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DISTORTION, ITS MEANING AND MEASUREMENT

In the last few years, a great deal has been written about distortion. But not all of this material has been understandable to the amplifier serviceman. Few authors have made it clear what distortion is and how it may be measured. In the final analysis, it is the serviceman who must do the job of restoring amplifiers to full operating efficiency. We feel, therefore, that we should explain the subject for his benefit and drop as many engineering frills as possible. This article aims to define distortion and to explain its qualitative and quantitative measurement.

What is distortion? In simple language, it is the disfiguring of a signal as it passes through an amplifier. If a certain tone (signal) is fed into an amplifier, the same tone should come out, only louder. When distortion is present, the original tone comes out of the amplifier mixed with one or more higher-pitched tones (harmonics or "overtones") which were not present in the original tone. This causes the amplified tone to sound unnatural. It may sound harsh when the amount of distortion is large. When we check distortion, we simply measure the percentage of these undesired harmonics.

In addition to establishing the **amount** of distortion, a distortion test should show at which point within the amplifier the distortion begins. There are a few simple **(qualitative)** tests for distortion which may be made quickly by the serviceman. These tests involve little or no calculation and require few, if any instruments. They usually serve only to establish the fact that distortion is present, but do not show the amount or kind. Their usefulness therefore is limited. The best distortion tests are **quantitative.** That is, they are concerned with **how much** distortion is present. There are several methods of making quantitative distortion tests. Each of these methods requires either special instruments, calculations, or a combination of instrument readings and calculations. Both qualitative and quantitative tests will be described in this article.

The Nature of Distortion

Three types of distortion ordinarily are encountered in audio amplifiers. These are **phase distortion, frequency distortion,** and **amplitude distortion.** It is amplitude distortion which is met most frequently and is of greatest importance in audio amplifier maintenance. Some authors refer to this same kind of distortion as **non-linear distortion.**

In order to see how amplitude distortion disfigures a signal as the latter passes through an amplifier, let us study Figures 1 and 2. For convenience in each instance, we have taken 1,000 cycles as the fundamental frequency of the signal fed into the amplifier. This signal is represented by the sine waves in Figures 1(A) and 2(A). In each case, the signal leaves the amplifier enlarged (amplified), as shown by 1(C) and 2(C). However, in Figure 1 a 2nd harmonic signal (2,000 cycles) has been generated within the amplifier and has been added to the output signal. And in Figure 2, a 3rd harmonic (3,000 cycles) has been set up and added. Figures 1(C) and 2(C) therefore represent distorted output signals.

Figures 1(C) and 2(C) show the actual pictures of distorted signals which we may see on an oscilloscope screen when the 'scope is connected to the amplifier output terminals. Notice, from Figure 1(C) that the 2nd harmonic affects only the top (positive) peaks of the output signal. Also, notice from 2(C) that the 3rd harmonic affects both peaks. This is a useful fact to remember, since it helps the

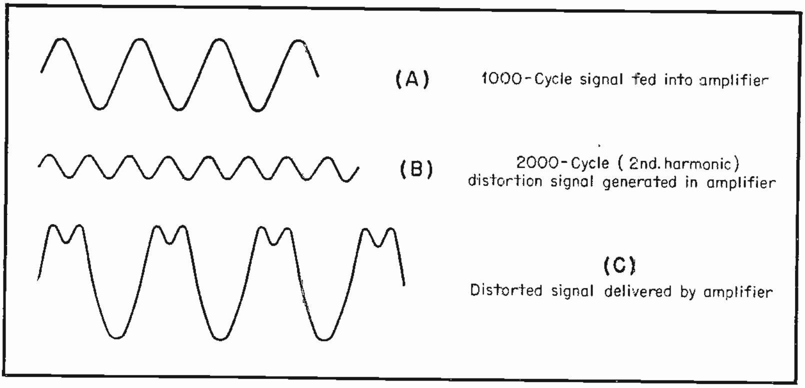

Fig. 1. Pronounced 2nd. harmonic distortion.

operator to identify roughly the type of distortion: **Even-numbered harmonics (2nd, 4th, 6th, etc.) always affect the positive peak,** as shown in Figure 1(C), **while odd-numbered harmonics (3rd, 5th, 7th, etc.) always affect both peaks similarly.** For these reasons, odd-numbered harmonics are said to produce symmetrical distortion; and even-numbered harmonics, assymetrical distortion.

Figures 1(C) and 2(C) show only two of the possible waveforms resulting from distortion. These are by no means the only ones. An entire catalogue of distortion waveforms would be too lengthy to include in this paper.

