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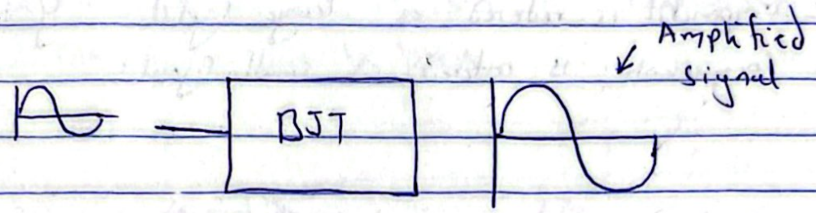
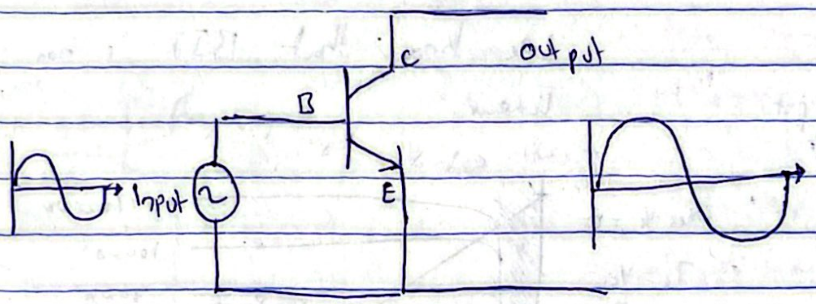
BJT Analysis

When we want to ~~g~~ Use a Transistor as an Amplifier we need to do 2 types of analysis

→ Dc analysis - to find Identify Operating point
→ Ac analysis - to find gain and Input and out put Impedence





Transistor Model

So we use basic transistor model as a equivalent representation of BJT Which Closely represent transistor Characteristics

Transistor Models

Based on the magnitude of the Input signal there are two transistor models

- Large signal model
- Small Signal Model

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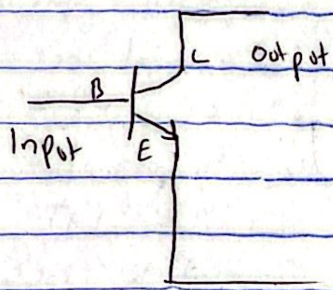
When transistor is used as an Amplifier then It Consist of 2 Components

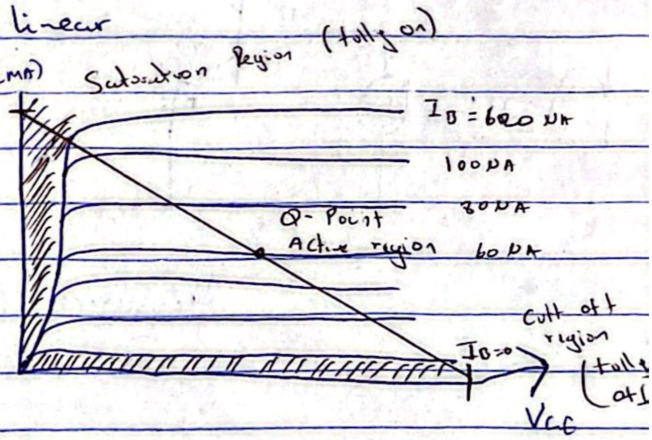
Dc Components – Used for biasing the transistor
Ac Components – time varying Signal, which we want to amplyfiy

So Dc component is refered as large signal } In Amplifier
Ac Components is refered as small signal } Analysis

→ To understand behavior of the device for Large Signal Large Signal model is used



We know that BJT is non linear



When $V_{CE} = 0$

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

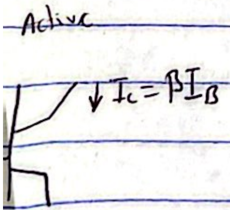
when

$I_C = 0$

$V_{CE} = V_{CC}$

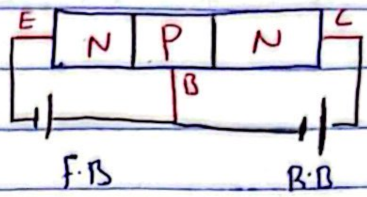
Amplification

During Amplification We bias the transistor so as to ensure It Operate in Active region

