



Analog Electronics Mod 1

Analog Electronics (APJ Abdul Kalam Technological University)



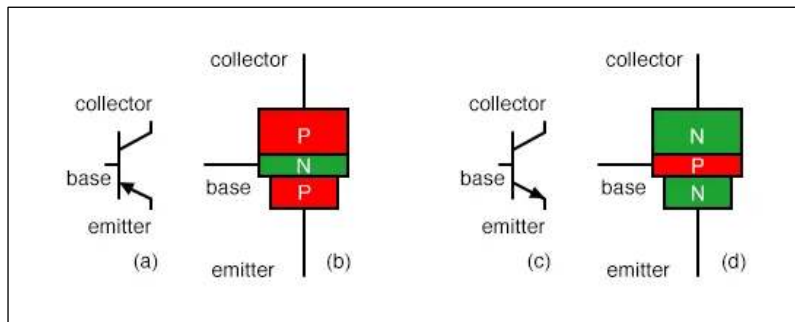
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Syllabus

Bipolar Junction Transistors: Review of BJT characteristics- Operating point of BJT -Factors affecting stability of Q point. DC Biasing-Biasing circuits: fixed bias, collector to base bias, voltage divider bias, role of emitter resistance in bias stabilisation. Stability factor (Derivation of stability factors for Voltage Divider Biasing only). Numerical problems. Bias compensation using diode and thermistor. **BJT Model- h-parameter model of BJT in CE configuration. Small signal low frequency ac equivalent circuit of CE amplifier -Role of coupling capacitors and emitter bypass capacitor. Calculation of amplifier gains and impedances using h parameter equivalent circuit.**

Bipolar Junction Transistors:

Transfer + Resistor → Transistor

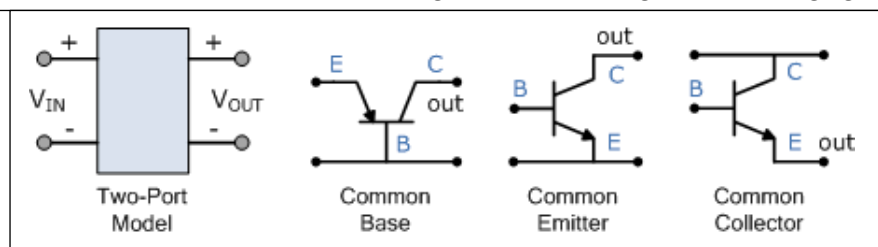


A Bipolar Junction Transistor (also known as a BJT or BJT Transistor) is a three-terminal semiconductor device consisting of two p-n junctions which are able to amplify or magnify a signal. **It is a current controlled device.**

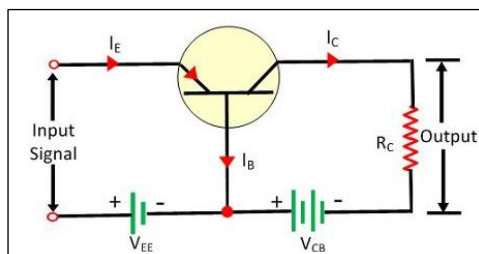
Review of BJT characteristics

There are three different configurations in which the BJT can function - common base, common emitter, and common collector.

- Common Base (CB) Configuration: no current gain but voltage gain
- Common Collector (CC) Configuration: current gain but no voltage gain
- Common Emitter (CE) Configuration: current gain and voltage gain



Common Base Connection (CB Configuration)



Current Amplification factor (α)

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

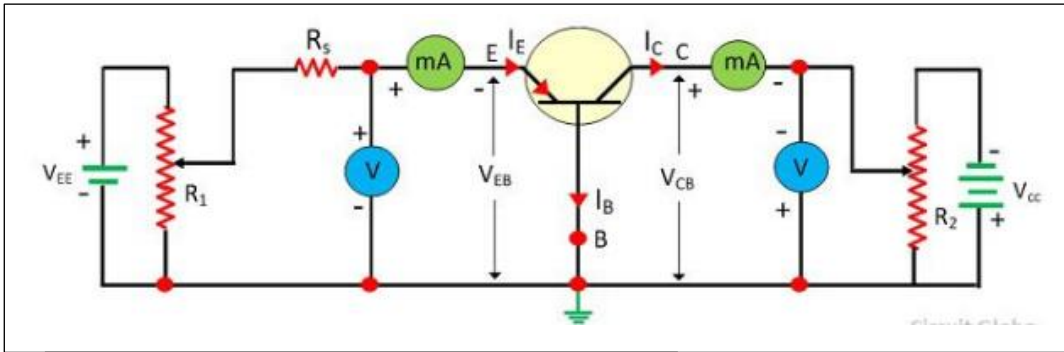
The practical value of the amplification factor varies from 0.95 to 0.99 in the commercial transistor.

$$\begin{aligned} I_E &= I_C + I_B \\ \Delta I_E &= \Delta I_C + \Delta I_B \\ \frac{\Delta I_C}{\Delta I_E} &= \frac{\Delta I_C}{\Delta I_E} + \frac{\Delta I_B}{\Delta I_E} \\ 1 &= \alpha + \frac{\Delta I_B}{\Delta I_E} \\ \alpha &= 1 - \frac{\Delta I_B}{\Delta I_E} \end{aligned}$$

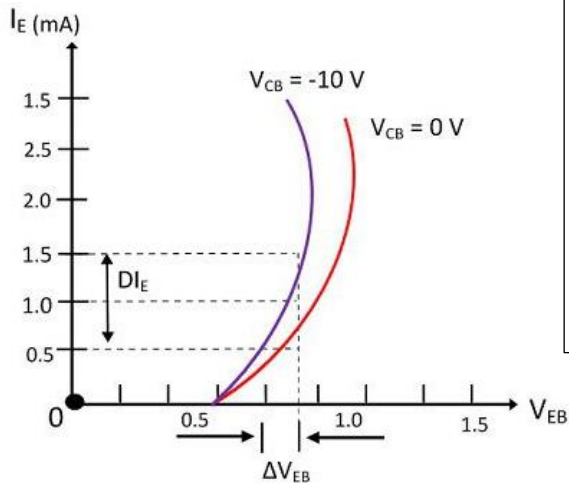
$$I_C = \alpha I_E + I_{leakage}$$

- The large percentage of emitter current that reaches the collector terminal, i.e., αI_E .
- The leakage current $I_{leakage}$. The minority charge carrier is because of the flow of minority charge carriers across the collector-base junction as the junction is heavily reversed. Its value is much smaller than αI_E .

