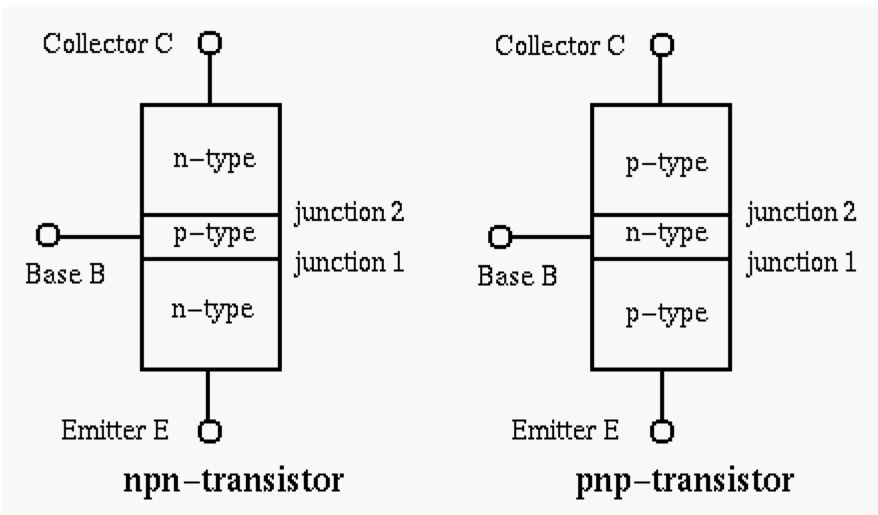
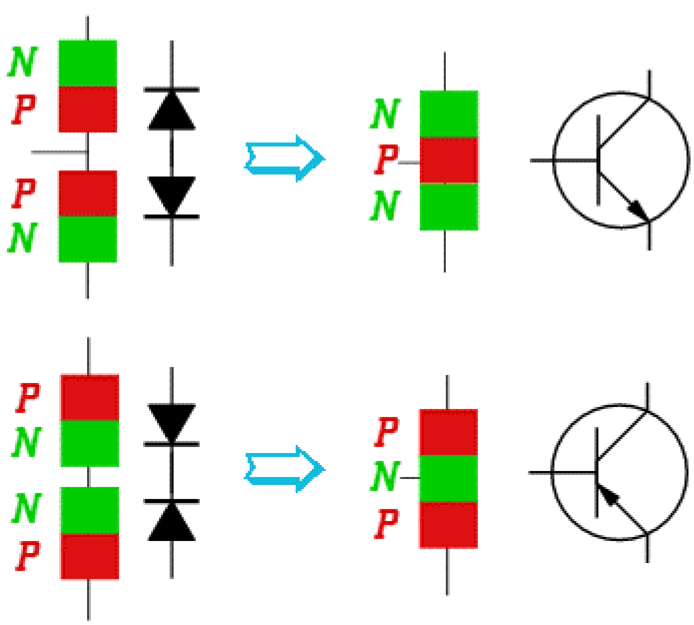
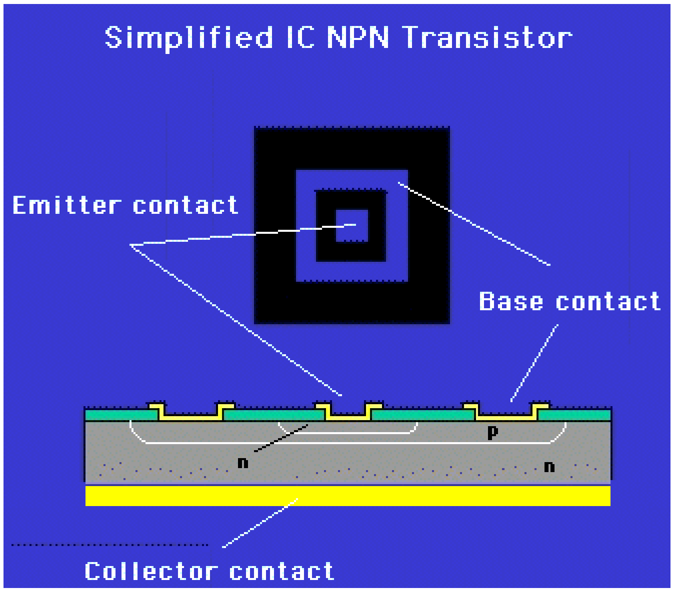
BIPOLAR JUNCTION TRANSISTOR

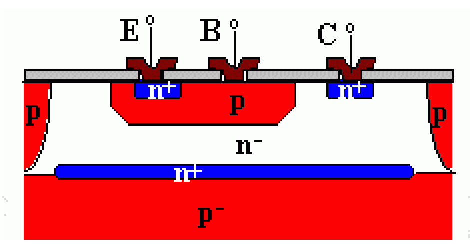
A Bipolar Junction Transistor (BJT) has three terminals connected to three doped semiconductor regions. In an npn transistor, a thin and lightly doped p-type material is sandwiched between two thicker n-type materials; while in a pnp transistor, a thin and lightly doped n-type material is sandwiched between two thicker p-type materials. In the following we will only consider npn BJTs.



