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# Audio Frequency Distortion Measurements

## Part 1, Methods of Measurement

*By the Engineering Department, Aerovox Corporation*

THIS is Part I of a series of two articles which will deal with audio frequency distortion measurements. Part II will give details of a simple, practical instrument designed to measure distortion in audio amplifiers.

The acoustical quality of an audio amplifier is related to the amount of distortion prevalent in the amplifier. If conforming to true Class A operation, the output plate current waveshape of the amplifier should duplicate the waveshape of the grid voltage input. Such not being the case, the amplifier has a certain percentage of harmonic distortion which, if excessive, deteriorates the audio quality and becomes annoying to the listener.

### *Types of Distortion*

There are three types of distortion found in an amplifier; (1) amplitude distortion (2) frequency distortion, and (3) phase shift. In amplitude distortion, the fundamental plus harmonics are observed in the output. Frequency distortion is caused by the amplifier's inability to amplify all frequencies equally. Phase shift is present when the amplifier has different delays for all frequencies. The amount of distortion increases as the tube is operated outside of the linear portion of the tube characteristic curve, as shown in Fig. 1.

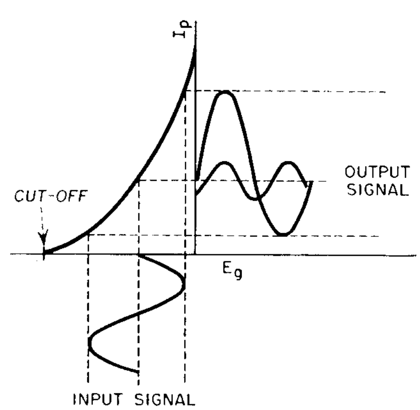
In addition to harmonic distortion, there is intermodulation distortion in audio amplifiers. Both are caused by non-linearity in the amplifier. Intermodulation results in the production of frequencies equal to the sums and differences of a low and high frequency (and harmonics). The intermodulation products of fundamental frequencies F1 and F2 are as follows: The intermodulation products do not resemble the original tones in the input.

$F_1 + F_2$ and $F_1 - F_2$

$2F_1 + F_2$ and $2F_1 - F_2$

$F_1 + 2F_2$ and $F_1 - 2F_2$, etc.

Intermodulation distortion measurements more closely correspond to the non-linear distortion detected by the average radio listener than does a measurement of total harmonic distortion. It is interesting to note that intermodulation distortion can be observed even after no harmonic distortion is measureable.




DISTORTION IN NON-LINEAR AMPLIFIER
FIG. 1

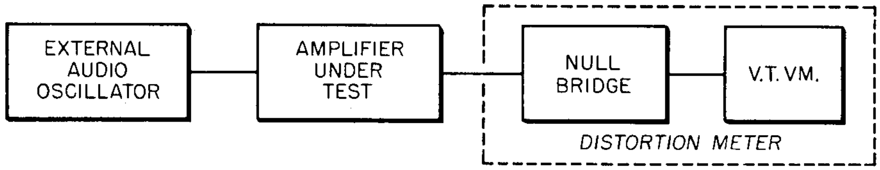
The percentage of total harmonic distortion, represented as the distortion factor, is equal to;

(1)

$$\sqrt{\frac{\text{Sum of squares of harmonic amplitudes}}{\text{Sum of squares of fundamental and harmonic amplitudes}}} \times 100\%$$

and is measured on the distortion meter. The distorted wave shape can be represented by the Fourier series, and the relative values of the terms of the series indicate the amplitudes of the harmonics in the complex wave.

The harmonic content of the signal includes all of the components which are higher in frequency than the fundamental. Signal components which are lower than the fundamental, such as noise from the power supply, are not usually measured. Total harmonic distortion measurements are most frequently made at 400 or 100 cycles per second. Even though this is the standard practice, additional distortion will usually be present at the lower frequencies. The Federal Communications Commission recommends a measurement of harmonics in audio equipment at frequencies of 30, 50, 100, 400, 1000, 5000, 7500, and 15,000 cps.




