University of Calcutta

Semester 4

PHYSICS

Paper: PHS-A-CC-4-10-TH (OLD SYLLABUS)

CURRENT GAIN OF A TRANSISTOR, LOAD LINE And Q-POINT

Solved Problems

Assignments

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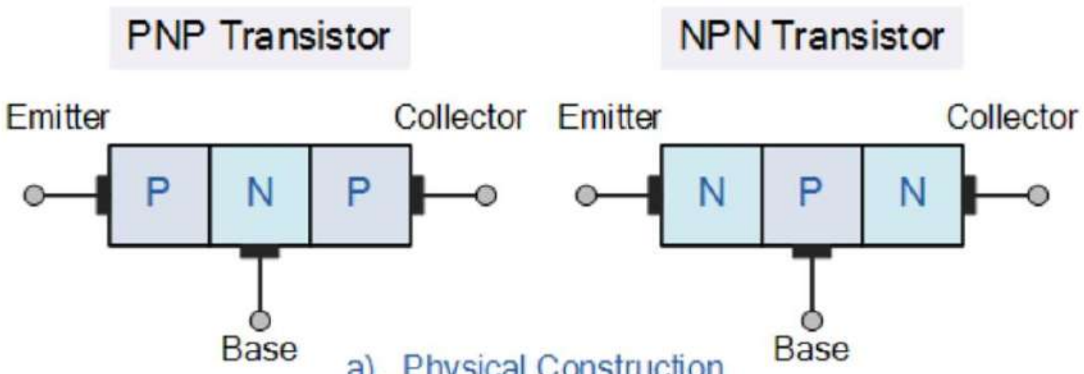
Basic knowledge of Bipolar junction transistor (BJT)

Bipolar Transistor Construction



a). Physical Construction

The **Bipolar Transistor** basic construction consists of two PN-junctions producing three connecting terminals with each terminal being given a name to identify it from the other two. These three terminals are known and labelled as the Emitter (E), the Base (B) and the Collector (C) respectively.

Bipolar Transistors are current regulating devices that control the amount of current flowing through them from the Emitter to the Collector terminals in proportion to the amount of biasing voltage applied to their base terminal, thus acting like a current-controlled switch. As a small current flowing into the base terminal controls a much larger collector current forming the basis of transistor action.

The principle of operation of the two transistor types PNP and NPN, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type.

Basic idea of alpha and beta

Transistor Equations

- Alpha Factor

$$\alpha = \frac{I_C}{I_E}$$

- Current Gain

$$\beta = \frac{I_C}{I_B}$$

- Kirchhoff's Current Rule

$$I_E = I_C + I_B$$

Relation between alpha and beta

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

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

CURRENT AMPLIFICATION FACTORS

What is alpha ??

What is Beta??

5.5 Alpha (α) and beta (β) of a transistor

The total collector current of a transistor consists of *two* parts:

(a) the leakage current I_{CBO} due to the movement of minority carriers across the collector junction when it is reversed biased and the emitter junction is open circuited, and

(b) a fraction of the emitter current which reaches the collector junction.

$$\therefore \quad \text{Collector current,} \quad I_C = I_{CBO} + \alpha I_E \qquad (5.5.1)$$

where the fraction α is known as ***transistor alpha***. The α is also called *large signal current gain* of a common-base transistor. Typical values of α lies in the range 0.9 to 0.995. In d.c mode of operation, α is defined as

$$\alpha_{dc} = \frac{I_C}{I_E} \qquad (5.5.2)$$

Here, α_{dc} is the ***dc current gain*** of the common-base transistor.