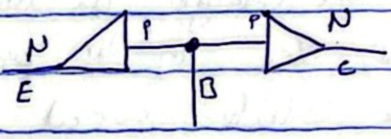


When the Input signal is large the behavior of signal is also non linear.
This is valid only when signal is operated in Active forward region

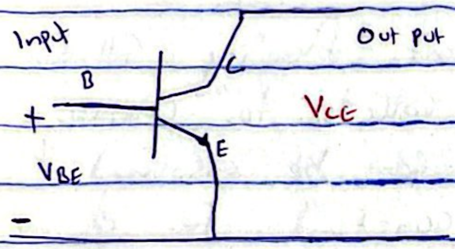
Foward Active region



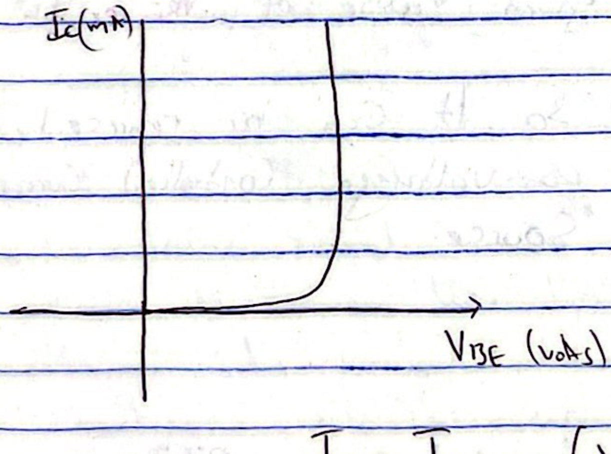
BJT has 2 PN Junctions and It Can be Visualized as 2 transistor Connected back to back



In Common emitter Configuration lets assume V_{CE} is Constant and we are varying V_{BE}



Now by Varying the Voltage V_{BE} It will look and measuring Collector Current I_C It will look Similler to Diode Characteristic by Drawing V I Char



$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \rightarrow$ Is the relation btn V_{BE} and I_C

I_S = Reverse Saturation - flowing cur It Its reverse biased

V_T = Thermal voltage

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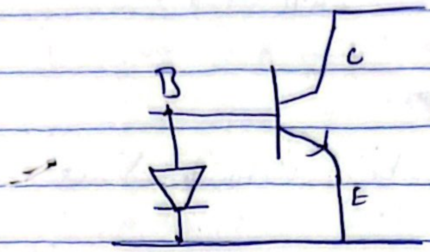
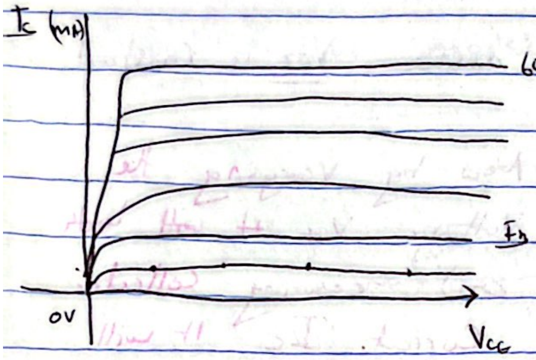
from this Curve we can say that the base emitter terminal can be replaced by (V_{BE}) by Diode

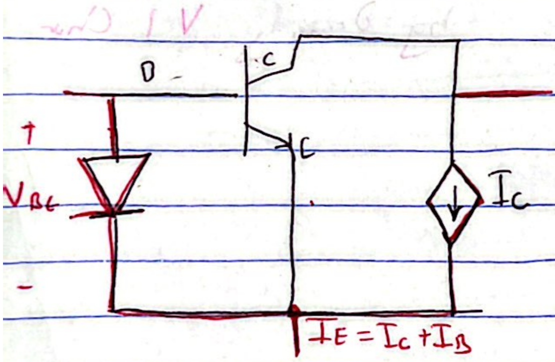


For common emitter Configuration I_C vs V_{CE} Curve

for the fixed value of I_b or V_{be}
If we change the voltage I_C V_{CE} In the active region the collector current almost remains Same (Constant)



→ The Current flowing Collector to from Collector to emitter terminal can be assumed to be constant for a given value of V_{BE} or I_b



* So It Can be represented as voltage Controlled Current ← Source.

