FEEDBACK AMPLIFIERS

FEEDBACK IS THE PROCESS OF FEEDING A FRACTION OF OUTPUT ENERGY (VOLTAGE OR CURRENT) BACK TO THE INPUT CIRCUIT. THE CIRCUIT EMPLOYED FOR THIS PURPOSE IS CALLED A FEEDBACK NETWORK.

Need for feedback:
An open loop amplifier with high gain generally suffers from poor stability in gain, small bandwidth, excessive distortion and noise. Moreover, the input impedance \( Z_i \) of amplifier should be high enough to avoid the loading effect with the output section of source (or preceding stage in multistage amplifiers) and the output impedance \( Z_o \) should be low so that maximum power can be delivered at the output.

To improve one or more of the above characteristics, feedback is employed in amplifiers. The amplifiers, which use the feedback, are called feedback amplifiers.

Basic amplifier (amplifier without feedback):
Figure shows the block diagram of a basic amplifier. \( v_i \) is the input signal and \( v_o \) is the output signal. If \('A'\) is the voltage gain of the amplifier, the output \( v_o \) is related to the input \( v_i \) by the equation

\[
A = \frac{v_0}{v_i}
\]

\[
\therefore v_o = A v_i
\]

Voltage gain \( 'A' \) is called the open loop gain and this type of system is called open loop or non-feedback system. In this system, if the output signal gets distorted, there is no mechanism to correct this and hence the distortion will continue to exist in the output signal.

Principle of feedback amplifiers:
Figure shows the block diagram of a feed back amplifier. It consists of two parts. They are, amplifier circuit (called as basic amplifier or amplifier without feedback) and feedback network. The feedback network (or \( \beta \) network) transfers a fraction \( \beta v_o \) of the output voltage back to the input section. This changes the net input voltage \( v_i \) to the internal amplifier (amplifier without feedback or basic amplifier). i.e., \( v_i = v_s \pm v_f \). Such a system is called closed loop system or feedback system.
Block diagram of a feedback amplifier:

[Basic amplifier is also called as “internal amplifier” or amplifier without feedback” or the “open loop amplifier”]. Figure shows the block diagram of a feedback amplifier, where $v_s$ is the source voltage or the input voltage to the feedback amplifier, $v_o$ is the output voltage and $v_i$ is the input voltage of internal amplifier whose gain $A$ is given by, $A = \frac{v_o}{v_i}$, $\beta$ is called the feedback ratio or feedback factor or reverse transmission factor. The product $A\beta$ is called loop gain $v_f = \beta v_0$ is the feedback voltage. Voltage gain $A_f$ of the feedback amplifier is given by, $A_f = \frac{v_o}{v_s}$. Due to the feedback, the net input to the internal amplifier changes to $v_s \pm \beta v_0$. Depending upon whether the feedback signal increases or decreases the net input for the internal amplifier, there are two types of feedback in amplifiers. They are positive feedback and negative feedback.

**POSITIVE FEEDBACK:** If the feedback signal (voltage or current) is applied in such a way that it is in phase with the input signal (i.e., source signal) and thus increases the net input to the internal amplifier, the feedback is said to be positive. Here, the net input to the internal amplifier is given by $v_i = v_s + v_f$. Positive feedback is also called as regenerative feedback or direct feedback. [The positive feed back increases the gain of an amplifier simultaneously introducing signal distortion and instability in gain. Due to this reason, this type of feedback is not generally used in amplifiers. But, positive feedback is employed in electronic oscillators].
NEGATIVE FEEDBACK: If the feedback signal (voltage or current) is applied in such a way that it is out of phase with the input signal (i.e. source signal) and thus decreases the net input to the internal amplifier, the feedback is said to be negative. Here, the net input to the internal amplifier is given by $v_i = v_s - v_f$.

Negative feedback is also called as degenerative feedback or reverse feedback. Negative feedback reduces the gain of an amplifier. However, it improves the performance of the amplifier in many other aspects.

**Advantages of negative feedback:**
1. It increases the stability of amplifier gain.
2. It reduces the distortion and noise.
3. It increases the input impedance.
4. It decreases the output impedance.
5. It increases the bandwidth.

**Four ways of applying negative feedback**
The negative feedback may be either voltage or current. This can be either in series or in parallel. Thus, there are four basic ways of providing the feedback signal; namely,

- a) Voltage-series feedback
- b) Voltage-shunt feedback
- c) Current-series feedback
- d) Current-shunt feedback.

