NOTES ON BJT TRANSISTORS

The **Bipolar Junction Transistor (BJT)** is an active device. In simple terms, it is a *current controlled* valve. The *base current* (I_B) controls the *collector current* (I_C).

Regions of BJT operation:

Cut-off region: The transistor is off. There is no conduction between the collector and the emitter. ($I_B = 0$ therefore $I_C = 0$)

Active region: The transistor is on. The collector current is proportional to and controlled by the base current ($I_C = \beta I_B$) and relatively insensitive to V_{CE}. In this region the transistor can be an amplifier.

Saturation region: The transistor is on. The collector current varies very little with a change in the base current in the saturation region. The V_{CE} is small, a few tenths of a volt. The collector current is strongly dependent on V_{CE} unlike in the active region. It is desirable to operate transistor switches in or near the saturation region when in their *on* state.

Rules for Bipolar Junction Transistors (BJTs):

- For an *npn* transistor, the voltage at the collector V_C must be greater than the voltage at the emitter V_E by at least a few tenths of a volt; otherwise, current will not flow through the collector-emitter junction, no matter what the applied voltage at the base. For *pnp* transistors, the emitter voltage must be greater than the collector voltage by a similar amount.
- For the *npn* transistor, there is a voltage drop from the base to the emitter of 0.6 V. For a *pnp* transistor, there is also a 0.6 V rise from the base to the emitter. In terms of operation, this means that the base voltage V_B of an *npn* transistor must be at least 0.6 V greater that the emitter voltage V_E; otherwise, the transistor will not pass emitter-to-collector current. For a *pnp* transistor, V_B must be at least 0.6 V less than V_E; otherwise, it will not pass a collector-to-emitter current.

BASIC EQUATIONS FOR THE BJT.

for npn : $V_B > V_E + 0.6\,\mathrm{V}$

for pnp : $V_B < V_E - 0.6\,\mathrm{V}$

for both npn & pnp anytime

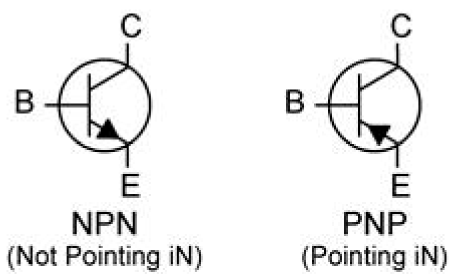
$$I_E = I_C + I_B$$

for both npn & pnp only in the active region

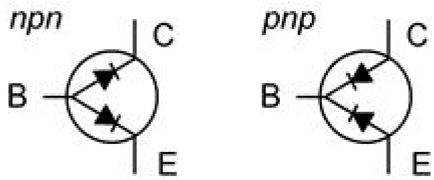
$$I_C = h_{FE} I_B = \beta I_B$$

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

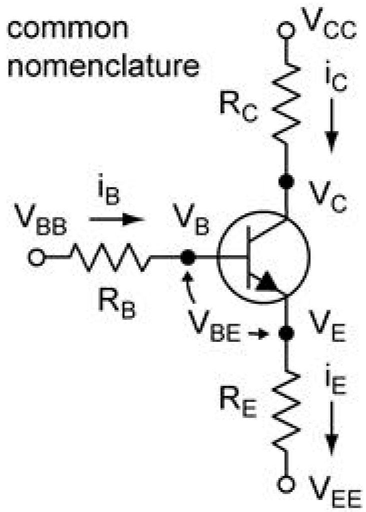
BJT Schematic Symbols (Mnemonics for remembering the direction of the arrows are in parenthesis.)



Ohmmeters view of the BJT. Clearly a transistor cannot be made on the bench by combining two diodes. (Why is that?) Most ohmmeters cannot only measure the resistance, but also measure the forward voltage drop across a diode. From this perspective you can identify the base and the type of transistor based on the following equivalent circuits.



Common Nomenclature (*npn* example).



