# Feedback Amplifier

## Learning Objectives:

- Discuss negative feedback and how it is used in amplifiers
- Describe the basic structures of feedback amplifier
- Explain effects of negative feedback on voltage gain, input and output impedances of an amplifier.
- Explain the advantages and disadvantages of negative feedback.

## *What is feedback?*

- A portion of the output is returned to the input to form part of the system excitation.

## Positive feedback

- The feedback signal increases the magnitude of the input signal.
- It increases the voltage gain and causes the instability of an amplifier.
- It is mainly used in oscillators.

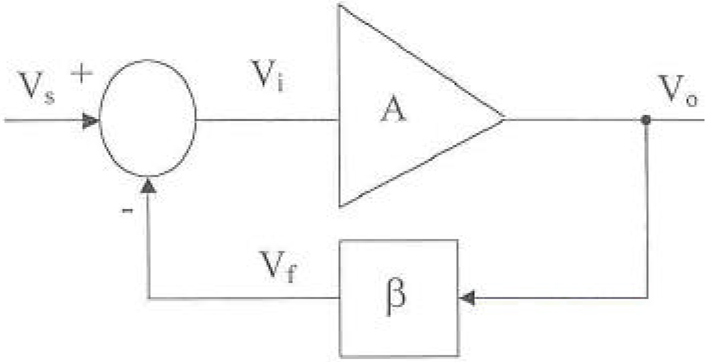
## Negative feedback

- The feedback signal reduces the magnitude of the input signal.

## *Why use negative feedback?*

- To control the voltage gain
- To control the input and output impedances
- To reduce the output noise
- To reduce the output signal distortion of amplifier.

*A feedback amplifier consists of a basic amplifier and a feedback network.*



Feedback signal: $V_f=\beta V_o$

## Feedback factor:

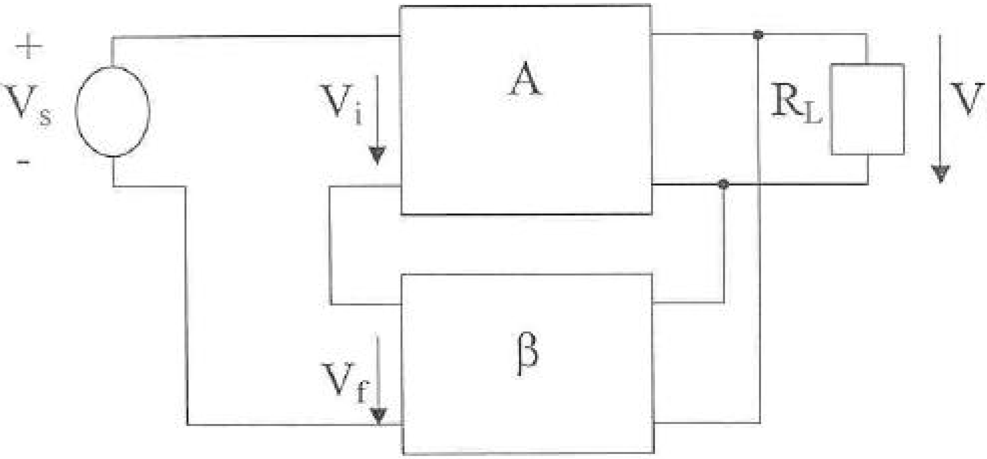
- $B=V_f/V_o$ excitation.

