Feedback Amplifier

Basic feedback configuration is shown in Figure 1. Here the output signal from the amplifier is sampled and fed back to the input of the amplifier by a summing network.

The sampling at the output can be done either by sampling

a) the output voltage (parallel sampling) or

b) the output current (series sampling)

The summing can be done either by

a) adding voltages (series summing)

b) adding currents (parallel summing)

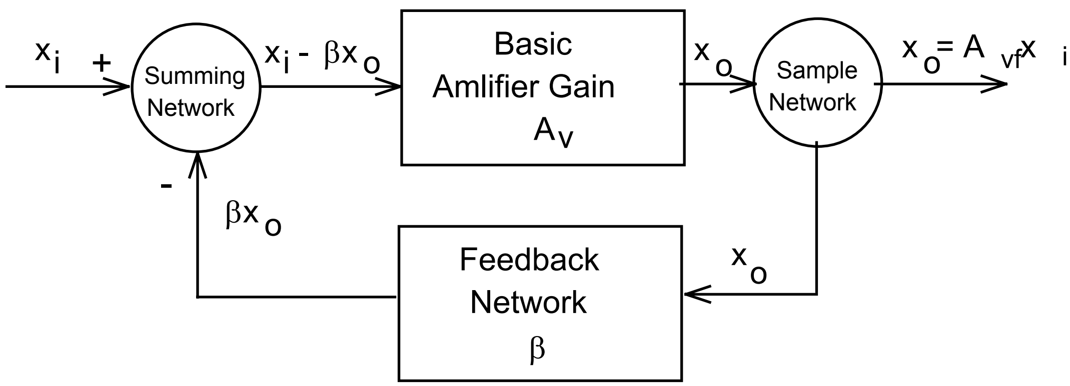

Figure 1

Basic amplifier gain, A_V, can be written as the ratio of the output voltage divided by the input voltage

$$A_v = \frac{x_o}{x_o - \beta x_o} = \frac{(x_o / x_i)}{1 - \beta\,(x_o / x_i)} = \frac{A_{vf}}{1 - \beta\, A_{vf}}$$

Here A_{vf} is the amplifier gain with the feedback (overall gain of the system).Solving for A_{vf}

$$A_{vf} = \frac{A_v}{1 + \beta\, A_v} \qquad \text{(Eq.1)}$$

Here

$A_{vf} > A_V$ if $\beta A_V < 0$ (positive feedback) and

$A_{vf} < A_V$ if $\beta A_V > 0$ (negative feedback)

If $A_V >> 1$, $A_{vf} = 1/\beta$.

If feedback quantity is voltage, input impedance increases (Figure 2a). Current at the input does not change and V_{in} of the basic amplifier is less than the input voltage V_s.

For voltage sampling, output is constant (Figure 2b)

For current sampling, output impedance is very large.

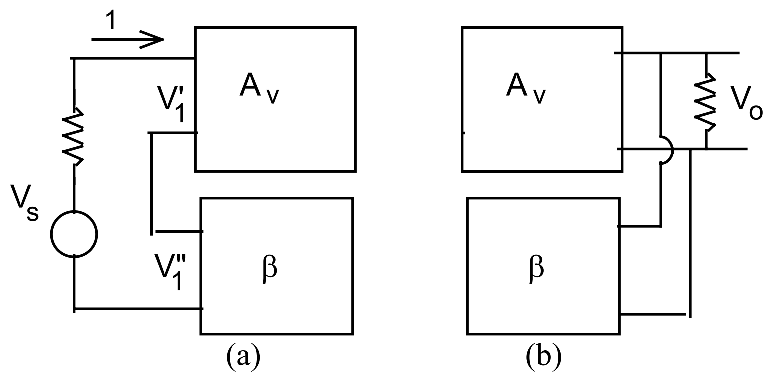

Figure 2

The effects of feedback on the frequency response of the amplifier.

