→ Two Stage RC coupled CE-CE Cascade Amplifier.

→ As shown in fig below the two stage RC coupled common emitter amplifier. The two transistors are identical and a common power supply is used. R_{C1} and R_{C2} is collector resistors [load]. Resistors R_{11}, R_{12}, R_{21}, R_{22} and R_E Provide the required bias. The output of the first stage gets coupled to the input of the second stage via coupling capacitor(C_c) which also serves as the blocking capacitor to keep the dc component of the output of the first stage from reaching the input of the second stage and to pass ac component.

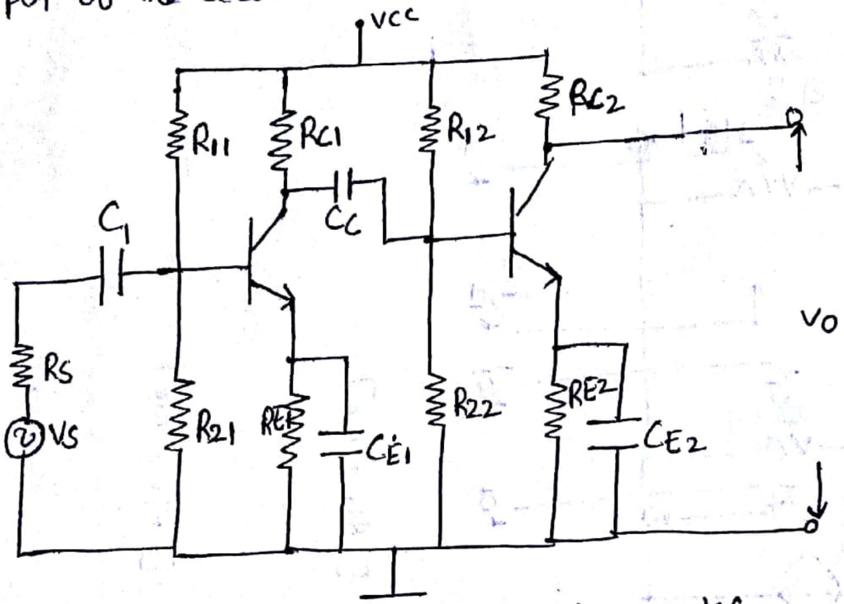
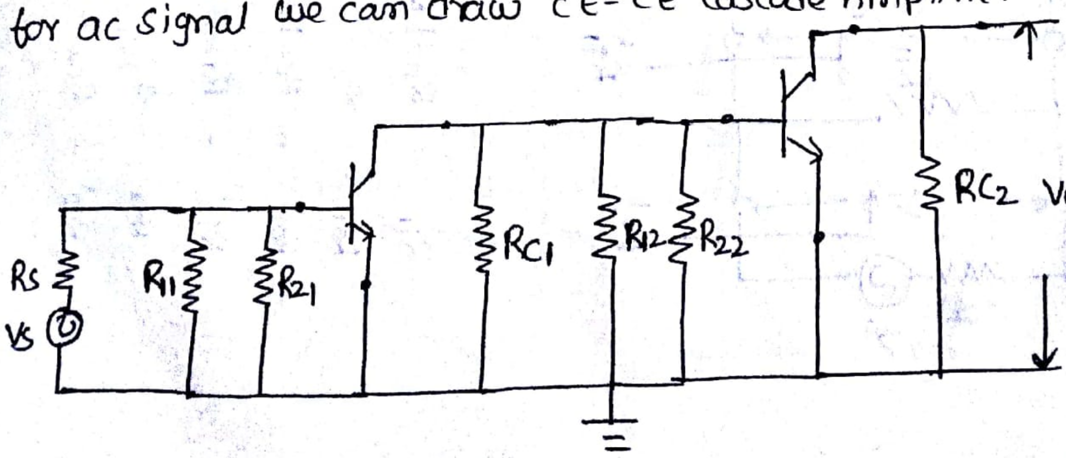
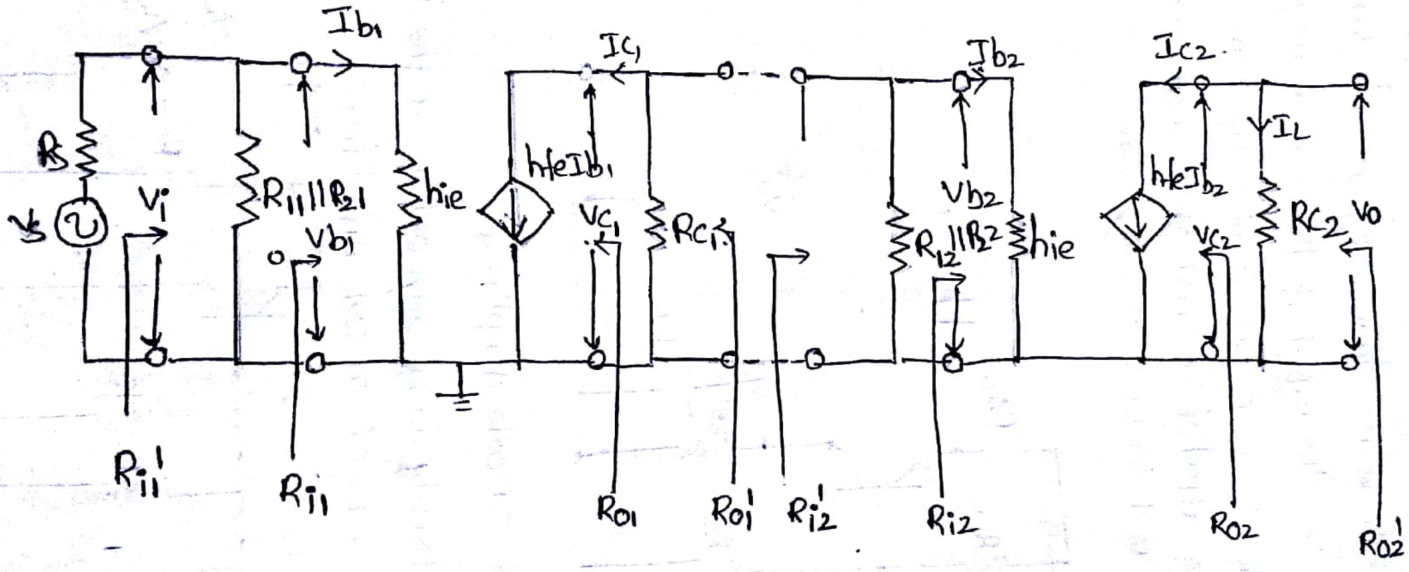


Fig : CE-CE Cascade Amplifier.

Assuming all capacitors arbitrarily large and act as a short circuit for ac signal we can draw CE-CE cascade Amplifier.



→ Two stage RC coupled CE-CE Cascade Amplifier by using h-Parameter model [approximate analysis].



$R_{i1}' = R_{11} \| R_{21} \| R_{i1}$ $\quad [R_{i1} = h_{ie}]$

$R_{o1} = \infty$

$R_{o1}' = R_{C1} \| \infty = R_{C1}$

$R_{i2}' = R_{12} \| R_{22} \| R_{i2}$ $\quad [R_{i2} = h_{ie}]$

$R_{o2} = \infty$

$R_{o2}' = R_{C2} \| \infty = R_{C2}$.

②

→ Analysis of second stage CE Amplifier.

(1) current gain (A_{i2}) $= \frac{I_o}{I_{b2}} = -\frac{I_{C2}}{I_{b2}} = -\frac{h_{fe} \cancel{I_{b2}}}{\cancel{I_{b2}}} = -h_{fe}$.

(2) Input Resistance (R_{i2}) $= \frac{V_{b2}}{I_{b2}} = \frac{h_{ie} I_{b2}}{I_{b2}} = h_{ie}$.

