Domain of Electronic Engineering: The output of an electronic device provides informationor intelligence.

Domain ofElectrical Engineering: The output of an electrical device (in the form of heat, mechanical motion, light, etc) is used to perform some function.

References

1- **electronic devices and circuit theory; By Robert L.Boylestad**
2- **electronic circuit; By By Dr. R.S. Sedha**

Bipolar Junction Transistors (BJTs)

BJTs are also simply known as bipolartransistors.

The term bipolar refers to the fact that both electrons and holes are involvedin the operation of a BJT. In fact, minority carrier diffusion plays the leading rolejust as in the PN junction diode. The word junction refers to the fact that PN junctionsare critical to the operation of the BJT.

- The invention of the BJT in 1947 at the Bell Telephone Laboratories ushered in the era of solid state circuits, which led to electronics changing the way we work.
- The reliability of BJT circuits under severe environmentalconditions makes them the dominant device in automotiveelectronics, an important and still-growing area.
- The BJT is still the preferred device in very demandinganalog circuit applications, both integrated and discrete.This is especially true in very-high-frequency applications,such as radio frequency (RF) circuits for wireless systems.

Device Structure and Physical Operation

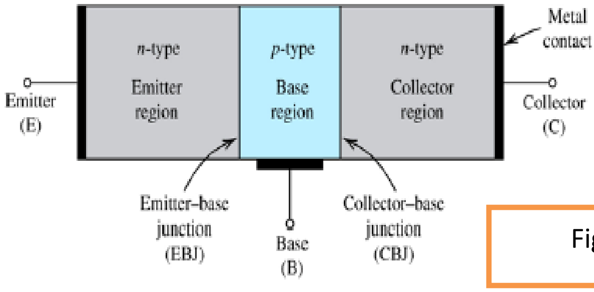
Physical structure of bipolar junction transistor (BJT)

Both electrons and holes participate in the conduction process for bipolar devices.

BJT consists of two *pn* junctions constructed in a special way and connected in series, back to back.The emitter–base junction (EBJ) and the collector–base junction (CBJ).

The transistor is a three-terminal device with **emitter**, **base** and **collector** terminals.

From the physical structure, BJTs can be divided into two groups: ***npn*** and ***pnp*** transistors.



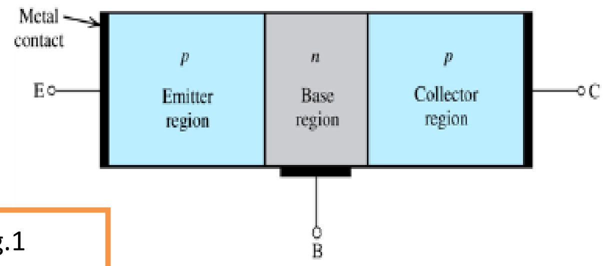


Fig.1

Modes of operation

- The two junctions of BJT can be either forward or reverse-biased.
- The BJT can operate in different modes depending on the junction bias.
- The BJT operates in active mode for amplifier circuits.
- Switching applications utilize both the cutoff and saturation modes.

Mode	EBJ	CBJ
Cut off	Reverse	Reverse
Active	Forward	Reverse
Saturation	forward	forward

Operation of the npn Transistor in the Active Mode

The npn transistor is widely used. Two external voltage sources are used to establishthe required bias conditions for active-mode operation. The voltage V_{BE} causes the p-type base to be higher inpotential than the n-type emitter, thus forward-biasingthe emitter–base junction. The collector–base voltageV_{CB} causes the n-type collector to be higher inpotential than the p-type base, thus reverse-biasing thecollector–base junction.