Characteristics of Common Base (CB) Configuration



Input Characteristic

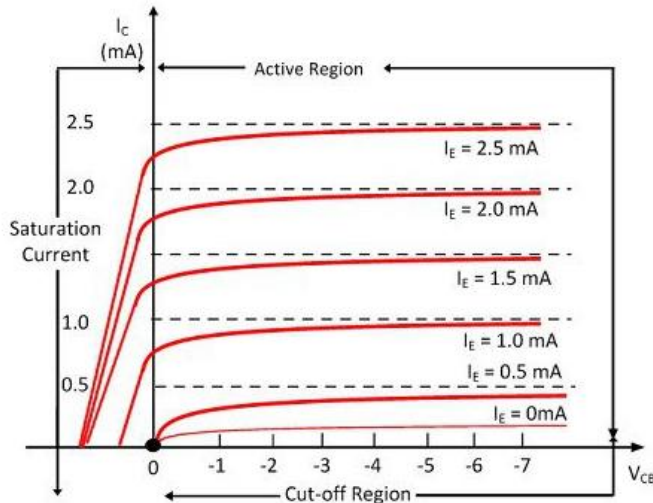


The input resistance is expressed by the formula

$$r_i = \frac{\Delta V_{EB}}{\Delta I_E}$$

The value of input resistance is very low, and their value may vary from a few ohms to 10 ohms.

Output Characteristic Curve



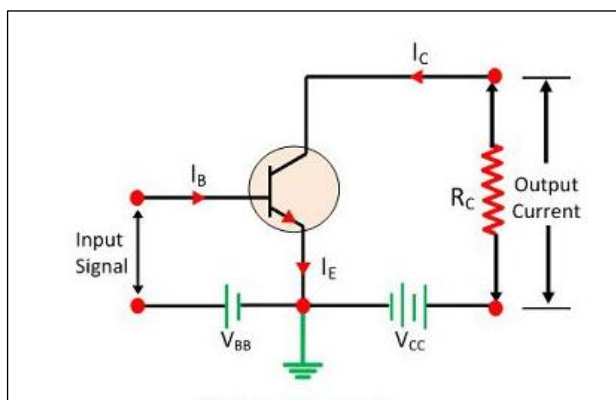
- 0.1 to 1.0 μA for silicon transistors and 2 to 5 μA for germanium transistors.

Output Resistance

The output resistance is very high, of the order of several kilometres.

$$r_o = \frac{\Delta V_{CB}}{\Delta I_C}$$

Common Emitter Connection (or CE Configuration)



Base Current Amplification Factor (β)

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

$$I_E = I_C + I_B$$

$$\Delta I_E = \Delta I_C + \Delta I_B$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C}$$

$$\beta = \frac{\frac{\Delta I_C}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{\alpha}{1 - \alpha}$$

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

$$I_E = I_C + I_B \dots \dots (1)$$

$$I_C = \alpha I_E + I_{CBO} \dots \dots (2)$$

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

$$I_C(1 - \alpha) = \alpha(I_B) + I_{CBO}$$

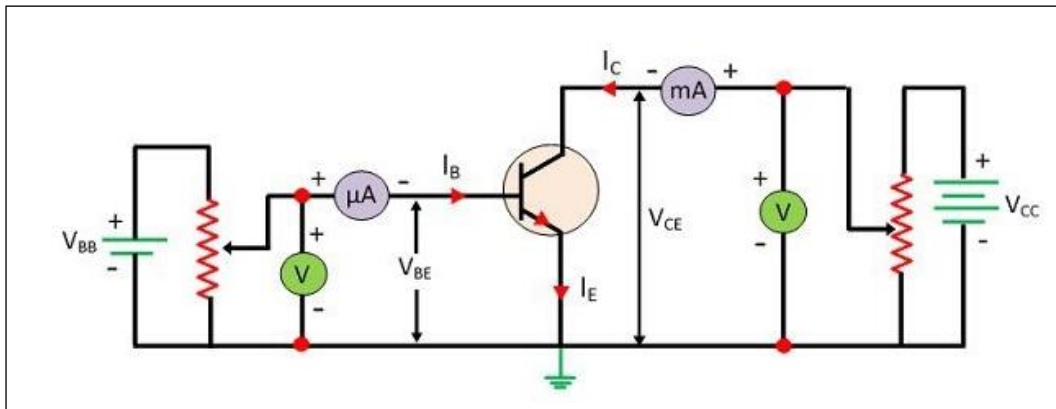
$$I_C = \frac{\alpha}{(1 - \alpha)}(I_B) + \frac{1}{(1 - \alpha)}I_{CBO} \dots \dots (3)$$

$$I_C = \frac{\alpha}{1 - \alpha}I_B + I_{CEO} = \beta I_B + I_{CEO}$$

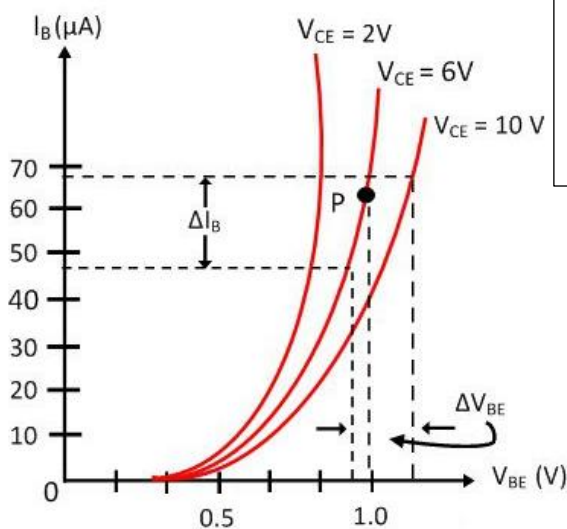
$$I_C = \beta I_B + I_{CEO}$$

If the base current is open (i.e., $I_B = 0$). The collector current is current to the emitter, and this current is abbreviated as I_{CEO} that means collector-emitter current with the base open.

Characteristics of Common emitter (CE) Configuration



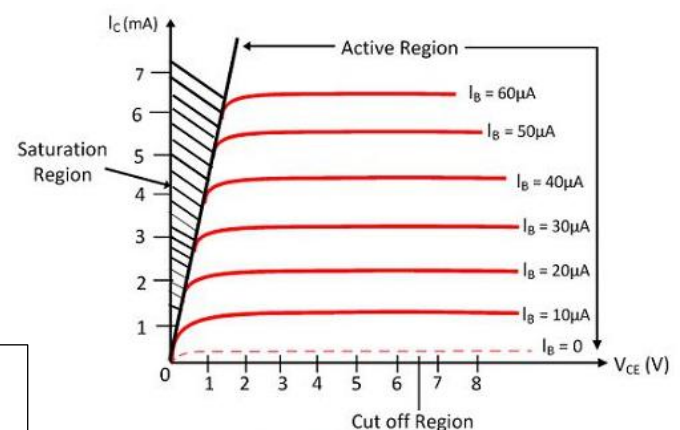
Input Characteristic



Input Resistance:

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

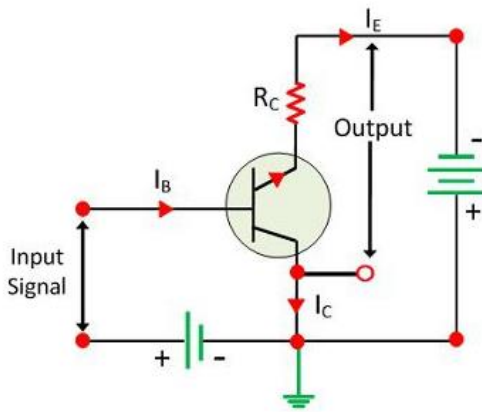
Output Characteristic Curve



$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B$$

Output Resistance

Common Collector Connection (or CC Configuration)



Current Amplifier Factor (γ)

Relation Between γ and α

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

$$\alpha = \frac{\Delta I_E}{\Delta I_B}$$

$$I_E = I_C + I_B$$

$$\Delta I_E = \Delta I_C + \Delta I_B$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

$$\gamma = \frac{\Delta I_E / \Delta I_E}{\Delta I_E / \Delta I_E - \Delta I_C / \Delta I_E}$$

$$\gamma = \frac{1}{1 - \Delta I_C / \Delta I_E}$$

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

Collector Current

$$I_C = \alpha I_E + I_{CBO}$$

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

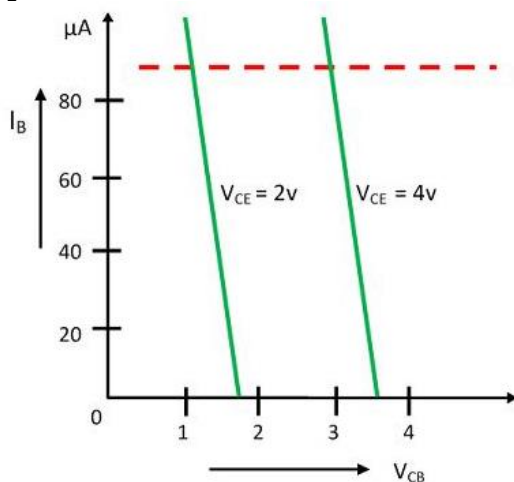
$$I_E(1 - \alpha) = I_B + I_{CBO}$$

$$I_E = I_B \left(\frac{1}{1 - \alpha} \right) + I_{CBO} \left(\frac{1}{1 - \alpha} \right)$$

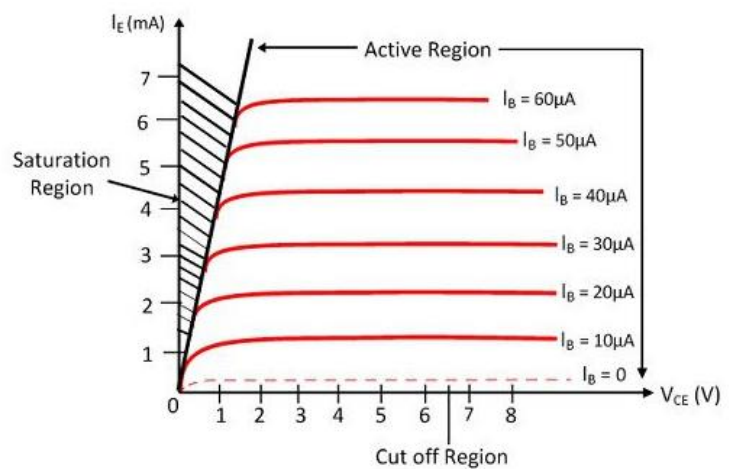
$$= (\beta + 1)I_B + (\beta + 1)I_{CBO}$$

Characteristics of Common emitter (CC) Configuration

Input Characteristic



Output Characteristic Curve



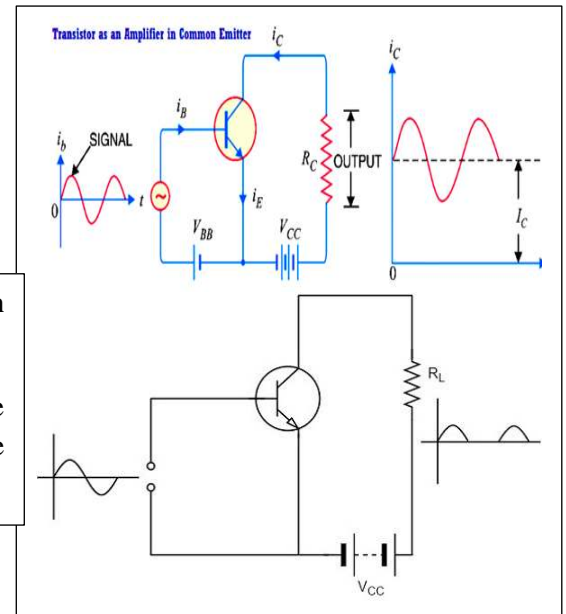
BJT-Operating point & stability

Key factors for Faithful Amplification

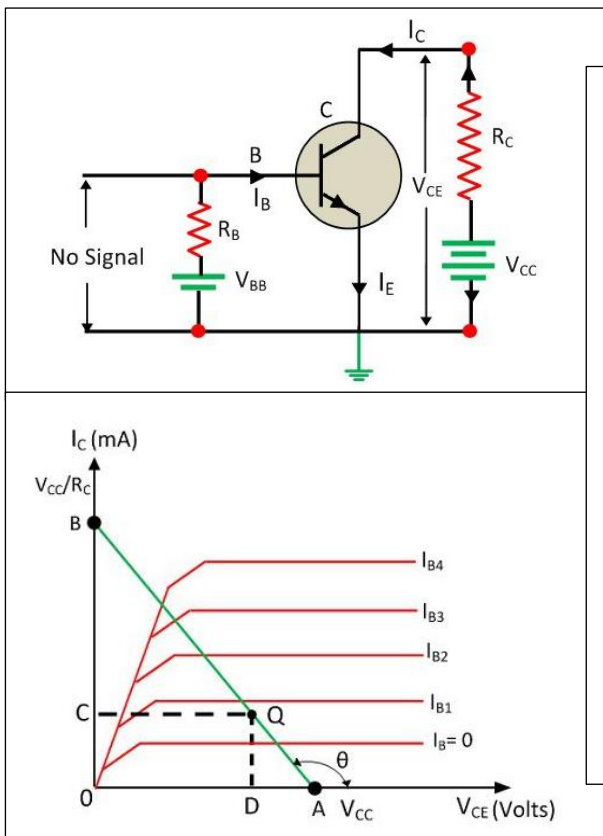
- Proper zero signal collector current
- Minimum proper base-emitter voltage (V_{BE}) at any instant.
- Minimum proper collector-emitter voltage (V_{CE}) at any instant.

The minimum base to emitter voltage V_{BE} should be greater than the cut-in voltage for the junction to be forward biased.

