MULTISTAGE AMPLIFIERS

Introduction

- Many applications cannot be handled with single-transistor amplifiers in order to meet the specification of a given amplification factor, input resistance and output resistance

- As a solution – transistor amplifier circuits can be connected in series or cascaded amplifiers

- This can be done either to increase the overall small-signal voltage gain or provide an overall voltage gain greater than 1 with a very low output resistance

Multistage Amplifiers

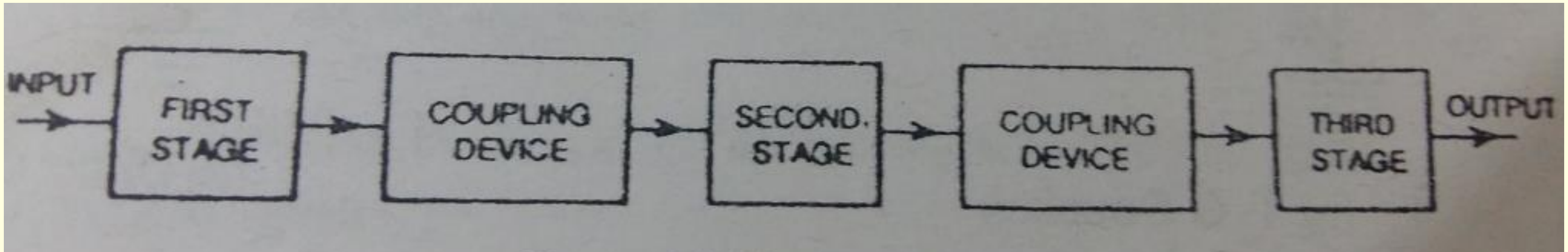
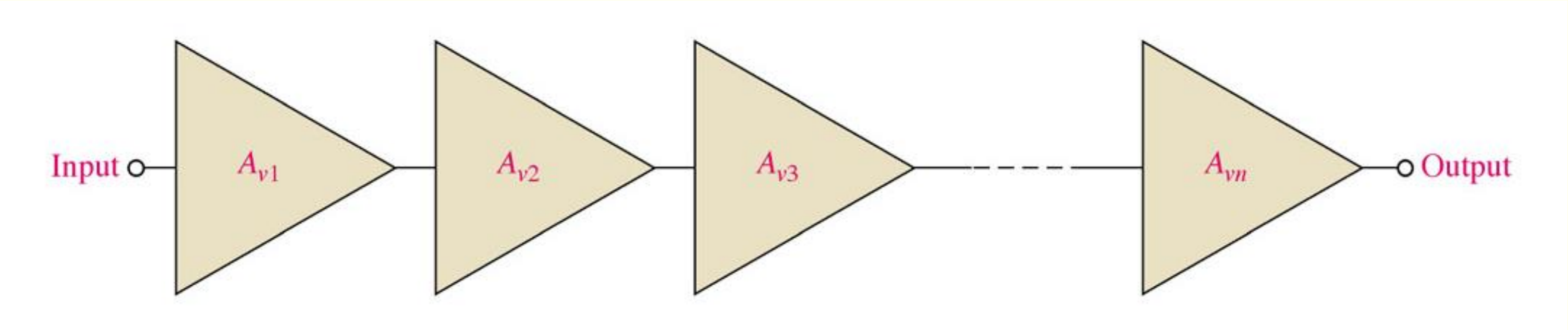


Fig. 1. Multistage Amplifier.

Multi-stage amplifiers are amplifier circuits cascaded to increase gain. We can express gain in decibels(dB).

Two or more amplifiers can be connected to increase the gain of an ac signal. The overall gain can be calculated by simply multiplying each gain together.

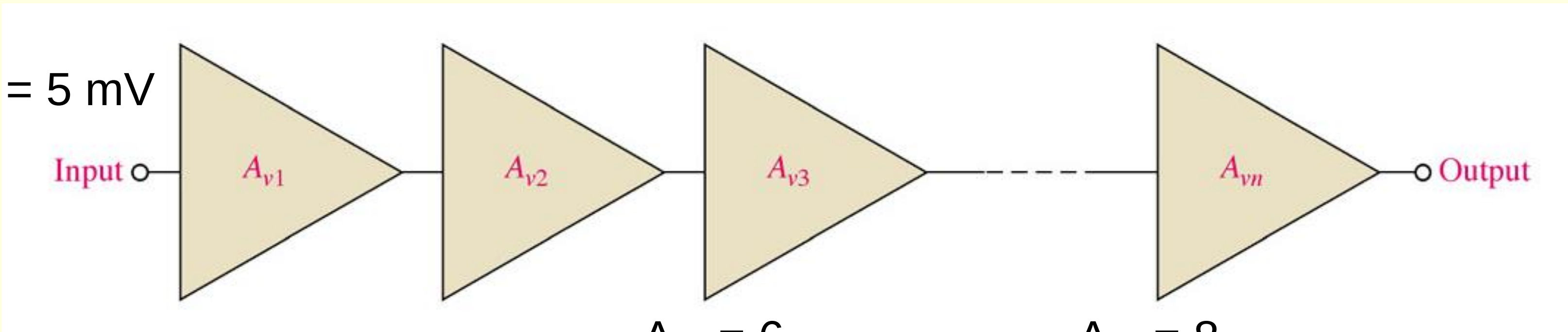
$$A'_v = A_{v1}A_{v2}A_{v3}\ldots\ldots$$



Example

Find V_{out}

V_{in} = 5 mV



A_{v1} = 5 A_{v2} = 10 A_{v3} = 6 A_{vn} = 8

Coupling

The object of coupling

1. to transfer a.c. output of one stage to the next stage

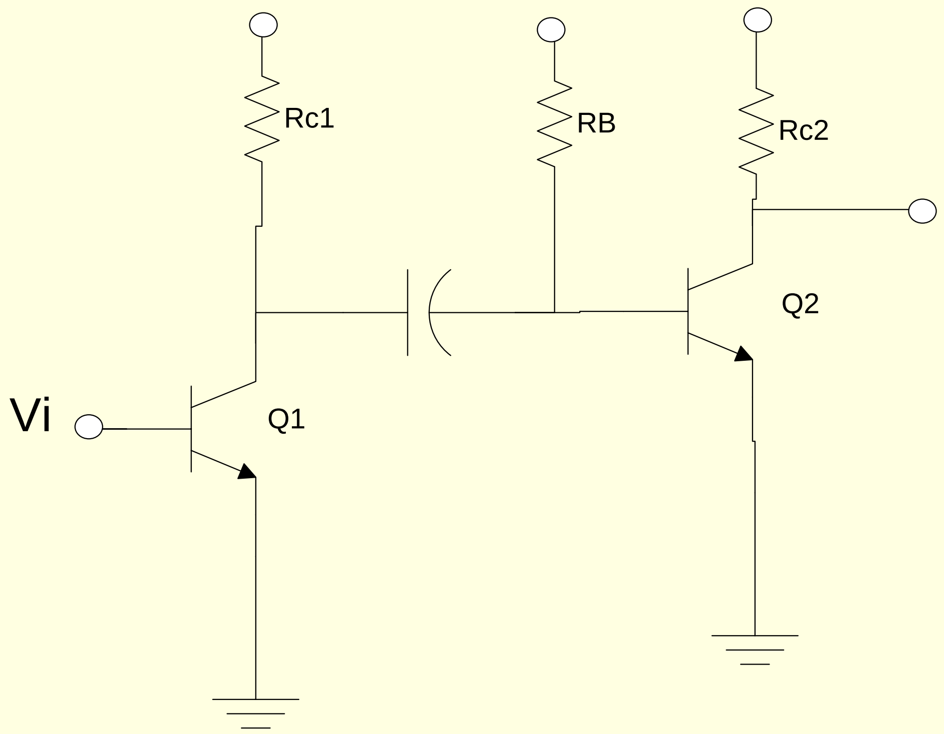
2. to isolate the d.c. conditions of one stage to the next stage

Types of coupling

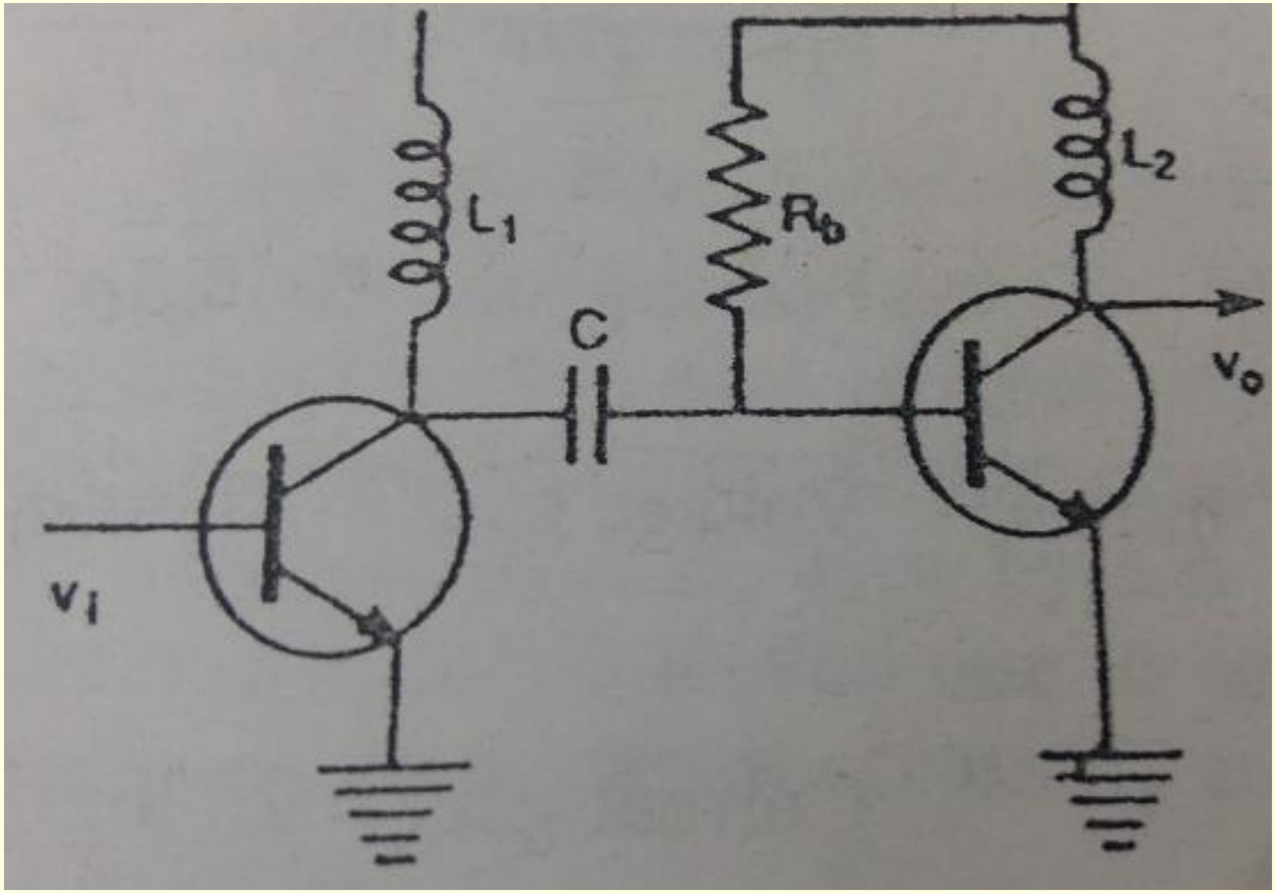
Four basic methods of coupling:

