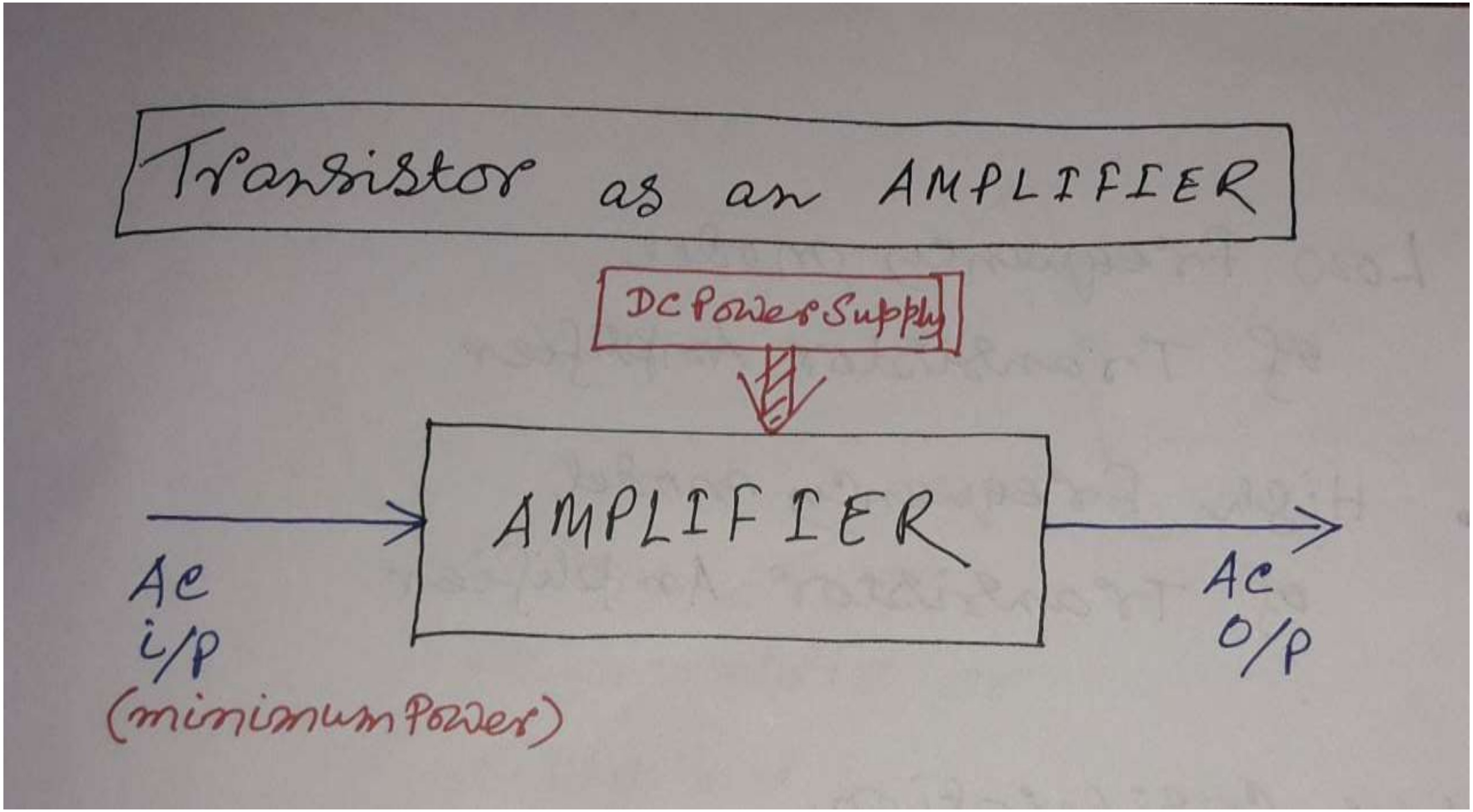
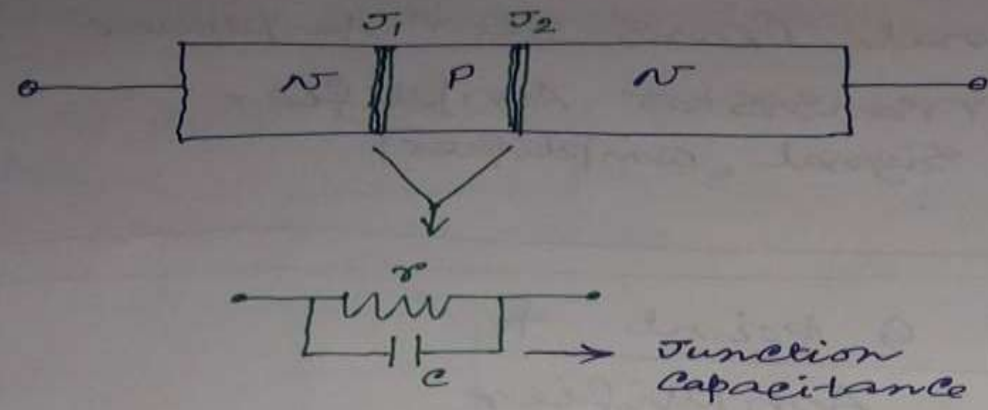
Transistor Amplifier

Transistor Amplifier



Transistor Amplifier



$$X_C = \frac{1}{2\pi f C}$$

At low frequency
$X_C \rightarrow$ high
(So may be neglected)

At high frequency
$X_C \rightarrow$ low
(Cannot be neglected)

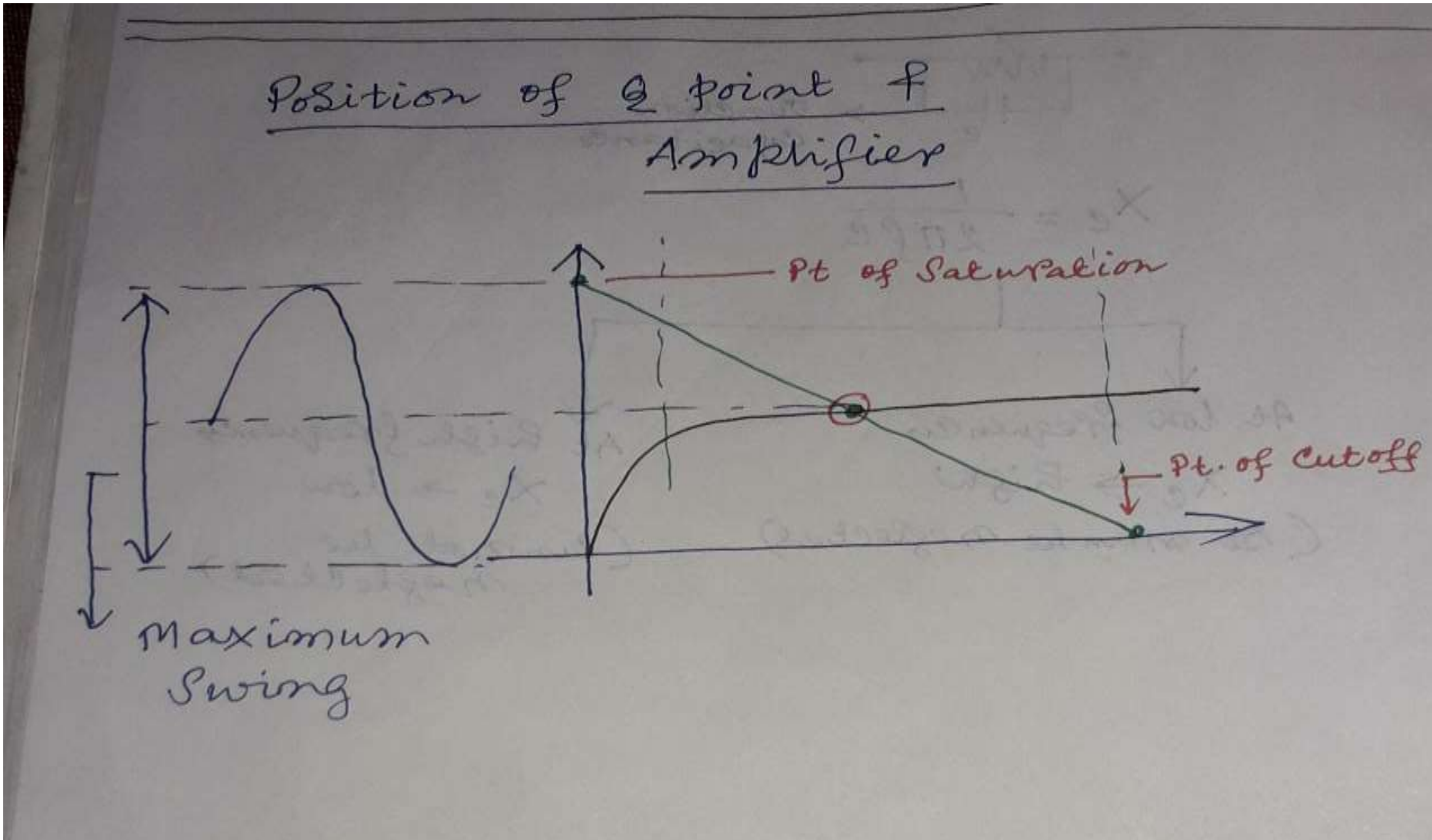
Transistor Amplifier

- Low frequency model of Transistor Amplifier
- High frequency model of Transistor Amplifier

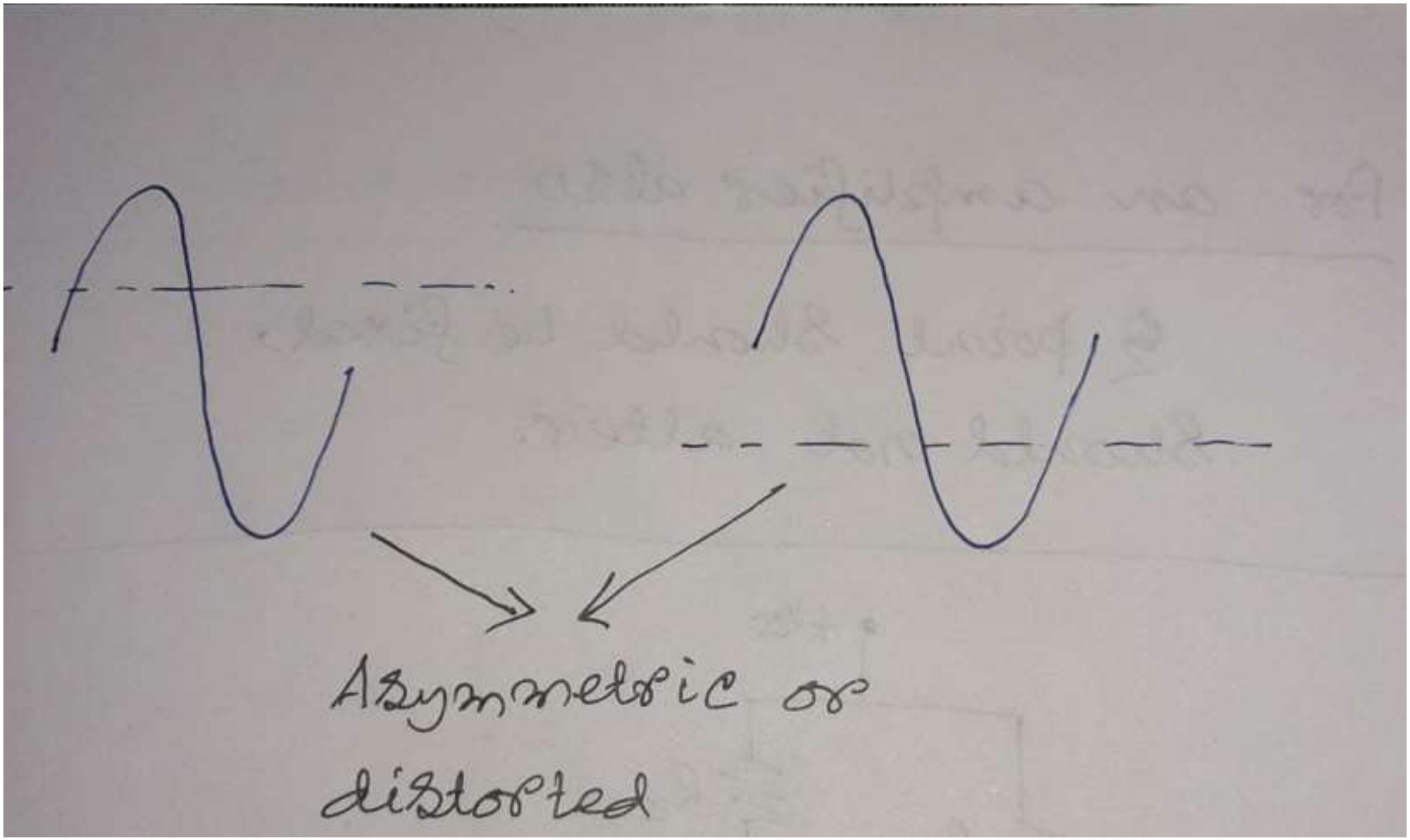
Another Consideration.

