(*iii*) Decibel gain. Although the gain of an amplifier can be expressed as a number, yet it is of great practical importance to assign it a unit. The unit assigned is *bel or decibel* (*db*).

The common logarithm (*log to the base 10*) *of power gain is known as* **bel power gain**

i.e.

Power gain = $\log_{10}\frac{Pout}{Pin}$ bel

1 bel = 10 *db*

Power gain = $10\log_{10}\frac{Pout}{Pin}$ db

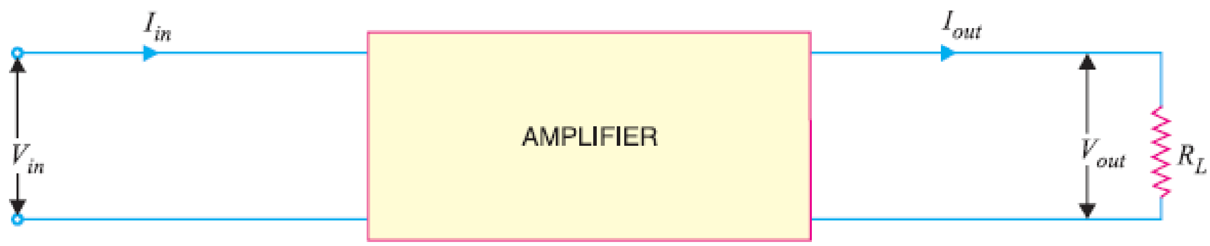

Fig.5: one stage amplifier

If the two powers are developed in the same resistance or equal resistances, then,

$$P_1 = \frac{V_{in}^2}{R} = I_{in}^2 R$$

$$P_2 = \frac{V_{out}^2}{R} = I_{out}^2 R$$

$$\text{Voltage gain in } db = 10\log_{10}\frac{V_{out}^2/R}{V_{in}^2/R} = 20\log_{10}\frac{V_{out}}{V_{in}}$$

$$\text{Current gain in } db = 10\log_{10}\frac{I_{out}^2 R}{I_{in}^2 R} = 20\log_{10}\frac{I_{out}}{I_{in}}$$

Advantages: The following are the advantages of expressing the gain in *db*:

(a) The unit *db*is a logarithmic unit. Our ear response is also logarithmic *i.e.* loudness of sound heard by ear is not according to the intensity of sound but according to the log of intensity of sound. Thus if the intensity of sound given by speaker (*i.e.* power) is increased 100 times, our ears hear a doubling effect (log10 100 = 2) *i.e.* as if loudness

were doubled instead of made 100 times. Hence, this unit tallies with the natural response of our ears.

(b) When the gains are expressed in *db*, the overall gain of a multistage amplifier is the sum of gains of individual stages in *db*. Thus referring to Fig.6

$$\text{Gain as number} = \frac{V_2}{V_1} \times \frac{V_3}{V_2}$$

$$\text{Gain in } db = 20 \log_{10} \frac{V_2}{V_1} \times \frac{V_3}{V_2}$$

$$= 20 \log_{10} \frac{V_2}{V_1} + 20 \log_{10} \frac{V_3}{V_2}$$

$$= \text{1st stage gain in } db + \text{2nd stage gain in } db$$

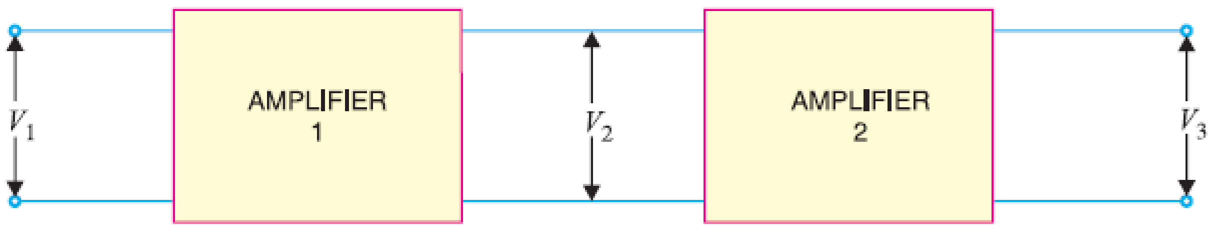

Fig.6: a multistage amplifier

(*iv*) Bandwidth. *The range of frequency over which the voltage gain is equal to or greater than 70.7% of the maximum gain is known as* **bandwidth**