To achieve a faithful amplification, the collector emitter voltage V_{CE} should not fall below the cut-in voltage, which is called Knee Voltage



DC Load Line



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

$$V_{CE} = V_{CC} - I_C R_C \dots \text{equ}(1)$$

The collector-emitter voltage V_{CE} is maximum when the collector current $I_C = 0$

$$V_{CE} = V_{CC} - 0 \times R_C$$

$$V_{CE} = V_{CC}$$

The collector current I_C becomes maximum when the collector-emitter voltage $V_{CE} = 0$

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

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

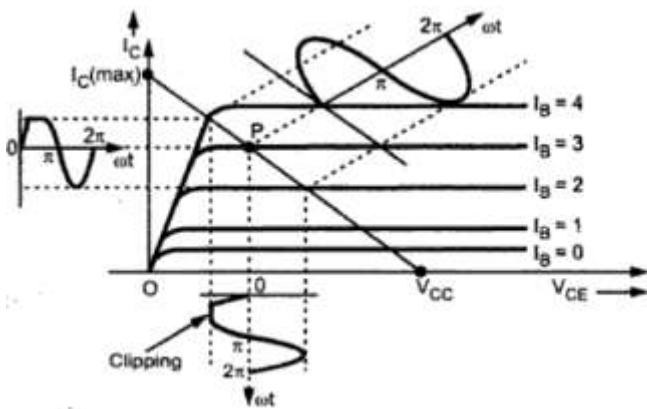
By adding the points A and B, the DC load line is drawn

Operating Point in Transistor

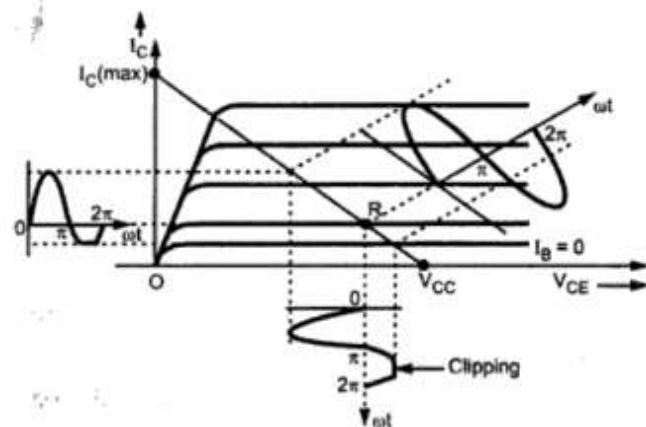
The point which is obtained from the values of the I_C (collector current) or V_{CE} (collector-emitter voltage) when no signal is given to the input is known as the operating point or Q-point in a transistor.

Criteria for fixing the operating point

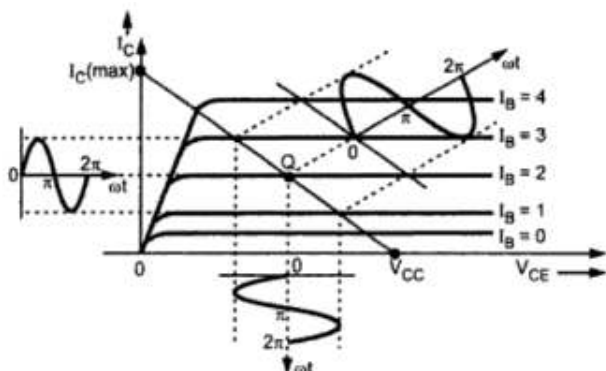
The operating point can be selected at three different positions on the dc load line: near saturation region, near cut-off region or at the centre i.e, in the active region.



Operating point near saturation region gives clipping at the positive peaks



Operating point near cut-off region gives clipping at the negative peaks



Operating point at the centre of active region is most suitable

Factors affecting operating point

The operating point shifts due to change in temperature.

- As temperature increases, the values of I_{CE} , β , V_{BE} gets affected.
- I_{CBO} gets doubled (for every 10° rise)
- V_{BE} decreases by 2.5mV (for every 10° rise)

Stabilization

The process of making the operating point independent of temperature changes or variations in transistor parameters is known as Stabilization.

Once the stabilization is achieved, the values of I_C and V_{CE} become independent of temperature variations or replacement of transistors. A good biasing circuit helps in the stabilization of operating points.

Need for Stabilization

Stabilization of the operating point has to be achieved due to the following reasons.

1. Temperature dependence of I_C
2. Individual variations
3. Thermal runaway

1. The collector leakage current I_{CBO} is greatly influenced by temperature variations.

$$I_C = \beta I_B + I_{CEO}$$

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

2. As the value of β and the value of V_{BE} are not the same for every transistor, whenever a transistor is replaced, the operating point tends to change.
3. The flow of collector current and also the collector leakage current causes heat dissipation. The self-destruction of such an unstabilized transistor is known as Thermal run away.

Stability Factor

The I_C should be kept constant in spite of variations of I_{CBO} or I_{CO} . The extent to which a biasing circuit is successful in maintaining this is measured by Stability factor. It is denoted by S .

By definition, the rate of change of collector current I_C with respect to the collector leakage current I_{CO} at constant β and I_B is called Stability factor.

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

Differentiating above expression with respect to I_C ,

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

$$\text{Since } \frac{dI_{CO}}{dI_C} = \frac{1}{S} \quad S = \frac{\beta + 1}{1 - \beta \left(\frac{dI_B}{dI_C} \right)}$$

Hence the stability factor S depends on β , I_B and I_{CO} .

$$S = \frac{dI_C}{dI_{CO}} \text{ at constant } I_B \text{ and } \beta$$

$S=1$ is the ideal value.

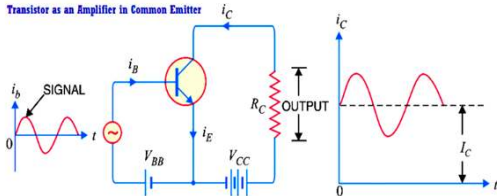
S. No.	Characteristics	CB Configuration	CE Configuration	CC Configuration
1	Input resistance	Very low (40Ω)	Low (50Ω)	Very high ($750k\Omega$)
2	Output resistance	Very high ($1M\Omega$)	High ($10k\Omega$)	Low (50Ω)
3	Current gain	Less than unity	High (100)	High (100)
4	Voltage gain	Small (150)	High (500)	Less than unity
5	Leakage current	Very small	Very large	Very large
6	Applications	For high frequency application	For audio frequency application	For impedance matching
7	Phase shift between input and output	0°	180°	0°

BJT-Biasing

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 circuit which provides transistor biasing is called the Biasing Circuit.

The biasing in transistor circuits is done by using two DC sources V_{BB} and V_{CC} .

