FEEDBACK IN AMPLIFIERS

FEEDBACK CONCEPT : It is the process in which a portion of output energy is transferred to the input of the system or amplifier . Feedback in amplifiers is of two types (1) positive feedback (2) negative feedback

POSTIVE FEEDBACK : When the feedback energy is in phase with the applied signal and thus increases the gain of amplifier is called positive feedback

NEGATIVE FEEDBACK : When the feedback energy is out of phase with the applied signal thus reduces the gain of amplifier is called negative feedback .

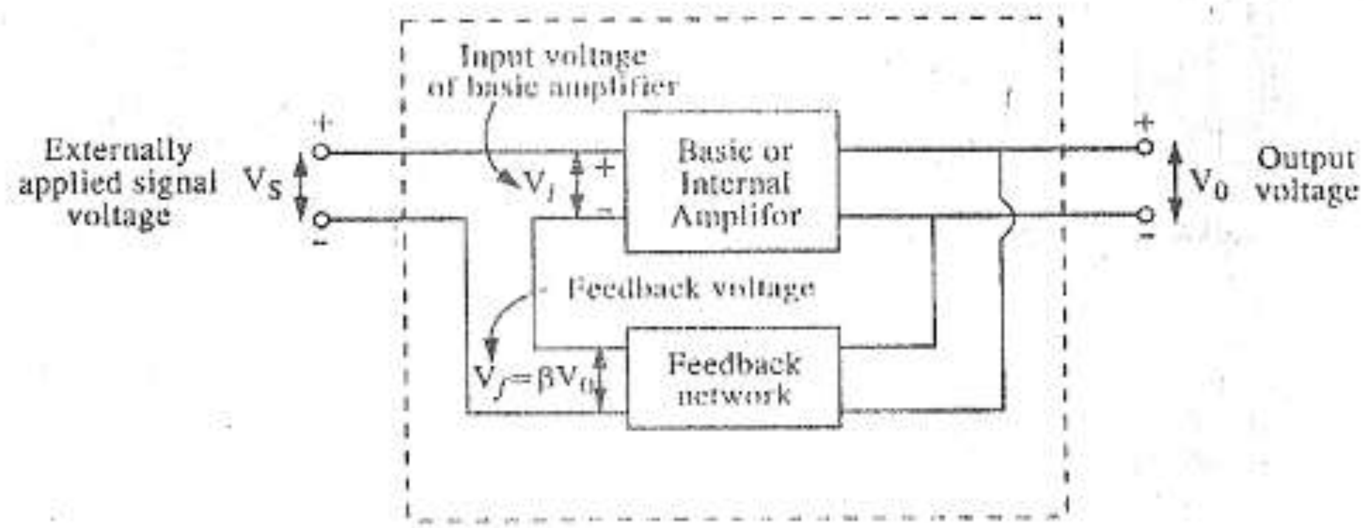
CLASFICATION OF FEEDBACK : Feedback is categorized into following classes:

Voltage feedback (ii) Current feedback

(iii) Compound feedback

GENERAL THEORY OF FEEDBACK in AMPLIFIERS : A feedback amplifier has two parts , an amplifier and feedback circuit . Feedback network is comprised of passive elements like resistance , inductance or capacitor and active elements like transistors . Dashed Box in fig on the next slide constitutes the feedback amplifier

FEEDBACK AMPLIFIER FIG



GENERAL THEORY OF FEEDBACK IN AMPLIFIERS CONT-----

A = gain of amplifier with no feedback

V_o = output of the internal amplifier

V_i =input voltage of the internal amplifier

V_s=input signal voltage to the feedback amplifier

V_f =feedback voltage

A_f=voltage gain with feedback

$\beta=V_f/V_0$

With Negative feedback input Voltage to the amplifier is $V_i=V_s-V_f$

Now $A_f= V_0/V_s = A/(1+A\beta)$

The following cases may arise from above equation If (i) $|1+A\beta| >1$ then the feedback is negative feedback which is used in amplifiers.

(ii) If $|1+A\beta| = 0$ then this means that the amplifier can give output without input signal, the amplifier becomes an oscillator.

(iii) If $|1+A\beta| < 1$ then feedback is positive feedback and causes instability in the oscillations and the operation of transistor .

Advantages of Negative Feedback

1. Gain of amplifier is stabilized against the variations in the values of transistor hybrid parameters .
2. It reduces the non-linear distortion and improves the signal handling capacity of amplifier .
3. The noise level in the output of the amplifier is reduced.
4. The phase distortion is reduced
5. The band width of amplifier is increased and frequency distortion is reduced.
6. Input and output impedances of amplifier may be modified.

Stability of gain or gain stabilization

Overall Gain of feedback amplifier is given by $A_f = A/(1+A\beta)$

Case I : For negative feedback when $(1+A\beta) > 1$ and if $|A\beta| >> 1$ then

$$A_f = 1/\beta$$

Gain of amplifier is independent of (A) gain of the internal amplifier and depends only on the passive elements of the feedback circuit .

