# Multistage Amplifiers

In many applications, a single amplifier cannot provide all the gains that is required to drive a particular kind of load.

- e.g. a loudspeaker represents a 'heavy' load (low $R_L$) in an audio amplifier system & several amplifier stages may be required to boost a signal originating at a microphone or magnetic tape head to a level sufficient to provide a large amount of power to the speaker.

- When the output of one amplifier stage is connected to the input of another amplifier, the amplifier stages are said to be in cascade.

- overall frequency

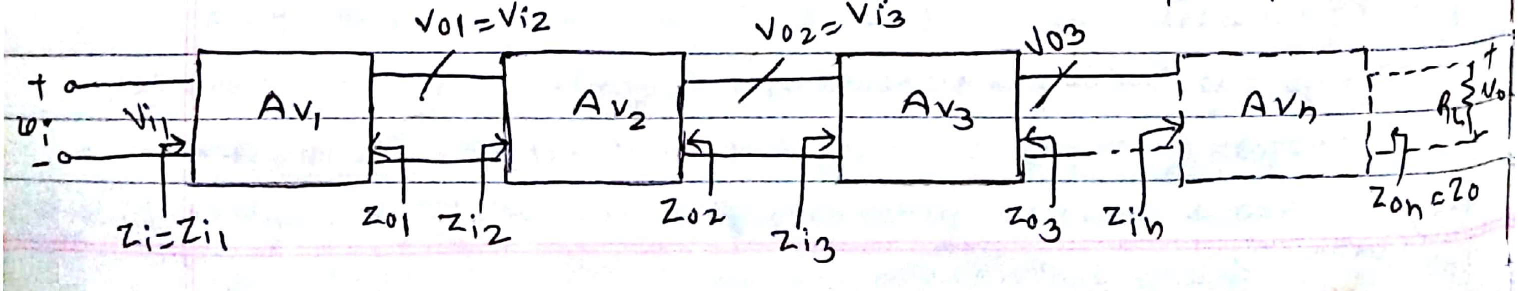
$Z_i$ - overall input impedance of a multistage amplifier = input impedance of the first stage.

$\boxed{\text{Note}}$: i/p stage is normally an FET amplifier or Darlington connected BJT amplifier for high i/p impedance applications.

$Z_o$ - overall output impedance of a multistage amplifier = output impedance of the last stage.

$\boxed{\text{Note}}$: The last stage is normally a common collector power stage or a CE transformer coupled power stage for driving a low resistance load such as a loudspeaker.

$A_{V_T} = A_{V_1} \cdot A_{V_2} \cdot A_{V_3} \cdots$



## Voltage Gain of a multistage Amplifier :-

If there are three stages cascaded,

$$A_v = \frac{v_o}{v_i} = \frac{v_{o3}}{v_{i1}} = \frac{A_{v3} \cdot v_{i3}}{v_{i1}}$$

$$= \frac{A_{v3} \cdot v_{o2}}{v_{i1}} = \frac{A_{v3} \cdot A_{v2} \cdot v_{i2}}{v_{i1}}$$

$$= \frac{A_{v3} \cdot A_{v2} \cdot v_{o1}}{v_{i1}} = \frac{A_{v3} \cdot A_{v2} \cdot A_{v1} \cdot v_{i1}}{v_{i1}}$$

$$A_v = A_{v1} \cdot A_{v2} \cdot A_{v3}$$

$$\therefore \boxed{\frac{v_o}{v_s} = A_{vs} = A_{v1} \cdot A_{v2} \cdot A_{v3} \cdot \left(\frac{Z_i}{Z_i + R_s}\right)}$$

where $A_{v1} = g_{m1}(Z_{o1} \| Z_{i2})$

$A_{v2} = g_{m2}(Z_{o2} \| Z_{i3})$

$A_{v3} = g_{m3}(Z_o \| R_L)$

## * Advantages of cascaded Multistage Amplifiers :-

① control over the input impedance :-

The i/p stage is usually required to provide a high i/p resistance in order to avoid loss of signal level when the amplifier is fed from a high resistance voltage source.

