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CHAPTER 62

Learning Objectives

CONTENTS

FEEDBACK AMPLIFIER

A feedback amplifier is one in which a fraction of the amplifier output is fed back to the input circuit

62.1. Feedback Amplifiers

A feedback amplifier is one in which a fraction of the amplifier output is fed back to the input circuit. This partial dependence of amplifier output on its input helps to control the output. A feedback amplifier consists of two parts : an amplifier and a feedback circuit.

(*i*) Positive feedback

If the feedback voltage (or current) is so applied as to increase the input voltage (*i.e.* it is in phase with it), then it is called positive feedback. Other names for it are : ***regenerative* or *direct*** feedback.

Since positive feedback produces excessive distortion, it is seldom used in amplifiers. However, because it increases the power of the original signal, it is used in oscillator circuits.

(*ii*) Negative feedback

If the feedback voltage (or current) is so applied as to reduce the amplifier input (*i.e.* it is 180° out of phase with it), then it is called negative feedback. Other names for it are : ***degenerative*** or ***inverse*** feedback.

Negative feedback is frequently used in amplifier circuits.

62.2. Principle of Feedback Amplifiers

For an ordinary amplifier *i.e.* one without feedback, the voltage gain is given by the ratio of the output voltage V_o and input voltage V_i. As shown in the block diagram of Fig. 62.1, the input voltage V_i is amplified by a factor of A to the value V_o of the output voltage.

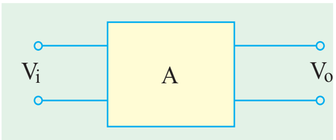

Fig. 62.1

$$\therefore \quad A = V_o/V_i$$

This gain A is often called ***open-loop*** gain.

Suppose a feedback loop is added to the amplifier (Fig. 62.2). If V_o' is the output voltage with feedback, then a fraction β* of this voltage is applied to the input voltage which, therefore, becomes $(V_i \pm \beta V_o')$ depending on whether the feedback voltage is in phase or antiphase with it. Assuming positive feedback, the input voltage will become $(V_i + \beta V_o')$. When amplified A times, it becomes $A(V_i + \beta V_o')$.

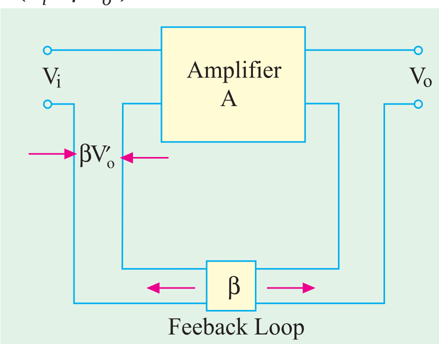

Fig. 62.2

$$\therefore \quad A(V_i + \beta V_o') = V_o'$$

$$\text{or} \quad V_o'(1 - \beta A) = AV_i$$

The amplifier gain A' with feedback is given by

$$A' = \frac{V_o'}{V_i} = \frac{A}{1 - \beta A}$$

$$\therefore \quad A' = \frac{A}{1 - \beta A} \qquad \text{— positive feedback}$$

$$= \frac{A}{1 - (-\beta A)} = \frac{A}{1 + \beta A} \qquad \text{— negative feedback}$$

The term 'βA' is called **feedback factor** whereas β is known as **feedback ratio**. The expression $(1 \pm \beta A)$ is called **loop gain**. The amplifier gain A' with feedback is also referred to as **closed-loop gain** because it is the gain obtained after the feedback loop is closed. The sacrifice factor is defined as $S = A/A'$.

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* It may please be noted that it is not the same as the β of a transistor (Art.57.9)

(*a*) Negative Feedback

The amplifier gain with negative feedback is given by $A' = \dfrac{A}{(1+\beta A)}$

Obviously, $A' < A$ because $|1 + \beta A| > 1$.
Suppose, $A = 90$ and $\beta = 1/10 = 0.1$
Then, gain without feedback is 90 and with negative feedback is

$$A' = \frac{A}{1+\beta A} = \frac{90}{1+0.1\times 90} = 9$$

As seen, negative feedback reduces the amplifier gain. That is why it is called ***degenerative*** feedback. A lot of voltage gain is sacrificed due to negative feedback. When $|\beta A| \gg 1$, then

$$A' \cong \frac{A}{\beta A} \cong \frac{1}{\beta}$$

It means that A' depends only on β. But it is very stable because it is not affected by changes in temperature, device parameters, supply voltage and from the aging of circuit components etc. Since resistors can be selected very precisely with almost zero temperature-coefficient of resistance, it is possible to achieve highly precise and stable gain with negative feedback.

(*b*) Positive Feedback

The amplifier gain with positive feedback is given by

$$A' = \frac{A}{1-\beta A}$$

Since $|1 - \beta A| < 1$, $A' > A$

Suppose gain without feedback is 90 and $\beta = 1/100 = 0.01$, then gain with positive feedback is

$$A' = \frac{90}{1-(0.01\times 90)} = 900$$

Since positive feedback increases the amplifier gain. It is called ***regenerative*** feedback. If $\beta A = 1$, then mathematically, the gain becomes infinite which simply means that there is an output without any input! However, electrically speaking, this cannot happen. What actually happens is that the amplifier becomes an oscillator which supplies its own input. In fact, two important and necessary conditions for circuit oscillation are

1. the feedback must be positive, **2.** feedback factor must be unity *i.e.* $\beta A = +1$.

62.3. Advantages of Negative Feedback

The numerous advantages of negative feedback outweigh its only disadvantage of reduced gain. Among the advantages are :

1. higher fidelity *i.e.* more linear operation,
2. highly stabilized gain,
3. increased bandwidth *i.e.* improved frequency response,
4. less amplitude distortion,
5. less harmonic distortion,
6. less frequency distortion,
7. less phase distortion,
8. reduced noise,
9. input and output impedances can be modified as desired.

Example 62.1. *In the series-parallel (SP) feedback amplifier of Fig. 62.3, calculate*
(*a*) *open-loop gain of the amplifier,* **(*b*)** *gain of the feedback network,*
(*c*) *closed-loop gain of the amplifier,* **(*d*)** *sacrifice factor, S.*

(Applied Electronics-I, Punjab Univ. 1991)

Solution. (*a*) Since 1 mV goes into the amplifier and 10 V comes out

$\therefore \quad A = \dfrac{10\text{ V}}{1\text{mV}} = \mathbf{10{,}000}$

(b) The feedback network is being driven by the output voltage of 10 V.

∴ Gain of the feedback network

$$= \frac{\text{output}}{\text{input}} = \frac{250\text{ mV}}{10\text{ V}} = \mathbf{0.025}$$

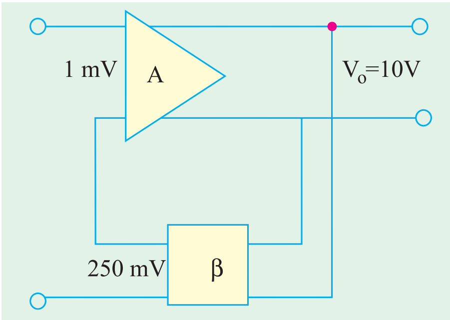

Fig. 62.3

(c) So far as the feedback amplifier is concerned, input is (250 + 1) = 251 mV and final output is 10 V. Hence, gain with feedback is

$A' = 10\text{ V}/251\text{ mA} = \mathbf{40}$

(d) The sacrifice factor is given by

$$S = \frac{A}{A'} = \frac{10{,}000}{40} = \mathbf{250}$$

By sacrificing so much voltage gain, we have improved many other amplifier quantities. (Art. 62.3)

Example 62.2. *Calculate the gain of a negative feedback amplifier whose gain without feedback is 1000 and β = 1/10. To what value should the input voltage be increased in order that the output voltage with feedback equals the output voltage without feedback ?*

Solution. Since | β*A* | » 1, the closed-loop gain is $A' \cong \dfrac{1}{\beta} \cong \dfrac{1}{1/10} = \mathbf{10}$

The new increased input voltage is given by

$V_i' = V_i(1 + \beta A) = 50\,(1 + 0.04 \times 100) = \mathbf{250\ mV}$

Example 62.3. *In a negative-feedback amplifier, A = 100, β = 0.04 and V_i = 50 mV. Find*
(a) *gain with feedback,* **(b)** *output voltage,*
(c) *feedback factor,* **(d)** *feedback voltage.* **(Applied Electronics, AMIEE, London)**