1. Resistance-capacitance coupling
2. Impedance coupling or Inductive coupling
3. Transformer coupling
4. Direct coupling

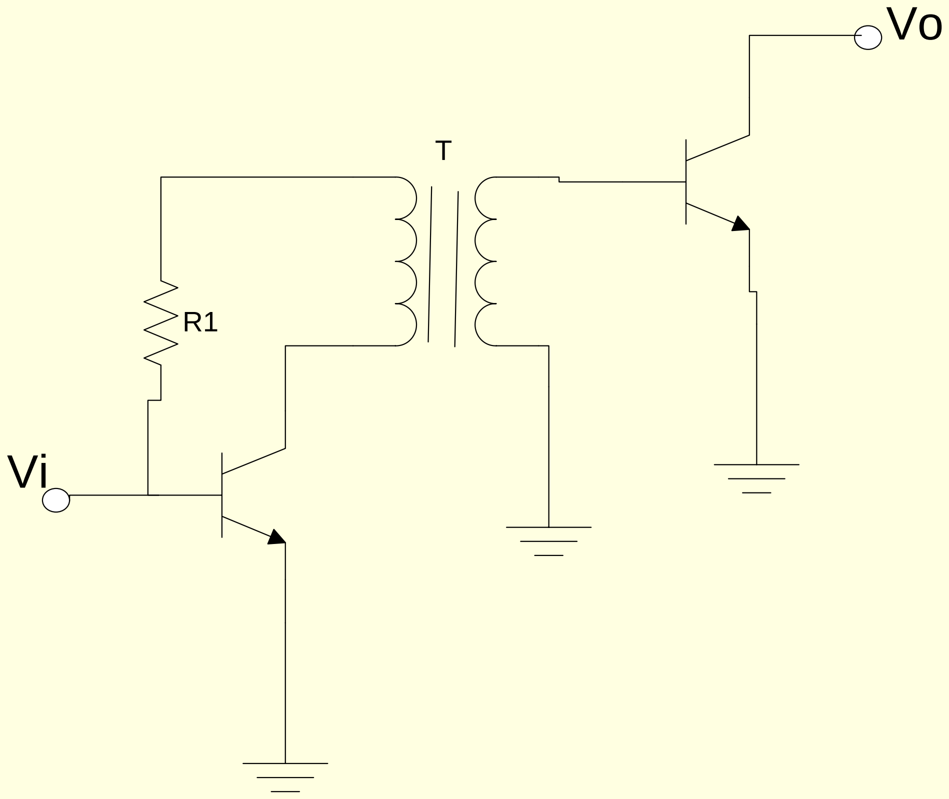
Resistance-capacitance coupling



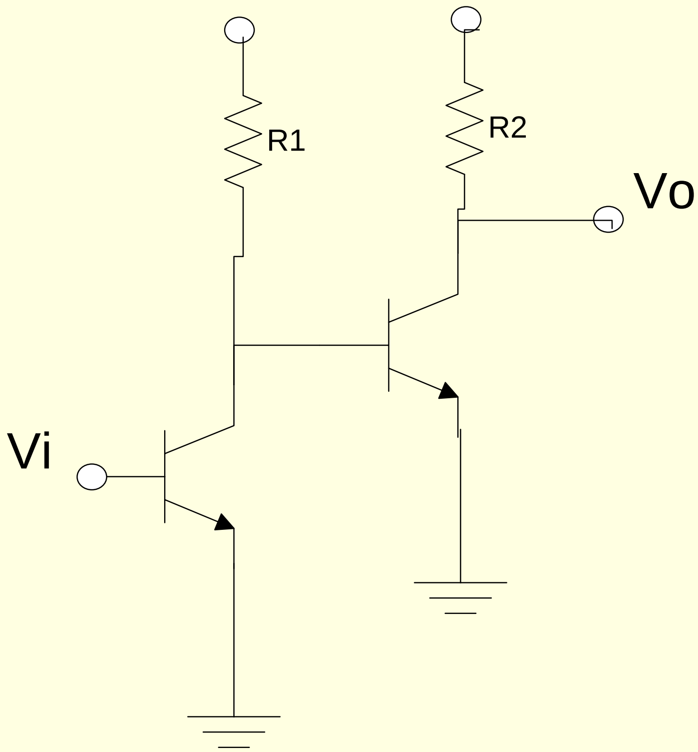
Impedance coupling or Inductive coupling



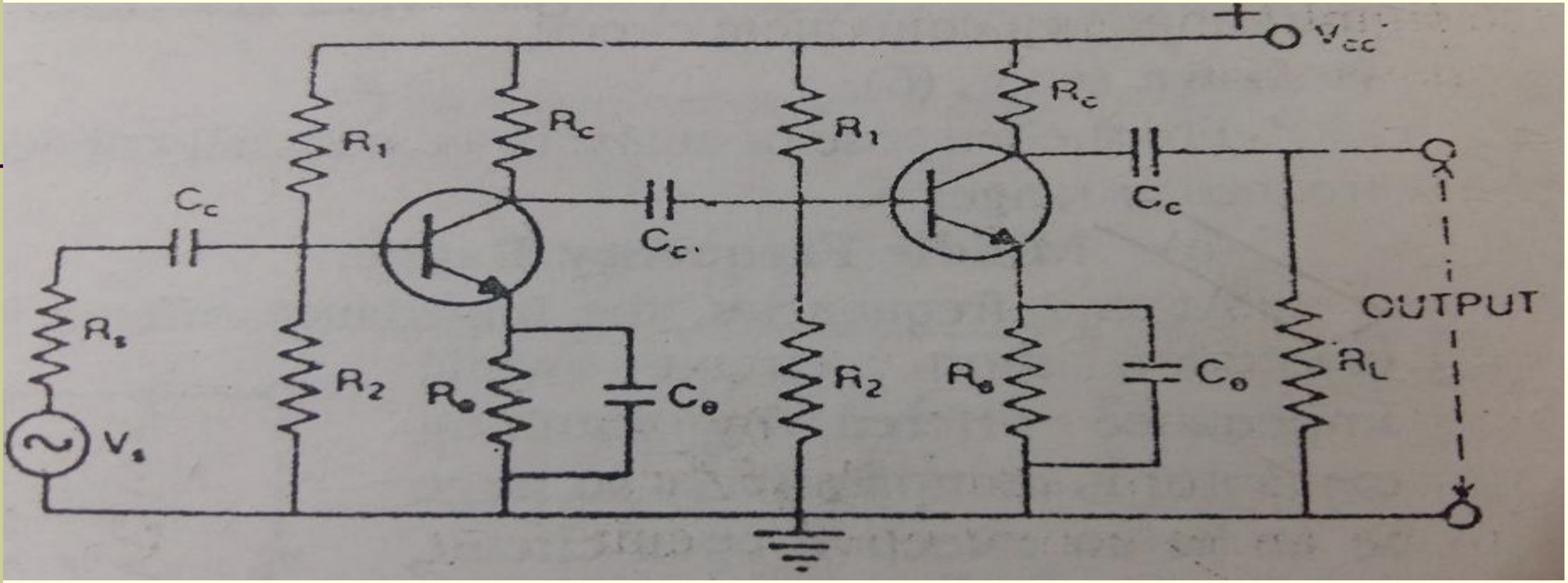
Transformer coupling



Direct coupling



R.C. coupled amplifier



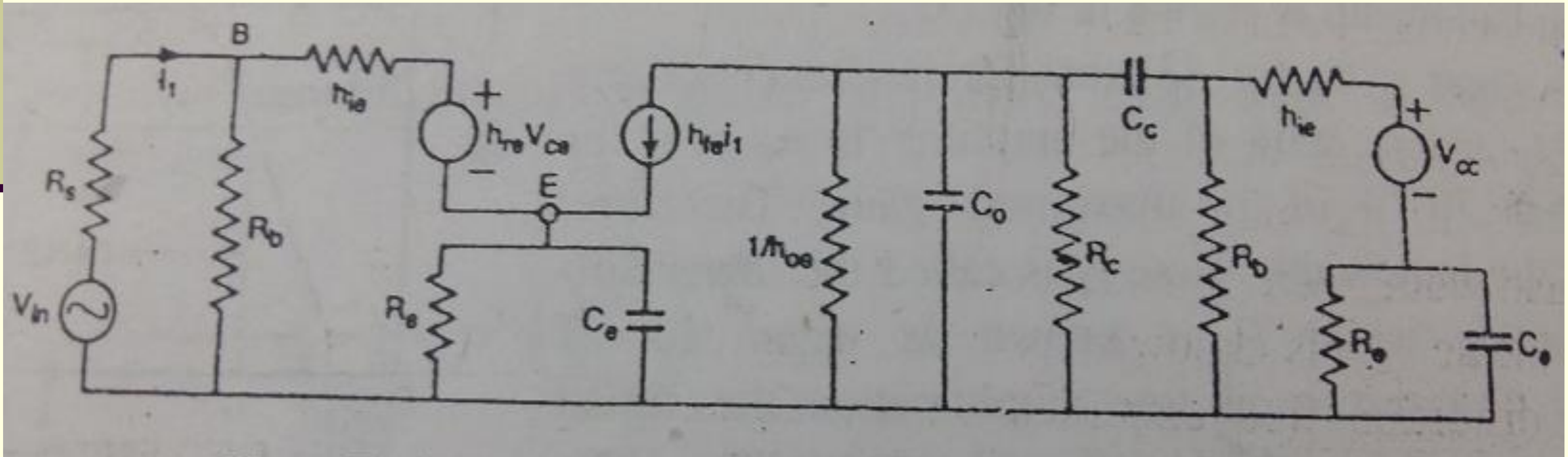


Fig. 5. Equivalent circuit for one stage of *RC* coupled amplifier.

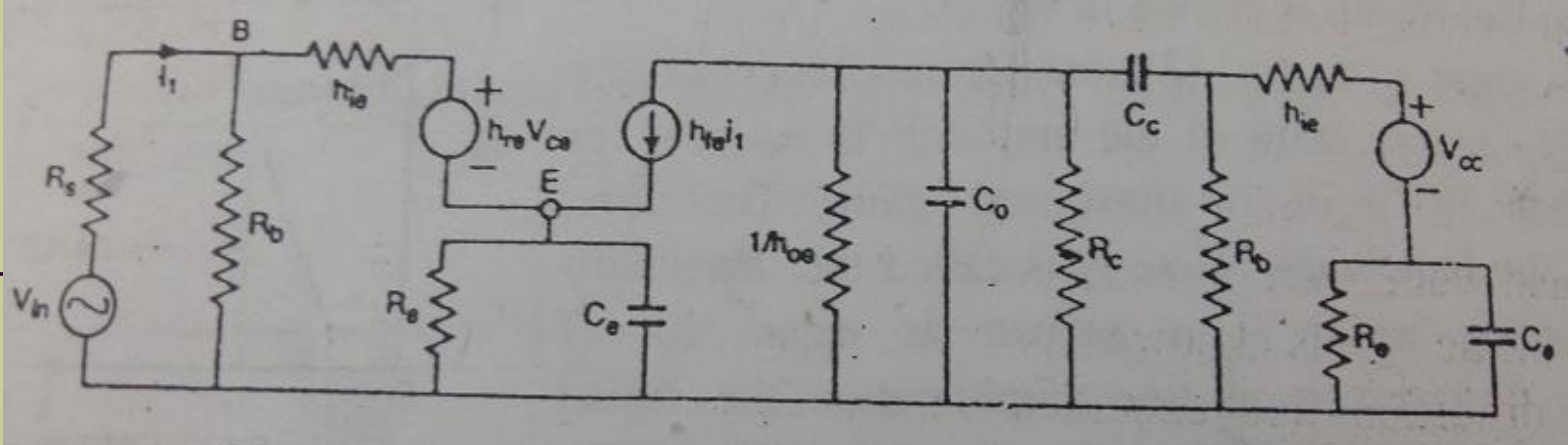


Fig. 5. Equivalent circuit for one stage of *RC* coupled amplifier.