Input voltage to the amplifier: $V_i=V_s-V_f$

The basic structure of the feedback amplifier

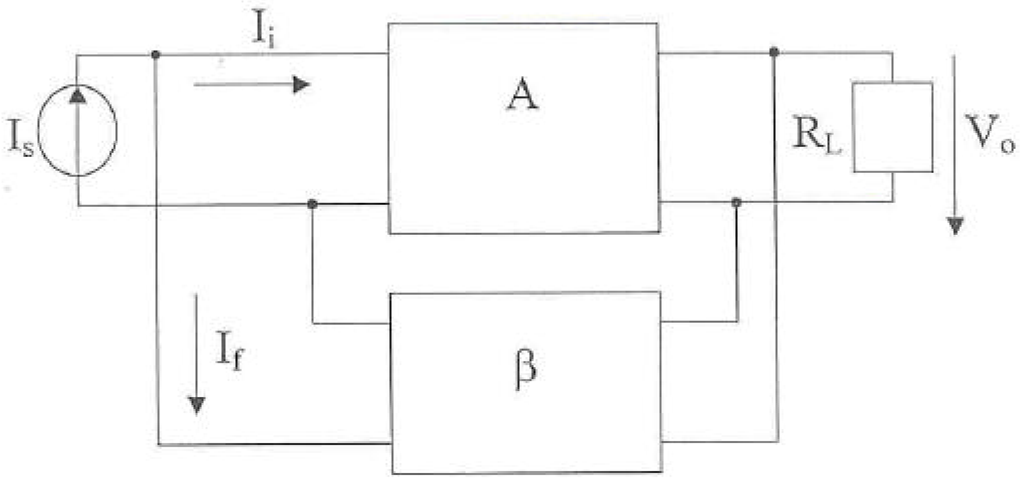
1. Voltage-series feedback (voltage summing and voltage sampling): ($A=V_o/V_i$, $\beta=V_f/V_o$)

(Input is a voltage, output is a voltage; voltage is fed back.)



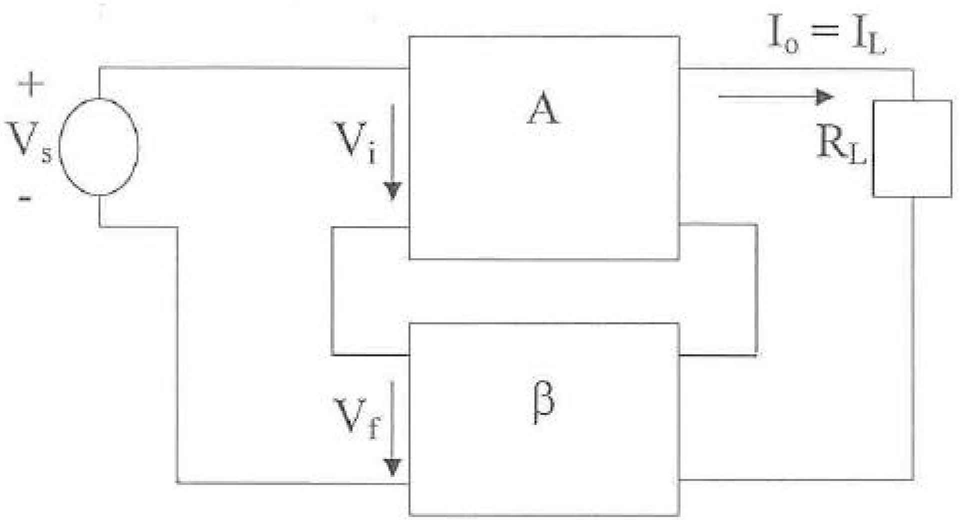
2. Voltage-shunt feedback (current summing and voltage sampling): ($A=V_o/I_i$, $b=I_f/V_o$.)

(Input is a current, output is a voltage, current is fed back).



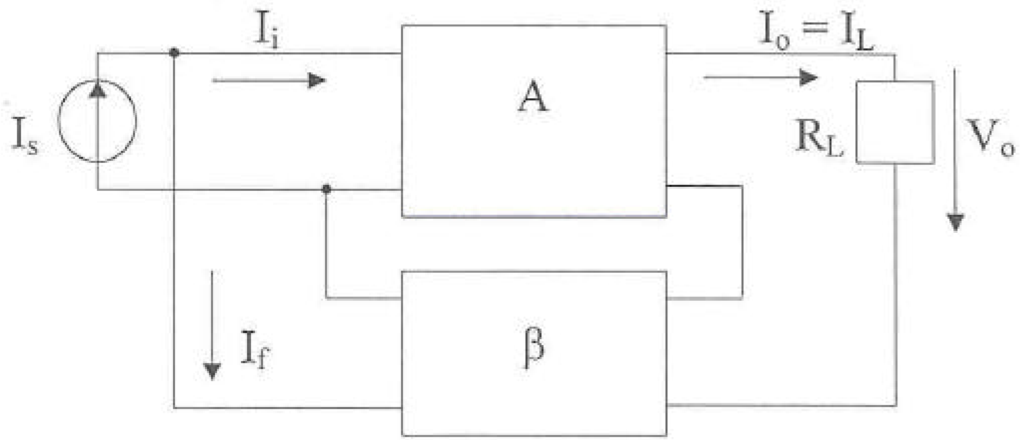
3. Current-series feedback (voltage summing and current sampling): ($A=I_o/V_i$, $\beta=V_f/I_o$)