Solution. (a) $A' = \dfrac{A}{1+\beta A} = \dfrac{100}{1 + 0.04 \times 100} = \mathbf{20}$

(b) $V_0' = A'\,V_i = 20 \times 50\text{ mV} = \mathbf{1V}$ **(c)** feedback factor $= \beta A = 0.04 \times 100 = \mathbf{4}$

(d) Feedback voltage $= \beta V_o' = 0.04 \times 1 = \mathbf{0.04\ V}$

Example 62.4. *An amplifier having a gain of 500 without feedback has an overall negative feedback applied which reduces the gain to 100. Calculate the fraction of output voltage feedback. If due to ageing of components, the gain without feedback falls by 20%, calculate the percentage fall in gain without feedback.* **(Applied Electronics-II, Punjab Univ. 1993)**

Solution. $A' = \dfrac{A}{1+\beta A} \qquad \therefore \qquad 1 + \beta A = \dfrac{A}{A'}$

$$\therefore \qquad \beta = \frac{1}{A'} - \frac{1}{A} = \frac{1}{100} - \frac{1}{500} = \mathbf{0.008}$$

Now, gain without feedback = 80% of 500 = 400

$$\therefore \qquad \text{New} \qquad A' = \frac{400}{1 + 0.008 \times 400} = 95.3$$

Hence, change in the gain with feedback in the two cases = 100 – 95.3 = 4.7

$$\therefore \qquad \text{Percentage fall in gain with feedback is} = \frac{4.7}{100} \times 100 = \mathbf{4.7\%}$$

Example 62.5. *An amplifier with negative feedback has a voltage gain of 100. It is found that without feedback an input signal of 50 mV is required to produce a given output whereas with feedback, the input signal must be 0.6 V for the same output. Calculate the value of voltage gain without feedback and feedback ratio.* **(Bangalore University 2001)**

Solution. $V_o' = A'V_i = 100 \times 0.6 = 60$ V and $V_o = AV_i$

Since the output voltage with and without feedback are required to be the same,

$\therefore$ 60 = A × 50 mV, $\therefore$ $A = \dfrac{60}{50\,\text{mV}}$ = **1200**

The amplifier gain with feedback,

$$A' = \frac{A}{1+\beta A} \quad \text{or} \quad \beta = \frac{A - A'}{AA'} = \frac{1200-100}{1200 \times 100} = \mathbf{0.009}$$

62.4. Gain Stability

The gain of an amplifier with negative feedback is given by $A' = \dfrac{A}{1+\beta A}$

Taking logs of both sides, we have $\log_e A' = \log_e A - \log_e(1 + \beta A)$

Differentiating both sides, we get

$$\frac{dA'}{A'} = \frac{dA}{A} - \frac{\beta . dA}{1+\beta A} = dA\left(\frac{1}{A} - \frac{\beta}{1+\beta A}\right) = \frac{1}{1+\beta A}\frac{dA}{A} = \frac{(dA/A)}{1+\beta A}$$

If βA » 1, then the above expression becomes

$$\frac{dA'}{A'} = \frac{1}{\beta A} \cdot \frac{dA}{A}$$

Example 62.6. *An amplifier has an open-loop gain of 400 and a feedback of 0.1. If open-loop gain changes by 20% due to temperature, find the percentage change in closed-loop gain.* **(Electronics-III, Bombay 1991)**

Solution. Here, $A = 400$, $\beta = 0.1$, $dA/A = 20\% =$ **0.2**

$$\text{Now,} \quad \frac{dA'}{A'} = \frac{1}{\beta A} \cdot \frac{dA}{A} = \frac{1}{0.1 \times 400} \times 20\% = \mathbf{0.5\%}$$

It is seen that while the amplifier gain changes by 20%, the feedback gain changes by only 0.5% *i.e.* an improvement of 20/0.5 = 40 times

62.5. Decreased Distortion

Let the harmonic distortion voltage generated within the amplifier change from D to D' when negative feedback is applied to the amplifier.

Suppose $D' = x\,D$ ... (*i*)

The fraction of the output distortion voltage which is fedback to the input is

$$\beta D' = \beta\, x\, D$$

After amplification, it become $\beta\, x\, D_A$ and is antiphase with original distortion voltage D. Hence, the new distortion voltage D' which appears in the output is

$D' = D - \beta\, x\, DA$ ... (*ii*)

From (*i*) and (*ii*), we get

$$xD = D - \beta\, x\, DA \quad \text{or} \quad x = \frac{1}{1+\beta A}$$

Substituting this value of x in Eq. (*i*) above, we have $D' = \dfrac{D}{1+\beta A}$

It is obvious from the above equation that $D' < D$. In fact, negative feedback reduces the amplifier distortion by the amount of loop gain *i.e.* by a factor of $(1 + \beta A)$.

However, it should be noted that improvement in distortion is possible only when the distortion is produced by the ***amplifier itself,*** not when it is already present in the input signal.

62.6. Feedback Over Several Stages

Multistage amplifiers are used to achieve greater voltage or current amplification or both. In such a case, we have a choice of applying negative feedback to improve amplifier performance. Either we apply some feedback across each stage or we can put it in one loop across the whole amplifier.

A multistage amplifier is shown in Fig. 62.4. In Fig. 62.4 (*a*) each stage of the *n*-stage amplifier has a feedback applied to it. Let A and β_1 be the open-loop gain and feedback ratio respectively of each stage and A_1 the overall gain of the amplifier. Fig. 62.4 (*b*) shows the arrangemnent where n amplifiers have been cascaded in order to get a total gain of A^n. Let the overall feedback factor be β_2 and the overall gain A_2. The values of the two gains are given as

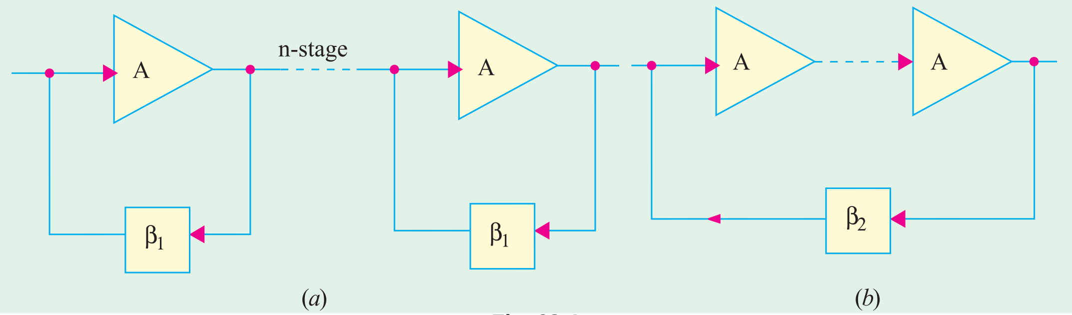

Fig. 62.4

$$A_1 = \left(\frac{A}{1+A\beta_1}\right)^n \qquad \text{and} \qquad A_1 = \frac{A^n}{1+A^n\beta_2} \qquad \text{... }(i)$$

Differentiating the above two expressions, we get

$$\frac{dA_1}{A_1} = \frac{n}{1+A\beta_1}\cdot\frac{dA}{A} \qquad \text{and} \qquad \frac{dA_2}{A_2} = \frac{n}{1+A^n\beta_2}\cdot\frac{dA}{A}$$

For the two circuits to have the same overall gain, $A_1 = A_2$. Hence, from Eqn. (*i*) above, we get $(1 - 1\beta)^n = 1 + A^n\,\beta_2$

$$\therefore \qquad \frac{dA_2 / A_2}{dA_1 / A_1} = \frac{1}{(1+A\beta)^{n-1}}$$

If $n = 1$, then the denominator in the above equation becomes unity so that fractional gain variations are the same as expected. However, for $n > 1$ and with $(1 + A\beta_1)$ being a normally large quantity, the expression dA_2/A_2 will be less than dA_1/A_1. It means that the overall feedback would appear to be beneficial as far as stabilizing of the gain is concerned.

Example 62.7. *An amplifier with 10% negative feedback has an open-loop gain of 50. If open-loop gain increases by 10%, what is the percentage change in the closed-loop gain ?*

(Applied Electronics-I, Punjab Univ. 1991)

Solution. Let A_1' and A_2' be the closed-loop gains in the two cases and A_1 and A_2 the open-loop gains respectively.

