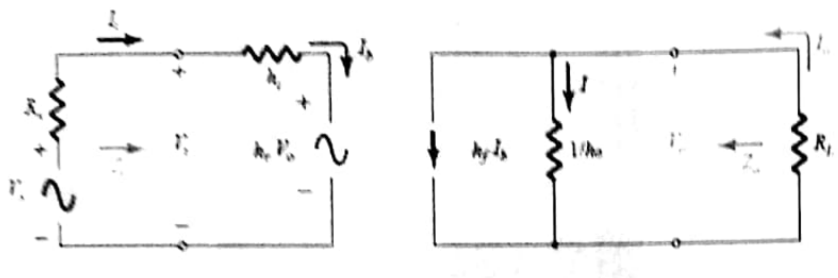
SOLUTION AND SCHEME OF EVALUATION

IAT-1: AEC

1. Derive an expression for input impedance, output impedance, voltage gain and current gain of transistor amplifier using complete hybrid-Model. **[10 Marks]**

COMPLETE HYBRID EQUIVALENT MODEL: **[2 Marks]**



Current Gain: **[2 Marks]**

Applying Kirchhoff's current law to the output circuit

$$I_o = h_f I_b + I = h_f I_i + \frac{V_o}{1/h_o} = h_f I_i + h_o V_o \quad as \ \ V_o = -I_o R_L \quad hence \ \ I_o = h_f I_i - h_o I_o R_L$$

$$I_o + h_o I_o R_L = h_f I_i => I_o(1 + h_o R_L) = h_f I_i => A_i = \frac{I_o}{I_i} = \frac{h_f}{1 + h_o R_L}$$

Voltage Gain: **[2 Marks]**

$$V_i = I_i h_i + V_O h_r \quad as \ \ I_i = \frac{(1 + h_o R_L) I_o}{h_f} \quad and \ \ I_o = \frac{-V_o}{R_L} \quad => V_i = \frac{-(1 + h_o R_L) h_i}{h_f R_L} V_o + V_O h_r$$

$$V_i = \frac{V_O h_r h_f R_L - (1 + h_o R_L) h_i V_o}{h_f R_L} => V_i = \frac{V_O h_r h_f R_L - h_i V_o - h_i V_o h_o R_L}{h_f R_L}$$

$$=> V_i = \frac{-V_o\left[h_i + \left(h_i h_o - h_r h_f\right) R_L\right]}{h_f R_L}$$

$$A_V = \frac{V_o}{V_i} => A_V = \frac{-h_f R_L}{h_i + \left(h_i h_o - h_r h_f\right) R_L}$$

Input Impedance: **[2 Marks]**

$$V_i = I_i h_i + h_r V_o \qquad and \ \ V_o = -I_o R_L \quad hence \ \ V_i = I_i h_i - I_o R_L h_r \quad as \ \ I_o = A_i I_i$$

$$V_i = I_i h_i - R_L h_r A_i I_i \quad and \ \ Z_i = \frac{V_i}{I_i} = h_i - R_L h_r A_i \quad as \ \ A_i = \frac{h_f}{1 + h_o R_L} \quad hence \ \ Z_i = h_i - \frac{R_L h_r h_f}{1 + h_o R_L}$$

output Impedance: The output impedance od an amplifier is defined to be the ratio of the output voltage to the output current with the signal V_S set to zero. **[2 Marks]**

