Semiconductor Devices, Analog and Digital Electronics

BLOCK – I SEMICONDUCTOR DIODES, TRANSISTORS AND AMPLIFIERS

UNIT 4: Feedback Amplifier

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Content

Objectives

After studying this unit, you should be able to-

1. Define Amplifier
2. Classification of Basic Amplifiers
3. Amplifier without Feedback or with Feedback
4. Understand the Basic Concept of Feedback
5. Get Knowledge About the Characteristics of Negative-feedback Amplifiers
6. Effect of negative feedback on input-output resistance
7. Application of negative feedback Amplifier
8. Method of identifying Feedback

Amplifier: Introduction

- In the feedback process a part of output is sampled and feedback to the input.
- The fed back signal can be in phase with or out of phase with the original input signal.

Definition of feedback:

- Feedback is defined as the process in which a part of output signal (voltage or current) is returned back to the input.
- The amplifier that operates on the principle of feedback is known as feedback amplifier.

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Classification of Amplifiers

- **Voltage Amplifier-** An amplifier provides a voltage output proportional to the voltage input and the proportionality factor does not depend on the magnitudes of the source and load resistance
- **Current Amplifier-** An amplifier which provides an output current proportional to the signal current .
- **Transconductance Amplifier-** An amplifier in which, the output current is proportional to the signal voltage, independent of the magnitudes of source and load resistance.
- **Transresistance Amplifier-** An amplifier in which output voltage is proportional to the signal current of the magnitudes of source and load resistance.

Types of Feedback

Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers *viz*

1. Positive feedback
2. Negative feedback

Positive feedback :

If the original input signal and the feedback signal are in phase, the feedback is called as positive feedback.

Negative feedback:

However if these two signals are out of phase then the feedback is called as negative feedback.

Amplifier Without Feedback

- In the amplifier without feedback the most important thing to understand is that the output and input terminals of this amplifier are not connected to each other in any way.
- Therefore the amplifier of is an amplifier without any feedback

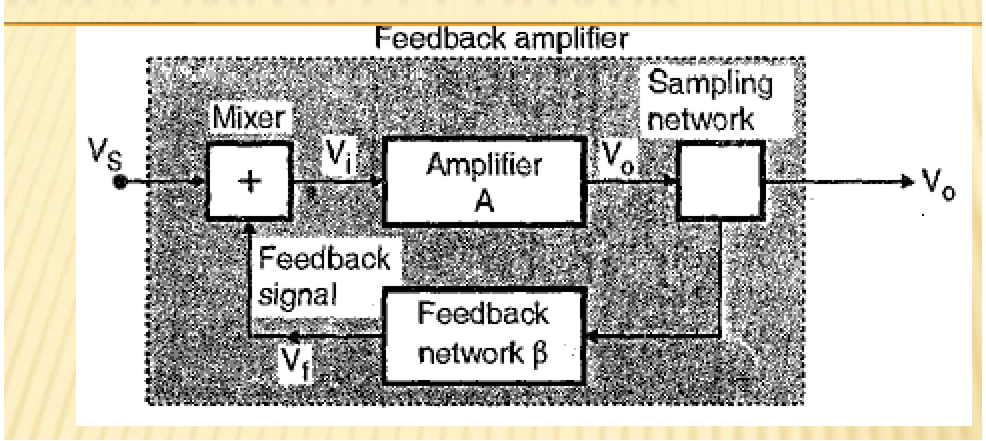
    - Gain without any feedback

$$A = \frac{V_o}{V_i}$$

Amplifier With Feedback

Refer to Fig. Here the same amplifier with a gain A is being used along with a mixer network, sampling network and a feedback network.

- The voltage gain of the feedback amplifier is given by,

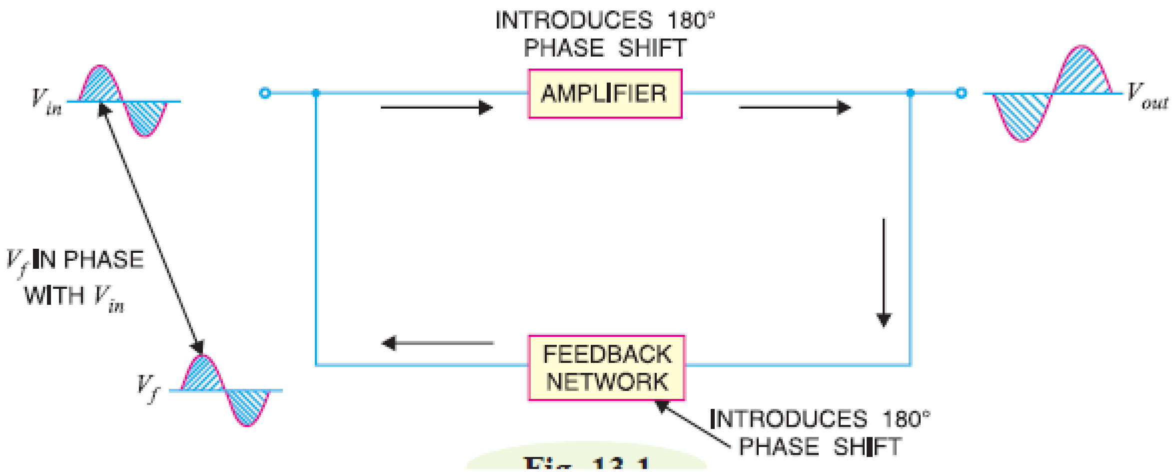


Gain with feedback

$$A_f = \frac{V_o}{V_s}$$

Amplifier With Positive Feedback

When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called positive feedback.
This is illustrated in Figure. Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around the loop, causing the feedback voltage Vf to be in phase with the input signal Vin.