(3). overall input resistance $R_{i2}' = R_{12} \| R_{22} \| R_{i2}$

[we know that $A_V = A_i \left[\frac{R_L'}{R_i}\right]$]

(4). voltage gain (A_{V2}) $= A_{i2} \times \left[\frac{R_{C2}}{R_{i2}}\right]$

→ Analysis of First stage :-

(5) $A_{i1} = -\frac{I_{C1}}{I_{b1}} = -\frac{h_{fe} I_{b1}}{I_{b1}} = -h_{fe} =$

(6) Input resistance (R_{i1}) $= \frac{V_{b1}}{I_{b1}} = \frac{h_{ie} I_{b1}}{I_{b1}} = h_{ie}$.

(7) overall input resistance $R_{i1}' = R_{11} \| R_{21} \| R_{i1}$

(8). voltage gain (A_{V1}) =

we know that voltage gain (A_V) $= A_i \left[\frac{R_L}{R_i}\right]$

so $A_{V1} = A_{i1} \left[\frac{R_L'}{R_{i1}}\right]$

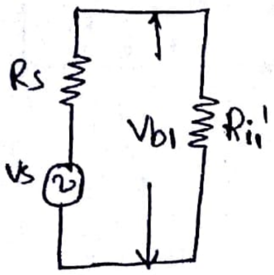
$R_L' = R_{C1} \| R_{12} \| R_{22} \| R_{i2}$

⑨ Overall voltage gain ~~with~~ (A_{vs}) (or) voltage gain with Source resistance.

$$A_{vs} = \frac{V_{c2}}{V_s} = \frac{V_{c2}}{V_{b2}} \times \frac{V_{b2}}{V_{c1}} \times \frac{V_{c1}}{V_{b1}} \times \frac{V_{b1}}{V_s} \qquad [\because V_{b2} = V_{c1}]$$

$$= \frac{V_{c2}}{V_{b2}} \times \frac{\cancel{V_{c1}}}{\cancel{V_{c1}}} \times \frac{V_{c1}}{V_{b1}} \times \frac{V_{b1}}{V_s}$$

$$= A_{V2} \times A_{V1} \times \left[\frac{V_{b1}}{V_s}\right]$$



$$V_{b1} = V_s \times \left[\frac{R_{i1}'}{R_s + R_{i1}'}\right]$$

$$\frac{V_{b1}}{V_s} = \left[\frac{R_{i1}'}{R_s + R_{i1}'}\right]$$

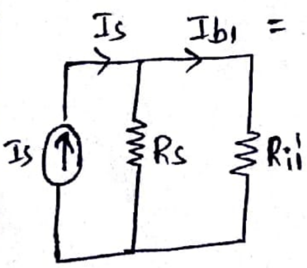
$$\boxed{A_{vs} = A_{V1} \times A_{V2} \times \left[\frac{R_{i1}'}{R_s + R_{i1}'}\right]}$$

⑩ Overall current gain (A_{is}) (or) current gain with source resistance.

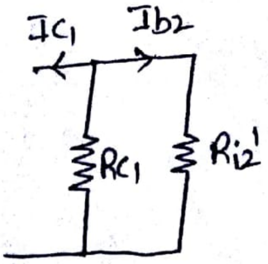
$$A_{is} = \frac{I_L}{I_s} = \frac{I_L}{I_{c2}} \times \frac{I_{c2}}{I_{b2}} \times \frac{I_{b2}}{I_{c1}} \times \frac{I_{c1}}{I_{b1}} \times \frac{I_{b1}}{I_s} \qquad \boxed{I_L = -I_{c2}}$$

$$= \left(-\frac{I_{c2}}{I_{c2}}\right) \times [A_{i2}] \times \frac{I_{b2}}{I_{c1}} \times (-A_{i1}) \times \left[\frac{I_{b1}}{I_s}\right]$$

$$= (-1) \times A_{i2} \times \left[\frac{I_{b2}}{I_{c1}}\right] \times A_{i1} \times \left[\frac{I_{b1}}{I_s}\right]$$



$$I_{b1} = I_s \times \left[\frac{R_s}{R_s + R_{i1}'}\right] \Rightarrow \frac{I_{b1}}{I_s} = \left[\frac{R_s}{R_s + R_{i1}'}\right]$$



$$I_{b2} = (-I_{c1}) \times \left[\frac{R_{c1}}{R_{c1} + R_{i2}'}\right] \Rightarrow \frac{I_{b2}}{I_{c1}} = -\left[\frac{R_{c1}}{R_{c1} + R_{i2}'}\right]$$

$$\boxed{A_{is} = A_{i1} \times A_{i2} \times \left[\frac{R_s}{R_s + R_{i1}'}\right] \times \left[\frac{R_{c1}}{R_{c1} + R_{i2}'}\right]}$$

→ Cascode Amplifier [CE-CB Amplifier]

→ The cascode amplifier consists of a Common emitter amplifier stage in series with a Common base Amplifier stage. The cascode amplifier gives the high input impedance of a common emitter amplifier as well as good voltage gain and high frequency performance of a common base circuit.

→ It is a Composite Amplifier pair with large Bandwidth used for radio frequency applications and as a video amplifier.

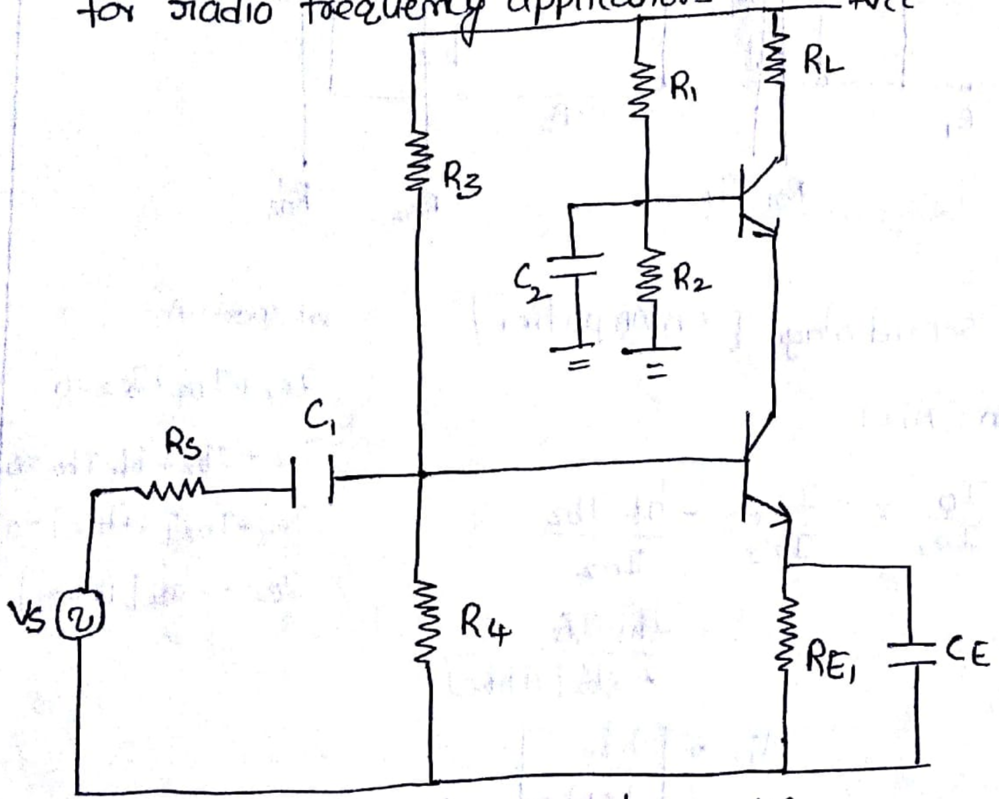
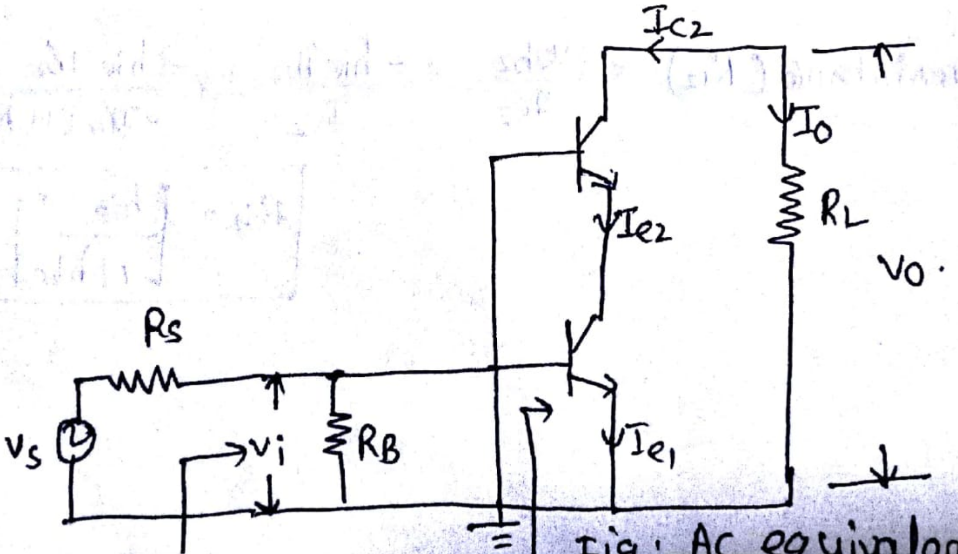