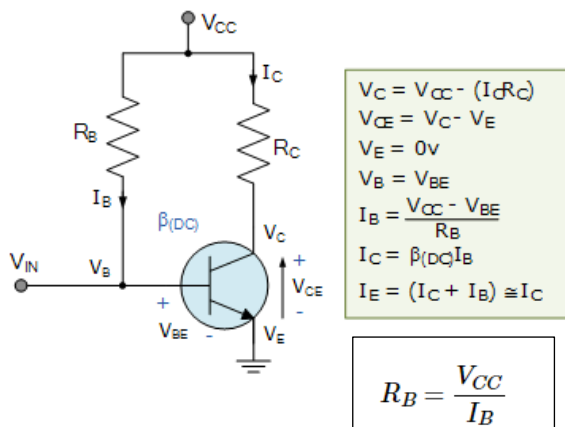


The commonly used methods of transistor biasing are

- Base Resistor method/Fixed Bias
- Collector to Base bias
- Voltage-divider bias

The circuit shown is called a “fixed base bias circuit”, because the transistors base current, I_B remains constant for given values of V_{CC} , and therefore the transistors operating point must also remain fixed.

Fixed Bias



Stability factor

$$S = \frac{\beta + 1}{1 - \beta \left(\frac{dI_B}{dI_C} \right)} \quad \frac{dI_B}{dI_C} = 0$$

$$S = \beta + 1$$

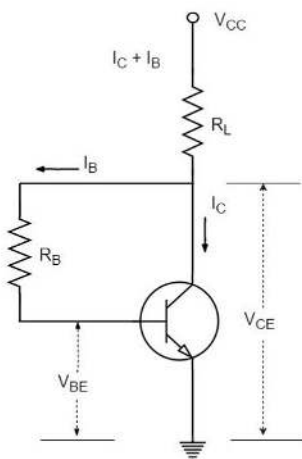
Advantages

- The circuit is simple.
- Biasing conditions are set easily.
- No loading effect as no resistor is present at base-emitter junction.

Disadvantages

- The stabilization is poor as heat development can't be stopped.
- The stability factor is very high. So, there are strong chances of thermal runaway.

Collector to Base Bias



This circuit helps in improving the stability considerably. If the value of I_C increases (due to any change in temperature or any parameter variations), the voltage across R_L increases and hence the V_{CE} will decrease. This in turn reduces the base current I_B resulting in reduced I_C . This action somewhat compensates the original increase.

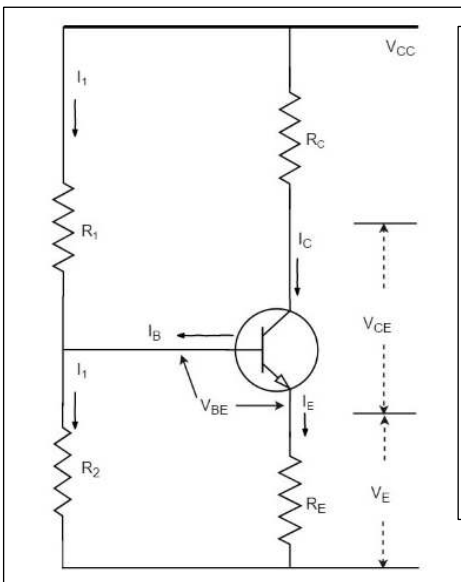
Advantages

- The circuit is simple as it needs only one resistor.
- This circuit provides some stabilization, for lesser changes.

Disadvantages

- The circuit doesn't provide good stabilization.
- The circuit provides negative feedback.

Voltage Divider Bias



$$I_1 = \frac{V_{CC}}{R_1 + R_2} \quad V_2 = \left(\frac{V_{CC}}{R_1 + R_2} \right) R_2$$

The voltage across resistance R_2 is

$$V_2 = V_{BE} + V_E$$

$$V_2 = V_{BE} + I_E R_E$$

$$I_E = \frac{V_2 - V_{BE}}{R_E}$$

Since $I_E \approx I_C$

$$I_C = \frac{V_2 - V_{BE}}{R_E}$$

I_C doesn't depend upon β . V_{BE} is so small that I_C doesn't get affected by V_{BE} at all. Thus I_C in this circuit is almost independent of transistor parameters and hence good stabilization is achieved.

Collector-Emitter Voltage, V_{CE}

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E \quad \text{Since } I_E \approx I_C = I_C R_C + V_{CE} + I_C R_E$$

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

R_E provides excellent stabilization in this circuit.

Suppose there is a rise in temperature, then the collector current I_C increases, which causes the voltage drop across R_E to increase. As the voltage drop across R_2 is V_2 , which is independent of I_C , the value of V_{BE} decreases. The reduced value of I_B tends to restore I_C to the original value.

Stability factor

Consider CE Loop

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

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

$$I_C \text{ IS APPROX. } = I_E$$

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

$$\text{VOLTAGE FROM E TO GROUND, } V_E = I_E R_E$$

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

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

$$V_B = V_{CC} - I_B R_B = V_{BE} + V_E$$

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

DIFFERENTIATE WRT I_C , CONSIDER V_{BE} IS INDEPENDENT OF I_C

$$0 = R_B \frac{dI_B}{dI_C} + R_E + R_E \frac{dI_B}{dI_C} = R_E + \frac{dI_B}{dI_C} (R_B + R_E)$$

$$\frac{dI_B}{dI_C} = -R_E / (R_B + R_E)$$

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

$$= \frac{1 + \beta}{1 - \beta \left(\frac{-R_E}{R_B + R_E} \right)} = \frac{1 + \beta}{1 + \beta \left(\frac{R_E}{R_B + R_E} \right)}$$

Bias Compensation

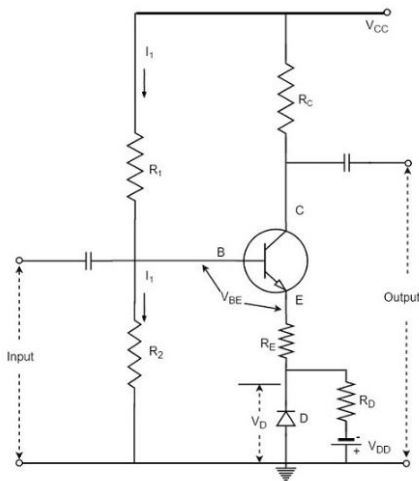
The stabilization occurs due to negative feedback action. The negative feedback, although improves the stability of the operating point, it reduces the gain of the amplifier.

1. Diode Compensation for Instability

- Diode compensation for instability due to V_{BE} variation
- Diode compensation for instability due to I_{CO} variation

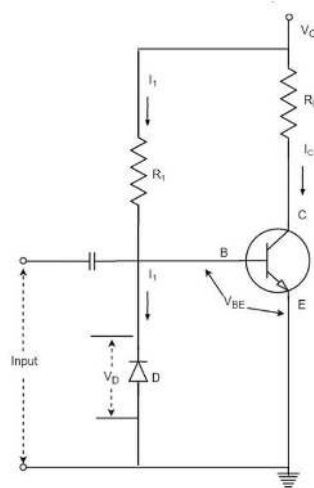
2. Thermistor Compensation

Diode Compensation for Instability due to V_{BE} Variation



The diode D is forward biased by the source V_{DD} and the resistor R_D . The variation in V_{BE} with temperature is the same as the variation in V_D with temperature, hence the quantity $(V_{BE} - V_D)$ remains constant. So the current I_C remains constant in spite of the variation in V_{BE} .