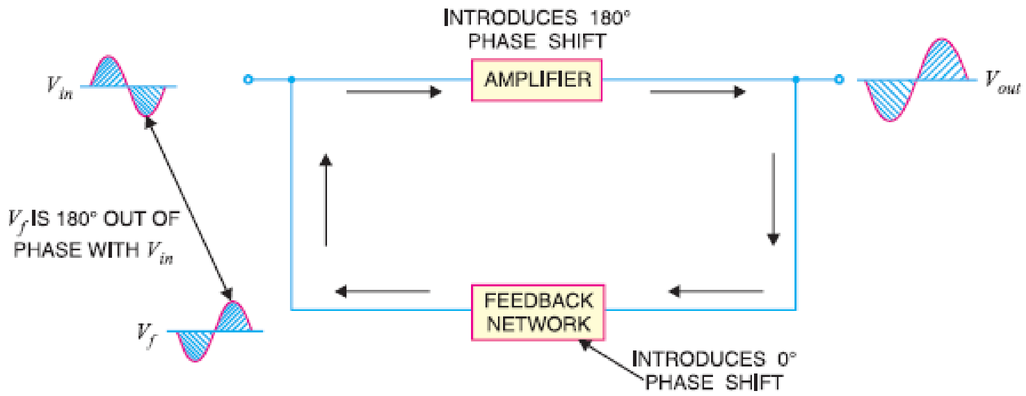


- The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability.
- Therefore, positive feedback is seldom employed in amplifiers.
- One important use of positive feedback is in oscillators.

Amplifier With Negative Feedback

➢When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called negative feedback. This is illustrated in Figure.

➢•As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (i.e., 0° phase shift). The result is that the feedback voltage V_f is 180° out of phase with the input signal Vin.



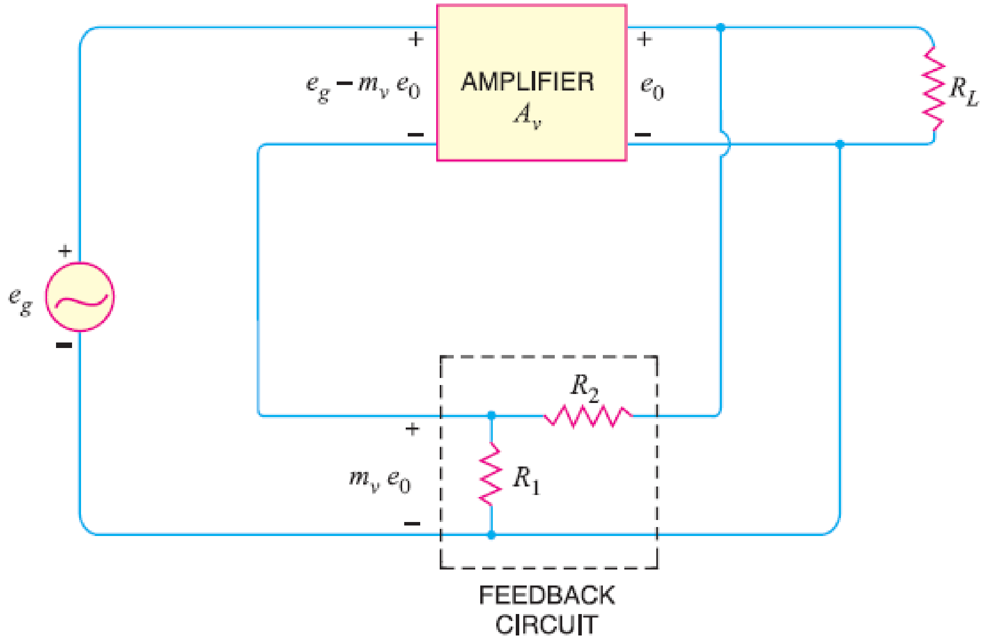
- Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stability in gain, increased bandwidth and improved input and output impedances.
- It is due to these advantages that negative feedback is frequently employed in amplifiers.

Feedback Circuit

- The function of the feedback circuit is to return a fraction of the output voltage to the input of the amplifier. Figure shows the feedback circuit of negative voltage feedback amplifier.
- It is essentially a potential divider consisting of resistances R_1 and R_2. The output voltage of the amplifier is fed to this potential divider which gives the feedback voltage to the input.
- Referring to Figure, it is clear that :

$$\text{Voltage across } R_1 = \left(\frac{R_1}{R_1 + R_2}\right) e_0$$

$$\text{Feedback fraction, } m_v = \frac{\text{Voltage across } R_1}{e_0} = \frac{R_1}{R_1 + R_2}$$



Principles of Negative Voltage Feedback In Amplifiers

A feedback amplifier has two parts viz an amplifier and a feedback circuit.