Since $I_{CBO} \ll I_C$, we have, from the relation (5.5.1),

$$I_C \approx \alpha I_E$$

$$\therefore \quad \alpha \approx \alpha_{dc} \qquad (5.5.3)$$

When a transistor is operated with a.c in common-base configuration, the parameter α' or α_{ac} is introduced. This α' or α_{ac} in known as the *small-signal short-circuit current transfer ratio or gain* of common-base transistor. It is defined as *the ratio of the change in collector current to the change in the emitter current at constant collector to base voltage*. Mathematically,

$$\alpha_{ac} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB}=\text{const.}} \qquad (5.5.4)$$

For a good transistor $\alpha \approx \alpha_{dc} \approx \alpha_{ac} \approx 1$. The parameter α is *not a constant*, but depends on the emitter current I_E, the collector to the base voltage V_{CB} and also on the temperature.

The current equation of a transistor gives

$$I_E = I_B + I_C \qquad (5.5.5)$$

Using the equation (5.5.5) in (5.5.1) we get,

$$I_C = \alpha(I_B + I_C) + I_{CBO}$$

$$= \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \qquad (5.5.6)$$

This is the expression for the *collector current* in terms of the parameter α.

Now, if we put $\beta = \alpha/(1-\alpha)$ in (5.5.6), it becomes

$$I_C = \beta I_B + (1+\beta) I_{CBO} \qquad (5.5.7)$$

This equation shows the *output current* I_C of a transistor in CE mode where the parameter β determines the maximum current gain. The parameter β is known as ***transistor beta***.

In d.c mode of operation of a common-emitter transistor, β is called *forward current transfer ratio* or the d.c current gain and it is denoted by β_{dc}.

The d.c current gain β_{dc} of a common-emitter transistor is defined as the ratio of the collector current I_C to the base current I_B i.e.,

$$\beta_{dc} = I_C / I_B \qquad (5.5.8)$$

Since $I_{CBO} \ll I_B$, we get from equation (5.5.7),

$$I_C \approx \beta I_B$$

$$\therefore \quad \beta \approx \beta_{dc} \qquad (5.5.9)$$

Typical values of β_{dc} lies in the range 50 to 400. The parameter β depends on the *temperature* and the *collector current* I_C.

When a transistor in CE mode is operated with a.c, the parameter β_{ac}, known as *small signal short-circuit current gain*, is introduced. It is defined as the ratio of the change in I_C to the change in I_B at a constant collector to emitter voltage V_{CE}. Mathematically,

$$\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}=\text{const.}} \qquad (5.5.10)$$

5.5.1 Relation between α and β

From the definition of α_{dc} and β_{dc}, we have

$$\alpha_{dc} = \frac{I_C}{I_E} \quad \text{and} \quad \beta_{dc} = \frac{I_C}{I_B}$$

The current equation for a transistor gives,

$$I_E = I_B + I_C \quad \text{or,} \quad \frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$$

$$\text{or,} \quad \frac{1}{\alpha_{dc}} = \frac{1}{\beta_{dc}} + 1 \quad \text{or,} \quad \beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} \qquad (5.5.11)$$

Since $\alpha_{dc} \approx \alpha$ and $\beta_{dc} \approx \beta$, we get from the above equation (5.5.11)

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

This is the relation between the parameters α and β and is useful in many computations.

More information about alpha and beta

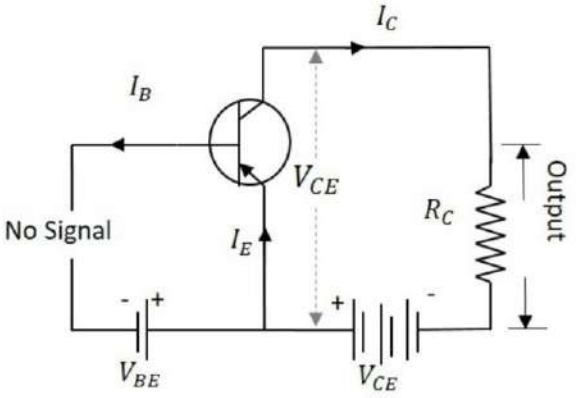
https://youtu.be/d2lmY-AMs24

https://youtu.be/4AgynmNJ6xQ

What is DC Load Line ??

