SPEAKER DAMPING

There is one other characteristic in amplifiers for driving loudspeakers that has become of greater importance as the speakers themselves have been improved. That is the source impedance presented to the loudspeaker by the amplifier output circuit, which determines the damping and the resultant effect on bass response.

The loudspeaker, being a transducer, is a combination of mechanical and electrical elements including numerous self-resonances. The most important of these is the so-called "bass resonance," that is, the resonance of the entire moving system, which is modified appreciably by the characteristics of the enclosure. Proper damping at higher frequencies may also be important, particularly when crossover networks (filters) are employed. The term "damping factor" has become common in describing the output characteristics of amplifiers and is defined as the ratio of the load impedance to the internal output impedance of the amplifier.

In the earlier days of triode output stages and no feedback, the optimum load impedance for "maximum undistorted power" (not power sensitivity) was approximately equal to twice the internal output impedance of the amplifier. Hence this became the common basis for loudspeaker design. The later pentode amplifiers without feedback, having a relatively high internal output impedance and operating into a lower impedance, required somewhat different speaker characteristics for best operation, although in small radio sets the exaggerated bass response caused by the low damping which resulted was often considered an advantage.

With inverse feedback, however, the internal output impedance, as well as other characteristics of an amplifier, can be modified to the point where the output stage becomes substantially a constant-voltage (low-impedance) or a constant-current (high-impedance) source, these two extremes being achieved, respectively, by large amounts of voltage or current feedback. By combining voltage and current feedback, practically any desired internal output impedance can be obtained while substantially constant gain and other characteristics are retained, including the low-distortion advantages of inverse feedback.

The type of feedback normally employed in the usual high-fidelity amplifier is mainly voltage feedback, and a low output impedance is the normal result of using enough feedback to provide a substantial decrease in distortion. Many writers have accepted this low impedance as a desirable objective in itself, which is not necessarily valid. It is known that large amounts of feedback do not always produce the best distortion characteristics, particularly in the region of overload, and for this reason extremely low output impedance alone should not be considered per se an indication of a high-quality amplifier.

Although many amplifier engineers have aimed at the lower output impedances, many speaker engineers have been pointing out that some commercial designs actually operate better from higher impedances. This is because the over-all bass characteristics of the speaker and enclosure frequently rely on resonance to maintain efficiency at low frequencies, and overdamping of the speaker reduces the apparent bass response. Also, in many speaker designs there is sufficient mechanical damping in the cone support itself and the enclosure to obviate the need for additional damping in the amplifier. Some amplifiers have employed fixed amounts of current feedback to provide the higher output impedance. A fixed arrangement is seldom satisfactory, however, since too high an output impedance can be far more disastrous to the over-all performance of the high-grade speaker than too low an impedance.

To the common explanation that such systems provide "power feedback," it is pointed out that any common combination of voltage and current feedback provides a definite *fixed* output impedance which can be measured or calculated.[1] The performance of such an amplifier, as far as the output impedance is concerned, is therefore no different from that of any other amplifier having the same output impedance, whether the impedance is determined by feedback or whether it is the normal output impedance of the tubes as reflected through the matching transformer. In either case the effects of the output impedance on the overall speaker frequency characteristics, damping, etc., are the same.

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[1] See F. E. Terman, ***Radio Engineers' Handbook***, p. 402, McGraw-Hill Book Company, New York, 1943; H. F. Mayer, "Control of the Effective Internal Impedance of Amplifiers by Means of Feedback," *Proc. IRE*, **27**, 213 (March, 1939).

A recent questionnaire to speaker manufacturers brought swers specifying, for commercial speakers in typical ensures, recommended source impedances ranging from 6 200% of the speaker impedance, representing damping tors from 16/1 to 0.5/1, respectively. Some manufacters specified different values for each model or each type loading such as bass-reflex, horn, and infinite baffle. Instingly, the trend, as distinguished from the indications amplifier literature, was for higher source impedances, d not a single manufacturer recommended zero or negae impedances. Also, the highest source impedance recomnded was twice the speaker impedance, giving a damping tor of 0.5/1, and this was only for two models of a single nufacturer, both models having very powerful magnets d consequently heavy self-damping) and operating in nite baffles.

