Semester-IV

CC-10

Input and Output Characteristics of a transistor

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Online-4 (BJT-2)

Characteristic Curves of Transistor

Like junction diode, Transistor is a nonlinear device. We do not have any exact analytical relationship between current and voltage ina transistor. So, we often take the help of experimentally drawn current-voltage characteristic curves.

Common base characteristics

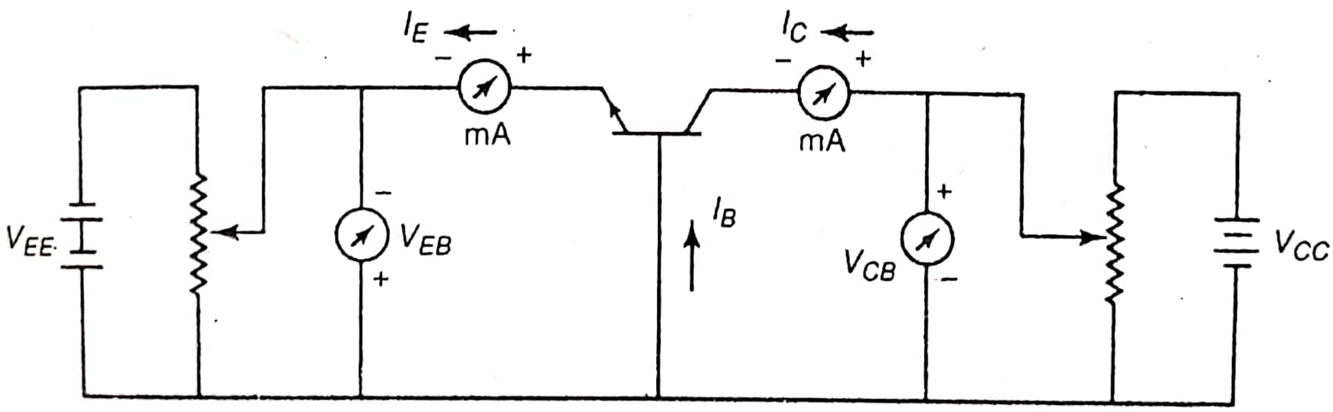

Fig. 1 Circuit arrangement to draw CB characteristic curves of a n-p-n transistor.

In C-B mode the variation of input emitter current (I_E) with input emitter-base voltage (V_{BE}) taking the output collector base voltage (V_{CB}) as parameter, gives the static input characteristics.

In the normal operating region of a transistor the emitter-base junction is forward biased and the input curves are similar to that of a forward biased p-n junction.

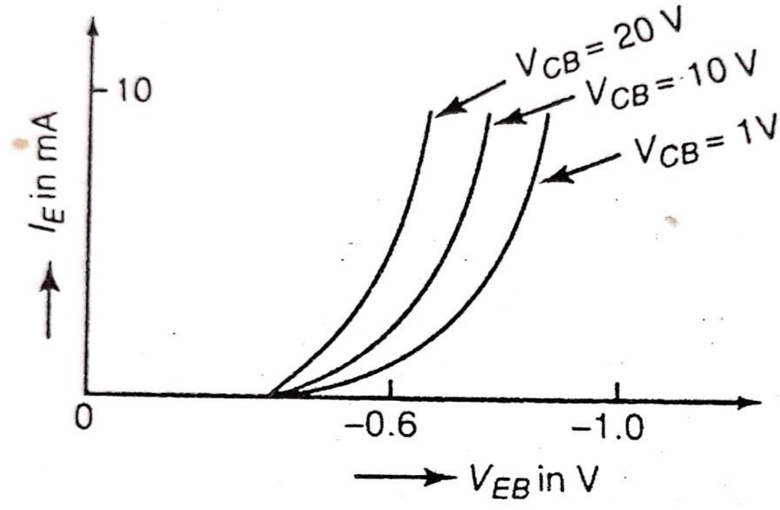

Fig.2 Input Characteristics of a Si Transistor in CB mode.

I_E increases exponentially with the increase of $|V_{EB}|$. There exists a cut-in voltage V_γ ($V_\gamma \sim 0.1$V for Ge and $V_\gamma \sim 0.5$ V for Si transistor) below which I_E is negligible. An increase in $|V_{CB}|$ causes I_E to increase at a given V_{EB}.

