عنوان البحث

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Abstract

A transistor is a semiconductor device used to amplify or switch electronic signals and electrical power. It is composed of semiconductor material with at least three terminals for connection to an external circuit. A voltage or current applied to one pair of the transistor's terminals controls the current through another pair of terminals.

Introduction

The Bipolar Junction Transistor usually (BJT) is a semiconductor device which can be used for switching or amplification. If we join two diodes, this will give us two PN-junctions sharing a common P or N terminal. The fusion of these two diodes produces a three-layer, two junction, three-terminal device forming the basis of a Bipolar Junction Transistor. The three terminals are labelled as the Emitter (E), the Base (B) and the Collector (C) respectively. Transistors are made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor’s ability to change between these two states enables it to have two basic functions: “switching” (digital) or “amplification” (analog).

Thus, BJTs can operate within three different regions:

- **Active Region**: the transistor operates as an amplifier, $I_c = \beta * I_b$
- **Saturation**: the transistor is operating as On-switch $I_c = I_{saturation}$
- **Cut-off**: the transistor is operating as Off-switch, $I_c = 0$

Figure1
A typical bipolar transistor

There are three possible ways to connect the BJT within an electronic circuit with one terminal being common to both the input and output.

- **Common Base Configuration** – has Voltage Gain but no Current Gain.
- **Common Emitter Configuration** – has both Current and Voltage Gain.
- **Common Collector Configuration** – has Current Gain but no Voltage Gain.

Research Project Contents

The Common Base (CB) Configuration:

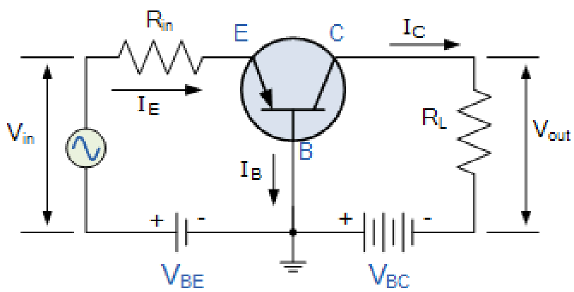


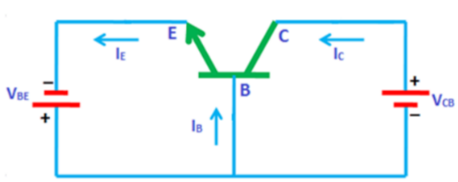
Figure 2 Common Base Transistor Circuit

In the Common Base or grounded base configuration, the **base connection** is common to both the input signal and the output signal. The input signal is applied between the transistors base and the emitter terminals, while the corresponding output signal is taken from between the base and the collector terminals as shown. The base terminal is grounded or can be connected to some fixed reference voltage point.

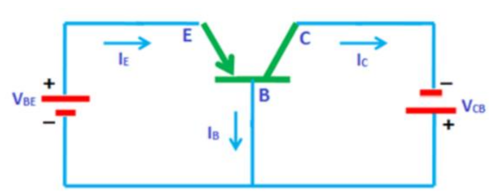
The input current flowing into the emitter is quite large as its the sum of both the base current and collector current respectively.

The Common Base Transistor Circuit

This type of amplifier configuration is a non-inverting voltage amplifier circuit, in that the signal voltages V_{in} and V_{out} are "in-phase". This type of transistor arrangement is not very common due to its unusually high voltage gain characteristics. Its input characteristics represent that of a forward biased diode while the output characteristics represent that of an illuminated photodiode.



(a)



(b)

Figure 3 common base configuration (a) NPN (b) PNP

The input characteristics describe the relationship between input current (I_E) and the input voltage (V_{BE}). To determine the input characteristics, the output voltage V_{CB} (collector-base voltage) is kept constant at zero volts and the input voltage V_{BE} is increased from zero volts to different voltage levels. For each voltage level of the input voltage (V_{BE}), the input current (I_E) is recorded. A curve is then drawn between input current I_E and input voltage V_{BE} at constant output voltage V_{CB} (0 volts). Next, the output voltage (V_{CB}) is increased from zero volts to a certain voltage level (8 volts) and kept constant at 8 volts. While increasing the output voltage (V_{CB}), the input voltage (V_{BE}) is kept constant at zero volts. After we kept the output voltage (V_{CB}) constant at 8 volts, the input voltage V_{BE} is increased from zero volts to different voltage levels. For each voltage level of the input voltage (V_{BE}), the input current (I_E) is recorded. A curve is then drawn between input current I_E and input voltage V_{BE} at constant output voltage V_{CB} (8 volts).

