Feedback Misconceptions and the Effect of Gain Bandwidth Product

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There are many misconceptions about feedback in electrical circuits. Lack of fundamental understanding of how feedback works has led some people who can be very vocal to either say that feedback can't work because the error has already occurred and on the other side that feedback can fix all ills. As with many other things, the reality is somewhere in between. There are some important audio perceptual factors to consider. If the resulting acoustical changes occur from the application of negative feedback are either below the amplitude threshold of hearing or outside the frequency range of hearing, they will have not be detectible as changes, but rather a cleaner signal. Those factors must be examined in any discussion of the merits of feedback. This discussion will not go into the mathematics of properly designing an effective feedback circuit, but rather take a philosophical approach to a few of the factors involved.

On a very basic level, what we are talking about is the concept of negative feedback. In this condition, an input signal going into a device is compared to the resulting output. If there is a difference or error, a signal is sent back through the device with an opposite polarity to the error to reduce that error and bring the output signal back into compliance with the input signal. It sounds very simple, but due to a myriad of factors, it is complicated. Gremlins such as stray inductance, parasitic capacitance, mutual coupling, and a host of other conditions can cause problems, some severe. Like everything else electronic, success depends on the designer having a firm grasp of the physical processes at play and the ability to design and fabricate a circuit that minimizes the pitfalls.

For the sake of this discussion, let's assume that the gremlins are absent and we can look at the basic philosophy. For the first group that says feedback can't work because the error has already occurred, they are partly correct, but the degree to which they are correct depends on the design of the feedback circuit and their concerns may prove to be moot. There are two factors to consider.

First, how fast can the feedback circuit recognize the error and create an inverse signal to correct that error. Given two extreme examples, with a typical audio frequency signal. if the feedback circuit took 1 second to attempt the correction, the signal would long since be gone and the correction applied would actually create another error. However, if the feedback circuit only took 1 nanosecond, that time displacement would be totally negligible for any frequency encountered in an audio circuit. That time corresponds to a frequency of one gigahertz, well beyond the ability of any speaker to reproduce or even the sharpest eared dog to hear. So, in reality, all else being equal, the faster the response or bandwidth of the feedback circuit, the less time the output will be in error and the more difficult for the ear to perceive the error. At some point, the error is corrected so quickly that it is not perceived by the ear and therefore the fact that the correction occurs after the error occurs is immaterial from an auditory standpoint.

Second, how much leverage does the feedback circuit have to reduce the error. That can be expressed as the gain of the circuit. The higher the gain, the more effect the feedback has in reducing the amplitude of the error. If the gain is insufficient, the resulting error as a percent of the signal will be greater and possibly still audible.

The two factors of speed and correcting power are commonly combined into a factor called Gain Bandwidth Product (GBWP). That equals the gain times the bandwidth. How does this affect the performance? Let's assume a circuit has a particularly bad GBWP of 20KHz. If the circuit tries to correct an error that occurs at a frequency of 1KHz, ie a fourth order harmonic of a 250 Hz signal, there is a gain of 20 available to reduce that error. If the same circuit tries to correct an error that occurs at a frequency of 10KHz, ie a fourth order harmonic of 2.5 KHz, there is only a gain of 2, which is really inadequate. On the other hand, modern operational amplifiers have GBWPs that are significantly higher. One of my current favorite Op Amps, the LME49870 that has outstanding audio characteristics has a GBWP of 55MHz. That means if you want to make a correction in for an error that occurs at a frequency of 1MHz, the gain available is 55.

It should now be fairly obvious that if you can make significant reductions in output errors in less than 1 microsecond and with sufficient level of correction, for audio circuits, the remaining distortion is now not only very low, but the original errors and also the corrections applied by the feedback occur at such high frequencies that the rest of the audio circuit and speakers cannot reproduce either as an audio signal. So, from an audible standpoint, the original errors that occurred seem to have never existed. No time machine was involved, rather good design and the limitations of human hearing.

Now we should look at the other camp that says any errors introduced by a limited design can be corrected by feedback. Again, to some degree that is true, but gross errors put high demands on the feedback circuit and limit how much correction can be achieved. In addition, exceptional demands on a feedback circuit make it more difficult to keep the inevitable circuit gremlins under control. I recently measured a highly rated amplifier that had vanishingly low harmonic distortion numbers using an 8 ohm load. In fact, at lower outputs into a resistive load, the distortion results were unmeasurable with the equipment I have. However, as the amp approached clipping, spikes on the top and bottom of the sine wave appeared as shown in Figure 1. *Insert Figure 1 here)* At clipping, instead of having a clean flat top to the sinewave, substantial oscillations occurred as shown in figure 2. *Insert Figure 2 here)* I also tested a 20KHz square wave into the resistive 8 ohms paralleled by a 1 uf capacitor. With most of my amplifiers that condition had minimal effect on the output. With this amplifier, it went into lots of oscillations to the point that the wave was almost unrecognizable as shown in figure 3. *Insert Figure 3 here)* I do not have the expertise to determine all the factors that accounted for that behavior but my guess is that a combination of very high feedback with loop instability were partial contributors. If that is true, the attempt to use high feedback to push the basic design to high performance numbers caused instability and shows that feedback alone can't solve all problems.

So, what is the bottom line? You should start with good circuit designs and then optimize with properly designed and implemented negative feedback. In addition to lower distortion, negative feedback has the additional benefit of lowering the output impedance of a circuit making it act more like a true voltage source. Negative feedback definitely can improve the audio performance of a circuit when properly designed and implemented.