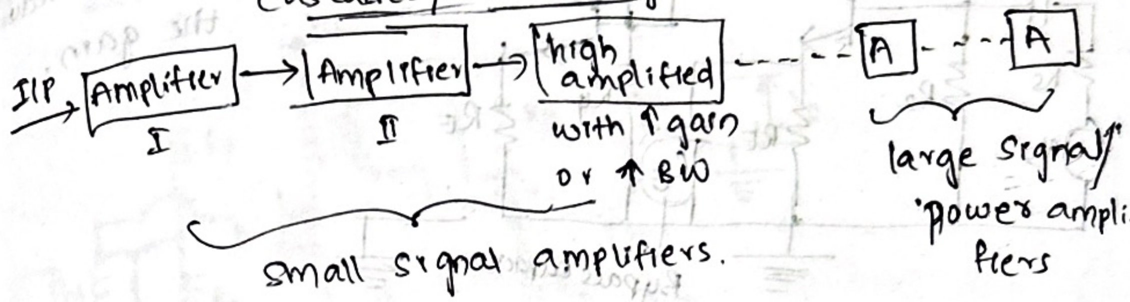
18/03:

UNIT-II:

MULTISTAGE AMPLIFIERS:

* If we increase the stage of the amplifier, then bandwidth ~~and~~ or gain of the amplifier increases.

cascaded/ Multi-stage.



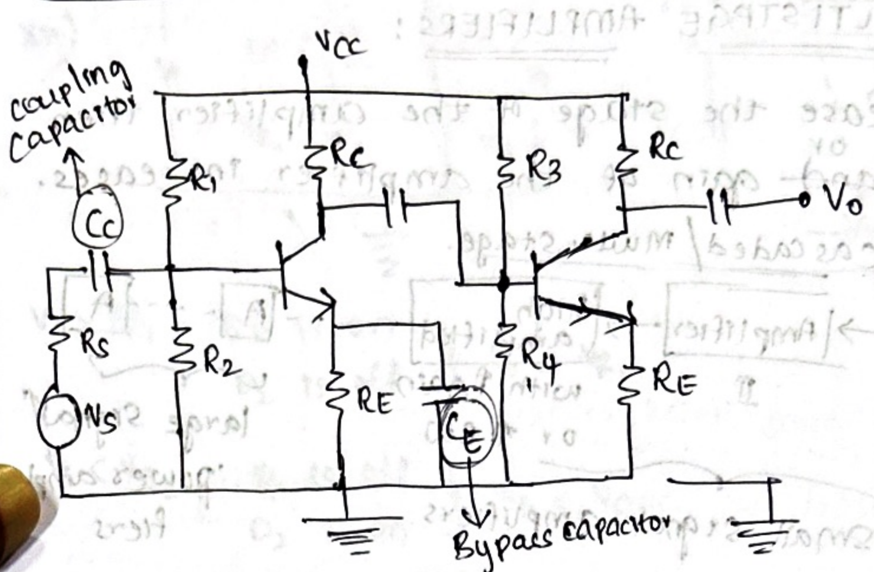
* RC N/w are coupling capacitors.
* For a faithful amplification an amplifier should posses, i) desired current gain
  ii) desired voltage gain
  iii) should match i/p impedance with the source
  iv) should match o/p impedance with the load.
* Bcoz of limitations of transistor parameters, the primary requirements of the amplifier are not achieved. Hence more than 1 amplifier stages are cascaded, such that i/p and o/p stages provide required impedance matching. and the intermediate stages provide required amplification.
* There are different types of coupling elements that can be employed for cascading the stages of the amplifiers. This is called inter stage coupling.

** Methods of interstage coupling:

1) RC coupling
2) Transformer coupling
3) Direct coupling
4)

8M → 3 001
uM → 1 only.

1) RC coupling: [CE-CE]

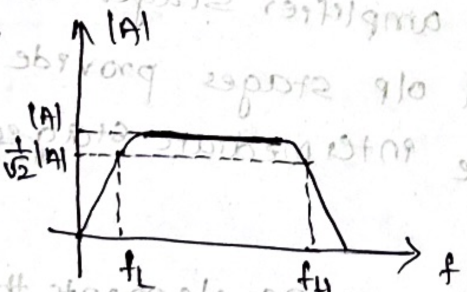


* In order to reduce the effect of R_E, we use Bypass capacitor. It will reduce the gain.

* the o/p of the first stage is coupled to the i/p of the 2nd stage through a coupling capacitor & resistive load at the o/p of the 1st stage.

* the coupling doesn't effect the Quiscent pt of the next stage. As, "Cc" bcoz the coupling capacitor "Cc" blocks the dc voltage of 1st stage from reaching the base of the 2nd stage.

⇒



* If bypass capacitor is added then gain ↑ or BW ↑

* Mid frequency range is 50 Hz - 20 KHz

* It is useful for audio frequency amplifiers.

$\boxed{BW = f_H - f_L}$

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

Advantages:

1) Low cost
2) Space required is less
3) Almost provides the constant gain in mid frequency range.

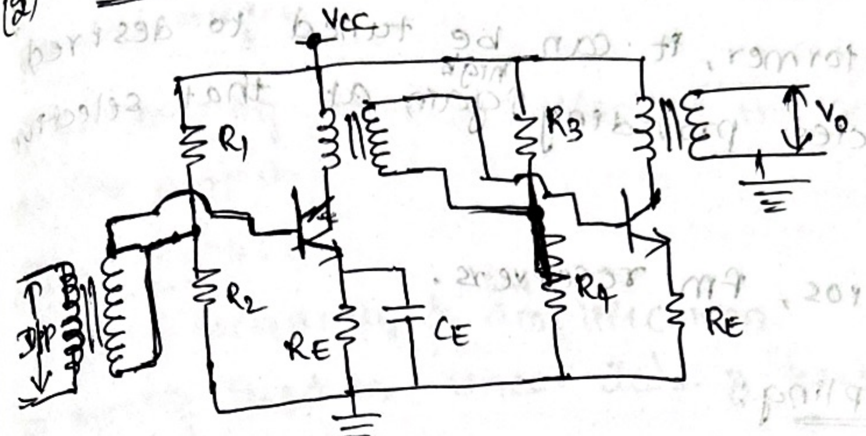
Disadvantages:

1) Small gain bcoz of loading effect of next stage.
2) Poor impedance matching.
3) Becomes noisy as time passes.

Applications:

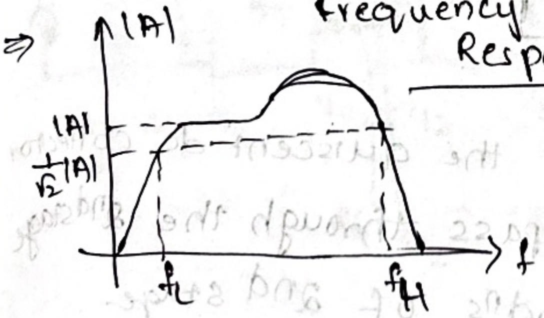
1) Audio frequency amplifiers
2) In early stages of Public addressing systems.
3) In tape recorders, TV, CD players.

(2) Transformer coupling: [CE-CE]



* The 1st stage is coupled to next stage through a imp-edance matching transformer used to match larger o/p resistance of A.F amplifier to a low impedance load like loud'speaker.

⇒ Frequency Response



$\boxed{BW = f_H - f_L}$

* The frequency response is poor for RC coupling bcoz of leakage inductance & inter-winding capacitance will not allow to amplify the signals in different frequency.

Advantages:

1) high gain is obtained by step-up coupling transformer.
2) No signal power is lost, as DC resistance of
3) ~~Has DC~~ transformer is low

Disadvantages:

1) Large in size
2) Costlier, as inductances are used.
3) Provides poor frequency response.

Applications:

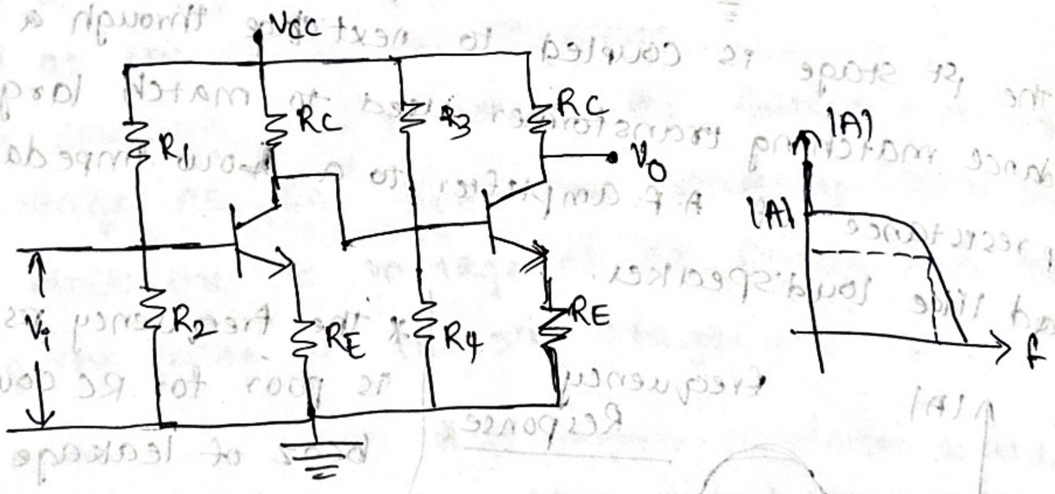
1) Used in power amplification.

2) Used for amplification of radio frequencies in range of 550KHz to 1600KHz.

3) By putting shunt capacitors across each winding of the transformer, it can be tuned to desired frequencies providing high gain at that selective frequency.

Eg: fm radios, fm receivers.

(3) Direct Coupling:



The direct coupling allows the quiscent dc collector current of 1st stage to pass through the 2nd stage affecting the biasing cond^ns of 2nd stage.

* The low frequency response is very good. But as frequency increases, the shunt and stray capacitances reduce the gain of the amplifier.

* Transistor parameters such as V_{BE} & β changes with temperature causing I_C & V_{CE} to change which appears at the base of the next stage producing an unwanted change in the output.

This is called drift.

