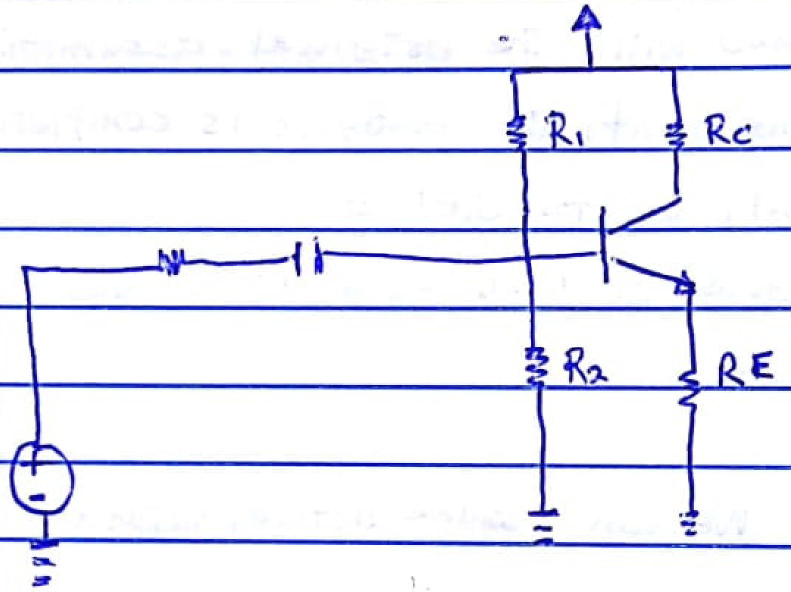
22/11/22 DC Analysis of Voltage Divider Bias



DC Analysis of BJT Amplifier Circuits

DC analysis of a common Emitter Amplifier circuits begins with determining the DC bias values and then removing coupling and by pass capacitors, the load resistor and signal sources to produce the equivalent circuit by applying the Thevenin's Theorem and KVL

Steps for DC Analysis of BJT circuits

=> To analysis BJT circuits with DC source must follow

These five steps

1 Assume an Operating Mode.

2 Enforce the equality condition of that mode.

3 Analyze the circuit with the enforce condition

4 Check the inequality condition of the mode for consistency with the original assumption

If consistent, the Analysis is complete, if inconsistent, Go to step 5.

5 Modify your original assumption and Repeat the steps.

(i) **Assume:** We can assume active, saturation or cutoff mode

(ii) **Enforce:**

Active mode → (F.B)

(a) $V_{BE} = 0.7V$ (npn), $V_{EB} = 0.7V$ (PNP)

(b) $I_C \propto I_B$

$I_C = \beta I_B$ β (current gain Amplifying function)

$I_C = \alpha I_E$

$I_E = (\beta+1) I_B$

Saturation Mode →

ⓐ $V_{BE} = 0.7V (npn) | 0.3V$

$V_{EB} = 0.7V (pnp) | 0.3V$

ⓑ $V_{CB} = -0.5V (npn)$

$V_{CB} = -0.5V (pnp)$

ⓒ $-V_{CE} = 0.2V$ (npn)

$-V_{EC} = 0.2V$ (pnp)

Cutoff Mode →

No current flow we can enforce

$I_C = 0 \quad I_E = 0 \quad I_B = 0$

(iii) Analyze:-

- Active:- The task in dc analysis of a BJT in active mode is to find one unknown current and one additional unknown voltage

ⓐ $I_C = \beta I_B$

$I_E = I_C + I_B$

$I_E = (\beta+1) I_B$

(b) $V_{BE} = 0.7V$

$V_{CE} = V_{CB} + V_{BE}$ (npn)

$V_{EC} = V_{BC} + V_{EB}$ (pnp)

for active Analysis :- I_B; I_C, I_E, V_{CE}, V_{CB}

- Saturation :- We know all BJT voltage but know nothing about BJT current.

  I_B, I_C, I_E

- Cutoff Mode :- All the currents are zero

  V_{BE}, V_{CB}, V_{CE} (any 2)

(4) CHECK:

- Active $V_{CB} > 0$

  $V_{CE} \geq 0.7$

  $I_B > 0$

  $I_C > 0$, $I_E > 0$

- saturation

  $I_C < \beta I_B$

  $I_B > 0$, $I_C > 0$, $I_E > 0$

- cutoff :- V_{BE}, V_C

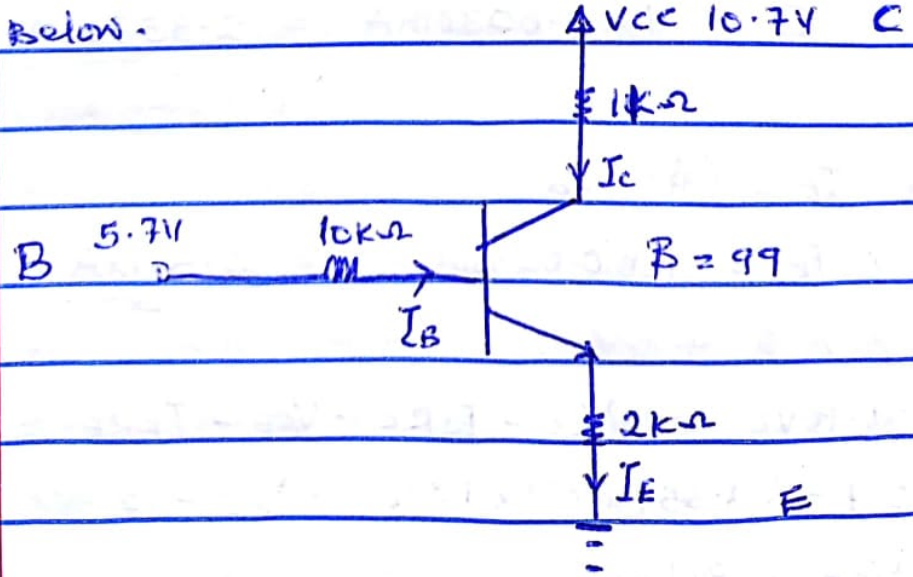
If The Result of our analysis are consistent with each of these inequality, Then we have made the correct analysis.

However, if any of The assumption is not correct, Then we have made the wrong assumption.

(5) MODIFY :- If one or more of The BJT are not in active mode, Then it must be either cutoff or saturation. We must change our assumption and start all over again.

Example one 2.

Determine I_B, I_C, I_E, V_{CE}, V_{CB} and V_B in The circuit below.



Assuming Activemode :-

$V_{BE} = 0.7V$

=> Input KVL $= V_B - I_B R_B - V_{BE} - I_E R_E = 0$

$5.7 - I_B(10\times10^3) - 0.7 - I_E(2\times10^3) = 0$

$5 - I_B(10\times10^{+3}) - I_E(2\times10^3) = 0$

But $I_E = (\beta+1)I_B$

$I_E = (99+1)I_B = 100 I_B$

$5 - I_B(10\times10^3) - 100 I_B(2\times10^3) = 0$

$5 - 10000 I_B - 200000 I_B = 0$

$I_B = \frac{5}{210000} = \underline{0.0238mA}$

From :- $I_C = \beta I_B$

$I_C = 99\times0.0238mA = \boxed{2.357mA}$

from $I_E = (\beta+1)I_B$

$I_E = (100)0.0238mA = \underline{2.38mA}$

=> Output KVL $= V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

$10.7 - (2.357\times10^{-3}\times1\times10^3) - V_{CE} - (2.38\times10^{-3}\times2000) = 0$

$V_{CE} = \boxed{3.58V}$

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

$= 10.7 - (2.357 \times 10^{-3} \times 1 \times 10^{-3})$

$= 8.34V$

$\Rightarrow$ $V_E = I_C R_E$

$= (2.38 \times 10^{-3} \times 2 \times 10^{3})$

$= 4.76V$

$\Rightarrow$ $V_{CE} = V_C - V_E$

$= (8.34 - 4.76)V$

$= 3.58V$

$\Rightarrow$ $V_{CB} = V_{CE} - V_{BE}$

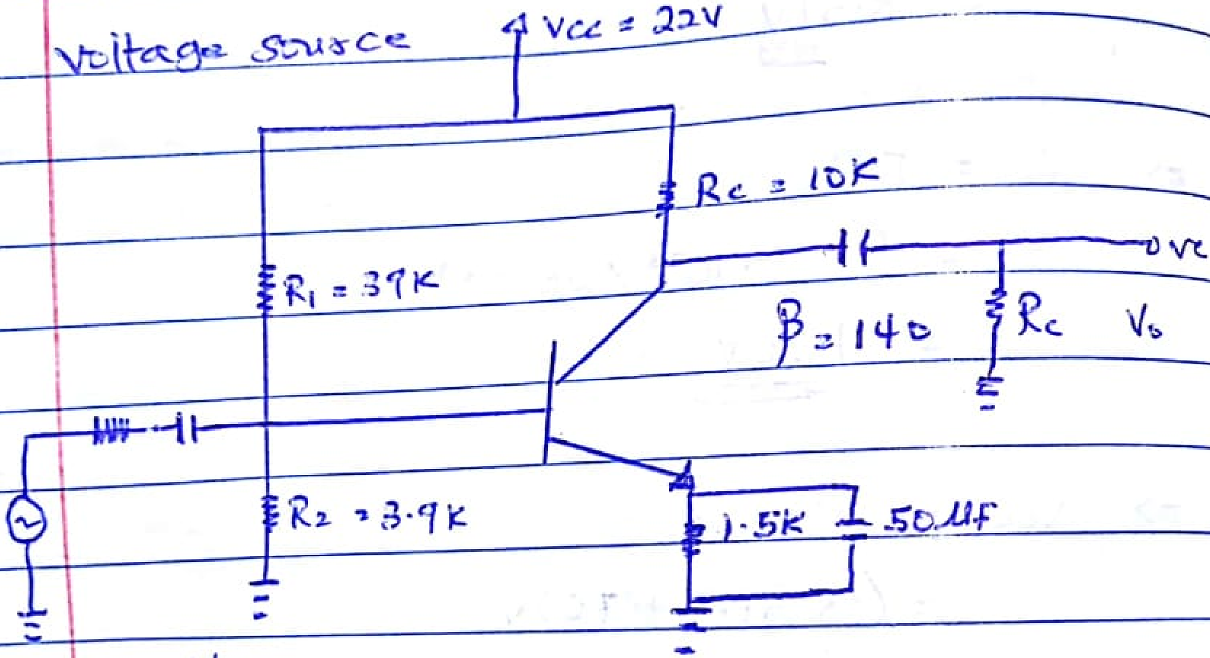
$= (3.58 - 0.7)$

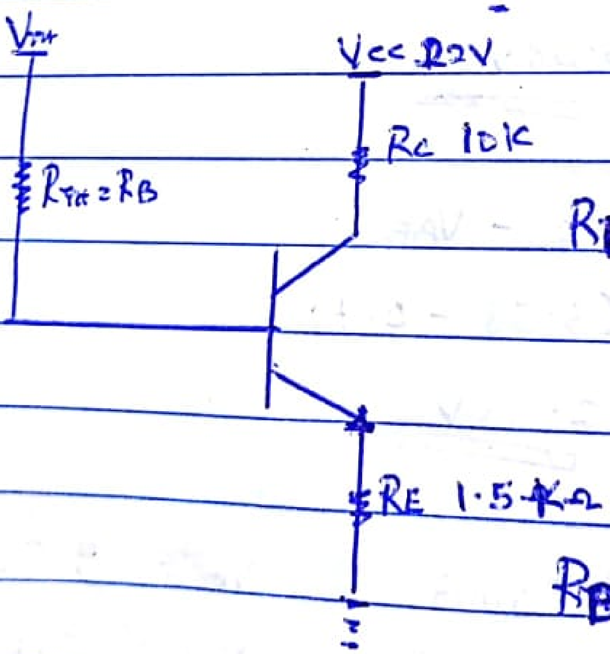
$= 2.88V$

$I_B = 0.0238mA$	$V_E = 4.76V$
$I_C = 2.357mA$	$V_{CE} = 3.58V$
$I_E = 2.38mA$	$V_{CB} = 2.88V$
$V_{CE} = 3.58V$	
$V_C = 8.34V$	

