Bipolar Junction Transistors (BJTs) as Amplifier

Introduction to Amplifiers

- **The BJT is an an excellent amplifier when biased in the forward-active region.**
- **In this regions, the transistors can provide high voltage, current and power gains.**
- **DC bias is provided to stabilize the operating point in the desired operation region.**
- **The DC Q-point also determines**
  - **The small-signal parameters of the transistor**
  - **The voltage gain, input resistance, and output resistance**
  - **The maximum input and output signal amplitudes**
  - **The overall power consumption of the amplifier**

BJT Transistor as an Amplifier

•The main utility of a transistor is its ability to amplify the week signal.

•Transistor amplification needed passive component:

a) Registers
b) Capacitors
c) Battery

Amplifier: It is an electronics circuit capable to amplify the week signal without distorting the original input.

Cascaded Amplifier: Arrangement of amplifiers such that the output of first stage is connected to the input of the second stage so on and ultimately output appears across the load.

Cascaded Amplifier

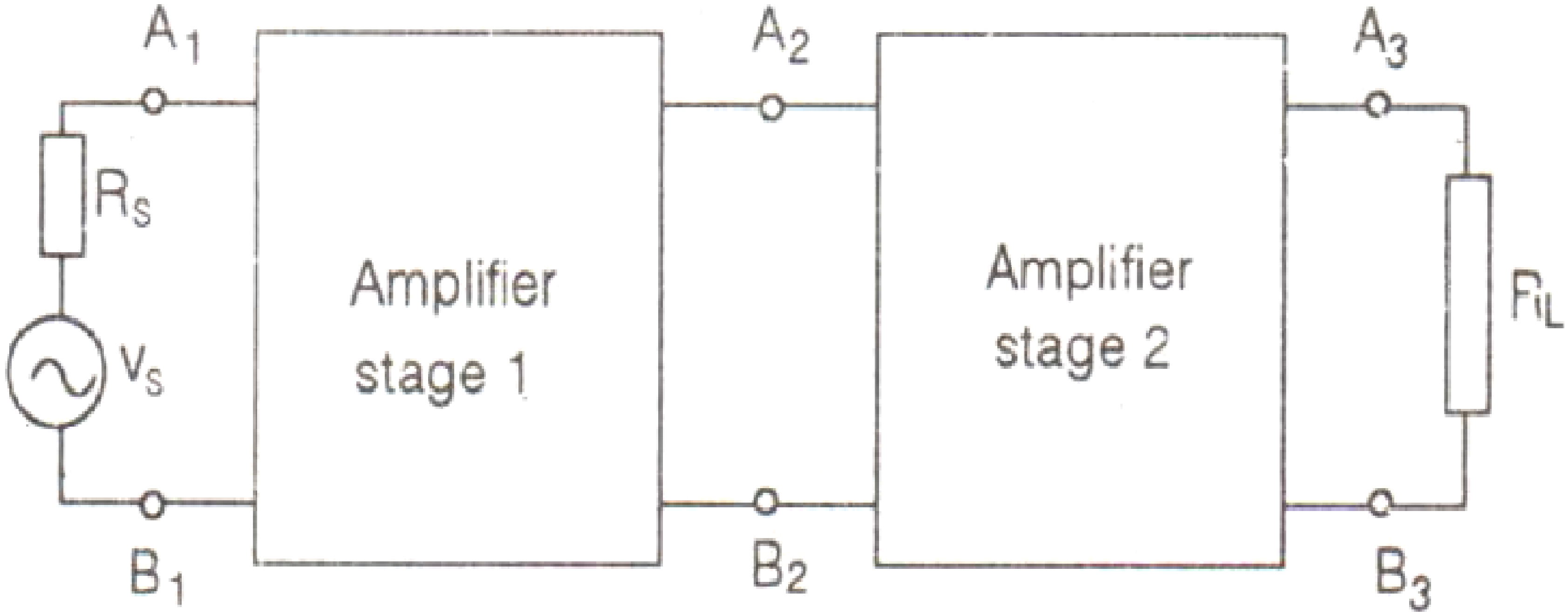


Fig. Two amplifier stages cascadedto increase amplifying action

- A good voltage source, have load resistance much greater than the source resistance.
- The output resistance of first stage should be low.
- Also the input resistance of second stage should be high.
- First stage serve as a voltage source for second stage.
- A good amplifier stage is one which has high input resistance and low output resistance.