TEST SET-UP USING DISTORTION METER
FIG. 2

*Distortion Meter*

Audio frequency distortion measurements can be made by using distortion meters, harmonic wave analyzers and intermodulation analyzers. The distortion meter will be discussed first.

A distortion meter gives the percentage of total harmonic content and does not show how much of each harmonic is present in the output. A block diagram of the meter is shown in Fig. 2. Basically, it consists of a null bridge and a vacuum tube voltmeter. The null bridge is tuned to the fundamental such as 400 cycles per second and the bridge is balanced at this frequency to entirely remove the fundamental. The vacuum tube voltmeter will then measure only the amplitude of the harmonics. For accurate measurements, the oscillator generating the fundamental test frequency should be completely free of harmonics. In addition, the **VTVM** should represent the **RMS** voltage as truly as possible. This can be insured by operating the **VTVM** in a manner such that the square root of the plate current versus grid voltage is a linear function.

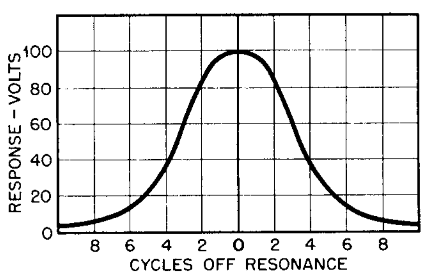
The distortion meter does not indicate which frequencies are present in the complex-distorted wave and the relative amplitude of each. In addition, certain random noises may be very disturbing to the listener and yet show only a small indication on the meter. Therefore, as in many test measurements, the operator must show sufficient skill to translate the results obtained with the meter into useful data.

A typical commercial distortion meter has a frequency range from 50 to 15,000 cps. The distortion percentage is read directly from a meter with calibrated full-scale deflections of 0.3%, 1%, 3%, 10% and 30% distortion. A diode vacuum tube voltmeter is used for measuring the percentage of total harmonic distortion. The scale is also calibrated in decibels. A 100,000 ohm unbalanced and a 600 ohm balanced bridge input circuit are provided. Distortion measurements are made on this instrument with an accuracy of approximately 5%. A distortion-free sine wave oscillator should be used with the meter. Otherwise a residual reading will be measured which represents the oscillator distortion rather than that of the amplifier or other audio device being tested. There should be no distortion even at the very low audio frequencies.

*Harmonic Wave Analyzer*

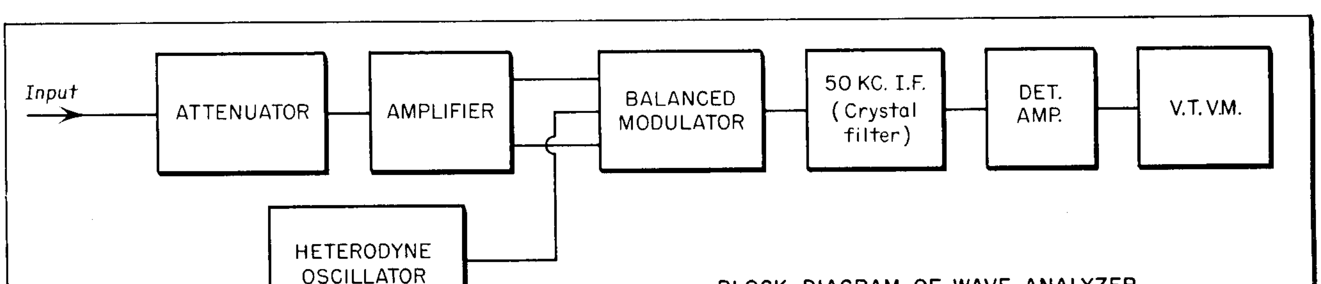
Unlike the distortion meter, the harmonic wave-analyzer is a precision method of measuring distortion and indicating separate components. The wave-analyzer tells the operator which frequencies other than the fundamental are in the complex waveform and also gives the amplitude of each harmonic.

