# Intermodulation Distortion

RICHARD C. HITCHCOCK*

**A brief and frank discussion of this form of distortion, and the description of some simple devices which will enable the experimenter to make his own measurements with a minimum of equipment expense.**

ONE WAY TO TEST an audio amplifier is to play records at full volume, and listen for "muddy" or "harsh" tones in the upper register. These happen when a high-frequency tone is affected by a low-frequency tone.

Testing the amplifier by listening is the final authority, of course. But it would be desirable if tests could be made to find out how much distortion the amplifier introduces. Even the best amplifier has some distortion. The only questions are, how much, and what kind?

As a start, let's consider three notes on an 88-note piano. The highest note, No. *88*, is *C*. Note No. *87*, next lower[1], is *B*. It you should strike these adjacent notes at the same time, you probably would call the result a "discord." You would hardly think an amplifier was very good if, when called on to reproduce the note *C* of the piano, it also gave the adjacent *B*, a few hundred cps lower. Yet this is what a poor amplifier does do—and here we arrive at an important fact. The amplifier adds the extra note, the *B*, only when a certain low-frequency tone *A* is played at the same time.

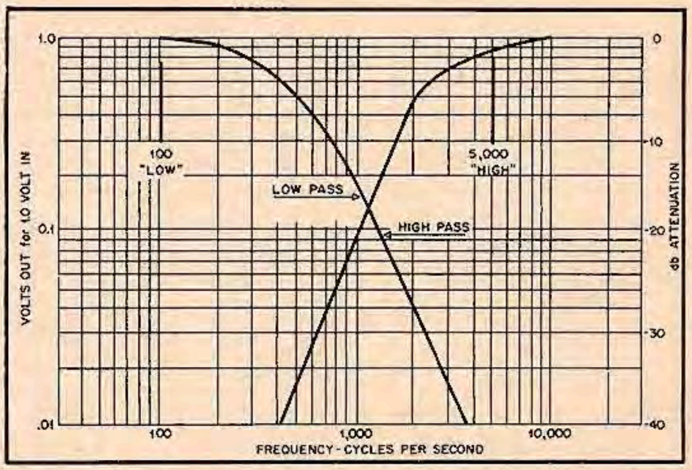



**Fig. 3. Transmission curves for high- and low-pass filters used in the author's measurements.**

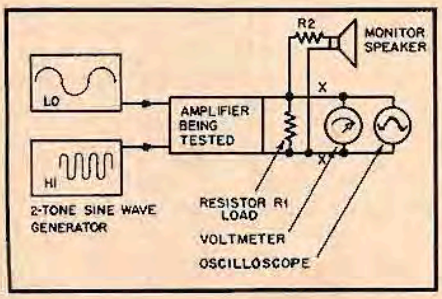



**Fig. 1. Basic circuitry used in preliminary set-up.**

To go over this again, a poor amplifier, called on to reproduce Numbers *38* and *88* on a piano, gives *38* (*A#*), *88* (*C*), plus the extra and unwanted notes *87* (*B*), and an even higher one which we may call No. *89* (*C#*) a half tone higher than is on the piano. The reason for this is the low-frequency note, No. *38* on the piano, the note[2] *A#*. This is one kind of intermodulation distortion.

Most music on records includes more than one tone at a time. The interacting of these tones cause more or less intermodulation distortion. For measurement, it is much simpler to consider only two pure tones, one high and one low. Working with these will give us some idea of amplifier distortion.

Incidentally, there is no accepted standard of a "high" or of a "low" tone. One company publishes data[3] on its amplifier tested at 60/7,000 and 40/12,000 cycles per second, with a low-to-high-note ratio of 4:1. Another[4] shows 40/2,000; 40/7,000; and 40/12,000 all with 4:1 ratios. An excellent article[5] from which many valuable ideas were taken for the tests indicated here, recommends 40/4,000 cycles with 4:1 low-to-high ratio. A recent paper[6] suggests 60/4,000 with any of three ratios; 4:1; 1:1; or 1:4. A test record[7] (33 r.p.m.) is available, using 100/7,000 cycles per second 4:1 ratio. It might be mentioned, in passing, that a record introduces another variable in an already complicated situation, and that the test of the amplifier alone is the best step to take first. Further, a test record wears, whereas an oscillator will work for a much longer time.