Various Transistor Configuration for Amplifiers

A. **Transistor with Common Base (CB): Input resistance low and high out put resistance**

B. **Transistor with Common Emitter (CE): High Input resistance and low out put resistance.**

(Preferred choice for amplifier application, voltage gain, current gain and power gain are greater than CB)

C. **Transistor with Common Collector (CC): Very High Input resistance and very low out put resistance**

(voltage gain is very low, used only specific application)

Common Emitter Amplifier Circuit

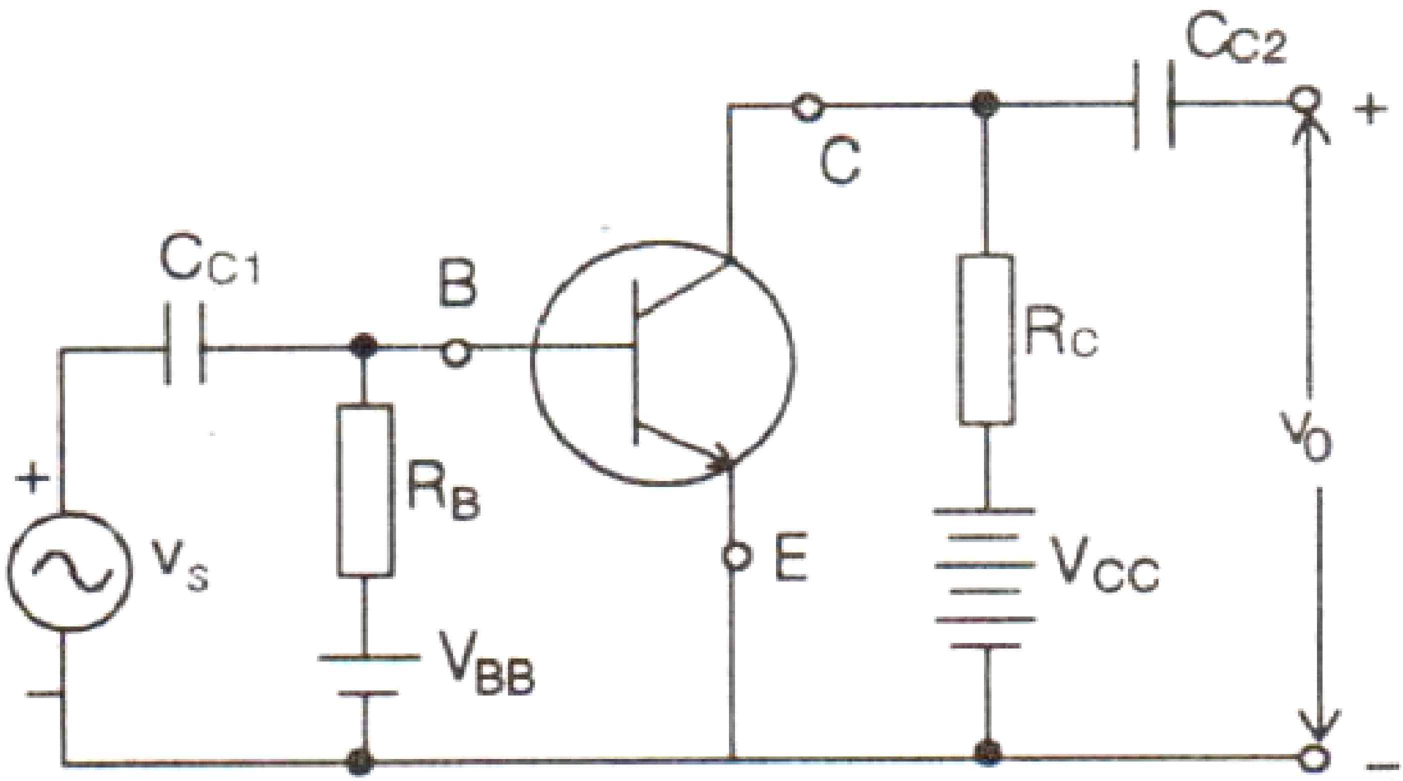


Fig. Basic CE amplifier circuit

DC Load Line

Apply the KVL to the collector circuit:

$$V_{CC} = I_C R_C + V_{CE} \qquad (1)$$

We can rearrange the terms of the above equation and put it as

$$I_C = \left(-\frac{1}{R_C}\right) V_{CE} + \frac{V_{CC}}{R_C} \qquad (2)$$

Eq. of straight line:

$$y = mx + c \qquad (3)$$

Here $m = -\dfrac{1}{R_C}$ (4)

