11·2 Transistor biasing

It has already been discussed that for faithful amplification, a transistor amplifier must satisfy three basic conditions, namely : (*i*) proper zero signal collector current, (*ii*) proper base-emitter voltage at any instant and (*iii*) proper collector-emitter voltage at any instant. It is the fulfilment of these conditions which is known as transistor biasing.

The proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage during the passage of signal is known as **transistor biasing**.

The basic purpose of transistor biasing is to keep the base-emitter junction properly forward biased and collector emitter junction properly reverse biased during the application of signal. This can be achieved with a bias battery or associating a circuit with a transistor. The latter method is more efficient and is frequently employed. The circuit which provides transistor biasing is known as *biasing circuit.* It may be noted that transistor biasing is very essential for the proper operation of transistor in any circuit.

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11·4 Stabilisation

The collector current in transistor changes rapidly when :

(*i*) the temperature changes,

(*ii*) the transistor is replaced by another of the same type. This is due to the inherent variations of transistor parameters. When the temperature changes or the transistor is replaced, the operating point (*i.e.* zero signal I_C and V_{CE}) also changes. However, for faithful amplification, it is essential that operating point remains fixed. This necessitates to make the operating point independent of these variations. This is known as stabilisation.

The process of making operating point independent of temperature changes or variation in transistor parameters is known as **stabilisation**.

Once stabilisation is done, the zero signal I_C and V_{CE} become independent of temperature variations or replacement of transistor *i.e.* the operating point is fixed. A good biasing circuit always ensures the stabilisation of operating point.

Need for stabilisation. Stabilisation of the operating point is necessary due to the following reasons :—

(*i*) Temperature dependence of I_C

(*ii*) Individual variations

(*iii*) Thermal runway.

(*i*) *Temperature dependence of* I_C. The collector current I_B is given by ;

$$\begin{aligned} I_C &= \beta I_B + I_{CEO} \\ &= \beta I_B + (\beta + 1) I_{CBO} \end{aligned}$$

The collector leakage current I_{CBO} is greatly influenced (especially in germanium transistor) by temperature changes. A rise of 10°C doubles the collector leakage current which may be as high as $0{\cdot}2 mA$ for low powered germanium transistors. As biasing conditions in such transistors are generally so set that zero signal $I_C = 1\ mA$, therefore, the change in I_C due to temperature variations current cannot be tolerated. This necessitates to stabilise the operating point *i.e.* to hold I_C constant inspite of temperature variations.

(*ii*) *Individual variations.* The value of β and V_{BE} are not exactly the same for any two transistors even of the same type. Further, V_{BE} itself decreases when temperature increases. When a transistor is replaced by another of the same type, these variations change the operating point. This necessitates to stabilise the operating point *i.e.* to hold I_C constant irrespective of individual variations in transistor parameters.

(*iii*) *Thermal runway.* The flow of collector current produces heat within the transistor. This raises the transistor temperature and if no stabilisation is done, the collector leakage current also increases. The increased collector leakage current further raises the transistor temperature. This rise in temperature further increases the collector leakage current. In this way, in a matter of seconds, the collector current may become very large, thus destroying the transistor.

The self-destruction of an unstabilised transistor is known as **thermal runway**.

In order to avoid thermal runway and consequent destruction of transistor, it is very important that operating point is stabilised.

11·5 Essentials of a transistor biasing circuit

It has already been discussed that transistor biasing is required for faithful amplification. The biasing network associated with the transistor should meet the following requirements :

(*i*) It should ensure proper zero signal collector current.

(*ii*) It should ensure that V_{CE} does not fall below 0·5V for *Ge* transistors and 1V for silicon transistors at any instant.

(*iii*) It should ensure the stabilisation of operating point.

11·6 Methods of transistor biasing

In the transistor amplifier circuits drawn so far biasing was done with the aid of a battery V_{BB} which was separate from the battery V_{CC} used in the output circuit. However, in the interest of simplicity and economy, it is desirable that transistor circuit should have a single source of supply—the one in the output circuit (*i.e.* V_{CC}). The following are the most commonly used methods of obtaining transistor biasing from one source of supply (*i.e.* V_{CC}) :

(*i*) Base resistor method

(*ii*) Biasing with feedback resistor

(*iii*) Voltage-divider bias.