Advantages:

1) Good frequency response at low frequency
2) DC amplification can be achieved
3) simple & low cost

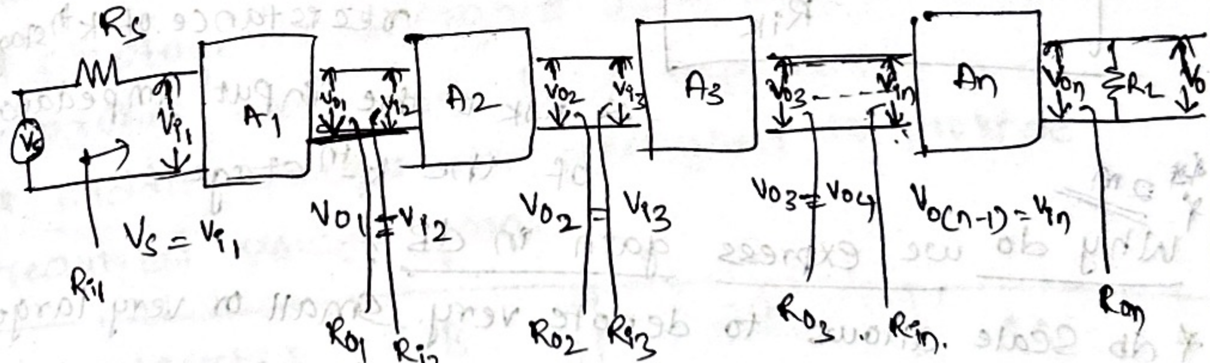
Disadvantages:

1) DC biasing effects effecting the next stage | 2) drift at the output.

Applications:

1) Low frequency & current amplification.
2) mostly used in linear IC's. & bioelectric measurements.

N stage Cascaded amplifier: ** 2M



* Cascading means ~~arrangi~~ arraying of objects in series (or) sequences. $A_{V_1}, A_{V_2}, A_{V_3}, \ldots A_{V_n}$ are loaded voltage gains.
* The load for 1st Amplifier stage is, "R_{i_2}".
* the load for 2nd stage is "R_{i_2}" & so on.

Consider a 2stage amplifier

Overall voltage gain, $\boxed{A_{V_1} = \frac{V_{o_1}}{V_{i_1}}}$

$$A_{V_2} = \frac{V_{o_2}}{V_{i_2}} = \frac{V_{o_2}}{V_{o_1}}$$

$$\boxed{A_{VS} = \frac{V_{O2}}{V_{i1}}}$$

$$= \frac{V_{O2}}{V_{O1}} \times \frac{V_{O1}}{V_{i1}}$$

$$\boxed{A_{VS} = A_{V2} \cdot A_{V1}}$$

* The total voltage gain is the product of individual voltage gain.

* Similarly, for an N-stage Amplifier;

$$\boxed{A_{VS} = A_{V1} \cdot A_{V2} \cdot A_{V3} \text{------} A_{Vn}}$$

for K^{th} stage, Voltage gain is,

$$\boxed{A_{VK} = \frac{A_{IK} \cdot R_{LK}}{R_{IK}}}$$

; where R_{LK} = effective load resistance of K^{th} stage & R_{IK} is the input impedance of the K^{th} stage.

* 2M

Why do we express gain in dB?

* db scale allows to denote, very small or very large quantities of linear scale by considerably small figures.

* Sound heard by human ear response to sound intensities on logarithmic scale. rather than linear scale. Hence db is more appropriate to represent amplifier gains.

* It is convenient to compare 2 powers in logarithmic scale rather than linear scale. The unit of logarithmic scale is decibals. It can be generally represented as

$$\boxed{N(dB) = 10 \log \frac{P_2}{P_1}}$$

P_2 - O/P power
P_1 - I/P power.

dP → represents power ratio

Gain of Multistage Amplifier in dB:

The overall gain of a multi-stage amplifier in dB is the sum of decibal voltage gains of the individual stages.

$$\therefore \boxed{A_{VT}(dB) = A_{V1}(dB) + A_{V2}(dB) + \text{---} A_{Vn}(dB)}$$

Selection of configuration in a cascaded amplifier:

Basically multi-stage amplifier is divided into 3 stages:

i) I/P stage

ii) intermediate/middle stage

iii) O/P stage.

* I/P stage is ~~defined~~ designed such that its i/p impedance matches with the source impedance.
* O/P stage is designed such that o/p impedance matches with the load impedance.
* middle stages are designed to provide required power gain.

characteristics	CB	CE	CC
I/P impedance	very low (20Ω)	low (1KΩ)	(500KΩ) high
O/P resistance	very high (1MΩ)	high (40KΩ)	low (50Ω)
current gain	less than 1	high	high
voltage gain	medium	medium	low
Applications	used as I/P stage; used as initial stage.	for aud io signal amplification., used as intermediate stage.	used as o/p stage., impedance matching.

Input stage selection:

1) source impedance is low, hence i/p impedance is also low. then CB amplifier can be used as initial stage.

O/P stage:

we need to drive a very low impedance load. then o/p resistance is low. It can be provided by CC amplifier

Intermediate stage:

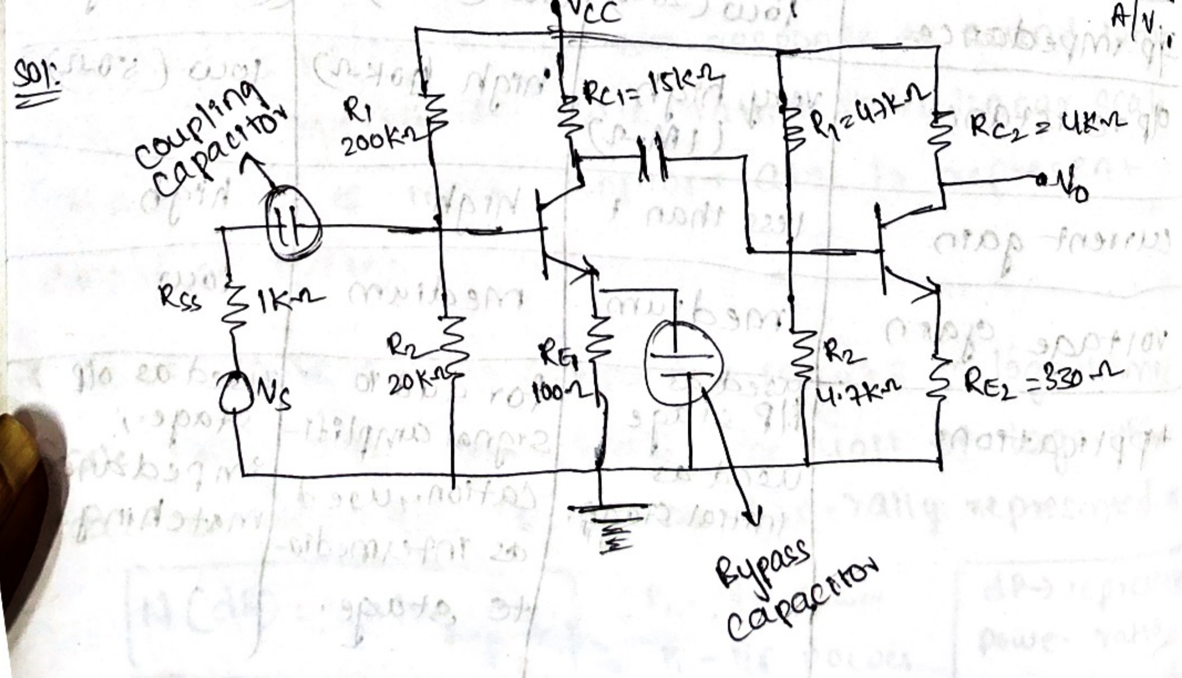
which gives better voltage gain & current gain CE amplifier satisfies above conditions.

20/03:

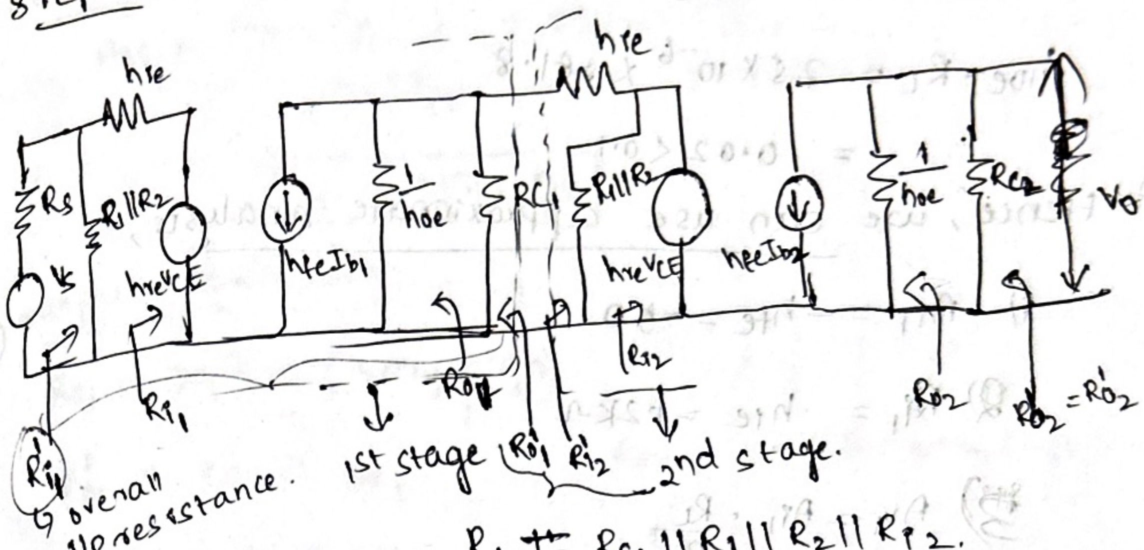
Q: Calculate R_i, A_I, A_V, R_i' & A_{Vs} & A_{Is} if the ckt parameters are $R_{ss} = 1K\Omega$, $R_{C_1} = 15K\Omega$, $R_{E_1} = 100\Omega$, $R_{C_2} = 4K\Omega$, $R_{E_2} = 330\Omega$, with $R_1 = 200K\Omega$ and $R_2 = 20K\Omega$ for the 1st stage and $R_1 = 47K\Omega$, $R_2 = 4.7K\Omega$ for the second stage of CE amplifier with 2 stages ~~with~~ being CE.