and its intercept on i_c axis is

$$I_C = \frac{V_{CC}}{R_C} \qquad (5)$$

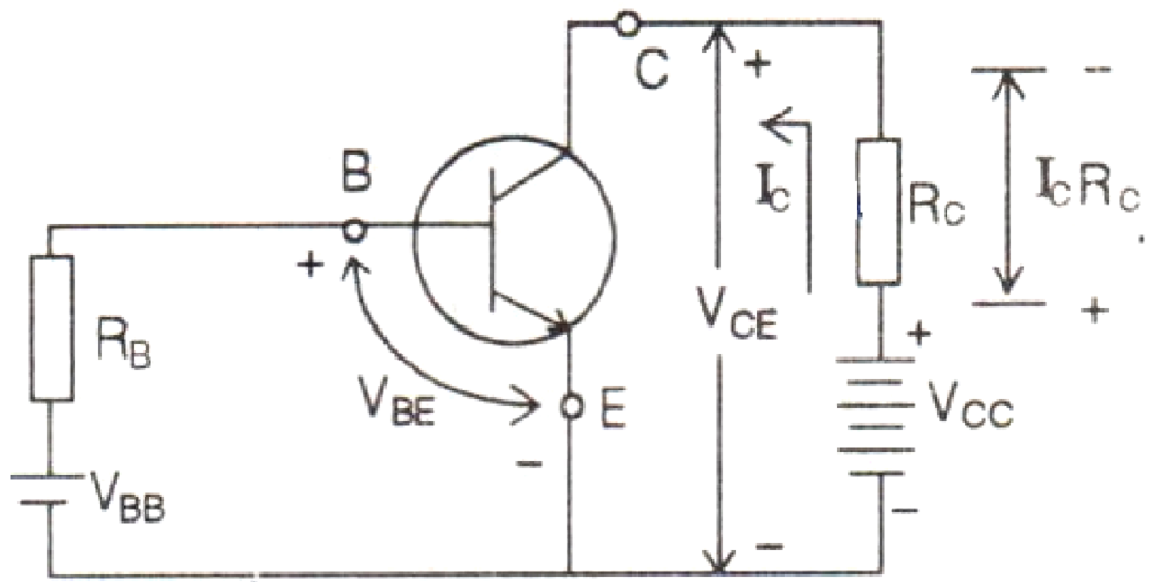


Fig. CE amplifier in quiescent condition

The straight line represented by Eq. 2 is called the dc load line

Find out two point on the Eq. 1 and 2 and take one point on V_{CE} and I_c the join both of them:

Case 1: (i) $V_{CE} = V_{CC}; I_C = 0$

Case 2: (ii) $V_{CE} = 0; \quad I_C = \frac{V_{CC}}{R_C}$

- ***This line between two points is know as dc load line***

- **The slope of this line ~(1/Rc), this is the dc resistance (dc load line) .**

- **The operation of a transistor decided by** ***V_{CE}, I_C, V_{CC}, R_C, R_B, V_{BE} and V_{BB}***

- **dc point on load line also decided by I_B and V_{BE}, V_{BB}, R_B**

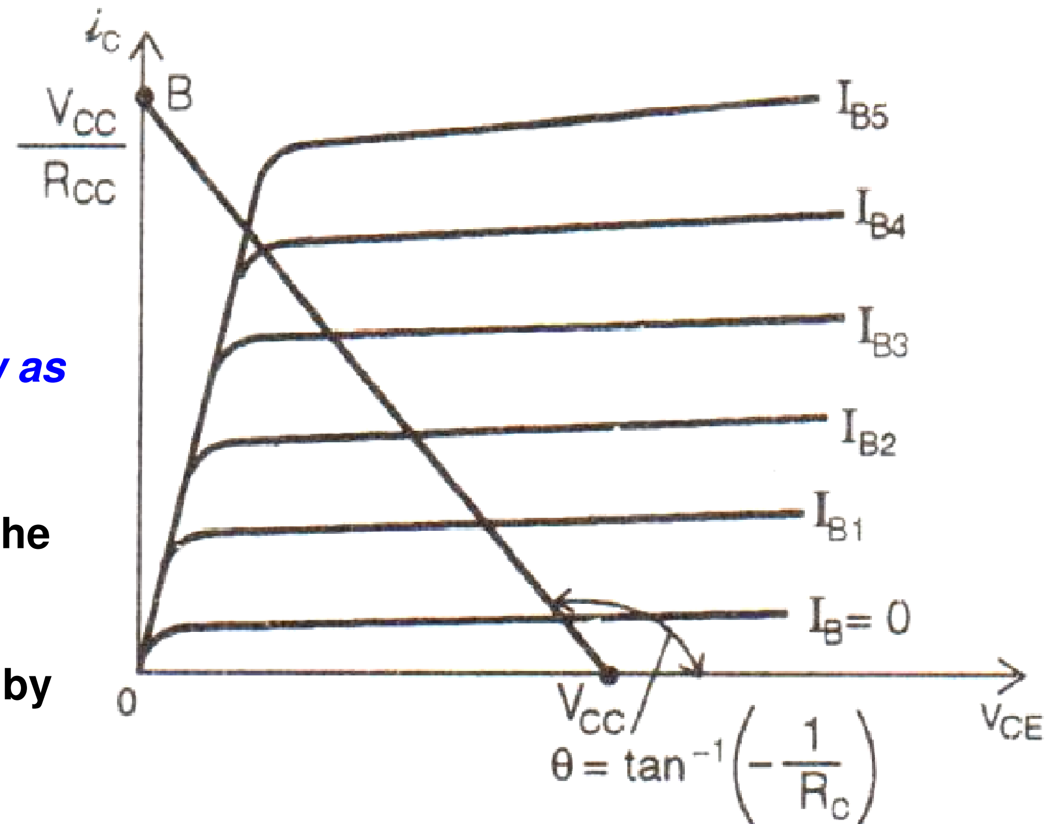


Fig. Plotting of dc load line on collector characteristics

Apply the Kirchhoff's voltage law to base circuit of transistor:

$$V_{BB} = I_B R_B + V_{BE} \tag{6}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \cong \frac{V_{BB}}{R_B} \tag{7}$$