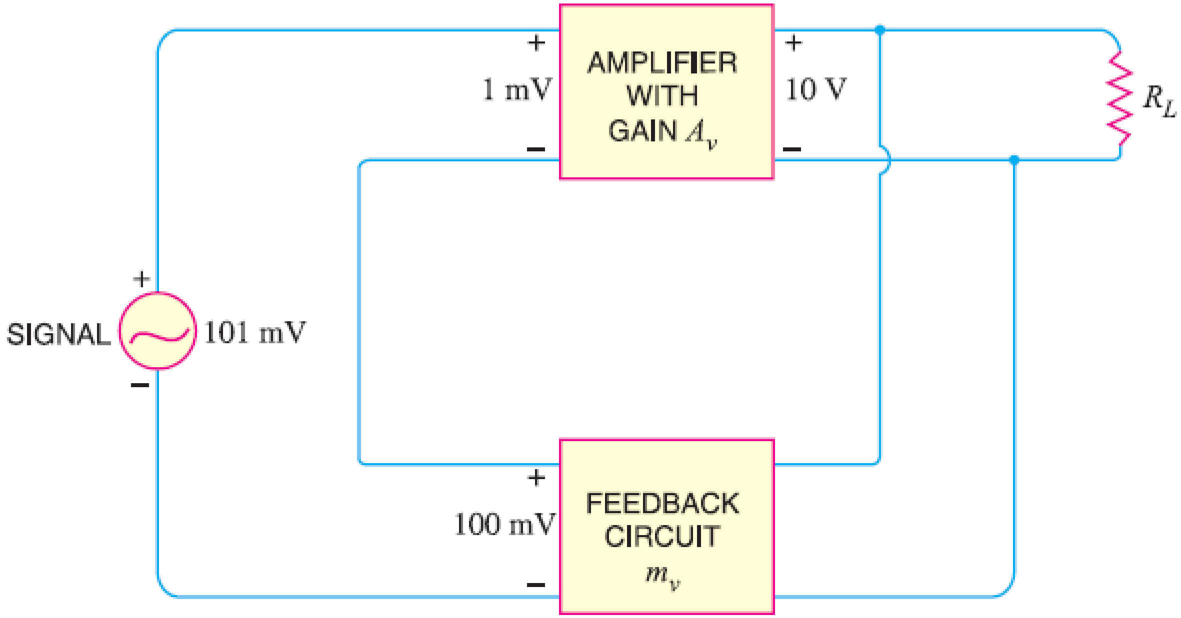
• The feedback circuit usually consists of resistors and returns a fraction of output energy back to the input.

• Figure shows the principles of negative voltage feedback in an amplifier.

• The output of the amplifier is 10 V. The fraction mv of this output i.e. 100 mV is feedback to the input where it is applied in series with the input signal of 101 mV.

• *As the feedback is negative, therefore, only 1 mV appears at* the input terminals of the amplifier.

Gain of amplifier without feedback, *Av = 10 V / 1 mV= 10, 000*



Fraction of output voltage fedback,

$m_v = 100\ mV / 10\ V = 0.01$

• Gain of amplifier with negative feedback,

$A_{vf} = 10\ V / 101\ mV = 100$

The following points are worth noting :

(i) When negative voltage feedback is applied, the gain of the amplifier is reduced. Thus, the gain of above amplifier without feedback is 10,000 whereas with negative feedback, it is only
100.

(ii) When negative voltage feedback is employed, the voltage actually applied to the amplifier is extremely small. In this case, the signal voltage is 101 mV and the negative feedback is 100 mV
so that voltage applied at the input of the amplifier is only 1 mV.

(iii) In a negative voltage feedback circuit, the feedback fraction m_v is always between 0 and 1.

(iv) The gain with feedback is sometimes called closed-loop gain while the gain without feedback
is called open-loop gain.

These terms come from the fact that amplifier and feedback circuits form a "loop".

- When the loop is "opened" by disconnecting the feedback circuit from the input, the amplifier's gain is Av, the "open loop" gain.
- When the loop is "closed" by connecting the feedback circuit, the gain decreases to A_{vf}, the "closed-loop" gain

Gain of Negative Voltage Feedback Amplifier

Consider the negative voltage feedback amplifier shown in Figure. The gain of the amplifier without feedback is A_v.

• Negative feedback is then applied by feeding a fraction m_v of the output voltage e_0 back to amplifier input. Therefore, the actual input to the amplifier is the signal voltage e_g minus feedback voltage mv e_0 i.e.,

Actual input to amplifier = $e_g - m_v e_g$

• The output e0 must be equal to the input voltage eg $- m_v e_0$ multiplied by gain A_v of the amplifier i.e.,