Since the analyzer must determine the fundamental frequency and all of the harmonics, it is necessary that the instrument be capable of tuning to each of these frequencies and of measuring the amplitude of each. The analyzer is really nothing more than a highly selective vacuum tube voltmeter, and is similar to the conventional superheterodyne receiver except that the intermediate frequency is much higher than the input audio signal under observation. The wave analyzer has a very narrow bandwidth, otherwise measurements of harmonics components at the very low audio frequencies would be impossible.




CRYSTAL FILTER CHARACTERISTIC
FIG. 4

The most commonly known wave analyzer is the heterodyne type. A block diagram is shown in Fig. 3 and is representative of a commercial analyzer. The incoming audio signal is heterodyned with the frequency from a variable frequency oscillator and the resultant frequency is amplified by the narrow bandwidth IF amplifier and read on a vacuum tube voltmeter. When the difference between the oscillator and the input signal frequency is 50Kc, the signal will be tuned to the IF amplifier and the amplitude can be measured on the **VTVM**. The three-crystal filter incorporated in the IF amplifier assures a very high selectivity. A response curve of the crystal filter is shown in Fig. 4. The heterodyne oscillator covers a frequency range of 34,000 to 49,980 cycles per second but the dial is calibrated from 0 to 16,000 c.p.s. Assume that the incoming signal is 500 c.p.s. This would correspond to an oscillator frequency of 49,500 since 49,500 plus 500 c.p.s. equals 50 kilocycles. A difference frequency f1-f2 (49,500—500) cannot be amplified. The bandwidth is only 4 cycles and harmonics can be measured easily at the lowest audio frequencies. The input impedance is one megohm, which is sufficiently high to make loading effects negligible. The **VTVM** is directly calibrated in volts and decibels and a 5% voltage accuracy is obtained on all



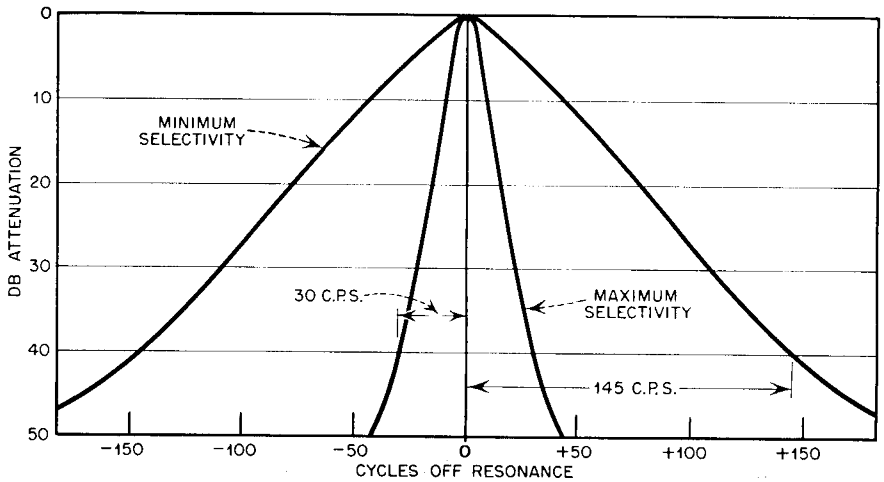

BLOCK DIAGRAM OF WAVE ANALYZER
FIG. 3

ranges from 300 microvolts to 300 volts full scale. The frequency calibration is accurate to ± (2% — 1 cycle).

Another commercial wave-analyzer has the feature of variable selectivity for raid analysis of the complex wave. Where the harmonics are spaced far apart, the bandwidth may be increased, thus making it easier to make measurements. If the harmonics are closely spaced, as at the very low frequencies, the instrument may be made more selective, to separate harmonics 30 cycles apart. A response curve of this analyzer is shown in Fig. 5.

The operation of a wave analyzer involves first tuning the oscillator dial to the fundamental and then adjusting the attenuator until the meter reads full scale. Then the harmonics are found by changing the oscillator frequency dial and recording the amplitude of each.