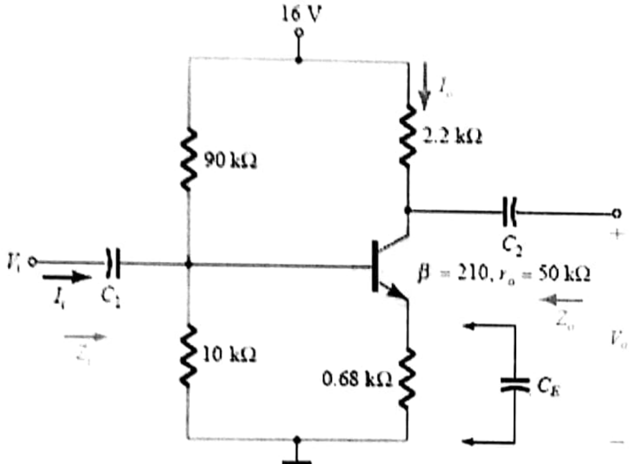
$V_S - I_i R_S - I_i h_i - h_r V_o = 0$ *for calculating* Z_o; V_S *has to be set to zero* $\Rightarrow I_i(R_S + h_i) = -h_r V_o$

$$I_i = \frac{-h_r V_o}{R_S + h_i}$$

$$I_o = h_f I_i + h_o V_o \Rightarrow I_o = \frac{-h_r h_f V_o}{R_S + h_i} + h_o V_o$$

$$Z_o = \frac{V_o}{I_o} = \frac{1}{h_o - \left[\frac{h_r h_f}{(R_S + h_i)}\right]}$$

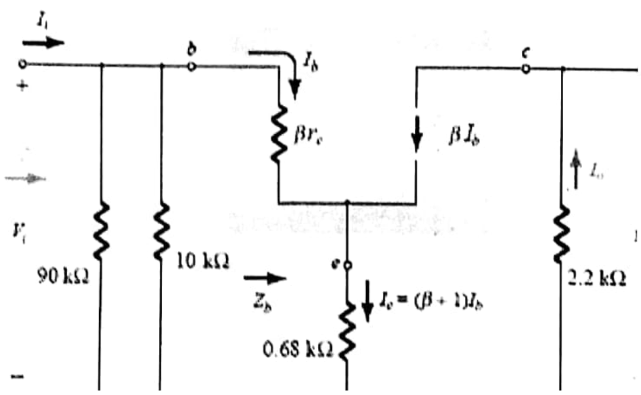
2. Calculate the following for the network shown in (Fig 1) with and without C_E and compare the voltage gain.(a) r_e (b) Z_i (c) Z_O (d) A_V (e) A_I **[10 Marks]**



(Fig 1)

ANSWER: (Without C_E) **[5 Marks]**

$\beta R_E \geq 10R_2 \Rightarrow 210 \times 0.68K\Omega \geq 10 \times 10K\Omega \Rightarrow 142.8K\Omega \geq 100K\Omega(Satisfied)$



$$V_B = \frac{V_{CC}R_2}{R_1 + R_2} = \frac{16 \times 10K\Omega}{90K\Omega + 10K\Omega} = 1.6V$$

$$V_E = V_B - V_{BE} = 1.6 - 0.7 = 0.9V$$

$$I_E = \frac{V_E}{R_E} = \frac{0.9}{0.68K\Omega} = 1.32mA$$

$$r_e = \frac{26mV}{I_E} = \frac{26mV}{1.32mA} = 19.69\Omega$$

$$Z_b = \beta r_e + (\beta + 1)R_E = 210 \times 19.69\Omega + (210 + 1)0.68K\Omega = 147.6K\Omega$$

$$R' = \frac{R_1 R_2}{R_1 + R_2} = \frac{90K\Omega \times 10K\Omega}{90K\Omega + 10K\Omega} = 9K\Omega$$

$$Z_i = R'||Z_b = 9K\Omega||147.6K\Omega = 8.48K\Omega$$

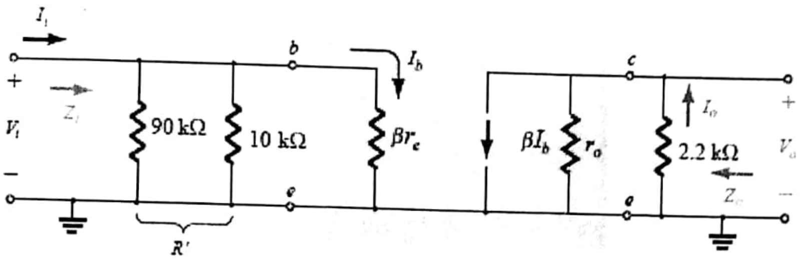
$$Z_o = R_C = 2.2K\Omega$$

$$A_V = \frac{-R_C}{(R_E + r_e)} = \frac{-2.2K\Omega}{(19.69\Omega + 0.68K\Omega)} = -3.14$$

$$A_i = -A_V \frac{Z_i}{R_C} = 3.14 \times \frac{8.48K\Omega}{2.2K\Omega} = 12.10$$