Case II : The stability of the gain can be highly improved by using negative feedback

The ratio of fractional change in overall gain of the amplifier to the fractional change in the gain of the internal amplifier, is called the sensitivity S.

$$S = \frac{1}{1+A\beta}$$

Reduction in non-linear distortion

The non- linearity in the transfer characteristics of the amplifier produces the distortion in the output signal when an input signal of large amplitude is applied to the amplifier.

Let A = Voltage gain of the internal amplifier

V_o = output voltage without feedback

V_s= signal voltage applied to the feedback amplifier.

D= Distortion produced in the final stage of the amplifier, Then $V_0 = AV_s + D$

Say V_0" =output voltage with feedback and distortion D ,then

$V_0'' = V_0' + D$; Where $V_0' = A V_i$

V_i =input signal voltage at the terminals of the internal amplifier.

Thus the output of amplifier with feedback becomes

$$V_0' = \frac{AV_s}{1+A\beta} - \frac{A\beta D}{1+A\beta}$$

$$V_0'' = \frac{AV_s}{1+A\beta} + \frac{D}{1+A\beta}$$

Second term in above equation shows that distortion gets reduced with negative feedback in amplifiers.

$$V_0'' = \frac{A V_s}{1+A \beta} + \frac{D}{1+A\beta}$$

Reduction in Noise

Say V_{no}=noise output voltage without feedback

V_n=input noise voltage without feedback

A=voltage gain of the internal amplifier

V_{no}'= noise output voltage with feedback

V_n'= noise input voltage with feedback

$V_{no}' = V_{no} / (1+A\beta)$

As $|1+A\beta| > 1$, therefore above equation indicates that negative feedback reduces the noise level in the output Voltage.

Improvement in frequency response

- Overall gain of the feedback amplifier is

- $A_f = A/(1+A\beta)$, when $A\beta >> 1$

  $A_f = 1/\beta$

  Since the feedback network consists of resistance components, the value of β is independent of the change in signal frequency, therefore the voltage gain of the amplifier remains constant over a wide range of signal frequencies.

Reduction in phase distortion

- The gain of the amplifier with no feedback is given as
- $A = |A|\cos\theta + j|A|\sin\theta$
- Gain A can also be written as
- $A = |A| \angle \theta$

In a negative feedback amplifier

$A_f = A/(1+A\beta)$

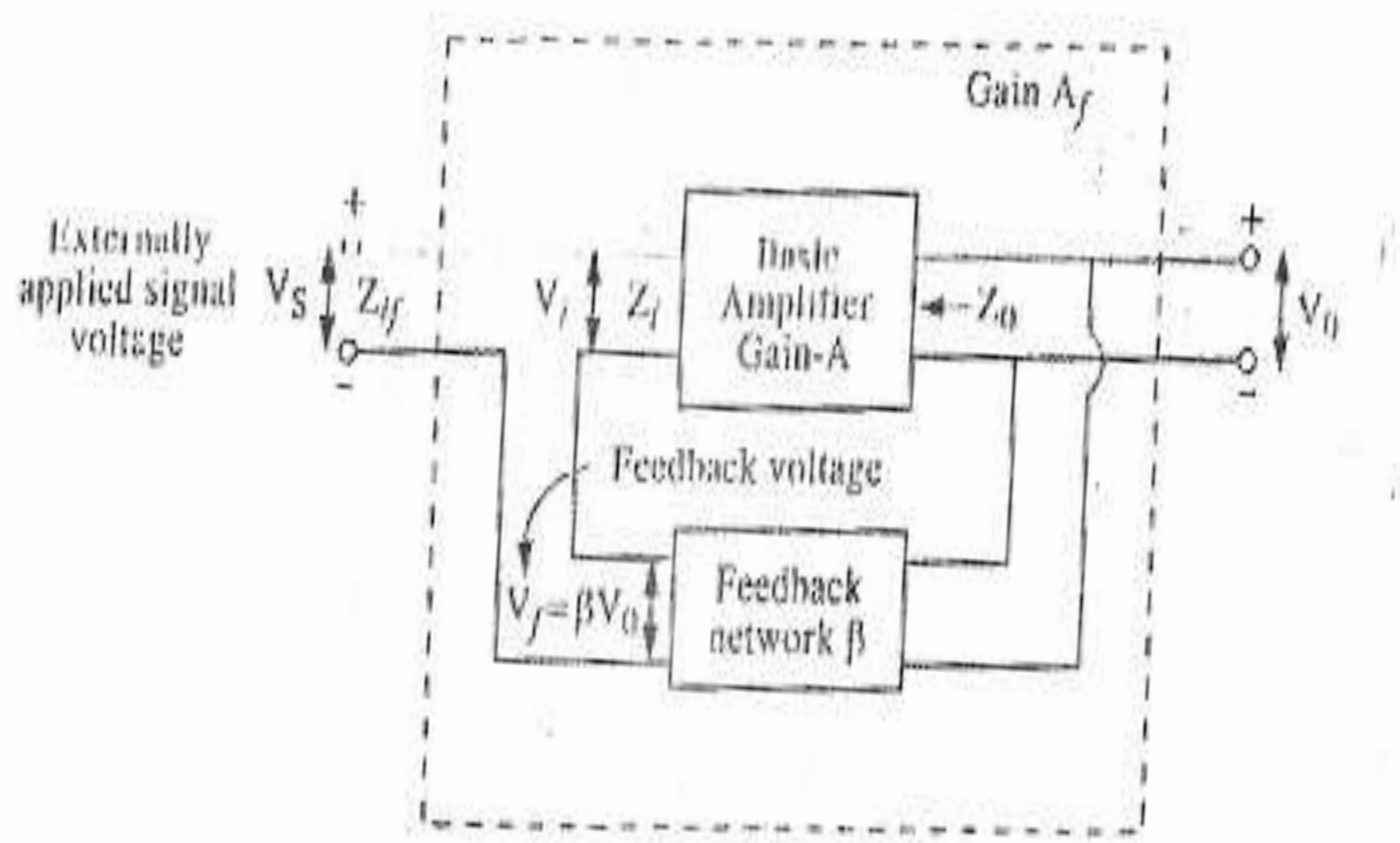
$$= \frac{|A| \angle \theta}{(1+\beta|A|\cos\theta) + j\beta|A|\sin\theta}$$