Assumptions:

1. $\boldsymbol{h_{re}}$ is so small that the voltage source $\boldsymbol{h_{re}v_{ce}}$ can be neglected
2. $(1/\boldsymbol{h_{oe}})$ is so large that it can be considered as open circuit

Reactance of $\boldsymbol{c_e}$ at any frequency is so parallel combination of $\boldsymbol{R_e}$ $\boldsymbol{and\ c_e\ h_{re}}$ are considered as short circuit

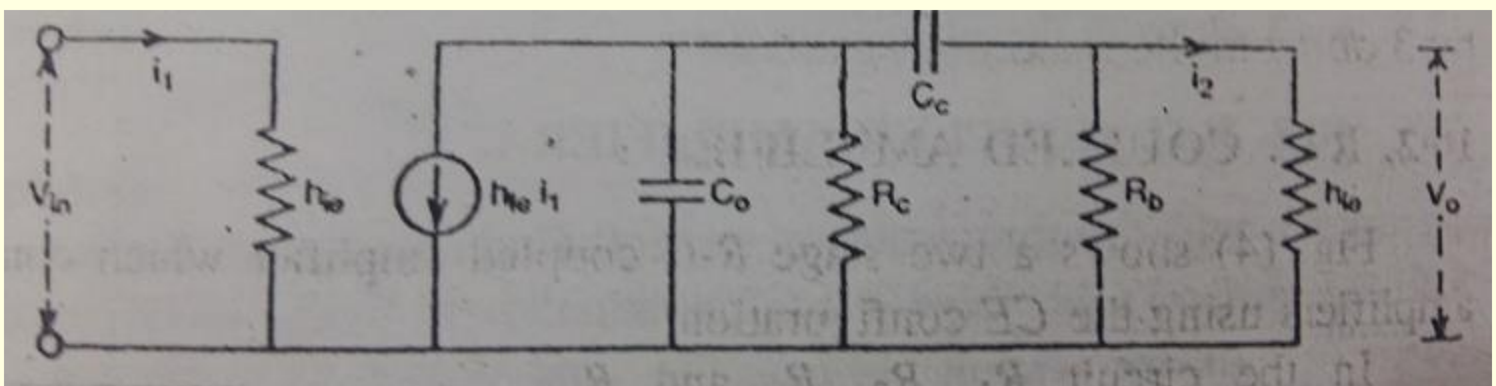


Fig. 6. Simplified equivalent circuit.

Analysis at Middle Frequency Range:

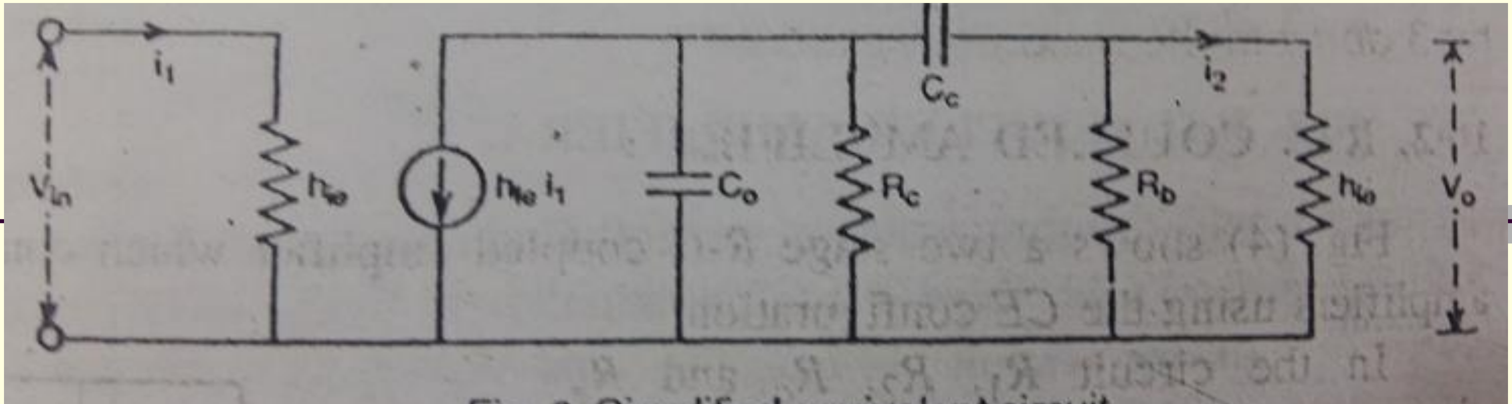


Fig. 6. Simplified equivalent circuit.

Impedance offered by c_c at mid-frequency is so small to be considered as short circuit

Impedance offered by c_o at mid-frequency is so large to be considered as open circuit

Both are eliminated in this mid-frequency range

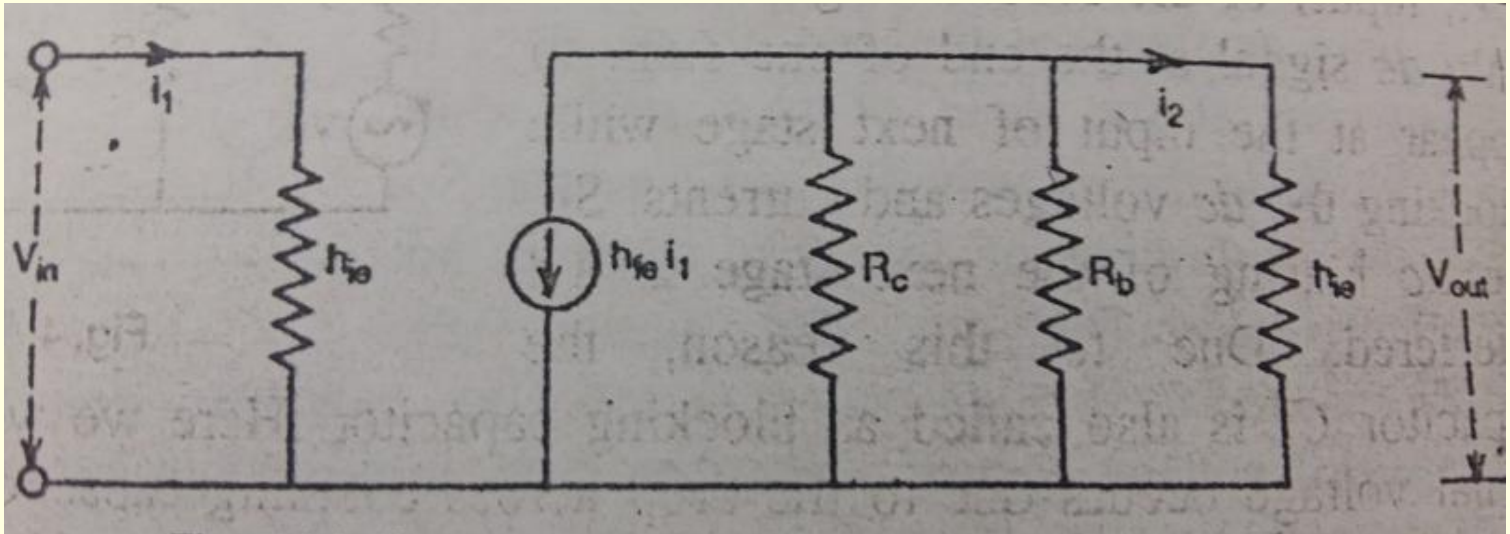


Fig. 7 (a). Equivalent circuit at middle frequency range.

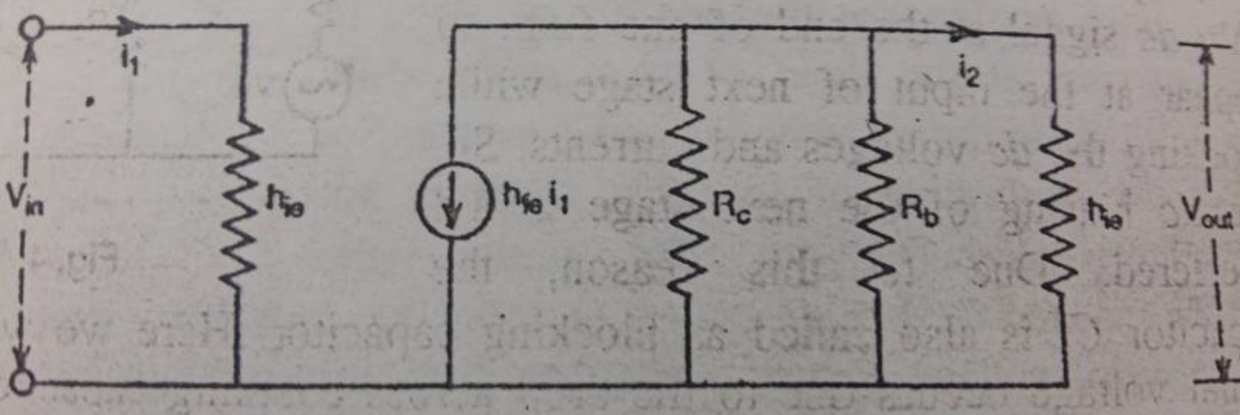


Fig. 7 (a). Equivalent circuit at middle frequency range.

