Basics of BJT amplifier

BJT amplifiers

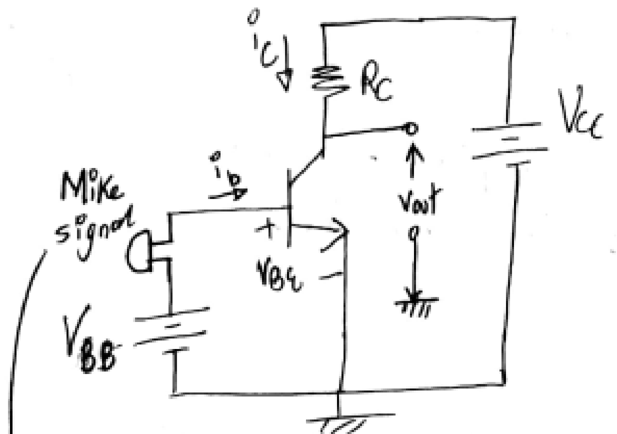
Understanding concepts of amplification with reference to input/output characteristics

• Amplifier requirements:-

1) Gain should be high
eg voltage gain of a voltage ampl^r → high
2) I/P impedance
3) O/P impedance
4) Linearity (O/P should be linear w.r.t I/P)

• BJT as a device should amplify → small time-varying signals.
→ This condition must be satisfied for BJT amplifier to be $\boxed{\text{Linear}}$

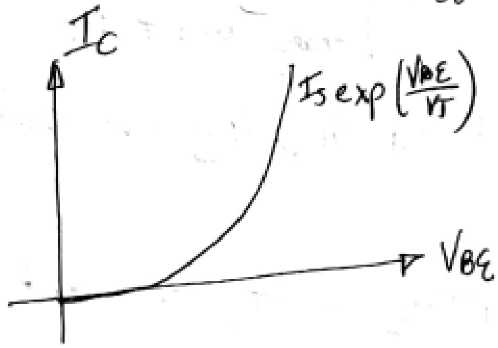
• Next, we need to superimpose small AC s/g with DC?
Why DC biasing is required → so that BJT wakes up & works in proper mode ie active region
→ so that it is used as amplifier

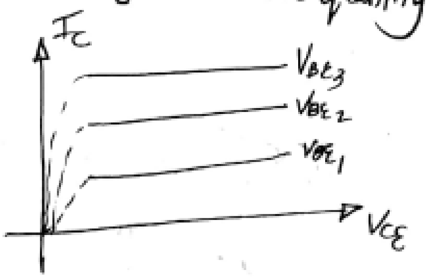


It acts a small-time varying I/P V_{in} ($V_{mike} = V_m \sin\omega t$)

→ BJT act as : <u>voltage-dependent current source</u>

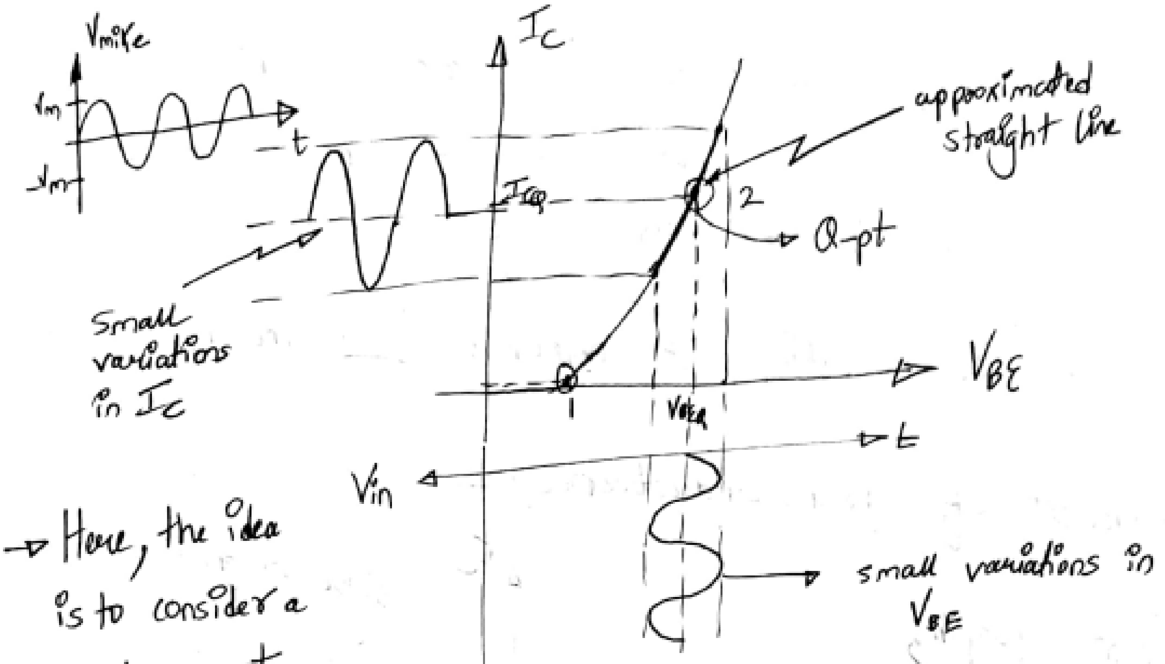
→ "converts" a voltage (V_{BE}) or V_{be} to a current (I_C) --- DC quantity
i_c --- AC quantity





