EXPERIMENT – 3.2
FEEDBACK AMPLIFIERS

3.2.1 OBJECTIVE
To study the various feedback amplifiers using op-amps.

3.2.2 HARDWARE REQUIRED
a. Power supply : Dual variable regulated low voltage DC source
b. Equipments : AFO, CRO and DMM
c. Resistors :
d. Capacitors :
e. Semiconductor : Diode 1N4002 and op-amp µA741
f. Miscellaneous : Bread board and wires

3.2.3 PRELAB QUESTIONS
1. An amplifier has a gain of $2 \times 10^5$ without feedback. Determine the gain if negative feedback is applied. Take feedback fraction $\beta=0.02$.
2. An amplifier has a gain of $10^4$ without feedback. With negative feedback, the gain is reduced to 50. Find the feedback fraction $\beta$.
3. A negative feedback amplifier has an internal gain $A_V=40$dB and feedback fraction $\beta=0.05$. If the input impedance of this circuit is $12\text{K}\Omega$, what would have been the input impedance if feedback were not present?
4. Calculate the gain of a negative feedback amplifier with an internal gain $A_V=75$ and feedback fraction $\beta=1/15$. What will be the gain of the feedback fraction if $A_V$ doubles?
5. With a negative voltage feedback, an amplifier gives an output of 10V with an input of 0.5V. When the feedback is removed, it requires 0.25V input for the same output. Calculate (i) gain without feedback and (ii) feedback fraction.
6. The gain of an amplifier without feedback is 50, whereas with negative voltage feedback, it falls to 25. If due to ageing, the amplifier gain falls to 40, find the % reduction in stage gain (i) without feedback and (ii) with negative feedback.
7. A negative voltage feedback amplifier is shown below. If the gain of the amplifier without feedback is 10,000, find (i) feedback fraction, (ii) overall voltage gain and (iii) output voltage if input voltage is 1mV.
8. For the negative voltage feedback amplifier shown in the previous problem, $A_V=10,000$, $R_i=10\, \Omega$ and $R_O=100\, \Omega$. Find (i) feedback fraction, (ii) gain with feedback, (iii) input impedance with feedback and (iv) output impedance with feedback.

9. The gain and distortion of an amplifier are 150 and 5% respectively without feedback. If the stage has 10% of its output voltage applied as negative feedback, find the distortion of the amplifier with feedback.

10. An amplifier has a gain of 1000 without feedback and cut-off frequencies are $f_1=1.5\, \text{KHz}$ and $f_2=501.5\, \text{KHz}$. If 1% of output voltage of the amplifier is applied as negative feedback, what are the new cut-off frequencies?

11. An amplifier has a voltage gain of 250 and a bandwidth of 400 KHz without feedback. If negative feedback ($\beta=0.01$) is applied, what is the bandwidth of the amplifier?

12. An amplifier has a current gain of 240 without feedback. When negative current feedback is applied, determine the effective current gain of the amplifier, given that $\beta=0.015$.

13. An amplifier has an open-loop gain, input impedance and output impedance of 200, 15 K$\Omega$ and 2 K$\Omega$ resp. If negative current feedback is applied, what is the effective input impedance and output impedance of the amplifier, given that the current attenuation, $\beta=0.012$?

14. Calculate the closed-loop gain for the negative feedback amplifier shown below. Also calculate the closed-loop gain when the open-loop gain is changed by $\pm50\%$. Note that $A_V=100,000$ and $\beta=1/100$. 
15. The input impedance of the amplifier shown below is $R_i=1\ \text{K}\Omega$ when negative feedback is not used, and the open-loop voltage gain is 100,000. Calculate the circuit input impedance with negative feedback.

![Amplifier Circuit Diagram]

16. Determine the voltage gain, input and output impedances with feedback for (i) voltage-series feedback, (ii) voltage-shunt feedback, (iii) current-series feedback and (iv) current feedback having $A=100$, $R_i=10\ \text{K}\Omega$, $R_O=20\ \text{K}\Omega$ and $\beta=0.1$.

3.2.4 THEORY

A practical amplifier has a gain of nearly one million, i.e., its output in one million times the input. Consequently, even a casual disturbance at the input will appear in the amplified form in the output. There is a strong tendency in amplifiers to introduce hum due to sudden temperature changes or stray electric and magnetic fields. Therefore, every high gain amplifier tends to give noise along with signal in its output. The noise in the output of an amplifier is undesirable and must be kept to as small as possible.