The voltage gain of an amplifier changes with frequency. Referring to the frequency response in Fig. 11.7, it is clear that for any frequency lying between $f1$ and $f2$, the gain is equal to or greater than 70.7% of the maximum gain. Therefore, $f1 - f2$ is the bandwidth. It may be seen that $f1$ and $f2$ are the limiting frequencies. The former ($f1$) is called *lower cut-off frequency* and the latter ($f2$) is known as *upper cut-off frequency*. For distortionless amplification, it is important that signal frequency range must be within the bandwidth of the amplifier.

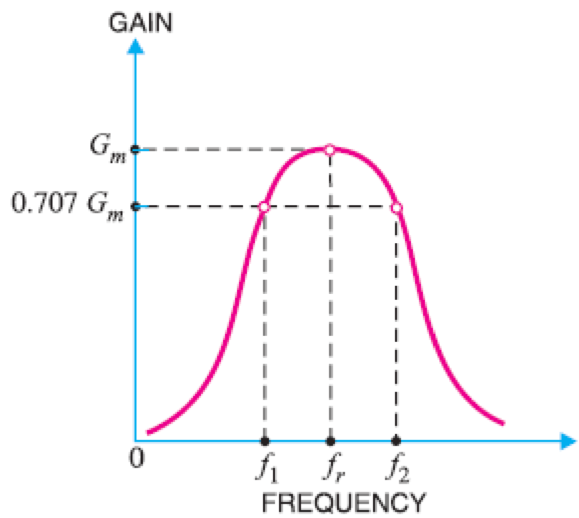

Fig.7: Bandwidth of frequency response

The bandwidth of an amplifier can also be defined in terms of *db*. Suppose the maximum voltagegain of an amplifier is 100. Then 70.7% of it is 70.7.

∴ Fall in voltage gain from maximum gain

$$= 20 \log_{10} 100 - 20 \log_{10} 70.7$$

$$= 20 \log_{10} \frac{100}{70.7} \, db$$

$$= 20 \log_{10} 1.4142 \, db = 3 \, db$$

Hence **bandwidth** *of an amplifier is the range of frequency at the limits of which its voltage gainfalls by 3 db from the maximum gain.*

The frequency *f*1 or *f*2 is also called 3-*db frequency* or *half-power frequency*.

The 3-*db* designation comes from the fact that voltage gain at these frequencies is 3*db* below the maximum value. The term half-power is used because when voltage is down to 0.707 of its maximum value, the power (proportional to V^2) is down to $(0.707)^2$ or one-half of its maximum value.

Example .*Express the following gains as a number:*

(i) Power gain of 40 db (ii) Power gain of 43 db

Solution.

(i) Power gain = 40 *db*= 4 *bel*

If we want to find the gain as a number, we should work from logarithm back to the originalnumber.

Gain = Antilog 4 = 10^4 = **10,000**

(ii) Power gain = 43 *db*= 4.3 *bel*

∴ Power gain = Antilog 4.3 = 2×10^4 = **20,000**

Alternatively. $$10 \log_{10} \frac{P_2}{P_1} = 43\ db$$

or $$\log_{10} \frac{P_2}{P_1} = 43/10 = 4.3$$

$$\therefore \quad \frac{P_2}{P_1} = (10)^{4.3} = \mathbf{20{,}000}$$

In general, we have,

$$\frac{V_2}{V_1} = (10)^{gain\ in\ db/20}$$

$$\frac{P_2}{P_1} = (10)^{gain\ in\ db/10}$$

Example .(*i*) *A multistage amplifier employs five stages each of which has a power gain of 30. What is the total gain of the amplifier in db*?

(*ii*) *If a negative feedback of 10 db is employed, find the resultant gain*.

