Module 2

Bipolar Junction Transistor & its Application

Syllabus

Bipolar Junction Transistors: BJT operation, BJT Voltages and Currents, BJT amplification, DC Load line and Bias Point, Base Bias, Voltage divider Bias.

Amplifiers and Oscillators: Introduction, Concept of feedback, Negative feedback, Types of amplifiers, Gain, Frequency response, Bandwidth, Phase shift. Positive feedback, Conditions for Oscillations, RC Phase shift Oscillator.

2. Transistors

There are many types of transistors in use. Each transistor is specialized in its application. The main classification is as follows.

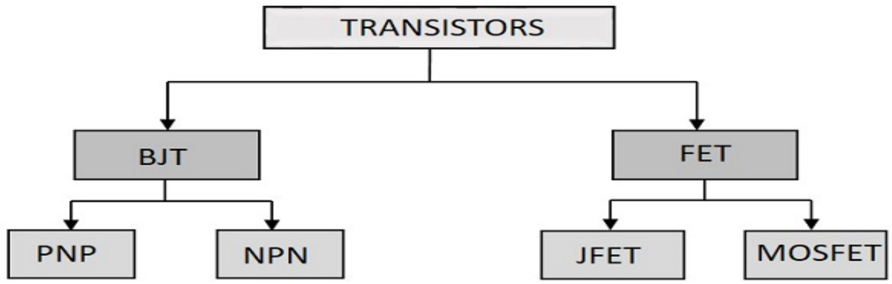


Fig 2.0 Transistor Classification

FET Transistor

An FET is a three-terminal unipolar semiconductor device. It is a voltage controlled device unlike a bipolar junction transistor (Current Controlled). The main advantage of FET is that it has a very high input impedance, which is in the order of Mega Ohms. It has many advantages like low power consumption, low heat dissipation and FETs are highly efficient devices. The following image shows how a practical FET looks like.

The FET is a unipolar device, which means that it is made using either p-type or n-type material as main substrate. Hence the current conduction of a FET is done by either electrons or holes.

Features of FET

The following are the varied features of a Field Effect Transistor.

- Unipolar − It is unipolar as either holes or electrons are responsible for conduction.
- High input impedance − The input current in a FET flows due to the reverse bias. Hence it has high input impedance.
- Voltage controlled device − As the output voltage of a FET is controlled by the gate input voltage, FET is called as the voltage controlled device.
- Noise is low − There are no junctions present in the conduction path. Hence noise is lower than in BJTs.

- Gain is characterized as transconductance. Transconductance is the ratio of change in output current to the change in input voltage.
- The output impedance of a FET is low.

Applications of FET

1. FETs are widely used as input amplifiers in oscilloscopes, electronic voltmeters and other measuring and testing equipment because of their high input impedance.
2. It is used in RF amplifiers in FM tuners and communication equipment's for the low noise level.
3. It is used as voltage variable resistors (VVRs) in operational amplifiers and tone controllers etc. because it is a voltage controlled device.
4. FETs are used in mixer circuits in FM and TV receivers, and communication equipment's because of their low intermodulation distortion.
5. FETs are used in low frequency amplifiers in hearing aids and inductive transducers because of the small coupling capacitors.
6. Another applications of FETs are it is used in digital circuits in computers, LSI and memory circuits because of very small size.

2.1 Bipolar Junction Transistor (BJT)

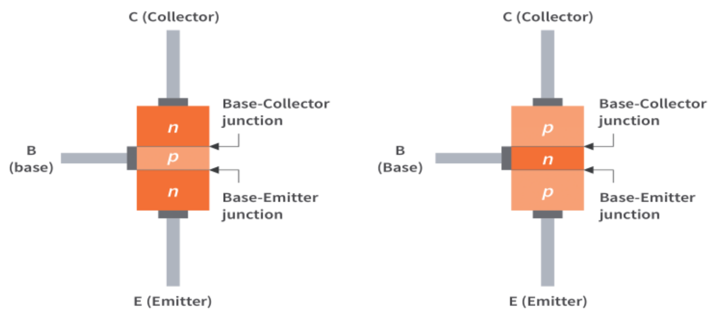
A bipolar junction transistor (BJT) has three layers of semiconductor material. These are arranged either in npn (n-type-p-type-n-type) sequence or in pnp sequence, and each of the three layers has a terminal. A small current at the central region terminal controls the much larger total current flow through the device. This means that the transistor can be used for current amplification. As will be explained, it can also perform voltage amplification.

2.1.1 BJT Operation

NPN and PNP Transistors

A bipolar junction transistor is simply a sandwich of one type of semiconductor material (p-type or n-type) between two layers of the opposite type. A block representation of a layer of p-type material between two layers of n-type is shown in Fig. 2.l.a. This is described as an npn transistor. Fig 2.1b shows a pnp transistor, consisting of a layer of n-type material between two layers of p-type. The centre layer is called the base, one of the outer layers is termed the emitter, and the other outer layer is referred to as the collector.

The emitter, base, and collector are provided with terminals, which are appropriately labeled E, B, and C. Two pn-junctions exist in each transistor: the collector base junction and the emitter-base junction.



(a) **(b)**

Fig 2.1 Block representation of npn and pnp bipolar junction transistors (BJTs).

Circuit symbols for pnp and npn transistors are shown in Fig. 2.2. The arrowhead on each symbol identifies the transistor emitter terminal and indicates the conventional direction of current flow. For an npn transistor, the arrowhead points from the p-type base to the n-type emitter. For a pnp device, the arrowhead points from the p-type emitter to the n-type base. Thus, the arrowhead always points from p to n.

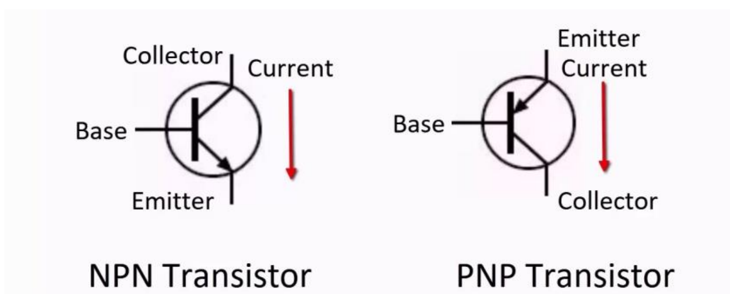


Fig. 2.2 Circuit symbols for pnp and npn transistors

2.1.1.1 NPN transistor operations

Fig 2.3 illustrate Depletion regions and barrier voltages at the junctions of an unbiased npn transistor. barrier voltages at the junctions of an unbiased npn transistor.

- The centre layer of the transistor is very much narrower than the two outer layers. The outer layers are also much more heavily doped than the centre layer, so that the depletion regions penetrate deep into the base, as illustrated.

- Because of this penetration, the distance between the two depletion regions is very short (within the base). Note that the junction barrier voltages are positive on the emitter and collector, and negative on the base of the npn device.

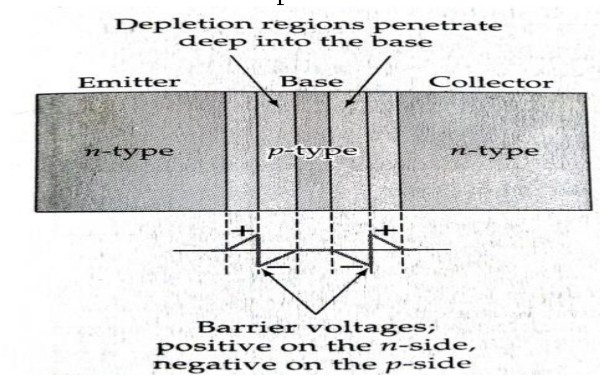


Fig. 2.3 Depletion regions and barrier voltages at the junctions of an unbiased npn transistor.