In a differential amplifier, the i/p stage must also provide large common-mode rejection.

② control over the output impedance :-

The main function of the last (ie o/p) stage of an amplifier is to provide a low o/p resistance (if o/p is a vtg signal) in order to avoid loss of gain when a low valued load resistance is connected to the amplifier

Also, the o/p stage should be able to supply the current required by the load in an efficient manner. ie without dissipating an unduly large amount of power in the o/p transistors.

③ Controlling the voltage gain ; $A_v = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots$

The function of the middle (intermediate) stages of an amplifier cascade is to provide the bulk of the voltage gain.

In addition, the middle stages provide such other functions as the conversion of the signal from differential mode to single ended mode & the shifting of the dc level of the signal.

④ Controlling the bandwidth :-

eg CE-CB or CS-CG configuration for wideband frequency applications.

* Types of coupling :-

There are three types of coupling

① RC coupling

② Direct coupling

③ Transformer coupling

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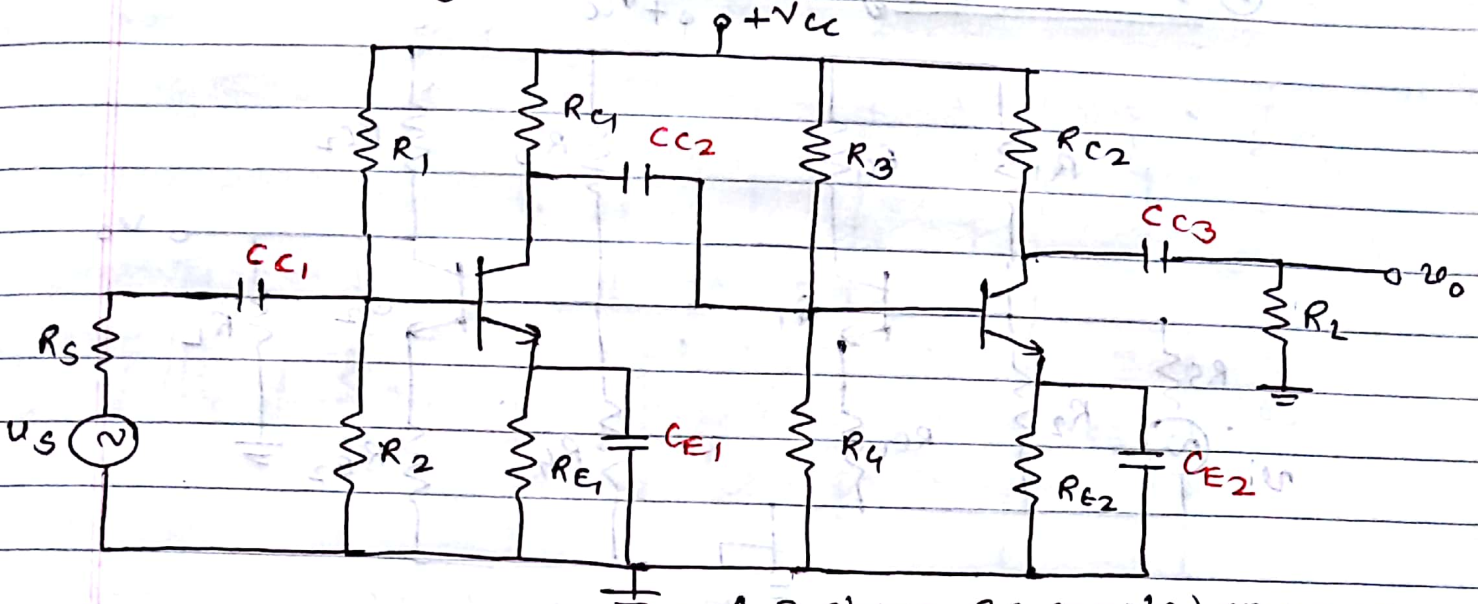
## ① RC coupling :-




A 2 stage RC coupled CE-CE config.

