DISTORTION IN AUDIO PHASE INVERTER AND DRIVER SYSTEMS

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SUMMARY

The distortion produced by certain widely used audio phase inverter and driver systems may be reduced considerably by changing the type of tubes used in the circuit or by making small changes in circuit component values. The decrease in driver distortion following these changes can result in a lower distortion output from the complete amplifier and a greater tolerance of the amplifier to a change in operating voltages or a change of tube characteristics.

A great deal of effort and money are spent on output transformers and associated output amplifier components in order to secure audio power that has a minimum of distortion. This effort and expenditure is negated to a degree when the remainder of the system is not as highly refined. This is an unfortunate situation because except for the transducers, other parts of the system are reasonably inexpensive and their refinement can be accomplished without much change in cost.

Fig. 1 shows the distortion characteristic of a Williamson type amplifier which was constructed with 12AU7 tubes in the driver circuit in place of the 6SN7's usually employed. The measured distortion in this amplifier was considerably higher than might be expected in a high quality amplifier. New tubes were substituted for the original ones without producing any significant change in the distortion. Other circuit components were checked for value and were found to be correct. Having previously found that 12AU7's produce more distortion at a given output than do 6SN7's, a pair of 6CG7's was substituted for the 12AU7's with the improvement which can be noted in the figure.[1] 6CG7's are exact electrical equivalents of 6SN7's and with only a change of heater connections at the sockets they may be substituted for 12AU7's. It should be kept in mind that they draw 300 ma. more heater current but in most cases this will not be a matter of importance.

A change of duty station soon after working on the amplifier just mentioned, delayed further study of the problem. About a year and a half later a more thorough study of the reduction of distortion in phase inverter and driver systems was begun. The study was limited to systems which would be capable of driving the newer high power tubes. A supply voltage of 400 was used and except for one circuit, the output voltage was applied to 100 K grid leaks. The input signal was 60 and 6000 cps at a 4 to 1 voltage ratio. The distortion is plotted against peak output thus allowing easy reference to the level needed for maximum amplifier output. The peak voltage required for maximum amplifier output is, of course, equal to the bias on the output tubes.

The system set up for the tests is shown in Fig. 2. An intermodulation signal generator is used to furnish the test signal, which is fed into the circuit under test. The output of the circuit under test was fed into a differential amplifier, which was designed to discriminate against any in phase components of the two signals which were applied to its input terminals. By this means this unit eliminated the portions of the even harmonics, which in a complete amplifier unit would be balanced out in the output transformer. The output of the differential amplifier was connected to the intermodulation analyzer from which the readings were taken. The voltmeters and the oscilloscope were used to measure input and output voltages and to make visual observations of the waveforms.

A test model of a Williamson driver system as shown in Fig. 3 was constructed so that either octal or miniature tubes could be plugged into the circuit. The distortion characteristics of this circuit with 12AU7's and with 6SN7's installed are shown in Fig. 4. The curves show that the 6SN7 gives up to a 3 to 1 improvement over the 12AU7. An increase in the bias resistor on the push-pull driver stage helps a little in the case of the 12AU7's but the 6SN7's still show a great advantage.

Figs. 5 and 6 show comparisons of the distortion present in each of the halves of the driver system with the distortion present in the push-pull output. The great amount of distortion which must be balanced out emphasizes the necessity for maintaining balance in the push-pull output stage including the output transformer.

On the assumption that the simplest circuit which will do a job well is the best, the next circuit to be tested was the 6AN8 connected as a pentode voltage amplifier and a triode split load phase inverter. The circuit is shown in Fig. 7. This circuit was built up and a series of measurements were made. The circuit was modified to work with other types of tubes and then reconnected for the 6AN8 to get some additional information.

Some of the results obtained during the second series of measurements were as much as 300% different from similar measurements made during the first series. Such an occurence is very discouraging to the experimenter unless a reason for the difference can be found. After considerable investigation it was found that the difference between the two series of measurements was the heater voltage applied to the tube. A new series of measurements were made with three different heater voltages. As can be seen from Fig. 8 this particular circuit using the 6AN8 is

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sensitive to changes in heater voltage.

Since it is difficult to control heater voltage in the usual set up, other means were sought to keep the distortion at the lower levels. It was found that increasing the pentode cathode resistor to 1.2K reduced the distortion over most of the useful range. Fig. 9 shows the characteristics of the circuit with the higher value cathode resistor.