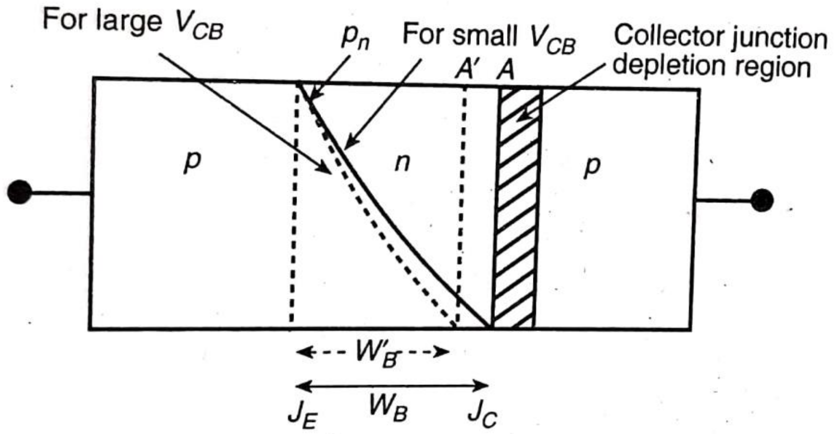

Fig.3 Early effect and minority carrier concentration profile in the base region of a p-n-p transistor.

If the reverse bias voltage $|V_{CB}|$ of collector junction is increased, the width of the depletion region of collector-base junction increases. This reduces the effective width of the base region. This change of effective width by collector voltage is known as Early effect or base width modulation. The reduction of the effective base width with increase in $|V_{CB}|$ enhances the minority carrier concentration in the base region. Thus the diffusion current which is proportional to the concentration gradient increases. Hence I_E increases with $|V_{CB}|$.

Output Characteristic Curves:

In CB mode variation of output collector current I_C with the output collector-base voltage $|V_{CB}|$ taking input emitter current I_E as parameter, gives the static output characteristics. There are three regions of output characteristics.

