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Analog Electronic
ICE Dept.
8th Batch

FEEDBACK AMPLIFIERS

11·1. FEEDBACK :

Feedback is a process in which a fraction of the output energy is combined to the input. Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers *i.e.*, *a positive feedback* and *a negative feedback*. When the feedback voltage (or current) is so applied that it increases the input voltage (or current) *i.e.*, it is in phase with the input, it is called as positive feedback or regenerative or direct feedback. Positive feedback increases the gain of the amplifier. However, it has the disadvantage of increased distortion and instability. So positive feedback is seldom employed in amplifiers. If the positive feedback is sufficiently large, it leads to oscillations and hence it is used in oscillators. When the feedback voltage (or current) is so applied that it decreases the input voltage (or current) *i.e.*, it is out of phase with the input, it is called as negative feedback or degenerative or inverse feedback. Negative feedback reduces the gain of the amplifier. However, the advantage of negative feedback are : reduction in distortion, stability in gain, increased bandwidth etc. So the negative feedback is frequently used in amplifier circuits.

11·2. PRINCIPLE OF FEEDBACK AMPLIFIERS :

For an ordinary amplifier, *i.e.*, without feedback, let V_o and V_i be the output voltage and input voltage respectively. If A be the voltage gain of the amplifier, then

$$A = V_o / V_i \quad \dots (1)$$

The gain A is often called as *open loop gain*.

The principle of an amplifier with feedback is shown in fig. (1). The amplifier has two parts : an amplifier and a feedback circuit. Let V_o' be the output voltage with feedback and a fraction B of this voltage is applied to the input voltage. Now the input voltage becomes $(V_i \pm BV_0')$ depending whether the feedback is positive or negative. This voltage is amplified A times by the amplifier. Considering positive feedback, we have

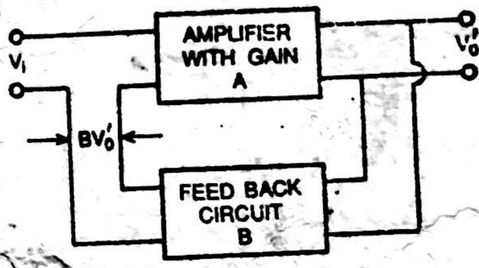


Fig. 1. Principle of feedback.

$$A\,(V_i + BV_o') = V_o'$$

or $\quad A\,V_i + ABV_o' = V_o' \quad$ or $\quad A\,V_i = V_o'\,[1 - BA]$

$$\therefore \quad \frac{V'_o}{V_i} = \frac{A}{1 - BA} \quad \dots (2)$$

The left hand side of eq. (2) represents the amplifier gain A' or A_f with feedback, *i.e.*,

$$A_f \text{ or } A' = \frac{A}{1 - BA} \quad \text{for positive feedback} \quad \dots (3)$$

$$\text{and} \quad A_f \text{ or } A' = \frac{A}{1 - (-BA)} = \frac{A}{1 + BA} \quad \text{for negative feedback} \quad \dots (4)$$

Here the term BA is called as feedback factor and B as feedback ratio. The term $(1 \pm BA)$ is known loop gain and amplifier gain A' with feedback is *closed loop gain* (feedback loop is closed).

11·3. ADVANTAGES OF NEGATIVE FEEDBACK

Following are the advantages of negative feedback :

(i) Highly stabilized gain. (ii) Reduction in non-linear distortion. (iii) Increased bandwidth *i.e.*, improved frequency response. (iv) Increased circuit stability. (v) Less amplitude distortion. (vi) Less frequency distortion (vii) Less phase distortion. (viii) Less harmonic distortion. (ix) Reduce noise (x) Increases input impedance and decreases output impedances *i.e.*, input and output impedances can be modified as desired.

11·4. REASONS FOR NEGATIVE FEEDBACK

(a) Increased stability :

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

In negative feedback amplifiers, the designer deliberately makes the product *BA* much greater than unity so that 1 may be neglected in comparison to it. Hence

$$A' \cong \frac{A}{BA} \cong \frac{1}{B} \qquad \ldots (2)$$

Thus *A'* depends only on *B* (feed back ratio) *i.e.* characteristics of feed back circuit. As feed back circuit is usually a voltage divider (resistive network) and resistors can be selected very precisely with almost zero temperature coefficient of resistance, therefore the gain is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence the gain of the amplifier is extremely stable.

Let us consider the situation in which there is a change in the gain of amplifier due to some reasons. Taking logs of both sides of equation (1), we get

$$\log A' = \log A - \log (1 + BA) \qquad \ldots (3)$$

Differentiating both sides, we get $\dfrac{dA'}{A'} = \dfrac{dA}{A} - \dfrac{B\,dA}{1 + BA} = \dfrac{dA}{A}\left[1 - \dfrac{BA}{(1 + BA)}\right]$

$$= \frac{dA}{A}\left[\frac{1}{(1 + BA)}\right]$$

$$\therefore \qquad \left|\frac{dA'}{A'}\right| = \left|\frac{dA}{A}\right| \frac{1}{|1 + BA|} \qquad \ldots (4)$$

where $BA >> 1$, we get $\left|\dfrac{dA'}{A'}\right| = \left|\dfrac{dA}{A}\right| \left|\dfrac{1}{|BA|}\right|$ ... (5)

This expression shows that even in this case, there is an improvement in the stability of the gain. This will be more clear by considering the following example : Let an amplifier has open loop gain of 400 and feed back is 0·1. If open loop gain changes by 20% due to temperature, find the percentage change in closed loop gain. Here

$$\left|\frac{dA'}{A'}\right| = 20\% \frac{1}{0{\cdot}1 \times 400} = 0{\cdot}5\%$$

So when the amplifier gain changes by 20% the feedback gain changes by only 0·5% *i.e.*, an improvement of 20/0·5 = 40 times.

(b) Reduction in non-linear distortion :

A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The use of negative feedback in large signal amplifiers reduces the non-linear distortion.

Let D = Distortion voltage generated in amplifiers without feed back

D' = Distortion voltage generated in amplifier with feed back

Suppose $D' = xD$ ... (1)

Now fraction of output distorted voltage feed back to input = $B\,D' = B\,x\,D$

This voltage is amplified by the amplifier. The amplified distorted voltage will be $Bx\,DA$. This is in antiphase with original distortion voltage *D*. So the new distorted voltage *D'* which appears in the output is

$$D' = D - B\,x\,D\,A \qquad \ldots (2)$$

From eqs. (1) and (2) we get

$x\,D = D - B\,x\,D\,A \quad \therefore \quad x\,(1 + B\,A) = 1 \quad \text{or} \quad x = 1/(1 + B\,A)$

Substituting this value in eq. (1), we get $D' = \dfrac{D}{(1 + B\,A)}$ i.e. $D' < D$

So the negative feed back reduces the amplifier distortion by a factor $(1 + B\,A)$. Here it should be remembered that the improvement in distortion is possible only when the distortion is produced by amplifier itself and not when it is already present in the input signal.

(c) Increased bandwidth.

We have seen that amplifier gain falls off at low and high frequencies. At low frequencies, the series capacitances can no longer be taken as short circuited and hence the gain falls off. At high frequencies, the shunt capacitances can not be considered as open circuited as at mid frequencies and hence due to the reactance of shunt capacitances, the amplifier gain falls off. Let f_1, and f_2 be the lower 3db frequency and upper 3db frequency respectively without feed back. Then the bandwidth of the amplifier will be $(f_2 - f_1)$. The bandwidth is shown in fig. (2). If A be the gain of the amplifier, then gain bandwidth product will be $A \times$ bandwidth.

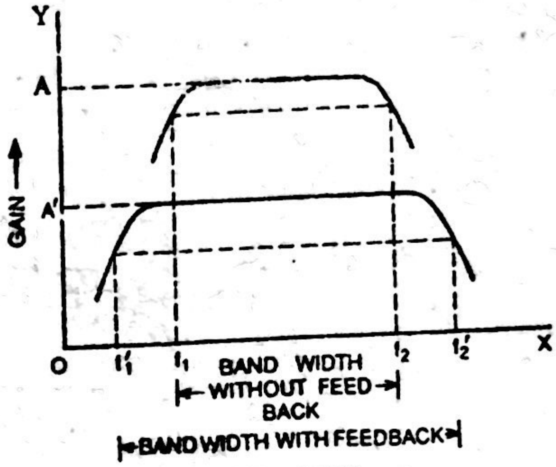


Fig. 2. Effect of feed back on bandwidth.