Solution. Absolute gain of each stage = 30

No. of stages = 5

(*i*) Power gain of one stage in *db* $= 10 \log_{10} 30 = 14.77$

$\therefore$ Total power gain $= 5 \times 14.77 =$ **73.85 db**

(*ii*) Resultant power gain with negative feedback

$= 73.85 - 10 =$ **63.85 db**

Example.*In an amplifier, the output power is 1.5 watts at 2 kHz and 0.3 watt at 20 Hz, while the input power is constant at 10 mW. Calculate by how many decibels gain at 20 Hz is below that at 2 kHz* ?

Solution.

db power gain at 2 kHz. At 2 kHz, the output power is 1.5 W and input power is 10 mW.

$$\text{Power gain in } db = 10 \log_{10} \frac{1.5\ \text{W}}{10\ \text{mW}} = 21.76$$

db power gain at 20 Hz. At 20Hz, the output power is 0.3 W and input power is 10 mW.

$$\text{Power gain in } db = 10 \log_{10} \frac{0.3\ \text{W}}{10\ \text{mW}} = 14.77$$

Fall in gain from 2 kHz to 20 Hz = 21.76 − 14.77 = **6.99 db**

Example 11.8. *An amplifier feeding a resistive load of 1kΩ has a voltage gain of 40 db. If the input signal is 10 mV, find (i) output voltage (ii) load power.*

Solution.

(*i*) $$\frac{V_{out}}{V_{in}} = (10)^{db\ gain/20} = (10)^{40/20} = 100$$

$$\therefore \quad V_{out} = 100 \times V_{in} = 100 \times 10\ \text{mV} = 1000\ \text{mV} = \mathbf{1\ V}$$

(*ii*) $$\text{Load power} = \frac{V_{out}^2}{R_L} = \frac{(1)^2}{1000} = 10^{-3}\ \text{W} = \mathbf{1\ mW}$$

Example 11.9. *An amplifier rated at 40W output is connected to a 10Ω speaker.*

(*i*) *Calculate the input power required for full power output if the power gain is 25 db.*

(*ii*) *Calculate the input voltage for rated output if the amplifier voltage gain is 40 db.*

Solution.

(*i*) $$\text{Power gain in } db = 10 \log_{10} \frac{P_2}{P_1} \quad \text{or} \quad 25 = 10 \log_{10} \frac{40\text{W}}{P_1}$$

$$\therefore \quad P_1 = \frac{40\text{W}}{\text{antilog } 2.5} = \frac{40\text{W}}{3.16 \times 10^2} = \frac{40\text{W}}{316} = \mathbf{126.5\ mW}$$

(*ii*) $$\text{Voltage gain in } db = 20 \log_{10} \frac{V_2}{V_1} \quad \text{or} \quad 40 = 20 \log_{10} \frac{V_2}{V_1}$$

$$\therefore \quad \frac{V_2}{V_1} = \text{antilog } 2 = 100$$

Now $$V_2 = \sqrt{P_2\ R} = \sqrt{40\text{W} \times 10\ \Omega} = 20\ \text{V}$$

$$\therefore \quad V_1 = \frac{V_2}{100} = \frac{20\text{V}}{100} = \mathbf{200\ mV}$$

Example 11.10. *In an amplifier, the maximum voltage gain is 2000 and occurs at 2 kHz. It falls to 1414 at 10 kHz and 50 Hz. Find :*

(i) Bandwidth (ii) Lower cut-off frequency (iii) Upper cut-off frequency.

Solution.

(*i*) Referring to the frequency response in Fig. 11.8, the maximum gain is 2000. Then 70.7% of this gain is 0.707 × 2000 = 1414. It is given that gain is 1414 at 50 Hz and 10 kHz. As bandwidth is the range of frequency over which gain is equal or greater than 70.7% of maximum gain,

∴ Bandwidth = **50 Hz to 10 kHz**

(*ii*) The frequency (on lower side) at which the voltage gain of the amplifier is exactly 70.7% of the maximum gain is known as *lower cut-off frequency.* Referring to Fig. 11.8, it is clear that :

Lower cut-off frequency = **50 Hz**

(*iii*) The frequency (on the higher side) at which the voltage gain of the amplifier is exactly 70.7% of the maximum gain is known as *upper cut-off frequency*. Referring to Fig. 11.8, it is clear that:

Upper cut-off frequency = **10 kHz**

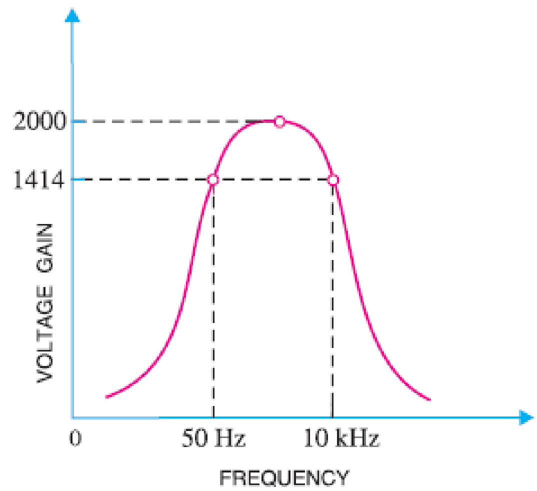

Fig. 11.8

Comments. As bandwidth of the amplifier is 50 Hz to 10 kHz, therefore, it will amplify the signal frequencies lying in this range without any distortion. However, if the signal frequency is not in this range, then there will be distortion in the output.

Note. The *db* power rating of communication equipment is normally less than 50 *db*.

Properties of db Gain

The power gain expressed as a number is called ordinary power gain. Similarly, the voltage gain expressed as a number is called ordinary voltage gain.

1. Properties of *db*power gain. The following are the useful rules for *db*power gain:
(*i*) *Each time the ordinary power gain increases (decreases) by a factor of 10, the db power gain increases (decreases) by 10 db.*
For example, suppose the ordinary power gain increases from 100 to 1000 (*i.e*. by a factor of 10).

$$\text{Increase in } db \text{ power gain} = 10\log_{10} 1000 - 10\log_{10} 100 = 30 - 20 = 10\,db$$

This property also applies for the decrease in power gain.
(*ii*) *Each time the ordinary power gain increases (decreases) by a factor of 2, the db power gain increases (decreases) by 3 db.*
For example, suppose the power gain increases from 100 to 200 (*i.e.* by a factor of 2).

$$\therefore \quad \text{Increase in } db \text{ power gain} = 10\log_{10}200 - 10\log_{10}100 = 23 - 20 = 3\ db$$

2. Properties of db voltage gain. The following are the useful rules for *db*voltage gain:

(*i*) *Each time the ordinary voltage gain increases (decreases) by a factor of 10, the db voltage gain increases (decreases) by 20 db.*

For example, suppose the voltage gain increases from 100 to 1000 (*i.e.* by a factor of 10).

$$\therefore \quad \text{Increase in } db \text{ voltage gain} = 20\log_{10}1000 - 20\log_{10}100 = 60 - 40 = 20\ db$$

(*ii*) *Each time the ordinary voltage gain increases (decreases) by a factor of 2, the db voltage gain increases (decreases) by 6 db.*

For example, suppose the voltage gain increases from 100 to 200 (*i.e.* by a factor of 2).

$$\therefore \quad \text{Increase in } db \text{ voltage gain} = 20\log_{10}200 - 20\log_{10}100 = 46 - 40 = 6\ db$$

1. RC Coupled Transistor Amplifier

- This is the most popular type of coupling because it is cheap and provides excellent audio fidelity over a wide range of frequency.
- Fig.9: shows twostages of an *RC* coupled amplifier. A coupling capacitor *CC* is used to connect the output of first stageto the base (*i.e. input*) of the second stage and so on. As the coupling from one stage to next isachieved by a coupling capacitor followed by a connection to a shunt resistor, therefore, such amplifiers are called *resistance - capacitance coupled amplifiers*.
- The emitter bypasscapacitor offers low reactance path to the signal. Without it, the voltage gain of each stage would be lost.
- The coupling capacitor *CC* transmits a.c. signal but blocks d.c.
- This prevents d.c. interference between various stages and the shifting of operating point.