- Small Signal Transistor Amplifier
- Power Transistor Amplifier [large signal amplifier]

Transistor Amplifier



Transistor Amplifier



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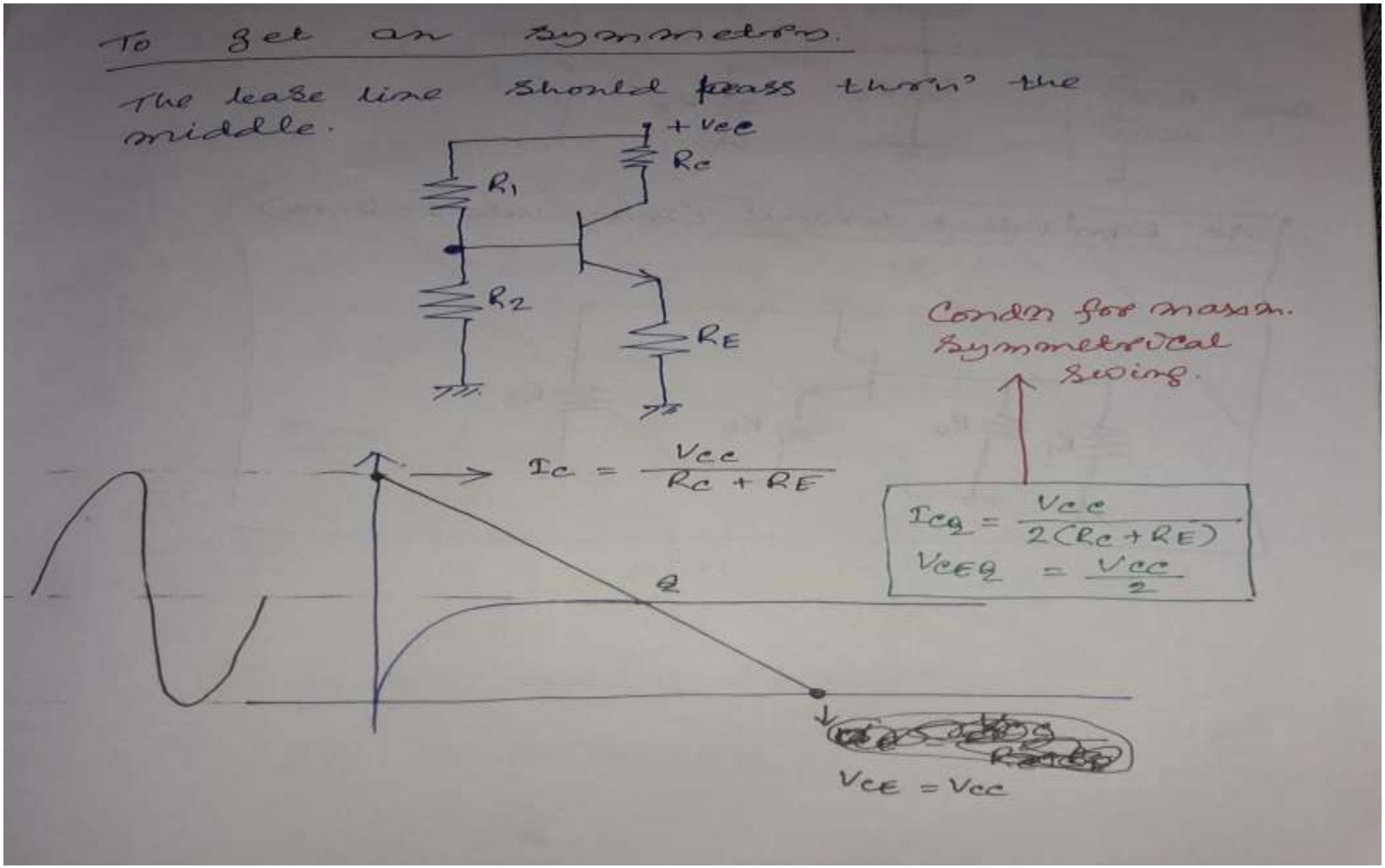
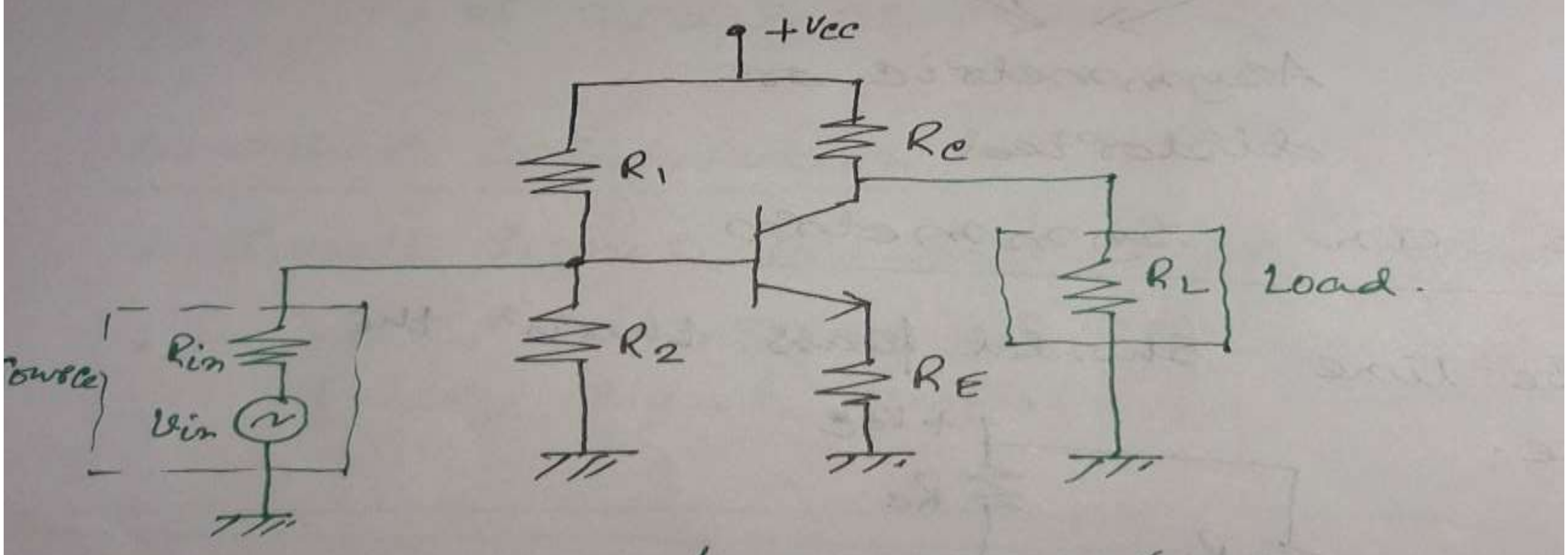


Transistor Amplifier

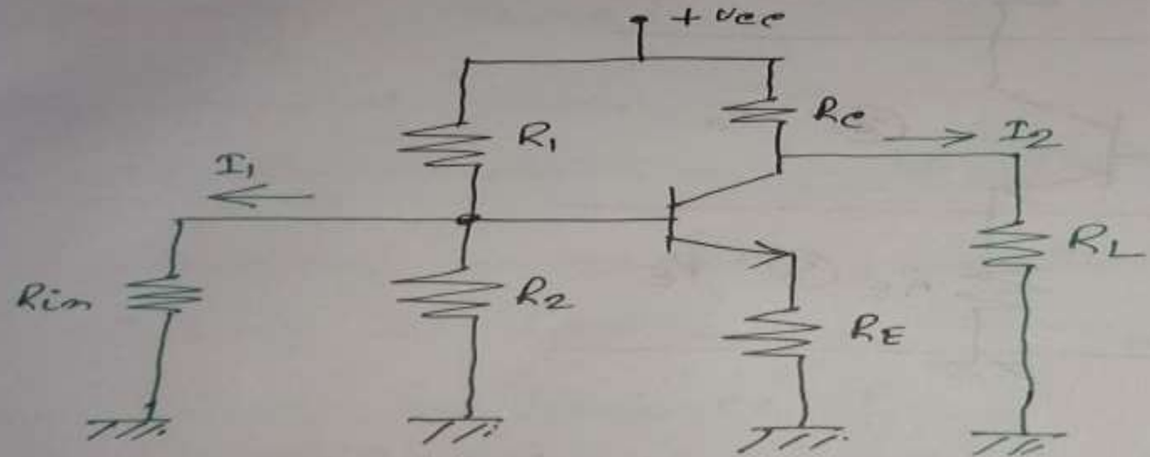
For an amplifier also

Q point should be fixed, should not alter.



Transistor Amplifier

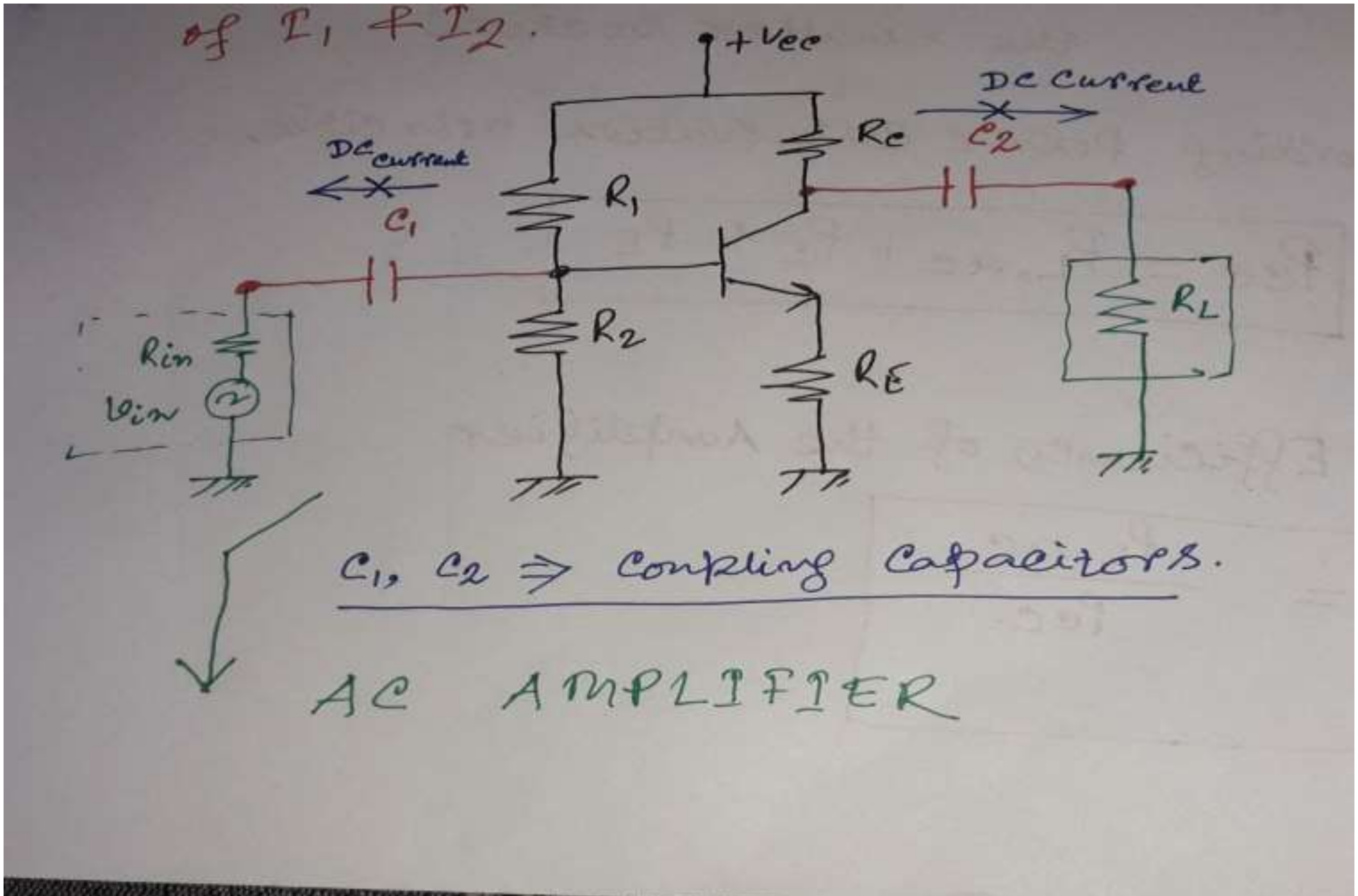
DC Equivalent circuit.