There has recently been some tendency to promote amplis with excessively high output impedances on the questable theory that they should "match" the speaker imance at the bass resonance peak and in some cases at higher frequencies. Such operation, of course, in terms impedance and damping approximates the old-fashioned tode output without feedback and is generally decried manufacturers of high-grade loudspeakers. The biggest dvantage is the resulting exaggerated bass resonance. A dspeaker is generally more efficient at its low-frequency k, and the speaker designer usually takes advantage of rise in impedance at this frequency automatically to ree the power input to the speaker at the resonant frency, thus tending to flatten the over-all response. Insing the source impedance above the optimum value as blished by the speaker designer, therefore, merely res in additional bass resonance, which is generally undele. There would seem to be little practical value, there, in confusing the user by providing him with adjustts beyond the ranges recommended by leading speaker ufacturers, since, with such adjustments, the user may e unwittingly operate his loudspeaker under conditions from ideal. Tonal balance can be better adjusted by the e customary means.

t has been claimed that some systems employing comtions of negative and positive feedback automatically tch" the speaker impedance at each frequency by prog an output impedance which varies in accordance with load impedance. The previously cited references[1] inte rigorously that this is impossible with any of the le voltage and current feedback systems. Given nts of current and voltage feedback provide a definite ut impedance which is *absolutely independent* of the impedance. All that any such system can do, there is to establish the output impedance at a definite value h may be higher or lower than the nominal speaker impedance, depending preferably on the speaker designer's recommendations. Merely to operate a speaker from a higher source impedance than the speaker designer intended will increase the bass response at the resonant frequency, and in some cases the treble response also. It will also decrease the damping, tending to cause objectionable boom. It should also be pointed out that such variation in output impedance to "match" the speaker impedance at all frequencies, if possible, would still be undesirable, unless the speakers were designed for this type of operation.

To clarify the confusion resulting from the many claims for various output systems, it should be pointed out that the "maximum undistorted power" (before clipping) available from a given amplifier does not depend directly on the impedance of the amplifier as modified by various feedback systems. The actual power which the output stage can deliver (including any power absorbed by feedback systems) depends on the output tubes, the operating voltages, and the load impedance connected to the output circuit. The overload point of the output stage does not change as the feedback is varied to vary the output impedance.

There is no requirement, therefore, that the output impedance should "match" the speaker impedance, and such a match would not increase the efficiency of the system in terms of available power output. The only effect of varying the output impedance, aside from varying the speaker damping, may be a change in power sensitivity, which is a function of the amplifier gain. The overall variation is easily offset by merely readjusting the amplifier gain; but, since the speaker impedance varies with frequency, the power sensitivity will change and thus the frequency response. The power-handling capacity of the amplifier at different frequencies is not affected.

If the output impedance of the amplifier is increased to provide a better "match" at the high impedance points in the speaker characteristic, this does not mean greater efficiency at those peaks but merely an increase in relative power sensitivity, which is obtained by reducing the relative power sensitivity throughout other parts of the speaker range. Nothing has been gained, therefore, unless a better overall frequency response and better damping are achieved, which will depend entirely on the individual speaker. In general, most high-fidelity loudspeakers are intended to operate from a source impedance of the same order of magnitude as that of the speaker impedance, or lower. Operation from an excessively high impedance may result in inadequate damping and exaggerate certain portions of the frequency response.

It is also possible, of course, by merely reversing the phase of the feedback to change it from negative to positive, thus providing a regeneration, as has been suggested by some writers. The supposed advantage of this is the ability to cancel a portion of the resistive component of the speaker impedance.

Speaker manufacturers who have expressed an opinion on the subject point out that this would be a benefit, if at all, only in the cheapest and worst class of speakers with inadequate magnets, and that the many disadvantages of negative impedance far outweigh the advantages. The most serious of these disadvantages is that a regenerative system exhibiting a negative impedance is, in fact, an oscillator circuit and hence is highly unstable. To minimize the possibility of oscillation it would generally be desirable to limit the regenerative effect to low frequencies only. This would cause the amplifier to have an output impedance varying with frequency, which would in turn cause the effective frequency characteristic to vary. Frequency-response variations, when required, are better supplied by the conventional tone controls and equalizers, which do not introduce the possibilities of amplifier instability. The output circuit of the type 265-A amplifier was intended to match the high-grade loudspeakers available to the high-fidelity enthusiast without introducing the hazards of unstable operation or indefinite variations in output impedance with frequency. As a matter of sound engineering policy, therefore, only positive output impedances are available.

