# Test Equipment For Transmission And Reproduction of Sound

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There is a growing tendency upon the part of the public to demand and purchase radio receiving sets, phonograph, and public address equipment which has a higher standard of reproduction than formerly was considered adequate. This higher standard of reproduction is accomplished by refinement in design of microphones, amplifiers, radio transmitters of both the AM and FM type, recording and reproducing equipment, and finally loudspeakers. Excellent frequency response was considered the prime requisite in the early days of sound. Later, in addition, emphasis was placed on the need for raising the maximum power requirements. The measurement of frequency response is accomplished by sweeping an audio oscillator continually over the band to be measured and the maximum power output is determined by measuring the individual harmonics generated when a pure sine wave is impressed on the system. In some cases the equipment was rated for 400 cycles only, and in other cases the percentage of harmonics were measured using fundamental waves of 50, 60, or 100 cycles. The harmonics of higher frequencies above 2000 cycles were not considered important because of their relatively low amplitudes. For this reason interest in distortion at the higher frequencies did not merit as much attention as the lower frequencies. Also in recording devices and in radio transmission, the signal to noise ratios were such that the higher harmonics of fundamentals above 5000 cycles were very difficult to measure and it was assumed by a large group, that if the harmonics were out of range of the ear or the reproducing equipment, no impairment in quality would result. Experience with so-called "wide-range" or "high fidelity" systems soon demonstrated that a measurement of frequency response and total harmonic content did not always yield sufficient data to produce a high quality system. Sound originating from a single musical instrument is usually harmonic in character and small relative amplitude changes in the harmonic structure are not easily detectable by ear. Hence, when such sounds are transmitted through a non-linear system (which may be an amplifier or recording system), the resulting distortion will merely change the amplitude relations of the harmonic content and if not too severe will not be especially noticeable. However, where sound originates from a group of sources such as dialog with musical instruments, bells, sound effects, etc., the resulting signal consists of frequency components not necessarily harmonically related. When such signals are transmitted through a non-linear system the resulting signal contains many new frequency components not present in the original signal. These new frequency components, known as intermodulation products, extend throughout the transmitted frequency band and are caused by the intermodulating of the signal frequencies with each other. Such a reproduced signal may be disagreeably harsh in quality and is usually easily detectable by ear. It is not unusual to note in listening to sound programs that a clear quality is obtained when the sound originates from a single instrument but becomes harsh when more complex sounds are added.

Recently, the publication of standards on good engineering practice in connection with FM broadcasts specify an audio frequency band width of 50-15,000 cycles, with very low distortion, since in the presentation of wide frequency range signals, it is necessary that all the elements of distortion be reduced to a very low degree. This is particularly true when the frequency range approaches the goal of utilizing the full capabilities of the human ear. If distortion is not satisfactorily controlled, the results of extending the frequency range will produce a quality which is less pleasing than that obtained with a limited band width.

This error has been repeated many times and in each case the public has reacted unfavorably to what was expected to be an improvement. Experience in the sound motion picture field has indicated that the frequency range is the last element to be widened. Reduction of distortion comes first and then with proper experience, if the distortion and noise level are sufficiently low, the frequency band can be extended. If the standards specifying a 50

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to 15,000 cycle band are to be properly met, a new set of standards for measuring permissible distortion is absolutely essential. I refer not only to distortions of frequency and amplitude, but also distortions through hum and noise and the distortion caused by the interaction of complex frequencies which have come to be known as intermodulation. In order for an amplifier system to provide excellent quality performance, without annoying distortion while transmitting the band from 50 to 15,000 cycles, the complete amplifier system should be capable of passing the following tests:

1. The total hum and other noises measured throughout the entire band should be at least 66 db below the full modulation or overload point.

2. As determined by means of an oscillator and oscilloscope, the maximum sine wave carrying capacity for the system should be determined for all frequencies in the transmitted band. It is desirable for the amplifier system to have reserve sine wave carrying capacity of at least 6 db beyond full modulation.

