audiology

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Feedback from Output Transformer Secondary

NEGATIVE OR INVERSE FEEDBACK has made possible extensive improvement in the performance of amplifier circuits. That form known as secondary feedback has been employed in many audio power amplifiers, and consists of sampling the output transformer secondary voltage and applying it in degenerative phase to an early portion of the amplifying system.

Whether the output voltage should be sampled at the primary, secondary, or tertiary winding is the outcome of many considerations; no one connection is best in all respects. Simply stated, principle would appear to support secondary feedback as the universal choice, because it includes the output transformer in the feedback path. Experience shows, however, that the improvement in fidelity made possible through choice of this form of feedback is often worth less than its added cost for equivalent stability and utility.

Briefly and broadly, amplitude variation, phase shift, and harmonic distortion are reduced through degenerative feedback roughly by the factor $1/(1 - A_v\beta)$, where A_v is the amplification in the absence of feedback, and β is the portion of amplifier output voltage fed back for comparison at the beginning of the feedback loop. In general, and particularly with secondary feedback, the original amplification A_v is a complex quantity; i.e., there is phase shift as well as change in amplitude. If β is real only (readily realizable in audio amplifiers with either primary or secondary feedback), then the gain with feedback is also real to the extent that $A_v\beta \gg 1$. Both phase shift and variations in amplification may be reduced by negative feedback methods.

The Case For Secondary Feedback

Features advantageous in principle, and accounting for attractiveness of the method are:

1. Assuming given gain reduction with feedback, the bandwidth over which response of fine flatness may be obtained is in general greater with secondary than with primary feedback. So long as the feedback factor $A_v\beta$ can be maintained negative and materially greater than unity over the required band, over-all amplification is essentially independent of the forward gain A_v, which of course includes the transformer.

2. At low frequencies, lower distortion due to core nonlinearity is obtainable with secondary feedback than in a primary feedback circuit having the same gain reduction, because of more favorable X/R ratio.[1]

3. Hum due to last-stage power-supply ripple is reduced by secondary (or tertiary) feedback. In contrast, hum at the load terminals due to this source is worse with primary feedback than with no feedback at all.

4. Feedback to single-ended (unbalanced) input stages from a push-pull output stage is more simply accomplished with secondary feedback than with primary feedback of satisfactory form for high-quality application.

5. For given gain reduction, amplifier internal output impedance is lower with secondary feedback than by other simple feedback methods, because as far as regulation is concerned, winding resistances are lumped in with the tube plate resistances, and effectively reduced by the feedback action.

Problems in Development of Secondary-Feedback Amplifiers

Difficulty far greater than mere loss of amplification with application of feedback

(*Continued on page 45*)

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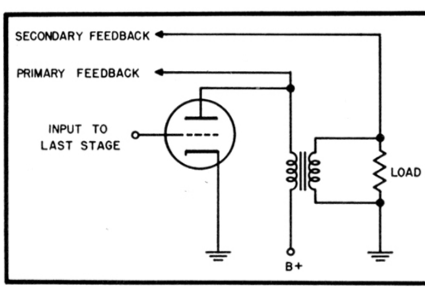
[1] *Audiology*, "Output transformer design consideration," AUDIO ENGINEERING, April 1953.



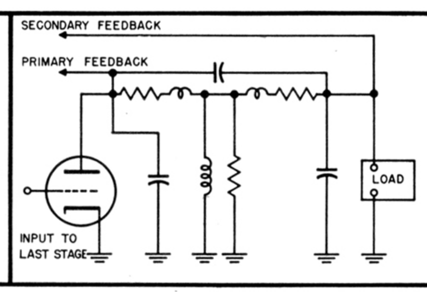


Fig. 1 (left). Simple equivalent circuit of transformer. Fig. 2 (right). Expanded circuit to represent impedances at frequency extremes, referred to the transformer primary.

AUDIOLOGY

(*from page 14*)

is that of maintaining the amplifier non-oscillatory under all conditions of signal and loading. Stated simply, amplification around the feedback loop must be less than unity at the frequency or frequencies at which phase relations are correct for oscillation. (Exceptions to this rule are of relatively little practical interest.) Generally satisfactory stability margins are 6 db in amplitude and 30 deg. in phase. That is, with phase relations correct for oscillation, the loop gain should be no more than one half; and for all frequencies at which the gain around the feedback loop is greater than unity, phase shift should be at least 30 deg. different from that correct for oscillation. An amplifier may pass resistive load tests with flying colors and fail miserably with reactive loads. Some practical details of stability measurement are planned for a future installment.

Nature of the secondary feedback problem, as presently compared with primary feedback, may be more clearly understood with reference to the drawings, shown single-ended for simplicity. The diagrammatic arrangement of *Fig.* 1 is expanded in *Fig.* 2 to more nearly represent the transformer effects at extreme frequencies, with all impedances referred to the primary side.

Series resistances and inductances shown represent winding copper losses and leakage inductances, respectively. Central shunt elements represent core losses and winding self-inductances, and are effective at low frequencies only. Terminating and bridging capacitances represent the more significant distributed and coupling capacities. Magnitudes of some of the principal circuit elements vary greatly with different secondary taps in use. Also, complex winding designs with numerous interleavings may exhibit spurious resonances not described with this assumed equivalent circuit. Inclusion of this maze in the feedback loop is usually the greatest claim and yet the greatest weakness of the secondary feedback method.

When the feedback voltage sample is taken from the vacuum-tube plate (primary feedback), the complex transformer situation at high frequencies affects the feedback loop only as an element in shunt with the point of low impedance as established by negative voltage feedback, and loop phase shift due to the transformer alone cannot possibly exceed 90 deg. But with secondary feedback, circuit complexity comprised by the transformer is within the loop, with source impedance usually equal to the unaltered plate resistance of the power amplifier stage; compared with phase relations at mid-frequencies, phase shift at high frequencies easily exceeds 180 deg. right in this portion of the feedback loop alone, and the system becomes regenerative instead of degenerative.

To permit operation at all, the important transformer high-frequency resonances must far outside the audio band. Assuming attention confined to high-quality equipment having extensive feedback, it follows that the transformer must be faultless in the audio band (within simple compensation limits) before feedback is applied. Including the transformer in the loop thus can afford little improvement in the useful band, even if by some means the stability problem is satisfactorily solved. What was promising in principle tends to be of little value in practice.

The Case Against Secondary Feedback

1. For general distortion reduction and gain stabilization, considerably less feedback can be applied with secondary feedback than with that of primary form, without serious sacrifice of stability margins.
2. In circuits requiring extensive feedback, need for reasonably low plate resistance as source impedance for the transformer imposes the restriction of using triodes, or multiple feedback loops.
3. General success of the amplifier design is dependent upon output transformer characteristics which are difficult to control in design and manufacture, as compared with those characteristics important in the stability of primary feedback systems.

These are related and severe disadvantages of secondary feedback, all due to inclusion of the complex high-frequency output transformer structure within the loop. To meet rigid requirements on margins of stability in both amplitude and phase, under any and all load conditions, the secondary feedback method is not readily applicable, unless only a small amount of feedback is needed to fulfill performance specifications.

Principal labor in including the transformer within the loop is directed more toward preventing oscillation outside the audio band than toward improvement of performance within the desired band. The price of secondary feedback can be a bit high compared with the added value of specification advantages resulting from its use. Spectacular results may be obtained by other feedback means, without sacrifice of stability.