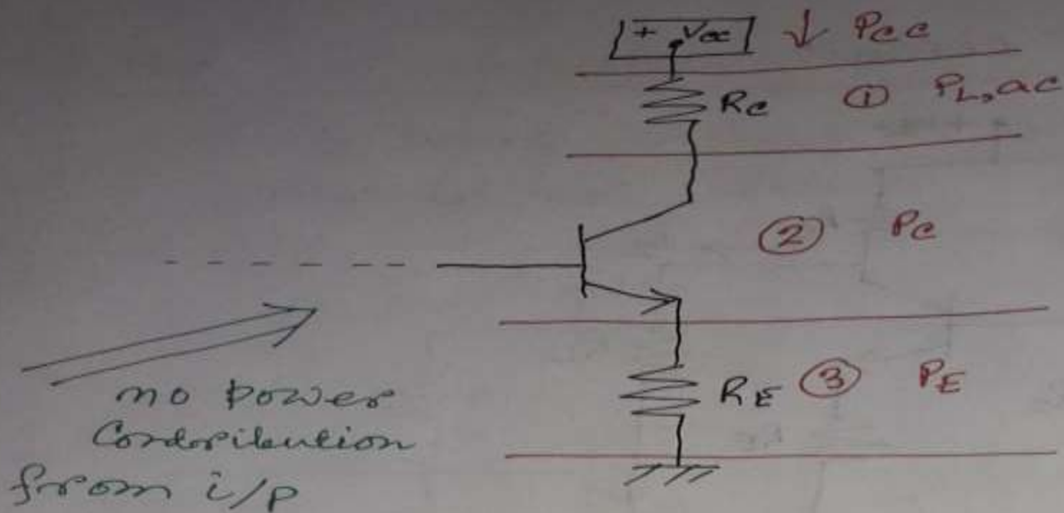
Additional currents (I_1, I_2) will cause the change of posn. of Q point.

By some means the posn. of the Q point should be as it is i.e we have to the stop the flow of I_1 & I_2.

Transistor Amplifier



Transistor Amplifier



P_{CC} = Power Supplied to Amplifier

$P_{L,ac}$ = Load Power Dissipation

P_C = Load Power Dissipation across C– E Junction
= Conduction Loss

P_E = Power Dissipation in the emitter Section

Transistor Amplifier

According power conservation principle,

$$\boxed{P_{CC} = P_{L,ac} + P_C + P_E}$$

η = Efficiency of the Amplifier

$$\boxed{\eta = \frac{P_{L,ac}}{P_{CC}}}$$

Transistor Amplifier

As P_{cc} is fixed, [$P_{cc} = V_{cc} \cdot I_{CQ}$]

So $\eta \uparrow$ $P_{L,ac} \uparrow$

we cannot alter P_C.

So recommendation is to reduce P_E.

But, according to stability factor analysis.

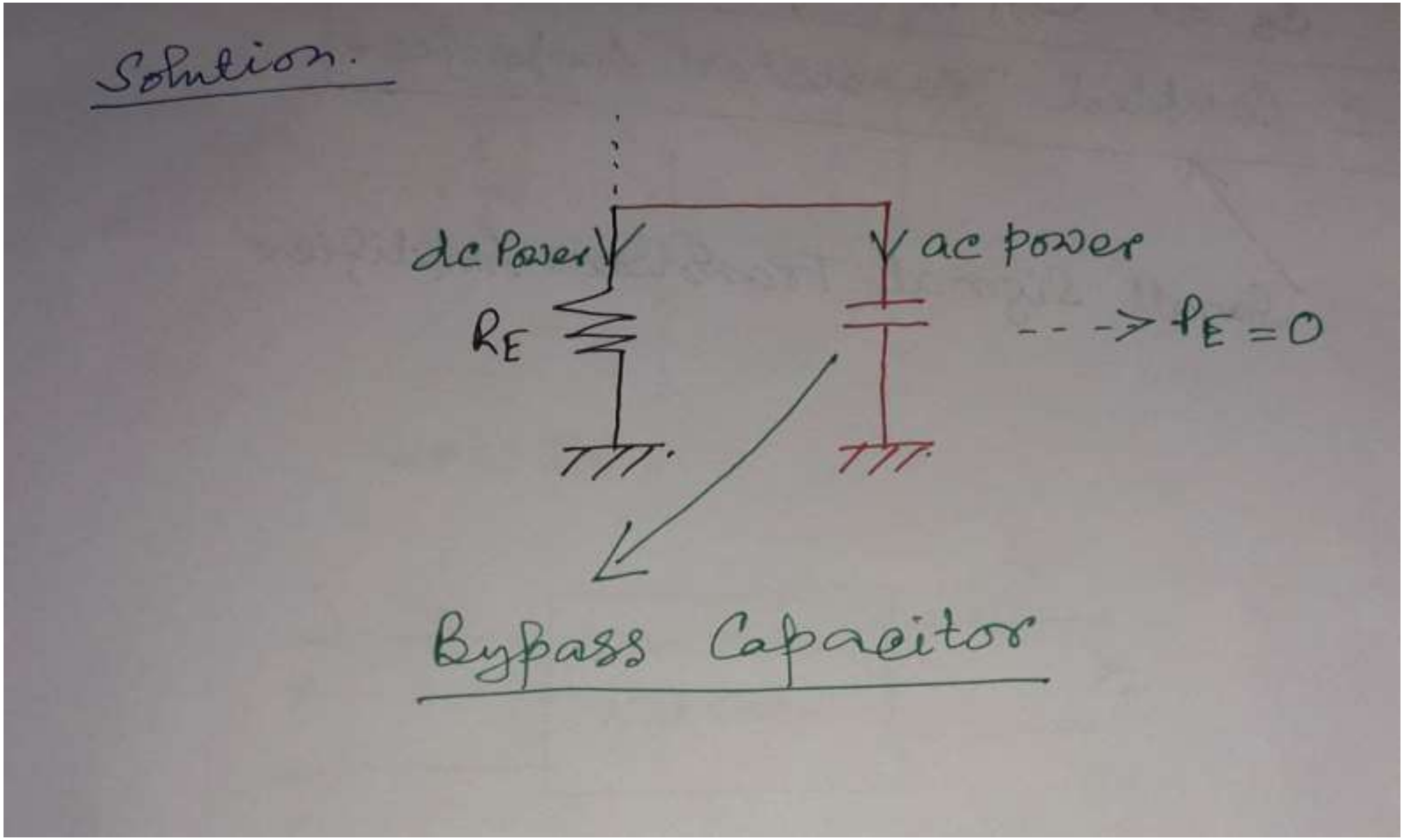
R_E should be large [$S_V = -\frac{1}{R_E}$]

then how to reduce P_E

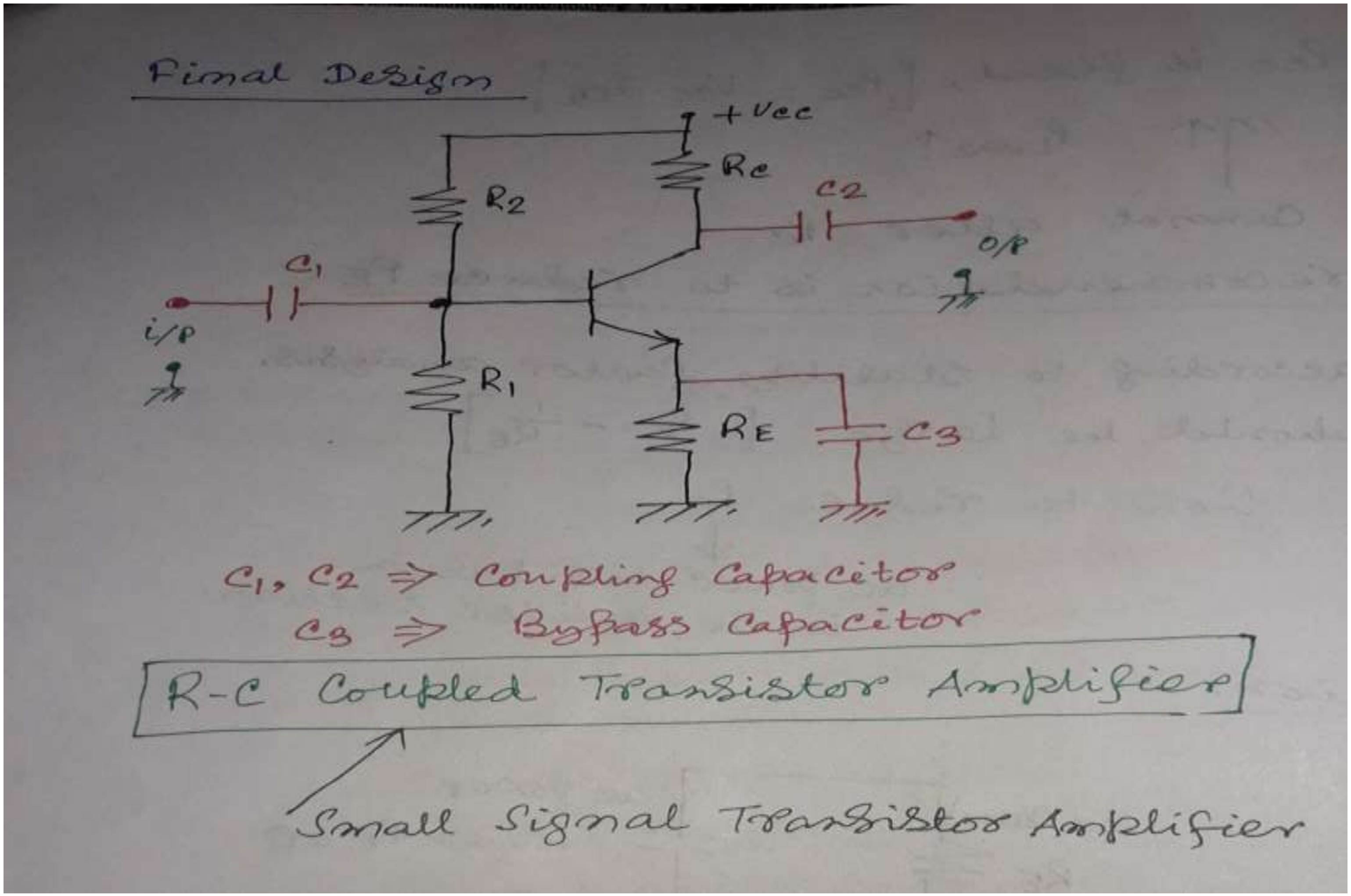
$\downarrow$

ac power dissipation in the emitter section.