Fig : Cascode Amplifier



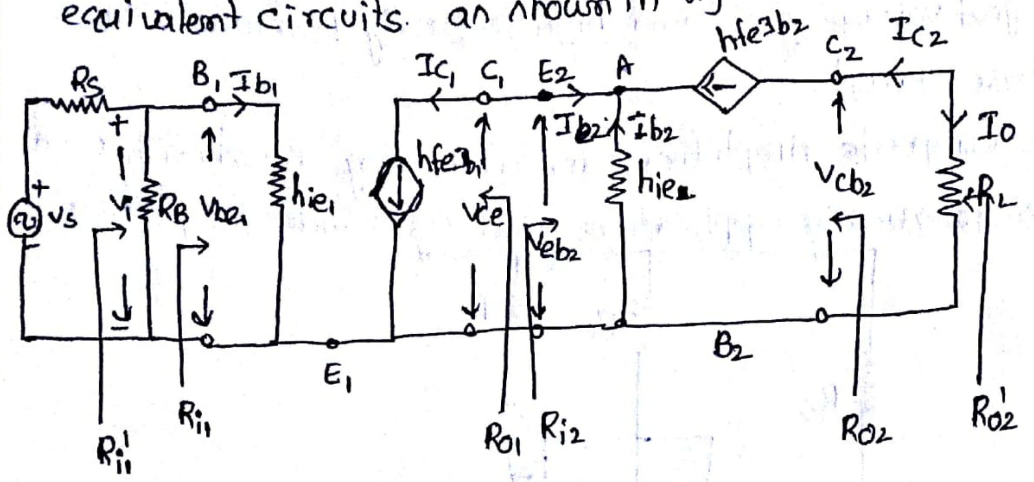
Ri RB = R3 || R4

Fig: AC equivalent circuit.

→ collector current $I_{c1} \simeq I_{e1}$ & I_{e2} is same as I_{c1}

$\therefore I_{c2} \simeq I_{e1}$

→ The simplified h-Parameter equivalent circuit for cascode Amplifier is drawn by replacing transistor with their simplified equivalent circuits as shown in fig below.



→ Analysis of second stage [CB Amplifier]

At node A

$I_{e2} + I_{b2} + I_{c2} = 0$

$I_{e2} + I_{b2} + h_{fe} I_{b2} = 0$

$I_{e2} + I_{b2}[1 + h_{fe}] = 0$

$I_{e2} = -I_{b2}[1 + h_{fe}]$

ⓐ current gain (A_{i2})

$$A_{i2} = \frac{I_o}{I_{e2}} = -\frac{I_{c2}}{I_{e2}} = -\frac{h_{fe} I_{b2}}{I_{e2}}$$

$$= \frac{+h_{fe} \cancel{I_{b2}}}{+\cancel{I_{b2}}[1 + h_{fe}]}$$

$$A_{i2} = \left[\frac{h_{fe}}{1 + h_{fe}}\right]$$

ⓑ Input resistance $(R_{i2}) = \frac{V_{eb2}}{I_{e2}} = -\frac{h_{ie} I_{b2}}{I_{e2}} = \frac{+h_{ie} \cancel{I_{b2}}}{+\cancel{I_{b2}}[1 + h_{fe}]}$

$$\boxed{R_{i2} = \left[\frac{h_{ie}}{1 + h_{fe}}\right]}$$

(5) voltage gain

$$A_{v2} = \frac{V_{cb2}}{V_{eb2}} = \frac{I_o R_L}{V_{eb2}} = \frac{-I_c R_L}{-h_{ie} I_{b2}} = \frac{-[h_{fe} R_L I_{b2}]}{-[h_{ie} I_{b2}]} = \left[\frac{h_{fe}}{h_{ie}}\right] R_L$$

→ Analysis of first stage (CE Amplifier)

(a) current gain (A_{i1})

(a) $A_{i1} = -\frac{I_{c1}}{I_{b1}} = \frac{-h_{fe} I_{b1}}{I_{b1}} = -h_{fe}$

(b) Input resistance $(R_{i1}) = \frac{V_{be1}}{I_{b1}} = \frac{h_{ie} I_{b1}}{I_{b1}} = h_{ie}$.

(c) voltage gain (A_{v1}) :

while calculating A_{v1} the load resistance of 1st stage = $\boxed{R_{L1} = R_{i2}}$

input resistance IInd stage.

$$A_{v1} = -A_{i1} \times \frac{R_{L1}}{R_{i1}} = A_{i1} \times \frac{R_{i2}}{R_{i1}} = -h_{fe} \times \left[\frac{R_{i2}}{R_{i1}}\right]$$

$R_{i1} = h_{ie}$

$R_{i1}' = R_B \parallel R_{i1} = R_3 \parallel R_4 \parallel R_{i1}$

(d) overall ~~voltag~~ input resistance : $R_{i1}' = R_B \parallel R_{i1}$

$= R_3 \parallel R_4 \parallel R_{i1}$

(e) overall output resistance $R_{o2}' = R_{o2} \parallel R_L$

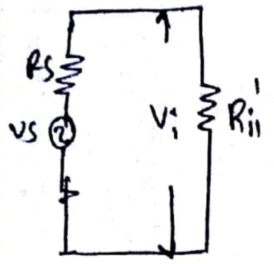
$R_{o2} = \infty$

$\therefore R_{o2}' = \infty \parallel R_L = R_L$

overall voltage gain (Av) = $Av_1 \times Av_2$

overall voltage gain (Av) with source resistance (Avs) = $\frac{V_o}{V_s}$

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \times \left[\frac{V_i}{V_s}\right] = A_v\left[\frac{V_i}{V_s}\right]$$
$$= Av_1 \times Av_2 \left[\frac{V_i}{V_s}\right]$$



$$V_i = V_s \times \left[\frac{R_{i1}'}{R_{i1}' + R_s}\right]$$

$$\frac{V_i}{V_s} = \left[\frac{R_{i1}'}{R_{i1}' + R_s}\right]$$

$$\boxed{A_{vs} = A_v \times \left[\frac{R_{i1}'}{R_{i1}' + R_s}\right]}$$

$$\boxed{R_{i1}' = R_{i1} \parallel R_3 \parallel R_4}$$

→ overall current gain(Ai) with source resistance :-

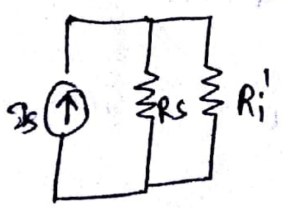
$$A_{is} = \frac{I_o}{I_s} = \frac{I_o}{I_{c2}} \times \frac{I_{c2}}{I_{e2}} \times \frac{I_{e2}}{I_{c1}} \times \frac{I_{c1}}{I_{b1}} \times \frac{I_{b1}}{I_s}$$

$$= \left[\left[\frac{-I_{c2}}{I_{c2}}\right] \times (-A_{i2}) \times \left(\frac{I_{e2}}{I_{c1}}\right) \times (-A_{i1}) \times \frac{I_{b1}}{I_s}\right]$$

$$= (+)\,(A_{i1} \times A_{i2})\left[\frac{I_{e2}}{I_{c1}}\right] \times \left[\frac{I_{b1}}{I_s}\right]$$