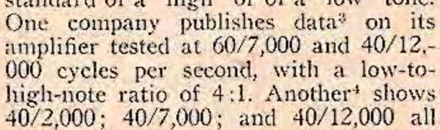



**Fig. 2. High-pass filter configuration.**

#### Preliminary Procedure

With the equipment of *Fig*. 1, play a high-frequency sine wave and notice that the amplifier output is a good sine wave, too. Set the timing rate of the 'scope so that it gives a full wave (or more) of the low tone, and with the high tone still playing, add the low-frequency tone. The picture on the 'scope will be pretty, but difficult to analyze. So next we open the circuit at XX and insert a high-pass filter, *Fig*. 2. This will allow only the high frequency to pass to the oscilloscope, in accordance with the transmission of the filter, shown in *Fig*. 3, and we can see what happens to the high note when the low note (blocked by the filter) is varied in volume. If you are doing this for the first time, you will be astounded to see how ragged the formerly smooth high note becomes.

Through the high-pass filter will go the notes *87*, *88*, and *89* of our example but No. *38*, the one which causes these extra *87* and *89* notes, will not get through. We can now see the effect of the low tone on the high one, but still we want to measure this effect, this distortion.

Now add a rectifier and low-pass filter, *Fig*. 4. The rectifier cuts off half the waves and the low-pass filter takes

* *Buhl Planetarium, Pittsburgh 12, Pa.*

1 For A = 440, the vibrations per second for Numbers 88 and 87 are 4143 and 3910 respectively. Their difference is 233 vibrations per second.

2 For International Pitch, A# is 238 vibrations per second.

3 Transformers in Williamson High-Fidelity Amplifier, Form 382, Standard Transformer Corp.

4 Ultra-Linear Williamson Amplifier, Acro Products Co.

5 Thomas Roddam, "Intermodulation distortion," *Wireless World*, April 1950.

6 Pierce J. Aubry, "Intermodulation testing," AUDIO ENGINEERING, Dec. 1951.

7 Cook Series 10 Test Record.

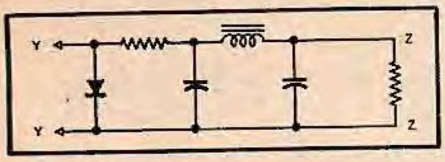



Fig. 4. Rectifier and low-pass filter circuit.

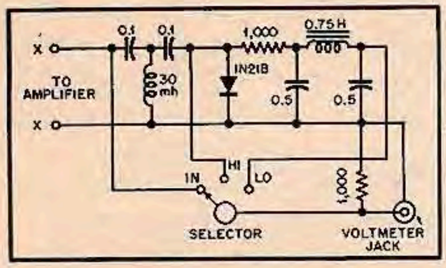



Fig. 5. Assembled circuit including high-pass filter, rectifier, low-pass filter, and suitable switching.

out the high-frequency tones. At ZZ, the end of the low-pass filter, is the distortion we want to measure. *Figure* 5 shows the complete arrangement, to be inserted at XX of *Fig.* 1, ahead of the oscilloscope and voltmeter. For compact reference, we shall call the voltage across XX (nearest the amplifier of *Figs.* 1 and 5) IN; across YY, HI; and across ZZ (next to the voltmeter and 'scope *Fig.* 5), LO. The distortion is the ratio LO/HI, or in percentage, 100 × LO/HI.

The equipment has been chosen to be useful for tests other than distortion. For instance, the high note has been chosen, not at the 4143-cps piano *C*, but at 5,000 cps, because this is a good place to test an amplifier for treble boost. For a similar reason, the low frequency is 100 cps; this also tests one of the low frequencies an amplifier should do well, and can be used to indicate bass boost, too.