Transistor Amplifier



Transistor Amplifier



Transistor Amplifier

$\boxed{\text{Low Frequency Model}}$

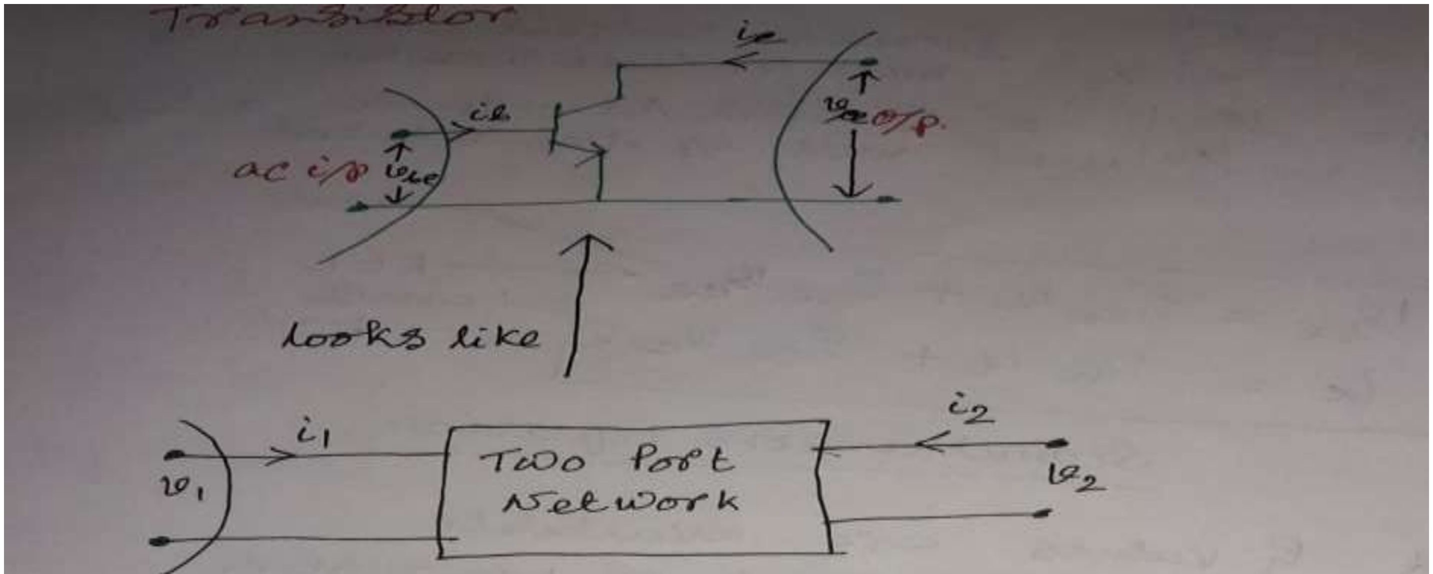
objective - <1> To findout Gain

(2) To findout Gain VS. frequency i.e frequency response [helps to get Bandwidth]

- Effect of the internal capacitances are not considered.

>> In the amplifier, frequency response of all components are known except Transistor.

Transistor Amplifier



$$\boxed{\begin{aligned} v_1 &= X_1 i_1 + X_2 v_2 \\ i_2 &= X_3 i_1 + X_4 v_2 \end{aligned}}$$

Simultaneous Equations

X_1, X_2, X_3, X_4 – Co-efficients

Transistor Amplifier

From fig.

$v_1 = v_{be},\ i_1 = i_b$

$v_2 = v_{ce},\ i_2 = i_c$

$$\boxed{\begin{aligned} v_{be} &= X_1 i_b + X_2 v_{ce} \\ i_c &= X_3 i_b + X_4 v_{ce} \end{aligned}}$$ ---- hybrid parameter

$X_1 = \left.\dfrac{v_{be}}{i_b}\right|_{v_{ce}=0}$ = Input Impedance with o/p short circuited $= h_{ie}$

$X_2 = \left.\dfrac{v_{be}}{v_{ce}}\right|_{i_b=0}$ = Reverse Voltage gain with i/p open circuited $= h_{re}$

$X_3 = \left.\dfrac{i_c}{i_b}\right|_{v_{ce}=0}$ = Forward current gain with o/p short circuited $= h_{fe}$

$X_4 = \left.\dfrac{i_c}{v_{ce}}\right|_{i_b=0}$ = Output Admittance with i/p open circuited $= h_{oe}$

$$\boxed{\begin{aligned} v_{be} &= h_{ie} i_b + h_{re} v_{ce} \\ i_c &= h_{fe} i_b + h_{oe} v_{ce} \end{aligned}}$$

eqn ① ← KVL

eqn ② ← KCL

Simultaneous Equation.

* h values are available in the datasheet of transistor.

Transistor Amplifier

$$\boxed{\begin{aligned} v_{be} &= h_{ie}\, i_b + h_{re}\, v_{ce} \\ i_c &= h_{fe}\, i_b + h_{oe}\, v_{ce} \end{aligned}}$$

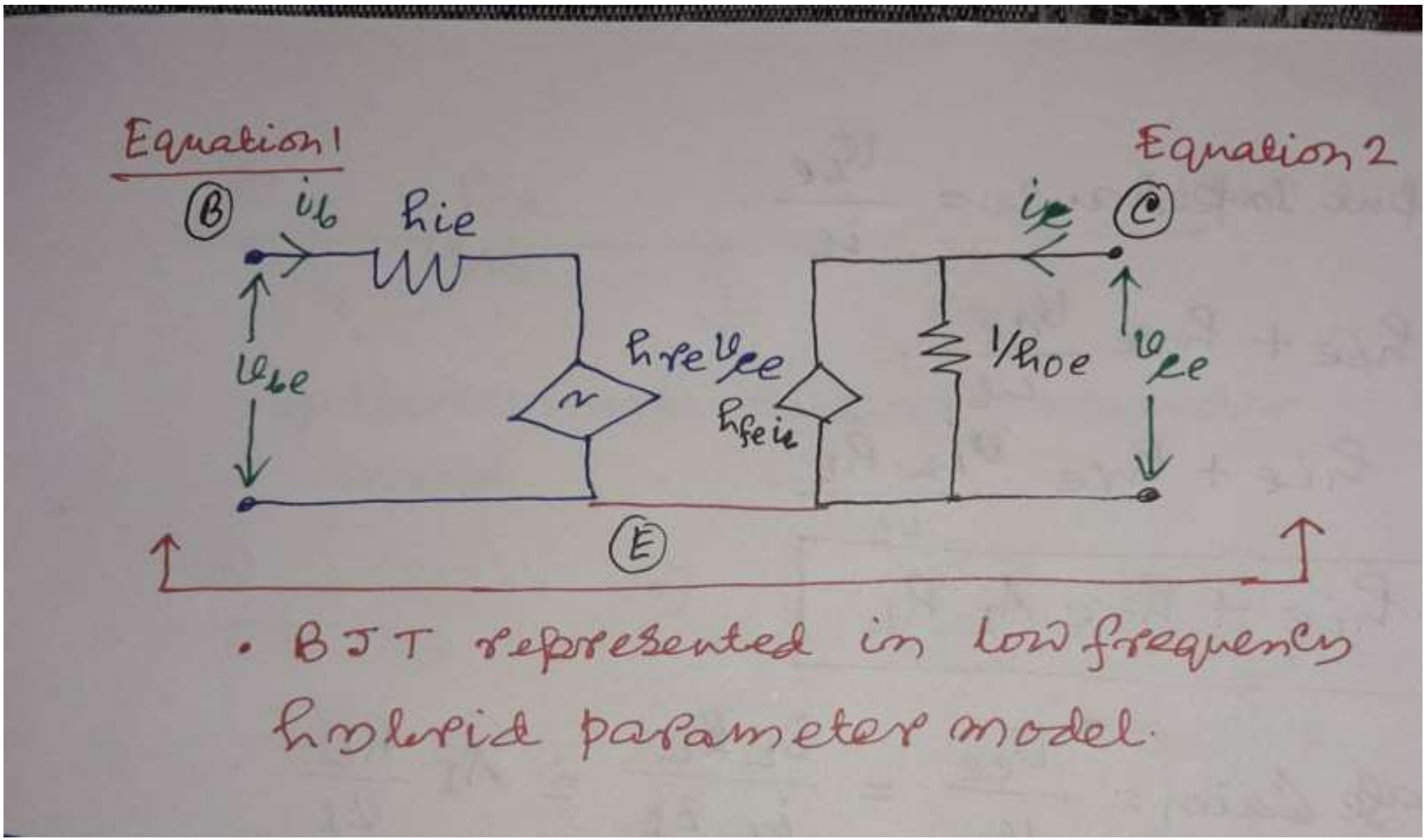
eqn ① — KVL

eqn ② — KCL

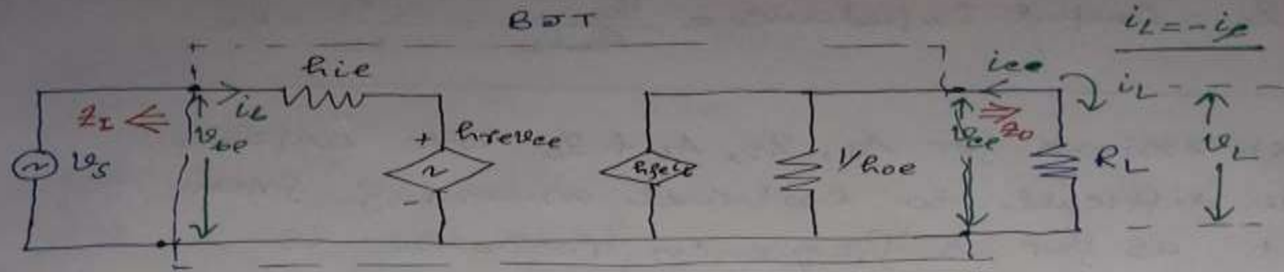
<u>Simultaneous Equation.</u>

* h values are available in the datasheet of transistor.

Transistor Amplifier



Transistor Amplifier

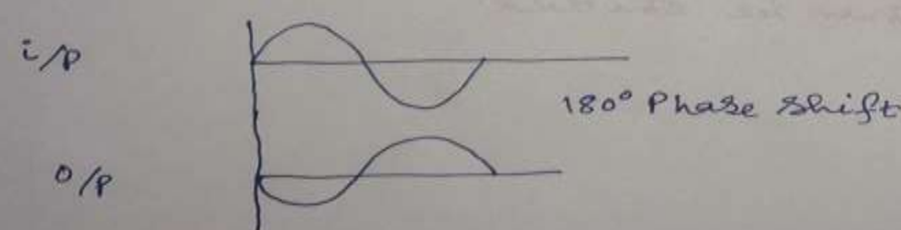


$$A_I = \frac{i_L}{i_b} = -\frac{i_c}{i_b}$$ = Current Gain

$$\therefore\ i_c = h_{fe} i_b + h_{oe}(-i_c R_L)$$

$$\therefore\ i_c[1+h_{oe}R_L] = h_{fe} i_b$$

$$\boxed{A_I = -\frac{h_{fe}}{1+h_{oe}R_L}}$$ Current Gain



Transistor Amplifier

$$Z_I = \text{Input Impedance} = \frac{v_{be}}{i_b}.$$

$$= h_{ie} + h_{re}\frac{v_{ce}}{i_b}.$$

$$= h_{ie} + h_{re}\frac{i_L \cdot R_L}{i_b}.$$

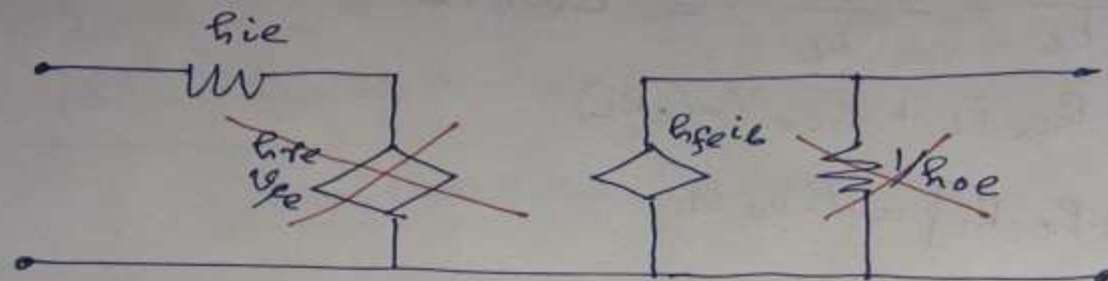
$$\boxed{Z_I = h_{ie} + h_{re} A_I R_L}$$

$$A_V = \text{Voltage Gain} = \frac{v_{ce}}{v_{be}} = \frac{i_L R_L}{i_b Z_I} \doteq A_I \frac{R_L}{Z_I}.$$

$$Z_O = \text{Output Impedance} = \frac{v_{ce}}{i_L} = \frac{i_L R_L}{i_L} = R_L$$