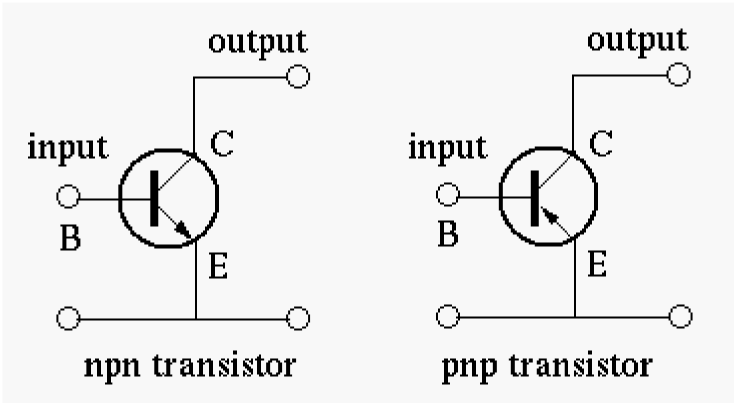


In many schematics of transistor circuits (especially when there exist a large number of transistors in the circuit), the circle in the symbol of a transistor is omitted.



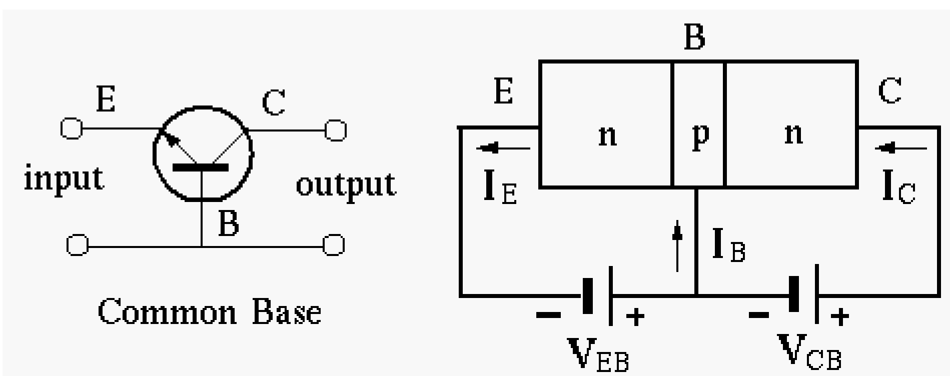


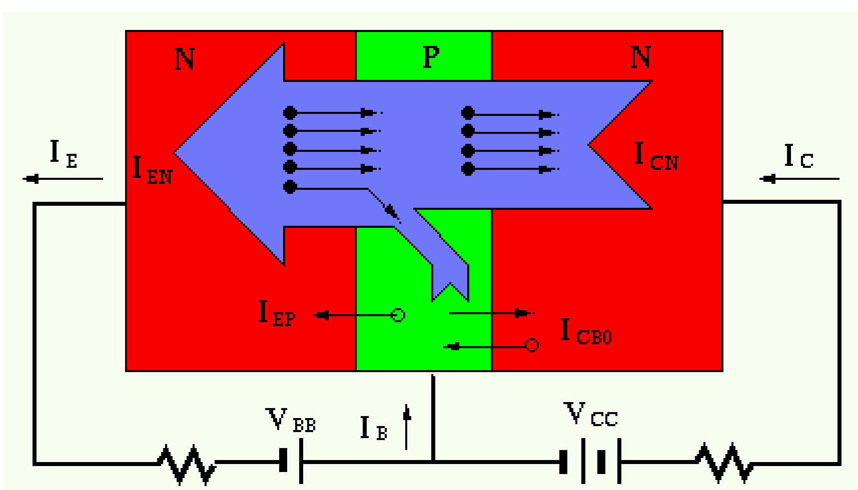
The three terminals of a transistor are typically used as the input, output and the common terminal of both input and output. Depending on which of the three terminals is used as common terminal, there are three different configurations: common emitter (CE), common base (CB) and common collector (CC). The CE configuration is the most widely used.



- **Common-Base (CB)**

Two voltages V_{BE} and V_{CB} are applied to the emitter E and collector C of the transistor with respect to the common base B. The BE junction is forward biased while the CB junction is reverse biased.





The behavior of the npn-transistor is determined by its two pn-junctions:

- The forward biased base-emitter (BE) PN-junction allows the free electrons to flow from the emitter through the PN-junction to form the emiiter current I_E.
- As the p-type base is thin and lightly doped, most electrons from the emitter αI_E (e.g. $\alpha \approx 0.99$) go through the base to reach the collector-base junction, only a small number of the electrons are combined with the holes in base to form the base current $I_B = (1 - \alpha) I_E$.
- The reverse biased collector-base (CB) PN-junction blocks the majority carriers (holes in the p-type base and electrons in n-type collector), but lets the minority carriers to go through, including the free electrons in the base coming from the emitter $I_{CN} = \alpha I_E$, and the reverse saturate current of the collector-base PN-junction $I_{CP} = I_{CB0}$.

