Analog Design
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Distortion Reduction
With Feedback

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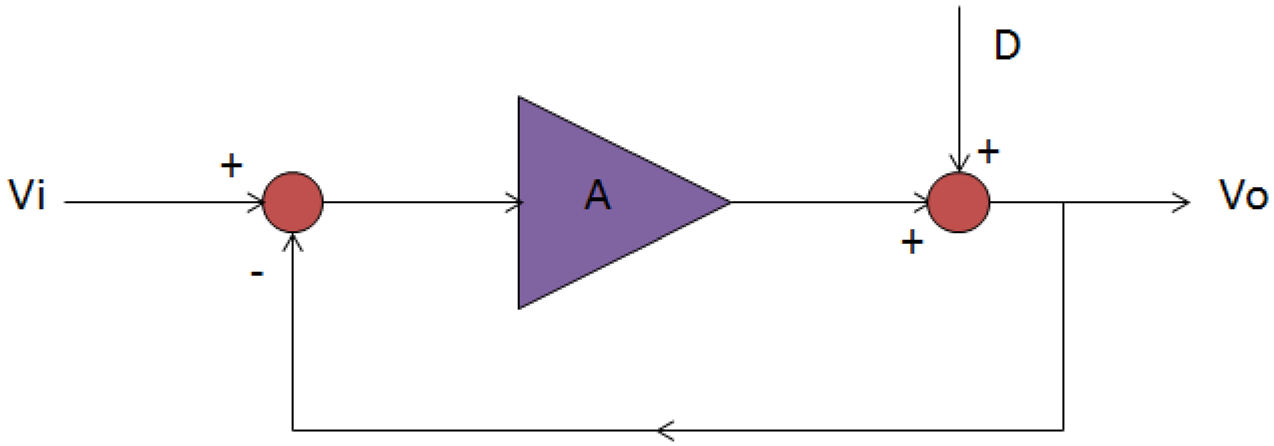
Overview

It is shown how feedback in an amplifier reduces amplifies distortion at the expense of a corresponding reduction in gain for the input signal. The approach taken here is a little different from some other standard references in that it is more directly shown that an amplifier with a non-linear transfer function has its distortion co-efficients reduced by a gain factor.

Analysis

A standard way of distortion analysis considers the following schematic.

Fig. 1



Here, it is assumed that there is a distortion error signal, D, added at the output of the amplifier. The signals may be presumed to be instantaneous voltages or currents. With such an assumption, the following derivation can be made:

$$(V_i - V_o)A + D = V_o$$

$$V_o(1 + A) = AV_i + D$$

$$V_o = \frac{AV_i}{(1+A)} + \frac{D}{(1+A)}$$

Ostensibly, showing that the distortion generated by the amplifier has been reduced by the factor 1+A. For an independent interfering signal, this argument is not unduly problematic, but it is not necessarily convincing for amplifier distortion, as the distortion in a real amplifier is a function of the input signal.

Consider an amplifier by expressing its output voltage as a transfer function of its input voltage by means of a non-linear power series.

$$V_o = a_1 V_d + \sum_{n=2}^{n=\infty} a_n V_d^{\,n}$$

Where V_d is the input to the amplifier and V_o is its output. For simplicity, the amplifier DC offset is neglected. An expression for the feedback amplifier shown above may be derived as follows:

$$V_o = a_1 (V_i - V_o) + \sum_{n=2}^{n=\infty} a_n (V_i - V_o)^n$$

Where the input, V_d, to the amplifier is V_i-V_o. Rearranging:

$$V_o (1 + a_1) = a_1 V_i + \sum_{n=2}^{n=\infty} a_n (V_i - V_o)^n$$

$$V_o = \frac{a_1 V_i}{(1 + a_1)} + \frac{\sum_{n=2}^{n=\infty} a_n (V_i - V_o)^n}{(1 + a_1)}$$