Consider Fig. 2.4, which shows an пpn transistor with external bias voltages. For normal operation, the base-emitter (BE) junction is forward-biased and the collector-base (CB) junction is reverse- biased. Note the external bias voltage polarities.

- The forward bias at the BE junction reduces the barrier voltage and causes electrons to flow from the n-type emitter to the p-type base. The electrons are emitted into the base region; hence the name emitter. Holes also flow from the p-type base to the n-type emitter, but because the base is much more lightly doped than the collector, almost all of the current flow across the BE junction consists of electrons entering the base from the emitter. Thus, electrons are the majority charge carriers in an npn device.

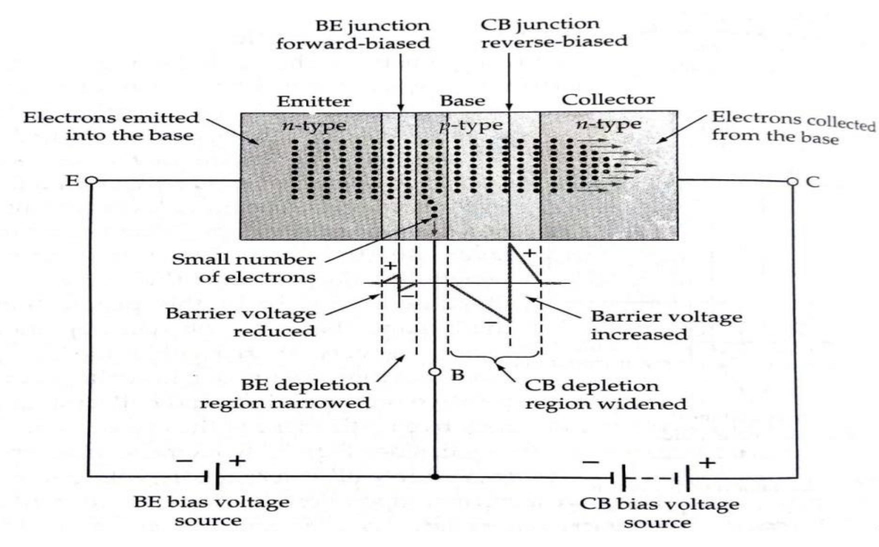


Fig. 2.4 : npn transistor with external bias voltages

- The reverse bias at the CB junction causes the CB depletion region to penetrate deeper into the base than when the junction is unbiased, (see Fig. 2.4). The electrons crossing from the emitter to the base arrive quite close to the large negative-positive electric field (or barrier voltage) at the CB depletion region. Because electrons have a negative charge, they are drawn across the CB junction by this bias voltage. They are said to be collected.

- Some of the charge carriers entering the base from the emitter do not reach the collector, but flow out via the base connection, as illustrated in Fig. 4-5. However, the path from the BE junction to the CB depletion region is much shorter than that to the base terminal. So, only a very small percentage of the total charge carriers flow out of the base terminal. Also, because the base region is very lightly doped, there are few holes in the base to recombine with electrons from the emitter. The result is that about 98% of the charge carriers from the emitter are drawn across the CB junction to flow via the collector terminal and the voltage sources back to the emitter.

2.1.1.2 PNP transistor operation:

In an unbiased pnp transistor, the barrier voltages are positive on the base and negative on the emitter and collector, (see Fig. 2.5). As in the case of the npn device, the collector and emitter are heavily-doped, so that the BE and CB depletion regions penetrate deep into the lightly-doped base.

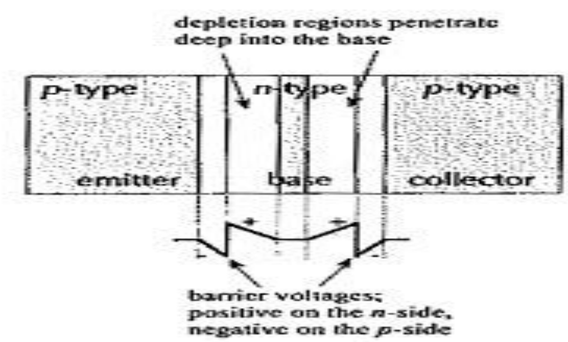


Fig. 2.5 Depletion regions and barrier voltages at the junctions of an unbiased npn transistor.

A pnp transistor behaves exactly the same as an npn device, with the exception that the majority charge carriers are holes. As illustrated in Fig. 2.6, the BE junction is forward biased by an external voltage source, and the CB junction is reverse biased. Holes are emitted from the p-type emitter across the forward-biased BE junction into the base. In the lightly doped n-type base, the holes find few electrons to absorb. Some of the holes flow out via the base terminal, but most are drawn across to the collector by the positive-negative electric field at the reverse-biased CB junction. Variation of the forward bias voltage at the BE junction controls the small base current and the much larger collector and emitter currents.

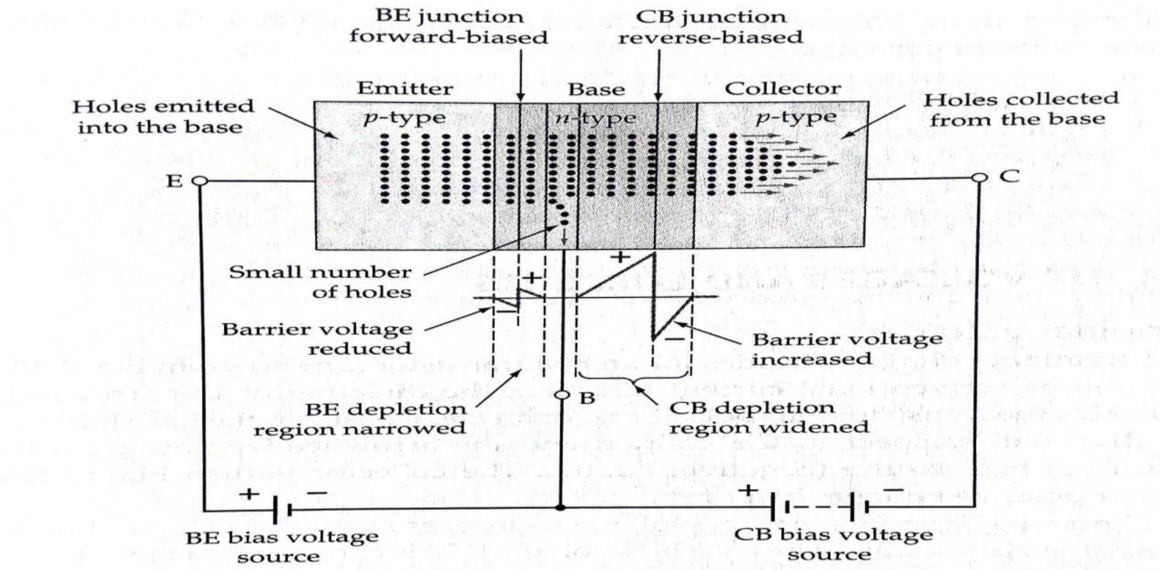


Fig. 2.6 : pnp transistor with external bias voltages

2.1.2 BJT Voltage and Current:

<u>Terminal Voltages:</u>

The Transistor Voltage polarities for an npn transistor are shown in Fig. 2-7(a). As well as conventional current direction, the direction of the arrowhead indicates the transistor bias polarities. For an npn transistor, the base is biased positive with respect to the emitter, and the arrowhead points from the (positive) base to the (negative) emitter. The collector is then biased to a higher positive Transistor Voltage than the base.

