HANDBOOK OF NOISE MEASUREMENT

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HANDBOOK

OF

NOISE MEASUREMENT

by

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Arnold P. G. Peterson
Leo L. Beranek

July, 1954

Cambridge, Mass., U. S. A.

CHAPTER I

INTRODUCTION

During the past decade more and more people have become concerned with the problem of noise in everyday life. Manufacturers of home appliances, such as vacuum cleaners, mixers, and washers, have found that a noisy product meets sales resistance. Manufacturers of large industrial equipment, such as distribution transformers, which must be located in or near residential areas have found that care must be taken in the construction and installation in order that noise levels are not annoying to the neighbors. Trucking companies receive complaints when mufflers are inadequate or become defective. Manufacturers of airplane propellers and engines, and particularly of jet engines, have found that the noise from their test stands has created a serious community problem.

There is danger of permanent hearing loss when exposure to an intense sound field is long and protective measures are not taken. This problem has of late become a matter of serious concern to industrial corporations, labor unions, and insurance companies.

Lack of proper sound treatment in the classroom may lead to excessive noise levels and reverberation, with resulting difficulties in adequate communication between teacher and class. The grade-school teacher's job may become a nightmare because a few corners were cut to decrease, by some small fraction, the initial cost of the classroom.

The General Radio Sound-Measuring System has been developed to help the many people whose job it is to determine the noise output from machines, trucks, airplanes, and appliances, or the noise environment in homes, schools, factories, and recreation centers.

In addition to the measurement of noise, or undesired sounds, this equipment has many applications in measuring the performance of systems transmitting music and speech, in evaluating the characteristics of acoustic materials, in psychoacoustic studies, and in many other fields of physical science, engineering, and the social sciences.

To the physicist, noise is a sound, whose character can be defined and whose properties can be measured with the same equipment that measures other sounds. To the psychologist, who is also interested in all types of sounds, noise is an undesired sound, as contrasted to music and speech, which are usually "desired" sounds. Whenever we deal with the effects of physical phenomena on human beings, we are working in a field where the interests of the psychologist and the physicist overlap. The result is usually a happy collaboration, and in no field has this collaboration been more fruitful than in the measurement and evaluation of the effect of noise.

The evolution of a system of measurement and interpretation involves the creation of a framework of definitions and descriptive terms and also a standardized system of measuring instruments. Both are necessary, the former in order that all workers in the field may understand one another, the second in order that results of different investigators may be compared and that procedures be standardized for use by other, and less specialized, workers.

The purpose of this booklet is to help those who are faced, possibly for the first time, with the necessity of making sound and noise measurements. It attempts to clarify the terminology and definitions used in sound measurement, to describe the measuring instruments and their use, to aid the prospective user in selecting the proper equipment for the measurements he must make, and to show how these measurements can be interpreted to solve typical problems.

Figure 2-1. Typical over-all sound levels measured with a sound-level meter (levels below 85 db are weighted according to the method given in Section 2.3). Sound-level measurements give only part of the information usually necessary to handle noise problems and are often supplemented by analysis of the noise spectra and by oscillographic studies.

CHAPTER II

THE DECIBEL—WHAT IS IT?

Air-borne sound is a variation in normal atmospheric pressure. For a pure tone, the number of times per second that the pressure changes through a complete cycle is the frequency of the sound. Thus, the standard tone "A" has a frequency of 440 cycles per second (frequently called "cycles" and abbreviated "cps" or "c").

The extent of variation in pressure is measured in terms of a unit called the microbar, which is a pressure of one dyne per square centimeter or approximately one-millionth of the normal atmospheric pressure (standard atmospheric pressure = 1,013,250 microbars). Actually, this unit is not often mentioned in giving the results of a noise measurement, but, as will soon appear, it is usually implied when the more common term, the "decibel", is used.

Although to many laymen the decibel (abbreviated "db") is uniquely associated with noise measurements, it is a term borrowed from electrical communication engineering, and it represents a relative quantity. When it is used to express noise level, a reference level is implied. Usually, this reference value is a sound pressure of 0.0002 microbar. For the present, the reference level can be referred to as "0 decibels", the starting point of the scale of noise levels. This starting point is about the level of the weakest sound that can be heard by a person with very good hearing in an extremely quiet location. Other typical points on this scale of noise levels are shown in Figure 2-1. For example, the sound level in a large office usually is between 60 and 70 decibels. Among the very loud sounds we have those produced by nearby airplanes, railroad engines, subways, riveting machines, thunder, and so on, which frequently are in the range above 100 decibels. These typical values should help the newcomer to develop a feeling for this term "decibel" as applied to sound level.

For some purposes it is not essential to know more about decibels than the above general statements. But when we need to modify or to manipulate the measured "decibels", it is desirable to know more specifically what the term means. There is then less danger of misusing the measured values. From a strictly technical standpoint, the decibel is a logarithm of a ratio of two values of power, and equal changes in decibels represent equal ratios. Thus, a change of 6 decibels represents a ratio of 4 to 1 in power.

While we shall use decibels for giving the results of power level calculations, the decibel is most often used in acoustics for expressing the sound-pressure level and the sound level. These are extensions of the original use of the term, and all three expressions will be discussed in the following sections. Before doing that, however, it is worthwhile to notice that the above quantities include the word "level". Whenever "level" is included in the name of the quantity, it can be expected that the value of this level will be given in decibels or in some related term and that a reference power, pressure, or other quantity is stated or implied.

2.1 POWER LEVEL

Because the range of acoustic powers that are of interest in noise measurements is about one billion billion to one (10^{18}:1), it is convenient to relate these powers on the decibel scale, which is logarithmic. The correspondingly smaller range of numerical values is easier to use, and, at the same time, some calculations are simplified.

The decibel scale can be used for expressing the ratio between any two powers; and tables for converting from a power ratio to decibels and vice-versa are given in Tables I and II in Appendix I, page 96 of this book. For example, if one power is four times another, the number of decibels is 6; if one power is 10,000 times another, the number is 40 decibels.

It is also convenient to express the power as a power level with respect to a reference power. Throughout this book the reference power will be 10^{-13} watt. Then the power level *(PWL)* is defined as

$$PWL = 10 \log \frac{W}{10^{-13}} \text{ db } re\ 10^{-13} \text{ watt}$$

where W is the acoustic power in watts, the logarithm is to the base 10, and *re* means referred to. This power level is conveniently computed from

$$PWL = 10 \log W + 130$$

since 10^{-13} as a power ratio corresponds to -130 db. The quantity 10 log W, which is the number of decibels corresponding to the numerical value of W watts, can be readily obtained from the decibel tables in the Appendix. For example, 0.02 watt corresponds to a power level of

$$-17 + 130 = 113 \text{ db.}$$

Some typical power levels for various acoustic sources are shown in Figure 2-2.

2.2 SOUND-PRESSURE LEVEL

It is also convenient to use the decibel scale to express the ratio between any two sound pressures; and tables for converting from a pressure ratio to decibels and vice-versa are given in the Appendix. Since sound pressure is usually proportional to the square root of the sound power, the sound-pressure ratio for a given number of decibels is the square root of the corresponding power ratio. For example, if one sound-pressure is twice another, the number of decibels is 6; if one sound pressure is 100 times another, the number is 40 decibels.

The sound pressure can also be expressed as a sound-pressure level with respect to a reference sound pressure. For air-borne sounds this reference sound pressure is, generally, 0.0002 microbar. For some purposes a reference pressure of one microbar has been used, but throughout this book the value of 0.0002 microbar will always be used as the reference for sound-pressure level. Then the definition of sound-pressure level *(SPL)* is

$$SPL = 20 \log \frac{P}{0.0002} \text{ db } re\ 0.0002 \text{ microbar}$$

where P is the root-mean-square sound pressure in microbars for the sound in question. For example, if the sound pressure is one microbar, then the corresponding sound pressure ratio is

$$\frac{1}{0.0002} \quad \text{or } 5000$$

From the tables, we find that the pressure level is 74 db *re* 0.0002 microbar. If decibel tables are not available, the level can, of course, be determined from a table of logarithms.

To measure sound-pressure level, an instrument is used which consists of a microphone, attenuator, amplifier, and indicating meter. This instrument must have an over-all response that is uniform ("flat") as a function of frequency, and the instrument is calibrated in decibels according to the above equation.

2.3 SOUND LEVEL

The apparent loudness that we attribute to a sound varies not only with the sound pressure but also with the frequency (or pitch) of the sound. In addition, the way it varies with frequency depends on the sound pressure. This effect can be taken into account to some extent for pure tones by including certain "weighting" networks in an instrument designed to measure sound-pressure level, and then the instrument is called a sound-level meter. In order to assist in obtaining reasonable uniformity among different instruments of this type, the American Standards Association, in collaboration with scientific and engineering societies, has established a standard to which sound-level meters should conform.

The current American Standard for Sound-Level Meters (Z24.3-1944) requires that three alternate frequency-response characteristics be provided in the instrument (see Figure 2-3). These three responses are obtained by weighting networks designated as A, B, and C. They are also referred to as "40-db", "70-db", and "flat", respectively. Responses A, B, and C selectively discriminate against low and high frequencies in accordance with certain equal-loudness contours, which will be described in a later section. Ordinarily, response A is used for sound levels below 55 db; response B between 55 and 85 db, and, response C for levels above 85 db. When sounds are measured according to this practice, the reading obtained is said to be the sound level. Only when the over-all frequency response of the instrument is "flat" are sound-pressure levels measured. As mentioned before, a scale of sound levels for typical noise sources is shown in Figure 2-1.

ACOUSTIC POWER

POWER (watts)	POWER LEVEL (db re 10^{-13} watts)	SOURCE
100,000	-180-	
		RAM JET TURBO-JET ENGINE WITH AFTERBURNER
10,000	-170-	TURBO-JET ENGINE, 7000-LB. THRUST
1,000	-160-	
		4-PROPELLER AIRLINER
100	-150-	
10	-140-	75-PIECE ORCHESTRA PIPE ORGAN } PEAK RMS LEVELS IN 1/8-SECOND INTERVALS
		SMALL AIRCRAFT ENGINE
1	-130-	
		LARGE CHIPPING HAMMER
		PIANO BB♭ TUBA } PEAK RMS LEVELS IN 1/8-SECOND INTERVALS
0.1	-120-	BLARING RADIO
		CENTRIFUGAL VENTILATING FAN (13,000 CFM)
0.01	-110-	4´ LOOM AUTO ON HIGHWAY
0.001	-100-	VANEAXIAL VENTILATING FAN (1500 CFM) VOICE - SHOUTING (AVERAGE LONG-TIME RMS)
0.0001	- 90-	
0.00001	- 80-	VOICE - CONVERSATIONAL LEVEL (AVERAGE LONG-TIME RMS)
0.000001	- 70-	
0.0000001	- 60-	
0.000,000,01	- 50-	
0.000,000,001	- 40-	VOICE - VERY SOFT WHISPER

Figure 2-2. Typical power levels for various acoustic sources.

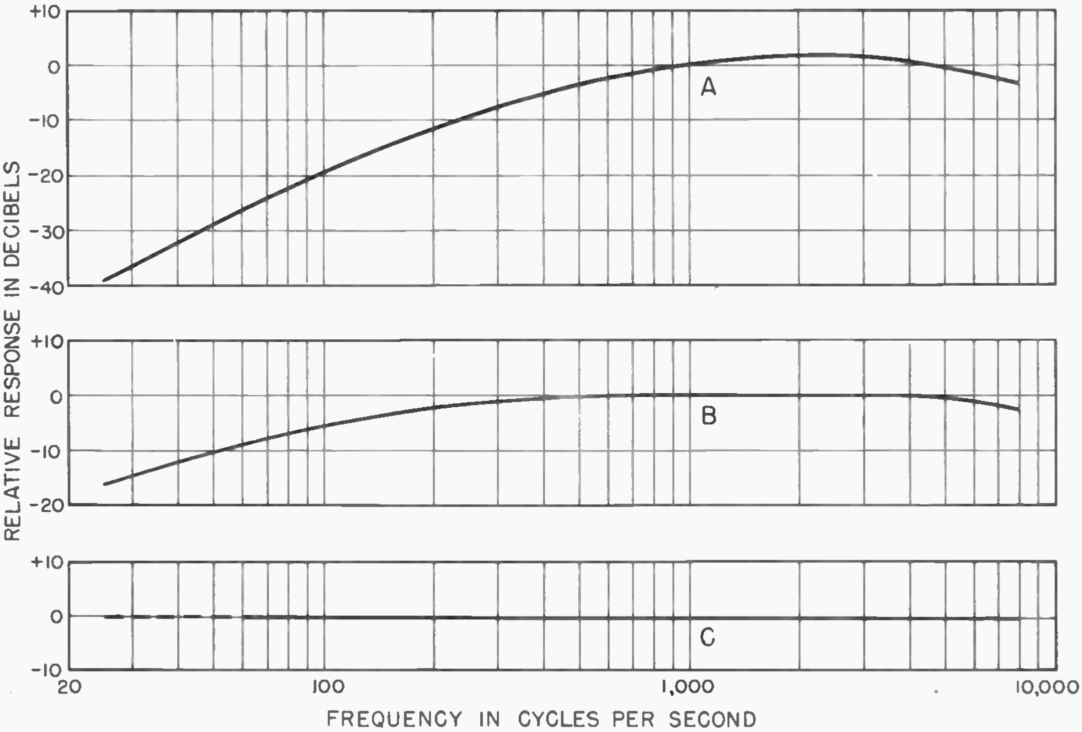


Figure 2-3. Frequency-response characteristics in the American Standard for Sound-Level Meters, Z24.3-1944.

2.4 COMBINING DECIBELS

There are a number of possible situations that require combining several noise levels stated in decibels. For example, we may want to predict the effect on the noise level of adding a noisy machine in an office where there is already a significant noise level, to correct a noise measurement for some existing background noise, to predict the combined noise level of several different noise sources, or to obtain a combined level of several levels in different frequency bands.

In none of these situations should the numbers of decibels be added directly. The method that is usually correct is to combine on an energy basis. The procedure for doing this is to convert the numbers of decibels to relative powers, to add or

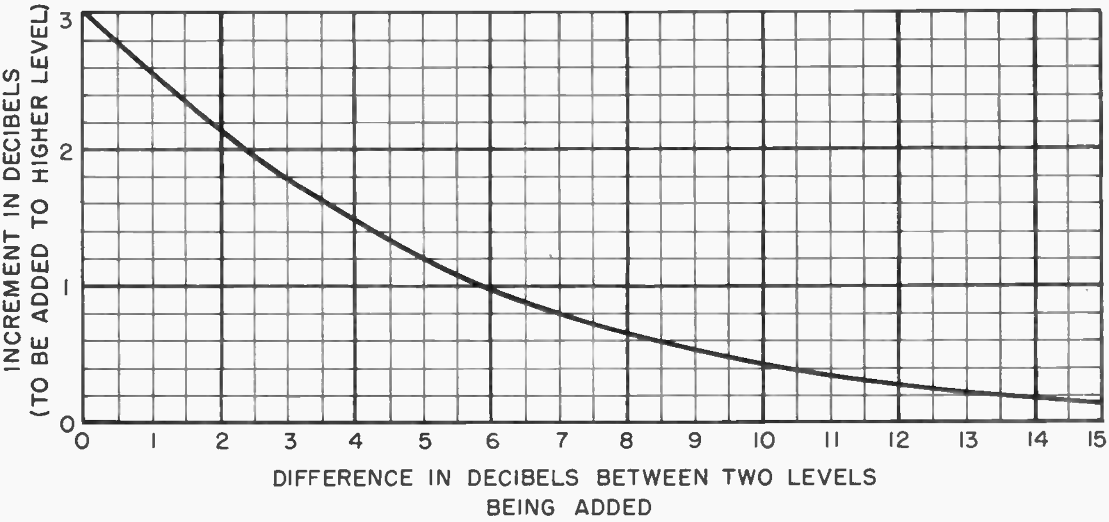


Figure 2-4. Chart for combining noise levels.

subtract them, as the situation may require, and then to convert back to the corresponding decibels. By this procedure it is easy to see that a noise level of 80 decibels combined with a noise level of 80 decibels yields 83 decibels and not 160 db. A simple chart for making this addition is given in Figure 2-4. Although this chart is intended primarily for combining two levels, it can be applied successively to combine any number. A similar chart for finding differences is given in the section on background levels. (Section 6.53).

2.5 SUMMARY

Reference levels and relations presented in this chapter included the following:

Reference sound pressure: 0.0002 microbar.

Reference power: 10^{-13} watt.

Power level (PWL)

$$PWL = 10 \log \frac{W}{10^{-13}} \text{ db } re\ 10^{-13} \text{ watt.}$$

where W is the acoustic power in watts.

Sound-pressure level (SPL)

$$SPL = 20 \log \frac{P}{0.0002} \text{ db } re\ 0.0002 \text{ microbar}$$

where P is the root-mean-square sound-pressure in microbars.

(Logarithims are taken to the base 10 in both *PWL* and *SPL* calculations.)

Important concepts from this chapter which aid in visualizing noise measurement results can be summarized as follows:

To measure sound level, use a sound-level meter with the frequency response weighting (A, B or C) selected according to the level of the measured sound.

To measure sound-pressure level, use a sound-level meter with the controls set for as uniform a frequency response as possible (usually C-weighting or "flat").

Decibels are usually combined on an energy basis, not added directly.

CHAPTER III

MAN AS A NOISE-MEASURING INSTRUMENT

That we are annoyed by a noisy device and a noisy environment, that noise may interfere with our sleep, our work, and our recreation, or that very intense noise may cause hearing loss is frequently the basic fact that leads to noise measurements and attempts at quieting. In order to make the most significant measurements and to do the job of quieting most efficiently, it is clearly necessary to learn about these effects of noise.

Unfortunately, not all the factors involved in annoyance, interference, and hearing loss are known at present. But a brief discussion of our reactions to sounds will serve to show some of the factors and their relative significance. This information will be useful as a guide for selecting electronic equipment to make the most significant measurements for the problem at hand.

3.1 PSYCHOACOUSTIC EXPERIMENTS

Scientists and engineers have investigated many aspects of man's reactions to sounds. For example, they have measured the levels of the weakest sounds that various observers could just hear in a very quiet room (threshold of hearing), they have measured the levels of the sounds that are sufficiently high in level to cause pain (threshold of pain), and they have measured the least change in level and in frequency that various observers could detect (differential threshold). These experimenters have also asked various observers to set the levels of some sounds so that they are judged equal in loudness to reference sounds (equal loudness), and they have asked the observers to rate sounds for loudness on a numerical scale.

In order to get reliable measures of these reactions, the experimenters have to simplify the conditions under which people react to sounds. This simplification is mainly one of maintaining unchanged as many conditions as possible while a relatively few characteristics of the sound are varied to observe the changing reaction. Some of the conditions that have to be controlled and specified are the following: the physical environment of the observer, particularly the background or ambient noise level; the method of presenting the changing signals, including the order of presentation, the duration, the frequency, and intensity; the selection of the observers; the training of the observers in the specific test procedure; the normal hearing characteristics of the observers; the instructions to the observers; the method of getting the responses; and the method of handling the data.

Variations in the conditions of the measurement will affect the result. Such interaction is the reason for requiring controlled and specified conditions. It is desirable to know, however, how much the various conditions do affect the result. For example, small changes in room temperature are usually of little significance. But if the observer is exposed to a noise of even moderate level just before a threshold measurement, the measured threshold level will, temporarily, be significantly higher than normal. This type of test is not only useful in determining what conditions need to be controlled and how well they need to be controlled, but it also is a useful psychoacoustic test in itself.

The basic method used by the observer to present his reaction to the signals is also important in the end result. Numerous methods have been developed for this presentation. Three of these psychophysical methods are as follows: 1. In the method of adjustment the observer sets an adjustable control to the level he judges suitable for the test. 2. In the method of the just noticeable difference the observer states when two signals differ sufficiently so that he can tell they are different. 3. In the method of constant stimuli the observer states whether two signals are the same, or which is the greater, if they seem to differ.

When psychoacoustic experiments are performed, the resultant data show variability in the judgments of a given observer as well as variability in the judgments of a group of observers. The data must then be handled by statistical methods to obtain an average result as well as a measure of the deviations from the average. In general it is the average result that is of most interest, but the extent of the deviations are also of value, and in some experiments these deviations are of major interest.

The deviations are not usually shown on graphs of averaged psychoacoustic data, but they should be kept in mind. To picture these deviations one might think of the curves as if they were drawn with a wide brush instead of a fine pen.

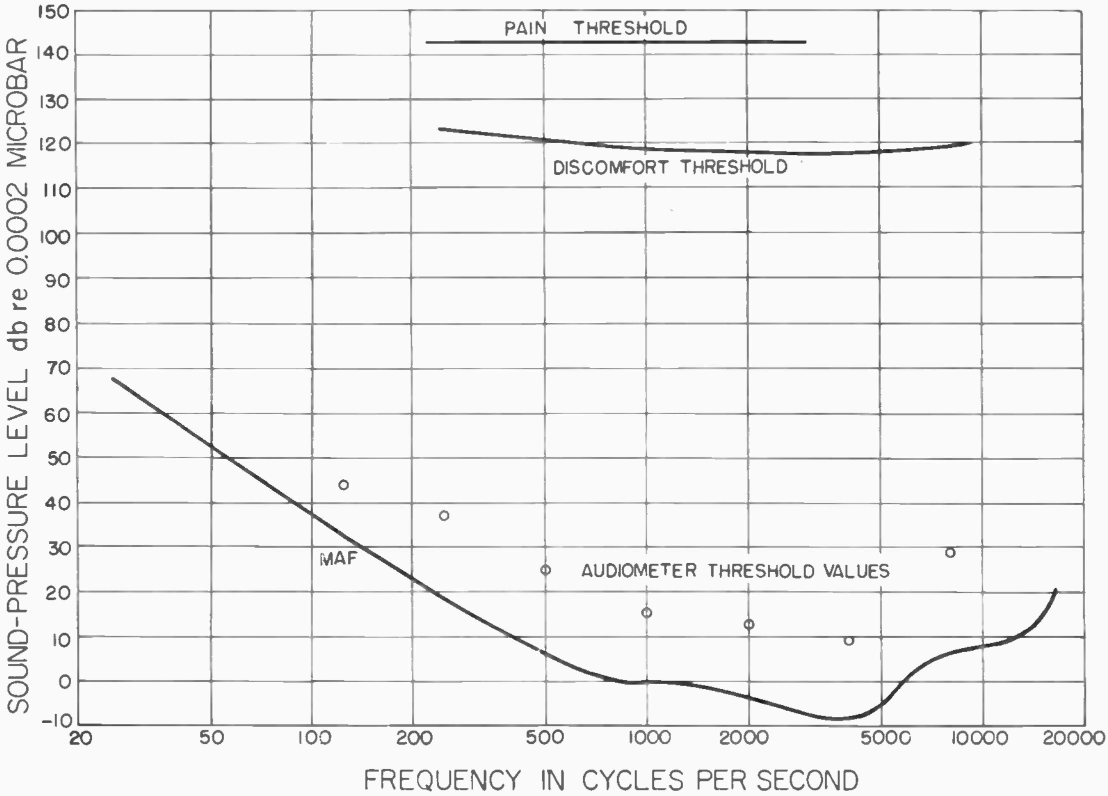
The measured psychoacoustic responses also have a certain degree of stability, although it is not the degree of stability that we find in physical measurements. In the normal course of events, if your threshold of hearing was measured yesterday, a similar measurement today should give the same threshold level within a few decibels.