Amplifier Analysis Using DC Load Line

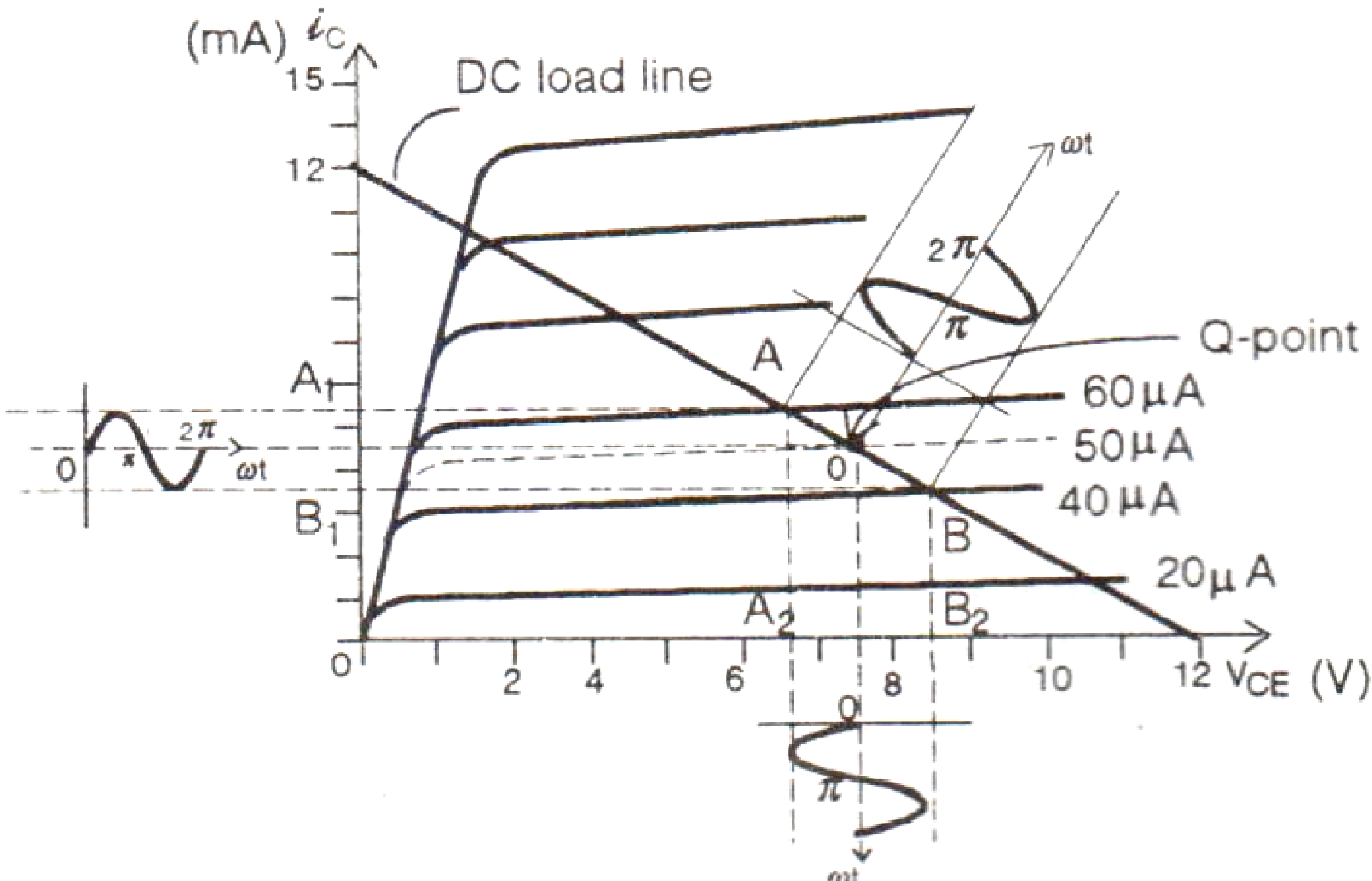


Fig. Variation in base current produces variation in collector current and voltage in a CE amplifier