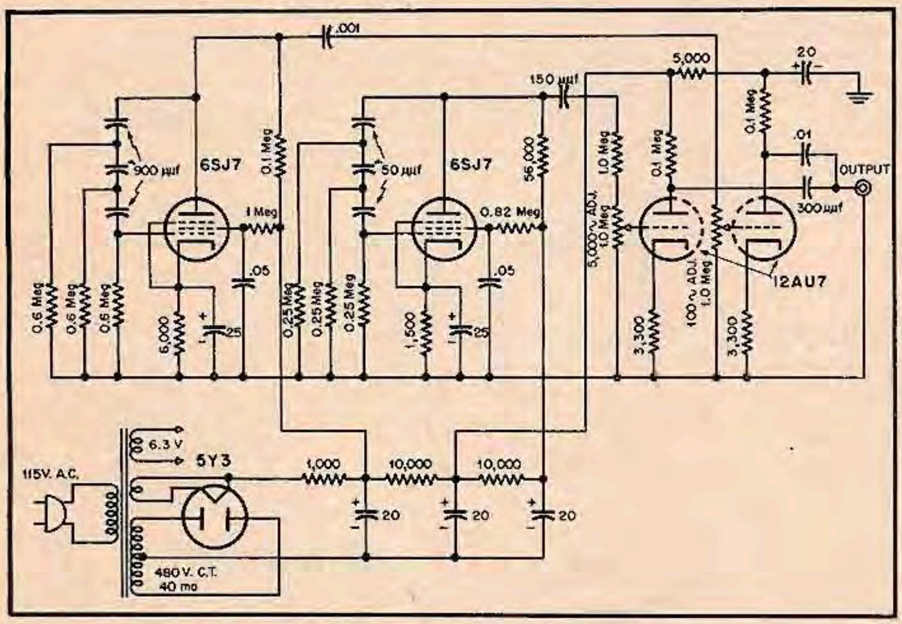
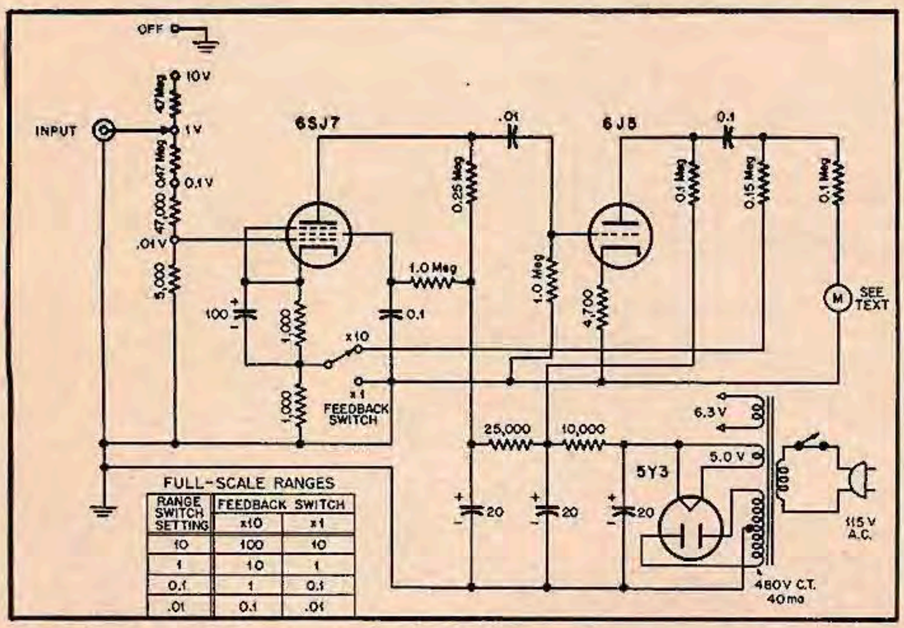



Fig. 6. Suggested circuit for two-tone IM signal generator.




| RANGE SWITCH SETTING | FEEDBACK SWITCH x10 | x1 |
|---|---|---|
| 10 | 100 | 10 |
| 1 | 10 | 1 |
| 0.1 | 1 | 0.1 |
| .01 | 0.1 | .01 |

Fig. 7. Simple a.c. vacuum-tube voltmeter useful for many other measurements in addition to IM testing.

#### Equipment Required

First, then, we need a two-tone sine-wave generator[8,9] having frequencies of 100 and 5,000 cps. Each must have its own volume control, so that any amount of each frequency can be supplied for test. *Figure* 6 shows a suitable instrument.

Second, we need a voltmeter which is good at audio frequencies, to read IN, HI, and LO. If the amplifier to be tested has less than 1 per cent distortion you will want to measure as low as .01 volts full scale. This means that your voltmeter must include an audio amplifier. *Figure* 7 shows a suitable vacuum-tube voltmeter with ranges 100/10/1/0.1/.01 volts full scale. Maximum stability is obtained by using 20 db feedback (10:1 in voltage) for all but the .01-volt range. The switch marked "x1 and x10" cuts the feedback out or in. Using feedback (x10) the sensitivity is 50,000 ohms per volt and the ranges are 100/10/1/0.1 volt full scale. With the "no feedback" (x1) setting, the meter has 500,000 ohms per volt, with ranges 10/1/0.1/0.01 volts full scale. The actual meter is a 100 microampere a-c meter which has an internal rectifier. A 100-μa d.c. meter could be used with an external bridge of four 1N34 germanium diodes. In any case, the instrument must be calibrated after completing the construction work.

The third requirement is the filter circuit of *Fig.* 5. This is a special purpose device, useful only for distortion tests. It is not very expensive, and the ability to make distortion tests quickly and accurately more than justifies its construction.