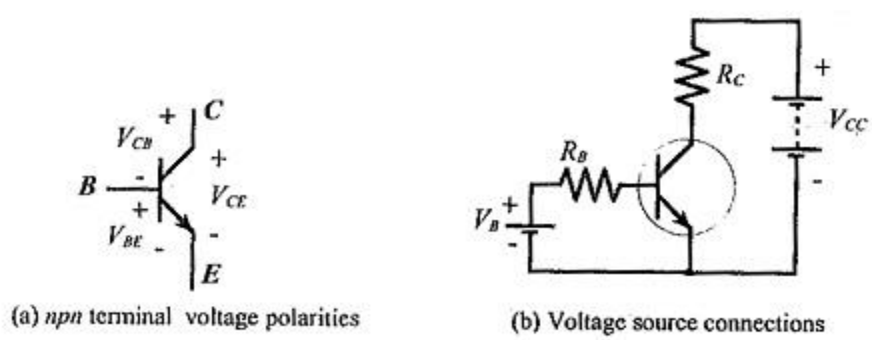


Fig. 2.7 : An npn transistor terminal voltages & source connection

Figure 2-7(b) shows that the Transistor Voltage sources are usually connected to the transistor via resistors. The base bias voltage (V_B) is connected via resistor R_B, and the collector supply

(V_{CC}) is connected via R_C. The negative terminals of the two voltage sources are connected at the transistor emitter terminal. V_{CC} is always much larger than V_B, and this ensures that the CB junction remains reverse biased; positive on the collector (n-side), and negative on the base (p-side).

For a pnp device [Fig. 4-11(a)] the base is biased negative with respect to the emitter. The arrowhead points from the (positive) emitter to the (negative) base, and the collector is made more negative than the base. Figure 4-11(b) shows the Transistor Voltage sources connected via resistors, and the source positive terminals connected at the emitter. With V_{CC} larger than V_B, the (p-type) collector is more negative than the (n-type) base, keeping the CB junction reverse biased.

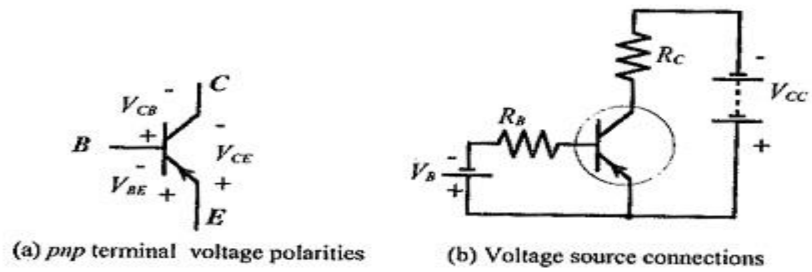


Fig. 2.7 : An npn transistor terminal voltages & source connection

Transistor Currents:

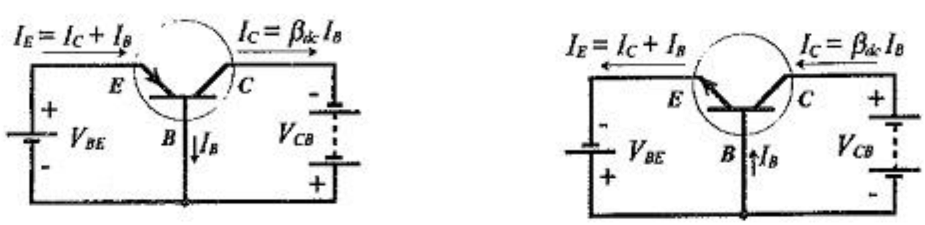


Fig. 2.8 : Transistor currents in PNP & NPN Transistor

The current flowing into the emitter terminal is referred to as the emitter current and is identified as I_E. For the pnp device shown, I_E can be thought of as a flow of holes from the emitter to the base. Note that the indicated I_E direction is the conventional current direction from positive to negative. Base current I_B and collector current I_C are also shown as conventional current direction. Both I_C and I_B flow out of the transistor. while I_E flows into the transistor.

In the case of an npn transistor is that I_B and I_C are assumed to flow into the device (conventional current direction), and I_E is taken as flowing out. As explained already, electrons are the majority charge carriers in an npn transistor, and they move in a direction opposite to conventional current direction

Relation between α_{dc} & β_{dc}:
from Fig.2.8 we can write

$$I_E = I_C + I_B \qquad (2.1)$$

α_{dc} (alpha dc) is the **emitter-to-collector current gain**, or the ratio of collector current to emitter current.

$$\alpha_{dc} = I_C / I_E. \qquad (2.2)$$

Numerically, α_{dc} is typically 0.96 to 0.995. So, the collector current is almost equal to the emitter current, and in many circuit situations I_C is assumed equal to I_E. For reasons that will be explained later, α_{dc} is termed the **common-base dc current gain**.

$$I_C = \alpha_{dc} I_E$$
$$= \alpha_{dc} (I_C + I_B)$$
$$= \frac{\alpha_{dc} IB}{1-\alpha_{dc}}$$
$$I_C = \beta_{dc} I_B \qquad (2.3)$$

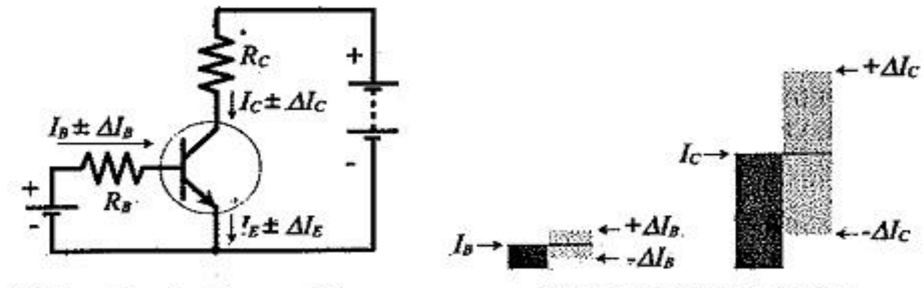
β_{dc} (beta dc) is the base-to-collector current gain, or the ratio of collector current to base current,
$\beta_{dc} = I_C / I_B$.

Typically, β_{dc} ranges from 25 to 300. β_{dc} is also termed the **common-emitter dc current gain**. Instead of β_{dc} another symbol for common-emitter dc current gain is h_{FE}.

2.1.3 BJT Amplification:

Current Amplification in Transistor – The transistor can be used for current amplification. A small change in the base current (ΔI_B) produces a large change in collector current (ΔI_C) and a large emitter current change (ΔI_E), [see Fig. 4-16(a) and (b)]. Rewriting Eq. 2.3, the current gain from the base to collector can be stated in terms of current level changes

$$\beta_{dc} = \frac{\Delta I_c}{\Delta I_B}$$



(a) Current levels and current changes (b) Base and collector currents

Fig. 2.9 : Current amplification

The increasing and decreasing levels of input and output currents may be defined as alternating quantities. In this case, small (lower-case) letters are used for the subscripts. Thus, I_b is an ac base current, I_c is an ac collector current, and I_e is an ac emitter current. The alternating current gain from base to collector may now be stated as,

$$\beta_{ac} = \frac{I_c}{I_b}$$

As in the case of dc current gain, two parameter symbols are available for common-emitter ac current gain; β_{ac}

Voltage Amplification in Transistor

Refer to the circuit in Fig. 2.10 (a) and assume that the transistor (Q_1) has $\beta_{dc} = 50$. Note that the 0.7 V dc voltage source (V_B) forward biases the transistor base-emitter junction. An ac signal source (υ_i) in series with V_B provides a ± 20 mV input voltage. The transistor collector is connected to a 20 V dc voltage source (V_{CC}) via the 12 kΩ collector resistor (R_1).