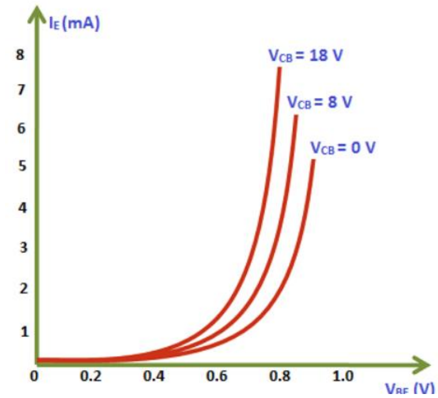


Figure 4 I/P characteristics CB configuration

This is repeated for higher fixed values of the output voltage (V_{CB}). When output voltage (V_{CB}) is at zero volts and emitter-base junction JE is forward biased by the input voltage (V_{BE}), the emitter-base junction acts like a normal p-n junction diode. So, the input characteristics are same as the forward characteristics of a normal pn junction diode. The cut in voltage of a silicon transistor is 0.7 volts and germanium transistor is 0.3 volts. In our case, it is a silicon transistor. So, from the above graph, we can see that after 0.7 volts, a small increase in input voltage (V_{BE}) will rapidly increase the input current (I_E). When the output voltage (V_{CB}) is increased from zero volts to a certain voltage level (8 volts), the emitter current flow will be increased which in turn reduces the depletion region width at emitter-base junction. As a result, the cut in voltage will be reduced. Therefore, the curves shifted towards the left side for higher values of output voltage V_{CB}.

The output characteristics describe the relationship between output current (I_C) and the output voltage (V_{CB}). To determine the output characteristics, the input current or emitter current I_E is kept constant at zero mA and the output voltage V_{CB} is increased from zero volts to different voltage levels. For each voltage level of the output voltage V_{CB}, the output current (I_C) is recorded. A curve is then drawn between output current I_C and output voltage V_{CB} at constant input current I_E (0 mA).

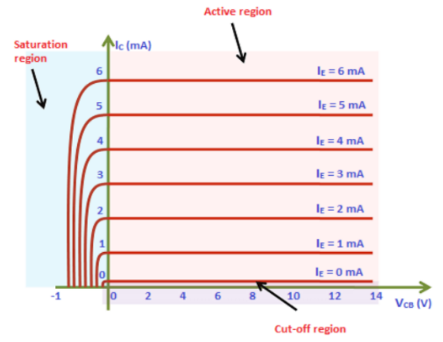


Figure 5 O/P characteristics CB configuration

When the emitter current or input current I_E is equal to 0 mA, the transistor operates in the cut-off region. Next, the input current (I_E) is increased from 0 mA to 1 mA by adjusting the input voltage V_{BE} and the input current I_E is kept constant at 1 mA. While increasing the input current I_E, the output voltage V_{CB} is kept constant.

After we kept the input current (I_E) constant at 1 mA, the output voltage (V_{CB}) is increased from zero volts to different voltage levels. For each voltage level of the output voltage (V_{CB}), the output current (I_C) is recorded. A curve is then drawn between output current I_C and output voltage V_{CB} at constant input current I_E (1 mA). This region is known as the active region of a transistor. This is repeated for higher fixed values of input current I_E. From the above characteristics, we can see that for a constant input current I_E, when the output voltage V_{CB} is increased, the output current I_C remains constant. At saturation region, both emitter-base junction JE and collector-base junction JC are forward biased. From the above graph, we can see that a sudden increase in the collector current when the output voltage V_{CB} makes the collector-base junction JC forward biased.