An this is the equivalent representation of BJT Is the large signal model of BJT In forward active region

$$I_B = \frac{I_S}{B} \exp\left(\frac{V_{BE}}{V_T}\right) , \quad I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$

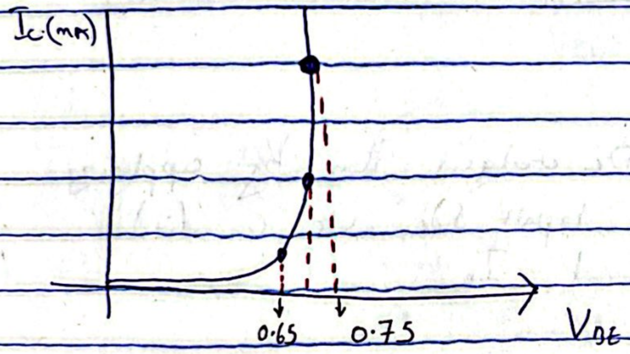
$I_c = \beta I_B$

I_E = ~~Sum~~ Summation of Collector Current and Base Current

$I_E = (\beta + 1) I_b$ $\qquad$ β = current gain = $\frac{I_C}{I_B}$

$I_E = (\beta + 1) \frac{I_S}{\beta} e^{\left(\frac{V_{BE}}{V_T}\right)}$

The collector current depends upon V_{BE} and the relationship is non linear



→ even if the voltage V_{BE} changes by small amount.
→ Then there is significant change in collector current

- If we do dc analysis of the circuit using this large signal model we always have to deal with this non linearity which will complicate the circuit so we never use non linear equations. So we approximate for the analysis

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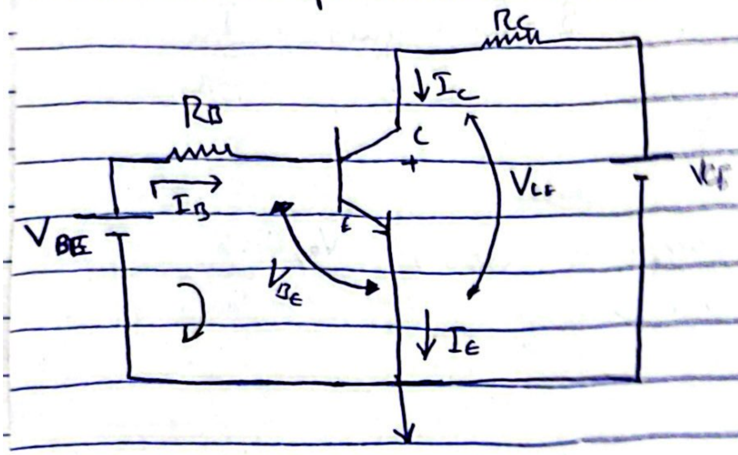
If we see I_C curve V_{BE} curve the variation in the voltage V_{BE} is very small.

So we approximate the value of V_{BE} as 0.7V



If we want to do DC analysis then by applying KVL equation on the input side we can find the value of base current I_B

And then using equation $I_C = \beta I_B$

we can find the value of collector current I_C as well as the voltage V_{CE}

- This method gives the approximate value of the operating point.