In the process of obtaining these measures which have a reasonable reliability and stability, the experimental conditions have been controlled to the point where they are rarely the conditions encountered in actual practice. They are then useful mainly as a guide in interpreting objective measurements in subjective terms provided one allows for those conditions that seriously affect the result. As a general rule, the trend of our reactions to changes in the sound is all that can be estimated with validity. A conservative approach in using psychoacoustic data with some margin as an engineering safety factor is usually essential in actual practice.

3.2 THRESHOLDS OF HEARING AND TOLERANCE

Many experimenters have made measurements of the threshold of hearing of various observers. When young persons with good hearing are selected for the observers, a characteristic similar to that labeled *MAF* (minimum audible field) in Figure 3-1 is usually obtained. This shows the

Figure 3-1. Thresholds of hearing and tolerance.



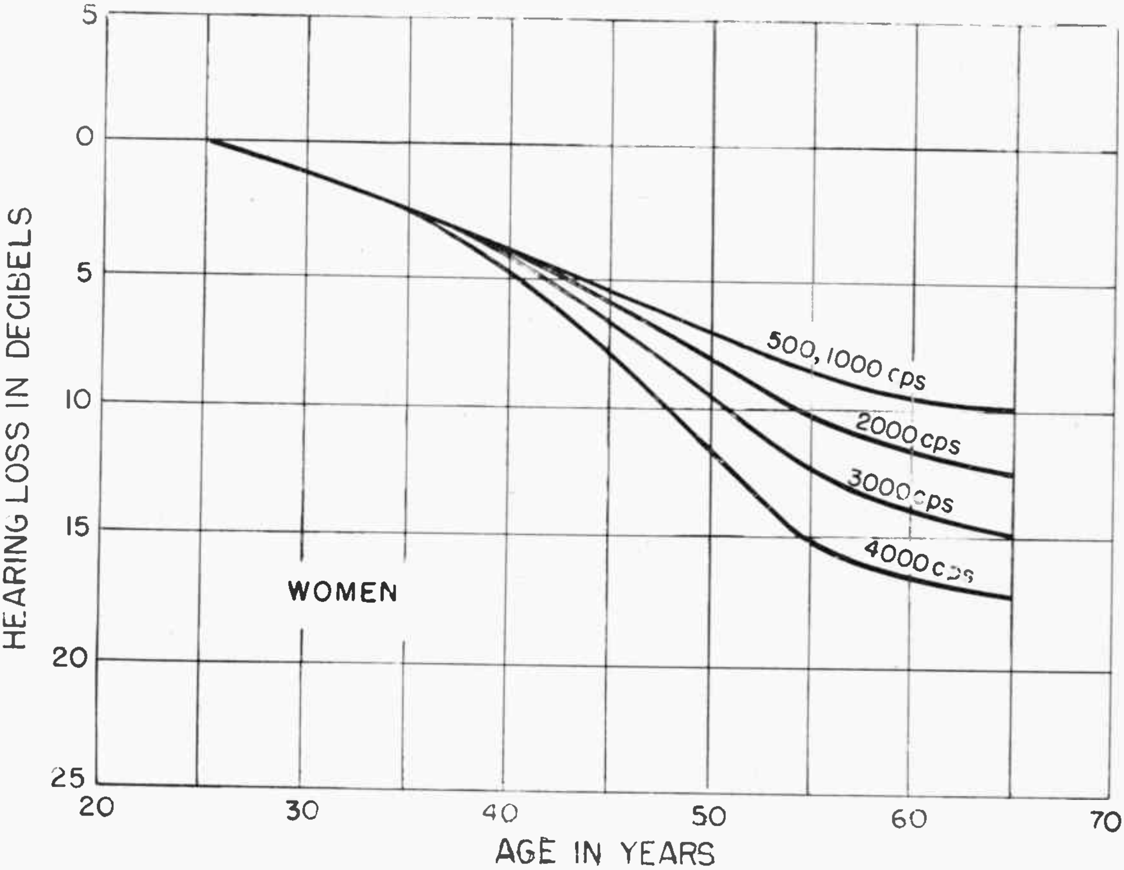
level of the pure tone that can just be heard in an exceptionally quiet location under free-field conditions (see Section 8.212 for an explanation of "free-field") as a function of the frequency of the pure tone. For example, if a pure tone having a frequency of 250 cps (about the same as the fundamental frequency of middle C) is sounded in a very quiet location, and if its sound-pressure level is greater than 18 db re 0.0002 microbar at the ear of the listener, it will usually be heard by a young person. Similarly, for a pure tone having a frequency equal to 1000 cps, the threshold is about 0.0002 microbar. In addition to the restrictions mentioned above there are a number of other factors that need careful attention in performing such an experiment. For example, what is meant by "can just be heard" needs definition. Further details on these experiments can be found in the bibliography at the end of this handbook.

Some variation in the threshold of a person can be expected even if the experiments are carefully controlled. Threshold determinations made in rapid succession may possibly differ by as much as 5 db, and with longer intervals more variation between particular values is possible. But the average of a number of threshold measurements will generally be more consistent with the average of another set than this 5 db variation among particular values.

The variability among individuals is, of course, much greater than the day-to-day variability of a single individual. For example, the sensitivity of some young people is slightly better than that shown in Fig. 3-1 as the minimum audible field, and, at the other extreme, some people have no usable hearing. Most noise-quieting problems, however, involve people whose hearing, on the average, is only somewhat poorer than the minimum audible field shown in Fig 3-1.

The threshold curve shows that at low fre-

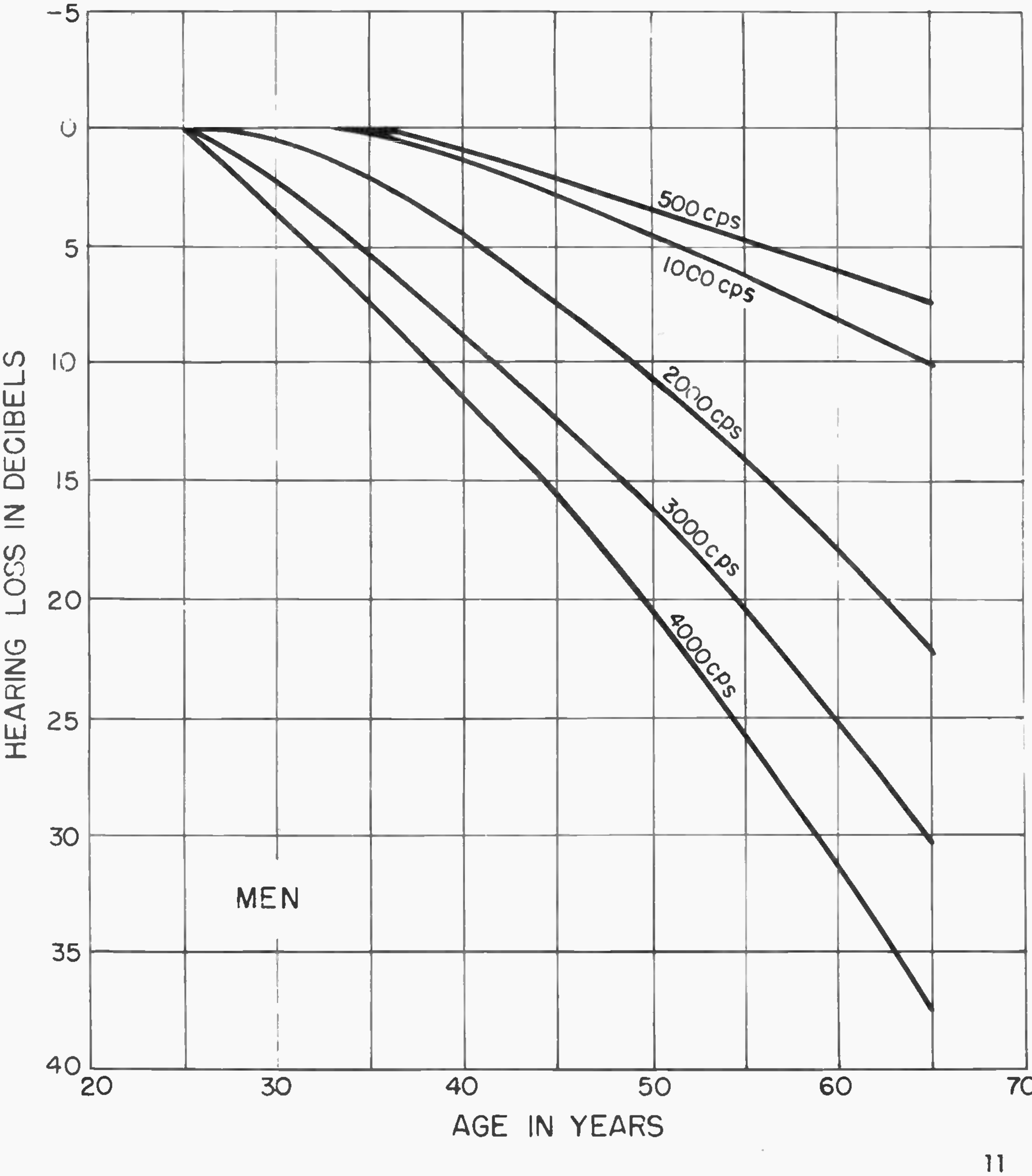
(Below and Right) Figure 3-2.
Presbycusis curves for women and men. These sets of curves show the average shifts with age of the threshold of hearing for pure tones. (ASA Subcommittee Z24-X-2, "The Relations of Hearing Loss To Noise Exposure," New York, 1954, pp. 16-17)



quencies the sound-pressure level must be comparatively high before the tone can be heard. In contrast we can hear tones in the frequency range from 500 to 10,000 cps even though the levels are very low. This variation in acuity of hearing with frequency is one of the reasons that in most noise problems it is essential to know the composition of the noise. For example, is it made up of a number of components all below 300 cps in frequency? Or, are they all between 1000 and 5000 cps? The importance of a given sound-pressure level is significantly different in those two cases.

The upper limit of frequency at which we can hear air-borne sounds depends on the condition of our hearing and on the intensity of the sound. This upper limit is usually quoted as being somewhere between 16,000 and 20,000 cps. For most practical purposes the actual figure used is not important. It is important, however, to realize that it is in this upper frequency region where we can expect to lose sensitivity as we grow older.

The aging effect (called "presbycusis") has been determined by statistical analysis of hearing



threshold measurements on many people. A recent analysis of such data* has given the results shown in Figure 3-2. This set of curves shows, for a number of pure tones of differing frequencies, the extent of the shift in threshold that we can expect, on the average, as we grow older.

Many threshold measurements are made by otologists and other hearing specialists in the process of analyzing the condition of a person's hearing. An instrument known as an audiometer is used for this purpose. Its calibration is made with respect to a "normal" threshold. This "normal" level, as used in the U.S.A., is also shown on the graph of Figure 3-1. The difference between the audiometer threshold and the minimum audible field can be ascribed to the differences in technique used in the tests, to the selection of a different sample of observers, and to generally prevailing ambient noise conditions during audiometer tests.

When a sound is very high in level, one can feel very uncomfortable listening to it. The "Discomfort Threshold" (Silverman) shown in Figure 3-1 is drawn in to show the general level at which such a reaction is to be expected. At still higher levels the sound may become painful, and the order of magnitude of these levels (Silverman) is also shown in Figure 3-1.

3.3 RATING THE LOUDNESS OF A SOUND

Many psychoacoustic experiments have been made in which listeners have been asked to rate the loudness of a sound. As a result of these experiments involving all sorts of sounds in various arrangements much has been learned about the concept of loudness in laboratory situations. The way in which the judgment of loudness has been obtained seems to affect the results sufficiently, however, so that it seems unwise at the present time to try to scale the sounds of everyday life on an absolute basis. In particular, it does not seem possible to give a numerical value to the loudness ratio of two sounds and have this ratio be reasonably independent of the conditions of comparison. It does seem possible, however, to rank a sound with satisfactory reliability according to its loudness. For example, if sound A is judged louder than sound B and if sound B is judged louder than sound C, then, in general, sound A will also be judged louder than sound C.

3.31 Equal-Loudness Contours and Loudness Level

One step in the direction of rating the loudness of a sound has been to determine the sound-pressure levels of pure tones of various frequencies that sound just as loud to an observer as a 1,000-cps tone of a given sound-pressure level. The results of this determination by Fletcher and Munson are given as equal-loudness contours in Figure 3-3. The number on each curve is the sound-pressure level of the 1,000-cycle tone used for comparison for that curve. To use the contours for determining the equally loud levels at other frequencies, we find the point on the curve corresponding to the desired frequency and read off the corresponding sound-pressure level as the ordinate. For example, the 60-db contour line shows that a 66-db level at 200 cycles is just as loud as a 60-db 1000-cycle tone. We can also interpolate between the curves to find that a 60-db 200-cycle tone is equal in loudness to a 51-db 1000-cycle tone. The corresponding sound-pressure level in db for the 1000-cycle tone has been defined as the *loudness level* in *phons*. Therefore, a 200-cycle tone at a sound-pressure level of 60 decibels has a loudness level of 51 phons.

As mentioned earlier, the weighting networks for the standard sound-level meter are based on these contours. The "A" and "B" weighting is in accordance with the 40 and 70-phon contours, but with modifications to take into account the usually random nature of the sound field in a room.

The loudness contours shown in Figure 3-3 have been widely used, but there is evidence that the contours are on the average not so uniform for low-frequency tones at moderately high levels as are those shown. Experiments now in progress should show the extent of the revision necessary.

A set of equal-loudness contours (Pollack) for bands of random noise are shown in Figure 3-4. Random noise is a common type of noise that occurs in ventilating systems, jets, blowers, combustion chambers, etc. It does not have a well defined pitch, such as characterizes a tone with the energy concentrated in discrete components of definite frequency. Rather, random noise has energy distributed over a band of frequencies. If the noise energy per cycle is uniform over a wide range, it is called ' white noise", being analogous in spectrum characteristics to white light. When the energy is distributed over a very wide band, it is a sort of hishing sound. When the broad-band noise has little energy at low frequencies, it is more of a hissing sound. When it is concentrated in narrower bands, the sound takes on some aspects of pitch. For example, low-frequency random noise may be a sort of roar.

The contours shown in Figure 3-4 are for relatively narrow bands of noise, such that 11 bands cover the range from 60 to 5800 cps. They are distributed uniformly on a scale of pitch for pure tones (see Section 3.72). The numbers on the curves are phons, that is, the sound-pressure levels of equally loud 1000-cycle tones, and the levels are plotted according to the centers of the

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*American Standards Association Subcommittee Z24-X-2, *The Relations of Hearing Loss to Noise Exposure*, January, 1954, New York.

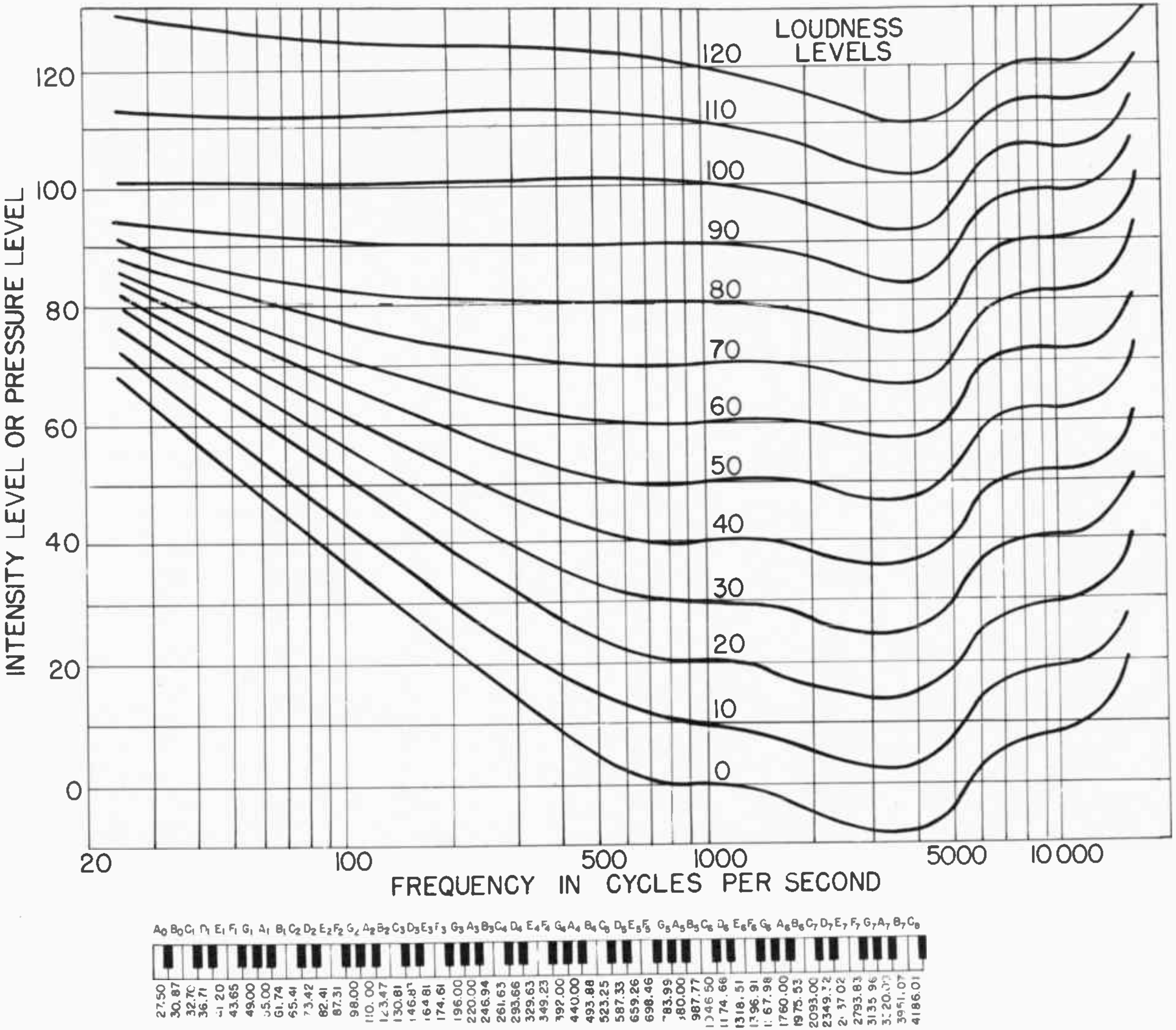

Figure 3-3. Free field equal-loudness contours of pure tones (Fletcher-Munson curves). Piano keyboard helps identify the frequency scale. Only the fundamental frequency of each piano key is indicated.

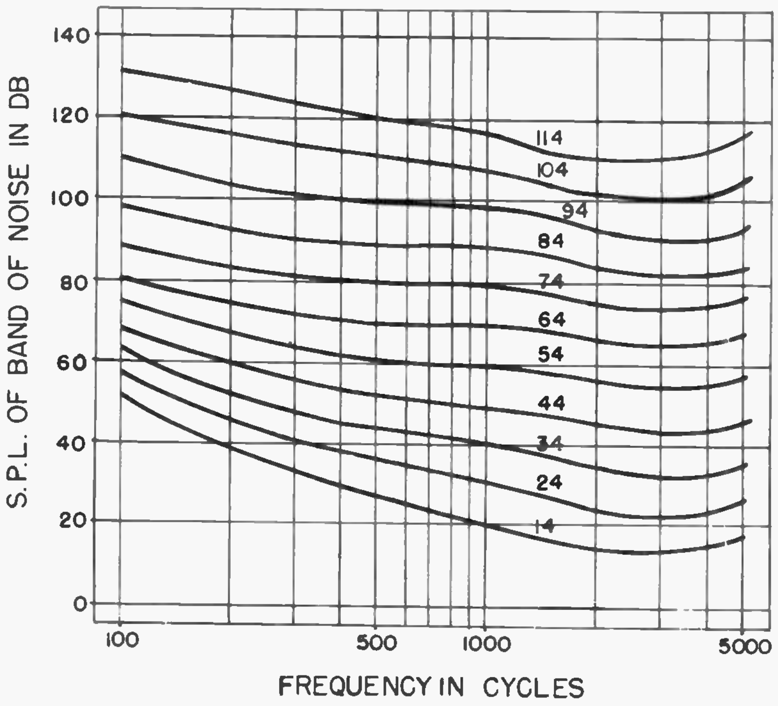

Figure 3-4. Equal-loudness contours for relatively narrow bands of random noise. The center frequency of the band is shown as the abscissa, and the numbers on the curves are phons. (Irwin Pollack, "The Loudness of Bands of Noise," Jour. Acoust. Soc. Am., Vol. 24, Sept., 1952, pp. 533-538)

bands. For example, one band covers the range from 350 to 700 cps. From the curves we can see that when the sound-pressure level of the noise in that band is 43 db re 0.0002 microbar, the indicated loudness level is about 34 phons.

3.32 Loudness and Loudness Level

Although we may remark that some sounds are louder than others, we do not ordinarily rate sounds for loudness on a numerical basis. Experimenters have asked observers to make judgments of the loudness ratio of sounds, that is, to state when one sound is twice, four times, one-half, etc., as loud as another. The resultant judgments depend to a considerable extent on how the problem is presented to the observer. But on the basis of such judgments a number of scales of loudness have been devised, which rate sounds from "soft" to "loud" in units of *sones*. As a reference, the loudness of a 1000-cycle tone with a sound-pressure level of 40 decibels re 0.0002 microbar (a loudness level of 40 phons) is taken to be 1 sone. A tone that sounds twice as loud has a loudness of 2 sones. This scale is shown on the vertical axis of Figure 3-5, and the horizontal scale is the sound-pressure level of the sound in decibels. The particular curves shown in this figure relate the loudness in sones to the sound-pressure level for a 1000-cycle pure tone (Fletcher) and for a wide band of random noise (adapted from Pollack and others). These curves show the general nature of the loudness function, but the particular numerical values are not unanimously accepted. Several experimenters have suggested curves that differ appreciably from those shown here.

The pure-tone curve is the one on which most statements about relative loudness are based. We can see that the judged loudness changes on a ratio basis less rapidly with sound-pressure level at high than at low levels. Incidentally, the general relations shown tend to refute the usual contention that the decibel is used in acoustics because we respond to sound levels in a logarithmic manner. At no level is a logarithmic variation approached.

The marked difference in apparent loudness for a pure tone and a wide band noise for the same sound-pressure level is also of interest. This difference is another reason that we usually need to know more about a sound than just its sound-pressure level or its sound level. If we know how the energy in a sound is distributed as a function of frequency, we can make a more useful estimate of its probable subjective effect than we can by knowing just its sound-pressure level. One of the ways such knowledge is used is in the calculation of loudness level.

3.33 Loudness Level Calculations from Measurements

If the sound to be measured is known to be a pure tone, the procedure for calculating loudness level is relatively simple. The sound-pressure level and the frequency of the tone are determined, and the equal loudness contours of Figure 3-3 can then be used to calculate the loudness level.

If the sound to be measured is more complex, a technique developed empirically has been found to give good results. The sound is analyzed by an octave-band analyzer into eight frequency bands covering the audio spectrum. A transfer value (see Section 7.2) for each band is determined from charts by using the measured sound-pressure level in the band. Then a total transfer value is obtained by summing the individual transfer values. This total value is then transformed into a calculated loudness level. Further details on this procedure will be found in Section 7.2.