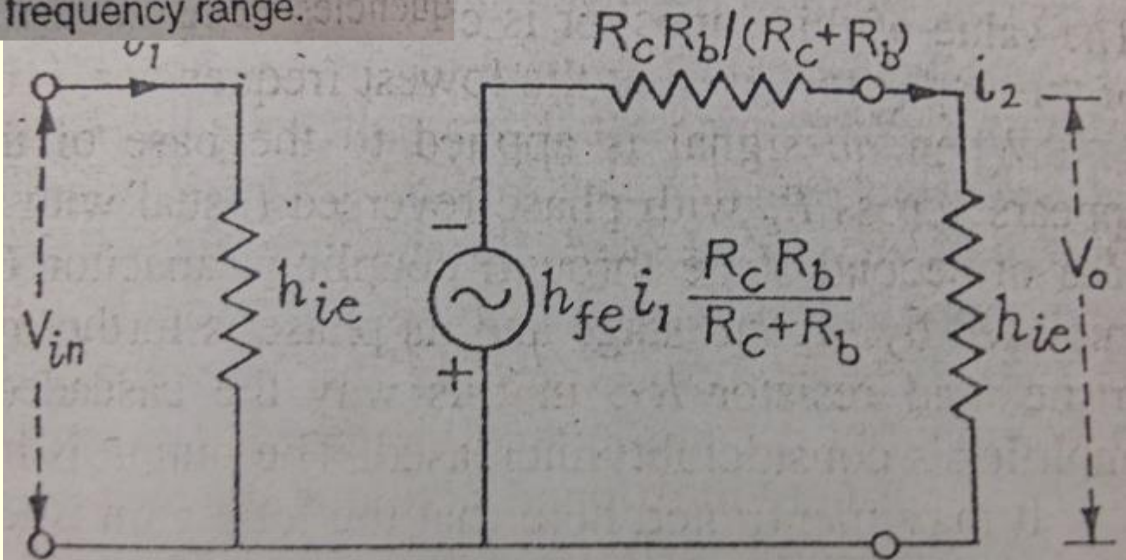


Fig. (7b). Equivalent circuit with voltage source by applying Thevenin's theorem.

$$i_2 = \frac{-h_{fe} i_1 \cdot \frac{R_c R_b}{R_c + R_b}}{h_{ie} + \frac{R_c R_b}{R_c + R_b}}$$

$$= \frac{-h_{fe} \cdot \frac{R_c R_b}{R_c+R_b}}{h_{ie} + \frac{R_c R_b}{R_c+R_b}} = \frac{-h_{fe} R_c R_b}{h_{ie}(R_c+R_b)+R_c R_b}$$

$$(A_v)_{mid} = \frac{V_{out}}{V_{in}} = \frac{-h_{fe} i_1 R_c R_b \times h_{ie}}{[h_{ie}(R_c+R_b)+R_c R_b]\times h_{ie} i_1} = \frac{-h_{fe} R_c R_b}{[h_{ie}(R_c+R_b)+R_c R_b]}$$

$$(A_i)_{mid} = (A_v)_{mid}$$

Frequency response

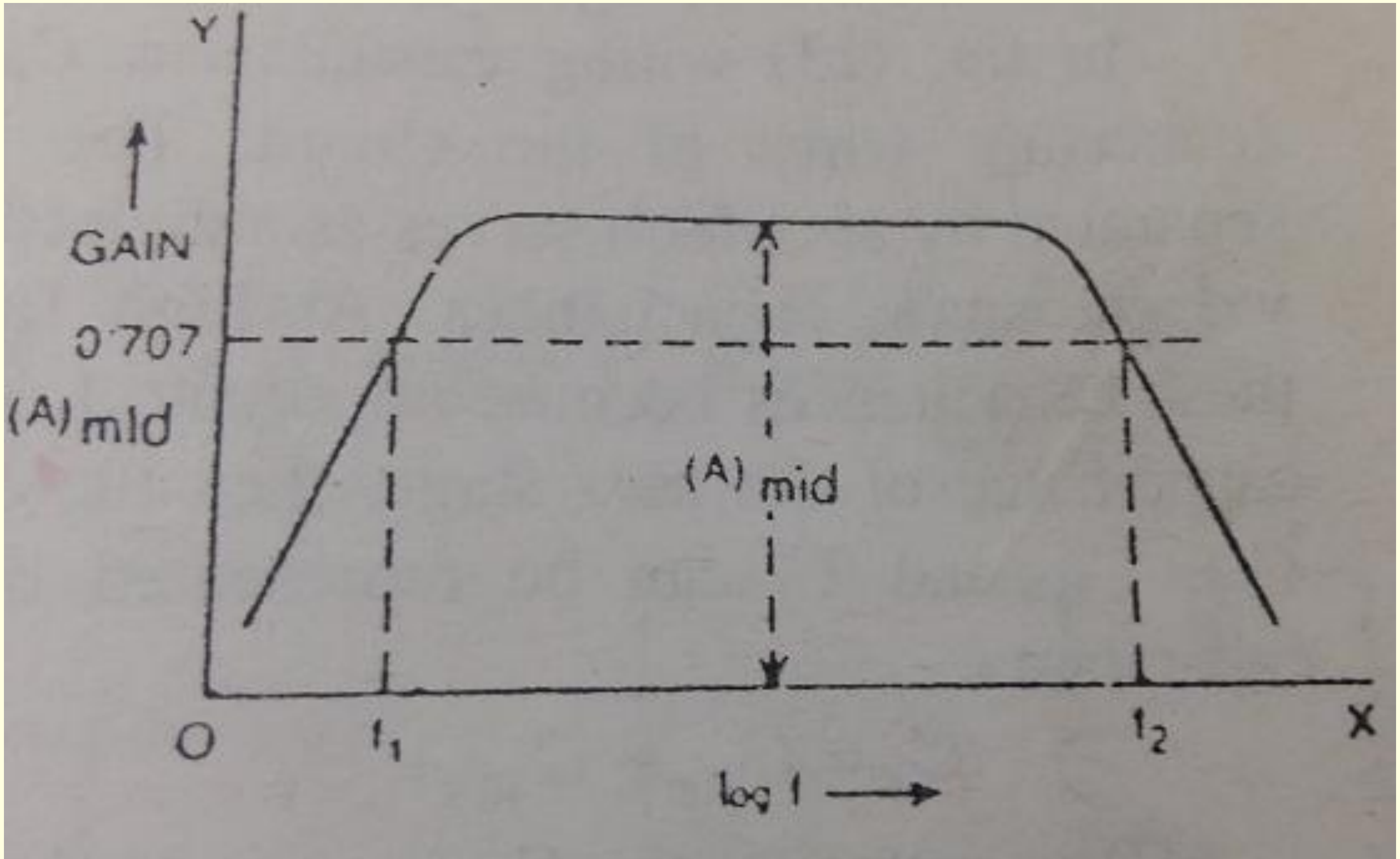


Fig. 10. Frequency response of *RC* coupled amplifier.

Advantages and Disadvantages of RC coupled amplifier

Advantages:

(i) small, light and inexpensive as it requires no expensive or bulky components and no adjustment

(ii) Excellent frequency response and the gain is constant over the audio frequency range

(iii) Minimum distortion as it does not use any coil or transformer

Disadvantages:

(i) Have a tendency to become noisy in moist climates

(ii) Impedance matching is poor as the output impedance is several hundred ohms while of a speaker is only few ohms.