In all these methods, the same basic principle is employed *i.e.* required value of base current (and hence I_C) is obtained from V_{CC} in the zero signal conditions. The value of collector load R_C is selected keeping in view that V_{CE} should not fall below 0·5 V for germanium transistors and 1V for silicon transistors.

For example, if $\beta = 100$ and the zero signal collector current I_C is to be set at 1 *mA*, then I_B is made equal to $I_C/\beta = 1/100 = 10\mu A$. Thus, the biasing network should be so designed that a base current of 10 μA flows in the zero signal conditions.

11·7 Base resistor method

In this method, a high resistance R_B (several hundred KΩ) is connected between the base and +ve end of supply for *npn* transistor (see Fig. 11·6) and between base and negative end of supply for *pnp* transistor. Here, the required zero signal base current is provided by V_{CC} and it flows through R_B. It is because now base is positive *w.r.t.* emitter *i.e.* base-emitter junction is forward biased. The required value of zero signal base current I_B (and hence $I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor R_B.

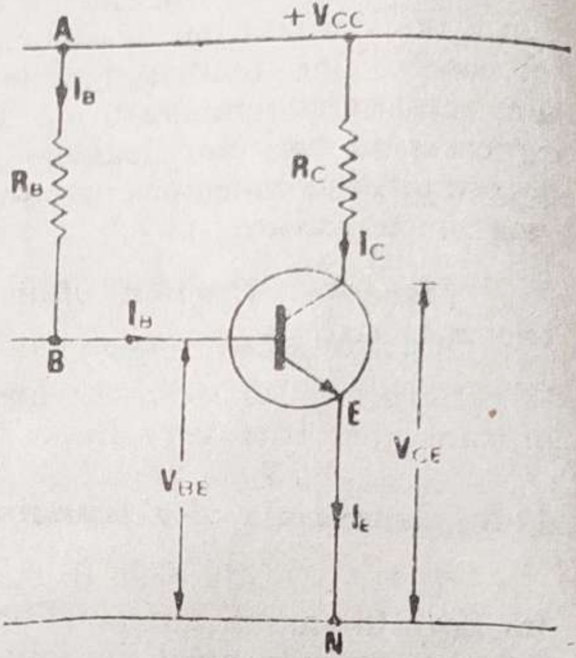

Fig. 11·6

Circuit analysis. It is required to find the value of R_B so that required collector current flows in the zero signal conditions. Let I_C be the required zero signal collector current.

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

Considering the closed circuit *ABENA* and applying Kirchhoff's voltage law, we get,

$$V_{CC} = I_B R_B + V_{BE}$$

or

$$I_B R_B = V_{CC} - V_{BE}$$

$$\therefore \quad R_B = \frac{V_{CC} - V_{BE}}{I_B} \qquad \ldots(i)$$

As V_{CC} and I_B are known and V_{BE} can be seen from the transistor manual, therefore, value of R_B can be readily found from exp. (*i*).

Since V_{BE} is generally quite small as compared to V_{CC}, the former can be neglected with little error. It then follows from exp. (*i*) that :

$$R_B = \frac{V_{CC}}{I_B}$$

It may be noted that V_{CC} is a fixed known quantity and I_B is chosen at some suitable value. Hence, R_B can always be found directly, and for this reason, this method is sometimes called *fixed-bias method*.

Advantages :

(*i*) This biasing circuit is very simple as only one resistance R_B is required.

(*ii*) Biasing conditions can be easily set and the calculations are simple.

(*iii*) There is no loading of the source by the biasing circuit since no resistor is employed across base-emitter junction.

Disadvantages :

(*i*) This method provides poor stabilisation. It is because there is no means to stop a self-increase in collector current due to temperature rise and individual variations. For example, if β increases due to transistor replacement, then I_C also increases by the same factor as I_B is constant.

(*ii*) There are strong chances of thermal runway.

Due to these disadvantages, this method of biasing is rarely employed.

11·8 Biasing with feed back resistor

In this method, one end of R_B is connected to the base and the other end to the collector as shown in Fig. 11·9. Here, the required zero signal base current is determined *not* by V_{CC} but by the collector–base voltage V_{CB}. It is clear that V_{CB} forward biases the base-emitter junction and hence base current I_B flows through R_B. This causes the zero signal collector current to flow in the ciruit.