When a feedback is applied, the gain of the amplifier is decreased but *gain bandwidth* remains the same. This indicates that the bandwidth must increase to compensate the decrease in gain. It can be shown that with negative feedback, the lower and upper 3db frequencies are expressed as

$$f_1' = \frac{f_1}{(1 + B\,A)} \quad \ldots (1) \qquad f_2' = f_2\,(1 + B\,A) \quad \ldots (2)$$

These frequencies are shown in fig. (2). It is clear from expressions (1) and (2) that f_1' decreases while f_2' increases. Thus the bandwidth increases, of course, gain bandwidth product remains the same *i.e.*,

$$A\,(f_2 - f_1) = A'\,(f_2' - f_1').$$

Let us derive the expression for the increase in bandwidth.

(i) *Lower cut off frequency of a feedback amplifier.*

The lower cut-off frequency f_1 is the frequency in the low frequency range at which the voltage gain falls to $1/\sqrt{2}$ of its mid-frequency range. In case of *RC* coupled amplifier, the voltage gain at frequency f is given by

$$A_l = \frac{A_m}{1 - j\,(f_1/f)} \quad \ldots (1)$$

where A_m is the voltage gain in mid frequency range and f_1 is the lower cut-off frequency.

With feed back, the voltage gains at mid-frequency range and low frequency range of the amplifier are given as

$$A'_m = \frac{A_m}{1 - B\,A_m} \quad \ldots (2) \qquad \text{and} \qquad A'_l = \frac{A_l}{1 - B\,A_l}. \quad \ldots (3)$$

Substituting the value of A_l from eq. (1) in eq. (3), we get

$$A'_l = \frac{A_m / \{1 - j\,(f_1/f)\}}{1 - B\,A_m / \{1 - j\,(f_1/f)\}} = \frac{A_m}{\{1 - j\,(f_1/f)\} - B\,A_m}$$

$$= \frac{A_m}{1 - B A_m - j\left(f_1 / f\right)} = \left(\frac{A_m}{1 - B A_m}\right)\left(\frac{1}{1 - j f_1 / f\left(1 - B A_m\right)}\right)$$

$$= \frac{A'_m}{1 - j\,(f' / f)} \quad \text{where } f_1' = \frac{f_1}{1 - B A_m} \qquad \ldots (4)$$

The frequency f_1' gives the lower cutoff frequency with feedback. For negative feedback B is negative. Hence $f_1' < f_1$ *i.e.*, the negative feedback decreases the lower cutoff frequency.

(ii) *Higher cut off frequency of a feedback amplifier.*

The higher cut off frequency f_2 is the frequency in the high frequency range at which voltage gain falls to $1/\sqrt{2}$ of its mid frequency value. The voltage gain at frequency f in the high frequency range of an RC coupled amplifier is given by

$$A_h = \frac{A_m}{1 + j\left(f / f_2\right)} \qquad \ldots (5)$$

where f_2 is higher cut off frequency with feed back $A'_m = A_m / (1 - B A_m)$ and $A'_h = A_h / (1 - B A_h)$

$$\therefore \quad A'_h = \frac{A_m / \left\{1 + j\left(f / f_2\right)\right\}}{1 - B A_m / \left\{1 + j\left(f / f_2\right)\right\}} = \frac{A_m}{1 + j\left(f / f_2\right) - B A_m}$$

$$= \frac{A_m}{1 - B A_m + j\left(f / f_2\right)} = \left(\frac{A_m}{1 - B A_m}\right)\left(\frac{1}{1 + j f / f_2\left(1 - B A_m\right)}\right)$$

$$= \frac{A'_m}{1 + j f / f_2'} \quad \text{where } f_2' = f_2\left(1 - B A_m\right) \qquad \ldots (6)$$

The frequency f_2' gives the upper cut off frequency with feedback. For negative feedback $f_2' = f_2\,(1 + B A_m)$ *i.e.*, $f_2' > f_2$. Thus negative feedback increases the higher cut off frequency.

The brandwidth with feedback is given by

$$(BW)' = f_2' - f_1'$$

$$= f_2\,(1 + B A_m) - f_1 / (1 + B A_m)$$

Thus the bandwidth is increased.

(d) Effect on input impedance of a transistor amplifier

In order to consider the effect of feedback on input impedance of a transistor amplifier, we assume that A is the normal gain of the amplifier without feedback. BV_0 is the fraction of the output voltage which is feedback to the input terminals as shown in fig. (3).

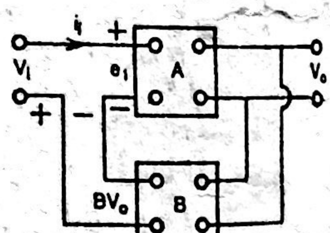


Fig. 3. Input impedance increases due to negative feedback.

Without feedback, the input impedance is

$$Z_i = \frac{e_1}{i_1} = \frac{V_1}{i_1} \quad (\text{since } V_1 = e_1)$$

With feedback, the input impedance Z_{if} is given by

$$Z_{if} = \frac{e_1 - B\,V_0}{i_1} = \frac{V_1 - BV_0}{i_1} = \frac{V_1 - BAV_1}{i_1}$$

$$= \frac{e_1 - B \times A\,e_1}{i_1} \quad \left(\because \; V_o = A\,e_1\right) = \frac{e_1}{i_1}[1 - B A] = Z_i(1 - A B) \qquad \ldots (1)$$

In negative feedback, $(1 - AB)$ is greater than unity and consequently, Z_{if} is greater than Z_i. That is, due to negative feedback, input impedance of a transistor amplifier increases.

(e) Effect of output impedance of a transistor amplifier

The output impedance without feedback is given by $Z_o = \dfrac{V_o}{i_o}$

In order to find out the output impedance of the amplifier with feedback, we short circuit the input source and connect a voltage source V_0 at the output terminals as shown in fig. (4). The output has been replaced by an equivalent voltage source $A\,B\,V_0$. Let i_0' be the current with feedback.

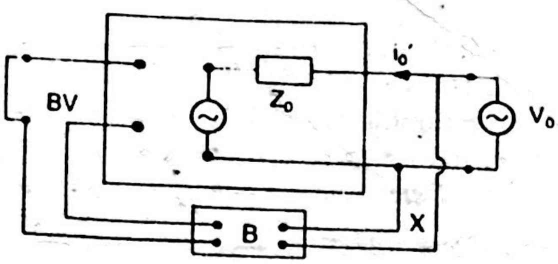


Fig. 4.

From figure, $Z_0\, i_0' = V_0 - A\,B\,V_0$

$$i_0' = \frac{V_0 - A\,B\,V_0}{Z_o} = \frac{V_o}{Z_o}(1 - A\,B)$$

So the output impedance is $$Z_{of} = \frac{V_o}{i_o'} = \frac{Z_o}{(1 - A\,B)} \quad \ldots (1)$$

Since in negative feedback $(1 - AB) > 1$, Z_{of} is less than Z_o. That is output impedance decreases due to negative feedback.

Example 1. *When the negative feedback is applied to an amplifier of gain 100, the overall gain falls to 50. Calculate*

(i) the fraction of output voltage feedback.

(ii) if this fraction is maintained, the value of the amplifier gain required if the overall stage gain is to be 75.

(i) We know that $A' = \dfrac{A}{1 + B\,A}$ or $50 = \dfrac{100}{1 + B \times 100}$

$\therefore$ $50\,(1 + 100\,B) = 100$ or $50 + 5000\,B = 100$

$\therefore$ $B = \dfrac{100 - 50}{5000} = \mathbf{0.01}$

(ii) Now $75 = \dfrac{A}{1 + 0{\cdot}01\,A}$ or $75 + 0{\cdot}75\,A = A$

$\therefore$ $A = \dfrac{75}{1 - 0{\cdot}75} = \mathbf{300}$

Example 2. *The gain of the amplifier without feedback is 50 whereas with negative feedback it falls to 25. If due to ageing, the amplifier gain falls to 40, find the percentage reduction in stage gain (i) without feedback and (ii) with negative feedback.*

Here $A' = \dfrac{A}{1 + A\,B}$ or $25 = \dfrac{50}{1 + 50\,B}$ or $B = \dfrac{1}{50} = 0{\cdot}02$

(i) *Without feedback.*

% reduction in stage gain $= \dfrac{50 - 40}{50} \times 100 = \mathbf{20\%}$

(ii) *With negative feedback.* When the gain without feedback was 50, the gain with negative feedback was 25. Now the gain without feedback falls to 40.

