iii) **High frequency Response:** – At high frequency that is above the mid-band frequency range (where the normalized gain is $A_{vm} = 1$), the amplifier behaves like a "simple low-pass" filter. Let us consider a Low-pass filter consisting of Resistance and capacitor as shown in fig-3.

Here,

$$V_i = I\left(R + \frac{1}{j\omega C}\right).$$

$$V_o = (1/j\omega C)\, I$$

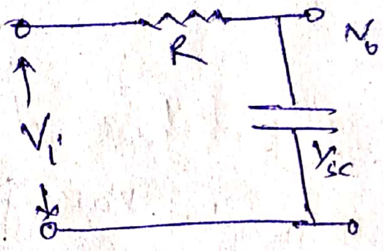

Fig-3

$$\therefore \frac{V_o}{V_i} = A_{v_h} = \frac{\cancel{I}(1/j\omega C)}{\cancel{I}\left(R + \frac{1}{j\omega C}\right)}$$

$$\text{or } A_{v_h} = \frac{1}{1 + jR\omega C} = \frac{1}{1 + j2\pi f RC} = \frac{1}{1 + j\cdot \frac{f}{\left(\frac{1}{2\pi RC}\right)}}$$

Here $f_H = \frac{1}{2\pi RC}$

Note:- A low-pass filter does not have zero at origin.

$$\Rightarrow \boxed{A_{v_h} = \frac{1}{1 + \frac{jf}{f_H}}}$$

$$\therefore |A_{v_h}| = \frac{1}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}}, \quad \angle A_{v_h} = \theta_h = \angle 0 - \tan^{-1}\left(\frac{f}{f_H}\right)$$

$$\theta_h = -\tan^{-1}\left(f/f_H\right).$$

Now, gain in dB —

$$|A_{v_h}| = 20 \log \left[1 + \left(\frac{f}{f_H}\right)^2\right]^{-1/2} = -10 \log \left[\left(\frac{f}{f_H}\right)^2 + 1\right]$$

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Since for high frequency band, $f >> f_H$

$$\Rightarrow \frac{f}{f_H} >> 1 \Rightarrow \left(\frac{f}{f_H}\right)^2 >> 1$$

$$\therefore |A_{v_h}|_{dB} = -10\log\left[1+\left(\frac{f}{f_H}\right)^2\right] \simeq -10\log\left(\frac{f}{f_H}\right)^2$$

$$\text{or } |A_{v_h}|_{dB} = -20\log\left(\frac{f}{f_H}\right)$$

Now, when $f = 100 f_H$, $|A_{v_h}|_{dB} = -20\log 10^2 = -40$ dB

" $f = 20 f_H$, $|A_{v_h}|_{dB} = -20\log\left(\frac{20 f_H}{f_H}\right) = -20\log 20 = -26$ dB

" $f = 10 f_H$, $|A_{v_h}|_{dB} = -20\log\left(\frac{10 f_H}{f_H}\right) = -20$ dB.

When, $f = f_H$ then, it is clear from

$$|A_{v_h}| = \frac{1}{\sqrt{1+\left(f/f_H\right)^2}}, \text{ that } |A_{v_h}| = \frac{1}{\sqrt{2}}$$

$\therefore$ At, $f = f_H$, $|A_{v_h}|_{dB} = -20\log\sqrt{2} = -10\log 2 = -3$ dB

When, $f << f_H$ i.e in mid-band range $\frac{f}{f_H} << 1$

which causes to $\left(\frac{f}{f_H}\right)^2 << 1$

$$\therefore |A_{v_h}| = \frac{1}{\sqrt{1+\left(f/f_H\right)}} \longrightarrow 1 \Rightarrow |A_{v_h}| \rightarrow 1$$

$\therefore$ At, $f << f_H$, $|A_{v_h}|_{dB} = 20\log 1 = 0$ dB.

