Example 14.8

ΔI_B = (30 – 20) µA = 10 µA, ΔI_C = (4.5 – 3.0) mA = 1.5 mA

Therefore, β_{ac} = 1.5 mA/ 10 µA = 150

For determining $\beta_{dc,}$ either estimate the value of I_B corresponding to I_C = 4.0 mA at V_{CE} = 10 V or calculate the two values of β_{dc} for the two characteristics chosen and find their mean.

Therefore, for I_C = 4.5 mA and I_B = 30 µA,

β_{dc} = 4.5 mA/ 30 µA = 150

and for I_C = 3.0 mA and I_B = 20 µA

β_{dc} =3.0 mA / 20 µA = 150

Hence, β_{dc} =(150 + 150) /2 = 150

14.9.3 Transistor as a device

The transistor can be used as a device application depending on the configuration used (namely CB, CC and CE), the biasing of the E-B and B-C junction and the operation region namely cutoff, active region and saturation. As mentioned earlier we have confined only to the CE configuration and will be concentrating on the biasing and the operation region to understand the working of a device.

When the transistor is used in the cutoff or saturation state it acts as a *switch*. On the other hand for using the transistor as an *amplifier*, it has to operate in the active region.

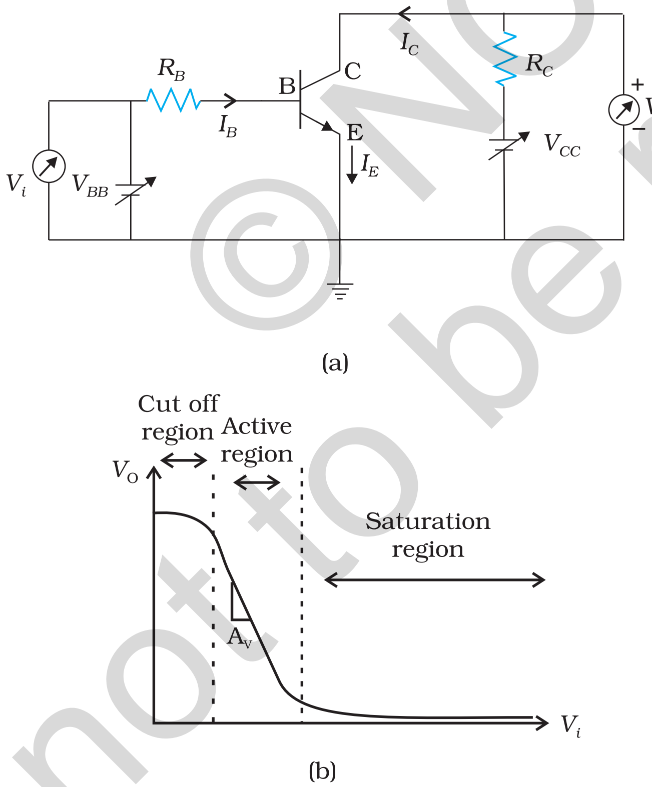

FIGURE 14.31 (a) Base-biased transistor in CE configuration, (b) Transfer characteristic.

(i) Transistor as a switch

We shall try to understand the operation of the transistor as a switch by analysing the behaviour of the base-biased transistor in CE configuration as shown in Fig. 14.31(a).

Applying Kirchhoff's voltage rule to the input and output sides of this circuit, we get

$$V_{BB} = I_B R_B + V_{BE} \quad (14.12)$$

and

$$V_{CE} = V_{CC} - I_C R_C. \quad (14.13)$$

We shall treat V_{BB} as the dc input voltage V_i and V_{CE} as the dc output voltage V_O. So, we have

$V_i = I_B R_B + V_{BE}$ and

$V_o = V_{CC} - I_C R_C$.

Let us see how V_o changes as V_i increases from zero onwards. In the case of Si transistor, as long as input V_i is less than 0.6 V, the transistor will be in cut off state and current I_C will be zero.

Hence $V_o = V_{CC}$

When V_i becomes greater than 0.6 V the transistor is in active state with some current I_C in the output path and the output V_o decrease as the term $I_C R_C$ increases. With increase of V_i, I_C increases almost linearly and so V_o decreases linearly till its value becomes less than about 1.0 V.