3. Frequency response runs should be made at the maximum level determined by Test #2. An additional frequency response measurement should be made at a level 30 db below that point and a third frequency run should be made at a level of 60 db down from the maximum operating level. There should be no significant difference in the frequency response of the amplifier system at these three levels of output power.

4. Determine the intermodulation products of the amplifier system by the methods outlined herein. For a direct transmission 6% intermodulation should not be exceeded anywhere in the frequency band. If the signal is to be recorded and re-recorded, or if it is to be transmitted through a network of amplifier systems, it is desirable for the intermodulation products to be held below 4%. Amplifier systems which will meet all these requirements can be built, but they require much greater attention to design than they have been previously accorded.

Amplifier systems which will not meet these tests will fail to meet the objectives of truly high quality reproduction. The measurements of hum and other noises, the measurement of maximum sine wave carrying capacity for the entire band, and the measurement of frequency response at the designated levels all utilize techniques with which the audio frequency engineer is familiar. Intermodulation tests consist of transmitting simultaneously two known frequencies through the equipment under test and then measuring the degree of interaction and distortion of these two frequencies by determining the amount of new frequencies which have been generated. The two known frequencies are applied to the input of the amplifier under test from the signal generator.

The output attenuator of the signal generator is adjusted so as to produce the required amount of power from the amplifier under test. The output of the amplifier or system being tested is connected to the input circuit of the intermodulation analyzer. The input attenuator on the analyzer is then adjusted until a carrier level meter reads 100%. The intermodulation percentage meter then reads directly the amount of distortion present.

## THE SIGNAL GENERATOR

Figure 1 shows a block diagram of the signal generator which contains two independent resistance-capacity sine wave oscillators. We have a choice of frequencies consisting of 40, 60, or 100 cycles from the low frequency oscillator and 2000, 7000, or 12,000 cycles from the high frequency oscillator. The output of each oscillator is transmitted by a cathode follower to a hybrid coil which combines the two oscillator outputs.

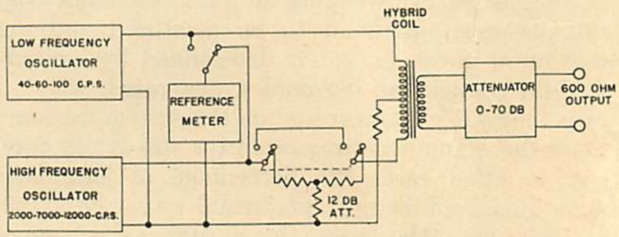



**Fig. 1. Signal generator block diagram.**

A 12 db fixed attenuator is provided in the high frequency oscillator output so that the low frequency is transmitted 12 db higher than the high frequency. This differential ratio of low to high frequency amplitudes is arbitrary and is used to obtain the maximum low frequency sensitivity of the test.

For other test conditions, in particular where distortion is predominantly at high frequencies, it may be advisable to use other amplitude ratios for the two test frequencies. For this reason a switch is provided to give either a 1-1 or 1-4 ratio of the two signals. An output meter, a variable attenuator of 30 db range and fixed attenuation of 20 and 40 db are available by means of a selector switch to control the output. A ganged dual potentiometer is provided at the input of the cathode followers for a vernier adjustment of the output power.

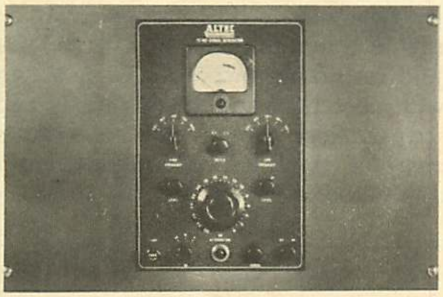


Fig. 2. The signal generator.

INTERMODULATION ANALYZER

A block diagram of the intermodulation analyzer is shown in Figure 3. The input attenuator system is adjustable over a 90 db range in 1 db steps, and is capable of dissipating 50 watts. The input impedance is 600 ohms.