$\therefore$ New gain negative feed back $= A\,/1 + BA = 40/[1 + (40 \times 0{\cdot}02)] = 22{\cdot}2$

Now % reduction in stage gain $= \dfrac{25 - 22{\cdot}2}{25} \times 100 = \mathbf{11.2\%}$

Example 3. *A transistor amplifier has a voltage gain of 50. The input resistance of the amplifier is 1KΩ and the output resistance is 40KΩ. The amplifier is now provided with 10% negative voltage feedback in series with the input. Calculate the voltage gain, input and output resistances with feedback.*

In this problem 10% negative voltage feed back has been provided *i.e.* $B = -10/100 = 0{\cdot}1$

(i) $A' = \dfrac{A}{1 - B\,A} = \dfrac{50}{1 - (-0{\cdot}1 \times 50)} = \dfrac{50}{6} = 8.33$

(ii) $Z_{if} = Z_i(1 - BA) = 1\text{ K}[1 - (-0{\cdot}1 \times 50)] = \mathbf{6K\Omega}$

(iii) $Z_{of} = \dfrac{Z_o}{1 - BA} = \dfrac{40\text{ K}}{1 - (-0{\cdot}1 \times 50)} = \dfrac{40\text{ K}}{6} = \mathbf{6.66\ K\Omega}$

Example 4. *An RC coupled amplifier has a mid frequency gain of 200 and a frequency respon from 100 Hz to 20 KHz. A negative feedback network with B = 0·02 is incorporated into the amplifi circuit. Determine the new system performance.*

Here $A' = \dfrac{A}{1 + BA} = \dfrac{200}{1 + 0{\cdot}02 \times 200} = \mathbf{40}$

$f_1' = \dfrac{f_1}{1 + BA} = \dfrac{100}{1 + 0{\cdot}02 \times 200} = \mathbf{20\ Hz}$

$f_2' = f_2(1 + BA) = 20(1 + 0{\cdot}02 \times 200) = \mathbf{100\ KHz}$

Bandwidth $dW' = f_2' - f_1' = 100\text{ KHz} - 20\text{ Hz} \equiv \mathbf{100\ KHz}$

Bandwidth without feedback $dW = f_2 - f_1 = 20\text{ KHz} - 100\text{ Hz} \equiv \mathbf{20\ KHz}$

As expected, bandwidth product remains the same

$$A\,dW = 200 \times 20 = 4000\text{ KHz}$$

and

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

Example 5. *An amplifier with negative feedback has an overall gain of 100. Variation of th gain of only ± 1% can be tolerated for some specific use. If the open-loop gain variations of 10% a expected owing to production spreads in device characteristics, determine the minimum value of t feedback fraction B and also the open loop gain to satisfy the above condition.*

We know that $\dfrac{dA'}{A'} = \dfrac{1}{1 + BA} \cdot \dfrac{dA}{A}$

Given that $\dfrac{dA'}{A'} = \pm 1\%$ and $\dfrac{dA}{A} = \pm 10\%$

$\therefore \quad 1 = \dfrac{1}{1 + BA} \times 10 \quad$ or $\quad 1 + BA = 10$ ...(1)

Again $A' = \dfrac{1}{1 + BA}$ Here $A' = 100$ and $1 + BA = 10$

$\therefore \quad 100 = \dfrac{A}{10} \quad$ or $\quad A = 1000$ ...(2)

From eqs. (1) and (2), $1 + 1000B = 10$ or $B = 9/1000 = \mathbf{0{\cdot}009}$.

Example 6. *We have an amplifier of 60 dB gain. It has an output impedance $Z_0 = 12\ K\Omega$. It required to modify its output impedance to 600 Ω by applying negative feedback. Calculate the value the feedback factor. Also find the percentage change in the overall gain, for 10% change in the gain the internal amplifier.*

We know that, $Z_{of} = \dfrac{Z_0}{1 + AB}$ (negative feedback)

Given that $A = 60\text{ dB} = 1000$, $Z_0 = 12000\ \Omega$ and $Z_{of} = 600\ \Omega$

$$\therefore \quad 600 = \frac{12000}{1 + 1000B}$$

or

$$1 = \frac{20}{1 + 1000B}$$

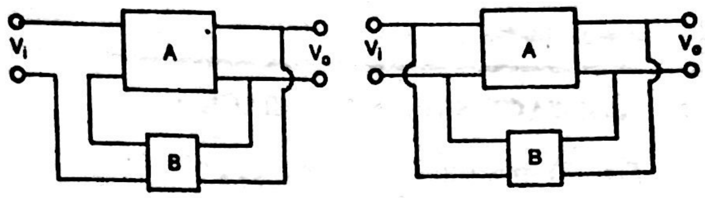
$$\therefore \quad B = \frac{19}{1000} = 0{\cdot}019 = 1{\cdot}9\ \%$$

Again
$$\frac{dA_f}{A_f} = \frac{1}{1+AB} \times \frac{dA}{A}$$
$$= \frac{1}{1 + 1000 \times 0{\cdot}019} \times (0{\cdot}1) = \frac{0{\cdot}1}{1+19} = \frac{0{\cdot}1}{20} = 0{\cdot}005 = 0{\cdot}5\ \%$$

11.5. NEGATIVE FEED BACK CIRCUITS

Negative feedback in an amplifier is a method for feeding a portion of the amplified output energy back to the input of the amplifier so as to oppose the input signal. There are two types of negative feedback circuits *i.e.*, (a) negative voltage feedback and (b) negative current feedback.

(a) Negative voltage feedback. In this method, the voltage feedback to the input of amplifier is proportional to the output voltage. This is further classified as : (i) voltage series feedback [fig. (5a)] and (ii) voltage-shunt feedback [fig. (5b)].



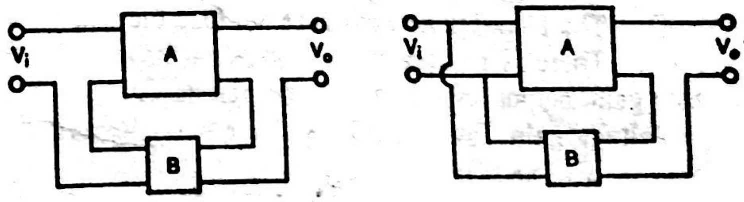
(a) Voltage series feedback. (b) Voltage-shunt feedback.

Fig. 5. Negative voltage feedback

(i) *Voltage-series feedback.* This is also known as shunt-derived series feedback. The amplifier circuit and feedback circuit are connected in series-parallel (*sp*). Here the output voltage is combined in series with the input voltage via feedback. As seen, the feedback network shunts the output but is in series with the input, hence output impedance decreases (parallel combination) while the input impedance increases (series combination) due to feedback.

(ii) *Voltage-shunt feedback.* This is also known as shunt-derived shunt fed feedback *i.e.*, a parallel-parallel (pp) prototype. Here a fraction of output voltage is combined with the input voltage in parallel (shunt). As seen, the feedback network shunts the output as well as input, hence both impedances (input and output) decrease due to feedback.

(b) Negative current feedback. In this method, the voltage feedback to the input of the amplifier is proportional to the output current. This is further classified as : (i) current-series feedback [fig. (6a)] and (ii) current-shunt feedback [fig. (6b)].



(a) Current series feedback. (b) Current-shunt feedback.

Fig. 6. Negative current feedback.

(i) *Current-series feedback.* This is also known as series derived series fed feedback *i.e.*, a series-series (ss) circuit. Here a part of the output current feedbacks a proportional voltage in series with the input. As seen, the feedback network is in series with input as well as output and hence both the impedances (input and output) increase due to feedback.

(ii) *Current-shunt feedback.* This is also known as series derived shunt fed feedback *i.e.*, a series-parallel (sp) circuit. Here a part of output current is feedback a proportional voltage in parallel with the input voltage. As seen, the feedback network is in series with output and in parallel with input and hence the output impedance is increased while the input impedance is decreased.

The effects of negative feedback on amplifier characteristics a resummarised in Table 1.

Table 1

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

11·6. VOLTAGE SERIES FEEDBACK :

Fig. (7) shows the schematic circuit of a voltage amplifier with voltage series feedback.

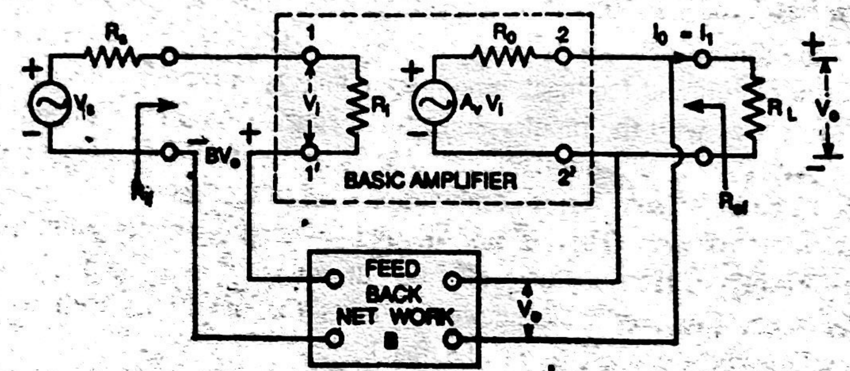


Fig. 7. Voltage amplifier with voltage series feedback.

Here the following two assumptions are made :

(i) The feedback network does not load the output circuit of the amplifier.

(ii) There is no forward transmission through the feedback network. Now we shall calcula voltage gain, output resistance and input resistance.

