ch 6

Multistage Amplifier

A transistor circuit containing more than one stage of amplification is known as multistage amplifier. The o/p of single stage amplifier is usually insufficient to drive an o/p device. So the o/p of each amplifier stage is coupled in some way to the i/p of next stage. The resulting system is said to be multistage amplifier.

In a multistage amplifier, a no. of single stage amplifier are connected in cascade arrangement i.e. o/p of 1st stage is connected to i/p of 2nd stage through a suitable coupling device & so on.

The purpose of coupling device is
i) to transfer ac o/p of one stage to next.
ii) to isolate the DC condition of one stage from next.

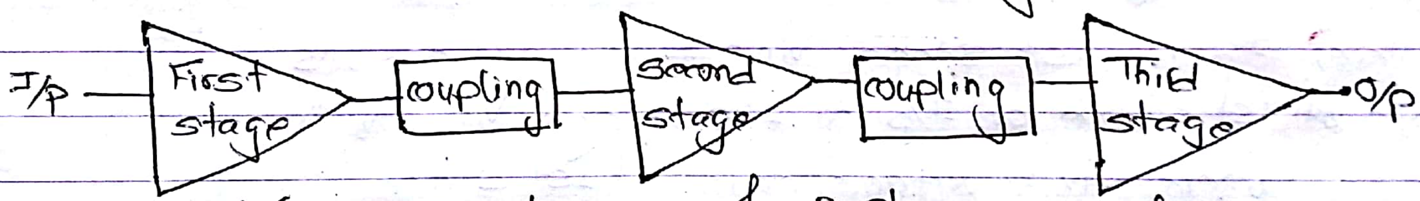


Fig: Block diagram of 3-stage amplifier.

There are different types of coupling

1) Capacitor coupled (RC coupled) amplifier
2) Transformer coupled amplifier
3) Direct coupled amplifier

In RC coupled amplifier, capacitor is used as a coupling device. The capacitor connects the o/p of one stage to i/p of next stage in order to pass AC signal & blocking DC bias voltage.

In transformer coupling, transformer is used as a coupling device. In addition to the two basic features, transformer coupling permits impedance matching.

In a direct or DC-coupling, the individual amplifier stage bias conditions are so designed that the two stages may be directly connected without the necessity for DC isolation.

N-stage Cascaded Amplifier

A n-stage cascaded multistage amplifier can be represented by a block diagram as

$V_s = V_{in}$ $\quad A_{v1}$ $\quad V_1$ $\quad A_{v2}$ $\quad V_2 \cdots V_{n-1}$ $\quad A_{vn}$ $\quad V_n$

Fig: n-stage cascaded amplifier

Here, I/p to first stage, V_{in} = signal voltage, V_s

O/p of 1st stage or I/p to 2nd stage, $V_1 = A_{v1} V_{in}$

where A_{v1} = voltage gain of 1st stage

O/p of 2nd stage or I/p to 3rd stage, $V_2 = A_{v2} V_1$

where A_{v2} = voltage gain of 2nd stage

Similarly, O/p of nth stage (i.e. final O/p) is,

$$V_n = A_{vn} V_{n-1}$$

Now, overall voltage gain of Amplifier is,

$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_1}{V_s} \times \frac{V_2}{V_1} \times \frac{V_3}{V_1} \times \cdots \times \frac{V_{n-1}}{V_{n-2}} \times \frac{V_n}{V_{n-1}}$$

$$\therefore A_v = A_{v1} \times A_{v2} \times A_{v3} \times \cdots * A_{vn-1} \times A_{vn}$$

i.e. The gain of multistage amplifier is equal to the product of gain of individual amplifier.

The gain in dB is expressed as,

$$A_v \text{ in dB} = 20\log_{10} A_{v1} + 20\log_{10} A_{v2} + \cdots + 20\log_{10} A_{vn}$$

A 3-stage amplifier has a 1st stage voltage gain of 100, 2nd stage voltage gain of 200 & 3rd stage voltage gain of 400. Find total voltage gain in dB.

Soln: Given is,

1st stage voltage gain, $A_{v1} = 100$

2nd " " " $A_{v2} = 200$

3rd " " " $A_{v3} = 400$

Now, Total voltage Gain in dB is;

$$A_v = 20\log_{10} A_{v1} + 20\log_{10} A_{v2} + 20\log_{10} A_{v3}$$

$$= 20\log_{10}(100) + 20\log_{10}(200) + 20\log_{10}(400)$$

$$= 20\times 2 + 20\times 2.3 + 20\times 2.6$$

$$= 40 + 46 + 52$$

$$= 138\text{ dB}.$$

A multistage amplifier employs 5 stages each of which has a power gain of 30. What is the total gain of amplifier in dB?

Soln: Here, Absolute gain of each stage = 30

No. of stages = 5

Power gain of each stage in dB $= 20\log_{10}(30)$

$= 14.77$

$\therefore$ Total power gain in dB $= 5\times 14.77$

$= 73.85$ dB.

Methods of Coupling

The o/p of the first stage is applied as i/p to the next stage through a coupling device. The use of coupling device is to transfer ac o/p of one stage to i/p of next stage & to isolate the dc condition (i.e. to block dc) from one stage to next stage.