The noise level in amplifiers can be reduced considerably by the use of a negative feedback, i.e., by injecting a fraction of output in phase opposition to the input signal.

3.2.4.1 Feedback

The process of injecting a fraction of output energy of some device back to the input of the same device is known as feedback. Depending on the relative polarity of the signal being feedback into a circuit, there are two basic types of feedback in amplifiers, namely

a. Positive feedback
b. Negative feedback.

Positive feedback

When the feedback signal (voltage or current) is in phase with the input signal and thus aids it, it is called positive feedback. Positive feedback increases the gain of the amplifier.
However, it has the disadvantage of *increased distortion and instability*. Therefore, positive feedback is seldom used for amplification. One important use of positive feedback is in *oscillators*.

**Negative feedback**

When the feedback signal (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback*. Negative feedback *reduces gain* of the amplifier. However, it has a number of advantages, among them being

a. Higher input impedance
b. Lower output impedance
c. Better stabilized voltage gain
d. Improved frequency response
e. Reduced noise
f. Increased bandwidth
g. More linear operation

It is due to these advantages, negative feedback is frequently employed in amplifiers.

### 3.2.4.2 Block diagram

In the feedback amplifiers, a part of the output is returned to the input. If this feedback reduces the net input, it is called negative feedback. If the feedback increases the net input, it is called positive feedback. The schematic representation of a generalized feedback amplifier is shown in Figure 3-2-1.

The signal $X_S$ can be a voltage or a current. The gain with feedback, $A_f$, is given by

$$A_f = \frac{A}{1 + A\beta} \quad (3-2-1)$$

where $A$ is the gain without feedback and $\beta$ is the feedback factor defined as $\beta = X_f/X_0$. 

![Fig.3-2-1 Basic schematic of feedback amplifier](image)
when $|A_f| < |A|$, the feedback is negative and when $|A_f| > |A|$, the feedback is positive. In general, the feedback also affects the input impedance, output impedance and bandwidth of the amplifier.

**Loop gain**

The difference signal, $X_d$ in fig. 3-2-1 is multiplied by $A$ in passing through the amplifier, is multiplied by $\beta$ in transmission through the feedback network, and is multiplied by -1 in the mixing network. A path of a signal from input terminals through basic amplifier, through the feedback network and back to the input terminals forms a loop. The gain of this loop is the product $-\beta A$. This gain is known as loop gain or return ratio.

**Desensitivity of gain**

The transfer gain of the amplifier is not constant as it depends on the factors such as operating point, temperature, etc. This lack of stability in amplifiers can be reduced by introducing negative feedback.

We know that $A_f = \frac{A}{1 + \beta A}$

Differentiating both sides with respect to $A$, we get

$$\frac{dA_f}{dA} = \frac{(1 + \beta A)1 - \beta A}{(1 + \beta A)^2} = \frac{1}{(1 + \beta A)^2}$$

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

Dividing both sides by $A_f$, we get

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

$$\left| \frac{dA_f}{A_f} \right| = \left| \frac{dA}{A} \right| \left| \frac{1}{(1 + \beta A)} \right|$$

Where $\frac{dA_f}{A_f} = \text{fractional change in amplification with feedback}$

$$\frac{dA}{A} = \text{fractional change in amplification without feedback.}$$

Looking at equation 3-2-2 we can say that the change in the gain with feedback is less than the change in gain without feedback by a factor $(1 + \beta A)$. The fractional change in amplification with feedback is divided by the fractional change without feedback is called the *sensitivity of the transfer*.
gain. Hence the sensitivity is \( \frac{1}{1 + \beta A} \). The reciprocal of the sensitivity is called the desensitivity \( D \).

It is given as,

\[
D = (1 + \beta A)
\]  \hspace{1cm} (3-2-3)

Therefore, stability of the amplifier increases with increase in desensitivity.

If \( \beta A \gg 1 \), then

\[
A_f = \frac{A}{1 + \beta A} = \frac{A}{\beta A} = \frac{1}{\beta}
\]  \hspace{1cm} (3-2-4)

and the gain is dependent only on the feedback network.

### 3.2.4.3 Effects of negative feedback

The following are some of the effects of negative feedback on the performance of feedback amplifier.