When, frequency is taken along x-axis and gain is taken along y-axis then we get a plot as shown in fig-4

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(4)

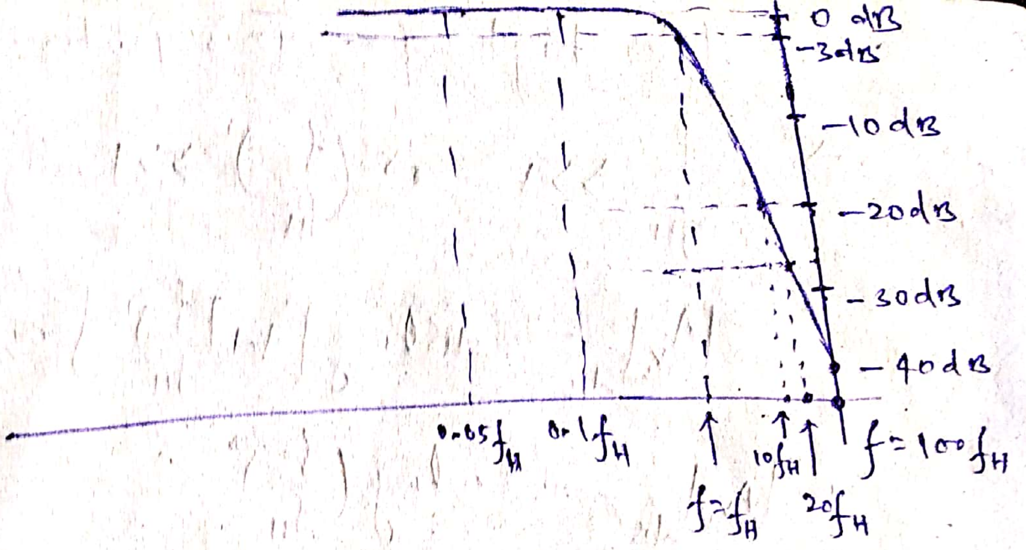
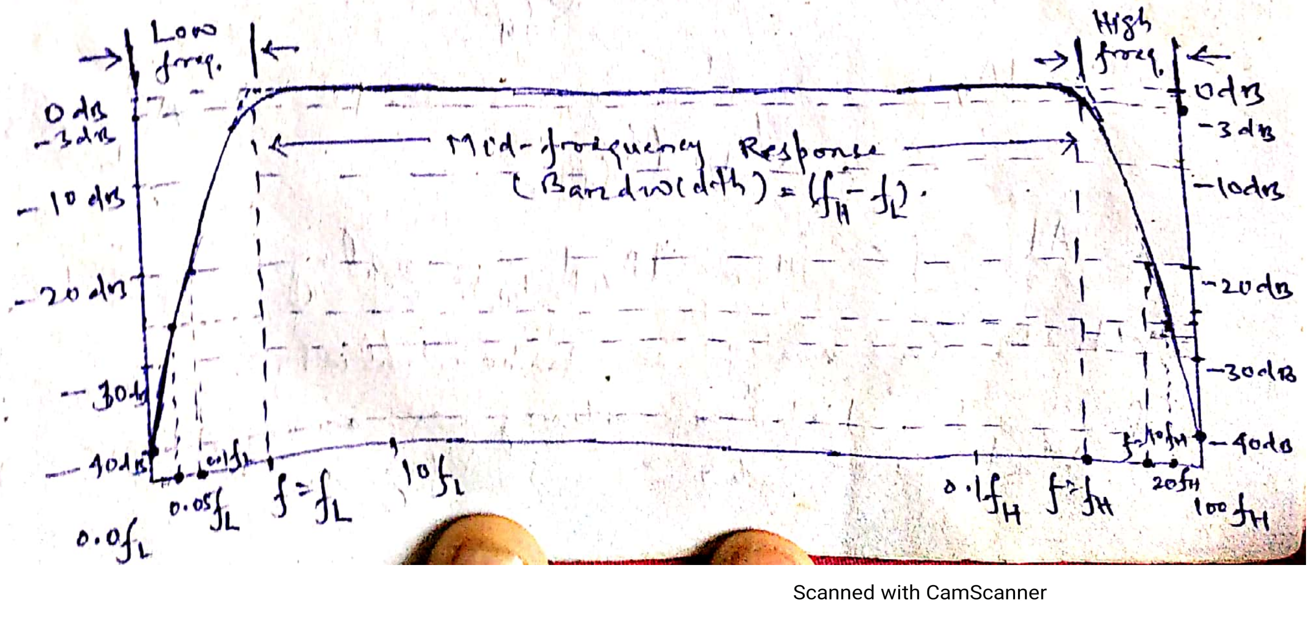