3.4 MASKING

It is common experience to have one sound completely drowned out when another, louder noise occurs. The reverse effect also happens. For example, during the early evening when a fluorescent light is on, the ballast noise may not be heard, because of the usual background noise level in the evening. But late at night when there is much less activity and correspondingly less noise, the ballast noise may become relatively very loud and annoying. Actually, the noise level produced by the ballast may not be different in the two cases. But psychologically the noise *is* louder at night, because there is less of the masking noise which reduces its apparent loudness.

Experimenters have found that the masking effect of sounds is greatest for those other sounds that are close to it in frequency. At low levels the masking effect covers a relatively narrow region of frequencies. At higher levels, above 60 db, say, the masking effect spreads out to cover a wide range, mainly for frequencies above the frequencies of the dominating components. In other words, the masking effect is asymmetrical with respect to frequency. Noises that include a wide range of frequencies will correspondingly be effective in masking over a wide-frequency range.

3.5 "WHAT NOISE ANNOYS AN OYSTER?"

No adequate measures of the annoyance levels of noises have yet been devised. Various aspects of the problem have been investigated, but the psychological difficulties in making these investigations are very great. For example, the extent of our annoyance depends greatly on what we are trying to do at the moment, it depends on our previous conditioning, and it depends on the character of the noise.

The annoyance level of a noise is sometimes assumed to be related directly to the loudness level of the noise. Although not completely justifiable, this assumption is sometimes helpful because a loud sound is usually more annoying than one of similar character that is not so loud.

Psychologists have found that high-frequency sounds (above about 2000 cps) are usually more annoying than lower frequency sounds of the same sound-pressure level. Therefore, when it is determined by analysis, by methods to be explained later, that a significant portion of the noise is in the higher frequency bands, considerable effort at reducing these levels from the viewpoint of annoyance may be justified.

A further effect concerns localization of sound. When a large office has acoustically hard walls, floor and ceiling, the room is "live", reverberant. The noise from any office machinery then is reflected back and forth, and the workers are immersed in the noise with the feeling that it comes from everywhere. If the office is heavily treated with absorbing material, the reflected sound is reduced, and the workers then get the feeling the noise is coming directly from the machine. This localized noise seems to be less annoying. While no adequate measures of this effect have been developed, the general principle discussed here seems to be accepted by many who are experienced in noise problems.

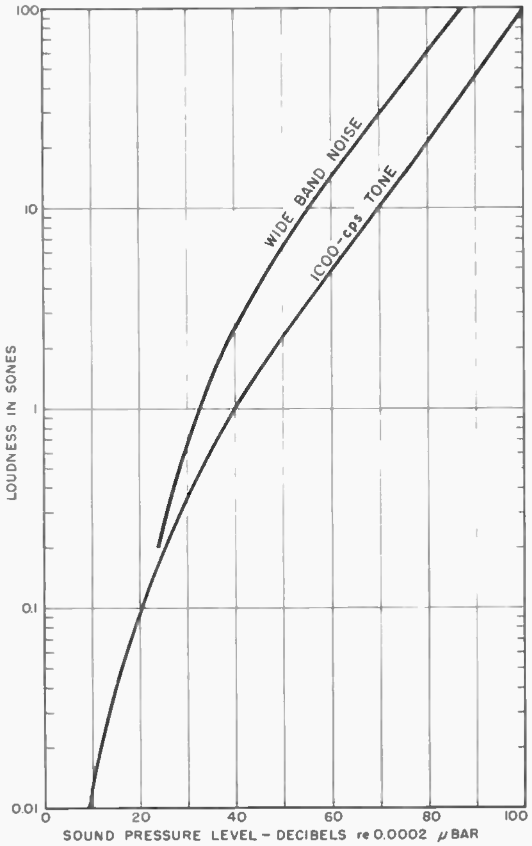

Figure 3-5.

Loudness versus sound-pressure level for wide-band random noise and a pure tone.

3.6 SPEECH-INTERFERENCE LEVEL

It is becoming relatively common to be in a place so noisy that conversation is difficult or impossible. The interference with speech reaches its maximum in airplanes, locomotives and some manufacturing plants. Because of the annoyance of interference with speech and also because noise interferes with work where speech communication is necessary, a noise rating based on the speech-interference level is frequently useful. We should know how to improve speech communication in a noisy place. In order to effect this improvement we shall find it useful to evaluate the speech-interference level of a noise. How this can be done will appear from a consideration of how noise interferes with speech.

Noise interference with speech is usually a masking process (see Section 3.4). The background noise increases our threshold of hearing, and, as a result, we may hear only a few or perhaps none of the sounds necessary for satisfactory intelligibility.

The consonants contain most of the information in speech; but, unfortunately, they are more readily masked than vowels, because the consonants are weaker than vowels. Noise of a certain level may then mask some speech sounds and not others depending on the talking level, the particular sound, and the relative frequency distribution of energy, of the sound and of the noise.

The energy of the various speech sounds is distributed over the frequency range from below 100 to above 10,000 cps. The actual instantaneous distribution depends on the particular speech sound. For example, the "s" sound has its energy broadly distributed in the range from 4000 to beyond 8000 cps. In contrast, most of the energy in the "ee" sound of "speech" is distributed in fairly definite groups (called "formants") below 4000 cps. All the frequency range of speech sounds is not necessary, however, for complete intelligibility. A number of experimenters have shown that nearly all the information in speech is contained in the frequency region from 200 to 6000 cps.

In any frequency subdivision that we may make of this range, the sound-pressure levels vary over a range of about 30 decibels as successive sounds occur. Tests have been run on the intelligibility of speech which show that if we can hear the full 30-decibel range in each of the frequency bands into which speech is divided, the contribution to intelligibility by that band will be 100 percent. If, however, noise limits the range that can be heard to only 15 decibels, the contribution will be about 50 percent, and so forth. Furthermore, if the range between 200 to 6000 cps is divided into a large number of frequency bands of equal importance to speech intelligibility, the total contribution to speech intelligibility is equal to the average of the contributions from the individual bands. This quantity is called the articulation index, because it is a measure of the percentage of the total possible information which we might have perceived of importance to speech intelligibility.

For many noises the measurement and calculation can be simplified even further by the use of a three-band analysis. The bands chosen are 600-1200, 1200-2400 and 2400-4800 cps. The arithmetic average of the sound-pressure levels in these three bands gives the quantity called the speech-interference level. One can use this level for determining when speech communication or telephone use is easy, difficult, or impossible; and one can determine what changes in level are necessary to shift from one order of difficulty to a lower order. The calculations and rating methods for making these determinations are given in Section 7.3.

3.7 ADDITIONAL HEARING CHARACTERISTICS

In addition to the characteristics already described, numerous others have been investigated, and a few of these are of interest for guiding one in noise-measurement problems. Therefore, we shall discuss briefly differential sensitivity for intensity and the pitch scale.

3.71 Differential Sensitivity for Intensity: One question that comes up in quieting a noisy place or device is: "Just how little a change in level is worth bothering with? Is one decibel change significant, or does it need to be twenty decibels?" This question is partially answered in the section on loudness, but there is additional help in the following psychoacoustic evidence. Psychologists have devised various experiments to determine what change in level will be usually noticed. When two different levels are presented under laboratory conditions to the observer with little delay between them the observer can notice as small a difference as ¼ decibel for a 1000-cycle tone at high levels. This sensitivity to change varies with level and the frequency, but over the range of most interest, this differential sensitivity is about ¼ to 1 decibel. For a wide-band random noise (a hishing sound) a similar test gives a value of about ½ decibel for sound-pressure levels of 30 to 100 decibels (re 0.0002 microbar). Under everyday conditions, a 1.0 decibel change in level is more likely to be the minimum detectable by an average observer. On the basis of these tests, we can conclude that 1 decibel total change in level is hardly worth much; 3, say, is usually significant; and 6 is usually worth while. It should be remembered, however, that many noise problems are solved by reducing the level by a number of changes, each of which result in only small reductions in level, but the final change totals large enough to be worth while. There is also the importance of a change in character of the noise. For example, the high-frequency level of a noise may be reduced markedly by acoustic treatment, but, because of strong low-frequency components, the overall level may not change appreciably. Nevertheless, the resultant effect may be very much worth while. This example illustrates one reason for making a frequency analysis of a noise before drawing conclusions about the noise.

3.72 Pitch and Mels: Just as they have done for loudness, psychologists have experimentally determined a scale for pitch. The unit for this scale is the "mel" (from "melody"), and a 1000-cycle tone at a level of 40 db is said to have a pitch of 1000 mels. In terms of frequency, this pitch scale is found to be approximately linear below 1000 cycles and approximately logarithmic above 1000 cycles. Some people have suggested that a frequency analysis with bands of equal width in mels would be more efficient for some types of noise analysis than would one with bands of other widths. At the present time there are no commercial analyzers of this type available, but some work has been done using such an analysis. In addition, the pitch scale has been found useful for some types of charts.

3.8 HEARING LOSS FROM NOISE EXPOSURE*

If we are exposed to intense noises, we may suffer a loss in hearing. This loss will appear as a shift in the hearing threshold. Some of the loss is usually temporary with partial or complete recovery in some minutes, hours or days. Any remaining hearing loss that persists indefinitely is called "permanent." The extent of the permanent loss will depend on many factors. For example, it depends on the susceptibility of the individual; on the duration of the exposure, including the time pattern; on the intensity of the noise; on the spectrum of the noise; on the type of noise, that is, impact, random, or pure tone; and on the nature of the ear protection used, if any.

Because of the many complicating factors, it is not possible to set up a single, simple relation between hearing loss and the exposure to noise. Furthermore, adequate data regarding comparative audiograms and a complete history of exposure including noise levels, type of noise, time pattern and frequency characteristics are not available. It should also be kept in mind that noise is not the only cause of permanent hearing loss. There is the normal loss of hearing with age (see Section 3.2), and some types of infection may produce permanent hearing loss.

Nevertheless, because of the importance of the problem, certain tentative ratings based on the presently available data for noise damage risk are given in Section 7.4. These suggested ratings are tentative and should be revised when a better understanding of the damage problem is available.

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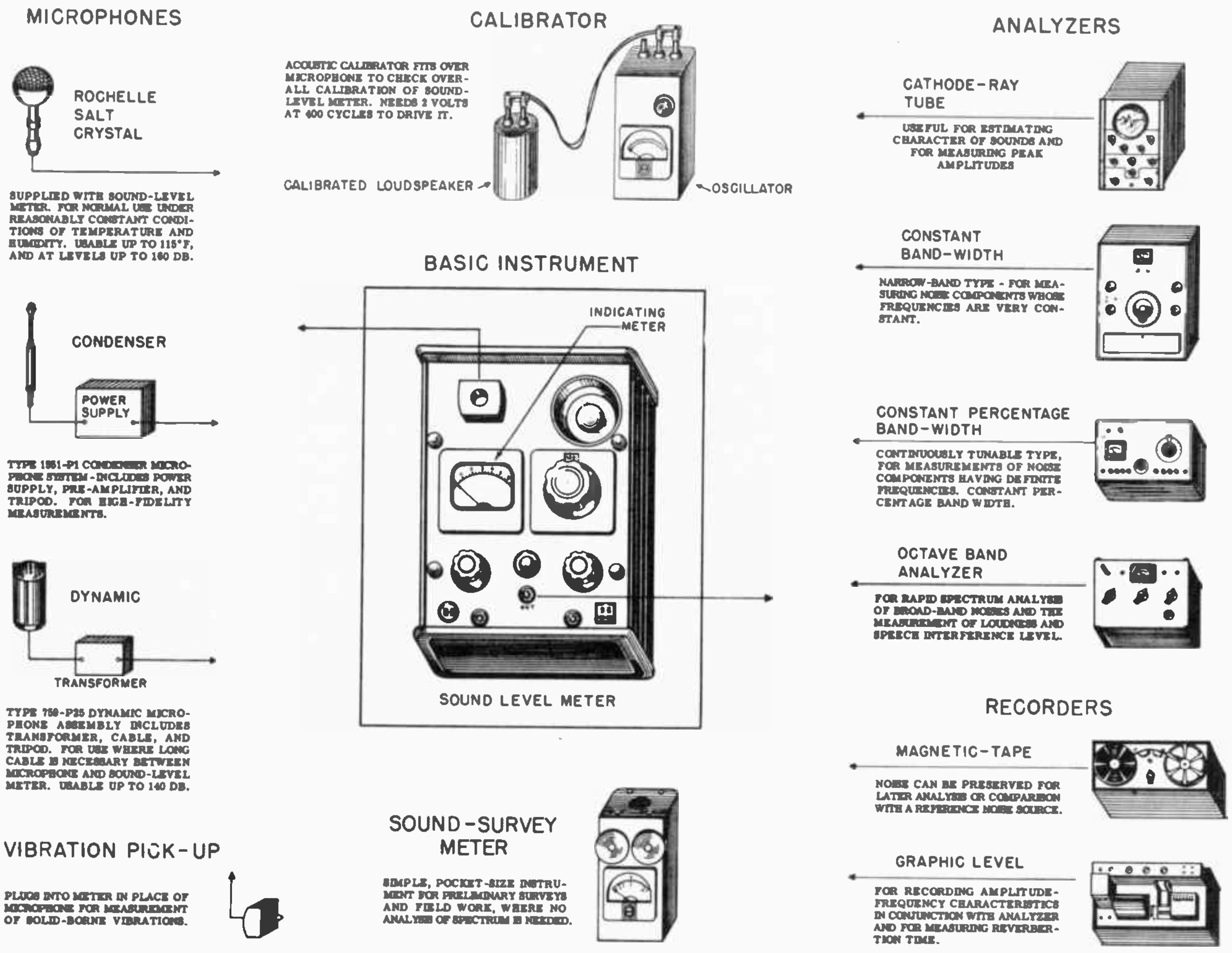
*American Standards Association Subcommittee Z24-X-2, *The Relations of Hearing Loss to Noise Exposure*, January, 1954, New York.



SUPPLIED WITH SOUND-LEVEL METER. FOR NORMAL USE UNDER REASONABLY CONSTANT CONDITIONS OF TEMPERATURE AND HUMIDITY. USABLE UP TO 115°F, AND AT LEVELS UP TO 160 DB.

TYPE 1551-P1 CONDENSER MICROPHONE SYSTEM - INCLUDES POWER SUPPLY, PRE-AMPLIFIER, AND TRIPOD. FOR HIGH-FIDELITY MEASUREMENTS.

TYPE 759-P25 DYNAMIC MICROPHONE ASSEMBLY INCLUDES TRANSFORMER, CABLE, AND TRIPOD. FOR USE WHERE LONG CABLE IS NECESSARY BETWEEN MICROPHONE AND SOUND-LEVEL METER. USABLE UP TO 140 DB.

PLUGS INTO METER IN PLACE OF MICROPHONE FOR MEASUREMENT OF SOLID-BORNE VIBRATIONS.

ACOUSTIC CALIBRATOR FITS OVER MICROPHONE TO CHECK OVER-ALL CALIBRATION OF SOUND-LEVEL METER. NEEDS 2 VOLTS AT 400 CYCLES TO DRIVE IT.

SIMPLE, POCKET-SIZE INSTRUMENT FOR PRELIMINARY SURVEYS AND FIELD WORK, WHERE NO ANALYSIS OF SPECTRUM IS NEEDED.

USEFUL FOR ESTIMATING CHARACTER OF SOUNDS AND FOR MEASURING PEAK AMPLITUDES

NARROW-BAND TYPE - FOR MEASURING NOISE COMPONENTS WHOSE FREQUENCIES ARE VERY CONSTANT.

CONTINUOUSLY TUNABLE TYPE, FOR MEASUREMENTS OF NOISE COMPONENTS HAVING DEFINITE FREQUENCIES. CONSTANT PERCENTAGE BAND WIDTH.

FOR RAPID SPECTRUM ANALYSES OF BROAD-BAND NOISES AND THE MEASUREMENT OF LOUDNESS AND SPEECH INTERFERENCE LEVEL.

NOISE CAN BE PRESERVED FOR LATER ANALYSIS OR COMPARISON WITH A REFERENCE NOISE SOURCE.

FOR RECORDING AMPLITUDE-FREQUENCY CHARACTERISTICS IN CONJUNCTION WITH ANALYZER AND FOR MEASURING REVERBERATION TIME.

Figure 4-1. Basic sound-measuring instrument, with various accessories commonly used in acoustic measurements.

CHAPTER IV

DESCRIPTION OF THE GENERAL RADIO SOUND-MEASURING SYSTEM

The General Radio sound-measuring system comprises a general-purpose sound-level meter and an ever-growing list of associated equipment. In addition, an extremely small, lightweight and low-cost meter, the Sound-Survey Meter is available.

The functional relation among the various instruments of the system is shown in Figure 4-1. A brief description of each instrument is given below (for complete descriptions and specifications, see Appendix II), and the applications are discussed in Chapter V.

4.1 THE SOUND-SURVEY METER (TYPE 1555-A)

The Type 1555-A Sound-Survey Meter is a small, simple meter for indicating the level of noise and other sounds in terms of a standard reference level. It consists of a microphone, a calibrated attenuator, weighting networks, an amplifier, and an indicating meter. As described in Chapter V, the Sound-Survey Meter is well-suited to a wide variety of general sound measurements.

The Sound-Survey Meter is small, light in weight, easy to use, reliable and inexpensive. It slips easily into a suit-coat pocket. Control settings and panel meter indication can be read at a glance. It can be mounted on a tripod, hand held, or placed on table or bench with equal facility. Readings and settings are easily made with microphone in vertical or horizontal position.

4.2 THE SOUND-LEVEL METER (TYPE 1551-A)

The basic instrument of the General Radio sound-measuring system is the Type 1551-A Sound-Level Meter. This instrument conforms to

Figure 4-2. The Type 1555-A Sound-Survey Meter.

Figure 4-3. The Type 1551-A Sound-Level Meter.

all the requirements set forth in the ASA *American Standard for Sound-Level Meters for the Measurement of Noise and Other Sounds* (Z24.3-1944)[1]. It is an accurate, portable, low-priced meter for reading in terms of a standard reference level (.0002 microbar at 1000 cps) the sound level at its microphone. Fundamentally, the instrument consists of a non-directional microphone, a calibrated attenuator, an amplifier, an indicating meter, and weighting networks to modify the amplifier response to conform with the response of the human ear to pure tones at specified sound levels.

The amplifier uses subminiature tubes, is stabilized by means of inverse feed-back and has a flat frequency response range of 20 cycles to 20 kilocycles. In addition to the three common sound-level meter responses A, B and C, which are specified between 25 cycles and 8000 cycles, this instrument has a fourth weighting-switch position which permits use of wide-band or high-fidelity microphones at its input, with the over-all frequency response being determined by the microphone.

ACCESSORIES FOR THE SOUND-LEVEL METER

4.3 MICROPHONES

4.31 Rochelle-Salt Microphone: The microphone regularly supplied with the Type 1551-A Sound-Level Meter is of the Rochelle-salt crystal diaphragm type. This is a low-cost device which meets the requirements for a sound-level-meter microphone very satisfactorily if it is connected directly to the input terminals of a sound-level meter and if the variations of temperature and humidity encountered are moderate.

When it becomes necessary to make measurements with the microphone separated from a sound-level meter by a long cable or when high temperatures and humidity are encountered, the Rochelle-salt microphone becomes a less satisfactory pickup. Its capacitance varies considerably as the temperature changes, so that the loss added by a long cable is markedly a function of temperature. These characteristics are discussed in Chapter VI.

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[1] American Standards Association, 70 East 45th Street, New York 17, New York.

4.32 Type 759-P25 Dynamic Microphone Assembly: The inconvenience and the possibility of errors caused by using a correction factor that is a function of temperature when the Rochelle-salt microphone is at the end of a long cable can be avoided by using a dynamic microphone. A suitable dynamic microphone for use with the Type 1551-A Sound-Level Meter is available, in combination with a transformer, a cable, and a tripod. This combination is known as the Type 759-P25 Dynamic Microphone Assembly.

The dynamic microphone, the Western Electric Type 633-A, now manufactured by Altec Lansing Corporation, is well established as a dependable and rugged instrument. Its output level is about —90 db *re* 1 volt per microbar compared to a level of —60 db for the crystal microphone, so that a transformer with a turns ratio of 30:1 is required to raise the output to the desired level. The Type 759-P26 Transformer does this with no effect on the frequency response over the working range of the microphone. In addition, the transformer is well shielded, so that pickup from stray magnetic fields is well below any such pickup by the microphone itself. The cable furnished is 25 feet of shielded, double conductor with vinylite sheath. A 100-foot cable is also available. Response characteristics are given in Chapter VI.

4.33 Type 1551-P1 Condenser Microphone System: The amplifier, attenuator, and meter frequency-response characteristics of the Type 1551-A Sound-Level Meter, with the weighting switch at "20 KC," are flat from 20 cycles to 20 kilocycles. This makes it possible to derive full benefit from some of the new wide-range microphones ([2], [3]) that have become available. These new microphones have high sensitivity and have excellent response characteristics well beyond 10 kilocycles. They are small in size so they create a minimum disturbance to the sound field at these higher frequencies. They are useful in testing the over-all response of high fidelity systems or in other wide-frequency-range acoustic investigations.

One of these wide-range microphones has been used in the Type 1551-P1 Condenser Microphone System, which is an assembly of preamplifier, power supply, microphone, and tripod. The microphone is an Altec 21-type. The power supply is attached to the end of the sound-level-meter cabinet. The frequency response of this microphone system extends out to 20 kc, and it also has a good low frequency response down to 20 cycles.

4.34 Massa M-141B Microphone: Another wide-range microphone that can be used with the Type 1551-A Sound-Level Meter is the Massa M-141B Standard Microphone, developed by the Massa Laboratories, Hingham, Massachusetts. The M-141B Microphone is particularly well adapted to measuring sounds of high intensity. It is small and rugged, and can be used for measurements of sounds having frequency components from 50 cycles to beyond 20 kilocycles over the range of sound-pressure levels from 80 to 190 decibels.

4.35 Vibration Pickup: The Type 759-P35 Vibration Pickup is an inertia-operated Rochelle-salt crystal device which generates a voltage proportional to the acceleration of the vibrating body. By means of integrating networks in the Type 759-P36 Control Box, voltages proportional to the velocity or the displacement as well as the acceleration of the vibrating body may be delivered to the input of a sound-level meter. This combination plugs into a sound-level meter in place of the microphone. For vibration measurements below a frequency of 20 cycles the General Radio Type 761-A Vibration Meter is better suited.

4.4 ANALYZERS

Even if a sound-level meter were perfect (i.e. fit with no tolerance all the design objectives of the ASA Standards), the reading obtained by it in any given noise field is inadequate for a complete understanding of the problem. It is easy to see why this is so. The number of decibels obtained when reading a sound-level meter tells nothing about the frequency distribution of the noise. It is true that by judicious use of the weighting networks in a sound-level meter one can learn something about the frequencies present, but this knowledge is only qualitative. For most important problems it is necessary to use some type of frequency analyzer to determine the noise spectrum.

A number of analyzers are available for use with the Type 1551-A Sound-Level Meter so that its range of usefulness can be extended. These analyzers vary in cost, complexity and ease of operation. Choice between them is generally determined by the amount of detailed information needed to solve a particular problem. In general, the more information required, the more selective the analyzer needed. The more selective the analyzer, the more time is required to gather the information.