The higher value of cathode resistor reduces the sensitivity of the circuit so that the driving voltage necessary to reach full output is increased by about 25%.

Other tube types were tested in this general circuit configuration and although some of them were less sensitive to heater voltage variations, none of them offered any significant advantage over the 6AN8.

The third complete system tested was an American variation on the Mullard circuit as shown in Fig. 10. This circuit consists of a pentode voltage amplifier driving a long-tailed pair phase inverter. As originally developed in England, the circuit was used to drive a pair of output tubes having a very low driving voltage requirement and having a high value of grid resistor. Also the long tailed pair used a high mu twin triode. The modification used in this country substitutes a medium mu twin triode for the high mu twin triode and used the resultant circuit to drive a pair of the new high power pentodes which require something on the order of 40 peak volts to be driven to full output. The result of these changed conditions is to require a much higher voltage out of the pentode voltage amplifier. This in turn raises the amount of distortion produced by the pentode amplifier.

As can be seen in Fig. 11 a great deal of this distortion can be eliminated by disconnecting the pentode amplifier cathode by-pass capacitor. An even greater reduction may be secured by also increasing the value of the cathode bias resistor to 3.9K. As in the case of the 6AN8 this increased bias resistor lowers the gain of the circuit thus requiring a greater input voltage for a given output. There seems to be enough gain remaining to allow a complete amplifier to be driven from any usual pre-amplifier.

Some work as done to determine the contribution of individual stages to the total distortion of a system. It was, of course, simple enough to determine the distortion produced in the individual stages but no way was found to predict the combined effect of two or more stages in cascade. Fig. 12 gives the distortion produced by various tubes connected as split load phase inverters. It can be seen that the 6SL7 gives only 1/10 to 1/4 as much distortion as the 6AN8 triode, however, when the 6SL7 was combined with the 6AN8 pentode the resulting combination gave more distortion than did the original circuit using the 6AN8 triode. The 6SN7 long tailed pair phase inverter alone produced less distortion with circuit component values different from those used in the circuit in Slide 11, however, when it was combined with the EF86 amplifier, these different values did not give any appreciable reduction in distortion.

Some measurements were made of high mu triode voltage amplifiers with split load phase inverters and with long-tailed phase inverters. Some of these combinations gave reasonable good distortion characteristics but in general the high mu triodes operating at low plate voltages were very sensitive to changes of signal source impedance and to the value of the first grid resistor. In connection with this the possibility of grid circuit distortion[2] made these circuits relatively unattractive.

Overall feedback in the finished amplifier has no effect on the grid circuit distortion contributed by the first tube and therefore on the assumption the 20 db. of feedback will be used, it is about ten times as undesirable as other types of distortion of the same general order.

If we assume that 1% IM in the driver system is a satisfactory level it can be seen that any of the three systems investigated will serve satisfactorily if the recommended modifications are made. On the basis of the difficulty of stabilization when feedback is applied the Williamson type loses out to the other two because it has an additional time constant or phase shift at both high and low frequency. Also it places the burden of the cancellation of even harmonic distortion on the output stage. The split load phase inverter circuit will have less phase shift than the long tailed pair however on the other hand the long tailed pair puts less of a requirement on the pentode voltage amplifier driving it than does the split load circuit.

A study of the information in Fig. 12 showed that it should be possible to build a driver system that would not produce more than 0.1% IM distortion which is the minimum measurable on the analyzer used in these tests. This objective was compromised somewhat in order to use only two tube envelopes in the system. The resulting circuit is shown in Fig. 13. It consists of a 6SH7 pentode voltage amplifier, a 6SN7 triode voltage amplifier and a 6SN7 split load phase inverter. Approximately 20 db. of feedback is applied from the cathode of the phase inverter. Fig. 14 shows the distortion characteristic of the feedback driver circuit. The use of only one half of the 6SN7 for the phase inverter and coupling it to 100K grid resistors did not give as high a voltage output as was planned. The addition of another tube or the substitution of a 6BL7 for the 6SN7 might increase the voltage output that can be reached before the distortion exceeds 0.1%.

