Considerations in the Design of Feedback Amplifiers

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Part I. A study of the practical application of feedback to both triode and tetrode amplifiers, and of some of the pitfalls which must be avoided.

An endless subject of debate in the audio field—one which has taken place with varying degrees of intensity over more than a decade—is that concerning the relative merits of amplifiers which use triode output tubes as contrasted with beam tetrodes. In recent years the argument has waxed as hot as ever, and even with lack of substantial evidence to the contrary, there is a group that supports the use of triodes not only in the output stage but in every amplifier stage.

This argument is likely to continue for some time to come, for every attempt to resolve its differences has led to engineering achievements which have produced great improvements in amplifiers as a whole. The point of diminishing returns has apparently not been reached where it might be said that each type is close to perfection. The trained ear is a hypercritical observer, and as fidelity is increasingly improved, for example, by the reduction of harmonic distortion to a negligible amount, other faults are unmasked which glare in the absence of distortion. After harmonic distortion—and it by-product, intermodulation—have been removed, the fidelity of transient reproduction is critically examined by the ear. All music and speech is basically transient by nature, and no method of measurement has been devised that will give an over-all figure of merit in terms of aural fidelity.

With these facts firmly in mind, the author has concluded that the triode-beam tetrode argument lacks substance when subjected to both theoretical and aural comparisons. Well designed amplifiers of both types have been heard which lack "character" of their own and do only the job intended—namely, magnify the power of the input signal with nothing added or removed in the process. However, it is true that the beam tetrode power stage has a bad reputation based upon the number of poorly designed amplifiers in service. In order to attain the high performance that the tetrode is capable of giving, inverse feedback must be used, and a poor amplifier is usually defective because of faults in the feedback loop.

A faulty feedback circuit causes not only inferior tetrode performance, but when applied to triodes, also produces the same disturbing results. Aurally speaking, these are experienced as transient hash, ringing, and a general blurring of tones. The disturbance is truly of a transient nature and does not show up on steady tone laboratory tests.

Effects of Feedback

The facts relating to the application of feedback and its effects on frequency response, distortion, and so on, are generally appreciated. It is also generally accepted that the benefits of inverse feedback increase proportionally according to the amount of feedback used.

To summarize, these effects are:

1. The output impedance of the amplifier is reduced.
2. Non-linear distortion, intermodulation, and noise, generated within the amplifier itself, are reduced.
3. Variation of gain due to aging of tubes and drift of circuit elements is reduced.
4. The apparent bandwidth of the amplifier is extended.

The reduction of output impedance is effected by the application of feedback of the voltage or shunt type. This is the form almost always used in connection with power amplifier design.

The limitations imposed on performance by increasing feedback indefinitely are not as well understood, and the idea seems prevalent that feedback is a cure-all for any amplifier deficiency. For example, the erroneous proposal has often been made that an output transformer having a poor frequency-response characteristic can be made to show a much better one in a circuit in which feedback is taken around the transformer. This is true at low levels only and to the minor extent that a relatively small amount of feedback may be used before the amplifier loses stability and sings. If the amount of feedback is reduced slightly below the point of self oscillation, the circuit conditions are still not favorable for good transient reproduction, and quality suffers. There is, moreover, practically no improvement in the power handling capacity of the transformer. It is therefore seen that the gain in frequency response is accompanied by a loss in over-all fidelity, and the benefits of applying feedback indiscriminately are questionable.

It is not to be inferred, however, that properly applied feedback will result in doubtful improvement. Amplifiers of high performance standards owe their performance to a correctly designed feedback loop. In general, the maximum benefits of feedback will be realized in a specific design only by first maximizing the performance of the amplifier alone, and by then applying feedback with judicious understanding. Near perfection in the amplifier proper allows a greater amount of feedback to be used before the ultimate point of instability is reached. The excellence of the design depends greatly upon the feedback margin between the actual amount of feedback used and the maximum feedback possible. The realization of the greatest amount of margin will permit the highest degree of transient stability to be obtained with a consequent faithfulness of transient reproduction.

The Feedback Loop

Inverse feedback, by definition, consists of the introduction to the input circuit of a voltage which is proportional to the output of the amplifier, with this voltage applied in opposite sense to that of the input voltage. At any one level of input voltage, this procedure reduces the output of the amplifier and results in a loss of gain. The numerical value of the loss expressed in decibels provides a measure of the amount of inverse feedback.

There are many ways in which inverse feedback can be taken around an amplifier. Some circuits make use of feedback on the individual stages only, and these circuits are said to employ local feedback. More commonly, feedback is carried in a single circuit from output to input, and the path is termed a single-loop type. Combinations of feedback may be employed, for example, from the output to each of two earlier cascaded stages. Such circuits are said to use a multiple-loop feedback system.

The choice of the type of feedback

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