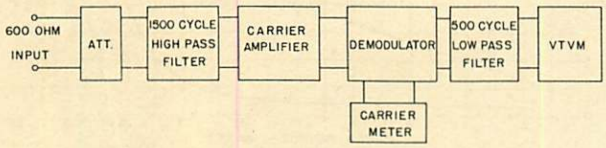



Fig. 3. Intermodulation analyzer block diagram.

The equipment under test receives its input from the signal generator and delivers its output to the input circuit of the analyzer. The output of the equipment under test consists of a low frequency with a high frequency superimposed upon it, plus harmonics of the original tones, plus intermodulation distortion. In order to measure this intermodulation, it is necessary to move the original low frequency component. This is accomplished by means of a 1500 cycle high pass filter which follows the attenuator. The output of the filter band now consists of what may be termed a carrier and its resultant side bands. This carrier is then amplified to a predetermined level and then demodulated. The reference level is obtained by adjustment of the input attenuator to provide a 100% reading on the carrier meter. The output of the demodulator is transmitted through a 500 cycle low pass filter which removes the carrier frequency and transmits only the ripple components up to 200 cycles.

Discussion in the literature has indicated that both first and second order intermodulation components generally are present in the distortion of audio frequency transmission equipment. For this reason it is considered essential that measuring equipment should record many such components rather than limit itself to only first order components, and in some cases it has been found that the measurement of 3rd, 4th, and 5th order is necessary to obtain an accurate analysis of the distortion.

The 500 cycle low pass filter has been set so that the 5th order terms will be accepted for all the original low frequencies, more being accepted for the 60 and 40 cycle tones.

The choice of the 1500 cycle cut-off for the high pass filter has been dictated by the requirement that at least 60 db of discrimination be inserted against all low frequencies available in order that values of intermodulation can be measured down to 0.1%.

The ripple components of intermodulation products are amplified and measured by the vacuum tube voltmeter. The meter is calibrated directly in percentage intermodulation and has six ranges with full scale sensitivities of 0.3, 1.0, 3.0, 10, 30, and 100%.

Terminals are provided on the front panel labeled "A scope" and "B scope." The "A" scope terminals are connected across the output of the carrier amplifier and the "B" scope is connected across the output of the vacuum tube voltmeter. By using an oscilloscope at either of these points, the order of distortion may be observed.

Figure 4 shows that the analyzer may be used as a voltmeter. The frequency range of the millivolt meter is flat within 1 db from 20 to 20,000 cycles and on the voltmeter scale its range is 20 to 50,000 cycles.

The inclusion of the vacuum tube voltmeter provides a method of measuring signals or noise levels accurately. The meter scales read in volts, with maximum sensitivity corresponding to a full scale reading of 0.3 millivolts, and in db relative to 1 milliwatt across 600 ohms. In shifting from the measurement of percentage intermodulation to voltage, the termination of the amplifier under test is not altered.

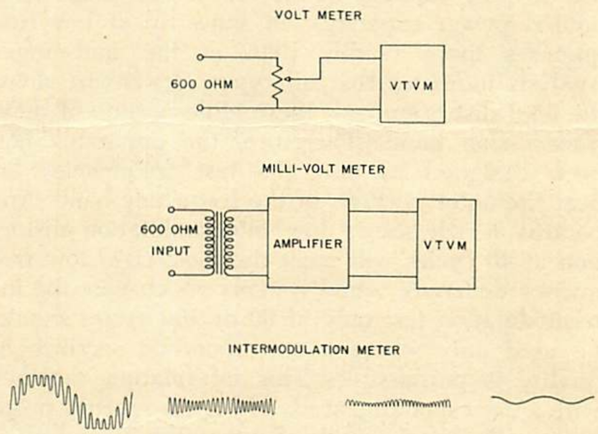



Fig. 4. Analyzer can be used as a voltmeter.