(Input is voltage, output is a current, voltage is feedback).



4. Current-shunt feedback (current summing and current sampling): ($A=I_o/I_i$, $\beta=I_f/I_o$)

(Input is a current, output is a current, current is fed back).



Gain with feedback:

1. Voltage series: $A=V_o/V_i$, $\beta=V_f/V_o$

The overall gain with feed back then is:

$A_f \quad =V_o/V_s=V_o/(V_i+V_f)$
$=V_o/(V_i+\beta V_o)$
$=(V_o/V_i)/(1+\beta V_o/V_i)$
$=A/(1+\beta A)$

2. Voltage shunt: $A=V_o/I_i$, $\beta=I_f/V_o$

$A_f \; =V_o/I_s=V_o/(I_i+I_f)=V_o/(I_i+\beta V_o)$
$=(V_o/I_i)/(1+\beta V_o/I_i)$
$=A/(1+\beta A)$

3. Current series: $A=I_o/V_i$, $\beta=V_f/I_o$

$A_f \quad =I_o/V_s=I_o/(V_i+V_f)=I_o/(V_i+\beta I_o)$
$=(I_o/V_i)/(1+\beta I_o/V_i)$
$=A/(1+\beta A)$

4. Current shunt: $A=I_o/I_i$, $\beta=I_f/I_o$

$A_f \quad =I_o/I_s=I_o/(I_f+I_f)=I_o/(I_i+\beta I_o)$
$=(I_o/I_i)/(1+\beta(I_o/I_i))$
$=A/(1+\beta A)$

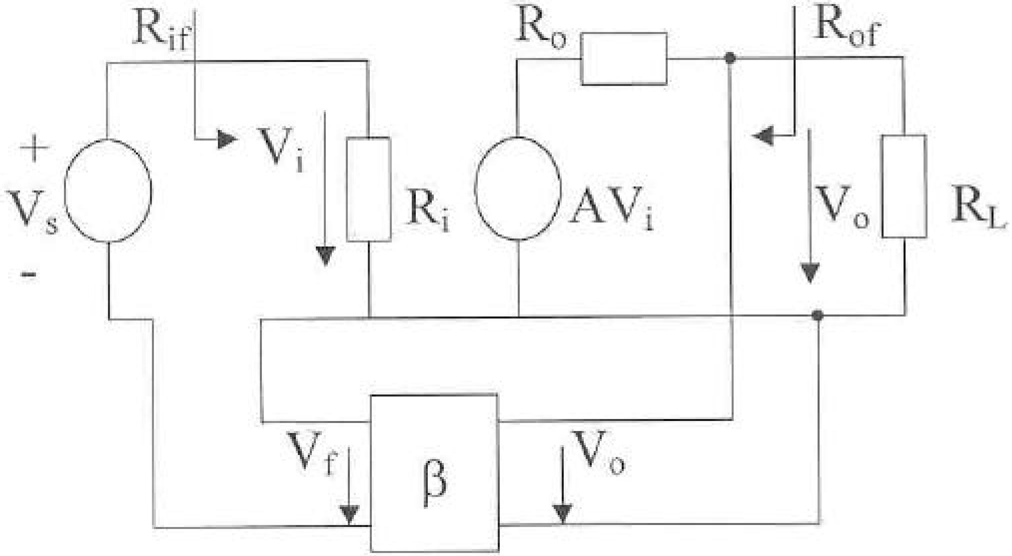
The overall gain of a negative feedback amplifier is

$A_f=A/(1+\beta A) \qquad \text{where} |1+\beta A|>1$

If $\beta A>>1$, then $A_f=A/(1+\beta A)\approx 1/\beta$, thus $A_f$ is independent of the gain of the basic amplifier, A, it depends entirely on the feedback network. Since the feedback network is usually a stable passive element, the supply voltage variations, manufacturing tolerances, aging and temperature variations, which have profound effects on A, will have negligible effects on $A_f$.