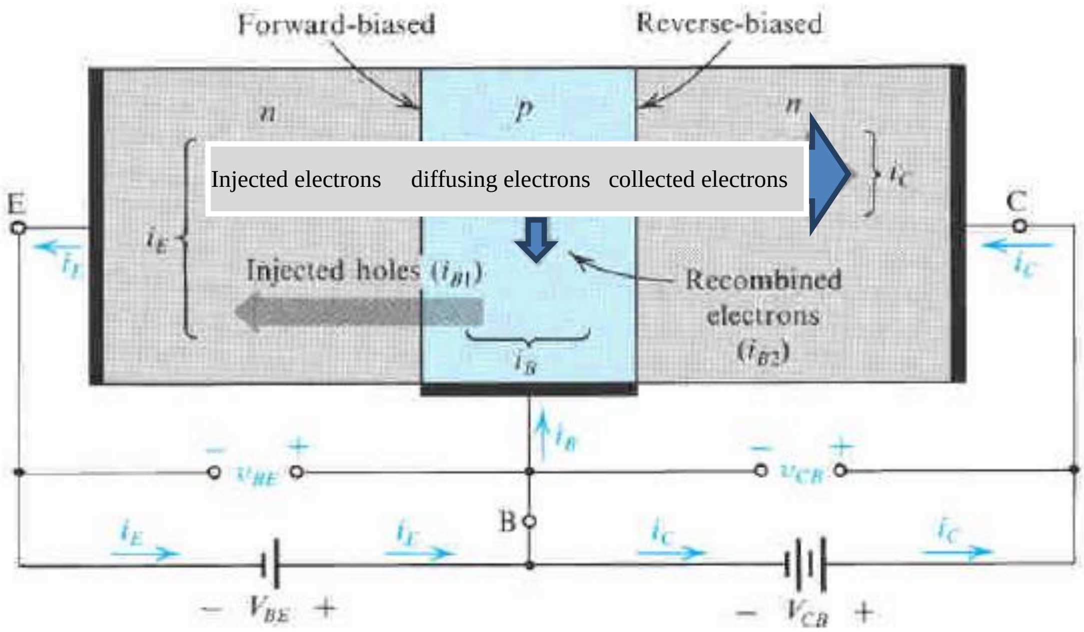


Fig.2: Current flow in an *npn* transistor biased to operate in the active mode. (Reverse current components due to drift of thermally generated minority carriers are not shown).

Note : V_{EE} and V_{CC} voltage are DC sources.

Current Flow

- The forward bias on the emitter–base junction will cause current to flow across this junction. Current will consist of two components: electrons injected from the emitter into the base, and holes injected from the base into the emitter.
- The direction of i_E is "out of"the emitter lead, which is in the direction of the hole current and opposite to the direction of the electron current, with the emitter current i_E being equal to the sum of these two components.
- the emitter current will be dominated by the electron component.
- Let us now consider the electrons injected from the emitter into the base. These electrons will be minority carriers in the p -type base region.
- The base has less impurities concentration around 5% recombine with holes from electrons that entering to the base while the majority of electrons go to the collector, this electrons draw the collector current(I_C) due to V_{CC} source.
- The electrons that recombining with the holes in the base are attracted by V_{EE} source then draw the base current (I_B).

- By applying Kirchhoff's current law at the junction point

$I_E = I_B + I_C$

- Due to the I_B current is very small so as usually neglected this cause the emitter current equal to collector current

$I_E \tilde{=} I_C$; $I_E = I_B(5\%) + I_C(95\%)$, meaning $I_B \ll I_C$

- Base region is very thin (lighting doping) but the Emitter region is heavily doping.