(*i*) $A'_1 = \dfrac{A_1}{1+\beta A_1} = \dfrac{50}{1+0.1\times 50} = \mathbf{8.33}$

(*ii*) When open-loop gain changes by 10%, then $A_2 = 50 + 0.1 \times 50 = 55$

$$\therefore \quad A_2' = \frac{A_2}{1+\beta A_2} = \frac{55}{1+0.1\times 55} = 8.46$$

∴ Percentage change in closed-loop gain is

$$= \frac{A_2' - A_1'}{A_1'} \times 100 = \frac{8.46-8.33}{8.33} \times 100 = \textbf{1.56\%}$$

Example 62.8. *Write down formulae for* **(i)** *gain* **(ii)** *harmonic distortion of a negative feedback amplifier in terms of gain and distortion without feedback and feedback factor. If gain without feedback is 36 dB and harmonic distortion at the normal output level is 10%, what is* **(a)** *gain and* **(b)** *distortion when negative feedback is applied, the feedback factor being 16 dB.*

(Electronic Engg. II, Warangal 1991)

Solution. For first part, please refer to Art. 62.6. Distortion ratio is defined as the ratio of the amplitude of the largest harmonic to the amplitude of the fundamental.

$$A_f = A' = \frac{A}{1+\beta A}$$

Now, dB gain = 20 $\log_{10} A$ ∴ 36 = 20 $\log_{10} A$, A = 63

dB feedback factor = 20 $\log_{10} \beta A$ 16 = 20 $\log_{10} \beta A$ or βA = 6.3

(a) A_f = $A/(1 + \beta A)$ = 63/(1 + 6.3) = **6.63** or **18.72 dB**

(b) D' = 10 per cent/(1 + 6.3) = **1.4 per cent**

Example 62.9. *The overall gain of a two-stage amplifier is 150. The second stage has 10% of the output voltage as negative feedback and has –150 as forward gain. Calculate* **(a)** *gain of the first stage* **(b)** *the second harmonic distortion, if the second stage introduces 5% second harmonic without feedback. Assume that the first stage does not introduce distortion.*

(Electronics-II, Madras Univ. 1992)

Solution. (a) For second stage $D_2' = \frac{D_2}{1+\beta A_2} = \frac{0.05}{1+150\times 0.1} =$ **0.31%**

(b) For the second stage, gain with feedback is

$$A_2' = \frac{A_2}{1+\beta A_2} = \frac{150}{1+150\times 0.1} = 9.38$$

Now, $A_1 \times A_2' = 150$; $A_1 = 150/9.38 =$ **16**

Example 62.10. *Determine the effective ga-*in of a feedback amplifier having an amplification without feedback of (–200 – j300) if the feedback circuit adds to the input signal, a p.d. which is 0.5 percent of the output p.d. and lags a quarter of a cycle behind it in phase. Explain whether the feedback in this case is positive or negative.* **(Applied Electronics-II, Punjab Univ. 1992)**

Solution. $A = -200 - j300 = 360 \angle -123.7°$

The feedback voltage V_β is 0.5 percent of the output voltage and lags 90° behind it.

$$\therefore \quad V_\beta = \left(\frac{0.5}{100}\angle -90°\right)V_0$$

$$\therefore \quad \beta = \frac{V_\beta}{V_0} = \frac{0.5}{100}\angle -90° = -j0.005$$

$$\therefore \quad \beta A = (-200 - j300)(-j0.005) = -1.5 + j1.0$$

In general, the stage gain with feedback is given by

$$A' = \frac{A}{1-\beta A} = \frac{360\angle-123.7°}{1-(-1.5+j1.0)} = \frac{360\angle-123.7°}{2.69\angle-21.8°} = \mathbf{134\angle-102°}$$

Since both the magnitude and the phase shift of the amplifier are reduced by feedback, the feedback must be negative.

Example 62.11. *An amplifier has a gain of 100 and 5 per cent distortion with an input signal of 1 V. When an input signal of 1 V is applied to the amplifier, calculate*
(i) output signal voltage, (ii) distortion voltage, (iii) output voltage

Solution. *(i)* Signal output voltage $V_{os} = AV_i = 100 \times 1 =$ **100 V**

(ii) Distortion voltage = $DV_o = 0.05 \times 100 =$ **5 V**

(iii) Amplifier output voltage $V_o = V_{os} + D = 100 + 5 =$ **105 V**

62.7. Increased Bandwidth

The bandwidth of an amplifier without feedback is equal to the separation between the 3 dB frequencies f_1 and f_2.

$$\therefore \quad BW = f_2 - f_1$$

where f_1 = lower 3 dB frequency,
and f_2 = upper 3 dB frequency.

If A is its gain, the gain-bandwidth product is $A \times BW$.

Now, when negative feedback is applied, the amplifier gain is reduced. Since the gain-bandwidth product has to remain the same in both cases, it is obvious that the bandwidth must increase to compensate for the decrease in gain. It can be proved that with negative feedback, the lower and upper 3 dB frequencies of an amplifier become.

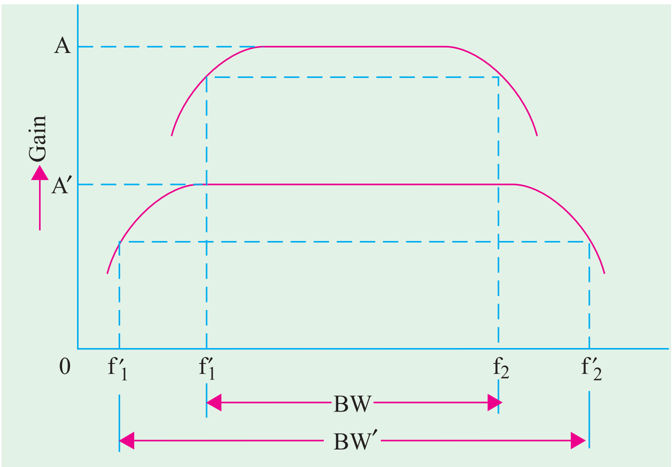

Fig. 62.5

$$(f')_1 = \frac{f_1}{(1+\beta A)} \quad \text{and} \quad (f')_2 = f_2(1+\beta A)$$

As seen from Fig. 62.5, f_1' has decreased whereas f_2' has increased thereby giving a wider separation or bandwidth. Since gain-bandwidth product is the same in both cases.

$\therefore \quad A \times BW = A' \times BW'$ or $A(f_2 - f'_1) = A(f'_2 - f'_1)$

Example 62.12. *An RC-coupled amplifier has a mid-frequency gain of 200 and a frequency response from 100 Hz to 20 kHz. A negative feedback network with β = 0.02 is incorporated into the amplifier circuit. Determine the new system performance.*

(Electronic Circuits, Mysore Univ. 1990)

Solution. $$A' = \frac{A}{1+\beta A} = \frac{200}{1+0.02\times 200} = \mathbf{40\ Hz}$$

$$f_1' = \frac{f_1}{1+\beta A} = \frac{100}{1+0.02\times 200} = \mathbf{20\ Hz}$$

$f_2' = f_0(1 + \beta A) = 20(1 + 0.02 \times 200) =$ **100 Hz**

$dW' = f_2' - f_1' \cong$ **100 kHz**

Incidentally, it may be proved that gain-bandwidth product remains constant in both cases.

$$dW = f_2 - f_1 \cong 20 \text{ kHz}$$

$$A \times dW = 200 \times 20 = 4000 \text{ kHz};$$

$$A' \times dW' = 40 \times 100 = 4000 \text{ kHz}$$

As expected, the two are equal.