Beyond this, the change becomes non linear and transistor goes into saturation state. With further increase in V_i the output voltage is found to decrease further towards zero though it may never become zero. If we plot the V_o vs V_i curve, [also called the transfer characteristics of the base-biased transistor (Fig. 14.31(b)], we see that between cut off state and active state and also between active state and saturation state there are regions of non-linearity showing that the transition from cutoff state to active state and from active state to saturation state are not sharply defined.

Let us see now how the transistor is operated as a switch. As long as V_i is *low* and unable to forward-bias the transistor, V_o is *high* (at V_{CC}). If V_i is *high* enough to drive the transistor into saturation, then V_o is *low*, very near to zero. When the transistor is not conducting it is said to be *switched off* and when it is driven into saturation it is said to be *switched on*. This shows that if we define low and high states as below and above certain voltage levels corresponding to cutoff and saturation of the transistor, then we can say that a *low* input switches the transistor off and a *high* input switches it on. Alternatively, we can say that a *low* input to the transistor gives a *high* output and a *high* input gives a *low* output. The switching circuits are designed in such a way that the transistor does not remain in active state.

(ii) Transistor as an amplifier

For using the transistor as an amplifier we will use the active region of the V_o versus V_i curve. The slope of the linear part of the curve represents the rate of change of the output with the input. It is negative because the output is $V_{CC} - I_C R_C$ and not $I_C R_C$. That is why as input voltage of the CE amplifier increases its output voltage decreases and the output is said to be out of phase with the input. If we consider ΔV_o and ΔV_i as small changes in the output and input voltages then $\Delta V_o/\Delta V_i$ is called the small signal voltage gain A_V of the amplifier.

If the V_{BB} voltage has a fixed value corresponding to the mid point of the active region, the circuit will behave as a CE amplifier with voltage gain $\Delta V_o/\Delta V_i$. We can express the voltage gain A_V in terms of the resistors in the circuit and the current gain of the transistor as follows.

We have, $V_o = V_{CC} - I_C R_C$

Therefore, $\Delta V_o = 0 - R_C \Delta I_C$

Similarly, from $V_i = I_B R_B + V_{BE}$

$\Delta V_i = R_B \Delta I_B + \Delta V_{BE}$

But ΔV_{BE} is negligibly small in comparison to $\Delta I_B R_B$ in this circuit.

So, the *voltage gain* of this *CE amplifier* (Fig. 14.32) is given by

$$A_V = -R_C \Delta I_C / R_B \Delta I_B$$

$$= -\beta_{ac}(R_C / R_B) \qquad (14.14)$$

where β_{ac} is equal to $\Delta I_C/\Delta I_B$ from Eq. (14.10). Thus the linear portion of the active region of the transistor can be exploited for the use in amplifiers. Transistor as an amplifier (CE configuration) is discussed in detail in the next section.

14.9.4 Transistor as an Amplifier (CE-Configuration)

To operate the transistor as an amplifier it is necessary to fix its operating point somewhere in the middle of its active region. If we fix the value of V_{BB} corresponding to a point in the middle of the linear part of the transfer curve then the dc base current I_B would be constant and corresponding collector current I_C will also be constant. The dc voltage $V_{CE} = V_{CC} - I_C R_C$ would also remain constant. The operating values of V_{CE} and I_B determine the operating point, of the amplifier.

If a small sinusoidal voltage with amplitude v_s is superposed on the dc base bias by connecting the source of that signal in series with the V_{BB} supply, then the base current will have sinusoidal variations superimposed on the value of I_B. As a consequence the collector current also will have sinusoidal variations superimposed on the value of I_C, producing in turn corresponding change in the value of V_O. We can measure the ac variations across the input and output terminals by blocking the dc voltages by large capacitors.

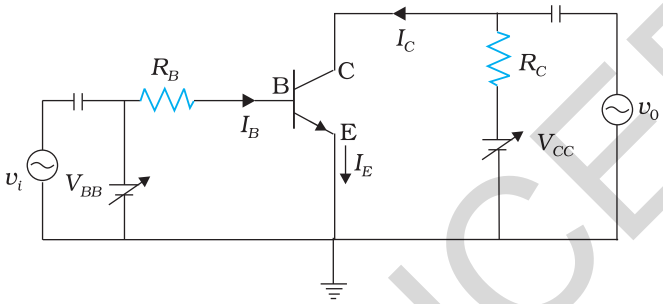

FIGURE 14.32 A simple circuit of a CE-transistor amplifier.