Transformer coupled amplifier

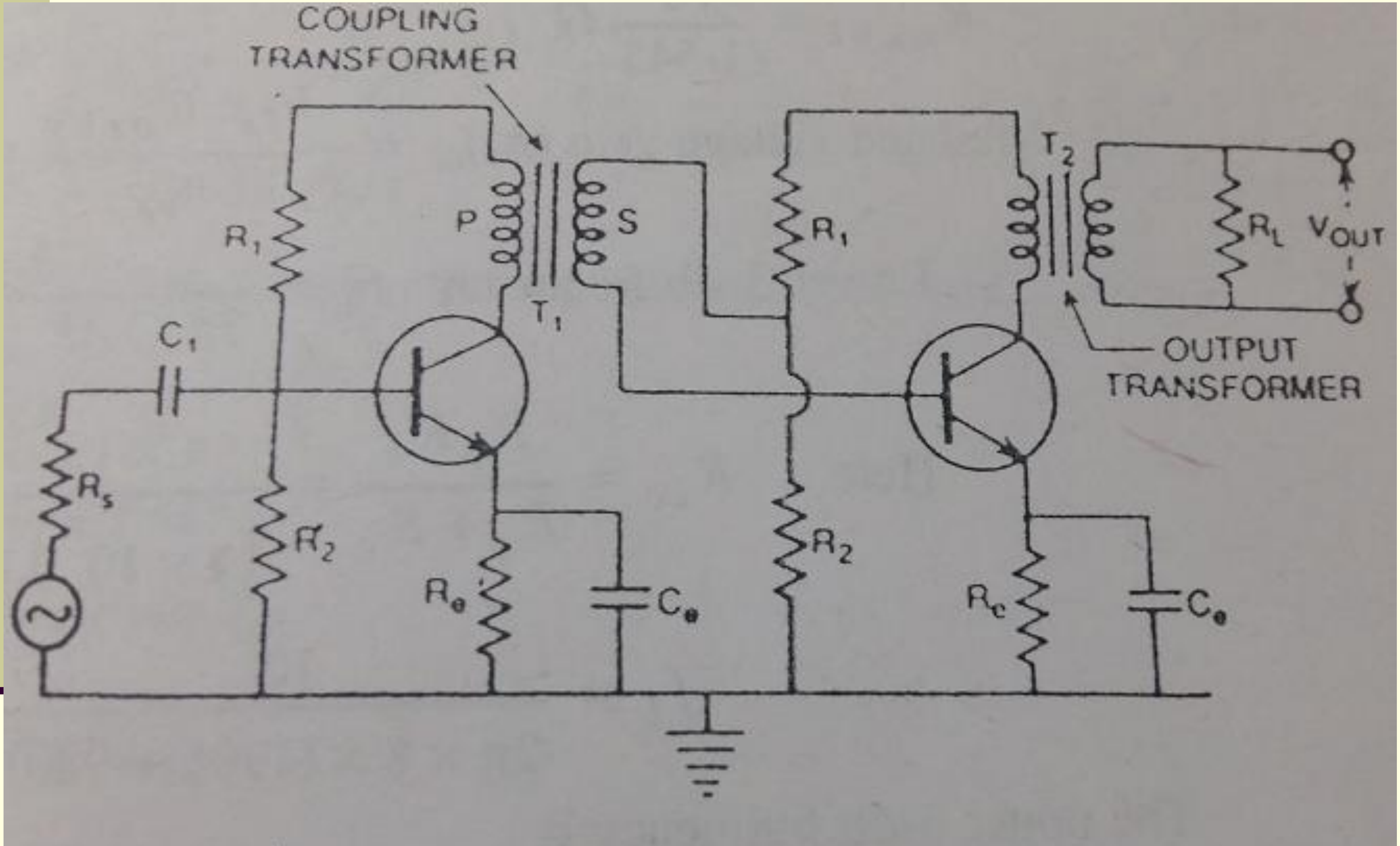


Fig. 19. Two stage transformer coupled amplifier

Equivalent circuit

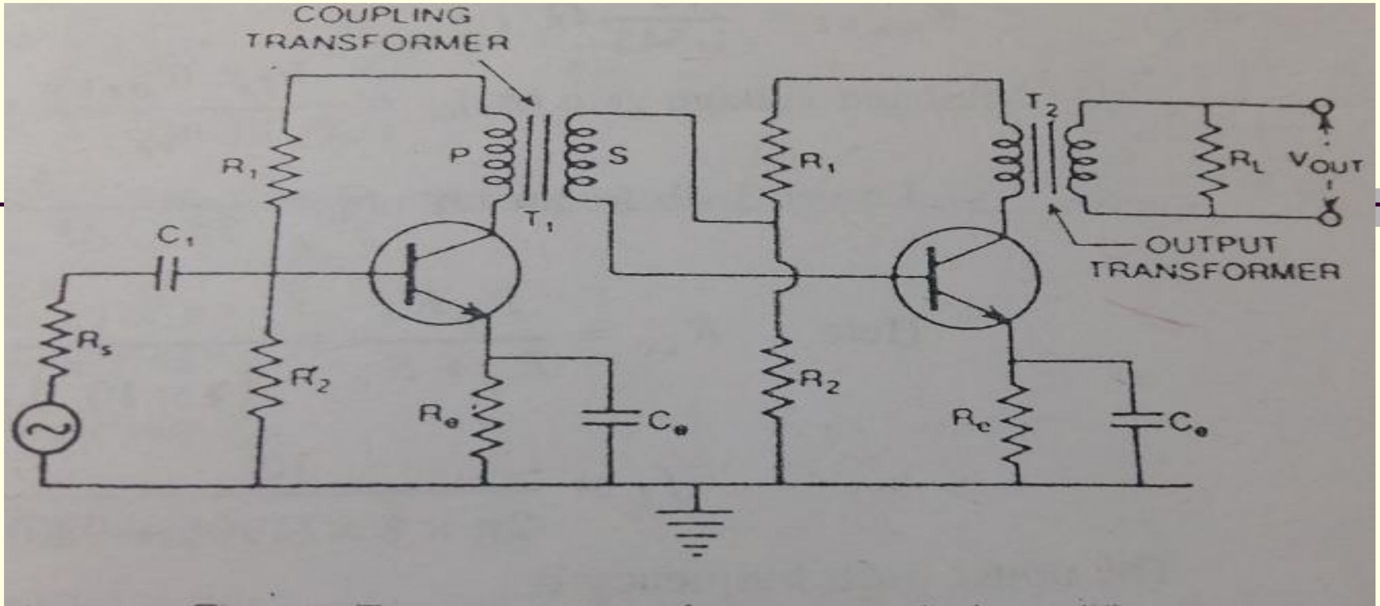
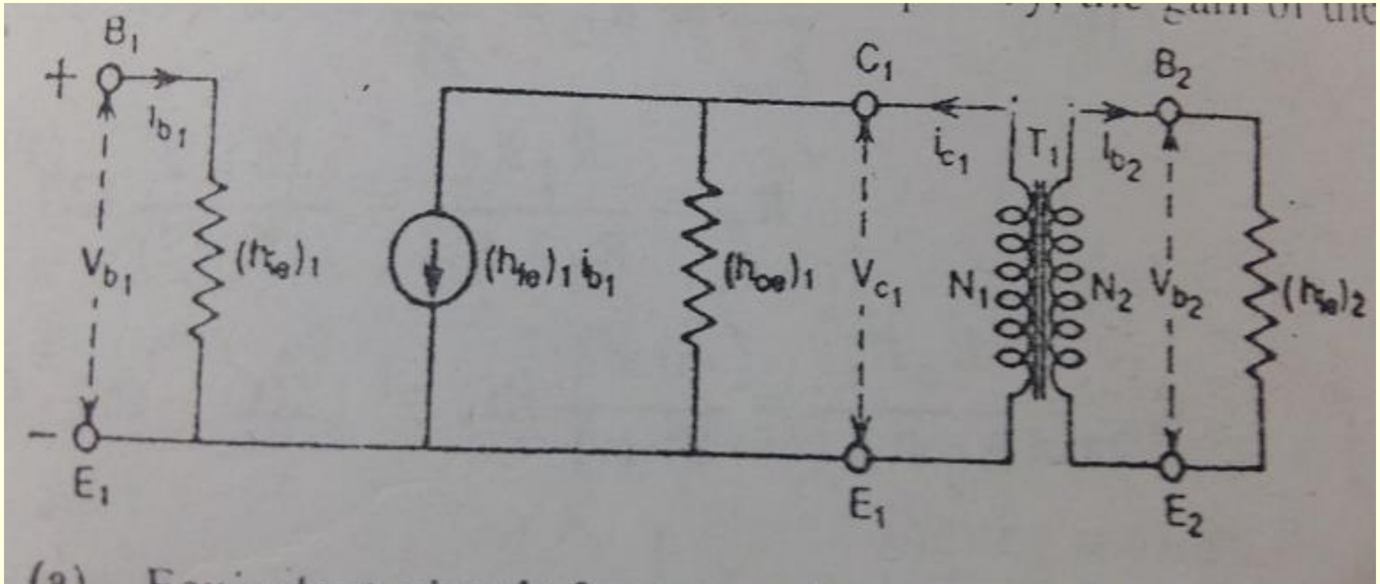
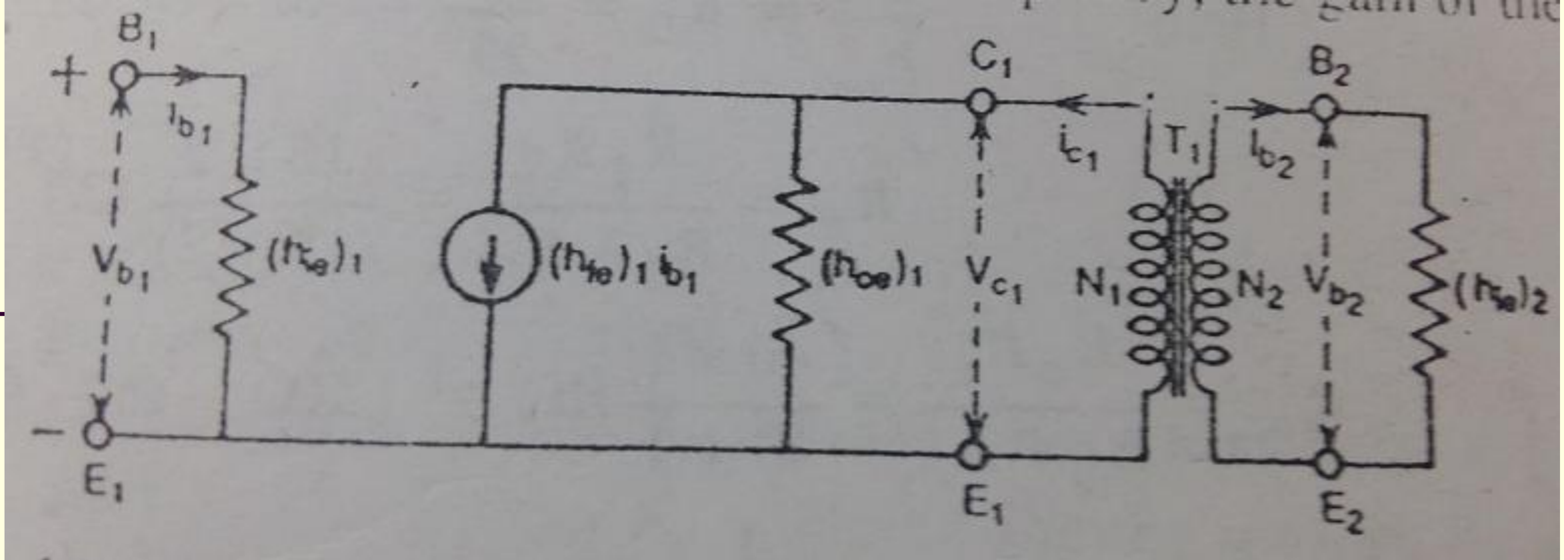


Fig. 19. Two stage transformer coupled amplifier

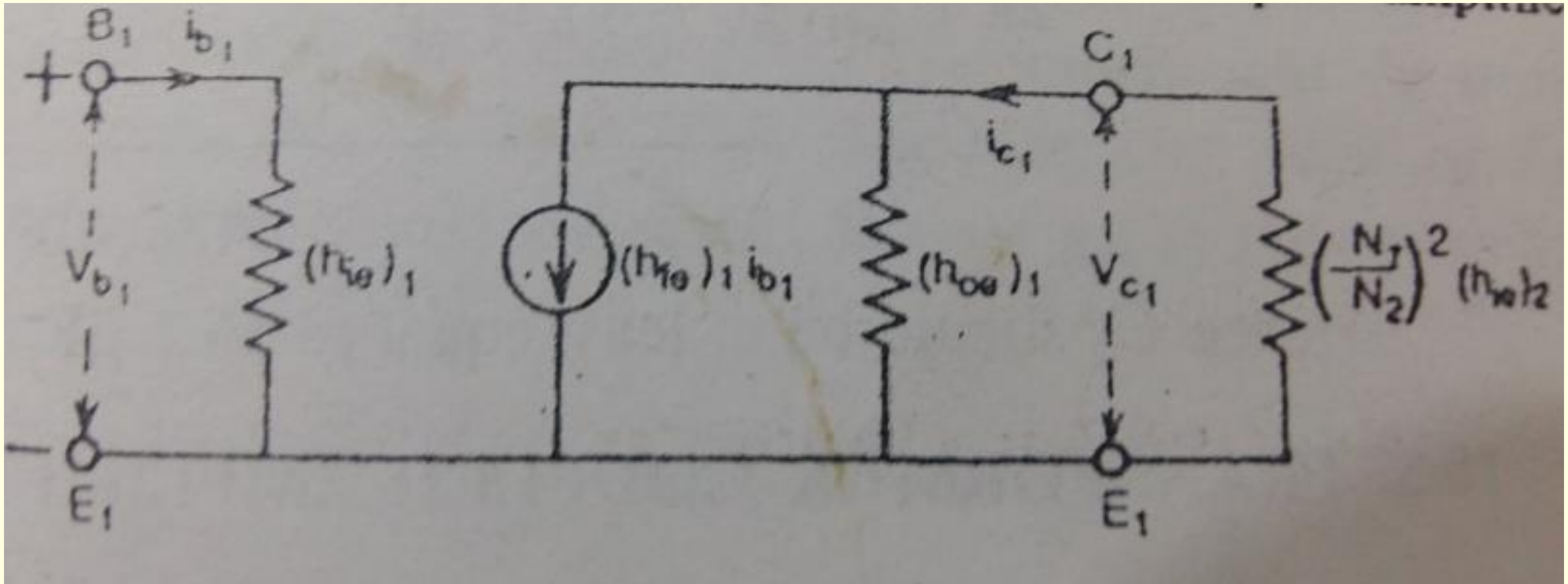


(a) Equivalent circuit for a transformer coupled amplifier.