On the basis of coupling N/w used, multistage amplifier can be any of following ~~tips~~ types:
1) Capacitor Coupled amplifier
2) Transformer " "
3) Impedance " "
4) Direct " "

1) Capacitor Coupled Transistor Amplifier (R-C Coupled Amplifier)

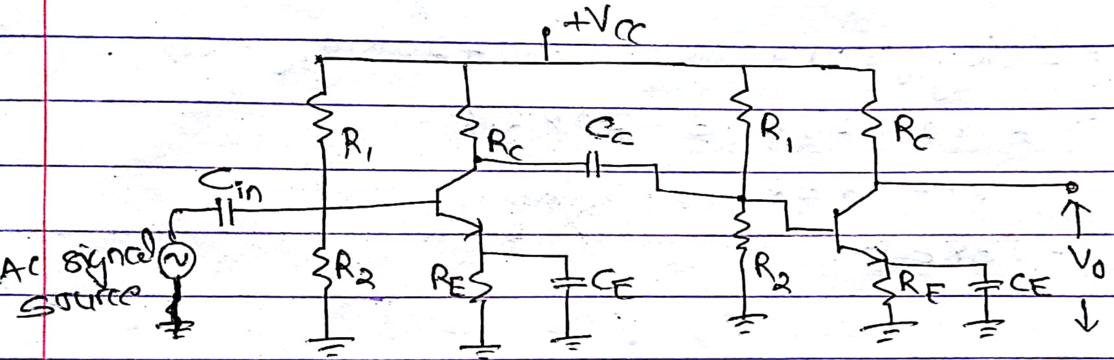


Fig: RC coupled amplifier

R-C coupled amplifier uses 2 independent transistor which are identical & common power source Vcc is used.

Here, "Cin" allows only ac current to flow from AC signal source into i/p circuit. Also the capacitor CE offers low reactance path to the signal & enhance gain and Cc transmits ac signal but blocks the dc signal of 1st stage to base of 2nd stage.

Operation:

When ac signal is applied to the base of 1st stage amplifier, it ~~ampli~~ appears in the amplified form across Rc. The amplified signal across Rc is given to base of next stage amplifier through coupling capacitor Cc. The 2nd stage does further amplification of the signal. In this way, the cascaded stages amplify the signal and

[f_1 to f_2 => mid freq. range]
↓
audio freq.

(distortion)

I* $f_1 < 50Hz$, at low freq. gain is small, because some part of ac o/p ~~lost~~ in C_c & at low freq, C_E offers high reactance ($X_C = 1/2\pi f C$) and couldn't shunt emitter resistance effectively,

the overall gain is considerably increased.

Advantages:

i) Excellent freq. response i.e. constant gain over the audio freq. range.

ii) cheaper in cost.

iii) stable Q-point (operating point).

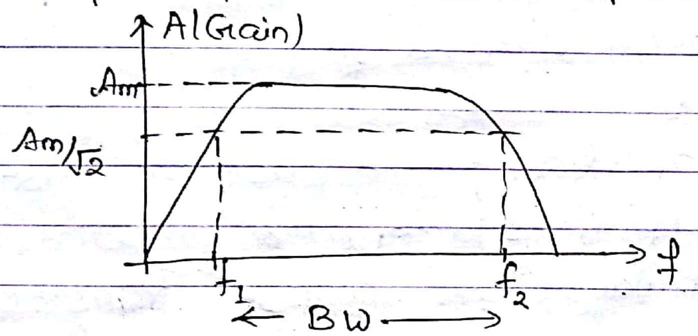
II* At mid freq. i.e. f_1 to f_2, gain is almost constant. If freq ↑, reactance of C_c ↓ & gain also ↑

Disadvantages:

i) Low voltage & power gain.

ii) Poor impedance matching due to the difference in impedances of R-C coupled capacitor o/p & that of speaker.

The freq response of R-C coupled transistor amplifier is,



III* At high freq > f_2 (200KHz), voltage gain drop off, reactance of C_C is very small & behave as short ckt, which increase load effect & reduce voltage gain.

Here, f_1 & f_2 are lower & upper-cut-off frequencies.

& $BW = f_2 - f_1$

2) Transformer Coupled (Transistor) Amplifier

The main cause of low voltage & power gain of RC coupled amplifier is reduction of effective load resistance of each stage. The low resistance of load ~~is~~ can be matched with o/p resistance of preceding stage by suitably selecting turn ratio of transformer. Here transformer is used as coupling device to feed the o/p of 1st stage to i/p of next stage. Collector load (~~resistance~~) R_C is replaced by primary winding of coupling transformer & secondary winding of coupling transformer replaced the wire both voltage divider & base of 2nd stage. Here C_E is used in the bottom of each 2ndary winding to get an ac grounded.

