C has both majority (from emitter) and minority carrier (from base) contribution

dc alpha (α_{dc}) = I_C/I_E – this is slightly less than 1
α is the fraction of emitter current reaches the collector

dc beta (β) = I_C/I_B *which is also known as current gain*

$I_E=I_C+I_B$
or, $I_C/\alpha = I_C + I_C/\beta$
Or, $1/\alpha=1+1/\beta$

$\alpha=\beta/(1+\beta)$
$\beta=\alpha/(1-\alpha)$

Now, $I_C = I_{C\,majority} + I_{C\,minority}$

$$= \alpha I_E + I_{CBO} = \alpha (I_B + I_C) + I_{CBO}$$

or, $I_C (1-\alpha) = \alpha I_B + I_{CBO}$

or, $I_C = \{\alpha/(1-\alpha)\} I_B + \{1/(1-\alpha)\} I_{CBO}$

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

General convention for using single subscript, double subscript, small letter and capital letter

- Capital letters will be used for DC (like I_E, I_C etc.) and small letters will be used for AC (like i_E, i_C etc.).
- For double subscripts - when the subscripts are same, the voltage represents a source (like V_{BB}, V_{CC}) *and* when the subscripts are different, the voltage is between the two points (like V_{BE}, V_{CE}).

Single subscripts are used for node voltages, that is, voltages between the subscripted point and ground. a double-subscript voltage of different subscripts can be estimated by subtracting its single-subscript voltages. E.g.