## Input resistance with feedback:

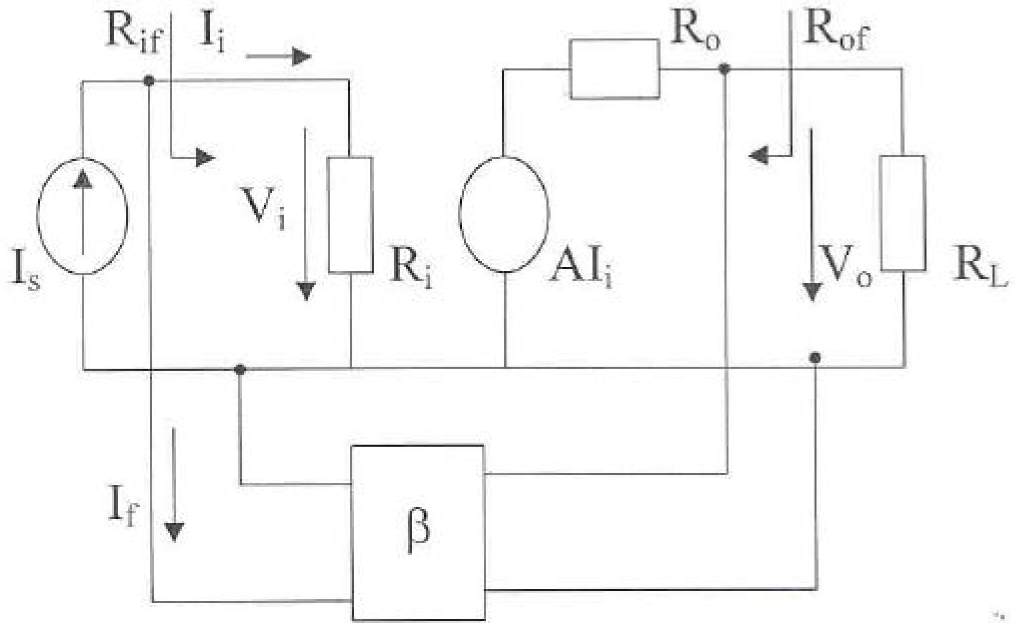
1. Voltage series feedback:
   $A=V_o/V_i$, $\beta=V_f/V_o$



$$\begin{aligned} R_{if} &= V_s/I_i=(V_i+V_f)/I_i \\ &= V_i(1+\beta V_i)/I_i \\ &= (V_i+\beta AV_i)/I_i \\ &= V_i(1+\beta A)/I_i \\ &= R_i(1+\beta A) \end{aligned}$$

*i.e. the input resistance is increased with the voltage series feedback.*
(*similar results can be obtained for current series feedback)

2. Voltage shunt feedback:
$(A=V_o/I_i$, $\beta=I_f/V_o)$, $\beta=I_f/V_o$



$$\begin{aligned} R_f &= V_i/I_s=I_iR_i/(I_i+I_f) \\ &= R_i/(1+I_f/I_i) \\ &= R_i/(1+\beta V_o/I_i) \\ &= R_i/(1+\beta A) \end{aligned}$$