$I_{e2} = -I_{c1}$

$$= (+) A_{i1} \times A_{i2} \times \left[\frac{I_{b1}}{I_s}\right]$$



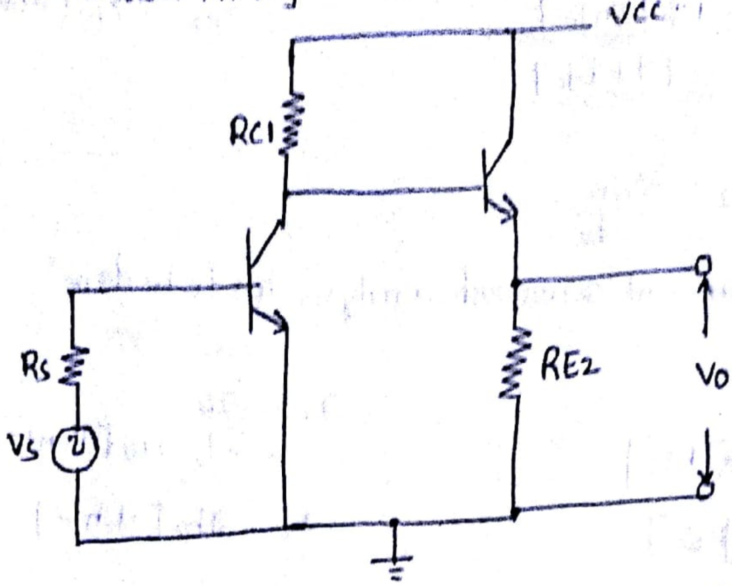
$$I_{b1} = I_s \times \left[\frac{R_s}{R_s + R_i'}\right]$$

$$\frac{I_{b1}}{I_s} = \left[\frac{R_s}{R_s + R_i'}\right]$$

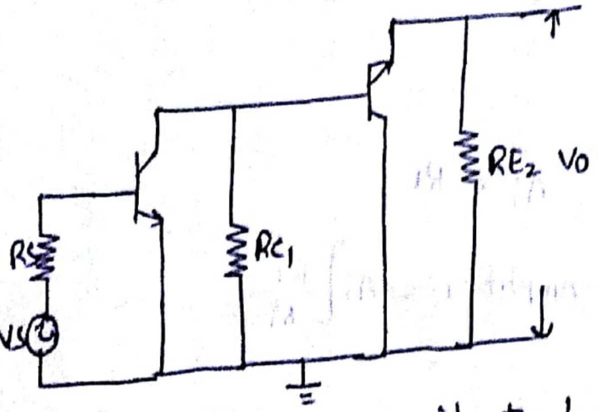
$$\boxed{A_{is} = A_{i1} \times A_{i2} \times \left[\frac{R_s}{R_s + R_i'}\right]}$$

→ Two stage RC coupled CE-CC Amplifier by using h-parameters (5)
[Approximate analysis].

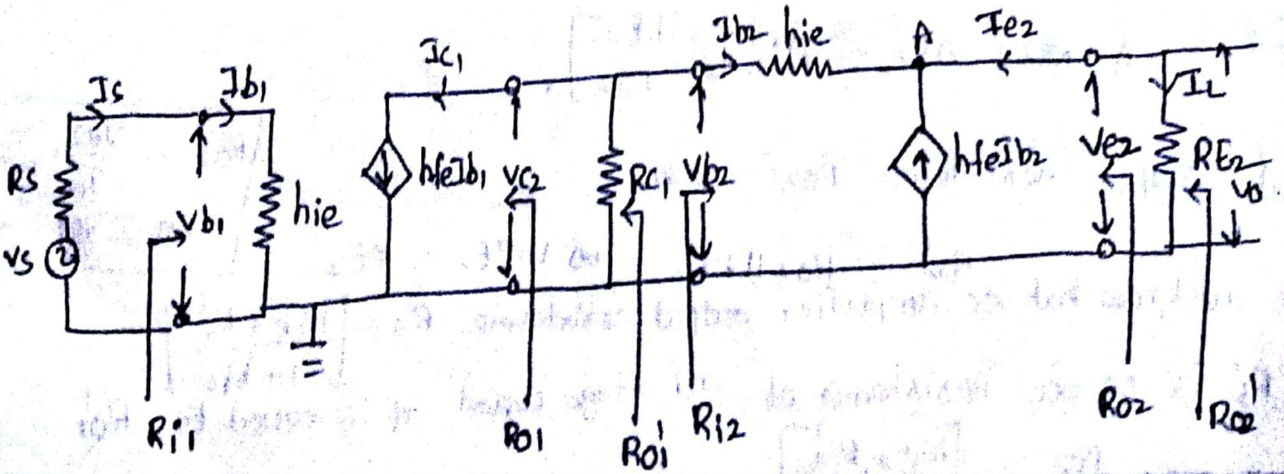
→ Consider a two stage amplifier circuit in CE-CC configuration as shown in fig below.



→ Let us Redraw the circuit Vcc is ground.



→ Let us Redraw the circuit the h-Parameter equivalent circuit.



Analysis of second stage CC Amplifier :-

Apply KCl at node A

$I_{b2} + I_{e2} + I_{c2} = 0$

$I_{b2} + I_{e2} + h_{fe} I_{b2} = 0$

$I_{b2}[1+h_{fe}] + I_{e2} = 0$

$I_{e2} = -I_{b2}[1+h_{fe}]$

(1) current gain $(A_{i2}) = \frac{I_L}{I_{b2}} = \frac{-I_{e2}}{I_{b2}}$

$$= -\left[\frac{-\cancel{I_{b2}}[1+h_{fe}]}{\cancel{I_{b2}}}\right]$$

$$A_{i2} = +[1+h_{fe}]$$

$$\boxed{A_{i2} = [1+h_{fe}]}$$

(2) Input resistance (R_{i2}) : $R_{i2} = \frac{V_{b2}}{I_{b2}}$

Since the current source is present supermesh analysis has to be done

$V_{b2} = h_{ie} I_{b2} + I_L R_{E2}$

$= h_{ie} I_{b2} + [I_{b2}[1+h_{fe}] R_{E2}]$

$V_{b2} = I_{b2}[h_{ie} + [1+h_{fe}]R_{E2}]$

$I_L = -I_e$

$= -[-I_{b2}[1+h_{fe}]]$

$I_L = I_{b2}[1+h_{fe}]$

$$R_{i2} = \frac{V_{b2}}{I_{b2}} = \frac{\cancel{I_{b2}}[h_{ie} + (1+h_{fe}) R_{E2}]}{\cancel{I_{b2}}} = h_{ie} + [1+h_{fe}] R_{E2}.$$

$$\boxed{R_{i2} = h_{ie} + [1+h_{fe}] R_{E2}}$$

(3) voltage gain (Ri2)[Av2] : $\frac{V_{e2}}{V_{b2}} =$

- we know that voltage gain of CC Amplifier $= A_i\left[\frac{R_L'}{R_i}\right]$

here $R_L' = R_{E2}$

$R_{i} = R_{i2}$

A Now $A_{V2} = A_{i2}\left[\frac{R_{E2}}{R_{i2}}\right]$.

(4) output resistance $R_{o2} = \infty$

we know that CC Amplifier output resistance $R_o = \left[\frac{h_{ie} + R_s'}{1+h_{fe}}\right]$

R_s' is source Resistance of 2nd stage and it is equal to R_{o1}

$$\therefore R_{o2} = \left[\frac{h_{ie} + R_{o1}}{1+h_{fe}}\right].$$

→ **Analysis Ist stage of CE Amplifier** ⑥

(5) current gain $A_{i1} = -\left[\frac{I_{c1}}{I_{b1}}\right] = -h_{fe}\left[\frac{I_{b1}}{I_{b1}}\right] = -h_{fe}$.

(6) Input resistance $(R_{i1}) = \frac{V_{b1}}{I_{b1}} = \frac{h_{ie} I_{b1}}{I_{b1}} = h_{ie}$.