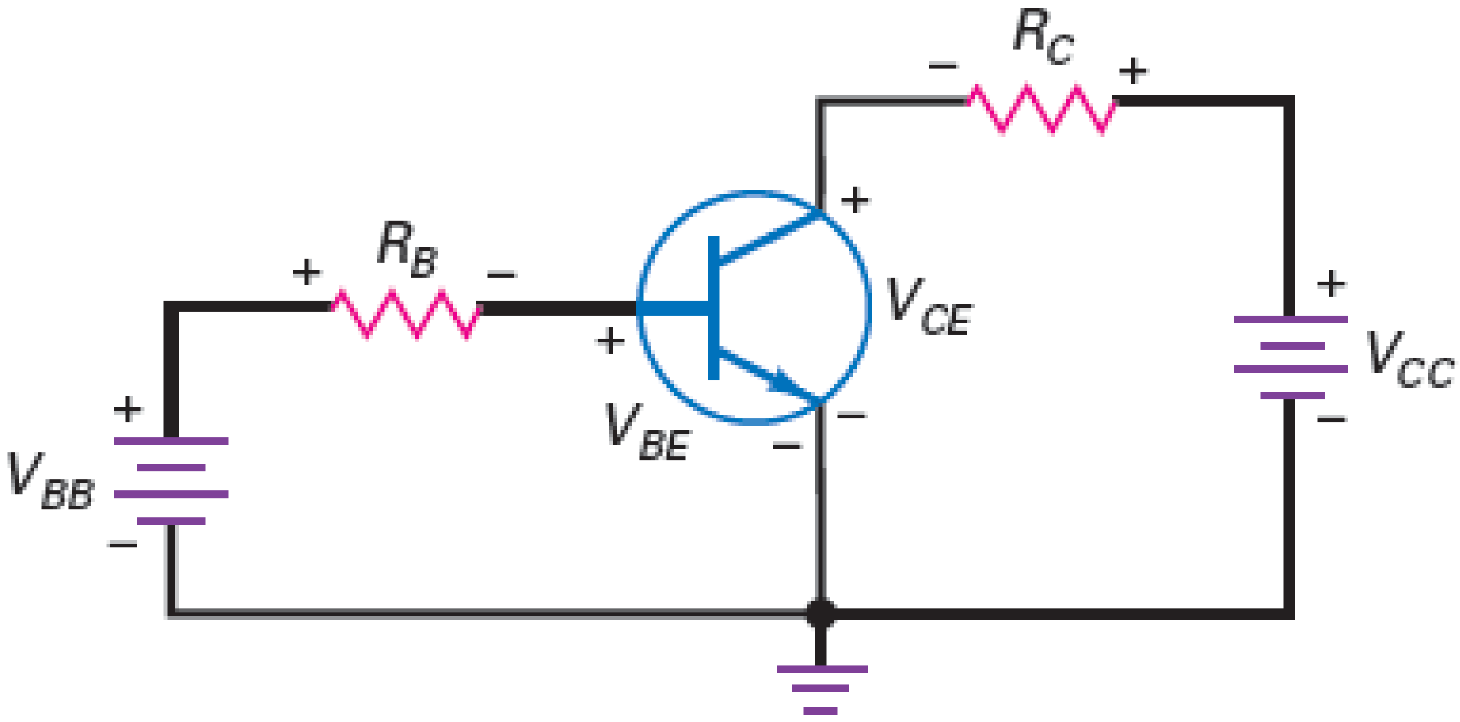
$V_{CE} = V_C - V_E$

$V_{CB} = V_C - V_B$

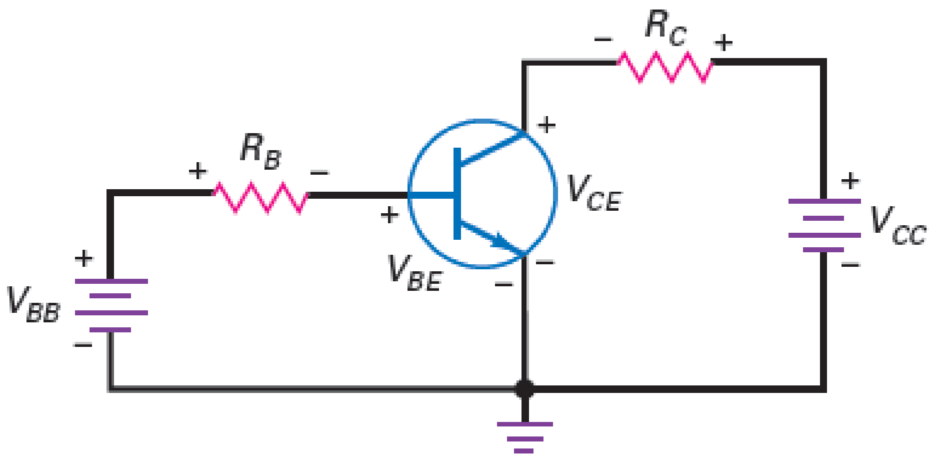
Modes of connection of BJT

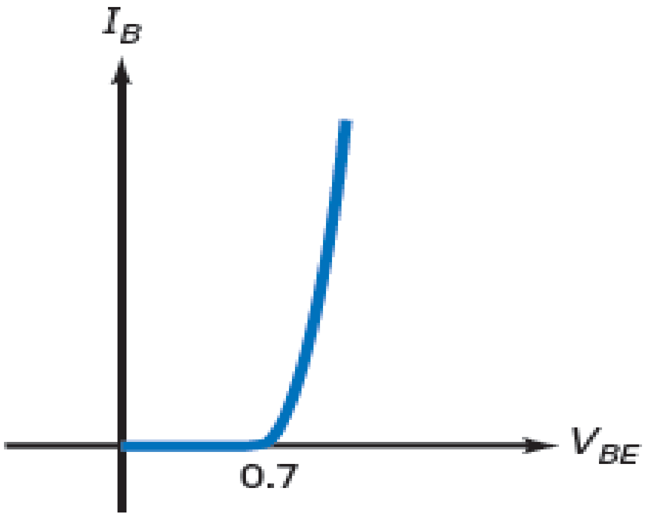
There are ways to connect a transistor: with a CE (common emitter), a CC (common collector), or a CB (common base).

CE Connection



Transistor analysis





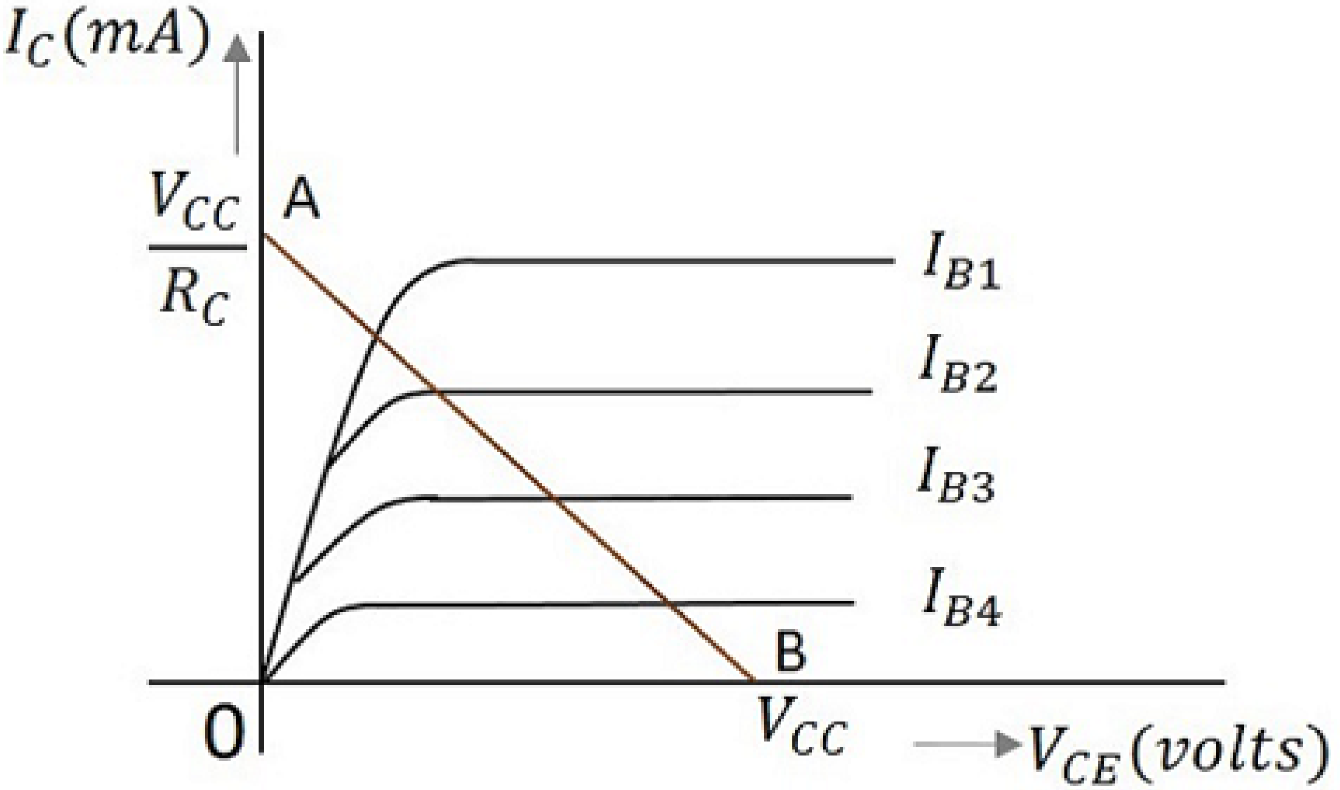
For emitter-base loop, $V_{BB} = V_{BE} + I_B R_B$

