The Sad Tale of a Half-Watt Resistor

OR

What a ten-cent component can do to your hi-fi ambitions.

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Recently an amplifier available in kit form had been assembled, and it was decided to check the actual performance against the specifications. This particular power amplifier is highly regarded by Hi-Fi enthusiasts, and had received quite favorable reviews and test reports. The amplifier has a rated output of 50 watts, and the distortion at this output is specified as less than one per cent.

An intermodulation analyzer was connected to the amplifier, and an attempt was made to drive it to full output. However, it showed that even with 40 watts output the intermodulation distortion exceeded the specifications. Various attempts were made, such as improving the balance between the plate currents of the output tubes by providing separate bias for them, all to no avail. As a matter of fact, in the course of a week's experimentation with the amplifier, the performance kept on deteriorating until at the end of this period the distortion was approximately nine per cent. The situation was indeed becoming desperate.

Up to this time the investigation had been confined to the measurement of distortion, since this was considered as the most important characteristic of the amplifier. Now it was decided to measure some of the other characteristics, in the hope that such investigations might throw a light on the deterioration of the performance. The first additional characteristic to be checked was the required input voltage for full output. The specifications stated that an input voltage of 1.5 volts is needed to obtain full power output. Lo and behold, *instead* of 1.5 volts, a signal of 3 volts was required to obtain full output. Now in an amplifier with a large amount of negative feedback, the gain from input to output is usually essentially determined by the feedback network, rather than by the actual gain of the amplifier. An examination of the diagram showed that feedback was obtained from the 16-ohm output terminal of the transformer through a series combination of a 1000-ohm and a 47-ohm resistor to the cathode of the input stage. To produce 50 watts in a load of 16 ohms requires 28.3 volts, and with a series combination of 1000 and 47 ohms this would feed back approximately 1.23 volts to the cathode of the input stage; the excess of 1.5 volt over 1.23 volt would then represent the actual input voltage required between cathode and grid of the amplifier.

The large discrepancy in the input requirements immediately threw suspicion on the feedback network. Measurement of the two resistors showed that the 1000-ohm resistor was well within tolerance limits, but that the 47-ohm resistor was around 100 ohms; replacing this resistor with a new 47-ohm resistor not only brought the input requirement down to the specified value, but brought the intermodulation distortion to approximately 0.3 per cent, therefore well within the specifications.

Not the Whole Story

The story could have ended here. But a little meditation showed that there was perhaps more to be learned from this incident. The change of the resistance value from 47 ohms to approximately double this value increased the feedback to about twice the original value; this was a perfectly logical explanation for the increased input requirements. However, as far as distortion is concerned, an increase in feedback should, if anything, decrease the distortion, rather than increase it (provided of course that the amplifier remains stable with the increased feedback, which it did). There was only one possible explanation, and one that is hard to swallow, namely that one of these two resistors had become nonlinear. Since it was the 47-ohm resistor which had changed its value, naturally suspicion centered on this resistor. The suspicious resistor was set up in a Wheatstone bridge circuit, as shown in *Fig.* 1. Note that the resistance placed in series with it is exactly of the same value as that found in the amplifier circuit, and that the bridge voltage was made equal to the a.c. voltage which appears across these two resistors in the amplifier under full-load conditions. The unbalance of the

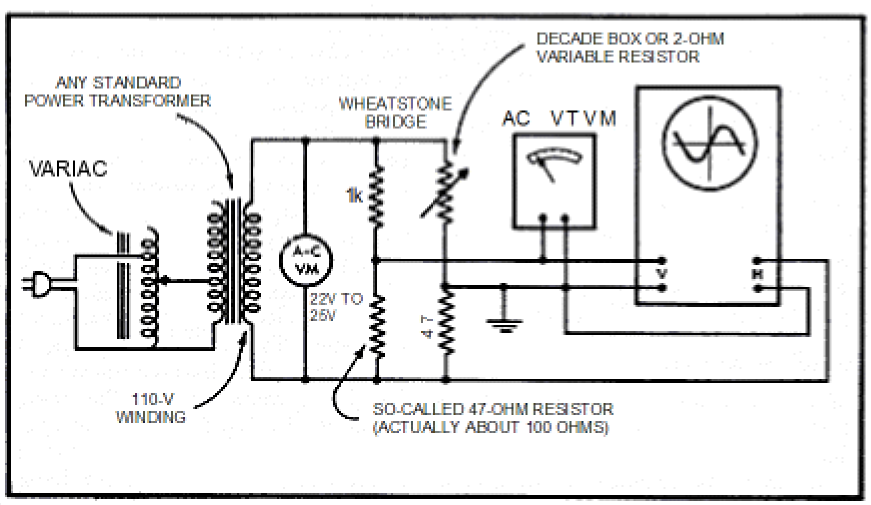

Fig. 1. Test circuit used to demonstrate non-linearity of the offending resistor.

bridge was observed on a cathode-ray oscilloscope as well as on a vacuum-tube a.c. voltmeter.