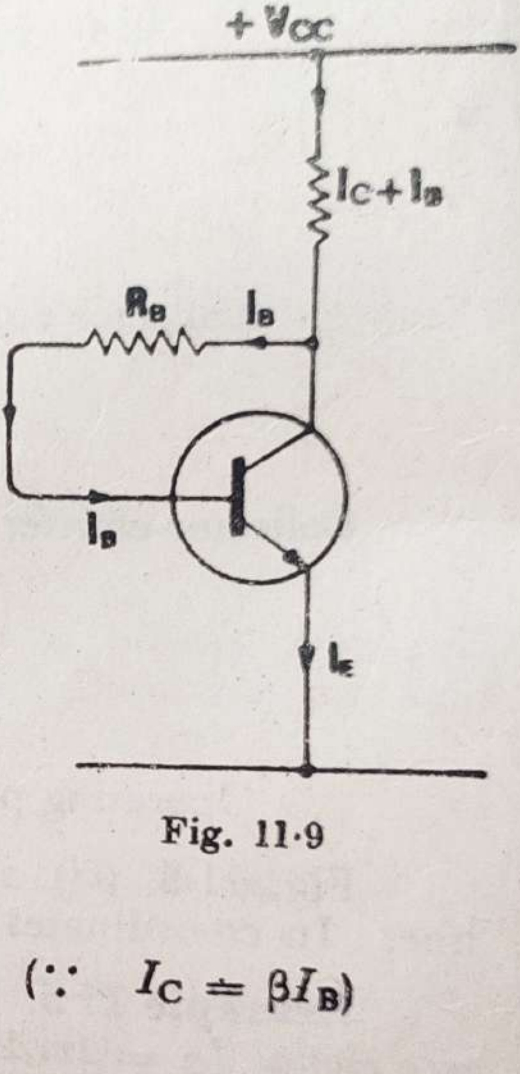

Fig. 11·9

Circuit analysis. The required value of R_B needed to give the zero signal current I_C can be determined as follows. Referring to Fig. 11·9,

$$V_{CC} = {}^*I_C R_C + I_B R_B + V_{BE}$$

or

$$R_B = \frac{V_{CC} - V_{BE} - I_C R_C}{I_B}$$

$$= \frac{V_{CC} - V_{BE} - \beta I_B R_C}{I_B} \qquad (\because \; I_C = \beta I_B)$$

---

*Actually voltage drop across $R_C = (I_B + I_C) R_C$ However, $I_B << I_C$ Therefore, as a reasonable approximation, we can say that drop across $R_C = I_C R_C$.

Advantages :

(*i*) It is a simple method as it requires only one resistance R_B.

(*ii*) This circuit provides some stabilisation of the operating point as discussed below :

Suppose that the temperature increases. This will increase collector leakage current and hence the total collector current. But as soon as the collector current increases, V_{CE} decreases due to greater drop across R_C. The result is that lesser voltage is available across R_B Hence, the base current decreases. The smaller I_B tends to decrease the collector current to original value.

Disadvantages :

(*i*) This circuit does not provide good stabilisation. It is because operating point does change, although to lesser extent, due to temperature variations and other effects.

(*ii*) This circuit provides a negative feed back which reduces the gain of the amplifier as explained hereafter. During the positive half-cycle of the signal, the collector current increases. The increased collector current would result in greater voltage drop across R_C. This will reduce the base current and hence collector current.

12·1 Single stage transistor amplifier

When only one transistor with associated circuitry is used for amplifying a weak signal, the circuit is known as **single stage transistor amplifier**.

A single stage transistor amplifier has one transistor, bias circuit and other auxiliary components. Although a practical amplifier consists of a number of stages, yet such a complex circuit can be conveniently split up into separate single stages. By analysing carefully only a single stage and using this single stage analysis repeatedly; we can effectively analyse the complex circuit. It follows, therefore, that single stage amplifier analysis is of great value in understanding the practical amplifier circuits.

12·2 How transistor amplifies ?