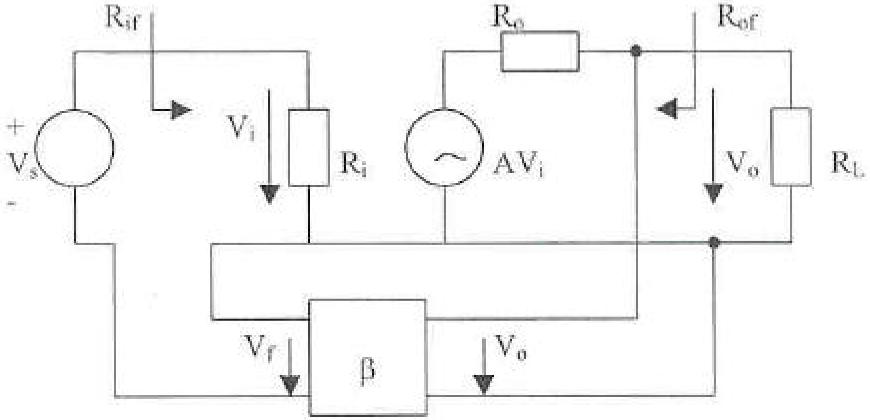
i.e. the input resistance is decreased with the voltage shunt feedback.
(*similar results can be obtained for current shunt feedback)

## Output resistance with feedback:

1. Voltage series feedback:

$V=V_o/V_i$, $\beta=V_f/V_o$

The output resistance is determined by the following steps, (a) make the input signal zero($V_s=0$),, (b) remove the load resistance RL, (c) applying a voltage a voltage source, V, across the load terminals, and (d) calculate the current I delivered by the voltage source.



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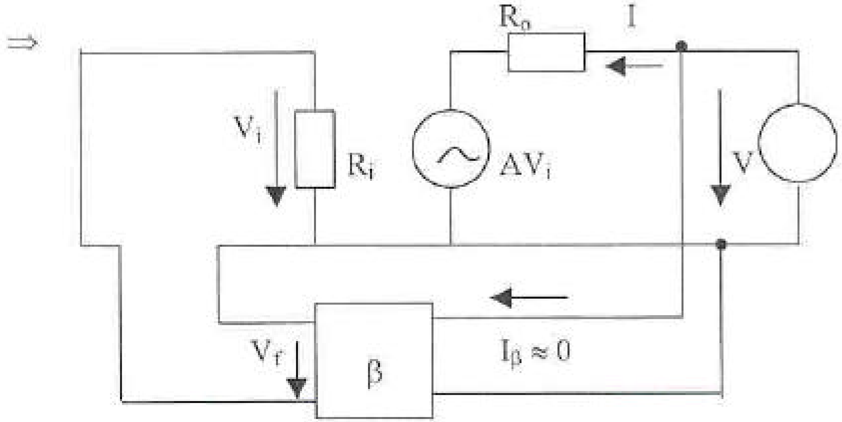


To simplify our analysis, we assume that the input impedance of the feedback network is infinite. Thus, the feedback network does not load the amplifier output.