$$= \frac{|A| \angle \theta}{|M| \varphi}$$

$$= \frac{|A| \angle \theta - \varphi}{|M|}$$

Thus, phase distortion is reduced by reducing the phase shift through an angle φ.

Effect on input impedance (Series Mixing)



Effect on input impedance (Series Mixing)

- Say V_S=Externally applied input signal
- V_i=Input to the basic amplifier
- V_f =Feedback voltage to the input
- Z_i =input impedance without feedback
- Z_{if}=input impedance with feedback
- Z_o =output impedance without feedback
- Z_{of} =output impedance with feedback
- I_i =input current without and with feedback.
- $Z_{if} = (1+A\beta) Z_i$
- As $(1+A\beta) >> 1$ Thus in series feedback circuit input impedance
- increases.

Input Impedance (Shunt mixing)

Feed back signal is mixed in parallel with the external signal and the input impedance is found to be decreased .

I_0 = output current without feedback

I_i = input current without feedback

$A = I_0 / I_i$

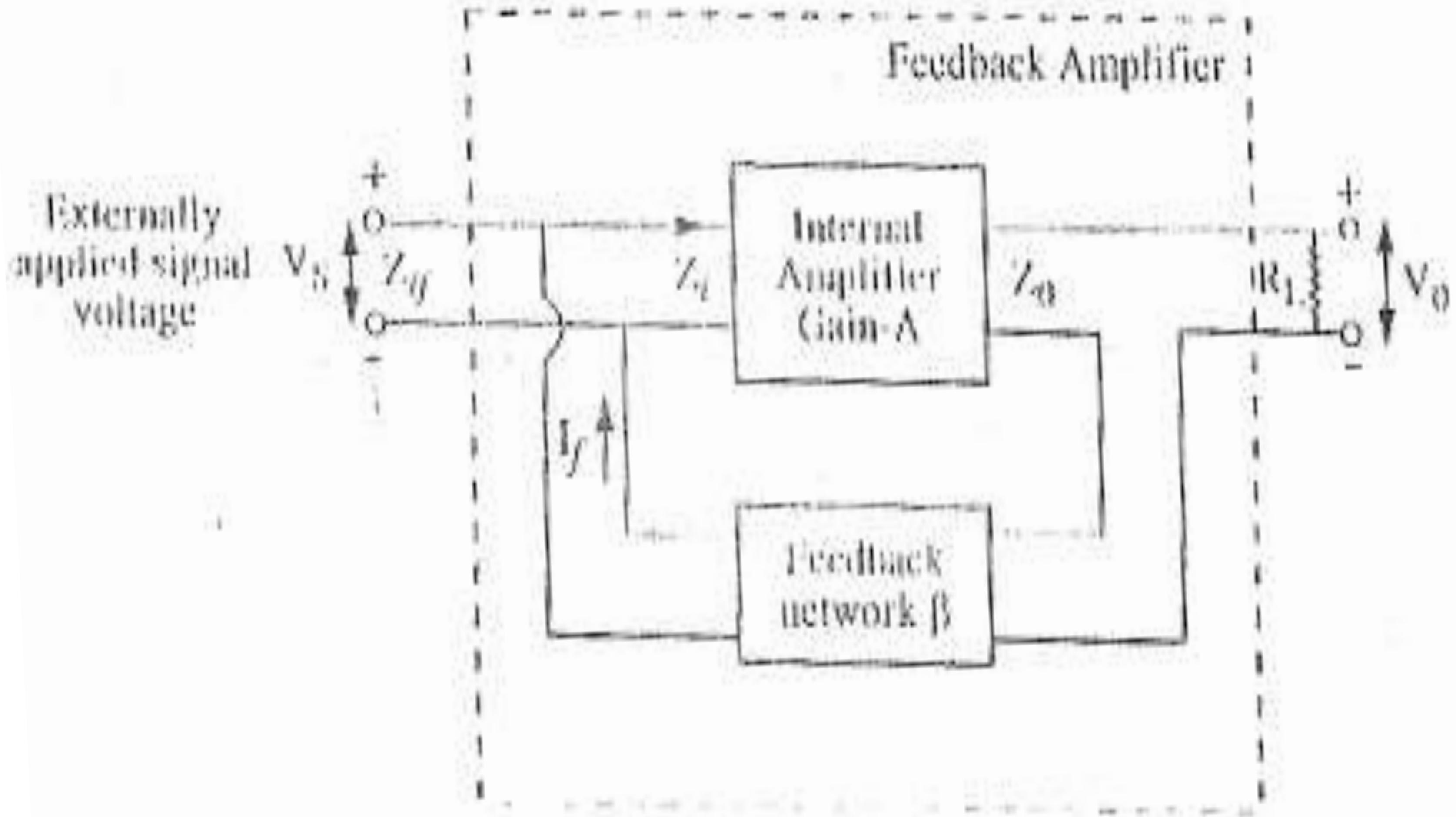
Input impedance without feedback is $Z_i = V_s / I_i$ because $V_s = V_i$