(a) **Increased gain stability**

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

We have,

\[
A_{vy} = \frac{A_v}{1 + \beta A}
\]

For negative feedback in an amplifier to be effective, the designer deliberately makes the product \( \beta A_v \) much greater than unity. Therefore, in the above expression, \( 1 \) can be neglected as compared to \( \beta A_v \). Hence,

\[
A_{vy} \approx \frac{A_v}{\beta A_v} \approx \frac{1}{\beta}
\]

It may be observed that the gain now depends only upon feedback fraction, \( \beta \). As the feedback network is usually made up of resistive components, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable.

(b) **Reduced non-linear distortion**

Large signal amplifiers suffer from non-linear distortions, such as amplitude distortion, harmonic distortion and intermodulation distortions. Those distortions can be effectively reduced by employing negative feedback in large signal amplifiers. It can be proved that

\[
D_f = \frac{D}{1 + \beta A}
\]

where \( D_f \) = distortion in amplifiers with feedback

\[
D = \text{distortion in amplifier without feedback}
\]
It is clear that by applying negative feedback to an amplifier distortion is reduced by a factor 
\((1+\beta A)\).

(c) **Increased bandwidth and improved frequency response**

It has been shown already that \(A_{vy} = \frac{1}{\beta}\) ie., the gain of the amplifier with feedback depends 
upon the feedback factor, \(\beta\) and independent of signal frequency. Therefore, the voltage gain of the 
amplifier will be substantially constant over a wide range of signal frequency. The negative 
feedback, thus improves the frequency response of the amplifier. It can be proved mathematically 
that

\[
BW_f = BW(1 + \beta A)
\]

where \(BW_f = \) bandwidth of amplifier with feedback

\(BW = \) bandwidth of amplifier without feedback

It is clear that by applying negative feedback to an amplifier, bandwidth is increased by a factor 
\((1+\beta A)\).

(d) **Decreased noise**

The noise level in amplifiers can be reduced considerably by the use of negative feedback. It 
can be proved mathematically that

\[
N_f = \frac{N}{1 + \beta A}
\]

where \(N_f = \) noise in amplifier with feedback

\(BW = \) noise in amplifier without feedback

It is clear that by applying negative feedback to an amplifier, noise is reduced by a factor \((1+\beta A)\).

(e) **Increased input resistance**

It is generally accepted that an increase in input resistance in a voltage amplifier is 
considered a definite advantage, since it serves the purpose of impedance matching. The effect of 
negative feedback on the input resistance depends upon the way in which the output is feedback to 
the input. Of the output voltage (or, current) is feedback in series with the input, the input 
resistance increases. It can be proved mathematically that

\[
R_{if} = R_i(1 + \beta A)
\]
where \( R_{if} \) = input resistance of amplifier with feedback and
\[ R_i = \text{input resistance of amplifier without feedback} \]

It is clear that by applying negative feedback to an amplifier, the input resistance is increased by a factor \((1 + \beta A)\).

(f) Output resistance

As with the input resistance, the effect of negative feedback on the output resistance depends upon the way in which the output is feedback to input. If the output voltage is feedback to the input (either in series or shunt), the output resistance decreases. It can be proved mathematically that

\[
R_{of} = \frac{R_o}{1 + \beta A}
\]

where \( R_{of} \) = output resistance of amplifier with feedback
\[ R_o = \text{output resistance of amplifier without feedback} \]

It is clear that by applying negative feedback to an amplifier, the output resistance is decreased by a factor \((1 + \beta A)\).

3.2.4.3 Feedback connection types

There are four basic ways of connecting the feedback signal. Both voltage and current can be feedback to the input in series or parallel. Specifically, there can be
a. Voltage-series feedback
b. Current-series feedback
c. Voltage-shunt feedback
d. Current-shunt feedback

In the list above, voltage refers to connecting the output voltage as input to the feedback network; current refers to tapping off some output current through the feedback network. Series refers to connecting the feedback signal in series with the input signal voltage; shunt refers to connecting the feedback signal in shunt with an input current source.