<u>Biasing:</u> Provide proper voltage (V_{BE}) & current (I_C) so that the transistor can amplifies (in the absence of signals)

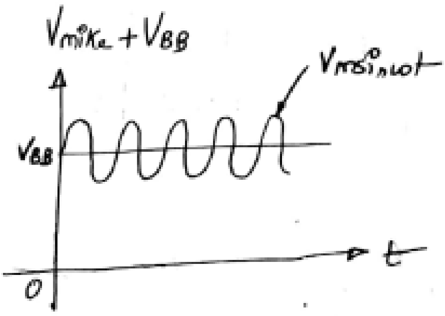
Operating point : The bias values chosen for V_{BE}, I_C, V_{CE}, --- --- etc.



→ Here, the idea is to consider a small segment of exponential curve to be $\boxed{\text{Linear}}$ → straight line

→ So our I/P limit should be within this Linear segment → Here, called as small sig

Combining transfer curve & time response



I_S - reverse satn current
eg $10^{-15}A$

Observations:- 1) At point A, in absence of sig, variations in collector current are very small ($\approx I_S$)
ie BJT is not biased & will not work in active region

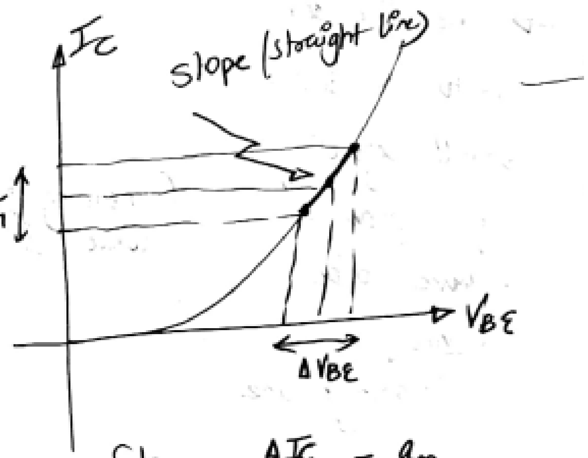
2) At point B, BJT is biased in active region, since it has sufficient value of I_C & V_{BE}

3) A bjt can acts as voltage-dependent current source → since I_C changes in response to its base-emitter voltage.

4) The operating point determine <u>how</u> the bjt responds.

- **Concept of transconductance :-**

From graph,



$$\boxed{g_m = \left.\frac{dI_C}{dV_{BE}}\right|_{Qpt}}$$

slope of I_C vs V_{BE} characteristics

unit : $\frac{1}{\Omega}$ or $\frac{mA}{V}$

$$\text{Slope} = \frac{\Delta I_C}{\Delta V_{BE}} = g_m$$

$$\boxed{\Delta I_C = \Delta V_{BE}\, g_m}$$

ΔI_C → Small changes in I_C

ΔV_{BE} → small changes in V_{BE}

g_m → slope → a constant

It suggest that base-to emitter voltage controls the collector current in a BJT

$$g_m = \frac{dI_C}{dV_{BE}}$$

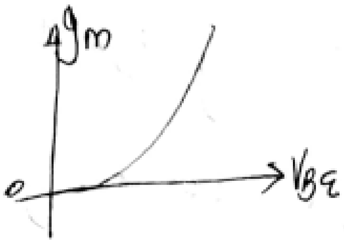
$$= \frac{d}{dV_{BE}}\left(I_S \exp\frac{V_{BE}}{V_T}\right)$$