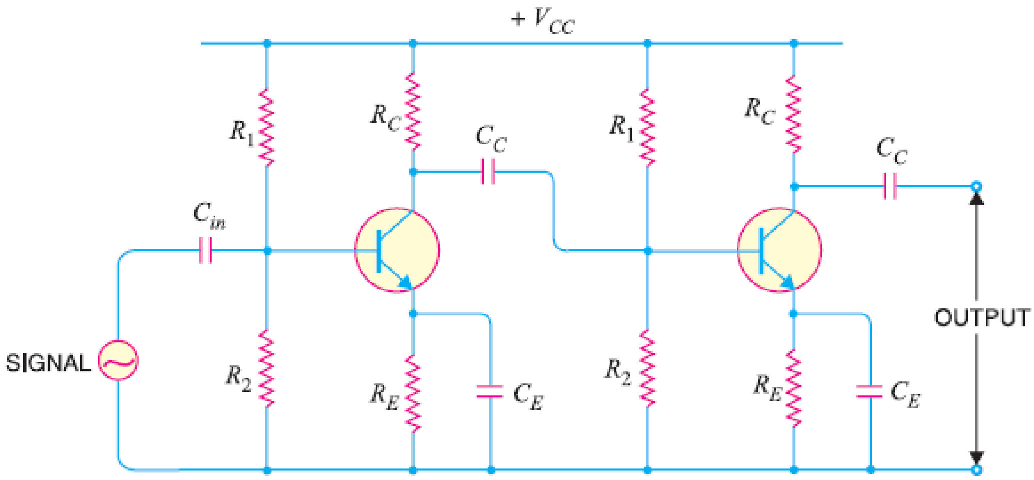

Fig.9: RC coupled transistor amplifier

It may be mentioned here that total gain is less than the product of the gains of individual stages.It is because when a second stage is made to follow the first stage, the *effective load resistance* of first stage is reduced due to the shunting effect of the input resistance of second stage. This reduces the gain of the stage which is loaded by the next stage. For instance, in a 3-stage amplifier, the gain of first and second stages will be reduced due to loading effect of next stage. However, the gain of the third stage which has no loading effect of subsequent stage, remains unchanged. The overall gain shall be equal to the product of the gains of three stages.

Frequency response of RC coupled. Fig.10 shows the frequency response of a typical RC coupled amplifier. It is clear that voltage gain drops off at low (< 50 Hz) and high (> 20 kHz) frequencies whereas it is uniform over mid-frequency range (50 Hz to 20 kHz). This behaviour of the amplifier is briefly explained below:

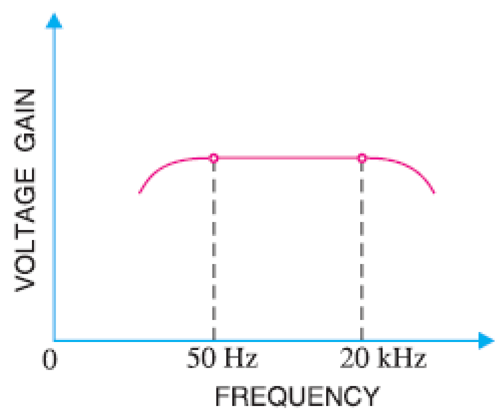

Fig.10: the frequency response of a typical RC coupled amplifier

(*i*) *At low frequencies* (< 50 Hz), the reactance ofcoupling capacitor $C_C$is quite high and hence very small part of signal will pass from one stage to the next stage. Moreover, *CE* cannot shunt the emitter resistance *RE* effectively because of its large reactance at low frequencies. These two factors cause a falling of voltage gain at low frequencies.

(*ii*) *At high frequencies* (> 20 kHz), the reactance of $C_C$is very small and it behaves as a short circuit. This increases the loading effect of next stage and serves to reduce the voltage gain. Moreover, at high frequency, capacitive reactance of base-emitter junction is low which increases the base current. This reduces the current amplification factor β. Due to these two reasons, the voltage gain drops off at high frequency.

(*iii*) *At mid-frequencies* (50 Hz to 20 kHz), the voltage gain of the amplifier is constant. Theeffect of coupling capacitor in this frequency range is such so as to maintain a uniform voltage gain. Thus, as the frequency increases in this range, reactance of $C_C$decreases which tends to increase the gain. However, at the same time, lower reactance means higher loading of first stage and hence lower gain. These two factors almost cancel each other, resulting in a uniform gain at mid-frequency.

Advantages

(i) It has excellent frequency response. The gain is constant over the audio frequency range which is the region of most importance for speech, music etc.