**Advantages**

1) Q point of 1st stage will not affect Q pt of 2nd stage
2) Bandwidth is more

**Disadvantages**

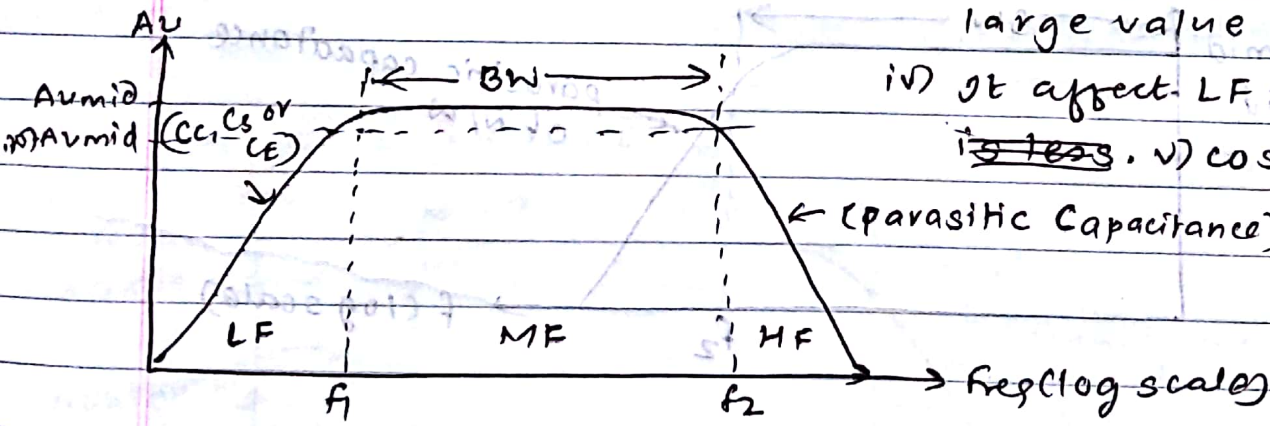
~~1) Q point of 1st stage affects Q pt of 2nd stage~~

i) It have poor impedance matching

ii) It is not used in integrate ckt (∵ it is difficult and uneconomical to fabricate large value capacitors)

iv) It affect LF resp. ~~BW is less~~. v) cost is more.