In addition to it's use for measuring the distortion in an amplifier, the wave-analyzer can be used for measuring distortion in oscillators, transmitters and telephone systems. It can also be used to determine the harmonics in power machinery and to analyze noise characteristics.




VARIABLE SELECTIVITY RESPONSE CURVES
FIG. 5

*The Intermodulation Analyzer*

A block diagram of a typical commercial intermodulation distortion meter is shown in Fig. 6. The amount of distortion is maximum at the highest and lowest transmitted frequencies. However, this discussion will be concerned mainly with intermodulation distortion measurements at the very low audio frequencies. At low frequencies, maximum power output from a tube is not realized because of impedance changes in transformers and reactances. The power output is similarly reduced at the higher frequency because of increased leakage and distributed capacity.

The operation, two frequencies shown on the diagram (Fig. 6) as 100 and 7000 c.p.s. are combined in the mixer. The purpose of the 7000 c.p.s. signal is to act as a carrier for the low frequency components. These two frequencies are commonly used, but a lower frequency ratio must be used if the amplifier under observation has insufficient bandpass. For best sensitivity, the amplitude of the lowest frequency should be 12db above the higher frequency—a voltage ratio of 4 to 1. The output of the mixer is fed to the amplifier under test and it's harmonics. The resultant signal, which is 7000 c.p.s. modulated by 100 c.p.s., is amplified and demodulated by the rectifier. It is then fed to a low pass filter to eliminate 7000 c.p.s., and the output is fed to a VTVM where the intermodulation products are present and the percent of intermodulation distortion is read directly from the meter.

There is no direct relationship between the percentage of total harmonic content and the percentage of intermodulation distortion. With a 12 db ration for the above frequencies, some authorities claim the percent intermodulation distortion is equivalent to;

$$(h_1 \; h_2 \; h_3 \ldots\ldots h_n) \times (n)$$

where h1, h2, etc. are the harmonics and is the order of harmonics. As an example, 10% intermodulation distortion is often equivalent to about 2.5% total harmonic distortion. Since there are no definite standards for these measurements, any figure of intermodulation distortion must be accompanied by a statement of test conditions.

It is hoped that this brief discussion of audio frequency distortion measurements will be helpful in clarifying the general subject distortion measurements. The next article will be especially helpful to those who wish to construct a simple meter for rapid measurement of the percentage of total harmonic distortion and identification of harmonic wave components.

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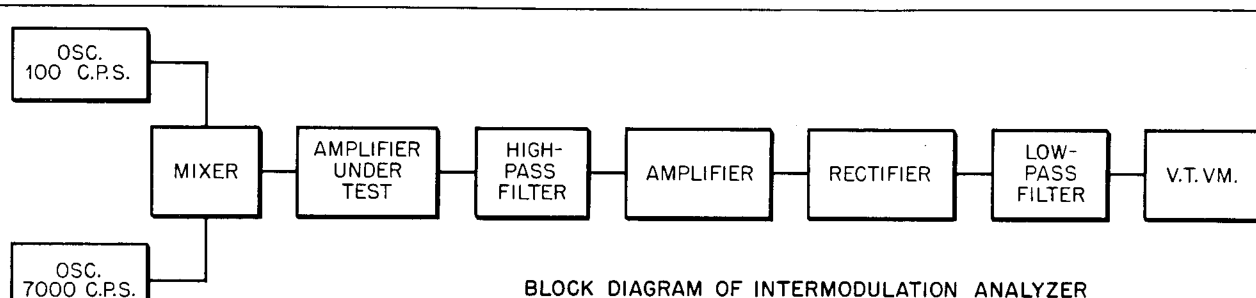


BLOCK DIAGRAM OF INTERMODULATION ANALYZER
FIG. 6


# SMALL SMALLER SMALLEST

## AEROVOX MINIATURIZED Capacitors

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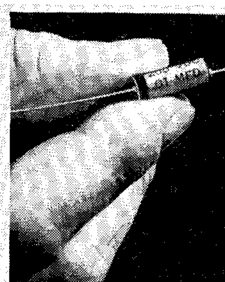

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