Assume, $h_{ie} = 1.2K\Omega$, $h_{fe} = 50$, $h_{re} = 2.5\times10^{-4}$, $h_{oe} = 25\times10^{-6}$ A/V.

Sol:



Step-1): Draw the H-parameter model



$R_L = R_{C_1} \| R_1 \| R_2 \| R_{i_2}$.

Step-2): To analyze the stages.

Always start the analysis with the 2nd stage than the 1st stage.

Analysis of 2nd stage: $\boxed{h_{oe} R_L < 0.1}$

For approximate analysis, $\boxed{R_L = R_{C_2}}$

1) $A_{i_2} = -h_{fe} = -50$

2) $R_{i_2} = h_{ie} = 1.2k\Omega$

3) $A_{V_2} = A_{i_2} \times \dfrac{R_L}{R_{i_2}}$ $\quad \boxed{R_L = R_{C_2}}$

$= -50 \cdot \dfrac{4 \times 10^3}{1.2 \times 10^3} = -166.66$.

Analysis of 1st stage:

$R_L = R_{C_1} \| R_1 \| R_2 \| R_{i_2}$

$= 15K \| 47K \| 4.7K \| 1.2K$

$= 15K \| \dfrac{47000}{11} \| 1.2K$

$= \dfrac{176250}{53} \| 1.2K$

$\boxed{R_L = 881.8\,\Omega}$

$h_{oe} \cdot R_L = 25 \times 10^{-6} \times 881.8$

$= 0.02 < 0.1$

Hence, we can use approximate analysis,

1) $A_{i_1} = -h_{fe} = -50$

2) $R_{i_1} = h_{ie} = 1.2k\Omega$

3) $A_{v_1} = A_{i_1} \cdot \frac{R_L}{R_i}$

$= -50 \cdot \frac{881.8}{1.2 \times 10^3}$

$\boxed{A_{v_1} = -36.74}$

4) Gain of two stages,

$A_{v_T} = A_{v_1} \cdot A_{v_2}$

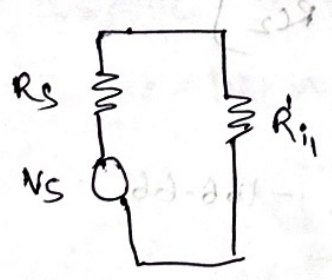
$= (-166.66)(-36.74)$

$\boxed{A_{v_T} = 6123.0884}$

$A_{i_T} = A_{i_1} \cdot A_{i_2}$

$\boxed{A_{i_T} = 2500}$

5) overall voltage gain,



$R'_{i_1} = R_1 || R_2 || R_{i_1}$

$= 200k || 20k || 1.2k$

$= 18.18k || 1.2k$

$\boxed{R'_{i_1} = 1.1257k}$

6) $A_{vs} = A_v \cdot \frac{R'_{i_1}}{R_s + R'_{i_1}}$

$= (6123.0884) \cdot \frac{1.1257k}{1.1257k + 1.2k}$

$\boxed{A_{vs} = 3242.58}$

7) overall current gain,

$$A_{is} = A_i \cdot \frac{R_s}{R_s + R'_{i_1}} = 2500 \cdot \frac{1K}{1K + 1.4237K}$$

$$\boxed{A_{is} = 1176.08}$$

8) output resistance:

$R_{o_1} = 25M\Omega$ (very high)

$R'_{o_1} = R_{o_1} \parallel R_{c_1}$

$= \infty \parallel 15K$

$$\boxed{R'_{o_1} = 15K\Omega}$$

$R_{o_2} = 25M\Omega$ (very high)

$R'_{o_2} = R_{o_2} \parallel R_{c_2}$

$= \infty \parallel 4K$

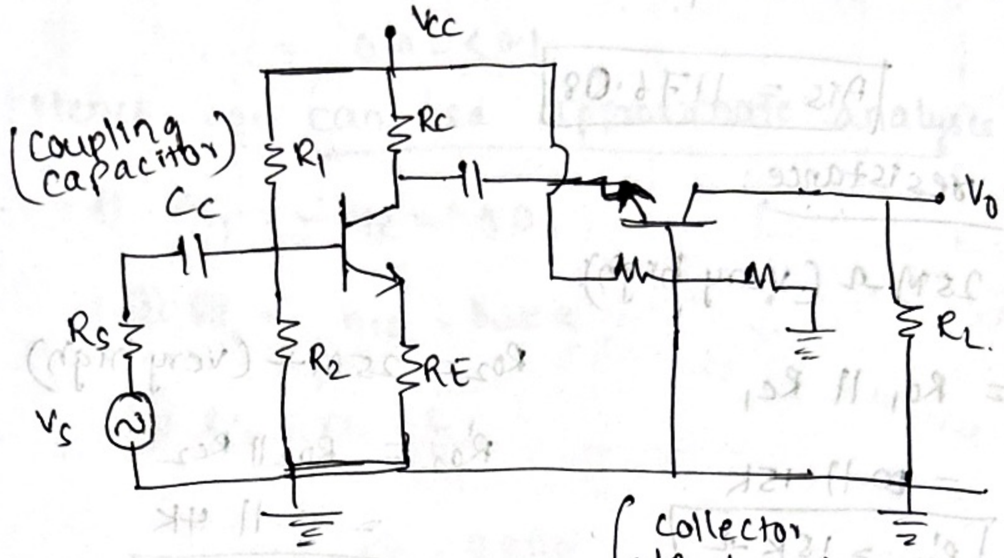
$$\boxed{R'_{o_2} = 4K\Omega}$$

⇒ Expressions for A_i, R_i, A_v, R_o, R_{ot} using approximate h-model

Quantity	CE	CB	CC
A_i	$-h_{fe}$	$\frac{h_{fe}}{1+h_{fe}}$	$1+h_{fe}$
R_i	h_{ie}	$\frac{h_{ie}}{1+h_{fe}}$	$h_{ie} + (1+h_{fe})R_L$
A_v	$h_{fe} \cdot \frac{R_L}{h_{ie}}$	$h_{fe} \cdot \frac{R_L}{R_E}$	$1 - \frac{h_{ie}}{R_i}$
R_o	∞	∞	$\frac{h_{ie}+R_s}{1+h_{fe}}$
R_{ot}	R_L	R_L	$R_o \parallel R_L$

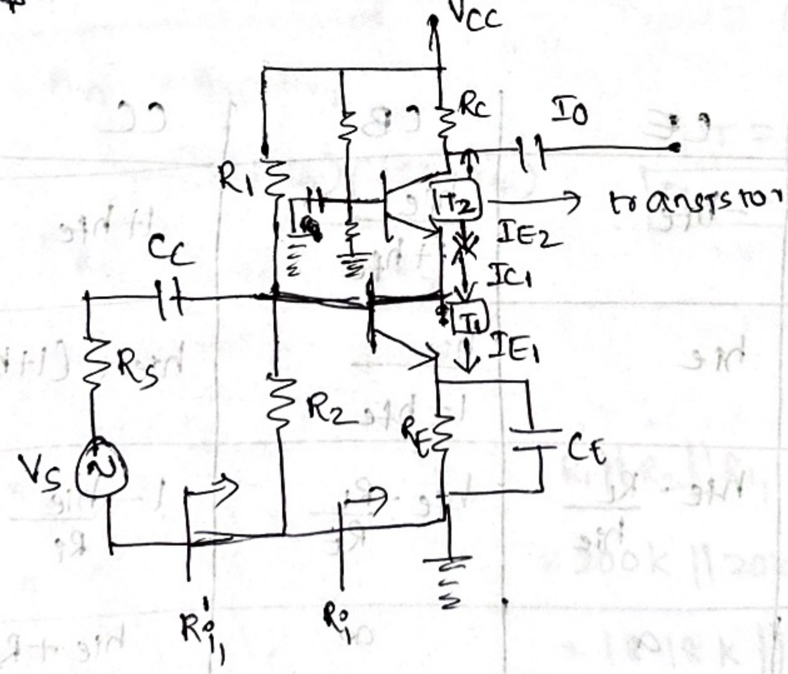
23/03:

Combination of CE & CB Amplifier / CASCADE Amplifier



(or) prefer this.

★★



→ CE amplifier acts as input stage and CB amplifier acts as output stage. A cascode amplifier consists of a CE amplifier in series with CB amplifier

→ It is a approach to solve the low impedance problem of CB amplifier.

→ I_{E_1} for T_1 is by V_{E_1} & R_{E_1}

$$\boxed{I_{E_1} = \frac{V_{E_1}}{R_{E_1}}}$$

$\Rightarrow \boxed{I_{C_1} = I_{E_1}}$

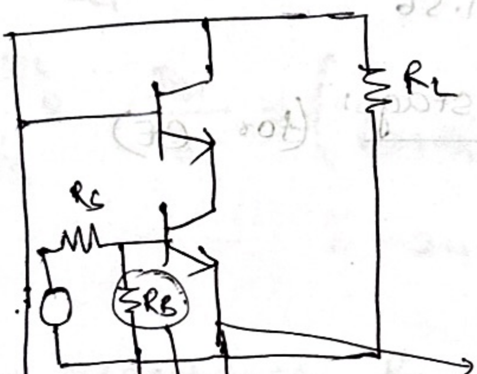
I_{E_2} is same as I_{C_1} $[I_{E_2} = I_{C_1}]$

we know that; $\boxed{I_{E_2} \approx I_{C_2}}$

$\boxed{I_{C_2} \approx I_{E_1}}$

$\therefore$ The current remains constant regardless of level of V_{B2} as long as V_{EE_1} is large enough for the current operation of T_1.