$$= \frac{I_S}{V_T}\exp\frac{V_{BE}}{V_T}$$

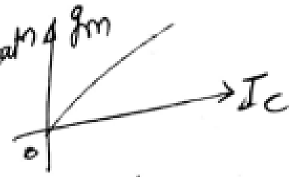
$$\boxed{g_m = \frac{I_C}{V_T}} \quad \text{ie} \quad \boxed{g_m = \frac{I_{CQ}}{V_T}}$$

($V_T = 26mV$ @ $27°C$)

$$\boxed{g_m = \frac{I_{CQ}}{V_T}}$$



1) With no bias $\Rightarrow I_C = 0 \Rightarrow g_m = 0$ $\rightarrow$ No amplification



2) For amplification, we need a certain $g_m \Rightarrow$ certain $I_{CQ} \rightarrow$ certain V_{BE}

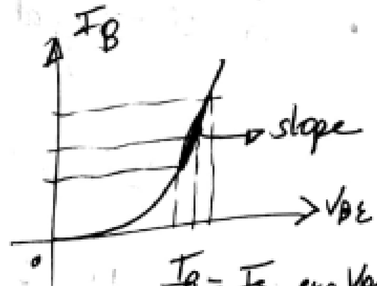
→ ~~Small-signal operation~~ :-

↳ The signal coming into the ckt is "small" ↳ comparable to V_T value.

→ The signal perturbs the bias (operating) point by only a small amount.

• Small-sig parameter (r_π) :-

Consider i/p characteristics of bjt



$$I_B = \frac{I_S}{\beta} \exp\frac{V_{BE}}{V_T}$$

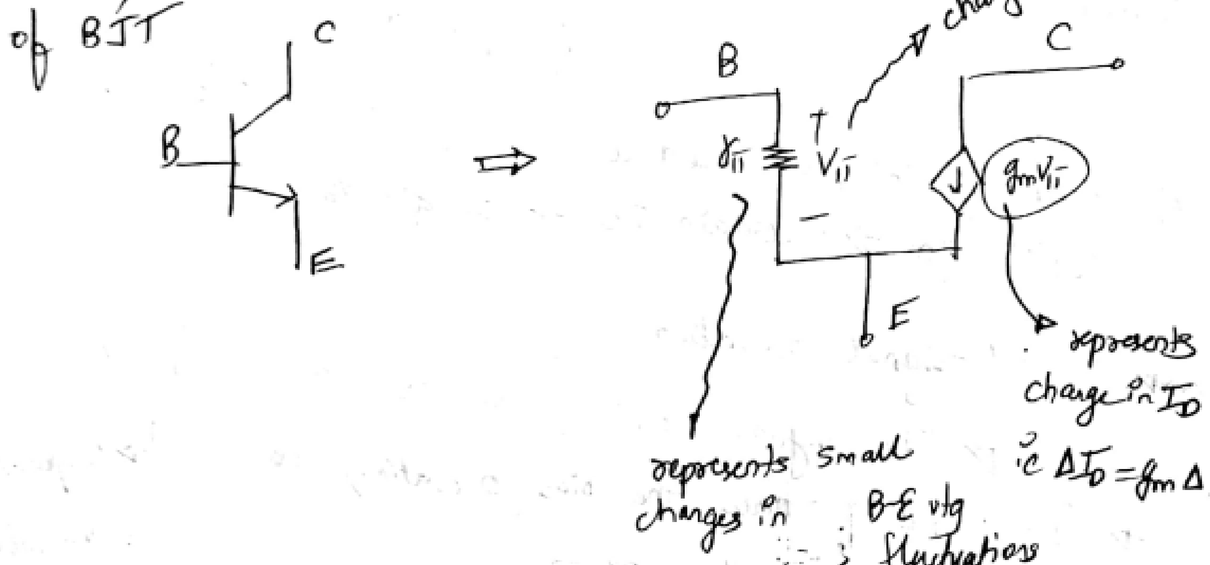
$$r_\pi = \frac{1}{\text{slope}} = \frac{\Delta I_B}{\Delta V_{BE}}\bigg|_{V_{BE} = \text{constant}}$$