4.41 Octave-Band Noise Analyzer (Type 1550-A): The Type 1550-A Octave-Band Analyzer makes possible the simple and rapid analysis of

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[2] J. K. Hilliard, "Miniature Condenser Microphone", *Journal of the Society of Motion Picture and Television Engineers*, Vol. 54, pp. 303-314 (March 1950).

[3] H. F. Olson and J. Preston, "Unobtrusive Pressure Microphone", *Audio Engineering*, Vol. 34, pp. 18-20 (July 1950).

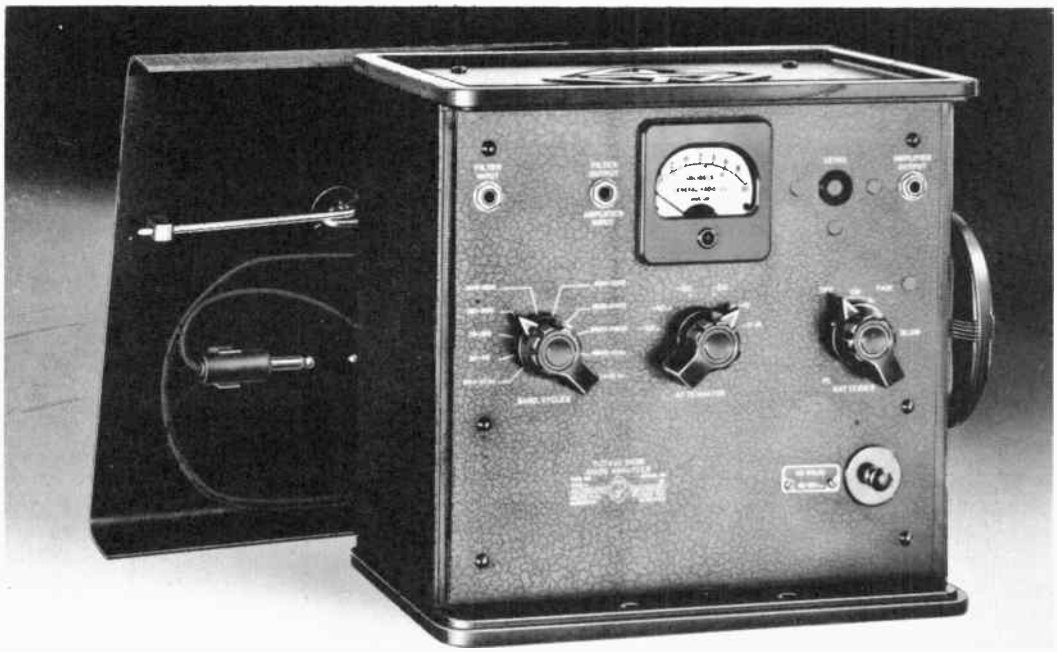


Figure 4-4. The Type 1550-A Octave-Band Analyzer.

noises having complex spectra. It operates directly from the output of a sound-level meter and is more convenient to use than narrow-band analyzers such as the Type 760-B Sound Analyzer or the Type 736-A Wave Analyzer. It can be used for all frequency analyses, except those requiring a detailed knowledge of the individual frequency components.

This analyzer consists of a set of 8 band-pass filters, selected by means of a rotary switch, followed by an attenuator and an amplifier, which drives both an indicating meter and a monitoring output.

Power is supplied by means of a self-contained battery block, but an a-c power pack that fits the battery compartment is available separately.

For convenience and flexibility, circuits and panel jacks are arranged so that the filter section or the amplifier can be used alone. Although intended for use at the output of a sound-level meter, the analyzer can be driven directly from the Type 759-P25 Dynamic Microphone Assembly or the Type 1551-P1 Condenser Microphone System when noise levels in the pass bands exceed 70 db but are less than 140 db.

4.42 Sound Analyzer (Type 760-B): The Type 760-B Sound Analyzer is a continuously tunable instrument. It is small, portable, and battery operated. It includes a three-stage direct-coupled amplifier which is made selective by means of a tunable null circuit in a negative-feedback loop. Operation is simple and convenient, and the entire frequency range of the instrument can be scanned quickly and easily. The frequency range is selected by means of a set of five pushbuttons, and the actual frequency is read from a single dial, which can be rotated continuously in either direction. The band width is a constant percentage of the frequency to which the analyzer is tuned, which facilitates measurements on machines that do not run at absolutely constant speed. No inductors are used, and the case is electrostatically shielded, so that this instrument is unaffected by ordinary electromagnetic and electrostatic fields.

In combination with a sound-level meter this analyzer provides a convenient means for measuring not only the actual sound-pressure level but also the relative amplitudes of the component frequencies. When component sound levels are in the range of 70 to 140 db, the Sound Analyzer can be driven directly by the Type 759-P25 Dynamic Microphone Assembly or the Type 1551-P1 Condenser Microphone System. An output jack is provided so that the filtered output can be monitored or recorded for future reference.

4.43 Wave Analyzer (Type 736-A): The Type 736-A Wave Analyzer is an a-c operated heterodyne-type vacuum-tube voltmeter. The interme-

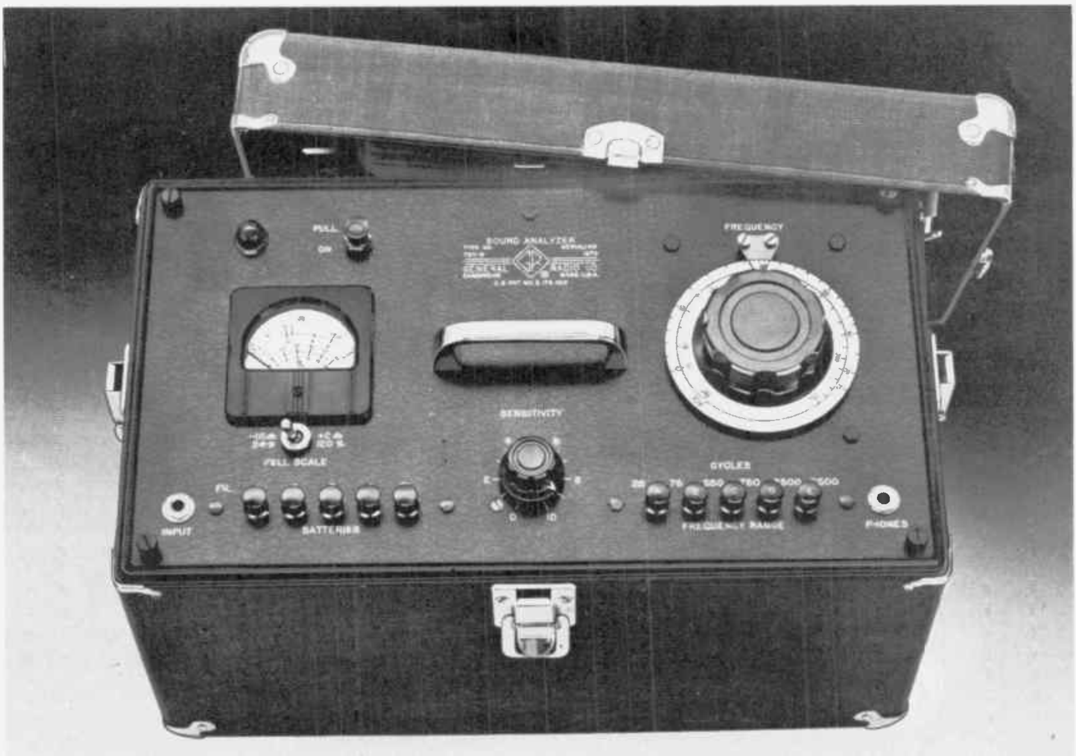
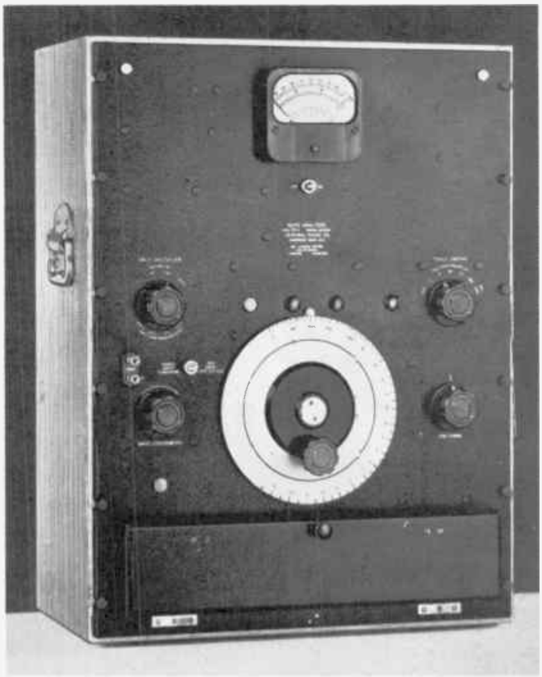


Figure 4-5. The Type 760-B Sound Analyzer.

diate-frequency amplifier includes a highly selective quartz-crystal filter. The use of a heterodyne method makes it possible to vary the response frequency while using a fixed frequency filter. This is a fairly complex instrument, better suited to laboratory use than to portable or field use. By its use, however, much can be learned about the frequency spectrum. It operates over a very wide range of input voltages (300 microvolts to 300 volts full scale). A direct-reading decibel scale is provided so that it is convenient to use in conjunction with a sound-level meter. It has a fixed band width of 4 cycles and high rejection outside the pass band. This band is so narrow that unless components in the spectrum are stable in frequency this analyzer becomes difficult to use at the upper audio frequencies. For this reason the Type 760-B Analyzer is better suited for noise measurements even though its rejection outside the pass band does not approach that of the Type 736-A. Figure 4-7 illustrates the difference in selectivity curves for the degenerative and the heterodyne-type analyzers.

Figure 4-6.
The Type 736-A Wave Analyzer.



4.5 ACOUSTIC CALIBRATOR (TYPE 1552-A)

The Type 1552-A Sound-Level Calibrator is a simple and convenient means for making an

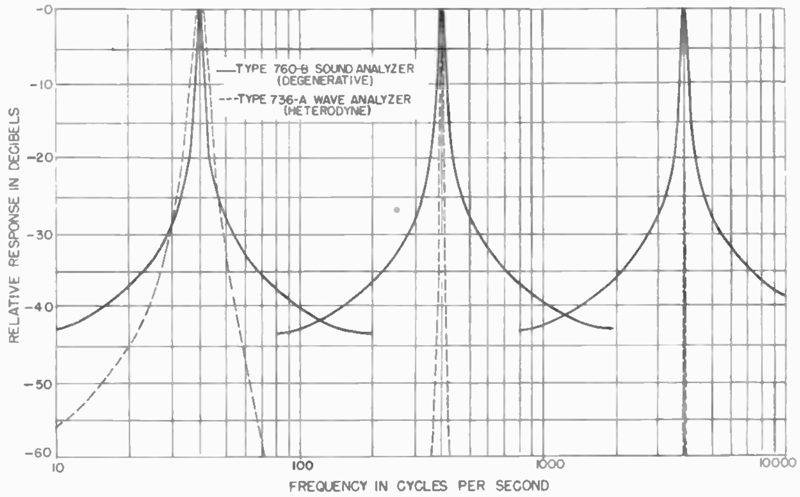


Figure 4-7. Selectivity curves for the degenerative and heterodyne-type analyzers.

over-all acoustical check, at 400 cycles, of the sensitivity of a sound-level meter including its microphone. An internal calibration system operating from any a-c power line is included within the Type 1551-A Sound-Level Meter and conveniently permits standardization of the electrical circuits, but this does not include a check on microphone sensitivity. It was to include the microphone in the calibration that the Type 1552-A Acoustic Calibrator was devised. It comprises a small, stabilized, and rugged loudspeaker mounted in an enclosure which fits over the microphone of the sound-level meter. The chamber is so designed that the acoustic coupling between loudspeaker and microphone is fixed and can readily be repeated. The level is high enough so that readings are unaffected by normal background noises.

The calibrator can be operated from any audio oscillator having reasonably good wave form (harmonic content should be 5% or less) and capable of supplying 2 volts at 400 cycles across an impedance of one microfarad in parallel with 2000 ohms. Most users find that they have available a suitable audio oscillator and a voltmeter for use with the calibrator. The Type 1307-A Transistor Oscillator is a small, simple oscillator that can supply this signal. It has an output voltmeter and a connecting cord that plugs into the terminals of the Calibrator.

4.6 ADDITIONAL EQUIPMENT OF OTHER MANUFACTURE

In addition to extended information gained by use of analyzers at the output of the sound-level meter, or special sources at the input such as the Type 1390-A Random-Noise Generator, the range and usefulness of the basic sound-level meter can be expanded by the use of a number of other pieces of associated equipment. The sound-level meter serves as an accurately calibrated preamplifier for the microphone. The Type 1551-A Sound-Level Meter provides a low-distortion, hum-free output, weighted to conform with specified frequency-response characteristics when desired, for the operation of such auxiliary equipment as the cathode-ray oscillograph, magnetic tape recorders, graphic level recorders, the Sonagraph, or a panoramic analyzer.

4.61 Cathode-Ray Oscillograph: The cathode-ray oscillograph is part of the equipment of

Figure 4-8. The Type 1552-A Sound-Level Calibrator placed on the microphone of a sound-level meter for calibration.

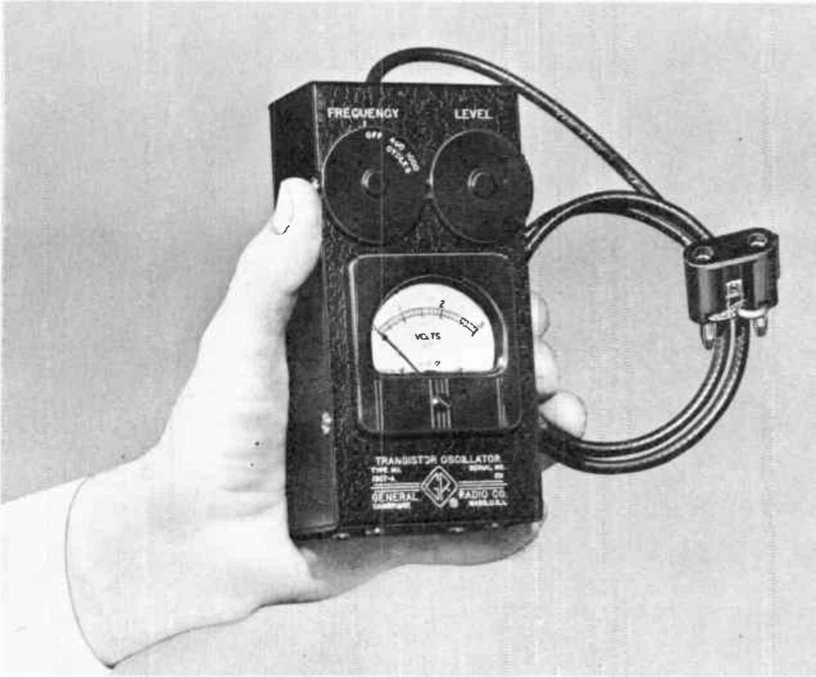


Figure 4-9. The Type 1307-A Transistor Oscillator, a recommended signal source for the Type 1552-A Sound-Level Calibrator.

almost any laboratory. It is a useful means for observing the wave form of a noise or other output signal from the sound-level meter. The oscillograph shows the amplitude of the signal as a function of time, in other words, it gives a time display of the signal. It is useful for observing many general noise patterns, particularly when measuring short duration or impact noises. It can be used to measure the peak amplitude, the rate of decay, and the shape of a wave.

4.62 Magnetic Tape Recorder: The magnetic tape recorder has become a very useful tool for the acoustical engineer both in research and in development. It stores a signal as variations in the magnetic state of the particles on the tape. The time scale then becomes a length scale on the tape.

The signal to be stored must be supplied to the recorder as an electrical signal; and, for recording noise as a function of time, this electrical signal is usually obtained from a high-quality microphone. When measurements are to be made on the stored signal, the recorded tape is played back on the recorder and measurements are made on the electrical output signal.

The magnetic-tape recorder is being used to perform the following functions in the field of noise measurements.

1. The preservation of a noise for later analysis or for comparison with a reference noise.
2. The obtaining of a series of short samples which may be analyzed in detail and compare with each other to determine statistical indexes.
3. The storage of a sample noise which ca be played through a filter and re-recorded an then played through the filter again to doubl the sharpness of the filter cut-offs.

The recorder selected must be a high qualit instrument if accurate analyses are desired. Thi means a flat frequency characteristic, low hu and noise level, low non-linear distortion, wid dynamic range, and constant speed.

4.63 Graphic Level Recorder: The graphi level recorder makes a permanent, chart recor of the level of the electrical signal supplied to i In the field of noise measurements this signal i usually obtained from the output of a sound level meter. The graphic level recorder can b used to record over periods of time the soun level at locations where one might question th maximum or minimum levels occurring due t effects of nearby traffic, airfields, or industria installations. It is also extensively used fo tracing frequency response curves and for measurement of reverberation time.

In conjunction with a sound analyzer it ca be used to record the curve of amplitude versu frequency of a noise source. In this application the motion of the paper in the recorder must b synchronized with the frequency of the analyze pass band. This may be accomplished either b a mechanical or an electrical link.

CHAPTER V

APPLICATIONS FOR THE GENERAL RADIO SOUND-MEASURING SYSTEM

5.1 INTRODUCTION

We have already seen that the General Radio Sound-Measuring System may consist of the Sound-Survey Meter or of the basic sound-level meter operated alone or with a wide variety of microphones, analyzers and recorders (see Figure 4-1). Confronted with so many possible choices, we ask, "What instruments should we select to do our job?"

The selection of the components of the sound-measuring system will depend entirely on what we wish to obtain from the measurements. If we are simply interested in comparing the noise in one office with that in another, the simple Sound-Survey Meter may be used. On the other hand, if we must determine the effect at all frequencies of adding a muffler to the exhaust of an automobile engine, a sound-level meter and an analyzer must be used. Similarly, we may want a measure of the loudness of the noise, the sound level, the sound-pressure level, the dominant pitch, the overtone structure, the extent to which it interferes with conversation, or some other characteristic, and for each of these we need to use a certain instrument or combination of instruments. It will be helpful in considering these possible end results to review the uses for the Sound-Survey Meter and the sound-level meter. Although the uses cited will not be all-inclusive, they should indicate the basis for a choice of equipment.

Figure 5-1. The Sound-Survey Meter being used to determine noise levels in a hospital area.

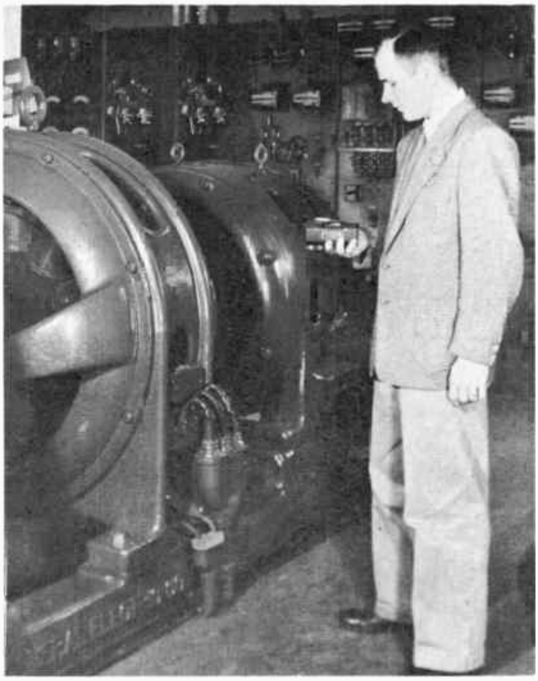


Figure 5-2. The Sound-Survey Meter being used to measure noise from rotating electrical machinery.

5.2 USES FOR THE TYPE 1555 SOUND-SURVEY METER

5.21 **In Industry:** There are many places where a sound survey is needed. For example, an industrial hygienist may be interested in measuring the noise levels in a factory so as to locate areas where there is a possibility of hearing damage. The Sound-Survey Meter is a very convenient instrument to use for this measurement. It makes possible a quick, initial survey, and, if the levels are low enough, no more is needed. It can also quickly show where more detailed measurements, including frequency analysis, are necessary. Even with the Sound-Survey Meter alone, an estimate of the frequency distribution of the noise is possible by the use of the weighting networks provided.

5.22 **By Architects:** The architect finds the Sound-Survey Meter useful in studying sites for office buildings, homes, and factories. He often considers noise in his selection of a proper place to put a building, in the same way that he considers other environmental factors such as prevailing winds, smoke nuisance, the nearness of schools, and so forth. The architect occasionally must determine the noise produced by ventilating systems to see if they conform to specifications or to see if remedial measures are necessary to quiet an existing system.

Another example of a problem that the architect may encounter is locating a broadcast studio within an existing building. With the Sound-Survey Meter he can measure the noise conditions on each floor of a building and from these data select the most suitable floor for locating the studio. Obviously, vibration may also have to be considered in this problem, necessitating the use of a vibration meter.

5.23 **By Engineers and Consultants:** Engineers and consultants use the Sound-Survey Meter as a preliminary guide to later, more detailed, measurements of sound fields. The meter is a rapid

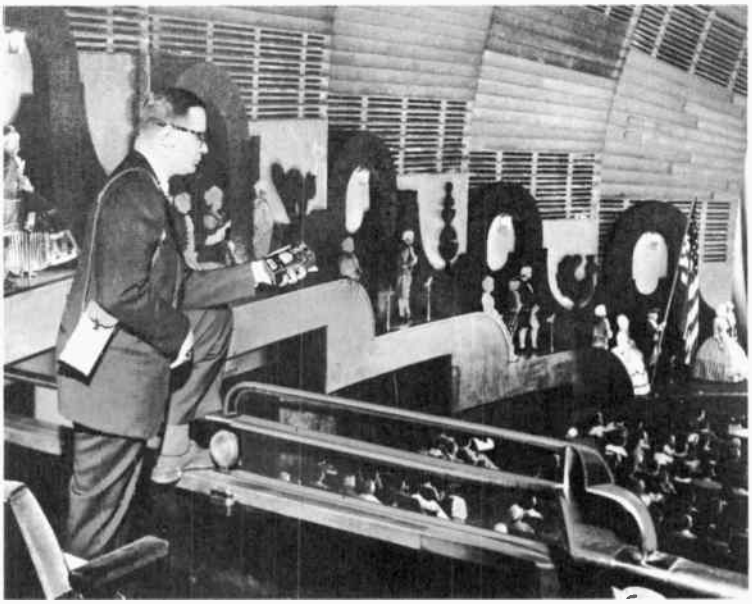


Figure 5-3. Performance checks of sound reinforcement system at Radio City Music Hall being made with Sound-Survey Meter.

means of collecting statistical data on a noise where a detailed knowledge of the spectrum is not needed.

5.24 In Theaters and for Sound Systems: The Sound-Survey Meter, because of its small size and ease of operation, is particularly useful in checking the level of reproduced sound in theaters and other sound systems. Sine-wave response characteristics of loudspeakers and rooms can be measured. On high-fidelity divided-speaker sound systems the survey meter is useful for determining the response characteristics through the crossover point and for measuring the dynamic range.

5.25 In Schools: Simple Sound-Survey-Meter measurements will tell the superintendent of a public-school system whether or not the noise in the classrooms is likely to affect the efficiency of the teachers. If the noise levels exceed approximately 40 db with the "A" scale, the students may have difficulty in understanding their teacher.