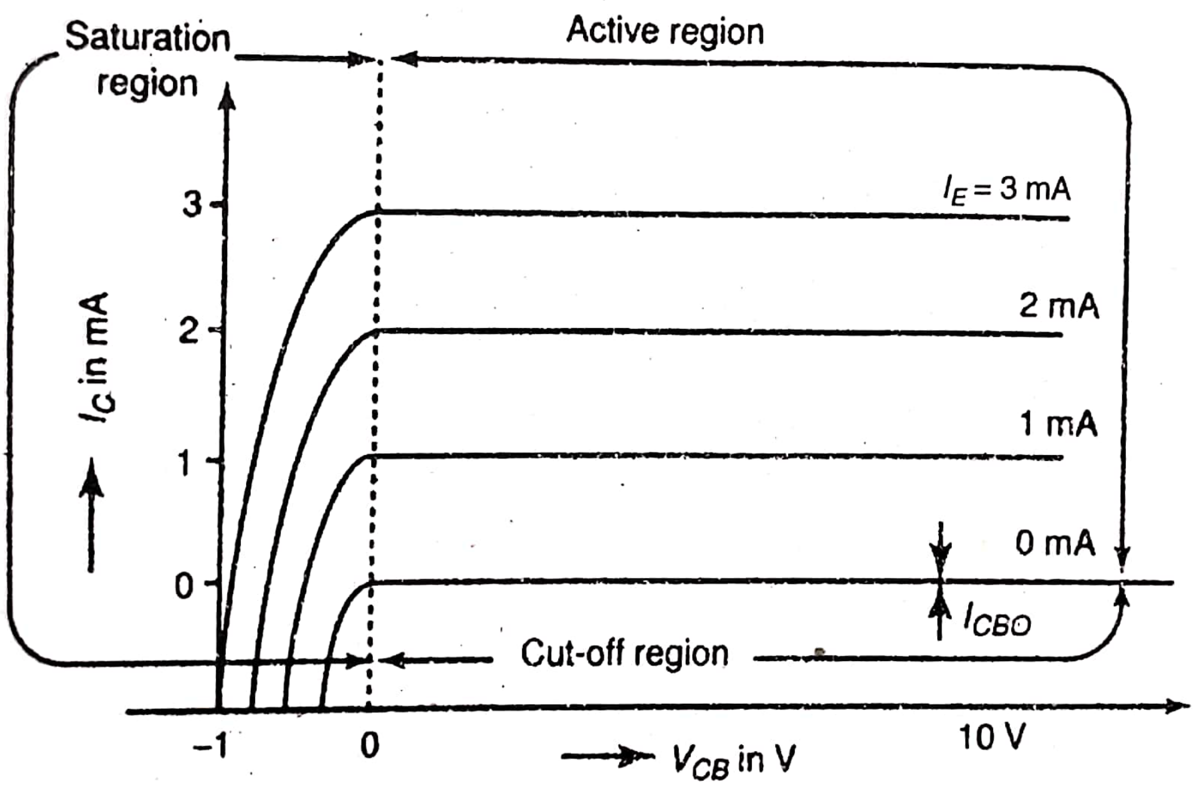

Fig.4 Output characteristics of an n-p-n transistor in CB mode.

<u>**Active region**</u>: **In the active region the emitter junction is forward biased and the collector junction is reverse biased.**

At the lower end of the active region, I_E=0 and the collector current is simply the reverse saturation current I_{CO}. I_{CO} is of the order of few μA for Ge and few nA for Si made transistor.

Now as I_E increases above zero, the collector current is given by the relation,

$$I_C = \alpha I_E + I_{CO} \approx \alpha I_E$$

Since α is close to unity, I_C is only slightly less than I_E. However, as I_E increases, α decreases and I_C differs appreciably from I_E .

In this region, collector current is almost independent of V_{CB}. However, because of Early effect I_C increases slightly with V_{CB}. Increase in V_{CB} decreases effective base width.

It reduces the probability of recombination of carriers while diffusing through the base. Thus I_C is increased. If V_{CB} is increased very much there may be collector junction breakdown causing sharp rise in I_C.

<u>Saturation region:</u> In the saturation region both the emitter and the collector junctions are forward biased.

In the Fig.4 , saturation region represents the region to the left of the ordinate V_{CB} = 0 and above the characteristic for I_E = 0.

It is seen that I_C is not zero even when V_{CB}=0. This is so because the injected carriers still find a potential down at the collector junction due to contact potential difference.

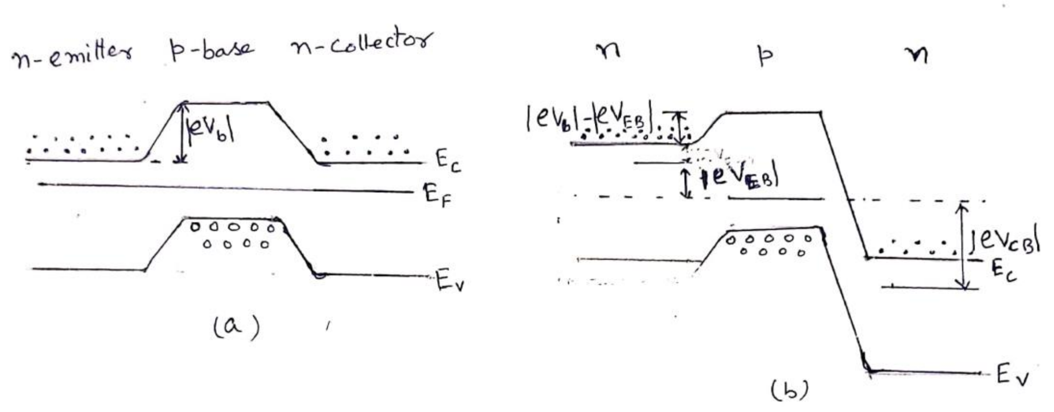

Fig. 5 energy band diagram of an n-p-n transistor.

To reduce I_C to zero, it is necessary to apply a small forward bias to the collector. With collector junction in n-p-n transistor under forward biased condition, electrons flow from n-collector to p-base. This is opposite to the flow of electrons injected from emitter and reaching the collector junction through the base. For sufficient forward biasing of the collector junction these two opposite flows make I_C=0 or even the direction of I_C may be reversed as indicated in Fig.4.

<u>Cut-off region:</u> In this region both the emitter and the collector junctions are reverse biased.

In Fig.4, the cut-off region represents the region to the right of the ordinate V_{CB}=0 and below the characteristic for I_E=0.