For emitter-collector loop, $V_{CC} = V_{CE} + I_C R_C$

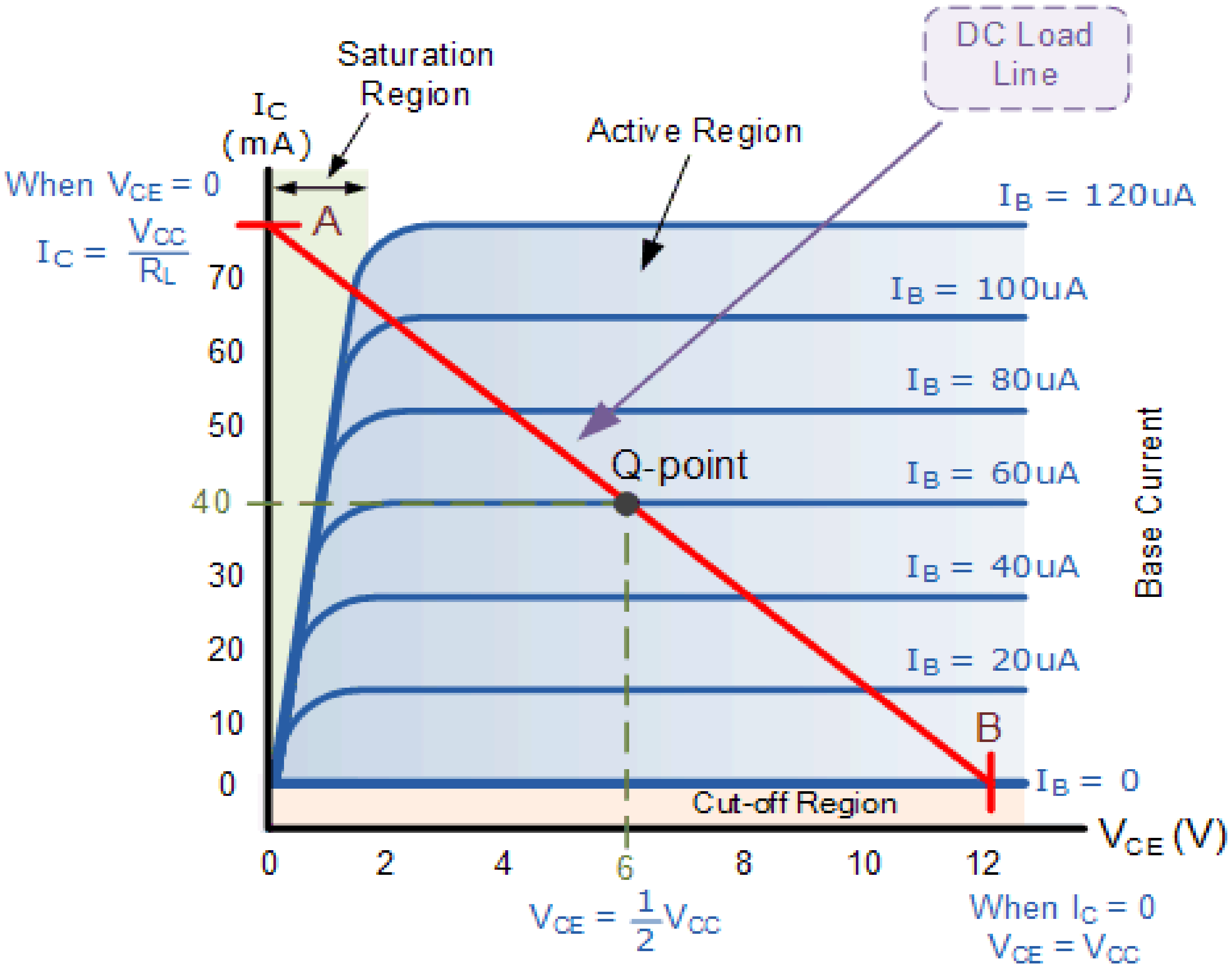
When $V_{CE} = 0$, $I_C = V_{CC}/R_C$

and when $I_C = 0$, $V_{CE} = V_{CC}$

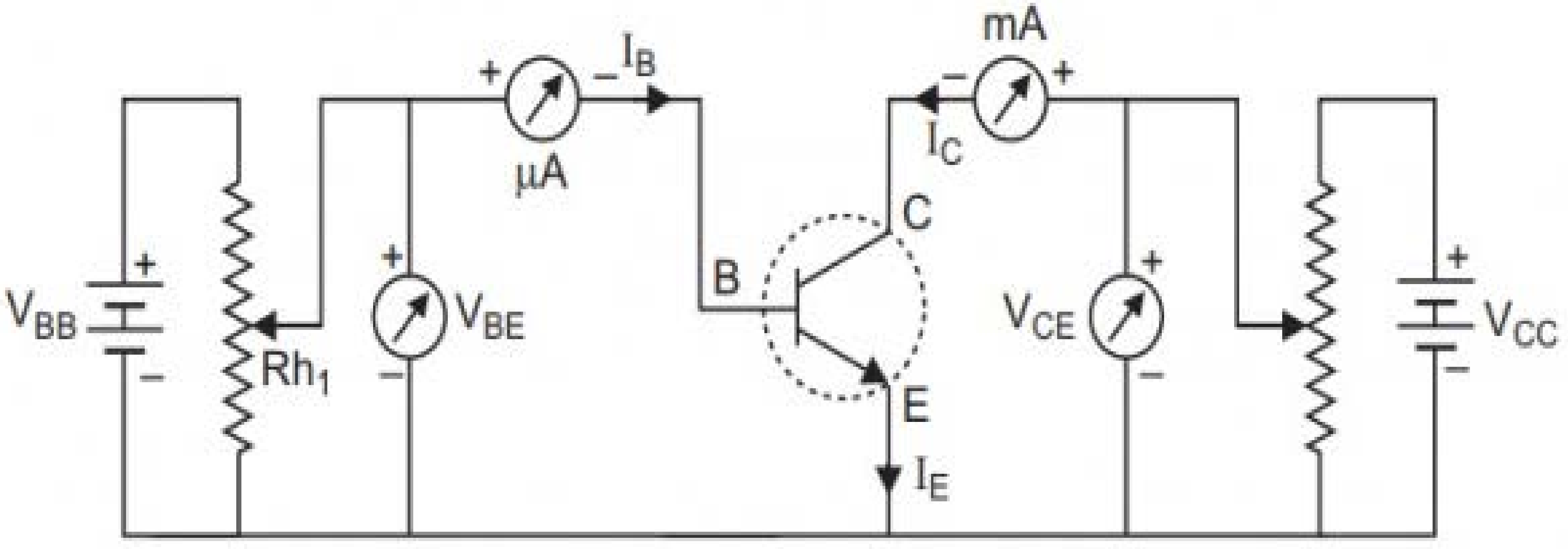
Transistor output characteristics and load line



Different regions of output characteristics



Circuit diagram to draw transistor characteristics at the laboratory



BJT Biasing

Bias establishes the DC operating point for proper linear operation of an amplifier which ensure undistorted amplification. Also if a signal of very small voltage is given to the input of BJT, it cannot be amplified. Because, for a BJT, to amplify a signal, two conditions have to be met.

The input voltage should exceed cut-in voltage for the transistor to be ON.

The BJT should be in the active region, to be operated as an amplifier.

If appropriate DC voltages and currents are given through BJT by external sources, so that BJT operates in active region and superimpose the AC signals to be amplified, then this problem can be avoided.