Fig-4

Here from curve or plot it is clear that the f_H (Higher cut-off frequency) is the frequency at which the gain of amplifier has fallen to $\frac{1}{\sqrt{2}}$ times of mid-band gain or −3dB gain. Hence here f_H is called −3dB upper cut-off frequency. It is also obvious from fig-4 that the gain in high frequency region is not uniform but decreases linearly and uniform only in mid-band range. Gain in mid-band range is 0dB. When we combine fig-2 & 4, then we obtain a plot as shown below —



1

MULTI-STAGE Amplifier

When amplified output signal of single stage amplifier is not sufficient to meet the requirement, then we apply this output to the next amplifier stage as input and so-on to the 3rd stage and again so-on, using a number of amplifiers, then this is called multi-stage amplifier.

The output of one-stage amplifier is fed or supply to the next stage through a circuit which is known as **coupling device**. The block diagram of shown in fig-1, represents a ~~multi~~ block diagram of multi-stage amplifier using two-stage amplifier.

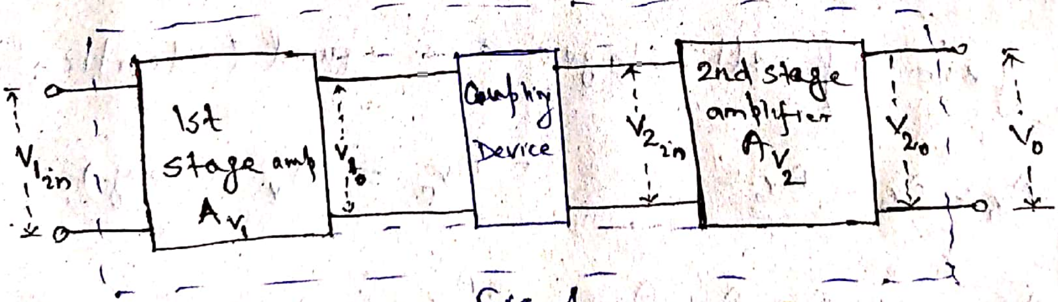


Fig-1.

Here $A_{V_{overall}} = \frac{V_o}{V_{1in}}$ $\Rightarrow A_V = \frac{V_o}{V_{2in}} \times \frac{V_{2in}}{V_{1in}}$

or, $A_{V_{overall}} = \underbrace{\frac{V_o}{V_{2in}}}_{A_{V_1}} \times \underbrace{\frac{V_{1o}}{V_{1in}}}_{A_{V_2}}$ $\Rightarrow \boxed{A_{V_{overall}} = A_{V_1} \cdot A_{V_2}}$

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(2) Thus, if n- number of single stages with gain $A_{v_1}, A_{v_2}, A_{v_3} \ldots A_{v_n}$ are used for multi-stage amplifier, then overall gain is given by —

$$\boxed{A_{v_{overall}} = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots\cdots A_{v_n}}$$

Gain in dB : (Taking "20 log" on both sides)

$$20 \log A_{v_{overall}} = 20 \log (A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdots, A_{v_n})$$

or $(A_{v_{overall}})_{dB} = 20 \log A_{v_1} + 20 \log A_{v_2} + 20 \log A_{v_3} + \cdots + 20 \log A_{v_n}$

$$\Rightarrow \boxed{(A_{v_{overall}})_{dB} = (A_{v_1})_{dB} + (A_{v_2})_{dB} + (A_{v_3})_{dB} + \cdots + (A_{v_n})_{dB}}$$

If gain of all stages are equal (identical), then,

$$A_{v_1} = A_{v_2} = A_{v_3} = \cdots\cdots = A_{v_n} = A_v \text{ (say)},$$

$$\therefore A_{v_{overall}} = A_v \cdot A_v \cdot A_v \cdots\cdots A_v$$

or $\boxed{A_{v_{overall}} = (A_v)^n}$

$$\boxed{(A_{v_{overall}})_{dB} = 20\, n \log A_v}$$

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(3) Note:- (i) Overall gain in Low-freq. range —

$$A_{V_{low(overall)}} = (A_{v_L})^n \; ; \; A_{v_L} = \frac{A_{V_m}}{1 - \frac{jf_L}{f}} \; ; \; f_L = \text{3-dB low-cut-off freq.}$$