(7) voltage gain $[A_{v1}]$ =

we know that voltage gain of CE Amplifier is $A_V = A_i \times \left[\frac{R_L'}{R_i}\right]$

Here $R_L' = \cancel{R_L} R_{c1} \parallel R_{i2}$

$R_{i1} = R_{i1}$

$$\boxed{A_{v1} = A_i \left[\frac{R_{c1} \parallel R_{i2}}{R_{i1}}\right]}$$

(8) output resistance of CE Amplifier $R_{o1} = \frac{V_{c1}}{I_{c1}}\Big|_{V_S = 0}$.

$V_S = 0,\ I_S = 0,\ I_{b1} = 0,\ I_{c1} = 0$

$R_{o1} = \frac{V_{c1}}{0} = \infty \Rightarrow \boxed{R_{o1} = \infty}$

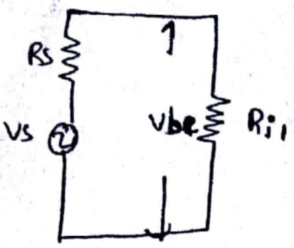
(9) overall voltage gain $(A_V) = \frac{V_{e2}}{V_S} = \frac{V_{e2}}{V_{b2}} \times \frac{V_{b2}}{V_{c2}} \times \frac{V_{c2}}{V_{b1}} \times \frac{V_{b1}}{V_S}$

$\therefore V_{b2} = V_{c2}$

$$A_V = \frac{V_{e2}}{V_{b2}} \times \frac{\cancel{V_{b2}}}{\cancel{V_{b2}}} \times \frac{V_{c2}}{V_{b1}} \times \frac{V_{b1}}{V_S}$$

$$A_V = A_{v2} \times A_{v1} \times \left[\frac{V_{b1}}{V_S}\right]$$

$$A_V = A_{v1} \times A_{v2} \times \left[\frac{V_{b1}}{V_S}\right]$$



$$V_{b1} = V_s \times \left[\frac{R_{i1}}{R_s+R_{i1}}\right]$$

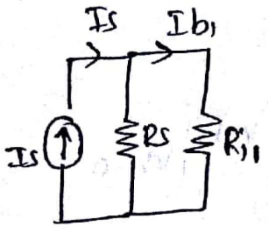
$$\frac{V_{b1}}{V_s} = \left[\frac{R_{i1}}{R_s+R_{i1}}\right]$$

$$\boxed{A_{vs} = A_{v1} \times A_{v2} \times \left[\frac{R_{i1}}{R_s+R_{i1}}\right]}$$

→ Overall current gain (A_{is}) $= \frac{I_o}{I_s} = \frac{I_o}{I_{e2}} \times \frac{I_{e2}}{I_{b2}} \times \frac{I_{b2}}{I_{c1}} \times \frac{I_{c1}}{I_{b1}} \times \frac{I_{b1}}{I_s}$

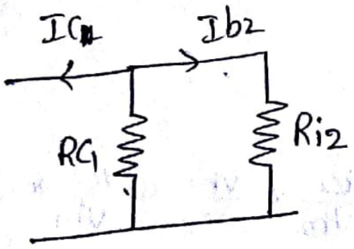
$$= -\frac{I_{b2}}{I_{e2}} \times (-A_{i2}) \times \frac{I_{b2}}{I_{c1}} \times [-A_{i1}] \times \left[\frac{I_{b1}}{I_s}\right]$$

$$= A_{i1} \times A_{i2} \times [-1] \times \frac{I_{b2}}{I_{c1}} \times \left[\frac{I_{b1}}{I_s}\right]$$



$$I_{b1} = I_s \times \left[\frac{R_s}{R_s+R_{i1}}\right]$$

$$\frac{I_{b1}}{I_s} = \left[\frac{R_s}{R_s+R_{i1}}\right]$$



$$I_{b2} = [-I_{c1}] \times \left[\frac{R_{c1}}{R_{i2}+R_{c1}}\right]$$

$$\frac{I_{b2}}{I_{c1}} = (-)\left[\frac{R_{c1}}{R_{i2}+R_{c1}}\right]$$

$$\boxed{A_{is} = A_{i1} \times A_{i2} \times \left[\frac{R_s}{R_s+R_{i1}}\right] \left[\frac{R_{c1}}{R_{i2}+R_{c1}}\right]}$$

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Darlington Pair :-

we have seen that out of three configuration (CB, CC and CE). Common collector has high input impedance. The input impedance considering biasing resistance is significantly less Because

$R_i' = R_1 \parallel R_2 \parallel R_i$

→ Typically it is 200kΩ to 300kΩ A single stage emitter follower circuit can give input impedance up to 500kΩ

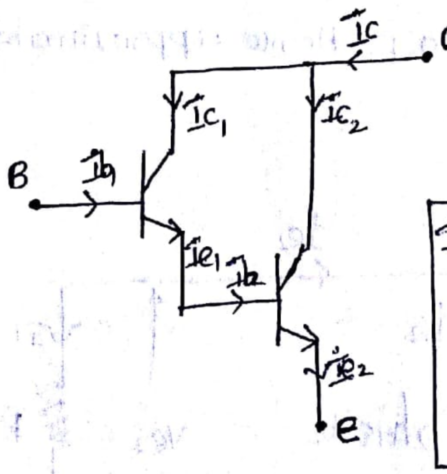
→ The input impedance of the circuit can be improved by direct coupling of two stages of emitter follower amplifier

① The input impedance can be increased using two techniques.

① Using direct coupling (Darlington connection) Emitter follower

② Bootstrap Emitter follower.

① Darlington connection (or) Super β transistor :-



$I_C = I_{C_1} + I_{C_2}$

$= \beta_1 I_{b_1} + \beta_2 I_{b_2}$

$I_C = \beta_1 I_{b_1} + \beta_2 (\beta_1 + 1) I_{b_1}$

$$\boxed{\begin{aligned} I_{b_2} &= I_{e_1} \\ &= I_{b_1} + I_{C_1} \\ &= I_{b_1} + \beta_1 I_{b_1} \\ I_{b_2} &= I_{b_1}[1+\beta_1] \end{aligned}}$$

$I_C = \beta_1 I_{b_1} + \beta_2 \beta_1 I_{b_1}$

$= \beta_1 I_{b_1} [1 + \beta_2]$

$I_C = \beta_1 \beta_2 I_{b_1}$

$\beta_D = A_i = \frac{I_C}{I_{b_1}}$

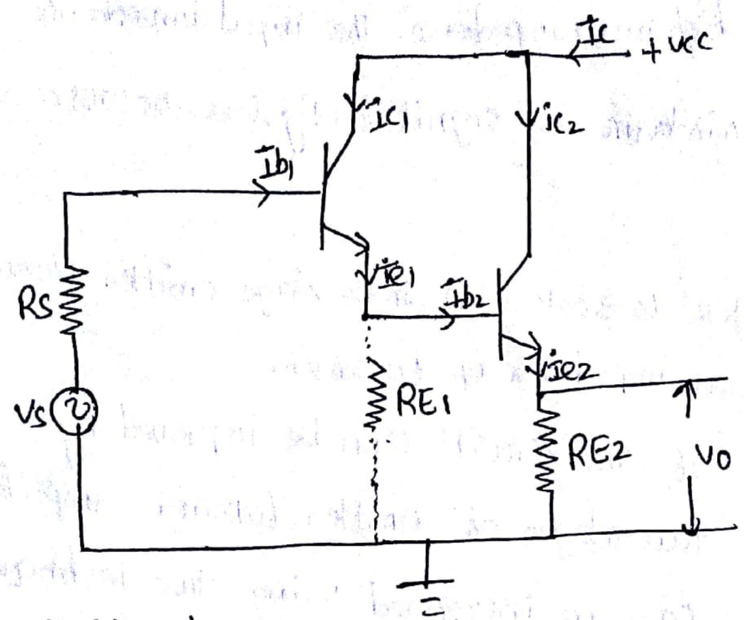
$$\boxed{\frac{I_C}{I_{b_1}} = \beta_1 \beta_2}$$