Approximate Analysis

From diagram one. Remove the capacitor, the voltage source





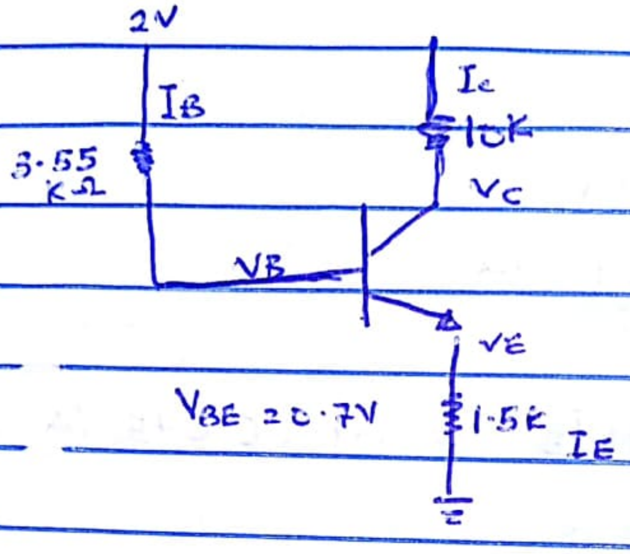
$$R_B = \frac{R_1 R_2}{R_1 + R_2}$$

$$= \frac{(39 \times 3.9)K}{(39 + 3.9)}$$

$$R_B = 3.55K\Omega$$

$$V_{TH} = \frac{R_2}{R_1 + R_2} \times V_{cc}$$ (Using Voltage Divider Rule)

$$= \frac{3.9K}{(39 + 3.9K)} \times 22V = 2V$$



⇒ Output KVL ⇒ $V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

But $I_C = \beta I_B$, $I_E = I_C + I_B = (\beta+1) I_B$

$I_C = 140 I_B$

$I_E = 141 I_B$

$22 - (140 I_B)(10k) - V_{CE} - (141 I_B)(1.5k) = 0$

$22 - 10k I_C - V_{CE} - 1.5k I_E = 0 \quad \ldots \quad (i)$

⇒ Input KVL ⇒ $V_{IH} - I_B R_B - V_{BE} - I_E R_E = 0$

$2 - 3.55k I_B - 0.7 - 1.5k I_E = 0 \quad \ldots \quad (ii)$

⇒ If $\beta R_E > 10 R_2$

$I_C \cong I_E$

Substitute $I_E = 141 I_B$ into eqn (ii)

$2 - 3.55k I_B - 0.7 - 1.5k(141 I_B) = 0$

$2 - 3550 I_B - 0.7 - 211500 I_B = 0$

$$I_B = \frac{1.3}{215050}$$

$$I_B = 6.045\,\mu A$$

$$I_E = 141 I_B = 141 \times 6.045\,\mu A = 0.852\,mA$$

$$I_C = 140 I_B = 140 \times 6.045\,\mu A = 0.846\,mA$$

From Equation one 2.

$$V_{CE} = 22 - 10k(0.846m) - 1.5k(0.852m)$$

$$V_{CE} = 12.25\,V$$

Half - Biased?

$$V_{CE} = \tfrac{1}{2} V_{CC}$$

$$= \frac{1}{2} \times 22 = 11\,V$$

Q- Point (V_{CEQ}, I_{CQ})

$$= (12.25\,V, 0.846\,mA)$$

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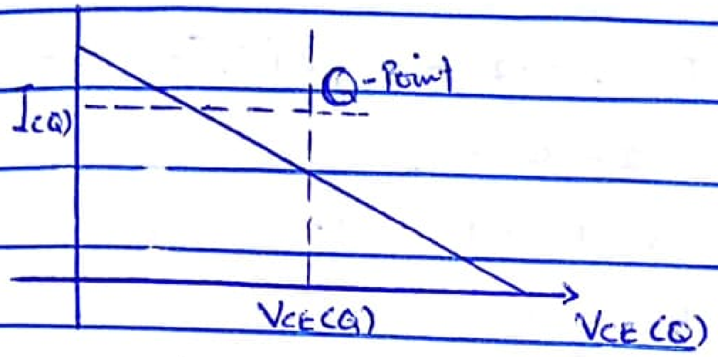

Q_2 change $\beta = 70$ is Amplification factor for common Emitter.

α is Amplification factor for common Base

γ is Amplification factor for common collector.

Input KVL $= V_{TH} - I_B R_B - V_{BE} - I_E R_E = 0$

$$2 - 3.55k I_B - 0.7V - 1.5k I_E = 0 \quad \ldots \text{(1)}$$

$I_C = \beta I_B$ $\qquad I_C = 70 I_B$

$I_E = I_C + I_B$ $\qquad I_E = 71 I_B$

$I_E = (\beta + 1) I_B$

Output KVL :- $V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

$$22 - 10k I_C - V_{CE} - 1.5k I_E = 0 \quad \ldots \text{(2)}$$

Approximate Analysis

$$\beta R_E \geq 10 R_2$$

$$70(1.5k) \geq 10(3.9k)$$

$$105k > 39k \quad \therefore I_C \cong I_E$$

$$2V - 3.55K I_B - 0.7 - 1.5K(71 I_B) = 0$$

$$I_B = \frac{2 - 0.7}{(3.55 + 106.5)K}$$

$$\underline{I_B = 11.81 \mu A}$$

$$I_E = 71 \times 11.81 \mu A$$

$$= \underline{0.839 mA}$$

$$I_C = 70 \times 11.81 \mu A$$

$$= \underline{0.8267 mA}$$

$$V_{CE} = 22 - 10K(0.8267m) - 1.5K(0.839m)$$

$$V_{CE} = \underline{12.47 V}$$

Q-Point (V_{CEQ}, I_{CQ}) $\underline{(12.47V, 0.827mA)}$

Assignment:

Calculate the DC Bias Voltage V_{CEQ} and I_{CQ} The network shown below

$V_{CC} = 12V$, $R_C = 1K\Omega$, $R_1 = 30K\Omega$, $R_2 = 10K\Omega$,

$R_E = 0.5K$, $C_1 = C_2 = C_3 = 10\mu F$, $C_3 = 100\mu F$.

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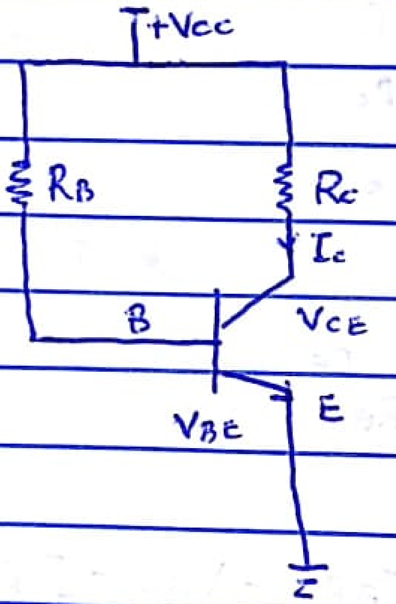
$\beta = 99$. Assume Active mode $V_{BE} = 0.7V$

24th November

DC Analysis of BJT Amplifier

Types of DC Biasing

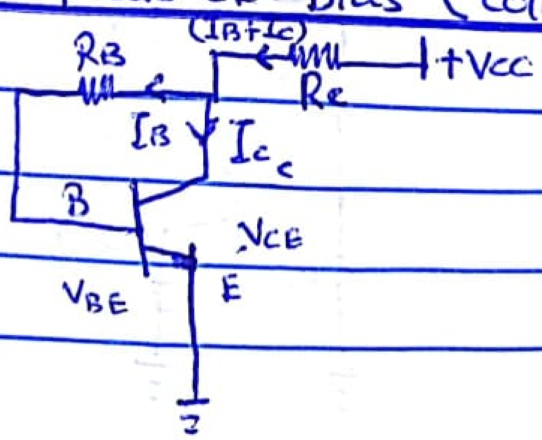
① Fixed Bias (Base Bias)



=> Input KVL = $+V_{cc} - I_B R_B - V_{BE} = 0$

=> Output KVL = $+V_{cc} - I_C R_C - V_{CE} = 0$

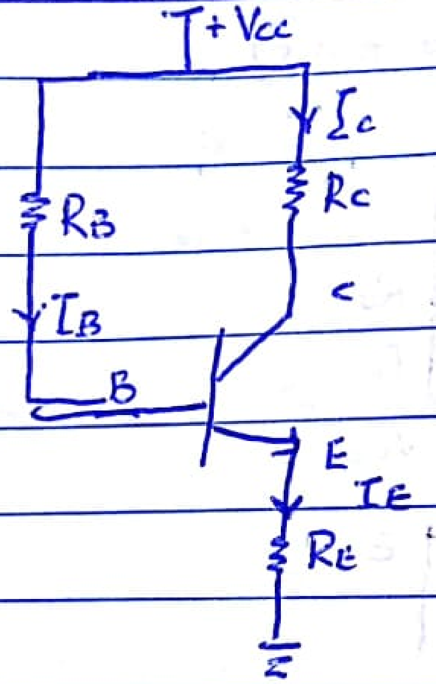
② Collector feedback Bias (Collector Base Bias)



$\Rightarrow$ Input KVL = $+V_{CC} - R_C(I_B + I_C) - I_B R_B - V_{BE} = 0$

$\Rightarrow$ Output KVL = $+V_{CC} - R_C(I_B + I_C) - V_{CE} = 0$

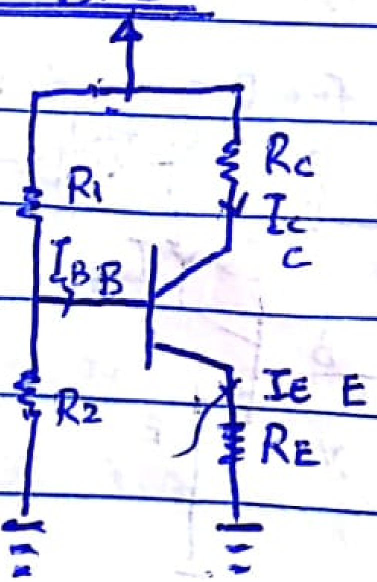
③ Fixed Bias with Emitter Resistor



$\Rightarrow$ Input KVL = $+V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$