Stability of biasing

The stability of biasing means the ability of a biasing arrangement to counteract any drift of Q-point.

The main factor that affect the operating point is the temperature. The operating point shifts due to change in temperature.

As temperature increases, the values of I_{CBO}, β, V_{BE} gets affected.

I_{CBO} gets doubled (for every 10^o rise)

V_{BE} decreases by 2.5mv (for every 1^o rise)

So the main problem which affects the operating point is temperature. Hence operating point should be made independent of the temperature so as to achieve stability. To achieve this, biasing circuits are introduced.

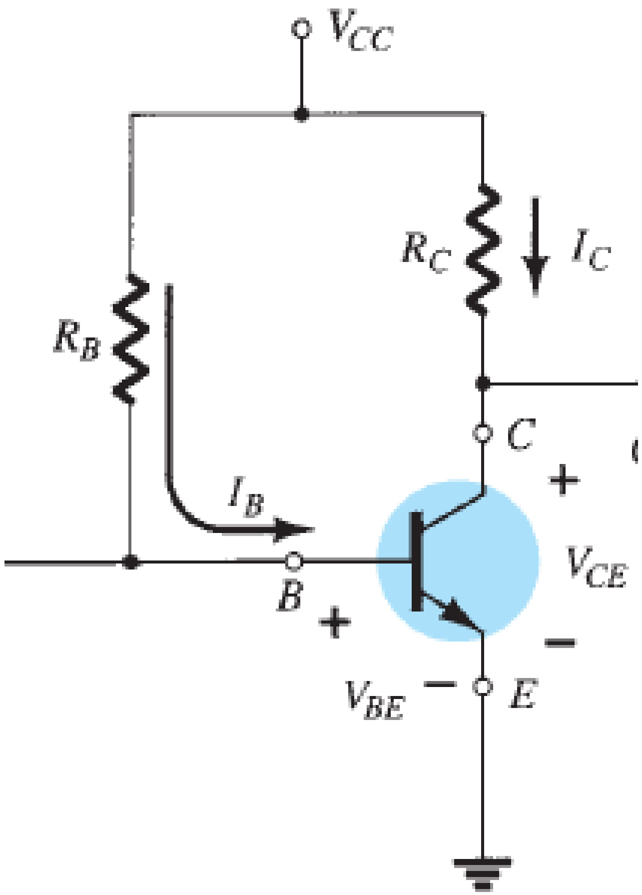
The process of making the operating point independent of temperature changes or variations in transistor parameters is known as Stabilization.

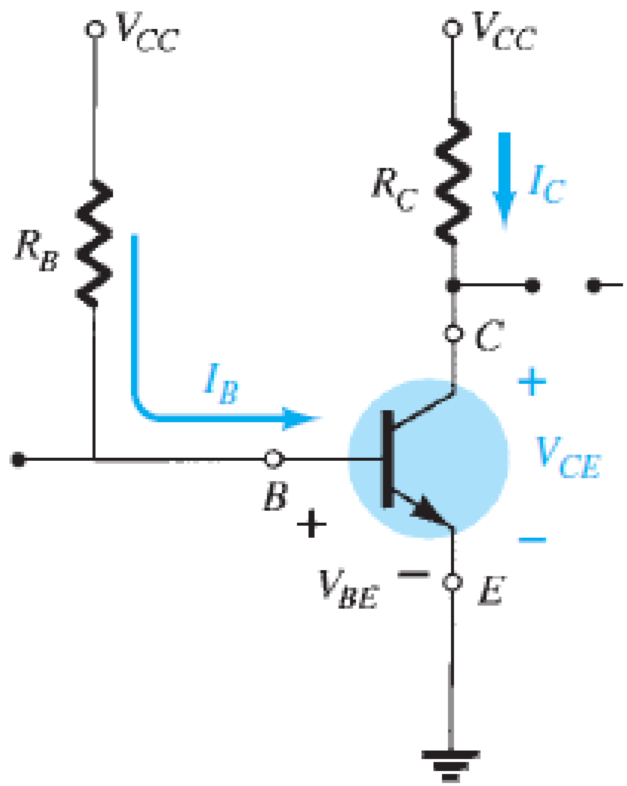
As stability depends on I_{CE}, β, V_{BE}, it can be expressed as:

$$S = \frac{\partial I_C}{\partial I_{CBO}},\ S' = \frac{\partial I_C}{\partial V_{BE}},\ S'' = \frac{\partial I_C}{\partial \beta}$$

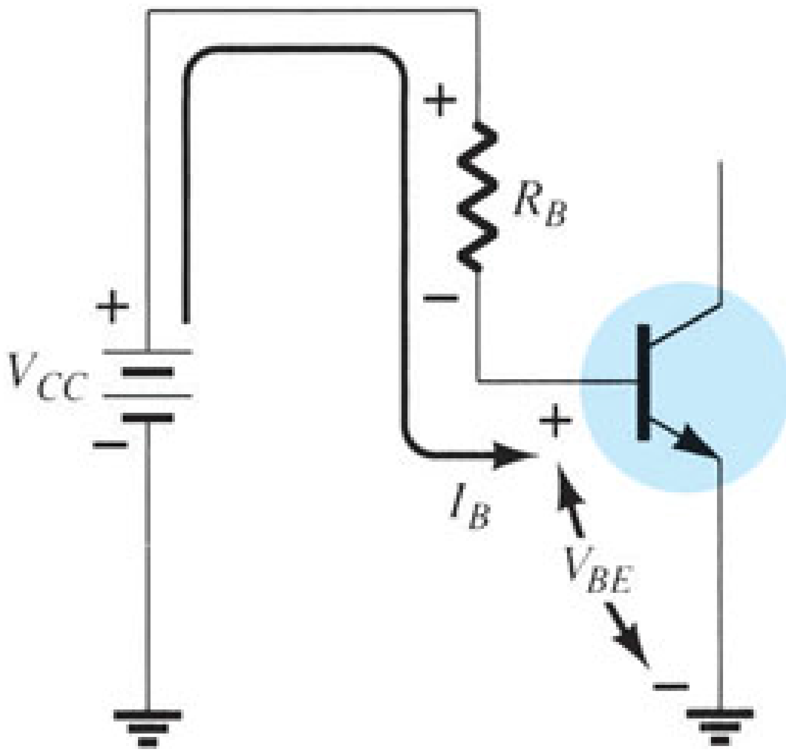
Biasing Circuits

Fixed Bias Circuit:





Base–emitter loop

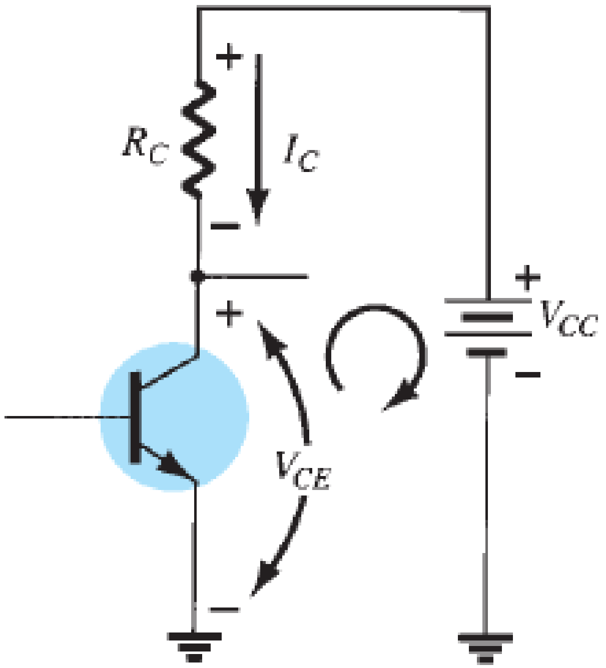


$$V_{CC} - I_B R_B - V_{BE} = 0$$

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

If $V_{CC} >> V_{BE}$, $I_B \approx V_{CC}/R_B$, So any change in V_{BE} due to temperature will have no effect on I_B. Since I_B is constant, the circuit is called fixed bias circuit.