In the discription of the amplifier given above we have not considered any ac signal. In general, amplifiers are used to amplify alternating signals. Now let us superimpose an ac input signal v_i (to be amplified) on the bias V_{BB} (dc) as shown in Fig. 14.32. The output is taken between the collector and the ground.

The working of an amplifier can be easily understood, if we first assume that $v_i = 0$. Then applying Kirchhoff's law to the output loop, we get

$$V_{cc} = V_{CE} + I_c R_L \tag{14.15}$$

Likewise, the input loop gives

$$V_{BB} = V_{BE} + I_B R_B \tag{14.16}$$

When v_i is not zero, we get

$$V_{BE} + v_i = V_{BE} + I_B R_B + \Delta I_B (R_B + r_i)$$

The change in V_{BE} can be related to the input resistance r_i [see Eq. (14.8)] and the change in I_B. Hence

$$v_i = \Delta I_B (R_B + r_i)$$

$$= r \Delta I_B$$

The change in I_B causes a change in I_c. We define a parameter β_{ac}, which is similar to the β_{dc} defined in Eq. (14.11), as

$$\beta_{ac} = \frac{\Delta I_c}{\Delta I_B} = \frac{i_c}{i_b} \tag{14.17}$$

which is also known as the *ac current gain* A_i. Usually β_{ac} is close to β_{dc} in the linear region of the output characteristics.

The change in I_c due to a change in I_B causes a change in V_{CE} and the voltage drop across the resistor R_L because V_{CC} is fixed.

These changes can be given by Eq. (14.15) as

$\Delta V_{CC} = \Delta V_{CE} + R_L \Delta I_C = 0$

or $\Delta V_{CE} = -R_L \Delta I_C$

The change in V_{CE} is the output voltage v_0. From Eq. (14.10), we get

$v_0 = \Delta V_{CE} = -\beta_{ac} R_L \Delta I_B$

The voltage gain of the amplifier is

$$A_v = \frac{v_0}{v_i} = \frac{\Delta V_{CE}}{r \Delta I_B}$$

$$= -\frac{\beta_{ac} R_L}{r} \qquad (14.18)$$

The negative sign represents that output voltage is opposite with phase with the input voltage.

From the discussion of the transistor characteristics you have seen that there is a current gain β_{ac} in the CE configuration. Here we have also seen the voltage gain A_v. Therefore the power gain A_p can be expressed as the product of the current gain and voltage gain. Mathematically

$$A_p = \beta_{ac} \times A_v \qquad (14.19)$$

Since β_{ac} and A_v are greater than 1, we get ac power gain. However it should be realised that transistor is not a power generating device. The energy for the higher ac power at the output is supplied by the battery.

Example 14.9 In Fig. 14.31(a), the V_{BB} supply can be varied from 0V to 5.0 V. The Si transistor has β_{dc} = 250 and R_B = 100 kΩ, R_C = 1 KΩ, V_{CC} = 5.0V. Assume that when the transistor is saturated, V_{CE} = 0V and V_{BE} = 0.8V. Calculate (a) the minimum base current, for which the transistor will reach saturation. Hence, (b) determine V_1 when the transistor is 'switched on'. (c) find the ranges of V_1 for which the transistor is 'switched off' and 'switched on'.

Solution

Given at saturation V_{CE} = 0V, V_{BE} = 0.8V

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

$I_C = V_{CC}/R_C$ = 5.0V/1.0kΩ = 5.0 mA

Therefore $I_B = I_C/\beta$ = 5.0 mA/250 = 20μA

The input voltage at which the transistor will go into saturation is given by

$V_{IH} = V_{BB} = I_B R_B + V_{BE}$

= 20μA × 100 kΩ + 0.8V = 2.8V

The value of input voltage below which the transistor remains cutoff is given by

V_{IL} = 0.6V, V_{IH} = 2.8V

Between 0.0V and 0.6V, the transistor will be in the 'switched off' state. Between 2.8V and 5.0V, it will be in 'switched on' state.

Note that the transistor is in active state when I_B varies from 0.0mA to 20mA. In this range, $I_C = \beta I_B$ is valid. In the saturation range, $I_C \leq \beta I_B$.