If we want to find exactly values then we do Iterations

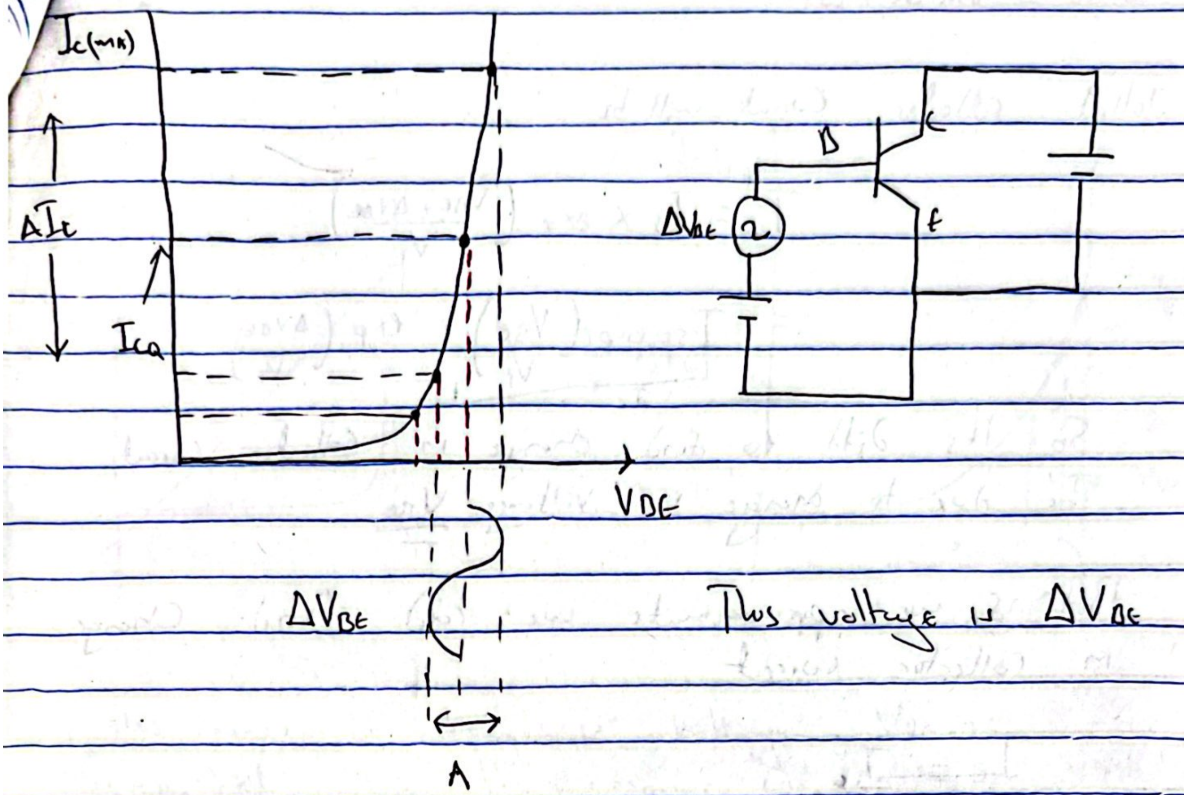
$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$

$$V_{BE} = V_T \ln\left[\frac{I_C}{I_S}\right]$$

Small

Small Signal analysis Model

We add a small ac signal in our DC signal analysis



Because of this small voltage there will be Change in collector current

So this change in collector current to change in ΔV_{BE} is given as Trans-Conductance

* measure how efficient a device such as transistor Coverts input voltage into out put current.

$$g_m = \frac{\Delta I_c}{\Delta V_{BE}} = A/V$$

→ The Small Signal is in Sinusoidal in Nature

$\Delta V_{BE} = V_m \sin \omega t$

Tollal collector Currat will be

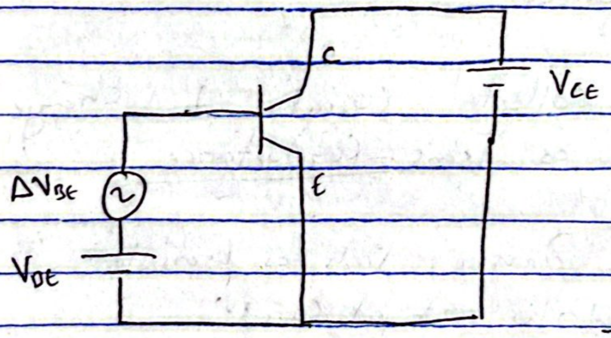
$$I_c' = I_s \times \exp\left(\frac{V_{BE} + \Delta V_{BE}}{V_T}\right)$$

$$= \underbrace{I_s \exp\left(\frac{V_{BE}}{V_T}\right)}_{I_c} \times \exp\left(\frac{\Delta V_{BE}}{V_T}\right)$$

So Its diff to find change in Collector Currat I_c' due to change in voltage $\underline{V_{BE}}$