Collector–Emitter Loop



$$V_{CE} + I_C R_C - V_{CC} = 0$$

$$V_{CE} = V_{CC} - I_C R_C$$

$$V_{CE} = V_C - V_E$$

$$V_{CE} = V_C$$

$$V_{BE} = V_B - V_E$$

$$V_{BE} = V_B$$

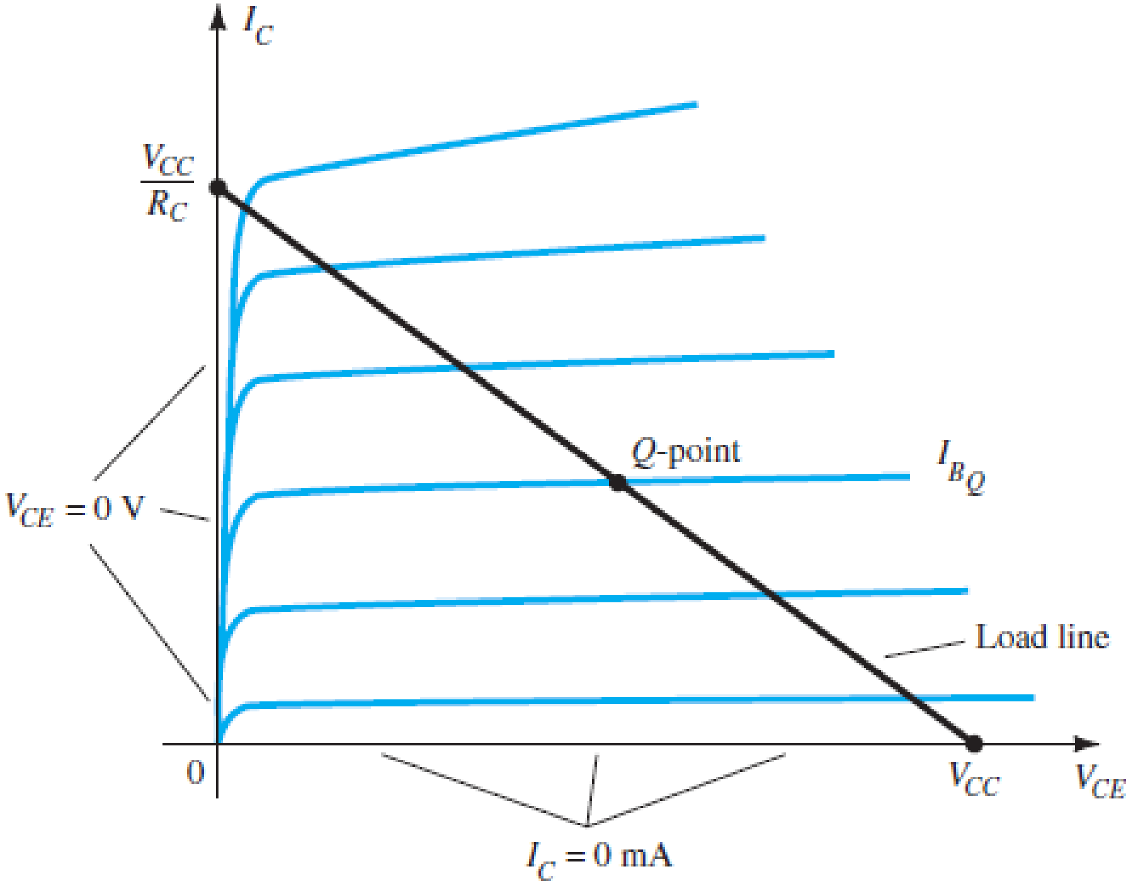
Load line

$$V_{CE} = V_{CC} - I_C R_C$$

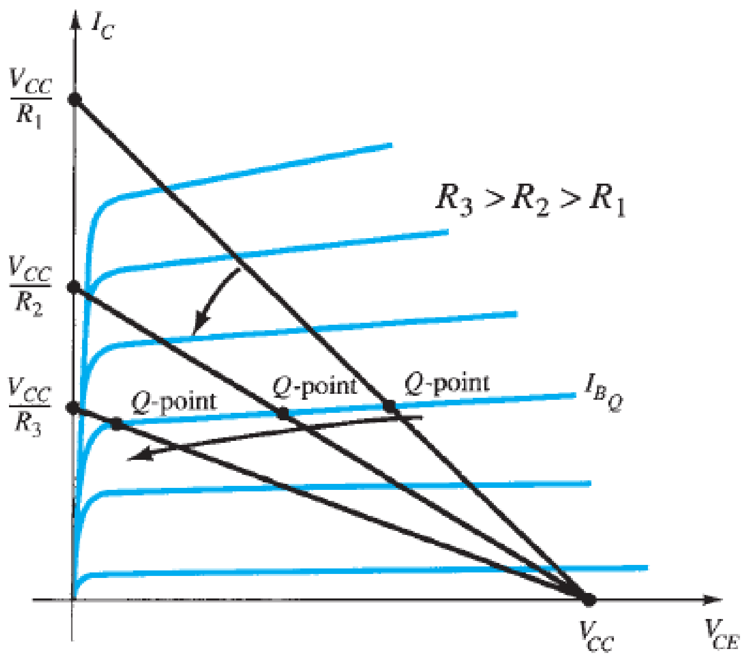
$$V_{CE} = V_{CC}\big|_{I_C=0}$$

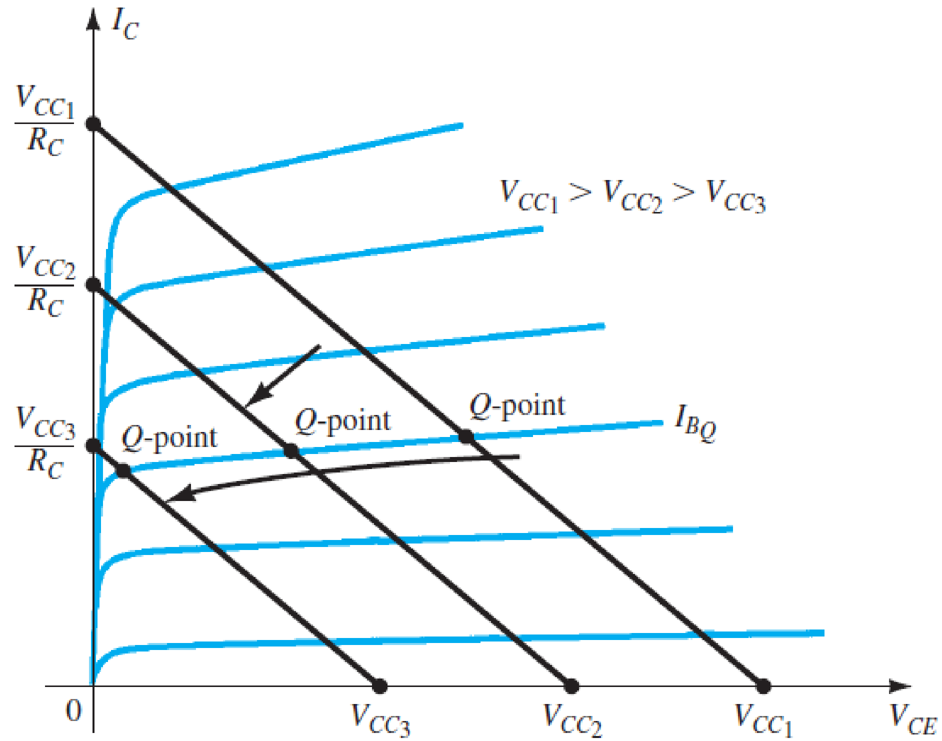
and

$$I_C = \frac{V_{CC}}{R_C}\bigg|_{V_{CE}=0}$$



Movement of Q - point

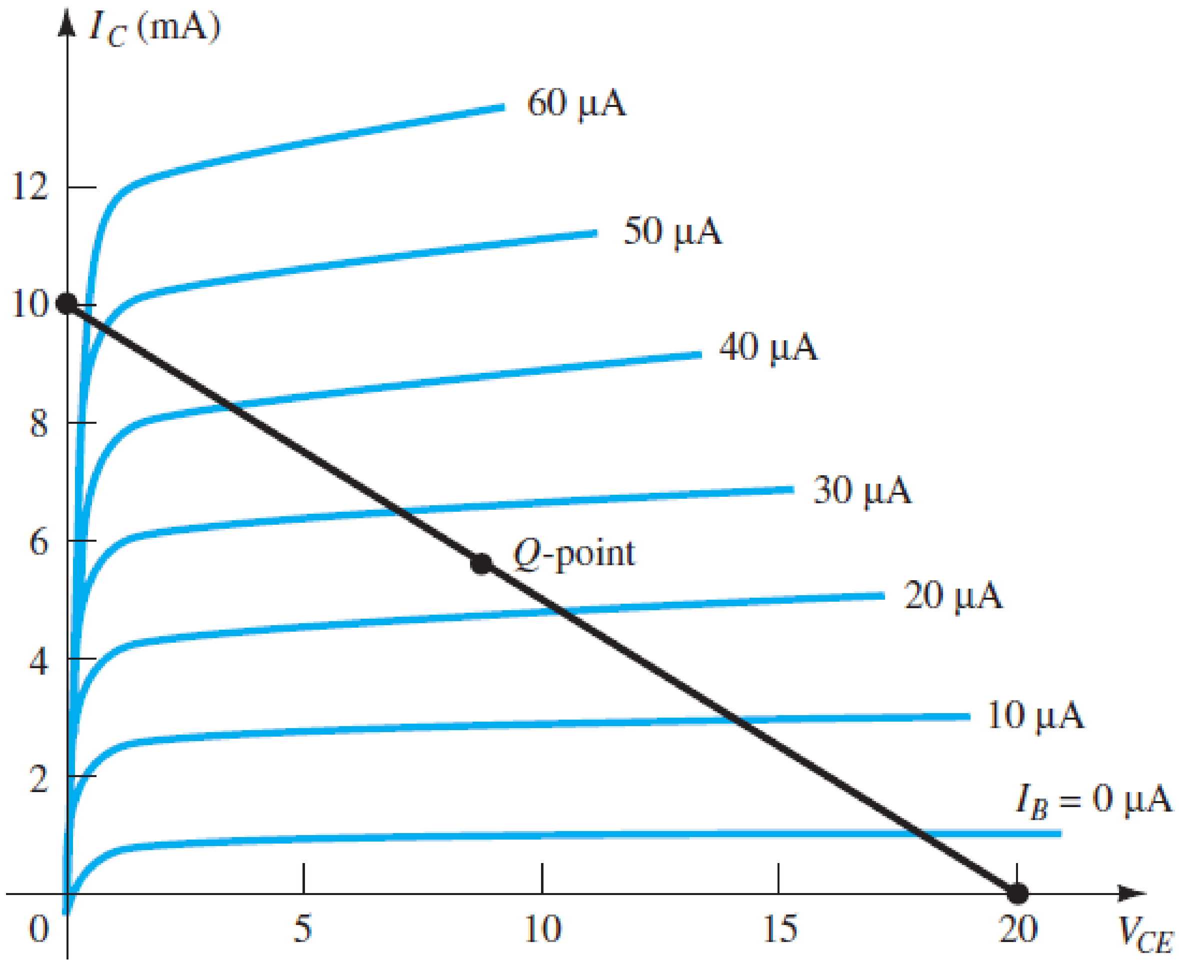




Effect of R_C on load line

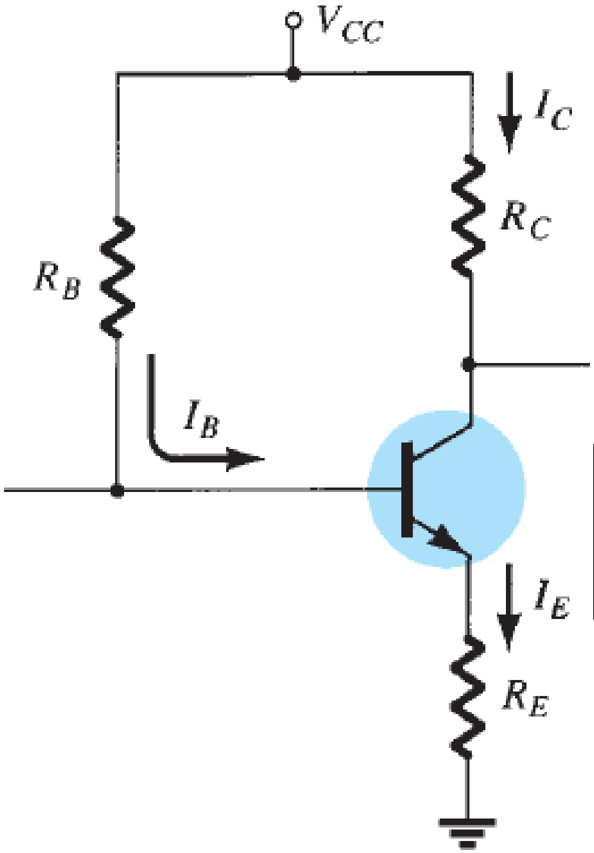
Effect of V_{CC} on load line

Output (V_{CE} vs I_C) characteristics of BJT in CE configuration



Please note that I_C ~ mA but I_B ~ μA

EMITTER-BIAS CONFIGURATION



Base-Emitter loop

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

$$I_B \downarrow = \frac{V_{CC} - V_{BE} - I_E R_E \uparrow}{R_B}$$