To prove that the feedback type driver is practical, it was substituted for the driver in a Williamson type. Fig. 15 shows the distortion curve for the entire amplifier. The second curve on Fig. 15 shows the effect of omitting the cathode by-pass capacitor on the output stage. It appears that the amplifier can be stabilized as easily as can others. The response and phase characteristic of the driver can be shaped by connecting an RC network from the plate of the triode voltage amplifier to the cathode of the pentode.

Some of the pitfalls confronting the experimenter might well be mentioned. A diode rectifier type voltmeter connected across a high impedance circuit will generate a considerable amount of IM. An amplifier type voltmeter should be used on all critical circuits. As mentioned previously certain tubes may create distortion in the grid circuit even though the grid is at a negative potential. In some cases the moving contact in a potentiometer will offer a non-linearity. If a very low variable voltage is required, it is preferable to operate the potentiometer at a reasonably high level and then to divide the output from the potentiometer with a network of fixed resistors.

Although this study is far from complete, it is hoped that it clearly demonstrates that further progress may be made in this field. It is hoped that interest has been generated to cause others to carry on work on this subject.

1. Bernard, Distortion in voltage amplifiers, Audio Engineering, Feb. 1953

2. Watkinson, Grid circuit distortion, Electronic & Radio Engineer, June 1957

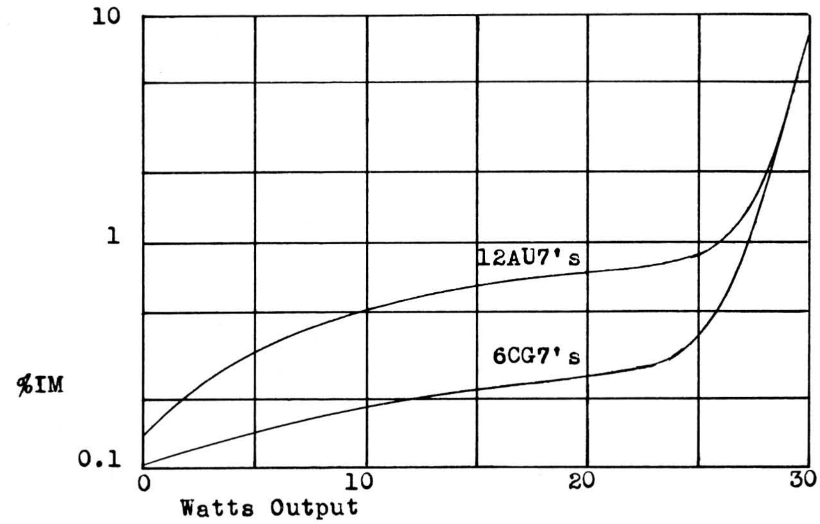

Fig. 1 Distortion in Williamson-type amplifier showing effect of changing tube types in driver circuit.

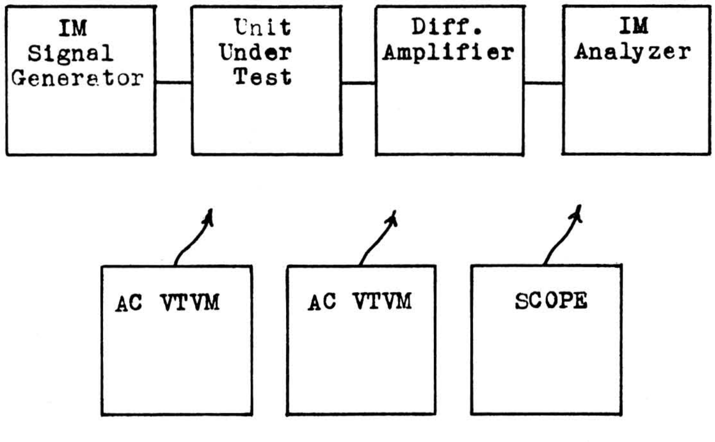

Fig. 2 Test setup for measurements.