I_s = input signal current from external source

Input impedance with feedback is $Z_{if} = V_s / I_s$ and $I_i = I_s - I_f$

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

As $(1 + A\beta) > 1$, the input impedance of the amplifier gets decreased with current shunt feedback.


Feedback Amplifier
Externally applied signal voltage
V_s
Z_{if}
Z_i
Internal Amplifier Gain-A
Z_o
R_L
V_o
I_f
Feedback network β

Effect on output impedance (Voltage sampling)

- In this case, refer fig on the previous slide, we adopt the following steps: (i) make the input signal $V_s=0$,(ii)remove the external load impedance and connect a hypothetical voltage generator V across the load terminals,(iii) calculate the current delivered by this hypothetical generator.
- Let I' = current sent by generator voltage V with no feed back , then output impedance without feedback is $Z_0 = V/I'$
- With feedback , the input voltage is $V_i = -\beta V$

Total Voltage at the output stage = $V - AV_i = (1+A\beta)V$

Output current supplied with feedback, $I = (1+A\beta)V/(Z_0)$ Hence output impedance with feedback $Z_{0f} = Z_0/(1+A\beta)$

Above equation shows that in voltage sampling the output impedance decreases by a factor $1/(1+A\beta)$.

Effect on output impedance (Current sampling)

- Here feedback network is connected in series with the output.

Let $V_s = 0$ $R_L = 0$,hypothetical voltage source be V

Z_0 =output impedance without feedback

I=current delivered by the voltage source with feedback

Output current with feedback, $I = \frac{V}{Z_0} - A\beta I$

Hence output impedance with feedback is $Z_{0f} = Z_0(1+A\beta)$

As $(1+A\beta)>1$, output impedance increases when feedback network is connected in series with the output.

Increase in bandwidth with negative feedback

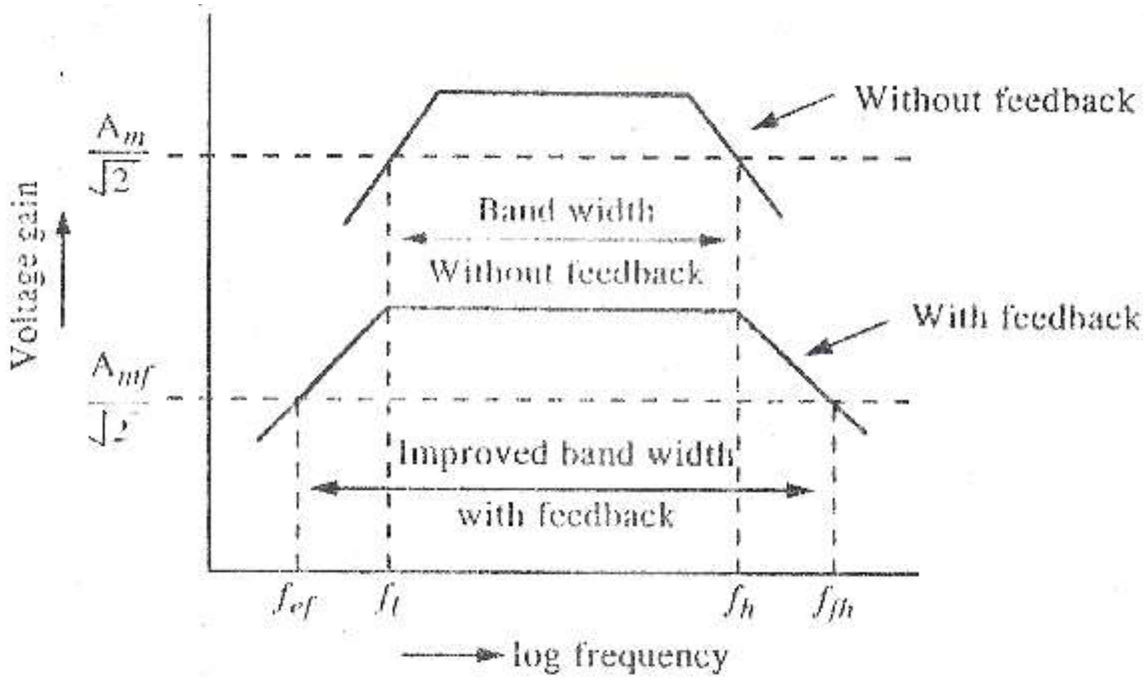
- Low frequency gain of the single stage amplifier is
- $A_l = A_m /(1-jf_l /f)$
- where A_m is the mid frequency gain and f_l is the lower half power frequency . Similarly high frequency gain of the single stage amplifier is
- $A_h = A_m/(1+jf /f_h)$
- where f_h is upper half power frequency.
- Overall gain with feedback at low frequency is
- $A_{lf} =A_{mf}/(1-jf_l f /f)$
- Where $A_{mf} = A_m / (1+\beta A_m)$ and $f_{lf} = f_l /(1+\beta A_m)$
  As $(1+A_m \beta) > 1$

