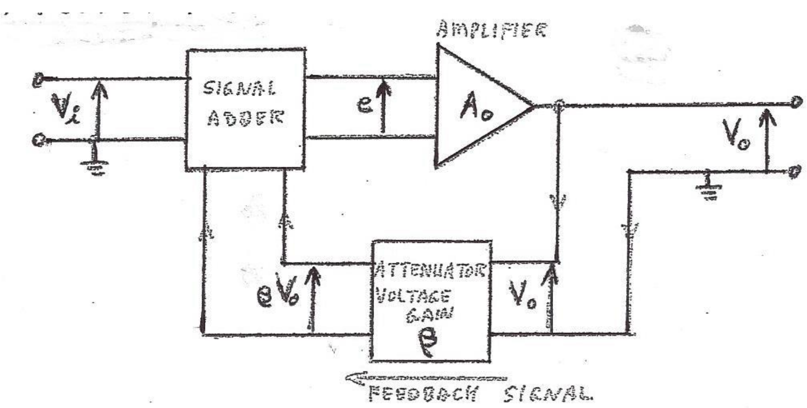
The necessity of feedback in general amplifier design.

In Design 1 (ECE-2201), amplifiers were designed using BJT's and/or MOSFET's where the voltage and current gains were a function of each devices specific characteristics(which would include temperature ,noise, etc.) and bias circuit. So for example, if a dozen amplifiers with exactly the same voltage gain were needed one would have to find 12 matching devices by selecting and measuring the characteristics and bias circuit of each. Not something that is practical and cost effective if a large number of amplifiers are needed. Fortunately there is a method using a concept called feedback circumvent a large part of these issues.

Using feedback transistor circuit characteristics can be made essentially independent of the individual transistor parameters. Essentially, the feedback process takes a portion of the output signal and returns it to the input to become part of the input excitation. In this course we will now be using OP Amps as the amplifying device which uses feedback to give easily repeatable operational characteristics.

In the study of ideal OP-Amps and related circuits, resistors are connected between the input and output terminals which form a feedback network. Under these conditions the voltage gain is a function of the ratio of just these resistors and not the individual transistor parameters which greatly simplifies amplifier design.

The general feedback concept might be better explained by the following diagram.



In the above diagram, the voltage gain of the entire amplifier with feedback can be defined as follows,

$$A_F = \frac{V_o}{V_i} \qquad 1$$

The signal at the input of the basic amplifier A_O is defined as,

$$e = V_i + \beta V_o \qquad 2$$

The signal at the output of this amplifier A_O would be,

$$V_o = A_o e \tag{3}$$

Now by substituting equation # 2 into equation # 3,

$$V_o = A_o(V_i + \beta V_o) \tag{4}$$

Rearranging the terms in equation # 4 and solving for V_o ,

$$V_o(1 - \beta A_o) = A_o V_i \tag{5}$$

Solving equation # 5 for $\frac{V_o}{V_i}$, the voltage gain with feedback maybe expressed as,

$$A_F = \frac{V_o}{V_i} = \frac{A_o}{(1 - \beta A_o)} \tag{6}$$

Hence the voltage gain with feedback is generally expressed as,

$$A_F = \frac{A_o}{(1 - \beta A_o)} \tag{7}$$

In general in the case here, the voltage gain A_o is often defined as the open-loop gain and the gain with feedback as A_F , the closed-loop gain. In this equation the gain is positive if the value of the `term βV_o is not equal to 1. However if $\beta V_o = 1$, in the above equation, this implies β is positive and the amplifier will have an output when there is no input signal V_i . When this occurs the amplifier becomes an oscillator at some frequency that is defined by that particular amplifiers circuit parameters and is defined as **Positive Feedback**.