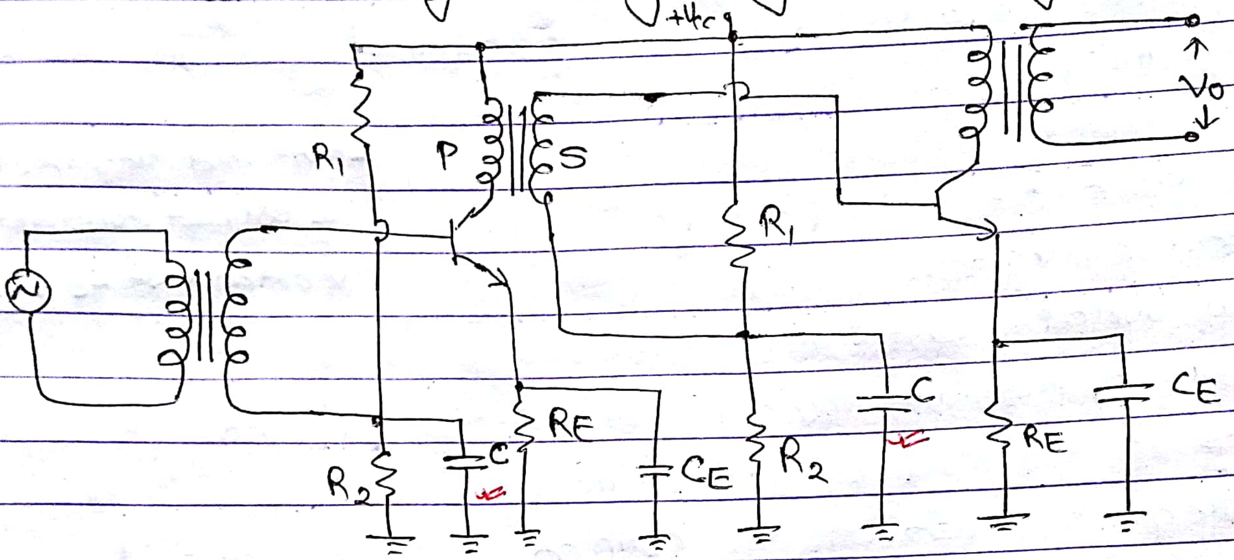


Fig: Transformer coupled amplifier

Operation:

When i/p ac signal is applied to the base of first transistor through (step-up) transformer, the amplied signal appears across the primary P of coupling transformer. The voltage developed across primary is transferred to the i/p of next stage by transformer secondary S as shown in above figure. The 2nd stage also performs the ampilification in similar manner.

Application:

Transformer coupled amplifiers are widely used for impedance matching. They are generally not used in the intermediate stage in cascaded amplifier because it is costly & bulky, but used in the initial or o/p stage. It is not used for amplifying low freq i.e. audio freq. signals. However they are widely used for amplifying radio frequency (above 20 KHz).

Advantages:

i) provides excellent impedance matching.

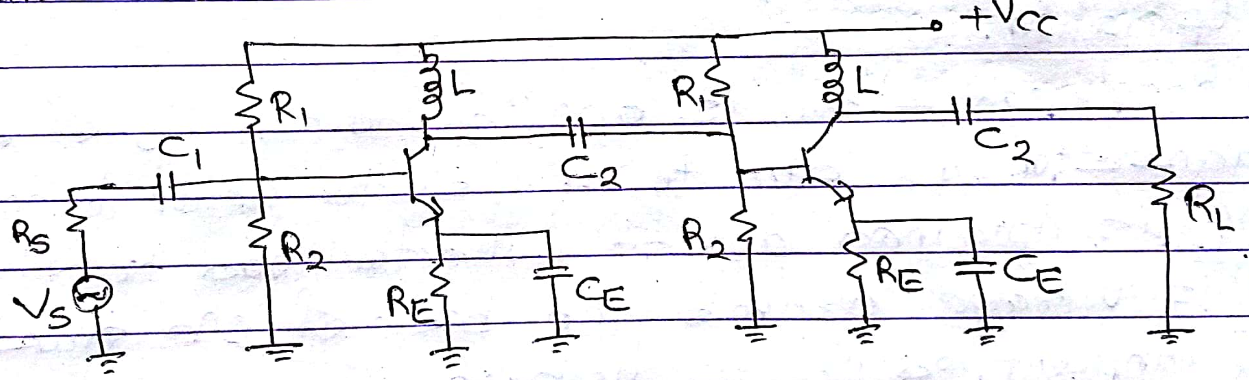
ii) provides high gain (due to excellent impedance matching).
iii) No dc power loss in primary side of transformer, so efficiency of transformer-coupled amplifier is higher than that of RC coupled amplifier.

Disadvantages:

i) has very poor freq. response
ii) bulky & costly system
iii) At radio freq, the inductance & inter-winding capa- ~~citance~~ citive reactance creates a lot of problems.
iv) tends to introduce hum in o/p.

3) Impedance Coupled Amplifier

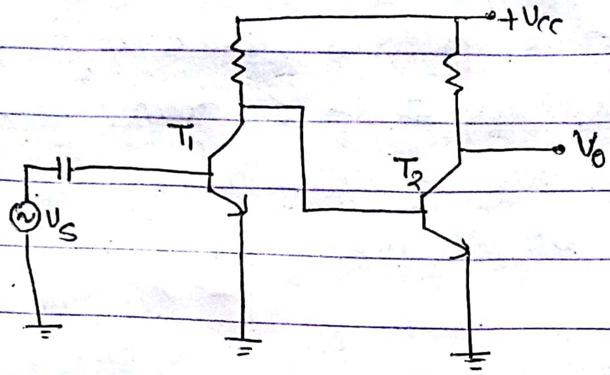
The 2-stage impedance coupled amplifier is as shown in figure below:



Impedance coupling is similar to R-C coupled amplifier. The difference is use of an impedance device (i.e. coil) to replace a load resistor R_C. Impedance matching enables max^m power to be delivered from source to to load. Since there is no power loss at inductor, its efficiency is high.

Here the magnetic field of coupling inductor doesn't affect the signal.

4) Direct Coupled Amplifier



It is used for very low freq amplification. For lower freq, coupling capacitor causes significant drop of signal across them resulting in gain reduction. Similarly the reactance of Bypass capacitor becomes compared to emitter resistance which affects bypass action. So, it can't use CE & Cc in lower freq range & need to coupled one stage directly with another.