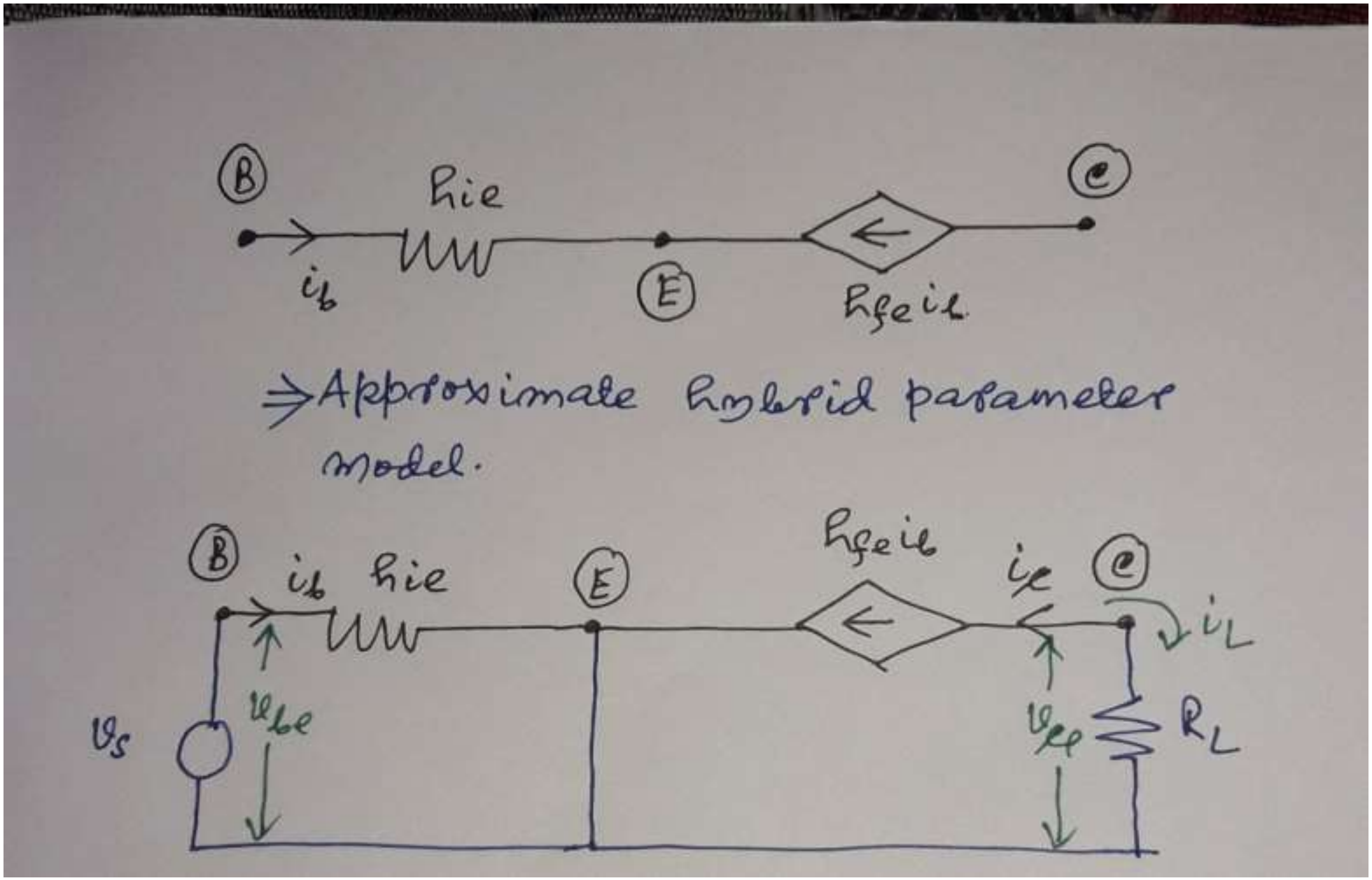
Transistor Amplifier

Expressions for A_I, Z_I, A_V & Z_0 are complex. So difficult to extract meaning from it as far as frequency response is concerned.



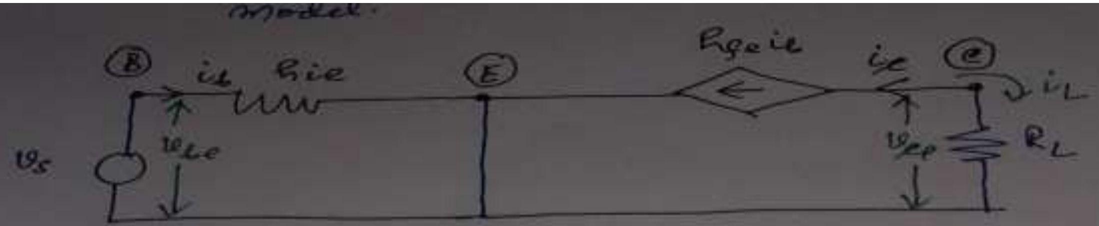
X — Contributions are less, so may be omitted.

Transistor Amplifier



Transistor Amplifier

model.



$$i_L = -i_c = -h_{fe} i_b .$$

$$A_I = \text{Current gain} = -h_{fe}$$

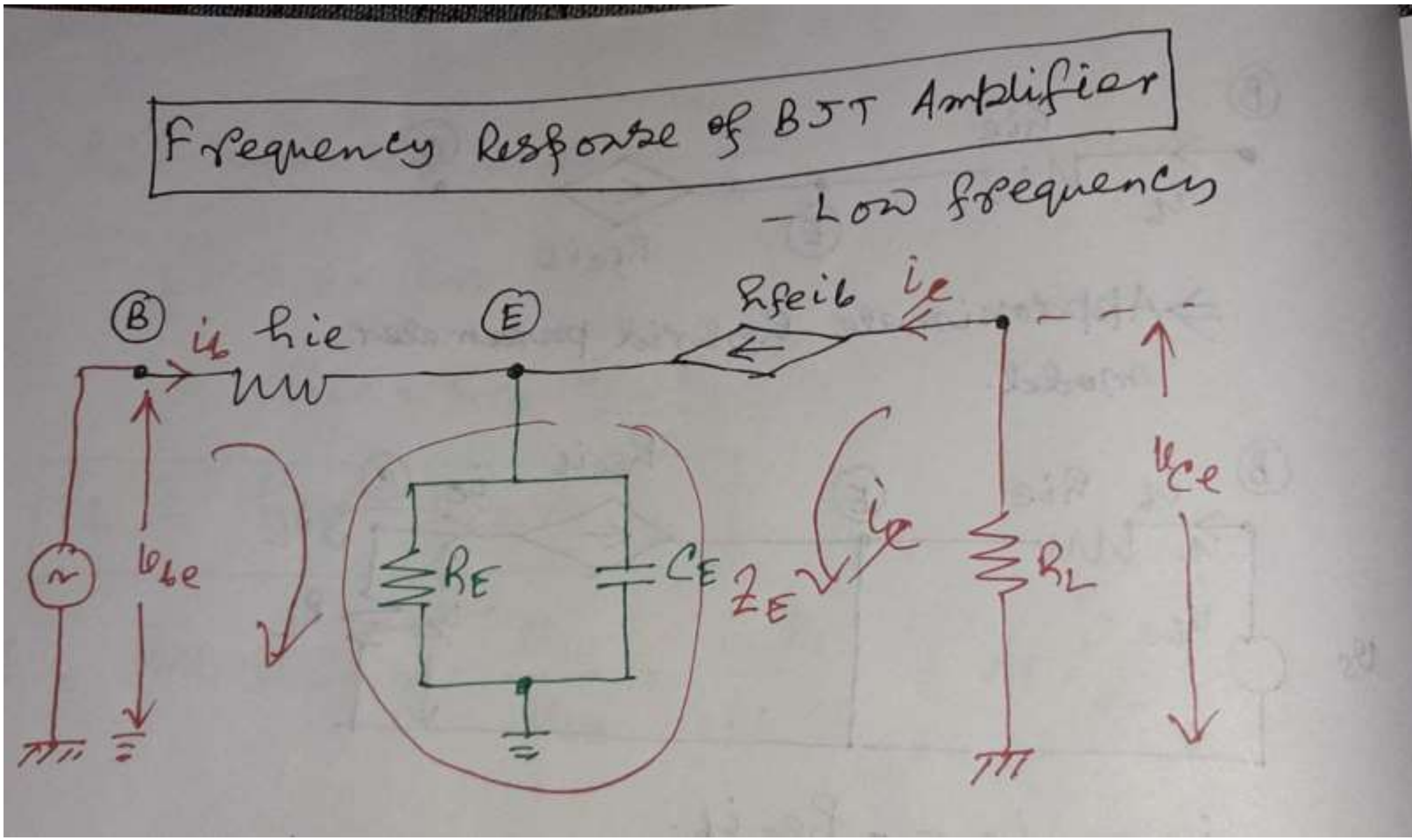
$$Z_I = \frac{v_{be}}{i_b} = \frac{h_{ie} i_b}{i_b} = h_{ie} .$$

$$Z_O = \frac{v_{ce}}{i_c} = R_L$$

$$A_V = \frac{v_{ce}}{v_{be}} = \frac{i_L R_L}{i_b h_{ie}} = A_I \cdot \frac{R_L}{h_{ie}} .$$

Available in the datasheet, mostly dependen of transistor parameters.

Transistor Amplifier



Transistor Amplifier

$j\omega C_E$

$i_e = h_{fe} i_b$

$$v_{be} = h_{ie} i_b + i_b Z_E + i_e Z_E$$

$$= i_b [h_{ie} + Z_E + h_{fe} Z_E]$$

$$= i_b [h_{ie} + Z_E (1 + h_{fe})]$$

$$v_{ce} = i_L R_L = - i_c R_L$$

$$= - h_{fe} i_b R_L .$$

$$A_v = \frac{v_{ce}}{v_{be}} = - \frac{h_{fe} \cancel{i_b} R_L}{\cancel{i_b} [h_{ie} + Z_E (1 + h_{fe})]} = \text{Voltage Gain.}$$

Transistor Amplifier

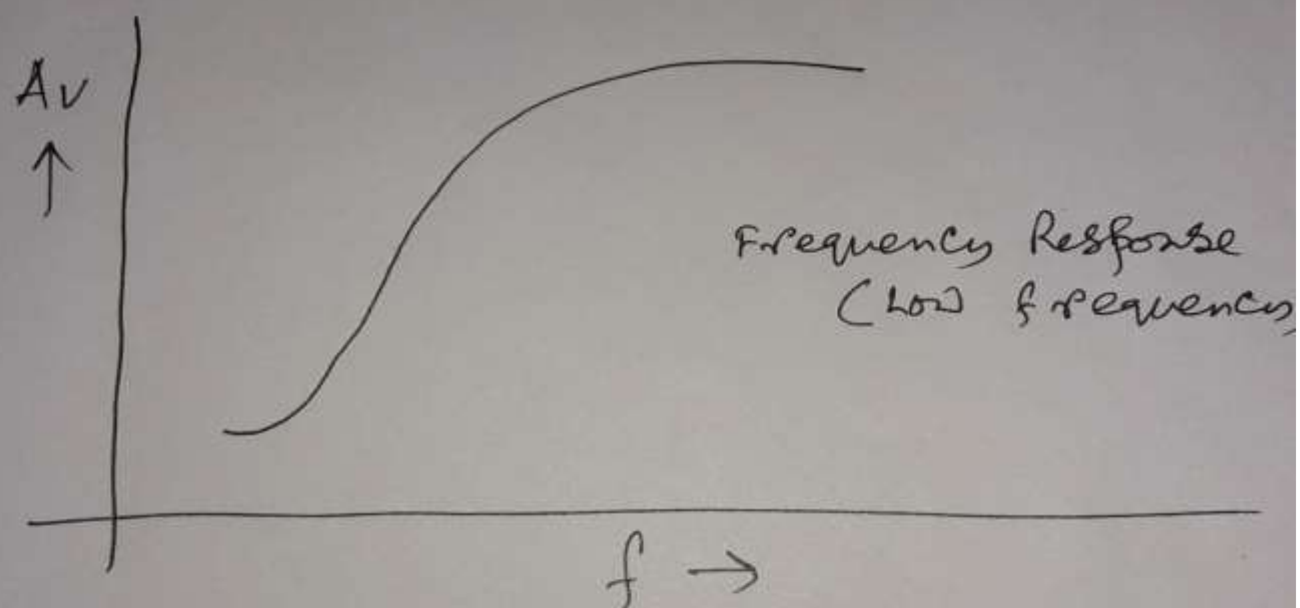
$$Z_E = \frac{R_E \cdot \frac{1}{j\omega C_E}}{R_E + \frac{1}{j\omega C_E}}$$