The sensitivity for zero on the db scale has a range from —70 to plus 40 dbm in twelve—10 db steps. Since the scale is calibrated so that a —20 db point is readable, a range down to —90 dbm is possible. Frequency response curves and noise levels may be obtained by using the voltmeter and millivoltmeter. The two scales enable the data to be taken in either decibels or volts. A bridging jack is also provided so that the vacuum tube voltmeter can be bridged across any portion of a circuit where a shunt of 1.0 megohm will not influence circuit conditions.

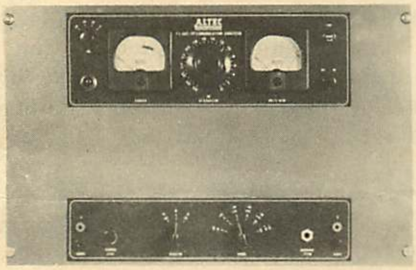



**Fig. 5. The Analyzer.**

The writer wishes to stress the importance of the transmission of the amplitudes and wave forms of low frequencies which occur simultaneously with the higher frequencies of speech and music. These low frequency components originate in drums and other percussion instruments, in the reproduction of gun shots, explosions, thunder, earthquakes, etc.

Unless a transmission system has the carrying capacity at low frequencies to handle these sound effects, extreme distortion may result. Therefore, it is considered essential to test a transmission system in such a manner as to stress these low frequencies. Transformers and other devices which change their impedance at low frequencies are a major cause of distortion because this impedance change limits the carrying capacity of the tubes. For this reason limited power capacity will show up at low frequencies more readily than in the mid-range. Analysis indicates that all types of systems show the least distortion near the middle portion of their transmission band. Therefore, the apparatus has been designed so that the test frequencies lie near the outer portions of the frequency band. Apparatus which shows low intermodulation distortion at 40 cycles will meet the most rigid low frequency demands, while systems which pass the intermodulation test only at 60 or 100 cycles should be used only where a corresponding sacrifice in quality is permissible. This information together with a corresponding study of high frequency properties will determine the band width for which a particular system is suitable.

Figure 6 shows the intermodulation curves on three classes of amplifiers. Curve "A" represents a poor public address amplifier which is not suitable for any application since even though the amplifier is rated at 14 watts the distortion is excessive at one or two watts. "B" is representative of the average high grade amplifier now in use for radio station and recording purposes. "C" is an amplifier which will meet the rigid specifications called for in this paper. Poor design and not cost alone is responsible for the high intermodulation at low levels in the case of curves A & B.

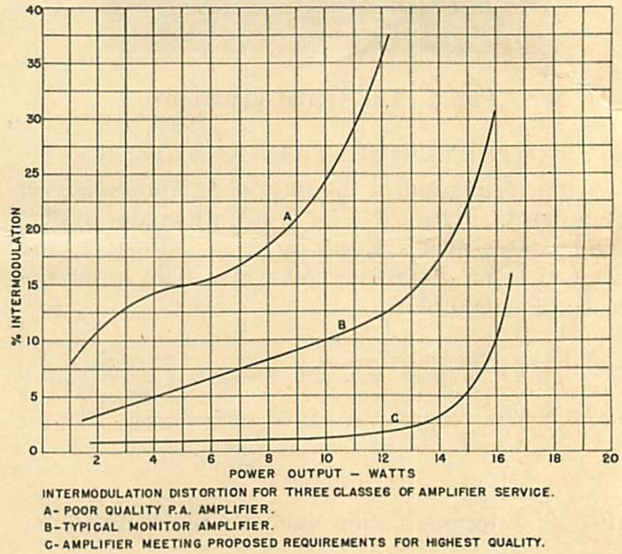



**Fig. 6. Intermodulation curves on three classes of amplifiers.**

Figure 7 shows the improvement which can be made in an amplifier by the substitution of an improved output transformer. It will be observed that the low frequency carrying capacity has been increased and the distortion has been reduced for all levels of operation. Most of these curves have shown conditions where overload occurs first at low fre-