**Voltage-series feedback amplifier:**

It is also called as shunt derived series fed feedback or voltage-voltage feedback amplifier. Here, a fraction of the output voltage is selected through feedback network and is applied in series with the input source signal $v_s$ (i.e., $v_i = \beta v_o$). This type of feedback increases the input impedance and decreases the output impedance. The transfer gain of this amplifier is Voltage amplification factor or Voltage gain as given by the equations $A_f = \frac{v_o}{v_s}$ and $A = \frac{V_o}{V_i}$ with and without feedback respectively. Therefore, this is an example of true voltage amplifier. In this type of feedback, $A$ and $\beta$ have no dimensions.
Voltage shunt feedback:

It is also called as shunt derived shunt-fed feedback connection or Voltage-Current feedback. Here, the Feedback signal ($i_f$) proportional to the output voltage is developed by passing through the feedback net-work and is applied in parallel with the input source signal. This type of feedback decreases both the input and output impedances.

The transfer gain of this amplifier given by the equations $A_f = \frac{v_o}{i_s}$ and $A = \frac{i_o}{v_i}$ with and without feedback respectively and have the dimensions of resistance. This type of amplifier is a **Trans-resistance Amplifier**. The feedback factor $\beta = \frac{i_f}{v_o}$ has the dimensions of conductance. Therefore, the loop gain $A\beta$ has no dimensions.

Current series feedback: It is also called as series derived, series-fed feedback amplifier or current-voltage feedback. Here, the feedback signal $v_f$ proportional to the output current $i_o$ is developed by the feedback network and then applied in series with the source signal. This type of feedback connection increases both the input and output impedances. The transfer gain of this amplifier given by the equations $A_f = \frac{i_o}{v_s}$ and $A = \frac{i_o}{v_i}$ with and without feedback respectively and have the dimensions of conductance.

This type of amplifier is a **Trans-conductance Amplifier**. The feedback factor $\beta = \frac{v_f}{i_o}$ has the dimensions of resistance. Therefore, the loop gain $A\beta$ has no dimensions.
**Current shunt feedback:** It is also called as *series-derived shunt-fed feedback* or *current-current feedback*. Here, the feedback signal $i_f$ proportional to the output current is developed by the feedback network and applied in parallel with the source signal. Hence, the input impedance decreases and the output impedance increases. The transfer gain of this amplifier is Current amplification factor or Current gain as given by the equations $A_f = \frac{i_0}{i_s}$ and

$$A = \frac{i_o}{i_i}$$

with and without feedback respectively. Therefore, this is an example of current amplifier. In this type of feedback, $A$ and $\beta$ have no dimensions.

Series feedback connections tend to increase the input impedance while the shunt feedback connections tend to decrease the input impedance. Voltage feedback tends to decrease the output impedance, while current feedback tends to increase the output impedance.

For most multistage amplifiers, high input impedance and low output impedance are desirable.

**VOLTAGE SERIES FEEDBACK AMPLIFIER EXHIBITS BOTH THESE CHARACTERISTICS AND HENCE IS GENERALLY EMPLOYED.**

**Expression for the Voltage gain of voltage series Negative feedback Amplifier**
Figure shows the block diagram of a voltage series feedback amplifier where, $v_s$ is the source voltage (input voltage to the feedback amplifier), $v_o$ is the output voltage. $v_f$ is the feedback voltage and is given by

$$v_f = \beta v_o \quad \rightarrow (1)$$

where, ‘$\beta$’ is the feedback ratio or reverse transmission factor.

$v_i$ is the input voltage to the internal amplifier and is given by,

$$v_i = v_s - v_f \quad \rightarrow (2)$$

Gain of the internal amplifier (amplifier without feedback) is given by,

$$A = \frac{v_o}{v_i} \quad \rightarrow (3)$$

∴ Output voltage of the feedback amplifier is given by,

$$v_o = A v_i = A (v_s - v_f) \quad [\text{from equation (2)}]$$

i.e. $v_o = A (v_s - \beta v_o)$ \quad [\text{from equation (1)}]

i.e. $v_o + A \beta v_o = A v_s$

i.e. $v_o (1 + A \beta) = A v_s$ \quad or \quad $\frac{v_o}{v_s} = \frac{A}{1 + A \beta} \quad \rightarrow (4)$

In the above equation (4), the term $\frac{v_o}{v_s}$ is the overall gain of the amplifier with feedback and is represented as $A_f$

i.e., $A_f = \frac{A}{1 + A \beta} \quad \rightarrow (5)$

The factor (-$A \beta$) is called the loop gain or return ratio. The voltage gain $A_f$ with feedback is sometimes called as closed loop gain. The gain $A$ without feedback is called as open loop gain.