$$\boxed{\therefore \beta_D = \beta_1 \beta_2}$$

If transistor β values are same

$$\boxed{\beta_D = \beta \times \beta = \beta^2}$$

*** Darlington composite emitter follower



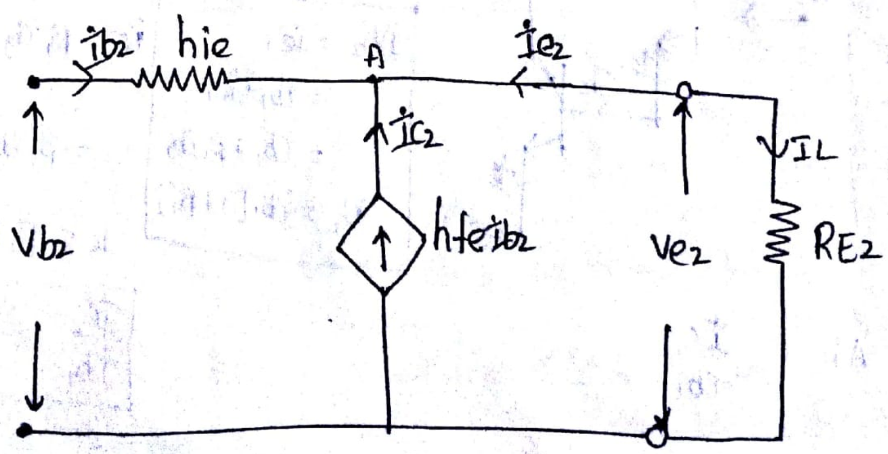
→ Emitter follower is used to have R_i of 500kΩ,

→ By using Darlington connection to get larger impedance MegaΩ

→ The input resistance of IInd stage is equal to the load resistance of Ist stage.

Analysis of second stage :-

→ Assume $h_{oe} \cdot R_L = h_{oe} \cdot R_{E2} \leq 0.1$. Hence approximate Analysis is used.



Applying KCL at node A

$$i_{b2} + i_{e2} + i_{c2} = 0.$$
$$i_{b2} + i_{e2} + h_{fe} i_{b2} = 0.$$
$$i_{e2} = -i_{b2}[1 + h_{fe}]$$

① current gain (A_{i2}) $= \frac{I_L}{I_{b2}} = \frac{-I_{e2}}{I_{b2}} = \frac{\cancel{I_{b2}}[1+h_{fe}]}{\cancel{I_{b2}}} = [1+h_{fe}]$

② Input resistance (R_{i2})

$$R_{i2} = \frac{V_{b2}}{I_{b2}}$$

$V_{b2} = h_{ie} I_{b2} + I_L R_{E2}$ [since from super mesh Analysis]

$$= h_{ie} I_{b2} + (-I_{e2}) R_{E2}$$
$$= h_{ie} I_{b2} + (-I_{b2})(1+h_{fe}] R_{E2}$$
$$V_{b2} = I_{b2}[h_{ie} + (1+h_{fe})R_{E2}]$$

$$R_{i2} = \frac{V_{b2}}{I_{b2}} = \frac{\cancel{i_{b2}}[h_{ie} + (1+h_{fe})R_{E2}]}{\cancel{i_{b2}}}$$

$$\boxed{R_{i2} = h_{ie} + (1+h_{fe})R_{E2}}$$

If h_{ie} is far less than $(1+h_{fe})R_{E2}$

$$\boxed{R_{i2} = (1+h_{fe}) R_{E2}}$$

③ Voltage gain (A_{V2}) $= \frac{V_{e2}}{V_{b2}} = \frac{I_L R_{E2}}{I_{b2}[h_{ie} + (1+h_{fe})R_{E2}}$

$$= \frac{-I_{e2} R_{E2}}{I_{b2}[h_{ie} + (1+h_{fe})R_{E2}}$$

$$= \frac{\cancel{I_{b2}}[1+h_{fe}] R_{E2}}{\cancel{I_{b2}}[h_{ie} + (1+h_{fe})R_{E2}} = \frac{(1+h_{fe})R_{E2}}{h_{ie} + (1+h_{fe})R_{E2}}$$

Add & subtract Nr with hie

$$A_{v2} = \frac{(1+h_{fe})R_{E2} + h_{ie} - h_{ie}}{h_{ie}+(1+h_{fe})R_{E2}}$$

$$= 1 - \left[\frac{h_{ie}}{h_{ie}+(1+h_{fe})R_{E2}}\right]$$

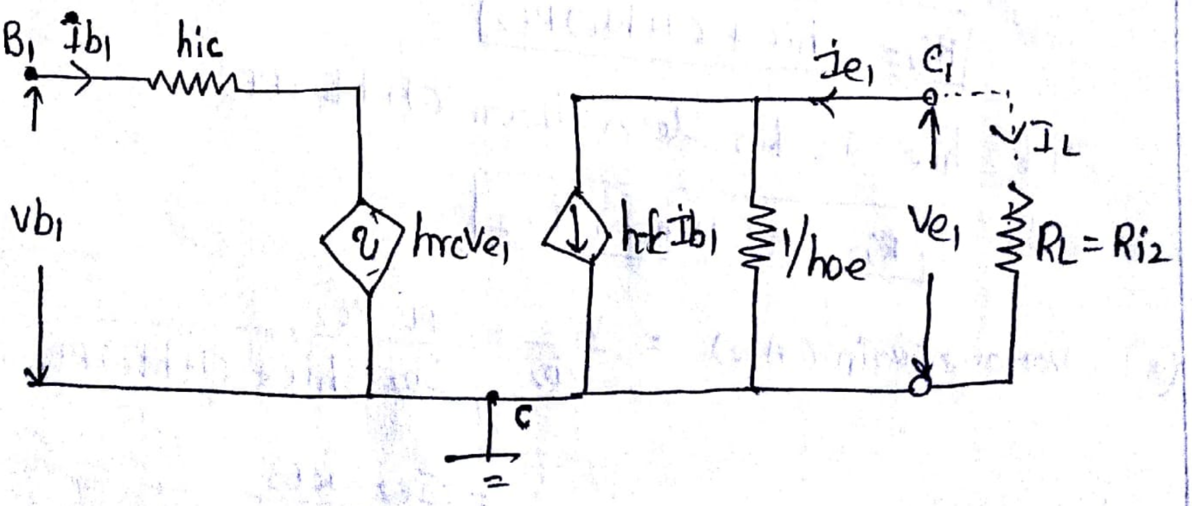
$$A_{v2} = 1 - \left[\frac{h_{ie}}{R_{i2}}\right]$$

$$\boxed{A_{v2} = 1 - \left[\frac{h_{ie}}{R_{i2}}\right]}$$

Analysis of Ist stage :-

* load resistance of Ist stage is equal to the input resistance of 2nd stage R_{i2} as R_{i2} is high

$h_{oe} R_L \geq 0.1$ & hence we have to do exact Analysis.
$h_{oe} R_{E2} \geq 0.1$



Convernion formula

$$Vb_1 = h_{ic}\, ib_1 + h_{rc}\, ve_1$$
$$Ie_1 = h_{fc} Ib_1 + h_{oc}\, ve_1$$

$$h_{ic} = h_{ie}$$
$$h_{rc} = 1$$
$$h_{fc} = -(1 + h_{fe})$$
$$h_{oc} = h_{oe}.$$

$$\text{Current gain } (A_{i1}) = \frac{IL}{Ib_1} = -\frac{Ie_1}{Ib_1}$$

$$= -\frac{[h_{fc} Ib_1 + h_{oc}\, Ve_1]}{Ib_1}$$

$$= -\frac{[h_{fc} Ib_1 + h_{oc}\, ve_1]}{ib_1}$$

$$Ie_1 = h_{fe} ib_1 + h_{oc}\, ve_1$$
$$= h_{fe} Ib_1 + h_{oc}[IL\, Ri_2]$$
$$= h_{fc} Ib_1 + h_{oc}[-Ie_1\, Ri_2]$$

$$Ie_1 + h_{oc} Ie_1\, Ri_2 = h_{fe} Ib_1$$

$$Ie_1 [1 + h_{oc} Ri_2] = h_{fe} Ib_1$$

$$\frac{Ie_1}{Ib_1} = \left[\frac{h_{fe}}{1 + h_{oc} Ri_2}\right]$$

$$h_{fc} \simeq \cancel{h_{fe}} - [1 + h_{fe}]$$
$$h_{oc} \simeq h_{oe}$$

$$\frac{Ie_1}{Ib_1} = -\left[\frac{1 + h_{fe}}{1 + h_{oe} Ri_2}\right]$$

$$A_{i1} = +\left[\frac{(h_{fe} + 1)}{1 + h_{oe} Ri_2}\right]$$

$$A_{i1} = \left[\frac{1 + h_{fe}}{1 + h_{oe} Ri_2}\right]$$

when $R_{i2} = h_{ie} + (1+h_{fe}) R_E$

$h_{ie} << (1+h_{fe}) R_E$

$R_{i2} = (1+h_{fe}) R_E$

$$A_{i1} = \frac{[1+h_{fe}]}{1+h_{oe}(1+h_{fe}) R_E}$$

$1+h_{fe} = h_{fe}$.