(ii) It has lower cost since it employs resistors and capacitors which are cheap.

(iii) The circuit is very compact as the modern resistors and capacitors are small and very light.

Disadvantages

(i) The RC coupled amplifiers have low voltage and power gain. It is because the low resistance presented by the input of each stage to the preceding stage decreases the effective load resistance (R_{AC}) and hence the gain.

(ii) They have the tendency to become noisy with age, particularly in moist climates.

(iii) Impedance matching is poor. It is because the output impedance of RC coupled amplifier isseveral hundred ohms whereas the input impedance of a speaker is only a few ohms. Hence, little power will be transferred to the speaker.

Applications

The *RC* coupled amplifiers have excellent audio fidelity over a wide range of frequency. Therefore, they are widely used as voltage amplifiers *e.g.* in the initial stages of public address system.

Example 11.11 *A single stage amplifier has a voltage gain of 60. The collector load RC = 500Ω and the input impedance is 1kΩ. Calculate the overall gain when two such stages are cascaded through R-C coupling.*

Solution. The gain of second stage remains 60 because it has no loading effect of any stage. However, the gain of first stage is less than 60 due to the loading effect of the input impedance of second stage.

$$\text{Gain of second stage} = 60$$

$$\text{Effective load of first stage} = R_C \| R_{in} = \frac{500 \times 1000}{500 + 1000} = 333\ \Omega$$

$$\text{Gain of first stage} = 60 \times 333/500 = 39.96$$

$$\text{Total gain} = 60 \times 39.96 = 2397$$

2. Direct-Coupled Amplifier

There are many applications in which very low frequency (< 10 Hz) signals are to be amplifiede.g. amplifying photo-electric current, thermo-couple current etc. The coupling devices such as capacitorsand transformers cannot be used because the electrical sizes of these components become verylarge at very low frequencies. Under such situations, one stage is *directly* connected to the nextstage without any intervening coupling device. This type of coupling is known as *direct coupling*.

Circuit details. Fig.11 shows the circuit of a three-stage direct-coupled amplifier. It usescomplementary transistors(This makes the circuit stable w.r.t. temperature changes.). Thus, the first stage uses *npn*transistor, the second stage uses *pnp*transistor and so on. This arrangement makes the design very simple. The output from the collectorof first transistor $T1$ is fed to the input of the second transistor $T2$ and so on.

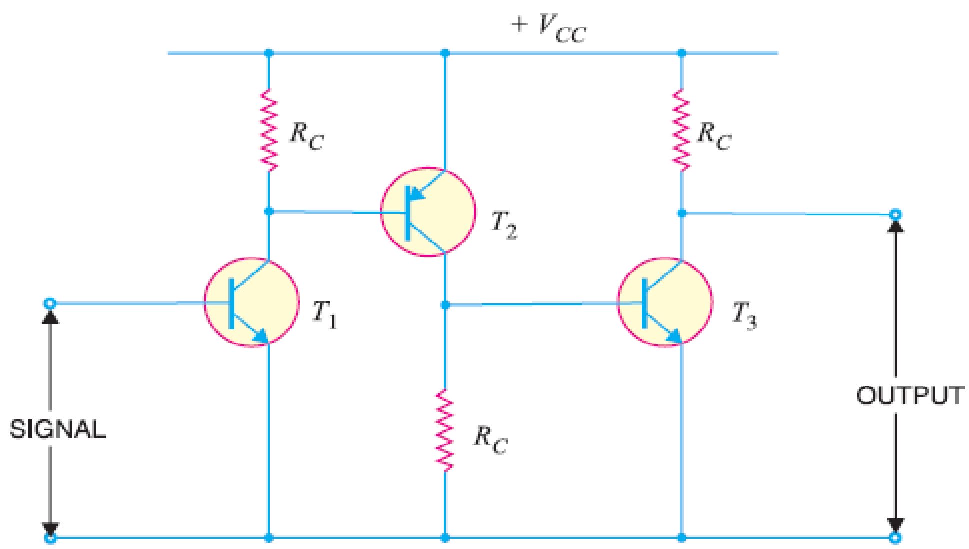

Fig.11: three stages direct coupled amplifier

The weak signal is applied to the input of first transistor $T1$. Due to transistor action, an amplifiedoutput is obtained across the collector load RC of transistor $T1$. This voltage drives the base of the second transistor and amplified output is obtained across its collector load. In this way, direct coupled amplifier raises the strength of weak signal.