#### Intermodulation Distortion Tests

Connect a resistor $R_1$ on the audio amplifier output, to "soak up" the audio energy; a resistor with the same ohmic value as the impedance of the speaker you intend using with the amplifier. The wattage rating of the resistor should be greater than the amplifier's rated output. You can use a monitor speaker at reduced volume, by employing a 100-ohm resistor in series with the speaker across the resistor load, as in *Fig.* 1.

Most of the energy will be in the low-frequency tone; turn up the 100-cps tone from the two-tone generator until the voltmeter across $R_1$ (IN) shows the voltage for rated amplifier output. Example: for a 10-watt amplifier, connected for an 8-ohm output, $P = E^2/R$; therefore $E^2 = P \times R = 10 \times 8 = 80$; $E = \sqrt{80} = 8.95$, approximately 9 volts. Use range 10 on voltmeter (x1) or range 1.0 (x10). This 9 volts should produce a clear sound in the monitor, or a smooth wave on the 'scope. If the wave is distorted, reduce the voltage sufficiently to get a clear sine wave, either audible or visual. Suppose you can get 8 volts

[*Continued on page 56*]

[8] Ginzton, and Hollingsworth, "Phase shift oscillator," *Proc. I.R.E.*, Feb. 1941.
[9] McIlvaine, Rectifier Tube, U. S. Pat. 1,946,354, Feb. 6, 1934.

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"clean" at 100 cps. Now turn down the volume of the 100-cps note to zero; and turn up the 5,000-cps note to an output one quarter that of the 100-cps note "clean", in this case 8/4 = 2 volts[10].

[10] With 8 volts at 100 cps and 2 volts at 5000 cps, the high frequency is 12 db down in volume from the low frequency.

Again this should sound "clean" on your monitor and be a smooth sine wave on your 'scope.

Now for the distortion measurements: Gradually increase the 100-cps tone, until the voltmeter (IN) reads 8 volts, which previously produced clean output. We now have an amplifier playing a double tone—8 volts at 100 cps, and 2 volts at 5,000 cps at the same time.[11]

[11] *(This is not absolutely exact when measured in this manner, since the presence of the 5000-cps tone will make a slight increase over the volume of the 100-cps tone when the two are combined. However, provided this same method is used consistently, results may be compared with reliability.* ED.)

We want to find out how much intermodulation distortion is appearing *near* the 5,000-cps note due to the 100-cps tone. Set voltmeter at HI, and read it (starting with high range, 10 v, x1). Suppose it shows 1.1 volts. Now switch to LO, and read. Let's say it is 0.05 volts. The intermodulation distortion for this case is 0.05/1.1 = 0.055 or 5.5%.

It is a good idea to make tests at different outputs; the distortion will be less for lower output powers. You may be surprised to find out how few watts your

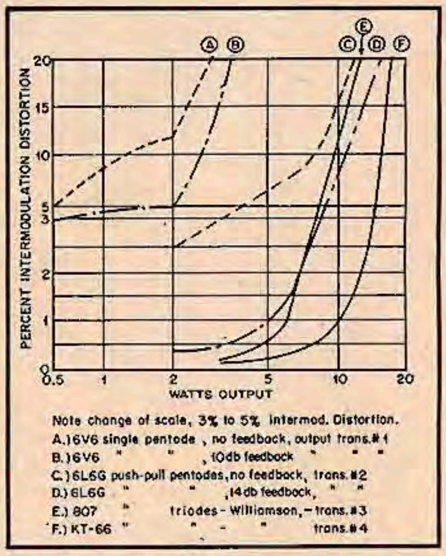


**Fig. 8. Typical IM distortion curves taken with various types of amplifiers.**

"10 watt" amplifier will do with low distortion.

#### General Comments and Conclusions

The whole problem of intermodulation distortion is relatively new—you can use frequencies and ratios to suit yourself. There is no accepted value of allowable distortion. There are even no generally recognized standards for the high or low frequency or for their relative ratios. As indicated before, a 4:1 volt ratio (12 db) of low to high tone is used by several, and a generator providing 100- and 5,000-cps tones can be a useful additional piece of equipment for amplifier testing. A high-sensitivity tube voltmeter, with low ranges, is always a handy piece of equipment. It will measure pickup output voltages, for example.

Perhaps after measuring some of your pet amplifiers, you will decide to take some drastic steps to reduce distortion, such as increased feedback, or some other such device. You will probably find, with the tests outlined, that a single pentode at full rated output without feedback will show over 20 per cent distortion and as low as 4 per cent with proper feedback. Single output triodes may have 10 per cent distortion without feedback, and below 0.5 per cent with suitable feedback. Push-pull amplifiers will have (maybe) one-fifth the distortion of single-ended ones. Good output transformers show up best, as is already well known. A few typical measurements are plotted in *Fig. 8.*