THE General Radio EXPERIMENTER

VOLUME XXV No. 10 MARCH, 1951

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

INTERMODULATION DISTORTION

● **NON-LINEAR DISTORTION** affects the reproduction of an acoustic signal by introducing components that are not present in the original. The effect of these extraneous components is one of annoyance to the listener, first, because they can interfere with, or mask, the desired signal, and, second, because they can make the reproduced signal sound unpleasant to the listener.

Both these effects are subjective. They are measurable only by psychological techniques and not by any existing objective tests with physical instruments. Such factors as annoyance, masking, and loudness are evaluated statistically from the results of a large number of tests on many listeners to give an average subjective impression of "normal" listeners. Much work has been done in this field, particularly by the Psycho-Acoustic Laboratory at Harvard University, the Bell Telephone Laboratories, some government laboratories, and numerous other university laboratories both here and abroad. Much remains to be done, particularly on the factor of annoyance, which is affected so much by past influences, by what one is trying to do at the moment,

We are finding it increasingly difficult without extending DO ratings to obtain the raw materials and precision components which are required for the manufacture of General Radio equipment.

In addition, so many priority-rated orders are being received that the delivery of material against unrated orders is becoming increasingly uncertain. We are still accepting unrated orders and are doing our utmost to fill them, but it becomes more difficult every day.

The Rating DO-98 can be obtained for the procurement of essential equipment by addressing a request to your Contracting Officer if you are a prime contractor of a military department. If you are a subcontractor, the request should be addressed to the prime contractor, who will in turn get in touch with the military department concerned.

We urgently request, therefore, that, to insure against unreasonable delay and to assist us in replacing inventory, you do everything possible to obtain and to extend to us priority on any of your unrated orders which we may now have or on any new orders which you will be placing with us.

and by the time sequence of events. In addition, there is the task of devising satisfactory physical tests for sound-reproducing equipment to evaluate factors that can be correlated with the results of the psychological tests. Some of these possible physical tests are considered here.

For many years the main test for nonlinear distortion has been the harmonic distortion test, which evaluates the harmonic components generated by nonlinear amplification and reproduction of the applied signal. It has long been recognized, however, that some systems with very low harmonic distortion still do not sound "right" to the hearer.

Because of this inadequacy of the harmonic distortion test, intermodulation tests have been developed. The first of these measures the modulation of a high-frequency tone by a low-frequency one, a method that gives satisfactory results on some systems and has been adopted by the Society of Motion Picture and Television Engineers (SMPTE).

Even this test is inadequate for some purposes, as will be shown later in this article, and a third method which measures the difference tones produced by the intermodulation of two high-frequency tones has been developed. For a single test method, this appears to be the most satisfactory.

The acceptability of this test, which is recommended by the International Telephonic Consultative Committee (CCIF), is shown by a series of distortion tests recently made on a hearing aid. These tests are discussed in terms of rating the hearing aid, and they are also used to illustrate possible effects that can cause trouble in other sound reproducing systems.

This hearing aid, a high-quality one and of excellent workmanship, was obtained through the courtesy of the Harvard University Psycho-Acoustic Laboratory, where quality ratings by subjective test had been made on it. It has a tone control that permits two settings, and the test panel rated the quality as markedly poorer with the tone control in the *A* position than in the *B* position. This is the reverse of what might be expected from the frequency response characteristics for the two positions, which show a better high-frequency re-