Voltage gain. From fig. (7), we have $$V_o = A_v V_i - I_L R_o \qquad \ldots (1$$

and $$V_i = \frac{R_i}{R_i + R_S}(V_S - B V_o) \qquad \ldots (2$$

Substituting the value of V_i from eq. (2) in eq. (1), we get

$$V_o = \frac{A_v R_i}{R_i + R_S}(V_S - B V_o) - I_L R_o = \frac{A_v R_i}{R_i + R_S} V_S - B \frac{A_v R_i}{R_i + R_S} V_o - I_L R_o$$

or $$V_o \left[1 + B \frac{A_v R_i}{R_i + R_S}\right] = \frac{A_v R_i}{R_i + R_S} V_S - I_L R_o$$

or $$V_o [1 + B A_{vs}] = A_{vs} \cdot V_S - I_L R_o \quad \text{where} \quad A_{vs} = \frac{A_v R_i}{R_i + R_S}$$

$$\therefore \quad V_o = \frac{A_{vs} V_S}{1 + B A_{vs}} - I_L \frac{R_o}{1 + B A_{vs}} \qquad \ldots ($$

Here A_{vs} represents the open circuit voltage gain, taking into account the source resistance R_S. Taking R_S into account, the overall voltage gain with feedback is given by

$$A_f = A_{vsf} = \frac{A_{vs}}{1 + BA_{vs}} \qquad \ldots (4)$$

If $|A_{vs} B| >> 1$, $A_{vsf} \cong 1/B$ and hence voltage gain is stabilized.

Output resistance. The output resistance with feed-back $R_{of} = \dfrac{R_o}{1 + BA_{vs}}$ ... (5)

For negative feedback, $|1 + BA_{vs}| > 1$ and hence $R_{of} < R_o$. It is also clear from eq. (5) that the output impedance with feedback depends somewhat on source resistance R_S as A_{vs} depends upon R_S.

The above expression (5) has been derived by considering R_o as the output resistance of the amplifier and treating R_L as the external load. If, however, R_L is considered as a part of the output resistance of the amplifier, then eq. (5) is modified as

$$R_{ofl} = \frac{R_{ol}}{1 + BA_{Vs}} \qquad \ldots (6)$$

where R_{olf} = Output resistance considering the load R_L as apart of the amplifier with feedback.
R_{ol} = Output resistance considering the load R_L as a part of the amplifier without feed-back. R_{ol} will be a parallel combination of R_o and R_L.
A_{Vs} = Gain of the amplifier taking both load and source resistance into account.

Input resistance. Without feedback, the input resistance R_i is given by V_i / I_i. With feedback, the input resistance is defined as $R_{if} = \dfrac{V_S}{I_i} - R_S$ ...(7)

From fig. (7), $V_S = I_i (R_S + R_i) + BV_0$

or
$$= I_i(R_S + R_i) + B\,\frac{A_v V_i . R_L}{R_L + R_0} = I_i(R_S + R_i) + BA_V R_i I_i \qquad \ldots (8)$$

where $V_i = R_i . I_i$ and $A_V = (A_v R_L / R_L + R_0)$

A_V is the voltage gain without feedback with $R_S = 0$ and taking load R_L into account.

Substituting eq. (8) in eq. (7), we get

$$R_{if} = (R_S + R_i) + BA_V R_i - R_S \quad \text{or} \quad R_{if} = R_i (1 + BA_V) \qquad \ldots (9)$$

For negative feedback $|1 + BA_V| > 1$. Hence $R_{if} > R_i$.

So *the negative voltage series feedback increases the input resistance of an amplifier.* It should also be noted that R_{if} depends somewhat on the load resistance since A_V is a function of R_L.

Notations regarding symbols. In this article, the following symbols are used :

A_v = Open circuit voltage gain ($R_L = \infty$) and $R_S = 0$

A_{vs} = Open circuit voltage gain ($R_L = \infty$) taking the source resistance into account ($R_S \neq 0$)

A_V = Voltage gain taking load resistance into account ($R_L \neq 0$) with $R_S = 0$

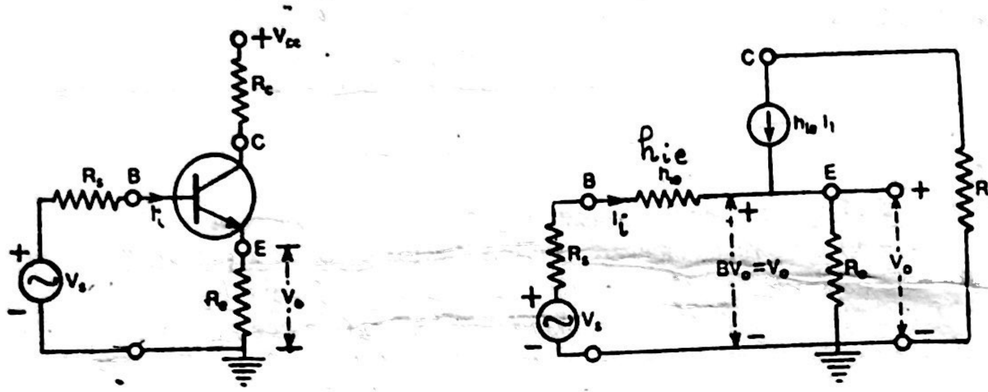
A_{Vs} = Voltage gain when both load resistance and source resistance are taken into account ($R_L \neq 0$) and ($R_S \neq 0$)

In case of feedback, an additional subscript f is attached to each symbol.

11·6–1. EMITTER FOLLOWER (An amplifier with voltage series Feedback)

Fig. 8 (a) gives the circuit of emitter follower using a resistance R_c in the collector circuit. In this case, the output voltage V_o is developed across R_e. Fig. 8 (b) give the approximate small signal equivalent circuit using the amplifier *CE* hybrid model. The voltage series feedback is provided by the load resistor R_c itself.

In case of emitter follower, the whole of the output voltage V_O is fed to the input side. So, the effective input voltage is $(V_s - V_O)$. As a result, the voltage gain of the amplifier is less than unity. Now the question is that why it is called as amplifier ? Actually, this is used as an *impedance matching device* because its input impedance is very high while the output impedance is very low. This is used as the last stage of a signal generator. Now when the signal generator is connected to a circuit, the oscillator is not loaded and its frequency remains constant. This is due to emitter follower because it is capable of giving power to a load without requiring much power at the input. So, it works as *buffer amplifier.*



(a) Emitter follower (b) Approximate small-signal equivalent circuit.

Fig. 8. Emitter follower (voltage series feed-back).

The following points are to denoted here :

(i) The whole output voltage V_o developed across R_e is returned to the input. Thus the feedback voltage is equal to the output voltage. So $B = 1$.

(ii) The input signal voltage to the transistor (V_i) between B and E is equal to the difference between the externally applied input voltage V_s and output voltage V_o *i.e.*, $V_i = V_s - V_o$. Hence feedback is negative.

(iii) This is a current feedback circuit because the voltage feedback is proportional to the emitter current. It is called emitter follower because voltage variations across base-emitter junction follow the emitter.

(iv) This makes an ideal circuit for impedance matching because its input impedance is high while output impedance is low.

Voltage gain. The voltage gain A_{Vs} without feedback may be obtained by connecting the grounded end of V_S to E. With this modification, we have

$$V_S = (R_S + h_{ie})\, I_i \quad \ldots(1)$$

and

$$V_o = h_{fe}\, I_i\, R_e \quad \ldots(2)$$

Hence

$$A_{Vs} = \frac{V_0}{V_S} = \frac{h_{fe}\, R_e}{R_S + h_{ie}} \quad \ldots(3)$$

From the circuit, it is clear that $B\, V_o = V_o$ *i.e.*, $B = 1$.

We know that voltage gain with feedback is given by

$$A_{Vsf} = \frac{A_{Vs}}{1 + A_{Vs}B} = \frac{A_{Vs}}{1 + A_{Vs}} \qquad (\because\ B = 1) \quad \dots (4)$$

From eq. (3), substituting the value of A_{Vs} in eq. (4) we get

$$A_{Vsf} = \frac{\dfrac{h_{fe} R_e}{R_S + h_{ie}}}{1 + \dfrac{h_{fe} R_e}{R_S + h_{ie}}} = \frac{h_{fe} R_e}{R_S + h_{ie} + h_{fe} R_e} \quad \dots (5)$$

Input resistance. Putting $R_S = 0$ in eq. (3), we get

$$A_V = \frac{h_{fe} R_e}{h_{ie}} \quad \text{and} \quad R_i = h_{ie} \quad \dots (6)$$

we know that
$$R_{if} = R_i (1 + B A_V) \quad \dots (7)$$

Substituting the value of A_V and R_i from eq. (6) in eq. (7), we get

$$R_{if} = h_{ie}\left[1 + 1 \cdot \frac{h_{fe} R_e}{h_{ie}}\right] = h_{ie} + h_{fe} R_e \quad \dots (8)$$

Output resistance. The output resistance without feedback is the ratio of output voltage to the output current *i.e.*, $R_o = V/I$, where V and I are respectively the open circuit output voltage and short circuit output current of the amplifier *i.e.*, with the grounded side of V_S in fig. 8 (b) connected to E. Since

$$V = \lim_{R_e \to \infty} V_o = \lim_{R_e \to \infty} \frac{h_{ie} R_e V_S}{R_S + h_{ie}} \quad \text{and} \quad I = \frac{h_{fe} V_S}{R_S + h_{ie}}$$

$$\therefore \quad R_o = \frac{V}{I} = \lim_{R_e \to \infty} R_e.$$

Hence the output resistance without feedback is infinite.