BJT Transistor Modeling: a model is an equivalent circuit that represents the AC characteristics of the transistor. Transistor small signal amplifiers can be considered linear for most application. A model is the best approximate of the actual behavior of a semiconductor device under specific operating conditions, including circuit elements

Transistor Models

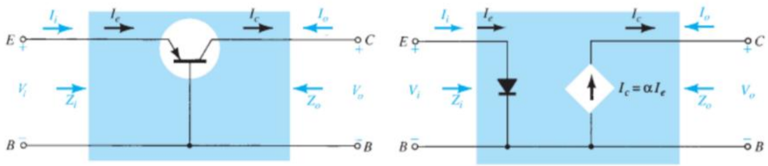
r_e- model: any region of operation, fails to account for output impedance, less accuracy

Hybrid model: limited to a particular operating conditions, more accuracy

The r_e Transistor Model

BJTs are basically current-controlled devices; therefore, the r_e models use a diode and a current source to duplicate the behavior of the transistor. One disadvantage to this model is its sensitivity to the DC level. This model is designed for specific circuit conditions.

Common-Base Configuration



(a) (b)

Figure 6 Common Base transistor r_e model

We know that from diode equation re is defined as follows

$$I_c = \propto I_e$$

$$r_e = \frac{26mV}{I_e}$$

Applying KVL to input and out circuit of figure 6 (b), we will get

input impedance: $z_i = r_e$

Output impedance: $z_o = \infty$

Voltage gain: $A_i = \frac{\propto R_L}{r_e} = \frac{R_L}{r_e}$

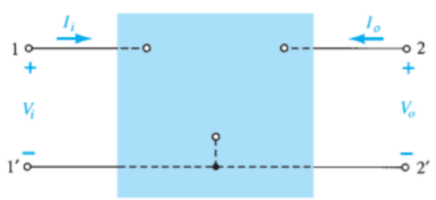
Current gain: $A_i = -\propto = -1$

H – Parameter model:

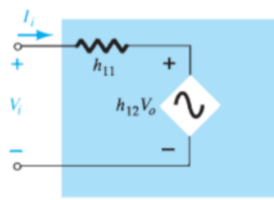
The equivalent circuit of a transistor can be dram using simple approximation by retaining its essential features. These equivalent circuits will aid in analyzing transistor circuits easily and rapidly.

Two port devices & Network Parameters:

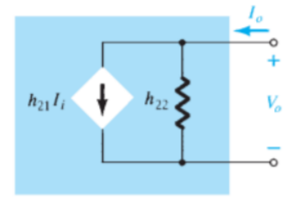
A transistor can be treated as a two-part network. The terminal behavior of any two part network can be specified by the terminal voltages V_i & V_o at parts 1 & 2 respectively and current i_i and i_o, entering parts 1 & 2, respectively, as shown in fig. 7.



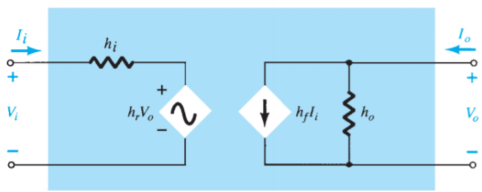
(a)



(b)



(c)



(d)

Figure 7 Two port Network

(a) Two-port system *(b) hybrid input equivalent circuit*

(c) hybrid output equivalent circuit *(d) Complete hybrid equivalent circuit.*

Hybrid parameters (or) h – parameters:

If the input current i_i and output Voltage V_o are takes as independent variables, the input voltage V_i and output current i_o can be written as

$$V_i = h_{11}\, i_i + h_{12}\, V_o$$

$$\mathrm{i_o = h_{21}\, i_1 + h_{22}\, V_2}$$

The four hybrid parameters h_{11} , h_{12}, h_{21} and h_{22} are defined as follows.

$h_{11} = \frac{V_i}{i_i}$ with $V_2 = 0$ Input Impedance with output part short circuited.

$h_{22} = \frac{i_o}{V_o}$ with $i_i = 0$ Output admittance with input part open circuited.

$h_{12} = \frac{V_i}{V_o}$ with $i_i = 0$ reverse voltage transfer ratio with input part open circuited.