$(e_g - m_v e_0) A_v = e_0$

or $A_v e_g - A_v m_v e_0 = e_0$

or $e_0 (1 + A_v m_v) = A_v e_g$

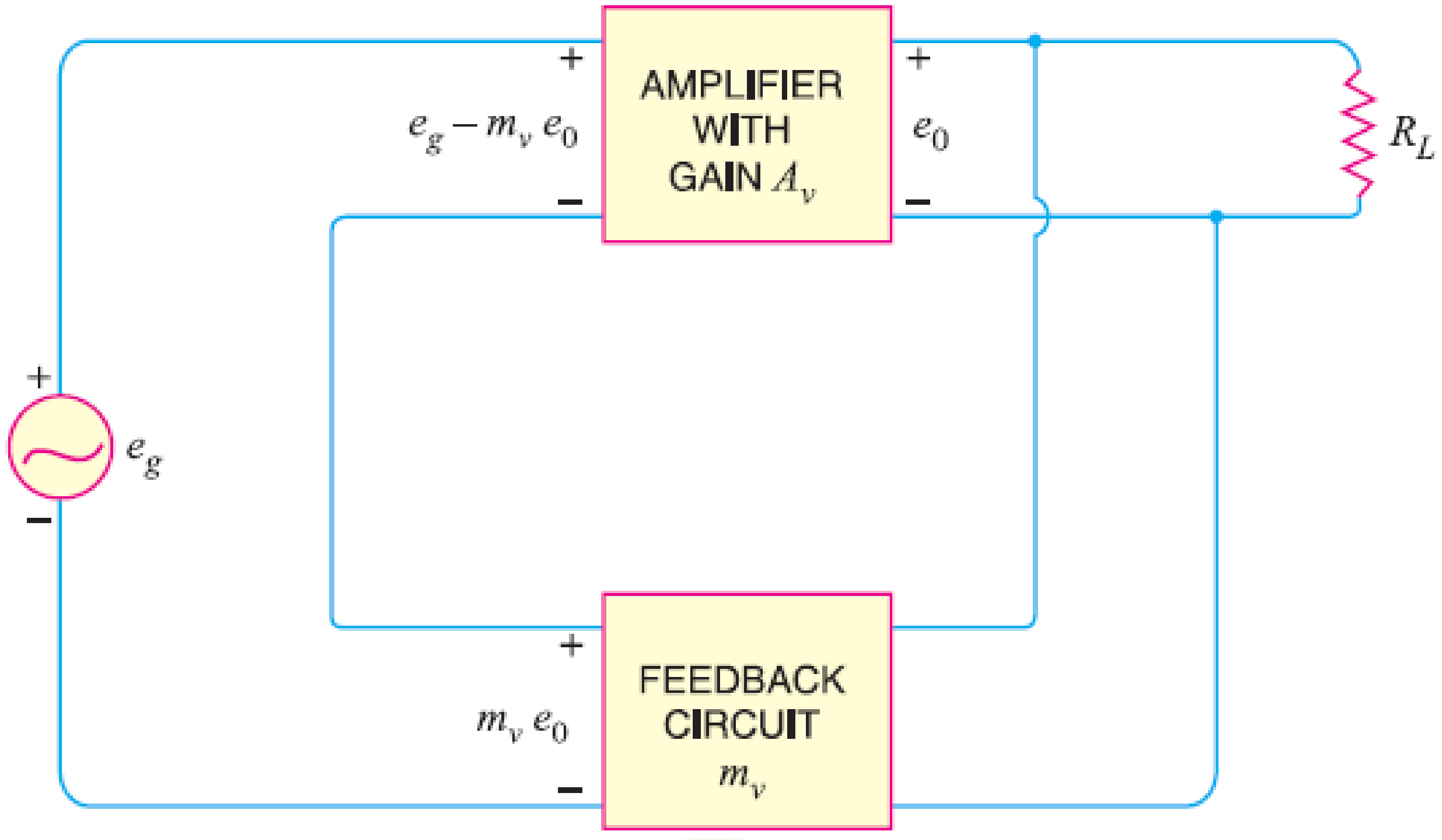
or $e_0 / e_g = A_v / 1 + A_v m_v$

But e_0/e_g is the voltage gain of the amplifier with feedback.

∴ Voltage gain with negative feedback is $A_{vf} = A_v / 1 + A_v m_v$

• It may be seen that the gain of the amplifier without feedback is A_v. However, when negative voltage feedback is applied, the gain is reduced by a factor $1 + A_v m_v$.

• It may be noted that negative voltage feedback does not affect the current gain of the circuit.



+
$e_g - m_v e_0$
−
AMPLIFIER WITH GAIN A_v
+
e_0
−
R_L
+
e_g
−
+
$m_v e_0$
−
FEEDBACK CIRCUIT m_v

Advantages of Negative Voltage Feedback

(i) Gain stability. An important advantage of negative voltage

feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations.

$A_{vf} = A_v / 1 + A_v\, m_v$

• For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product Av mv much greater than unity. Therefore, in the above relation, 1 can be neglected as compared to $A_v\, m_v$ and the expression becomes :

$A_{vf} = A_v / A_v\, m_v = 1 / m_v$

• It may be seen that the gain now depends only upon feedback fraction m_v i.e., on the characteristics of feedback circuit

(ii) Reduces non-linear distortion

• A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The negative voltage feedback reduces the nonlinear distortion in large signal amplifiers. It can be proved mathematically that :

$D_{vf} = D / 1 + A_v\, m_v$

where *D = distortion in amplifier without feedback* D_{vf} = *distortion in amplifier with negative feedback*

• It is clear that by applying negative voltage feedback to an amplifier, distortion is reduced by a factor $1 + A_v\, m_v$..

(iii) Improves frequency response.

• As feedback is usually obtained through a resistive network, therefore, voltage gain of the amplifier is independent of signal frequency. The result is that voltage gain of the amplifier will be substantially constant over a wide range of signal frequency.

• The negative voltage feedback, therefore, improves the frequency response of the amplifier.

(iv) Increases circuit stability

• The output of an ordinary amplifier is easily changed due to variations in ambient temperature, frequency and signal amplitude.

• This changes the gain of the amplifier, resulting in distortion.