If Q_1 has the I_B/V_{BE} characteristic shown in Fig. 2.10 (b), the 0.7 V level of V_B produces a 20 μA base current. This gives,

$$I_C = \beta_{dc} I_B = 50 \times 20\ \mu A$$
$$= 1\ mA$$

The dc level of the transistor collector voltage can now be calculated as,

$$V_C = V_{CC} - (I_C R_1) = 20\ V - (1\ mA \times 12\ k\Omega)$$
$$= 8\ V$$

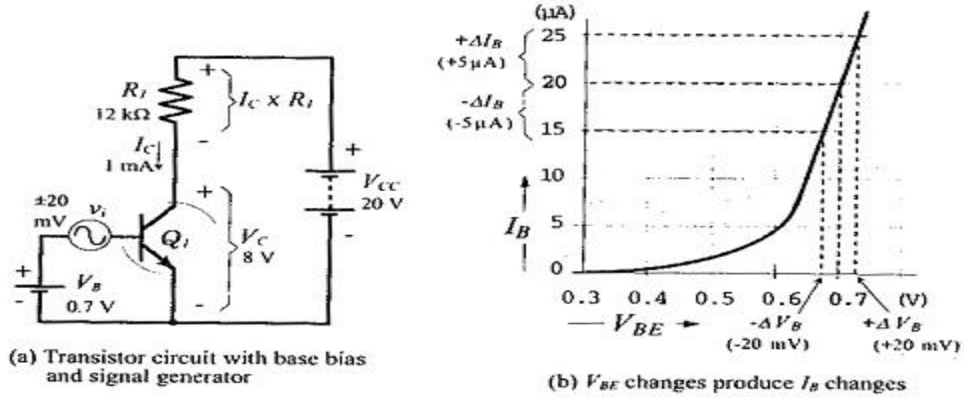


Fig. 2.10 : Voltage Amplification

While the ac input voltage (υ_i) is zero, the transistor collector voltage remains at 8 V. When υ_i causes a base voltage variation (ΔV_B) of ±20 mV, the base current changes by ±5 µA, as shown in Fig. 2.10(b). The I_B change produces a collector current change.

$$\Delta I_C = \beta_{dc} \Delta I_B = 50 \times (\pm 5\ \mu A) \\ = \pm 250\ \mu A$$

Figure 2.10 (a) shows that ΔI_C causes a change in the voltage drop across R_1, and thus produces a variation in the transistor collector voltage.

$$\Delta V_C = \Delta I_C R_1 = \pm 250\ \mu A \times 12\ k\Omega \\ = \pm 3\ V$$

The circuit ac input is the base voltage change (ΔV_B), and the ac output is the collector voltage change (ΔV_C). Because the output is greater than the input, the circuit has a voltage gain; it is a voltage amplifier. The voltage gain (A_υ) is the ratio of the output voltage to the input voltage.

$$A_\upsilon = \frac{\Delta V_C}{\Delta V_B} = \frac{\pm 3\ V}{\pm 20\ mV} \\ = 150$$

BJT as a Switch

Fig. 2.9 illustrates the basic operation of a BJT as a switching device. In part (a), the transistor is in the cutoff region because the base-emitter junction is not forward-biased. In this condition, there is, ideally, an open between collector and emitter, as indicated by the switch equivalent. In part (b), the transistor is in the saturation region because the base emitter junction and the base-collector junction are forward-biased and the base current is made large enough to cause the collector current to reach its saturation value. In this condition, there is, ideally, a short between collector and emitter, as indicated by the switch equivalent. Actually, a small voltage drop across the transistor of up to a few tenths of a volt normally occurs, which is the saturation voltage, $V_{CE(sat)}$.

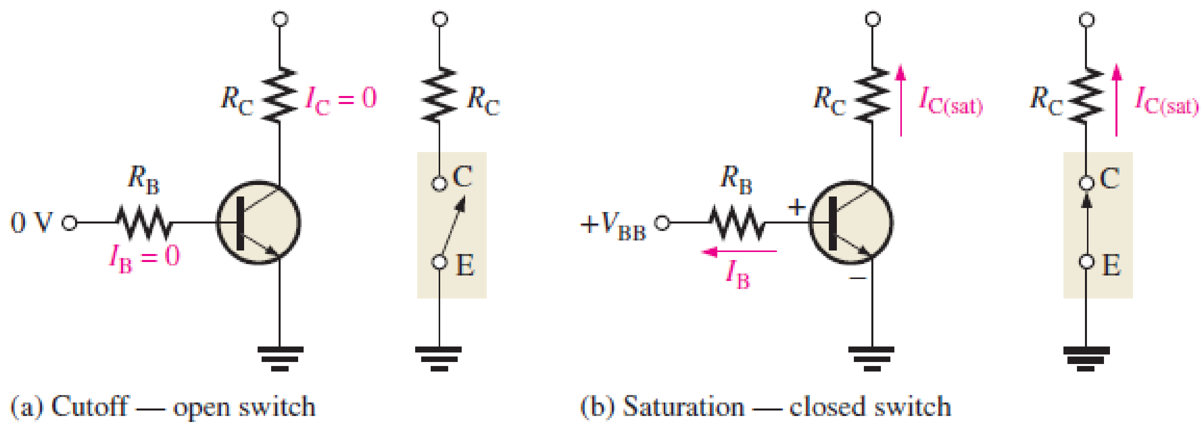


Fig. 2.10 : BJT as switch

Conditions in Cutoff: As mentioned before, a transistor is in the cutoff region when the base-emitter junction is not forward-biased. Neglecting leakage current, all of the currents are zero, and VCE is equal to VCC.

$$V_{CE(cutoff)} = V_{CC} \quad . \qquad (2.4)$$

Conditions in Saturation As you have learned, when the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. The formula for collector saturation current is

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} \qquad (2.5)$$

Since $V_{CE(sat)}$ is very small compared to V_{CC}, it can usually be neglected. The minimum value of base current needed to produce saturation is

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} \quad (2.6)$$

Normally, I_B should be significantly greater than $I_{B(min)}$ to ensure that the transistor is saturated.

2.1.4 DC Load Line of BJT Biasing Circuit:

The DC Load Line of BJT Biasing Circuit is a straight line drawn on the transistor output characteristics. For a common-emitter (CE) circuit, the load line is a graph of collector current (I_C) versus collector-emitter voltage (V_{CE}), for a given value of collector resistance (R_C) and a given supply voltage (V_{CC}). The load line shows all corresponding levels of I_C and V_{CE} that can exist in a particular circuit.

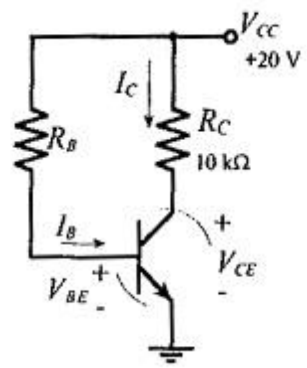


Fig. 2.11 : Common Emitter circuit

Consider the common-emitter circuit in Fig. 2.11. Note that the polarity of the transistor terminal voltages are such that the base-emitter junction is forward biased and the collector-base junction is reverse biased. These are the normal bias polarities for the transistor junctions. The DC Load Line of BJT Biasing Circuit in Fig. 2.11 is drawn on the device common-emitter characteristics in Fig. 2.12. From Fig. 2.11, the collector-emitter voltage is,

$$V_{CE} = \text{(supply voltage)} - \text{(voltage drop across } R_C)$$
$$V_{CE} = V_{CC} - I_C R_C$$

If the base-emitter voltage (V_{BE}) is zero, the transistor is not conducting and $I_C = 0$. Substituting the V_{CC} and R_C values from Fig. 5-1 in the above equation

$$V_{CE} = 20\text{ V} - (0 \times 10\text{ k}\Omega) = 20\text{ V}$$

Plot point A on the common-emitter characteristics in Fig. 2.12 at $I_C = 0$ and $V_{CE} = 20$ V. This is one point on the DC Load Line of BJT Biasing Circuit.