Now

$$R_{of} = \frac{R_o}{1 + B A_{vs}} = \frac{\lim_{R_e \to \infty} R_e}{1 + 1 \cdot \dfrac{h_{fe} R_e}{R_S + h_{ie}}} = \lim_{R_e \to \infty} \frac{R_S + h_{ie}}{\dfrac{R_S + h_{ie}}{R_e} + h_{fe}} = \frac{R_S + h_{ie}}{h_{fe}} \quad \dots (9)$$

This gives the output resistance.

Here voltage gain, input resistance and output resistance are derived by assuming that there is no forward transmission through feedback network.

11·7. CURRENT SERIES FEEDBACK

Fig. (9) shows the circuit of a current series feedback amplifier. The emitter resistor R_e is not bypassed by any condensor and the negative feedback is provided by this resistor. The a.c. developed across R_e is applied at the input circuit of the amplifier. Thus it provides a feedback voltage proportional to the current in the load. Since $R_L >> R_e$, the presence of R_e in the emitter circuit does not substantially change the current gain of the amplifier. This is known as series derived feedback and it tends to maintain constant current in the load.

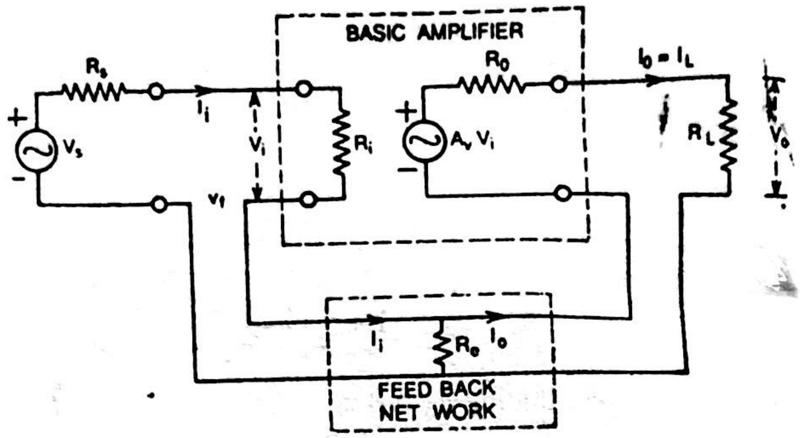


Fig. 9. Amplifier with current series negative feed-back

Voltage gain and input resistance. Applying Kirchhof's voltage law to the output circuit, we have

$$V_o = A_v V_i - I_L (R_o + R_e) + I_i R_e = A_v R_i I_i - I_L (R_o + R_e) + I_i R_e$$
$$= (A_v R_i + R_e) I_i - I_L (R_o + R_e) \quad \ldots(1)$$

Applying Kirchhof's voltage law to the input circuit, we have

$$V_S + I_L R_e = I_i (R_S + R_i + R_e) \quad \text{or} \quad I_i = \frac{V_S + I_L R_e}{R_S + R_i + R_e} \quad \ldots(2)$$

Substituting the value of I_i from equation (2) in equation (1), we get

$$V_o = \frac{(A_v R_i + R_e)(V_S + I_L R_e)}{(R_S + R_i + R_e)} - I_L (R_o + R_e)$$

or
$$V_o = V_S \frac{(A_v R_i + R_e)}{(R_S + R_i + R_e)} - I_L \left[R_o + R_e \left\{ 1 - \frac{A_v R_i + R_e}{(R_S + R_i + R_e)} \right\} \right]$$

or
$$V_o = V_S \cdot A_{vs} - I_L R_{of} \quad \ldots(3)$$

where
$$A_{vs} = \frac{(A_v R_i + R_e)}{(R_S + R_i + R_e)} \quad \ldots(4) \quad \text{and} \quad R_{of} = [R_o + R_e (1 - A_{vs})] \quad \ldots(5)$$

The value of load current can be calculated as follows : $V_o = I_L R_L$

Substituting this value of V_o in eq. (3), we get

$I_L R_L = V_S \cdot A_{vs} - I_L [R_o + R_e (1 - A_{vs})]$ or $I_L = [R_L + R_o + R_e (1 - A_{vs})] = V_S \cdot A_{vs}$

$$\therefore \quad I_L = \frac{V_S A_{vs}}{[R_L + R_o + R_e (1 - A_{vs})]} \quad \ldots(6)$$

If $| R_e A_{vs} | >> R_L + R_o + R_e$, then $I_L \cong \dfrac{V_S \cdot A_{vs}}{R_e A_{vs}} \cong \dfrac{V_S}{R_e}$ ...(6

The voltage gain A_{Vsf} is given by $A_{Vsf} \equiv \dfrac{V_o}{V_s} = \dfrac{I_L R_L}{V_S}$ ...(7)

Substituting the value of I_L from eq. (6) in eq. (7), we get

$$A_{Vsf} = -\frac{V_S R_L}{V_S R_e} \cong -\frac{R_L}{R_e} \quad \ldots(8)$$

From eq. (8), we conclude that A_{Vsf} is stable provided that R_L and R_e are stable resistances.

Input resistance. The input resistance without feedback R_i is defined by $R_i \equiv V_i$ where I_i is the input current. The input resistance with feedback is defined by

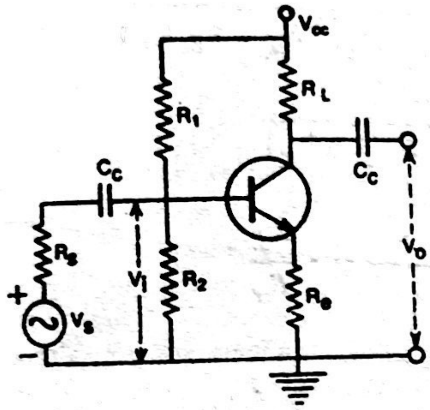
$$R_{if} = \frac{V_S}{I_i} - R_S \quad \ldots (9)$$

From eq. (9) and (2), we get $R_{if} = R_i + R_e(1 - A_I)$ ... (10)

where the current gain A_I is defined by $A_I = I_L / I_i$. ... (11)

•11·7–1. CE AMPLIFIER WITH UNBYPASSED EMITTER RESISTOR

One of the most common methods of introducing current feedback is to place a resistor in the emitter lead of a *CE* amplifier. When a bypass condensor C_e placed across R_e, then R_e provides dc bias stabilization but there is no ac feedback. When C_e is removed, an ac voltage is developed across R_e. This voltage serves to reduce the input voltage between base and emitter. So the output voltage is reduced. Fig. 10 (a) shows the *CE* amplifier with a resistor in emitter lead and fig. 10 (b) a simplified diagram for ac quantities.



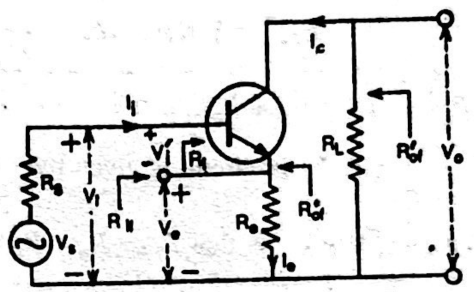


Fig. 10. *CE* amplifier with resistor in emitter lead.