$\Rightarrow$ Output KVL = $+V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

④ Voltage Divider Bias

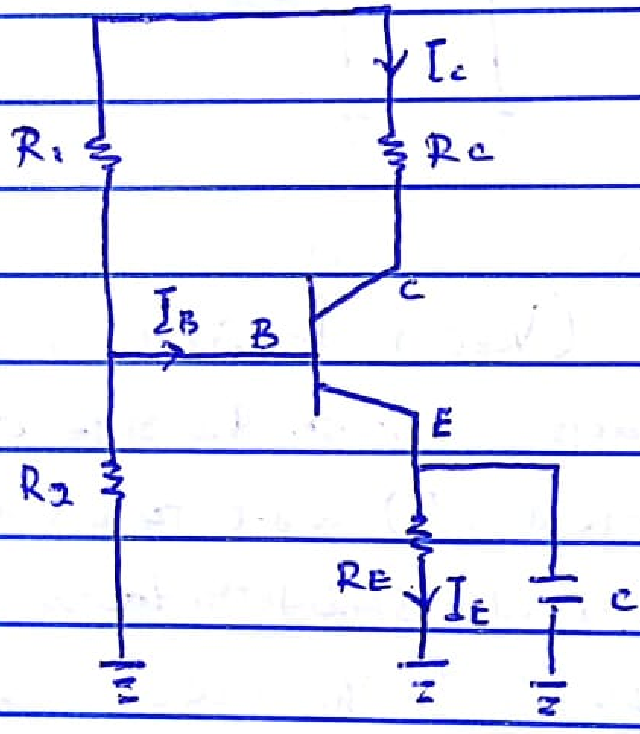


=> Input KVL $= V_{TH} - I_B R_B - V_{BE} - I_E R_E = 0$

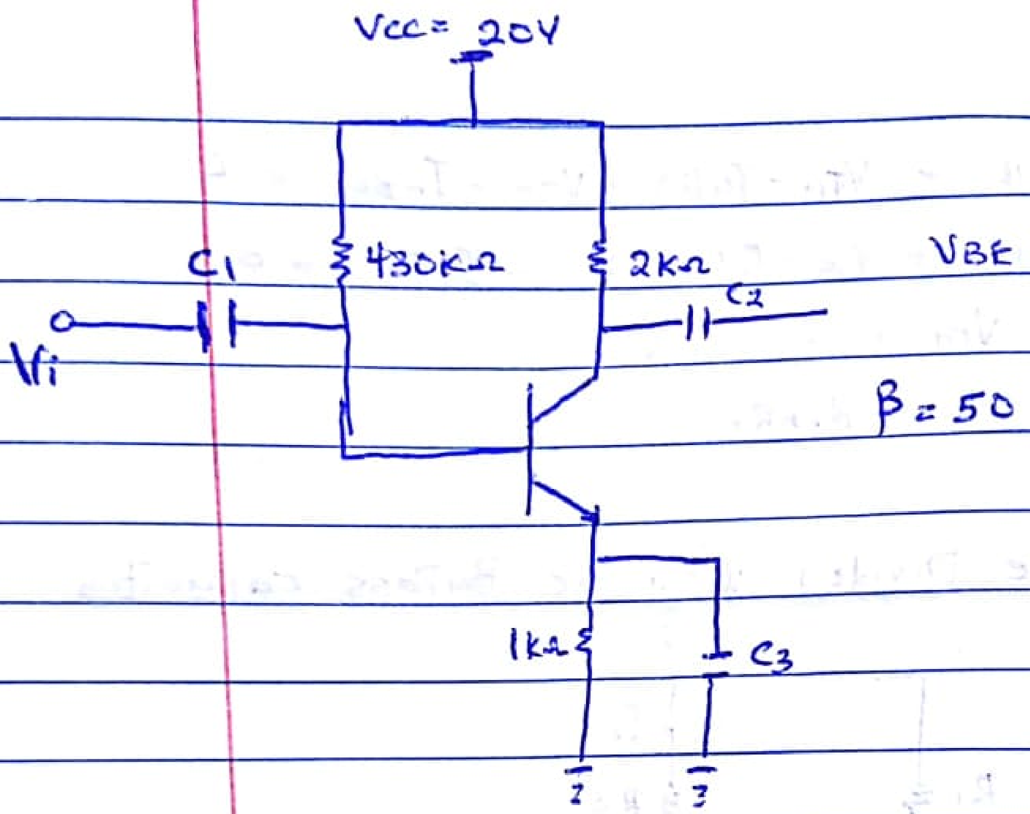
=> output KVL $= V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

=> where $V_{TH} = \frac{R_2}{R_1 + R_2} \times V_{CC}$

5) Voltage Divider with AC Bypass capacitor:



Example: find the Q-Point and the stability factor of the circuit given below



<u>Solution</u>

Q-point = $(V_{CE(Q)}, I_{C(Q)})$

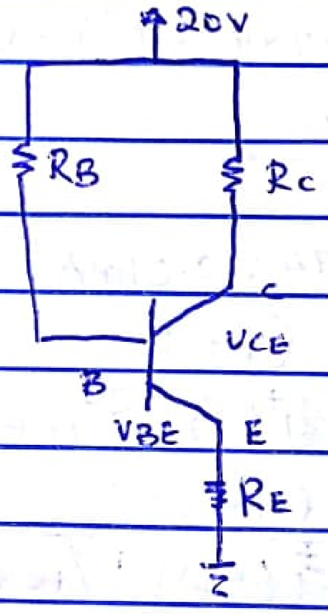
Stability factor indicate the rate of change in collector current (I_c) w.r.t to change in collector leakage current. Stability factor should be as Low as possible. Anything above "25" would result in unsatisfactory performance of the transistor Amplifier.

$$\text{Stability factor } (S) = \frac{(1+\beta)}{1+\beta\left[R_E/R_E+R_B\right]}$$

$\boxed{S < 25}$

Very important

Step one :- We start by opening all capacitors



$\Rightarrow$ Input KVL $= V_{cc} - I_B R_B - V_{BE} - I_E R_E = 0$

$I_E = (\beta + 1) I_B$

$= 20 - R_B I_B - V_{BE} - (\beta+1) R_E I_B = 0$

$$I_B = \frac{V_{cc} - V_{BE}}{R_B + (\beta+1) R_E} = \frac{20 - 0.7}{430k + (51)1k\Omega}$$

$= 40\mu A$

$I_c = \beta I_B = 50 \times 40\mu A = 2.01 mA$

$I_E = (\beta+1) I_B = 51 \times 40\mu A = 2.04 mA$

$\Rightarrow$ Output KVL $= V_{cc} - I_B R_c - V_{CE} - I_E R_E = 0$

$\cancel{V_{CE} = 20 - (2.04\times10^{-3} \times 10^{3}) - (40\times10^{-6} \times 430\times10^{3})}$

$V_{CE} = 20 - (2.04\times10^{3}\times10^{3}) - (2\times10^{3} \times 2.01\times10^{-3})$

$V_{CE} = \underline{13.94V}$

Q-Point = (13.94V, 2.01mA)

$$\text{Stability factor} = \frac{(1+\beta)}{1+(\beta)\left[R_E/R_E+R_B\right]}$$

$$= \frac{(1+50)}{1+(50)\left[1K/1K+430K\right]}$$

$$= \cancel{\frac{51}{\;}}$$

$$= 45.69$$

The circuit is less stable

⇒ Coupling capacitor

C_1 and C_2 are coupling capacitor, they're used in the ~~amplifyer~~ amplifier circuit to isolate DC, so that the biasing of the amplifier is not disturbed. Therefore:

(i) It allows AC and DC voltage to be applied to the Transistors without affecting each other.

(2) Increase coupling between the input and output & ~~circuits~~ signals.

(3) coupling the base and collector current of the transistor.

(4) increase the DC voltage gain.

⇒ **By-Pass Capacitor**

It allows Ac signals to bypass the emitter Resis[illegible]
This ~~respectivel~~ effectively removes it from the out[illegible]
gain equation resulting in an increase in the amplifie[illegible]
Ac gain.

Relationship between α, β and γ

(1) Amplification factor in common Base configuration "α"

There are two types of α $\begin{cases} \alpha_{dc} \\ \alpha_{ac} \end{cases}$

$$\alpha_{dc} = I_C / I_E$$
$$\alpha_{Ac} = \Delta I_C / \Delta I_E \Big|_{V_{CB} = \text{constant}}$$

(2) Amplification factor for common Emitter configuration "β"

$$\beta_{dc} = I_C / I_B$$
$$\beta_{Ac} = \Delta I_C / \Delta I_B \Big|_{V_{CB} = \text{constant}}$$

③ Amplification factor in common collector configuration

$$\gamma_{DC} = I_E / I_B$$

$$\gamma_{AC} = \Delta I_E / \Delta I_B \,\Big|\, V_{CE} = \text{constant}$$

$$I_E = I_C + I_B$$

$$\frac{I_E}{I_B} = \frac{I_C}{I_B} + \frac{I_B}{I_B}$$

$$\boxed{\gamma = \beta + 1}$$ Relationship between γ and β

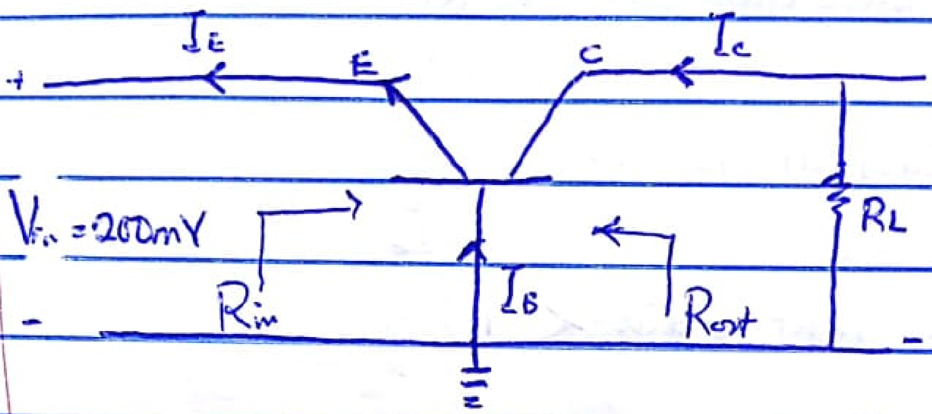
rom :- $$\beta = \frac{\cancel{\gamma}\alpha}{1-\alpha}$$

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

$$\boxed{\gamma = \frac{1}{1-\alpha}}$$ Relationship between γ and α

$$\boxed{\gamma = \beta + 1 = \frac{1}{1-\alpha}}$$ Relationship between α, β and γ