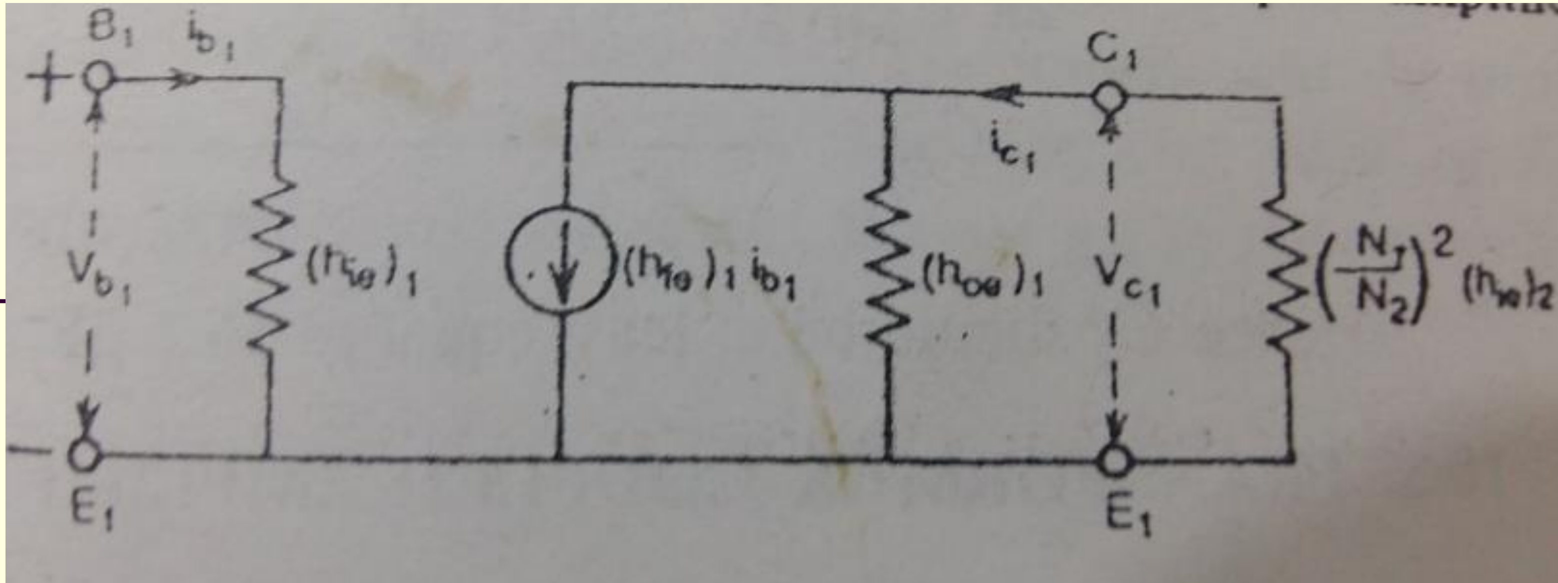


(a) Equivalent circuit for a transformer coupled amplifier.

Transferring load in the primary from secondary



(b) Simplified equivalent circuit.



(b) Simplified equivalent circuit.

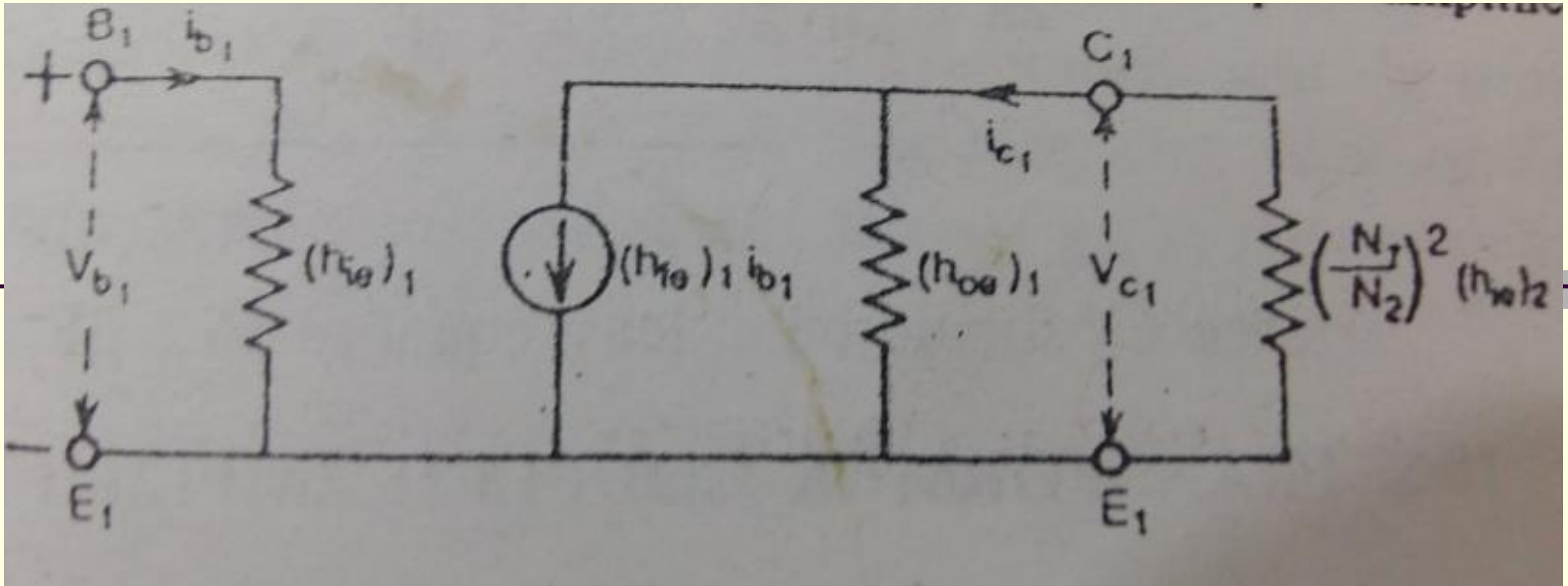
Effective load of first transistor $\left(\frac{N_1}{N_2}\right)^2 (h_{ie})_2$

Output impedance of first transistor $\frac{1}{(h_{Oe})_1}$

For maximum power transfer

$$\left(\frac{N_1}{N_2}\right)^2 (h_{ie})_2 = \frac{1}{(h_{Oe})_1}$$

$$\frac{N_1}{N_2} = \frac{1}{\sqrt{\{(h_{ie})_2 (h_{Oe})_1\}}}$$



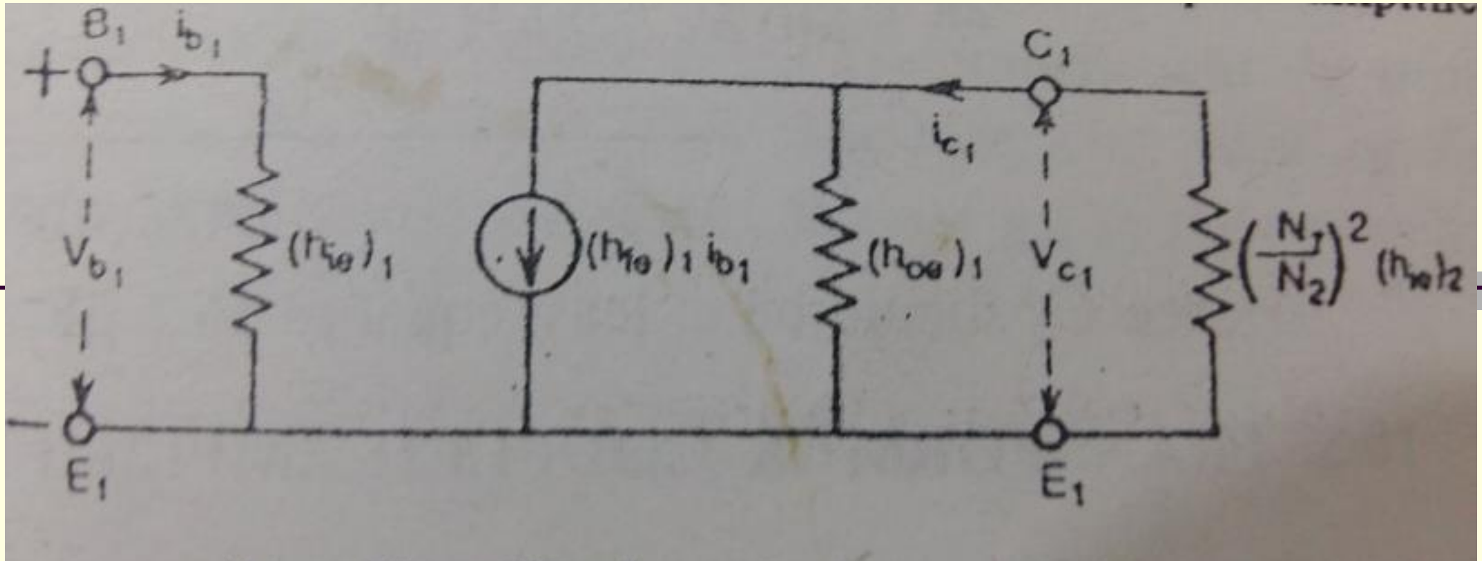
(b) Simplified equivalent circuit.

The current generator is $\left(h_{fe}\right)_1 (i_b)_1$

$$(i_c)_1 = \frac{\left(h_{fe}\right)_1 (i_b)_1}{2}$$

$$(i_b)_2 = \frac{N_1}{N_2}(i_c)_1 = \frac{N_1}{N_2}\frac{\left(h_{fe}\right)_1 (i_b)_1}{2}$$

The current gain $(A_i)_{mid} = \frac{i_{b2}}{i_{b1}} = \frac{N_1}{N_2}\frac{\left(h_{fe}\right)_1}{2}$



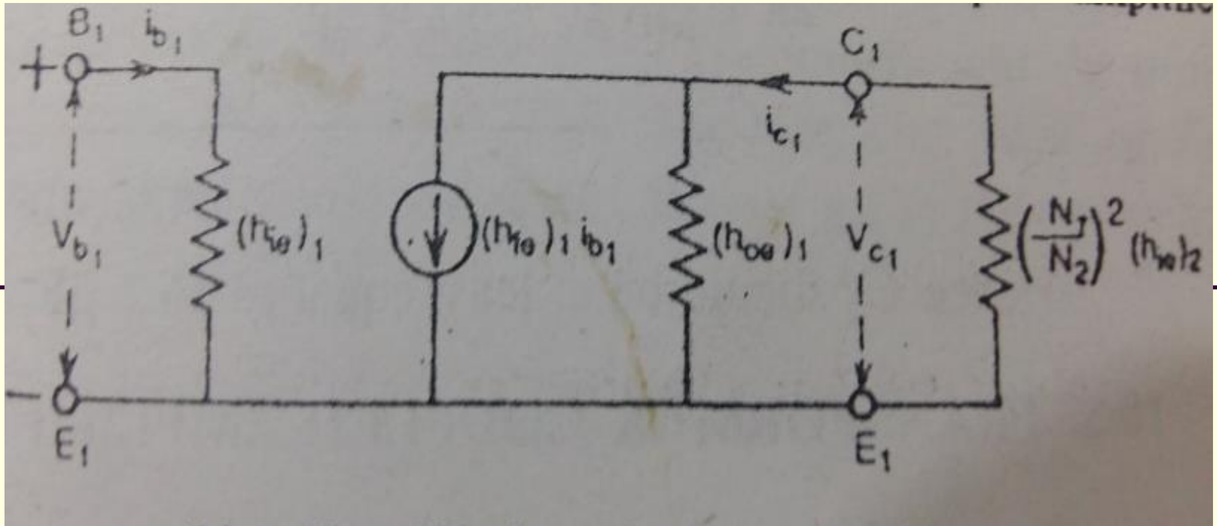
(b) Simplified equivalent circuit.

$$\boxed{V_{c_1} = -(i_c)_1 \times \left\{\left(\frac{N_1}{N_2}\right)^2 (h_{ie})_2\right\}}$$

$$(i_c)_1 = \frac{(h_{fe})_1 (i_b)_1}{2}$$

$$(i_b)_1 = \frac{V_{b1}}{(h_{ie})_1}$$

$$\boxed{V_{c_1} = -\frac{(h_{fe})_1}{2} \frac{V_{b1}}{(h_{ie})_1} \times \left\{\left(\frac{N_1}{N_2}\right)^2 (h_{ie})_2\right\}}$$



(b) Simplified equivalent circuit.