(With C_E)

[5 Marks]



$$R' = \frac{R_1 R_2}{R_1 + R_2} = \frac{90K\Omega \times 10K\Omega}{90K\Omega + 10K\Omega} = 9K\Omega$$

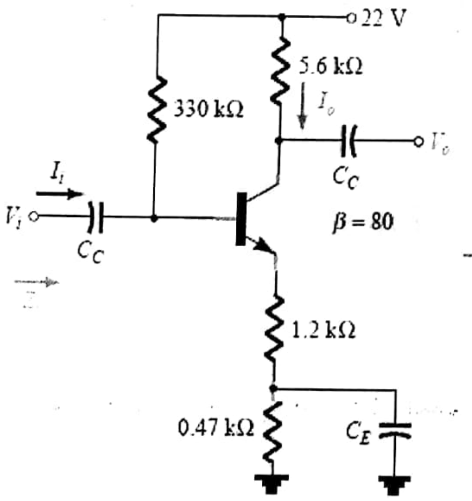
$$A_V = \frac{-R_C}{r_e} = \frac{-2.2K\Omega}{19.69\Omega} = -111.73$$

$$Z_i = R'||\beta r_e = 9K\Omega||4.135K\Omega = 2.83K\Omega$$

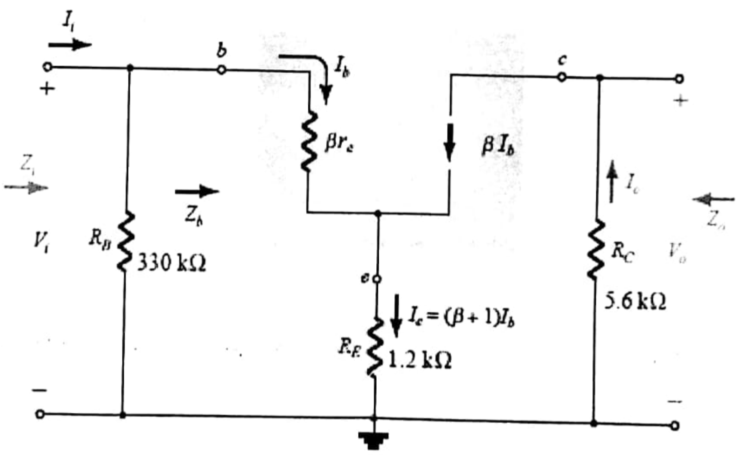
$$A_i = -A_V \frac{Z_i}{R_C} = 111.73 \times \frac{2.83K\Omega}{2.2K\Omega} = 143.72$$

$$Z_o = R_C = 2.2K\Omega$$

3. For the network shown in (Fig 2). Determine r_e, Z_i, Z_O, A_V, A_i **[10 Marks]**



(Fig 2)



$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \frac{22 - 0.7}{330 \times 10^3 + (80 + 1)(1.2 + 0.47) \times 10^3} = 45.77\mu A$$

$$I_E = (\beta + 1)I_B = (80 + 1)45.77\mu A = 3.708mA$$
$$r_e = \frac{26mV}{I_E} = \frac{26mV}{3.708mA} = 7.01\Omega$$