  $f_{lf} < f_l$ $_I$ It shows that negative feedback decreases the value of lower half power frequency . Overall gain at high frequencies with feedback is

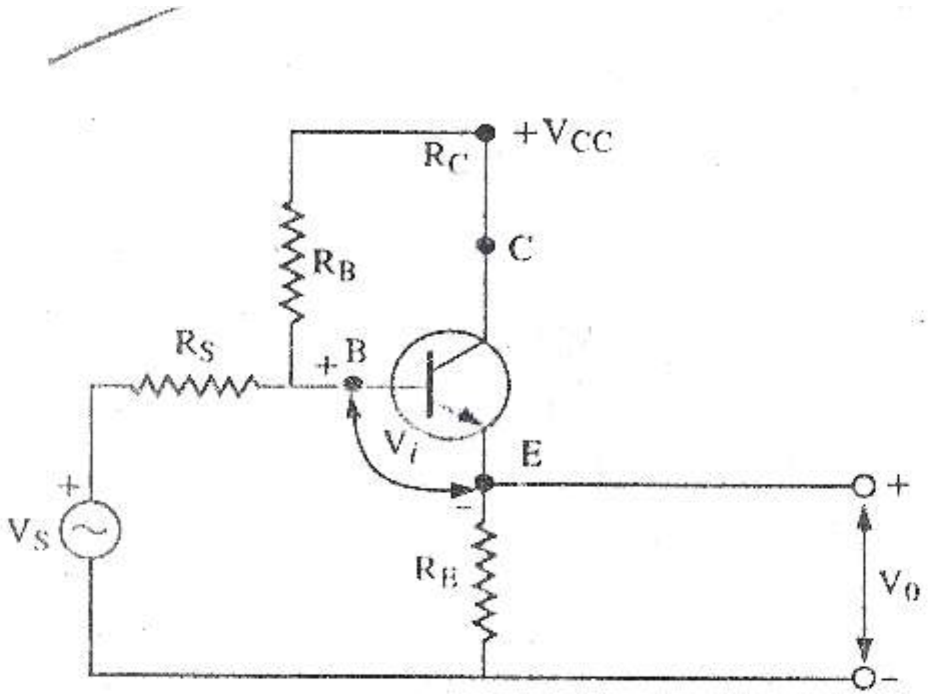
  $A_{hf} = A_m/(1+jf/f_{fh})$ where $A_{mf} = A_m /(1+\beta A_m)$ and $f_{fh} = (1+\beta A_m)$ f_h

Above equation shows that negative feedback increases the upper half power frequency. Since the band width is the difference between the upper half power frequency and lower half power frequency , the difference shows that with negative feedback , band width is enhanced and the frequency distortion is reduced.

Increase in bandwidth with negative feedback



Emitter Follower



Emitter Follower

It is the special Common –emitter amplifier where output is taken from the emitter terminal and no collector resistance R_c is used. With the application of signal voltage V_s , emitter current i_E starts flowing across R_E

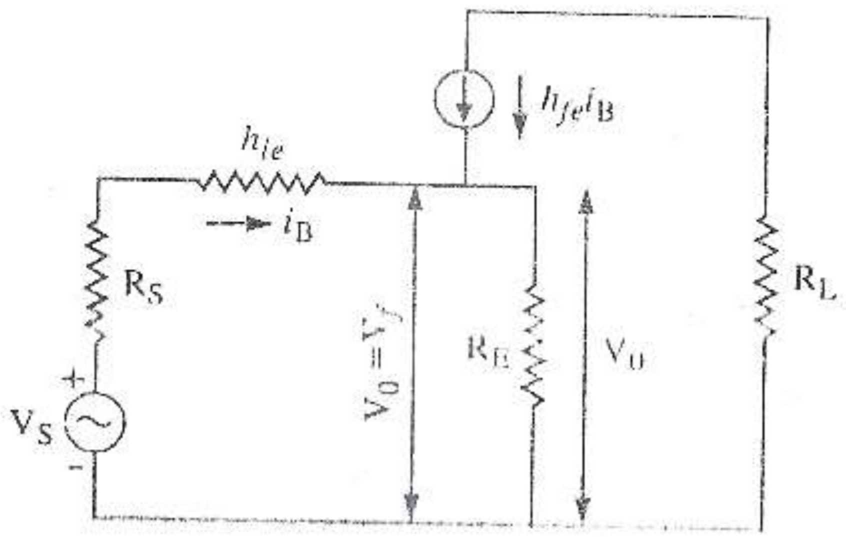
The Output Voltage $V_0 = i_E R_E$ is completely returned to the input . Input and feedback voltages are out of phase . Emitter base junction is forward biased through resistance R_B

The type of feedback in the emitter follower circuit is negative feedback . Here d. c emitter voltage follows the d. c base voltage

Since output Voltage $V_0 = i_E R_E$ is completely returned to the input therefore

$\beta = V_f / V_0 = 1$ i.e. there is 100% feedback in the emitter follower.