If temp. increases, I_{CBO} increases – means I_E increases keeping I_B low which will decrease I_C.

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

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

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

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

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

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

Stability factor calculation:

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

Now, put $I_E = I_B + I_C$

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

Now, put $I_C = \beta I_B + (i+\beta) I_{CBO}$

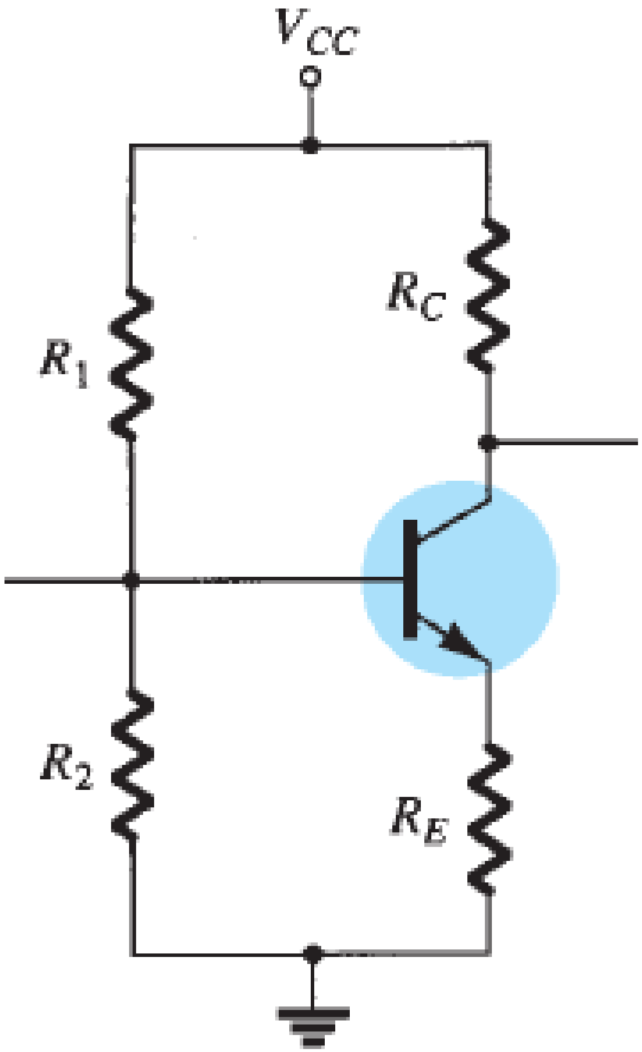
$$I_C = \frac{\beta(V_{CC} - V_{BE} - I_C R_E)}{R_B + R_E} + (1+\beta) I_{CBO}$$

$$I_C\left(1 + \frac{\beta R_E}{R_B + R_E}\right) = \frac{\beta(V_{CC} - V_{BE})}{R_B + R_E} + (1+\beta) I_{CBO}$$