The term $1/(1+A \beta)$ is called Sensitivity factor and the term $(1+A \beta)$ is called desensitivity.

Equation (5) shows that the gain of the negative feedback amplifier is less than the gain of amplifier without feedback.

{Note: The voltage gain of a positive feedback amplifier is given by $A_f = \frac{A}{1 - A \beta}$}
Equation 5 can be studied under the following cases.

1. If \((1 + A\beta) > 1\), then \(A_f < A\) and the feedback is negative.

2. If \((1 + A\beta) < 1\), i.e., if the loop gain \(A\beta\) is negative, \(A_f > A\) and the feedback is positive.

3. If \((1 + A\beta) = 0\), i.e., \(A\beta = -1\), \(A_f = \infty = \frac{V_o}{V_S}\).

This means that the amplifier is capable of giving maximum output even when the input is zero. This implies that the amplifier behaves like an oscillator. This is the special case of a positive feedback amplifier employed in oscillators.

**1. Stabilisation of gain due to negative feedback:**

[The gain of an amplifier may change due to change in power supply voltage, temperature or change in the parameters of the active device (like the current gain \(\beta\) of the transistor). By applying the negative feedback to such an amplifier, stability of the voltage gain can be improved].

Consider a feedback amplifier of gain \(A_f\). Let the gain without feedback be represented as \(A\).

We know that the gain of a negative feedback amplifier is,

\[
A_f = \frac{A}{1 + A\beta} \quad \text{(1)}.
\]

**Case 1:** If the open loop gain ‘\(A\)’ of the amplifier is very high, then \(A\beta \gg 1\).

\[A_f = \frac{A}{\beta} \quad \text{(a)}\]

Equation (a) shows that the gain of a negative feedback amplifier \(A_f\) depends only on \(\beta\) which is fairly constant by using high precision resistors like Metal Film Resistors (\(\therefore \beta = \frac{R_1}{R_1+R_2}\)).

Therefore, the gain \(A_f\) is stabilised. This is possible if \(A\beta \gg 1\). Even if this condition is not fully met, gain of negative feedback amplifier is stable to some extent as shown in the next case.

**Case 2:** If the loop gain \(A\beta\) is not very high when compared to 1:

Differentiating equation (1) with respect to \(A\), we get,

\[
\frac{dA_f}{dA} = \frac{d}{dA} \left[ \frac{A}{1 + A\beta} \right]
\]
i.e. \[
\frac{dA_f}{dA} = \frac{(1 + A\beta) \times 1 - (A \times \beta)}{(1 + A\beta)^2} = \frac{1}{(1 + A\beta)^2}
\]

\[
dA_f = \frac{dA}{(1 + A\beta)^2}
\]

or

Dividing the above equation by equation (1), we get,

\[
\frac{dA_f}{A_f} = \frac{dA}{(1 + A\beta)^2} \times \frac{1 + A\beta}{A} = \frac{1}{(1 + A\beta)} \frac{dA}{A}
\]

\[\Rightarrow \frac{dA_f}{A_f} = \frac{dA}{A} \left( \frac{1}{1 + A\beta} \right) \rightarrow (2)\]

In equation (2),

\[dA \rightarrow \text{change in gain without feedback.}\]

\[dA_f \rightarrow \text{change in gain with feedback.}\]

\[A \rightarrow \text{gain without feedback.}\]

\[A_f \rightarrow \text{gain with feedback.}\]

Since \((1 + A\beta) > 1\) for negative feedback, the term \(\frac{1}{1 + A\beta}\) < 1. Therefore,

\[\frac{dA_f}{A_f} < \frac{dA}{A}. \quad \text{Gain is comparatively stable with negative feedback.}\]

2. Reduction in ‘Distortion’ and ‘Noise’:-
Negative feedback decreases the distortion and noise in the output signal.

When the input signal to a transistor amplifier is large, signal distortion occurs due to the non-linearity of the transfer characteristics of the transistor. This results in distortion in the shape of the signal. Due to the proper amount of negative feedback, strength of the input signal to the internal amplifier decreases.