Input resistance. The input resistance with feedback is given by

$$R_{if} = \frac{V_i}{I_i} = \frac{V_i' + V_e}{I_i} \qquad (\because V_i = V_i' + V_e)$$

$$= \frac{V_i'}{I_i} + \frac{V_e}{I_i} = R_i + \frac{R_e I_e}{I_i} = R_i + \frac{R_e I_e}{I_e - I_c} = R_i + \frac{R_e}{1 - (I_c / I_e)}$$

But $I_c / I_e = h_{fe} / (1 + h_{fe})$ $\therefore$ $R_{if} = R_i + (1 + h_{fe}) R_e$ ... (1)

or $R_{if} = h_{ie} + (1 + h_{fe}) R_e$ (where $R_i = h_{ie}$) ... (2)

If the bias resistors $R_1 = R_1 \parallel R_2$ are taken into account, then $R'_{if} = R_{if} \parallel R$

Voltage gain. According to eq. (4) of article 11·7, we have $A_{vs} = \dfrac{A_v R_i + R_e}{R_S + R_i + R_e}$

where $A_v = -h_{fe} / (h_{oe} . h_{ie})$ and $R_i = h_{ie}$

So the open circuit voltage gain considering the source resistance is given by

$$A_{vs} = \frac{\dfrac{-h_{fe}}{h_{oe} . h_{ie}} . h_{ie} + R_e}{R_S + h_{ie} + R_e}$$

or

$$A_{vs} = \frac{1}{h_{oe}} . \left[\frac{-h_{fe} + h_{oe} R_e}{R_S + h_{ie} + R_e}\right] \quad \ldots (2)$$

Now we shall calculate the load current. According to eq. (6) of article 11·7, we have

$$I_L = \frac{V_S \cdot A_{vs}}{\left[R_L + R_o + R_e\left(1 - A_{vs}\right)\right]} \quad \ldots (3)$$

Substituting the value of A_{vs} from eq. (2) in eq. (3), we get

$$I_L = \frac{\frac{1}{h_{oe}}\left[\frac{h_{fe} + h_{oe} R_e}{\left(R_S + h_{ie} + R_e\right)}\right] V_S}{R_L + \frac{1}{h_{oe}} + R_e\left[1 - \frac{1}{h_{oe}}\left\{\frac{-h_{fe} + h_{oe} R_e}{R_S + h_{ie} + R_e}\right\}\right]}$$

or

$$I_L = \frac{\left(-h_{fe} + h_{oe} R_e\right) V_S}{\left[1 + h_{oe}\left(R_e + R_L\right)\right]\left(R_S + h_{ie} + R_e\right) - R_e\left(-h_{fe} + h_{oe} R_e\right)}$$

Assuming that $h_{oe}(R_e + R_L) << 1$. then $I_L \approx \dfrac{-h_{fe} V_S}{R_S + h_{ie} + R_e\left(1 + h_{fe}\right)}$ ... (4)

Again if, $h_{fe} R_e >> (R_S + h_{ie} + R_e)$, then $I_L \approx V_S / R_e$

$\therefore$ Voltage gain with R_L in circuit is given by $A_{Vsf} \approx \dfrac{I_L R_L}{V_S} \equiv -\dfrac{R_L}{R_e}$ ... (5)

Output Resistance. We know that $R_{of} = R_o + R_v (1 - A_{vs})$

where $R_o = \dfrac{1}{h_{oe}}$ and $A_{vs} = \dfrac{1}{h_{oe}}\left[\dfrac{-h_{fe} + h_{oe} R_e}{R_S + h_{ie} \times R_e}\right]$

$$\therefore \quad R_{of} = \frac{1}{h_{oe}} + R_e\left[1 - \frac{1}{h_{oe}}\left\{\frac{-h_{fe} + h_{oe} R_e}{R_S + h_{ie} + R_e}\right\}\right]$$

On simplification, we get $R_{of} = \dfrac{1}{h_{oe}}\left[\dfrac{R_e\left(1 + h_{fe}\right) + R_S + h_{ie}\left(1 + h_{oe} R_e\right)}{\left(R_S + h_{ie} + R_e\right)}\right]$ ... (6)

Voltage gain in current feedback (Alternative treatment)

The equivalent circuit of current feedback is shown in fig. (10c).

From figure, the output voltage V_o is given by

$$V_o = -I_c R_L$$

The feedback voltage V_{fb} is developed across R_e and is given by

$$V_{fb} = (I_b + I_c) R_e \approx I_c R_e$$

$\therefore$ Fraction B of the voltage applied to input

$$B = \frac{I_c R_e}{-I_c R_L} = -\frac{R_e}{R_L} \quad \ldots (6)$$

We know that in case of common emitter, the voltage gain A_{ve} without feedback is given by

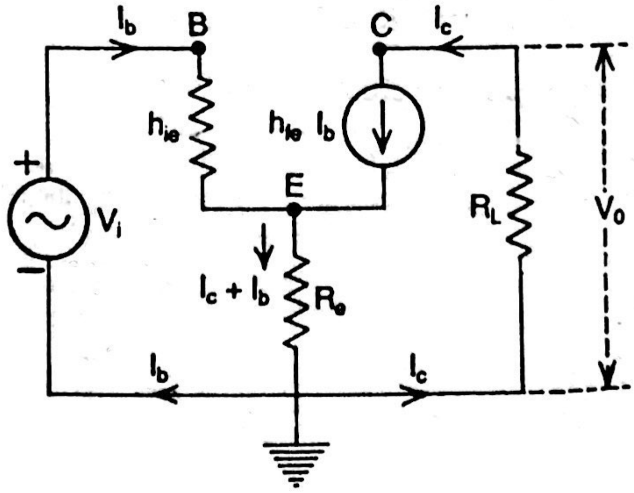


Fig. 10 (c)

$$A_{ve} = -\frac{h_{fe} R_L}{h_{ie}} \qquad \ldots (2)$$

The relationship between voltage gain without feedback A_{ve} and voltage gain with feedback $(A_{ve})_f$ is given by

$$\left(A_{ve}\right)_f = \frac{A_{ve}}{1 + B A_{ve}} \qquad \ldots (3)$$

Substituting the values of A_{ve} and B from equations (2) and (1) in eq. (3), we get

$$\left(A_{ve}\right)_f = \frac{\left(-h_{fe} R_L / h_{ie}\right)}{1 + \left(-R_e / R_L\right)\left(-h_{fe} R_L / h_{ie}\right)} = -\frac{h_{fe} R_L}{h_{ie} + h_{fe} R_e} \qquad \ldots (4)$$

The above equation may also be derived from the equivalent circuit in the following manner :

From fig. (10b), $I_c = h_{fe} I_b \quad \therefore \quad V_o = -I_c R_L = -h_{fe} I_b R_L \qquad \ldots (5)$

Further, considering the input side,

$$\begin{aligned} V_i &= I_b h_{ie} + (I_c + I_b) R_e \\ &= I_b h_{ie} + (h_{fe} I_b + I_b) R_e \\ &= I_b [h_{ie} + (h_{fe} + 1) R_e] \end{aligned} \qquad \ldots (6)$$

$$\therefore \quad \left(A_{ve}\right)_f = \frac{V_o}{V_i} = \frac{-h_{fe} I_b R_L}{I_b\left[h_{ie} + \left(h_{ie} + 1\right) R_e\right]} = \frac{-h_{fe} R_L}{\left[h_{ie} + \left(h_{ie} + 1\right) R_e\right]}$$

$$\cong \frac{-h_{fe} R_L}{h_{ie} + h_{fe} R_e} \qquad (\because \ h_{fe} >> 1) \qquad \ldots (7)$$

Example. *For the amplifier shown in fig. 10 (a), the transistor has h_{fe} = 50 and h_{ie} = 1K ohm. With R_L = 1K ohm, R_e = 100 ohms, $R = R_1 \| R_2$ = 100 ohms, calculate the following :*

(i) The gain A_v if R_e were adequately bypassed and R_i (ii) The approximate feedback factor B (C_e removed) (iii) The input resistance with feedback R_{if} and R'_{if}, (iv) A_{vf}.

(i) $A_V = \dfrac{A_i R_L}{R_i} \approx \dfrac{-h_{fe} R_L}{h_{ie}} = \dfrac{-50 \times 1K}{1K} = -$ **50**, $R_i = h_{ie} =$ **1K ohm**.

(ii) $B \approx \dfrac{R_e}{R_L} = \dfrac{100}{1000} = 0{\cdot}1$ or **10%**.

(iii) $R_{if} = h_{ie} + (1 + h_{fe}) R_e = 1\text{ K} + (1 + 50)\, 100 =$ **6·1 K ohm.**

$R'_{if} = R_{if} \| R = 6{\cdot}1 \| 10K =$ **3·8K ohm**

(iv) $R_{Vf} = \dfrac{-h_{fe} R_L}{R_{if}} = \dfrac{-50 \times 1K}{6{\cdot}1\text{ K}} = -$ **8·2.**

11·8. VOLTAGE SHUNT FEEDBACK

Fig. (11) shows the circuit of *CE* amplifier stage with voltage shunt negative feedback. The feedback is obtained through resistor R_f connected from collector to base. The circuit arrangement is the same as used to provide stabilization of the operating point against temperature variations.