[2 Marks]

$$Z_b = \beta r_e + (\beta + 1)R_E = (80 \times 7.01\Omega) + (80 + 1)1.2K\Omega = 97.76K\Omega$$

$$Z_i = R_B || Z_b = 330K\Omega || 97.76K\Omega = 75.41K\Omega$$

[2 Marks]

$$Z_o = R_C = 5.6K\Omega$$

[2 Marks]

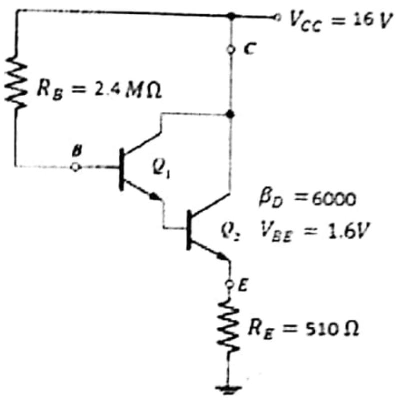
$$A_V = \frac{-R_C}{(R_E + r_e)} = \frac{-5.6K\Omega}{(1.2K\Omega + 7.01\Omega)} = -4.639$$

[2 Marks]

$$A_i = -A_V \frac{Z_i}{R_C} = 4.639 \times \frac{75.41K\Omega}{5.6K\Omega} = 62.469$$

[2 Marks]

4. (a)Calculate the DC bias voltages and Currents for the given circuit (Fig 3). **[5 Marks]**



(Fig 3)

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta_D + 1)R_E}$$

[2 Marks]

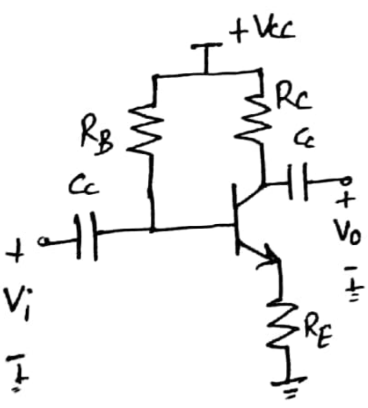
$$I_B = \frac{16 - 1.6}{2.4 \times 10^6 + (6000 + 1)510} = 2.637\mu A$$
$$I_E = (\beta_D + 1)I_B = (6000 + 1)2.637\mu A = 15.82mA$$

[2 Marks]

$$V_E = I_E R_E = 15.82 \times 10^{-3} \times 510 = 8.0709V$$

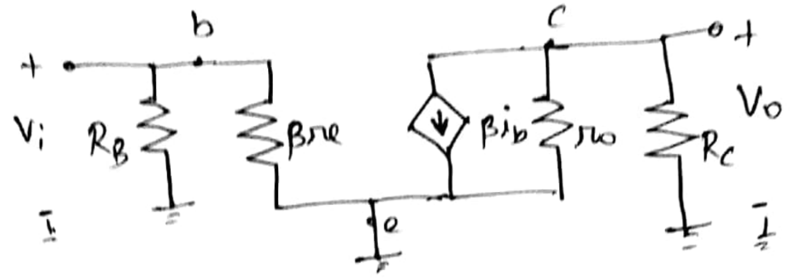
[1 Mark]

(b) Effect of R_E resistance in fixed bias common emmitter amplifier [5 Marks]



Input impedance [3 Marks]