Advantages

(*i*) The circuit arrangement is simple because of minimum use of resistors.

(*ii*) The circuit has low cost because of the absence of expensive coupling devices.

Disadvantages

(*i*) It cannot be used for amplifying high frequencies.

(*ii*) The operating point is shifted due to temperature variations.

Example 11.12. *Fig. 11.11 shows two-stage RC coupled amplifier. If the input resistance R_{in} of each stage is 1kΩ, find : (i) voltage gain of first stage (ii) voltage gain of second stage (iii) total voltage gain.*

Solution.

$$R_{in} = 1\text{ k}\Omega\ ; \quad \beta = 100\ ; \quad R_C = 2\text{ k}\Omega$$

(*i*) The first stage has a loading of input resistance of second stage.

$\therefore$ Effective load of first stage, $R_{AC} = R_C \parallel R_{in} = \dfrac{2 \times 1}{2 + 1} = 0.66\text{ k}\Omega$

$\therefore$ Voltage gain of first stage $= \beta \times R_{AC} / R_{in} = 100 \times 0.66 / 1 = 66$

(*ii*) The collector of the second stage sees a load of only R_C (= 2 kΩ) as there is no loading effect of any subsequent stage.

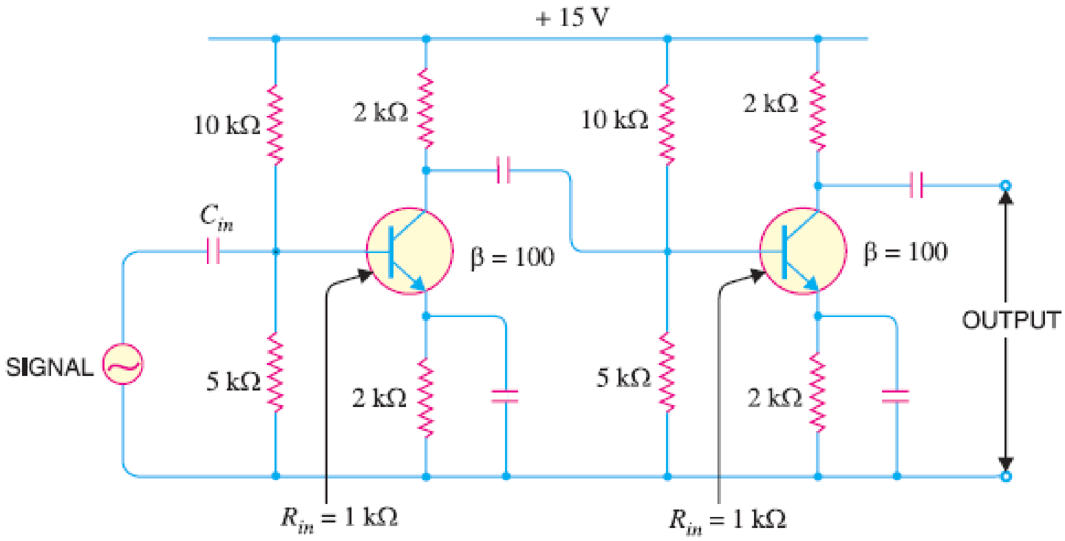

Fig. 11.11

∴ Voltage gain of second stage

$$= \beta \times R_C / R_{in} = 100 \times 2/1 = 200$$

(iii) Total voltage gain $= 66 \times 200 = 13200$

Example 11.13. *A single stage amplifier has collector load $R_C = 10$ kΩ; input resistance R_{in} = 1kΩ and β = 100. If load $R_L = 100\Omega$, find the voltage gain. Comment on the result.*

Solution. Effective collector load, $R_{AC} = R_C \,||\, R_L = 10\text{ k}\Omega \,||\, 100\ \Omega = {}^{*}100\ \Omega$

∴ $$\text{Voltage gain} = \beta \times \frac{R_{AC}}{R_{in}} = 100 \times \frac{100}{1000} = 10$$