$$V_{c_1} = -\frac{(h_{fe})_1}{2}\frac{V_{b1}}{(h_{ie})_1} \times \left\{\left(\frac{N_1}{N_2}\right)^2 (h_{ie})_2\right\}$$

$$\frac{V_{c_1}}{V_{b1}} = -\frac{(h_{fe})_1}{2} \times \left(\frac{N_1}{N_2}\right)^2 \frac{(h_{ie})_2}{(h_{ie})_1}$$

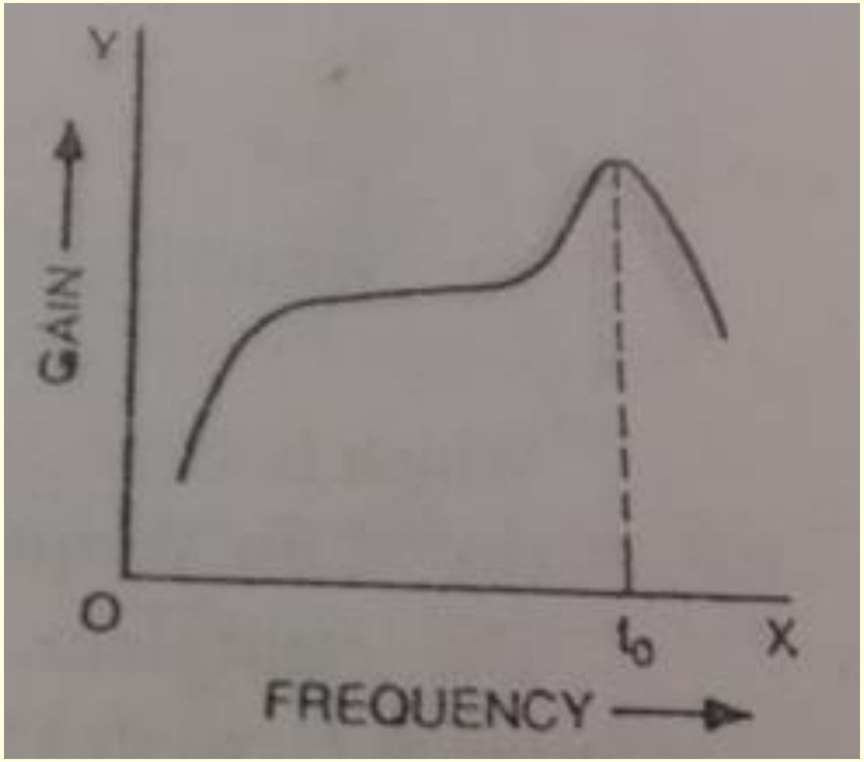
$$\therefore \frac{V_{c_1}}{V_{b2}} = -\frac{N_1}{N_2}$$

$$-\frac{N_1}{N_2}\frac{V_{b2}}{V_{b1}} = -\frac{(h_{fe})_1}{2} \times \left(\frac{N_1}{N_2}\right)^2 \frac{(h_{ie})_2}{(h_{ie})_1}$$

$$\therefore V_{c_1} = -\frac{N_1}{N_2} V_{b2}$$

$$(A_v)_{mid} = \frac{V_{b2}}{V_{b1}} = \frac{(h_{fe})_1}{2} \times \frac{N_1}{N_2} \times \frac{(h_{ie})_2}{(h_{ie})_1} = \frac{(h_{fe})_1}{2}\frac{N_1}{N_2}$$

Frequency response



Advantages and Disadvantages of Transformer coupled amplifier

Advantages:

(i) No loss of signal power in collector or base resistors

(ii) Provides higher voltage gain

(iii) Excellent Impedance matching

Disadvantages:

(i) Costly and bulky, specially at audio frequencies because of its heavy iron core.

(ii) Poor frequency response.

(iii) Introduces hum in the output

(iv) At radio frequencies, inductance and winding capacitance produce a lot of problems.

(v) Frequency distribution is higher i.e. low frequency signals are less amplified as compared to high frequency signal

Direct Coupled Transistor Amplifier

There are many applications in which extremely low frequency signals i.e. below 10 Hz are to be amplified, for example, amplifying photo-electric current, thermo-couple current etc.

In such applications, use of coupling devices such as capacitors and transformers make such amplifiers bulky due to the large electrical size of these components at low frequencies.

Hence, in such cases, one stage is directly connected to the next stage without any intervening coupling device. This type of coupling is known as direct coupling.

Direct Coupled Transistor Amplifier

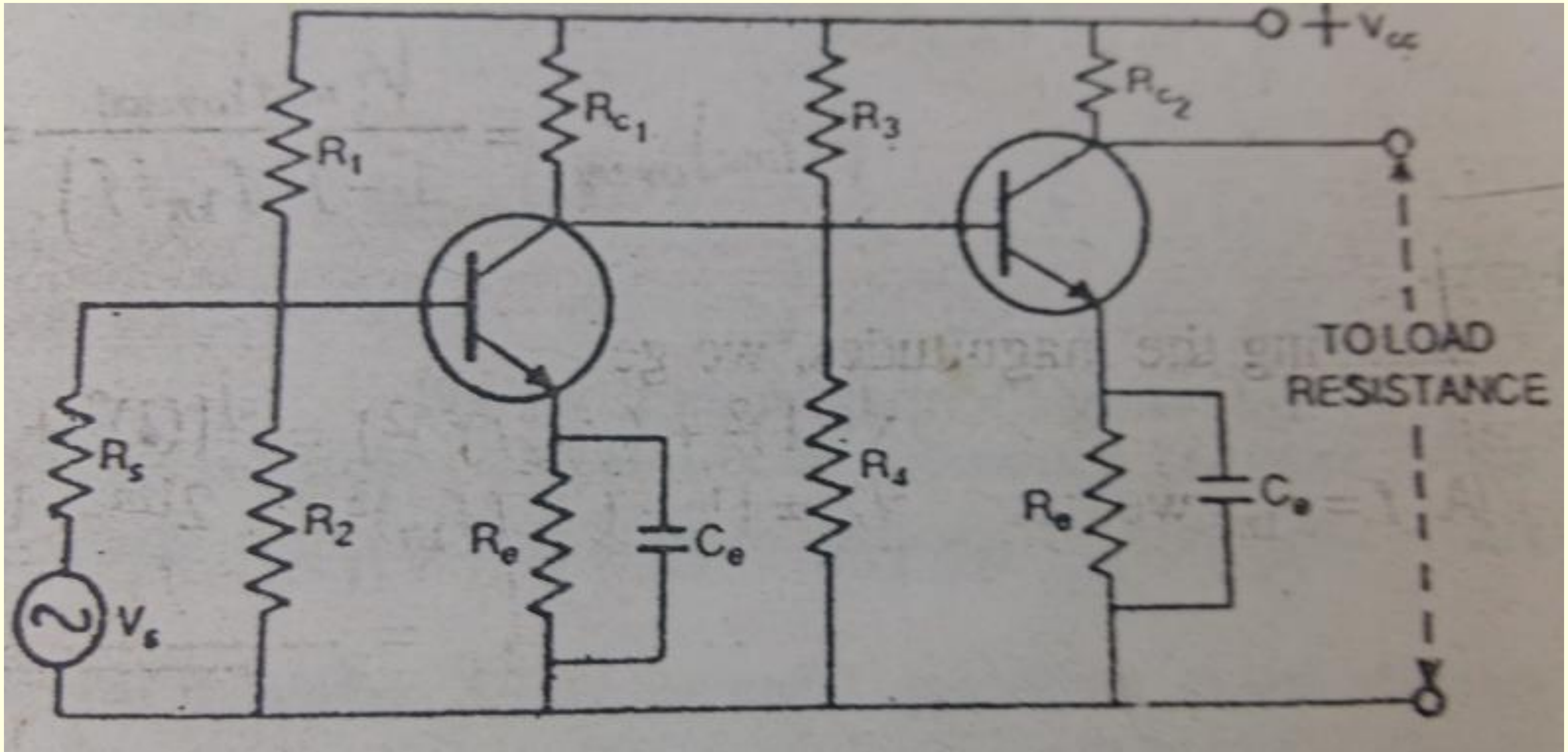


Fig. 25. Two stage direct coupled Amplifier.

Frequency response

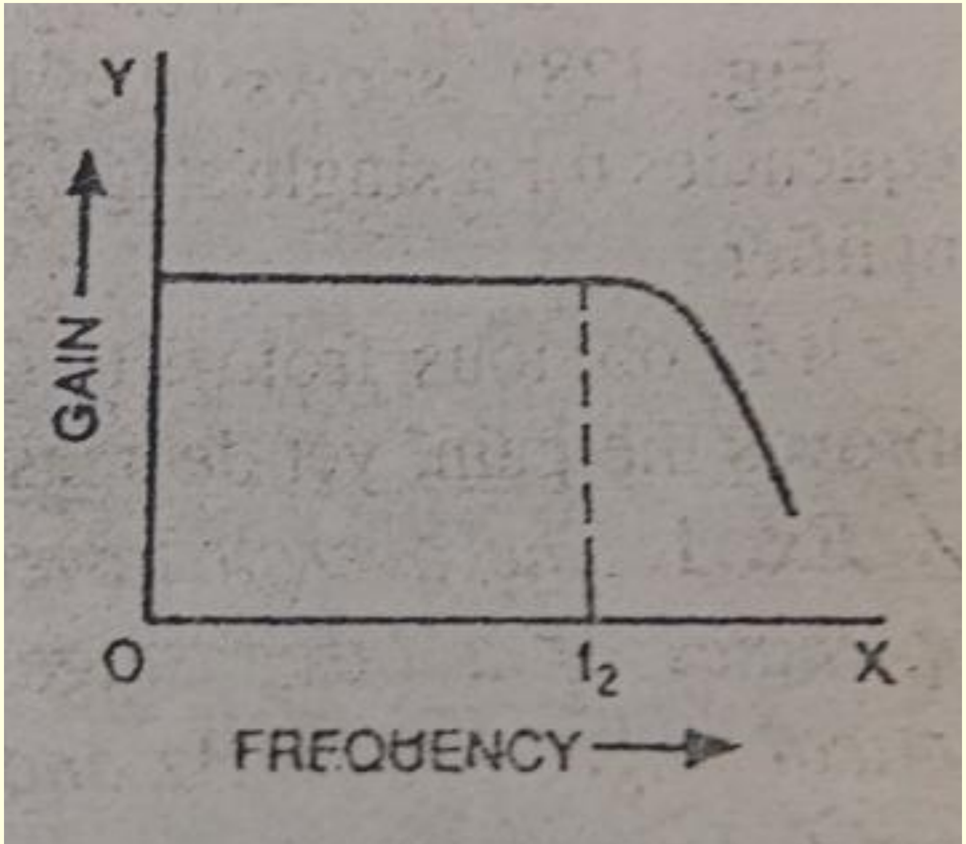


Fig. 26.

Direct Coupled Transistor Amplifier

Advantages

1. Circuit is simple because of minimum use of resistors.
2. Cost is low because of the absence of expensive coupling devices.
3. It has outstanding ability to amplify direct current at low frequency signals.

Disadvantages

1. This amplifier can not be used for amplifying high frequency signals.
2. The operating point is shifted due to temperature variations.