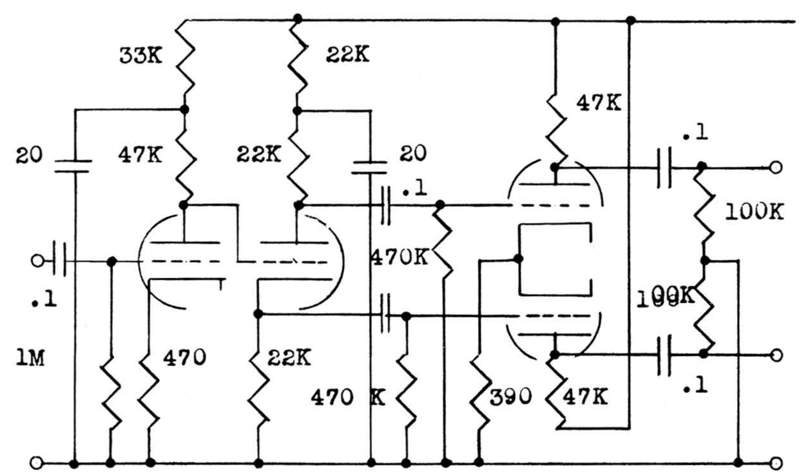

Fig. 3 Williamson-type driver circuit.

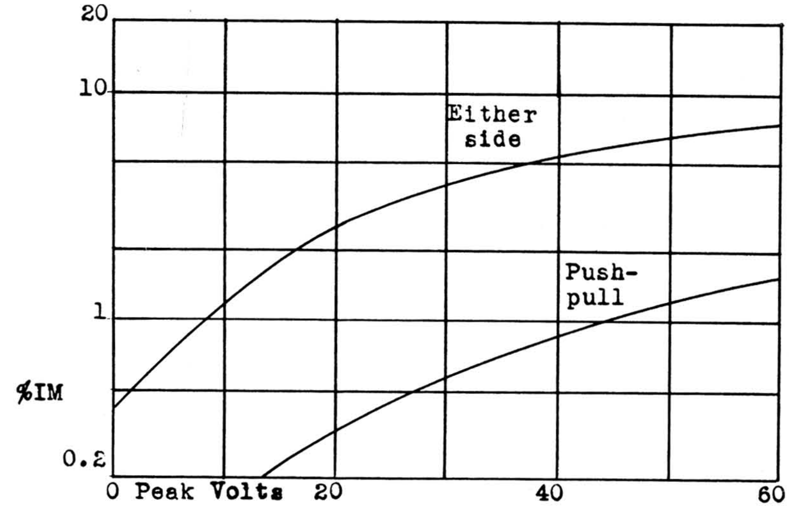

Fig. 5 Distortion in Williamson-type driver system employing 6SN7 tubes showing the cancellation of distortion due to push-pull action.

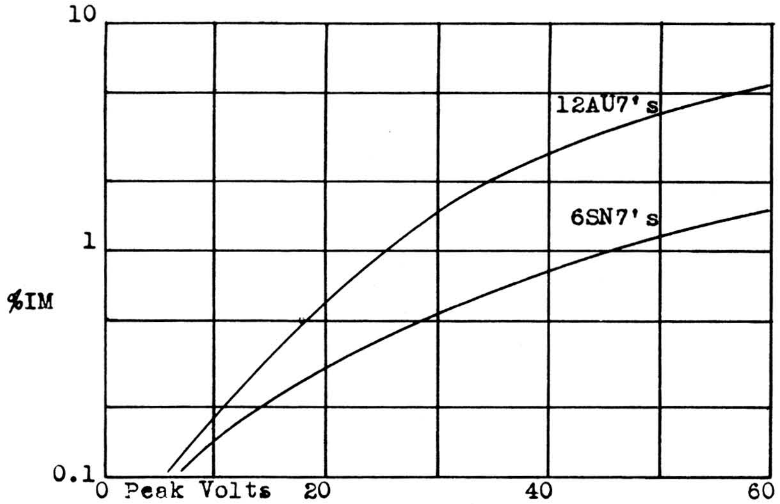

Fig. 4 Distortion in Williamson-type driver circuit showing effect of changing tube type.