Common emitter characteristics

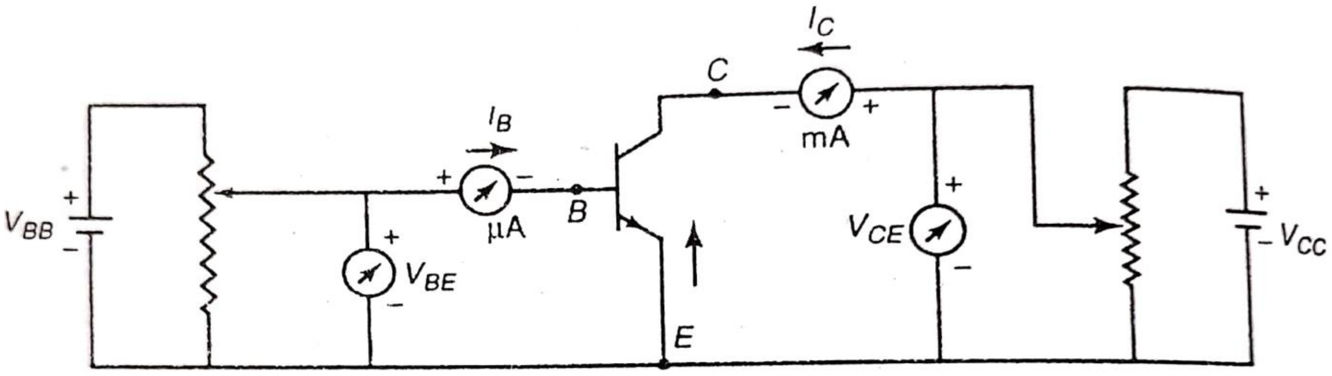

Fig.6 Circuit arrangement to draw CE characteristics of an n-p-n transistor.

Input characteristics: The variation of input base current I_B with input base-emitter voltage V_{BE} taking output collector emitter voltage V_{CE} as a parameter gives the CE input characteristics.

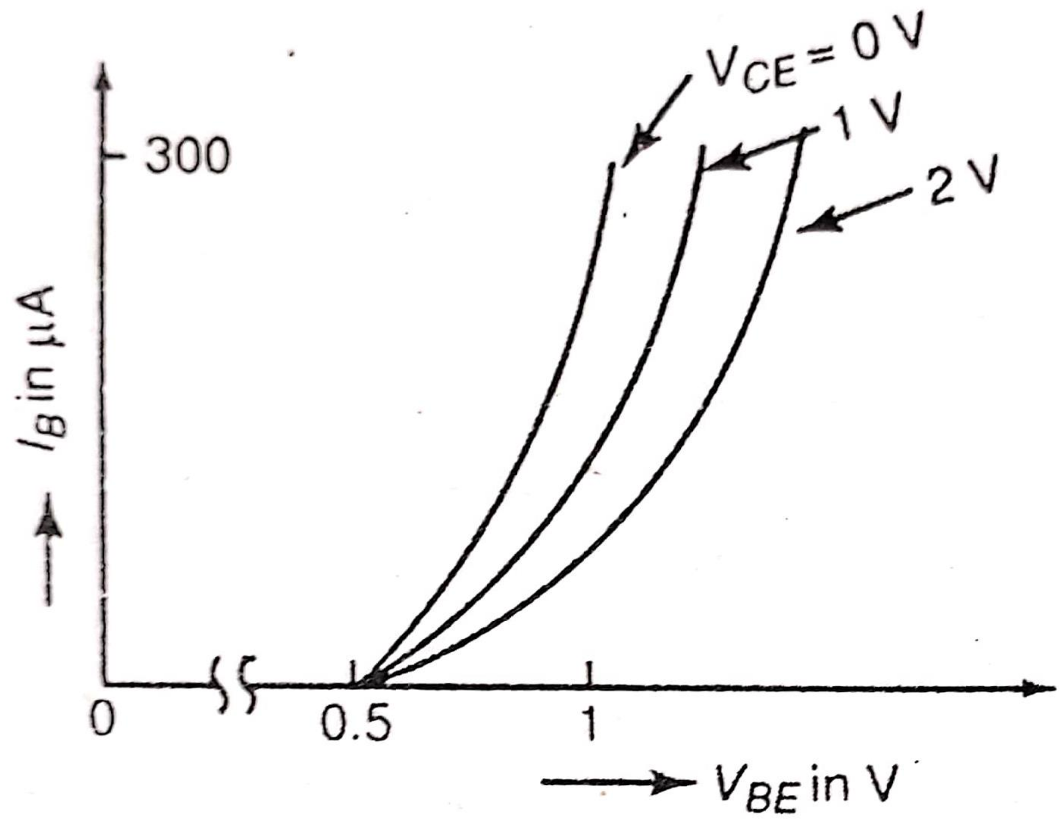

Fig.7 Input characteristics of an n-p-n Si transistor in CE mode.