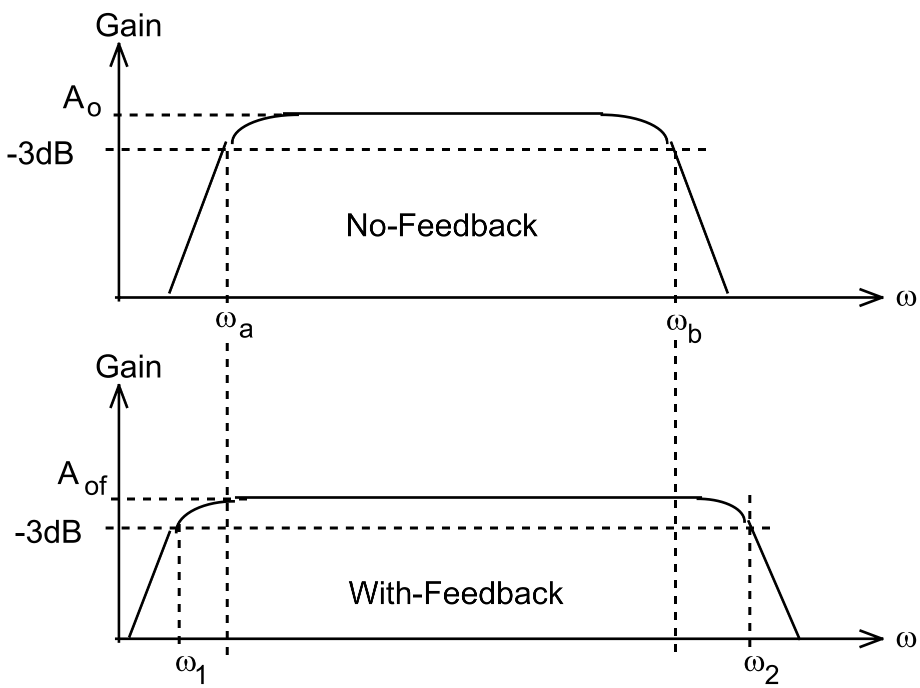

Figure 3.

Assume that the amplifier without feedback has the frequency response shown in Figure 3. Here the mid-frequency gain of the amplifier is A_o and has a low frequency -3 dB response of ω_a and a high frequency -3 dB response of ω_b.

The frequency response near the lower frequencies can be written as

$$A(\omega) = \frac{A_o}{1 + j\left(\frac{\omega_a}{\omega}\right)} \qquad \text{(Eq.2)}$$

Here as $\omega >> \omega_a$, $A(\omega) = A_o$ and for $\omega=\omega_a$, the gain becomes $|A(\omega)|=A_o/2^{1/2}$.
Substituting Eq.2 into Eq.1 and manipulating the fraction, we obtain

$$A_{vf} = \frac{\frac{A_o}{1 + j\,(\omega_a/\omega)}}{1 + \beta\left(\frac{A_o}{1 + j\,(\omega_a/\omega)}\right)}$$

$$A_{vf} = \frac{A_o}{(1 + j\,(\omega_a/\omega)) + \beta\, A_o} = \frac{\frac{A_o}{(1+ \beta\, A_o)}}{\frac{(1 + j\,(\omega_a/\omega)) + \beta\, A_o}{(1+ \beta\, A_o)}} = \frac{A_{fo}}{1 + j\left(\frac{\omega_a}{(1+\beta\, A_o)\,\omega}\right)}$$

$$A_{vf} = \frac{A_{fo}}{1 + j\left(\frac{\omega_1}{\omega}\right)}$$

Here ω_1 is given by

$$\omega_1 = \frac{\omega_a}{1 + j\,\beta\, A_o} \qquad \text{(Eq.3)}$$

Therefore for negative feedback (βA_o>0), the lower -3 dB frequency of the amplifier with feedback decreases becomes lower as can be seen in Figure 3.
Similarly, the upper -3dB response can be written as

$$A(\omega) = \frac{A_o}{1 + j\left(\frac{\omega}{\omega_b}\right)}$$

Manipulating the terms

$$A_{vf} = \frac{\dfrac{A_o}{1 + j\,(\omega/\omega_b)}}{1 + \beta\left(\dfrac{A_o}{1 + j\,(\omega/\omega_b)}\right)}$$