For typical amplifiers, a_n is small, say below 0.1 or 10% (distortion) and the amplifier gain is greater than unity, say > 10. In which case, V_i-V_o is also relatively small. The product of two small numbers is a much smaller number, therefore V_o can be approximated by:

$$V_o \sim \frac{a_1 V_i}{(1 + a_1)}$$

This approximation can then be substituted back into the second term of the full expression:

$$V_o = \frac{a_1 V_i}{(1 + a_1)} + \frac{\sum_{n=2}^{n=\infty} a_n \left(V_i - \frac{a_1 V_i}{(1 + a_1)}\right)^n}{(1 + a_1)}$$

$$V_o = \frac{a_1 V_i}{(1 + a_1)} + \frac{\sum_{n=2}^{n=\infty} a_n V_i^n \left(1 - \frac{a_1}{(1 + a_1)}\right)^n}{(1 + a_1)}$$

$$V_o = \frac{a_1 V_i}{(1 + a_1)} + \frac{\sum_{n=2}^{n=\infty} a_n V_i^n \left(\frac{(1 + a_1) - a_1}{(1 + a_1)}\right)^n}{(1 + a_1)}$$

$$V_o = \frac{a_1 V_i}{(1 + a_1)} + \frac{\sum_{n=2}^{n=\infty} a_n V_i^n}{(1 + a_1)^{n+1}}$$

However, the output voltage in this expression for the amplifier with feedback, is not the same nominal value as that of the amplifier without feedback. To compare apples with apples, the input signal must be increased by (1 + a_o) to obtain :

$$V_o = a_1 V_i + \frac{\sum_{n=2}^{n=\infty} a_n (V_i(1+a_1))^n}{(1+a_1)^{n+1}}$$

$$V_o = a_1 V_i + \frac{\sum_{n=2}^{n=\infty} a_n V_i^n}{(1+a_1)}$$

Where it can now be seen that the amplifier output has the same main output voltage as for the non feedback case, but that the distortion terms that existed for that condition have now been reduced by the factor (1 + a_1). It may be said that gain has been exchanged for distortion reduction.

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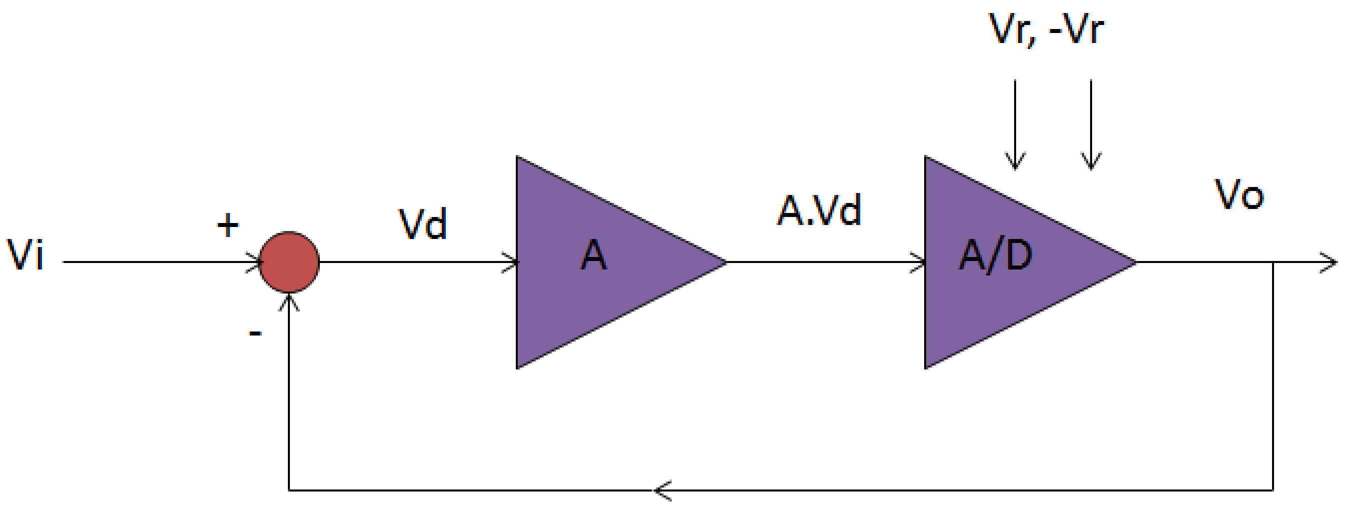
1 Bit A/D