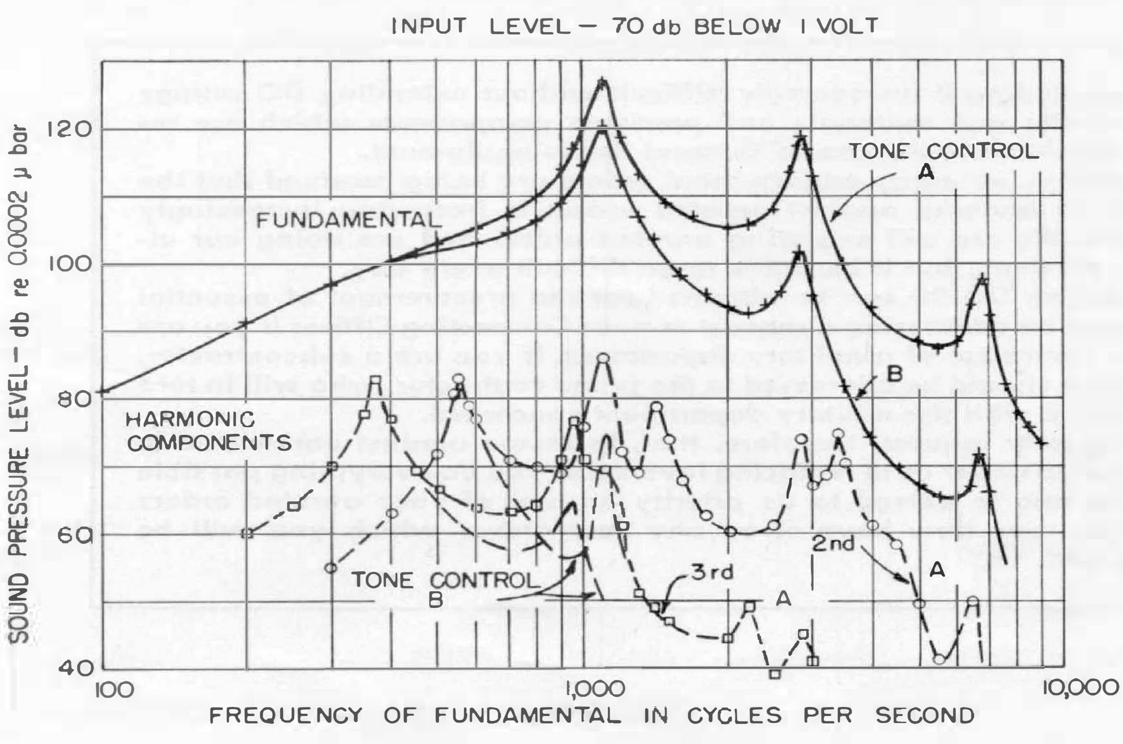


Figure 1. Sound-pressure level produced by the earphone as a function of frequency for the two positions of the tone control. Fundamental and harmonic components are plotted at the fundamental frequency.

sponse for the *A* position. These curves show the marked resonances that are typical of hearing aids (see Figure 1).

TEST CONDITIONS

The hearing aid was tested for non-linear distortion by supplying an electrical input at the microphone terminals from a General Radio TYPE 1303-A Two-Signal Audio Generator[1].

The earphone of the hearing aid unit was connected to an approximate equivalent of the standard 2-c.c. coupler[2], using an Altec Lansing 21B Microphone as the transducer. The output of the microphone was analyzed by a General Radio TYPE 736-A Wave Analyzer. In each figure, the levels shown are sound-pressure levels in the 2-c.c. coupler, and the operating level was selected to correspond approximately to that for which the quality ratings were made.

HARMONIC DISTORTION

The harmonic distortion results of Figure 1 show the typical resonance peaks normally found in these measurements. They do show that the distortion in the *B* position is lower than in the *A* position, which is in the right direction. However, in the region above 700 cycles, where there is a difference, the distortion components are, in either case, 40 to 50 db down from the fundamental. They are therefore almost completely masked by the fundamental. For either position of the tone control, the distortion is in the range of what is normally considered good quality.

INTERMODULATION SMPTE METHOD

The results of some measurements by the second method are shown in Figure 2 as a function of frequency. A high-frequency signal and a lower-frequency signal were simultaneously applied at the input. The output levels of these signals are shown for reference. In one case a signal of 1 kc was used as the high-frequency signal, and in another the high-frequency signal was 7 kc. In general the distortion components are 40 to 50 db below the level of the desired

[1]A. P. G. Peterson, "An Audio-Frequency Signal Generator for Non-Linear Distortion Tests," *General Radio Experimenter*, August, 1950.

[2]ASA Z24.9-1949, "American Standard Method for the Coupler Calibration of Earphones."