First of all we shall show that this configuration confirms the shunt feedback. In the circuit, the output voltage V_o is much greater than the input voltage V_i and is 180° out of phase with V_i. Hence

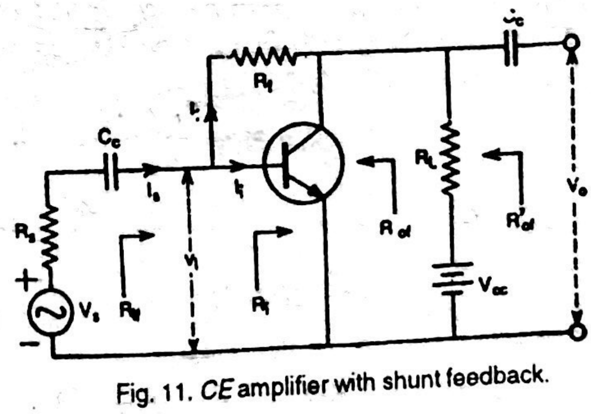
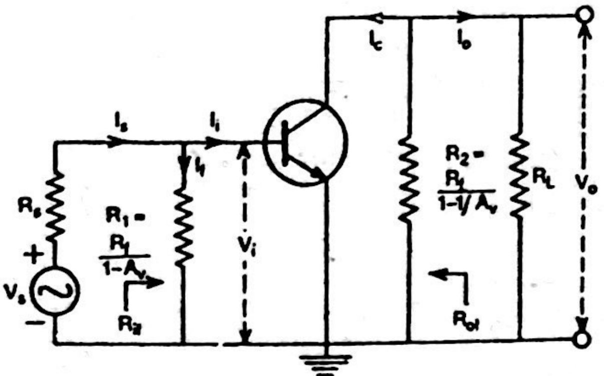


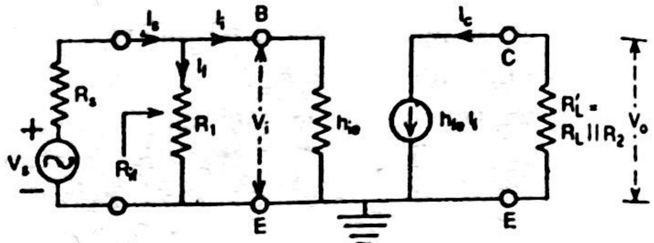
Fig. 11. *CE* amplifier with shunt feedback.

$$I_f = \frac{V_i - V_o}{R_f} \approx \frac{-V_o}{R_f} = B\,V_o, \quad \text{where } B = -\frac{1}{R_f}$$

Since the feedback current is proportional to the output voltage, the circuit is an example of a *voltage shunt feedback amplifier.*



(a) *CE* amplifier obtained on using Miller's theorem.



(b) Equivalent circuit of voltage shunt feedback.

Fig. 12. *CE* equivalent circuit.

Fig. 12 (a and b) shows the equivalent circuit using the Miller's theorem wherein feedback resistor R_f has been replaced by two resistors.

Input resistance. It is obvious from fig. 12 (b) that input resistance is a parallel combination of h_{ie} and R_i, *i.e.,*

$$R_{if} = h_{ie} \parallel R_1 \qquad \dots (1)$$

where
$$R_1 = \frac{R_f}{1 - A_V}.$$

Here $A_V = \dfrac{V_0}{V_i} = \dfrac{-h_{fe}\,R_L'}{h_{ie}}$ and $R'_L = R_L \parallel R_2 \approx R_L \parallel R_f$ (Assuming $|A_V| >> 1$)

Thus R_{if} is small since R_1 is small.
The resistance seen by voltage source $= R_{if} + R_S$ ... (2)

Overall voltage gain. The overall voltage gain is given by $A_{Vsf} = A_V \dfrac{R_{if}}{R_S + R_{if}}$ ... (3)

Output resistance. The output resistance is given by $R_{of} = \dfrac{R_f}{R_S} \cdot \dfrac{(R_S + h_{ie})}{h_{fe}}$. ... (4)

Example 1. *For a common emitter shunt feedback amplifier,* $h_{ie} = 1$ KΩ, $h_{fe} = 50$, $R_L = 1$KΩ. $R_f = 40$KΩ *and* $R_S = 600$ *ohms. Calculate input resistance, overall voltage gain,* R_{of} *and, overall voltage gain with feedback.*

Here $A_V = \dfrac{-h_{fe} \times R_L}{h_{ie}}$ where $R_L' = R_L \parallel R_f$

$$\frac{1}{R_L'} = \frac{1}{R_L} + \frac{1}{R_f} = \frac{1}{1} + \frac{1}{40} = \frac{40+1}{40} = \frac{41}{40}, \quad \therefore \quad R_L' = \frac{40}{41} K\Omega$$

Now $A_V = \dfrac{-50 \times (40/41)}{1} = -49$ and $R_1 = \dfrac{R_f}{1 - A_V} = \dfrac{40}{1-(-49)} = \dfrac{40}{50} = \dfrac{4}{5} K\Omega$

so $R_{if} = 1\text{ K}\Omega = \frac{4}{5}\text{ K}\Omega = \frac{4}{9}\text{ K}\Omega = 444\ \Omega \cong \mathbf{440\ \Omega}$

$$A_{Vsf} = A_V \cdot \frac{R_{if}}{R_S + R_{if}} = -49 \cdot \frac{440\Omega}{600\Omega + 440\Omega} = -\mathbf{21}$$

$$R_{of} = \frac{R_f}{R_S} \cdot \frac{(R_S + h_{ie})}{h_{fe}} = \frac{40\ \text{K}\Omega}{600\ \Omega} \cdot \frac{(600\ \Omega + 1\text{K}\Omega)}{50} = -\ \mathbf{2 \cdot 1\ K\Omega}$$

Example 2. *For a common emitter shunt feedback amplifier, find (i) A_V (ii) R_{if} and also the resistance seen by V_S and (iii) A_{Vsf}. Given that $R_L = 4\text{K}\Omega$, $R_f = 40\text{K}\Omega$, $R_S = 10\text{K}\Omega$, $h_{ie} = 1{\cdot}1\text{K}\Omega$ and* $h_{fe} = 50$.

(i) $A_V = \dfrac{-h_{fe} R_L'}{h_{ie}}$ where $R_L' = R_L \parallel R_f$

Now $\dfrac{1}{R_L'} = \dfrac{1}{R_L} + \dfrac{1}{R_f} = \dfrac{1}{4\text{K}\Omega} + \dfrac{1}{40\text{K}\Omega} = \dfrac{10+1}{40} = \dfrac{11}{40}\text{K}\Omega$ $\quad \therefore \quad R_L' = 3{\cdot}64\ \text{K}\Omega$

$\therefore \quad A_V = \dfrac{-50 \times 3{\cdot}64}{1{\cdot}1} = -\mathbf{166}$

Hence the assumption that $|A_V| >> 1$, is justified.

(ii) $R_{if} = h_{ie} \parallel R_1$ where $R_1 = \dfrac{R_f}{1 - A_V}$

Now $\qquad R_1 = \dfrac{40\ \text{K}\Omega}{1 + 166} = \dfrac{40\ \text{K}\Omega}{167} = 0{\cdot}24\ \text{K}\Omega$

$\therefore \quad R_{if} = 1{\cdot}1\ \text{K}\Omega \parallel 0{\cdot}24\ \text{K}\Omega = \dfrac{(1{\cdot}1) \times (0{\cdot}24)}{1{\cdot}34} = 0{\cdot}2\ \text{K}\Omega = \mathbf{200\ \Omega}$

so the input impedance is quite small as predicted.

The resistance as seen by the signal source

$$= R_S \parallel R_{if} = 10\text{K}\Omega + 0{\cdot}20\text{K}\Omega = \mathbf{10.2\ K\Omega}$$

(iii) $A_{Vsf} = A_V \cdot \dfrac{R_{if}}{R_S + R_{if}} = -166 \cdot \dfrac{0{\cdot}2}{10 + 0{\cdot}2} = -\ \mathbf{3.26}$.

Approximate equation of A_{Vsf} is given by

$$A_{Vsf} = -\frac{R_f}{R_S} = -\frac{40}{10} = -\ \mathbf{4}.$$

11·9. CURRENT SHUNT FEEDBACK

Fig. (13) shows the circuit of a current amplifier using current shunt feedback. The circuit utilizes two *CE* stages in cascade, with feedback from second emitter to the first base through resistor R_f.

Now we shall consider the following two points :

(i) The connection of fig. (13) produces negative feedback.

(ii) The configuration of fig. (13) approximates a current shunt feedback pair.

(i) Due to voltage gain of transistor T_1, V_{i_2} is much larger than V_{i_1}. Moreover V_{i_2} is 180° out of phase with V_{i_1}. Because of the emitter follower action, V_{e_2} is slightly smaller than V_{i_2}. These two voltages are in phase. This shows that V_{e_2} **is** greater than V_{i_1} (in magnitude). The two voltages are 180° out of phase. When the input signal increases, I_S increases and consequently I_f also increases. Now I_i (= $I_S - I_f$) is smaller than it would be if there were no feedback. This action is the characteristic of negative feedback.