$$A_{vf} = \frac{A_o}{(1 + j\,(\omega/\omega_b)) + \beta\,A_o} = \frac{\dfrac{A_o}{(1+\beta\,A_o)}}{\dfrac{(1 + j\,(\omega/\omega_b)) + \beta\,A_o}{(1+\beta\,A_o)}} = \frac{A_{fo}}{1 + j\left(\dfrac{\omega}{(1+\beta\,A_o)\,\omega_b}\right)}$$

$$A_{vf} = \frac{A_{fo}}{1 + j\left(\dfrac{\omega}{\omega_2}\right)}$$

Here

ω_2 is given by

$\omega_2 = \omega_b\,(1 + \beta\,A_o)$

Thus the upper frequency response of the amplifier with feedback increases.

Realizing the Negative feedback amplifier.

AC equivalent circuit of a two stage feedback amplifier is shown in Figure 4. Here the coupling capacitors and bias and load resistors are not shown, The bias and load resistors are included in R_B, R_{C1} and R_{C2}.

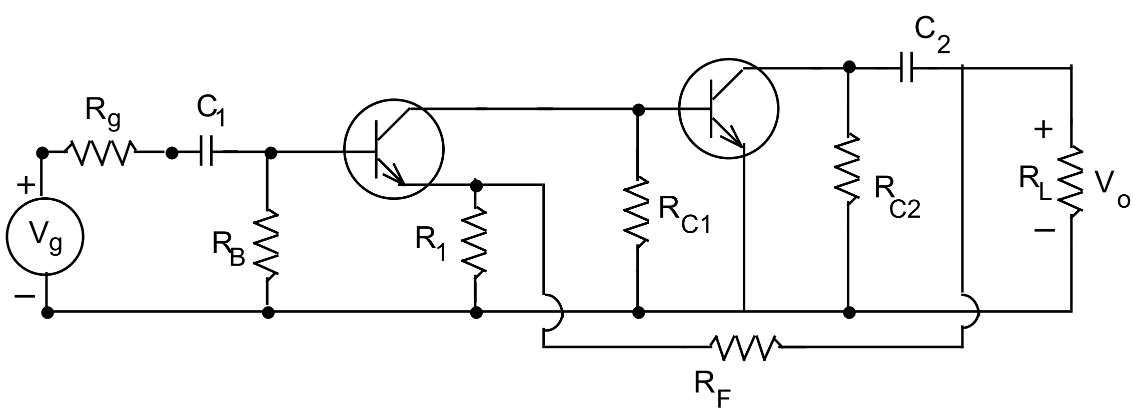

Figure 4

Here a portion of the output voltage is sampled through the R_F and R_1 and is fed back to the emitter leg of the first stage.

The feedback circuit can be converted to an equivalent hybrid [h] matrix by the following procedure (Figure 5).

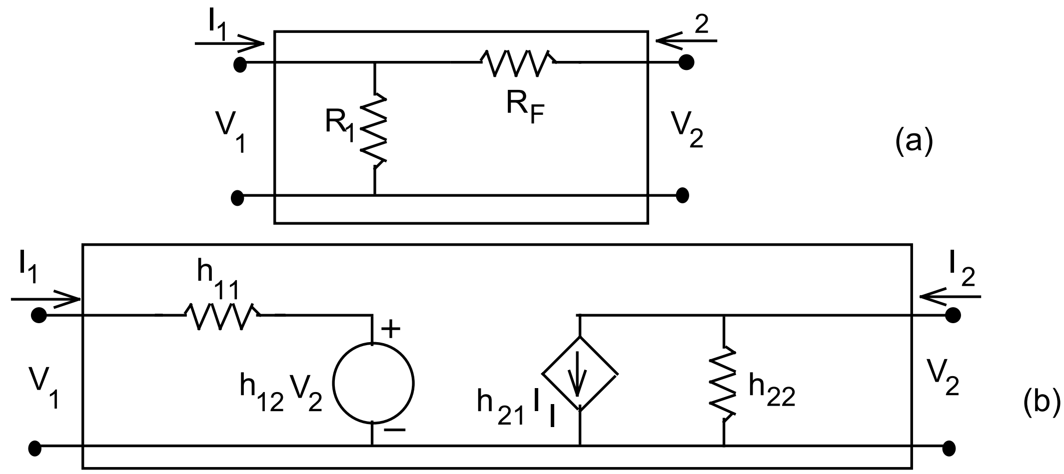

Figure 5

The feedback circuit is shown in Figure 5a. To convert it to the an equivalent [h] parameters, by definition

