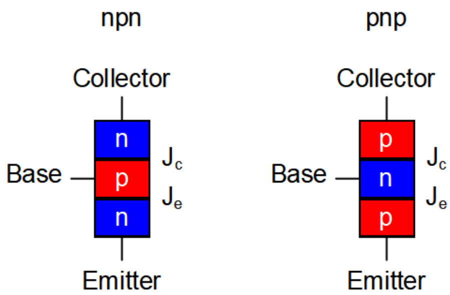
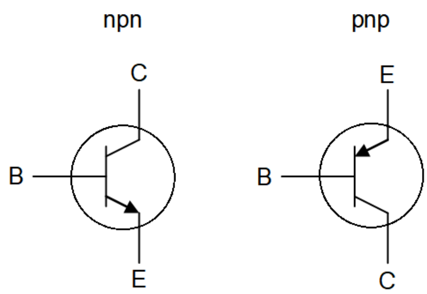
BJT

The BJT (bipolar junction transistor) is an active electronic component with three terminals (base - collector - emitter).

Its interior is composed of two alternately doped semiconductor junctions n and p. The two types of BJT that can be obtained are: the npn model and the pnp model.

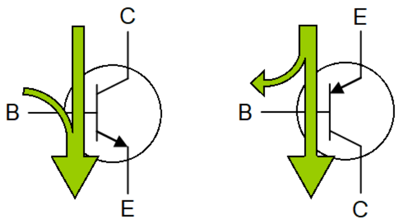


The circuit symbol is:



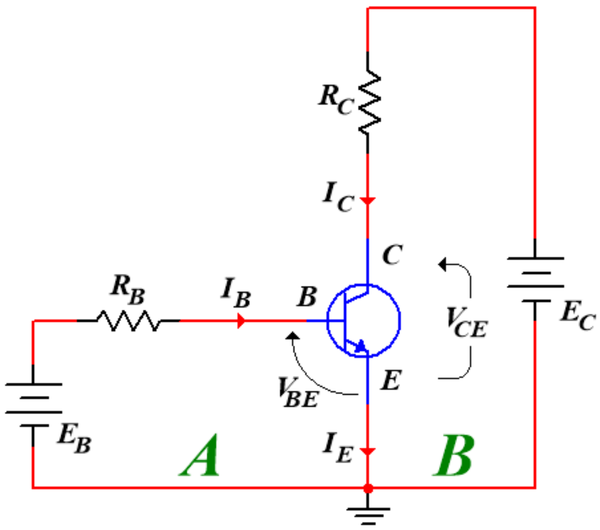
The BJT can be used as a simple switch or as an amplifier. The operation is always controlled by the base-emitter junction J_e which is forward biased, while if reverse biased the BJT is turned off. The base-collector J_c junction is forward biased for use as a switch, while it is reverse biased for use as an amplifier.

For the npn transistor, a small current entering the base favors the passage of current from the collector to the emitter. For the pnp transistor, a small current coming out of the base favors the passage of the current from the emitter to the collector.

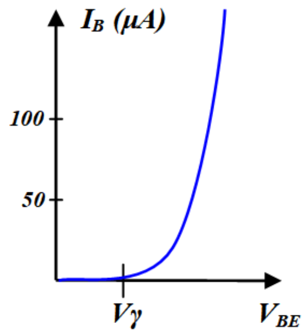


Therefore, the electric current flowing in the emitter is: $I_E = I_B + I_C$

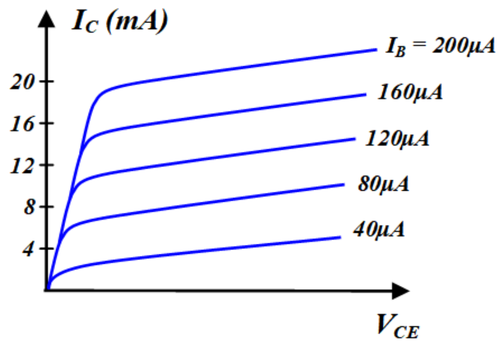
Let's consider the following circuit:



We have the input mesh (A) characterized by V_{BE} and I_B, and the output mesh (B) characterized by V_{CE} and I_C.



The input characteristic represents the trend of the current I_B as a function of the V_{BE} therefore we refer to the junction J_e between the base and the emitter, directly biased. The characteristic is that of a diode with threshold voltage $V\gamma$=0.7V, so V_{BE}=0.7V when the BJT is directly biased.



The output characteristics represent the trend of the current I_C as a function of the V_{CE} for constant values of I_B. It is therefore a family of curves.

