PEARL Inc.
Web: http://www.pearl-hifi.com 86008, 2106 33 Ave. SW, Calgary, AB; CAN T2T 1Z6
E-mail: custserv@pearl-hifi.com Ph: +.1.403.244.4434 Fx: +.1.403.245.4456
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Some unexpected things happen in feedback amplifiers. This article tells the reasons and cures for some of them

why feed back so far?

By N. H. CROWHURST

At first glance, the general idea behind feedback seems sound enough: Plenty of feedback improves amplifier performance, and to get a large amount of feedback we must feed back a voltage from the output to a stage where the signal voltage is quite small. Bland acceptance of this fact as the only requirement has encouraged the design of a number of amplifiers in which feedback is applied from the output stage back almost, if not quite, to the input stage.

The snags

The owner of such an amplifier will probably be all too familar with some of the snags attending over-all feedback, but there are others that are perhaps less obvious. Many proud possessors of high-fidelity equipment have been puzzled by experiences like this: The complete chain sounds horrible—shrill resonances, intermodulation, and other forms of distortion; a check of the amplifier with dummy load shows everything O.K. in that part of the system; the speaker sounds fine on another amplifier; all impedances match correctly: the chain works nicely on phono input but not on radio (or maybe *vice versa*): but everything is O.K. when a different speaker is used. Where does the trouble lie? To see how such snags arise let's consider first how feedback is obtained.

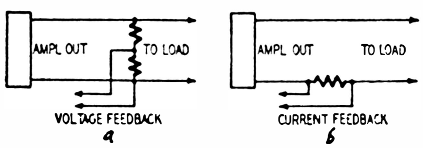

Fig. 1—The standard feedback systems.

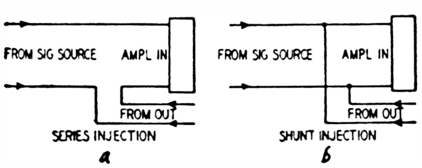

Fig. 2—The two methods of injection.

From the viewpoint of the output end there are two kinds of feedback: voltage and current. See Fig. 1. In the first (Fig. 1-a) the signal fed back is proportional to the voltage developed across the output load; in the second (Fig. 1-b) it is proportional to the current drawn by the output load.

From the viewpoint of the *input* end there are two methods of applying the feedback: series injection and shunt injection. See Fig. 2. In the former the signal fed back is injected *in series* with the original input signal (Fig. 2-a), while in the latter (Fig. 2-b) it is injected *in shunt* with it.

A point that is often overlooked is that when the feedback loop includes both the input and output circuits of an amplifier, the impedance of the input-signal source, and the impedance of the output load affect the amount of feedback.

For example, with voltage feedback, if the load impedance is reduced to zero there will be no feedback at all; similarly, when current feedback is used there will be no feedback at all if the load impedance is an open circuit.

At the input end of the amplifier the method used to inject the feedback depends on the impedance of the signal source. With series injection the source impedance connected to the input must be low compared to the grid-circuit impedance of the first stage, or it will reduce the amount of feedback; if the input source impedance becomes an open circuit there is no feedback.

In practice the input circuit is closed either by the secondary of an input transformer or by a grid resistor, so that there is always a complete feedback path, although the impedance connected to the input will still modify the feedback characteristic somewhat.

Shunt feedback injection depends on the source impedance connected to the input being high, since a short circuit across the input will reduce the feedback to zero.

The reader is probably quite familiar with the properties of inverse feedback in improving frequency response, reducing distortion, and modifying input and output impedances. For example, the internal output impedance of the amplifier, which serves as loudspeaker damping, can be reduced considerably by the liberal use of inverse feedback. Similarly, the input impedance can be modified—made either higher or lower—according to whether series or shunt injection respectively is used.

Where an input transformer introduces an undesirable resonance peak, appropriate connection of the feedback circuit may damp out this resonance, and produce a satisfactory over-all response; but a change in the load impedance connected across the output will alter the actual amount of feedback reaching the input, and thus change the effective response of the input transformer again. Similarly, changing the input impedance can sometimes affect the damping at the output.