Hence the device is prevented from going into saturation and cut off points of its characteristics. The feedback signal in negative feedback tends to decrease the strength of both the input signal and the noise signal [because, along with the feedback of the fraction of actual output signal, negative feedback of the noise signal also takes place]. Therefore, the noise output decreases.
Thus, the distortion and noise are reduced in the output signal. In the output signal, if $D$ is the distortion without feedback, $D_f$ is the distortion with negative back and if $N$ is the noise without feedback, $N_f$ is the noise after negative feedback, we can write

$$D_f = \frac{D}{1 + A\beta} \quad \text{and} \quad N_f = \frac{N}{1 + A\beta}$$

Since \( \left( \frac{1}{1 + A\beta} \right) < 1 \), $D_f < D$ and $N_f < N$.

### 3. Improvement in frequency response:

Let $BW_f$ be the bandwidth of the amplifier with feedback and $BW$ be the Bandwidth without feedback and let $\beta$ be the feedback ratio, $A$, the voltage gain of the amplifier without feedback and $A_f$, the voltage gain of the amplifier with feedback.

Since the product of voltage gain and bandwidth is a constant (with and without feedback) for an amplifier, it can be written that

$$G \times BW = \text{Constant} \quad \rightarrow \quad (1)$$

To satisfy the above equation for the amplifier with and without feedback, it can be written as, $BW_f \times A_f = BW \times A$. where, the variables are defined as above. (i.e., if the voltage gain decreases from $A$ to $A_f$ due to negative feedback, the Bandwidth increases from $BW$ to $BW_f$ so that the gain band width product remains constant).

Substituting the relation $A_f = \frac{A}{1 + A\beta}$ in the above equation, we get
\[
BW_f \times \frac{A}{1 + A\beta} = BW \times A.
\]

i.e.,
\[
BW_f = BW (1 + A\beta) \quad \to \quad (2)
\]

As per the above equation, negative feedback increases the bandwidth by a factor equal to \((1 + A\beta)\). Further, the cutoff frequencies are also affected by the negative feedback as shown below. If \(f_1\) and \(f_1^\prime\) are the lower cutoff frequencies without and with feedback respectively, it can be shown that,
\[
f_1^\prime = \frac{f_1}{1 + A\beta} \quad \to \quad (3)
\]

i.e., the lower cutoff frequency decreases from \(f_1\) to \(f_1^\prime\).

Similarly, if \(f_2\) and \(f_2^\prime\) are the upper cutoff frequencies without and with feedback respectively, it can be shown that,
\[
f_2^\prime = f_2 (1 + A\beta) \quad \to \quad (4),
\]

i.e., the upper cutoff frequency increases from \(f_2\) to \(f_2^\prime\). Therefore, bandwidth with negative feedback is given by \(BW_f = f_2^\prime - f_1^\prime\)

4. **Increase in the input impedance:**

Consider a voltage series feedback amplifier.

The input impedance \(Z_i\) of the internal amplifier (amplifier without feedback) is given by,
\[
Z_i = \frac{\nu_i}{\nu_i} \quad \to \quad (1)
\]

Where \(\nu_i\) is the input voltage to the internal amplifier and \(i_i\) is the input current.

With negative feedback, the input impedance is given by,
Output voltage of an amplifier is given by,

$$v_0 = A v_i \quad \rightarrow (3)$$

We know that for negative feedback amplifier, the net input $v_i$ to the internal amplifier is

$$v_i = v_S - v_f$$

i.e $v_S = v_i + v_f$

i.e $v_S = v_i + \beta v_0$, Substituting equation (3), above equation becomes,

$$v_S = v_i + \beta A v_i$$

i.e. $v_S = v_i (1+A\beta)$, Substituting in equation (2) we get

$$Z_{if} = \frac{v_i (1+A\beta)}{i_i} \quad \rightarrow (4).$$

From equation (1) and (4),

$$Z_{if} = Z_i (1+A\beta)$$

Since, $(1+A\beta)>1$ for negative feedback,

$$Z_{if} > Z_i$$ by a factor of $(1+A\beta)$.