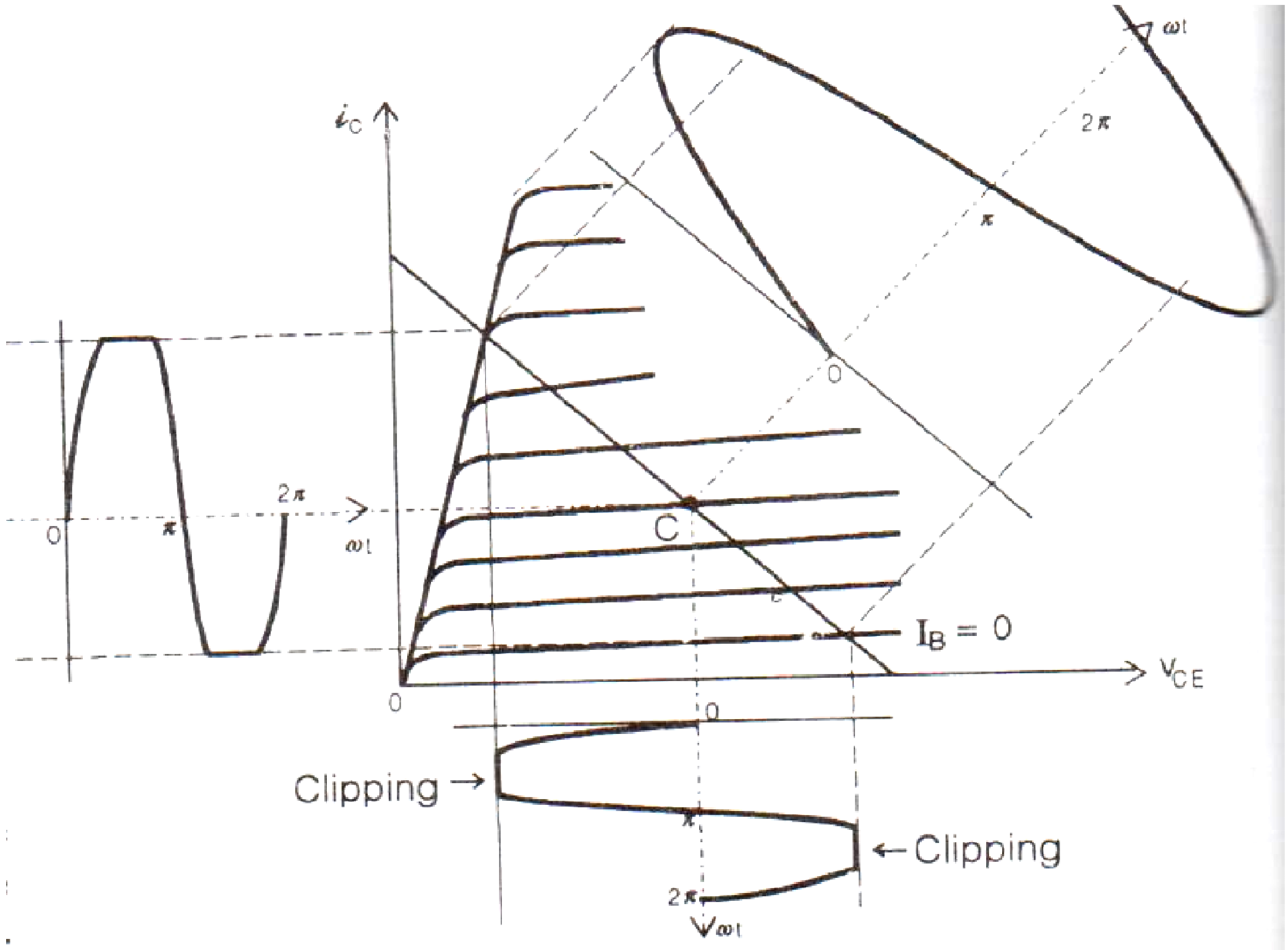
Current gain, voltage gain and the power gain of amplifier

(i) Current gain, $A_1 = \dfrac{\Delta i_C}{\Delta i_B}$

(ii) Voltage gain, $A_v = \dfrac{\Delta v_{CE}}{\Delta v_{BE}}$

(iii) Power gain $= \dfrac{\text{output ac power}}{\text{input ac power}} = \dfrac{I_c V_{ce}}{I_b V_{be}}$

Transistor Biasing and Stabilization of Operating Point



Stability Factor (S)

The extent to which the collector current I_C is stablished with varying I_{CO} is measured by stability factor S. It is defined as the rate of change of collector current I_C with respect to the collector base leakage current I_{CO}, keeping both the current I_B and the current gain β constant.

$$S \approx \frac{S\, I_C}{S\, I_{CO}} \simeq \frac{dI_C}{dI_{CO}} \approx \frac{\Delta I_C}{\Delta I_{CO}}, \beta \text{ and } I_B \text{ constant}$$

The collector current for a CE amplifier is given by

$$I_C = \beta I_B + (\beta + 1) I_{CO}$$

Differentiating the above equation with respect to I_C, we get.

$$1 = \beta \frac{dI_B}{dI_C} + (B + 1)\frac{dI_{CO}}{dI_C}$$

Therefore,

$$1 - \frac{\beta\, dI_B}{dI_C} = \frac{(1+\beta)}{S}$$

$$\boxed{\mathbf{S} = \frac{1 + \beta}{1 - \beta\left(\frac{dI_B}{dI_C}\right)}}$$

Cont….

From this equation, it is clear that this factor S should be as small as possible to have better thermal stability.

Stability factor S' and S'' → The stability factor S' is defined as the rate of change of I_C with V_{BE}, keeping I_{CO} and β constant.

$$S' = \frac{S\,I_C}{S\,V_{BE}} \approx \frac{I_C}{\Delta V_{BE}}$$

The stability factor S'' is defined as the rate of change of I_C with respect to β, keeping I_{CO} and V_{BE} constant.

$$S'' = \frac{S\,I_C}{S_\beta} \approx \frac{\Delta I_C}{\Delta \beta},$$

Requirements of a Biasing Circuit

(*i*) Establish the operating point in the centre of the active region of the characteristics, so that on applying the input signal the instantaneous operating point does not move either to the saturation region or to the cut-off region, even at the extreme values of the input signal.

