Distortion in Voltage Amplifiers

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A discussion of the distortion characteristics of commonly used low-level tubes in typical voltage amplifiers employed to drive low-distortion output amplifiers.

THE ART OF DESIGNING and building audio output amplifiers has been developed to the point where it is not difficult to obtain full output from the amplifier with 1 or 2 per cent intermodulation. Many constructors are building high-quality power amplifiers and feeding them from preamplifier-and-tone-control stages which may produce as much as 10 per cent intermodulation distortion when they are driving the output amplifier at a high level. A discussion of the difficult question of what is a tolerable amount of distortion may lead to arguments and recriminations, however, it seems safe to say that there is no advantage in spending considerable time and money to build a good low-distortion output amplifier if we are going to drive it with a high-distortion input amplifier.

Having constructed an intermodulation analyzer, the author used it on some of his own creations and on the creations of some of his acquaintances. After checking the results of these tests and curing a number of input stage difficulties it seemed that a systematic study of distortion in voltage amplifiers might be worthwhile. A very comprehensive survey of this field seemed out of the question for an individual study so the measurements were limited to the following types which comprise a high percentage of the audio voltage amplifiers encountered:

6SN7 6SL7 6SJ7 12AU7 12AX7

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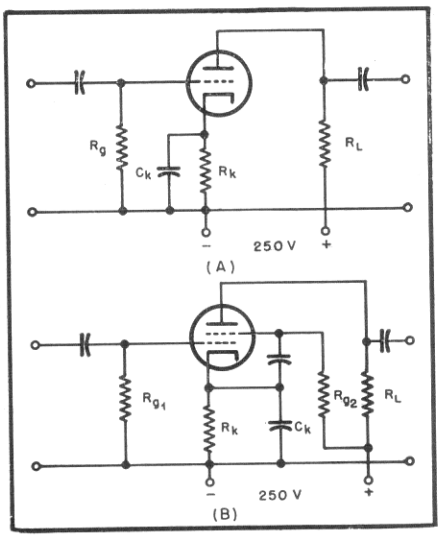
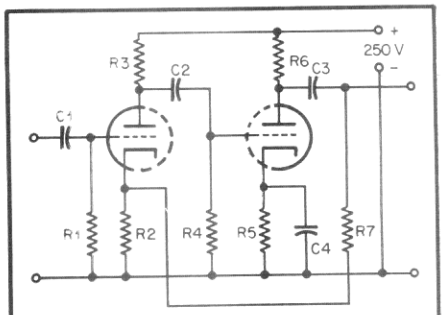


Fig. 1. Typical circuits used in making measurements. (A), for triodes; (B), for pentodes.

Figure 1 shows the test set up for these individual tubes. Five units of each type were tested using circuit constants generally recommended in tube handbooks. Readings were taken with and without a cathode by-pass capacitor and the 6SL7 and 12AX7 were also tested with grid-leak bias instead of cathode bias. All tubes were operated with a 250-volt plate supply.

In order to determine what negative feedback could accomplish in the way of distortion reduction, the 6SN7 and 6SL7 were connected to make a two-stage feedback amplifiers as shown in *Fig 2.*

Since these feedback amplifier measurements were intended only as a comparison and because of the great many variables which might be introduced, only one set of circuit constants was used in each test and only one tube, selected from the previously tested group, was used. The tube selected in each case was the one nearest the average of the five tested. All tests were made to determine the percentage intermodulation produced in the circuits under test using a combined 50- and 5000-cps signal, the level of the high-frequency signal being 12 db below the level of the low-frequency signal. The residual reading of the set up when fed directly into the intermodulation analyzer was about 0.1 per cent except when the level control was at very low settings when it rose to about 0.25 per cent. It



	6SN7	6SL7	6SL7 (Gridleak bias)
R1	1.0 meg	1.0 meg	1.0 meg
R2	4,700	4,700	4,700
R3	0.27 meg	0.27 meg	0.27 meg
R4	1.0 meg	1.0 meg	5.6 meg
R5	2,700	2,700	0
R6	0.1 meg	0.1 meg	0.27 meg
R7	47,000	0.22 meg	0.22 meg

Fig. 2. Two-stage amplifier typical of common practice, with values used in making measurements.

is thought that the contact in the level control might be non-linear at very low signal levels. This condition has been noted in a number of potentiometers, both carbon and wire-wound, when they were operated at levels of less than 50 millivolts.