Diode Compensation for Instability due to I_{CO} Variation



$$I = \frac{V_{CC} - V_{BE}}{R} \cong \frac{V_{CC}}{R} = \text{Constant}$$

$$I_B = I - I_O$$

$$I_C = \beta(I - I_O) + (1 + \beta)I_{CO}$$

If $\beta \gg 1$,

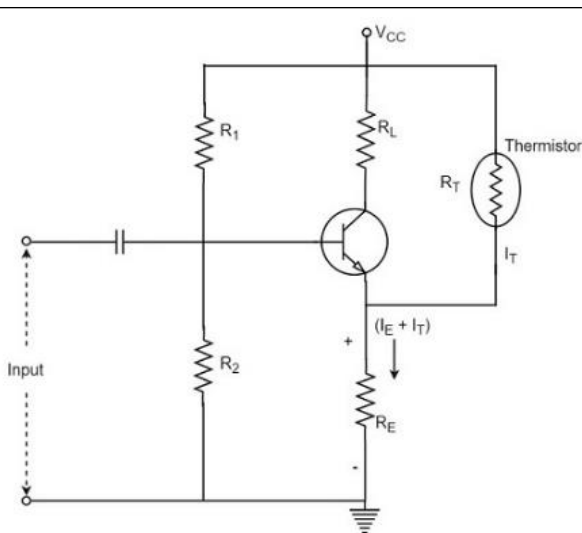
$$I_C = \beta I - \beta I_O + \beta I_{CO}$$

So, the reverse saturation current I_O of the diode will increase with temperature at the same rate as the transistor collector saturation current I_{CO} .

The diode D is reverse biased by V_{BE} and the current through it is the reverse saturation current I_O .

I is almost constant and if I_O of diode and I_{CO} of transistor track each other over the operating temperature range, then I_C remains constant.

Thermistor Compensation



Thermistor is a temperature sensitive device. It has negative temperature coefficient. The resistance of a thermistor increases when the temperature decreases and it decreases when the temperature increases.

As the temperature increases, the resistance R_T of the thermistor decreases, which increases the current through it and the resistor R_E . Now, the voltage developed across R_E increases, which reverse biases the emitter junction. This reverse bias is so high that the effect of resistors R_1 and R_2 providing forward bias also gets reduced. This action reduces the rise in collector current.

BJT-Modeling

A model is an equivalent circuit that represents the AC characteristics of the transistor.

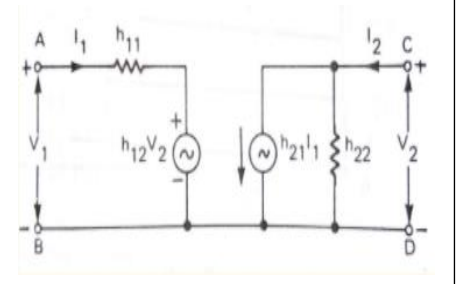
Input voltage V_i and output current I_o are the dependent variables, whereas input current I_i and output voltage V_o are independent variables.

$$V_i = f_1(I_i, V_o)$$

$$I_o = f_2(I_i, V_o)$$

$$V_i = h_{11} I_i + h_{12} V_o$$

$$I_o = h_{21} I_i + h_{22} V_o$$



Definitions of h – parameter

- $h_{11} = V_i / I_i$ where $V_o = 0$, input resistance with output short – circuited, in ohms
- $h_{12} = V_i / V_o$ where $I_i = 0$, Fraction of output voltage at input with input open circuited. This parameter is ratio of similar quantities, hence unitless
- $h_{21} = I_o / I_i$ where $V_o = 0$, Forward current transfer ratio or current gain with output short circuited. This parameter is a ratio of similar quantities, hence unitless.
- $h_{22} = I_o / V_o$ where $I_i = 0$, Output admittance with input open-circuited, in mhos.

- a) With output short circuited :
 $h_{11} = h_i$: Input resistance
 $h_{21} = h_f$: Short circuit current gain
- b) With input open circuited :
 $h_{12} = h_r$: Reverse voltage transfer ratio
 $h_{22} = h_o$: output admittance.

Benefits of h-parameters

- Real numbers at audio frequencies.
- Easy to measure.
- Can be obtained from the transistor static characteristics curves.
- Convenient to use in circuit analysis and design.
- Most of the transistor manufacturers specify the h-parameters.

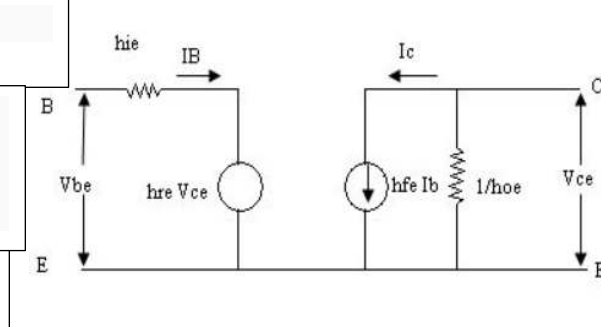
The main limitation of the parameter is that it cannot depict the behaviour of the circuit at high frequency.

H – parameters equivalent circuit for CE configuration

$$V_{be} = h_{ie} I_b + h_{re} V_{ce}$$

$$I_c = h_{fe} I_b + h_{oe} V_{ce}$$

I_b = input current
 I_c = output current
 V_{be} = input voltage
 V_{ce} = output voltage.



$$h_{ie} = \left. \frac{\Delta V_{BE}}{\Delta I_B} \right|_{V_{CE} \text{ constant}}$$

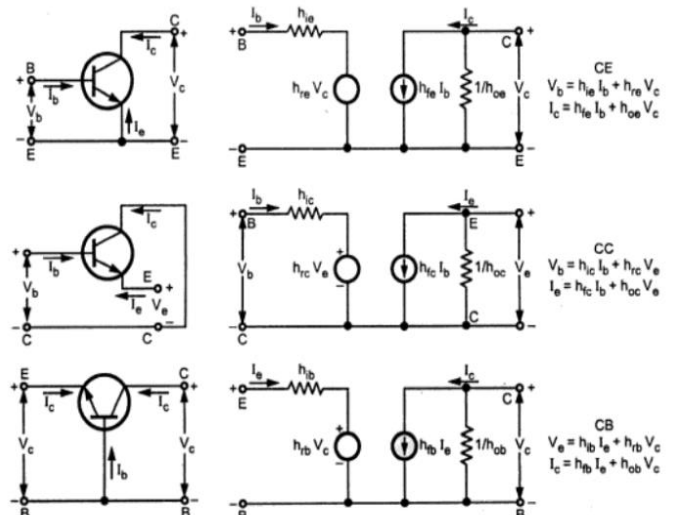
$$h_{re} = \left. \frac{\Delta V_{BE}}{\Delta V_{CE}} \right|_{I_B \text{ constant}}$$