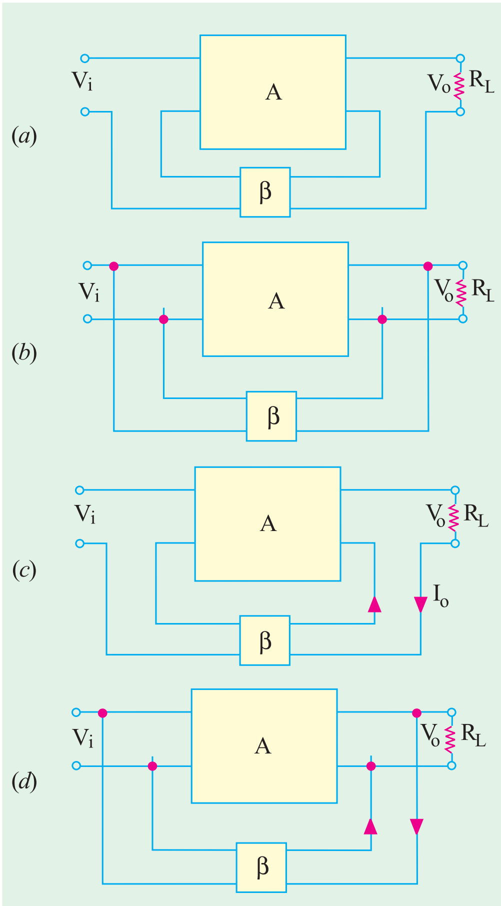

Fig. 62.6

62.8. Forms of Negative Feedback

The four basic arrangements for using negative feedback are shown in the block diagram of Fig. 62.6. As seen, both voltage and current can be fedback to the input either in series or in parallel. The output voltage provides input in Fig. 62.6 (*a*) and (*b*). However, the input to the feedback network is derived from the output current in Fig. 62.6 (*c*) and (*d*).

(*a*) Voltage-series Feedback

It is shown in Fig. 62.6 (*a*). It is also called shunt-***derived series-fed feedback.*** The amplifier and feedback circuit are connected series-parallel. Here, a fraction of the output voltage is applied in series with the input voltage via the feedback. As seen, the input to the feedback network is in parallel with the output of the amplifier. Therefore, so far as V_o is concerned, output resistance of the amplifier is reduced by the shunting effect of the input to the feedback network. It can be proved that

$$R'_o = \frac{R_o}{(1+\beta A)}$$

Shunt Voltage

Similarly, V_i sees two circuit elements in series :

(*i*) the input resistance of the amplifier and

(*ii*) output resistance of the feedback network.

Hence, input resistance of the amplifier as a whole is increased due to feedback. It can be proved that

$$R_i' = R_i(1 + \beta A)$$

In fact, ***series feedback always increases the input impedance by a factor of (1 + βA).***

(*b*) Voltage-shunt Feedback

It is shown in Fig. 62.6 (*b*). It is also known as ***shunt-derived shunt-fed feedback*** *i.e.* it is parallel-parallel (*PP*) prototype. Here, a small portion of the output voltage is coupled back to the input voltage parallel (shunt).

Since the feedback network shunts both the output and input of the amplifier, it decreases both its output and input impedances by a factor of $1/(1 + \beta A)$

A shunt feedback ***always decreases input impedance.***

(*c*) Current-series Feedback

It is shown in Fig. 62.6 (*c*). It is also known as ***series-derived series-fed feedback.*** As seen, it is a series-series (*SS*) circuit. Here, a part of the output current is made to feedback a proportional voltage in series with the input. Since it is a series pick-up and a series feedback, both the input and output impedances of the amplifier are increased due to feedback.

(*d*) Current-shunt Feedback

It is shown in Fig. 62.6 (*d*). It is also referred to as ***series-derived shunt-fed feedback.*** It is a parallel-series (*PS*) prototype. Here, the feedback network picks up a part of the output current and develops a feedback voltage in parallel (shunt) with the input voltage. As seen, feedback network shunts the input but is in series with the output. Hence, output resistance of the amplifier is increased whereas its input resistance is decreased by a factor of loop gain.

The effects of negative feedback on amplifier characteristics are summarized below :

Characteristics	***Type of Feedback***			
	Voltage series	Voltage shunt	Current series	Current shunt
Voltage gain	decreases	decreases	decreases	decreases
Bandwidth	increases	increases	increases	increases
Harmonic Distortion	decreases	decreases	decreases	decreases
Noise	decreases	decreases	decreases	decreases
Input Resistance	increases	decreases	increases	decreases
Output Resistance	decreases	decreases	increases	increases

62.9. Shunt-derived Series-fed Voltage Feedback

The basic principle of such a voltage-controlled feedback is illustrated by the block diagram of Fig. 62.7. Here, the feedback voltage is derived from the voltage divider circuit formed of R_1 and R_2.

As seen, the voltage drop across R_1 forms the feedback voltage V_f.

$$\therefore \quad V_f = V_o \frac{R_1}{R_1 + R_2} = \beta V_o$$

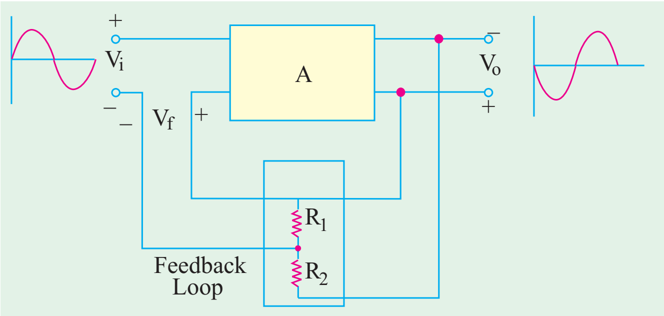

Fig. 62.7

Example 62.13. *In the voltage-controlled negative feedback amplifier of Fig. 62.8, calculate **(a)** voltage gain without feedback **(b)** feedback factor **(c)** voltage gain with feedback. Neglect V_{BE} and use r_e = 25 mV/I_E.*

Solution. (*a*) $A = \dfrac{r_L}{r_e} = \dfrac{R_3}{r_e}$

Now, $I_B = \frac{15\,V}{1.5\,M} = 10\,\mu A$

$I_E = \beta IB = 100 \times 10 = 1\,mA$

$r_e = 25/1 = 25\,\Omega$;

$A = \frac{10K}{25\Omega} = \mathbf{400}$

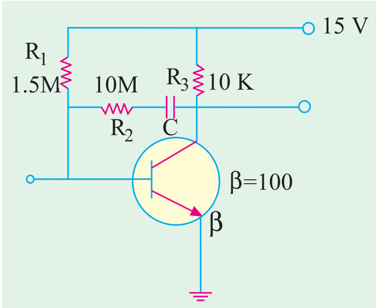

Fig. 62.8

(b) $\beta = \frac{R_1}{R_1 + R_2} = \frac{1.5 \times 10^6}{(1.5 + 10) \times 10^6} = 0.13$

$\therefore \quad \beta A = 0.13 \times 400 = \mathbf{52}$

(c) $A' = \frac{A}{1 + \beta A} = \frac{400}{1 + 52} = \mathbf{7.55}$

62.10. Current-series Feedback Amplifier

Fig. 62.9 shows a series-derived series-fed feedback amplifier circuit. Since the emitter resistor is unbypassed, it effectively provides current-series feedback. When I_E passes through R_E, the feedback voltage drop $V_f = I_E R_E$ is developed which is applied in phase opposition to the input voltage V_i. This negative feedback reduces the output voltage V_0. This feedback can, however, be eliminated by either removing or bypassing the emitter resistor.

It can be proved that

$$\beta = \frac{R_E}{R_C} \quad ; \quad A' = \frac{R_C}{r_e + R_E} \quad ; \quad A = \frac{R_C}{r_e}$$

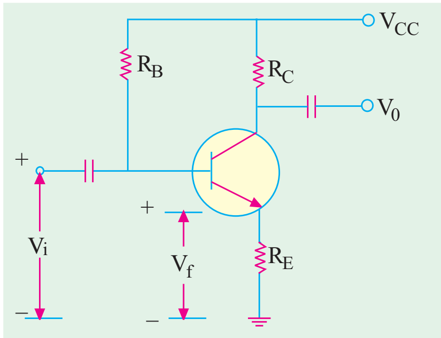

Fig. 62.9

Example 62.14. *For the current-series feedback amplifier of Fig. 62.10, calculate* **(i)** *voltage gain without feedback,* **(ii)** *feedback factor,* **(iii)** *voltage gain with feedback. Neglect V_{BE} and use $r_e = 25\ mV/I_E$.* **(Electronics-I, Madras Univ. 1990)**