$h_{21} = \frac{i_o}{i_i}$ with $V_o = 0$ Forward current gain with output part short circuited.

The dimensions of h – parameters are as follows:

h_{11} - Ω

h_{22} – mhos

h_{12}, h_{21} – dimension less.

as the dimensions are not alike, (i.e.) they are hybrid in nature, and these parameters are called as hybrid parameters.

$i = 11$ = input; $o = 22$ = output;

$f = 21$ = forward transfer; $r = 12$ = Reverse transfer.

Notations used in transistor circuits:

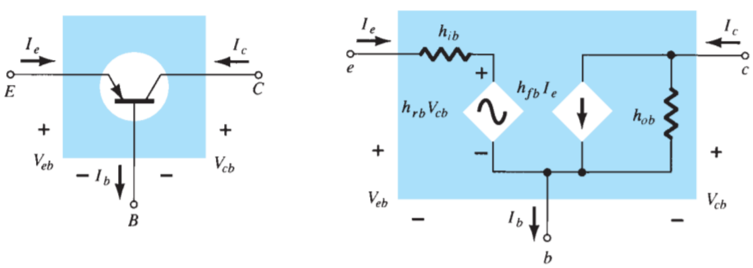
$h_i = h_{11}$ = Short circuit input impedance

$h_o = h_{22}$ = Open circuit output admittance

$h_r = h_{12}$ = Open circuit reverse voltage transfer ratio

$h_f = h_{21}$ = Short circuit forward current Gain.

For the **common-base configuration** of Fig. 8 , $I_i = I_e, I_o = I_c$ with $V_{eb} = V_i$ and $V_{cb} = V_o$. The networks of Figs. 8 are applicable for pnp or npn transistors.



(a) (b)

Figure 8 Common-base configuration: (a) graphical symbol; (b) hybrid equivalent circuit

Define and derive the ac circuit parameters $\boldsymbol{Z_i, Z_o, A_i, A_v}$ for the network shown in Fig 9, replacing the transistor with its $\boldsymbol{r_e}$ model.

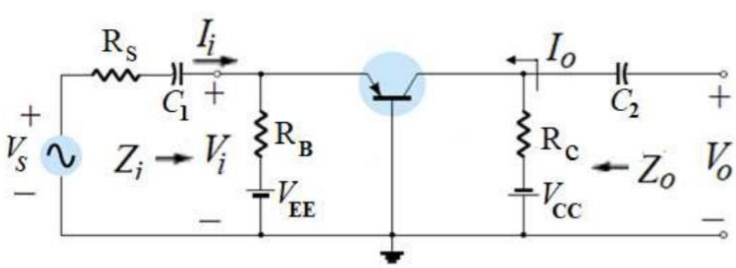
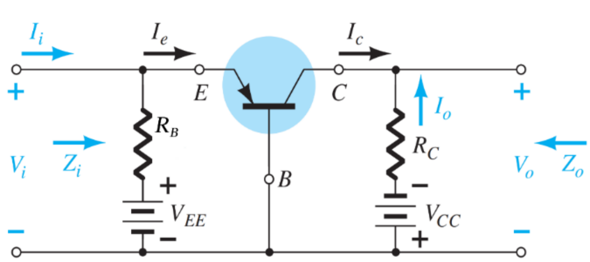
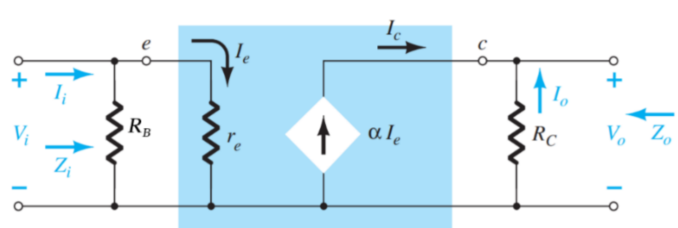