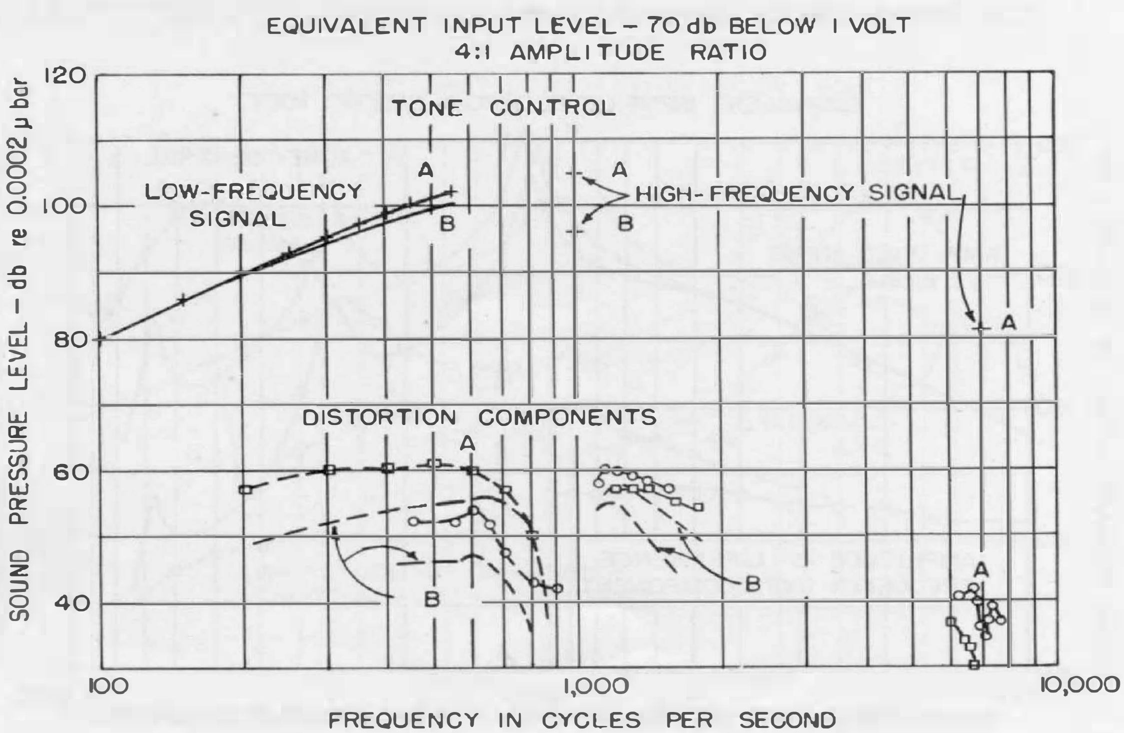


Figure 2. Sound-pressure level of intermodulation distortion components as determined by the SMPTE method. Each component is plotted at its own frequency. Upper curves show the level of the amplified input signals.

signals, so far down that they are completely masked by the desired signals. Here again we have no satisfactory indication of serious distortion.

INTERMODULATION CCIF METHOD

The final method of test is the difference-frequency intermodulation method, and some results by this method are shown in Figure 3. Two sinusoidal test signals of equal amplitude were simultaneously applied, and the difference in frequency between the two was kept at 1100 cycles. The amplitude of the undesired first-difference component at 1100 cycles is shown here as a function of the frequency of the lower-frequency signal. The amplitude of the amplified input signals is also shown for comparison.

At low frequencies the distortion is relatively low, and this part is in agreement with the harmonic test. But at frequencies above 1500 cycles, the distortion becomes very large for the tone control in the *A* position. This result is markedly different from that obtained by the harmonic test where the distortion at high frequencies was small. Thus the harmonic test would lead one to assume that the distortion problem was mainly a low-frequency one, while this test shows that the really serious distortion occurs at the high frequencies.

Considered from the viewpoint of masking effects, it is clear that this 1100-cycle component is strongly audible when input signals above 2000 cycles are used. The dissymmetrical nature of the masking curve at high levels[3] makes this form of distortion particularly noticeable, because the unwanted component is at a lower frequency than the desired components.

Another important point to notice in this figure is that the distortion for *B* position of the tone control is much less than for the *A* position. This degree of reduction is sufficient to lead one to expect a marked improvement in quality when the tone control is changed from the *A* position to the *B* position. Here is the first objective test that has shown definite confirmation of the subjective result.