$$= \frac{R_E / j\omega C_E}{\dfrac{j\omega C_E R_E + 1}{j\omega C_E}}$$

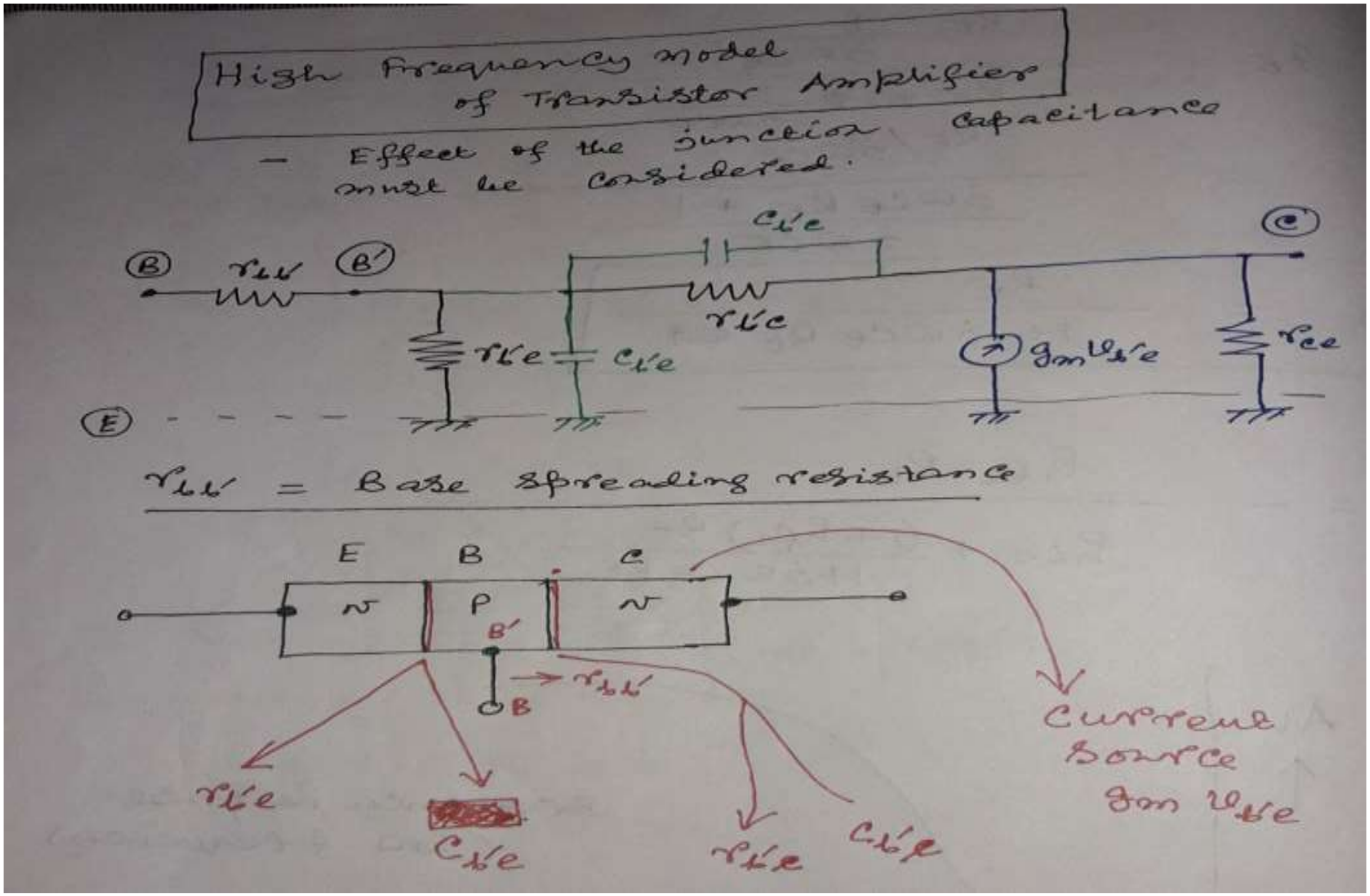
$$\boxed{Z_E = \frac{R_E}{1 + j\omega C_E R_E}}$$

Transistor Amplifier

$$A_V = -\frac{h_{fe} R_L}{h_{ie} + \dfrac{(1+h_{fe}) R_E}{1 + j\omega C_E R_E}}$$



High Frequency Model



High Frequency Model

r values & g_m are not available in the datasheet.

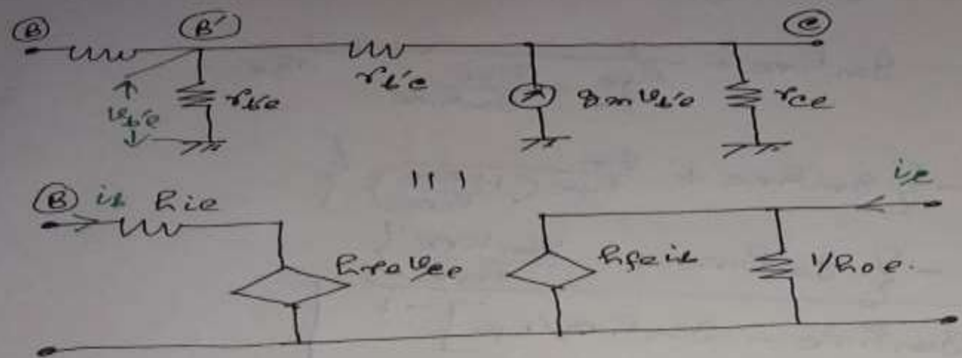
$$g_m = \text{trans conductance} = \frac{i_c}{v_{b'e}} = \frac{\alpha i_e}{v_{b'e}}.$$

$$= \frac{\alpha}{v_{b'e}/i_e} = \frac{\alpha}{r_e}$$

$$\boxed{r_e = \frac{25\,mV}{I_E}}$$

High Frequency Model

Low Frequency Equivalent of High frequency model



$$h_{re} = \left.\frac{v_{b'e}}{v_{ce}}\right|_{i_b=0} = \frac{r_{b'e}}{r_{b'e} + r_{b'c}}$$

$$\therefore \quad 1 + \frac{r_{b'c}}{r_{b'e}} = 1/h_{re}.$$

$$\therefore \quad \frac{r_{b'c}}{r_{b'e}} = \frac{1}{h_{re}} - 1 = \frac{1 - h_{re}}{h_{re}} \approx \frac{1}{h_{re}}$$

$$h_{fe} = \left.\frac{i_c}{i_b}\right|_{v_{ce}=0} = \frac{g_m v_{b'e}.}{v_{b'e}/r_{b'e}} \Rightarrow \boxed{r_{b'e} = \frac{h_{fe}}{g_m}}$$

$$\therefore \boxed{r_{b'c} = \frac{h_{fe}.}{h_{re} \cdot g_m}}$$

High Frequency Model

$r_{bb'} + r_{b'e} = h_{ie}$.

$\therefore r_{bb'} = h_{ie} - r_{b'e} \Rightarrow \boxed{r_{bb'} = h_{ie} - \frac{h_{fe}}{g_m}}$

High Frequency Model

$$i_c = g_m v_{b'e} + \frac{v_{ce}}{r_{b'e} + r_{b'c}} + \frac{v_{ce}}{r_{ce}}$$

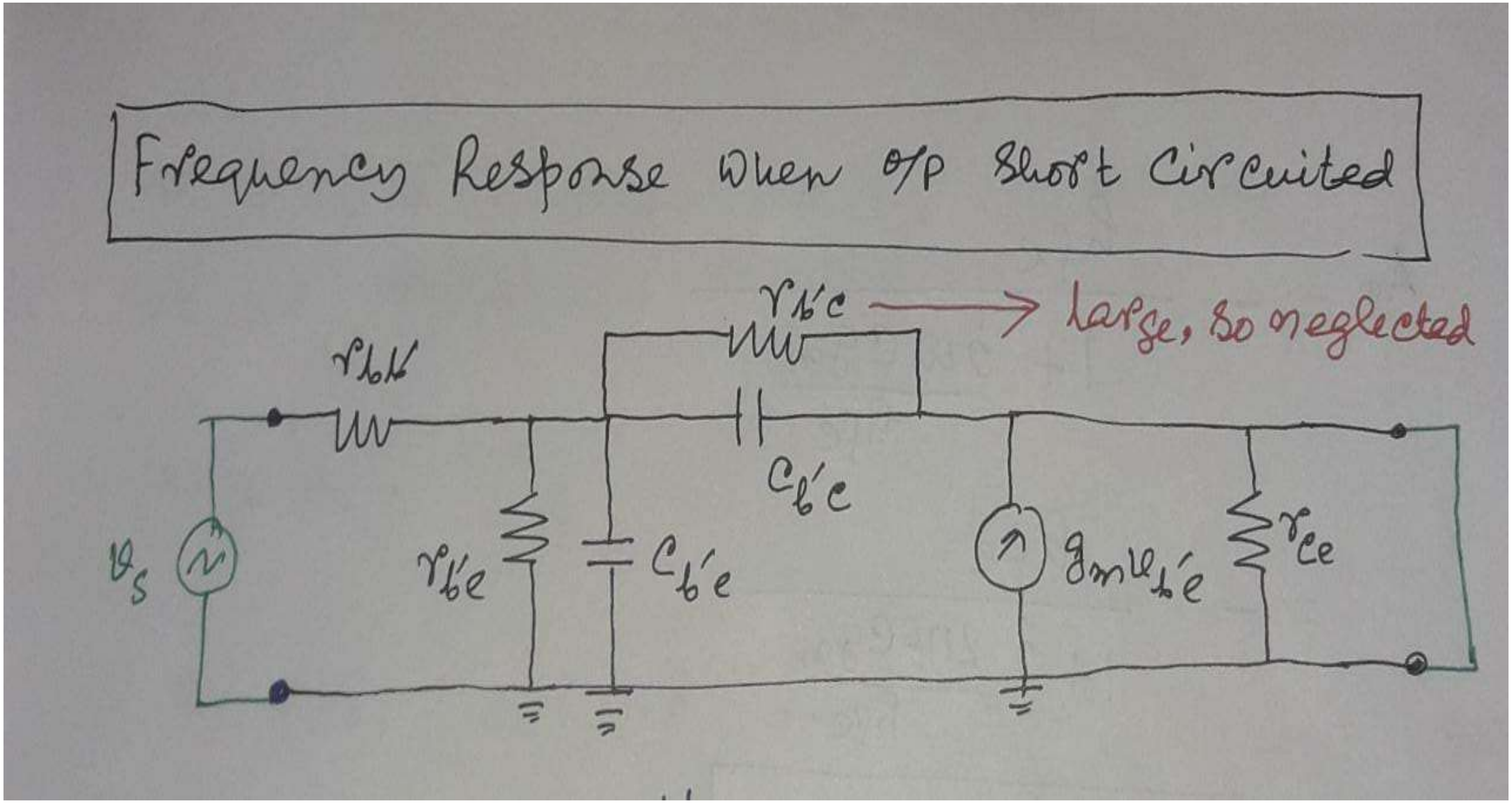
$$\therefore \left.\frac{i_c}{v_{ce}}\right|_{i_b=0} = h_{oe} = g_m h_{re} + \frac{1}{\frac{h_{fe}}{g_m} + \frac{h_{fe}}{g_m h_{re}}} + \frac{1}{r_{ce}}$$

$$\therefore \frac{1}{r_{ce}} = h_{oe} - \left\{ g_m h_{re} + \frac{g_m}{h_{fe}\left(\frac{1+h_{re}}{h_{re}}\right)} \right\}$$