The BJT is a 3-terminal device: 2 types: PNP and NPN

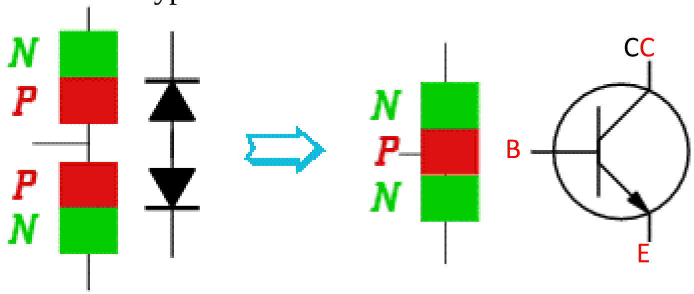


Fig. 3: construction and symbol of NPN transistor

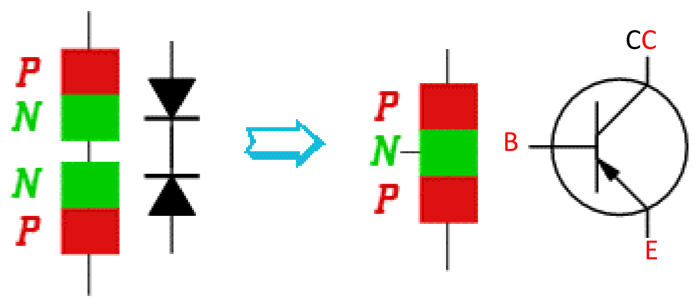


Fig. 4: construction and symbols of PNP transistor

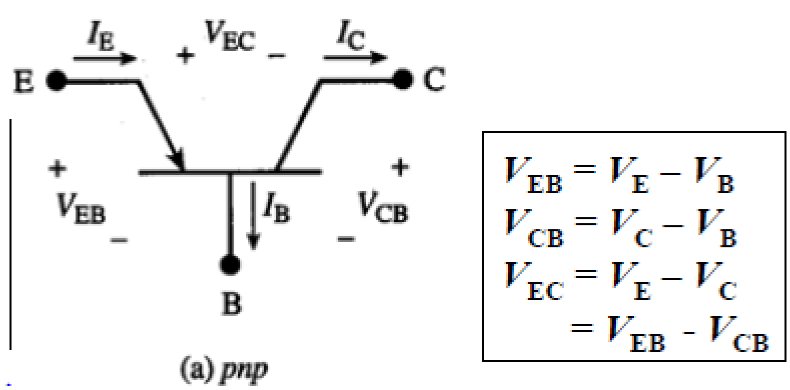
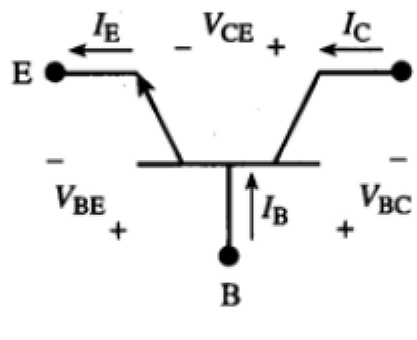


Fig. 5: potential voltages drops for terminals of PNP transistor



(b) *npn*

$$V_{BE} = V_B - V_E$$
$$V_{BC} = V_B - V_C$$
$$V_{CE} = V_C - V_E$$
$$= V_{CB} - V_{EB}$$

Fig. 6: potential voltages drops for terminals of NPN transistor

Characteristics of a Transistor

The static characteristic curve shows relationship between voltage and current for transistor.

Charact.	The relationship	constant
Input charact.	Input voltage and input current	For given output voltage
Output charact.	Output voltage and output current	For given input current

- Input resistance (r_i) = $[\frac{\Delta VBE}{\Delta IB}]$for V_{CE} is constant, its can found from the input characteristic curve, the value is in KΩ
- Output resistance (r_o) = $[\frac{\Delta VCE}{\Delta IC}]$for I_B is constant,its can found from the output characteristic curve, the value is between 50 to 100KΩ.
- Common-emittercurrent gain (β) = $[\frac{\Delta IC}{\Delta IB}]$for V_{CE} is constant, its can found from the active region of the output characteristic curve.
- Trans conductance (g_m) = $\frac{\Delta IC}{\Delta VB}$ the unit of g_m is mho