$V=IR_o+AV_i$, for $V_s=0$, $V_i=-V_f$

So that $V=IR_o-Av_f=IR_o-A\beta V$

$V+A\beta V=IR_o$

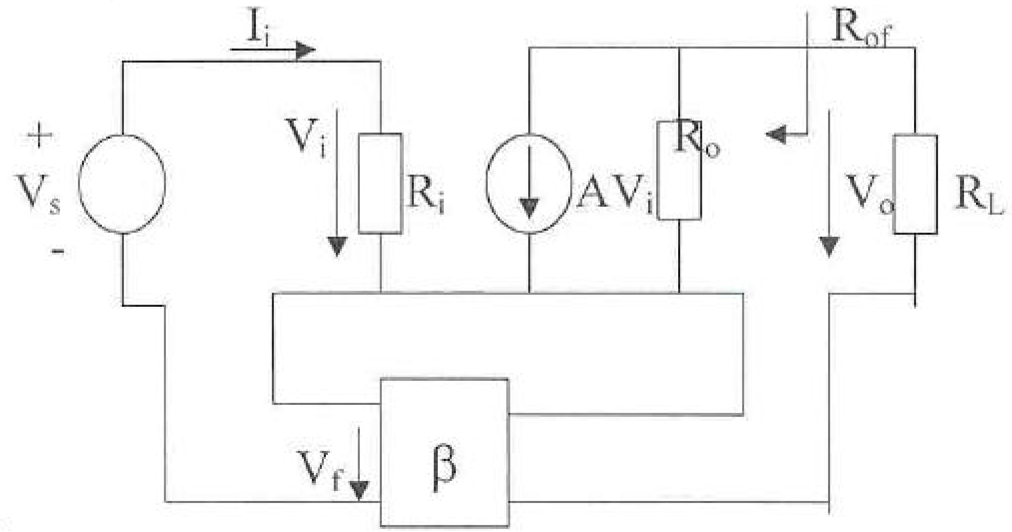
$R_{of}=V/I=R_o/(1+\beta A)$

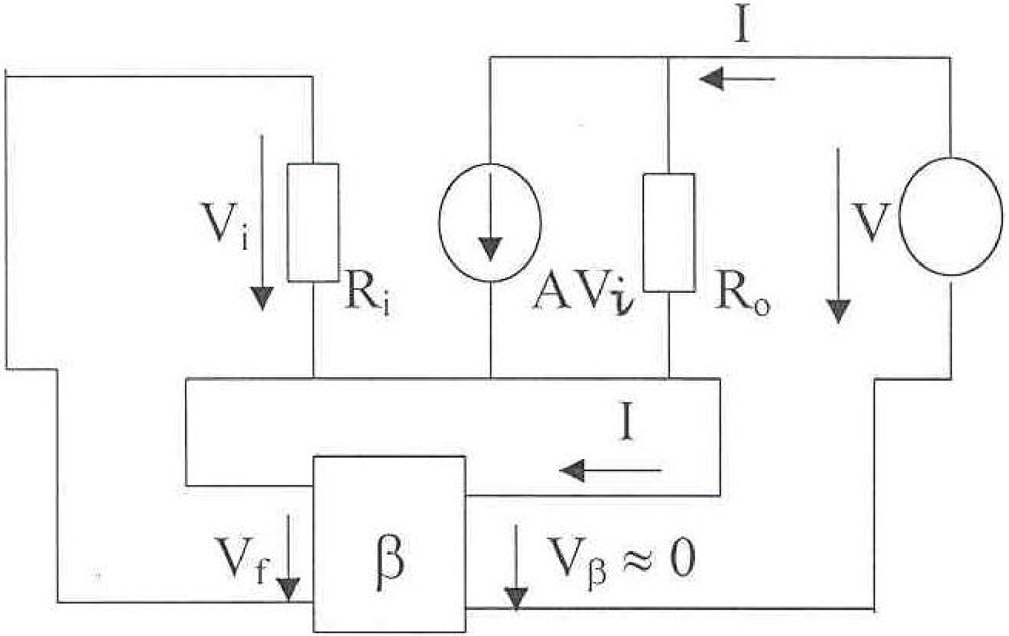
*i.e. the output resistance is decreased with the voltage series feedback.*

*(*Similar results can be obtained for voltage shunt feedback.)*

2. Current series feedback:

$A=I_o/V_i$, $\beta=V_f/I_o$





$I=V/R_o+AV_i$, for $V_s=0$, $V_i=-V_f$

So that $I=V/R_o-AV_f=V/R_o-A\beta I$

$V=IR_o+A\beta IR_o$

$R_{of}=V/I=R_o(1+\beta A)$

*i.e. the output resistance is increased with the current series feedback.*
(*similar results can be obtained for current shunt feedback).

## Other effects of negative feedback:

### 1. Gain sensitivity reduction:

$A_f=A/(1+\beta A)$ where $|1+\beta A|>1$

If β is a constant, then

$$\begin{aligned} dA_f/dA &= 1/(1+\beta A)-A\beta/(1+\beta A)^2 \\ &= 1/(1+\beta A)^2 \end{aligned}$$