In practical PA amplifier maintenance, the 2nd, 3rd, and 4th harmonics usually are the most troublesome distortion components. The 2nd harmonic may be eliminated, or at least reduced considerably, simply by employing a pushpull output stage in the amplifier. Distortion arises from tubes; improperly selected resistors, capacitors, choke-couplers, or transformers; mismatched input or output circuits; poorly designed circuits; worn or de-

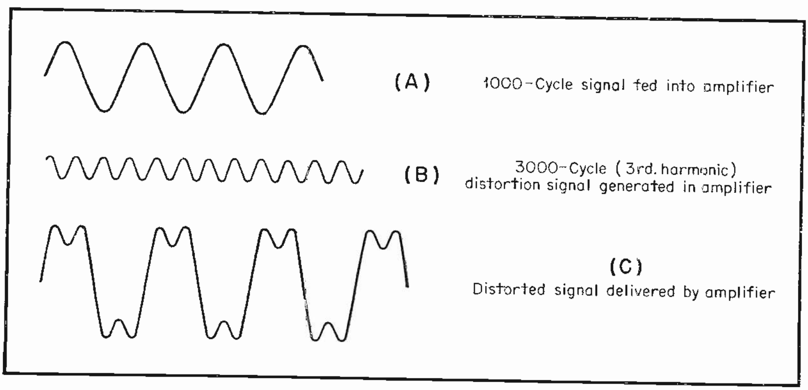

Fig. 2. Pronounced 3rd. harmonic distortion.

fective components; defective loudspeakers; and similar causes. Tube tables give the various distortion percentages which may be expected from tubes. For example: from tube tables, the total harmonic distortion for cathode-biased type 6A3 tubes in pushpull is found to be 5.0%. Type 6L6 as a single-tube class-A_1 300-volt amplifier with cathode bias is listed at 11%.

From the foregoing discussion, it is seen that distortion is caused by harmonics which are generated within the amplifier and which combine in the output signal with the original fundamental frequency. These harmonics have various strengths but ordinarily have lower voltage amplitudes than the fundamental. The 2nd harmonic has one voltage amplitude, the 3rd harmonic another, and so on.

A distortion measurement consists of either (1) measuring the voltage of each individual harmonic separately, determining its percentage with respect to the fundamental, and totaling the percentages **in the proper manner;** or (2) measuring the total harmonic distortion directly.

Each separate harmonic percentage may be found in the following manner:

$$(1) \quad D = \frac{E_2}{E_1} \text{ X } 100$$

Where D is the harmonic distortion at a single harmonic (such as the 2nd)

E_1 is the voltage of the fundamental signal only

and E_2, the voltage of the harmonic only.

Each separate harmonic percentage must be calculated in the same manner separately if we use the first method of distortion measurement. It is important to note, however, that we cannot simply add up these separate percentages to obtain the total distortion. Instead, we must square each percentage, add the squares, and find the square root of this sum. This square root then will indicate the total distortion percentage. The following formula is employed:

$$(2) \quad D = \sqrt{D_2^2 + D_3^2 + D_4^2 + D_5^2 ...... + D_n^2}$$

D is the total distortion percentage. D_2, D_3, D_4, and D_5 are, respectively, the separate percentages of the 2nd, 3rd, 4th, and 5th harmonics. D_n is the percentage of any other harmonic (such as the 6th) which might have been discovered and measured. D_2, D_3, D_4, D_5, and D_n each must be calculated according to Equation (1).

In order to measure each harmonic voltage separately, a wave analyzer is needed. The wave analyzer is an instrument which may be tuned separately, like a radio receiver, to each audio harmonic and which will indicate the voltage of each. The wave analyzer is an expensive laboratory instrument which seldom is found in amplifier service shops. A second, simpler and less expensive instrument, the **distortion analyzer,** will perform the same task, provided a single fundamental test frequency is employed. The **sonic analyzer,** also a laboratory caliber instrument, is of the nature of an automatically-tuned wave analyzer. It pictures the entire audio spectrum on a cathode ray screen, showing the fundamental voltage and each harmonic voltage as peaks or pips of different height.

Another way of checking individual harmonics is to use an oscilloscope. This method involves getting a picture of the output signal (similar to Figure 1-C or 2-C) on the 'scope screen and measuring the height of each harmonic, as well as that of the fundamental. The oscilloscope method is much more complicated than it would seem to be, since the distortion patterns often are not as clearly defined as those shown in Figures 1(C) and 2(C). Also, the oscilloscope method is a time-consuming procedure which many servicemen assert cannot be used profitably.