But if we approximate we can find Chang in Collector Current

$\underline{I_c' = I_c}$



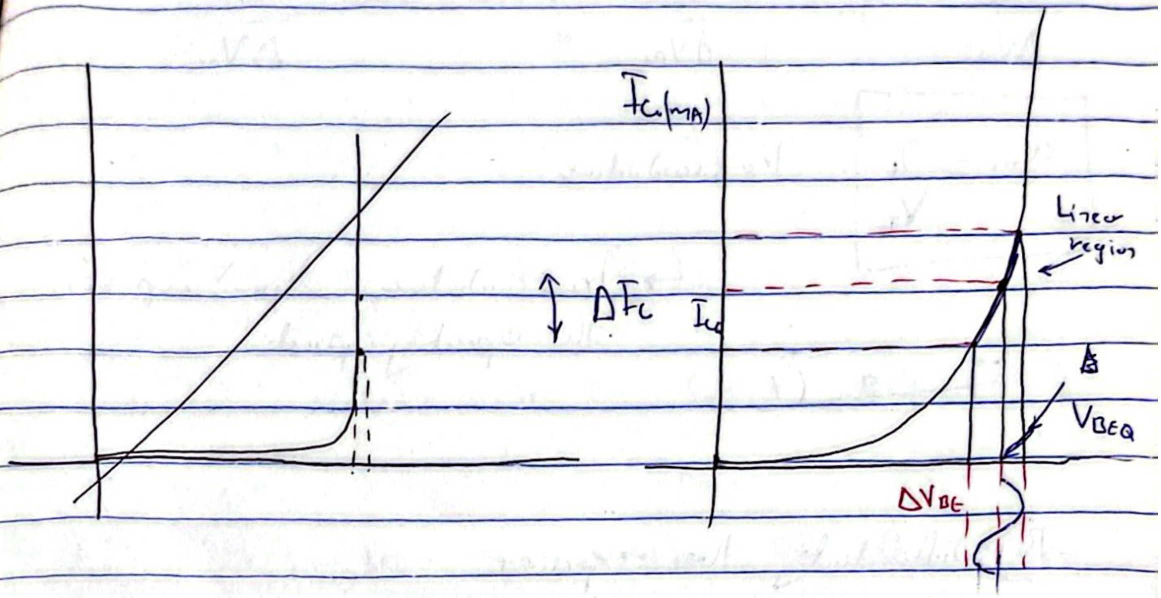
$$\underline{I_c' = I_c \times \exp\left(\frac{\Delta V_{BE}}{V_T}\right)}$$

Voltage ΔV_{BE} = Very Small

When devide by $\frac{\Delta V_{BE}}{V_T}$ is much less than One

$\ll 1$

hen ΔV_{BE} is very small this means that we are operating on the linear region of the exponential curve



This means if change in voltage V_{BE} is sinusoidal, then the change in collector will also be ~~sin~~ sinusoidal

and we can express as $I_C' = I_C \times \left(1 + \frac{\Delta V_{BE}}{V_T}\right)$

$$\exp\left(\frac{\Delta V_{BE}}{V_T}\right) = 1 + \frac{\Delta V_{BE}}{V_T}$$

for small value ~~x~~

can be expanded $e^x = 1 + x + \frac{x^2}{2!} \cdots$

so we can say $1 + x$

$$\boxed{I_C' = I_C + \underbrace{I_C \frac{\Delta V_{BE}}{V_T}}_{\Delta I_C}}$$

ΔI_C ← This is

⑩

$$\Delta I_C = \frac{I_C \times \Delta V_{BE}}{V_T} \quad = \quad \frac{\Delta I_C}{\Delta V_{BE}} = \frac{I_C}{V_T}$$

↓ ↙ as we discussed

$$\frac{\Delta I_C}{\Delta V_{BE}} = g_m = \frac{d(I_C)}{dV_{BE}} \longrightarrow \text{for Small } \frac{\Delta I_C}{\Delta V_{BE}}$$

$$\boxed{g_m = \frac{I_C}{V_T}}$$ Transconductance

→ Transconductance depend upon the operating point

~~I_C ↑ g_m (↑~~

By differentiating these expressions

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right)$$

$$\frac{dI_C}{dV_{BE}} = I_S \exp\left(\frac{V_{BE}}{V_T}\right) \times \frac{1}{V_T}$$

$$\boxed{g_m = I_C \frac{1}{V_T}}$$ Transconductance expression

This depends on opperating point as the value of I_C increases the transconductor will also increase

If I_C ↑ for the same change in base emitter voltage there will be more change in collector current.