With over-all feedback this interaction is always present, even though it may pass unnoticed. An effect that *does not* pass unnoticed, however, is that the stability of the amplifier depends on the impedances connected to it. For example, an amplifier with over-all feedback like the one in Fig. 3 may be perfectly stable with a 3-ohm loudspeaker of one particular make; but some form of instability may show up when another speaker of slightly different impedance is connected. In addition, many amplifiers with over-all feedback are not stable when the output load is disconnected, or if a 15-ohm loudspeaker is used in place of a 3-ohm type.

Various arguments in their favor have been used by designers and manufacturers of such amplifiers, but I believe that with a really good amplifier we should not be so fussy about the impedances connected to it. Correct matching is obviously desirable, but one cannot prevent the loudspeaker impedance from having a frequency characteristic (Fig. 4) and affecting the feedback.

Internal noise

Another feature detracting from the advantages of over-all feedback is its effect on output hiss and other noises generated in all high-gain amplifiers. It has generally been preached that inverse feedback, however used, reduces distortion and noise, but this is not quite true. Harmonic and intermodulation distortion are periodic signals added to the original signal; with inverse feedback we can build up an out-of-phase component of the distortion signal and combine the two so as to reduce it; but noise, especially output hiss, *is not a periodic signal.* Rather, it is a random movement of charges or currents occurring over an infinitely wide range of time intervals so that it contains frequency components effectively from zero to infinity. It is true that the frequency response of the amplifier restricts the range of noise frequencies that reach the output, but the foregoing statement is true *at the point where noise is generated.* This means that to neutralize noise completely, an out-of-phase signal of the same amplitude must be fed back absolutely instantaneously coincident with each "happening." The fact that every amplifier has a restricted frequency response makes this impossible, so it is obviously impossible for feedback to produce the same cancellation for noise that it does with distortion.

Taking the over-all result when inverse feedback is used, extra gain is required to offset that used up by the feedback. This means that in a feedback amplifier the output noise will receive far more amplification than in the same amplifier without feedback. If feedback could cancel noise to the same extent that it can cancel harmonic distortion, the noise would finish up at about the same level as in the amplifier without feedback, provided the over-all gain remained the same; but because the inverse feedback is unable to cancel the noise as completely as it does the periodic distortion waveforms, the resulting noise in the output of the feedback amplifier is actually higher. This explains what some workers have noted: that a feedback amplifier seems to have more hiss than a non-feedback amplifier with the same gain but without feedback.

The alternative

All these disadvantages of over-all feedback can be overcome by restricting the number of amplifier stages over which feedback is applied.

Fortunately, coupling impedances between stages are not subject to variation as source and load impedances are, so the possibility of impedance changes *at both ends* of the loop no longer arises. Besides, it is generally unnecessary to apply feedback to reduce distortion in the early stages of an amplifier where signal level is so small that curvature distortion cannot arise anyway; in fact, it is better to operate the low-level stages at maximum gain to maintain a good signal-to-noise ratio. Sometimes single-stage feedback may be used in a low-level stage for tone control, but this can still be applied *after* sufficient amplification has been provided to overcome output-hiss troubles.

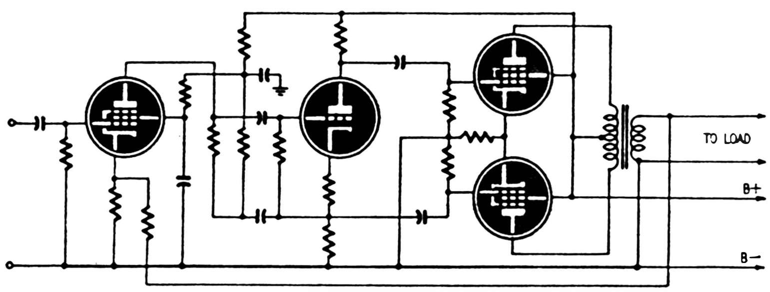

Fig. 3—Circuit of a typical amplifier with over-all voltage feedback.

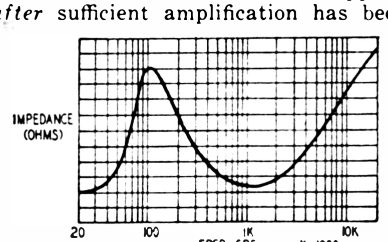

Fig. 4—Voice coil impedance variation.