DC Load line

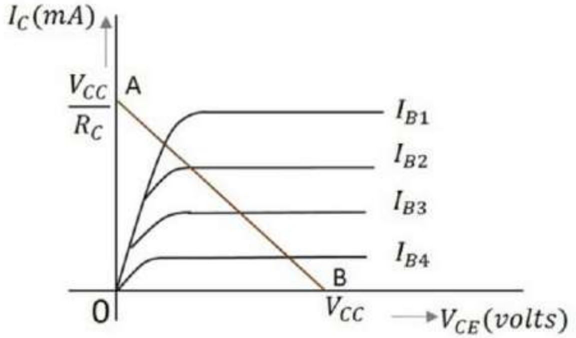
When the transistor is given the bias and no signal is applied at its input, the load line drawn at such condition, can be understood as **DC** condition. Here there will be no amplification as the signal is absent. The circuit will be as shown below.



The value of collector emitter voltage at any given time will be

$$V_{CE} = V_{CC} - I_C R_C$$

As V_{CC} and R_C are fixed values, the above one is a first degree equation and hence will be a straight line on the output characteristics. This line is called as **D.C. Load line**. The figure below shows the DC load line.



To obtain the load line, the two end points of the straight line are to be determined. Let those two points be A and B.

To obtain A

When collector emitter voltage V_{CE} = 0, the collector current is maximum and is equal to V_{CC}/R_C. This gives the maximum value of V_{CE}. This is shown as

$$V_{CE} = V_{CC} - I_C R_C$$

$$0 = V_{CC} - I_C R_C$$

$$I_C = \frac{V_{CC}}{R_C}$$

To obtain B

When the collector current IC = 0, then collector emitter voltage is maximum and will be equal to the VCC. This gives the maximum value of IC. This is shown as

$$V_{CE} = V_{CC} - I_C R_C$$

$$= V_{CC}$$

(As $I_C = 0$)

This gives the point B, which means ($OB = V_{CC}$) on the collector emitter voltage axis shown in the above figure.

Hence we got both the saturation and cutoff point determined and learnt that the load line is a straight line. So, a DC load line can be drawn.

The importance of this operating point is further understood when an AC signal is given at the input. This will be discussed in AMPLIFIERS tutorial.

What is operating point or Q-point??

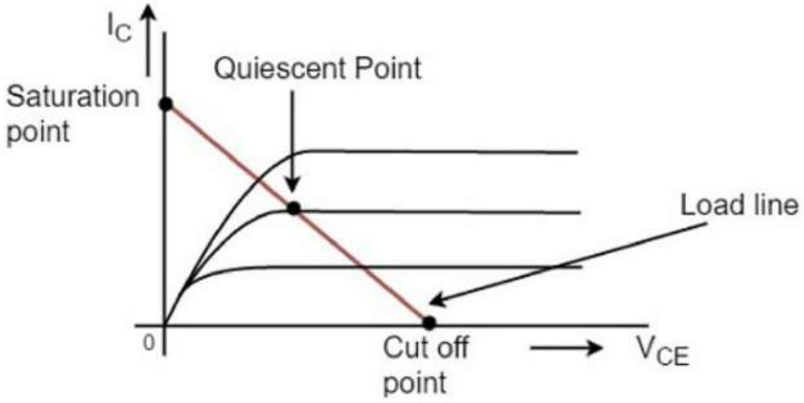
The **operating point** of a device, also known as a bias **point**, quiescent **point** or **Q-point**, is the steady-state DC voltage or current at a specified terminal of an active device such as a **transistor** with no input signal applied.

Load Line and Q-point are really related to each other???

When a line is drawn joining the saturation and cut off points, such a line can be called as **Load line**. This line, when drawn over the output characteristic curve, makes contact at a point called as **Operating point**.

This operating point is also called as **quiescent point** or simply **Q-point**. There can be many such intersecting points, but the Q-point is selected in such a way that irrespective of AC signal swing, the transistor remains in the active region.

The following graph shows how to represent the operating point.