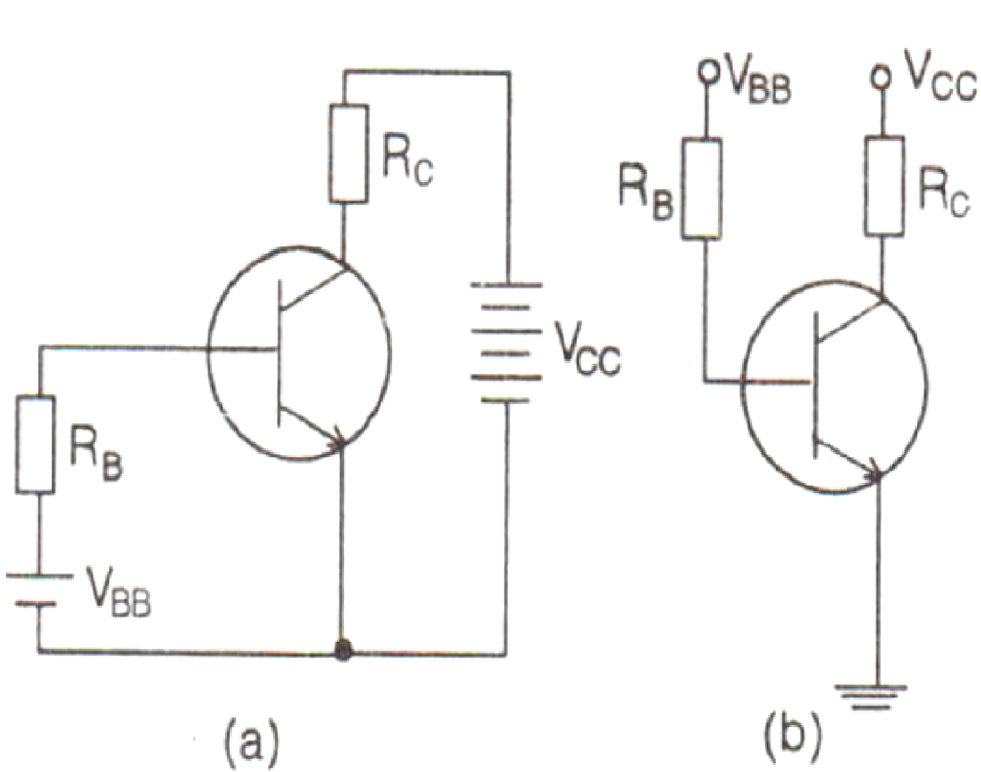
(*ii*) Stabilize the collector current against temperature variations.

(*iii*) Make the operating point independent of the transistor parameters so that it does not shift when the transistor is replaced by another of the same type in the circuit.

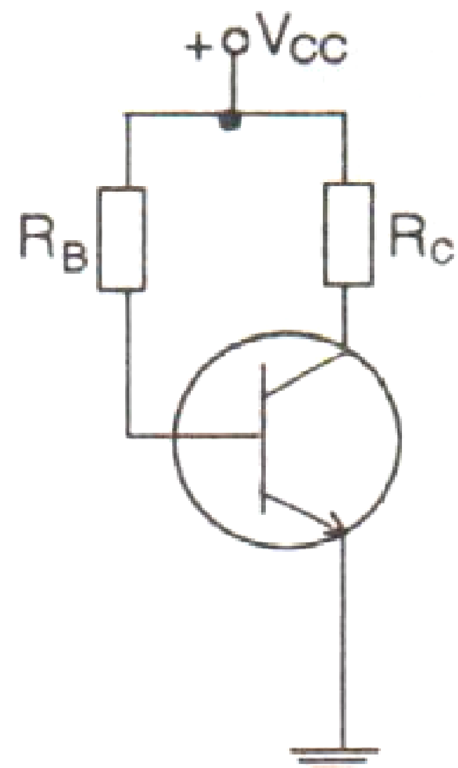
Different Biasing Circuits and Fixed Bias Circuits

•The requirement of I_B is low and similarly Ic also low, thus the resistance added base and collector terminals.

•As per requirement the positive terminal of batteries should connect with the collector and base resistor.



Fixed Bias Circuits (a) & (b)