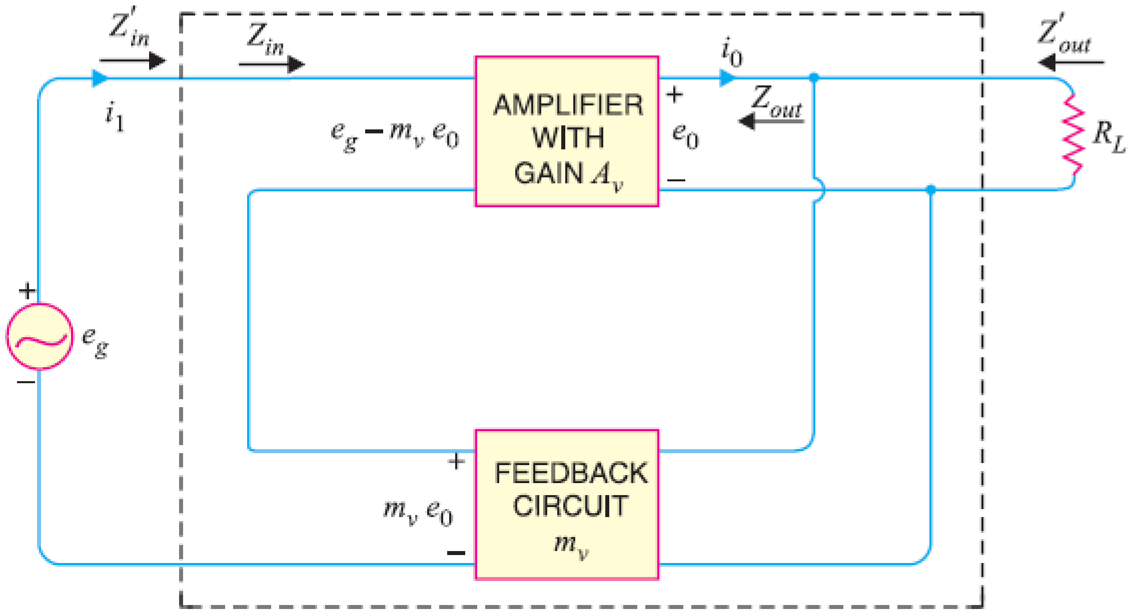
However, by applying negative voltage feedback, voltage gain of the amplifier is stabilized or accurately fixed in value.

(v) Increases input impedance and decreases output impedance.

• The negative voltage feedback increases the input impedance and decreases the output impedance of amplifier.

(a) Input impedance. The increase in input impedance with

negative voltage feedback can be explained by referring to Figure. Suppose the input impedance of the amplifier is Z_{in} *without feedback and* Z'_{in} *with negative feedback. Let us* further assume that input current is i_1.



$$e_g - m_v e_0 = i_1 Z_{in}$$

Now

$$\begin{aligned} e_g &= (e_g - m_v e_0) + m_v e_0 \\ &= (e_g - m_v e_0) + A_v m_v (e_g - m_v e_0) \qquad [\because e_0 = A_v (e_g - m_v e_0)] \\ &= (e_g - m_v e_0)(1 + A_v m_v) \\ &= i_1 Z_{in} (1 + A_v m_v) \qquad [\because e_g - m_v e_0 = i_1 Z_{in}] \end{aligned}$$

or

$$\frac{e_g}{i_1} = Z_{in}(1 + A_v m_v)$$

But $e_g/i_1 = Z'_{in}$, the input impedance of the amplifier with negative voltage feedback.

$$\therefore \quad Z'_{in} = Z_{in}(1 + A_v m_v)$$

It is clear that by applying negative voltage feedback, the input impedance of the amplifier is increased by a factor $1 + A_v m_v$. As $A_v m_v$ is much greater than unity, therefore, input impedance is
increased considerably.

(b) Output impedance

• Following similar line, we can show that output impedance with negative voltage feedback is given by :

$$Z'_{out} = \frac{Z_{out}}{1 + A_v m_v}$$

where Z'_{out} = output impedance with negative voltage feedback

Z_{out} = output impedance without feedback

It is clear that by applying negative feedback, the output impedance of the amplifier is decreased by a factor $1 + A_v m_v$.

Eg: The voltage gain of an amplifier without feedback is 3000. Calculate the voltage gain of the amplifier if negative voltage feedback is introduced in the circuit. Given that feedback fraction m v = 0.01.

Solution. $A_v = 3000, \quad m_v = 0.01$

∴ Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v m_v} = \frac{3000}{1 + 3000 \times 0.01} = \frac{3000}{31} = 97$$

EX: The overall gain of a multistage amplifier is 140. When negative voltage feedback is applied, the gain is reduced to 17.5. Find the fraction of the output that is fedback to the input.

Solution. $A_v = 140, \quad A_{vf} = 17.5$

Let m_v be the feedback fraction. Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v m_v}$$

or

$$17.5 = \frac{140}{1 + 140\, m_v}$$

or

$$17.5 + 2450\, m_v = 140$$

$\therefore$

$$m_v = \frac{140 - 17.5}{2450} = \frac{\mathbf{1}}{\mathbf{20}}$$

EX: When negative voltage feedback is applied to an amplifier of gain 100, the overall gain falls to 50.

(i) Calculate the fraction of the output voltage fedback.

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

Solution.

(i) Gain without feedback, $A_v = 100$

Gain with feedback, $A_{vf} = 50$

Let m_v be the fraction of the output voltage fedback.