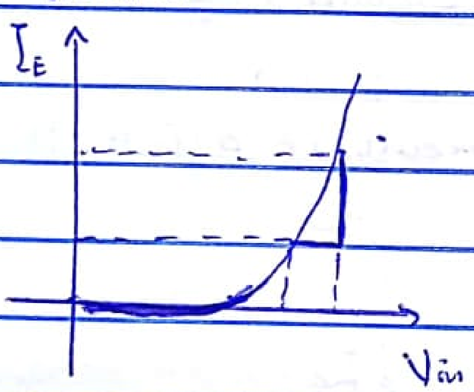
Example: Transistor Amplification Action



AC Amplification

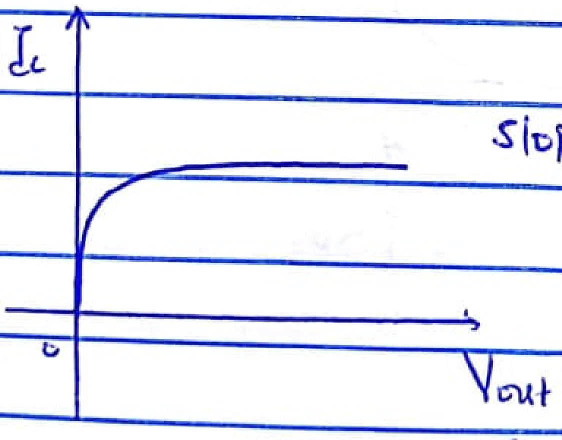
$V_i = 200mV$

$$\boxed{I_E = \frac{V_i}{R_i}}$$



$V_i = I_i \cdot R_i = I_E R_i$

$\text{slope} = \frac{1}{R_i}$ OR $\frac{\Delta I_E}{\Delta I_E R_i}$



slope = 0 (slope of a straight Line)

$\alpha < 1$ [within the range 0.95 - 0.99]

$I_c = \alpha I_E$ since $\alpha \cong 1$

$$\boxed{I_c = I_E}$$

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$\boxed{V_{out} = I_C R_{out}}$

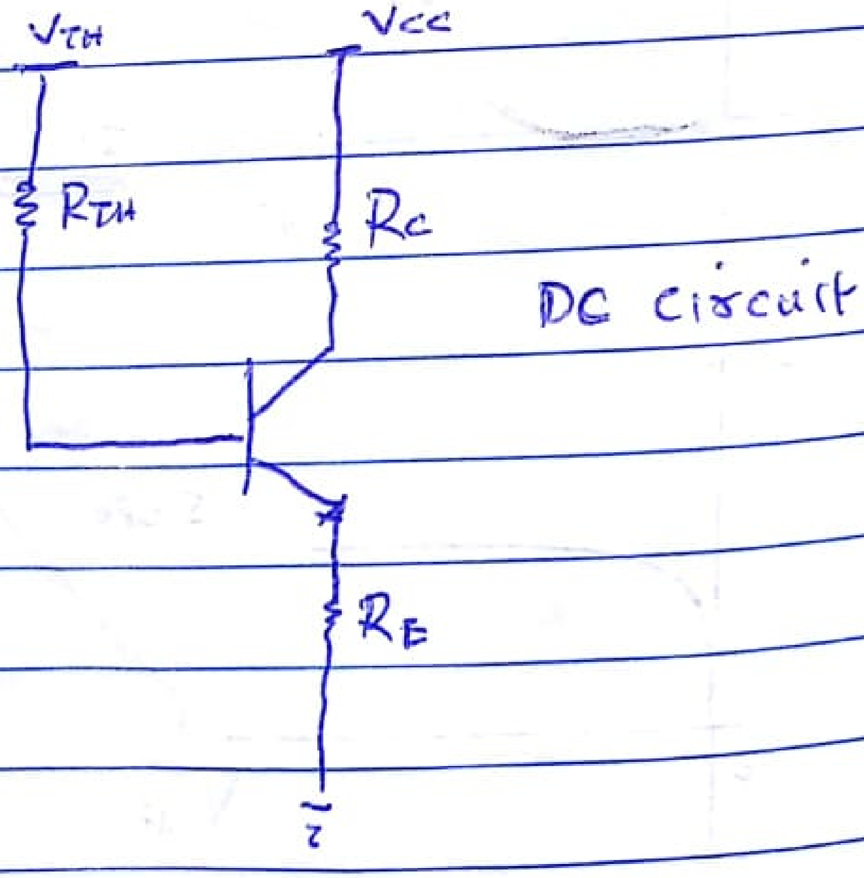
Voltage Gain $(A_V) = \frac{V_{out}}{V_{in}}$

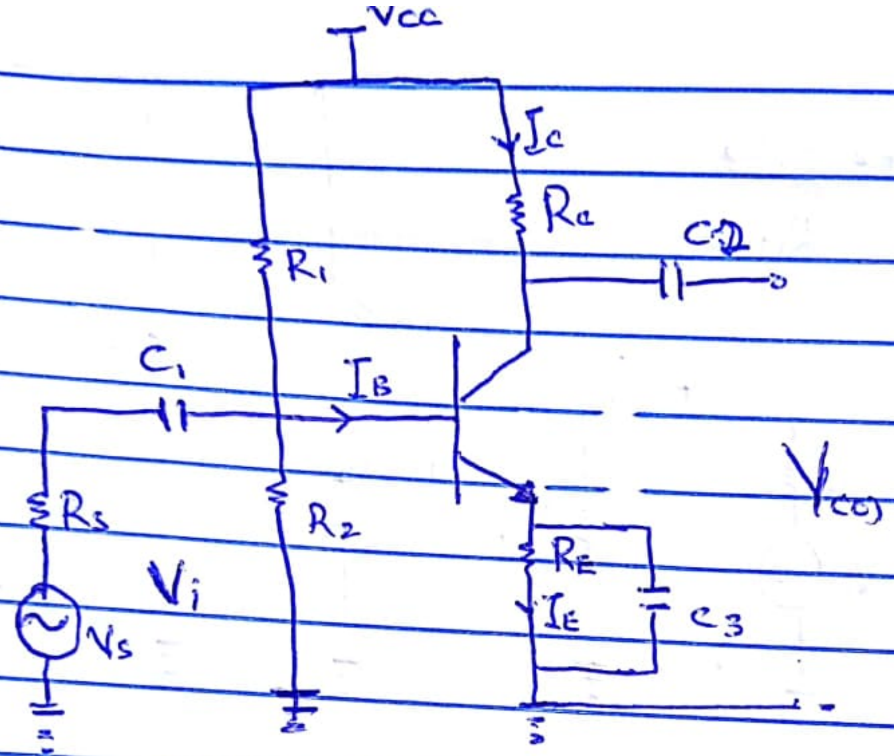
Current Gain $(A_i) = \frac{I_C}{I_E}$

(Current Gain < 1) Always

Ac Equivalent Circuit (Ac Analysis) of BJT Amplifier

Ac Equivalent circuit of BJT Amplifier



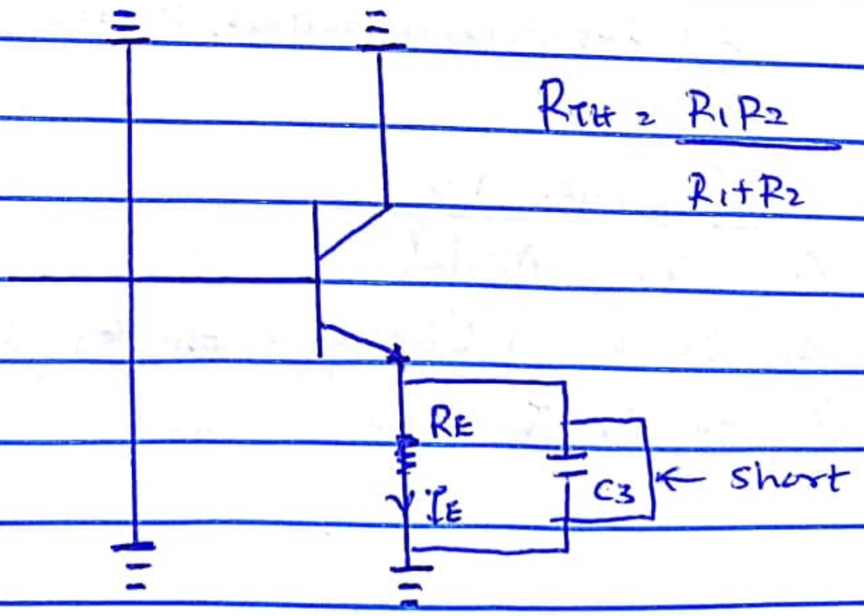


AC Circuit

① **Step one:** Short-circuit all DC sources (connect to Ground)

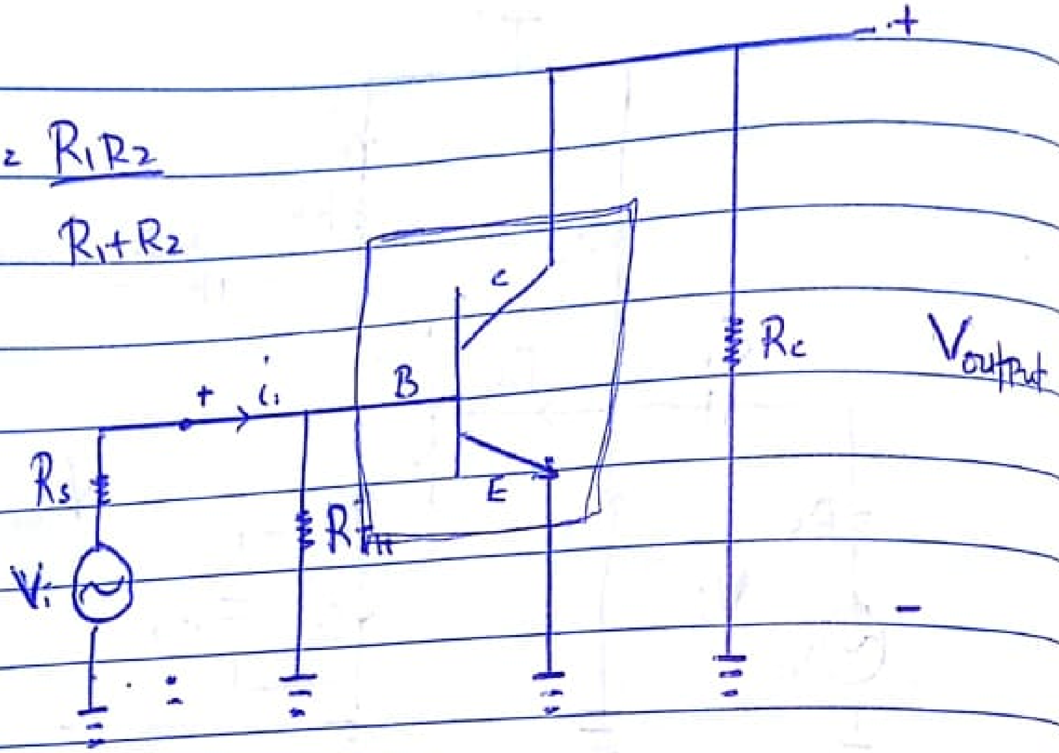
② **Step two:** Short all capacitors

③ **Step three:** Redraw the network



$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

$R_{TH} = \dfrac{R_1 R_2}{R_1 + R_2}$



Equivalent model of the Transistor.