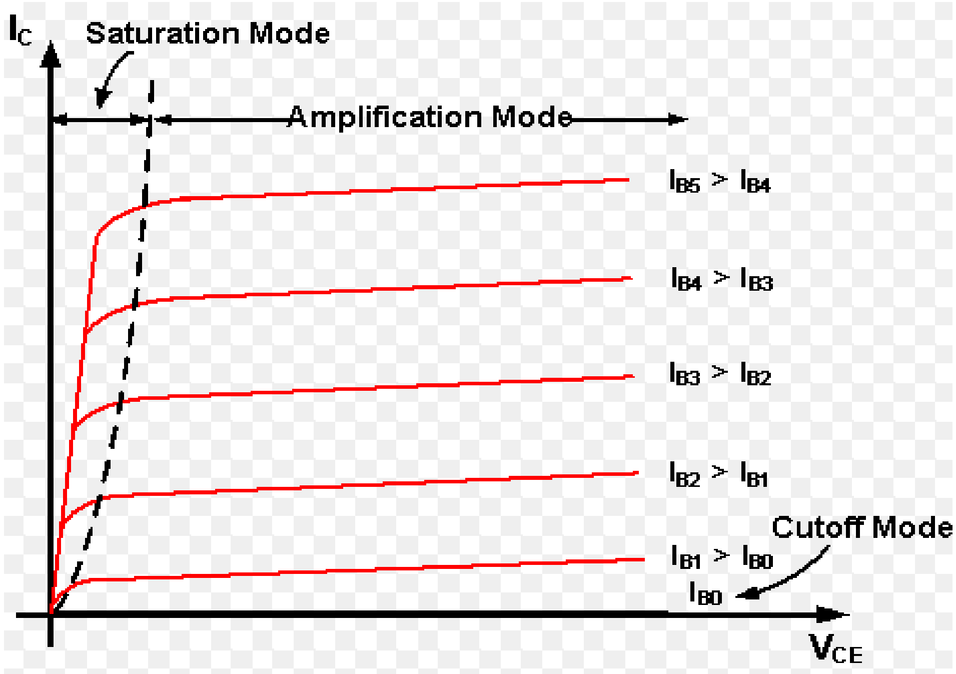


Fig.7: active, cutoff and saturation modes in transistor

- I_{CBo} is the collector current that flow at cutoff region (when the transistor is open)
- The plot in Fig.8 shows the exponential relationship between I_C and V_{BE}. V_{BE} value is around 0.2 V for Ge (germanium) and 0.7 V for Si (silicon).

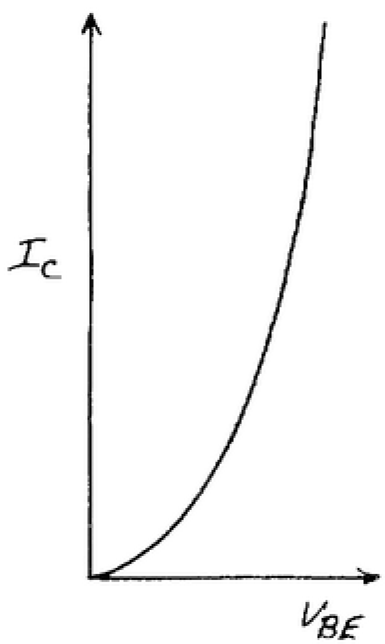


Fig.8: for input voltage vs. output current

The transistor Currents

Most of the diffusing electrons will reach the boundary of the collector–base depletion region. Because the collector is more positive than the base (by V_{CB}volt),

$$i_C = I_S e^{v_{BE}/V_T}$$

Where I_S is saturation current, $V_{BE}$is the forward base–emitter bias voltage, and $V_T$is thethermal voltage, which is equal to approximately 25mV at room temperature.

And,

$$i_B = \frac{i_C}{\beta}$$

$$i_E = i_C + i_B$$

$$i_E = \frac{\beta + 1}{\beta} i_C$$

$$i_E = \frac{\beta + 1}{\beta} I_S e^{v_{BE}/V_T}$$

$$i_C = \alpha i_E$$

$$\alpha = \frac{\beta}{\beta + 1}$$

$$i_E = (I_S/\alpha) e^{v_{BE}/V_T}$$

$$\beta = \frac{\alpha}{1 - \alpha}$$

- α is a constant (for the particular transistor) that is less than but very close to unity. For instance, if $\beta = 100$, then $\alpha \fallingdotseq 0.99$ (αextended from 0.90 to 0.998)
- Small changes in α correspond to very large changes in β.
- α is called the **common-base current gain.**
- Becauseα and β characterize the operation of the BJT in the “forward active”mode, they are often denoted $\alpha_F$and β_F.
- $I_C = \alpha I_E + I_{CB0}$ for I_E is zero then $I_C = I_{CB0}$
- For $\alpha_{ac} = \frac{\Delta Ic}{\Delta IE} \Big|\, V_{CB\,=\,constant}$

Operation Configuration of BJTs

The bipolar transistor can be biased in one of three different configurations. Each configuration has own benefit. The configuration chosen depend on the type applications.