Most busy servicemen prefer to check the total distortion, rather than that of separate harmonics. This type of test may be made quickly and will show the complete distortion picture.

A simple apparatus setup for measuring total distortion is described later in this article under the heading **Quantitative Distortion Test.**

Qualitative Tests of Distortion

A qualitative test of any kind involves no figures but usually serves only to establish the presence or absence of some factor. The qualitative distortion test shows simply whether or not distortion is present and in which stage it originates. The common qualitative tests, which may be made in the service shop or "on location" are described separately in the following paragraphs.

Ear Appraisal. Some idea of distortion can be gained merely by listening to an amplifier. If the amplifier output signal does not sound natural, something is wrong. Distortion is pretty sizeable, however, before the ear even recognizes it (the ear will tolerate a total distortion up to about 5%). Spotting distortion by ear depends upon so many uncertain factors, such as mental and physiological conditions, that even the trained ear must be regarded as an unreliable instrument.

Plate Current Check. In a class-A_1 amplifier, the plate current remains steady when the signal is applied, if there is no distortion. Any shifting of the zero-signal plate current indicates distortion. The plate current test may not be applied to class-AB_1, AB_2, and B amplifiers, however, since the maximum-signal plate current in each of these types normally is higher than the zero-signal current. To locate distortion by this method, it is not necessary to break the plate circuit and insert a milliammeter. The same result may be obtained by connecting a high-resistance d. c. voltmeter across the cathode resistor of the amplifier stage under test. The cathode voltage should not change when the audio signal is applied or removed.

Grid Current Check. When a class-A_1 or AB_1 amplifier is operating properly, without distortion, no grid current flows. Any tests showing the flow of grid current reveals distortion. A simple test for grid current may be made with an electronic d. c. voltmeter. Simply connect the meter from control grid to ground in the amplifier stage under test. A negative voltage, due to the bias voltage is obtained. This voltage, like the plate current, will not fluctuate unless distortion is present. This test, like the preceding plate current test, can be applied only to class-A_1 and AB_1 amplifiers, since a certain amount of grid current normally flows in class-AB_2 and class-B stages.

Oscilloscope Test. The cathode ray oscilloscope is very useful in tracing out and localizing distortion in the various stages of an amplifier. Particular advantages of this instrument are (1) its wide frequency response, (2) high input impedance, and (3) ability to reproduce waveforms. Two methods of checking with an oscilloscope are described in the following paragraphs.

Method 1

(1) Set the oscilloscope for sine wave patterns (that is, switch-on the internal sweep oscillator) and connect a good sine-wave audio oscillator to the input terminals of the amplifier under test. Place the amplifier and oscillator into operation, along with the oscilloscope.

(2) Connect a test prod with shielded lead to the vertical amplifier input terminals of the oscilloscope. Connect the ground (common) terminal of the oscilloscope to the amplifier chassis or B-minus terminal. Touch the test prod first to the amplifier input terminal and adjust the oscilloscope sweep and amplifier controls to give 2 or 3 **stationary** cycles on the screen.

(3) Touch the test prod successively to the control grid terminal of each stage in the amplifier under test. At no point should the smooth sine-

wave pattern become distorted. A common indication of distortion (usually caused by overdriving the stage under test) is shown in Figure 3(A). Here, the top of each peak is flattened off, resembling a square wave

(3) Distortion is indicated whenever the line or the ellipse loses its smoothness, becoming broken, ragged, or fuzzy, as in Figures 3-D and 3-E.

Quantitative Distortion Test

Figure 5 shows a simple circuit for making quantitative measurements of **total** amplifier distortion. This setup may be used to check a complete amplifier or a single amplifier stage. Because of its function, the circuit often is referred to as a **harmonic totalizer.**

The theory of operation of the device is simple: A bridged-T null network is formed by the iron-core choke, capacitors C_1 and C_2, and resistor R_2. The networks constants have so been chosen that the null frequency equals the fundamental test frequency. This means that the network will remove the fundamental frequency from a distorted wave but will permit all of the harmonics to pass. It is then only

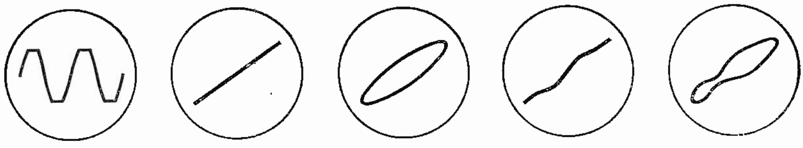

Fig. 3. Oscilloscope patterns for qualitative distortion.