Operation:

When weak signal is applied to the i/p of first transistor T_1, due to transistor action an amplified o/p is obtained across collector load Rc of T_1. This voltage drives the base of 2nd transistor & amplified o/p is obtained across its collector load. In this way direct coupled amplifier increases the strength of weak signal.

Advantages

i) Simple ckt arrangement.

ii) Low cost.

Disadvantages

i) It can't be used for amplifying high freq.

Choice of Configuration in Cascade

→ The common emitter configuration has high current & voltage gain. Also has moderate I/p & O/p resistance. So, CE is preferred for amplification.

→ The common base configuration also has high voltage gain, but its I/p resistance is very low. So CB configuration can't be used in intermediate stages while cascading.

→ The common collector configuration has less than unity voltage gain. So it is also not used for amplification. It has a very high I/p impedance (resistance). Thus CC is used in intermediate stages while cascading.

Comparision of CE, CB & CC configuration

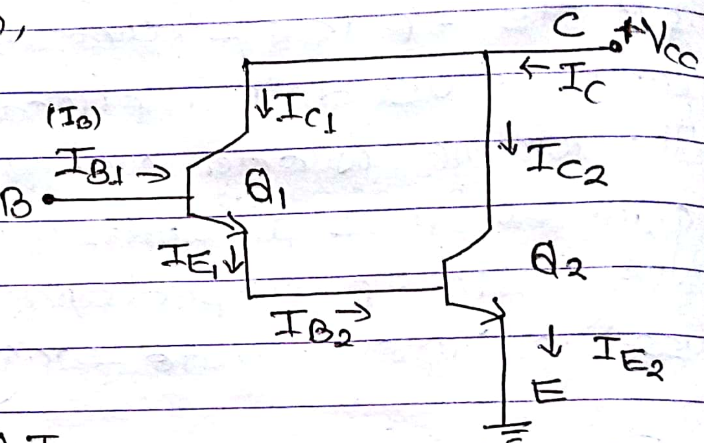
Configuration parameter	CE	CB	CC
current gain	High	Low	High
voltage gain	High	High	Low
I/p impedance	Medium	Low	High
O/p impedance	Medium	High	Low
Application	Audio amplifier	RF amplifier	Impedance matching

Darlington-Pair Amplifier (Super Beta Transistor)

The darlington-pair amplifier is a compound structure containing two transistors connected in such a way that the current amplified by 1st transistor is further amplified by 2nd transistor.

⇒ The darlington-pair amplifier (or super Beta transistor) consisting of two transistor are kept inside a package & 3-terminals are brought out (i.e. E, B & C) as shown in figure. The composite transistor acts as a single unit that has a high current gain β_2 (where as that of emitter follower is β) & high I/P impedance $\beta_2 R_E$ (whereas that of emitter follower is βR_E). It has enormous impedance transformation capability i.e. it can transform a low impedance load to a high impedance load.

From the circuit diagram,



$$I_{C1} = \beta_1 I_{B1}$$

$$I_{E1} = (\beta_1 + 1) I_{B1}$$
$$= I_{B2}$$

And,
$$I_{C2} = \beta_2 I_{B2}$$
$$= \beta_2 \cdot (\beta_1 + 1) I_{B1}$$

Now,
$$I_C = I_{C1} + I_{C2}$$
$$= \beta_1 I_{B1} + \beta_2(\beta_1 + 1) I_{B1}$$
$$= [\beta_1 + \beta_2(\beta_1 + 1)] I_{B1}$$
$$= (\beta_1 + \beta_2 + \beta_1\beta_2) I_{B1}$$

Since,
$$I_{B1} = I_B$$

So,
$$I_C = (\beta_1 + \beta_2 + \beta_1\beta_2) I_B$$

or,
$$\frac{I_C}{I_B} = (\beta_1 + \beta_2 + \beta_1\beta_2)$$

or,
$$\beta_D = \beta_1 + \beta_2 + \beta_1\beta_2$$

where, β_D = Darlington Amplifier Gain

If $\beta_1 = \beta_2 \simeq \beta$
$$\beta_D = \beta + \beta + \beta \cdot \beta = 2\beta + \beta^2$$

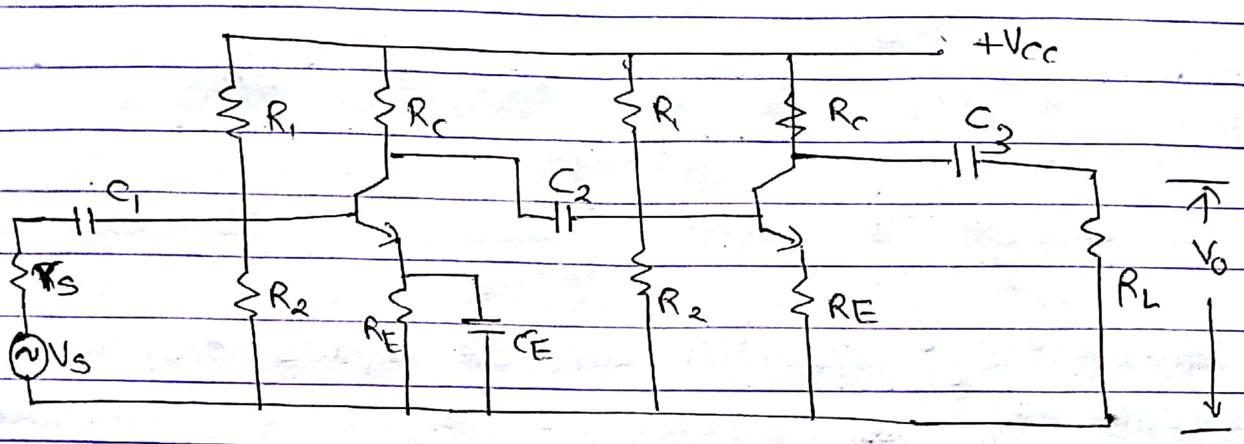
Since $2\beta << \beta^2$, 2β can be neglected

Thus, gain of darlington amplifier is,
$$\beta_D = \beta^2$$ (i.e. gain is very high)

Thus darlington amplifier is called super-beta transistor.