Figure 9

solution





$$Z_i = R_B || r_e$$

$$Z_o = R_C$$

$$V_o = -I_oR_C = -(-I_c)R_C = \alpha I_eR_C$$

$$with\ I_e = V_i$$

$$r_e$$

$$so\ that\ V_o = \alpha\left(\frac{Vi}{re}\right)R_C$$

$$and\ A_v = \frac{V_o}{Vi} = \frac{\alpha R_C}{r_e} \cong \frac{R_C}{r_e}$$

$$Assuming\ that\ R_E \gg r_e\ yields$$

$$I_e = I_i$$

$$and\ I_o = -\alpha I_e = -\alpha I_i$$

$$with\ A_i = \frac{I_o}{I_i} = -\alpha \cong -1$$

Define and derive the ac circuit parameters $\boldsymbol{Z_i', Z_o', A_i, A_v}$ for the network shown in Fig.2, replacing the transistor with its **hybrid model**.

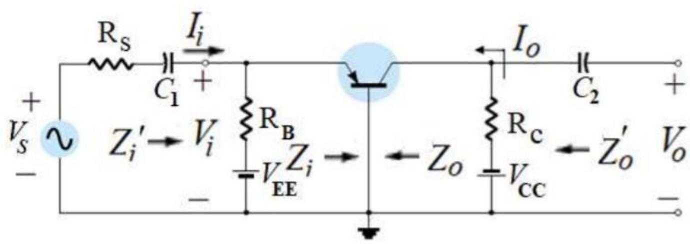


Figure 10

Solution: The common-base hybrid parameters are derived from the common-emitter parameters using the approximate equations of Appendix B:

$$h_{ib} \cong \frac{h_{ie}}{1 + h_{fe}}$$

Or

$$h_{ib} = r_e = \frac{h_{ie}}{\beta}$$

Also,

$$h_{rb} \cong \frac{h_{ie}h_{oe}}{1 + h_{fe}} - h_{re}$$

$$h_{fb} \cong -\frac{h_{fe}}{1 + h_{fe}}$$

$$h_{ob} \cong \frac{h_{oe}}{1 + hfe}$$

Substituting the common-base hybrid equivalent circuit into the network of Fig 10 results in the small-signal equivalent network of Fig 11.

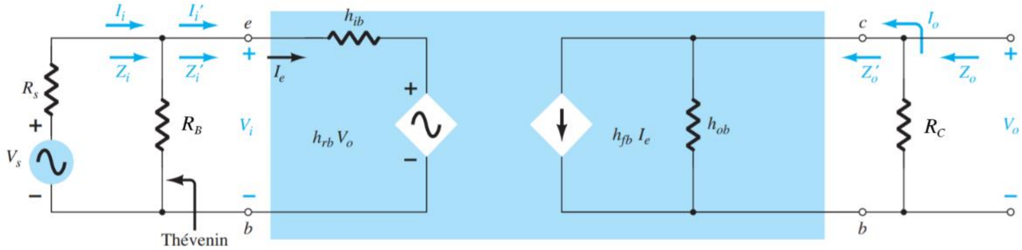


Figure 11

$$V_i = h_{ib}I'_i + h_{rb}V_o$$

$$Substituting\ V_o = -I_oR_L$$

$$we\ have\ V_i = h_{ib}I'_i - h_{rb}R_LI_o$$

$$Because\ A_i = \frac{I_o}{I'_i}$$

$$I_o = A_iI'_i$$

so that the equation above becomes

$$V_i = h_{ib}I'_i - h_{rb}R_L\,A_iI'_i$$

$$Solving\ for\ the\ ratio\ V_i/I'_i, we\ obtain$$

$$Z'_i = \frac{V_i}{I'_i} = h_{ib} - h_{rb}R_LA_i$$

$$and\ substituting$$

$$A_i = \frac{h_{fb}}{1 + h_{ob}R_L}$$

$$yields\ Z'_i = \frac{V_i}{I'_i} = h_{ib} - \frac{h_{fb}h_{rb}R_L}{1 + h_{ob}R_L}$$

The familiar form of $Z'_i = h_{ib}$ is obtained if the second factor in the denominator $(h_{ob}R_L)$ is sufficiently smaller than one.