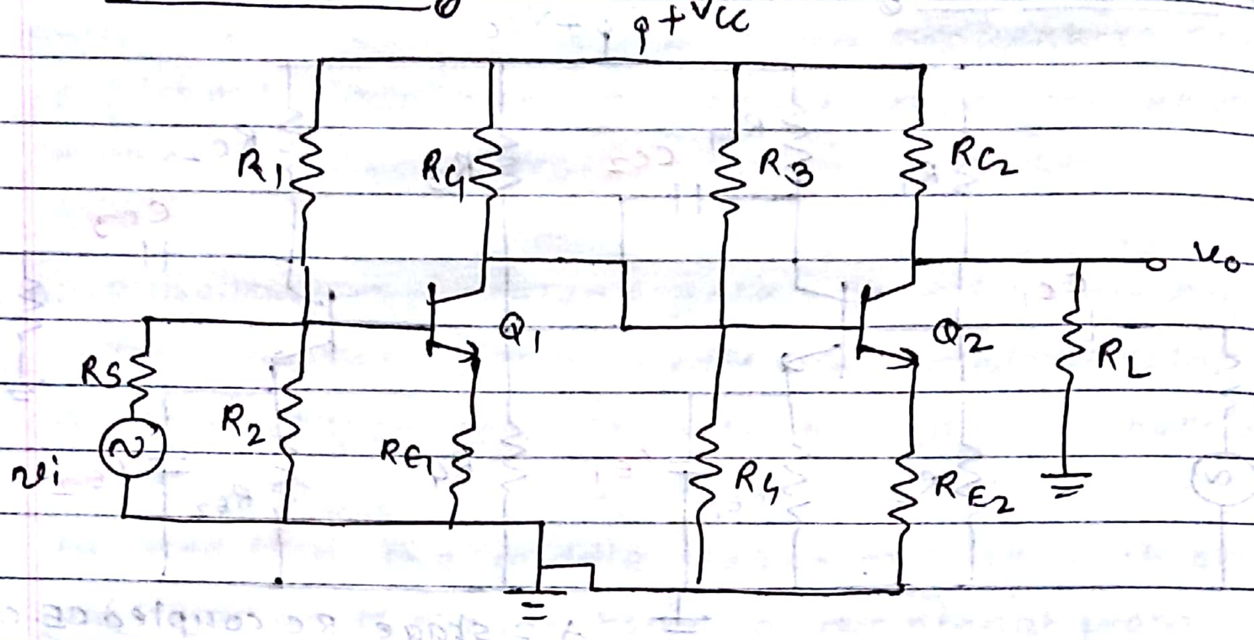
**Frequency Response** :-




**Applications** :-

— used in Audio amplifiers.

## ② Direct coupling :-



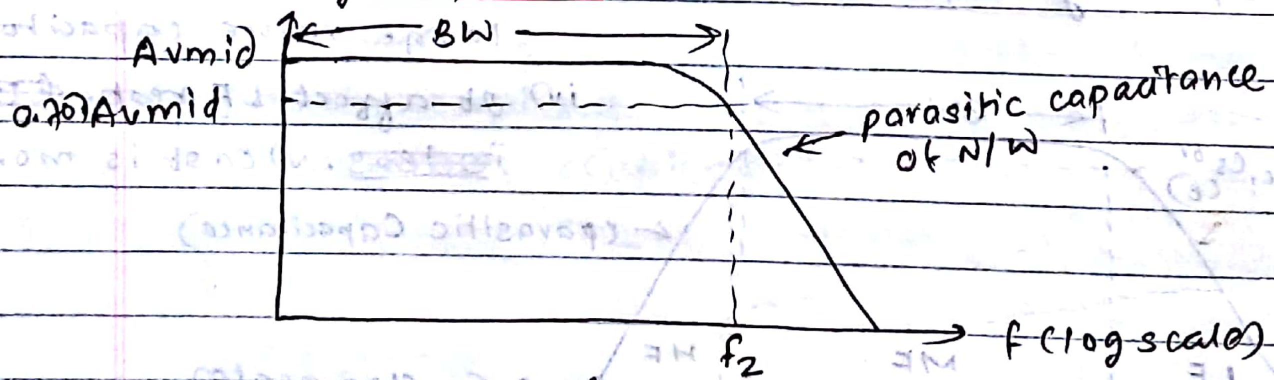

**Advantages**

i) ckt is simple
ii) No. of component required is less
iii) space required is less
iv) cost is less

**Disadvantages**

i) Q point of 1st stage will affect Q pt of next stage (Unstable)
ii) BW is less.