$$\boxed{A_{i1} = \frac{1+h_{fe}}{1+h_{oe} h_{fe} R_E}}$$

(ii) $R_{i1} = \frac{V_{b1}}{I_{b1}}$

$v_{b1} = I_{b1} h_{ic} + h_{rc} v_{e1}$

$$R_{i1} = \frac{v_{b1}}{i_{b1}} = \frac{I_{b1} h_{ic} + h_{rc} (-I_{e1} \times R_{i2})}{I_{b1}}$$

$$= \frac{i_{b1} h_{ic}}{i_{b1}} + h_{rc} \left[\frac{-I_{e1}}{I_{b1}}\right] \times R_{i2}$$

$R_{i1} = h_{ic} + h_{rc} A_{i1} R_{i2}$

from conversion $h_{ic} = h_{ie}$
$h_{rc} = 1$

$$R_{i1} = h_{ie} + [A_{i1} \times R_{i2}]$$

$$= h_{ie} + \left[\frac{1+h_{fe}}{1+h_{oe} h_{fe} R_E}\right] [1+h_{fe}] R_E$$

$$R_{i1} = h_{ie} + \frac{[1+h_{fe}]^2 R_E}{1+h_{oe} h_{fe} R_E}$$

$$h_{ie} << \frac{[1+h_{fe}]^2 R_E}{1+h_{oe} h_{fe} R_E}$$

$$\boxed{R_{i1} = \frac{[1+h_{fe}]^2 R_E}{1+h_{oe} h_{fe} R_E}}$$

$$A_{V1} = \frac{V_{e1}}{V_{b1}} = \frac{-I_{e1} R_{i2}}{I_{b1}(R_{i1})}$$

$$= A_{i1}\left[\frac{R_{i2}}{R_{i1}}\right]$$

$$= \left[\frac{1+h_{fe}}{1+h_{oe} h_{fe} R_E}\right]\left[\frac{(1+h_{fe}) R_E}{R_{i1}}\right]$$

Add & sub Num hie.

$$= \frac{(1+h_{fe})^2 R_E + h_{ie} - h_{ie}}{(1+h_{oe} h_{fe} R_E) R_{i1}}$$

$$= \frac{(1+h_{fe})^2 R_E + h_{ie}}{(1+h_{oe} h_{fe} R_E) R_{i1}} - \frac{h_{ie}}{R_{i1}(1+h_{oe} h_{fe} R_E)} \simeq 1 - \frac{h_{ie}}{R_{i1}}$$

$$\simeq \left[\frac{\cancel{R_{i1}}}{\cancel{R_{i1}}} - \frac{h_{ie}}{R_{i1}}\right]$$

$$\boxed{A_{V1} = \left[1 - \frac{h_{ie}}{R_{i1}}\right]}$$

overall voltage gain

$$A_V = A_{V1} \times A_{V2}$$

$$= \left[1 - \frac{h_{ie}}{R_{i1}}\right]\left[1 - \frac{h_{ie}}{R_{i2}}\right]$$

$$= 1 - \frac{h_{ie}}{R_{i2}} - \frac{h_{ie}}{R_{i1}} + \frac{h_{ie} \times h_{ie}}{R_{i1} \times R_{i2}}$$

$R_{i1} >> R_{i2}$ Negelecting 3rd & 4th terms

$$\boxed{A_V = 1 - \left[\frac{h_{ie}}{R_{i2}}\right]}$$

overall current gain $(A_i) = A_{i1} \times A_{i2}$

$$= \left[\frac{[1+h_{fe}]}{1+h_{oe}[1+h_{fe}]R_E}\right] \times (1+h_{fe}]$$

$$\boxed{A_i = \frac{(1+h_{fe})^2}{1+h_{oe}[1+h_{fe}]R_E}}$$

output impedance (R_{o2}) :-

For Exact Analysis $R_{o1} = \dfrac{1}{h_{oc} - \left[\dfrac{h_{fc}h_{rc}}{R_s+h_{ie}}\right]}$

For Conversion formula

$h_{oc} = h_{oe}$

$h_{fc} = -[1+h_{fe})$

$h_{rc} = 1$

$h_{ic} = h_{ie}$.

$R_{o1} = \dfrac{1}{h_{oe} + \left(\dfrac{1+h_{fe}}{h_{ie}+R_s}\right]}$ $\qquad h_{oe} << \left[\dfrac{1+h_{fe}}{h_{ie}+R_s}\right]$

$R_{o1} = \left[\dfrac{h_{ie}+R_s}{1+h_{fe}}\right]$

we can see that R_{o1} the First stage is source resistance for second stage

$$\boxed{R_{s2} = R_{o1}}$$

$R_{o2} = \dfrac{R_{s2}+h_{ie2}}{1+h_{fe}} = \left[\dfrac{h_{ie}+R_s}{1+h_{fe}}\right] + h_{ie} / [1+h_{fe}]$

$= \dfrac{h_{ie1}+R_s}{(1+h_{fe})^2} + \dfrac{h_{ie}}{[1+h_{fe}]}$

$= \dfrac{\cancel{[1+h_{fe}]h_{ie2}} + \cancel{R_s}}{(1+\cancel{h_{fe}})^2} =$

$\boxed{h_{ie1} = (1+h_{fe})h_{ie2}}$

$= \left[\dfrac{h_{ie2}}{1+h_{fe}}\right] + \dfrac{R_s}{[1+h_{fe}]^2} + \dfrac{h_{ie2}}{[1+h_{fe}]}$

$$\boxed{R_{o2} = \frac{R_s}{(1+h_{fe})^2} + 2\left[\frac{h_{ie2}}{1+h_{fe}}\right]}$$

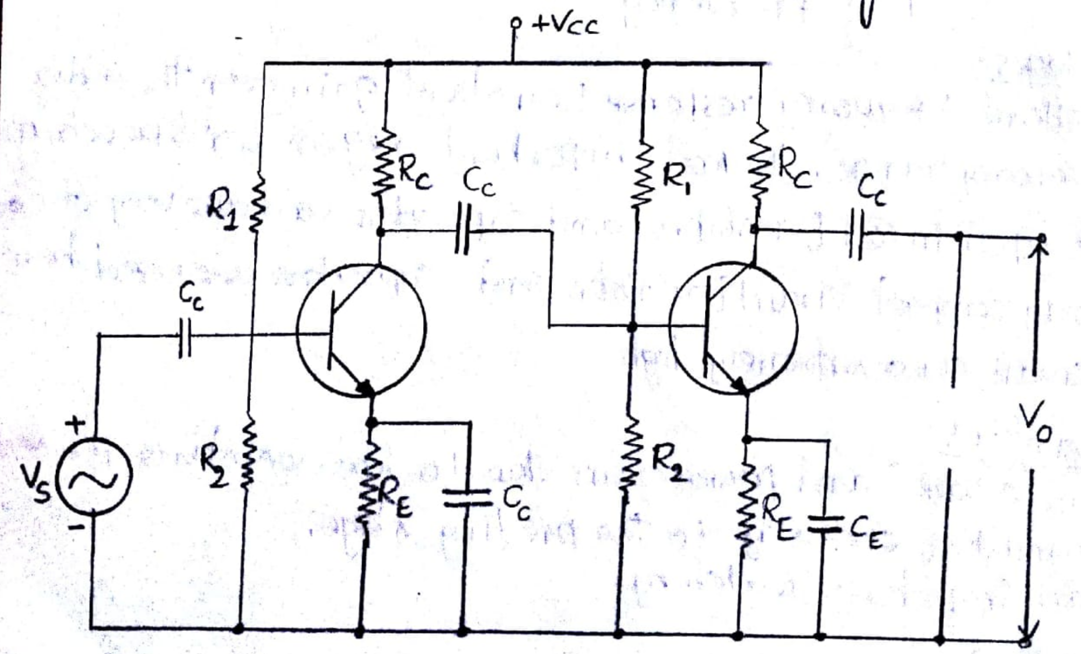
* Different Coupling Schemes Used in Amplifiers:-