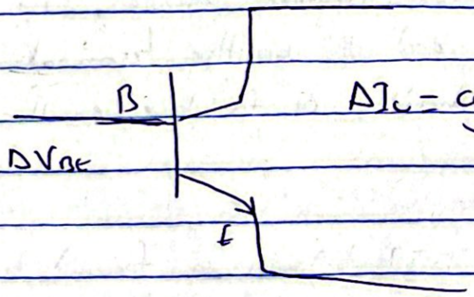
$$\underbrace{I_s \times e^{\left(\frac{V_{BE}}{V_T}\right)}}_{\text{Dc biasing Voltage } V_{BE}} + \underbrace{g_m \Delta V_{BE}}_{\Delta I_c}$$

'Collector current in Large model' - Small change in Signal I_c

So we can separate the Signals

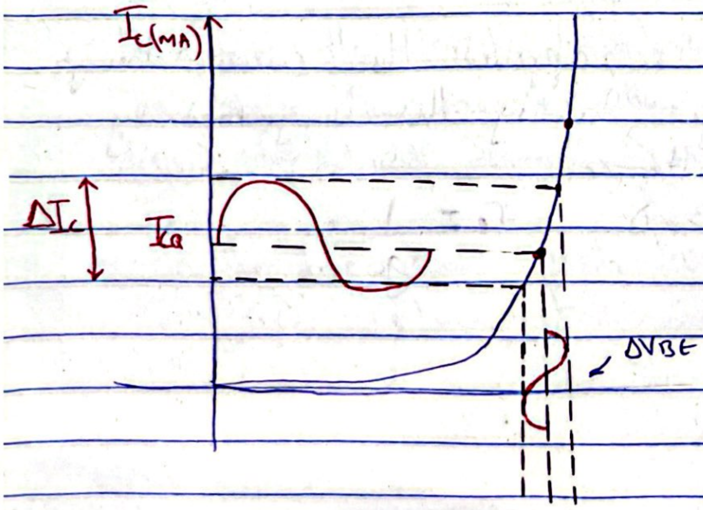
- During dc analysis we can consider all Sources to zero

During Ac analysis we consider all dc Source to zero

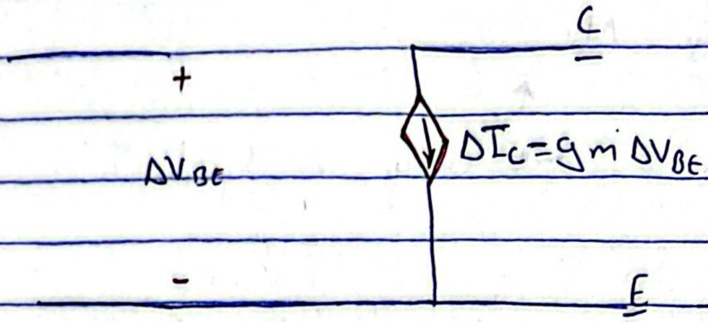


$\Delta I_c = g_m \Delta V_{BE}$

Change in I_c is linearly proportional to change in V_{BE}



So In Small Signal model we can represent as Voltage Controlled ~~Source~~ Current Source.