To match exactly all types of speakers in accordance with the manufacturer's specifications, therefore, it is desirable to have available a reasonable range of damping factors based on the requirements of available high-grade loudspeakers. Some of the ways in which this can be accomplished are shown in Fig. 7. A conventional method of providing voltage feedback is through a tap or voltage divider on the output transformer secondary. Current feedback is most satisfactorily obtained by a resistance in series with the load. In Fig. 7A the voltage feedback signal, V_1, obtained from a tap on the transformer and the current feedback voltage developed across the resistor, R_2, are mixed in the potentiometer, R_p, in any desired proportion while substantially constant over-all feedback is maintained. Figure 7B shows a similar arrangement but with the transformer tap replaced by the voltage divider, R_1. In either case, the resulting feedback can be adjusted to maintain any predetermined balance between voltage and current feedback, thus providing a simple means of adjusting the output impedance to any desired value depending on the setting of R_p and independent of the load impedance connected to the output terminals.

Actually in the type 265-A amplifier a somewhat more elaborate system is employed, as shown in Fig. 7C. Since the resistance, R_2, is in series with the load impedance, it obviously absorbs some of the power which would otherwise be available to the load. It was decided, therefore, that the maximum tolerable value was 0.2 ohm, which absorbs only about 0.1 db with a 16-ohm load and amounts of power which remain negligible at lower load impedances. Since the voltage available across this low resistance is correspondingly low, it must be fed back to a lower level point in the circuit than is desirable with the voltage feedback signal. Consequently, R_1 and R_2 in the type 265-A are independent potentiometers or variable resistors ganged together mechanically, thus providing two separate feedback voltages which are applied to two different points in the preceding amplifying stages. The voltage and current feedback loops are therefore kept independent, with a beneficial effect on over-all amplifier stability, particularly at the extremes of the frequency range.

It should be pointed out that with the addition of variable damping no advantages of previous amplifier designs have been sacrificed. Output connections to match load impedances ranging from 16 to 2 ohms are available and the power dissipated in the current feedback system is negligible because of the low value of R_2 compared to the load impedances. As a practical matter, with these impedance taps, loads between 1 and 30 ohms can be used without noticeable changes in operating characteristics.

The frequency response of the type 265-A amplifier is shown in Fig. 8. It should be noted that there is no significant change in frequency response between minimum and maximum damping. The slight level difference represents only a gain difference and no change in maximum power

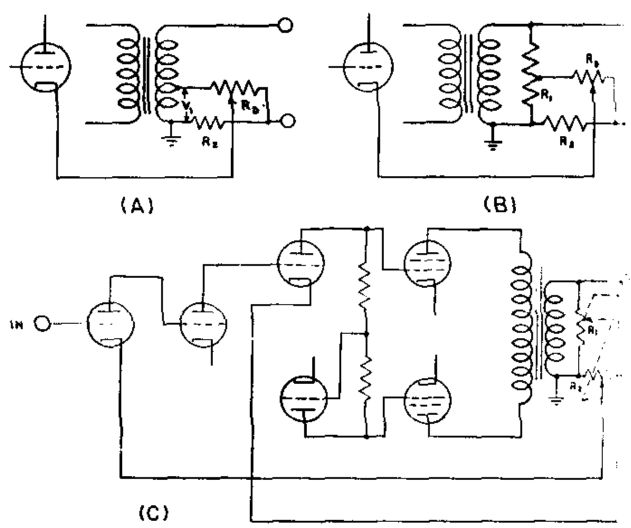

FIG. 7. Typical methods of simultaneously adjusting current and voltage feedback provide variable output impedance and damping. A and B are simple systems combining voltage and current feedback in a single loop, adjustable by variation of R_p. C shows arrangement used in type 265-A amplifier having separate voltage and current feedback loops. R_2 (0.2 ohm) can therefore be very small, limiting reduction in output power to approximately 0.1 db.

output. The damping control circuit was designed so that the gain of the amplifier remains substantially constant.

Figure 9 shows the range of damping factors available at different output taps. Although 16 ohms is most common for high-fidelity speakers, 8 ohms is also encountered. Use of several speakers in parallel may necessitate even lower taps, such as 4 ohms or 2 ohms. Provision of several taps which may be employed simultaneously allows correct parallel operation of speakers of different impedances.