Fig. 12·1 shows a single stage transistor amplifier. When a weak a.c. signal is given to the base of transistor, a small base current (which is a.c.) starts flowing. Due to transistor action, a much larger (β times the base current) a.c. current flows through the collector load R_C. As the value of R_C is quite high (usually 4–10$K\Omega$), therefore, a large voltage appears across R_C. Thus, a weak signal applied in the base circuit appears in amplified form in the collector circuit. It is in this way that a transistor acts as an amplifier.

The action of transistor amplifier can be beautifully explained by referring to Fig. 12·1. Suppose a change of 0·1V in signal voltage produces a change of $2mA$ in the collector current. Obviously, a signal of only $0{\cdot}1V$ applied to the base will give an output voltage $= 2mA \times 5K = 10V$. Thus, the transistor has been able to raise the voltage level of the signal from $0{\cdot}1V$ to $10V$ *i.e.* voltage amplification or stage gain is 100.

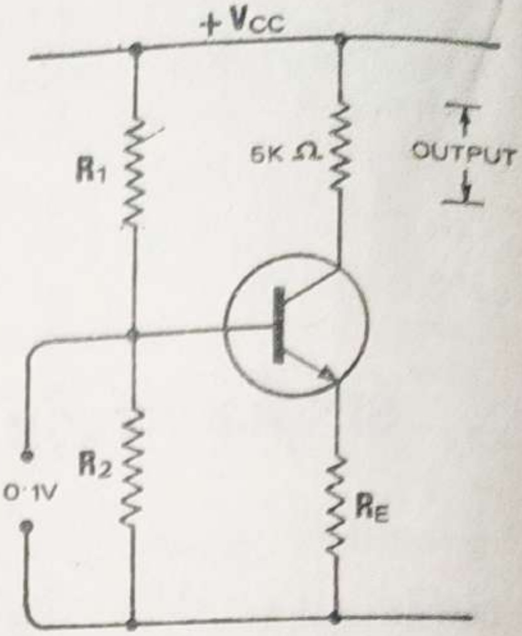

Fig. 12·1

12·3 Graphical demonstration of transistor amplifier

The function of transistor as an amplifier can also be explained graphically. Fig. 12·2 shows the output characteristics of a transistor in CE configuration. Suppose the zero signal base current is $10\mu A$ *i.e.* this is the base current for which the transistor is biased by the biasing network. When an a.c. signal is applied to the base, it makes the base, say positive in the first half-cycle and, negative in the second half-cycle. Therefore, the base and collector currents will increase in the first half-cycle when base-emitter junction is more forward-biased. However, they will decrease in the second half-cycle when the base-emitter junction is less forward biased.

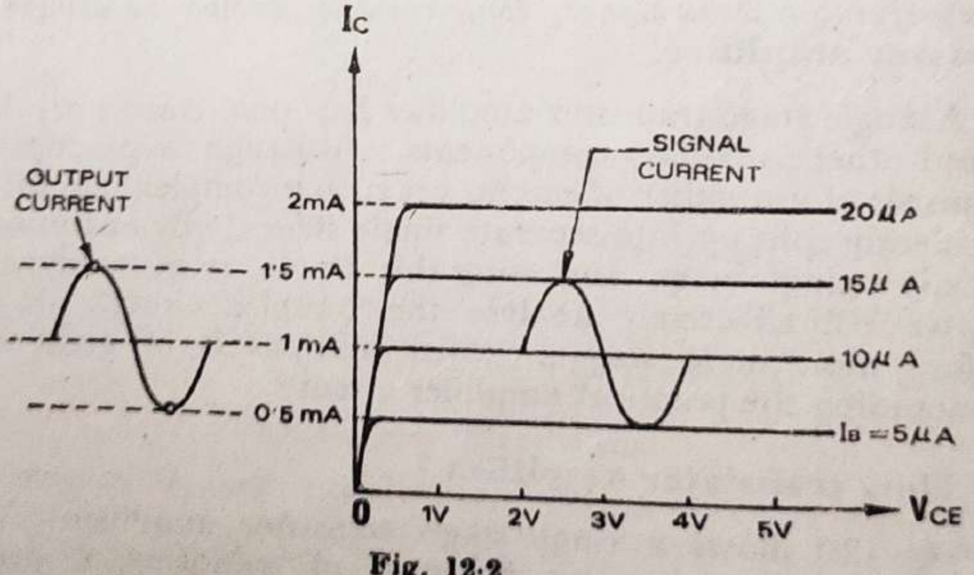

Fig. 12·2

For example, consider a sinusoidal signal which increases or decreases the base current by $5\mu A$ in the two half-cycles of the signal. Referring to Fig. 12·2, it is clear that in the absence of signal, the base current is $10\mu A$ and the collector current is $1mA$.