This being an a.c. bridge, exact balance is, of course, possible only when the resistive as well as the reactive components are in balance. However, with a frequency of 60 cps, and the relatively low resistance values in the bridge, stray capacitance and inductance have only a minor effect; if due to these influences a small reactive unbalance remains, it will show itself on the scope, as an ellipse, and it can usually be balanced out by placing a variable capacitor across one of the four arms. But in this test, the unbalanced voltage could not be brought below approximately 80 millivolts, and the trace observed on the screen of the cathode-ray tube showed that the remaining unbalanced voltage was a 180-cps voltage, in other words a third harmonic, which could not be balanced out. This means that with a 60-cps sinusoidal current flowing through this so-called resistor, there appeared across it not only a 60-cps voltage of approximately 2 volts, as one would expect, but additionally a 180-cps voltage of approximately 80 millivolts, which is 4 per cent of the 60-cps voltage. A resistor with a built-in harmonic distortion of 4 per cent.

Just to make sure, that this startling result was not by any chance caused by a faulty method of analysis, the simple series combination of 1000 ohms and the suspicious resistor were connected once more to the intermodulation analyzer, interposing an amplifier of known and very low distortion between the analyzer and the series combination. The voltage applied to the two resistors in series was considered as input voltage, the voltage across the defective resistor was considered as output voltage. This simple network now showed an inter-modulation distortion of 15 per cent. (Evidently between taking the resistor out of the circuit and completing these measurements, further deterioration had taken place.) In the April, 1948, issue of the Proceedings of the IRE, W. J. Warren and W. R. Hewlett published a paper entitled "An Analysis of the intermodulation Method of Distortion Measurement". In this paper it is shown that if the distortion is due to a non-linearity of the transfer characteristic of a network or an amplifier, a well defined relation exists between harmonic and intermodulation distortion. The paper shows that if the non-linearity is caused by a third harmonic, the ratio between intermodulation distortion and harmonic distortion is approximately 3.8. The measurement with the Wheatstone bridge method indicated a harmonic distortion of 4 per cent, which would result in 4 x 3.8 =15.2 per cent intermodulation distortion, according to this paper. With this degree of agreement between the results obtained by two entirely different methods, there can be no reasonable doubt about the non-linearity of the resistor.

Over-all Effects

For the high fidelity enthusiast the implications presented by this investigation are positively frightening. In his eternal quest for the elusive goal, perfection, he is forever replacing good components with better components. If the advertisements for the new SuperTriple-X amplifier state that it provides 99.44 per cent perfect reproduction, he cheerfully plunks down 250 dollars or so, and discards his previous amplifier, which had 1 per cent distortion and was therefore only 99 per cent perfect. Whether he personally can hear this difference, is probably of less importance than the fact that he can now brag about his new equipment, and feel superior to the poor boobs who haven't the new Super-Triple-X. So what, if a resistor goes bad in the Triple-X and the distortion goes up to 1, 2, or 3 per cent? You still can brag and feel superior about "having the best" (which naturally means the most expensive). This writer can, of course, not speak for others, but he knows definitely that he can not hear the difference between 1 and 2 per cent distortion, as a matter of fact, suspects that it would take 4 or 5 per cent before he would notice it, and a good deal more before it would become disagreeable. He considers himself quite fortunate, not to he cursed with a so-called "Golden Ear," but makes good use of his "Tin Ears" to enjoy thoroughly his library of 800 or so LP records (mostly classical), many of which undoubtedly have more than a modest 3 per cent distortion built right into them. So he can not help but feel a little bit sorry for those who actually can hear 1 per cent distortion, because this evidently not only puts severe limitations on the amount of program material available to them, but puts them at the mercy of every component in their system, from 10-cent resistors to 40-dollar output transformers, all of which must be in perfect condition. It is, however, highly probable and fortunate that most of us do not possess the kind of ears that detect with agony a deviation of 2, 3, or even 5 per cent from perfection, otherwise the enjoyment of recorded music would he almost an impossibility.

The investigation and measurements reported here were made in the laboratory of Mr. E. D. Nunn, President, Audiophile Records, Saukville, Wis., and in the writer's own laboratory. Mr. Nunn's interest and cooperation in securing this information is gratefully acknowledged.