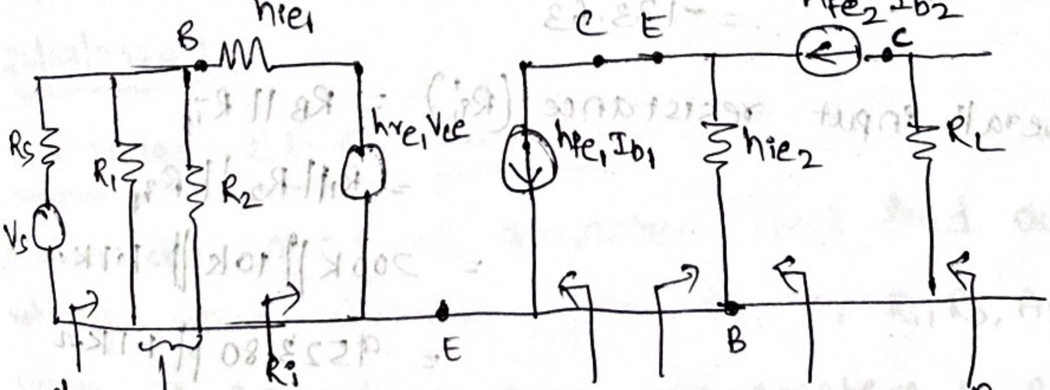
AC Equivalent circuit for Cascode Amplifier:



As bypass capacitor shorted, no resistance

parallel combination of R_1 & R_2

H-parameter model of Cascode Amplifier:



parallel combination of R_1 & R_2 is R_B.

$\rightarrow$ Consider the circuit parameters $R_S = 1k\Omega$, $R_1 = 200k\Omega$, $R_2 = 10k\Omega$, $R_L = 3k\Omega$, Transistor parameter for both transistors are $h_{ie} = 1.1k\Omega$, $h_{fe} = 50$

Analysis of the second stage:

1) A_{i2} (current gain) $= \dfrac{h_{fe}}{1+h_{fe}}$ (for CB)

$= 0.98$

2) $R_{i2} = \dfrac{h_{ie}}{1+h_{fe}} = 21.56\,\Omega$

3) $A_{v2} = A_{i2} \times \dfrac{R_L}{R_{i2}}$

$= 0.98 \times \dfrac{3\times10^3}{21.56} = 136.36$

Analysis of the 1st stage: (for CE)

1) $A_{i1} = -h_{fe} = -50$

2) $R_{i1} = h_{ie} = 1.1\,K\Omega$

3) $A_{v1} = A_{i1} \times \dfrac{R_L}{h_{ie}} = -50 \times \dfrac{21.56}{1.1K} = -0.98$

4) A_{vT} (voltage gain of 2 stages) $= A_{v1} \times A_{v2}$

$= -0.98 \times 136.36$

$= -133.63$

5) overall input resistance $(R_{i1}') = R_B \parallel R_{i1}$

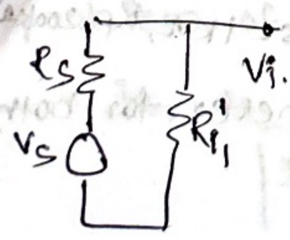
$= R_1 \parallel R_2 \parallel R_{i1}$

$= 200k \parallel 10k \parallel 1.1K\Omega$

$= 9523.80 \parallel 1.1K\Omega$

$= 986\,\Omega$

6) overall voltage gain:



$A_{vs} = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_i} \times \dfrac{V_i}{V_s}$

$\dfrac{V_i}{V_s} = \left(\dfrac{R_{i1}'}{R_s + R_{i1}'}\right) \times A_{vT}$

$$= \left(\frac{986}{1\times10^3+986}\right)\times(-133.63)$$

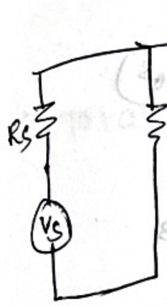
$$= -66.34$$

7) $A_{IS} = \frac{I_0}{I_S} = \frac{I_0}{I_{C2}} \times \left(\frac{I_{C2}}{I_{E2}}\right) \times \frac{I_{E2}}{I_{C1}} \times \left(\frac{I_{C1}}{I_{E1}}\right) \times \frac{I_{E1}}{I_S}$

$\frac{I_{C2}}{I_{E2}} \rightarrow A_{I2}$, $\frac{I_{C1}}{I_{E1}} \rightarrow A_{I1}$, I_{B1}, $I_S \rightarrow$ find out

$\Rightarrow \frac{I_0}{I_{C2}} = -1 \hookrightarrow$ opp. dire

$\frac{I_{E2}}{I_{C1}} = -1$



$$\frac{I_{B1}}{I_S} = \left(\frac{R_S}{R_S+R_{I1}'}\right)\times A_{IT}$$

$A_{IT} \hookrightarrow A_{I1}\times A_{I2} = -50\times0.98$ (-49)

$$= -24.67$$

8) output resistance $R_0 = \begin{bmatrix} R_{O1}=\infty \\ R_{O2}=\infty \end{bmatrix}$

$\therefore R_0 = R_{O2} \,||\, R_L$

$= \infty || 3K\Omega$

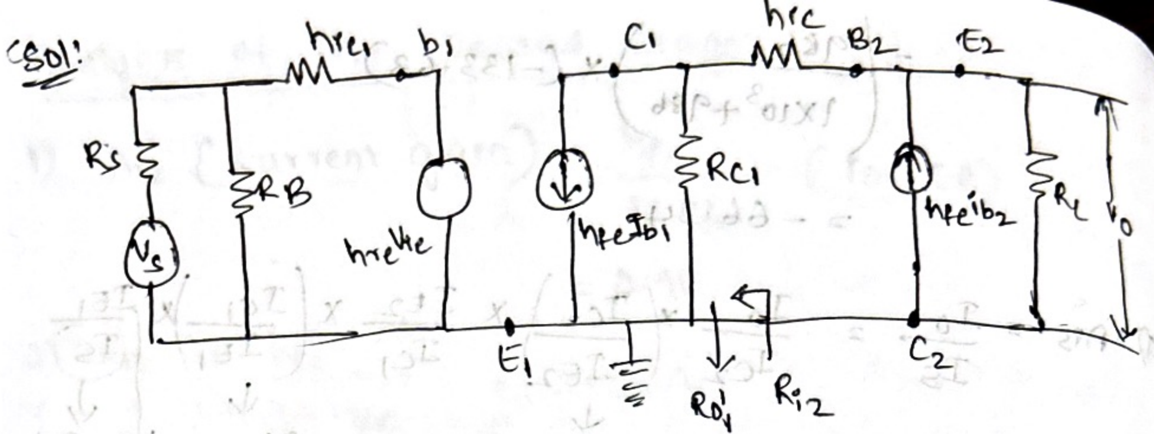
$$\boxed{R_0 = 3K\Omega}$$

26/03/2024:

Two stage CE-CC Amplifier:

Q: Consider a CE-CC amplifier and find out voltage gain, current gain, $A_V, A_I, R_i, R_o, A_{VS}, A_{IS}$ with CE amplifier stage parameters as $R_S = 1K\Omega$, $R_1 = 50K\Omega$, $R_2 = 2K\Omega$, $R_C = 1K\Omega$, $R_L = 1.2K\Omega$, $h_{fe} = 80$, $h_{ie} = 2K$, $h_{oe} = 25\mu A/V$, $h_{re} = 6\times10^{-4}$ and for CC amplifier the transistor parameters are $h_{ic} = 2K$, $h_{fc} = -51$, $h_{rc} = 1$, $h_{oc} = 25\mu A/V$ (go exact Analysis)

Sol:



Analysis of 2nd stage CC Amplifier:

1) current gain $(A_{i2}) = \frac{-h_{fc}}{1+(h_{oc})R_L}$

$$= \frac{-(-51)}{1+(25\times10^{-6})(1.2\times10^{3})}$$

$$= \frac{51}{1+(25\times1.2)\times10^{-3}}$$

$$\boxed{A_{i2} = 49.51}$$

2) $R_{i2} = h_{ic} + h_{rc} \times A_{i2} \times R_{e2}$

$= 2\times10^3 + 1\times49.51 \times 1.2\times10^3$ $(R_L = R_{e2})$

$$\boxed{R_{i2} = 61.4\,k\Omega}$$

3) voltage gain $(A_{v2}) = A_{i2} \times \frac{R_L}{R_{i2}}$

$$= (49.5) \times \frac{1.2\times10^3}{61.4\times10^3}$$

$\boxed{A_{v2} = 0.96}$ (voltage gain is less than 1)

Analysis of 1st stage:

1) Net load resistance $(R_{o1}') = R_{C1} \parallel R_{i2}$

$= 1k\Omega \parallel 61.4k\Omega$

$= \frac{(61.4k)(1k)}{(1+61.4)10^3} = 1k\Omega$ (approx)

2) A_{i_1} (current gain) $= \dfrac{-h_{fe}}{(1+h_{oe})\,R_{o_1}'} = -48.78$

3) Input impedance $(R_{i_1}) = h_{ie} + h_{re}\,A_{i_1} - R_{o_1}'$

$$= 2\times10^3 + (6\times10^{-4})(-48.78)(1\times10^3)$$

$$= 1.9\,k\Omega$$

4) voltage gain $(A_{v_1}) = A_{i_1} \times \dfrac{R_{o_1}'}{R_{i_1}}$

$$= -48.78 \times \frac{1\times10^3}{1.9\times10^3}$$

$$= -25.67$$

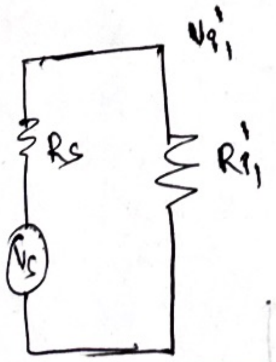
5) Total voltage gain $(A_{v_T}) = A_{v_1} \times A_{v_2}$

$$= 0.96 \times -25.67$$

$$= -24.64$$

6) overall voltage gain $(A_{vs}) = \dfrac{V_o}{V_s} = \dfrac{V_o}{V_{i_2}} \times \dfrac{V_{o_1}}{V_{i_1}}$

$$= A_{v_2} \times A_{v_1} \times \frac{V_{i_1}}{V_s}$$



$$\therefore \left[\frac{V_{i_1}}{V_s} = \frac{R_{i_1}'}{R_s + R_{i_1}'}\right]$$

$$= \boxed{A_{v_2} \times A_{v_1} \times \frac{R_{i_1}'}{R_s + R_{i_1}'}}$$

$\boxed{R_{i_1}' = R_1 \,||\, R_2 \,||\, R_{i_1}}$

$\boxed{R_{i_1}' = 0.95\,k\Omega}$

$0.955\,k\Omega$

$955\,\Omega$

$$= 0.96 \times (-25.67) \times \frac{0.95K}{1K + 0.95K}$$

$$\boxed{A_{vs} = -12.00}$$

7) overall current gain $(A_{is}) = \dfrac{I_{e_2}}{I_s} = \underbrace{\dfrac{I_{e_2}}{I_{b_2}}}_{A_{i_2}} \times \dfrac{I_{b_1}}{I_{c_1}} \times \underbrace{\dfrac{I_{c_1}}{I_{b_1}}}_{A_{i_1}} \times \dfrac{I_{b_1}}{I_s}$