Solution. (i) $A = \frac{R_C}{r_e}$

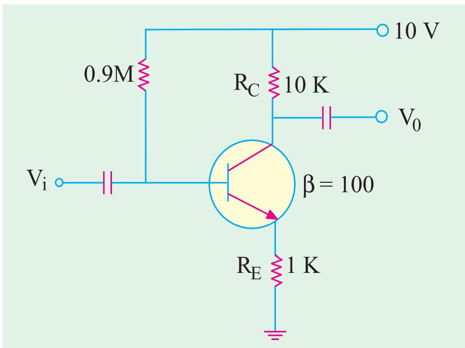

Fig. 62.10

Now, $I_E = \frac{V_{CC}}{R_E + R_B/\beta}$

$= \frac{10}{1 + 900/100} = 1\,mA$

$\therefore \quad r_e = 25/I_E = 25\ \Omega$

$\therefore \quad A = \frac{10K}{25\Omega} = \mathbf{400}$

(ii) $\beta = \frac{R_E}{R_C} = \frac{1}{10} = 0.1$

$\beta A = 0.1 \times 400 = \mathbf{40}$

(*iii*) $A' = \dfrac{R_C}{r_e + R_E} = \dfrac{10,000}{20+1000} = \mathbf{9.756}$

or $A' = \dfrac{A}{1+\beta A} = \dfrac{400}{1+400} = \mathbf{9.756}$

62.11. Voltage-shunt Negative Feedback Amplifier

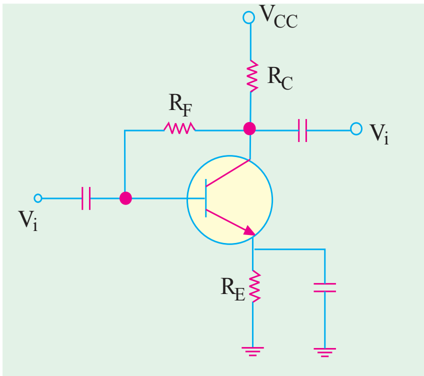

Fig. 62.11

The circuit of such an amplifier is shown in Fig. 62.11. As seen, a portion of the output voltage is coupled through R_E in parallel with the input signal at the base. This feedback stabilizes the overall gain while decreasing both the input and output resistances. It can be proved that $\beta = R_C/R_F$.

62.12. Current-shunt Negative Feedback Amplifier

The two-stage amplifier employing such a feedback is shown in Fig. 62.12. The feedback circuit (consisting of C_F and R_F) samples the output current and develops a feedback voltage in parallel with the input voltage. The unbypassed emitter resistor of Q_2 provides current sensing.

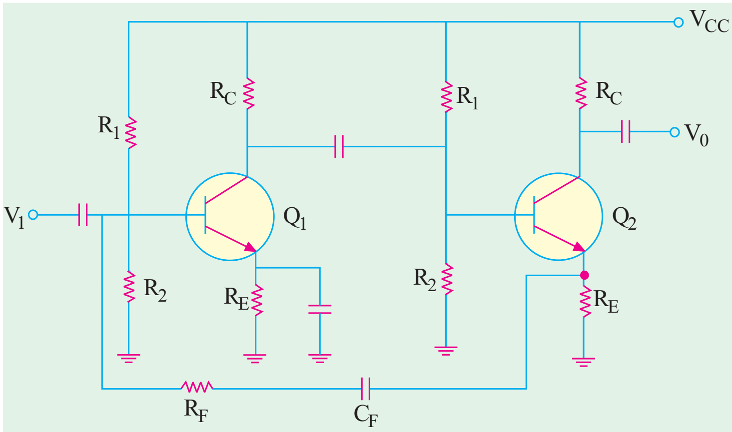

Fig. 62.12

The polarity of the feedback voltage is such that it provides the negative feedback.

Example 62.15. *Calculate A, $r_{in(stage)}$ and $I_{o(stage)}$ of the cascaded amplifier shown in Fig. 62.13 with and without voltage series feedback. The transistor parameters are : h_{fe} = 100,. h_{ie}. = 2 K and h_{oe} = 0.* **(Applied Electronics-I, Punjab Univ. 1992)**

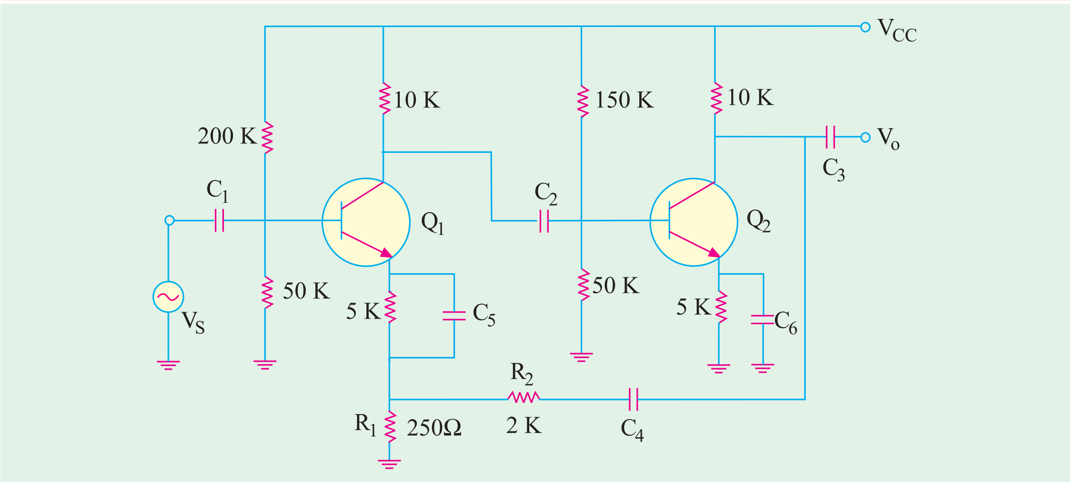

Fig. 62.13

Solution. (*i*) Without Feedback. The $r_{in(base)}$ for Q_1 is = h_{ie}. = 2K. Same is the value for Q_2.
Also, $r_{in(stage)}$ or r_{i-1} for Q_1 = 200 K || 50 K || 2 K = 1.9 K

$r_{0.2}$ or $r_{L.2}$ for Q_2=10 K || (2.0 + 0.25) K = 1.83K

$r_{0.1}$ or $r_{L.1}$ for Q_1 = 10 K ||

150 K // 50 || 2K = 1.6 K

$$\therefore \quad A_{v1} = \frac{h_{fe.1}\, r_{0.1}}{h_{ie}} = \frac{h_{fe.1}\, r_{L.1}}{h_{ie}}$$

$$= \frac{100 \times 1.6}{2} = 80$$

$$A_{v2} = \frac{h_{fe.2} r_{0.2}}{h_{ie}} = \frac{h_{fe.2}\, r_{L2}}{h_{ie}} = \frac{100 \times 1.83}{2} = 92$$

Overall gain, $A_v = A_{v1} \cdot A_{v2}$ = 80 × 92 = **7360**

(*ii*) With Feedback

The feedback factor, $\beta = \dfrac{R_1}{R_1 + R_2} = \dfrac{0.25}{0.25+2.0} = \dfrac{1}{9}$

$$r_{02f} = \frac{r_{o2}}{1+\beta A} = \frac{1.83}{1+(1/9)\times 7360} = \mathbf{2.2\ \Omega}$$

$r_{i.1f} = r_{i-1}(1 + \beta A)$ = 1.9 × 819 = **1556 K**

$$A_f = \frac{A}{(1+\beta A)} = \frac{7360}{819} = \mathbf{8.9}$$

Example 62.16. *In the two-stage R_C coupled amplifier (Fig. 62.14) using emitter feedback, find the overall gain. Neglect V_{BE} and take $\beta_1 = \beta_2 = 100$.*

Solution. In this amplifier circuit, voltage gain has been stabilized to some extent with the help of 500 Ω unbypassed emitter resistance. This 500 Ω resistance swamps out r_e.

$$\therefore \quad A_{v.2} = \frac{r_{L.2}}{r_e + r_E} \cong \frac{r_{L.2}}{r_E} = \frac{10\text{K} \,||\, 10\text{K}}{500\,\Omega} = 10$$

Now, βr_E = 100 × 500 = 50 K

r_{i-2} = 80 K || 40 K || 50 K

$r_{L.1} = R_{C.1} \,||\, r_{i.2}$

= 10 K || 80 K || 40 K || 50 K = 6.3 K

$$\therefore \quad A_{v.1} = \frac{r_{L1}}{r_E} = \frac{6.3\times 10^3}{500} = 12.6$$

∴ A = 10 × 12.6 = **126**

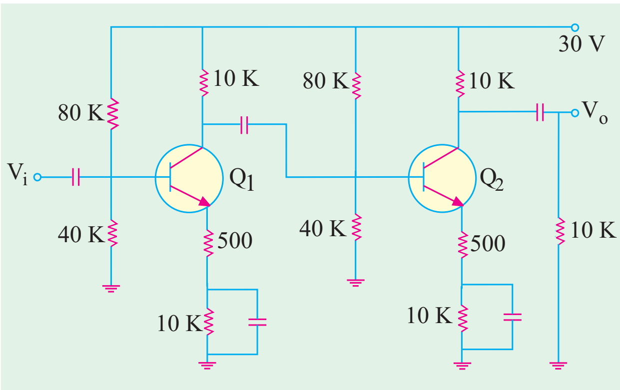

Fig. 62.14

62.13. Noninverting Op-amp With Negative Feedback

The closed-loop noninverting op-amp circuit using negative feedback is shown in Fig. 62.15. The input signal is applied to the noninverting input terminal. The output is applied back to the input terminal through the feedback network formed by R_i and R_f.