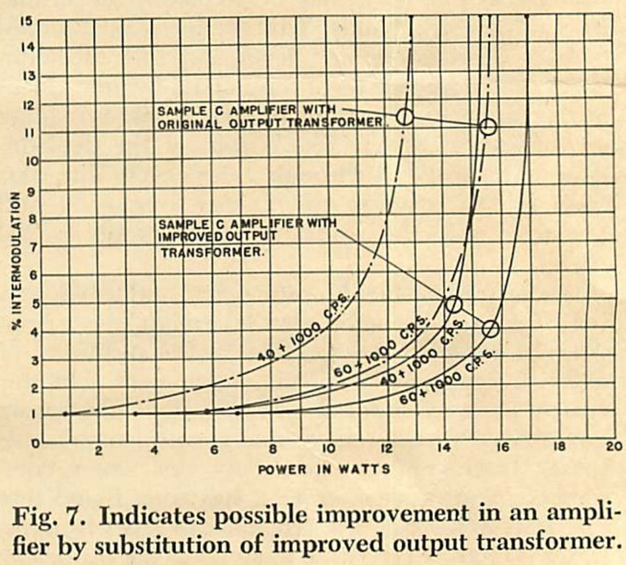
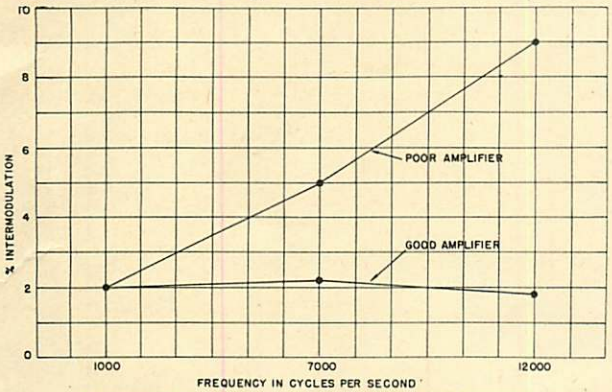



**Fig. 7. Indicates possible improvement in an amplifier by substitution of improved output transformer.**

quencies. Figure 8 indicates a condition where high frequency distortion predominates.




MEASUREMENT OF INTERMODULATION DUE TO HIGH FREQUENCY DISTORTION.
LEVEL OF HIGH FREQUENCY SIGNAL EQUALS LEVEL OF LOW FREQUENCY SIGNAL.

**Fig. 8.**

An amplifier having low intermodulation distortion at all frequencies was modified so as to reduce its power handling capacity at high frequencies without destroying its low frequency properties. For the test the two frequencies from the signal generator were adjusted to be of equal amplitude. It is clear from the curves that the intermodulation measurements will indicate the presence of high frequency distortion when it is not masked by low frequency distortion.

The intermodulation test equipment is extremely useful in making tuning adjustments on radio transmitters. It has been demonstrated that the optimum adjustment can be obtained in considerably less time with two frequencies than with the conventional meter tuning on one frequency. In most cases also a reduction in distortion can be obtained by the intermodulation method since the two widely separated frequencies such as 60 and 12,000 cycles check both the proper tube adjustment and flatness of tuning circuits required to pass a given band width.

## CONCLUSION

Without exception it has been the writer's experience that listening tests will confirm the relative intermodulation test figures. All other things being equal, critical listeners will select the system having the lowest percentage of intermodulation in a performance test.

The intermodulation test does not of itself provide all the information required by the engineers. It needs to be supplemented by the frequency response, noise, and power tests mentioned earlier in this paper. When used in conjunction with these other tests, it is the writer's belief that this intermodulation method of testing represents a major tool which is essential in the design, production, and maintenance of amplifier systems which can meet the objectives of the FCC standards on good engineering practice.

The writer wishes to acknowledge the important work done by Mr. W.C.B. Evans who has shared the responsibilities of designing the equipment.