The 1100-cycle difference frequency was selected because of the strong response peak at that frequency. The question then arises: Is the distortion

[3]S. S. Stevens and H. Davis, *Hearing*, New York, John Wiley & Sons, Inc., 1938, Chapter 8.

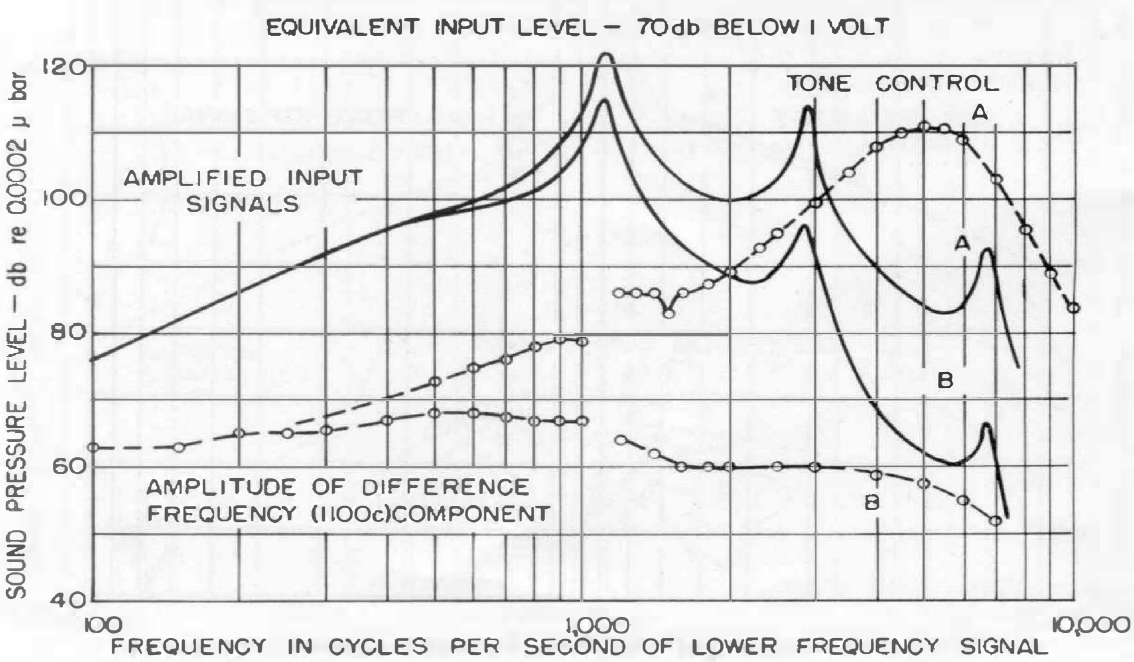


Figure 3. Sound-pressure level of first-order intermodulation component plotted as a function of the lower-frequency input signal.

for other values of difference frequency also large? Results for other values are shown in Figure 4. The 1100-cycle results are reproduced here, and in addition there are distortion characteristics for difference frequencies of 900 cycles, 1500 cycles, and 2850 cycles. The 2850-cycle value is also at a response peak, but the other two values are away from the peaks of response. All show the same general tendency of a gradual rise to high values of distortion at the higher frequencies, but the distortion components in the vicinity of peaks of response are the most important.

The results as a function of level for a particular pair of input signals are shown in Figure 5. At the left is the analyzed sound pressure for the tone control in the *A* position and on the right, for the *B* position. The levels of the desired signals at 3000 and 4100 cycles are shown by the solid lines, and the levels for the distortion components are shown by dashed lines. In both cases the level of the higher-order difference terms at 1900 and 5200 cycles are small compared to the level of the first difference of 1100 cycles. At the assumed operating input level of 70 db below 1 volt, the 1100-cycle distortion component for the *A* position is only 4 db lower in level than the stronger of the two desired components. In the *B* position the level of distortion has dropped to 28 db below the strong 3000-cycle signal. This 24 db improvement certainly would be expected to show up in a subjective test as a marked improvement in quality, which is in agreement with the subject test.