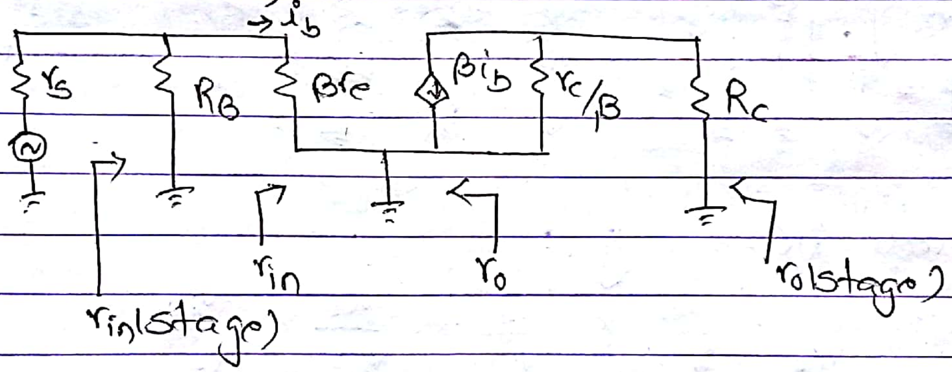
Voltage Gain of 2-stage RC coupled Amplifier

Consider a 2-stage RC coupled amplifier



For 1st stage amplifier,

Its re-model is,



Here, $r_{in} = \beta r_e$

$r_{in}(stage) = R_B // r_{in} = R_B // \beta r_e$

$\therefore r_{i1} = r_{in}(stage) = R_B // r_{in}$

$r_o = r_c/\beta$

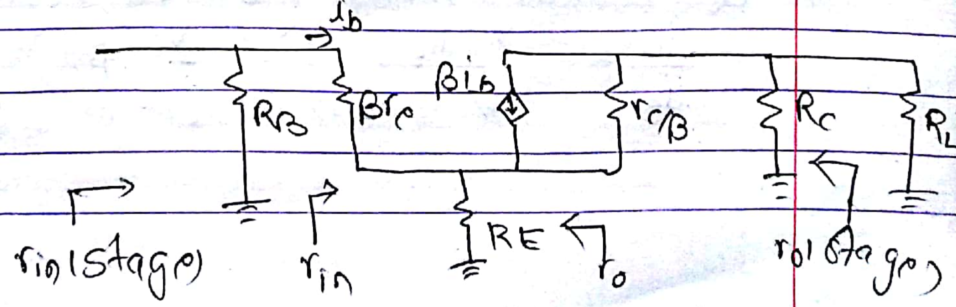
$r_o(stage) = r_o // R_c = (r_c/\beta) // R_c \simeq R_c$

$\therefore r_{o1} = r_o(stage) = R_c$

Voltage gain $(A_{v1}) = -\dfrac{R_c}{r_e}$ $\left(= \dfrac{-i_c R_c}{i_b \cdot \beta r_e} = \dfrac{-\beta i_b R_c}{i_b \beta r_e} = -\dfrac{R_c}{r_e} \right)$

For 2nd stage,

The re-model is,



Here, $r_{in} = \beta(r_e + R_E)$

$r_{in}(stage) = R_B // r_{in}$

$\therefore r_{i2} = r_{in}(stage) = R_B // r_{in}$

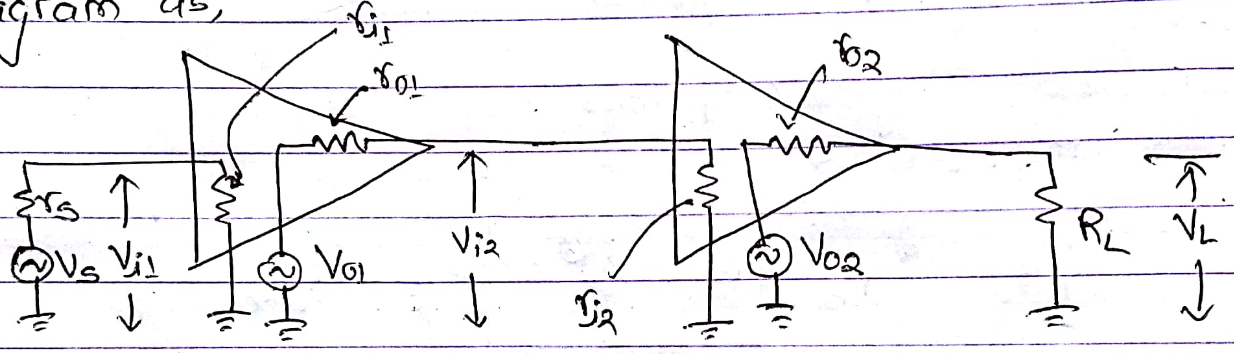
$r_o = r_c/\beta$

$r_o(stage) = R_c // r_o = R_c // (r_c/\beta) \simeq R_C$

$\therefore r_{o2} = r_o(stage) = R_c$

$$\text{Voltage gain } (A_{V2}) = \frac{-R_c}{r_e + R_E}$$

Now, 2-stage amplifier can be represented in block diagram as,



Overall voltage gain,

$$\frac{V_L}{V_s} = \frac{V_L}{V_{o2}} \times \frac{V_{o2}}{V_{i2}} \times \frac{V_{i2}}{V_{o1}} \times \frac{V_{o1}}{V_{i1}} \times \frac{V_{i1}}{V_s}$$

$$= \frac{V_L}{V_{o2}} \times A_{V2} \times \frac{V_{i2}}{V_{o1}} \times A_{V1} \times \frac{V_{i1}}{V_s}$$