Types of Amplifiers.

The transistor is a three terminal device, thus the input and the output must share one terminal in *common*. This is the origin of the nomenclature of the three types of transistor amplifiers: common collector, common emitter, and common base.

Definition of Gain.

Gain is defined as the ratio of the output signal to the input signal. Because transistor amplifiers often have a quiescent output (a non zero output when the input is zero) we define gain as the derivative of the output with respect to the input. For systems where the quiescent output is zero, this reduces to the ratio of the output to the input. Thus gain is defined as the ratio of the change in output to the change in input.

So far we have not specified the output quantity, the reason is that we can define the gain with respect to any given output and input quantity.

$$\text{General definition} \ : \quad A = \frac{\mathrm{d}(Output)}{\mathrm{d}(Input)} \qquad \text{if } (Output) = 0 \text{ when } (Input) = 0, \text{ then } A = \frac{(Output)}{(Input)}$$

$$\text{Voltage Gain} : \quad A_V = \frac{\mathrm{d}V_{out}}{dV_{in}} \qquad \text{if } V_{out} = 0 \text{ when } V_{in} = 0, \text{ then } A = \frac{V_{out}}{V_{in}}$$

$$\text{Current Gain} : \quad A_I = \frac{\mathrm{d}I_{out}}{dI_{in}} \qquad \text{if } I_{out} = 0 \text{ when } I_{in} = 0, \text{ then } A = \frac{I_{out}}{I_{in}}$$

$$\text{Power Gain} : \quad A_P = \frac{\mathrm{d}P_{out}}{dP_{in}} \qquad \text{if } P_{out} = 0 \text{ when } P_{in} = 0, \text{ then } A = \frac{P_{out}}{P_{in}}$$

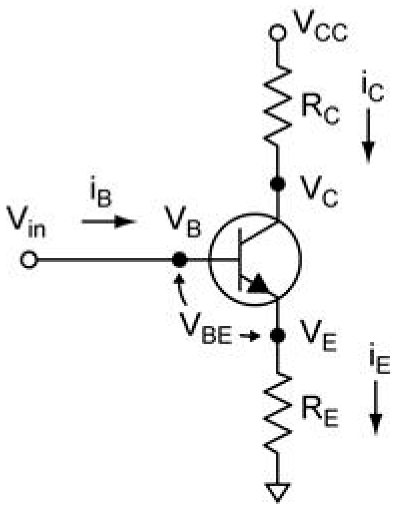
Note that a negative gain means that the sign of the signal is inverted. Negative gain is not possible for Power Gain. |A| less than unity indicates that the output is smaller than the input.

The quantities need not be the same. If the input and output quantities are different, the gain is no longer unitless. The most common examples are transimpedance gain and transadmittance gain.

$$\text{Transimpedance Gain: } A_Z = \frac{d V_{out}}{d I_{in}} \qquad \text{if } V_{out} = 0 \text{ when } I_{in} = 0, \text{ then } A = \frac{V_{out}}{I_{in}}$$

$$\text{Transadmittance Gain: } A_Y = \frac{d I_{out}}{d V_{in}} \qquad \text{if } I_{out} = 0 \text{ when } V_{in} = 0, \text{ then } A = \frac{I_{out}}{V_{in}}$$

Input Impedance of a Transistor.



Impedance is defined as $Z = V/I$. In linear circuits (with resistors, capacitors, inductors, batteries, etc.) this ratio is the reciprocal of the slope of the I versus V graph. In circuits with nonlinear elements such as a transistor, the input impedance of the transistor is defined as the reciprocal of the slope of the I versus V graph. This is simply the derivative of V_{in} with respect to I_{in}.

$$Z_{in} = \frac{d V_{in}}{d I_{in}}$$

We can easily find Z_{in} from what we know already of the behavior of the transistor. We know that the sum of V_{BE} and the IR drop across R_E must equal V_{in}.