The results shown have been obtained on only one hearing unit, and, consequently, no final conclusions can be drawn. But these results are probably typical because of the usual over-all reduced power handling capacity of hearing-aid units at high frequencies, and because of the marked response peaks occurring in most hearing aids. Therefore, it is highly probable that the difference-frequency intermodulation test is generally the most significant non-linear distortion test for hearing-aid units.

The foregoing results should not be interpreted as indicating that hearing aids are low-quality devices. Both the performance requirements and the design limitation of a device to compensate for hearing loss differ considerably from those of a system to reproduce sound in

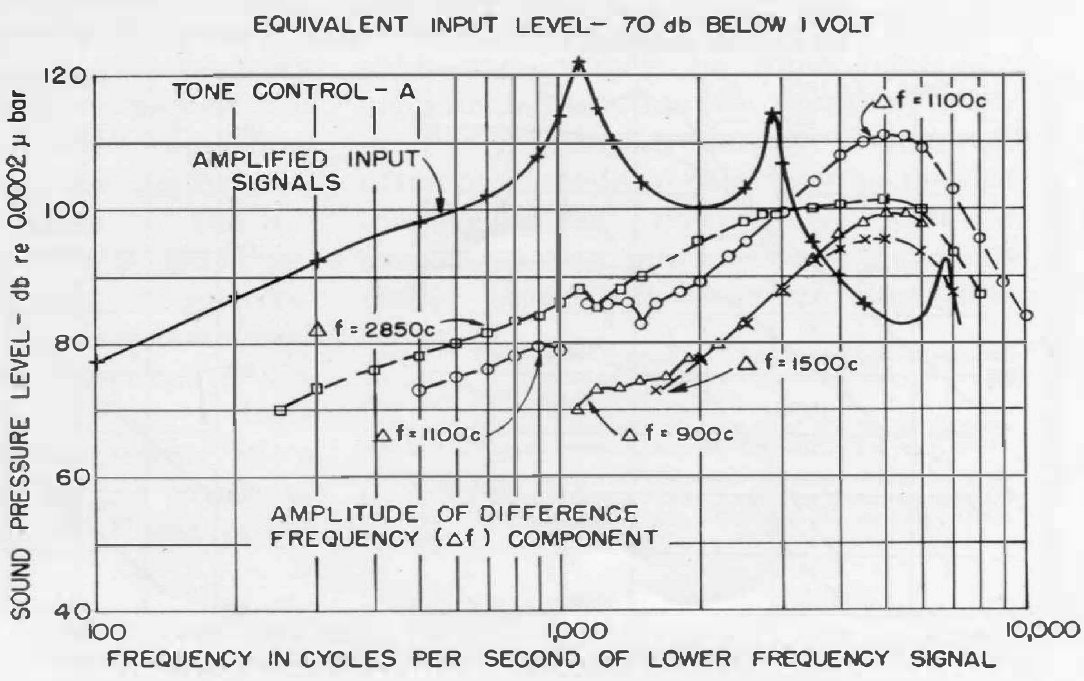


Figure 4. First-order intermodulation distortion for four values of difference frequency.