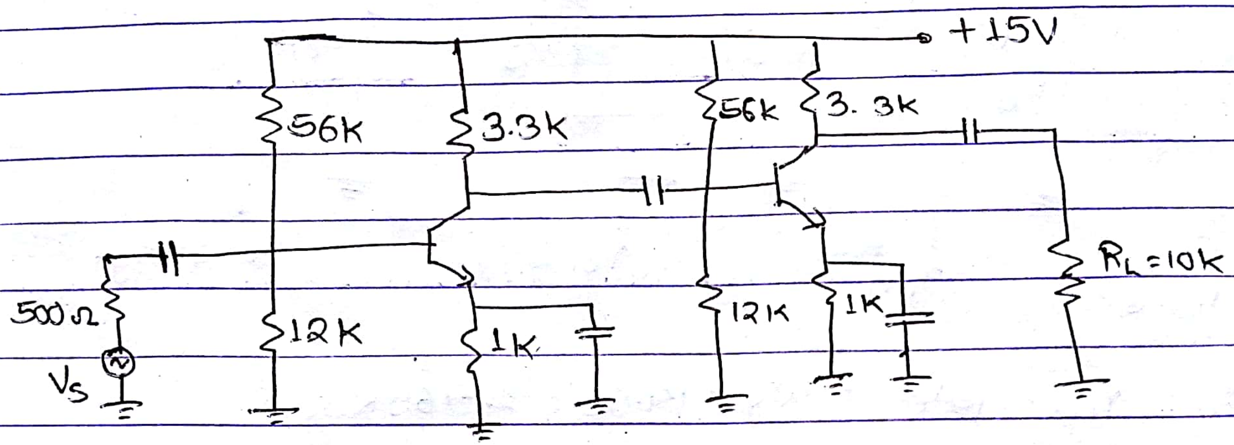
$$= \left(\frac{R_L}{r_{o2} + R_L}\right) \times A_{V2} \times \left(\frac{r_{i2}}{r_{o1} + r_{i2}}\right) \times A_{V1} \times \left(\frac{r_{i1}}{r_s + r_{i1}}\right)$$

$$\therefore \frac{V_L}{V_s} = A_{V1} A_{V2} \left(\frac{r_{i1}}{r_s + r_{i1}}\right)\left(\frac{r_{i2}}{r_{i2} + r_{o1}}\right)\left(\frac{R_L}{r_{o2} + R_L}\right)$$

& overall current gain is,

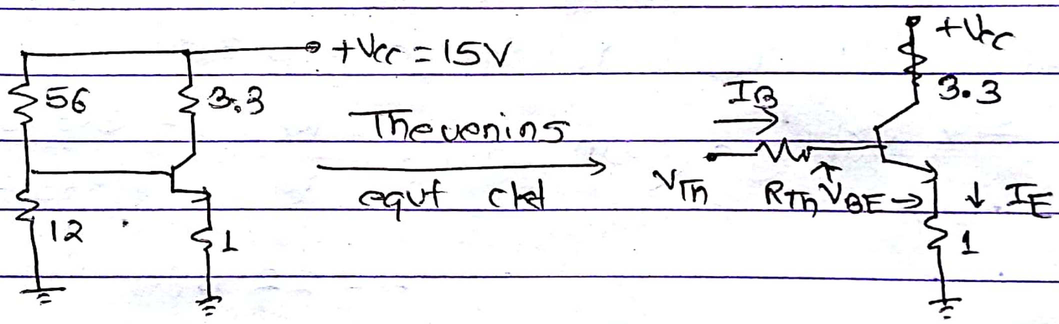
$$\frac{i_L}{i_s} = \frac{V_L / R_L}{V_s / (r_s + r_{i1})} = \frac{V_L}{V_s}\left(\frac{r_s + r_{i1}}{R_L}\right)$$

For given 2-stage RC coupled amplifier shown, find the overall voltage gain. (Assume $\beta_1 = \beta_2 = 100$)



Soln: We have, $r_e = \frac{0.026}{I_E}$

To find I_E, we need to perform dc analysis in stage 1,



Here, $R_{Th} = R_1 // R_2 = 56 // 12 = 9.88K$

$V_{Th} = \frac{R_2}{R_1 + R_2} \times V_{cc} = \frac{12}{12+56} \times 15 = 2.647V$