Two other effects influence the quality of a classroom. In a highly reverberant room, the syllables of speech are smeared by the reflected sounds, so that the intelligibility is reduced. In a room with heavy acoustic treatment, the attenuation may be so great that at the rear of the room the teacher's voice is but poorly heard through the background noise.

In the physics or science laboratories, the teacher can demonstrate with the Sound-Survey Meter the relation between sound levels and the sensation of hearing, and he can also use it for acoustical experiments. Teachers of psychology can use it to demonstrate the relation between loudness and loudness level and the dependence of hearing on the intensity of the sound.

5.26 In Dramatics and Music: Directors of musical and dramatic productions can use the Sound-Survey Meter to help actors and musicians to find the correct voice level for a given auditorium or theater. Similarly, teachers of voice and dramatics find it an aid in teaching students to use microphones properly.

5.3 USES FOR THE TYPE 1551 SOUND-LEVEL METER

The Type 1551 Sound-Level Meter is a precision instrument, which, when combined with a suitable microphone and analyzing or recording equipment, can be used to measure noise and other sounds accurately. It can also be used in the same way that the Sound-Survey Meter is used, because it has embodied in it the same type of weighting networks and is nearly as simple to use. Furthermore, it is more stable, and it is built to closer tolerances than is the Sound-Survey Meter. It meets all the requirements of the American Standard Specification for Sound-Level Meters. In addition it supplies a low-distortion output signal, and it has a sufficient dynamic range so that analyzing equipment may be used with it.

The sound-level meter can be used without an analyzer for many types of surveys, for measurement of the over-all sound level as required by test codes, for production tests of equipment noise, or for comparing two machines of similar design and performance. For example, if a maximum acceptable noise level has been established for a given model of electric motor, then the sound-level meter can be used with the weighting network in the most appropriate one of its three positions to determine whether or

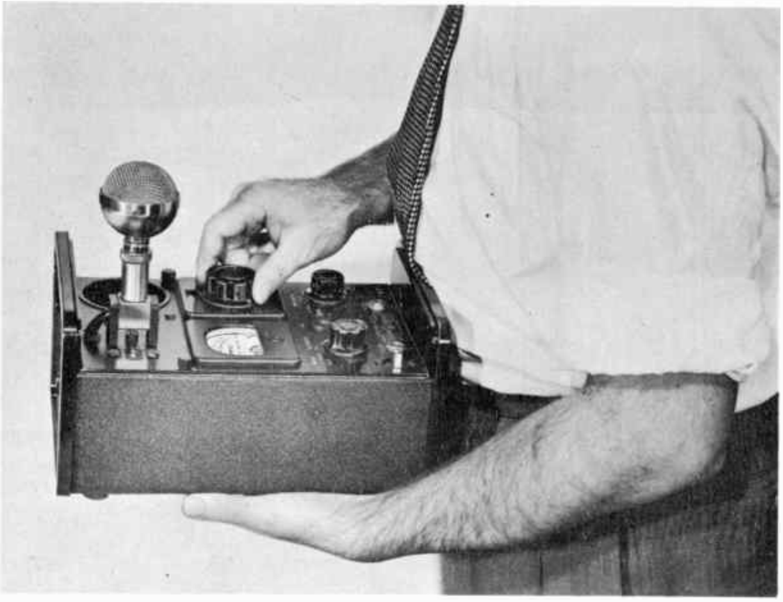
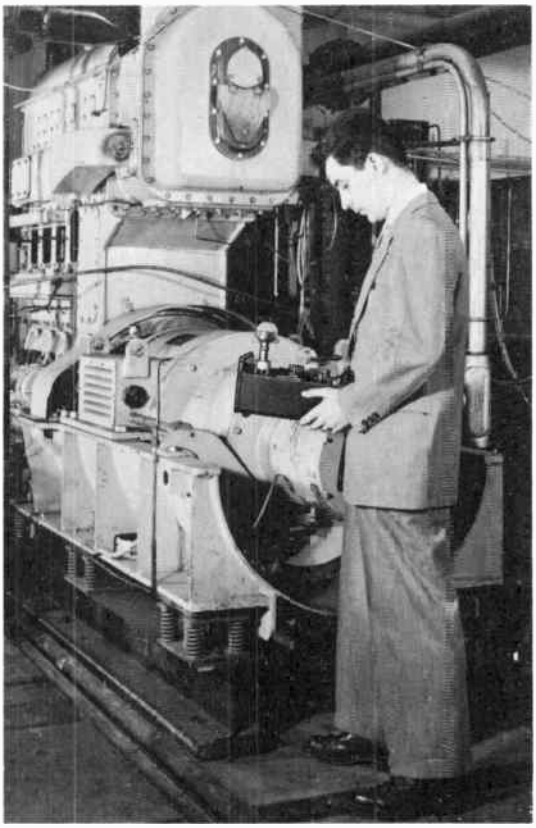


Figure 5-4. Hand-held operation of the sound-level meter. See Section 6.52 for recommendations.

Figure 5-5.
The General Radio Sound-Level Meter, being used to measure blower, combustion and injection valve noise of a two-stroke diesel engine.



not other similar motors are sufficiently quiet to meet the production standards. As another example, the noise due to the operation of a particular jet engine test cell in the vicinity of a manufacturing plant may be measured frequently to see that wind and operating conditions do not cause the sound to exceed an acceptable level.

5.31 Noise Test Codes: Some special groups have prepared test codes for making noise measurements on various devices. Examples of these devices are fans, blowers, water-cooling towers, transformers and airplanes. Almost invariably the code specifies the use of a sound-level meter conforming to the requirements of the American Standard Sound-Level Meter for Measurement of Noise and Other Sounds, Z24.3-1944. When a device must be tested according to such a code, it is recommended that the Type 1551 Sound-Level Meter be used.

The code usually specifies the conditions of the test, for example, the mounting and location of the device and the microphone placement. The American Standard Test Code for Apparatus Noise Measurement, Z24.7-1950[1], gives typical conditions.

It is usually important for reliability of measurement as well as from the standpoint of obtaining a favorable result to test in as dead (acoustically) a room as practical and to have the background noise level low. Sections 6.51 and 6.53 will show how far it is necessary to go in these respects.

These codes have been prepared to permit noise ratings to be made in a relatively uniform manner. When different models of the same type of device have the same noise rating, however, they will not necessarily give the same noise level in a given room, even if mounting and operating conditions are carefully controlled. In order to be able to predict how two different models will compare in the noise level they produce in a live room, it is often necessary to determine the acoustic power rating and the directivity index of each device as a function of frequency. The methods for determining these are given in Chapter VIII.

5.32 Analysis of the Noise: When the effect of noise on the hearer is to be predicted, an analyzer is ordinarily used with the sound-level meter. Analysis is also useful in determining changes in behavior of machines and their parts, the characteristics of sound sources, and the effects of rooms on noise.

In general the narrow-band type of analyzer (Type 760-B Sound Analyzer) is used when the noise has a characteristic pitch, such as that produced by rotating machinery, when there are resonant structures in the noise source that produce marked peaks of energy in the spectrum, when the noise source is a multiple one that includes strong pitched components, and when the levels from separate sources of different frequencies are required. The octave-band-type (Type 1550-A Octave-Band Noise Analyzer) is usually more suitable for noises of a broad-band character such as hissing, swishing, and sizzling noises, rattles, and buzzes, as well as many machinery noises and aircraft noises. Examples of this type are ventilating systems, oil burners, jets, blowers, cooling towers, looms, tumbling mills. It is also useful when more information about a noise is required than can be given by a sound-level meter directly, but a more detailed analysis than eight band levels cannot be justified because of the time required. Furthermore, the sound-pressure levels determined in the eight bands form the basis for the approximate calculation of

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[1] **American Standards Association, 70 East 45th Street, New York 17, New York.**

Figure 5-6. Another example of the sound-level meter in use: measuring over-all noise level in a commercial office.

the loudness level of a noise, and they give the speech-interference level. See Sections 7.2 and 7.3.

As another example, the background noise in an audiometric room should be low in level in order that accurate audiometric examinations can be made. It is particularly important to have a low noise level at low frequencies. An octave-band analysis of the background noise is then desirable in order to insure that these levels are satisfactory.

5.33 Quieting Machine Noises: In the development of a new machine it may be necessary to determine accurately the noise components that are radiated by the machine and that are principally important in the production of noise. As an example, let us consider an air-conditioning machine that produces too high a noise level. Analysis with a narrow-band sound analyzer, such as the General Radio Type 760-B may reveal that the frequencies of the principal noise components can be associated with certain time-periodic rotating or reciprocating actions in the machine. When it has been determined which of these noise sources are the principal ones, the Engineering Design Department can quiet them. In this example it is not necessary, from the engineer's standpoint, to know accurately the magnitude of the sound pressure or the total acoustic power radiated by the device. He only needs to know which are the loudest components and how many decibels he needs to reduce them in order to make them be no more intense than other noises from the machine.

A common use for the sound-level meter is to determine the noise level produced by competitive machines. If the machines are of similar design so that they radiate sound in much the same manner, it is only necessary that the microphone be located in the same position relative to each machine. The sound-pressure levels are determined as a function of frequency either with an octave-band noise analyzer or the sound analyzer. Some examples of noise spectra measured with an octave-band analyzer and with a narrow-band analyzer are shown in Figures 6-5 and 6-7.

If the machines under comparison are dissimilar in design, it is necessary to determine the total acoustic power radiated by the machine as a function of frequency. The method of measurement will be discussed in Chapter VIII. Acoustic power data are particularly important when a machine is to be operated in a closed room, such as an office, factory space, or schoolroom. The noise spectrum built up in a closed room is dependent principally on the spectrum of the acoustic power from the machine, the size of the room, the acoustical absorption properties of the boundaries, and the number of people in the room.

If a machine is used indoors in a reverberant room and if the noise level produced by it is of importance only at a distance of fifteen or more feet from the machine, the only information needed is the total radiated acoustic power as a function of frequency. If, however, this same machine is to be operated out-of-doors or in a room which is not highly reverberant, the directivity pattern of the noise becomes important and must be determined. By the directivity pattern we mean the acoustic power radiated by the machine in various directions. Obviously, there is no point in reducing the noise if the people who are subjected to it are at such an angle from the machine that very little acoustic power is radiated toward them.

5.34 Measurements on Acoustical Properties of Rooms—Studios—Acoustical Materials: The General Radio Type 1551 Sound-Level Meter is an important tool for physicists or engineers who are interested in laboratory measurements or in the acoustical properties of rooms and studios. It can be used with a wide variety of microphones, including high-fidelity types with frequency ranges extending out to 20,000 cycles. The sound-level meter can be used with a high-speed, graphic-level recorder to determine the reverberation time in a room. It can also be used to measure the noise level built up in the room by a source of known power output. The sound-level meter is useful for determining the uniformity of distribution of sound in a room from a source located at a particular point. It is often used with a suitable analyzer, to determine the sound-pressure spectrum of the ambient noise in a room. Acoustical laboratories find the sound level meter useful in the study of acoustical materials, both as installed in rooms and for ventilating systems.

5.4 LOUDNESS AND LOUDNESS LEVEL

A number of workers in noise measurements have found it useful to translate their noise measurements into loudness terms. Then they can say the measured sound was, for example, about equal in loudness to another, more familiar, sound. To some groups, such as executives and lay clients, this type of statement is seemingly more meaningful than quoting levels in decibels.

In a general way we discussed in Section 3.33 the procedure for calculating the loudness level from measured levels in octave bands. These levels are determined by using the Type 1550-A Octave-Band Noise Analyzer, and the calculation procedure is given in detail in Section 7.2.

5.5 SPEECH-INTERFERENCE LEVEL

Most of us have been in locations where it was impossible to hear over a telephone because the noise level was too high; and, in order to hear, production machinery had to be turned off, resulting in time and money lost. Even direct discussions can be difficult and tiring because of excessive noise. Excessive noise may make it impossible to give danger warnings by shouting or to give directions to workers. How serious these conditions are and how much change in noise level is necessary to shift to a less serious condition can be determined by the speech-interference level. Then it is possible to prepare a plan of acoustic treatment on an engineering basis to remedy the situation, if possible.

The speech-interference level is calculated from the results of a frequency analysis of the noise, using the Type 1550-A Octave-Band Noise Analyzer. The methods for using this level are discussed in Section 7.3.

5.6 HEARING LOSS FROM EXPOSURE TO NOISE

The noise near some machines is intense enough to cause permanent hearing damage if the exposure to the noise continues for months

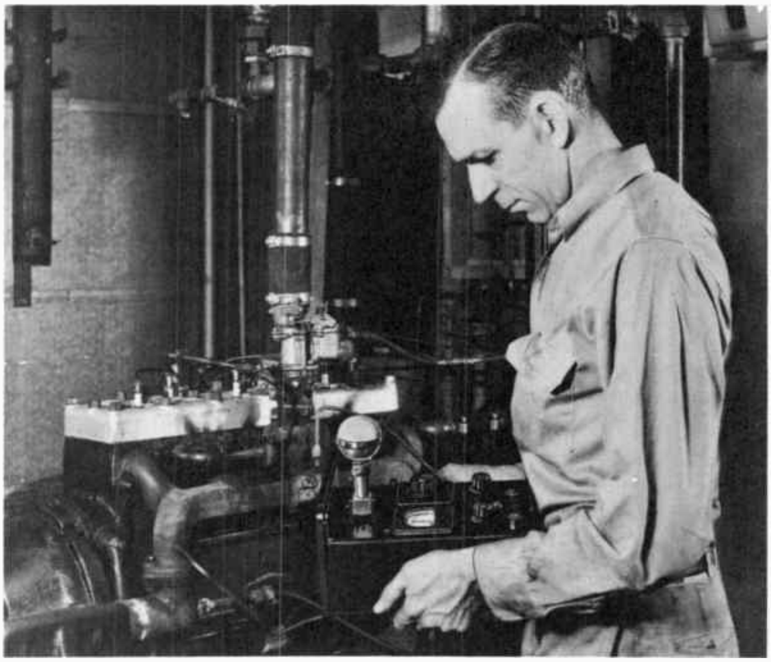

Figure 5-7.
Determining noise level of automobile engine during a test run.

or years. Noises of the same overall level but with different amounts of energy in various frequency bands have different effectiveness in giving rise to hearing loss, and noise concentrated in a narrow range of frequencies is apparently more serious than if the same energy is spread out over a wide frequency range. Furthermore, equal hearing losses in different frequency regions are not equally serious from the point of view of understanding speech. Because of these facts, a thorough frequency analysis of the noise is usually necessary if the noise levels are high. Naturally, if an over-all level check is found to be sufficiently low that there is no cause for alarm, no analysis is necessary. But beyond a certain level, analysis will show more definitely what kind, if any, damage is likely.

Therefore, for an initial survey a Type 1555-A Sound-Survey Meter or a Type 1551-A Sound-Level Meter can be used to measure the noise level at the person's ears. With these instruments alone there will be a considerable range of level for which the prediction regarding damage will be uncertain because the frequency spectrum of the noise is not known. In the doubtful range, therefore, the spectrum should be determined by analysis with the Type 1550-A Octave-Band Noise Analyzer or the Type 760-B Sound Analyzer. But because of the lack of adequate evidence, because of the variability among people, and because of the great differences resulting from the length and repetitiousness of the exposure, there will remain a considerable uncertainty regarding the level of danger for a given individual.

Impact noises, such as those produced by drop forges, should be investigated by an octave-band analyzer and an oscillographic display to observe the peak levels and the duration of the peaks.

Some industrial and governmental organizations have set up a program that includes periodic hearing tests* and records of noise exposure of their employees. The noise exposure records give the octave-band analysis of the noise to which the particular employee is exposed, the duration of exposure to the noise, and the protective measures, such as ear protectors, used. Such a systematic approach is recommended for organizations having many employees exposed to high-level noise.

As a preliminary aid to determining possible damaging noise level conditions, tentative rating charts are given in Section 7.4.

5.7 SUMMARY

Some of the measurement applications discussed in this chapter are summarized in the charts of Figures 5-8 and 5-9 concerning environmental noise and measurements on noisy devices. In addition, a summary of suggested steps in following apparatus test code requirements and for evaluating product noise are given in the charts below.

Steps in Following Apparatus Test Code Requirements

Successive Steps	See Section
1. Selection of location for measurements	(6.51) (6.53)
2. Apparatus Mounting	(6.57)
3. Selection of Microphone	(6.4)
4. Location of Microphone	(6.58) (6.51)
5. Number of Measurements	(6.58)
6. Weighting Characteristics	(6.2)
7. Maintenance Checks	(6.6)
8. Background Noise	(6.53) (6.54) (6.55) (6.56)
9. Measurement	(6.52) (6.2) (6.3)
10. Repeat of Maintenance Checks	(6.6)
11. Recording Data	(6.8)

The specific test code, of course, supersedes any suggestions made in the referenced sections.

Steps in Evaluating Product Noise

Title	See Section
1. Selection of location for measurements	
a. Outdoors, Large Room	(8.3) (8.44)
b. Reverberant Room, Room Constant	(8.331) (8.441)
2. Apparatus Mounting	(6.57)
3. Selection of Microphone	(6.4)
4. Measurement Locations for Microphone	
a. Points on Sphere or Hemisphere	(8.41)
b. Distance compared with source diameter and lowest frequency	(8.223)
5. Maintenance checks of sound-level meter and analyzer	(6.6)
6. Background Noise in each Band (For each microphone location)	(6.53) (6.54) (6.55) (6.56)
7. Measurement in each Band (For each microphone location)	(8.41)
8. Repeat Maintenance Check	(6.6)
9. Recording Data	(6.8)
10. Calculation of Acoustic Power and Directivity Pattern for each Band	(8.42) (8.43) (8.442) (8.443)

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*cf. Subcommittee on Noise in Industry of the Committee on Conservation of Hearing, American Academy of Ophthalmology and Otolaryngology, "A Guide for Conservation of Hearing in Industry."

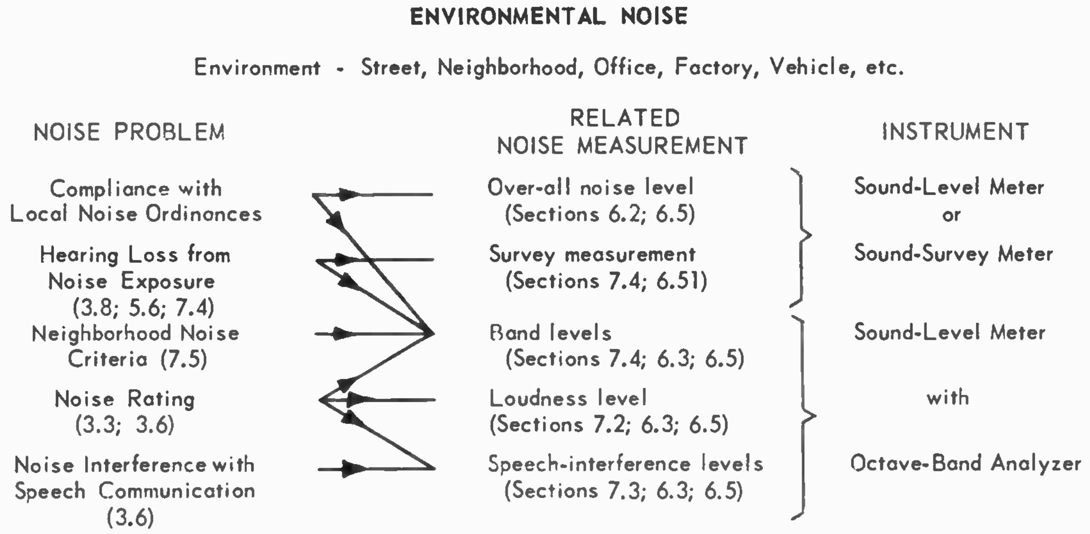

Figure 5-8. A summary of noise measurements as applied to environmental noise. (Pertinent sections are given in parentheses.) The arrows are used to suggest the noise measurements that may help in understanding the noise problem and in doing something about it. Factors other than level may also be of great importance, and some of these factors are discussed in the referenced sections.

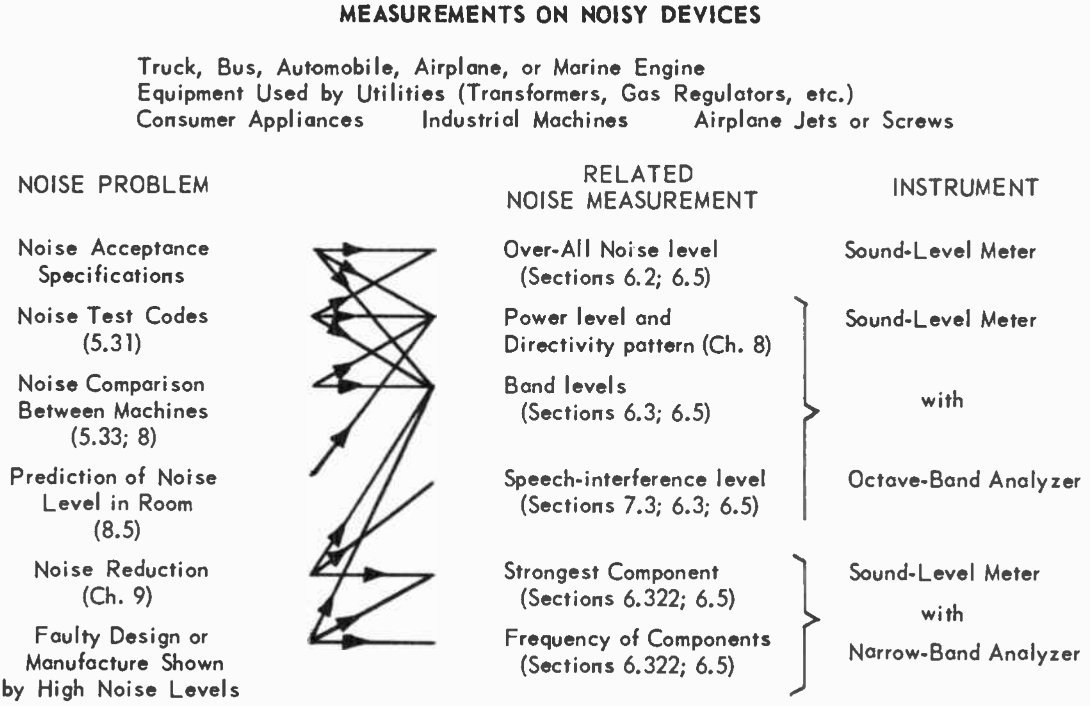

Figure 5-9. A summary of measurements on noisy devices. (Pertinent sections are given in parentheses.) As above, the arrows suggest the noise measurements that may help in understanding the noise problem and in doing something about it.

CHAPTER VI

MEASUREMENT OF SOUND LEVEL AND SOUND-PRESSURE LEVEL

6.1 INTRODUCTION

Most of the applications discussed in the previous chapter require a measurement of either sound-pressure level as a function of frequency or of sound level. These quantities are measured at a single point or at a number of points that are determined by the conditions of the application. The method of measuring these quantities is discussed in this chapter, while the procedure for determining from the measured data the calculated loudness level, the speech-interference level, and the possibility of hearing damage is given in the next chapter. In Chapter 8, we discuss the more difficult problem of predicting from the measured data the noise level that a noise source will produce when placed in any location.