The characteristic curves are similar to that of a forward biased p-n junction. For a constant V_{BE}, I_B decreases with increase in V_{CE}.

Increase in V_{CE} decreases the effective base width and hence the probability of recombination of the injected carriers in the base. As a result the recombination base current decreases.

Output Characteristics:

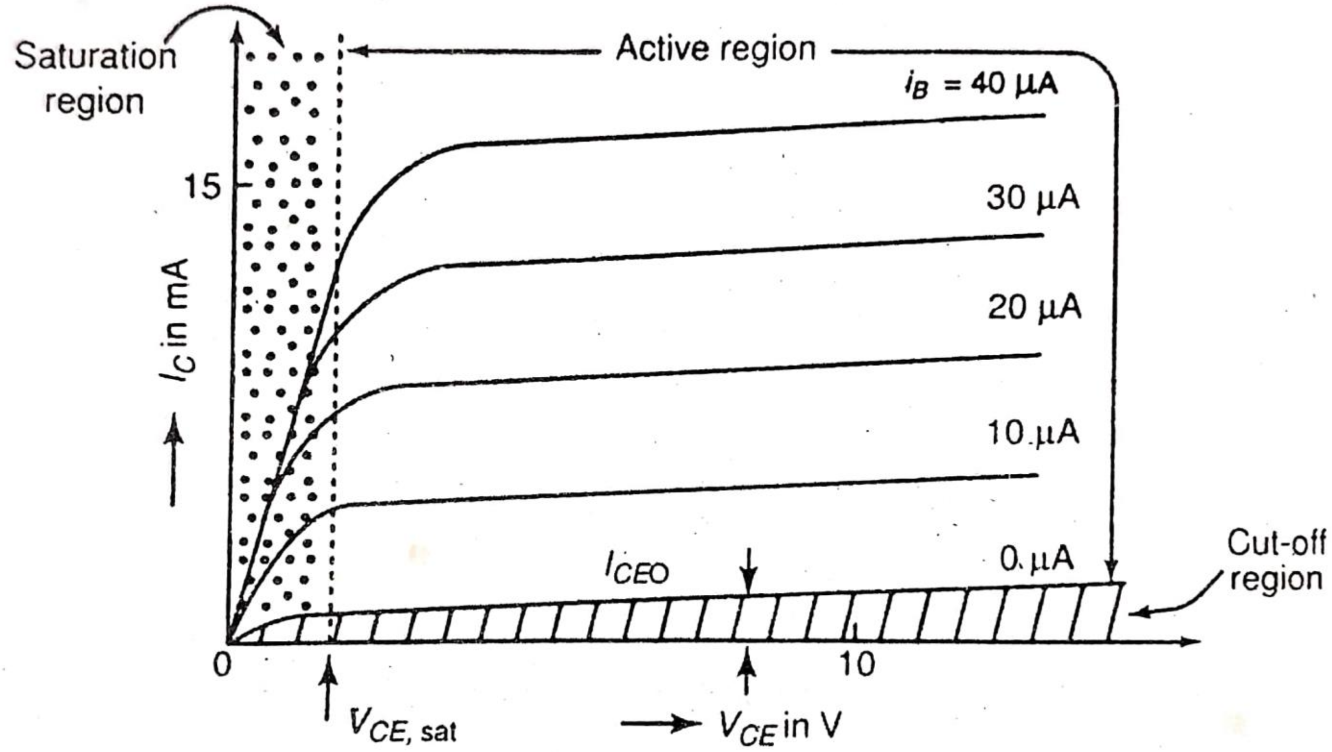

Fig.8 Output characteristics of an n-p-n Si transistor in CE mode.

Three regions:

Active region: In active region the emitter junction is forward biased and the collector junction is reverse biased.

It is the region to the right of the ordinate $V_{CE} \approx V_{CE,sat}$ and above the characteristic for $I_B = 0$. $V_{CE,sat}$ is typically 0.1 to 0.2V for low power transistors. In active region the curves are almost straight and equidistant.

If a transistor is to be used as an amplifier with minimum distortion its operation should be restricted to the active region. In this region I_c increases significantly with the increase in V_{CE}. This can be explained by considering the relation $I_C = \beta I_B + (1+\beta)I_{CO}$, where $\beta = \frac{\alpha}{1-\alpha}$.