1. Common base configuration
2. Common emitter configuration
3. Common collector configuration

1. Common base configuration

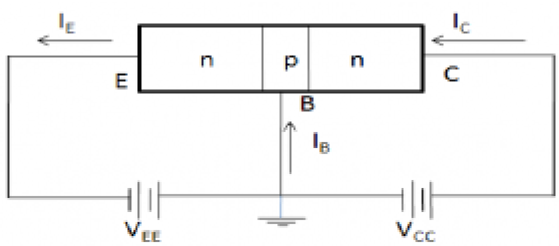


Fig.9: common-base NPN configuration

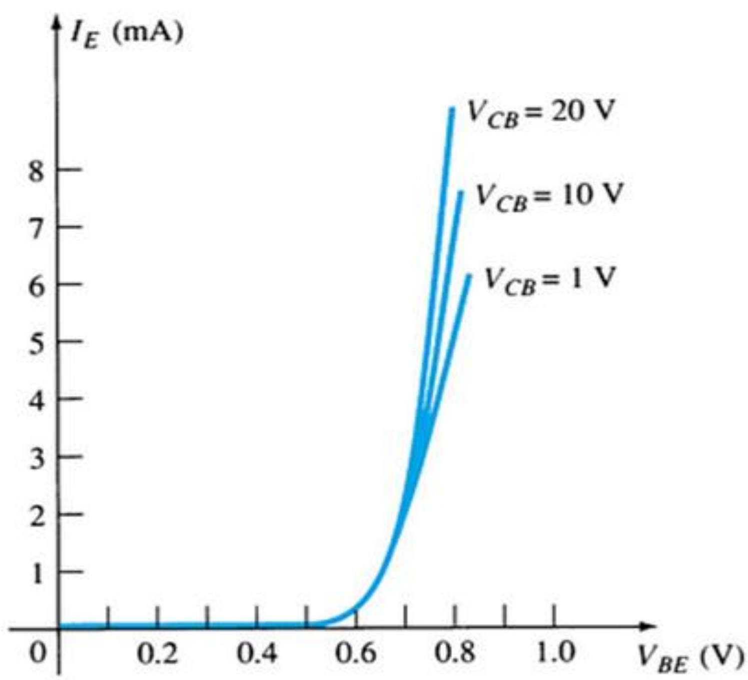


Fig.10: input characteristic for a common –base transistor amplifier

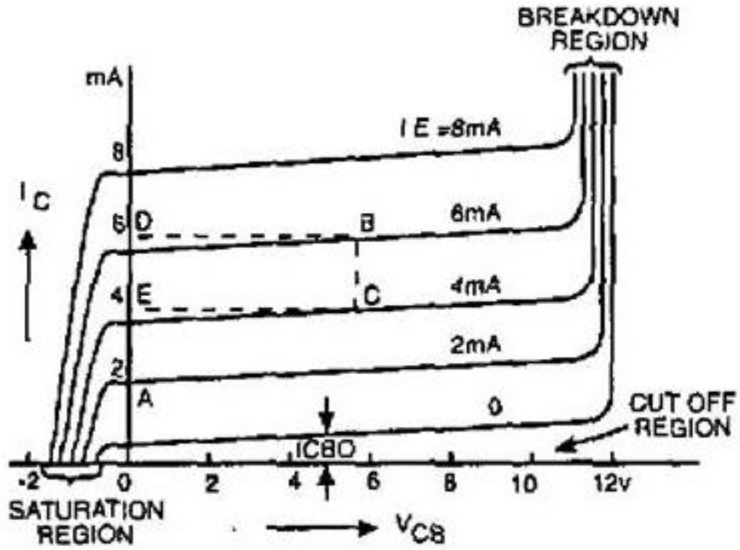


Fig.11: output characteristic for common-base transistor amplifier

- $I_{CO} = I_{CBO}$ measured in µA very small with respect to I_C that measured in mA. I_{CB0} effected by temperature then increased rapidly with temperature.
- Almost negligible effect of V_{CB} on the collector current for the active region
- At active region approximation the relation between I_C and I_E is:

$I_C \cong I_E$