EMITTER FOLLOWER



Emitter Follower

- Input voltage $V_i = (R_s + h_{ie}) i_B$
- Output voltage $V_0 = h_{fe} i_B R_E$
- Voltage gain without feedback $A = h_{fe} R_E / (R_S + h_{ie})$
- Voltage gain with feedback, $A_f = A/(1+A)$ because $\beta = 1$
- Therefore

$$A_f = \frac{h_{fe} R_E}{R_S + h_{ie} + h_{fe} R_E}$$

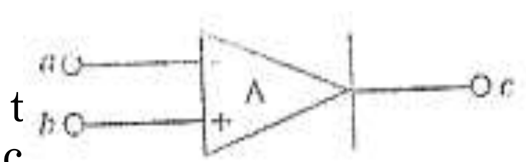
- Which shows that $A_f < 1$.

Operational Amplifier

An operational amplifier is a direct –coupled, high-gain, differential amplifier.

The operational amplifier is abbreviated as OP-AMP . It is designed to perform certain mathematical operations like addition, subtraction sign changing differentiation, integration in analogue computers . In addition to these operations OP-AMP can be used in signal amplification , impedance transformation , filters , oscillators , voltage regulators , analog to digital , digital to analog converters etc

SYMBOL : The symbol used for circuit representation of an OP-AMP is



It Consists of two t ıe output terminal c . The terminal marked as (-) is c . The terminal marked as (+) sign is called the non inverting terminal and output voltage at terminal c is proportional to the difference of two input signals voltages applied at a and b input terminals.

CHARACTERISTICS OF OPERATIONAL AMPLIFIER

I Input impedance of the OP-AMP is infinite .

ii Output impedance is zero .

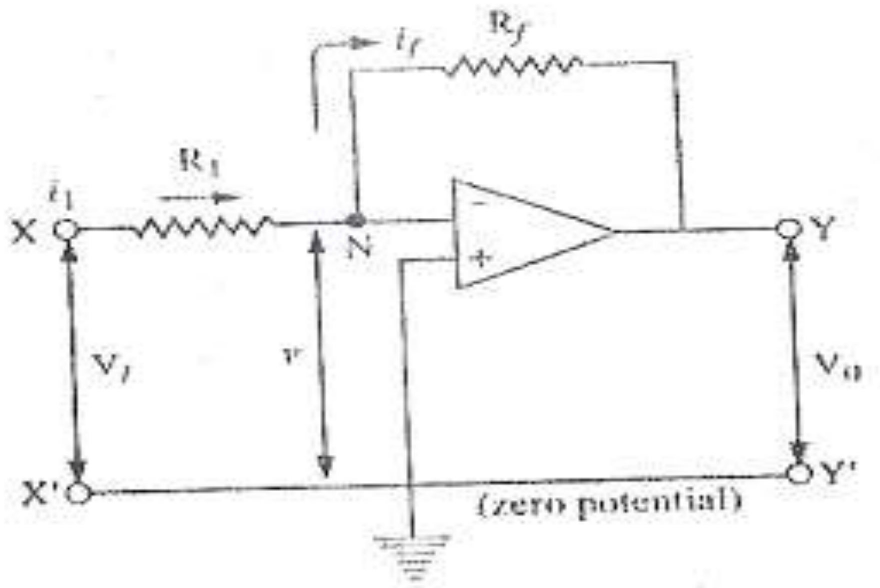
Iii It has indefinite voltage gain .

iv It has infinite band width .

v No drifting of characteristics takes place with temperature variations .

Vi It has perfect balance i.e. output voltage $V_0 = 0$ when two equal voltages are applied at the two input "a" and " b" terminals .

APPLICATIONS OF OP-AMP
INVERTING AMPLIFIER



INVERTING AMPLIFIER :

V_i= input signal voltage

R_i= Input resistance connected to the inverting terminal of OP-AMP

R_f= resistance connects the output terminal with the input inverting terminal.

V_0= output signal voltage .
say v voltage at the input inverting terminal N

A =open loop voltage gain of the OP-AMP which is infinite.