In Multistage Amplifier, the output Signal of Preceding (first) stage is to be Coupled to the input Circuit by Succeeding stage. For this interstage Coupling, different types of Coupling elements Can be employed. These are:

1. RC Coupling
2. Transformer Coupling
3. Direct Coupling

(1) * RC Coupling:-

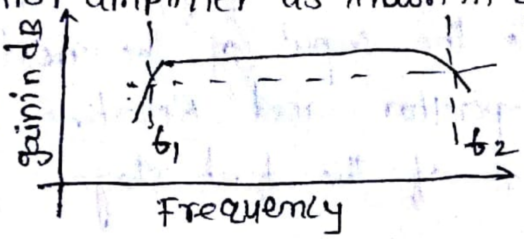
Circuit shows RC Coupled amplifier using transistors. As Shown in below the output Signal of first Stage is Coupled to the input of the next Stage through Coupling Capacitor and Resistive Load at the output terminal of the first stage.



Two stage RC Coupled amplifier using transistors

The coupling does not affect the quiescent point of the next stage since the coupling capacitor (C_c) blocks the d.c. voltage of the first stage from reaching the base of the second stage. The RC network is broadband in nature. Therefore, it gives a wideband frequency response without peak at any frequency and hence used to cover a complete AF amplifier bands. However its frequency response drop off at very low frequencies due to coupling capacitors and also at high frequencies due to shunt capacitors such as stray capacitance.

→ The frequency response curve of a typical RC coupled transistor amplifier as shown in below.



Advantages:

① Excellent frequency response [constant gain over the audio frequency range, the most important region for speech, music)

② cheaper in cost [resistors and capacitors used are very cheap.

③ very compact circuit [resistors and capacitors are used being small and extremely high.

Disadvantages:

① Low voltage and power gain due to low resistance presented by the input of each stage to the preceding stage.

② Poor impedance matching.

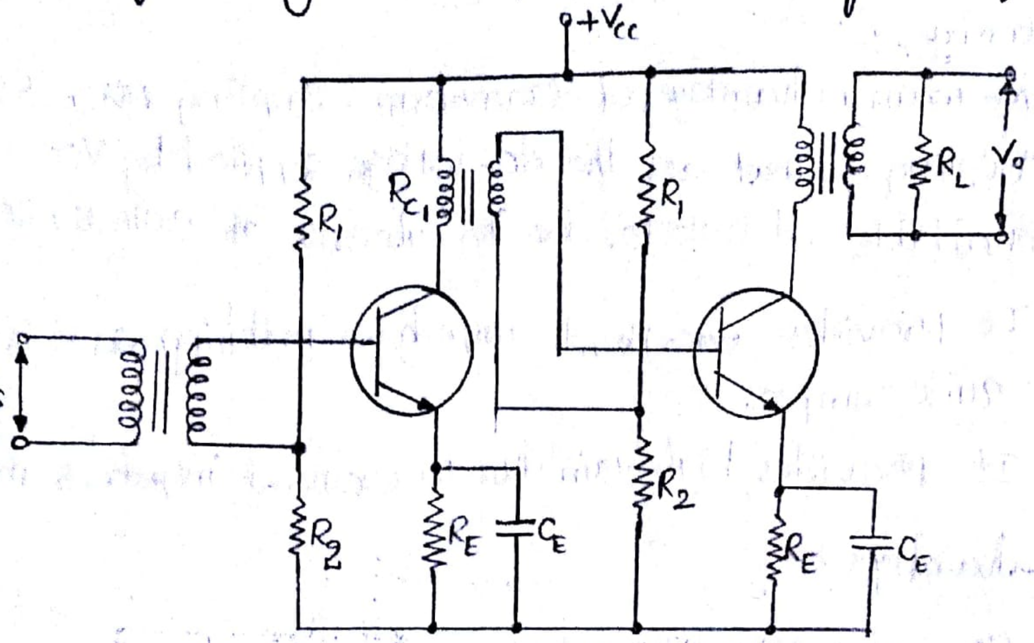
Application :-

① RC coupled transistor amplifier are widely used as voltage amplifier.

② RC-coupling is rarely employed in the final stages.

(2) Transformer Coupling :-

Circuit Shows transformer Coupled amplifier using transistors. As shown in the circuit, the output Signal of first stage is Coupled to the input of the next stage through an impedance matching transformer.

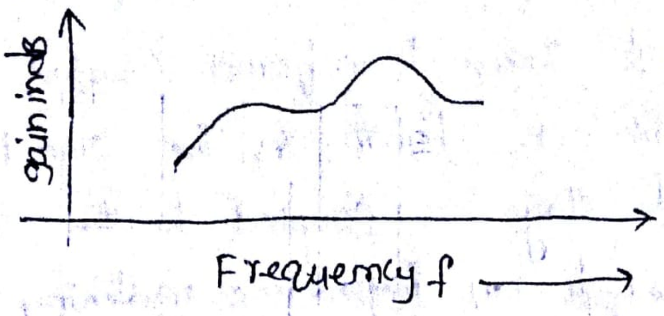


Two stage Transformer Coupled amplifier using Transistors

This type of Coupling is used to match the impedance matching between output and input Cascaded stage. Usually, it is used to match the Larger output resistance of AF power Amplifier to a Low impedance Load Like Loud Speaker.

Frequency Response of Transformer Coupled amplifier is poor in Comparison with that of an Coupled amplifier. Its Leakage Inductance and interwinding Capacitance does not allow amplifier to amplify the Signals of different frequencies equally well.

Frequency Response of transformer coupled Amplifier



Advantages:-

① The main advantages of transformer coupling over RC-coupling is that all the dc-voltage supplied by Vcc is available at collector due to absence of collector resistor Rc

② It provides excellent impedance matching as it is quite simple.

③ It provides high gain due to excellent impedance matching.

Disadvantages:

① Poor frequency response

② Bulky and costly system [transformer being bulky and costlier in comparison to resistors and capacitors]

③ At radio frequencies, the Inductance and interwinding capacitance presents lot of problems.

Applications:-

① Transformer coupled amplifiers are not used for amplifying low frequency [audio frequency] signal, they are widely used for amplifying radio-frequency [above 20kHz]

②. Transformer coupled amplifier is generally not used for intermediate stages in cascaded amplifier. It is used at input (or) output stage where it can conveniently provide impedance matching.

(*) Comparison between Various Cascading Methods

Parameter	RC coupled	Transformer Coupled	Direct coupled
Coupling Components	Resistor and Capacitor	Impedance matching transformer	–
Block d.c	Yes	Yes	No
Frequency Response	Flat at Middle Frequencies	Not Uniform, high at Resonant frequency and Low at other frequencies	Flat at middle frequency, and improvement in the Low frequency Response.
Impedance matching	Not achieved	Achieved	Not Achieved.
d.c. amplification	No	No	Yes
Weight	Light	Bulky and Heavy	–
Drift	Not present	Not present	Present
Hum	Not present	Present	Not present
Application	Used in all audio Small Signal amplifiers, Used in Record players, tape recorders, Public Recievers and Television Recievers.	Used in amplifier where impedance matching is an important Criteria. Used in output stage of public address system to match the impedance of Loudspeakers, as a tuned Voltage amplifier.	Used in amplification of Slow varying Parameters and where DC amplification is required.