Application

Normally in integrated circuits, most of the operational amplifiers are direct coupled

iii) Darlington Pair/Connection

-The main feature is that the composite transistor acts as a single unit with a current gain that is the product of the current gains of the individual transistors
-Provide high current gain than a single BJT
-The connection is made using two separate transistors having current gains of

$$\beta_1 and \beta_2$$

So, the current gain

$$\beta_D = \beta_1 \beta_2$$

$$If, \beta_1 = \beta_2 = \beta$$

The Darlington connection provides a current gain of

$$\beta_D = \beta^2$$

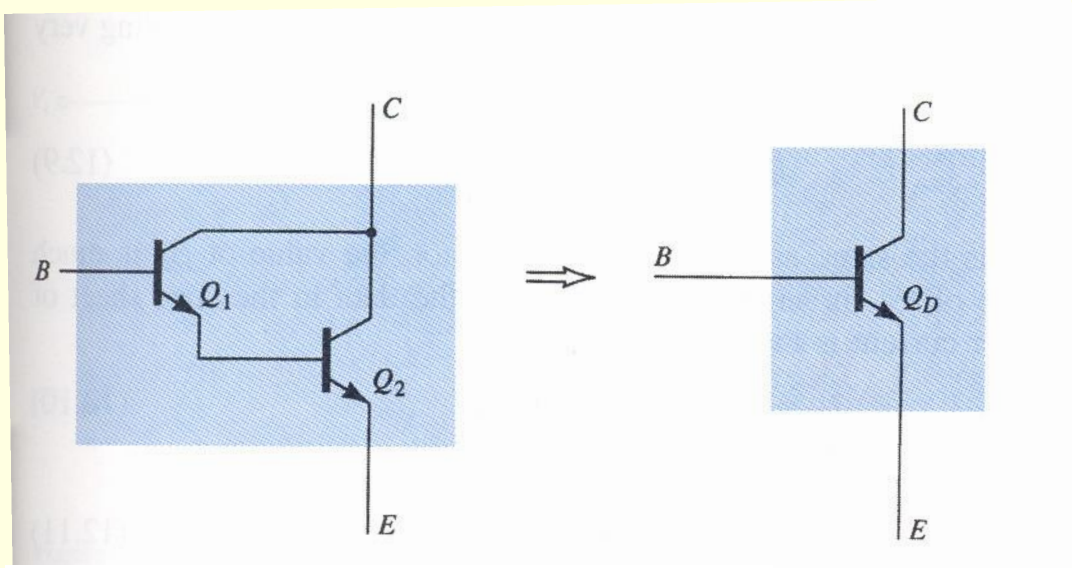


Figure 1: Darlington transistor

Effect of cascading on frequency response

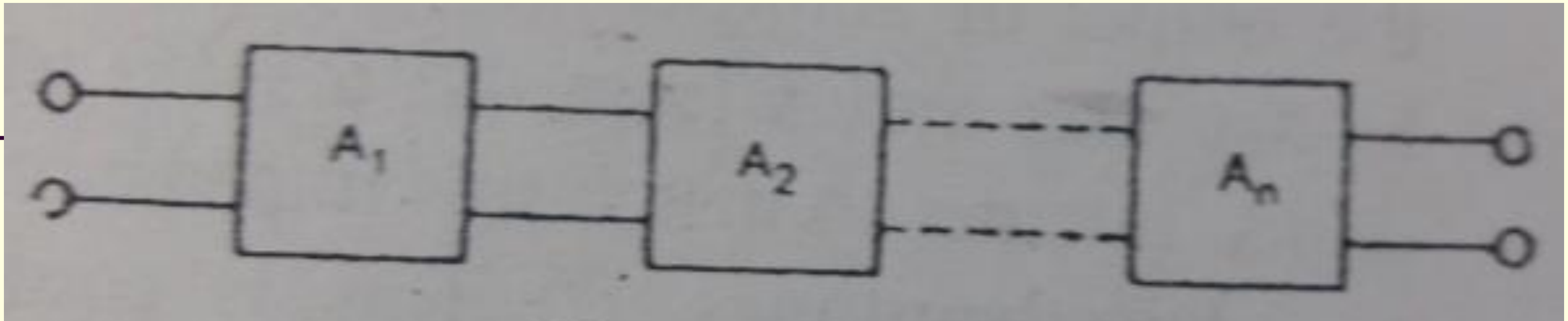


Fig. 27. Cascade amplifiers

$\boxed{(A_{mid})_{overall}}$ be the mid-band gain of *n* cascaded stages

$$\boxed{(A_{mid})_{overall} = (A_{mid})^n}$$

Low frequency gain for each stage $\boxed{A_{low} = \frac{A_{mid}}{1-j\left(\frac{f_1}{f}\right)}}$

$If \;\; (A_{low})_{overall}$ be the overall low frequency gain, then

$$\boxed{(A_{low})_{overall} = \left[\frac{A_{mid}}{1-j\left(\frac{f_1}{f}\right)}\right]^n}$$

$If\ f_{1n}$ be the overall lower cut-off frequency, then

$$(A_{low})_{overall} = \frac{(A_{mid})_{overall}}{1-j\left(\frac{f_{1n}}{f}\right)} = \left[\frac{A_{mid}}{1-j\left(\frac{f_1}{f}\right)}\right]^n$$

As $(A_{mid})_{overall} = (A_{mid})^n$

Equating the magnitudes, we get $$\sqrt{\left\{1^2 + \left(\frac{f_{1n}}{f}\right)^2\right\}} = \sqrt{\left\{1^2 + \left(\frac{f_1}{f}\right)^2\right\}^n}$$

$At\ f = f_{1n},$

$$\sqrt{2} = \left\{1 + \left(\frac{f_1}{f_{1n}}\right)^2\right\}^{\frac{n}{2}}, \quad 2^{\frac{1}{2}} = \left\{1 + \left(\frac{f_1}{f_{1n}}\right)^2\right\}^{\frac{n}{2}},$$

$$2^{\frac{1}{n}} = \left\{1 + \left(\frac{f_1}{f_{1n}}\right)^2\right\}, \quad 2^{\frac{1}{n}} - 1 = \left(\frac{f_1}{f_{1n}}\right)^2,$$

$$\sqrt{2^{\frac{1}{n}} - 1} = \frac{f_1}{f_{1n}},$$

Overall lower cut off frequency $f_{1n} = \dfrac{f_1}{\sqrt{2^{\frac{1}{n}} - 1}}$

If, n=2, then $\sqrt{2^{\frac{1}{2}} - 1} = 0.63$

$$f_{12} = 1.6\, f_1$$

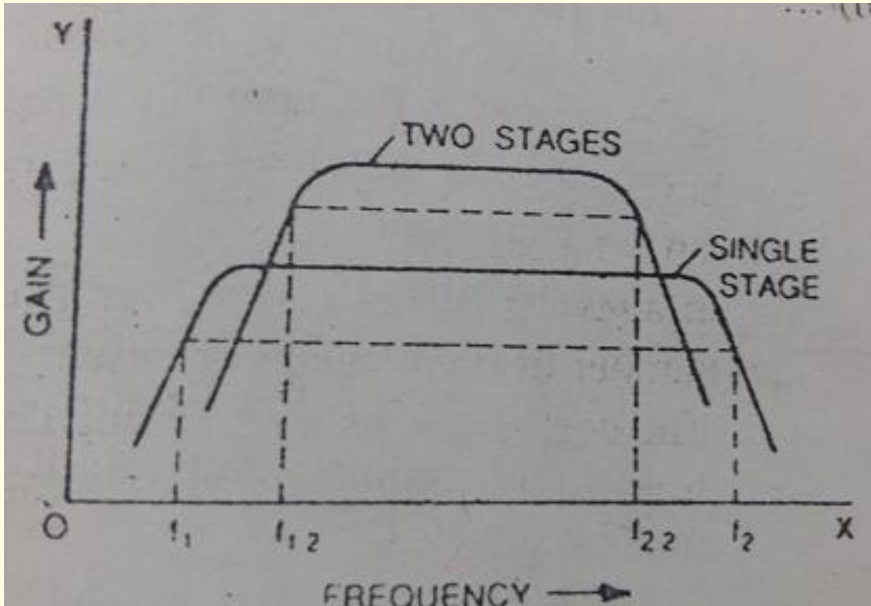


Fig. 28. Effect of cascading on band-width.

$If\ f_{2n}$ be the overall upper cut-off frequency, then

$$(A_{high})_{overall} = \frac{(A_{mid})_{overall}}{1+j\left(\frac{f}{f_{2n}}\right)} = \left[\frac{A_{mid}}{1+j\left(\frac{f}{f_2}\right)}\right]^n$$

As $(A_{mid})_{overall} = (A_{mid})^n$

$$At\ f = f_{2n},\quad \sqrt{2} = \left\{1+\left(\frac{f_{2n}}{f_2}\right)^2\right\}^{\frac{n}{2}},\quad 2^{\frac{1}{2}} = \left\{1+\left(\frac{f_{2n}}{f_2}\right)^2\right\}^{\frac{n}{2}},$$

$$2^{\frac{1}{n}} = \left\{1+\left(\frac{f_{2n}}{f_2}\right)^2\right\},\quad 2^{\frac{1}{n}}-1 = \left(\frac{f_{2n}}{f_2}\right)^2$$

$$\sqrt{2^{\frac{1}{n}}-1} = \frac{f_{2n}}{f_2},\quad f_{2n} = \sqrt{2^{\frac{1}{n}}-1}\ f_2$$

If, n=2, then $\sqrt{2^{\frac{1}{2}}-1} = 0.63$

$f_{2n} = 0.63\ f_2$

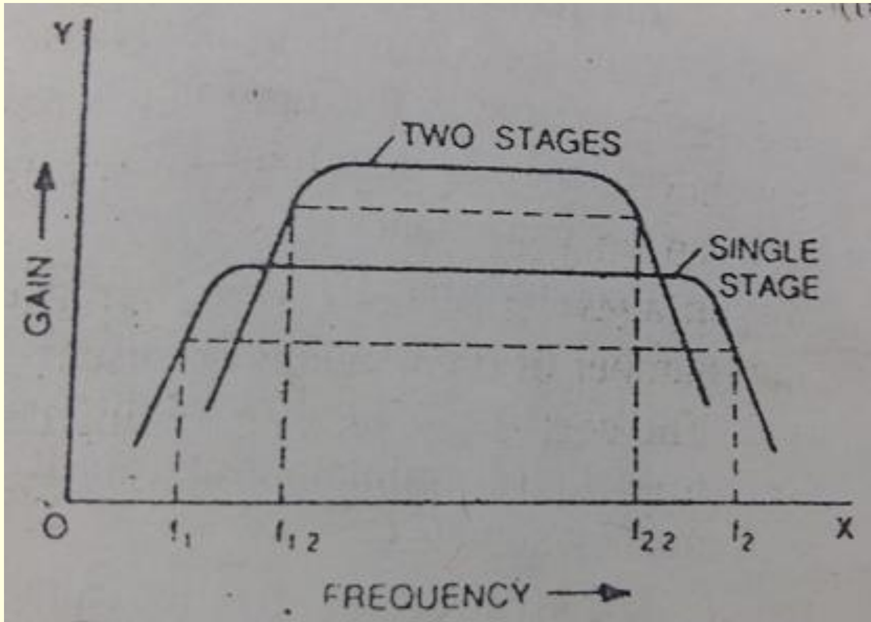


Fig. 28. Effect of cascading on band-width.