Now $$A_{vf} = \frac{A_v}{1 + A_v m_v}$$

or $$50 = \frac{100}{1 + 100\, m_v}$$

or $$50 + 5000\, m_v = 100$$

or $$m_v = \frac{100 - 50}{5000} = \mathbf{0.01}$$

(ii) $$A_{vf} = 75; \quad m_v = 0.01; \quad A_v = ?$$

$$A_{vf} = \frac{A_v}{1 + A_v m_v}$$

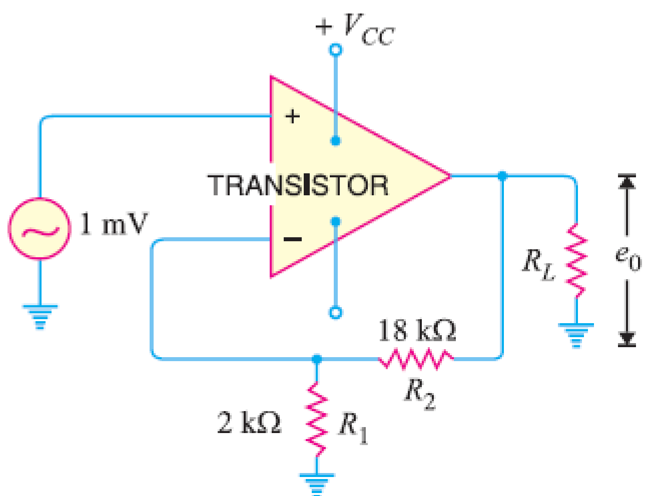
or $$75 = \frac{A_v}{1 + 0.01\, A_v}$$

or $$75 + 0.75\, A_v = A_v$$

$\therefore$ $$A_v = \frac{75}{1 - 0.75} = \mathbf{300}$$

EX: Fig. shows the negative voltage feedback amplifier. If the gain of the amplifier without feedback is 10,000, find :

- (i) feedback fraction (ii) overall voltage gain (iii) output voltage if input voltage is 1 mV.



Solution. $A_v = 10{,}000, \quad R_1 = 2\text{ k}\Omega, \quad R_2 = 18\text{ k}\Omega$

(i) Feedback fraction, $m_v = \dfrac{R_1}{R_1 + R_2} = \dfrac{2}{2+18} = \mathbf{0.1}$

(ii) Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{10{,}000}{1 + 10{,}000 \times 0.1} = \mathbf{10}$$

(iii) Output voltage $= A_{vf} \times$ input voltage

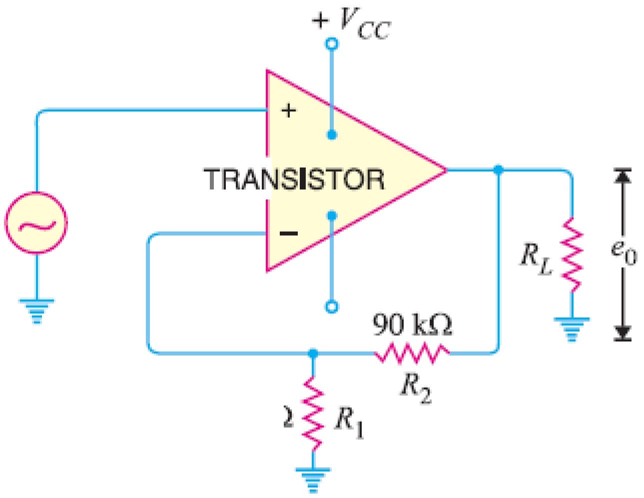
$= 10 \times 1\text{ mV} = \mathbf{10\text{ mV}}$

Figure shows the circuit of a negative voltage feedback amplifier. If without feedback, Av = 10,000, Zin = 10 kΩ, Zout = 100 Ω, find :

(i) feedback fraction (ii) gain with feedback

(iii) input impedance with feedback

(iv) output impedance with feedback.



Solution.

(*i*) Feedback fraction, $m_v = \dfrac{R_1}{R_1 + R_2} = \dfrac{10}{10+90} = \mathbf{0.1}$

(*ii*) Gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{10{,}000}{1 + 10{,}000 \times 0.1} = \mathbf{10}$$

(*iii*) With negative voltage feedback, input impedance is increased and is given by :

$$\underset{(feedback)}{Z'_{in}} = (1 + A_v\, m_v)\, Z_{in}$$

$$= (1 + 10{,}000 \times 0.1)\ 10\ \text{k}\Omega$$

$$= 1001 \times 10\ \text{k}\Omega$$

$$= \mathbf{10\ M\Omega}$$

(*iv*) With negative voltage feedback, output impedance is decreased and is given by ;

$$\underset{(feedback)}{Z'_{out}} = \frac{Z_{out}}{1 + A_v\, m_v} = \frac{100\ \Omega}{1 + 10{,}000 \times 0.1} = \frac{100}{1001} = \mathbf{0.1\ \Omega}$$

Principles of Negative Current Feedback

•In this method, a fraction of output current is fedback to the input of the amplifier. In other words, the feedback current (I_f) is proportional to the output current (I_{out}) of the amplifier.

• Figure shows them principles of negative current feedback. This circuit is called current-shunt feedback circuit.

• A feedback resistor R_f is connected between input and output of the amplifier. This amplifier has a current gain of Ai without feedback. It means that a current I_1 at the input terminals of the amplifier will appear as $A_i I_1$ in the output circuit i.e., $I_{out} = A_i I_1$.

• Now a fraction m_i of this output current is feedback to the input through R_f. The fact that arrowhead shows the feed current being fed forward is because it is negative feedback.

