Chapter one Feedback amplifiers

Feedback implies feeding back (i.e., returning back) a part of the processed signal to the input side so as to enhance or diminish the input signal. When the input signal (current or voltage) is diminished, it is considered as negative feedback. When the input signal is enhanced, it is known as positive feedback. Negative feedback is employed in amplifying systems to achieve certain special characteristics that are not obtainable from the basic amplifier. Positive feedback is employed to produce signal generator, such as oscillators. In this chapter we shall consider the case of negative feedback ,Basic concepts and benefits of negative feedback. Interconnections and associated circuit models of the amplifier and the feedback network. Analysis techniques with examples for the four basic amplifier configurations (VCVS,CCCS,VCCS,CCVS) Negative feedback and stability- phase and gain margins.

Basic negative feedback system

Consider the Figure below. The source signal could be a current or voltage. The basic amplifier has a gain A from left to right direction. A part of the output signal xo is fed back by the factor B , from right to left, and subtracted (added with a phase inversion) from the input signal xs.

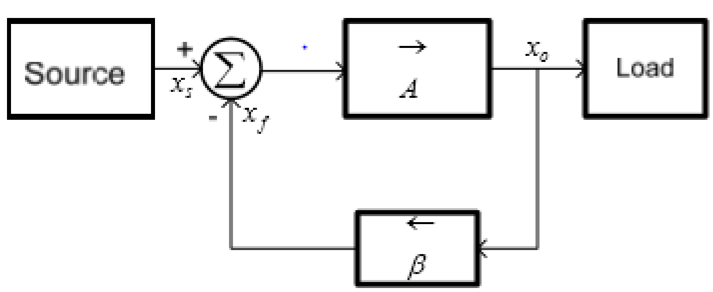


Figure Basic negative feedback system

While the basic amplifier has a gain A (i.e., x_o / x_I), the overall gain of the feedback system x_o / x_s is A_f which is $A/(1 + A\beta)$. This gain is called the gain with feedback. The quantities A and A_f could be any one of the four different kinds of function, i.e., (a) voltage gain, (b) current gain, (c) trans-resistance gain and (d) trans-conductance gain. Some special features of the negative feedback system can be appreciated very easily.

The quantity $A\beta$ is called the *loop gain* of the system. The term $1 + A\beta$ is referred to as the *feedback factor*.

Benefits of negative feedback

Gain de-sensitivity

This implies that if there occurs a variation by certain amount in the gain A of the main amplifier, the gain A_f of the feedback system is not altered as much i.e., the gain variation is desensitized by negative feedback.

Assume β is constant. Then if we take differential of A_f, we get $dA_f = \dfrac{dA}{(1+A\beta)^2}$

Thus it is evident that the variation dA in A has been reduced by the factor $(1+A\beta)^2$ because of negative feedback

.: *Bandwidth extension*

This implies that if the band width of the gain A has certain values (say 1MHz), by applying negative feedback, it can be increased. The increase, however, happens by sacrificing the value of the gain A.

Thus, consider $A = \dfrac{A_M}{1+ s/\omega_H}$ This has a high frequency band with of ω_H rad/sec. If we apply negative feedback around the amplifier, the gain A_f will become:

$$A_f(s) = \frac{A(s)}{1+\beta A(s)} = \frac{A_M \big/ (1+\frac{s}{\omega_H})}{1+\beta\, A_M \big/ (1+\frac{s}{\omega_H})}$$

After simplification : $A_f(s) = \dfrac{A_M/(1+A_M\beta)}{1+s/[\omega_H(1+A_M\beta)]} = \dfrac{A_{Mf}}{1+\dfrac{s}{\omega_H(1+A_M\beta)}} = \dfrac{A_{Mf}}{1+\dfrac{s}{\omega_{Hf}}}$

where, $A_{Mf} = \dfrac{A_M}{1+A_M\beta}$, and $\omega_{Hf} = \omega_H(1+A\beta)$

The above result implies a mid-band gain of A_{Mf} and a high frequency band width of ω_{Hf}. It can be clearly seen that the new mid-band gain is $(1+A\beta)$ times smaller than the mid-band gain without feedback, but the high frequency band width is $(1+A\beta)$ times larger than the band width without feedback. Thus an extension of band width by the factor $(1+A\beta)$ has been achieved.

Reduction of non-linear distortion in amplifiers

It is known that most practical amplifiers have a non-linear output input transfer characteristics. The non- linearity arises out of (i) non-linear response characteristic of the devices (i.e., transistors), and/or (ii) finite DC power supply values.

A non-linear transfer curve represents a gain (~ slope of the graph) which varies depending upon the location of operation on the curve (i.e., the operating point). Thus one can define a series of gains, say, A_1, A_2, .. along the transfer characteristics. Under negative feedback the corresponding gains become $A_1/(1 + A_1\beta)$, $A_2/(1 + A_2\beta)$, and so on. If the loop gain values (i.e., $A_1\beta$, $A_2\beta$) are very high (i.e., >>1), the feedback gain values approximate to $1/\beta$ in each case. Thus, the gains under negative feedback at different segments of the transfer characteristic appear to remain constant at a value $1/\beta$. A constant gain (~constant slope) implies a linear curve, i.e., a straight line. This is how the non-linearity in the response characteristic of the amplifier is reduced, and hence the attendant distortion gets reduced.