Now assume a collector current of 2 mA, and calculate the corresponding collector-emitter voltage level.

$$V_{CE} = 20\text{ V} - (2\text{ mA} \times 10\text{ k}\Omega) = 0\text{ V}$$

Plot point B on Fig. 2.12 at $V_{CE} = 0$ and $I_C = 2$ mA. The straight line drawn through point A and point B is the dc load line for $R_C = 10$ kΩ and $V_{CC} = 20$ V. If either of these two quantifies is changed, a new load line must be drawn.

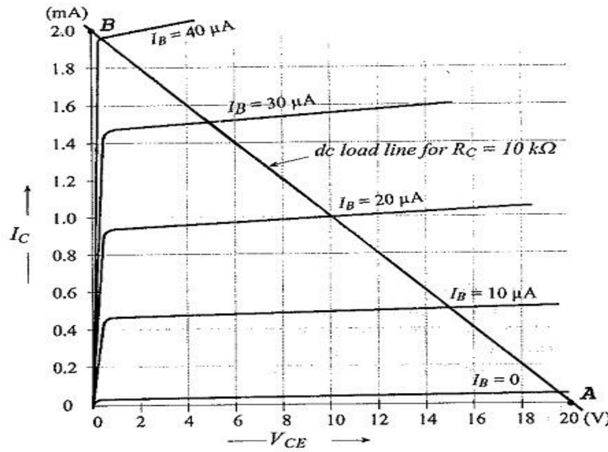


Fig. 2.12 : DC Characteristic

2.1.4.1 DC Bias Point (Q-Point):

The dc bias point, or **quiescent point** (**Q-point**) (also known as the dc operating point), identifies the transistor collector current and collector-emitter voltage when there is no input signal at the base terminal. Thus, it defines the dc conditions in the circuit. When a signal is applied to the transistor base, I_B varies according to the instantaneous amplitude of the signal. This causes I_C to vary, and consequently produces a variation in V_{CE}.

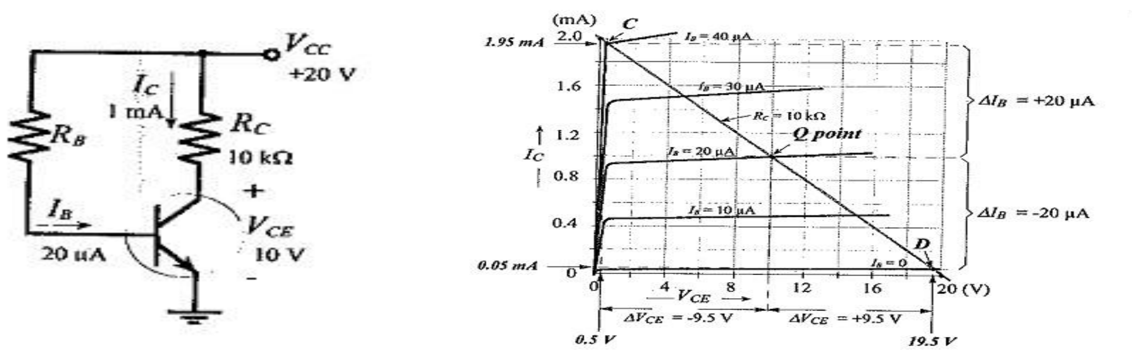


Fig. 2.12 : CE BJT Circuit & DC load line

Consider the circuit in Fig. 2.12, and the 10 kΩ load line drawn for the circuit . Assume that the bias conditions are as identified by the Q-point on the load line,

$$I_B = 20\ \mu A,\ I_C = 1\ mA,\ \text{and}\ V_{CE} = 10\ V$$

When I_B is increased from 20 µA to 40 µA, I_C becomes approximately 1.95 mA and V_{CE} becomes 0.5 V, as illustrated at point Con the load line. The V_{CE} change from the Q-point is,

$$\begin{aligned}\Delta V_{CE} &= 10\ V - 0.5\ V \\ &= 9.5\ V\end{aligned}$$

So, increasing I_B by 20 µA (from 20 µA to 40 µA) caused V_{CE} to decrease by 9.5 V, (from 10 V to 0.5 V).

Now look at the effect of decreasing the base current. When I_B is reduced from 20 µA to zero, I_C goes down to approximately 0.05 mA, and V_{CE} goes up to 19.5 V (point D on the load line in Fig. 2.12). So, the V_{CE} change is,

$$\begin{aligned}\Delta V_{CE} &= 19.5 - 10\ V \\ &= 9.5\ V\end{aligned}$$

Decreasing I_B by 20 μA (From 20 μA to zero) caused V_{CE} to increase by 9.5 V (from 10 V to 19.5 V). It is seen that with the Q-point at I_C = 1 mA and V_{CE} = 10 V, an I_B variation of ±20 μA produces a collector voltage swing of ΔV_{CE} = ±9.5 V.

Q-point Selection:

When used as an amplifier, the transistor output (collector-emitter) voltage must swing up and down by equal amounts; that is, the output voltage swing must be symmetrical above and below the bias point. In many cases circuits are designed to have the Q-point at the center of the load line to give the largest possible symmetrical output voltage swing. This is especially true for some large signal amplifiers.

Need of Biasing

- To fix the operating point at the middle of active region.
- Stabilize the collector current against temperature variations.
- Operating point independent of transistor parameters

2.1.5 Base Bias in BJT:

Circuit Operation and Analysis – The transistor bias arrangement shown in Fig. 2.13 is known as **Base Bias in BJT** and also as **fixed current bias**. The base current is a constant quantity determined by supply voltage V_{CC} and base resistor R_B. Because V_{CC} and R_B are constant quantities. I_B remains fixed at a particular level. Unlike some other bias circuits, the base current in a Base Bias in BJT circuit is not affected by the transistor current gain.

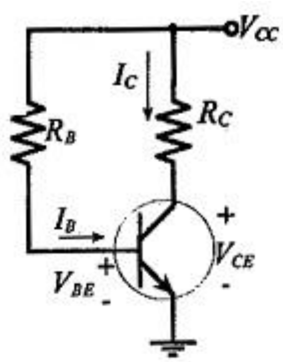


Fig. 2.13 : Base Bias Circuit

From Fig. 2.13, the voltage drop across R_B is (V_{CC} – V_{BE}) , and the base current & collector current is given by

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \qquad I_C = h_{FE} I_B \qquad (2.8)$$

In Eq. 2.8 the base-emitter voltage (V_{BE}) is taken as 0.7 V for a silicon transistor, and as 0.3 V for a germanium device.

The collector current is now used with Eq. 2.8 ($V_{CE} = V_{CC} – I_C R_C$) to calculate the collector-emitter voltage. Thus, when the supply voltage and component values are known, a Base Bias in BJT is easily analysed to determine the circuit current and voltage levels.

Advantages

- Circuit design and calculation are simple.
- Due to the absence of the resistor at the junction of the base-emitter, there is no chance of occurrence of the loading effect.

Disadvantages

- Due to the development of heat, the stabilization criterion of the circuit gets degraded.
- As the value of the stability factor gets high results to thermal runaway.

2.1.6 Voltage Divider Bias Circuit:

Circuit Operation – Voltage Divider Bias Circuit, also known as **emitter current bias**, is the most stable of the three basic transistor bias circuits. A voltage divider bias circuit is shown in Fig. 2.14(a), and the current and voltage conditions throughout the circuit are illustrated in Fig. 2.14(b). It is seen that, as well as the collector resistor (R_C), there is an emitter resistor (R_E) connected in series with the transistor. As discussed already, the total dc load in series with the transistor is ($R_C + R_E$), and this total resistance must be used when drawing the dc load line for the circuit. Resistors R_1 and R_2 constitute a voltage divider that divides the supply voltage to produce the base bias voltage (V_B).