The basic procedure for measuring the sound level or the sound-pressure level at a given point is to locate the sound-level meter microphone at that point and to note the reading of the sound-level meter. Some preliminary exploration of the sound field is usually necessary to determine that the point selected is the correct one, and this exploration is discussed later in this chapter. Other practical details regarding this measurement are also given in this chapter, but the actual manipulation of the individual instrument controls is discussed in the instruction books that are furnished with the instruments.

We shall discuss the selection of the basic instruments for the job, the choice of microphone and auxiliary apparatus, the effects of extraneous influences, the recording of adequate data, the calibration of the instruments, and the interpretation of the data. Finally, an example of a measurement problem is given. Much of this discussion is necessary because no ideal instrument or combination of instruments and accessories is available that would be suitable for all conditions. For example, microphones of different types differ in uniformity of response, in susceptibility to damage, and in cost.

6.2 MEASUREMENT OF SOUND LEVEL—WEIGHTING NETWORKS

When a single reading of sound level is desired in conformance with the established standard[1], the General Radio Type 1551 Sound-Level Meter should be used. For many applications, however, the Type 1555-A Sound-Survey Meter can be used instead to obtain an equivalent measurement. As explained in Section 3.31, the A and B weighting networks in these instruments are designed to approximate the frequency characteristics of the ear for pure tones as determined by equal loudness contours at 40 db for the A network and 70 db for the B network, while the C network has an approximately flat response.[2] Typical frequency response curves for the two instruments, shown in Figures 6-1 and 6-2, illustrate these characteristics.

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[1] ASA, Z24.3-1944

[2] To obtain an approximately flat response using the Rochelle-salt type crystal microphones normally supplied with General Radio sound-measuring equipment, the C network is used. When a microphone with a truly flat response is employed with the General Radio Type 1551 Sound-Level Meter, the "20-kc" network should be used (see "20 kc" curve, Figure 6-1).

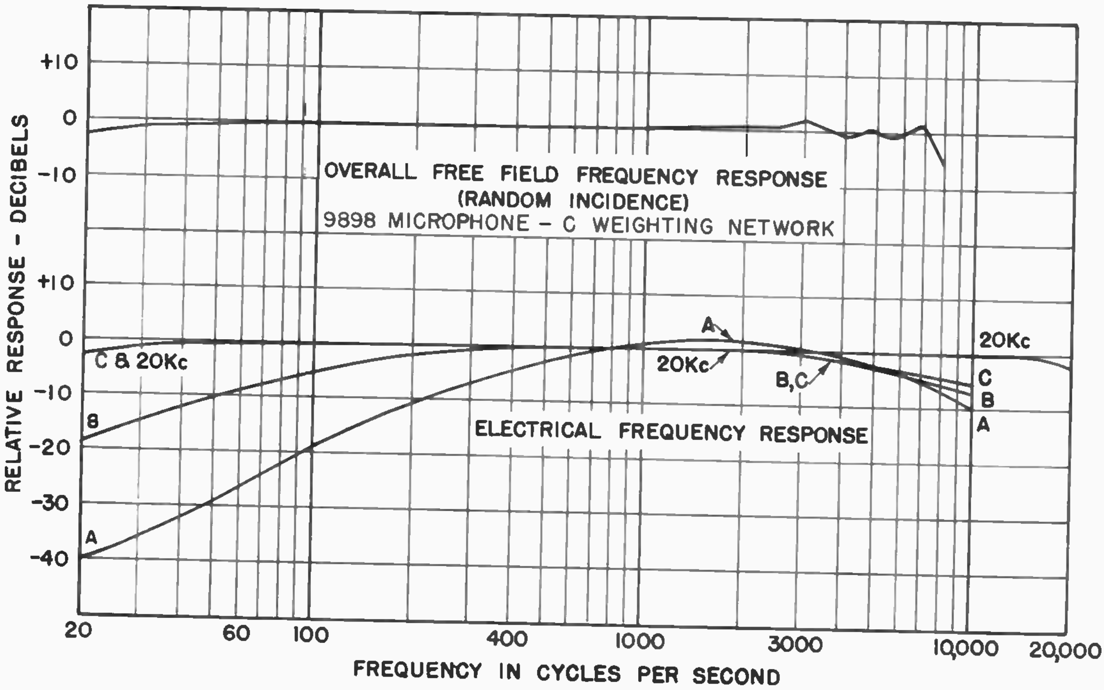


Figure 6-1. Typical average acoustical and electrical calibration curves for the Type 1551-A Sound-Level Meter.

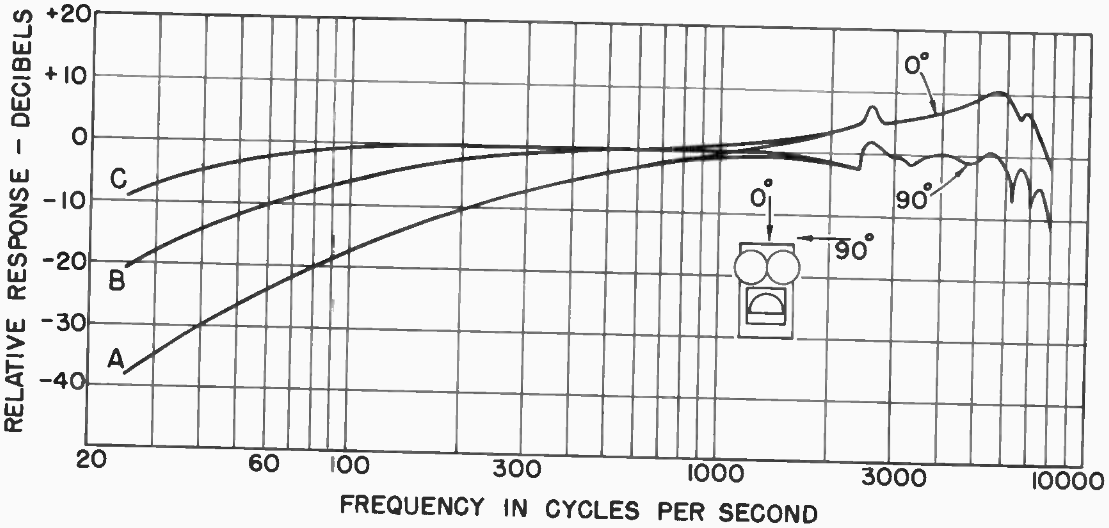


Figure 6-2. Typical over-all free-field response characteristics of the Type 1555-A Sound-Survey Meter.

If a single sound-level reading (not sound-pressure level) is desired, it is customary to select the weighting positions as follows:

Sound-Level Range	Weighting
below 55 db	A
55-85 db	B
above 85 db	C

For example, on a particular noise, sound-level meter readings were as follows: 60 db with C weighting, 50 db with B weighting, and 40 db with A weighting. The quoted sound level is then 40 db, since neither of the first two readings fall within the specified ranges for that weighting.

The weighting position used should always be recorded with the observed level. Some test codes specify the weighting network to be used regardless of level, and, when tests according to such codes are made, that specification should be followed.

When the noise is predominantly of low-frequency components, the selection method mentioned above may become ambiguous. Then some experimenters have recommended the following schedule:

Sound-Level Range	Weighting
below 45 db	A
45-65 db	Average of A and B
65-75 db	B
75-90 db	Average of B and C
above 90 db	C

(where "Average of A and B" indicate that the average in decibels of the readings obtained with the A and B weighting should be used)

In general, it is recommended that readings on all noises be taken with *all three* weighting positions. This procedure avoids the ambiguities mentioned above, and, at the same time, the three readings provide some indication of the frequency distribution of the noise. If the level is essentially the same on all three networks, the sound probably predominates in frequencies above 600 cps. If the level is greater on the C network than on the A and B networks by several decibels, much of the noise is probably below 600 cps.

A more complete statement of this approximate analysis is given by the charts of Figure 6-3, which can be used to give an approximation of the sound distribution in three frequency bands. These charts should be used only as a guide for determining in a preliminary way what the spectrum might be, and they should not be regarded as obviating a complete octave-band analysis. There are occasions, however, when it is impractical to make more than this preliminary analysis, and then the charts of Figure 6-3 may help in making a more satisfactory decision about a noise problem than can be done with only one reading of a noise meter.

Certain noises in which the energy is localized at one end or the other of the lower and middle bands of this approximate analysis cannot be analyzed using this method. This type of spectrum will usually give sound-level readings that do not fit on the charts. Similarly, the dotted portions of the curves are regions of poor accuracy of analysis.

The level in the "high" band (above 600 cycles), as determined from the charts of Figure 6-3, is usually the most important, and for preliminary surveys one can estimate the speech-interference level as 6 db lower than this high-band level. This approximate speech-interference level can then be used according to the methods given in Section 7.3.

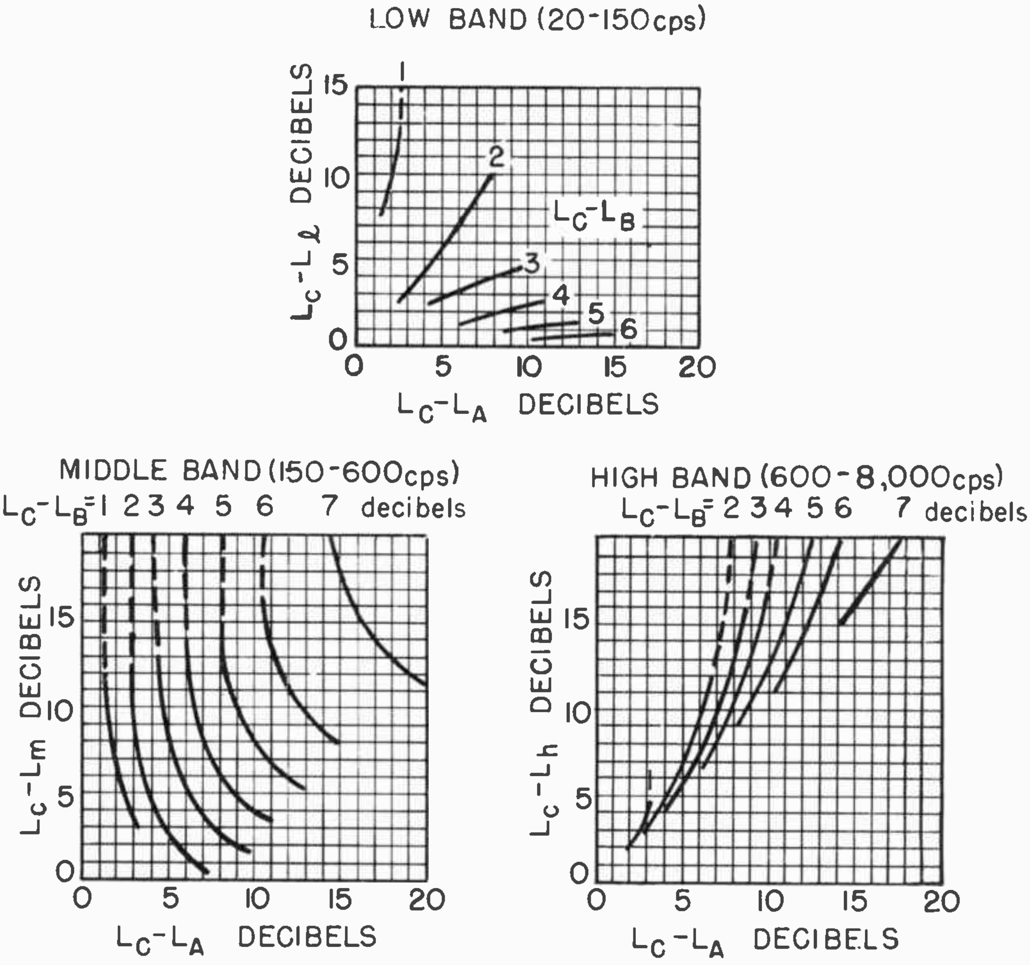
In the measurement of the noise produced by distribution and power transformers, the difference in readings of level with the C-weighting and A-weighting networks (L_c—L_a) is frequently noted. This difference in decibels is called the "harmonic index". It serves, as indicated above, to give some idea of the frequency distribution of the noise.

6.3 MEASUREMENT OF SOUND-PRESSURE LEVEL

The sound-pressure level of a noise is measured with the sound-level meter operating with a uniform ("flat") frequency-response characteristic. For most meters this means that the weighting network should be in position "C"; and this network is commonly called the "flat" network. The "C" network on the Type 1551-A Sound-Level Meter has an electrical response which drops noticeably at frequencies above 4 kc (see Figure 6-2). This drop tends to compensate for some of the rise in response of the microphone supplied with the sound-level meter. When this regular microphone is used, the "C" network is recommended for measuring sound-pressure level. When a different microphone is used, particularly if its response is more uniform at high frequencies than the regular one, it is recommended that the "20 kc" position be used. The electrical response of the meter exclusive of the microphone is essentially flat from 20 cps to 20 kilocycles when the weighting switch is in this "20 kc" position.

6.31 Over-all Sound-Pressure Level: The sound-level meter with a "flat" over-all response is used independent of any frequency analyzer to determine the over-all sound-pressure level, given directly by the reading of the sound-level meter in decibels. This over-all level is adequate if the frequency distribution of the sound is of no importance or if it is a single, known frequency.

Figure 6-3. Curves for calculating an approximate frequency analysis in three bands from level readings taken when using the three sound-level meter weighting networks. The measured value of L_C-L_A is entered at the abscissa of each graph, proceeding vertically to the curve labeled with the measured value of L_C-L_B, then horizontally to the ordinate value for each of the three bands corresponding to the difference between the individual band levels and the over-all level. (This method of analysis was developed by J. R. Cox, Liberty Mutual Insurance Company.)



L_C = Level reading obtained when using the C-weighting network = Over-all Level.

L_C-L_A = Difference in readings of level with C-weighting and A-weighting networks.

L_C-L_B = Difference in readings of level with C-weighting and B-weighting networks.

L_C-L_l = Level to be subtracted from the C-weighting level to obtain "Low-Band" (20-150 cps) level.

L_C-L_m = Level to be subtracted from the C-weighting level to obtain "Middle-Band" (150-600 cps) level.

L_C-L_h = Level to be subtracted from the C-weighting level to obtain "High-Band" (600-8,000 cps) level.

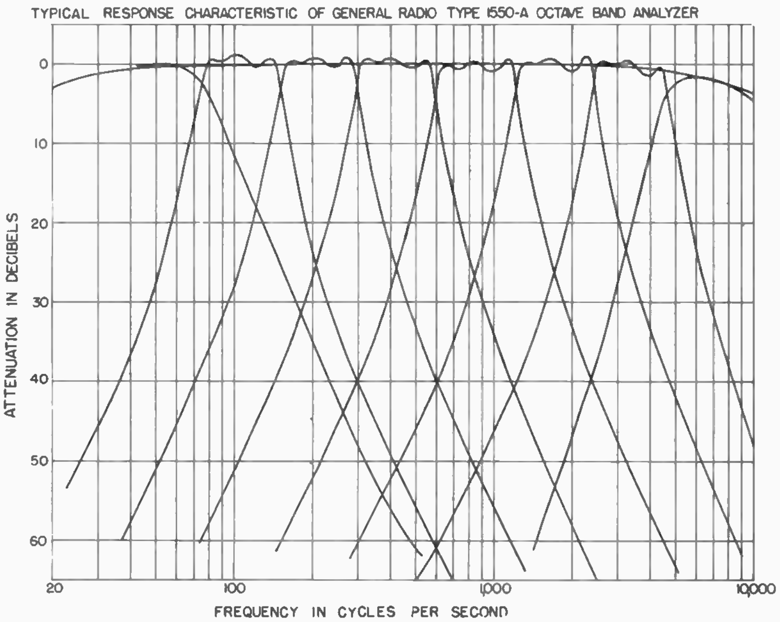


Figure 6-4.
Typical response characteristics of the Type 1550-A Octave-Band Noise Analyzer.

For most applications, however, a frequency analyzer should be used with the sound-level meter, and then this over-all level is commonly used as the reference level for the levels in the various bands of the analyzer.

6.32 **Frequency Spectrum and Band Levels:** An analyzer is required to obtain the frequency spectrum, that is, the distribution of sound pressure as a function of frequency. For field measurements either a Type 1550-A Octave-Band Noise Analyzer or a Type 760-B Sound Analyzer is commonly used. The analyzer is usually connected to the output of the sound-level meter, which is set for a uniform response characteristic.

6.321 **Octave-Band Analyzer:** The Type 1550-A Octave-Band Noise Analyzer divides the audio spectrum into eight bands. The nominal cut-off frequencies of these bands are 20-75, 75-150, 150-300, 300-600, 600-1200, 1200-2400, 2400-4800, and 4800-10000 cps. Typical response characteristics for this analyzer are shown in Figure 6-4. When this instrument is used with the sound-level meter, the sound-pressure levels obtained in these bands are called octave-band pressure levels.

As mentioned above, the sound-level meter weighting is set for uniform response (usually the "C" position) when readings are taken on the eight bands of the octave-band analyzer. As a practical matter, sometimes measurements should also be made in the four upper bands (600-1200, 1200-2400, 2400-4800, 4800-10000) with the sound-level meter in the A-weighting position. This additional measurement should be

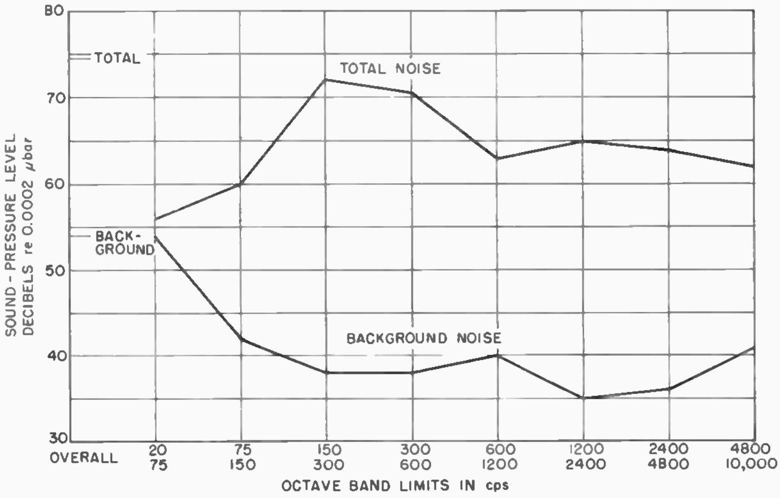


Figure 6-5.
A plot of the octave-band analysis of noise from a calculating machine.

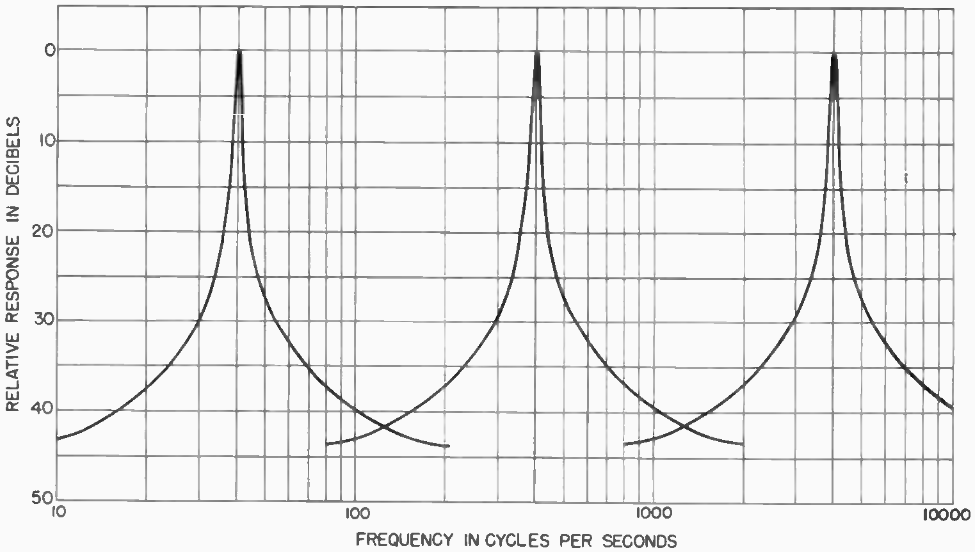


Figure 6-6. Typical response characteristics of the Type 760-B Sound Analyzer for three representative frequency settings.

made if the level in any one of these four upper bands is 30 db or more *below* the over-all level. Of course, in this A-weighting position, the attenuator on the sound-level meter needs to be reset to bring its meter on scale. This additional measurement provides more range for analysis in the upper bands by reducing the inherent noise in the measuring system. If the levels in the upper four bands obtained by the two sets of measurements differ by more than 3 db, the lowest value is the one that is more nearly correct.

It is also good practice to check that the sum of the individual band levels (see Section 2.4) is equal within 1 or 2 db to the over-all level. If this result is not obtained, an error exists, either in the summing or the measurement procedure, because of faulty or incorrectly used equipment, or because the noise is of an impact type. Impact-type noises sometimes give over-all levels appreciably less than the sum of the levels in the individual bands even when the "FAST" position of the meter switch is used. This result is obtained because of the inability of the meter to indicate the instantaneous levels occurring in very short intervals. The narrow-band levels at low frequencies tend to be nearer the peak value in those bands, while the over-all and high-frequency bands are significantly less than the peak value. When this type of discrepancy is observed, an oscillographic measurement (see Section 6.73) is desirable.

When a graph is made of the results of octave-band pressure level measurements, a frequency scale is commonly provided by allowing equal intervals between the position designated for each band and the position for the band adjacent to it in frequency. The pressure level in each band is plotted as a point on each of these positions along the other axis. Adjacent points are then connected by straight lines. An example of a plot of this type is given in Figure 6-5.

6.322 Narrow-Band Analyzer: The Type 760-B Sound Analyzer is continuously tunable from 25 to 7500 cps, in five ranges. Typical responses of this analyzer at some representative settings of the tuning control are shown in Figure 6-6. The calibration on the tuning control shows the frequency of maximum response, and the responses at frequencies 1% lower and 1% higher than this frequency of maximum response are 3 db below the maximum response. The effective band width for random noise is about 3%, so that this analyzer divides the range from 25 to 7500 cps into about 190 bands. The detail of the analysis is consequently much finer and more information is obtained than for the octave bands, but the time required for this analysis is correspondingly much greater. Because of this time factor, it is becoming increasingly common for this narrow-band analysis to be made from a magnetic-tape recording of the noise being investigated. The use of a recorder in this fashion is discussed in Section 6.713.

The sound-pressure levels obtained from this analyzer used on the output of a sound-level meter are usually plotted as a function of frequency with the frequency coordinates on a logarithmic scale. An example of this type of

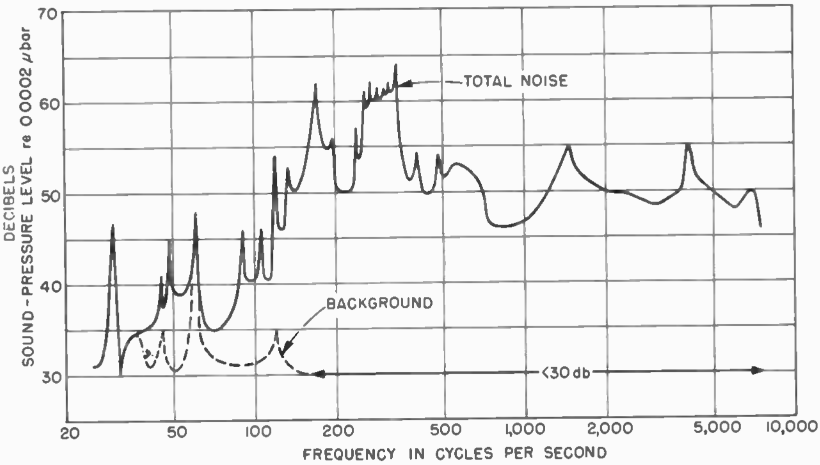


Figure 6-7. A plot of the noise analysis made with a Type 760-B Analyzer on the same machine as in Figure 6-5.

graph is shown in Figure 6-7.