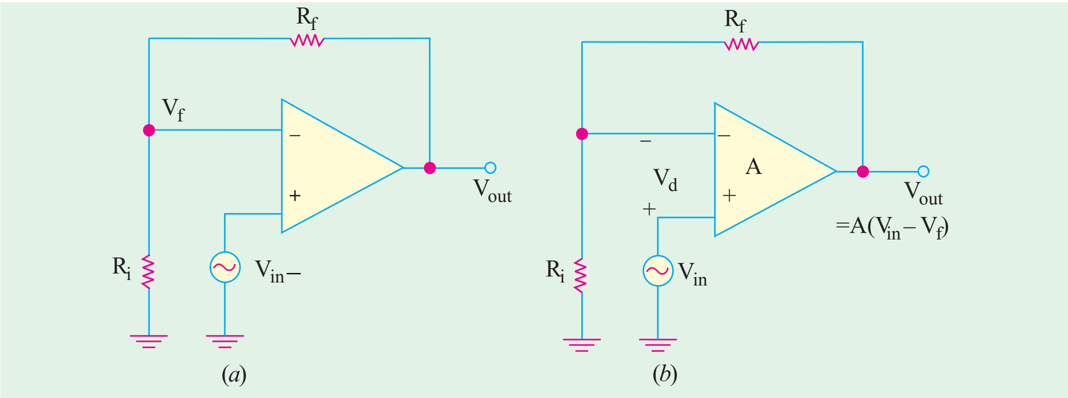

Fig. 62.15

The op-amp acts as both the difference circuit and the open-loop forward gain. The differential input to the op-amp is $(V_{in} - V_f)$. This differential voltage is amplified A times and an output voltage is produced which is given by

$$V_{out} = A_{v1} = A(V_{in} - V_f)\ ; \qquad \text{where } A \text{ is the open-loop gain of the op-amp}$$

Since, $(R_i + R_f)$ acts as voltage divider across V_{out},

$$\therefore \qquad V_f = V_{out}\frac{R_i}{R_i + R_f}$$

Now, $\qquad \beta = R_i/(R_i + R_f)$, hence $V_f = \beta V_{out}$

Substituting this value in the above equation, we get

$$V_{out} = A\,(V_{in} - \beta\, V_{out}) \text{ or } V_{out}\,(1 + \beta A) = AV_{in}$$

Hence, voltage gain A' with negative feedback is

$$A' = \frac{V_{out}}{V_{in}} = \frac{A}{1+\beta A} = \frac{A}{1 + AR_i\,(R_i + R_f)}$$

If A is so large that 1 can be neglected as compared to βA, the above equation becomes

$$A' = \frac{A}{\beta A} = \frac{1}{\beta} = \frac{R_i + R_f}{R_i}$$

It is seen that closed-loop gain of a noninverting op-amp is essentially independent of the open-loop gain.

Example 62.17. *A certain noninverting op-amp has R_i = 1K, R_f = 99 K and open-loop gain A = 500,000. Determine **(i)** β, **(ii)** loop gain, **(iii)** exact closed-loop gain and **(iv)** approximate closed-loop gain if it is assumed that open-loop gain A = ∞.*

(Power Electronics, AMIE 1991)

Solution. ***(i)*** $\beta = \frac{R_i}{R_i + R_f} = \frac{1}{1+99} = 0.01$, ***(ii)*** loop gain = βA = 500,000 × 0.01 = **5000**

(iii) $A' = \frac{A}{1+\beta A} = \frac{500{,}000}{1+5000}$ = **9998**

(*iv*) approx. $A' = \frac{1}{\beta} = \frac{1}{0.01} = \mathbf{100}$

It is seen that the gain changes by about 0.02%.

62.14. Effect of Negative Feedback on R_{in} and R_{out}

In the previous calculations, the input impedance of an op-amp was considered to be infinite and its output resistance as zero. We will now consider the effect of a finite input resistance and a non-zero output resistance. Since the two effects are different and their values differ by several order of magnitude, we will focus on each effect individually.

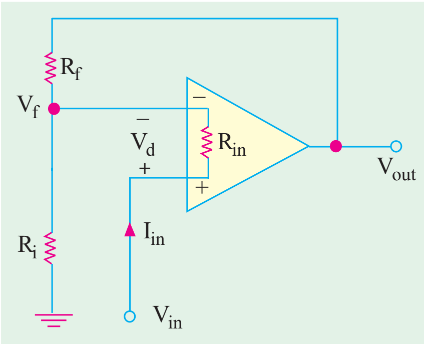

Fig. 62.16

(*a*) R_{in} of Noninverting Op-amp

For this analysis, it would be assumed that a small differential voltage V_d exists between the two inputs of the op-amp as shown in Fig. 62.16. It, in effect, means that neither the input resistance of the op-amp is assumed to be infinite nor its input current zero.

Now, $V_d = V_{in} - V_f$ or $V_{in} = V_d + V_f = V_d + \beta\, V_{out}$

Also, $V_{out} = A.\, V_d$ where A is the open-loop gain of the op-amp.

$\therefore$ $V_{in} = V_d + A\beta\, V_{out} = (1 + \beta A)\, V_d = (1 + \beta A)\, I_{in} R_{in}$ $\quad -(\because V_d = I_{in} R_{in})$

where R_{in} is the open-loop impedance of the op-amp (*i.e.* without feedback)

$$\therefore \qquad R'_{in} = \frac{V_{in}}{I_{in}} = (1+\beta A)\, R_{in}$$

where R_{in} is the closed-loop input resistance of the non-inverting op-amp.

It will be seen that the closed-loop input resistance of the non-inverting op-amp is much greater than the input resistance without feedback.

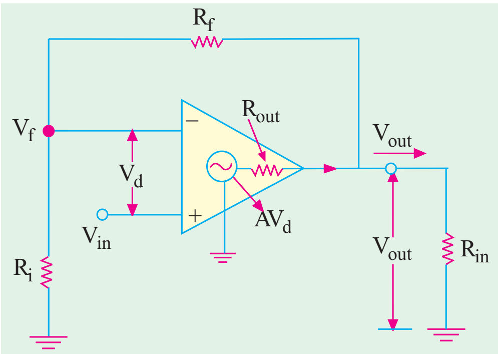

Fig. 62.17

(*b*) R'_{out} of Noninverting Op-amp

An expression for R'_{out} would be developed with the help Fig. 62.17. Using *KVL*, we get

$V_{out} = AV_d - I_{out} R_{out}$

Now, $V_d = (V_{in} - V_f)$ and neglecting $I_{out} R_{out}$ as compared to AV_d, we have

$V_{out} = A(V_{in} - V_f) = A(V_{in} - \beta V_{out})$

or $AV_{in} = (1 + \beta A)\, V_{out}$

If, with negative feedback, output resistance of the noninverting op-amp is R'_{out}, then $V_{out} = I_{out}.\, R'_{out}$.

Substituting this value in the above equation, we get

$$AV_{in} = (1 + \beta A)\, I_{out} R'_{out} \quad \text{or} \quad \frac{AV_{in}}{I_{out}} = (1 + \beta A)\, R'_{out}$$

The term on the left is the internal output resistance R_{out} of the op-amp because without feedback, $AV_{in} = V_{out}$.

or $\quad R_{out} = (1 + \beta A)\, R'_{out}$ or $R'_{out} = \dfrac{R_{out}}{(1+\beta A)}$

Obviously, output resistance R'_{out} with negative feedback is much less than without feedback (i.e. R_{out}).