In order to use the amplifier with feedback to amplify input signals the feedback must be negative. In this case β can be made negative which implies it will subtract from the input signal instead of adding to it. So if the amplifier is using **Negative Feedback,** the gain with feedback can be expressed as,

$$A_F = \frac{A_o}{(1 + \beta A_o)} \tag{8}$$

In most practical designs,

$$\beta A_o \gg 1 \tag{9}$$

Which implies,

$$A_o \gg \frac{1}{\beta} \tag{10}$$

Simplifying equation # 8,

$$A_F \approx \frac{A_o}{\beta \ A_o} \qquad 11$$

Therefore,

$$A_F \approx \frac{1}{\beta} \qquad 12$$

The final equation above states that as long as the open-loop gain is much larger than the closed-loop gain (hundreds or more times greater), then the closed-loop gain is independent of the amplifier characteristics and dependent only on β . This feedback fraction, β , usually depends only upon just two resistors in a potential divider.

Distortion and Negative Feedback :

Non-linear distortion can be seen as an unwanted addition by the amplifier to the original signal. Remember, any distortion signal can be reduced to a sum of appropriate harmonics. These harmonics when added up would yield the original signal. So if we let the distorted signal be represented by V_{DO} , caused by the amplifier and the open-loop voltage gain A_o , then the output voltage before the feedback network is connected can be expressed as,

$$V_o = A_o V_i + V_{DO} \qquad 13$$

Now the feedback network is connected to the input of the amplifier feeding a fraction $-\beta$ of the output back to the input. Like before let the input signal to the amplifier be "**e"**, where,

$$e = V_i - \beta V_o \qquad 14$$

Then V_O can be expressed as,

$$V_o = A_o e + V_{DO} \qquad 15$$

Substituting equation # 14 into equation # 15,

$$V_o = A_o(V_i - \beta V_o) + V_{DO} \qquad 16$$

$$V_o = A_o V_i - \beta V_o A_o + V_{DO} \qquad 17$$

Solving for V_O by rearranging terms,

$$V_o \ (1 + \beta A_o) = A_o V_i + V_{DO} \qquad 18$$

Dividing both side by $(1+\beta A_o)$,

$$V_o \quad = (\frac{A_o}{(1+\beta A_o)})V_i + \frac{V_{DO}}{(1+\beta A_o)} \qquad 19$$

Finally yielding,

$$V_o \quad = A_F V_i + \frac{V_{DO}}{(1+\beta A_o)} \qquad 20$$

Note that when negative feedback is applied to the amplifier the distortion is reduced by the factor $(1+\beta A_o)$. Note before the feedback was applied the amplifier gain was A_O and after feedback was added the gain was reduced by $(1+\beta A_o)$ which defines the gain with feedback A_F .

Some Feedback Precautions :

1. Note, negative feedback is only effective as long as the open-loop gain A_O remains much greater than the closed loop gain A_F .
    a) The above may not be the case at high frequencies where capacitance has a shunting effect.
    b) The open loop gain can drop suddenly whenever the amplifier overloads and the output stage is either cutoff or saturated on part of the signal waveform.
    c) In a badly designed amplifier, crossover distortion can be so severe that the gain actually falls to zero at the crossovers.
2. It is possible for βA_o to become positive in an amplifier, usually as a result of A_o changing sign at high frequencies where the signal phase-shift produced by stray capacitances add up to a total 180 degrees phase-shift between input and output. If this happens at high frequencies the amplifier could become an oscillator.

    The maximum phase shift which can be produced by one capacitor and resistor is 90 degrees. So a common method of overcoming the phase-shift problem is with one relatively large compensating capacitor which dominates the high frequency response and ensures a smooth first-order roll-off in gain(6db for each doubling of frequency, such a roll-off indicates a phase-shift of 90 degrees). At frequencies high enough for the stray capacitances to shift the phase around 180 degrees, roll-off due to the compensating capacitor ensures that the open-loop gain is so small that $\beta A_o \gg 1$ and instability cannot arise. It is this type of compensation that gives rise to the severe high frequency roll-off produced in the open-loop frequency response of the Op-Amp.

JOR Notes