$$V_{in} = V_B = V_{BE} + V_E = V_{BE} + I_E R_E \qquad I_E = I_C + I_B = \beta I_B + I_B = I_B(\beta + 1)$$

$$V_{in} = V_{BE} + I_E R_E = V_{BE} + I_B(\beta + 1) R_E \qquad I_B = I_{in}$$

$$V_{in} = V_{BE} + I_{in}(\beta + 1) R_E$$

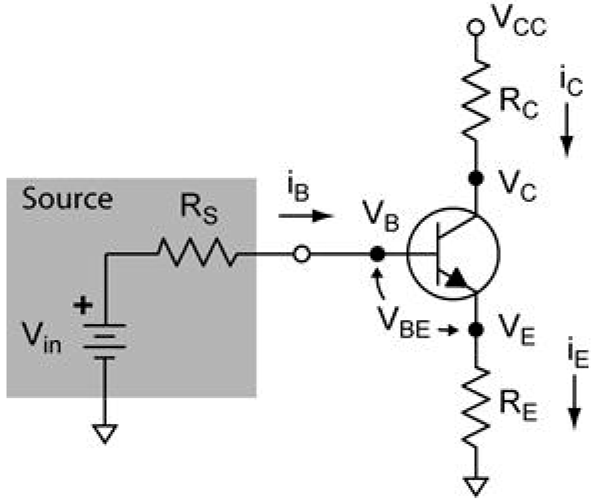
Taking the derivative of V_{in} with respect to I_{in}, remembering that V_{BE} is a constant, we get the result:

$$Z_{in} = \frac{\mathrm{d}V_{in}}{\mathrm{d}I_{in}} = \frac{\mathrm{d}}{\mathrm{d}I_{in}}\left(V_{BE} + I_{in}(\beta+1)R_E\right) = (\beta+1)R_E$$

$$\boxed{Z_{in} = (\beta+1)R_E \approx \beta R_E}$$

Because $I_E = I_B(\beta + 1)$ The IR drop across R_E is greater than it would be for I_B alone. The amplification of the base current causes R_E to appear larger to a source looking into the input by $(\beta + 1)$.

<u>Output Impedance of a Transistor for the Emitter Follower (Common Collector).</u>



The output impedance seen by the load (R_E in this example) is defined as:

$$Z_{out} = -\frac{\mathrm{d}V_{out}}{\mathrm{d}I_{out}}$$

The minus sign in the derivative comes from the fact the output impedance has the effect of decreasing V_{out}. The output current I_{out} is just the emitter current I_E which is related to the base current.

$$V_{in} = I_B R_S + V_{BE} + V_E \qquad V_{out} = V_E$$

$$V_{out} = V_E = V_{in} - I_B R_S - V_{BE} \qquad I_{out} = I_E \qquad I_B = \frac{I_E}{\beta+1}$$

$$V_{out} = V_{in} - \left(\frac{I_E}{\beta+1}\right)R_S - V_{BE} = V_{in} - \left(\frac{I_{out}}{\beta+1}\right)R_S - V_{BE} = -I_{out}\left(\frac{R_S}{\beta+1}\right) + \left(V_{in} - V_{BE}\right)$$

$$Z_{out} = -\frac{\mathrm{d}V_{out}}{\mathrm{d}I_{out}} = -\frac{\mathrm{d}}{\mathrm{d}I_{out}}\left(-I_{out}\left(\frac{R_S}{\beta+1}\right) + \left(V_{in} - V_{BE}\right)\right) = \left(\frac{R_S}{\beta+1}\right)$$

Thus we obtain the result that the impedance of the source, as viewed by the load, is reduced by the factor ~1/β.

$$\boxed{Z_{out} = \left(\frac{R_S}{\beta+1}\right) \approx \frac{R_S}{\beta}}$$

Source : http://www.nhn.ou.edu/~bumm/ELAB/Lect_Notes/BJT_FET_transitors_v1_1_1.html