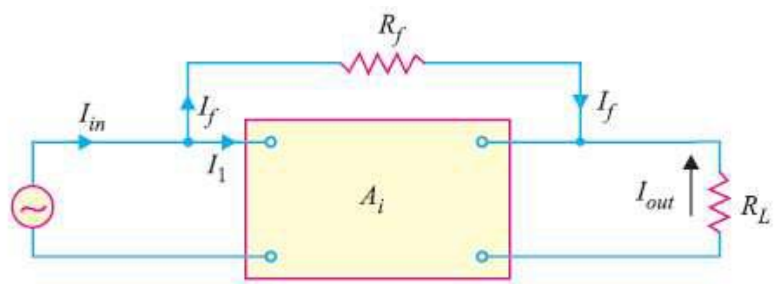


Fig. 13.10

Feedback current, $I_f = m_i I_{out}$

$$\therefore \quad \text{Feedback fraction, } m_i = \frac{I_f}{I_{out}} = \frac{\text{Feedback current}}{\text{Output current}}$$

Note that negative current feedback reduces the input current to the amplifier and hence its current gain.

Current Gain with Negative Current Feedback

$$I_{in} = I_1 + I_f = I_1 + m_i I_{out}$$

But $I_{out} = A_i I_1$, where A_i is the current gain of the amplifier without feedback.

$\therefore$ $$I_{in} = I_1 + m_i A_i I_1 \qquad (\because I_{out} = A_i I_1)$$

$\therefore$ Current gain with negative current feedback is

$$A_{if} = \frac{I_{out}}{I_{in}} = \frac{A_i I_1}{I_1 + m_i A_i I_1}$$

or $$A_{if} = \frac{A_i}{1 + m_i A_i}$$

The following points may be noted carefully :

(i) The current gain of the amplifier without feedback is A_i. However, when negative current feedback is applied, the current gain is reduced by a factor $(1 + m_i A_i)$.

(ii) The feedback fraction (or current attenuation) m_i has a value between 0 and 1.

(iii) The negative current feedback does not affect the voltage gain of the amplifier.

EX: The current gain of an amplifier is 200 without feedback. When negative current feedback is applied, determine the effective current gain of the amplifier. Given that current attenuation mi = 0.012.

Solution.

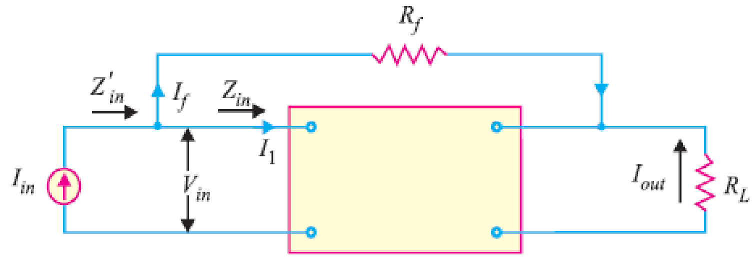
$$A_{if} = \frac{A_i}{1 + m_i A_i}$$

Here $A_i = 200\,; \quad m_i = 0.012$

$$\therefore \quad A_{if} = \frac{200}{1 + (0.012)(200)} = \mathbf{58.82}$$

Effects of Negative Current Feedback

(i) Decreases the input impedance.
The negative current feedback decreases the input impedance of most amplifiers.
Let Z_{in} = Input impedance of the amplifier without feedback Z'_{in} = Input impedance of the amplifier with negative current feedback



$$Z_{in} = \frac{V_{in}}{I_1}$$

and $$Z'_{in} = \frac{V_{in}}{I_{in}}$$

But $$V_{in} = I_1 Z_{in} \quad \text{and} \quad I_{in} = I_1 + I_f = I_1 + m_i I_{out} = I_1 + m_i A_i I_1$$

$\therefore$ $$Z'_{in} = \frac{I_1 Z_{in}}{I_1 + m_i A_i I_1} = \frac{Z_{in}}{1 + m_i A_i}$$

or $$Z'_{in} = \frac{Z_{in}}{1 + m_i A_i}$$

Thus the input impedance of the amplifier is decreased by the factor $(1 + m_i A_i)$.

(*ii*) **Increases the output impedance.** It can be proved that with negative current feedback, the output impedance of the amplifier is increased by a factor $(1 + m_i A_i)$.

$$Z'_{out} = Z_{out}(1 + m_i A_i)$$

where Z_{out} = output impedance of the amplifier without feedback

Z'_{out} = output impedance of the amplifier with negative current feedback

(*iii*) **Increases bandwidth.** It can be shown that with negative current feedback, the bandwidth of the amplifier is increased by the factor $(1 + m_i A_i)$.

$$BW' = BW(1 + m_i A_i)$$

where BW = Bandwidth of the amplifier without feedback

BW' = Bandwidth of the amplifier with negative current feedback

EX: An amplifier has a current gain of 240 and input impedance of 15 kΩ without Feedback. If negative current feedback (m_i = 0.015) is applied, what will be the input impedance of the amplifier ?

Solution. $$Z'_{in} = \frac{Z_{in}}{1 + m_i A_i}$$

Here $Z_{in} = 15\ \text{k}\Omega;\quad A_i = 240;\quad m_i = 0.015$

$\therefore$ $$Z'_{in} = \frac{15}{1 + (0.015)(240)} = \mathbf{3.26\ k\Omega}$$

EX: An amplifier has a current gain of 200 and output impedanceb of 3 kΩ without feedback. If negative current feedback (m_i = 0.01) is applied; what is the output impedance of the amplifier ?