The link between I_C and I_B is defined by the direct current gain h_{FE}, also called static gain, given by:

$$h_{FE} = \frac{I_C}{I_B}$$

In transistors, the value of h_{FE} tends to decrease both at high and low currents, while it increases with increasing V_{CE} with constant I_B.

The bias of the transistor is obtained by identifying on the output characteristics the intersection between the load line and the output curve corresponding to the specific current V_{CE} value.

$$E_C = V_{R_C} + V_{CE} \quad \rightarrow \quad V_{R_C} = -V_{CE} + E_C \quad \rightarrow \quad R_C I_C = -V_{CE} + E_C$$

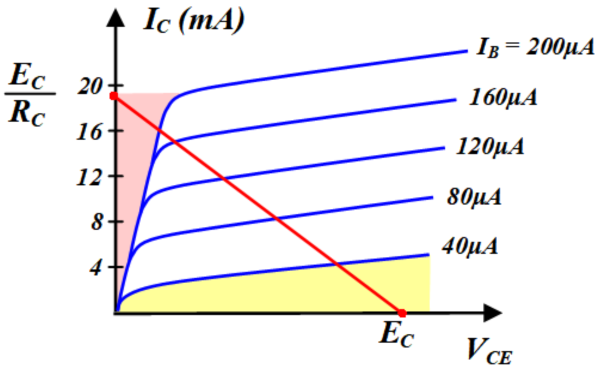
This last equation represents the load line outgoing on the BJT. Rewriting it:

$$I_C = -\frac{1}{R_C} V_{CE} + \frac{E_C}{R_C}$$

To trace the load line, we find the points of intersection with the axes by setting:

$$\begin{cases} V_{CE} = 0 & \rightarrow & I_C = \dfrac{E_C}{R_C} \\ I_C = 0 & \rightarrow & V_{CE} = E_C \end{cases}$$

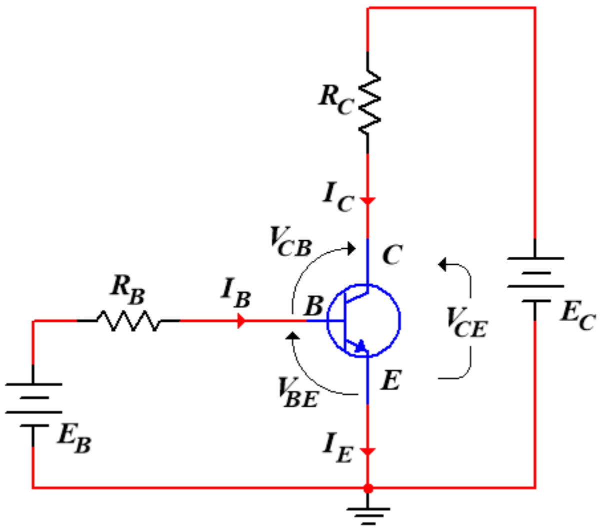
The intersection between the load line and the output characteristic (for an assigned value of I_B) identifies the working point of the transistor.



- active area (white): this is the central area of the output characteristics, also known as linear operation;
- saturation zone (red): with low V_{CE} values in which all the output curves tend to merge into a single almost vertical section;
- zone of interdiction (yellow): almost coincident with the abscissa axis in which both I_B and I_C have negligible values.

If you want to use the BJT as an amplifier, therefore in a linear way, the working point must be appropriately chosen within the active zone.
If you want to use the BJT as a switch, the duty point can only switch between the interdiction zone and the saturation zone.

Let's consider the circuit again:



1. With E_B<Vγ the junction BE does not conduct, as we certainly have V_{BE}<Vγ. The CB junction is reverse biased due to the polarity of the E_C generator. In this situation the BJT is in interdiction, so we have I_C≈0 and V_{CE}=E_C.
2. With E_B>=Vγ the BE junction is forward biased and starts conducting. The base current is:

$$I_B = \frac{E_B - V_\gamma}{R_B}$$

Regarding the CB junction:

$$V_{CB} = E_C - V_{BE} - V_{R_C} = E_C - V_{BE} - R_C I_C$$

The following considerations can then be made:

- If V_{CB}>0, the CB junction is reverse biased and the BJT is in the active zone. At this point $I_C \approx h_{FE} I_B$, regardless of the V_{CE} value.
- As the E_B value increases, the intensity of the base current increases (in fact we will always have V_{BE}≈Vγ) and therefore that of the collector. An I_C increase in turn determines an increase of V_{RC} and thus a decrease of V_{CE}. The increase in I_C ends up by directly biasing the CB junction (V_{CB}<0) causing it to enter into conduction. At this point both junctions are forward biased and the BJT is in saturation.