Applying KVL at i/p loop of Thevenins equt ckt,

$$V_{Th} = I_B R_{Th} + V_{BE} + I_E R_E$$

$$= I_E/\beta \, R_{Th} + V_{BE} + I_E R_E$$

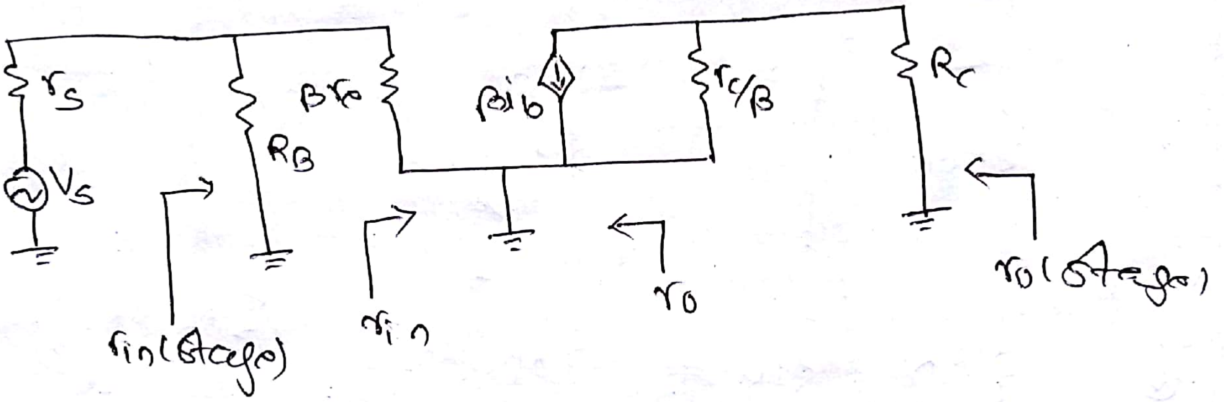
$$\Rightarrow I_E = \frac{V_{Th} - V_{BE}}{R_{Th}/\beta + R_E}$$

$$= \frac{2.647 - 0.7}{[(9.88/100) + 1] \times 10^3} = 1.77 \times 10^{-3}$$

$$= 1.77 mA$$

Thus, $r_e = \dfrac{0.026}{1.77\times10^{-3}} = 14.69\Omega$

Its r_e-model is,



Here, $r_{in} = \beta r_e = 100\times14.69 = 1.469K\Omega$

$r_{in}(stage) = R_B // r_{in} = 9.88 // 1.469 = 1.278k\Omega$

$\therefore r_{i1} = r_{in}(stage) = 1.278K$

& $r_o(stage) = R_c // r_c/\beta \simeq R_c = 3.3k$

$\therefore r_{o1} = r_o(stage) = 3.3K$

So, voltage gain, $A_{v1} = \dfrac{-R_c}{r_e} = \dfrac{-3.3K\Omega}{14.69\Omega}$

$= -224.64$

For stage 2,

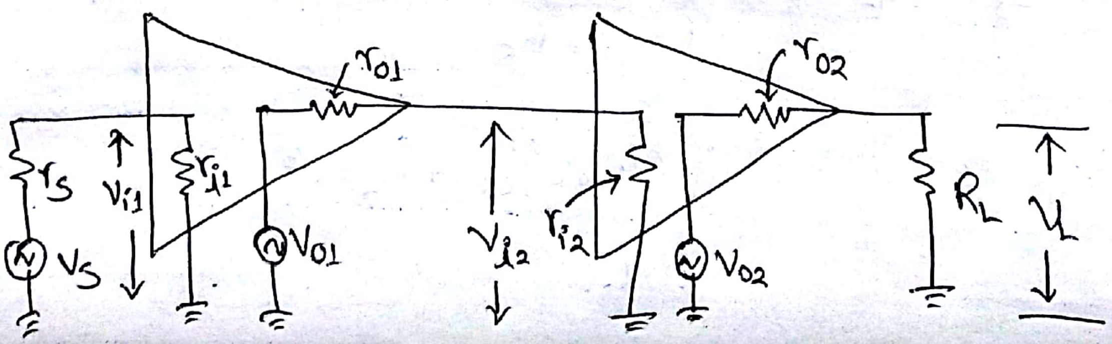
Since stage 1 & stage 2 are identical,

$r_{i2} = r_{i1} = 1.278K$

$r_{o2} = r_{o1} = 3.3K$

$A_{v2} = A_{v1} = -224.64$

Now, the 2-stage amplifier is,



Thus, the overall voltage gain is,

$$\frac{V_L}{V_S} = A_{V1} \cdot A_{V2} \cdot \left(\frac{r_{i1}}{r_S + r_{i1}}\right) \cdot \left(\frac{r_{i2}}{r_{o1} + r_{i2}}\right) \cdot \left(\frac{R_L}{R_L + r_{o2}}\right)$$

$$= 224.64 \times 224.64 \times \frac{1.278}{0.5 + 1.278} \times \frac{1.278}{3.3 + 1.278} \times \frac{10}{10 + 3.3}$$