$$h_{fe} = \left. \frac{\Delta I_C}{\Delta I_B} \right|_{V_{CE} \text{ constant}}$$

$$h_{oe} = \left. \frac{\Delta I_C}{\Delta V_C} \right|_{I_B \text{ constant}}$$

H-parameters for all three configurations

Common Base	Common Emitter	Common Collector	Definitions
$h_{ib} = \frac{V_{eb}}{i_e}$	$h_{ie} = \frac{V_{be}}{i_b}$	$h_{ic} = \frac{V_{bc}}{i_b}$	Input Impedance with Output Short Circuit
$h_{rb} = \frac{V_{eb}}{V_{cb}}$	$h_{re} = \frac{V_{be}}{V_{ce}}$	$h_{rc} = \frac{V_{bc}}{V_{ec}}$	Reverse Voltage Ratio Input Open Circuit
$h_{fb} = \frac{i_c}{i_e}$	$h_{fe} = \frac{i_c}{i_b}$	$h_{fc} = \frac{i_e}{i_b}$	Forward Current Gain Output Short Circuit
$h_{ob} = \frac{i_c}{V_{cb}}$	$h_{oe} = \frac{i_c}{V_{ce}}$	$h_{oc} = \frac{i_e}{V_{ec}}$	Output Admittance Input Open Circuit

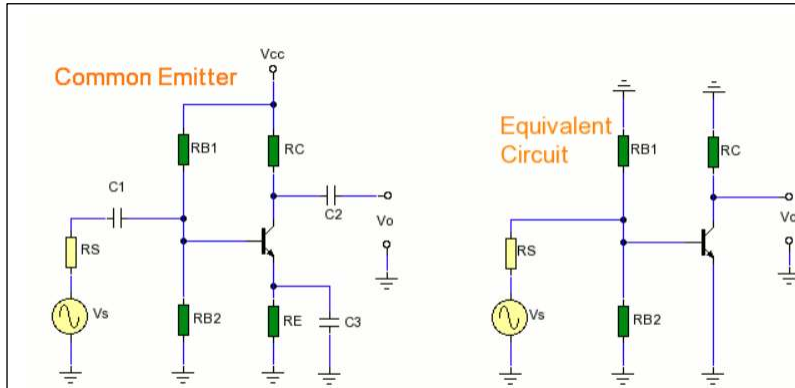


BJT-Modeling of CE Amplifier(Small signal Analysis)

The small-signal ac response can be described by two common models: the *hybrid model* and *re model*.

The models are equivalent circuits (or combination of circuit elements) that allow methods of circuit analysis to predict performance.

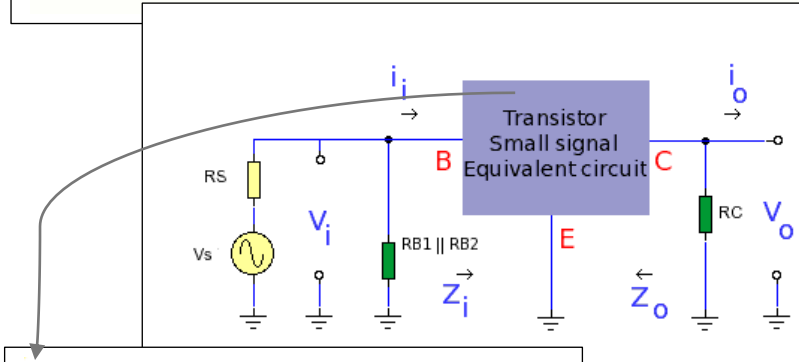
Transistor Hybrid Model



At ac the reactance of coupling capacitors C1 and C2 is so low that they are virtual short circuits, as does the bypass capacitor C3.

$$x_c = \frac{1}{2\pi f c}$$

RB1 and RB2 are now in parallel the input impedance will be $RB1 \parallel RB2$. The collector resistor RC also appears from collector to emitter (as emitter is bypassed).



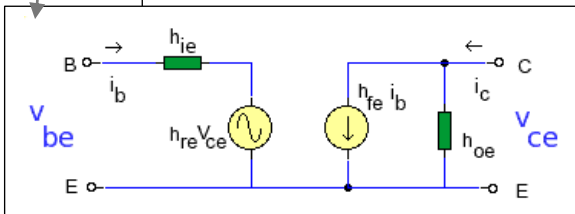
hie input impedance (Ω)

hre reverse voltage ratio (dimensionless)

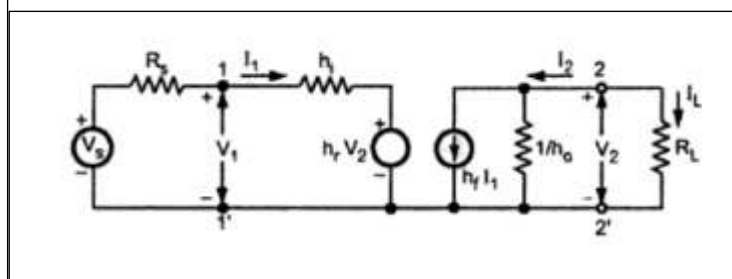
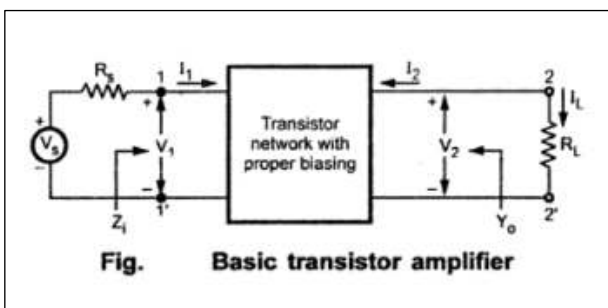
hfe forward current transfer ratio (dimensionless)

hoe output admittance (Siemen)

The "h" stands for hybrid because the parameters are a mix of impedance, admittance and dimensionless units.