$= (-1)$ opp direction

$$= A_{i_2} \times (-1) \times A_{i_1} \times \frac{R_S}{R'_{i_1} + R_S}$$

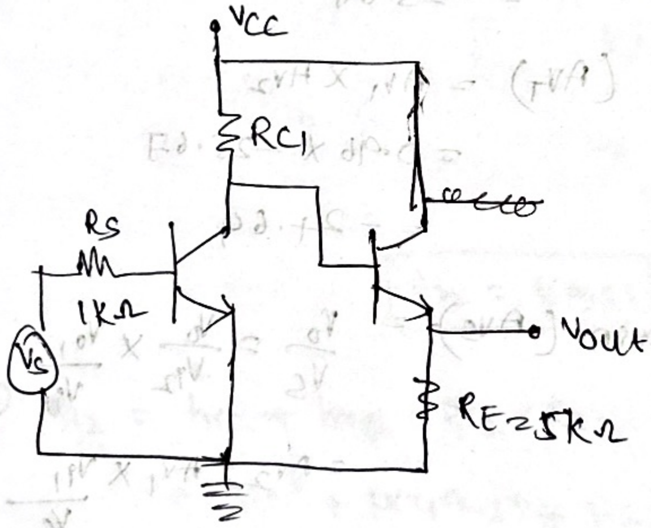
$$= \boxed{- A_{i_2} \times A_{i_1} \times \frac{R_S}{R'_{i_1} + R_S}}$$

$$= -(49.51)(-48.78) \times \frac{1k\Omega}{0.95k + 1k}$$

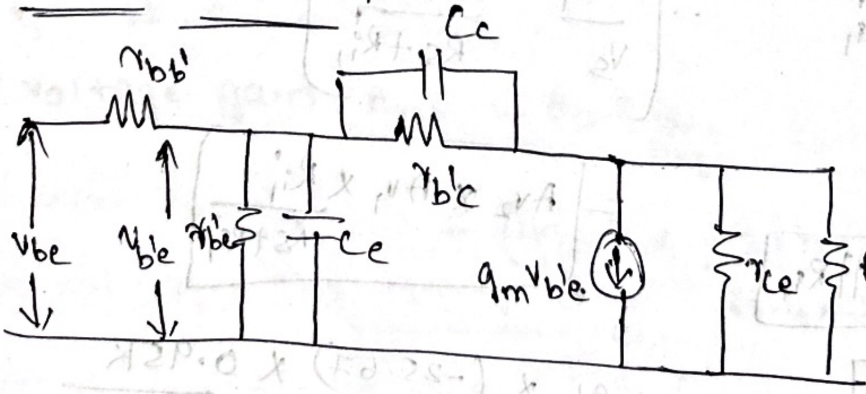
Home Assignment

$$= \boxed{+1238.511}$$

Q) Design a CE-CC Amplifier with $R_S = 1k\Omega$, $R_{C1} = 10k\Omega$, $R_{E_2} = 5k\Omega$. assume $h_{ie} = 2k\Omega$, $h_{ic} = 2k\Omega$, $h_{fe} = 50$, $h_{fc} = $, $h_{re} = 6 \times 10^{-4}$, $h_{rc} = 1$, $h_{oe} = h_{oc} = 25\mu A/V$



Millers Theorem:



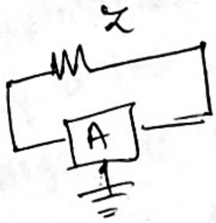
* Short circuit current gain is derived by considering $\boxed{R_L = 0}$ this is required to maintain transistor in active region. This figure shows the CE hybrid π-model.

* $r_{b'c}$ and C_c acting as feedback common to both i/p & o/p side.

* when there is an impedance common to both i/p & o/p using "Miller's theorem." the Z-impedance can be seperated to two individual impedances.

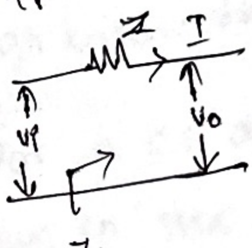
Miller's Theorem:

consider a circuit where the impedance z is common to both i/p and o/p



Then the impedance z can be seperated as Z_1, Z_2

The miller's theorem states that "the effect of i/p circuit is the ratio of i/p voltage to current".



$$Z_1 = \frac{V_i}{I}$$

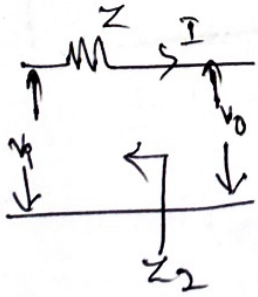
$$I = \frac{V_i - V_o}{Z} \Rightarrow Z_1 = \frac{V_i}{\frac{V_i - V_o}{Z}}$$

divide N^r & D^r with V_i

$$Z_1 = \frac{Z}{1 - \frac{V_o}{V_i}} \Rightarrow Z_1 = \frac{Z}{1 - A_v}$$

$$\boxed{Z_1 = \frac{Z}{1-K}} \quad \left(K = A_v = \frac{V_o}{V_i}\right)$$

Similarly, the effect of resistance at o/p circuit is the ratio of o/p voltage to current.



$$Z_2 = \frac{V_o}{I}$$

$$I = \frac{V_o - V_i}{Z}$$

$$Z_2 = V_o \Big/ \frac{V_o - V_i}{Z} \Rightarrow \frac{Z V_o}{V_o - V_i}$$

Divide N^r and D^r with V_i

$$Z_2 = \frac{Z \cdot \frac{V_o}{V_i}}{\frac{V_o}{V_i} - 1}$$

$$Z_2 = \frac{Z \cdot A_V}{A_V - 1}$$

$$\boxed{Z_2 = Z \cdot \frac{K}{K-1}}$$

Using miller's theorem,

$$Z_1 = \frac{r_{b'c}}{1-K} ; \quad C_c(1-K)$$

$$Z_2 = \frac{r_{b'c}K}{K-1} ; \quad \frac{K}{C_c(K-1)}$$

H-parameters for exact Analysis:

1) $A_i = \frac{-h_f}{1+h_o R_L}$

2) $A_V = A_i \cdot \frac{R_L}{R_i}$

3) $R_i = h_i + h_r A_i R_L$

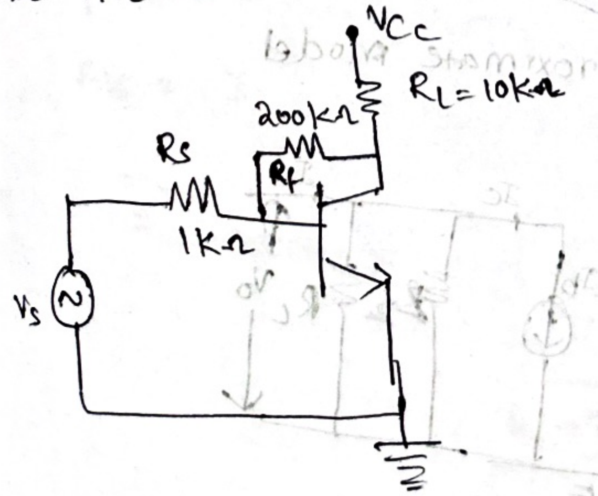
4) $R_o = \frac{R_s + h_i}{h_o R_s + [h_o h_i - h_f h_r]}$

Q): Why CE-CB called Cascode Amplifier:

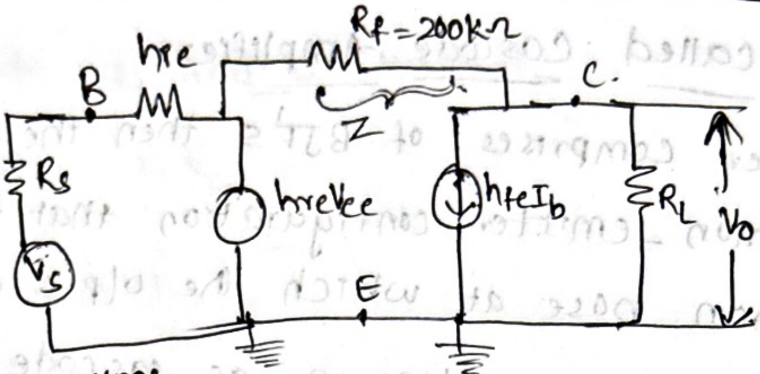
- If an amplifier comprises of BJT's then the i/p stage is common-emitter configuration that feeds to the common base at which the o/p is collected. This type of amplifier is known as cascode amplifier
- The CB Amplifier is known for wider BW, the low i/p impedance of CB is a limitation for many applications. The solution is to precede the CB stage by a low gain CE stage which has moderately high i/p impedance.
- It can have different characteristics like high i/p / o/p isolation, high i/p / o/p impedance, high Bandwidth.