(ii) Overall gain in mid-freq. range —

$$A_{V_{mid(overall)}} = (A_{V_m})^n$$

(iii) Overall gain in high-freq. range —

$$A_{V_{high(overall)}} = (A_h)^n$$

$$A_{V_h} = \frac{A_{V_m}}{1 + \frac{jf}{f_H}} \; ; \; f_H = \text{3-dB high-cut-off frequency.}$$

Effect on gain and Band-width

Effect on gain :- The over-all gain of multi-stage amplifier increases as it is clear from above discussion.

Effect on Band-width :- Band-width decreases. It can be under-stand in better way by following analysis:-

since,

$$A_{V_{low(overall)}} = (A_{v_L})^n \quad \text{and,} \quad A_{v_L} = \frac{A_{V_m}}{\left(1 - \frac{jf_L}{f}\right)}$$

$$\therefore A_{V_{low(overall)}} = \left[\frac{A_{V_m}}{1 - \frac{jf_L}{f}}\right]^n$$

(4)

or, $$A_{V_{l(overall)}} = \frac{(A_{V_m})^n}{\left(1 - \frac{jf_L}{f}\right)^n} = \frac{A_{V_{mid(overall)}}}{\left(1 - \frac{jf_L}{f}\right)^n}$$

or, $$\frac{A_{V_{l(overall)}}}{A_{V_{mid(overall)}}} = \frac{1}{\left(1 - \frac{jf_L}{f}\right)^n}$$

or, $$\left|\frac{A_{V_{l(overall)}}}{A_{V_{mid(overall)}}}\right| = \left|\frac{1}{\left(1 - \frac{jf_L}{f}\right)^n}\right|$$; (Modulus on both sides)

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

For new 3-dB lower cut-off frequency, $f = f_L'$

$$\left|\frac{A_{V_{l(overall)}}}{A_{V_{mid(overall)}}}\right| = \frac{1}{\sqrt{2}}$$

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

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

squaring on both sides —

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

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

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(5) Thus, $f_L' > f_L$; $\because \frac{1}{\sqrt{2^{1/n}-1}} > 1$

i.e, now new lower cut-off frequency increases.

Similarly,

For high frequency 3-dB cut-off freq.

$$\because A_{V_{h(overall)}} = \left[\frac{A_{mid}}{1+\frac{jf}{f_H}}\right]^n \quad \text{or,} \quad \left|\frac{A_{V_{h(overall)}}}{A_{mid(overall)}}\right| = \left|\frac{1}{1+\frac{jf}{f_H}}\right|^n$$

For, new 3-dB upper cut-off freq, $f = f_H'$;

$$\left|\frac{A_{V_{h(overall)}}}{A_{mid(overall)}}\right| = \frac{1}{\sqrt{2}}$$

$$\therefore \left[\frac{1}{\sqrt{1+\left(\frac{f_H'}{f_H}\right)^2}}\right]^n = \frac{1}{\sqrt{2}} \quad \text{or,} \quad \left[1+\left(\frac{f_H'}{f_H}\right)^2\right]^n = 2$$

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

Clearly,

$$f_H' < f_H$$

i.e, new upper 3-dB cut-off frequency decreases.

$$\therefore (BW)_{overall} = f_H' - f_L' = \left[f_H\sqrt{2^{1/n}-1} - \frac{f_L}{\sqrt{2^{1/n}-1}}\right]$$

Thus, we can say that Bandwidth shrinking or decreases. But, Band~~ga~~ width - gain product remain constant.