However, when the signal is applied in the base circuit, the base current and hence collector current change continuously. In the first half-cycle peak of the signal, the base current increases to $15\mu A$ and the corresponding collector current is $1{\cdot}5mA$. In the second half-cycle peak, the base current is reduced to $5\mu A$ and the corresponding collector current is $0{\cdot}5mA$. For other values of the signal, the collector current is in between these values *i.e.* $1{\cdot}5mA$ and $0{\cdot}5mA$.

It is clear from Fig. 12·2 that $10\mu A$ base current variations result in $1mA$ $(1{,}000\mu A)$ collector current variations *i.e.* by a factor of 100. This large change in collector current flows through colle-tor resistance R_C. The result is that output signal is much larg than the input signal. Thus, the transistor has done amplification.

12·4 Practical circuit of transistor amplifier

It is important to note that a transistor can accomplish faithful amplification only if proper associated circuitry is used with it. Fig. 12·3 shows a practical single stage transistor amplifier. The various circuit elements and their functions are described below :

(*i*) *Biasing circuit.* The resistances R_1, R_2 and R_E form the biasing and stabilisation circuit. The biasing circuit must establish a proper operating point otherwise a part of the negative half-cycle of the signal may be cut off in the output.

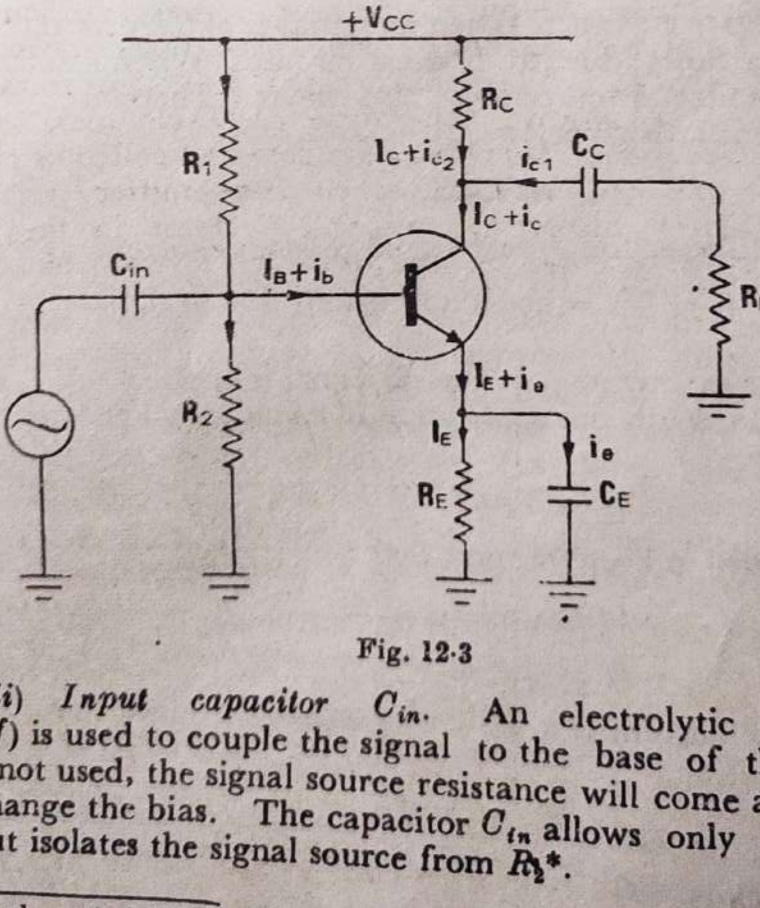

Fig. 12·3

(*ii*) *Input capacitor* C_{in}. An electrolytic capacitor C_{in} $(\simeq 10\mu f)$ is used to couple the signal to the base of the transistor. If it is not used, the signal source resistance will come across R_2 and thus change the bias. The capacitor C_{in} allows only a.c. signal to flow but isolates the signal source from R_2*.