INVERTING AMPLIFIER

$i_1 = (V_i - v)/R_1$

Similarly current through resistance R_f is,,,, $I_f = (v - V_0)/R_f$

using $i_1 = I_f$ and putting v=0 (as point N is virtually grounded)

we get $A = -(R_f/R_i)$

Input Resistance of the inverting system is

$$R_{in} = \frac{\text{Input Voltage}}{\text{Input current}} = V_i/(V_i - v)/R_1$$

as v=0

Thus $R_{in} = R_1$

SCALE CHANGER :

Say ratio $R_f/R_i = k$ is a real constant value then

$-(V_0/V_i) = k$ or $V_0 = -kV_i$

It shows that scale of output voltage is equal to the scale of input voltage multiplied by k called the scale factor

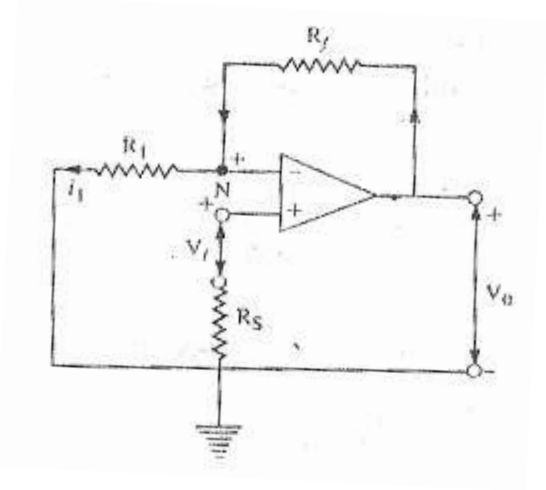
It

PHASE SHIFTING

Resistances R_1 and R_f are replaced by the impedances Z_i and Z_f.

- Then $V_0/V_i = -Z_f/Z_i = -(|Z_f|e^{j\theta f}/|Z_i|e^{j\theta i})$ where Z_f and Z_i are complex quantities which are equal in magnitude but have different values of phase angles.
- Say $|Z_f| = |Z_i|$
- Then, $\frac{V_o}{V_i} = \exp[\, i\, (\pi + \theta_f - \theta_i)\,]$
-
- Above equation indicates that voltage V_o leads voltage V_i by an angle $(\pi + \theta_f - \theta_i)$. Thus, the phase of the input signal has been shifted without changing its magnitude . Phase shift can be of any value between 0^0 to 360^0 .

NON- INVERTING AMPLIFIER



NON-INVERTING AMPLIFIER

V_i = Input voltage applied to the non-inverting terminal .

V_i is also the voltage at the inverting point N. Since the voltage gain of the OP-AMP is infinite, the input to the amplifier is to be nearly zero and

the current flowing through the amplifier is very small.

Applying current Kirchhoff's law at point N

$(V_0-V_i)/R_f=(V_i-0)/R_1$

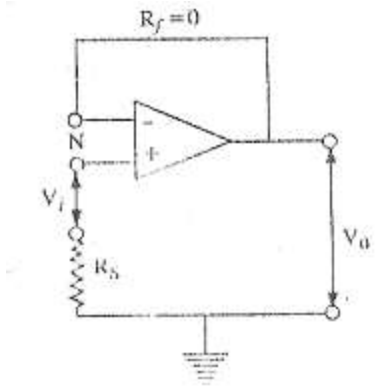
Or $V_0/V_i=(R_f/R_1)+1$

Right hand side of above equation is a positive quantity indicating that input and output voltages are in phase.

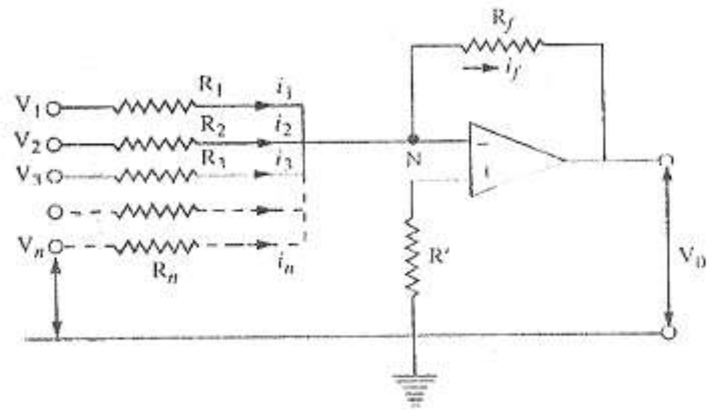
Also the gain of the non-inverting amplifier is slightly more than the inverting amplifier.

UNITY FOLLOWER

Considering gain of the non –inverting amplifier, when R_f=0 and R_1=∞,we have (V_0/V i)=1 and the non-inverting amplifier is called unity follower.