27/03:

Q: For a CE amplifier with collector to base bias, shown in the figure, Calculate R_i, A_I, A_V, A_{VS}, R_o. The transistor parameters are $h_{ie} = 1.1k\Omega$, $h_{fe} = 50$, $h_{oe} = h_{re} = 0\Omega$



Sol:



Let assume, gain = $\frac{V_o}{V_i}$

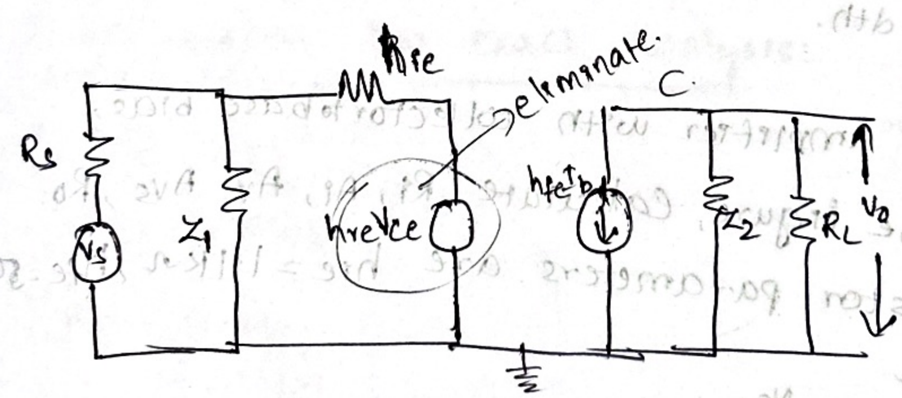
for a CE amplifier,

gain >> 1

$\boxed{A_v \text{ (or) } K >> 1}$

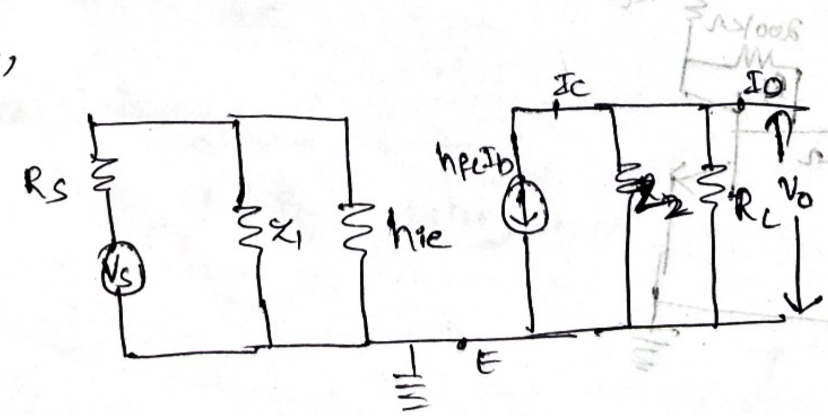
$\therefore Z_2 = Z \cdot \frac{K}{K-1}$ $\quad (\because K >> 1)$

$\therefore Z_2 = \frac{\cancel{Z}\cancel{K}}{\cancel{K}} \Rightarrow \boxed{Z_2 = Z = 200k\Omega}$



Here, we will use Approximate model

so,



As $\boxed{h_{oe} = 0}$; we can use approximate analysis

~~$A_i = \frac{-h_{fe}}{1 + h_{oe} R_L}$~~ $\quad \boxed{A_i = -h_{fe} = -50}$

$$\boxed{R_i = h_{ie} = 1.1K\Omega}$$

$$A_V = h_{fe} \cdot \frac{R_L}{h_{ie}} = \frac{50 \times 10K}{1.1K}$$

$$= \frac{500}{1.1} = \frac{5000}{11}$$

$$\boxed{A_V = -454.54 = K}$$

$$\boxed{R_O = \infty}$$

$$\cancel{A_{VS} = A_V \times \frac{Z_i}{R_s + Z_i}}$$

$$= \cancel{454.54 +}$$

$$R_i' = Z_1 \,||\, R_i$$

$$=$$

$$Z_1 = \frac{Z}{1-K}$$

$$= \frac{200}{1+454.54}$$

$$A_{VS} = \frac{V_o}{V_i} \times \frac{V_i}{V_s}$$

$$\boxed{A_{VS} = A_V \times \frac{R_i'}{R_i' + R_s}}$$

$$\boxed{Z_1 = 439.02\Omega}$$

$$R_i' = \frac{439.02 \times 1.1K}{(1.1K + 439.02)}$$

$$A_{VS} = -454.54 \times \frac{313.78}{313.78 + 1K}$$

$$\boxed{R_i' = 313.78\,\Omega}$$

$$\boxed{A_{VS} = -108.56}$$

$$A_{IS} = \frac{I_o}{I_s} = \frac{I_o}{I_c} \times \underbrace{\left(\frac{I_c}{I_b}\right)}_{A_I} \times \frac{I_b}{I_s}$$

$$= \cancel{A_I \times R_s}$$

$$\frac{Z_2}{R_L + Z_2} \qquad \frac{Z_1}{Z_1 + R_s}$$

$$\therefore A_{IS} = \frac{Z_2}{R_L + Z_2} \times A_I \times \frac{R_s}{R_i' + R_s}$$

$$= \frac{200K}{10K + 200K} \times -50 \times \frac{1K}{313.78 + 1K}$$

$= 0.952 \times -50 \times 0.7611$

$$\boxed{A_{IS} = -36.22}$$

$\cancel{R_o' = R_L ||}$ $R_o' = \infty || R_L || Z_2$

$= R_L || Z_2$

$= 10k || 200k$

$R_o' = 9523.8\,\Omega$

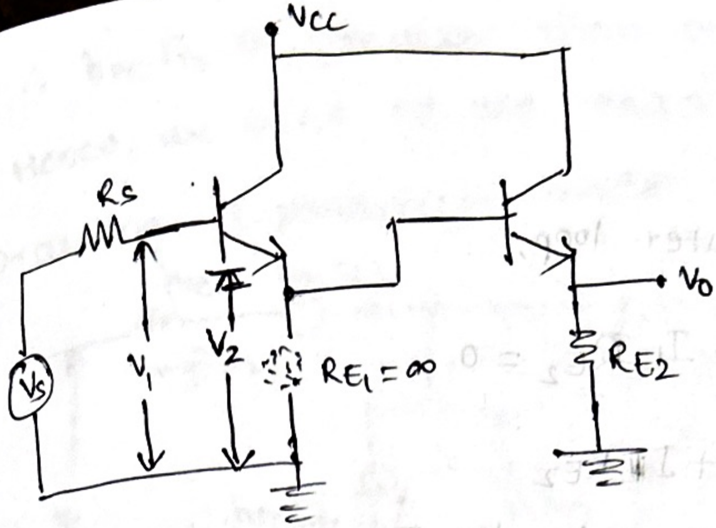
$$\boxed{R_o' = 9.5k\Omega}$$

*** High Input Resistance Transistor Circuits:/

Darlington Pair:

The input impedance of the CC amplifier is high but bcoz of biasing resistors, where, $\boxed{R_i' || R_1 || R_2}$, the input impedance becomes significantly less. This can be improved by direct coupling of 2 emitter follower amplifier stages.

* the cascaded connection of 2 emitter followers is called darlington connection/ darlington pair.

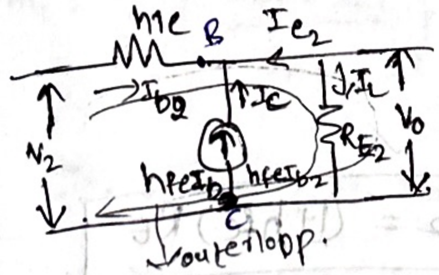


Assume that, the load resistance (R_L) is such that,

$\boxed{h_{oe} \cdot R_L << 0.1}$

Hence, we use approximate model for analyzing the 2nd stage.

The H-parameter model for 2nd stage is given as



$$A_{I_2} = \frac{I_L}{I_{b_2}} = \frac{-I_{e_2}}{I_{b_2}} \qquad [I_e = I_b + I_c]$$

$$= \frac{-[I_{b_2} + I_{c_2}]}{I_{b_2}}$$

$$= \frac{-[I_{b_2} + h_{fe} I_{b_2}]}{I_{b_2}}$$

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

$$\boxed{A_{I_2} = 1 + h_{fe}}$$

$$R_{i_2} = \frac{V_2}{I_{b_2}}$$

Apply KVL to outer loop,

$$V_2 - h_{ie} I_{b_2} - I_L R_{E_2} = 0$$

$$V_2 = h_{ie} I_{b_2} + I_L R_{E_2}$$

dividing on both sides by I_{b_2}

$$\frac{V_2}{I_{b_2}} = h_{ie} + \frac{I_L}{I_{b_2}} R_{E_2} \qquad \left[R_{E_2} = R_E \ \because R_{E_1} = \infty \right]$$

$$\boxed{R_{i_2} = h_{ie} + A_{i_2} R_{E_2}}$$

$$R_{i_2} = h_{ie} + (1+h_{fe}) R_{E_2}$$

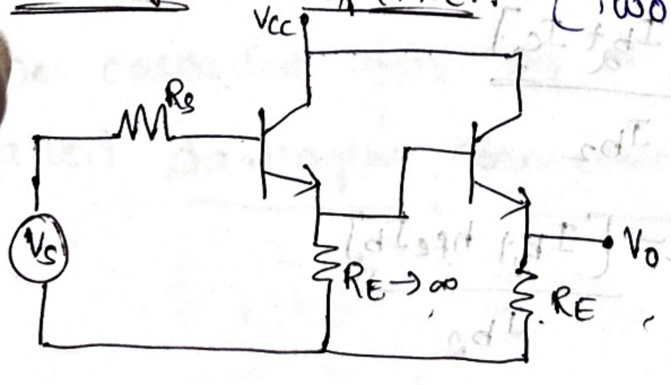
$$\boxed{R_{i_2} = h_{ie} + (1+h_{fe}) R_E}$$

As $h_{ie} \lll (1+h_{fe}) R_E$; $\boxed{R_{i_2} = (1+h_{fe}) R_E}$

30/03:

Darlington Amplifier: (Two stage CE)

Emitter follower circuits.



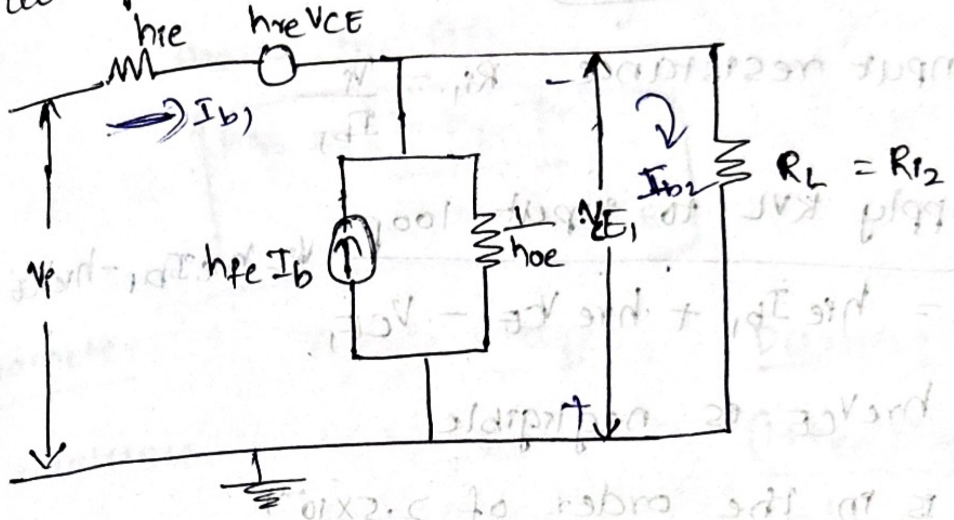
Analysis of 1st stage,

The load resistance of 1st stage is input resistance of the second stage which is R_{i_2}. Generally, R_{i_2} is very high.