Equivalent model is a combination of circuit elements properly chosen to best represent the actual behavior of the device under specified operating conditions.

E.g. Resistors, Capacitors, Voltage or Current sources

Transistor Model

① Hybrid Model

② r_e model (Dynamic Emitter Resistance Model)

③ Hybrid π model

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Transistor Models

- Hybrid model
- r_e model (Dynamic emitter Resistance model)
- Hybrid π model

are for small signals

Hybrid model: (h-model or h-Parameters model)

Hybrid model is the equivalent model of transistors used in small signal analysis. Hybrid model was widely used in the early years before the Popularity of r_e model.
In hybrid model, the Parameters are defined in general terms for any operating condition, but in case of r_e model, the Parameters are defined by the actual operating conditions (advantage of r_e model).

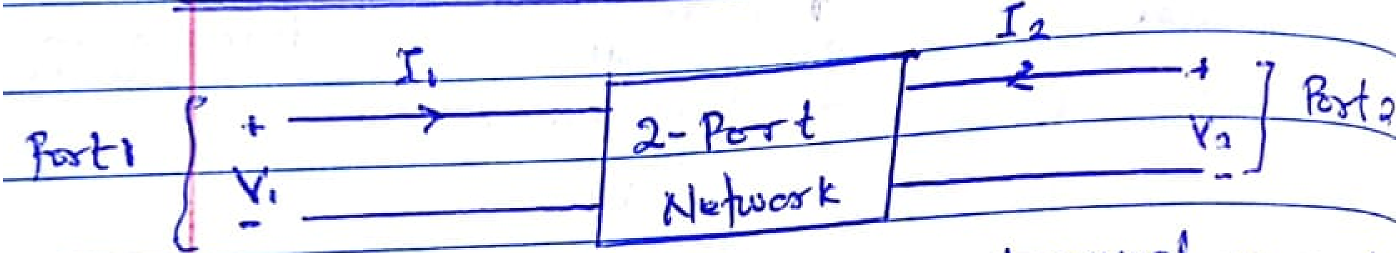
In hybrid Model, the h-Parameters need to be determined, then used to draw the equivalent circuit.

Calculation of h-parameters: (h- stands for hybrid)

What is the significance of the word hybrid? Hybrid means mixed - These Parameters have mixed dimensions.
These are 4 important parameter in the small-signal

amplifiers and they can be obtained using only Impedance (Z-Parameters) or Admittance (Y-Parameters)

General 2-Port Network:



We are only interested in the terminal currents and terminal voltages. Transistor circuit is also a 2-port Network:

Total current/Voltage = dc Value + ac Values

I_1, I_2, V_1, V_2 — are sum of their respective dc and ac values.

Taking 2 quantities as dependent variables and the other 2 quantities as independent variables

Let say: V_1 & I_2 => Dependent Quantities

V_2 & I_1 => Independent Quantities

Let say: $V_1 = f_1(I_1, V_2)$

$I_2 = f_2(I_1, V_2)$

we cand find the changes in V_1 and I_2 as

Total differentials:-

$$dV_1 = \frac{\partial V_1}{\partial I_1} \cdot dI_1 + \frac{\partial V_1}{\partial V_2} \cdot dV_2 \quad \ldots\ldots (1)$$

similarly;

$$dI_2 = \frac{\partial I_2}{\partial I_1} \cdot \partial I_1 + \frac{\partial I_2}{\partial V_2} \cdot dV_2 \quad \ldots\ldots (2)$$

$\Rightarrow$ $\frac{\partial V_1}{\partial I_1}$ $\Rightarrow$ has a unit of impedance (i.e V/I) = h_{11}

$\frac{\partial V_1}{\partial V_2}$ $\Rightarrow$ Dimensionless = h_{12} (Voltage Gain)

$\frac{\partial I_2}{\partial I_1}$ $\Rightarrow$ Dimensionless = h_{21} (Current Gain)

$\frac{\partial I_2}{\partial V_2}$ $\frac{\partial I_2}{\partial V_2}$ $\Rightarrow$ has unit of Admittance = h_{22}

We can re-write equations (1) and (2) as:

$$V_1 = h_{11} i_1 + h_{12} V_2 \quad \ldots (3)$$

$$i_2 = h_{21} i_1 + h_{22} V_2 \quad \ldots (4)$$

Applicable to all the Transistor configurations CB, CE, CC

Make $V_2 = 0$ in equation (3) and (4)

From eqn (3) $\Rightarrow$ $h_{11} = V_1/i_1 \big|_{V_2 = 0}$ $\rightarrow$ Input impedance with the output short circuited or "Z_i"

$V_2 = 0$ (By short-circuiting the Voltage)

h_{ic} → input impedance for all collector configuration

from eqn ④ ⇒ $h_{21} = \frac{i_2}{i_1}\Big|_{V_2=0}$ (Forward current Gain) when output voltage is shortcircuited

Forward current Gain when the output is short circuited

So we can write?

$$h_i = h_{11} = V_1/i_1 \quad \text{and} \quad h_f = h_{21} = i_2/i_1$$

From ③ : If $i_1 = 0$

$$h_r = h_{12} = V_1/V_2 \Big|_{i_1=0}$$

Reverse voltage gain with it input open circuited

From ④

$$h_o = h_{22} = i_2/V_2 \Big|_{i=0}$$

output Admittance with the input open circuited

So the 4 h-Parameters are h_i, h_f, h_r and h_o

h_i	V_1/i_1 when $V_2 = 0$	input Impedance
h_f	i_2/i_1 when $V_2 = 0$	Forward current Gain
h_r	V_1/V_2 when $i_1 = 0$	Reverse Voltage Gain
h_o	i_2/V_2 when $i_1 = 0$	Output Admittance

Nomenclature of h- Parameters:

$h_{L_1L_2}$

where:

=> $\boxed{L_1}$ denotes the nature of the Parameter as (i/p impedance, forward current gain, Reverse Voltage gain or o/p admittance)

=> $\boxed{L_2}$ denotes the transistor configuration (CB, CE or CC)

Examples:-

(i) If we have input impedance of CE => h_{ie}

(ii) Reverse Voltage gain of CB => h_{rb}

(iii) Output Admittance of CC => h_{oc}

(iv) Forward current gain of CB => h_{fb}

(v) Write: h_{fe}, h_{fc}, h_{ob}, h_{re} and h_{rc} in full.

Hybrid Model Equivalent Circuit

Re-writing equations (3) and (4)

$$V_1 = h_i i_1 + h_r V_2 \quad \ldots\ldots \quad (5)$$

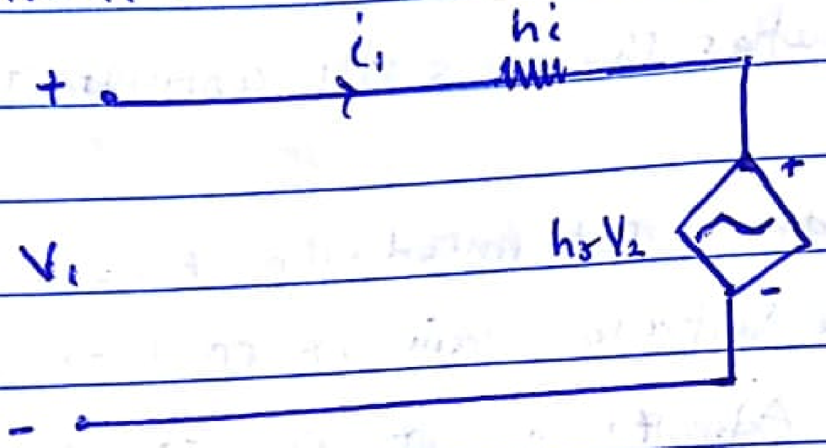
$$i_2 = h_f i_1 + h_o V_2 \quad \ldots\ldots \quad (6)$$

each term of equation (5) is having a unit of Volts:

$$V_1 (\text{Volts}) = h_i i_1 (\text{volts}) + h_r V_2 (\text{Volts})$$

So to obtain the equivalent circuit of equation ⑤,
we will use KVL $\Rightarrow + V_i - h_i i_1 - h_r V_2 = 0$

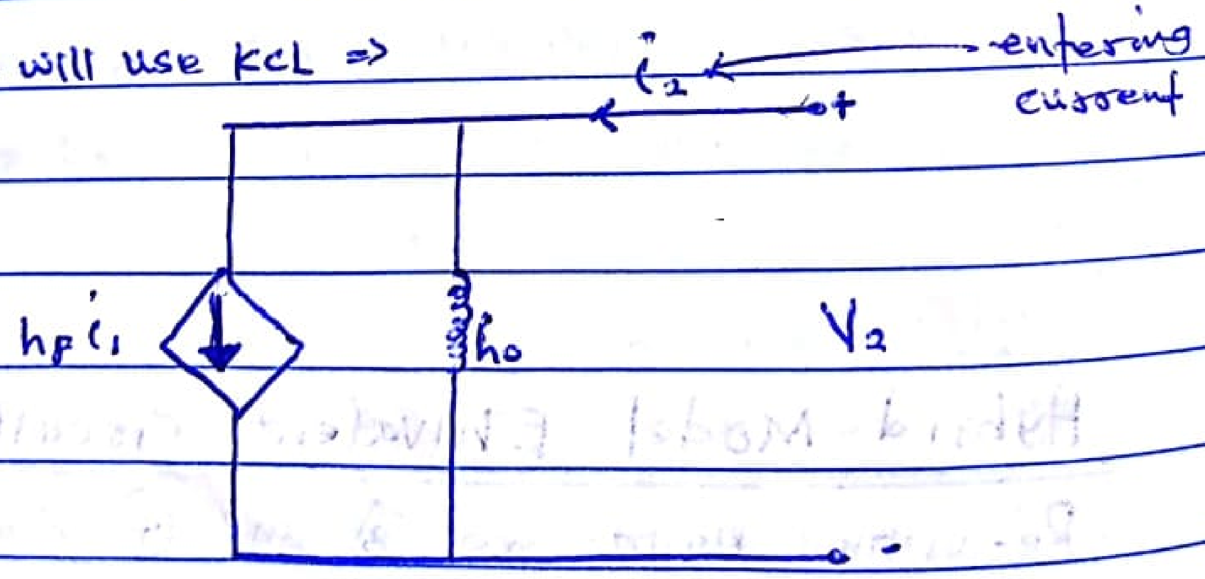
The circuit is:



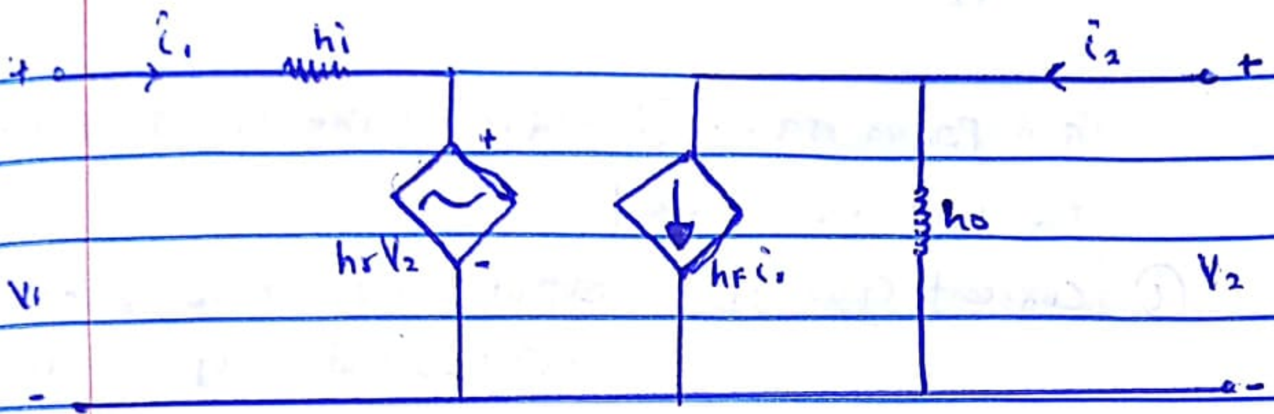
In equation ⑥, each term is having a unit of Amps.