6.33 Spectrum Level: The spectrum level of a noise is the level that would be measured if an analyzer had an ideal response characteristic with a band width of 1 cycle. The main use of this concept is for comparing data taken with analyzers of different band widths. Charts for converting to this spectrum level from the band levels obtained with the Type 1550-A and the Type 760-B Analyzers are given in Figures 6-8 and 6-9.

This conversion has meaning only if the spectrum of the noise is continuous within the measured band and if the noise does not contain prominent pure-tone components. For this reason the results of using this conversion should be interpreted with great care to avoid drawing false conclusions.

The sloping characteristic given for the Type 760-B Analyzer in Figure 6-9 results from the fact that this analyzer is a constant-percentage band width analyzer, that is, its band width increases in direct proportion to the increase in the frequency to which the analyzer is tuned. For that reason a noise that is uniform in spectrum level over the frequency range will give higher level readings for high frequencies than for lower frequencies, with this analyzer.

Figure 6-8. Table giving number of decibels to be subtracted from Type 1550-A levels to obtain spectrum level.

Band	Decibels	Geometric Mean Frequency
20 c - 75 c	18	39 c
75 c - 150 c	19	106 c
150 c - 300 c	22	212 c
300 c - 600 c	25	425 c
600 c - 1200 c	28	850 c
1200 c - 2400 c	31	1700 c
2400 c - 4800 c	34	3400 c
4800 c - 10 kc	38	6900 c

6.34 Fluctuating Sounds: Two ballistic characteristics are provided for the meter on the sound-level meter. The "FAST" position is the one that should normally be used. It will be noticed, however, that most sounds do not give a constant level reading. The reading fluctuates often over a range of a few decibels and sometimes over a range of many decibels. The maximum and minimum readings should usually be noted. These levels can be entered on the data sheet as, say, 85-91 db or 88 ±3 db.

When an average sound-pressure level is desired and the fluctuations are less than 6 db, a simple average of the maximum and minimum levels is usually taken. If the range of fluctuation is greater than 6 db, the average sound-pressure level is usually taken to be three decibels below the maximum level. In selecting this maximum level, it is also customary to ignore any unusually high levels that occur infrequently.

Sometimes it is convenient to use the "SLOW" meter speed to obtain an average reading when the fluctuations on the "FAST" position are rapid and variable. On steady sounds the reading of the meter will be the same for either the "SLOW" or "FAST" position, while on fluctuating sounds the "SLOW" position provides a long-time average reading. Usually, the reading in the "SLOW" position is nearly the same as the average determined by the method given in the previous paragraph.

For some impact sounds it is desirable to know the value of the peak sound-pressure level during the impact. This peak level should normally be determined by oscillographic means as described in Section 6.73, since on drop-forge impacts, for example, the peak-sound pressure level

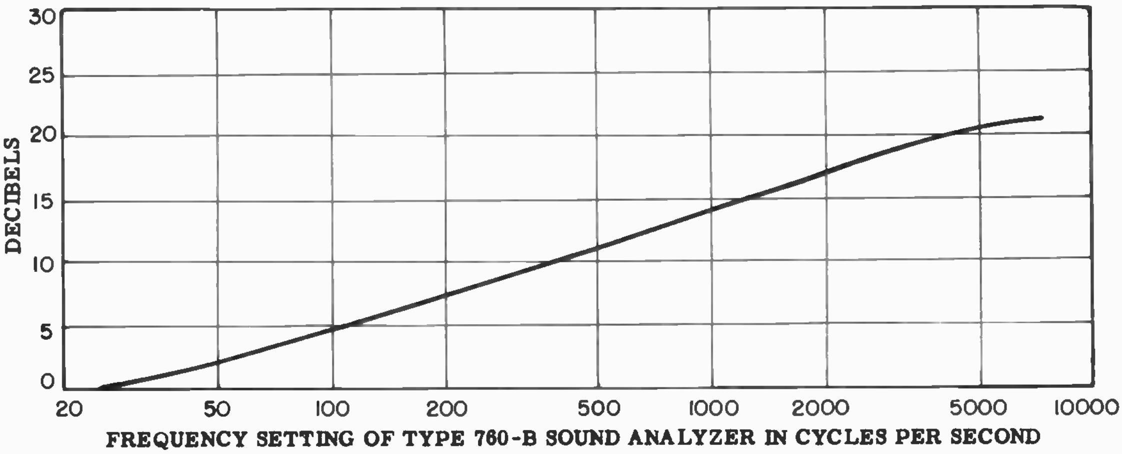


Figure 6-9. Plot showing number of decibels to be subtracted from Type 760-B readings to obtain spectrum level.

may be as much as 30 db above the maximum deflection observed on the sound-level meter even when using the "FAST" position. Many sounds of this type, however, do not rise and fall as rapidly, so that the discrepancies are usually much less than 30 db.

6.4 CHOICE OF MICROPHONE

No single type of microphone is suitable for use under all the conditions encountered in noise measurement problems. The Rochelle-salt type microphones supplied with the Types 1551-A Sound-Level Meter and 1555-A Sound-Survey Meter, nevertheless, are suitable for most applications. When high temperatures are encountered, however, these microphones can not be used. In addition, the measurement of high sound levels, the use of long cables between the microphone and the sound-level meter, and the measurement of high-frequency sounds with good accuracy may require the use of different types of microphones. These problems, as well as others that influence the choice of the microphone are discussed in the following paragraphs.

6.41 **Low Sound Levels:** A microphone used to measure low sound levels must have low "self-noise", and it must produce an output voltage sufficient to override the circuit noise of the amplifier in the sound-level meter. The Rochelle-salt type of microphone supplied with the sound-level meter is very good in this respect, and sound levels down to about 24db can be measured with it. The Type 759-P25 Dynamic Microphone Assembly is even better, provided there are no strong low-frequency electromagnetic fields present (See Section 6.55). The Type 1551-P1 Condenser Microphone System is not so suitable because even under the best conditions its self noise is equivalent to about 40-db sound-pressure level.

Microphone manufacturers build some units that have a better signal-to-self-noise ratio than the microphones regularly used for noise measurements, but this advantage is obtained with a considerable sacrifice in uniformity of frequency response. Microphones of this type are then not strictly suitable for sound-level measurements, but they might be considered for some special low-level measurements.

6.42 **High Sound Levels:** The Rochelle-salt crystal microphone, the Type 759-P25 Dynamic Microphone Assembly, and the Type 1551-P1 Condenser Microphone System may be used for the measurement of sound-pressure levels that do not exceed about 140 db. For higher levels, a specially designed condenser microphone can be obtained for use with the Type 1551-P1 Condenser Microphone System. Alternatively, the Massa Type M-141B can be used directly with the Type 1551-A Sound-Level Meter for sound-pressure levels up to 190 db.

6.43 **Low-Frequency Noise:** The Rochelle-salt crystal type and the condenser type microphones are well suited for measuring low-frequency noise. In fact, with either of these two types of microphones, measurements may be made down to only a few cycles per second if special amplifiers, such as that provided by the Type 761-A Vibration Meter, are used. The Type 1551-A Sound-Level Meter is designed to cover the frequency range down to 20 cps, and even at 10 cps the response is down only 10 db. This 20-cps limit is adequate for almost all types of low-frequency noise.

The Type 759-P25 Dynamic Microphone Assembly is not usually suitable for measuring low-frequency noise. Its response, shown in Figure

6-10b, drops abruptly below 35 cps so that important low-frequency components may be seriously attenuated.

6.44 **High-Frequency Noise:** The primary requirements on the microphone for accurate measurement of high-frequency sounds are small size and uniform frequency response at high frequencies. The three microphones in the General Radio Sound Measuring System arranged in the order of *increasingly* good high-frequency performance are: 1. Rochelle-salt microphone, 2. Dynamic microphone, and 3. Condenser microphone. This fact is brought out most clearly by comparing the three typical response curves of Figure 6-10a, 6-10b, and 6-10c.

Most machinery noises do not include strong high-frequency components so that for measuring over-all sound levels the high-frequency characteristic is not so important. In contrast, some noises have much energy in the high-frequency end of the spectrum. Examples of these are noises produced by high-speed production equipment, textile looms and knitters, braiders, wood-working machinery, and jet and air blasts. Then the high-frequency performance determines the ultimate accuracy to be expected from the measurement. Similarly, if good accuracy is required in the region above 2000cps in determining the frequency spectrum by analysis, the microphone performance must be good or accurately known. When such a frequency analysis is made, corrections can be applied for the frequency characteristic of the microphone as described in Section 6.63.

The Type 1551-P1 Condenser Microphone System can be used for measurements up to 20,000 cps, and it is very rare that measurements need to be made on air-borne sounds at frequencies higher than 20,000 cps. For some research investigations much higher frequencies have been measured by using microphones specially designed for the purpose.

6.45 **High or Varying Temperature:** While most noise measurements are made indoors at average room temperatures, some measurement conditions expose the microphone to much higher or lower temperatures. When these conditions are encountered, it is essential to know the temperature limitations of the equipment.

The maximum safe operating temperature for Rochelle-salt crystal units is about 45°C (113°F). At 55.6°C (132°F) the Rochelle-salt crystal is irreversibly changed. It is, therefore, not safe to put a Rochelle-salt microphone in the trunk or back of a car that is to be left standing in the sun.

The maximum safe operating temperature for the microphone probe of the Type 1551-P1 Condenser Microphone System is about 100°C (212°F), and the microphone in the Type 759-P25 Dynamic Microphone Assembly will operate at about 75°C (167°F).

Fortunately, it is usually possible to keep the sound-level meter itself at more reasonable temperatures. Its behavior at extreme temperatures is limited by the batteries. Temperatures of even 130°F will result in much shortened battery life. Operation below -10°F is not ordinarily possible without using special low-temperature batteries.

The calibration of microphones is usually made at normal room temperatures. If a microphone is operated at other temperatures, its sensitivity will be somewhat different, and a correction should be applied. The correction for sensitivity for the Rochelle-salt crystal microphone as a function of its operating temperature is shown in Figure 6-11. When the microphone is operated directly into the sound-level meter, the correction is relatively small. When the microphone is at the end of a long cable, the correction becomes large, because the capacitance of the microphone varies markedly with temperature as shown in Figure 6-11. This change in capacitance is relatively unimportant when the microphone operates directly into the sound-level meter. But when a cable is used, the capacitance of the cable acts with the capacitive source impedance of the crystal as a voltage divider. Since the crystal capacitance depends on temperature, the voltage division will also depend on temperature.

The sensitivity of the dynamic microphone also varies with temperature, but the variation is not the same at all frequencies. The variation in sensitivity is not large for normal changes of ambient temperature. Over much of the frequency range the variation for 50°F change appears to be less than 1 db.

The condenser microphone used on the Type 1551-P1 Condenser Microphone System has a temperature coefficient of sensitivity of about —0.04 db/°F.

6.46 **Humidity:** Long exposure of any microphone to very high humidity should be avoided. In particular, the chemical Rochelle-salt gradually dissolves if the humidity is too high (above about 84%). The Rochelle-salt crystal unit in the microphone, however, is protected by a coating so that it is relatively unaffected by high humidity. Nevertheless, it is wise to avoid unnecessary exposure. A Rochelle-salt microphone should not be stored for long periods in a very dry atmosphere, since it can dry out.

The condenser microphone on the Type 1551-P1 Condenser Microphone System is not damaged by exposure to high humidity, but its operation may be seriously affected unless proper precautions are taken. For proper operation it is essential that very little electrical leakage occur

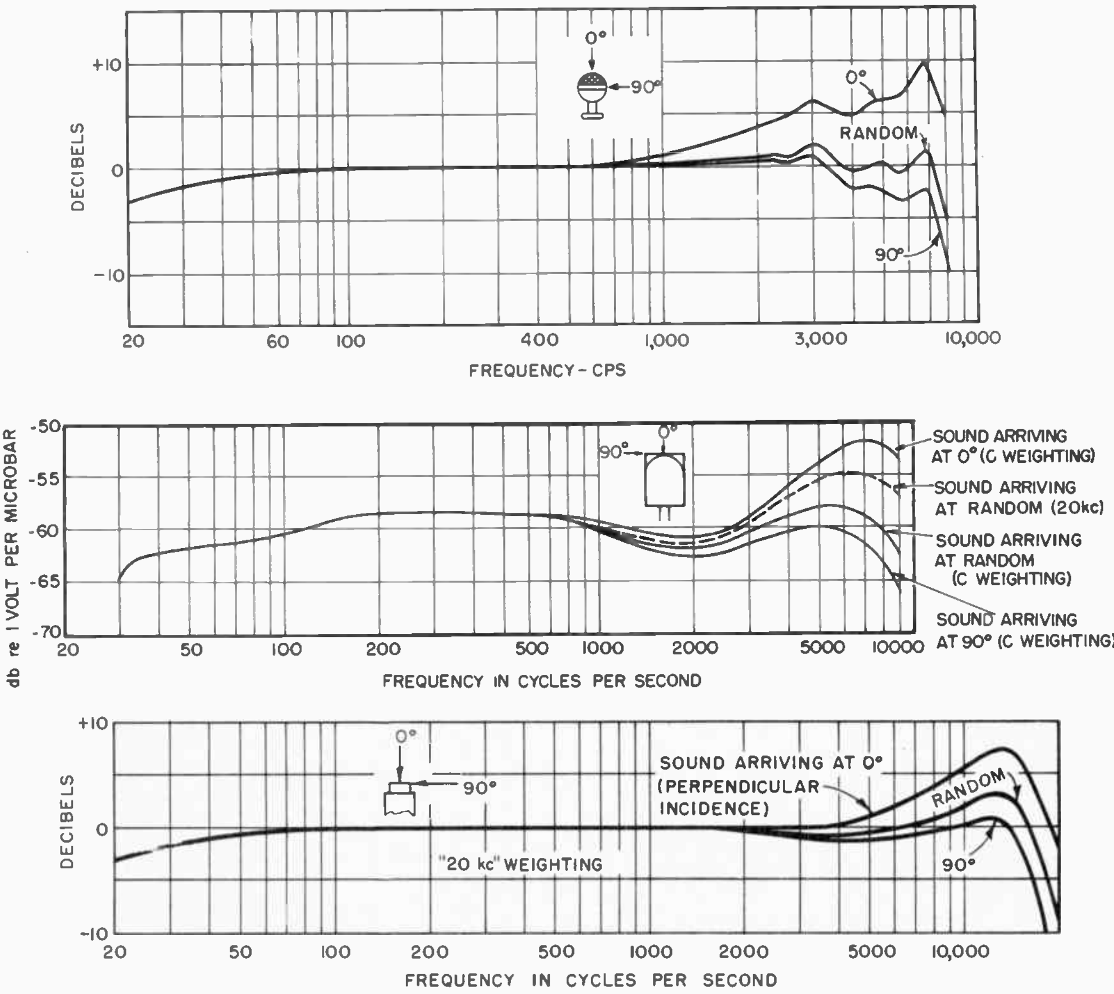


Figure 6-10. Typical response curves for three different microphones when used with the Type 1551-A Sound-Level Meter. (From top to bottom) (a) Rochelle-salt crystal microphone normally supplied with the Type 1551-A; (b) the Type 759-P25 Dynamic Microphone; and (c) the Type 1551-P1 Condenser Microphone. Random response assumes that the microphone is placed in a diffuse sound field.

across the microphone. The exposed insulating surface in the microphone has been specially treated to maintain this low leakage even under conditions of high humidity. In spite of this precaution, the leakage may become excessive under some conditions. Then it may be advisable to keep the microphone at a higher temperature than the surroundings to reduce the leakage. In climates where the humidity is normally high, it is recommended that the microphone itself be stored in a small jar containing silica gel.

The dynamic microphone is relatively unaffected by normal changes in humidity.

6.47 **Long Cables:** Frequently, at the time of the measurement, it is impossible or inadvisable for the observer to be near the microphone, which must be placed at the point where the sound-pressure level is desired. Then an extension cable is ordinarily used to connect the microphone to the instruments. If this cable is short, any of the microphones can be used. A correction for level is necessary, however, when the Rochelle-salt type microphone is used with an extension cable as shown in Figure 6-11. This level correction depends on the temperature of the microphone (not the cable) at the time the measurement is made. This correction can be determined from Figure 6-11 or by using the Type 1552-A Sound-Level Calibrator as described in Section 6.62.

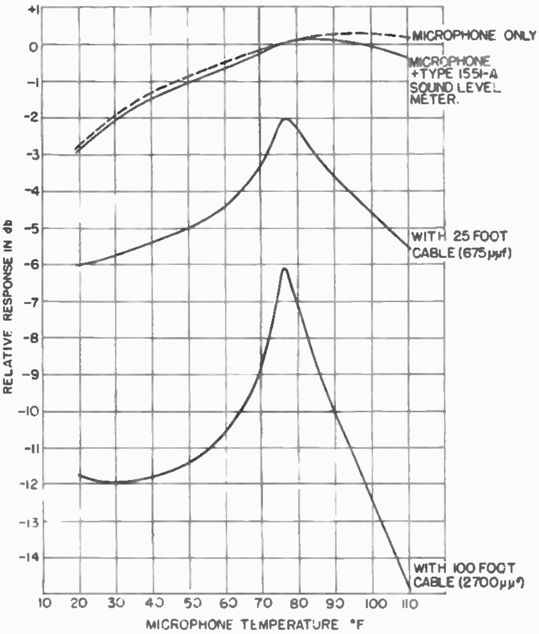


Figure 6-11.
Variation in response as a function of microphone temperature for the Rochelle-salt crystal microphone alone and with various lengths of cable between microphone and Type 1551-A Sound-Level Meters.

The Type 759-P25 Dynamic Microphone Assembly can be used with shielded, twisted-pair cables of almost any reasonable length. This cable is inserted between the microphone and the transformer unit; and when either the Type 759-P23 25-foot Cable or the Type 759-P22 100-foot Cable is used, no corrections are necessary.

The Type 1551-P1 Condenser Microphone System includes a 10-foot cable between the microphone base and the power supply. If more separation between the microphone and the sound-level meter is required, another cable, such as the Type 759-P30 Extension Cable, should be used between the Type 1551-P1 Power Supply and the Type 1551-A Sound-Level Meter. The use of this cable will result in a slight reduction in sensitivity at high frequencies as explained in the instruction book for the Type 1551-P1 Condenser Microphone System.

6.48 Direction of Arrival of Sound at the Microphone: Some microphones are designed to be directional at all frequencies. That is, the response of the microphone depends on the direction of arrival of the sound wave. Most of the microphones used for sound measurements, however, are essentially non-directional at low frequencies (below about 1 kc). At frequencies so high that the size of the microphone is comparable to the wave length of the sound in air, even these microphones will show directional effects. This variation in response with direction should be considered in positioning the microphone for a measurement. The extent of these variations is shown by the frequency response characteristics of the different microphones (see Figure 6-10). The microphone is usually positioned so that the response to the incident sound is as uniform as possible.

When sound-pressure level is measured in a reverberant room at a point that is not close to a noise source, the sound arrives at the microphone from a very large number of different directions. Then the orientation of the microphone is not critical, and the response is assumed to be that labeled "RANDOM" incidence. Under these conditions, nevertheless, it is usually desirable to avoid having the microphone pointing at a nearby hard surface from which high-frequency sounds could be reflected to arrive perpendicular (0° incidence) to the plane of the diaphragm. (For all the microphones used in the General Radio Sound Measurement System this perpendicular incidence is along the axis of cylindrical symmetry of the microphone. This axis is used as the 0° reference line.) If this condition cannot be avoided, the possibility for errors from this effect can be reduced by placing some acoustic absorbing material on the reflecting surface.

When measurements are made in a reverberant room at varying distances from a noise source, the microphone should generally be oriented so that a line joining the microphone and the source is at an angle of about 75° from the axis of the microphone. When the microphone is near the source most of the sound comes directly from the source, and a 75° incidence response applies. On the other hand, near the boundaries of the room the incidence is more nearly random, and the random-incidence response applies. These two response curves are nearly the same so that there is little change in the effective response characteristic as the microphone is moved about the room. This desirable result would not be obtained if the microphone were pointed at the noise source.

6.5 ADDITIONAL EFFECTS ON MEASURED DATA

6.51 Effect of Room and Nearby Objects: The sound that a noise source radiates in a room is reflected by the walls, floor, and ceiling. The reflected sound will again be reflected when it strikes another boundary, with some absorption of energy at each reflection. The net result is that the intensity of the sound is different from what it would be if these reflecting surfaces were not there.

Close to the source of sound there is little effect from these reflections, since the direct sound dominates. But far from the source, unless the boundaries are very absorbing, the reflected sound dominates, and this region is called the reverberant field. The sound-pressure level in this region depends on the acoustic power radiated, the size of the room, and the acoustic absorption characteristics of the materials in the room. These factors and the directivity characteristics of the source also determine the region over which the transition between reverberant and direct sound occurs.

If we are interested in completely evaluating the characteristics of the source of noise, all these factors are important, and they will be considered more completely in Chapter VIII. If, in this evaluation, we are merely trying to follow a test code, the problem reduces to satisfying the strict requirements of the code and to arranging the room characteristics and other extraneous influences so that the measurement is reliable and reproducible. For uniformity, then, it is customary to insist that reflected sound should not contribute appreciably to the measured value. This requirement usually means that the room should be heavily treated with absorbing material. Acoustic absorbing material, however, is not uniformly absorbing over the full audio range, so that the effect of reflected sound may vary with frequency.

In order to make certain that the room characteristics are satisfactory, the *American Standard Test Code for Apparatus Noise Measurement,* Z24.7-1950, requires the following:

> "3.1.1 . . . To insure that reflected sound does not contribute appreciably to the readings, the average sound level measured at the selected measuring points should be at least 8 db larger than the average sound level measured at more distant points from the sound-producing apparatus, where reflected sound predominates."

This limit of 8 db means that on the average the contribution of reflected sound will be less than 1 db.

A second effect of reflected sound is that measured sound does not necessarily decrease steadily as the measuring position is moved away from the source. At certain resonant frequencies of a live room, marked patterns of variations of sound pressure with position may be observed. Variations of up to 10 db are common and, in particular situations, much more may be found. These variations are usually of the following form: As the measuring microphone is moved away from the source, the measured sound pressure decreases to a minimum, rises again to a maximum, decreases to a minimum again, etc. These patterns are called standing waves. They are noticeable mainly when the sound source has strong frequency components in the vicinity of one of the very many possible resonances of the room. They also are more likely to be observed when a frequency analysis is made; and the narrower the band width of the analyzer, the more marked these variations will be.

The measurement room used for evaluating a noise source should be sufficiently well treated so that no appreciable standing wave exists. Any small standing wave pattern that remains can be averaged out by taking the average of the maximum and minimum decibel readings if the differences are small. If the differences are more than 6 decibels, the level should be taken as 3 decibels below the maximum readings that occur frequently. This standing-wave pattern, however, should not be confused with the normal decrease in level with distance from the source or with the directivity pattern of the source, which is considered in Chapter VIII.