Consider an amplifier driving a 1 bit A/D converter, i.e. a comparator, as an example of very non linear system. It is shown here that the approximation used above fails when the error is as large as occurs in such systems. That is, the output is always either +/- Vref, and is only grossly related to the input by way of when the input is greater or less than zero.

This is intuitively obvious. Clearly if the output of a block can only be one of two values by design, nothing can be done to change those values. It is however instructive to formally show this by the using the general feedback argument used above.

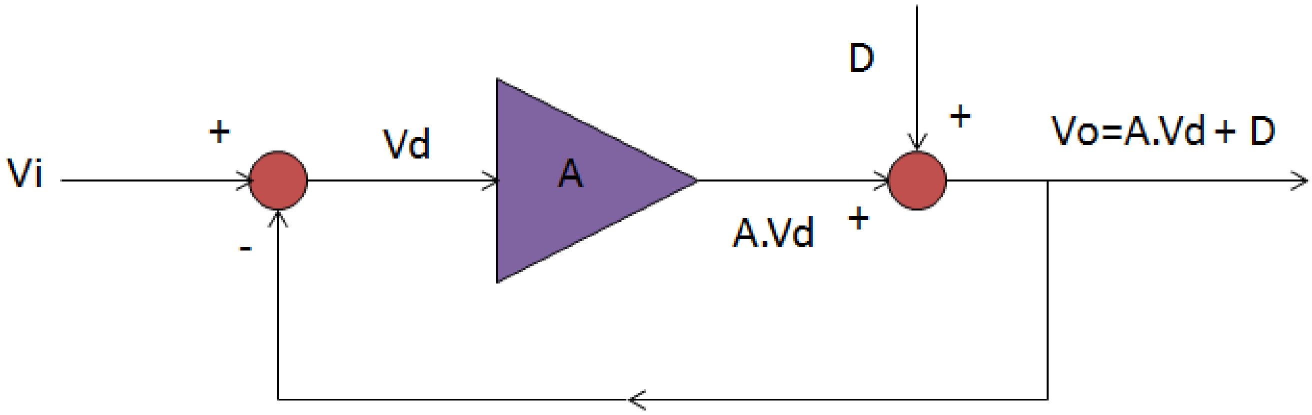
Fig. 2



V_o is either V_r or – V_r depending on whether $A.V_d$ is greater or less than zero.

It is sometimes proposed to model such a system by the same model of Fig. 1.:

Fig. 3



For the non feedback case, an expression for the output V_o is assumed to be of the form:

$$V_o = S + D$$

That is, the *wanted signal, S*, plus an *error term D.*

In which case, the relations for S and D would be, for Vi > 0_+:

$$S = AV_i$$

$$D = (1 - \frac{AV_i}{V_r})V_r$$

$$V_o = AV_i + (1 - \frac{AV_i}{V_r})V_r$$

Because for any value V_i greater than zero, the output, V_o, is the constant V_r. A similar expression may be written for the case is less than zero. Applying feedback by letting V_i -> V_i - V_o:

$$V_o = A(V_i - V_o) + (1 - \frac{A(V_i - V_o)}{V_r})V_r$$

$$V_o(1 + A - A) = AV_i + (1 - \frac{AV_i}{V_r})V_r$$

$$V_o = AV_i + (1 - \frac{AV_i}{V_r})V_r$$

This expression is, as expected, clearly, the same as the original expression, therefore, for a 1 Bit A/D, voltage/current transfer function feedback can do nothing to the inherent signal to distortion/error ratio.