ie $$\frac{dI_B}{\Delta V_{BE}} = \frac{d}{dV_{BE}}\left(\frac{I_S}{\beta}\exp\frac{V_{BE}}{V_T}\right) = \frac{I_S}{\beta \times V_T}\exp\left(\frac{V_{BE}}{V_T}\right)$$

ie $$\frac{dI_B}{dV_{BE}} = \frac{I_B}{V_T}$$ ∴ ie $$\boxed{\frac{dV_{BE}}{dI_B} = r_\pi = \frac{I_{BQ}}{V_T}}$$

- **Small-slg hybrid-π model of bjt :-**

Now, we are ready to draw small-signal model of BJT

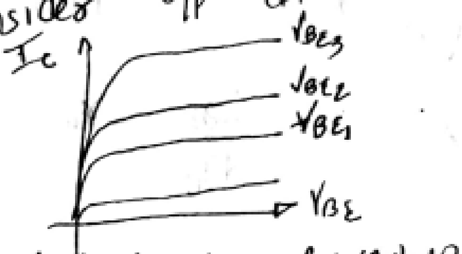


i.e. $\Delta I_D = g_m \Delta V_D$

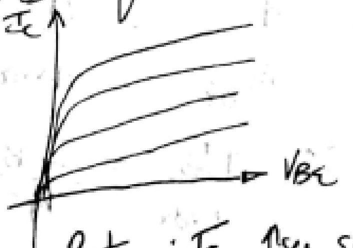
- **Small-signal model** ⟶ (represents only time-varying quantities)
  ⟶ represent only changes in parameters.

- **Early effect** (Small-slg o/p resistance/impedance) (r_o OR r_d)

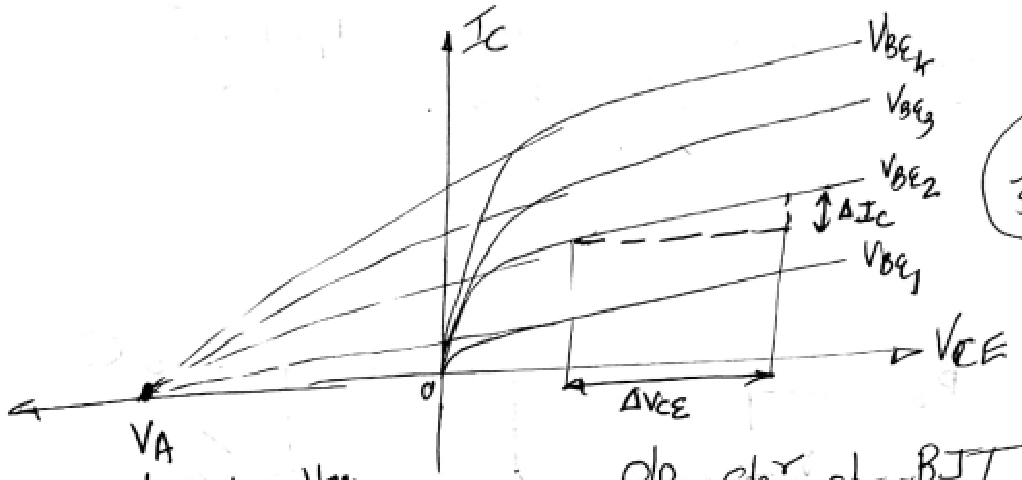
Let's consider o/p characteristics of BJT



We think, I_c remains constant



But, I_c ↑ses slightly with V_{BE}



$$\frac{1}{\text{slope}} = r_o \text{ or } r_d$$

o/p chʳ of BJT

- In above graph, if we extrapolate I_C curve to -ve axis of V_{CE}, these family of curves meet at a point called "Early voltage" V_A.