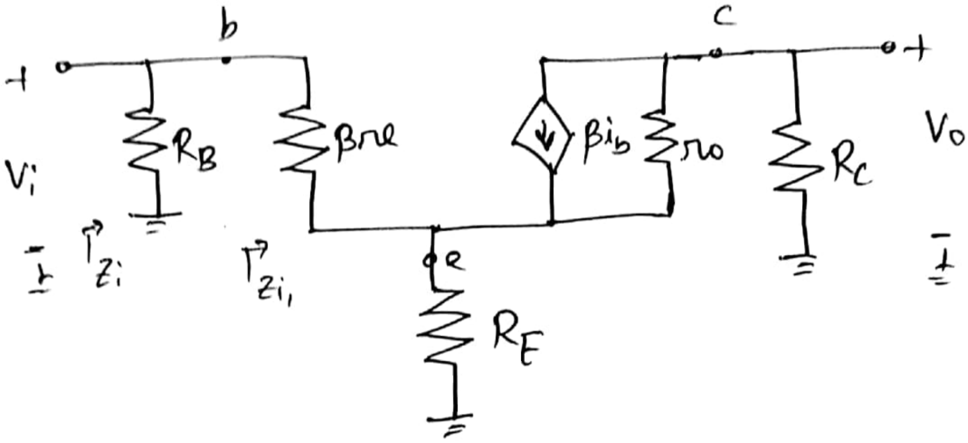
without R_E



$$\boxed{Z_i = R_B \parallel \beta r_e}$$

$$Z_i \approx \beta r_e$$

with R_E



$$Z_i = R_B \parallel (\beta r_e + (1+\beta)R_E)$$

The input impedance increases substantially with inclusion R_E resistance.

Voltage Gain $A_V = \frac{V_o}{V_i}$ [3 Marks]

without R_E

$$A_V = -\frac{R_C}{r_e}$$

with R_E

$$A_V = -\frac{R_C}{R_E + r_e}$$

The gain of the amplifier is reduced but the stability increases substantially.

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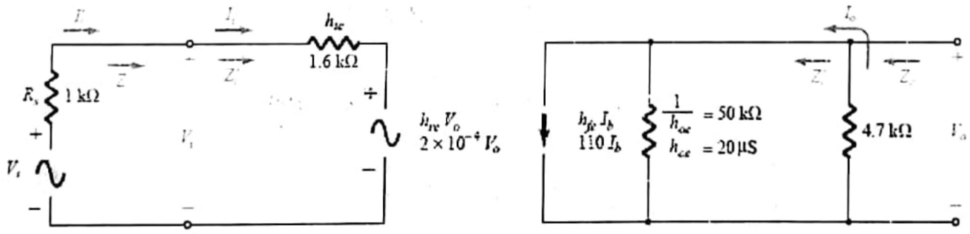
[2 marks]



[2 marks]

$$Z'_i = h_{ie} - \frac{R_L h_{re} h_{fe}}{1 + h_{oe} R_L} \Rightarrow Z'_i = 1.6K\Omega - \frac{(4.7K\Omega)(2 \times 10^{-4})110}{1 + (20\mu S \times 4.7K\Omega)} = 1.505K\Omega$$

$Z_i = 470K\Omega || Z_i \Rightarrow Z_i = 1.5K\Omega$ **[2 marks]**

$$A_V = \frac{-h_{fe} R_L}{h_{ie} + (h_{ie} h_{oe} - h_{re} h_{fe}) R_L} \Rightarrow A_V = \frac{-110(4.7K\Omega)}{1.6K\Omega + (1.6K\Omega \times 20\mu S - (2 \times 10^{-4}) \times 110)(4.7K\Omega)}$$

$A_V = -313.9$

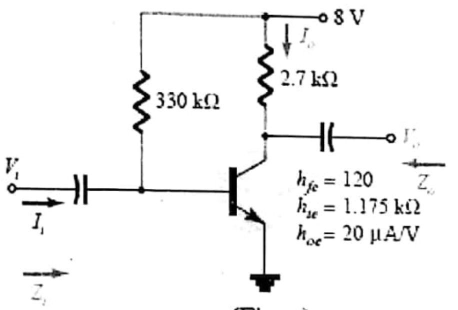
$$A_i = \frac{I_o}{I_i} = \frac{h_{fe}}{1 + h_{oe}R_L} = \frac{110}{1 + (20\mu S \times 4.7K\Omega)} = 100.54$$ **[1 mark]**