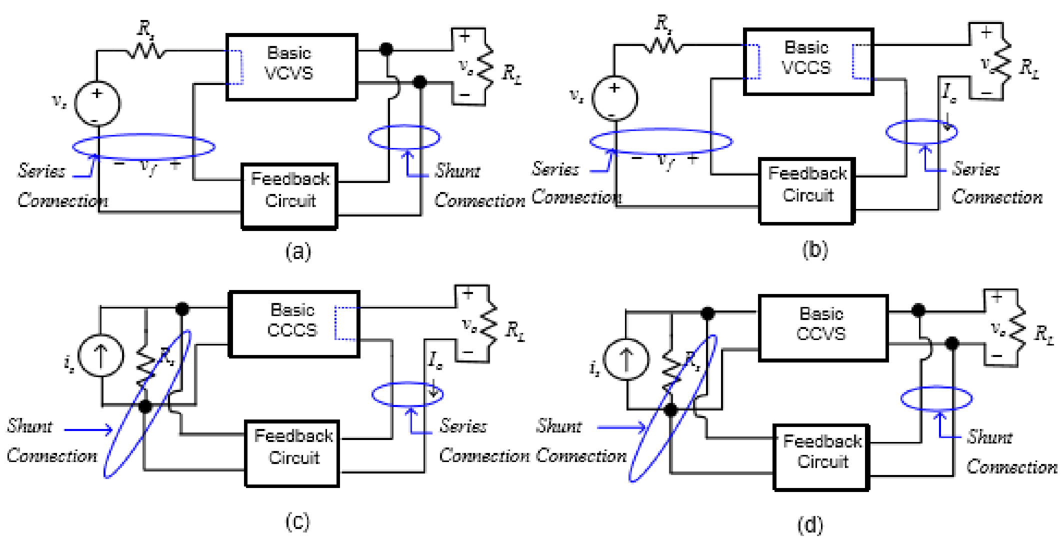
Interconnections for the negative feedback systems

We will now consider the four distinct types of negative feedback connections and their respective characteristics as regards the overall gain, input and output impedances. The classification basically depends upon the four distinct types of amplifiers, namely, (a) voltage amplifier (VCVS), (b) current amplifier (CCCS), (c) trans-resistance amplifier (CCVS), and (d) trans-conductance amplifier (VCCS).

For each case, the topology (i.e., the style of interconnection) of the negative feedback network follows a regular pattern relative to the topology of the basic amplifier. Thus, for a voltage amplifier (VCVS), whose equivalent circuit model has (i) a series connection at the input through the input resistance, and (ii) a series connection at the output (i.e., the output controlled voltage source and its associated resistance connected in series), the feedback circuit will have (i) a series connection at the input, and (ii) a shunt (parallel) connection at the output. A *rule of thumb* is: the feedback *connection at input matches* with that of the basic amplifier, but the *connection at the output is opposite* to that of the basic amplifier.

-. <u>System diagrams for the feedback connections</u>

Consider figures 2(a)-(d) which depict the *four* possible interconnection styles (*topology*) around the *four* basic electronic amplifier systems.



Four possible feedback connections

Model of the input source according to the feedback connection style

The operation at the input of a feedback amplifier system involves *mixing* of signals. *Mixing* is possible only for signals of the *same type* i.e., voltage with voltage, current with current, and so on. Similarly, the operation at the output of the amplifier under feedback is called *sampling*. *Sampling* can be done for only *one kind* of signal i.e., a voltage or a current.

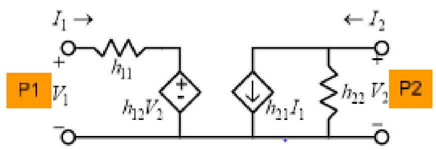
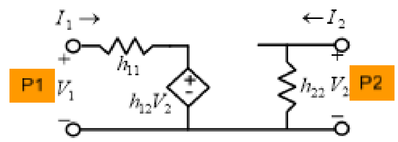
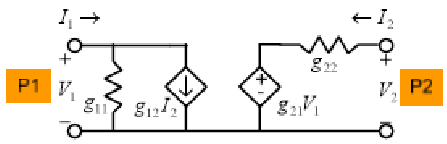
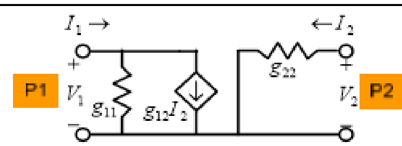
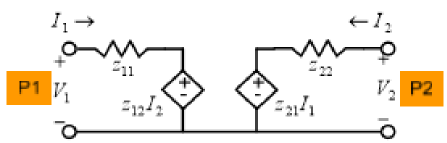
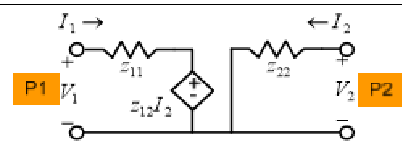
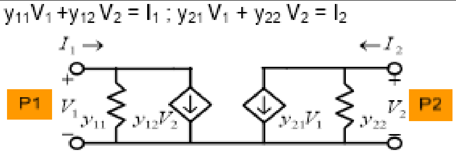
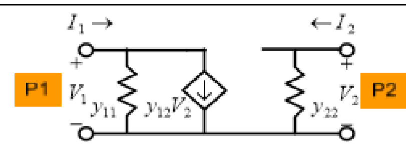
Model of the basic amplifier according to the feedback connection style