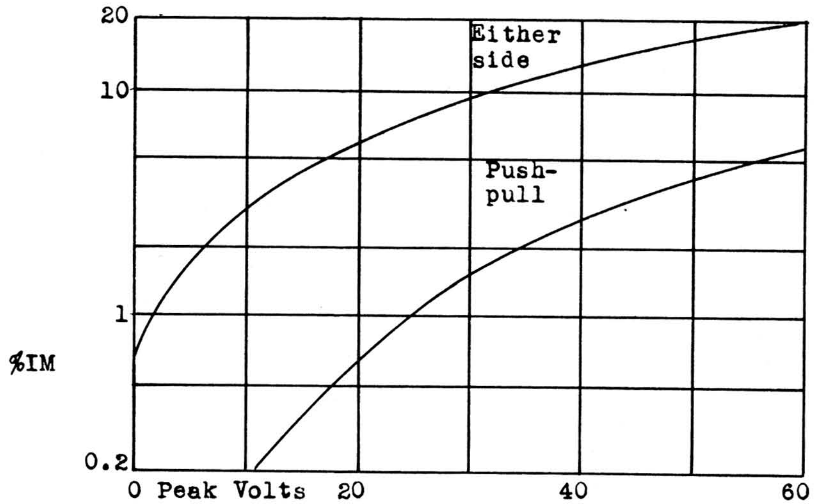

Fig. 6 Distortion in Williamson-type driver system employing 12AU7 tubes showing the cancellation of distortion due to push-pull action.

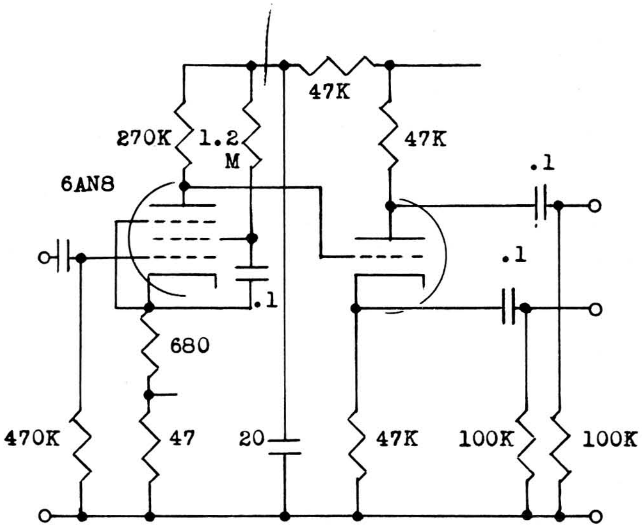

Fig. 7 6AN8 driver circuit.

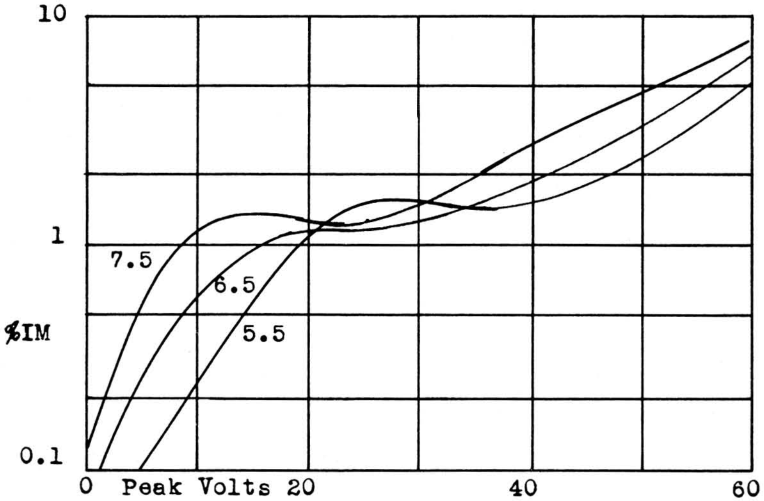

Fig. 8 Distortion in 6AN8 driver circuit showing the effect of variation of heater voltage, RK 680 ohms.

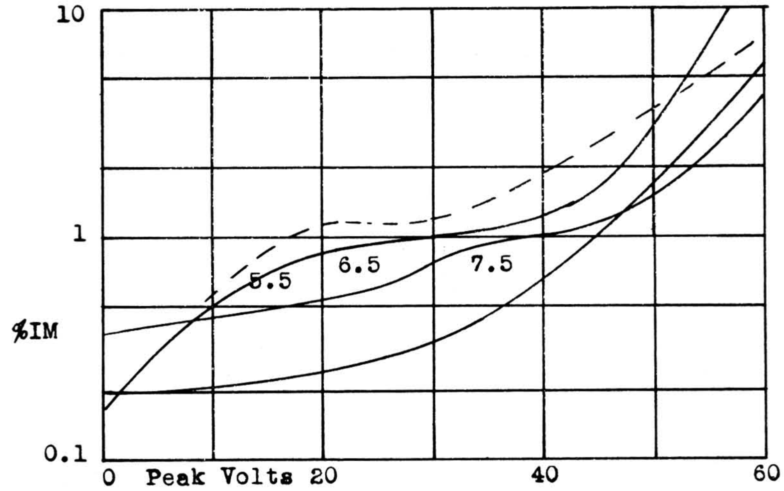

Fig. 9 Distortion in 6AN8 driver circuit showing the effect of variation of heater voltage, RK 1.2K. Dotted curve is 6.5 v curve for RK 680 ohms.