When there is Change in I_C there is also Change In Base Current I_B

$$\Delta I_B = \frac{\Delta I_C}{\beta} = g_m \frac{\Delta V_{BE}}{\beta}$$

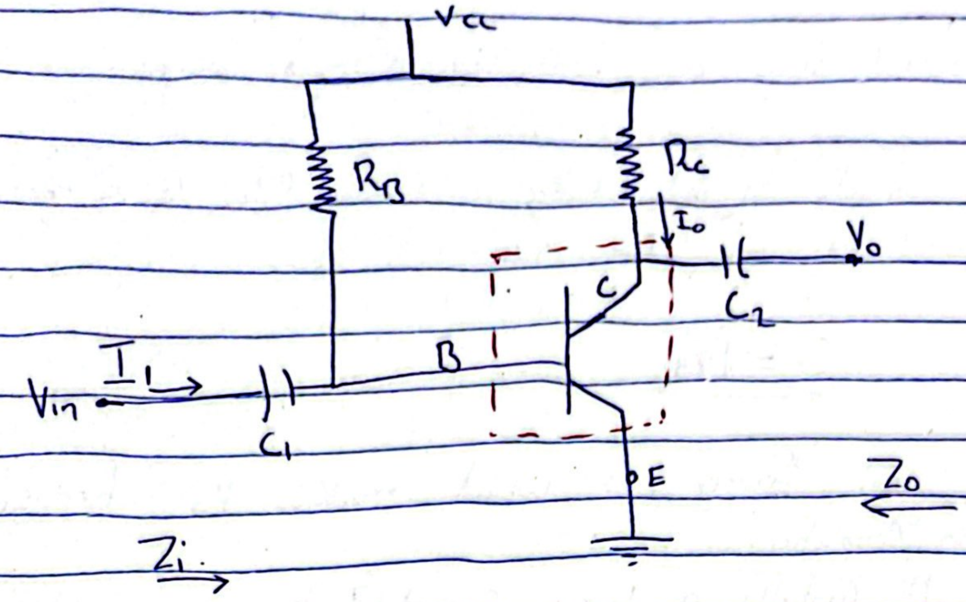
This relation-Ship is linear

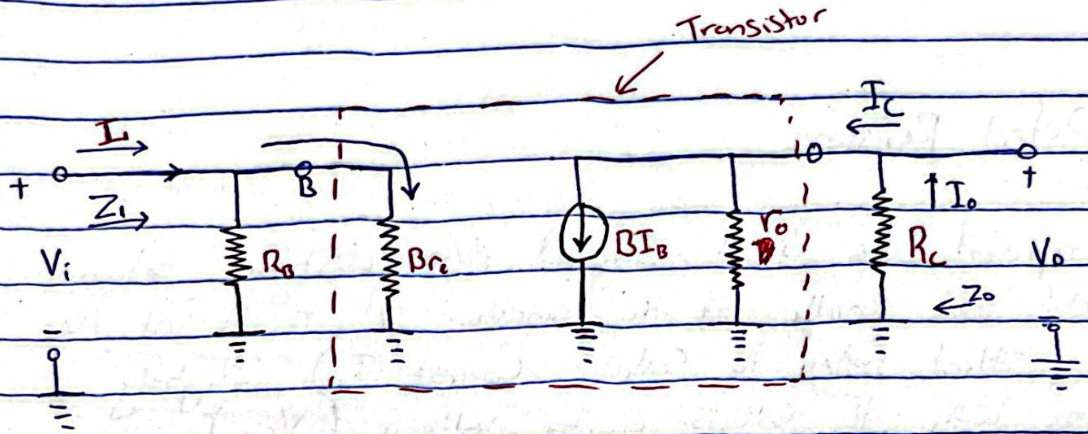
→ We can say that in the Small-Signal model, the resistor exists between the base and the emitter terminal. because there is diode like behavior of the base emitter junction

- The base emitter junction of BJT behaves as forward bias diode during operation

→ when a Small Signal is applied the current through Base emitter junction changes Slightly this is governed by Diode incremental resistance

r_e (dynamic resistance) $r_e = \frac{1}{g_m}$





βr_e :- Base-emitter resistance btn base and emitter of a transistor. It models the fact that base emitter junction behaves like forward-bias diode

- It affect the Input Impedence of transistor
- The higher βr_e Increases the Input Impedence, which is desired for Input Signal Sensitivity

→ It determine how much Input Voltage (V_i) is needed to drive certain base current (i_B)

$\beta I_B \rightarrow$ Current Gain and Controlled Current Source

- The Small-Signal Collector Current (i_c) is Directly proportional to base current (i_B)

$$i_c = \beta i_B$$

The Current Source is what makes the transistor as an Amplifier.
- As It Controlls a Large Current (I_C) using Small Current (I_B)

$r_o \rightarrow$ Output Resistance

- It represent the Small Signal O/P resistance between Collector and emitter of the transistor. It result of the Early effect, when the Collector Current (I_C) Slightly Increases with the Collector emitter voltage (V_{CE})

- r_o models the non-Ideal behavior of the transistor
- In Ideal transistor, r_o would be Infinite $\rightarrow$ meaning the Output Current (I_C) would be Independent of (V_{CE})

$\rightarrow$ The Small-Signal equivalent Circuit Incoperates

1) Input Side:- The Input Voltage (V_i) applied across ~~r_e~~ βr_e Which determines the base current (i_B)

2) Amplification:- The transistor amplifies the Base current (I_B) Into collector Current (I_C) $i_c = (\beta i_B)$ using Controlled Current Source (βi_B)

) Output Side:- The amplified current (i_c) flows through the o/p resistance (r_o) and load resistance (R_C), determining the o/p voltage (V_o.)