- In reality, I_C ↑ses slightly with V_{CE} due to early effect.

$$I_C = \left(I_S \exp \frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

V_A : Early voltage

$$\text{Slope} = \frac{dI_C}{dV_{CE}} = \left(\frac{I_S}{V_A} \exp \frac{V_{BE}}{V_T}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

ie $$\frac{dI_C}{dV_{CE}} = \frac{I_{CQ}}{V_A}$$

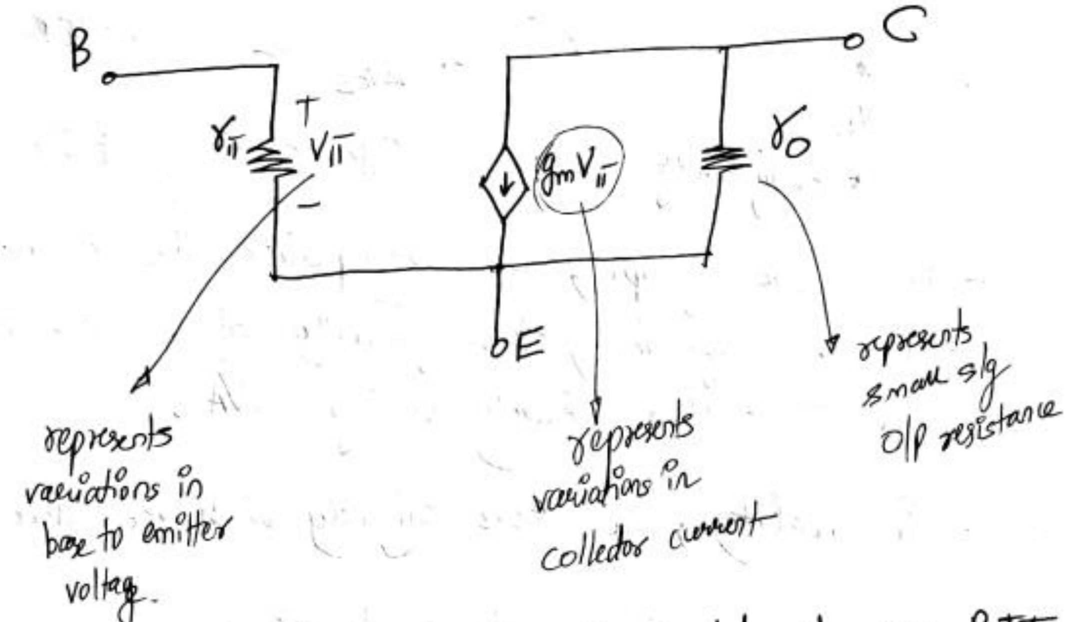
ie $$r_o = r_d = \frac{dV_{CE}}{dI_C} = \frac{V_A}{I_{CQ}}$$

$$\boxed{\text{ie } r_o = r_d = \frac{V_A}{I_{CQ}}}$$

- We need to include r_o, in small-sig model.

small-sig o/p resistance of a BJT biased in forward active region.