***It may be noted that a capacitor offers infinite reactance to d.c. and blocks it completely whereas it allows a.c. to pass through it.**

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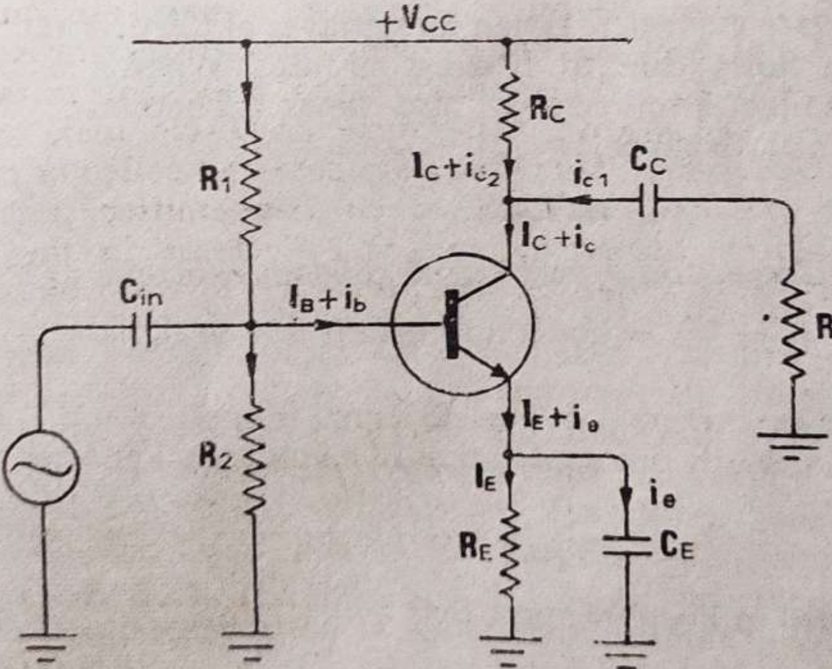

Fig. 12·3

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*It may be noted that a capacitor offers infinite reactance to d.c. and blocks it completely whereas it allows a.c. to pass through it.

(*iii*) *Emitter bypass capacitor* C_E. An emitter bypass capacitor C_E ($\simeq 100 \mu F$) is used in parallel with R_E to provide a low reactance path to the amplified a.c. signal. If it is not used, then amplified a.c. signal flowing through R_E will cause a voltage drop across it, thereby reducing the output voltage.

(*iv*) *Coupling capacitor* C_C. The coupling capacitor C_C ($\simeq 10 \mu F$) couples one stage of amplification to the next stage. If it is not used, the bias conditions of the next stage will be drastically changed due to the shunting effect of R_C. This is because R_C will come in parallel with the upper resistance R_1 of the biasing network of the next stage, thereby altering the biasing conditions of the latter. In short, the coupling capacitor C_C isolates the d.c. of one stage from the next stage, but allows the passage of a.c. signal.

Various circuit currents. It is useful to mention the various currents in the complete amplifier circuit. These are shown in the circuit of Fig. 12·3.

(*i*) *Base current*. When no signal is applied in the base circuit, a d.c. base current I_B flows due to biasing circuit. When a.c. signal is applied, a.c. base current i_b also flows. Therefore, with the application of signal, total base current i_B is given by ;

$$i_B = I_B + i_b$$

(*ii*) *Collector current*. When no signal is applied, a d.c. collector current I_C flows due to biasing circuit. When a.c. signal is applied, a.c. collector current i_c also flows. Therefore, the total collector current i_C is given by ;

$$i_C = I_c + i_c$$

where $I_C = \beta I_B$ = zero signal collector current

$i_c = \beta i_b$ = collector current due to signal.

(*iii*) *Emitter current*. When no signal is applied, a d.c. emitter current I_E flows. With the application of signal, total emitter current i_E is given by ;

$$i_E = I_E + i_e$$

It is useful to keep in mind that :

$$I_E = I_B + I_C$$

$$i_e = i_b + i_c$$

Now base current is usually very small, therefore, as a reasonable approximation,

$$I_E \simeq I_C \text{ and } i_e \simeq i_c$$