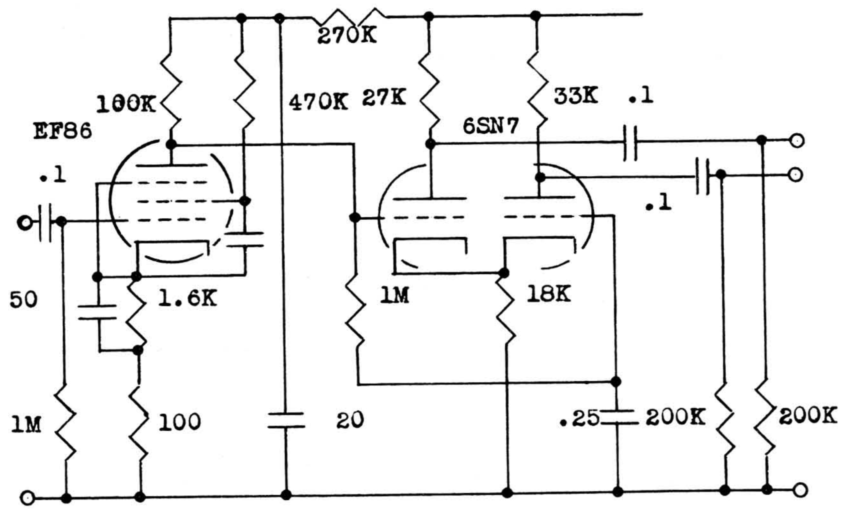

Fig. 10 EF86 amplifier with 6SN7 long-tailed pair phase inverter.

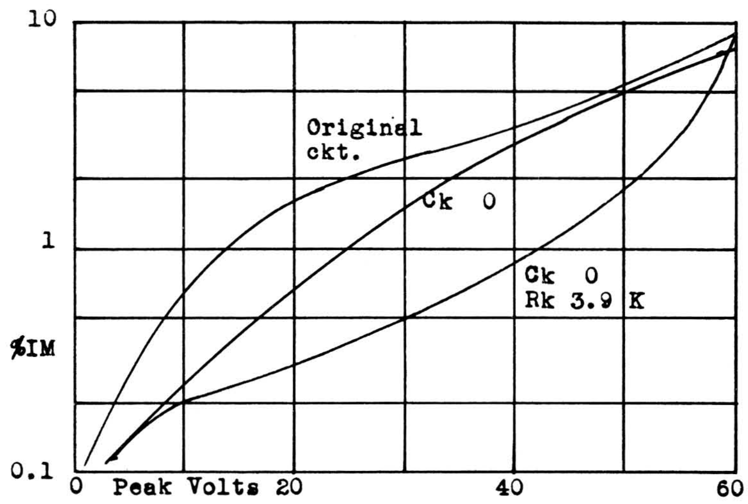

Fig. 11 Distortion in EF86, 6SN7 circuit showing effect of changing component values.

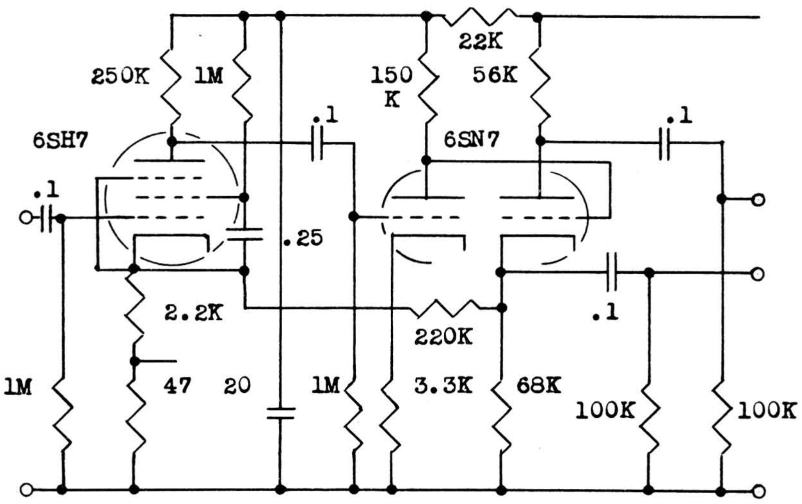

Fig. 13 Driver circuit consisting of feedback pair and split load phase inverter.