Complete small-s/g model of npn BJT including early effect is given below



Small-signal hybrid-π model of npn BJT

→ Small-signal parameters :-

1. $\boxed{r_\pi = \dfrac{\beta}{g_m}}\ \Omega$

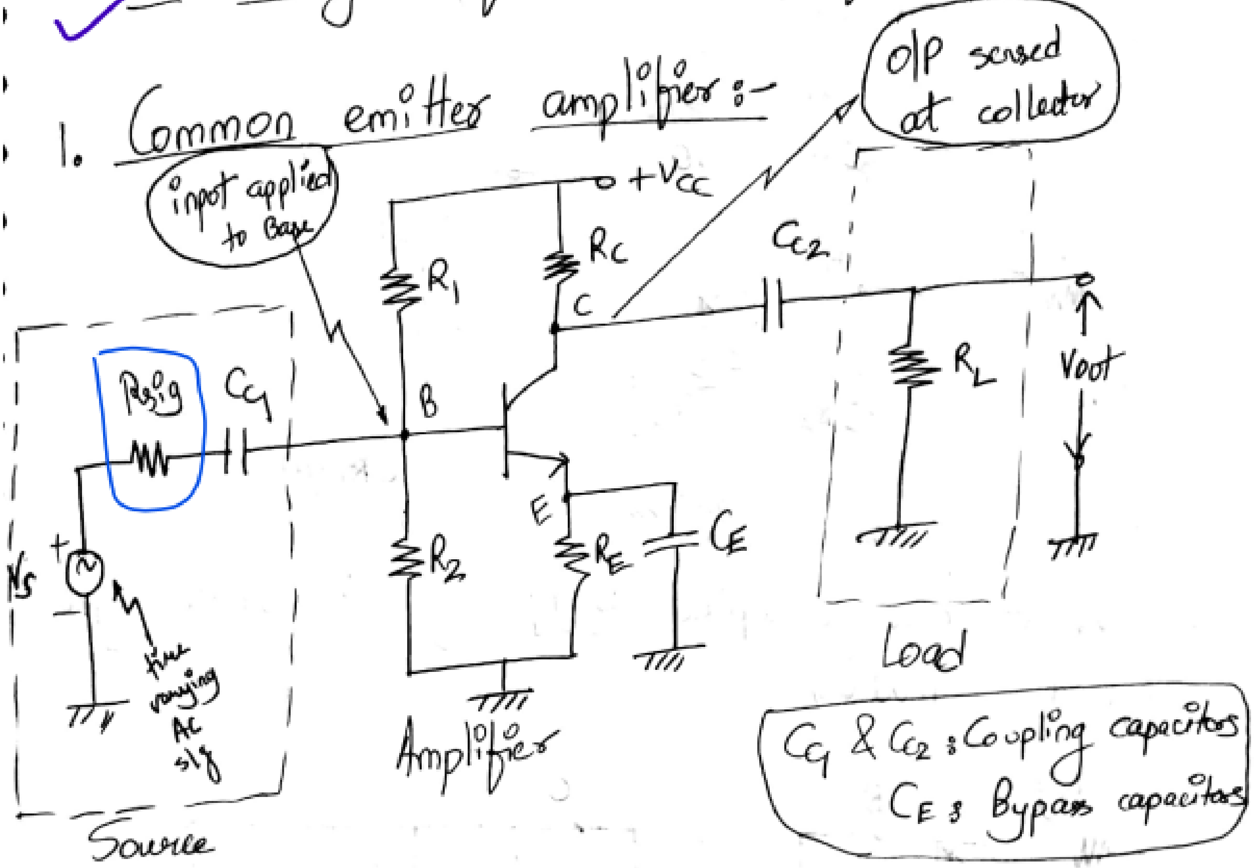
3. $\boxed{r_o = \dfrac{V_A}{I_{CQ}}}\ K\Omega$

2. $\boxed{g_m = \dfrac{I_{CQ}}{V_T}}\ \dfrac{mA}{V}$

Common emitter amplifier with internal resistance Rsig

AC Analysis of BJT amplifiers:- 09

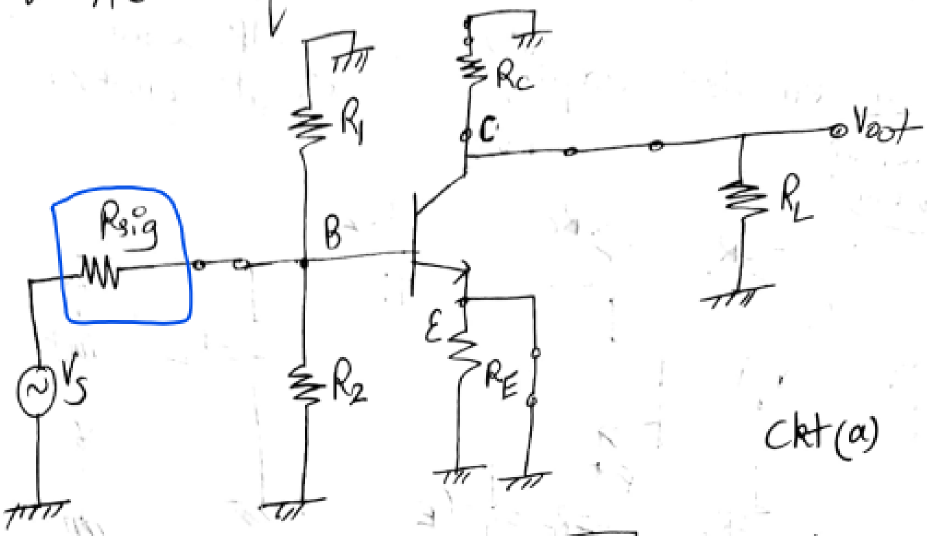
1. Common emitter amplifier:-



Observations:

1. In CE amplifier, i/p signal is applied to the "base" terminal and o/p is sensed at the "Collector" terminal.
2. For AC analysis, all the capacitors are replaced by a short circuit → as the capacitive impedances $\left(X_C = \frac{1}{2\pi f C}\right)$ are very low at mid-frequencies
3. DC supply is also replaced by a short circuit for small signal (AC) analysis.

→ AC equivalent circuit is,



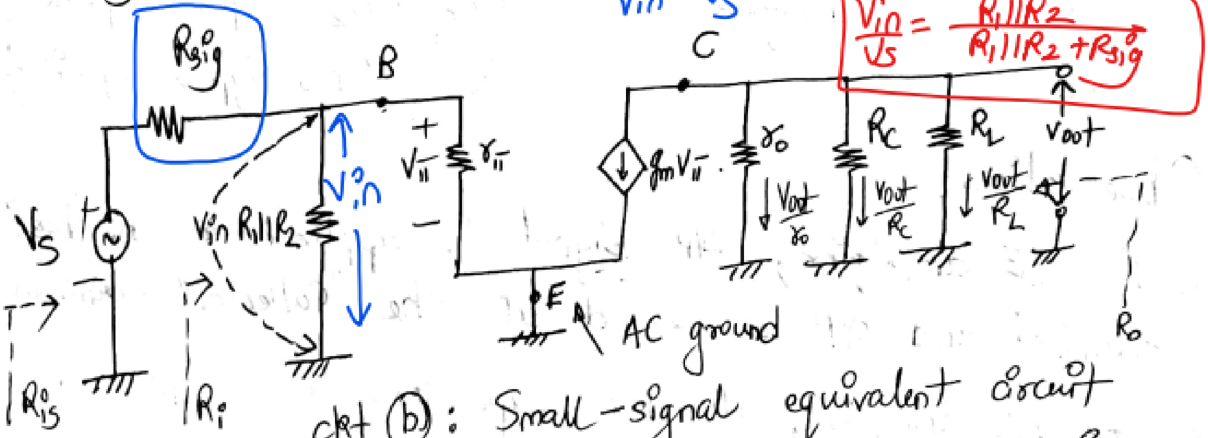
ckt(a)

→ Now, we have to replace $\boxed{\text{BJT}}$ by its small-signal hybrid-π model,

$$A_{V_f} = \frac{V_{out}}{V_{in}} \frac{V_{in}}{V_S}$$

$$A_{V_f} = \frac{V_{out}}{V_S}$$

$$\boxed{\frac{V_{in}}{V_S} = \frac{R_1 || R_2}{R_1 || R_2 + R_{sig}}}$$



ckt (b): Small-signal equivalent circuit

Analysis: i) To find A_v : voltage gain expression

· From ckt b, $V_{in} = V_\pi$

KCL at Collector terminal,

$$g_m V_\pi + \frac{V_{out}}{r_o} + \frac{V_{out}}{R_C} + \frac{V_{out}}{R_L} = 0$$

$$g_m V_{in} = -V_{out}\left(\frac{1}{r_o} + \frac{1}{R_C} + \frac{1}{R_L}\right)$$

$$\Rightarrow \boxed{A_V = \frac{V_{out}}{V_{in}} = -g_m\left(r_o \parallel R_C \parallel R_L\right)}$$

small-slg voltage gain of amplifier

-ve sign indicates that I/P & o/p are out-of phase

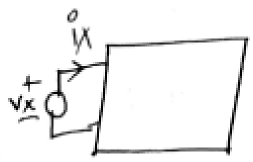
Now, $A_{VS} = \frac{V_{out}}{V_S} = \frac{V_{out}}{V_{in}} \times \frac{V_{in}}{V_S} = A_V \times \frac{V_{in}}{V_S}$