$\Rightarrow$ $i_2(A) = h_f i_1(A) + h_o V_2(A)$

So to obtain the equivalent circuit for equation ⑥,
we will use KCL $\Rightarrow$



Therefore by combining the 2 circuits, we will have the final equivalent circuit as:



For ac analysis, the Transistor is replaced with the formal equivalent circuit (General Model). Information like the transistor configuration are not added. Additional subscripts will tell us the transistor configuration.

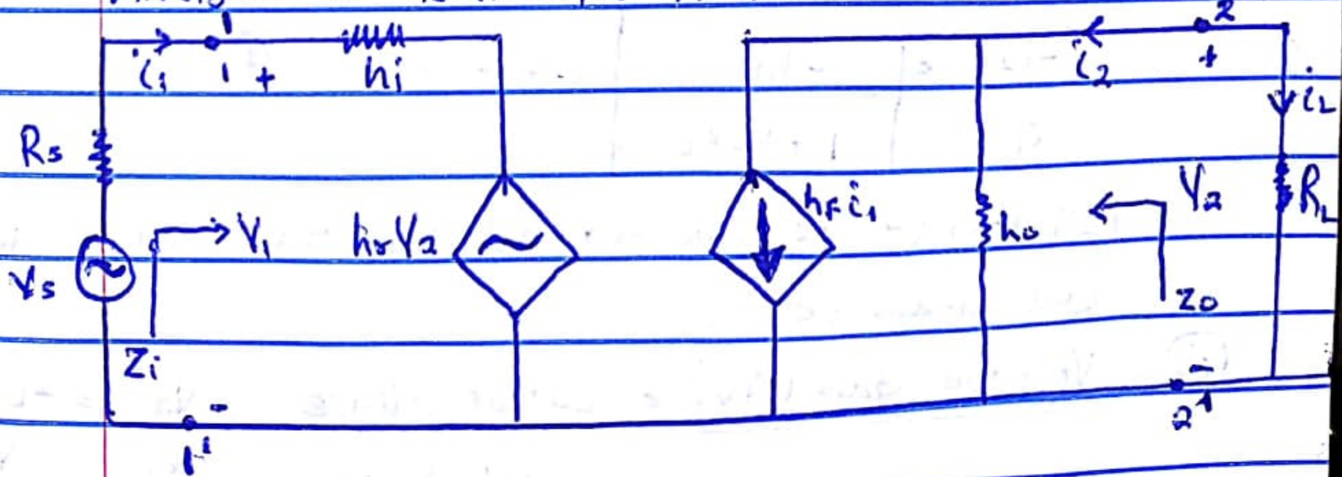
In common-Emitter configuration : $h_i \rightarrow h_{ie}$

$h_f \rightarrow h_{fe}$

$h_o \rightarrow h_{oe}$, $i_1 = I_B$, $i_2 = I_C$

$h_r = h_{re}$, $V_1 = V_{BE}$, $V_2 = V_{CE}$

Analysis of Transistor Amplifier Using h-Parameters:



To find the expressions for Current gain, Voltage gain

i_L = Load current

and Power gain. [Introducing the i/p supply and the load Resistance].

① **Current Gain (A_i)** = $\dfrac{\text{output current}}{\text{input current}} = \dfrac{i_L}{i_1} = \dfrac{-i_2}{i_1}$

(V_2) = Voltage drop across $R_L = V_2 = i_L R_L = -i_2 R_L$

From eqn ⑥ of h-parameter equations:

$$i_2 = h_f i_1 + h_o V_2$$

$$i_2 = h_f i_1 + h_o(-i_2 R_L)$$

$$i_2 + h_o i_2 R_L = h_f i_1$$

$$i_2(1 + h_o R_L) = h_f i_1$$

$$i_2 = \frac{h_f i_1}{(1+h_o R_L)}$$

but the current gain, $A_i = \dfrac{-i_2}{i_1}$

$$\frac{-i_2}{i_1} = \boxed{\frac{-h_f}{1+h_o R_L}} \quad \text{.......} \quad ⑦$$

Equation ⑦ is true for all the transistor configurations (CB, CE and CC)

② **Voltage Gain (A_v)** = $\dfrac{\text{output voltage}}{\text{input voltage}} = \dfrac{V_2}{V_1} = \dfrac{-i_2 R_L}{V_1}$

but $A_i = \frac{-i_2}{i_1} \Rightarrow -i_2 = i_1 A_i$

$$\therefore A_v = \frac{i_1 A_i R_L}{V_i} = \frac{A_i R_L}{(z_i)} \quad \dots\dots (8)$$

where $z_i = \frac{v_1}{i_1}$

But $z_i = \boxed{h_i - \frac{h_r h_f}{1/R_L + h_o}}$ → To drive it later

But $A_i = \boxed{\frac{-h_f}{1 + h_o R_L}}$ i.e equation (7)

Now substitute for z_i and A_i in to equation (8)

$$\Rightarrow A_v = \frac{-h_f R_L}{h_i + (h_i h_o - h_r h_f) R_L}$$

where $\Delta h = (h_i h_o - h_r h_f)$

$$\Rightarrow A_v = \frac{-h_f R_L}{h_i + \Delta h R_L} \quad \dots\dots \text{equation } (9)$$

Equation (9) is also true for all the transistor configurations (CE, CB and CC) i.e the expression for voltage gain

(iii) **Power Gain, (A_p)** $= A_v \times A_i$

$$A_p = \left[\frac{-h_f R_L}{h_i + \Delta h R_L}\right] \times \left[\frac{-h_f}{1 + h_o R_L}\right]$$

$$\boxed{A_p = \frac{h_f^2 R_L}{(h_i + \Delta h R_L)(1 + h_o R_L)}} \quad \text{.......... eqn (10)}$$

Equation (10) is the expression for the Power gain (A_p) is true for CE, CB and CC configurations

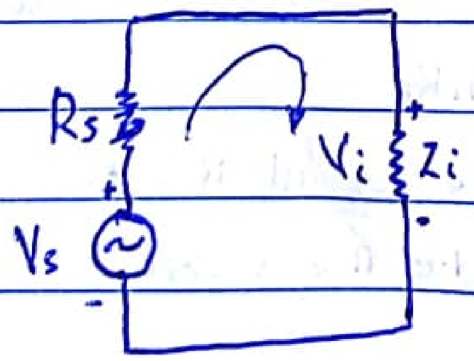
(vi) Overall Voltage Gain (A_{vs}) = V_2/V_s

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

but the voltage gain, $\boxed{A_v = V_2/V_1}$

$$\boxed{A_{vs} = A_v \cdot \frac{V_1}{V_s}} \quad \text{.......... eqn (11)}$$

From the circuit, we can redraw the input as:



V_1 is the input voltage and is the voltage across Z_i

Using KVL: $V_s - iR_s - iZ_i = 0$

$$\Rightarrow i = \frac{V_s}{R_s + Z_i}$$

$V_i = i z_i$

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

$$\Rightarrow \frac{V_i}{V_s} = \frac{Z_i V_s}{R_s + Z_i} \times \frac{1}{V_s} = \frac{Z_i}{R_s + Z_i} \quad \text{.... eqn (12)}$$

Substitute eqn (12) into (11)

$$A_{vs} = A_v \left(\frac{Z_i}{R_s + Z_i} \right) \quad \text{...... eqn (13)}$$

Equation (13) is the final expression for the overall voltage gain, but if an ideal voltage source is consider

V_s = Ideal $\rightarrow$ $R_s = 0$ and

$\boxed{A_{vs} = A_v}$ $\rightarrow$ for ideal voltage source

(v) <u>Overall current Gain (A_{is})</u>: is the ratio of the output current to the current delivered by the source

$$A_{is} = \frac{i_L}{i_s} \times \frac{i_1}{i_1} = \frac{i_L}{i_1} \times \frac{i_1}{i_s}$$

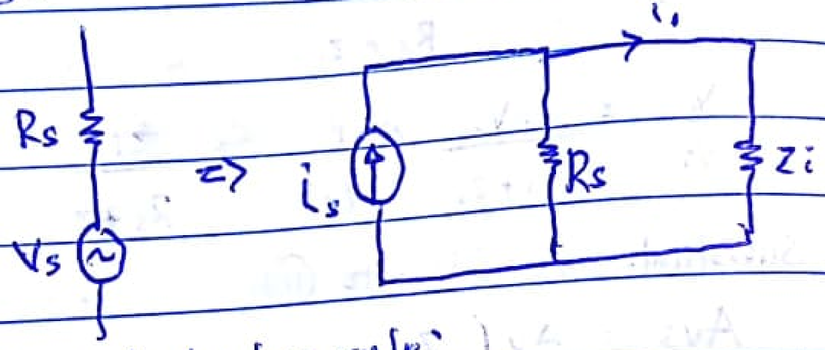
and $i_L = -i_2$

$$\Rightarrow A_{is} = \frac{-i_2}{i_1} \cdot \frac{i_1}{i_s} = \boxed{A_i \cdot \frac{i_1}{i_s}} \quad \text{... eqn (14)}$$

where $\boxed{A_i = \frac{-i_2}{i_1}}$

To Find i_1/i_s = ?

converting:



Using current divider rule;

$$i_1 = \left[\frac{R_s}{R_s + Z_i}\right] \times i_s$$

$$\Rightarrow \frac{i_1}{i_s} = \frac{R_s}{R_s + Z_i} \quad \text{.... eqn (15)}$$