EXAMPLE 14.9

Example 14.10 For a CE transistor amplifier, the audio signal voltage across the collector resistance of 2.0 kΩ is 2.0 V. Suppose the current amplification factor of the transistor is 100, What should be the value of R_B in series with V_{BB} supply of 2.0 V if the dc base current has to be 10 times the signal current. Also calculate the dc drop across the collector resistance. (Refer to Fig. 14.33).

Solution The output ac voltage is 2.0 V. So, the ac collector current i_C = 2.0/2000 = 1.0 mA. The signal current through the base is, therefore given by $i_B = i_C /\beta$ = 1.0 mA/100 = 0.010 mA. The dc base current has to be 10× 0.010 = 0.10 mA.
From Eq.14.16, $R_B = (V_{BB} - V_{BE}) / I_B$. Assuming V_{BE} = 0.6 V,
R_B = (2.0 – 0.6)/0.10 = 14 kΩ.
The dc collector current I_C = 100×0.10 = 10 mA.

EXAMPLE 14.10

14.9.5 Feedback amplifier and transistor oscillator

In an amplifier, we have seen that a sinusoidal input is given which appears as an amplified signal in the output. This means that an *external input is necessary to sustain ac signal in the output for an amplifier.* In an oscillator, we get ac output without any external input signal. In other words, the output in an oscillator is *self-sustained.* To attain this, an amplifier is taken. A portion of the output power is returned back (feedback) to the input *in phase* with the starting power (this process is termed *positive feedback)* as shown in Fig. 14.33(a). The feedback can be achieved by inductive coupling (through mutual inductance) or *LC* or *RC* networks. Different types of oscillators essentially use different methods of coupling the output to the input (feedback network), apart from the resonant circuit for obtaining oscillation at a particular frequency. For understanding the oscillator action, we consider the circuit shown in Fig. 14.33(b) in which the feedback is accomplished by *inductive coupling* from one coil winding (T_1) to another coil winding (T_2). Note that the coils T_2 and T_1 are wound on the same core and hence are inductively coupled through their mutual inductance. As in an amplifier, the base-emitter junction is forward biased while the base-collector junction is reverse biased. Detailed biasing circuits actually used have been omitted for simplicity.

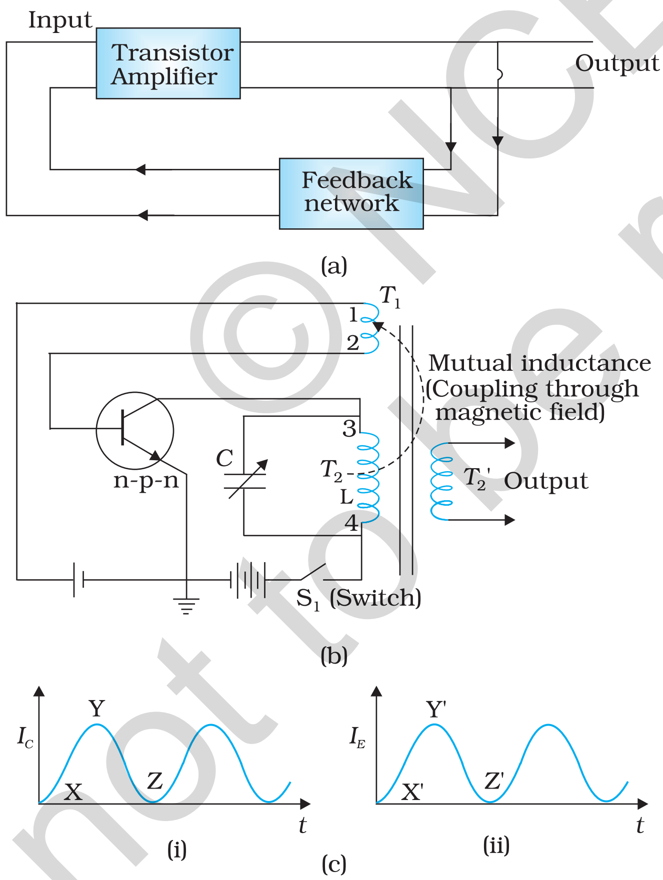

FIGURE 14.33 (a) Principle of a transistor amplifier with positive feedback working as an oscillator and (b) Tuned collector oscillator, (c) Rise and fall (or built up) of current I_c and I_e due to the inductive coupling.

Let us try to understand how oscillations are built. Suppose switch S_1 is put *on* to