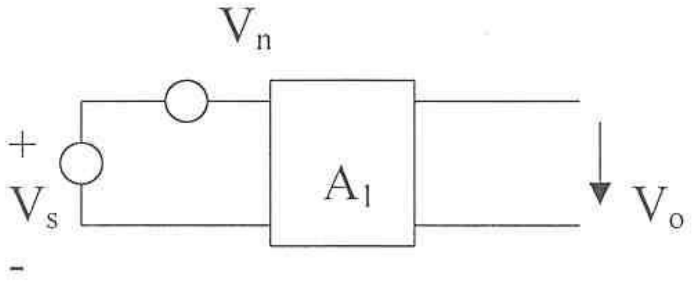
then

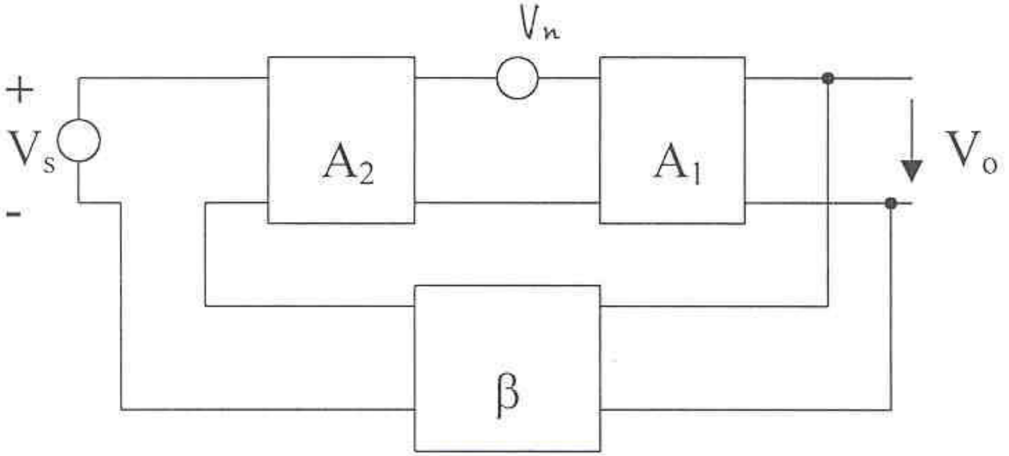
$$\begin{aligned} dA_f/A_f &= [dA/(1+\beta A)^2]/(A/(1+\beta A)) \\ &= [1/(1+1+\beta A)]dA/A \end{aligned}$$

i.e. a better stabilized gain can be obtained.

*The overall gain of the negative feedback amplifier is stabilized.*

### Noise reduction:





The signal-to-noise ratio for the amplifier A1 is $S/N=V_s/V_n$

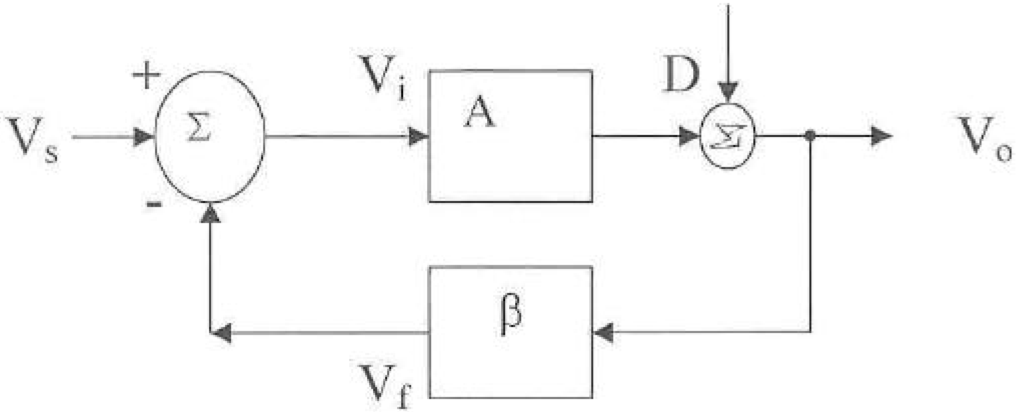
We may precede the the original amplifier A1 by the clean amplifier A2 and apply negative feedback

$$V_o=V_sA_1A_2/(1+A_1A_2\beta)+V_nA_1/(1+A_1A_2\beta)$$

$$\begin{aligned} &S/N \\ &=[V_sA_1A_2/(1+A_1A_2\beta)]/[1+A_1A_2\beta]] \\ &=(V_s/V_n)A_2 \end{aligned}$$

*The signal-to-noise ration is increased by the use of negative feedback.*

### Distortion reduction:



When a large-amplitude signal is applied to the input of an amplifier, the output signal may be distorted due to nonlinearity in the transfer characteristics of the amplifier active device (such as a transistor). Thus a distortion voltage, in addition to the signal component, appears at the output of the amplifier.