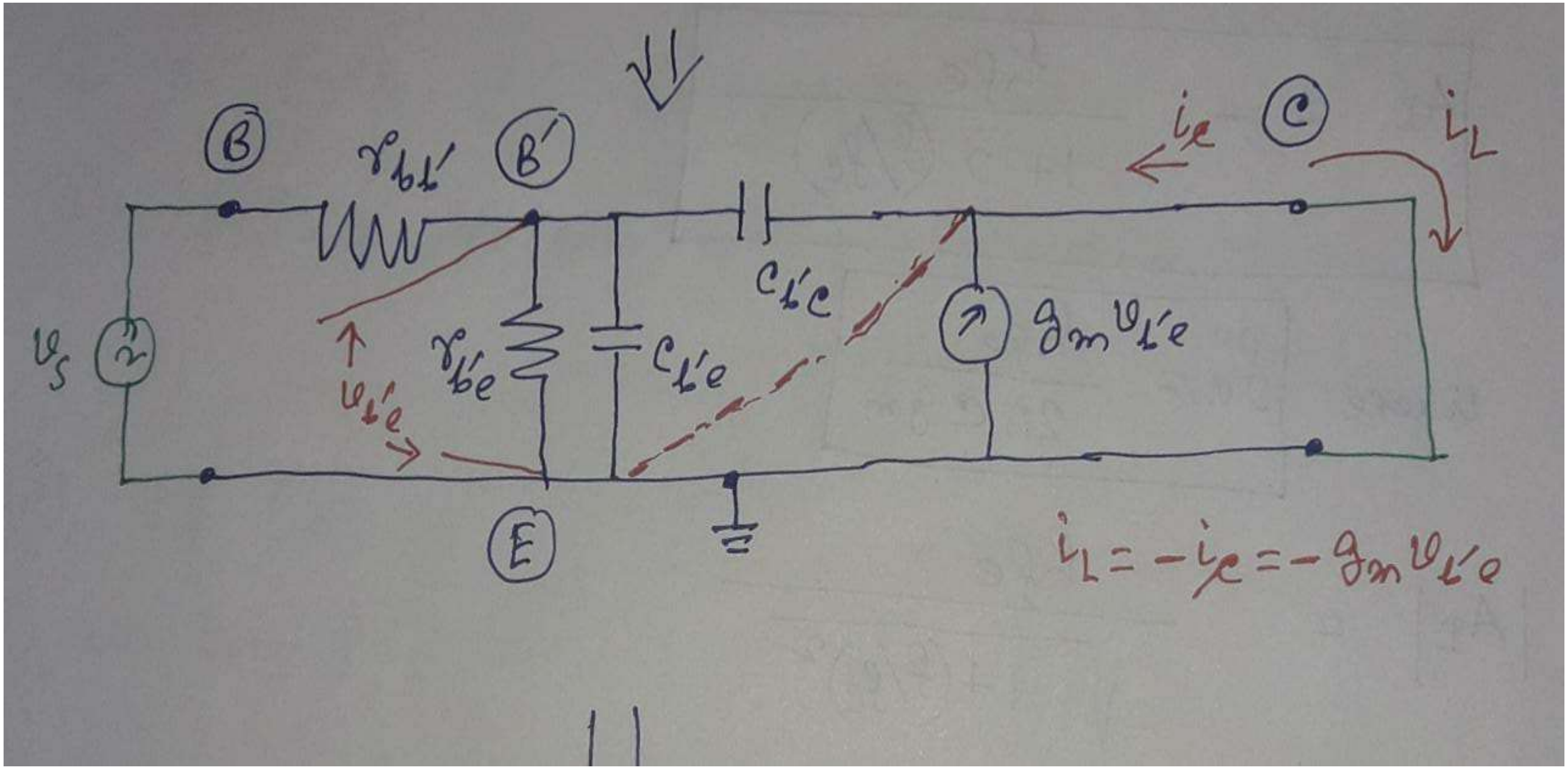
$$= h_{oe} - \left\{ g_m h_{re} + \frac{g_m h_{re}}{h_{fe}} \right\}$$

$$\boxed{r_{ce} = \left[h_{oe} - g_m h_{re} - g_m h_{re}/h_{fe}\right]^{-1}}$$

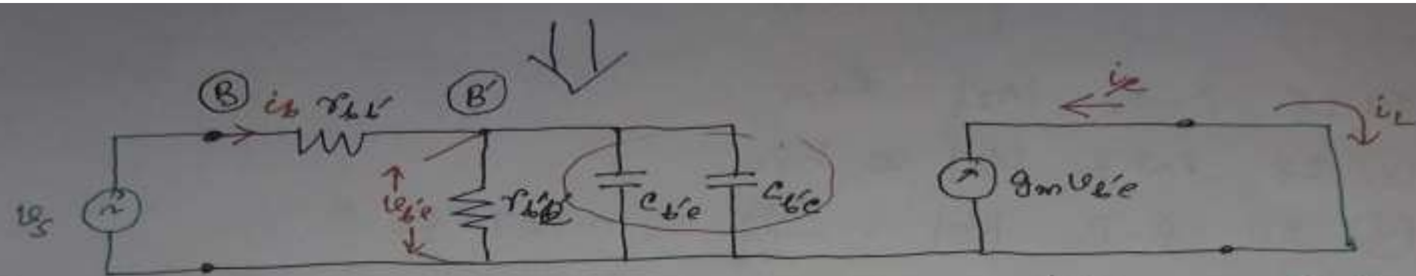
High Frequency Model



High Frequency Model



High Frequency Model



$$i_L = -i_c = -g_m v_{b'e}$$

$$C = C_{b'e} + C_{b'c}$$

$$i_b = v_{b'e}\left[\frac{1}{r_{b'e}} + j\omega C\right]$$

$$= v_{b'e}\left[\frac{g_m}{h_{fe}} + j\omega C\right]$$

$$\therefore \quad A_I = \frac{i_L}{i_b} = -\frac{g_m v_{b'e}}{v_{b'e}\left[\frac{g_m}{h_{fe}} + j\omega C\right]}$$

High Frequency Model

$$A_I = - \frac{h_{fe}}{1 + \frac{j\omega C\, h_{fe}}{g_m}}$$

$$= - \frac{h_{fe}}{1 + j\,\frac{2\pi f C\, h_{fe}}{g_m}}$$

$$\boxed{A_I = - \frac{h_{fe}}{1 + j\,(f/f_c)}}$$

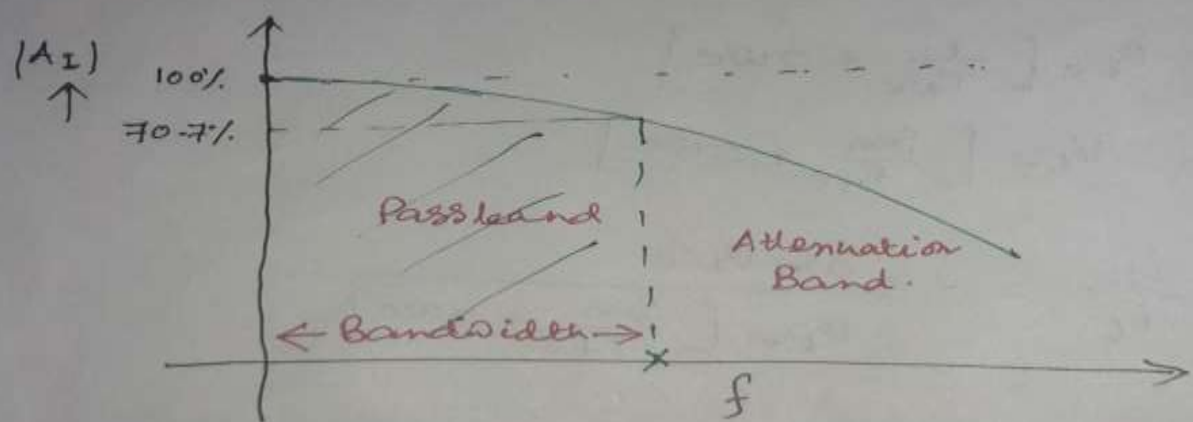
where $\boxed{\cancel{f_c = \frac{h_{fe}}{2\pi C\, g_m}}}$ $\boxed{f_c = \frac{g_m}{2\pi C\, h_{fe}}}$

$$|A_I| = \frac{h_{fe}}{\sqrt{1 + (f/f_c)^2}}$$

High Frequency Model

$$|A_I| = \frac{h_{fe}}{\sqrt{1+(f/f_c)^2}}$$

1. If $f = 0$, $|A_I| = h_{fe}$
2. If $f \ll f_c$ $|A_I| \simeq h_{fe}$
3. If $f = f_c$ $|A_I| = \frac{h_{fe}}{\sqrt{2}} = 0.707\, h_{fe}$
4. If $f \gg f_c$ $|A_I| = h_{fe} \cdot \frac{f_c}{f}$



High Frequency Model

As $|A_I|$ is a large quantity, normally it is expressed in terms of dB.

$$|A_I| \text{ in dB} = 20 \log_{10} |A_I|$$

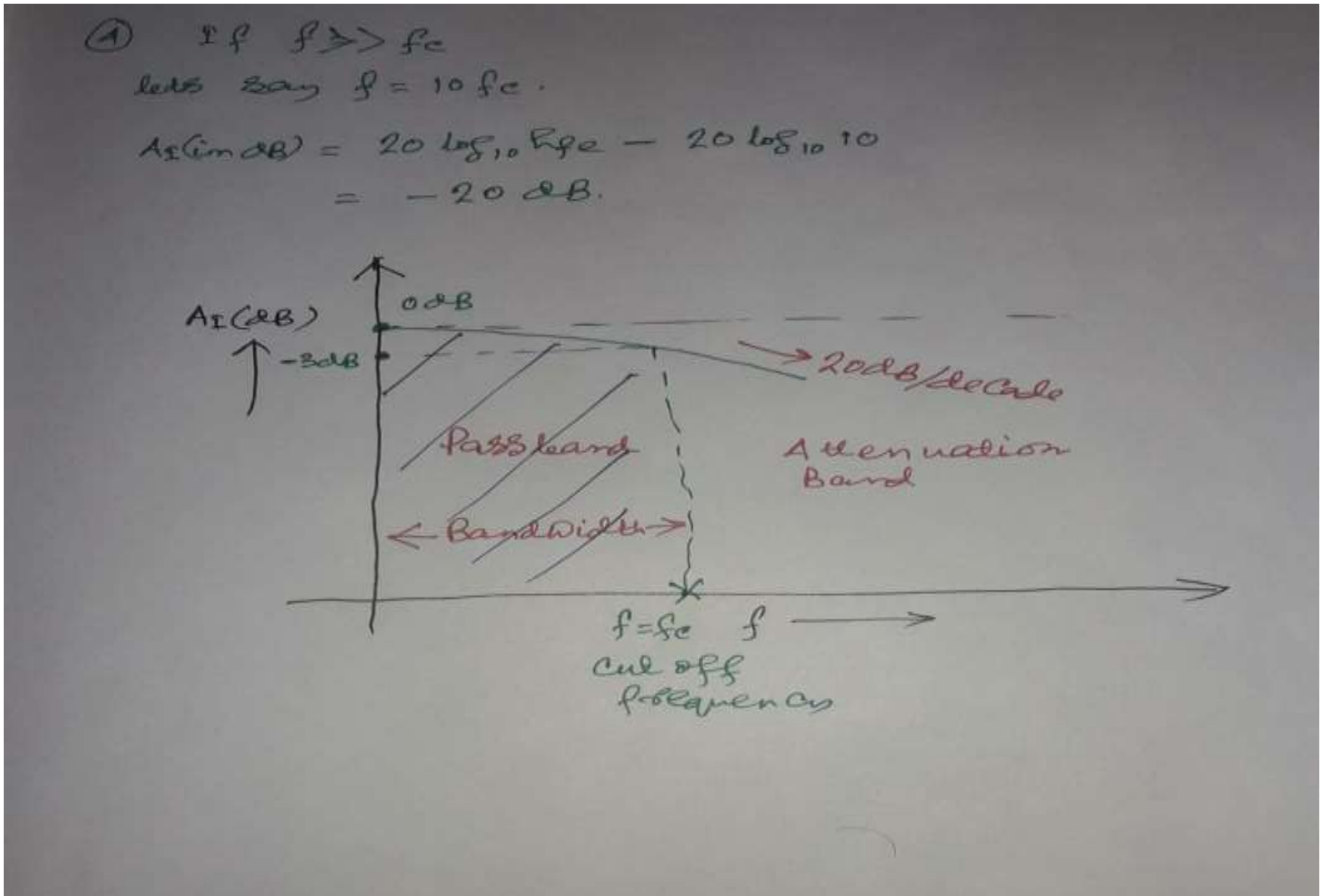
① If $f = 0$, $|A_I| \text{ in dB} = 20 \log_{10} h_{fe}$ - - - (maxm.) - - - 0 dB