Applying inverse feedback from the output *over not more than two stages*—and preferably only as far back as the driver stage—will prevent instability troubles with changes in the output load. It can even improve amplifiers that are perfectly stable *with* over-all feedback, but whose performance may be affected in other ways by changes in the output load.

The next question is: Why don't more people use this short-loop feedback arrangement?

The difficulty

When it comes to applying feedback from the output of an amplifier to the driver stage, the difficulty that arises is that the signal at the point to which feedback is applied is not very much smaller than at the point from which it is obtained. If the feedback is taken from the low-impedance secondary of an output transformer (Fig. 5-a) the voltage may not be high enough to give as much feedback as you want. On the other hand, if feedback is taken from the *primary* of the output transformers, (Fig. 5-b) there is plenty of voltage available, but the voltage-divider resistors required to produce sufficient feedback at the cathode of the preceeding stage are so low that they absorb an appreciable proportion of the available output power, which is clearly undesirable.

The solution

Basically, the solution is fairly simple, but (as usual) there is a practical snag which explains why it has not yet been more widely applied. As we explained above, the impedance on the primary side of the output transformer is high, so that, although more than adequate voltage for feedback purposes is available, the feedback resistor chain will absorb more current than can be spared. On the transformer secondary the resistance of the feedback arrangement absorbs negligible energy because plenty of current is available, but the voltage is insufficient. What we need is an impedance between these extremes.

An amplifier designed to feed constant-voltage lines makes the matter quite simple because both the voltage and the impedance are about right to give a reasonable degree of feedback without absorbing an undue proportion of the output power. But it is not necessary to use constant-voltage output with an additional transformer in the loudspeaker merely to get satisfactory feedback.

The output transformer can still provide for direct connection to the voice

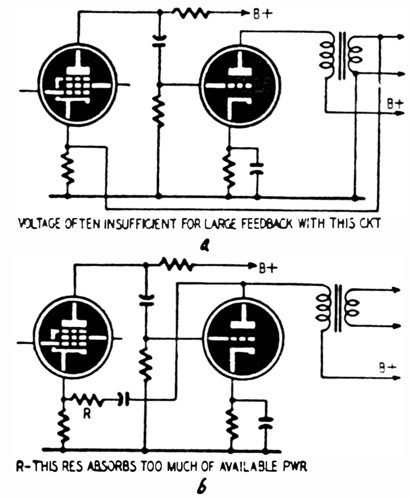

Fig. 5—Types of short-loop feedback.

coil, if it has taps on the primary (Fig. 6-a) *or an additional winding*, (Fig. 6-b) so that a suitable intermediate impedance point is available for feedback purposes. The separate-feedback-winding (tertiary) method is preferable because it eliminates the blocking capacitors needed when taps on the primary are used. Because the feedback circuit consumes negligible power, the tertiary can be wound with fine-gauge wire, and need occupy only negligible space.

The idea of a separate feedback winding on the output transformer is not new; in fact, several transformer manufacturers already include models with this provision in their lines.

There is another advantage in having an extra tapped winding on the output transformer from the development angle. When the development engineer has his amplifier on the bench, and is experimenting with various values in the feedback circuit, he can select different values of resistors and capacitors immediately from stock and simply connect them in until suitable results are achieved; but if he wants an additional winding on the output transformer it involves a tantalizing delay; it cannot just be connected in but means ordering another transformer or waiting while the winding shop produces the modifications. END

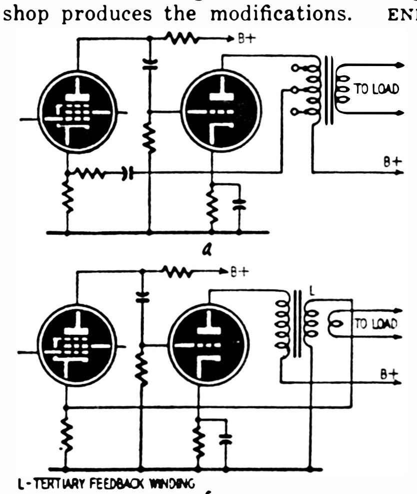

Fig. 6—Two better feedback circuits.