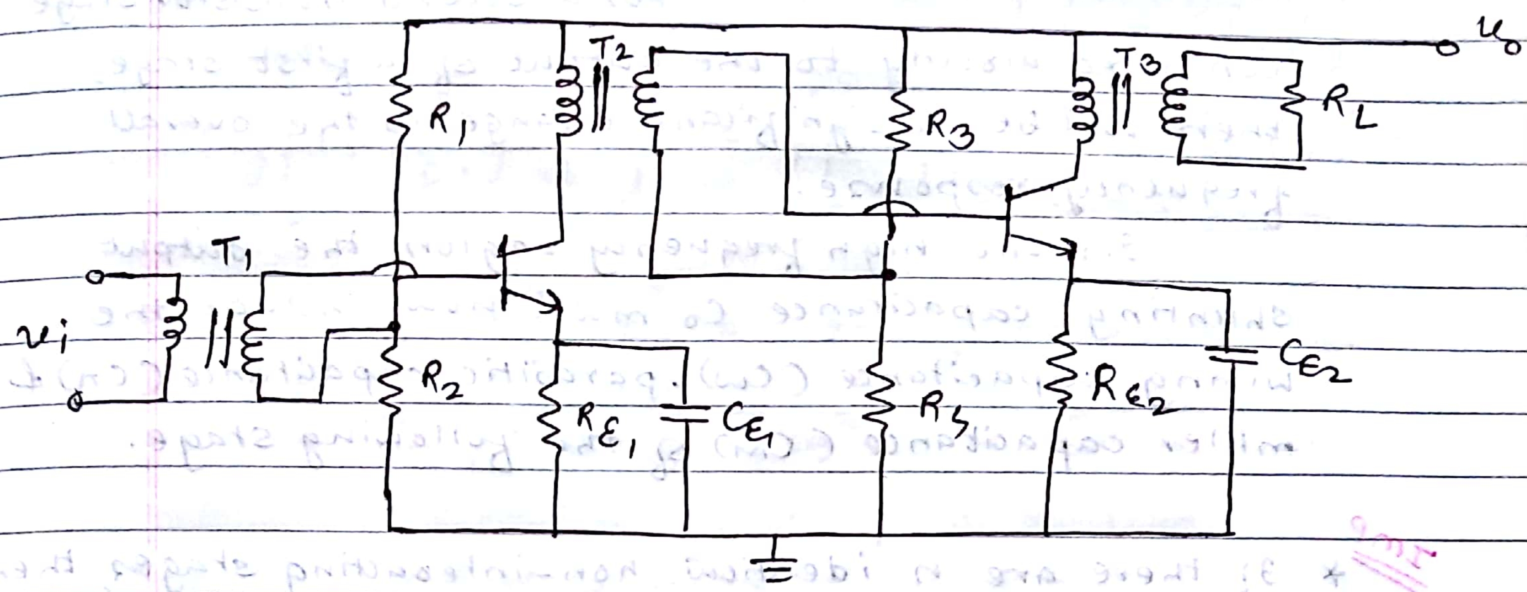
**Frequency Response.**




**Applications** :-

- It is used in integrated ckts (eg op-amp ckts)

## ③ Transformer coupling :-




**Advantages**

i) Electrical isolation is achieved betn the two stages.

ii) Q pt of first stage will not affect the next stage

iii) Impedance matching is achieved with the help of transformer.