$V_1 = h_{11}I_1 + h_{12}V_2$

$I_2 = h_{21}I_i + h_{22}V_2$ (Eq.4)

In terms of the voltages and the currents, the circuit that corresponds to Eq.4 is shown in Figure 5b.

Here by definition and applying these to the feedback circuit (Figure 5a), we can write by inspection

$$h_{11} = \frac{V_1}{I_1}\bigg|_{V_2=0} = R_F//R_1$$

$$h_{12} = \frac{V_1}{V_2}\bigg|_{I_i=0} = \frac{R_1}{R_1 + R_F}$$

$$h_{21} = \frac{I_2}{I_1}\bigg|_{V_2=0} = 0 \text{ (open circuit)}$$

$$h_{22} = \frac{I_2}{V_2}\bigg|_{I_1=0} = \frac{V_2/(R_1+R_F)}{V_2} = \frac{1}{R_1 + R_F}$$

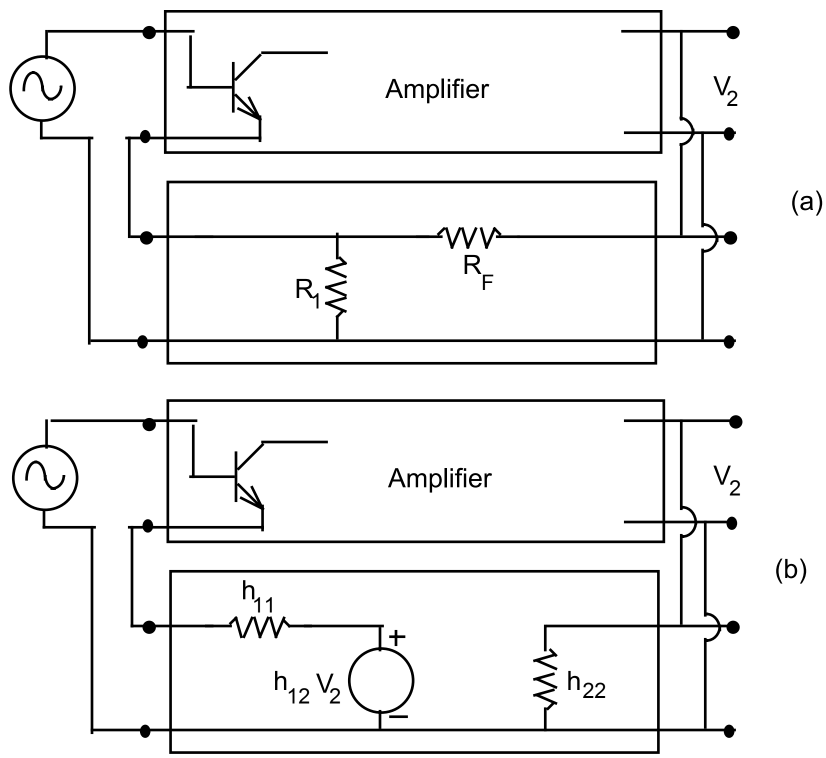

Figure 6

Thus the feedback circuit shown in Figure 1 can be isolated and shown to be equivalent to Fig.6a. Replacing the actual feedback circuit with the [h] equivalent circuit, We obtain Figure 6b.

Figure 6b can be reduced to Figure 7 by using the theorem:

"In any two terminal network, a voltage source in one leg can be replaced with identical voltage sources in each of the other two legs without effecting the terminal conditions."