② If $f << f_e$, $|A_I| \text{ in dB} \simeq 20 \log_{10} h_{fe}$ - - - - -

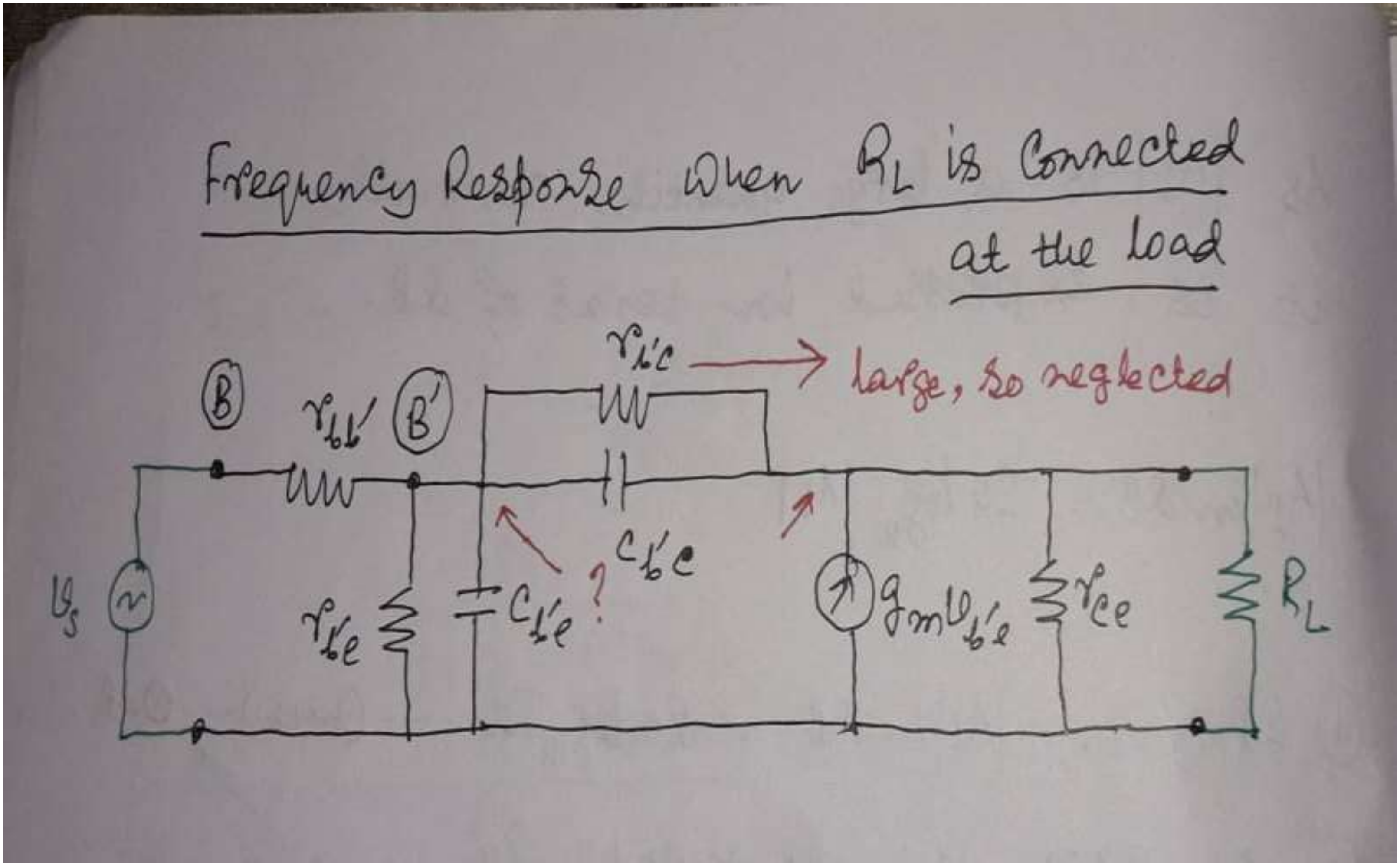
③ If $f = f_e$ $|A_I| (dB) = 20 \log_{10} h_{fe} - 20 \log_{10} \sqrt{2}$

$$= 0 \text{ dB} - 3 \text{ dB} = -3 \text{ dB}$$

High Frequency Model

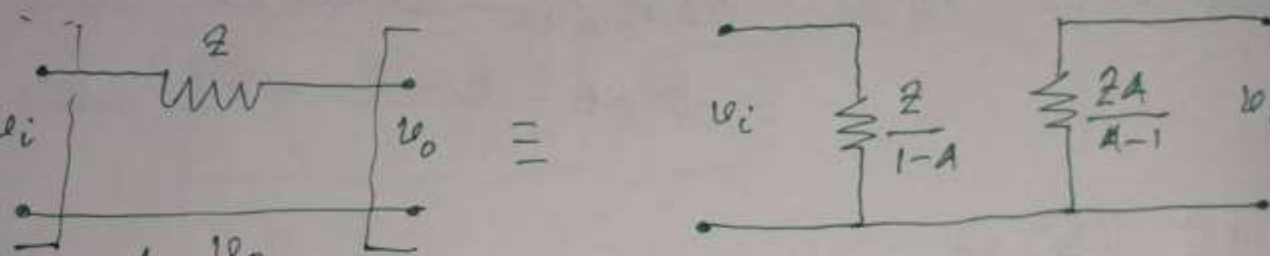


High Frequency Model

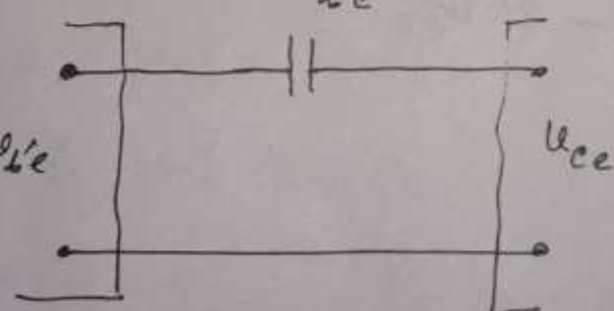


High Frequency Model

Use Miller's Theorem



$$A = \frac{v_o}{v_i}$$



$$A = \frac{v_{ce}}{v_{b'e}} = -\frac{g_m v_{b'e} R_L}{v_{b'e}}$$

$$\boxed{A = -g_m R_L}$$

High Frequency Model

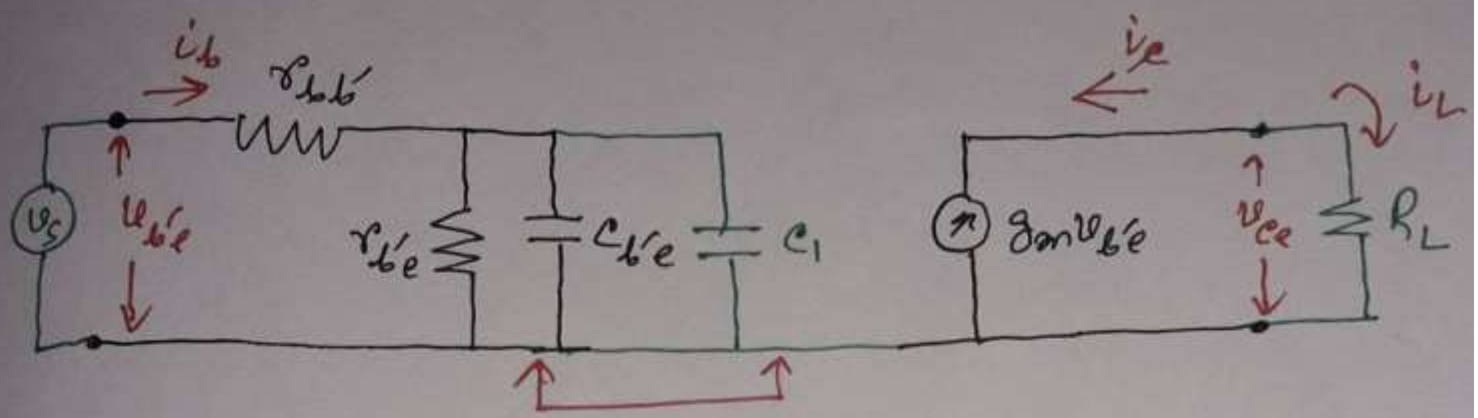
$$\frac{Z}{1-A} = \frac{\frac{1}{j\omega C_{b'c}}}{1+g_m R_L} = \frac{1}{j\omega C_{b'c}(1+g_m R_L)}$$

$$= \frac{1}{j\omega C_1}$$

where $C_1 = C_{b'c}(1+g_m R_L)$

$$\frac{ZA}{A-1} = \frac{(-g_m R_L)\frac{1}{j\omega C_{b'c}}}{-g_m R_L - 1} \approx \frac{1}{j\omega C_{b'c}}$$

High Frequency Model



$$C = C_{b'e} + C_1$$

$$i_b = v_{b'e}\left[\frac{1}{r_{b'e}} + j\omega C\right]$$

$$= v_{b'e}\left[\frac{g_m}{h_{fe}} + j\omega C\right]$$

High Frequency Model

$$A_I = \frac{i_L}{i_b} = \frac{-g_m v_{b'e}}{v_{b'e}\left[\frac{g_m}{h_{fe}} + j\omega C\right]}$$

$$= -\frac{h_{fe}}{1 + \frac{j\omega C h_{fe}}{g_m}}$$

$$\boxed{A_I = -\frac{h_{fe}}{1 + j\left(\frac{f}{f_e}\right)}}$$

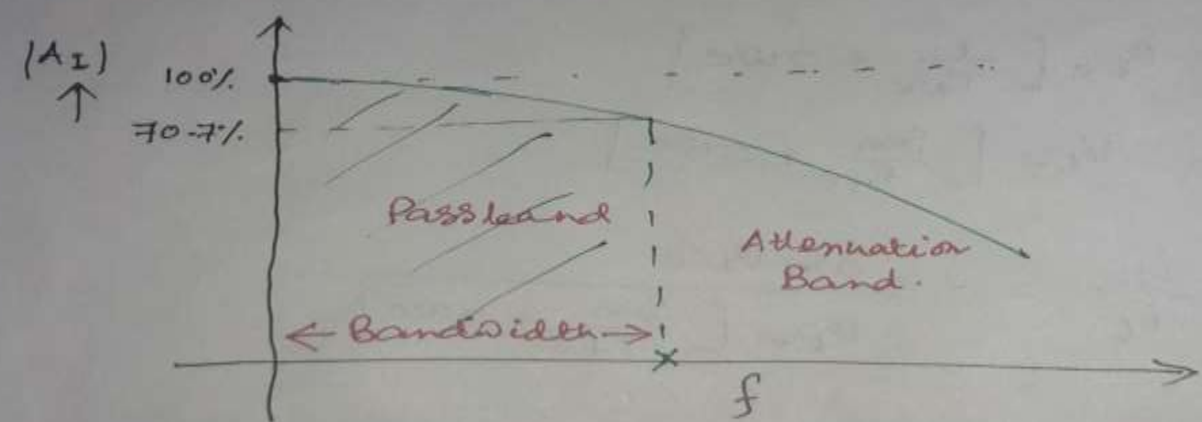
where $f_e = \frac{g_m}{2\pi C h_{fe}}$

$$\boxed{C = C_{b'e} + C_{b'c}(1 + g_m R_L)}$$

High Frequency Model

$$|A_I| = \frac{h_{fe}}{\sqrt{1+(f/f_c)^2}}$$

1. If $f = 0$, $|A_I| = h_{fe}$
2. If $f \ll f_c$ $|A_I| \simeq h_{fe}$
3. If $f = f_c$ $|A_I| = \frac{h_{fe}}{\sqrt{2}} = 0.707\, h_{fe}$.
4. If $f \gg f_c$ $|A_I| = h_{fe} \cdot \frac{f_c}{f}$



High Frequency Model

As $|A_I|$ is a large quantity, normally it is expressed in terms of dB.

$$|A_I| \text{ in dB} = 20 \log_{10} |A_I|$$

① If $f = 0$, $|A_I|$ in dB $= 20 \log_{10} h_{fe}$ - - - (maxm.) - - - 10 dB

② If $f << f_c$, $|A_I|$ in dB $\approx 20 \log_{10} h_{fe}$ - - - - -

③ If $f = f_c$ $|A_I|$ (dB) $= 20 \log_{10} h_{fe} - 20 \log_{10} \sqrt{2}$

$= 0 \text{ dB} - 3 \text{ dB} = -3 \text{ dB}$

High Frequency Model

(1) If $f >> f_c$

lets say $f = 10 f_c$.

$A_I(\text{in dB}) = 20 \log_{10} h_{fe} - 20 \log_{10} 10$

$= -20\ \text{dB}.$