(6)

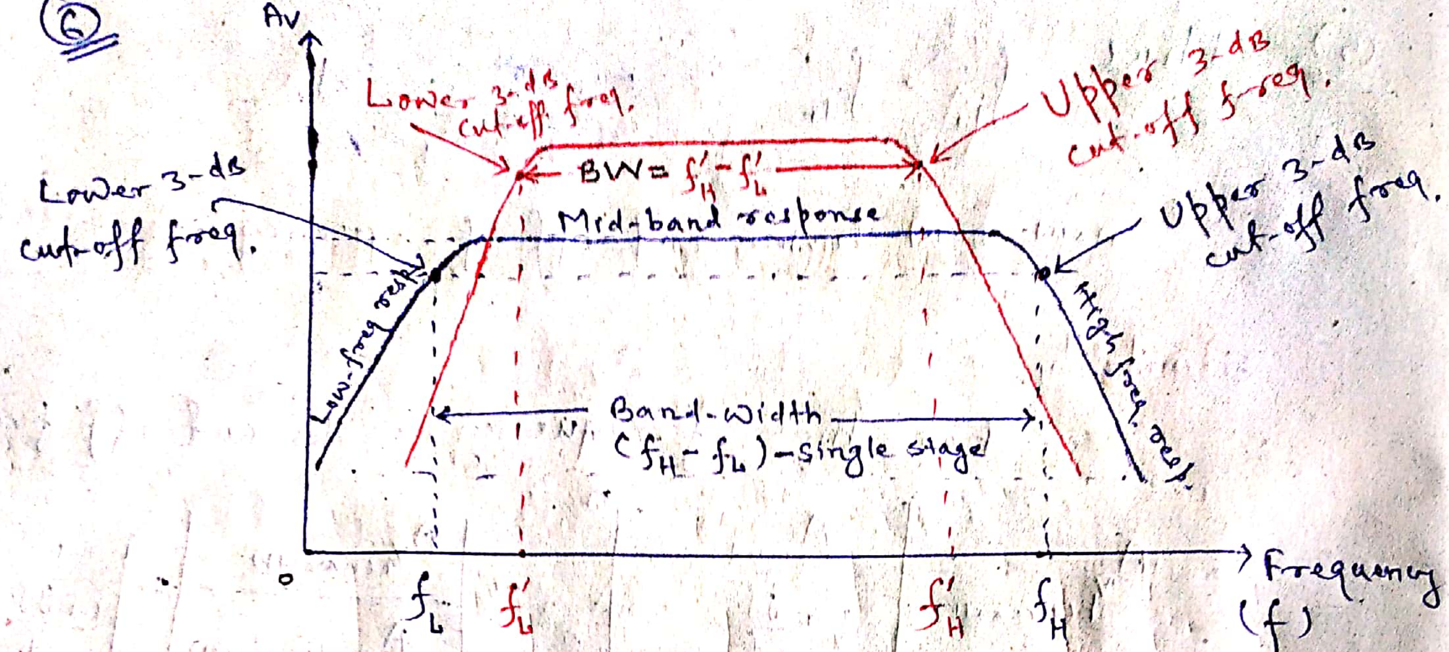

Fig-2.

Fig. 2 shows frequency response curve of multi-stage amplifier.

Coupling Devices.

The process by which output of one stage amplifier is supplied to the next stage amplifier, is called coupling and ckt used for this purpose is called coupling circuit or device.

Purposes of coupling device

i) To transfer a.c output ~~of~~ from one stage to the next stage

ii) To block the d.c component to pass from one stage to next stage causes to disturb the biasing of next stage.

7. There are following types of coupling commonly used ———

i> RC coupling

ii> Transformer coupling

iii> L.C or Impedance coupling

iv> Direct coupling

1> RC Coupling :- The coupling in which coupling circuit orientation consist of capacitor and resistance, is called RC coupling. Fig. 3 shows RC coupling where output of of 1st-stage is supplied to 2nd stage