Solution. $$Z'_{out} = Z_{out}(1 + m_i A_i)$$

Here $Z_{out} = 3\ \text{k}\Omega;\quad A_i = 200;\quad m_i = 0.01$

$\therefore$ $$Z'_{out} = 3[1 + (0.01)(200)] = \mathbf{9\ k\Omega}$$

EX: An amplifier has a current gain of 250 and a bandwidth of 400 kHz without feedback. If negative current feedback (m_i = 0.01) is applied, what is the bandwidth of the amplifier?

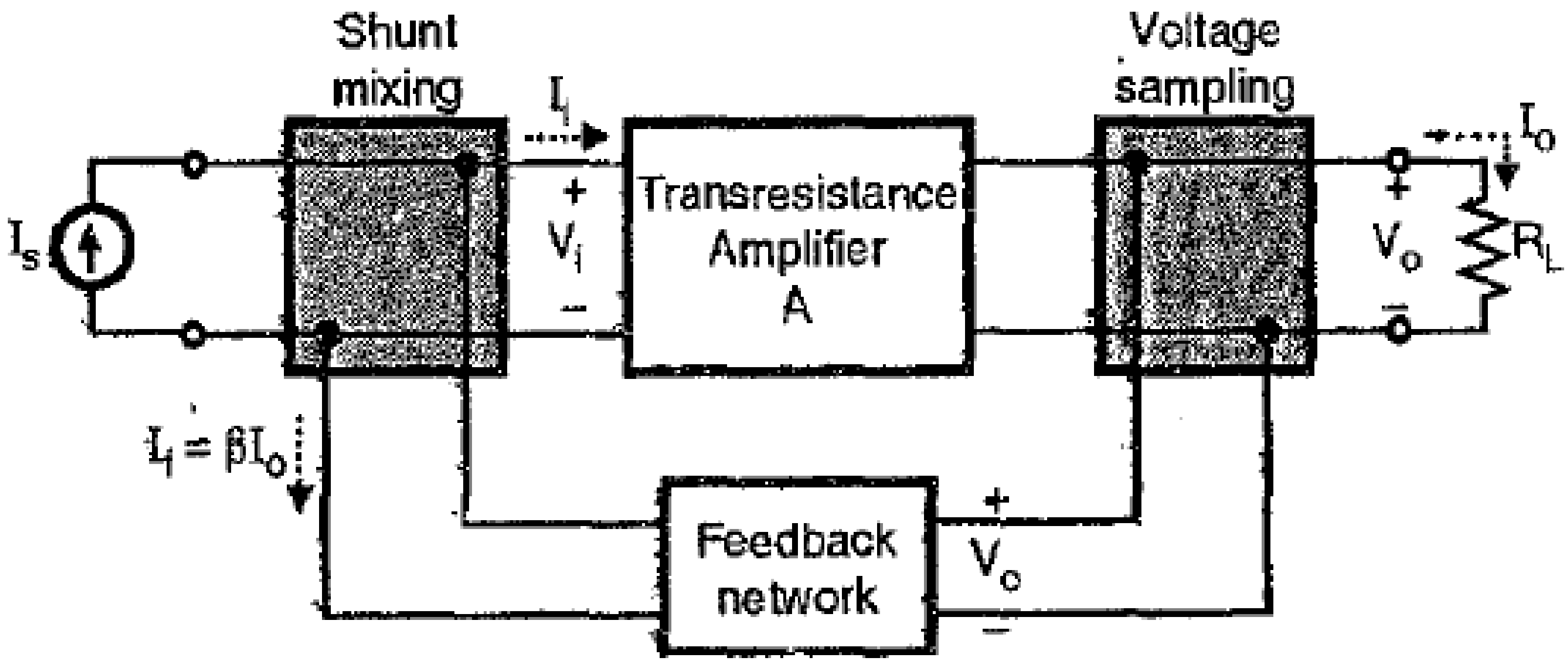
Solution. $$BW' = BW(1 + m_i A_i)$$

Here $BW = 400\ \text{kHz};\quad m_i = 0.01;\quad A_i = 250$

$\therefore$ $$BW' = 400[1 + (0.01)\,250] = \mathbf{1400\ kHz}$$

❑The block diagram of an amplifier with voltage shunt feedback amplifier is shown in Fig. Voltage Shunt Feedback = Voltage Sampling + Shunt Mixing.

 The voltage shunt feedback is present in the trans resistance amplifier.



Advantages and disadvantages

Advantages

- ❑ Negative feedback stabilizes the gain of the amplifier.
- Input resistance increases for certain feedback configurations.
- Output resistance decreases for certain feedback configurations.
- Operating point is stabilized.

Disadvantages

- Reduction in gain.
- Reduction in input resistance in case of voltage shunt and current shunt type amplifiers.
- Increase in output resistance in case of current shunt and current series feedback amplifiers.

Applications of negative feedback

- In a1most all the electronic amplifiers.
- In the regulated power supplies.
- In wideband amplifiers (amplifiers having a large bandwidth)

Some Useful Links

https://www.youtube.com/watch?v=hU8zx0RGJGQ

https://www.youtube.com/watch?v=0nXEUkFBd8A

https://www.youtube.com/watch?v=VulmfTrHdsQ

https://www.youtube.com/watch?v=O_pqCNPs6xw

Thanks