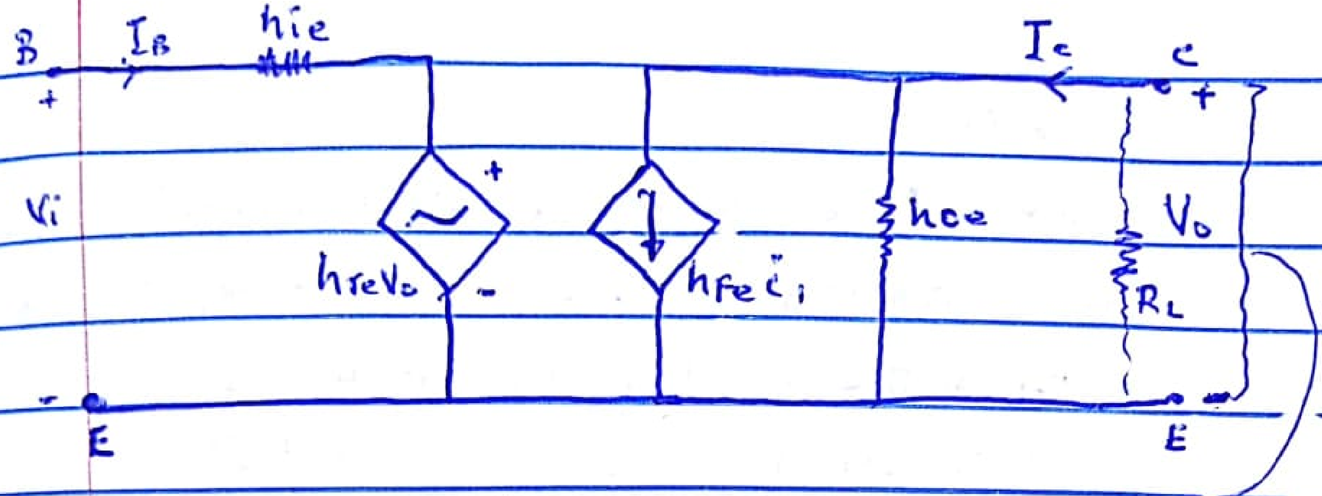
Substitute (15) into (14)

$$A_{is} = A_i \cdot \left[\frac{R_s}{R_s + Z_i}\right] \quad \text{.... eqn (16)}$$

Equation (16) is the overall expression for the overall current gain. For an ideal current source, the resistance $R_s = \infty$, then:

$$\boxed{A_{is} = A_i}$$

Approximate Hybrid Equivalent Model of C-E Transistor



model for CE configuration

For CE and CB configurations, the magnitude of hr and ho are such that the results obtained for the parameters such as Zi, Zo, Av and Ai will not change.

h_o = output admittance => $1/h_o$ = output impedance (very large)

=> $1/h_o \gg R_L$

OR $1/h_o \gg (R_C \| R_L)$ – for fixed-bias configuration

=> ho can be replaced with open circuits.

And $h_{re} = \frac{V_o}{V_o} \neq 0$ => $h_{re}V_o \simeq 0$, so $h_{re}V_o$ can be replaced with a short circuit as shown below

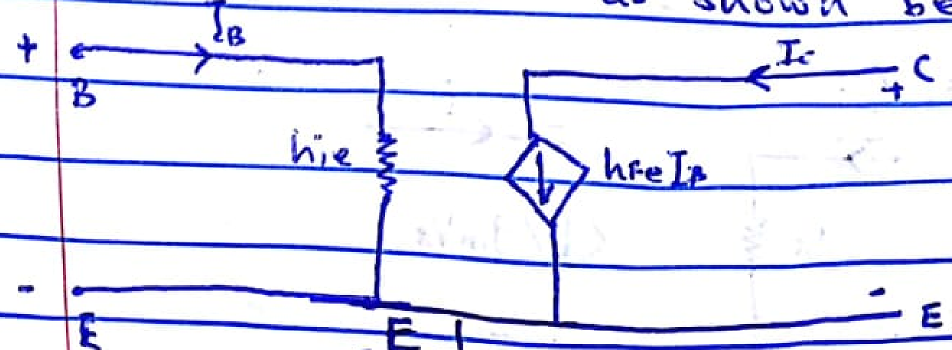


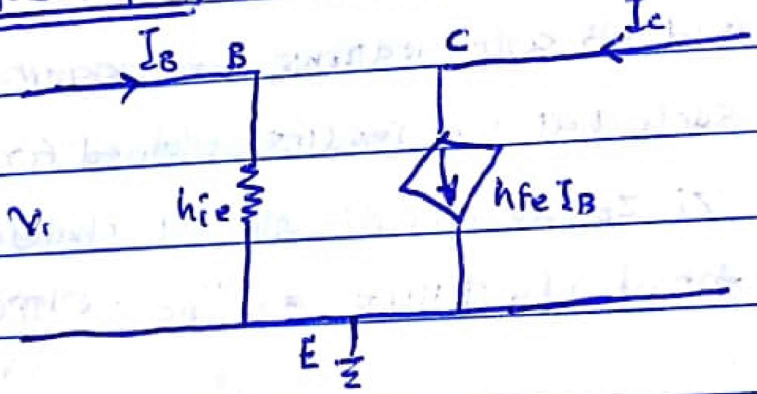
Figure ccx^n

$i_i = I_B$

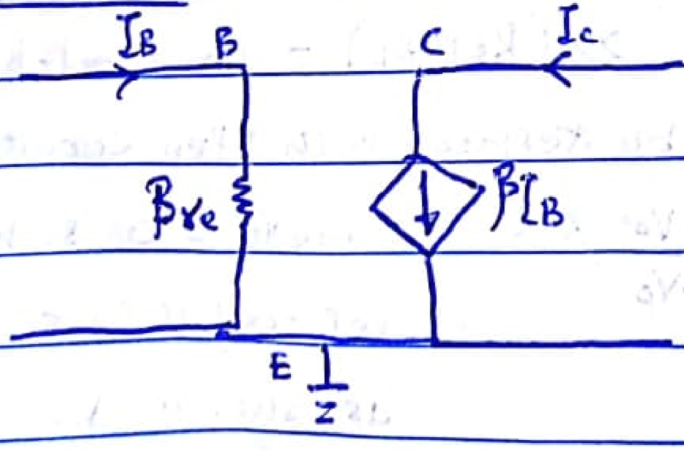
Figure "X" is the approximate equivalent model for the CE configuration and is used to replace the transistor in the small-signal AC Analysis.

Comparison of the 3-models of BJT.

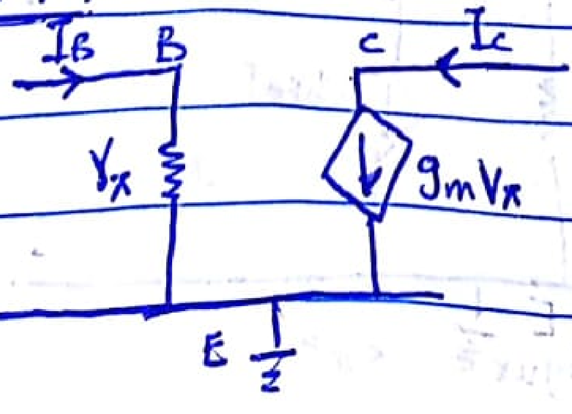
⇒ **h-Parameter:**



⇒ **Re-model:**



⇒ **Hybrid π:**



$\Rightarrow h_{ie} \equiv \beta r_e \equiv r_\pi$ . . . . (1)

$\Rightarrow h_{fe} I_B \equiv \beta I_B \equiv g_m V_\pi$ . . . . (2)

Where g_m = Transconductance

What is V_π? $V_\pi = I_B r_\pi$

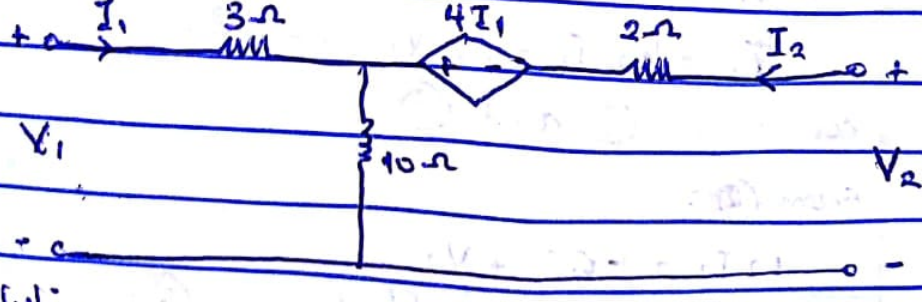
$\Rightarrow h_{fe} I_B = \beta I_B = g_m I_B r_\pi$

$\therefore h_{fe} = \beta = g_m r_\pi \Rightarrow g_m = \beta / r_\pi$

Note:- AC Analysis cannot be carried out without DC Analysis

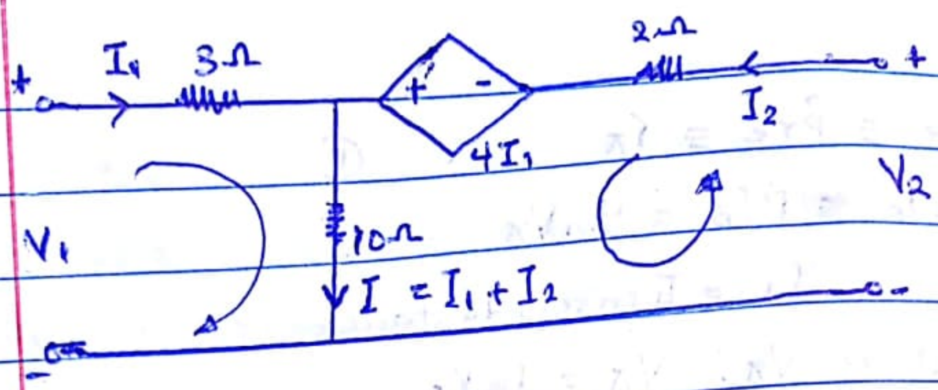
Transconductance g_m is the expression of the Performance of a BJT or FET. In general, the larger the transconductance figure for a device, the greater the gain (Amplification). it is capable of delivering when all other factors are held constant.