Example 62.18. **(a)** *Calculate the input and output resistance of the op-amp shown in Fig. 62.18. The data sheet gives : R_{in} = 2M, R_{out} = 75 Ω. and A = 250,000* **(b)** *Also, calculate the closed-loop voltage gain with negative feedback.*

(Industrial Electronics, Mysore, Univ. 1992)

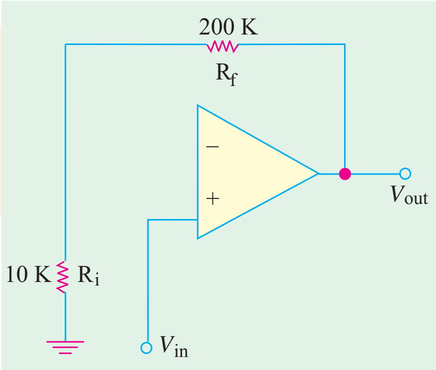

Fig. 62.18

Solution. **(a)** The feedback ratio β is given by

$$\beta = \frac{R_i}{R_i + R_f} = \frac{10}{10+200} = \frac{10}{210} = 0.048$$

$$R'_{in} = (1 + \beta A)\, R_{in} = (1 + 250{,}000 \times 0.048) \times 2$$
$$= \mathbf{24{,}002\ M}$$

$$R'_{out} = \frac{R_{out}}{1+\beta A} = \frac{75}{1 + 12000} = \mathbf{0.006\ \Omega}$$

(b) $A' = 1/\beta = 1/0.048 =$ **20.8**

62.15. R_{in} and R_{out} of Inverting Op-amp with Negative Feedback

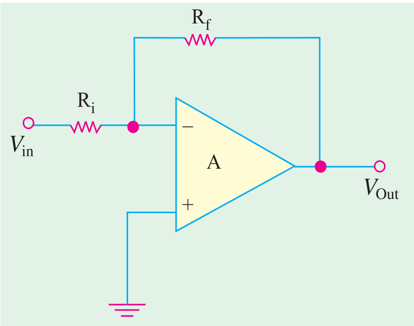

Fig. 62.19

The input resistance R_{in} of the inverting op-amp with negative feedback will be found by using Fig. 62.19. Since both the input signal and the negative feedback are applied to the inverting terminal. Miller's theorem will be applied to this configuration. According to this theorem, the effective input resistance of an amplifier with a feedback resistor from output to input is given by

$$R_{in(Miller)} = \frac{R_f}{1 + A} \quad \text{and} \quad R_{out(Miller)} = R_f\left(\frac{A}{1 + A}\right)$$

The Miller equivalent of the inverting op-amp is shown in Fig. 62.20 (*a*)

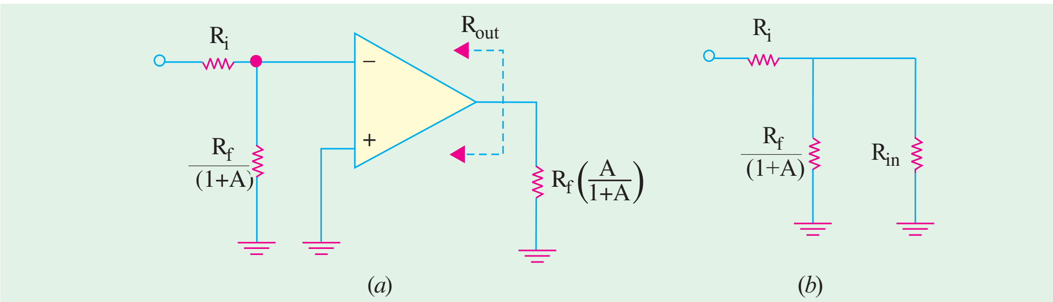

Fig. 62.20

As shown in Fig. 62.20 (*b*), the Miller input resistance appears in parallel with the internal resistance of the op-amp (without feedback) and R_i appears in series with this

$$\therefore \quad R'_{in} = R_i + \frac{R_f}{(1+A)} \parallel R_{in}$$

Typically, the term $R_f(1 + A)$ is much less than R_{in} of an open-loop op-amp. Hence,

$$\frac{R_f}{(1+A)} \| R_{in} \cong \frac{R_f}{1+A}$$

Moreover, $A \gg 1$, hence, $\therefore \quad R'_{in} \cong R_i + \frac{R_f}{A}$

Now, R_i appears in series with (R_f/A) and if $R_i \gg R_f/A$, we have, $R'_{in} \cong R_i$

As seen from Fig. 62.20 (*b*), Miller output resistance appears in parallel with R_{out} of the op-amp.

$$\therefore \qquad R'_{out} = R_f\left(\frac{A}{1+A}\right) \| R_{out}$$

Normally, $A \gg 1$ and $R_f \gg R_{out}$ so that R'_{out} simplifies to $R'_{out} = R_{out}$

Example 62.19. *For the inverting op-amp circuit of Fig. 62.21, find (a) input and output resistances and (b) the closed-loop gain. The op-amp has the following parameters :*

A =100,000, R_{in} = 5 M Ω. and R_{out} = 50 Ω

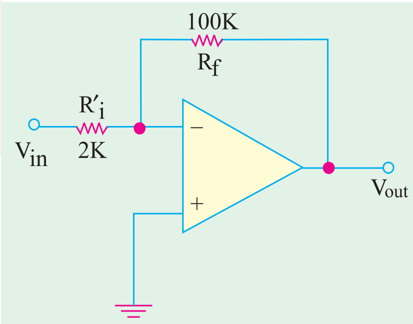

Fig. 62.21

Solution. (*a*) $R'_{in} \cong R_i \cong$ **2 kΩ**

$R'_{out} \cong R_{out}$ = **50 Ω**

(*b*) $A' = \frac{R_f}{R_i} = -\frac{100}{2} =$ **50**

The negative sign indicates the inherent sign inversion in the process.

Tutorial Problems No. 62.1

1. For the series-parallel feedback amplifier shown in Fig. 62.22. Calculate

(*i*) open-loop gain,

(*ii*) gain of feedback loop,

(*iii*) closed-loop gain,

(*iv*) sacrifice factor.

[(*i*) 10^6 (*ii*) 0.025 (*iii*) 40 (*iv*) 25.000]

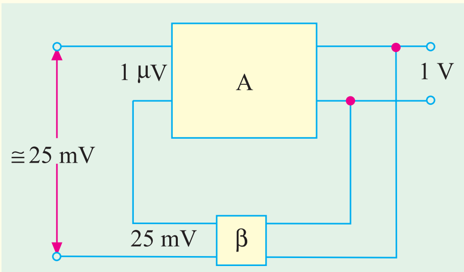

Fig. 62.22

2. A negative-feedback amplifier has the following parameters :

A = 200, β = 0.02 and V_i = 5 mV

Compute the following :

(*i*) gain with feedback, (*ii*) output voltage,

(*iii*) feedback factor, (*iv*) feedback voltage.

[(*i*) 40 (*ii*) 200 mV (*iii*) 4 (*iv*) 8 mV]

3. An amplifier has an open-loop gain of 500 and a feedback of 0.1. If open-loop gain changes by 25% due to temperature etc., find the percentage change in closed-loop gain. **[0.5%]**

4. An *RC*-coupled amplifier has a mid-frequency gain of 400 and lower and upper 3-dB frequencies of 100 Hz and 10 kHz. A negative feedback network with β = 0.01 is incorporated into the amplifier circuit. Calculate

(*i*) gain with feedback,
(*ii*) new bandwidth. **[(*i*) 80 (*ii*) 75 kHz]**

5. In an amplifier with constant signal input of 1 volt, the output falls from 50 to 25 V when feedback is applied. Calculate the fraction of the output which is fed back. If, due to ageing, the amplifier gain fell to 40, find the percentage reduction in stage gain

(*i*) without feedback (*ii*) with the feedback connection.