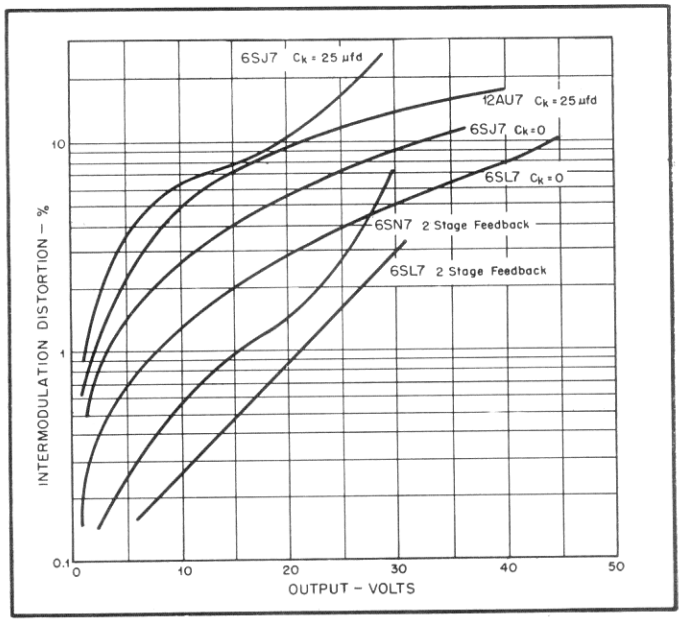


Fig. 3. Distortion measured on various tube types in circuits of Figs. 1 and 2.

Results

Figure 3 shows representative curves for several tubes and circuits. The 6SN7 and 6SL7 two-stage feedback amplifier curves are shown. The 6SL7 with unbypassed cathode was selected as the triode with lowest distortion. The 12AU7 with bypassed cathode was the triode of the highest distortion. Since the 6SJ7 was the only pentode tested its highest and

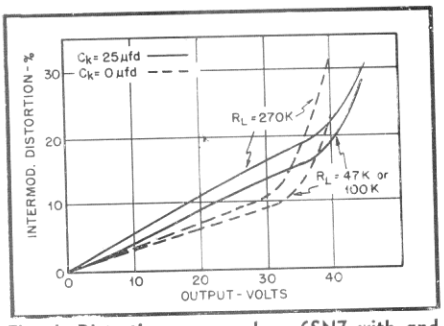


Fig. 4. Distortion measured on 6SN7 with and without bypassed cathode resistor.

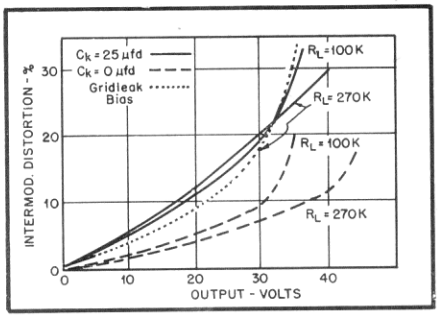


Fig. 5. Measurements on 6SL7 in several conditions of operation.

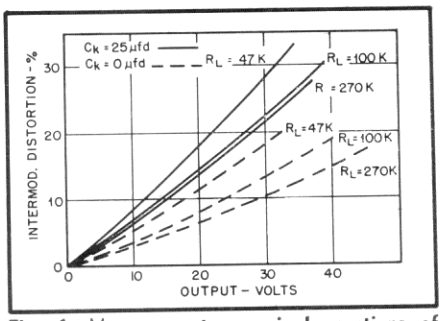


Fig. 6. Measurements on single sections of 12AU7 with different load resistors and both with and without bypass capacitor across cathode resistor.

lowest distortion modes are shown. From these curves it can be seen that the 6SL7 two-stage feedback amplifier is superior to the 6SN7 two-stage amplifier and that either of these two-stage amplifiers is considerably superior to any of the single units. The triode units are somewhat better than the pentode 6SJ7. Also, for maximum output without clipping the 6SJ7 was much more sensitive to operating conditions than the triodes were.