$\therefore h_{oe} R_{i_2}$ is greater than 0.1

Hence, we need to use exact analysis.

Drawing H-parameter model for 1st stage.



$$A_{i_1} = \frac{I_{e_1}}{I_{b_1}} = \frac{I_{e_1}}{I_{b_1}}$$

$$A_{i_1} = -\left[\frac{I_{b_1} + I_{c_1}}{I_{b_1}}\right]$$

$$I_{c_1} = h_{fe} I_b + h_{oe} V_{CE_1}$$

$$V_{CE_1} = -I_{b_2} \cdot R_L$$

$$I_{C_1} = h_{fe} I_b + h_{oe} \left(-I_{b_2} \cdot R_{L}\right)$$

$$= h_{fe} I_b + h_{oe} \cdot I_{e_1} R_{L_1}$$

$$I_{E_1} = -\left(I_{b_1} + h_{fe} I_{b_1} + h_{oe} I_{e_1} \cdot R_L\right)$$

$$I_{E_1}\left(1 + h_{oe} R_L\right) = -I_{b_1}\left(1 + h_{fe}\right)$$

$$A_{i_1} = \frac{-I_{e_1}}{I_{b_1}} = \frac{1 + h_{fe}}{1 + h_{oe} R_L}$$

$$\boxed{A_{i_1} = \frac{1 + h_{fe}}{1 + h_{oe}(1 + h_{fe}) R_E}}$$

As $h_{fe} >> 1$

$$\boxed{A_{i_1} = \frac{1+h_{fe}}{1+h_{oe}h_{fe}R_E}}$$

Input resistance $R_{i_1} = \frac{V_i}{I_{b_1}}$

Apply KVL to input loop $V_i = h_{ie}I_{b_1} - h_{re}V_{CE} + V_{CE_1}$

$V_i = h_{ie}I_{b_1} + h_{re}V_{CE} - V_{CE_1}$

$h_{re}V_{CE}$ is negligible

h_{re} is in the order of 2.5×10^{-4}

$\therefore V_i$ can be written as

$V_i = h_{ie}I_{b_1} - V_{CE_1}$

$V_{CE_1} = I_{b_2} R_{L_1}$

$I_{b_2} = I_{c_1}$

$\therefore V_i = h_{ie}I_{b_1} + I_{e_1}R_{L_1}$

dividing on both sides by I_{b_1}

$$\frac{V_i}{I_{b_1}} = h_{ie} + \frac{I_{e_1}}{I_{b_1}} R_{L_1}$$

$R_{i_1} = h_{ie} + A_{i_1} \cdot R_{L_1}$

$R_{i_1} = h_{ie} + A_{i_1}(1+h_{fe}) R_E$

Sub A_{i_1} we get,

$$\boxed{R_{i_1} = h_{ie} + \frac{(1+h_{fe})}{1+h_{oe}h_{fe}R_E} \cdot (1+h_{fe})R_E}$$

As h_{ie} is very small compared with 2nd term.

$$\boxed{R_{i_1} = \frac{(1+h_{fe})^2 \cdot R_E}{1+h_{oe} h_{fe} R_E}}$$

The overall current gain

$$A_{IS} = A_{I_1} \cdot A_{I_2}$$

$$\boxed{A_{IS} = \frac{(1+h_{fe})^2}{1+h_{oe} h_{fe} R_E}}$$

⇒

parameter	single stage	Darlington
I/p resistance	$(1+h_{fe}) R_E$ $= 168.3\,k\Omega$	$\frac{(1+h_{fe})^2 \cdot R_E}{1+h_{oe}(1+h_{fe})R_E}$ $1.64\,M\Omega$
current gain	$1+h_{fe}$ 51	$\frac{(1+h_{fe})^2}{1+h_{oe} h_{fe} R_E}$ 500

2) If $R_i = 3.3K$, $h_{ie} = 1100$, $h_{re} = 2.5 \times 10^{-4}$, $h_{fe} = 50$, $h_{oe} = 25\,\mu A/V$

	Single	Darlington
I/p resistance	$168.3\,K\Omega$	$1.648\,M\Omega$
A_I	51	$499.47 \approx 500$

⇒ with this arrangement it is clear that the connection improved input impedance as well as current gain of the ckt.

Overall voltage gain,

$$A_{v_1} = A_{i_1} \cdot \frac{R_{L1}}{R_{i_1}} \quad , \quad A_{v_2} = A_{i_2} \cdot \frac{R_L}{R_{i_2}}$$

Considering second stage A_{v_2},

$$1 - A_{v_2} = 1 - A_{i_2} \cdot \frac{R_L}{R_{i_2}}$$

$$1 - A_{v_2} = \frac{R_{i_2} - A_{i_2} \cdot R_L}{R_{i_2}}$$

We know,

$$R_{i_2} = h_{ie} + A_{i_2} \cdot R_L$$

$$1 - A_{v_2} = \frac{R_{i_2} - A_{i_2} R_L}{R_{i_2}}$$

$$\Rightarrow \quad 1 - A_{v_2} = \frac{h_{ie} + \cancel{A_{i_2} R_L} - \cancel{A_{i_2} R_L}}{R_{i_2}}$$

$$1 - A_{v_2} = \frac{h_{ie}}{R_{i_2}}$$

$$A_{v_2} = 1 - \frac{h_{ie}}{R_{i_2}}$$

Similarly, $A_{v_1} = A_{i_1} \cdot \frac{R_{L_1}}{R_{i_1}}$

$$1 - A_{v_1} = 1 - \frac{A_{i_1} R_L}{R_{i_1}}$$

$$1 - A_{v_1} = \frac{R_{i_1} - A_{i_1} R_{L_1}}{R_{i_1}}$$

We know, $R_{i_1} = h_{ie} + A_{i_1} R_{L_1}$

$$1 - A_{v_1} = \frac{h_{ie} + \cancel{A_{i_1} R_{L_1}} - \cancel{A_{i_1} R_{L_1}}}{R_{i_1}}$$

$$A_{V_1} = 1 - \frac{h_{ie}}{R_{i_1}}$$

$$A_{V_S} = A_{V_1} \cdot A_{V_2}$$

$$= \left(1 - \frac{h_{ie}}{R_{i_1}}\right)\left(1 - \frac{h_{ie}}{R_{i_2}}\right)$$

As R_{i_1} & R_{i_2} are very large, then

$\frac{h_{ie}}{R_{i_1}}$, $\frac{h_{ie}}{R_{i_2}}$ becomes very small

Then, the overall voltage gain A_{VS} approaches $\underline{1}$.

output impedance, R_{O_2}

$$Y_O = h_{oc} - \frac{h_{fc} \cdot h_{rc}}{h_{ic} + R_S}$$

$h_{rc} = 1$, $h_{ic} = h_{ie}$, $h_{oc} = h_{oe}$

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

$$Y_{O_1} = h_{oe} + \frac{(1+h_{fe})}{h_{ie} + R_S}$$

neglecting h_{oe},

$$\boxed{Y_{O_1} = \frac{1+h_{fe}}{h_{ie_1} + R_S}}$$

$$\boxed{R_{O_1} = \frac{h_{ie_1} + R_S}{1+h_{fe_1}}}$$

01/04:

R_{O_1} of the 1st stage is the source resistance of the 2nd stage.

$\therefore R_{O_1} = R_{S_2}$

$$\therefore \boxed{R_{O_2} = \frac{R_{S_2} + h_{ie_2}}{1+h_{fe_2}}}$$

$$\therefore R_{O_2} = \frac{\left(\frac{h_{ie_1} + R_S}{1+h_{fe}}\right) + h_{ie_2}}{1+h_{fe}}$$

$$R_{O_2} = \frac{h_{ie_1} + R_S + h_{ie_2}(1+h_{fe})}{(1+h_{fe})^2}$$

$$\boxed{R_{O_2} = \frac{h_{ie_1} + R_S}{(1+h_{fe})^2} + \frac{h_{ie_2}}{(1+h_{fe})}}$$

⇒ As current in t_2 is $(1+h_{fe})$ times the current in t_1.

$$h_{ie_1} = (1+h_{fe})\, h_{ie_2}$$

$\frac{h_{ie_1} + (1+h_{fe})h_{ie_2}}{(1+h_{fe})^2}$

$\frac{h_{ie_1}}{(1+h_{fe})^2} + \frac{h_{ie_2}}{(1+h_{fe})}$

h_{ie_1}

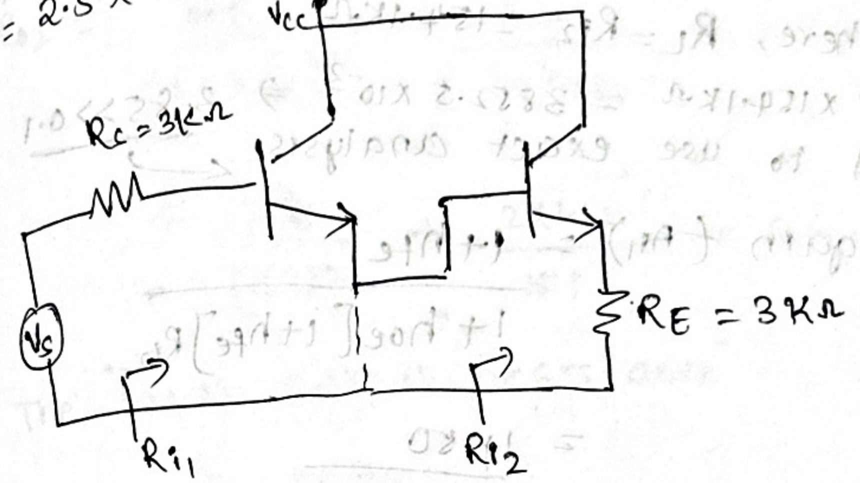
$$\Rightarrow \boxed{R_{O_2} = \frac{R_S}{(1+h_{fe})^2} + \frac{2h_{ie_2}}{1+h_{fe}}}$$

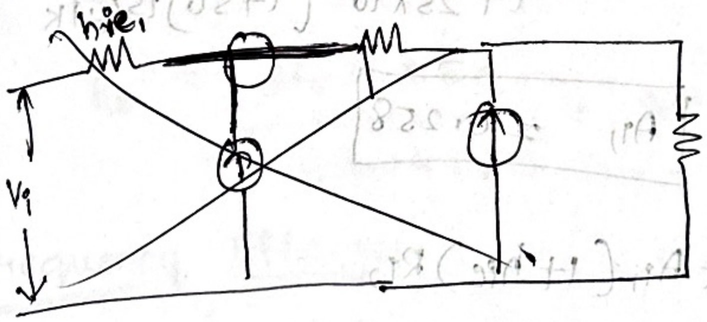
⇒ H-parameters of t_1 & t_2 are identical.