The operating point should not get disturbed as it should remain stable to achieve faithful amplification. Hence the quiescent point or Q-point is the value where the **Faithful Amplification** is achieved.

Load Line And Operating Point

https://youtu.be/oAF5rPnB_8I

https://youtu.be/jQb199olY5U

Solved problems

▶ **Example 1.** *When the emitter current of a transistor changes by* 1 mA, *its collector current changes by* 0.995 mA. *Calculate* α *and* β. (Osmania Univ.)

Solution : Given, the change in collector current $\Delta I_C = 0.995\,\text{mA}$.

and the change in emitter current $\Delta I_E = 1\,\text{mA}$

So, the change in base current is $\Delta I_B = \Delta I_E - \Delta I_C = 1 - 0.995\,\text{mA} = 0.005\,\text{mA}$

$\therefore$ By definition,

$$\boldsymbol{\alpha} = \frac{\Delta I_C}{\Delta I_E} = \frac{0.995}{1} = \mathbf{0.995}$$

and

$$\boldsymbol{\beta} = \frac{\Delta I_C}{\Delta I_B} = \frac{0.995}{0.005} = \mathbf{199}$$

▶ **Example 2.** *Calculate the α-parameter of a transistor if $\beta = 99$.* **(Guru Nanak Univ.)**

Solution: The relation between α- and β-parameters of a transistor is

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

$$\Rightarrow \quad 99 = \frac{\alpha}{1-\alpha}$$

$$\text{or,} \quad 100\alpha = 99$$

$$\text{or,} \quad \boldsymbol{\alpha = 0.99}$$

▶ **Example 3.** *In a common base circuit $\alpha = 0.96$. If the base current is $90\,\mu A$, what are the collector current and the emitter current?* **(Punjab Univ.)**

Solution: Given, the α-parameter of the transistor $= 0.96$ and the base current, $I_B = 90\mu A$. To find the collector current and the emitter current.

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = 24$$

$$\Rightarrow \quad \frac{I_C}{I_B} = 24, \quad (\because \beta = I_C/I_B)$$

$$\text{or,} \quad I_C = 24 I_B = 24 \times 90\mu A$$

$$= 2160\mu A = \mathbf{2.16\,mA}$$

$$\text{Since } \alpha = \frac{I_C}{I_E} \Rightarrow I_E = \frac{I_C}{\alpha} = \frac{2.16}{0.96}\,\text{mA} = \mathbf{2.25\,mA}$$

▸ Example 4. *β of a transistor is 99. Calculate the collector current when the emitted current is 5 mA.* **(Meerut Univ.)**

Solution : Here β of the transistor is 99 and the emitter current $I_E = 5\,\text{mA}$.

$$\text{Now,}\quad \beta = \frac{\alpha}{1-\alpha}$$

$$\therefore\quad 99 = \frac{\alpha}{1-\alpha} \Rightarrow 100\alpha = 99 \text{ or, } \alpha = 0.99$$

$$\text{By definition, we have}\quad \alpha = \frac{I_C}{I_E}$$

$$\text{or, } 0.99 = I_C/5 \text{ or, } I_C = 5 \times 0.99 = \mathbf{4.95}$$

$\therefore$ The collector current is **4.95 mA**

Assignments

1. For a *p-n-p* transistor in CE mode, $\beta = 100$. What is the value of α? If $I_{C0} = 10\ \mu A$, what is the collector current for an emitter current of 2 mA?
(**Ans.** 0.99, 1.99 mA)

2. If β 16.5, $I_E = 1.8$ mA and $I_{C0} = 12\ \mu A$, calculate I_C and I_B when the transistor is used in the CE configuration. (**Ans.** 1.71 mA, 90 μA)

2. The current gain of a transistor in common emitter (CE) configuration is 49. What will be the current gain of the same transistor in common base (CB) configuration? **(Benaras Univ.)** [0.98]

3. If the current gain of a common base amplifier is 0.995, find the current gain of common emitter amplifier. **(Guru Nanak Univ.)** [199]