[1 mark]

$$Z'_o = \frac{1}{h_{oe} - \left[\frac{h_{re}h_{fe}}{(R_S + h_{ie})}\right]} = \frac{1}{20\mu S - \left[(2 \times 10^{-4}) \times \frac{110}{(1K\Omega + 1.6K\Omega)}\right]} = 86.67K\Omega$$

$$Z_O = R_C || Z_o \Rightarrow Z_O = 4.7K\Omega || 86.67K\Omega \Rightarrow Z_O = 4.45K\Omega$$ **[2 marks]**

6. (a) Determine the input impedance, output impedance, voltage gain and current gain for the circuit shown below (Fig 5). **[5 Marks]**



(Fig 5)

(a) $Z_i = R_B \| h_{ie} = 330\text{ k}\Omega \| 1.175\text{ k}\Omega$
$\cong h_{ie} = 1.171\text{ k}\Omega$ **[1 mark]**

(b) $r_o = \frac{1}{h_{oe}} = \frac{1}{20\ \mu A/V} = 50\text{ k}\Omega$

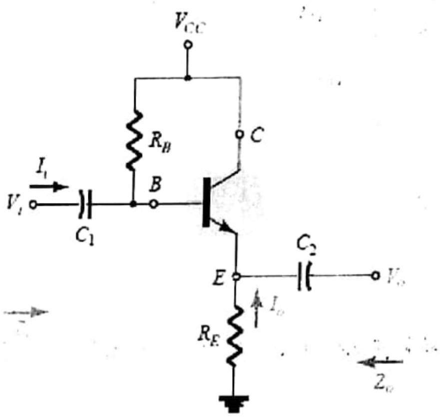
$Z_o = \frac{1}{h_{oe}} \| R_C = 50\text{ k}\Omega \| 2.7\text{ k}\Omega = 2.56\text{ k}\Omega \cong R_C$ **[1 mark]**

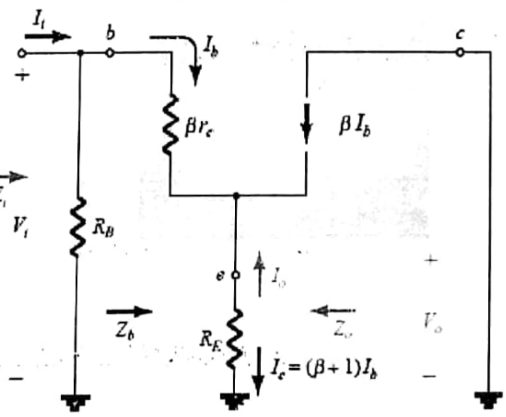
(c) $A_V = -\frac{h_{fe}(R_C \| 1/h_{oe})}{h_{ie}} = -\frac{(120)(2.7\text{ k}\Omega \| 50\text{ k}\Omega)}{1.171\text{ k}\Omega} = -262.34$ **[1 mark]**

$$A_i = -A_V\frac{Z_i}{R_C} = 262.34 \times \frac{1.171K\Omega}{2.7K\Omega} = 113.77$$ **[1 Mark]**

(b) Analyze the r_e parameter model for emitter follower circuit and derive Z_i, Z_o, A_V, A_i **[5 Marks]**

<u>EMITTER FOLLOWER CIRCUIT/COMMON COLLECTOR CONFIGURATION:</u>





[1 Mark]

For emitter follower circuit the output is taken from the emitter terminal. The output is slightly less than the input signal hence $A_V \approx 1$

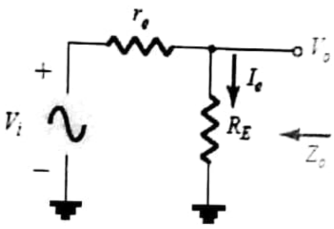
$$V_i = I_b\beta r_e + I_eR_E \Rightarrow V_i = I_b\beta r_e + (\beta + 1)I_bR_E$$

$$Z_b = \frac{V_i}{I_b} => Z_b = \beta r_e + (\beta + 1)R_E$$

$$=> Z_b \approx \beta(r_e + R_E)$$

$$Z_i = R_B || Z_b$$

[1 Mark]