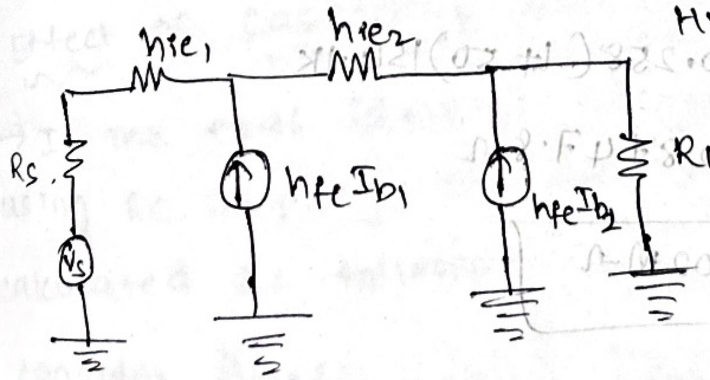
* Cascading of n-stages is not possible in darlington pair bcoz, i) the dc o/p of 1^{st} stage is $\boxed{(1+h_{fe})I_{b_1}}$. If n-stages are considered then the o/p current would be amplified by $\boxed{(1+h_{fe})^n I_{b_1}}$ providing, a very high current gain which may have the power stage which is not required for the amplifier circuits.

ii) The leakage current is the 1st transistor is amplified by the 2nd transistor, increasing the overall leakage current. which is not desirable

Q: For a ckt, of a darlington amplifier calculate R_i, A_I, A_V, and R_o given, $h_{ie} = 1.1K$, $h_{fe} = 50$, $h_{re} = 2.5 \times 10^{-4}$, $h_{oe} = 25 \mu A/V$, $R_S = 3K\Omega$, $R_E = 3K\Omega$







H-parameter, equivalent model

$\Rightarrow \boxed{h_{oe} \cdot R_L < 0.1} \Rightarrow$ condⁿ for ~~exact~~ approximate analysis.

$(25 \times 10^{-6} \times 3 \times 10^{3}) < 0.1$

$0.075 < 0.1$

$\therefore$ we need to go for approximate analysis.

Approximate analysis: of 2nd stage:

$R_{i_2} = (1 + h_{fe}) R_E + \cancel{h_{ie}} = \cancel{154K\Omega}$ $h_{ie} = 154.1K\Omega$

$A_{i_2} = 1 + h_{fe}$

$A_{I_2} = 1 + 50 = 51$

$$A_{V_2} = 1 - \frac{h_{ie}}{R_{i_2}} = 1 - \frac{1.1K}{153K} = 0.99$$

$R_{i_2} = h_{ie} + (h_{fe}+1) R_E = 1.1K + (51) 3K = 154.1K\Omega$

Analysis of 1st stage:

R_L of 1st stage is input impedance of 2nd stage

$\Rightarrow h_{oe} \cdot R_L$; here, $R_L = R_{i2} = 154.1K\Omega$

$\Rightarrow = 25\times10^{-6} \times 154.1K\Omega = 3852.5 \times 10^{-3} \Rightarrow 3.85 >> 0.1$

$\rightarrow$ we need to use exact analysis.

i) current gain $(A_{I_1}) = \dfrac{1+h_{fe}}{1+h_{oe}[1+h_{fe}]R_{i_2}}$

$$= \frac{1+50}{1+25\times10^{-6}[1+50]154.1K}$$

$$\boxed{A_{I_1} = 0.258}$$

$\Rightarrow R_{i_1} = h_{ie} + A_{I_1}(1+h_{fe}) R_{i_2}$

$= 1.1K + 0.258(1+50)154.1K$

$= 2028747.8\Omega$

$$\boxed{R_{i_1} = 2.02M\Omega}$$

$A_{V_1} = 1 - \dfrac{h_{ie}}{R_{i_1}}$

$= 1 - \dfrac{1.1K}{2.02M} = 0.99$

$A_{VS} = A_{V_1} \cdot A_{V_2}$

$= (0.99)(0.99) \simeq 0.99 = 0.9801$

$$\boxed{A_{VS} = 0.9801}$$

$$R_{o1} = \frac{R_s + h_{ie}}{1+h_{fe}}$$

$$= \frac{3K + 1.1K}{1+50} = \frac{4.1K}{51} = 80.39\,\Omega$$

$$R_{o2} = \frac{R_s}{(1+h_{fe})^2} + \frac{2h_{ie}}{1+h_{fe}}$$

$$= \frac{3K}{(51)^2} + \frac{2\times 1.1K}{51} = 44.29\,\Omega$$

$\therefore$ The total output resistance

$$R_o = R_{o2} \parallel R_E$$

$$R_o = \frac{44.29 \times 3K}{44.29 + 3K} = 43.64\,\Omega$$

Frequency Effects:

Effect of cascading on Gain:

→ If the no. of identical stages are cascading using RC coupling, the overall gain can be calculated as follows,

consider $A_{mid}(\text{overall}) = |A_m|^n$

For a single stage,

$$\left|\frac{A_L}{A_{mid}}\right| = \frac{1}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}} \Rightarrow \text{for a single stage}$$

then the overall low frequency gain will be

$$\left|\frac{A_L}{A_{mid}}\right|^n = \frac{1}{\left[\sqrt{1+\left(\frac{f_L}{f}\right)^2}\right]^n}$$

The lower 3dB frequency for overall low frequency gain can be defined at $f = f_L$.

$$\left|\frac{A_L}{A_{mid}}\right|^n = \frac{1}{\sqrt[n]{1+\left(\frac{f_L}{f}\right)^2}} = \frac{1}{\left[1+\left(\frac{f_L}{f}\right)^2\right]^{n/2}}$$

$$f = f_L \Rightarrow \boxed{\left|\frac{A_L}{A_{mid}}\right| = \frac{1}{\sqrt{2}}}$$

For n-stages, $$\boxed{\left|\frac{A_L}{A_{mid}}\right|^n = \frac{1}{\left[1+\left(\frac{f_L}{f_{L(n)}}\right)^2\right]^{n/2}}}$$

Similarly, the overall high frequency gain is,

$$\boxed{\left|\frac{A_H}{A_{mid}}\right|^n = \frac{1}{\sqrt{2}} = \frac{1}{\left[1+\left(\frac{f_{H(n)}}{f_H}\right)^2\right]^{n/2}}}$$

Then the gain of multistage amplifier at any frequency below the cutoff frequency of individual stage is given as

$$\boxed{A_V = \frac{(A_{V\,mid})^n}{\left[1+\left(\frac{f_L}{f}\right)^2\right]^{n/2}}}$$

Similarly, the gain of the multistage amplifier at any frequency above higher cutoff frequency of individual stage is

$$\boxed{A_V = \frac{(A_{V\,mid})^n}{\left[1+\left(\frac{f}{f_H}\right)^2\right]^{n/2}}}$$

Q: A multistage amplifier with 4 identical stages each of which has a lower cutoff frequency of 20Hz & upper cutoff frequency of 20KHZ. Calculate the gain of multistage amplifier at 7.5HZ and at 200KHZ. Assume mid band voltage gain of each stage is 10.

$\boxed{n=4}$

$$A_{V_1} = \frac{(10)^4}{\left[1+\left(\frac{20}{7.5}\right)^2\right]^2}$$

$$\boxed{A_{V_1} = 151.998}$$

$$A_{V_2} = \frac{(10)^4}{\left[1+\left(\frac{200K}{20K}\right)^2\right]^2}$$

$$\boxed{A_{V_2} = 0.9802}$$

Effect of cascading on Bandwidth:

The bandwidth of cascading amplifier is always less than that of BW of single stage amplifier.

consider a lower 3dB frequency of n-identical cascading stage. $f_L(n)$

$$\frac{1}{\left[1+\left(\frac{f_L}{f_L(n)}\right)^2\right]^{n/2}} = \frac{1}{\sqrt{2}}$$

S.O.B.S

$$\left[1+\left(\frac{f_L}{f_L(n)}\right)^2\right]^n = 2$$

Taking nth root on both sides,

$$(2)^{1/n} = 1 + \left(\frac{f_L}{f_L(n)}\right)^2$$

$$2^{1/n} - 1 = \left[\frac{f_L}{f_L(n)}\right]^2$$

$$\therefore \cancel{(f_L(n))^2 = \frac{2^{1/n}-1}{(f_L)^2}}$$

$$\cancel{f_L(n) = \frac{\sqrt{2^{1/n}-1}}{f_L}}$$

$$(f_L(n))^2 = \frac{(f_L)^2}{2^{1/n}-1}$$

$$\boxed{f_L(n) = \frac{f_L}{\sqrt{2^{1/n}-1}}}$$

↓

decreases.

Upper 3dB frequency:

$$\frac{1}{\sqrt{2}} = \frac{1}{\left[1+\left(\frac{f_H(n)}{f_H}\right)^2\right]^{n/2}}$$

$$\sqrt{2} = \left[1+\left(\frac{f_H(n)}{f_H}\right)^2\right]^{n/2}$$

$$2 = \left[1+\left(\frac{f_H(n)}{f_H}\right)^2\right]^{n}$$

$$2^{1/n} - 1 = \left(\frac{f_H(n)}{f_H}\right)^2$$

$$\left[\sqrt{2^{1/n}-1}\right] f_H = f_H(n)$$

$$\boxed{f_H(n) = \left[\sqrt{2^{1/n}-1}\right] f_H}$$

↓

increases