Now due to Early effect α increases slightly with the increase in V_{CE}. A small change in α causes a very large change in β. For example if α changes from 0.98 to 0.99, β changes from 49 to 99. For this CE output curves have significant upward slope. If V_{CE} is increased very much there may be collector junction breakdown causing sharp rise in I_C. It may damage the transistor.

Cut off region: With $I_B=0$, $I_C = (1+\beta)I_{CO} = I_{CEO}$ is the collector current with base open. Since β>>1, I_{CEO} has significant value and hence it is not enough to make $I_B=0$ to cut off the transistor. The cut off is defined as $I_E=0$, $IB=-I_{CO}$ and $I_C=I_{CO}$. This requires reverse biasing of the emitter junction by a voltage of the order of 0.1V for Ge and about 0V for Si transistor.

Saturation region: In the saturation region both the emitter and collector junctions are forward biased by at least the cut-in voltage. Since the forward biasing voltages V_{EB} and V_{CB} are only a few tenths of a volt, $V_{CE,sat} = V_{CB} - V_{EB}$ is also a few tenths of a volt. So the region to the left of the ordinate $V_{CE= V_{CE,sat}}$ where all curves merge and fall rapidly towards origin is the saturation region. In this region, collector current is almost independent of base current for a given V_{CE}.

<u>Transistor Amplifying Action:</u>

The basic amplifying action of the transistor can be understood by using the network of Fig.9

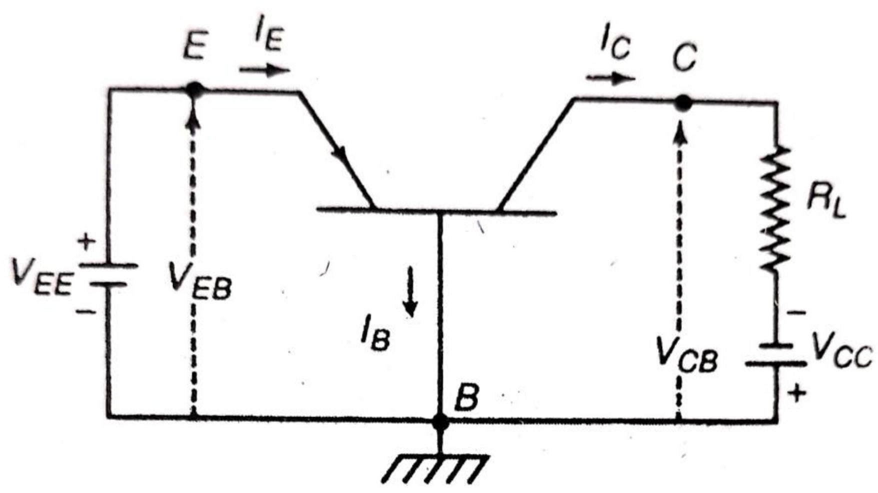

Fig.9 p-n-p transistor in CB mode

A small change ΔV_i of the input emitter base voltage causes a relatively large change ΔI_E of the input emitter current. This change in emitter current causes very nearly equal change ΔI_C in collector current, which passes through the load resistor R_L. Since R_L is usually large the change in output voltage across the load i.e., $\Delta V_o = \Delta I_C . R_L$ may be many times larger than ΔV_i. Thus the transistor can act as an amplifier.

If r_e is the dynamic resistance of the emitter junction then $\Delta V_i = \Delta I_E . r_e$ where r_e is given by $\frac{dV}{dI} = \frac{\eta kT}{e} \times \frac{1}{I}$

Therefore, voltage gain $A_V = \frac{\Delta V_o}{\Delta V_i} = \frac{\Delta I_C . R_L}{\Delta I_E . r_e} = \alpha_{a.c.} \frac{R_L}{r_e}$

Where $\alpha_{a.c.}$ is the a.c. current gain in CB mode. Since $\alpha_{a.c.} \approx 1$, $R_L \gg r_e$, A_V can be much greater than unity.

Amplifying action is produced by transferring an almost same current from low resistance input circuit to the high resistance output circuit.

Transistor can also provide current gain and power gain.

Power gain can be written as $A_P = \frac{(\Delta I_C)^2 R_L}{(\Delta I_E)^2 r_e} = (\alpha_{a.c.})^2 \frac{R_L}{r_e}$

So in order to use transistor as a power amplifier, I_C should be made very close to I_E.