The relationship between the output I_C and the input I_E can be found as:

$$I_C = I_{CN} + I_{CP} = \alpha I_E + I_{CB0} \approx \alpha I_E$$

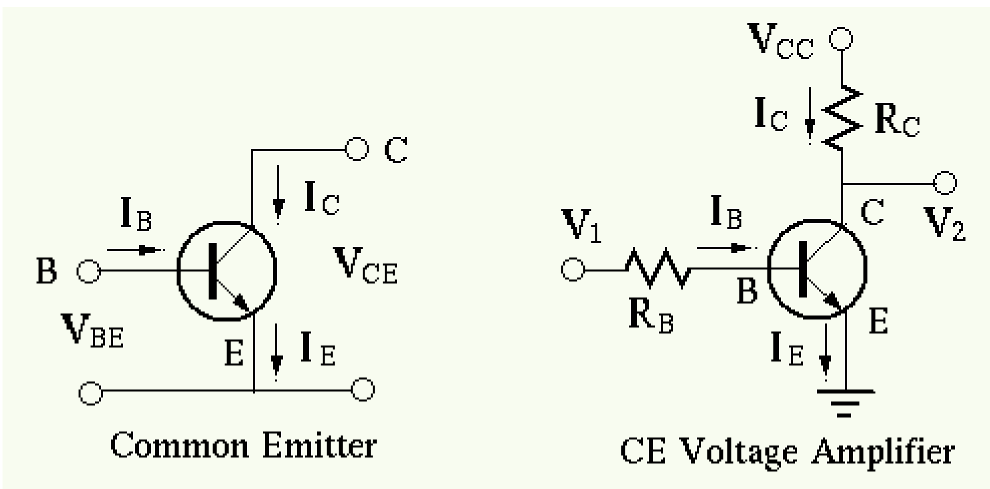
The base current I_B is the small difference between two nearly equal currents I_E and I_C:

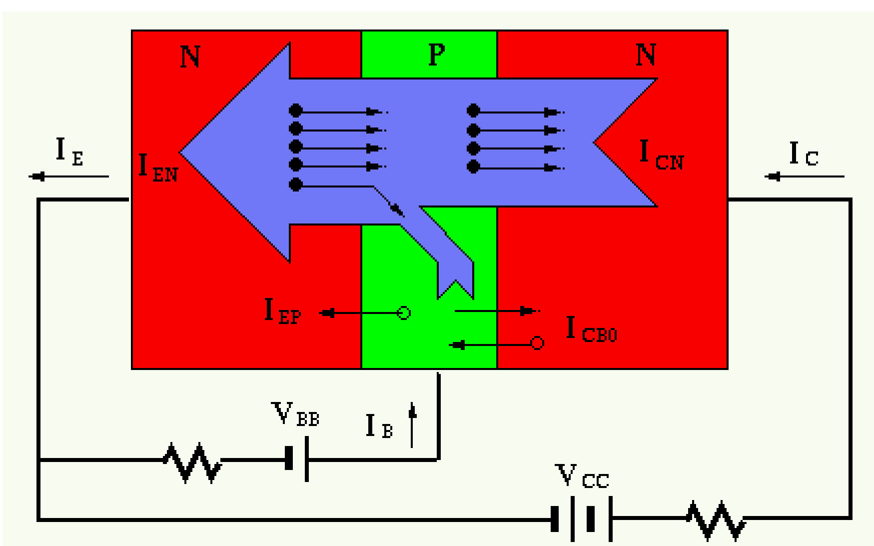
$$I_B = I_E - I_C \approx I_E - \alpha I_E = (1 - \alpha) I_E$$

- **Common-Emitter (CE)**

Two voltages V_{BE} and V_{CE} are applied to the base B and collector C of the transistor with respect to the common emitter E. The BE junction is forward biased while the CB junction is reverse biased. The voltages of CB and CE configurations are related by:

$$V_{CE} = V_{CB} + V_{BE}$$





The input current is I_B, and the output current is

$$I_C = \alpha I_E + I_{CB0} = \alpha(I_C + I_B) + I_{CB0} \approx \alpha(I_C + I_B)$$

Solving this equation for I_C, we get the relationship between the output I_C and the input I_B:

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CB0} = \beta I_B + (\beta+1) I_{CB0} = \beta I_B + I_{CE0} \approx \beta I_B$$

Here $\beta \stackrel{\triangle}{=} \alpha/(1-\alpha)$ is the **current-transfer ratio** for CE (e.g., $\alpha = 0.99$ and $\beta = 99$), and $I_{CE0} = (\beta+1) I_{CB0}$ is the reverse saturation current between collector and emitter. In summary:

$$\left\{ \begin{array}{l} I_C = \beta I_B \\ I_E = I_C + I_B = (\beta + 1) I_B \end{array} \right.$$