**Disadvantages**

i) Transformer size is large

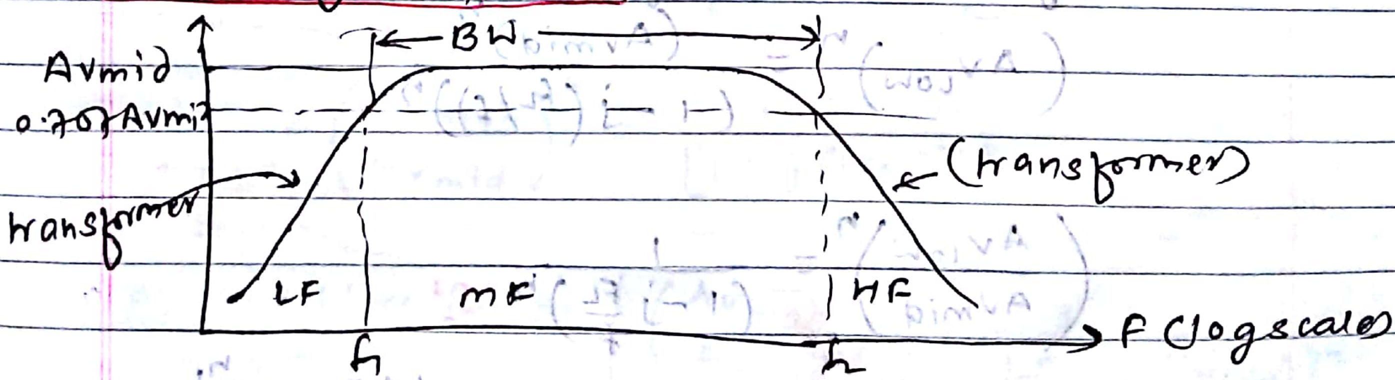
ii) cost is high

iii) space required is more

iv) losses in transformer are more

v) cannot be used in integrated ckt becoz of large size (of x'mer)

**Frequency Response** :-




**Applications** :-

- It is used in power amplifiers.

## * Multistage frequency Effects :-

For a second transistor stage connected directly to the output of a first stage, there will be a significant change in the overall frequency response.

In the high frequency region, the output shunting capacitance $C_o$ must now include the wiring capacitance ($C_w$), parasitic capacitance ($C_\pi$) & miller capacitance ($C_M$) of the following stage.

Imp

* If there are $n$ identical non-interacting stages, then it can be shown that, the overall lower & upper cut off frequencies are :-

$$f_L' = \frac{f_L}{\sqrt{2^{1/n}-1}} \quad \& \quad f_H' = f_H\sqrt{2^{1/n}-1}$$

**Proof**

for $\boxed{\text{LF region,}}$ $A_{V_{Low}} = \dfrac{A_{V_{mid}}}{1-j(f_L/f)}$

$\therefore$ For n-stage ampl$^r$, $A_{V(overall)(low)} = A_{V1(low)} \times A_{V2(low)} \times \ldots$

$\because$ each stage is identical, $A_{V_1(low)} = A_{V_2(low)} = \ldots A_{V_n(low)}$

$\therefore$ overall gain in the LF region,

$$\left(A_{V_{Low}}\right)^n = \frac{(A_{V_{mid}})^n}{(1-j(f_L/f))^n}$$

$$\left(\frac{A_{V_{low}}}{A_{V_{mid}}}\right)^n = \frac{1}{\left(1-j\frac{f_L}{f}\right)^n}$$

At cut off freq, $f = f_L'$ $|(A_{V_{Low}})^n| = \dfrac{|(A_{V_{mid}})^n|}{\sqrt{2}}$

$$\therefore \left|\left(\frac{A_{V\,low}}{A_{V\,mid}}\right)^n\right| = \frac{1}{\sqrt{2}} = \frac{1}{\left[\sqrt{1+\left(\frac{f_L}{f_L'}\right)^2}\right]^n}$$

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

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

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

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

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

$$\therefore \boxed{f_L' = \frac{f_L}{\sqrt{2^{1/n}-1}}}$$

Similarly for $\boxed{\text{HF region}}$

$$A_{V\,High} = \frac{A_{V\,mid}}{1+j(f/f_H)}$$

overall gain in the high frequency region for n-identical stages, $$(A_{V\,High})^n = \frac{(A_{V\,mid})^n}{[1+j(f/f_H)]^n}$$

$$\therefore \left(\frac{A_{V\,High}}{A_{V\,mid}}\right)^n = \frac{1}{[1+j(f/f_H)]^n}$$

At cut off freq $f = f_H'$ $$\left|\left(\frac{A_{V\,high}}{A_{V\,mid}}\right)^n\right| = \frac{1}{|[1+j(f_H'/f_H)]^n|} = \frac{1}{\sqrt{2}}$$