[0.02% (*i*) 20% (*ii*) 11.12%]

6. An amplifier has a gain of 1000 without feedback. Calculate the gain when 0.9 per cent of negative feedback is applied. If, due to ageing, gain without feedback falls to 800, calculate the percentage reduction in gain (*a*) without feedback and (*b*) with feedback. Comment on the significance of the results of (*a*) and (*b*) and state two other advantages of negative feedback. **[100 (*a*) 20% (*b*) 2.44%](*City & Guilds, London*)**

7. The open-loop gain of an amplifier is 1000 $\angle 70°$ and the feedback factor is – 0.02 $\angle 20°$. Calculate the amplifier gain with negative feedback. What is the limiting value of β to make the amplifier unstable ? **[49.9 $\angle -17.1°$; 0.001 $\angle -70°$] (*I.E.E. London*)**

8. When voltage feedback is applied to an amplifier of gain 100, the overall stage gain falls to 50. Calculate the fraction of the output voltage fed back. If this fraction is maintained, calculate the value of the amplifier gain required if the overall stage gain is to be 75. **[0.01 ; 300]**

(*City & Guilds, London*)

9. An amplifier having a gain of 100 has 9 per cent voltage negative feedback applied in series with the input signal. Calculate the overall stage with feedback.

If a supply voltage variation causes the gain with feedback to all by 10 percent, determine the percentage change in gain with feedback.

[10; 52.6%] (*City & Guilds, London*)

10. If the gain of an amplifier without feedback is (800 – *j*100) and the feedback network of β = –1/(40 – *j*20) modifies the output voltage to V_{fb} which is combined in series with the signal voltage, determine the gain of the ampplifier with feeback.

[38.3 – j18.3] (*I.E.R.E., London*)

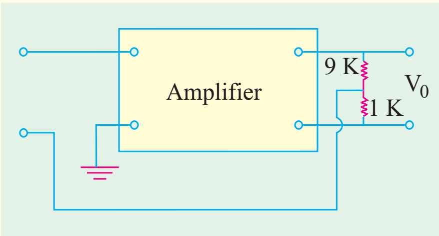

Fig. 62.23

11. Give three reasons for using negative feedback.

In Fig. 62.23, the box represents an amplifier of gain –1000, input impedance 500 kΩ and negligible output impedance.

Calculate the voltage gain and input impedance of the amplifier with feedback.

[– 9.9, 50.5 MΩ]

12. An amplifier with negative feedback has a voltage gain of 100. It is found that without feedback an input signal of 50 mV is required to produce a given output; whereas with feedback, the input signal must be 0.6V for the same output. Calculate the value of voltage gain without feedback and feedback ratio.

(Electronics Engg., Bangalore Univ. 2001)

OBJECTIVE TESTS – 62

1. The advantage of using negative feedback in an amplifier is that its gain can be made practically independent of

(*a*) temperature changes
(*b*) age of components
(*c*) frequency
(*d*) all of the above.

2. Feedback in an amplifier always helps to
   (*a*) control its output
   (*b*) increase its gain
   (*c*) decrease its input impedance
   (*d*) stabilize its gain.
3. The only drawback of using negative feedback in amplifiers is that it involves
   (*a*) gain sacrifice
   (*b*) gain stability
   (*c*) temperature sensitivity
   (*d*) frequency dependence.
4. Closed-loop gain of a feedback amplifier is the gain obtained when
   (*a*) its output terminals are closed
   (*b*) negative feedback is applied
   (*c*) feedback loop is closed
   (*d*) feedback factor exceeds unity.
5. A large sacrifice factor in a negative feedback amplifiers leads to
   (*a*) inferior performance
   (*b*) increased output impedance
   (*c*) characteristics impossible to achieve without feedback
   (*d*) precise control over output.
6. Negative feedback in an amplifier
   (*a*) lowers its lower 3 dB frequency
   (*b*) raises its upper 3 dB frequency
   (*c*) increases its bandwidth
   (*d*) all of the above.
7. Regarding negative feedback in amplifiers which statement is WRONG ?
   (*a*) it widens the separation between 3 dB frequencies
   (*b*) it increases the gain-bandwidth product
   (*c*) it improves gain stability
   (*d*) it reduces distortion.
8. Negative feedback reduces distortion in an amplifier only when it
   (*a*) comes as part of input signal
   (*b*) is part of its output
   (*c*) is generated within the amplifier
   (*d*) exceeds a certain safe level.
9. An amplifier with no feedback has a gain-bandwidth product of 4 MHz. Its closed-loop gain is 40. The new band-width is
   (*a*) 100 kHz
   (*b*) 160 MHz
   (*c*) 10 MHz
   (*d*) 20 kHz.
10. The shunt-derived series-fed feedback in an amplifier
   (*a*) increases its output impedance
   (*b*) decreases its output impedance
   (*c*) increases its input impedance
   (*d*) both (*b*) and (*c*).
11. A feedback amplifier has a closed gain of –200. It should not vary more than 50% despite 25% variation in amplifier gain *A* without feedback. The value of *A* is
   (*a*) 800
   (*b*) – 800
   (*c*) 1000
   (*d*) –1000
12. The gain of a negative feedback amplifier is 40 dB. If the attenuation of the feedback path is 50 dB, then the gain of the amplifier without feedback is
   (*a*) 78.92
   (*b*) 146.32
   (*c*) 215.51
   (*d*) 317.23
13. In a common emitter amplifier, the unbypassed emitter resistor provides
   (*a*) voltage-shunt feedback
   (*b*) current-series feedback
   (*c*) negative-voltage feedback
   (*d*) positive-current feedback

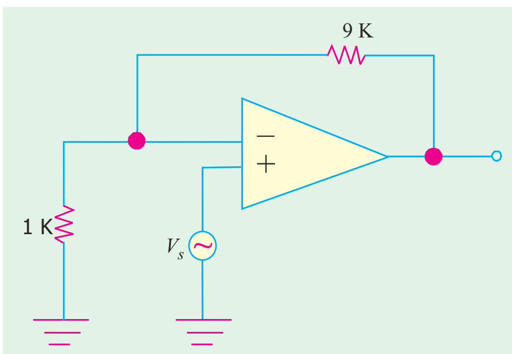

Fig. 62.24

14. The *OP-AMP* circuit shown in Fig. 62.24 has an input impedance of MΩ and an open-loop gain of 10^5. The output impedance seen by the source V_s is

(*a*) 10^{11}Ω

(*b*) 10^{10} Ω

(*c*) 10 kΩ

(*d*) 1 kΩ

15. An *OP-AMP* with an open-loop gain of 10,000, R_{in} = 2 K Ω and R_0 = 500 Ω is used in the non-inverting configuration shown in Fig. 62.25. The output resistance R'_0 is

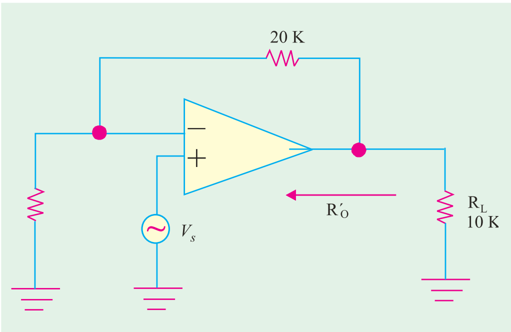

Fig. 62.25

(*a*) 250.5 Ω (*b*) 21 Ω

(*c*) 2 Ω (*d*) 0.998 Ω

16. The feedback used in the circuit shown in Fig. 62.25 can be classified as

(*a*) shunt-series feedback

(*b*) shunt-shunt feedback

(*c*) series-shunt feedback

(*d*) series-series feedback

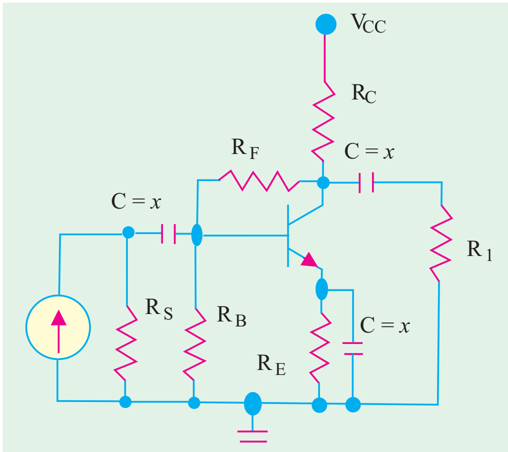

Fig. 62.25

ANSWERS

1. (*d*)	**2.** (*a*)	**3.** (*a*)	**4.** (*c*)	**5.** (*c*)	**6.** (*d*)	**7.** (*b*)	**8.** (*c*)
9. (*a*)	**10.** (*d*)	**11.** (*d*)	**12.** (*b*)	**13.** (*b*)	**14.** (*b*)	**15.** (*d*)	**16.** (*b*)

GO To FIRST