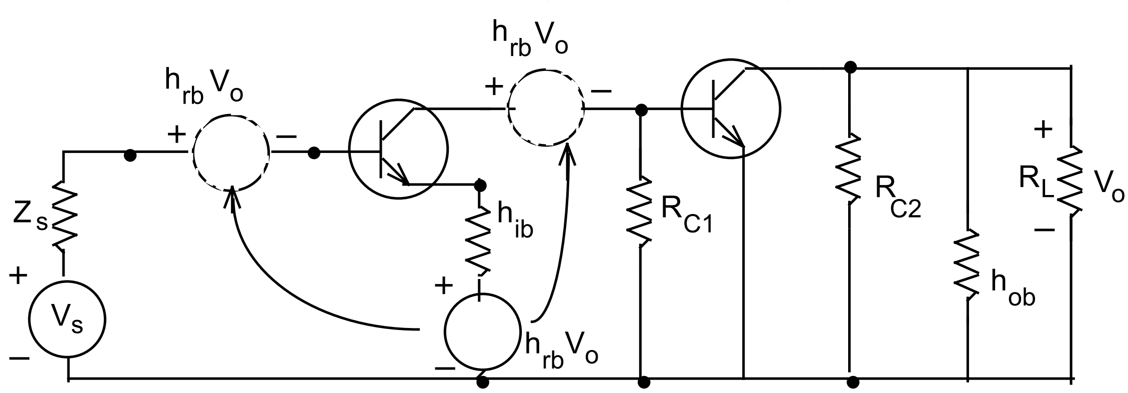

Figure 7

Therefore the voltage source at the emitter leg of the transistor is replaced by two voltage sources at the base circuit and the collector circuit of the first transistor. The voltage source at the collector can be removed since it will be in parallel with the current source at the collector end of the transistor (not true at high frequencies because of the transistor C_μ). Finally, Figure 7 can be simplified to

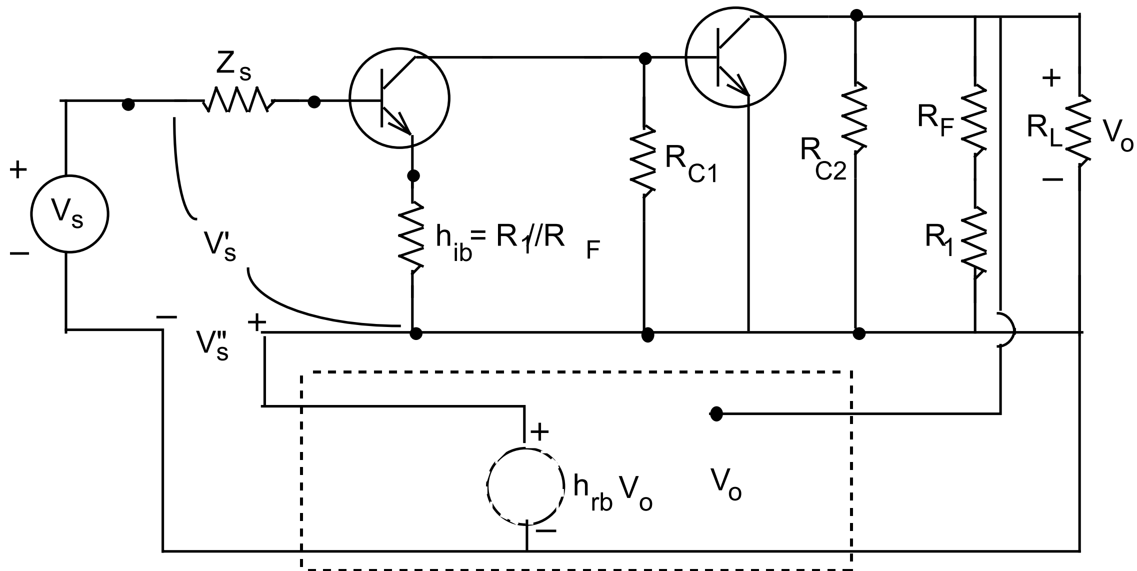

Figure 8

As can be seen from this figure that the input is series and output is in parallel. Note that upper portion of the figure should be used in calculating the amplifier gain A_V without feedback