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

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

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

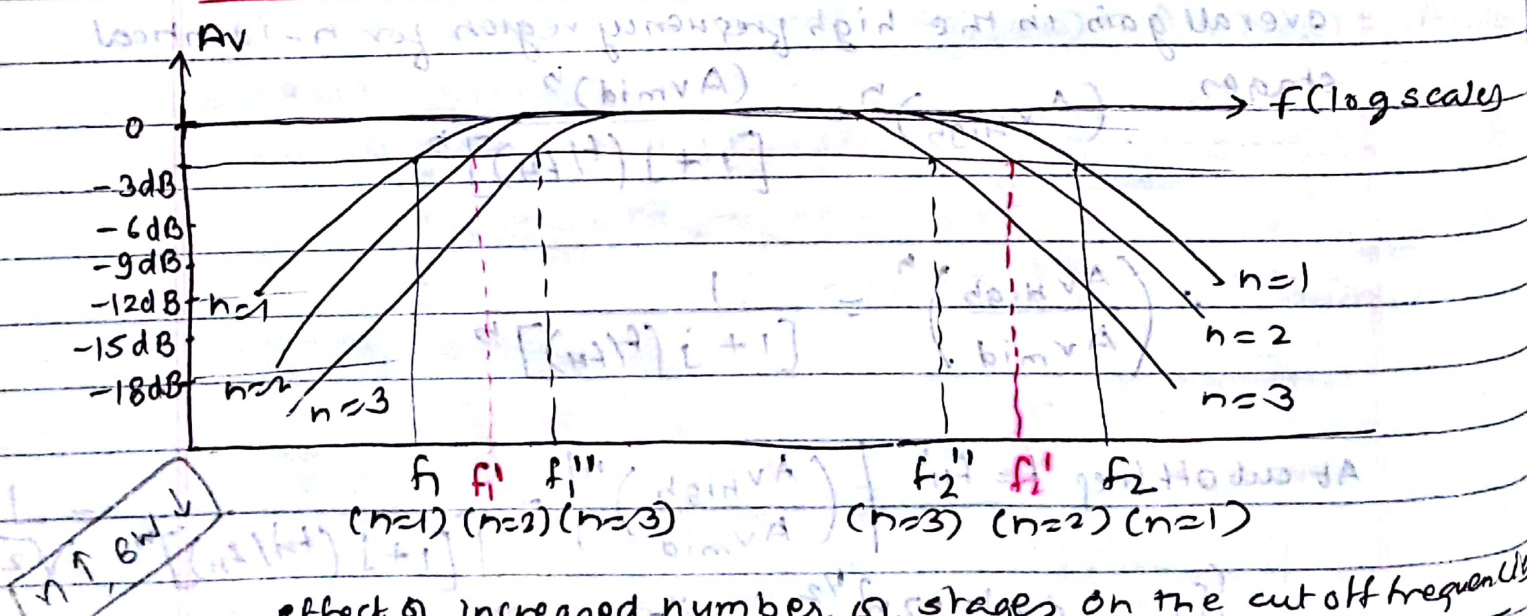
$$\left(\frac{f_H'}{f_H}\right) = \sqrt{2^{1/n} - 1}$$

$$\boxed{f_H' = f_H \sqrt{2^{1/n} - 1}}$$

| $n$ | $\sqrt{2^{1/n}-1}$ | $f_H'$ | $f_L'$ |
|---|---|---|---|
| 1 | 1 | $f_H$ | $f_L$ |
| 2 | 0.64 | $0.64 f_H$ | $1.56 f_L$ |
| 3 | 0.51 | $0.51 f_H$ | $1.96 f_H$ |

For an identical two stage non-interacting amplifier the upper cut off freq becomes 64% for a single stage while the lower cut off freq becomes $1.56 f_L$. for $n=3$, upper cut off freq is approx. 50% of a single stage while $f_L'$ becomes almost twice the single stage value.

## * frequency Response of cascaded/multistage amplifiers :-




effect of increased number of stages on the cut off frequencies & BW