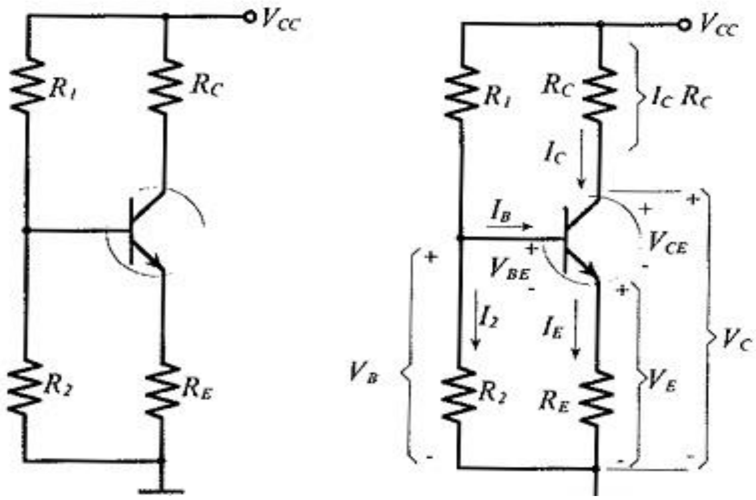


Fig. 2.14 Voltage Divider Bias Circuit

Voltage Divider Bias Circuit are normally designed to have the voltage divider current (I_2) very much larger than the transistor base current (I_B). In this circumstance, V_B is largely unaffected by I_B, so V_B can be assumed to remain constant.

Referring to Fig. 2.14 (b),

$$V_B = \frac{V_{CC} \times R_2}{R_1 + R_2}$$

With V_B constant, the voltage across the emitter resistor is also a constant quantity,

$$V_E = V_B - V_{BE}$$

This means that the emitter current is constant,

$$I_E = \frac{V_B - V_{BE}}{R_E}$$

The collector current is approximately equal to the emitter current, so I_C is held at a constant level.

Again referring to Fig. 2.14 (b), the transistor collector voltage is,

$$V_C = V_{CC} - (I_C R_C)$$

The collector-emitter voltage is,

$$V_{CE} = V_C - V_E$$

V_{CE} can also be determined as,

$$V_{CE} \approx V_{CC} - I_C(R_C + R_E)$$

Clearly, with I_C and I_B constant, the transistor collector-emitter voltage remains at a constant level. It should be noted that the transistor h_{FE} value is not involved in any of the above equations.

Advantage

- More than one type of voltage divider circuit can be incorporated by making use of this bias.
- Highly stable

Disadvantages

- The signals tend to get mixed while using this bias in the circuits.

2.2 Amplifiers and Oscillators

2.2.1 Feedback Amplifier

Feedback Amplifiers are designed to use feedback for better output production. A part of the output is taken as feedback and used as input to minimise the losses. An amplifier is a device that amplifies the signal applied to its input. However, an amplifier strengthens the input signal, regardless of whether it contains information or noise at the input. Because of this, the output of an amplifier tends to produce an amplified version of both noise and signal at the output, which is undesirable, so we mostly use feedback amplifiers to reduce the noise and stabilize the system.
Feedback amplifiers greatly reduce the effect of noise in an amplifier; negative feedback feeds the output back to the input with phase reversal. Feedback amplifiers are divided into two types: positive feedback and negative feedback.

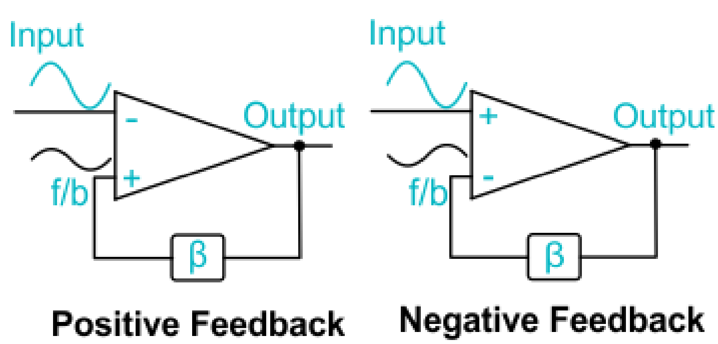


Fig. 2.15 : Types of feedback network

2.2.2 Negative Feedback Amplifier

In a negative feedback amplifier, a small portion of the output voltage is fed back to the input. The instantaneous polarity of the feedback voltage is normally opposite to the signal voltage polarity, (they are in series-opposition). So, the feedback voltage is negative with respect to the signal voltage; hence the term negative feedback.

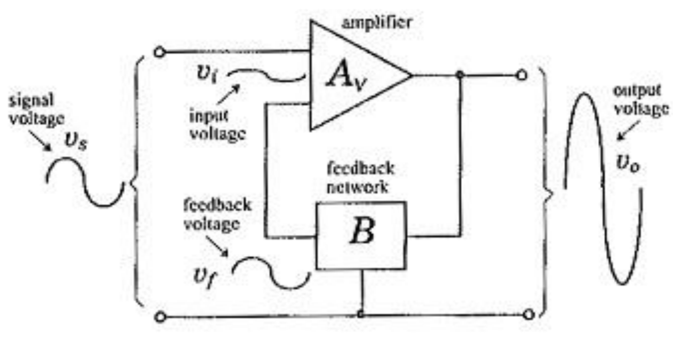
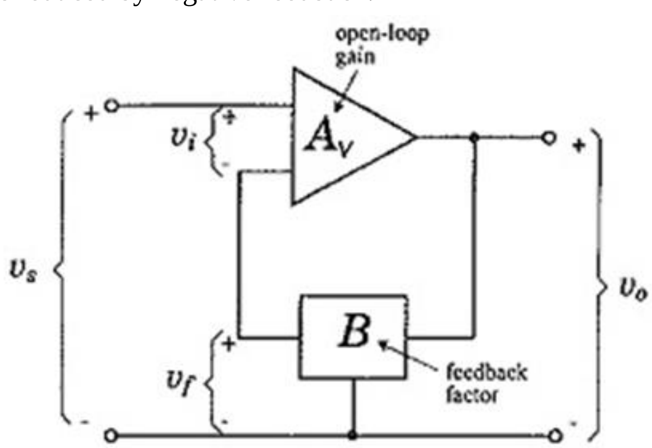


Fig. 2.16 : Negative feedback network

Consider the illustration in Fig. 2.16 An amplifier with two input terminals and one output is shown (in triangular representation). The amplifier has a voltage gain (A_v), and its output voltage (v_o) is applied to a feedback network that reduces v_o by a factor (B) to produce a feedback voltage (v_f). TAt the amplifier input, the instantaneous level of v_f is applied negative with respect to v_s, so that the amplifier input terminal voltage is,

$$v_i = v_s - v_f$$

Because the amplifier Input voltage is lower than the signal voltage, the output voltage is lower than that produced when negative feedback is not used. This means, of course, that the overall voltage gain (v_o/v_i) is reduced by negative feedback.



$$open\ loop\ gain\ A_v = \frac{v_o}{v_i}$$

$$feedback\ factor\ B = \frac{v_f}{v_o}$$

$$closed\ loop\ gain\ A_{CL} = \frac{A_v}{1 + A_v B}$$

The closed loop gain is given by

$$A_{CL} = \frac{A_v}{1 + A_v B}$$

2.2.2 Types of amplifier

Many different types of amplifier are found in electronic circuits. Before we explain the operation of transistor amplifiers in detail, we shall briefly describe the main types of amplifier.

a.c. coupled amplifiers

In a.c. coupled amplifiers, stages are coupled together in such a way that d.c. levels are isolated and only the a.c. components of a signal are transferred from stage to stage.

d.c. coupled amplifiers

In d.c. (or direct) coupled amplifiers, stages are coupled together in such a way that stages are not isolated to d.c. potentials. Both a.c. and d.c. signal components are transferred from stage to stage.