Applying Kirchhoff's current law to the output circuit yields

$$I_o = h_f I_b + I = h_f I_i + \frac{V_o}{1/h_o} = h_f I_i + h_o V_o$$

$$Substituting\ V_o = -I_o R_L\ gives$$

$$I_o = h_f I_i - h_o R_L I_o$$

Rewriting the equation above, we have

$$I_o + h_o R_L I_o = h_f I_i$$

$$and\ I_o(1 + h_o R_L) = h_f I_i$$

$$so\ that\ A_i = \frac{I_o}{I_i} = \frac{h_f}{1 + h_o R_L}$$

Note that the current gain reduces to the familiar result of $A_i = h_f\ if\ the\ factor\ h_o R_L$ is sufficiently small compared to 1.

Applying Kirchhoff's voltage law to the input circuit results in

$$V_i = I_i h_{ib} + h_{rb} V_o$$

$$Substituting\ I_i = \frac{(1 + h_{ob} R_L) I_o}{h_{fb}} from\ Eq. (5.167) and\ I_o = -\frac{V_o}{RL}$$

$$from\ above\ results\ in$$

$$V_i = -\frac{(1 + h_{ob} R_L) h_{ib}}{h_{fb} R_L} Vo + h_{rb} V_o$$

Solving for the ratio $V_o > V_i$ yields

$$A_v = \frac{V_o}{V_i} = -\frac{h_{fb} R_L}{h_{ib} + \left(h_{ib} h_{ob} - h_{fb} h_{rb}\right) R_L}$$

In this case, the familiar form of $A_v = -h_{fb} R_L > h_{ib}$ returns if the factor $\left(h_{ib} h_{ob} - h_{fb} h_{rb}\right) R_L$ is sufficiently small compared $to\ h_i$.

$$A_v \cong -\frac{h_{fb} R_L}{h_{ib}}$$

The output impedance of an amplifier is defined to be the ratio of the output voltage to the output current with the signal V_s set to zero. For the input circuit with $V_s = 0$,

$$I_i = -\frac{h_{rb} V_o}{(R_s + h_{ib})}$$

Substituting this relationship into the equation from the output circuit yields

$$I_o = h_{fb}I_i + h_{ob}V_o = -\frac{h_{fb}h_{rb}V_o}{R_s + h_{ib}} + h_{ob}V_o$$

$$\text{and } Z'_o = \frac{V_o}{I_o} = \frac{1}{h_{ob} - \left[\frac{h_{fb}h_{rb}}{h_{ib} + R_s}\right]}$$

In this case, the output impedance is reduced to the familiar form $Z_o = 1/h_o$ for the transistor when the second factor in the denominator is sufficiently smaller than the fir

Preamplifier

The primary function of a preamplifier is as its name implies: an amplifier used to pick up the signal from its primary source and then operate on it in preparation for its passage into the amplifier section. Typically, a preamplifier will amplify the signal, control its volume, perhaps change its input impedance characteristics, and if necessary, determine its route through the stages to follow—in total, a stage of any system with a multitude of functions.

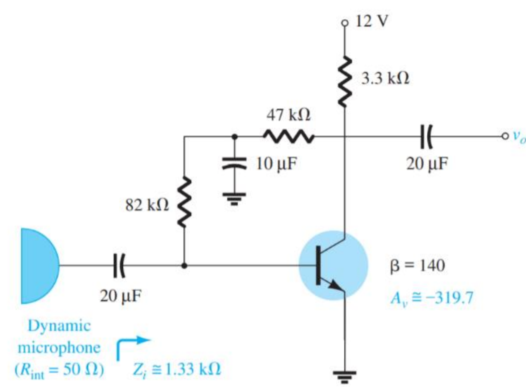


Figure 12 Preamplifier for a dynamic microphone.

A preamplifier such as shown in Fig. 12 is often used with dynamic microphones to bring the signal level up to levels that are suitable for further amplification or power amplifiers. Typically, dynamic microphones are low-impedance microphones because their internal resistance is determined primarily by the winding of the voice coil. The basic construction consists of a voice coil attached to a small diaphragm that is free to move within a permanent magnet. When one speaks into the microphone, the diaphragm moves accordingly, and causes the voice coil to move in the same manner within the magnetic field. In accord with Faraday's law, a voltage will be induced across the coil that will carry the audio signal.

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