Series feedback connections tend to increase the input resistance, while shunt feedback connections tend to decrease the input resistance. Voltage feedback tends to decrease the output resistance while current feedback tends to increase the output resistance. Typically, higher input resistance and lower output resistance are desired for most cascade amplifiers. Both of these provided using the voltage-series feedback connection. Figure 3-2-2 shows these configurations.
Fig. 3-2-2 Four configurations of feedback amplifiers: (a) Current-Series, (b) Voltage-Shunt, (c) Voltage-Series, and (d) Current-Shunt feedback

The effects of feedback on input impedance, output impedance and bandwidth of the amplifier are given below:

(i) Input impedance with feedback, $Z_{\text{inf}}$

for series feedback to input, $Z_{\text{inf}} = Z_{\text{in}}(1 + A\beta)$ \hspace{1cm} (3-2-2)

for shunt feedback to input, $Z_{\text{inf}} = Z_{\text{in}}/(1 + A\beta)$ \hspace{1cm} (3-2-3)

(ii) Output impedance with feedback, $Z_{\text{outf}}$

for voltage feedback, $Z_{\text{outf}} = Z_{\text{out}}/(1 + A\beta)$ \hspace{1cm} (3-2-4)

for current feedback, $Z_{\text{outf}} = Z_{\text{out}}(1 + A\beta)$ \hspace{1cm} (3-2-5)

(iii) Bandwidth with feedback, $(f_{\text{hf}} - f_{\text{lf}})$

$f_{\text{hf}} = f_{\text{h}}(1 - A\beta)$ \hspace{1cm} and \hspace{1cm} $f_{\text{lf}} = f_{\text{l}}/(1 + A\beta)$ \hspace{1cm} (3-2-6)

where $f_{\text{h}}$ and $f_{\text{l}}$ represent the higher and lower cut-off frequencies without feedback. The bandwidth increases with negative feedback because the higher cut-off frequency is pushed up and the lower cut-off frequency is pulled down.

Near ideal controlled (dependent) current and voltage sources can easily be realized using op-amps and feedback circuitry. In an ideal amplifier, the input power drawn from the signal source is zero and the output load power is finite. In order for the output power to be zero, either of the following conditions should be satisfied.
(i) \( V_i = 0 \) and \( I_i \) finite \( (Z_{in} \to 0) \)
(ii) \( I_i = 0 \) and \( V_i \) finite \( (Z_{in} \to \infty) \)

On the output side, the output can behave as an ideal voltage source \( (Z_{out} \to 0) \) or an ideal current source \( (Z_{out} \to \infty) \) and the value of the output voltage or current depends upon input voltage or input current.

Thus, the ideal amplifiers are classified in four different ways as mentioned below:

I. Voltage Controlled Voltage Source (VCVS) or the ideal voltage amplifier
\( (Z_{in} \to \infty, Z_{out} \to 0, A = A_V) \)

II. Current Controlled Voltage Source (CCVS) or the ideal tran resistance amplifier
\( (Z_{in} \to \infty, Z_{out} \to 0, A = R_m) \)

III. Voltage Controlled Current Source (VCCS) or the ideal transresistance amplifier
\( (Z_{in} \to \infty, Z_{out} \to \infty, A = G_M) \)

IV. Current Controlled Current Source (CCCS) or the ideal transresistance amplifier
\( (Z_{in} \to \infty, Z_{out} \to \infty, A = A_i) \)

The four configurations shown in Figure 3-2-2, therefore, result into:

1. Voltage series feedback amplifier (VCVS)
2. Voltage shunt feedback amplifier (CCVS)
3. Current series feedback amplifier (VCCS)
4. Current shunt feedback amplifier (CCCS)

The circuit diagrams of these four feedback amplifiers using op-amp are shown in [a](a) and [b](b).
Experiment 3.2: Feedback amplifiers

**Fig. 3-2-3 Feedback Amplifier circuits:** (a) Voltage-Series circuit, (b) Voltage-Shunt circuit, (c) Current-Series circuit, and (d) Current-Shunt circuit

The expressions for the performance parameters of these four controlled source are tabulated in Table 3-2-1.