Output impedance is calculated by setting V_i to zero hence $Z_o = R_E || r_e$ **[1 Mark]**

$$V_o = \frac{V_i R_E}{R_E + r_e} => A_V = \frac{V_o}{V_i} = \frac{R_E}{R_E + r_e} \quad as\ R_E + r_e \approx R_E \quad => A_V \approx 1$$ **[1 Mark]**

the + ve sign indicates there is no phase shift between V_o & V_i

$$I_b = \frac{I_i R_B}{R_B + Z_b} => I_i = \frac{(R_B + Z_b)I_b}{R_B} \quad and\ I_o = -I_e = -(\beta + 1)I_b$$

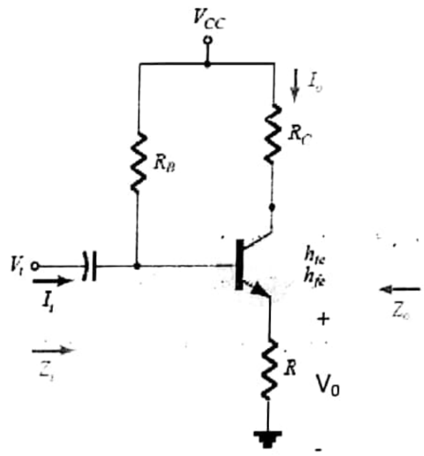
$$A_i = \frac{I_o}{I_i} = \frac{-(\beta+1)I_b}{\left[\frac{(R_B + Z_b)I_b}{R_B}\right]} = -(\beta+1)I_b \times \frac{R_B}{(R_B + Z_b)I_b} = \frac{-(\beta+1)R_B}{R_B + Z_b} = \frac{-\beta R_B}{R_B + Z_b} \quad as\ \beta + 1 \approx \beta$$

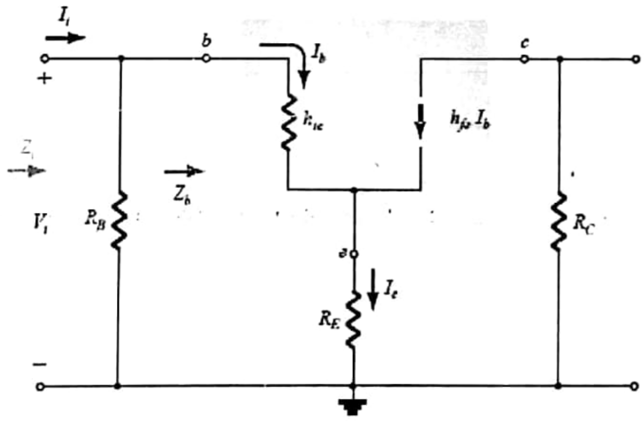
The current gain can also be calculated as

$$A_i = -A_V \frac{Z_i}{R_E}$$ **[1 Mark]**

7. **(a) Describe the h-parameter model for emitter bias circuit and derive Z_i, Z_o, A_V, A_i using approximate hybrid model.** **[5 Marks]**

EMITTER BIAS CONFIGURATION:





$$Z_b = h_{ie} + (h_{fe} + 1)R_E$$

$$Z_i = R_B || Z_b$$

$$Z_O = r_e$$

$$A_V = \frac{V_o}{V_i} = 1$$

$$I_o = (1 + h_{fe})I_b \quad and \qquad and \;\; I_b = \frac{I_i R_B}{R_B + Z_b} => I_i = \frac{(R_B + Z_b)I_b}{R_B}$$

$$A_i = \frac{I_o}{I_i} = \frac{[h_{fe} I_b]}{\left[\frac{(R_B+Z_b)I_b}{R_B}\right]} = h_{fe} I_b \times \frac{R_B}{(R_B+Z_b)I_b} = \frac{h_{fe} R_B}{Z_b + R_B} = h_{fe}$$

The current gain can also be calculated as $A_i = -A_V \frac{Z_i}{R_C}$