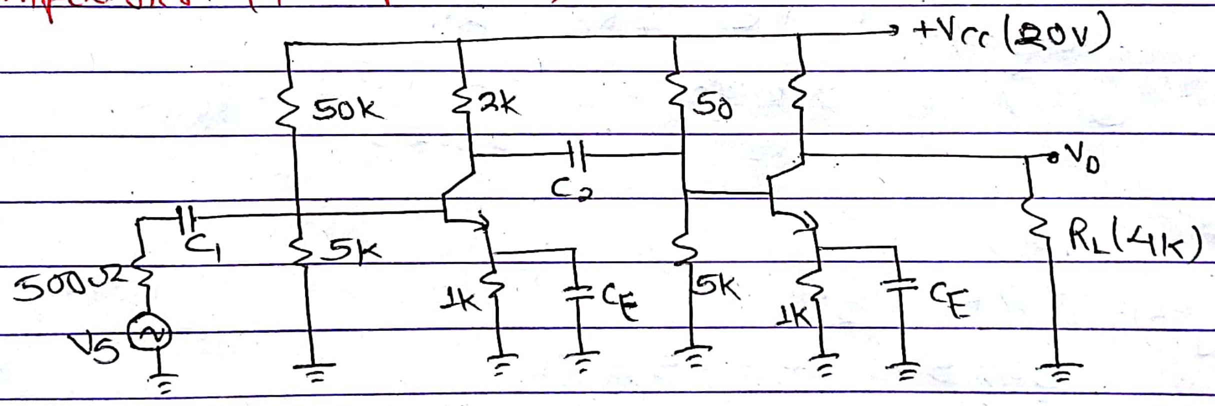
$$= 7613.36$$

& gain in decibles is $= 20\log_{10}(V_L/V_S)$

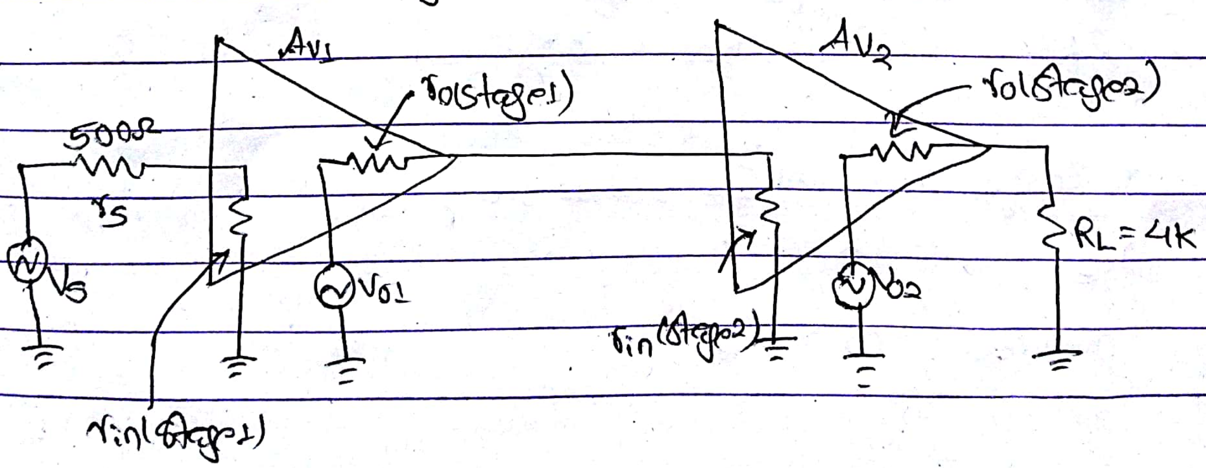
$$= 20\log_{10}(7613.36)$$

$$= 77.63 \text{ dB}.$$

Find overall voltage gain for the 2-stage RC coupled amplifier. ($\beta_1 = \beta_2 = 100$)



Soln: The 2-stage RC coupled amplifier is,



For the first stage,

$r_{in}(\text{Stage }1) = R_1 // R_2 // \beta_1 r_{e_1}$

where $r_{e_1} = \dfrac{0.026}{I_E}$

$$I_E = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E}$$

Here, $V_B = \dfrac{R_2}{R_1 + R_2} \times V_{CC} = \dfrac{5}{5+50} \times 20 = 1.82V$

Then $I_E = \dfrac{1.82 - 0.7}{1 \times 10^3} = 1.118mA$

So, $r_{e_1} = \dfrac{0.026}{1.118 \times 10^{-3}} = 23.25\Omega$

So, $r_{in}(\text{Stage }1) = 50 // (100 \times 23.25) // 5K = 1.53K$

Similarly,

$r_o(\text{Stage }1) = r_{o1} // R_{C1} \approx R_{C1} = 2K$

& $A_{V1} = \dfrac{r_o \text{Stage}_1}{r_{e_1}} = \dfrac{-2 \times 10^3}{23.25} = -86.02$

For 2nd stage,

$r_{in}\text{ Stage}_2 = R_1 // R_2 // \beta_2 r_{e_2}$

$= 50 // 5 // 2.32 = 1.53 K\Omega$

where, $r_{e_1} = r_{e_2} = 23.25\Omega$

$r_i \text{stage}_2 = 50 // 5 // 2.32 = 1.53K$

& $r_o \text{ Stage }2 = r_{o2} // R_{C2} = R_{C2} = 3K\Omega$

&

$A_{V2} = \dfrac{-r_o \text{ Stage}_2}{r_{e_2}} = \dfrac{3 \times 10^3}{23.25} = -129.03$

Now, the overall gain is,

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$$\frac{V_L}{V_S} = A_{V1} \times \frac{r_{in}(\text{Stage }1)}{r_s + r_{in}(\text{Stage }1)} \times A_{V2} * \frac{r_o(\text{Stage }2)}{r_o\,\text{Stage}1 + r_{in}\,\text{Stage}2} \times \left(\frac{R_L}{r_o\text{Stage}2 + R_L}\right)$$

$$= (-86.02) \times \frac{1.53}{0.5+1.53} \times (-129.03) \times \frac{1.53}{2+1.53} \times \frac{4}{(3+4)}$$

$$\therefore \frac{V_L}{V_S} = 2071.91$$

For a given 2-stage RC coupled common emitter transistor amplifier, find overall voltage gain and a current gain.