Method 2

(1) Set up the oscilloscope, amplifier, and audio oscillator as described in the previous test, except do not use the internal sweep of the oscilloscope. Instead, connect the horizontal amplifier input of the 'scope to the audio oscillator (See Figure 4).

(2) If there is no phase shift within the amplifier under test, a smooth slanting line will be seen on the screen (Figure 3-B) when the test prod is touched to any signal point in the amplifier. In most instances, however, there is some phase shift and a smooth ellipse (Figure 3-C) will be obtained instead of the line.

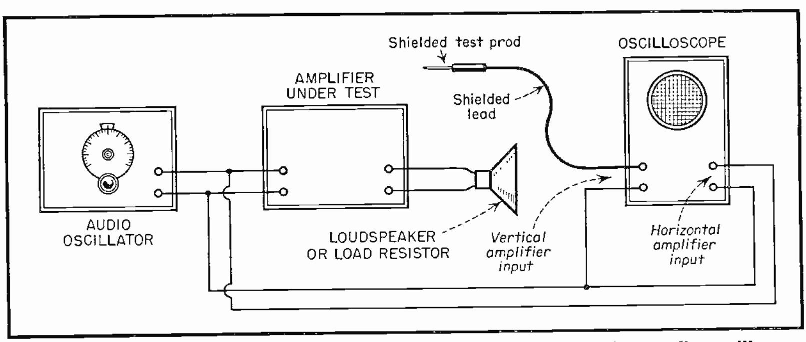

Fig. 4. Showing how 'scope horizontal amplifier input is connected to audio oscillator.

necessary to measure the total harmonic (distortion) voltage (which is the voltage left after the network has removed the fundamental) and to compare this voltage with the full signal voltage. A high-input-impedance a. c. vacuum tube voltmeter or an oscilloscope may be used for the voltage measurement.

After the instrument is completed, it is given its initial adjustment in this manner: (1) Connect a sine-wave audio oscillator to the input terminals of the distortion test circuit. (2) Set the oscillator to 400 or 1,000 cycles (depending upon which values have been chosen for C_1 and C_2). (3) Throw switch S to its left-hand position. (4) Set potentiometer R_1 to its top (full-voltage) position. (5) Adjust rheostat R_2, while at the same timing tuning the oscillator carefully, until the lowest deflection of the voltmeter or oscilloscope is obtained. The network now is nulled, and rheostat R_2 ordinarily will not need to be touched again.

To use the distortion checker: (1) Connect the audio oscillator (set to the null frequency) to the input terminals of the amplifier under test, and set the amplifier gain control for desired power output. (2) Connect the input terminals of the distortion checker to the loudspeaker voice coil or amplifier load resistor. (3) Throw switch S to its right-hand position (this short-circuits the choke and disconnects rheostat R_2, thereby permitting the entire signal voltage to reach the voltmeter). (4) Adjust potentiometer R_1 for full-scale deflection of the meter or a full-screen pattern on the oscilloscope screen. Record this voltage as E_1. (5) Without touching any of the other controls, throw switch S to its left-hand position (the network now is thrown into the circuit and will remove the fundamental frequency) and read whatever voltage remains at null. Record this voltage as E_2. (6) Find the total distortion by means of the following formula:

$$(3) \quad D\% = \frac{E_2}{E_1} \times 100$$

The distortion checker may be built into a small box or case about the size of the conventional serviceman's multimeter.

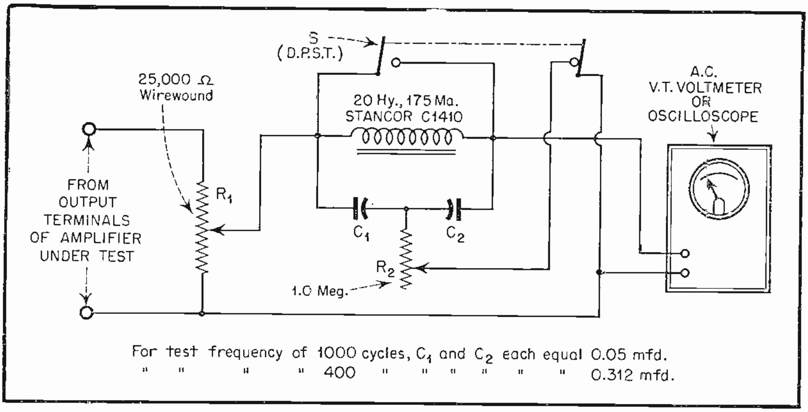

Fig. 5. Simple total-distortion meter.

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