Large-signal amplifiers

Large-signal amplifiers are designed to cater for appreciable voltage and/or current levels (typically from 1 V to 100 V or more).

Small-signal amplifiers

Small-signal amplifiers are designed to cater for low-level signals (normally less than 1 V and often much smaller). Small-signal amplifiers have to be specially designed to combat the effects of noise.

Audio frequency amplifiers

Audio frequency amplifiers operate in the band of frequencies that is normally associated with audio signals (e.g. 20 Hz to 20 kHz).

Wideband amplifiers

Wideband amplifiers are capable of amplifying a very wide range of frequencies, typically from a few tens of hertz to several megahertz.

Radio frequency amplifiers

Radio frequency amplifiers operate in the band of frequencies that is normally associated with radio signals (e.g. from 100 kHz to over 1 GHz). Note that it is desirable for amplifiers of this type to be frequency selective and thus their frequency response may be restricted to a relatively narrow band of frequencies (see Fig. 7.9 on page 139).

Low-noise amplifiers

Low-noise amplifiers are designed so that they contribute negligible noise (signal disturbance) to the signal being amplified. These amplifiers are usually designed for use with very small signal levels (usually less than 10 mV or so).

2.2.3 Frequency response

The frequency response characteristics for various types of amplifier are shown in Fig. 7.9. Note that, for response curves of this type, frequency is almost invariably plotted on a **logarithmic scale**. The frequency response of an amplifier is usually specified in terms of the upper and lower **cut-off frequencies** of the amplifier. These frequencies are those at which the output power has dropped to 50% (otherwise known as the **−3 dB points**) or where the voltage gain has dropped to 70.7% of its mid-band value.

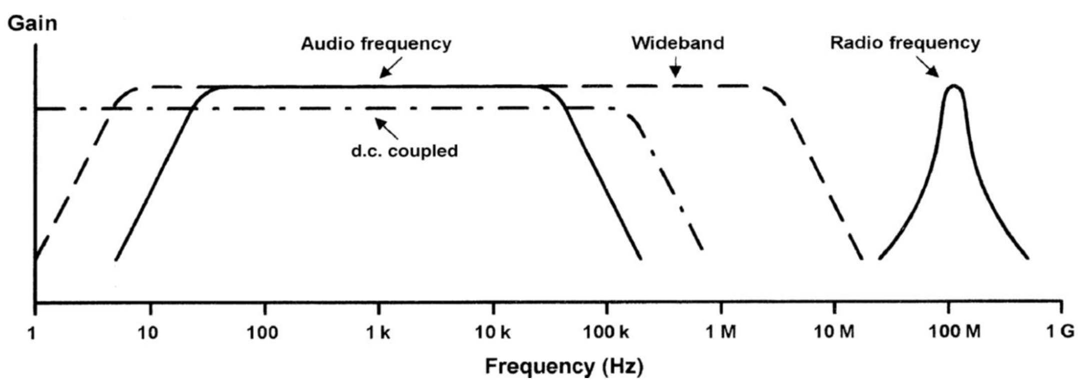


Fig. 2.17 : Frequency Response

2.2.4 Bandwidth

The bandwidth of an amplifier is usually taken as the difference between the upper and lower cut-off frequencies (i.e. $f2 - f1$ in Figs 2.18).

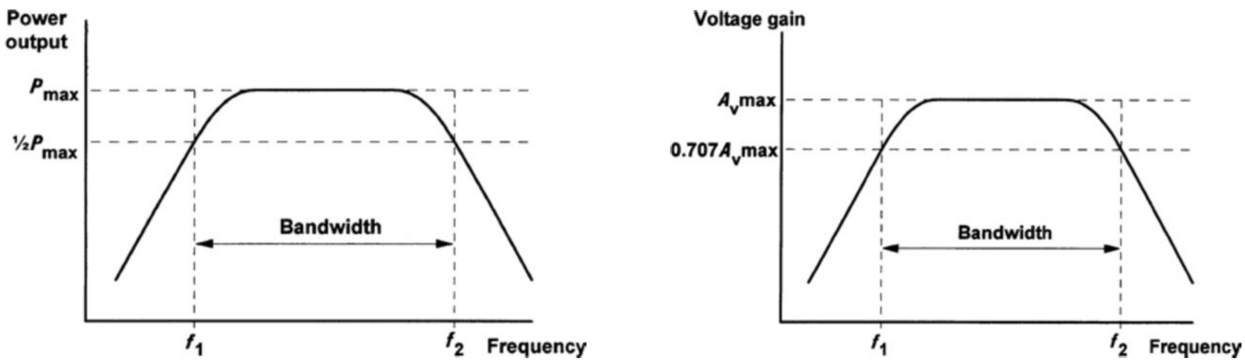


Fig. 2.18 : Frequency Response curve for Band width calculation

2.2.5 Phase shift

Phase shift is the phase angle between the input and output signal voltages measured in degrees. The measurement is usually carried out in the mid-band where, for most amplifiers, the phase shift remains relatively constant.

2.2.6 Positive Feedback Amplifier

Positive feedback is characterized by the condition wherein a portion of the output voltage of an amplifier is fed back to the input with no net phase shift, resulting in a reinforcement of the output signal. This basic idea is illustrated in Figure 2.19 (a). As you can see, the inphase feedback voltage, is amplified to produce the output voltage, which in turn produces the feedback voltage. That is, a loop is created in which the signal sustains itself and a continuous sinusoidal output is produced. This phenomenon is called *oscillation.* In some types of amplifiers, the feedback circuit shifts the phase and an inverting amplifier is required to provide another phase shift so that there is no net phase shift. This is illustrated in Figure 2.19 (b).

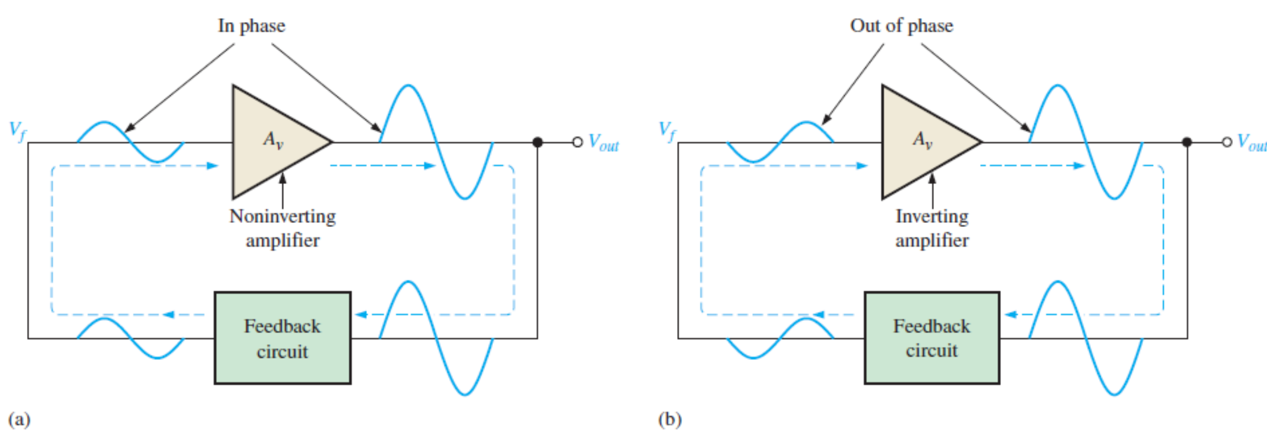


Fig. 2.19 : Positive feedback network

2.2.7 BARKHAUSEN CRITERION

- Conditions which are required to be satisfied to operate the circuit as an oscillator are called as "Barkhausen criterion" for sustained oscillations.
- The Barkhausen criteria should be satisfied by an amplifier with positive feedback to ensure the sustained oscillations.
- For an oscillation circuit, there is no input signal "V_s", hence the feedback signal V_f itself should be sufficient to maintain the oscillations.
- The Barkhausen criterion states that:
    - The loop gain is equal to unity in absolute magnitude, that is, $|\beta A| = 1$
    - The phase shift around the loop is zero or 360_0 (OR an integer multiple of 2π: $\angle \beta A = 2\pi n, n \in 0, 1, 2\ldots$)
    - The product βA is called as the "loop gain".