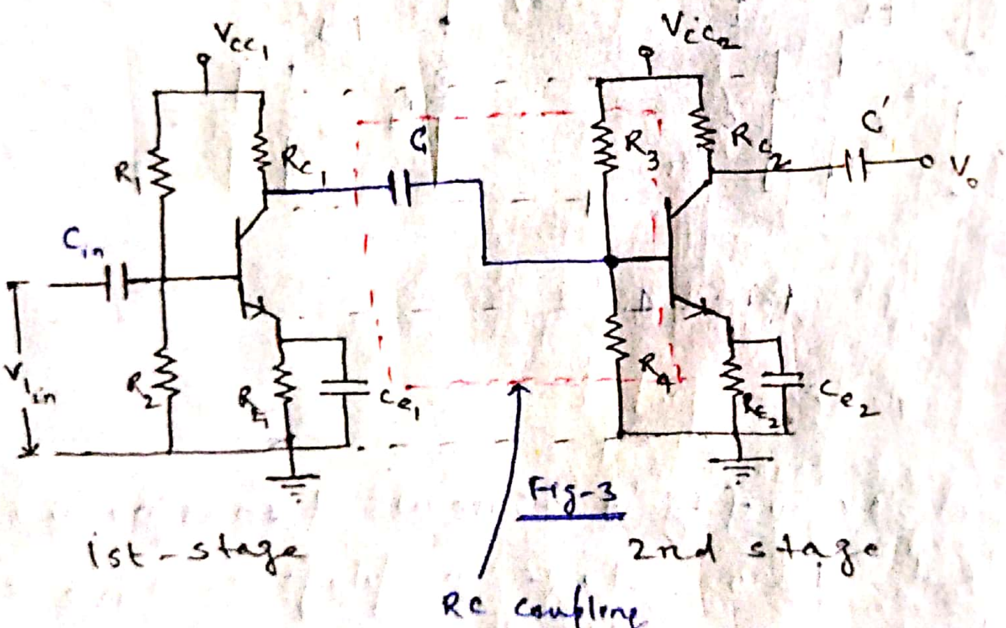

Fig-3

by $(R_3 || R_4) \cdot C = RC$

Advantages

i> Simple network, less space and weight.

ii> Cost effitive

iii> Minimum possible non-linear distortion

iv> Used for Audio frequency. ← Application

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~~Thus if n number of sta~~

Dis-advantages of RC coupling

(i) Not good for impedance matching
(ii) Noise is high

2> Transformer coupling :-

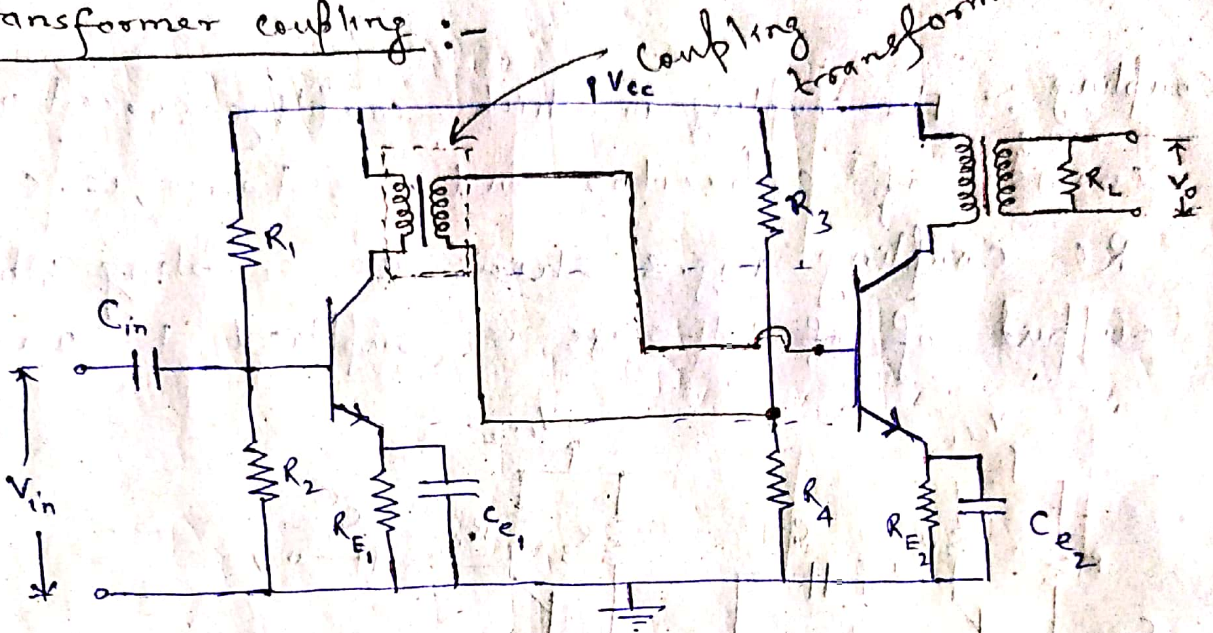

Fig - 4.