<table>
<thead>
<tr>
<th>Circuit</th>
<th>$\beta$</th>
<th>Gain</th>
<th>Input Impedance</th>
<th>Output Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage-series feedback</td>
<td>$\frac{V_f}{V_o}$</td>
<td>$A = A_f = \frac{V_o}{V_i} = 1 + \left(\frac{R_1}{R_2}\right)$</td>
<td>$Z_{in} (1 + \beta A)$</td>
<td>$Z_{out} \left(1 + \beta A\right)$</td>
</tr>
<tr>
<td>amplifier (VCVS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage shunt feedback</td>
<td>$\frac{R_s}{R_s + R}$</td>
<td>$A = R_m = \frac{V_o}{I_i} = R$</td>
<td>$\frac{R}{1 + A}$</td>
<td>$Z_{out} \left(1 + \beta A\right)$</td>
</tr>
<tr>
<td>amplifier (CCVS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage series feedback</td>
<td>$\frac{R}{R_L + R}$</td>
<td>$A = G_m = \frac{I_o}{V_i} = \frac{1}{R}$</td>
<td>$Z_{in} (1 + \beta A)$</td>
<td>AR</td>
</tr>
<tr>
<td>amplifier (VCCS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage shunt feedback</td>
<td>$\frac{I_f}{I_o}$</td>
<td>$A = A_i = \frac{I_o}{I_i} = 1 + \left(\frac{R_{1}}{R_2}\right)$</td>
<td>$\frac{Z_{in}}{1 + \beta A}$</td>
<td>$Z_{out} (1 + \beta A)$</td>
</tr>
<tr>
<td>amplifier (CCCS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3-2-1 Performance parameters of four types of circuits**
3.2.5 EXPERIMENT

Use μA741 op-amp with ±15 V power supply.

1. **Voltage series feedback amplifier (VCVS)**

   1.1 Assemble the circuit shown in Figure 3-2-3 (a). Connect a load RL across the output terminals. Choose each resistance value to be equal to 10 kΩ. Apply 1 V, 1 kHz ac input signal, \( V_s \). Measure the voltage gain \( V_o/V_i \).

   1.2 Repeat the measurements for four different values of \( V_i \) keeping \( R_L \) constant.

   1.3 Repeat the measurements for four different values of \( R_L \) keeping \( V_i \) constant.

   1.4 Compare the measured values with the calculated values.

2. **Voltage shunt feedback amplifier (CCVS)**

   2.1 Assemble the circuit shown in Figure 3-2-3(b). Choose \( R_s = 47 \text{ kΩ}, R_L = 4.7 \text{ kΩ} \) and \( R = 47\text{kΩ} \). Note that the current source, I, in parallel with resistor, \( R_s \), can be replaced by a voltage source, \( V_s = I \times R_s \) in series with \( R_s \). In this case \( I_i = V_s/R_s \). Apply 10V, 1 kHz ac input signal. Measure the transresistance \( V_o/I_i \).

   2.2 Repeat the measurements for four different values of \( V_s \) keeping \( R_L \) constant.

   2.3 Repeat the measurement for four different values of \( R_L \) keeping \( V_s \) constant.

   2.4 Compare the measured values with the calculated values.

3. **Current series feedback amplifiers (VCCS)**

   3.1 Assemble the circuit shown in Figure 3-2-3(c). Choose \( R_L = 4.7 \text{ kΩ} \) and \( R = 100 \text{ Ω} \). Apply 1V, 1 kHZ ac input signal. Measure the transconductance \( I_o/V_i \).

   3.2 Repeat the measurements for four different values of \( V_i \) keeping \( R_L \) constant.

   3.3 Repeat the measurements for four different values of \( R_L \) keeping \( V_i \) constant.

   3.4 Compare the measured values with the calculated values.

4. **Current shunt feedback amplifiers (CCCS)**

   4.1 Assemble the circuit shown in Figure 3-2-3(d). Choose \( R_s = 47 \text{ kΩ}, R_1 = 4.7 \text{ kΩ}, R_2 = 1\text{kΩ} \) and \( R_2 = 100\text{Ω} \). Apply 10 V, 1 kHZ ac input signal. Measure the current gain \( I_o/I_i \).

   4.2 Repeat the measurements for four different values of \( V_s \) keeping \( R_L \) constant.

   4.3 Repeat the measurements for four different values of \( R_L \) keeping \( V_s \) constant.

   4.4 Compare the measured values with the calculated values.
3.2.6 POST-LAB QUESTIONS

Compare the calculated values of performance parameters of the four feedback amplifiers with the measured values. Refer table 3-2-1 for the formulae for performance parameters of the feedback amplifiers, and manufacturer’s data sheet for the electrical characteristics of μA741 IC.