2.2.8 RC PHASE-SHIFT OSCILLATORS

Ideally a simple RC network is expected to have an output which leads the input by 90^o.However, in reality, the phase-difference will be less than this as the capacitor used in the circuit cannot be ideal.

RC phase-shift oscillator is formed by cascading three RC phase-shift networks, each offering a phase-shift of 60^o, as shown by Figure 2.20.

From Figure, TR1 operates as a conventional common-emitter amplifier stage with R1 and R2 providing base bias potential and R3 and C1 providing emitter stabilization. The total phase shift provided by the C–R ladder network (connected between collector and base) is 180° at the frequency of oscillation. The transistor provides the other 180° phase shift in order to realize an overall phase shift of 360° or 0° (note that these are the same).

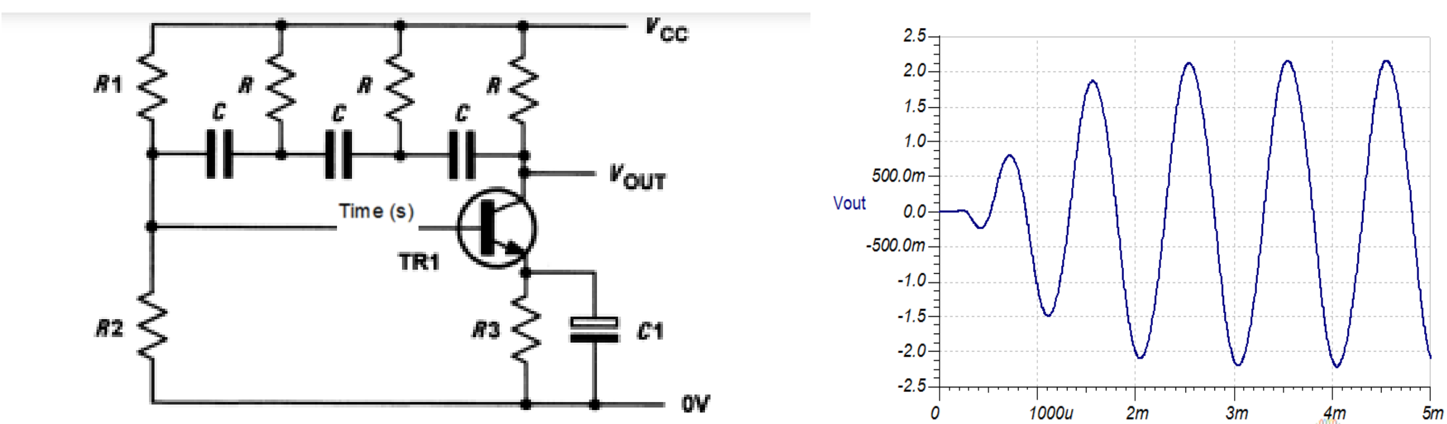


Fig. 2.20: RC Phase shift oscillator

The frequency of oscillation of the circuit shown in Fig 2.20 is given by:

$$f = \frac{1}{2\pi \times \sqrt{6}CR}$$

The loss associated with the ladder network is 29, thus the amplifier must provide a gain of at least 29 in order for the circuit to oscillate. In practice this is easily achieved with a single transistor.

Numerical

1. Find the value of β if (i) α = 0.9 (ii) α = 0.98 (iii) α = 0.99.

Solution :

(i) α = 0.9

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9}{1-0.9} = \mathbf{9}$$

(ii) α = 0.98

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = \mathbf{49}$$

(iii) α = 0.99

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = \mathbf{99}$$

2. Calculate I_E in a transistor for which β = 50 and I_B = 20 μA.

Solution :

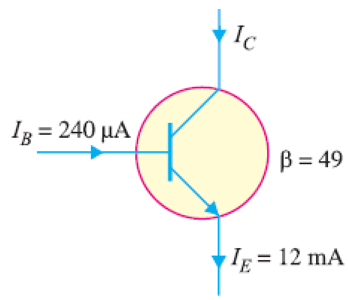
Here $\beta = 50, \quad I_B = 20\mu A = 0.02 \text{ mA}$

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

$\therefore \quad I_C = \beta I_B = 50 \times 0.02 = 1 \text{ mA}$

Using the relation, $I_E = I_B + I_C = 0.02 + 1 = \mathbf{1.02\ mA}$

3. Find the α rating of the transistor shown in Fig. Hence determine the value of I_C



Solution :

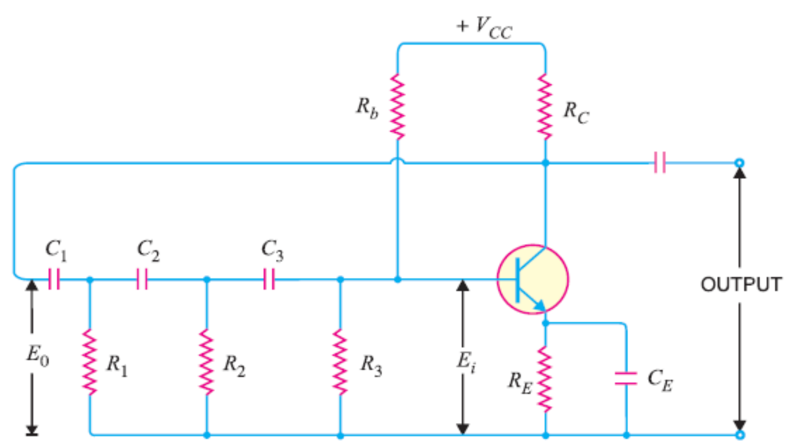
$$\alpha = \frac{\beta}{1+\beta} = \frac{49}{1+49} = \mathbf{0.98}$$

The value of I_C can be found by using either α or β rating as under :

$$I_C = \alpha I_E = 0.98\ (12\ \text{mA}) = \mathbf{11.76\ mA}$$

Also $$I_C = \beta I_B = 49\ (240\ \mu\text{A}) = \mathbf{11.76\ mA}$$

4. In the phase shift oscillator shown in Fig., R1 = R2 = R3 = 1MΩ and C1 = C2 = C3 = 68 pF. At what frequency does the circuit oscillate ?



Solution.

$$R_1 = R_2 = R_3 = R = 1\,M\Omega = 10^6\,\Omega$$
$$C_1 = C_2 = C_3 = C = 68\,pF = 68 \times 10^{-12}\,F$$

Frequency of oscillations is

$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$
$$= \frac{1}{2\pi \times 10^6 \times 68 \times 10^{-12}\sqrt{6}}\ \text{Hz}$$
$$= \mathbf{954\ Hz}$$

5. A phase shift oscillator uses 5 pF capacitors. Find the value of R to produce a frequency of 800 kHz.

Solution.

$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$

or

$$R = \frac{1}{2\pi f_o C\sqrt{6}} = \frac{1}{2\pi \times 800 \times 10^3 \times 5 \times 10^{-12} \times \sqrt{6}}$$
$$= 16.2 \times 10^3\,\Omega = \mathbf{16.2\ k\Omega}$$