$$
\begin{aligned}
V_i &= V_s - V_f = V_s - \beta V_o \\
&= V_s - \beta(Av_i + D) \\
&= V_s - \beta AV_i - bD \\
\Rightarrow V_i(1+\beta A) &= V_s - \beta D \\
\Rightarrow V_i &= (V_s - \beta D)/(1+\beta A) \\
\Rightarrow V_o &= V_f/\beta = (V_s - V_i)/\beta \\
&= [V_s - (V_s - \beta D)/(1+\beta A)]/\beta \\
&= (1/\beta[(V_s\beta A + D)/(1+\beta A)] \\
&= (V_sA + D)/(1+\beta A) \\
&= V_sA/(1+\beta A) + D/(1+\beta A)
\end{aligned}
$$

for a given output signal Vo, distortion D is fixed but its effective magnitude at the output has been reduced by times a factor $1/(1+\beta A)$.

*The signal distortion is decreased by the use of negative feedback.*

### **Disadvantage of negative feedback**

- Gain reduction

Example

If an amplifier with gain of –1000 and feedback factor of b=-0.1 has a gain change of 20% due to temperature, calculate the change in gain of the feedback amplifier.

Solution:

Since bA>>1, we have

|dAf/Af|=|[1+bA]dA/A|≈|1/bA||dA/A|=(1/100)20%=0.2% the improvement is 100 times. Thus, while the amplifier gain changes from |A|=1000 by 20%, the gain with negative feedback changes from |Af|=100 by only 0.2%.

Examples of feedback circuit:

1. Emitter follower:

To emitter follower gives an example of voltage-series feedback circuit.

Here the output voltage is developed across the load resistance connected to the emitter. The whole of this voltage is returned to the input. Thus, in this case, the feedback voltage is equal to the output voltage

$V_f = V_o \Rightarrow \beta = V_f/V_o = 1$

$V_i = V_{be} = V_s - V_f = V_s - V_o$

$A_{vf} = V_o/V_s = (1+h_{fe})R_L/[h_{ie} + (1+h_{fe})R_L/[h_{ie} + (1+h_{fe})R_L]$

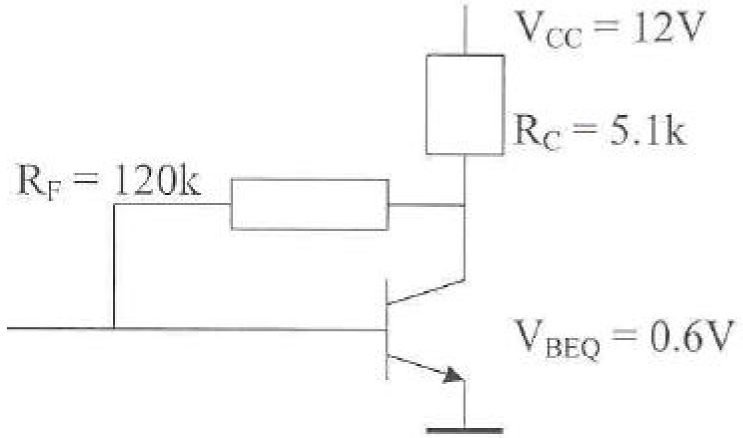
2. Common-emitter amplifier:
3. This circuit is an example of current-series feedback.
4. Avf=Vo/Vs=-hfeIbRC/{hie+(1+hfe)RE}Ib}=-hfeRC/[hie+(1+hfe)RE]

### **Reviewing questions:**

1. What are the benefits and disadvantages of negative feedback?
2. Explain a feedback amplifier with the help of a block diagram.
3. Discuss the effects of negative feedback on amplifier characteristics.

### **Exercise Problems (Feedback Amplifiers)**

1. In the circuit as shown, calculate the corresponding operating point values for $I_{CQ}$ and $V_{CEQ}$ when the values β changes from 20 to 100.



2. Determine the input resistance $R_{if}$, output resistance $R_{of}$ and the voltage gain $Av_f$ of the feedback amplifier as shown in Fig. 2.