Example:- Find the hybrid Parameters for the two-Port network given below. i.e $h_{11}, h_{12}, h_{21}, h_{22}$



solution

Step one:- Mark all the currents in the 2-Port Network



step 2: Obtain the o/p KVL equation and the i/p KVL eqn

Open loop KVL in loop one:

$$+v_i - 3I_1 - 10[I_1 + I_2] = 0$$

$$V_1 = 13I_1 + 10I_2 \quad \ldots \quad (1)$$

Open loop KVL in loop two:

$$+V_2 - 2I_2 + 4I_1 - 10(I_1 + I_2) = 0$$

$$V_2 = 6I_1 + 12I_2 \quad \ldots \quad (2)$$

Remember:

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} \rightarrow \text{Dependent Variables} = f\begin{bmatrix} I_1 \\ V_2 \end{bmatrix} \rightarrow \text{Independent Variables}$$

$$\Rightarrow V_1 = h_{11}I_1 + h_{12}V_2 \quad \ldots \quad (3)$$

$$I_2 = h_{21}I_1 + h_{22}V_2 \quad \ldots \quad (4)$$

comparing (4) and (2)

From (2):

$$12I_2 = -6I_1 + V_2$$

$$I_2 = -\tfrac{1}{2}I_1 + \tfrac{1}{12}V_2 \quad \ldots \quad (5)$$

Substitute eqn (5) into (1):

$V_1 = 13 I_1 + 10 I_2$

$V_1 = 13 I_1 + 10 \left[\frac{-1}{2} I_1 + \frac{1}{12} V_2 \right]$

$V_1 = 13 I_1 - 5 I_1 + 5/6 V_2$

$V_1 = 8 I_1 + 5/6 V_2$ ---- (6)

Compare eqn (6) and (3) :

We can find that

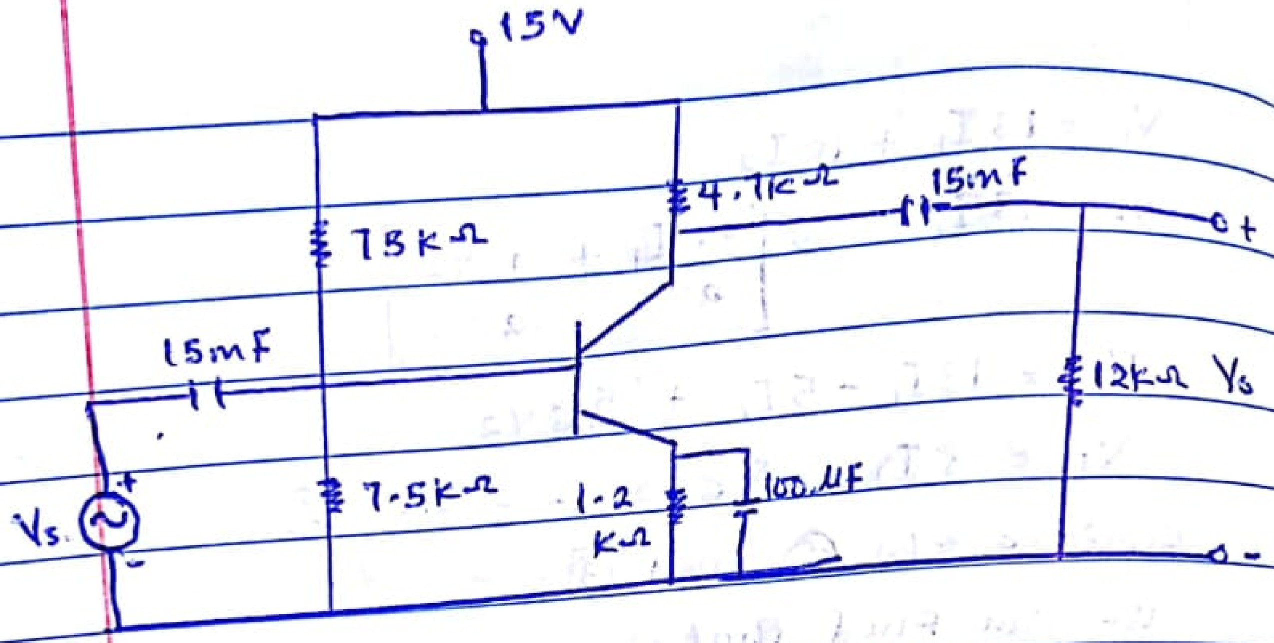
$h_{11} = 8$, $h_{12} = 5/6$ (no unit)

Compare (4) and (5)

$h_{21} = -1/2$, $h_{22} = 1/12$ (mho or S)

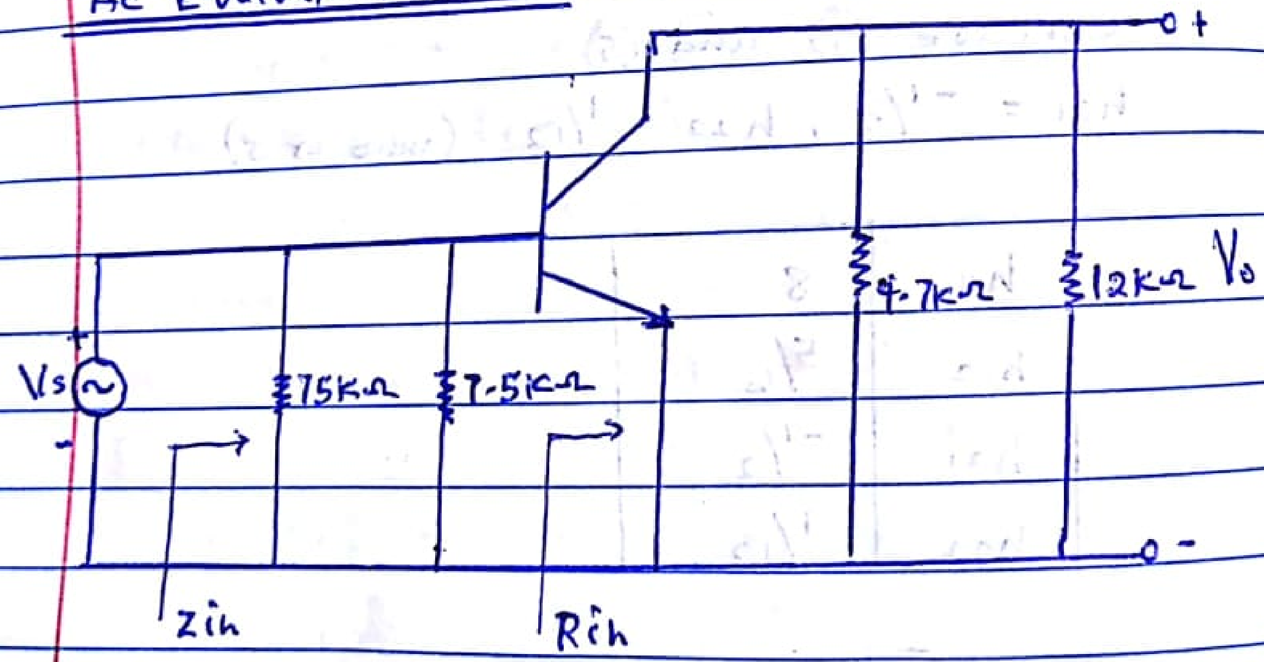
h_{11}	8
h_{12}	$5/6$
h_{21}	$-1/2$
h_{22}	$1/12$

Example :- Determine (i) Voltage gain (ii) input impedance (iii) Q-point of the transistor amplifier shown below ($\beta = 100$ and $R_{th} = 2k\Omega$). Neglect V_{BE}



Solution:

Ac Equivalent Model



① Voltage gain: $A_V = V_o/V_i = \dfrac{-h_{fe} \times R_L}{h_{ie}}$

$\Rightarrow R_L = R_{ac} = R_c \| R_L = \dfrac{4.7K \times 12K}{4.7K + 12K} = 3.38K\Omega$

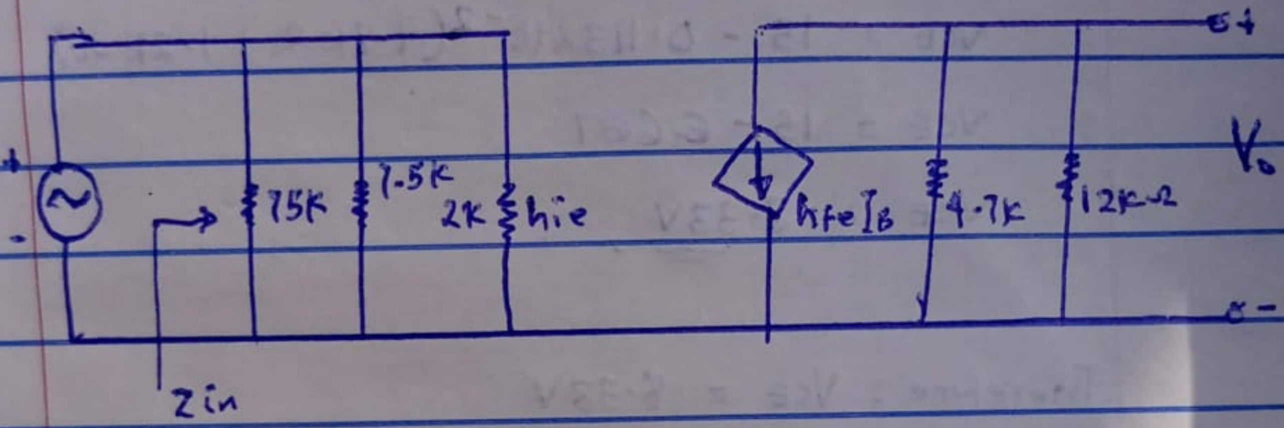
$h_{fe} = \beta$

And $h_{ie} = r_{in} = 2k\Omega$

$$\therefore A_V = \frac{-\beta R_{ac}}{r_{in}} = \frac{-100 \times 3.38k}{2k} = 169$$

$\therefore A_V = 169$

(ii) $Z_{in} =$



$Z_{in} = 75k \| 7.5k \| 2k$

$$= 75k \| \frac{7.5(2)}{7.5+2} = 75k \| 1.58k$$

(iii) Q-Point : DC Analysis (I_{CQ}, V_{CEQ})

$$V_B = \frac{R_2}{1+R_2} \cdot V_{cc} = \frac{7.5k}{75k+7.5k} \times 15 = 1.36V$$

$V_{BE} = V_B - V_E$

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$V_E = V_{BE} + V_B = 0 + 1.36V = 1.36V$

$\therefore I_E = \frac{V_E}{R_E} = \frac{1.36}{\cancel{1.2}K\ 1.2K} = \cancel{0.113}\ \cancel{0.113mA}\ 1.13mA$

Open loop KCL :

$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

Approximate Analysis $I_C \simeq I_E$

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

$V_{CE} = 15 - 0.113 \times 10^{-2}(4.7K\Omega + 1.2K\Omega)$

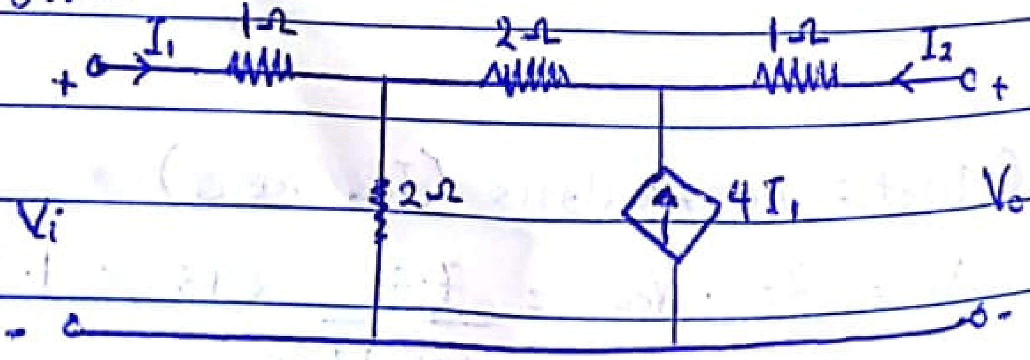
$V_{CE} = 15 - 6.667$

$V_{CE} = \underline{8.33V}$.

Therefore : $V_{CE} = 8.33V$

Q-Point $= 8.33V, \underline{1.13mA}$

Home-work Determine the Hybrid Parameters in the network given



(1) connect 1V source at Port 1 and Let Port 2 be

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shortcircuted.

(ii) connect 1V source at Port 2 and let Port 1 be open circuited.