ADDER



ADDER

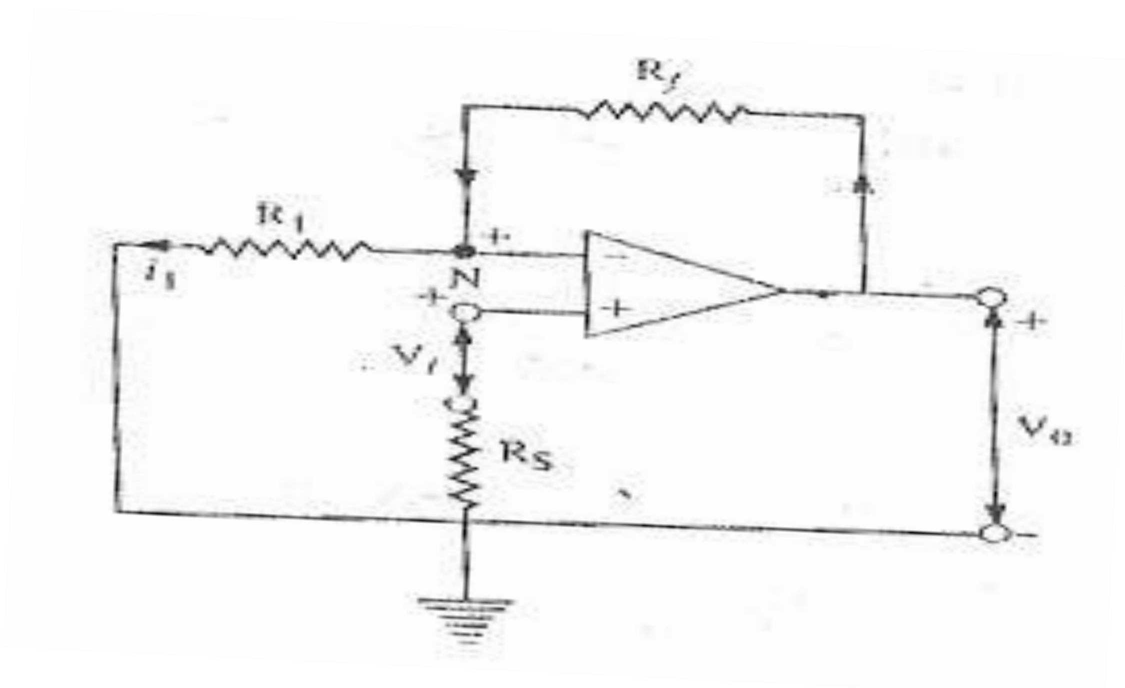
- In the circuit diagram on the previous slide, point N is virtually grounded. The inverting adder amplifier has n inputs through resistances R_1 R_2--------R_n and current through these resistances be i_1 i_2--------i_n. The current through R_f is I_f=. $i_1 + i_2 +$ --------$+i_n$

$- V_0/R_f = V_1/R_1 + V_2/R_2 +$----------$+ V_n/R_n$

- $V_0 = -(V_1 + V_2 +$----------$+ V_n)$.

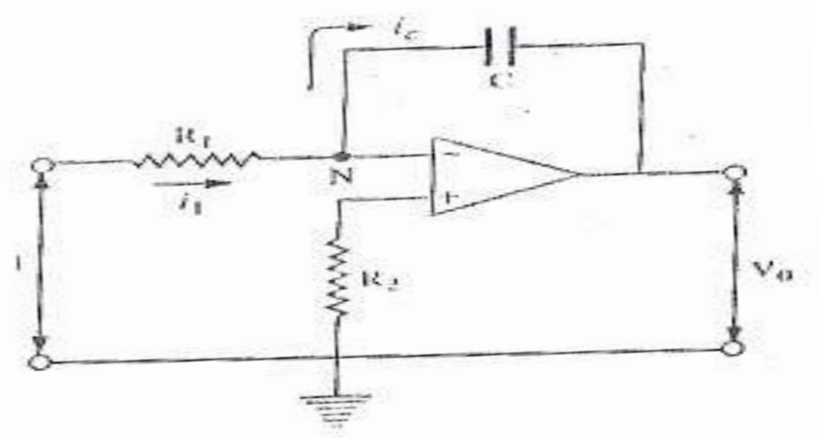
SUBTRACTOR

- In this case, both inverting and non-inverting terminals are used simultaneously ,circuit is shown below.



SUBTRACTOR

- Using superposition theorem, resultant output $V_0=V_{01}+V_{02}$
- $V_{01} = -(R_f/R_1)V_1$ (Where V_1 =input to the inverting terminal and V_{01} is the corresponding output.
- $V_{02}=(1+R_f/R_1)\ V_M$ (whereV_2=input to the non-inverting terminal and V_{02} is the corresponding output, V_M=input voltage at point M .
- Putting the values of V_{01} and V_{02} in the expression for V_0 and using $R_1=R_2$ and $R_3=R_f$.
- We get $V_o=R_f/R_1(V_2 - V_1)$ which shows that the amplifier functions as a subtractor .



INTEGRATOR

In the figure given on the previous slide, i_1= input current passing through R_1 and the same amount of current will pass through capacitor C , i.e $i_1=i_C$

Or $i_1=V_1/R_1$

Voltage across the capacitor $V_C = Q/C = (1/CR_1) \int V_1 dt$

Since $V_0 + V_C = 0$ thus $V_0 = -(1/CR_1) \int V_1 dt$

Thus circuit functions as an integrator.

DIFFERENTIATOR

Say V_1=input voltage applied to the inverting terminal

$V_1=q/C$ (q is the charge on the capacitor)

$(dV_1/dt)=i/c$

i is the current flowing through the resistance R_1 as OP-AMP has infinite input impedance . Also $V_0=-V_{R1}= -iR_1$

$V_0=-CR_1(dV_1/dt)$

Thus circuit functions as a differentiator as shown on the next slide

Differentiator