(ii) We have shown that $V_{e_2} >> V_{i_1}$. Neglecting the base current of V_2, compared with the collector current,

$$I_f = \frac{V_{i_1} - V_{e_2}}{R_f} \cong -\frac{V_{e_2}}{R_f} \quad \ldots(1) \qquad V_{e_1} \approx -I_o R_e \quad \ldots(2)$$

From eq. (1) and eq. (2), we get

$$I_f \approx \frac{I_o R_e}{R_f} \equiv B I_o \qquad \text{where} \qquad B = \frac{R_e}{R_f} \quad \ldots(3)$$

Eq. (3) shows that the feedback current is proportional to the output current I_o. Hence this circuit forms an example of current shunt feedback.

To analyse the current shunt feedback, we first simplify the network of fig. (13) by applying the Miller's theorem. The equivalent circuit is shown in fig. (14).

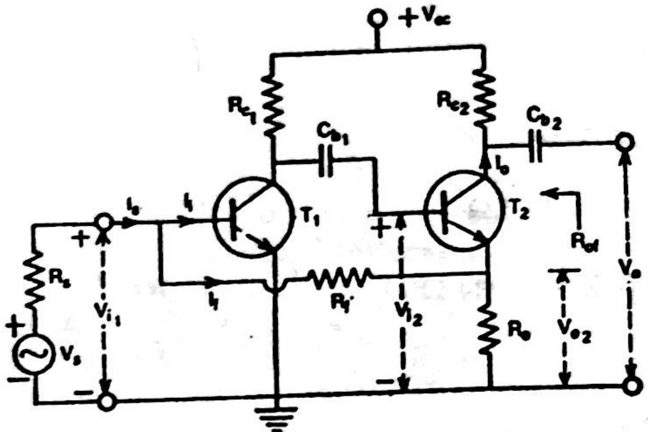


Fig. 13. Current amplifier with current shunt feedback.

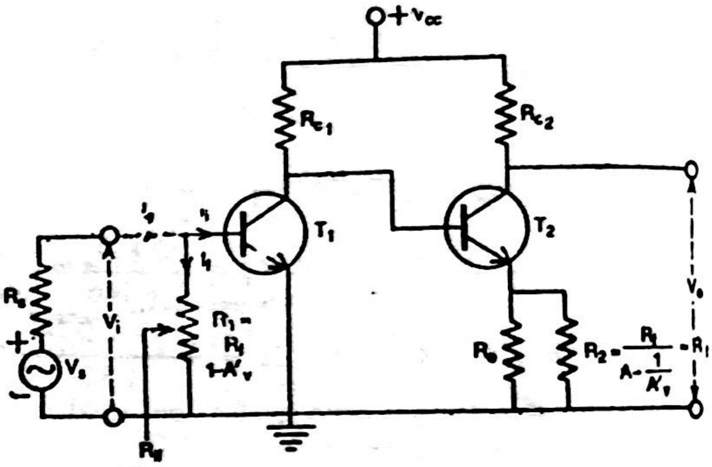


Fig. 14. Equivalent circuit of the amplifier.

(1) Voltage gain A_V' from base of T_1 to emitter of T_2.

The input resistance of transistor T_2 is given by

$$R_{i_2} = h_{ie} + (1 + h_{fe}) R_e' \quad \ldots(4)$$

where $\quad R_e' = R_e \parallel R_f \qquad \left(\because \; R_2 = \frac{R_f}{1 - \frac{1}{A_V'}} \approx R_f \text{ because } A_V' >> 1 \right)$

The voltage gain from base to emitter of T_2 is $A'_{V_2} = 1 - \frac{h_{ie}}{R_{i_2}}$ ...(5)

The effective load of T_1 is given by $R'_L = R_{c_1} \parallel R_{c_2}$ ...(6)

The voltage gain from base of T_1 is $A_{V_1} = \frac{-h_{fe} R'_L}{h_{ie}}$ ...(7)

The voltage gain A'_V from the base of T_1 to emitter of T_2 is given by

$$A_V' = A'_{V_1} \cdot A'_{V_2} \quad \ldots(8)$$

(2) Input Resistance R_{if}. $R_{if} = R_1 \parallel h_{ie}$ . ...(9)

The resistance seen by the signal source $= R_S + R_{if}$ ...(10)

(3) Overall voltage gain with feedback A_{Vsf} .

The voltage gain A_{V_2} of transistor T_2 from base to collector

$$A_{V_2} = -\frac{h_{fe} R_{c_2}}{R_{i_2}} \quad \ldots (11)$$

The voltage gain A_V from the first base to the second collector $A_V = A_{V_1} A_{V_2}$ ... (12)

Thus the overall voltage gain with feedback

$$A_{Vsf} = \frac{V_o}{V_S} = \frac{V_o}{V_{i_1}} \times \frac{V_{i_1}}{V_S} = A_V \left[\frac{R_{if}}{(R_{if} + R_S)}\right] \quad \ldots (13)$$

EXERCISES AND PROBLEMS

1. What do you understand by feedback ? List as many advantages of negative feedback as you can think of indicating any possible restrictions or disadvantages associated with each.
2. Discuss the principles of negative feedback in amplifiers with neat diagram. Why is negative feedback applied in high gain amplifiers.
3. Explain how negative feedback can increase the value of bandwidth in an amplifier.
4. Derive an expression for the gain of negative feedback amplifier. Why is the voltage gain of an amplifier with negative feedback smaller than with no feedback ?
5. (i) What types of negative feedback are there ?
   (ii) Which one always produce an increase in input resistance ?
   (iii) Which type increases input resistance and decreases output resistance ?
6. Describe the action of emitter follower. Derive expressions for voltage gain, output resistance and input resistance.
7. How is current-series feedback introduced in a *CE* amplifier ? What happens to the voltage gain, input resistance and output resistance in a *CE* amplifier with current series negative feedback ?
8. Calculate voltage gain, input resistance and output resistance in a *CE* amplifier with current shunt negative feedback.
9. An *RC* coupled amplifier has a mid frequency gain of 400 and lower and upper 3db frequencies of 100 Hz and 15 KHz. A negative feedback network with $\beta = 0{\cdot}01$ is incorporated into the amplifier circuit. Calculate
   (i) gain with feedback and (ii) new bandwidth. **[Ans.** (i) 80, (ii) 75 KHz]
10. (i) If an amplifier has a bandwidth of 200 KHz and a voltage gain of 100, what will be the new bandwidth and gain if 5% negative feedback is introduced.
    (ii) What is the product of gain and bandwidth before and after adding negative feedback in (*i*) ?
    [Ans. (i) 1·2 MHz, 16·7; (ii) 2×10^7 Hz]
11. A transistor with $h_{ie} = 1{\cdot}5$ K ohms and $h_{fe} = 75$ is used in an emitter follower circuit. If $R_e = R_L$ = 860 ohms and $R_1 \parallel R_2$ = 20K ohms, Calculate,
    (a) A_i, (b) R_i, (c) R'_i, (d) A_V, (e) R_o, (f) R'_o assuming $R_S = 1$ K ohm.
    [Ans. (a) 76, (b) 66·9 KΩ, (c) 15·4 KΩ, (d) 0·978, (e) 32·9 Ω, (f) 31·7 Ω]
12. An amplifier consists of three identical stages as shown below in fig. (15). Each stage has a gain of 50. If 1/100 of the output of the last stage is feedback to the second stage as a negative voltage feedback. Calculate the overall gain of the amplifier.

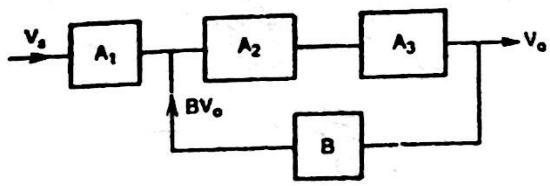


Fig. 15.

13. An amplifier has a gain of 70 and a normal input signal of 0·1 volt. Negative feedback with a feedback factor 0·1 is added. Find the system gain and the input voltage to get the same output voltage.

$$A_{V_2} = -\frac{h_{fe} R_{c_2}}{R_{i_2}} \quad \ldots (11)$$

The voltage gain A_V from the first base to the second collector $A_V = A_{V_1} A_{V_2}$ ... (12)

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$$A_{Vsf} = \frac{V_o}{V_S} = \frac{V_o}{V_{i_1}} \times \frac{V_{i_1}}{V_S} = A_V \left[\frac{R_{if}}{(R_{if} + R_S)}\right] \quad \ldots (13)$$

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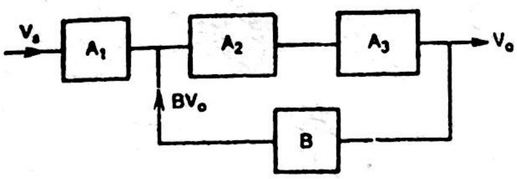

Fig. 15.

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