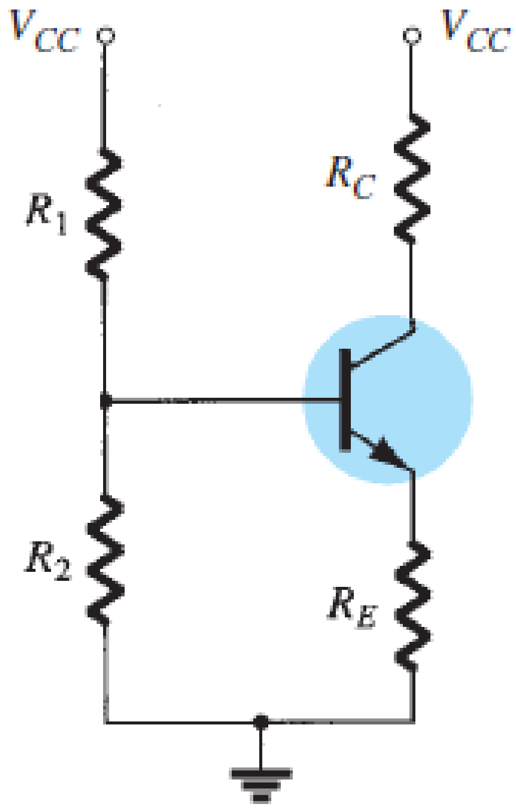
$$S = \frac{\partial I_C}{\partial I_{CBO}} = \frac{1+\beta}{1+\frac{\beta R_E}{R_B + R_E}} = (1+\beta)\frac{R_B + R_E}{R_B + R_E + \beta R_E} = (1+\beta)\frac{1+\frac{R_B}{R_E}}{(1+\beta)+\frac{R_B}{R_E}}$$

If, $\frac{R_B}{R_E} \ll 1$, $S \rightarrow 1$, If $\frac{R_B}{R_E} \gg (1+\beta)$, $S \rightarrow (1+\beta)$

Voltage-Divider Bias

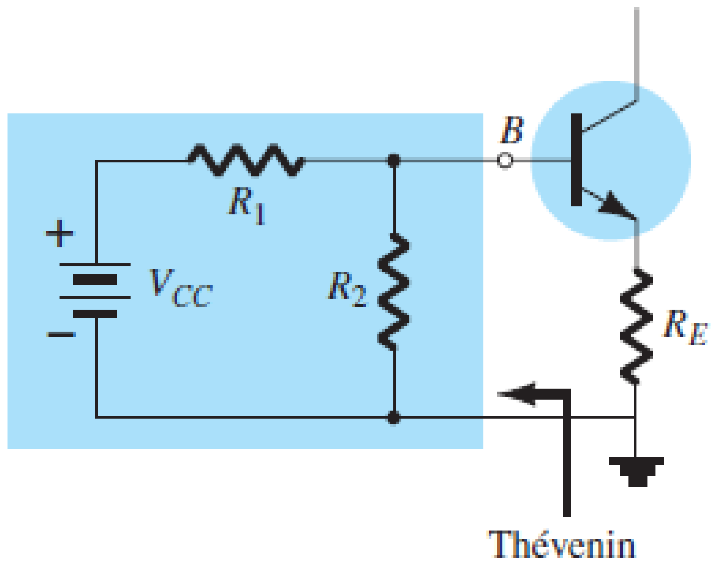


Voltage-divider bias circuit

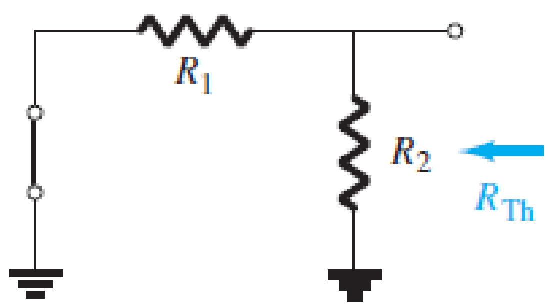


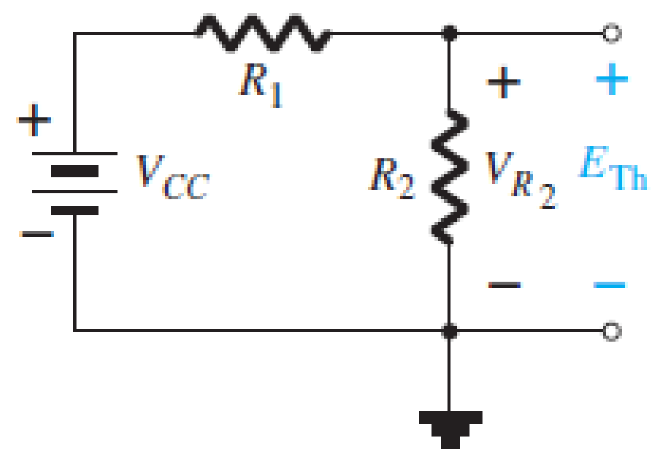
DC components of the voltage divider configuration

Analysis by applying Thevenin



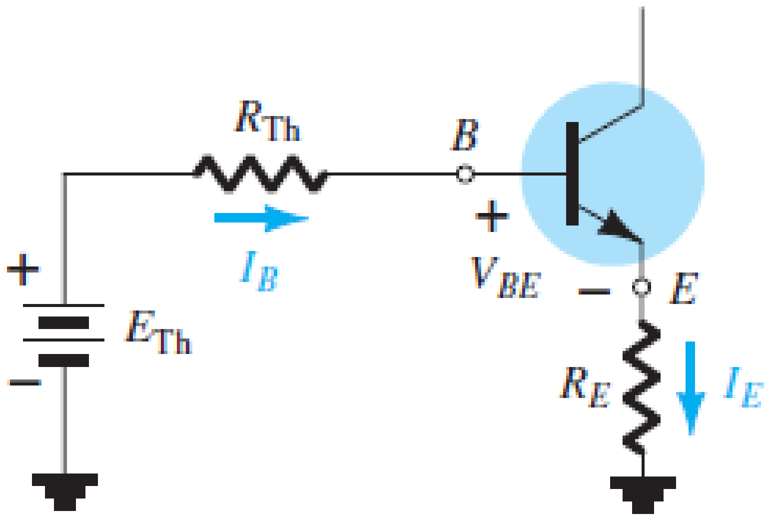
$$R_{Th} = R_1 \| R_2$$





The voltage source is replaced by a short-circuit equivalent

$$E_{Th} = V_{R_2} = \frac{R_2 V_{CC}}{R_1 + R_2}$$



Thevenin equivalent circuit

$$E_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

Substituting $I_E = (\beta + 1)I_B$

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

Once I_B is known, the remaining quantities of the network can be found in the same manner as developed for the emitter-bias configuration

$$V_{CE} = V_{CC} - I_C(R_C + R_E)$$