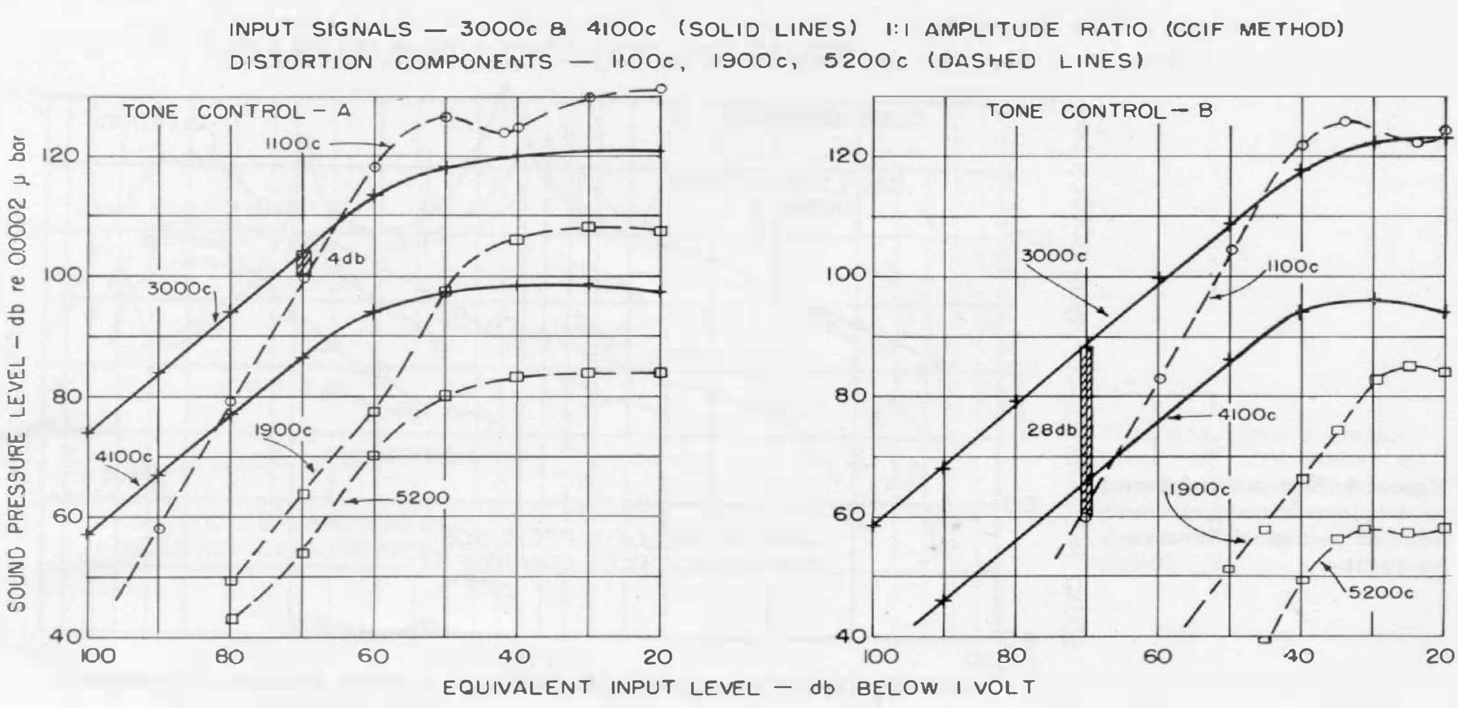
a communication system. Small size and light weight are essential, and the amplifier seems unbelievably small to the engineer accustomed to working with audio power amplifiers. The desirable frequency response characteristic is determined by subjective tests which, for this product, are the ultimate proof of consumer acceptability.

The measurements on the hearing aid were made because of the available psychological data and because the electrical setup was simple. This type of investigation should be extended, and we should like to encourage those who are interested and capable of doing so to pursue the problem for other communication elements. In order to encourage this further investigation, a few possibilities are discussed below, but it should be noted that adequate experimental proof of these possibilities is not yet available.

OTHER AUDIO SYSTEMS

Effects which are similar to those shown here for hearing aids occur in audio amplifiers, radio receivers, public address systems, and other electroacoustic devices. One of these is the effect of resonant peaks of response. These peaks of response can exaggerate components produced by distortion to a serious degree. For example, most loudspeakers used on radio receivers do not have a smooth and uniform response characteristic as a function of frequency. The poor characteristic is mainly a result of the great difficulty, and consequently great expense, of obtaining a better characteristic. In addition, some loud-speakers are intentionally made to have markedly higher response in the moderately low-frequency range. This hump in the characteristic gives a typical boominess that is desired by some, but that quickly becomes annoying to others. With this type of response from a reproducer, one hears a boominess associated with speech and most music, even when there obviously are no strong low-frequency tones present in the original. It is easy to see that these components can be produced by non-linear distortion. The intermodulation of two higher-frequency tones produces the

Figure 5. Intermodulation distortion as a function of input level. The operating level for the subjective tests corresponds to an input level of approximately 70 db below 1 volt.



lower-frequency tone as a difference frequency. Then because of the exaggerated response at the low frequencies this tone can become relatively strong with the associated effects described above. In measuring the magnitude of this distortion, it is necessary to include the loud-speaker in the measurements, and an excellent microphone is required as a pickup. After determining an over-all response characteristic, the CCIF test can be made as a function of frequency with the difference frequency set to the various maxima in the response characteristic.