Fixed Bias Circuit Using Single Battery

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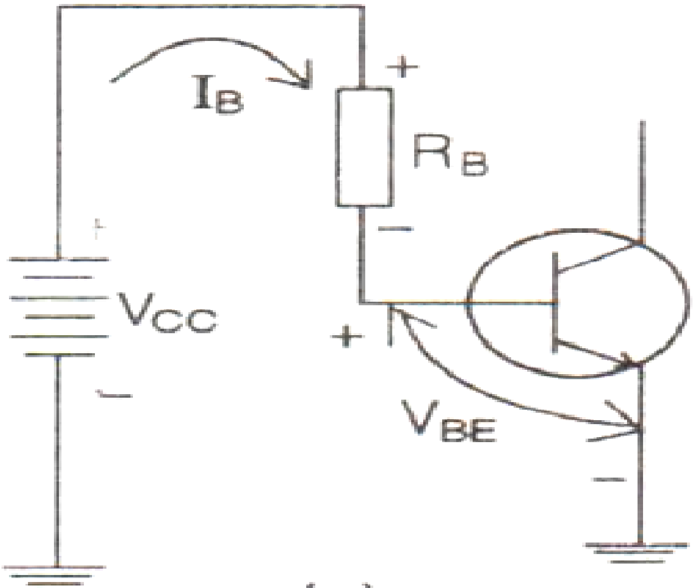
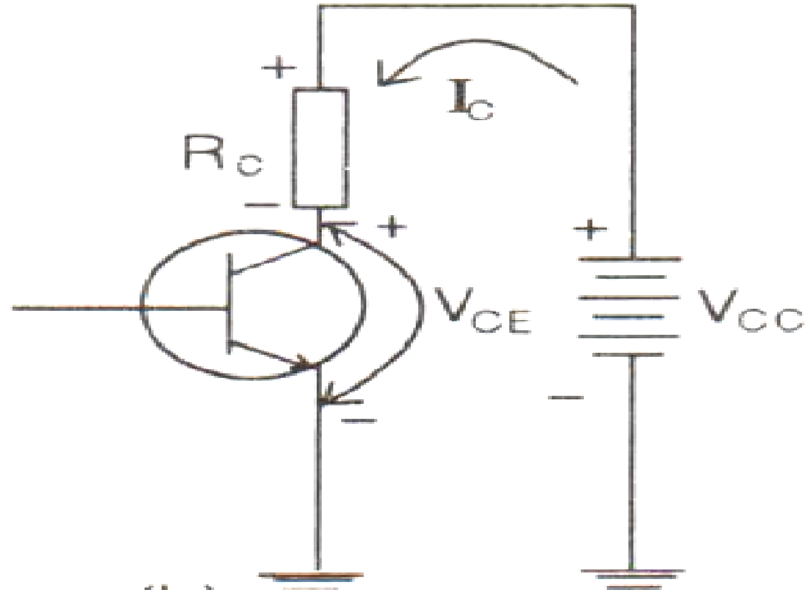


(a)
Input of FB



(b)
Output of FB

For Input Loop:-

Apply KVL for input $V_{CC} = I_B R_B + V_{BE}$ (1)

from which the base current is given as

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \qquad (2)$$

Base Current $I_B \cong \frac{V_{CC}}{R_B \; R_E}$ (3)

For Output loop:-

The collector current Ic:

$$I_C = \beta I_B + I_{CEO} \qquad (4)$$

By approximation collector current

$$I_C = \beta I_B \qquad (6)$$

Collector current

$$I_C \leqslant \frac{V_{CC}}{R_C} \qquad (7)$$

Apply KVL to output loop

$$V_{CC} = I_C R_C + V_{CE} \qquad (5)$$

Common emitter voltage (8)

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

$$I_{C(\text{sat})} = \frac{V_{CC}}{R_C} \qquad (9)$$

Stability factor for fixed bias method

From the analysis of input circuit we have

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

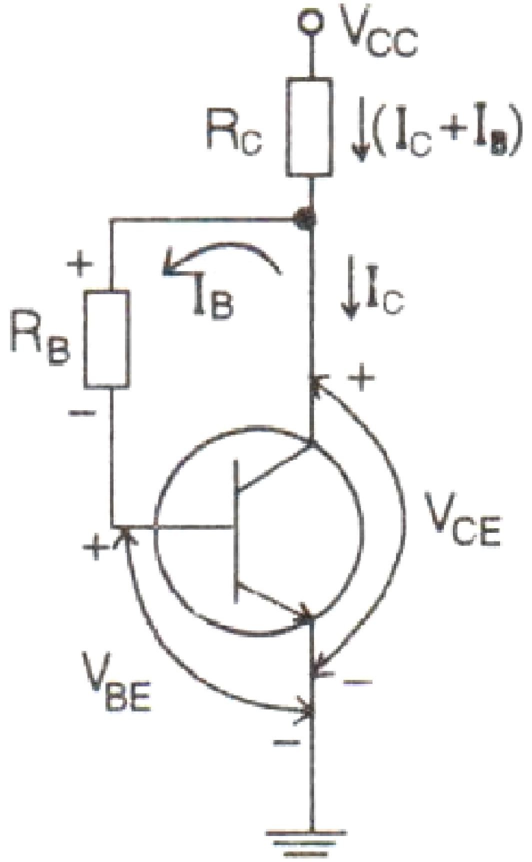
$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

Since this equation is independent of I_C $\therefore$ $\dfrac{d\,I_B}{d\,I_C} = 0$

$$\text{Stability factor } S = \frac{1+\beta}{1-\beta\dfrac{d\,I_\beta}{d\,I_C}}$$

$\therefore$ $\boldsymbol{S = 1 + \beta}$, which is very large and hence this circuit shows poor stability.