Analysis of Transistor Amplifier using h Parameter



Current Gain

Current Gain (A_i) :

For transistor amplifier A_i is defined as the ratio of output to input currents. It is given by,

$$A_i = \frac{I_L}{I_1} = -\frac{I_2}{I_1}$$

Here I_L and I_2 are equal in magnitude but opposite in sign, i.e. $I_L = -I_2$

From the circuit of Fig.

$$I_2 = h_f I_1 + h_o V_2$$

Substituting $V_2 = -I_2 R_L$ in the equation we obtain

$$I_2 = h_f I_1 + h_o (-I_2 R_L)$$

$$\therefore I_2 + h_o I_2 R_L = h_f I_1$$

$$\therefore (1 + h_o R_L) I_2 = h_f I_1$$

$$\therefore \frac{I_2}{I_1} = \frac{h_f}{1 + h_o R_L}$$

$$\therefore A_i = -\frac{I_2}{I_1} = \frac{-h_f}{1 + h_o R_L}$$

Current Gain (A_{is}) :

It is the current gain taking into account the source resistance, R_s , if the model is driven by the current source instead of voltage source. It is given by,

$$A_{is} = -\frac{I_2}{I_s} = -\frac{I_2}{I_1} \cdot \frac{I_1}{I_s}$$

$$= A_i \cdot \frac{I_1}{I_s}$$



(a) Input section of hybrid model

(b) Input section of hybrid model with current source instead of voltage source

$$I_1 = \frac{I_s R_s}{Z_i + R_s}$$

$$\therefore \frac{I_1}{I_s} = \frac{R_s}{Z_i + R_s}$$

and hence $A_{is} = \frac{A_i R_s}{Z_i + R_s}$

Input Impedance

$$R_i = \frac{V_1}{I_1}$$

From the input circuit of Fig. we have

$$V_1 = h_i I_1 + h_r V_2$$

Hence $Z_i = \frac{V_1}{I_1} = \frac{h_i I_1 + h_r V_2}{I_1}$

$$\therefore Z_i = h_i + h_r \frac{V_2}{I_1}$$

Substituting $V_2 = -I_2 R_L = A_i I_1 R_L$

In the above equation we get,

$$Z_i = h_i + \frac{h_r A_i I_1 R_L}{I_1} = h_i + h_r A_i R_L$$

Substituting $A_i = \frac{-h_f}{1 + h_o R_L}$

we get, $Z_i = h_i - \frac{h_r h_f R_L}{1 + h_o R_L}$

Dividing numerator and denominator by R_L we get

$$Z_i = h_i - \frac{h_r h_f}{1/R_L + h_o}$$

$$\therefore Z_i = h_i - \frac{h_r h_f}{Y_L + h_o} \quad \text{where } Y_L = \frac{1}{R_L}$$

Voltage Gain

$$A_v = \frac{V_2}{V_1}$$

$$A_v = \frac{A_i I_1 R_L}{V_1} = \frac{A_i R_L}{Z_i}$$

Since, $\frac{I_1}{V_1} = \frac{1}{Z_i}$

Voltage Gain (A_{vs}) : It is voltage gain including the source. It is given by,

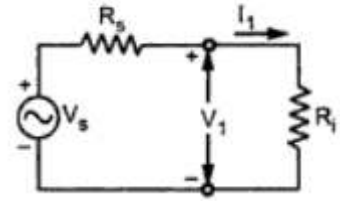
$$A_{vs} = \frac{V_2}{V_s} = \frac{V_2}{V_1} \times \frac{V_1}{V_s}$$

$$\therefore A_{vs} = A_v \times \frac{V_1}{V_s}$$

Substituting value of $\frac{V_1}{V_s}$ in equation

$$A_{vs} = A_v \cdot \frac{Z_i}{R_s + Z_i}$$

$$= \frac{A_i R_L}{R_s + R_i} \quad \therefore A_v = \frac{A_i R_L}{Z_i}$$



$$V_1 = \frac{Z_i}{R_s + Z_i} V_s$$

$$\therefore \frac{V_1}{V_s} = \frac{Z_i}{R_s + Z_i}$$

Output Admittance

It is the ratio of output current I_2 to the output voltage V_2 . It is given by,

$$Y_o = \frac{I_2}{V_2} \text{ with } V_s = 0$$

$$I_2 = h_f I_1 + h_o V_2$$

Dividing above equation by V_2 we get,

$$\frac{I_2}{V_2} = \frac{h_f I_1}{V_2} + h_o$$

$$\therefore Y_o = h_f \frac{I_1}{V_2} + h_o$$

From Fig. with $V_s = 0$ we can write,

$$R_s I_1 + h_i I_1 + h_r V_2 = 0$$

$$\therefore (R_s + h_i) I_1 = -h_r V_2$$

$$\therefore \frac{I_1}{V_2} = \frac{-h_r}{R_s + h_i}$$

Substituting value of $\frac{I_1}{V_2}$

$$Y_o = h_o - \frac{h_f h_r}{h_i + R_s}$$

Power Gain

Power Gain (A_p) : It is the ratio of average power delivered to the load R_L , to the input power. Output power is given as

$$P_2 = V_2 I_L = -V_2 I_2$$

Since the input power is $P_1 = V_1 I_1$ the operating power gain A_p of the transistor is defined as

$$A_p = \frac{P_2}{P_1} = -\frac{V_2 I_2}{V_1 I_1} = A_v A_i = A_i^2 \frac{R_L}{Z_i} \quad \therefore A_v = \frac{A_i R_L}{Z_i}$$

$$A_i = -\frac{h_f}{1 + h_o R_L}$$

$$A_{is} = \frac{A_i R_s}{Z_i + R_s}$$

$$Z_i = h_i + h_r A_i R_L = h_i - \frac{h_f h_r}{h_o + Y_L}$$

$$A_v = \frac{A_i R_L}{Z_i}$$

$$A_{vs} = \frac{A_v R_i}{Z_i + R_s} = \frac{A_i R_L}{Z_i + R_s} = \frac{A_{is} R_L}{R_s}$$

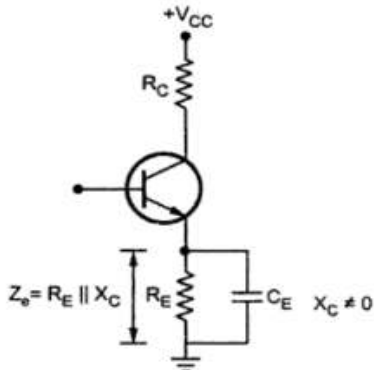
$$Y_o = h_o - \frac{h_f h_r}{h_i + R_s} = \frac{1}{Z_o}$$

$$A_p = A_v A_i = A_i^2 \frac{R_L}{Z_i}$$

BJT-Roll of C_C and C_E

Effect of Bypass Capacitor

We have seen that resistance R_E in the voltage divider bias is useful to obtain stable biasing (dc) conditions. However, when unbypassed drop across it reduces the voltage gain of the amplifier. This problem can be solved by connecting bypass capacitor across R_E . The bypass capacitor acts as a short circuit for ac signals and allows us to create an ac ground in an amplifier without disturbing its Q point.



At low frequencies emitter is not at ac ground

At lower frequencies, the bypass capacitor C_E is not a short. So, the emitter is not at ac ground. X_C in parallel with R_E creates an impedance. The signal voltage drops across this impedance reducing the circuit gain. This is illustrated in Fig.

Effect of Coupling Capacitors

Recall that the reactance of a capacitor is $X_C = 1/2\pi fC$. At medium and high frequencies the factor f makes X_C very small, so that all coupling capacitors behave as short circuits. At low frequencies, X_C increases. This increase in X_C drops the signal voltage across the capacitor and reduces the circuit gain. As signal frequencies decrease, the capacitor reactances increase and circuit gain continues to fall, reducing the output voltage.