Above fig-4 shows transformer coupled two-stage amplifier. The coupling in which the output of one stage is taken across primary coil of a transformer rather than resistor, and secondary of transformer is connected to the next stage as shown in fig-4, is called transformer coupling.

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(9) Advantages of transformer coupling

i> Excellent impedance matching
ii> High gain (voltage gain)
iii> No loss of signal (d.c power) (No power loss in collector and base).
Application → iv> Used in power amplifier.

Disadvantages

i> Bulky
ii> Costly and require more space
iii> Frequency distortion goes to high
iv> Poor frequency response
v> Transformer tends to produce humming noise.

3> Direct coupling :- The method of coupling in which no any component is used to couple signal from one-stage to the next stage, (as shown in fig-5) but directly, is called Direct coupling.

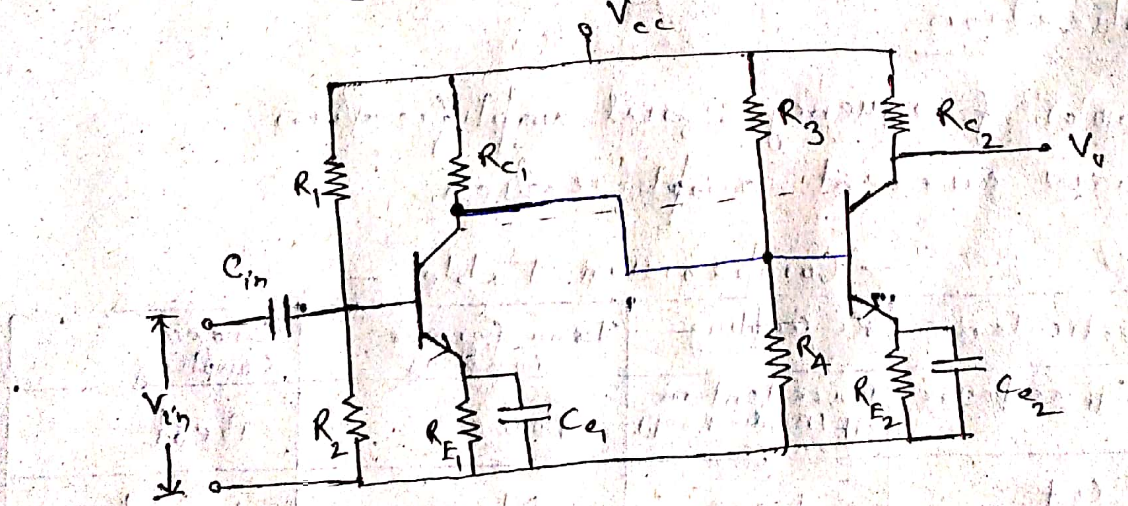

Fig-5

Advantages of Direct coupling

i> Simple circuit
ii> Cost effective
iii> Good freq. response in low-freq. applicatⁿ
iv> Ability to amplify d.c and low-freq. signal.
v> Good impedance matching.

Note:-(i) Darlington-pair, Cascode connection are example of direct coupling.

Dis-advantages

i> Direct coupling can not be used for high frequency amplification.
ii> Operating point is shifted due to temperature variation. i.e, Poor Q-point stability.
iii> Efficiency is very less because both stages are connected directly which causes the d.c power loss.

Application

i> Low-frequency signal amplification
ii> Low current amplification.

— Comparision Table —

Particulars	RC coupling	Transformer coupling	Direct coupling
freq. response	Excellent in AF (Audio Freq.) range	Poor	Best
Cost	Less	More	Least
space and weight	Less	More	Least
Impedance matching	Not good	Excellent	Good
Application	For voltage amplificatⁿ (AF)	For power amplification	For amplifying extremely Low-Frequency