Collector to Base Bias Circuit/Voltage Feed Back Bias Circuits



$$V_{CC} = R_C(I_C + I_B) + I_B R_B + V_{BE} \quad (1)$$

or

$$V_{CC} = R_C I_C + (R_C + R_B) I_B + V_{BE} \quad (2)$$

or

$$I_B = \frac{(V_{CC} - I_C R_C) - V_{BE}}{R_C + R_B} \quad (3)$$

From the output section of the circuit, we have

$$V_{CE} = V_{CC} - (I_C + I_B) R_C \quad (4)$$

or

$$V_{CE} \simeq V_{CC} - I_C R_C \quad (\text{since } I_B < I_C) \quad (5)$$

Substituting Eq. (5) in Eq. (3), we get

$$I_B = \frac{V_{CE} - V_{BE}}{R_C + R_B} \quad (6)$$

For determining the operating point, we substitute βI_B for I_C in Eq.

$$V_{CC} = R_C \beta I_B + (R_C + R_B) I_B + V_{BE} \quad (7)$$

or

$$V_{CC} = V_{BE} + [R_B + (\beta + 1) R_C] I_B$$

or

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_C} = \frac{V_{CC}}{R_B + \beta R_C} \quad (8)$$

Since $I_C = \beta I_B$, we can determine the collector current.

Now, from output circuit

$$V_{CC} = (I_B + I_C) R_C + V_{CE}$$

$\therefore$

$$V_{CE} = V_{CC} - I_C R_C \quad \{\because I_B \text{ is very small}\} \quad (9)$$

Stability factor for collector to base bias method.

From the analysis of input circuit, we have

$$V_{CC} = (I_C + I_B) R_C + I_B R_B + V_{BE}$$

$$V_{CC} = I_C R_C + I_B (R_C + R_B) + V_{BE} \quad (10)$$

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

$\therefore$

$$\frac{d I_B}{d I_C} = \frac{- R_C}{R_C + R_B}$$

We know,

$$\mathbf{S} = \frac{1 + \beta}{1 - \beta \frac{d I_B}{d I_C}} \quad (11)$$

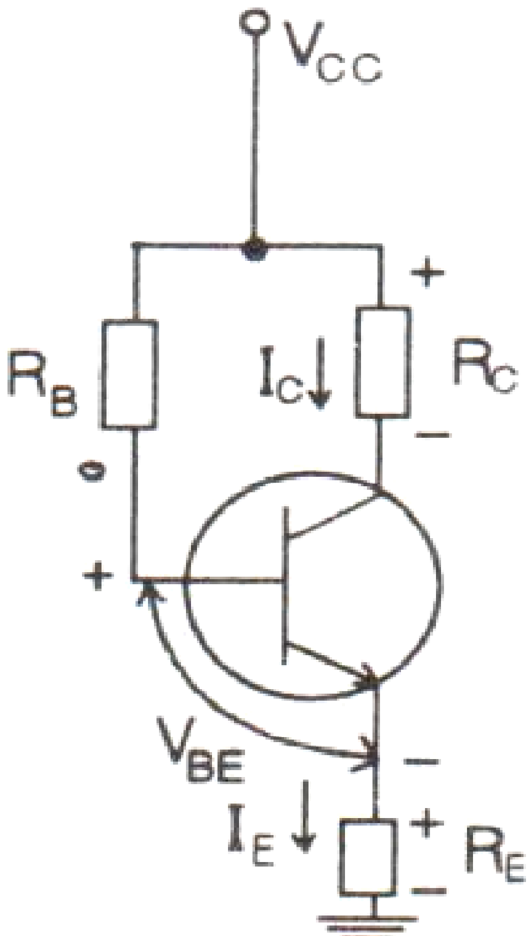
$\therefore$

$$\mathbf{S} = \frac{1 + \beta}{1 + \beta \left(\frac{R_C}{R_C + R_B} \right)} \quad (12)$$

This value is smaller than fixed bias, hence this circuit is better than fixed bias

Biasing of Circuit with Emitter Resistor

Fixed bias circuit can modify to emitter resistor:



The loop equation for the input circuit:

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

$$I_B = \frac{(V_{CC} - I_E R_E - V_{BE})}{R_B} \qquad (1)$$

$$I_B \simeq \frac{(V_{CC} - I_E R_E)}{R_B} \quad \text{(since } V_{BE} \text{ is very small)} \qquad (2)$$

In case transistor replaced by another same type then also this circuit provides the stabilization of Q point:

To determine the Q point :- $V_{CC} = I_B R_B + V_{BE} + (\beta + 1) I_B R_E \quad (\text{since } I_E = (\beta + 1) I_B)$ (3)

or $$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1) R_E} \simeq \frac{V_{CC}}{R_B + \beta R_E} \tag{4}$$

We can calculate the collector current easily, since

$$I_C = \beta I_B = \frac{\beta V_{CC}}{R_B + \beta R_E} = \frac{V_{CC}}{R_E + (R_B/\beta)} \tag{5}$$

To find V_{CE}, we write the loop equation for the output section,

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E \tag{6}$$

$$V_{CE} = V_{CC} - (R_C + R_E) I_C \qquad (\text{since } I_C \simeq I_E) \tag{7}$$

The R_E present outside as well inside the circuit and feedback occurs through the resistor and feedback voltage proportional to emitter current and circuit is know as current feedback biasing.