The extensive use of pre-emphasis of high frequencies in present-day communication systems has increased the power handling requirements at high frequencies. The CCIF test is the best for determining the effect of the pre-emphasis. If intermodulation occurs after pre-emphasis to produce a lower-frequency difference tone, then this component becomes more important after de-emphasis, since the higher-frequency desired components are reduced more in level than the undesired low-frequency component. The usual recording systems of today use pre-emphasis of the high frequencies. But most of them are fortunately arranged to be essentially symmetrical in action so that under normal conditions very little of this first difference component is produced. For example, the symmetrical nature of the magnetization characteristic of magnetic tape is one of the important factors in its success. However, if an unbalance occurs in the magnetization, either because of dissymmetrical biasing or residual d-c components, distortion can occur to produce a first-difference frequency component of a magnitude depending on the extent of the dissymmetry. This CCIF test for the first difference can be a sensitive check on proper biasing, and the test for the second difference can be used to show up additional distortion[4].

A few radio manufacturers have attempted to compensate for poor high-frequency response in loud-speakers by boosting or pre-emphasizing the high frequencies. This process is intended as a step toward high fidelity and increased brilliance of reproduction. However, the increased power handling ability that this requires at high frequencies is frequently not provided. The result is increased distortion. The characteristic drop in output at high frequencies in the loud-speaker then reduces the level of the high-frequency signals compared to any lower-frequency intermodulation components. The usual result is that the radio reproduction sounds better when the controls are set at a normal position rather than at this so-called "high-fidelity" position. The proper method of checking for this type of trouble is by the CCIF test with the loud-speaker included as a part of the system.

Because of non-linearity in the loud-speaker suspension and cone material, subharmonics can be generated in many loud-speakers.[5,6] These occur at a number of distinct frequencies, and the subharmonic may be some relatively complicated fraction, for example, 5/13, of the exciting frequency. When an attempt is made to excite subharmonics directly, a high power level must be used, and the subharmonics build up rather slowly. Because of this slow

[4] L. C. Holmes, "Techniques for Improved Magnetic Recording," *Electrical Engineering*, Vol. 68, No. 10, October, 1949, pp. 836-841.

[5] H. F. Olson, *Elements of Acoustical Engineering*, New York, D. Van Nostrand, Second Edition, 1947, pp. 167ff.

[6] H. H. Hall and H. C. Hardy, "Measurements for Aiding in the Evaluation of the Quality of Loud-speakers," Abstract, *J. Acous. Soc. Am.*, Vol. 20, No. 4, July, 1948, pp. 596f.

build-up, it has been suggested that these subharmonics cannot become a significant factor in the reproduction of music and speech. However, because these signals are complex, other factors may enter to make occasional generation of subharmonics possible of sufficient magnitude to become annoying. One tone appearing in a signal may be at a frequency for which subharmonics can occur and it may have associated with it a tone different in frequency from the first by a value approximately equal to the subharmonic. Then non-linear distortion in the driving amplifier may generate enough of this difference frequency to aid in subharmonic generation at a level much lower than normal. In addition it can produce an initial signal to cause build-up of the subharmonic to a significant level in a much shorter time than is otherwise possible.

EQUIPMENT

In general an investigation of effects of the type described requires a versatile signal source. Not only are two tones required for the intermodulation tests, but also each tone must be adjustable in frequency over a wide frequency range. The General Radio Type 1303-A Signal Generator[1] provides this versatile signal source, and the General Radio Type 736-A Wave Analyzer is a suitable, highly selective voltmeter to use as a detector for determining the extent of the non-linear distortion.

—A. P. G. Peterson

[1] Loc. cit.

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company address, type of business company is engaged in, and title or position of individual.

GENERAL RADIO COMPANY
275 MASSACHUSETTS AVENUE
CAMBRIDGE 39 MASSACHUSETTS
TELEPHONE: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK 6, NEW YORK
90 WEST STREET
TEL.—WOrth 2-5837

LOS ANGELES 38, CALIFORNIA
1000 NORTH SEWARD STREET
TEL.—HOllywood 9-6201

CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE
TEL.—WAbash 2-3820

PRINTED IN U.S.A.