It was noted during the tests that when the input signal was increased until grid clipping began, the intermodulation distortion might fall below the amount which existed just before clipping began. This occurred because the clipping counteracted to some extent the distortion caused by curvature of the plate characteristic of the tube. This could correspond to a decrease in second harmonic distortion and an increase in higher-order harmonics. In the two-stage feedback amplifiers there is very little distortion present until clipping begins so the distortion begins to increase rapidly once this level is reached. Under such circumstances it cannot be said that a given percentage of intermodulation distortion would necessarily give the same results in a listening test if in one case it were caused by the gentle curvature of the tube characteristic and in another case by a sharp bend in the characteristic such as might occur because of clipping at the grid or by cutting off the plate current.

Figures 4 to 9 show the result of the tests on the individual tubes. The peak-to-r.m.s. value of the complex intermodulation signal is about 20 per cent greater than the peak-to-r.m.s. value of a sine wave. The voltage values plotted in *Figs.* 4 to 9 are the r.m.s. values of the intermodulation signal. The voltages plotted in *Fig.* 3 are increased 20 per cent to indicate equivalent sine wave voltages since these are the ones usually used in amplifier design work.

A comparison of the curves shows that leaving the cathode resistor unbypassed on a single unit, resulting in negative current feedback, reduced the intermodulation distortion encountered over the usable range of output voltages. This also cuts down the gain and raises the output impedance of the stage which may be undesirable in some cases. Leaving the cathode resistor of the second stage unbypassed in the two-stage feedback amplifier makes little difference in the gain and distortion, but it does raise the output impedance of the stage.

Negative feedback will not, to any great extent, reduce the distortion caused by a sharp bend in the characteristic of a circuit since the incremental amplification of the circuit may go to zero if the grid clipping or plate current cut-off are absolute. For this reason the two-stage feedback amplifier using gridleak bias on the second stage does not reach as low a level of distortion as do the same amplifiers using cathode bias.

Conclusions

Although the measurements made do not cover the complete field of voltage amplifiers the amount of data obtained seems adequate to come to a few conclusions:

1) A voltage amplifier tube should not be used without negative feedback when a plate signal level of more than 1 or 2 volts r.m.s. is desired.

2) Grid leak biased units should not be used, even inside feedback loops.

3) More negative feedback can be used in amplifiers using high-mu triodes than in amplifiers using low-mu triodes. Since the triodes without feedback give comparable amounts of distortion, the feedback amplifier using the high-mu triodes should give lower distortion.

4) Treble- or bass-boost circuits which operate on a voltage-divider principle, thus dropping the level between one plate and the next grid 15 to 20 db at flat response setting, should be operated at a very low level or should be replaced by circuits which obtain boost from selective negative feedback.

Horrible Example

Figure 10 shows one of the authors early efforts which violates most of the rules listed above. Unfortunately one still finds similar circuits being described and recommended for construction. The voltages indicated at the various points are the voltages resulting from a 10-mv, 1000-cps signal impressed at the GE type preamplifier input. The volume control is set to give an output of 1.0 volts from the tone-control circuit.

The GE type preamp shown in *Fig.* 10 was tested by the application of an intermodulation signal consisting of a 2.5-mv high-frequency signal and a low-frequency signal which was set to give an output from the preamp in which the low-frequency component was 12 db higher in level than the high-frequency component. The GE type preamp introduced 4 per cent IM at this signal level. This is higher than would be anticipated considering the signal levels involved but the tubes are operated with very low plate voltage and the plate load resistors are lower than would normally be used with high mu triodes. The same 6SL7 tube was moved to a feedback type preamp and the same signal was applied. In this case the IM reading was 0.1 per cent which is the minimum reading of the meter.

The portion of the amplifier to the right of the volume control was tested with the regular intermodulation test signal as was used for testing individual tubes. The results of this test is shown in *Fig.* 11. For comparison the IM curve for one of the later input amplifier-and-tone-control circuits built by the author is also shown in *Fig.* 11. This newer

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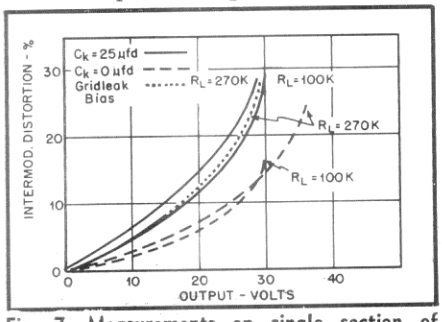

Fig. 7. Measurements on single section of 12AX7.