From ckt ⓑ, $A_{VS} = A_V \frac{V_{in}}{V_S}$

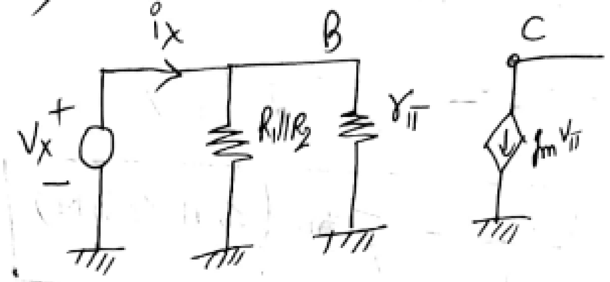
$$\Rightarrow \boxed{\frac{V_{in}}{V_S} = \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_{sig}}}$$ --- by V.D.R

ie $$\boxed{A_{VS} = A_V \times \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_{sig}}}$$

2) Input impedance/resistance (Z_i/R_i):



From ckt (b),



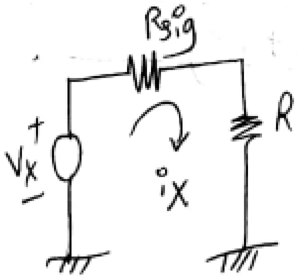
Since, B–C junction is reverse-biased & open-ckt, no current flows from B to C in ckt above,

$\therefore$ Current i_x flows into $(R_1 \| R_2)$ branch & r_π branch

$$\therefore \frac{V_x}{i_x} = R_1 \| R_2 \| r_\pi$$

i.e. $\boxed{R_i = R_1 \| R_2 \| r_\pi}$

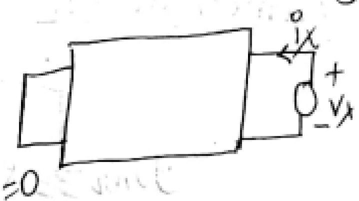
Now, if we include source resistance R_{sig}, we have



$$R_{is} = \frac{V_x}{i_x} = R_{sig} + R_i$$

i.e. $\boxed{R_{is} = R_{sig} + R_1 \| R_2 \| r_\pi}$

3. O/P impedance/resistance : (Z_o/R_o)



For o/p resistance calculation, we short-ckt i/p source.

ie $V_{in} = 0$ ie $V_s = 0$

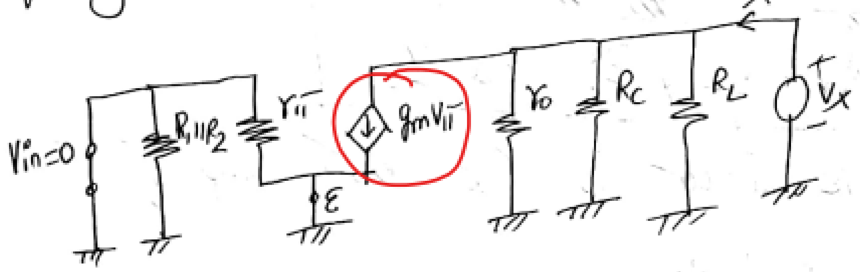
ie Since $V_{in} = V_\pi \Rightarrow V_\pi = 0$; $g_m V_\pi = 0$

It means that a current source being zero

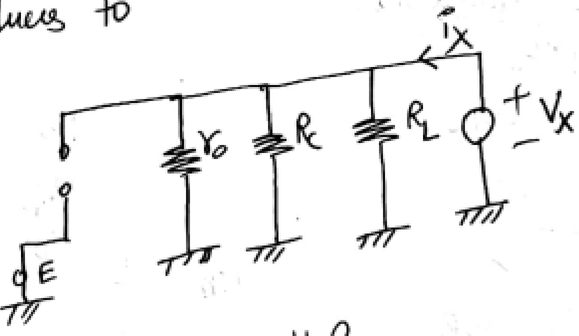
↓

it is replaced by open-ckt

Referring ckt (b), we get



Above ckt reduces to



ie $\dfrac{V_x}{i_x} = r_o \parallel R_C \parallel R_L$

ie $\boxed{R_o = r_o \parallel R_C \parallel R_L}$