### 5. Decrease in the output impedance:

To find the output impedance ($Z_{of}$) of a voltage series negative feedback amplifier, the input signal is made zero and a hypothetical generator of voltage $V_O$ is connected across the output terminals. Since the source signal is zero, the feedback signal alone is the net input to the internal amplifier as shown in the figure. i.e, $v_i = -v_f. \quad \rightarrow (1)$

This signal gets amplified in the basic amplifier and appears at the output section as $A v_i$.

From the basic theory of the feedback, $v_f = \beta v_o \quad \rightarrow (2)$. 

$$Z_{of} = \frac{\beta v_o}{i_o}$$

$$Z_{of} = \frac{Z_i (1+A\beta) \beta v_o}{\beta v_o} \quad \rightarrow (5)$$

$$Z_{of} = Z_i (1+A\beta)$$

Therefore, $Z_{of} > Z_i$ by a factor of $(1+A\beta).$
Where, \( A \) and \( \beta \) are the Gain without feedback and feedback ratio respectively.

Let \( Z_o \) be the output impedance of the amplifier without feedback and \( i_{of} \) be the output current with feedback.

Assuming the input impedance of the \( \beta \) network to be very high, the fraction of output current passing through the input section of the \( \beta \) network can be neglected.

Therefore, for the output loop, we can write the following equation.

\[
\begin{align*}
  v_o &= i_{of}Z_o + A v_i. \\
  v_o &= i_{of}Z_o + A(-v_f). \\
  v_o &= i_{of}Z_o - A\beta v_o \quad \text{i.e.} \quad i_{of}Z_o = v_o + A\beta v_o = v_o(1+A\beta).
\end{align*}
\]

i.e. \[
\frac{v}{i_{of}} = \frac{Z_o}{1 + A\beta} \quad \text{where,} \quad \frac{v}{i_{of}} = Z_{of} \quad \text{the output impedance with feedback.}
\]

\[
\therefore Z_{of} = \frac{Z_o}{1 + A\beta} \quad \text{------} \Rightarrow (3).
\]

For negative feedback, the term \((1+A\beta) > 1\).

\[
\therefore Z_{of} < Z_o. \quad \text{Thus, the output impedance is reduced by a factor \((1+A\beta)\).}
\]

Circuit examples of different types of negative feedback:

1. **Voltage Series feedback:**

Circuit of Common collector amplifier shown here is an example of voltage series negative feedback amplifier. The feedback voltage \( v_f \) is same as the emitter voltage \( v_E \) which is nothing but the output voltage. i.e., \( v_E = v_o \).

Applying KVL to the input section of the circuit we get the relation for the effective input voltage in terms of the input signal voltage and the feedback voltage as
\[ v_S = v_i + v_o, \] hence the net input voltage \( (v_i = v_{BE}) \) to the emitter-base junction (internal amplifier) is given by \( v_{BE} = v_s - v_o \). In this circuit feedback signal depends only on the output voltage and this is fed in series with the original signal, hence the name. In this circuit feedback fraction is given by \( \beta = v_f / v_o = v_o / v_o = 1 = 100\% \)

Since the whole of the output voltage is fed back to the input, the negative feedback here is 100%.

2. Current Series feedback:
The circuit shown is a Common Emitter amplifier without emitter bypass capacitor. Since the emitter resistor is uncovered all the a.c emitter current will flow through the emitter resistor and there will be a.c voltage drop across the resistor. This voltage is feedback to the input with opposite phase (CE mode). The feedback voltage \( v_f \) is proportional to the output current \( i_E \) (\( \approx i_c \)) and is in series with the original signal hence the name current series negative feedback. The feedback voltage is given by \( v_f = v_E = i_E R_E \).

The feedback voltage gets subtracted from the input source signal and hence the net input voltage \( (v_i = v_{BE}) \) to the emitter-base junction (internal amplifier) is given by \( v_{BE} = v_s - i_E R_E \). The feedback fraction in this circuit is given by \( \beta = i_E / v_o \)

3. Voltage Shunt feedback:
The circuit employing the voltage shunt negative feedback is shown in the fig. Feedback is through the Resistor \( R_B \) connected between the collector and the base. The feedback signal is the current \( i_f \). It is proportional to the output voltage \( v_o \). The feedback factor is given by \( \beta = i_f / v_o \). This circuit exhibits low input and output impedances.
4. Current Shunt feedback:
The circuit shown is an example for current shunt feedback. The feedback current $i_f$ proportional to the output current $i_0$ (emitter current $i_E$) is selected through the feedback network and is applied in parallel with the input current source.

![Feedback network diagram]