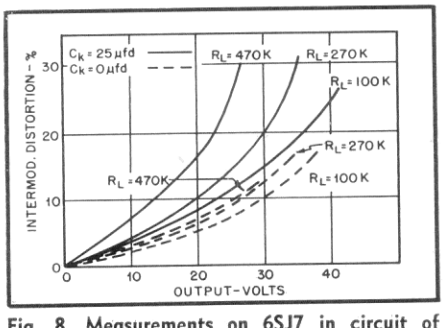

Fig. 8. Measurements on 6SJ7 in circuit of Fig. 1 (B).

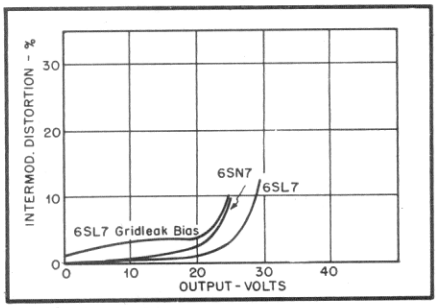

Fig. 9. Distortion measurements on tw-stage feedback amplifier of Fig. 2 with 6SN7 and 6SL7.

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amplifier uses one more tube than the earlier version but it seems well worth while to put this extra effort into the early stages to insure that they are at least as good as the output stage on which we spend considerable time and money to achieve low distortion.

It is hoped that the information set forth in this article will dispel any notions that voltage amplifier stages operating at low signal levels do not introduce distortion. Fortunately it is not difficult or expensive to remedy these conditions; voltage amplifiers are cheap and we are not limited too greatly in the amount of feedback we can apply when we have no transformers in the circuits. Good engineering practice is all that is needed to stop the feeding of 1-per cent IM output amplifiers from 5- to 10-per cent IM input amplifiers.

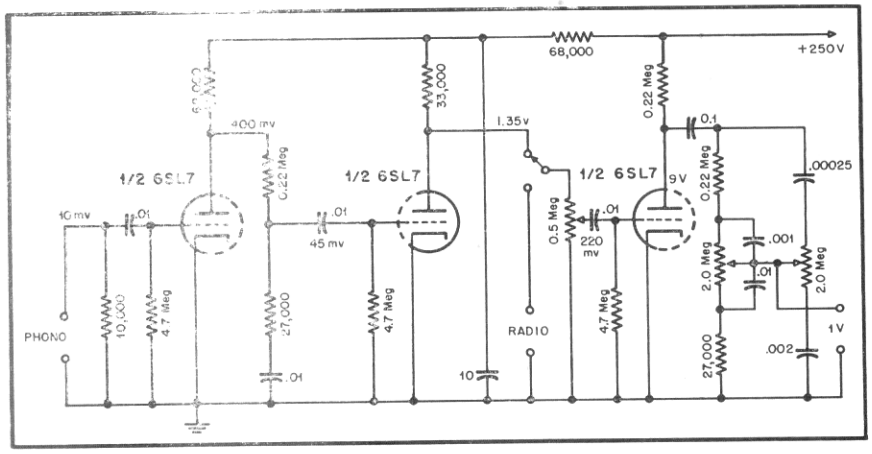

Fig. 10. Typical circuit encountered in "front end." Measurements indicate this to be the "Horrible example."

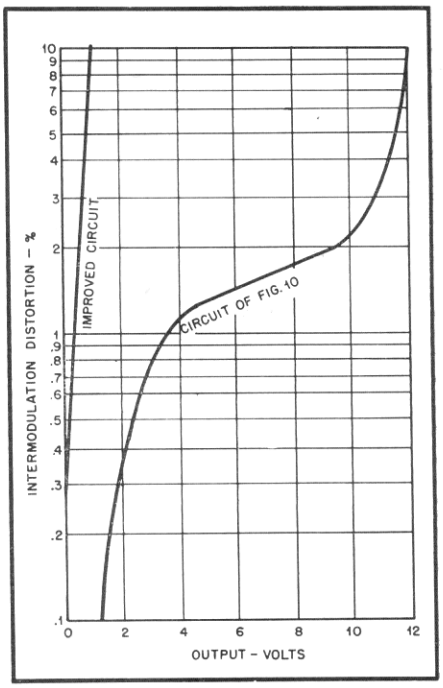

Fig. 11. Distortion of portion of circuit to right of volume control in Fig. 10, compared with similar circuit after using IM tests to make improvements.