a shunt connection at the output will imply a series connection style at the output of the amplifier. A series connection implies a voltage source with a series resistance. Now to put both the input and output feedback connections together, a series in-shunt out connections will imply a VC (for series in) VS (for shunt out), i.e., a VCVS amplifier model. Similarly, a series connection at the output will imply a shunt connection style at the output of the amplifier. A shunt connection implies a current source with a shunt resistance. Now putting the input and output feedback connections together, a series inseries out connections will imply a VC (for series in) CS (for shunt out), i.e., a VCCS amplifier model.

Input, output resistances under negative feedback

If we realize that resistances connected in series produces an increase in the resistance while resistances connected in parallel (shunt connection) produces a decrease of resistance, one can immediately infer that at the series connection location of the feedback system there will be an increase in the resistance value. Similarly, at the point where the feedback connection is in shunt, the resistance will decrease after feedback connection.

An important characteristic of the various feedback systems is that if the *loaded* gain A and the *feedback* gain β can be determined, the expressions for various gain and resistance values can be easily calculated. These follow certain easy to remember

Model name	General formulations (equations & circuit models)	Approximate circuit model	Feedback
[h]	$h_{11}I_1 + h_{12}V_2 = V_1$; $h_{21}I_1 + h_{22}V_2 = I_2$ 		Series-Shunt
[g]	$g_{11}V_1 + g_{12}I_2 = I_1$; $g_{21}V_1 + g_{22}I_2 = V_2$ 		Shunt-Series
[z]	$z_{11}I_1 + z_{12}I_2 = V_1$; $z_{21}I_1 + z_{22}I_2 = V_2$ 		Series-Series
[y]	$y_{11}V_1 + y_{12}V_2 = I_1$; $y_{21}V_1 + y_{22}V_2 = I_2$ 		Shunt-Shunt

(Summary of the formulae, $A_f = {X_o}/{X_S} = \frac{A}{1+A\beta}$ for all cases)

Feedback connection	A	β	Basic Amplifier	Z_{if}	Z_{of}
Series-shunt	V_o/V_I	V_f/V_o	VCVS	$Z_I(1+A\beta)$	$Z_o/(1+A\beta)$
Shunt-series	I_o/I_I	I_f/I_o	CCCS	$Z_I/(1+A\beta)$	$Z_o(1+A\beta)$
Series-series	I_o/V_I	V_f/I_o	VCCS	$Z_I(1+A\beta)$	$Z_o(1+A\beta)$
Shunt-shunt	V_o/I_I	I_f/V_o	CCVS	$Z_I/(1+A\beta)$	$Z_o/(1+A\beta)$

It may be seen from the above table that whenever the feedback network has series interconnection, the corresponding (i.e., input or output) impedance is *increased* by the factor $(1+A\beta)$, while a shunt connection *reduces* the impedance at the pertinent location (i.e., input or output) by the factor $(1+A\beta)$. These observations can be of aid to remember the formulae.

Example

Determine the voltage gain, input, and output impedance with feedback for voltage series feedback having $A = -100$, $R_i = 10\ \text{k}\Omega$, $R_o = 20\ \text{k}\Omega$ for feedback of (a) $\beta = -0.1$ and (b) $\beta = -0.5$.

Solution

Using Eqs. (18.2), (18.4), and (18.6), we obtain

(a) $A_f = \frac{A}{1+\beta A} = \frac{-100}{1+(-0.1)(-100)} = \frac{-100}{11} = \mathbf{-9.09}$

$Z_{if} = Z_i\,(1+\beta A) = 10\ \text{k}\Omega\ (11) = \mathbf{110\ k\Omega}$

$Z_{of} = \frac{Z_o}{1+\beta A} = \frac{20\times 10^3}{11} = \mathbf{1.82\ k\Omega}$

(b) $A_f = \frac{A}{1+\beta A} = \frac{-100}{1+(0.5)(100)} = \frac{-100}{51} = \mathbf{-1.96}$

$Z_{if} = Z_i\,(1+\beta A) = 10\ \text{k}\Omega\ (51) = \mathbf{510\ k\Omega}$

$Z_{of} = \frac{Z_o}{1+\beta A} = \frac{20\times 10^3}{51} = \mathbf{392.16\ \Omega}$