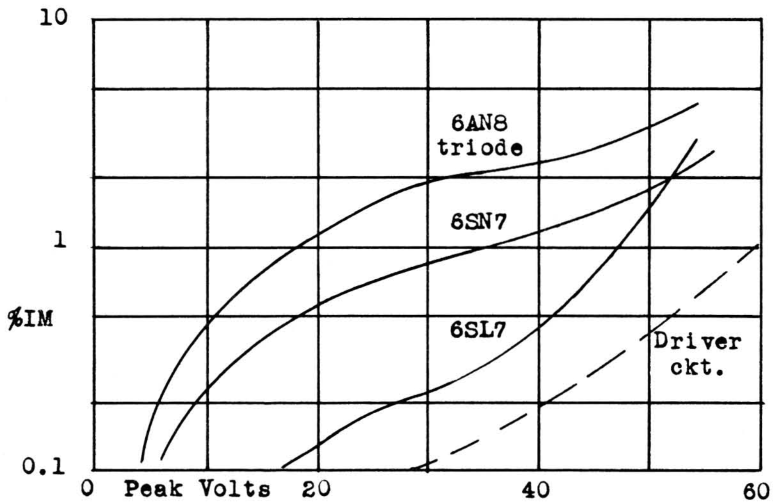

Fig. 12 Distortion in split load phase inverters.

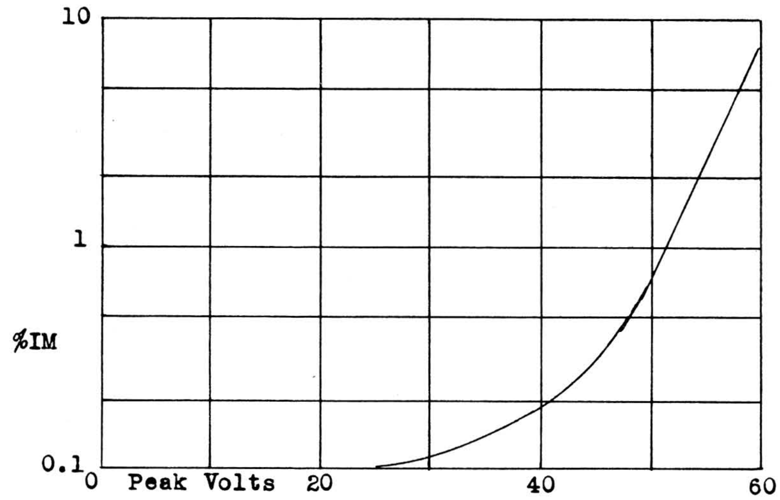

Fig. 14 Distortion in feedback-type driver circuit.

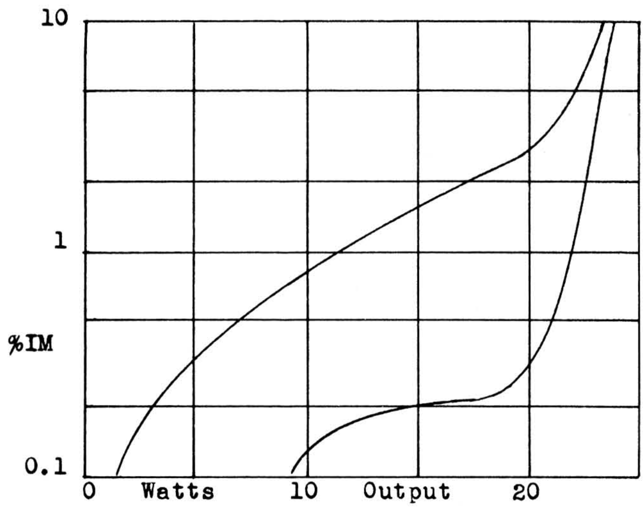

Fig. 15 Distortion in double feedback loop amplifier.