The appearance of the 265-A is shown in Fig. 10. From left to right the controls are: dynamic power monitor, level (gain), and damping. We feel that this power amplifier

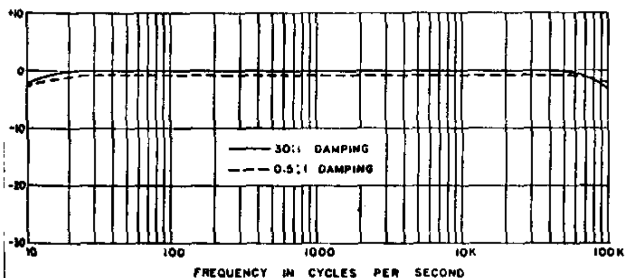

FIG. 8. Frequency characteristics of the type 265-A amplifier t minimum and maximum damping. Adjustment of the control r any desired damping factor provides substantially constant mping over the entire frequency range. This is particularly imrtant when crossover networks are used and is in accordance ith the recommendations of speaker manufacturers.

corporates all the improvements possible in the present ate of the art to provide the best possible performance in e reproduction of music.

CONCLUSION

Power amplifiers have been accepted for years without estion, and the user has generally become quite skeptical extravagant claims for infinitesimal distortion, infinite mping, and other factors which, even if actually availle, are of little or no consequence. Again and again, listers have concluded that there is less difference among wer amplifiers than among almost any other parts of the h-fidelity system, with the result that the greatest emsis and the greatest interest have rested in preamplifiers h their flexible equalization characteristics, noise supssors, tone controls, and other devices which directly aft the tonal color of the reproduced sound.

We have, however, reached a point where the performance of the power amplifier should be examined to b that, regardless of whatever high degree of performan been designed and built into it, we are getting all th can for a given degree of complexity and expense.

Amplifiers designed primarily for the reproduction o sic should be rated on the basis of their performanc this type of signal. For this purpose, a reasonable red in long-time power-handling capacity can be advantag exchanged for a somewhat greater increase in shor power-handling capacity. We believe, also, that wi tremely high-powered amplifiers, the dynamic power tor, which automatically limits the output power on dental overload, will save many dollars and much tim lost in speaker repairs, by protecting the speaker from tinuous high overload.

Last, but not least, for those systems where the most cal match is required, the output impedance of the am may be adjusted to coincide exactly with the speaker facturer's specifications. This should preferably b complished with a system which does not appreciably the normal feedback and other characteristics of the a fier, so that no quality is sacrificed in order to obta variable output impedance. The requirements in this

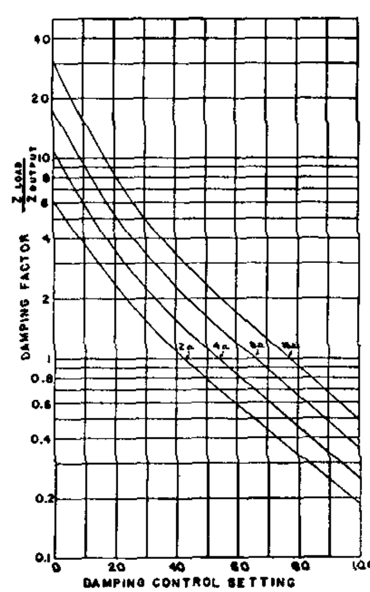

FIG. 9. Calibration of damping control. Note that wide of damping factors is available at 8-, 4-, and 2-ohm outp well as at 16 ohms.

tion tend generally in the direction of higher output impedance than that normally available in present-day amplifiers, with no demand for excessively high, zero, or negative impedances. Conventional feedback systems provide a definite output impedance which is independent of the load impedance.

Amplifiers incorporating these principles and improvements have been designed for commercial manufacture so that the music enthusiast or "hi-fi" hobbyist can now have a power amplifier commensurate in engineering with the latest and most elaborate preamplifiers and control units.

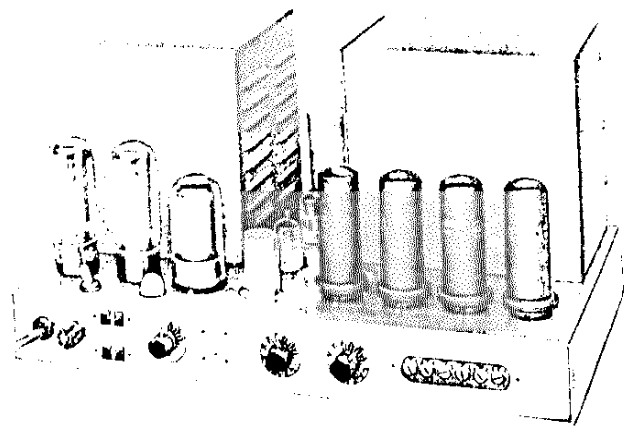

FIG. 10. Type 265-A amplifier. From left to right the controls are for dynamic power monitor, level (gain), and damping factor. An extra low-level input is provided for use with low-output preamplifiers.