Objects in the room reflect the sound waves just as do the walls of the room. Consequently, all unnecessary hard-surface objects should be removed from the measurement room when a source is being measured. In general, no objects, including the observer, should be close to the microphone. If it is impractical to follow this principle, the objects should usually be treated with absorbing material.

One troublesome but not frequent effect of nearby objects results from sympathetic vibrations. A large, thin metal panel if undamped can be set into vibration readily at certain frequencies. If one of these frequency components is present in the noise, this panel can be set into motion either by air-borne sound or by vibration transmitted through the structure. This panel vibration can seriously upset the noise field in its vicinity. One way of checking that this effect is not present to any important degree is to measure the sound field as a function of the radial distance from the source. The sound should decrease, when not very close to the source, about 6 decibels as the distance is doubled. This procedure also checks for reflections in general; and, for careful measurements, the check should be made in each octave band when analyzing.

When the acoustic environment is being measured, no change should be made in the usual location of equipment, but the sound field should

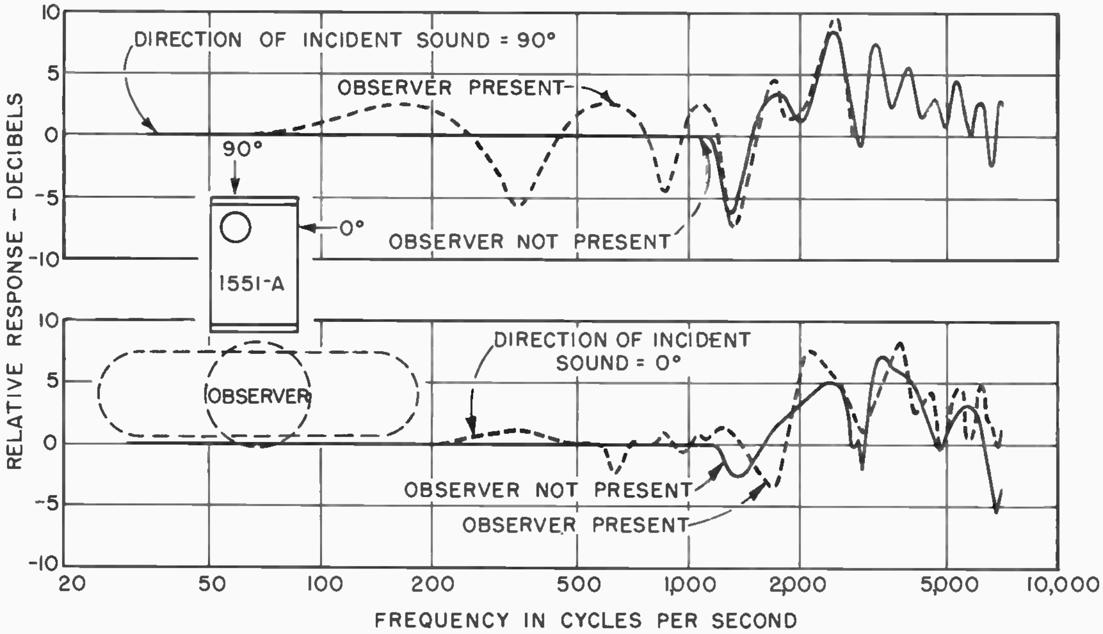


Figure 6-12. The effect on the frequency response of using the microphone directly on the swivel post of the instrument with and without an observer present. The decibel readings were obtained using a single-frequency, plane, acoustic wave in an anechoic chamber, and they are the differences between the response under conditions shown and the response of the microphone alone.

be carefully explored to make sure that the selected location for the microphone is not in an acoustic shadow cast by a nearby object or is not in a minimum of the directivity pattern of the noise source.

6.52 **Effect of Observer and Meter Case on Measured Data:** As mentioned in the previous section, the observer can affect the measured data if he is close to the microphone. When measurements are made in a live room and not close to a source, the effect is usually not important. But if measurements are made near a source, it is advisable for the observer to stand well to the side of the direct path between the source and the microphone. For precise measurements in a very dead room, such as an anechoic chamber, it is customary to have the instruments and the observer in another room with only the source, the microphone, the extension cable, and a minimum of supporting structure in the dead room.

For a wide variety of measurements, however, it is most convenient to be able to carry the sound-level meter or sound-survey meter around while making the measurement. Then there is a best way of holding the instrument with respect to the source of sound in order to have a minimum of error. The sound-level meter should be held in front of the observer with the sound coming in from the side. The magnitude of the error that can be caused by the way the instrument is held can be evaluated from the data shown in Figure 6-12. These data show the difference between the readings of the meter with and without the observer present, as a function of frequency. Two locations are shown: (1) the sound-level meter is between the observer and the noise source, (2) the noise source is located to one side of the observer, and the sound-level meter is held in front of the observer. It is apparent that if the instrument is held properly, little error in reading of the over-all level will occur for most noises. The only important exceptions are those noises that have very strong high-frequency components.

The meter case itself may also disturb the sound field at the microphone as shown by the other characteristic curves in Figure 6-12. There is practically no effect below 1000 cps, and, again, on most noises, little error in measuring over-all level will result if the microphone is left on the instrument. When an analyzer is used with the sound-level meter, however, it is advisable to separate the microphone from the instruments and to use an extension cable. This refinement is not necessary, however, if the only data that are of interest are below 1000 cps or if only comparative data from one machine to a similar one are desired.

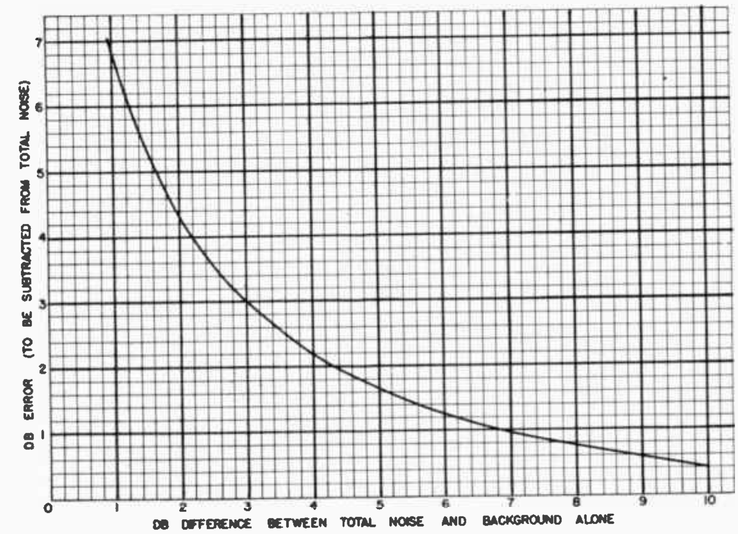


Figure 6-13.
Background noise correction
for sound-level
measurements.

6.53 Effect of Background Noise: Ideally, when a noise source is measured, the measurement should determine only the direct air-borne sound from the source, without any appreciable contribution from noise produced by other sources. In order to insure isolation from other sources, the measurement room may need to be isolated from external noise and vibration. As a test to determine that this requirement has been met the *American Standard Test Code for Apparatus Noise Measurement*, Z24.7-1950, specifies the following:

> "3.1.2 Ambient Sound. The ambient sound level at the test location should be at least 8 db, preferably 10 db or more, lower than the sound level due to the apparatus. Corrections for ambient levels in factory tests are not generally permissible where erratic variations occur frequently in the ambient noise."

If the background noise level and the apparatus noise level are steady, a correction may be applied to the measured data according to the graph of Figure 6-13. The procedure is as follows: After the test position has been selected according to the test code and after exploration of the field as outlined in Section 6.51, the background noise level is measured in the test position. Then the sound level is measured with the apparatus operating. The difference between the sound level with the apparatus operating and the background level determines the correction to be used. If this difference is less than 3 db, the apparatus noise is less than the background noise; and the level obtained by using the correction should be regarded as only indicative of the true level and not as an accurate measurement. If the difference is greater than 10 db, the effect of the background noise can usually be neglected; and the reading with the apparatus operating is the desired level. An example of a situation intermediate between these two is as follows: The background noise level is 77.5 db, and the total noise with the machine under test operating is 83.5 db. The correction, from the graph of Figure 6-13, for a 6.0-db difference, is 1.2 db, so that the corrected level is 82.3 db.

When apparatus noise is analyzed, the background noise level in each band should also be analyzed to determine if correction for the level in each band is necessary and possible. The spectrum of the background noise is usually different from that of the noise to be measured, and the corrections in each band will be different.

If this difference between background level and total noise level is small, an attempt should be made to lower the background level. Usually the first step is to work on the source or sources of this background noise to reduce the noise directly. The second step is to work on the transmission path between the source and the point of measurement. This step may mean simply closing doors and windows if the source is external to the room or it may mean erecting barriers, applying acoustic treatment to the room, and opening doors and windows if the source is in the room. The third step is to improve the difference by the method of measurement. It may be possible to select a point closer to the apparatus, or an exploration of the background noise field may show that the measuring position can be shifted to a minimum of this noise. This latter possibility is more likely when an analysis is being made and the background level in a particular band is unusually high. It may also be possible to point the microphone at the apparatus to obtain an improvement at high frequencies (see Figure 6-10); it may be necessary to use a directional microphone; or it may be desirable to use a vibration pickup (see Section 6.74).

6.54 Effect of Circuit Noise When Low Noise Levels are Measured: When low noise levels are to be measured, the inherent circuit noise may contribute to the measured level. This effect is usually noticeable in the range below 40 db when the Type 1551-P1 Microphone System is used or a Rochelle-salt crystal microphone is used on the end of a very long cable. If the Rochelle-salt microphone is directly on the sound-level meter, the level at which this effect may be important is below 30 db if the C weighting is used or even lower if the A or B weighting is used. To measure the circuit noise the microphone may be replaced by a well-shielded capacitor of 6 micromicrofarads for the Type 1551-P1 or of 2000 micromicrofarads for the Rochelle-salt microphone. A correction can then be made for this noise, if necessary, by the same procedure as outlined for background noise in Section 6.53. If the circuit noise is comparable to the noise being measured, some improvement in the measurement can usually be obtained by using an octave-band analyzer. The circuit noise in each band should be checked also to see if correction is necessary. (See also Section 6.32.)

6.55 Hum Pickup: When noise is measured near electrical equipment, a check should be made that there is no appreciable pickup of electromagnetic field in the sound-measuring system. This check is particularly important for the Type 759-P25 Dynamic Microphone, and, if the field is strong, when an octave-band analyzer is used. The procedure depends on the directional character of the field. The orientation of the instruments should be changed to see if there is any significant change in level. If an analyzer is used, it should be tuned to the power-supply frequency, usually 60 cps, which would be the 20 to 75 c band for the octave-band analyzer, when this test is made. If no analyzer is included the C-weighting should be used in this test to make the effect of hum most noticeable, and a good quality pair of earphones with tight-fitting ear cushions should be used to listen to the output of the sound-level meter.

Tests should be made with different orientations of the microphone, with the microphone disconnected, and with the sound-level meter disconnected from the analyzer. If there is pickup in the microphone, proper orientation may be adequate to make a measurement possible, or electromagnetic shielding may be necessary. Otherwise one should consider using the Rochelle-salt or condenser-type microphones, which are relatively free from hum pickup.

If the hum pickup is in the instruments, they can usually be moved away from the source of the electromagnetic field, or, alternatively, a proper orientation is usually sufficient to reduce the pickup to a negligible value.

When a-c operated instruments are used as part of the measuring setup, a check should be made for 120-cycle as well as 60-cycle hum. This hum may be in the instruments, or it may appear as a result of the interconnection of different instruments. These two possibilities may be distinguished by checking the instruments individually. If they are separately essentially free from hum, different methods of grounding, balancing, or shielding should be tried. Sometimes reversal of the power-plug connection to the line helps to reduce the hum.

6.56 Microphonics at High Sound Levels: All vacuum tubes are affected by mechanical vibration. Those used in the sound-measuring equipment have been selected to be less sensitive to vibration than the usual types. But at sufficiently high sound levels, even these tubes can be vibrated to such an extent that they contribute an undesired signal to the output. Trouble from this effect, which is called microphonics, is not usually experienced until the sound levels are above 100 db, unless the instruments are placed on supports that carry vibrations directly to the instruments.

The usual test for microphonics is to disconnect the microphone and observe whether or not the residual signal is appreciably lower than the signal with the microphone connected. For the octave-band analyzer, the input cord can be disconnected to see if the indicated level comes from the input signal or if it is generated within the instrument. The instruments can also be lifted up from the support on which they have been placed to see whether or not the vibrations are transmitted through the supports or if it is the air-borne sound that is causing the tube vibration.

Possible remedies for microphonic troubles are as follows: 1. Place the instruments on soft rubber pads. 2. Remove the instruments from the strong field to another room and interconnect with long cables. 3. Put in deadened sound barriers between the instruments and the sound source. 4. Mount the instruments in well sealed boxes with glass covers and tight-fitting drive shafts to manipulate the controls.

Mechanical vibration also affects the microphone itself, in that the output of the microphone is dependent on the air-borne and solid-borne vibrations that are impressed upon it. The effects of the solid-borne vibrations are not usually important in the standard, sensitive microphones because of the type of construction used; but these vibrations are usually of great importance for the low-sensitivity microphones used in the measurement of high sound levels. A mechanically soft mounting should generally be used for such a microphone in order to avoid trouble from these vibrations. Often merely suspending the microphone by means of its connecting cable is adequate.

6.57 **Mounting of the Device under Test:** It is common to notice that the noise level produced by a machine is highly dependent on its mounting. A loose mounting may lead to loud rattles and buzzes, and contact to large resonant surfaces of wood or sheet metal may lead to a sounding-board emphasis of various noise components. For these reasons particular care should be given to the method of mounting. In general, the mounting should be as close to the method of final use as possible. If the machine is to be securely bolted to a heavy concrete floor, it should be tested that way. If the actual conditions of use cannot be duplicated, the noise measurements may not be sufficient to predict the expected behavior, because of the difference in transmission of noise energy through the supports. The usual alternative is to use very resilient mounting means so that the transmission of energy to the support is negligible. (See also ASA Standard Z24.7-1950, Section 3.1.3)

6.58 **Position of Microphone:** In previous sections of this chapter some comments have been made on various aspects of the problem of placing the microphone in the most satisfactory position for making the noise measurement. Because of the importance of this placement, this section will summarize these comments. In general, the location is determined by the type of measurement to be made. For example, the noise of a machine is usually measured by locating the microphone near the machine according to the rules of a test code, or if its characteristics as a noise source are desired, a comparatively large number of measurements are made according to the methods and the placement given in Chapter VIII.

General principles that should be followed in locating a microphone for a test code measurement are given in the *American Standard Test Code for Apparatus Noise Measurement,* Z24.7-1950.

The locations specified in this standard (½ to 3 feet) are typical of test codes, but they are generally too close to the source for use in determining the acoustic power radiated by the machine, and the requirements for that measurement will be given in Chapter VIII.

This standard points out the importance of exploring the noise field before deciding on a definite location (see Section 6.51) for the microphone. It also mentions the necessity for using a large number of measurement locations for specifying the noise field, particularly if the apparatus produces a noise that is highly directional. Further discussion of directionality will be given in Chapter VIII.

The microphone should also be kept out of any appreciable wind, if possible. Wind on the microphone produces a noise, which is mainly a low-frequency noise. This added noise may seriously upset the measurement, particularly when using microphones that have a good low-frequency response. If it is not possible to avoid wind on the microphone, a wind screen should be used. This screen can be made up by putting a single layer of silk or nylon cloth on a wire frame that encloses the microphone. The frame should be much larger than the microphone.

If the noise level is measured for calculation of the speech-interference level or loudness level or for determination of deafness risk, it is also important to explore the noise field to make sure that the measurement made is representative. The possible effects of obstacles in upsetting the distribution of sound, particularly at high frequencies, should be kept in mind when making this exploration.

At first thought, it seems logical, when measurements regarding noise exposure are made, to mount the microphone at the operator's ear. Actually, because of the variables introduced by the effect of the operator's head being close to the microphone, this technique is not used, except in certain scientific tests with special probe microphones. All ratings of speech-interference, loudness, and deafness risk are based on a measurement with no person in the immediate vicinity of the microphone. The microphone should, however, be about where the operator's ear would normally be.

6.6 CALIBRATION AND CORRECTIONS

Satisfactory noise measurements depend on the use of measuring equipment that is kept in proper operating condition. Although the instruments are inherently reliable and stable, in time the performance of the instruments may change. In order to insure that any important changes will be discovered and corrected, certain simple checks have been provided for the General Radio line of sound-level equipment, and these will be discussed in this section. These checks can be made as routine maintenance checks, and some of them (Sections 6.61 and 6.62) should usually be made before and after any set of noise measurements.

In addition to these routine checks, more complete calibration of the system may be desirable

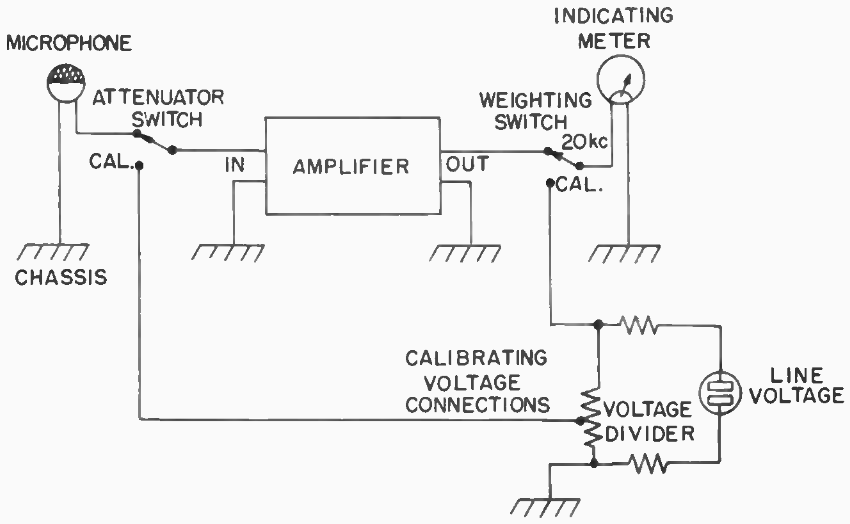


Figure 6-14. Schematic diagram of the sound-level meter electrical calibration circuit. For calibration the attenuator switch is turned to the "CAL" position. The weighting switch is turned back and forth between "20 kc" and "CAL", and the gain control of the amplifier is is then set so that the deflection of the indicating meter is the same for the two switch positions.

for accurate measurements, particularly above 1000 cps. These calibrations are also discussed in this section.

6.61 Electrical Circuit Calibration: In the Type 1551-A Sound-Level Meter the electrical calibration circuit, shown in simplified form in Figure 6-14, permits standardization of the gain of the amplifier in terms of an attenuator provided in the instrument. This attenuator is set in the laboratory to give the correct check for the sensitivity of the microphone supplied with the sound-level meter. Incidentally, the use of a different microphone with a different sensitivity will require that a correction for sensitivity be applied.

The test is made by using the calibration cord to supply a voltage from the power line at the terminals provided on the instrument. The controls are set and adjustments made according to the method given in the instruction book. This test is particularly important, before measurements are made, to insure that the calibration control has not been set incorrectly.

This test does not check the sensitivity of the microphone and the indicating instrument. Tests which include the microphone and the indicating instrument are discussed in the next section. The indicating instrument is rugged and relatively unaffected by temperature changes. Its temperature coefficient is about —0.02 db/°F.

6.62 Acoustic Calibration at 400 cps: The Type 1552-A Sound-Level Calibrator (see Figure 4-8) has been developed to provide a single calibration of the over-all system at 400 cps. When driven by a 400-cycle oscillator at a 2-volt level and mounted on the Rochelle-salt microphone supplied with the sound-level meter, this calibrator produces an 85-db sound-pressure level. It can be used also on the Type 1555 Sound-Survey Meter, on the Type 759-P25 Dynamic Microphone (Altec Type 633), on the Brush BR-2S (used on some early Type 759-A Sound-Level Meters), and on the Type 1551-P1 Condenser Microphone System (by means of an adaptor); but the level developed for each microphone type will be different. The level to be expected is stated in the instruction sheets for the calibrator or the microphone.

When the calibrator is used, it is desirable to check the background noise level with the calibrator in place but with no signal applied. This level should be 10 db or more below the level produced by the calibrator, or a correction should be applied (see Figure 6-13). If the total level with the signal applied to the calibrator is not at least 4 db higher than the background level, the instrument should be moved to a quieter location for calibration.

Although this calibrator is unusually stable, considering its low cost, it should not be regarded as completely unchangeable, and it should be handled with care. It does provide an extra check, so that one is not completely dependent on the microphone stability. If, after the electrical circuit calibration, the acoustic calibration agrees within about 1 decibel, including temperature corrections, the system can be assumed to be operating correctly. Then the routine corrections should be used and, usually, not the level indicated by the calibrator. If, however, the acoustic check differs by 2 or more db, the level determined by the calibrator should be temporarily accepted as correct. Then as soon as possible an investigation should be made to find the cause of the discrepancy. If the reason for the discrepancy cannot be located, the problem should be discussed with the nearest branch office or the service department at the factory in Cambridge. If it is not convenient to bring the equipment to the office, they may suggest that the calibrator be sent in for a check, since it is relatively simple to ship the calibrator.

In the interests of maintaining accuracy in sound measurements, another calibration service is provided for owners of General Radio sound-level meters and Sound-Survey Meters. If these instruments are brought in to one of the General Radio offices (in Cambridge, New York, Chicago, and Los Angeles) the level at 400 cps will be checked using an acoustic calibrator. This calibration will usually show if the instrument is operating correctly. If there is a serious discrepancy, the situation will have to be handled as a regular service problem. Before bringing in an instrument, please call the office (the Service Department, if the call is to Cambridge) to make certain that someone will be available to make the calibration check.

The calibrator can also be used to measure the microphone cable correction (see Section 6.45) provided the background noise is sufficiently low. The procedure is as follows: 1. After the noise measurement has been made, the calibrator is put on the microphone with the microphone at the end of the cable, and a level reading is taken on the sound-level meter. 2. The microphone is removed from the end of the cable and put directly on the sound-level meter. The calibrator is put on the microphone at the sound-level meter, and a second level reading is taken. 3. The difference between these two level readings is the cable correction.

6.63 Complete Microphone Calibration: The acoustic calibrator makes possible a test of the sensitivity at 400 cps. If this test shows the microphone to be operating normally, there is reasonable assurance that the microphone has not changed appreciably at other frequencies. For most noises the low-frequency components dominate, and then this check is usually helpful in making sure that an accurate measurement can be made. It must be realized, however, that this test is not a complete check of the behavior; and when the noise consists of strong high-frequency components, a more complete knowledge of the performance is necessary for maximum accuracy.

The microphone is the element whose performance is less uniform with frequency than any other element of the sound system. In order to get high accuracy in measurements above 2000 cps it is usually essential to have a calibration of the microphone response characteristic as a function of frequency. When this calibration is available and an analysis of a noise is made, correction can be made for the deviation from uniformity of the microphone frequency response characteristic.

Making accurate calibrations of microphones over a wide frequency range is a difficult process. For example, it is relatively simple to make a calibration of a microphone over a wide frequency range with a given laboratory facility; but when the same microphone is calibrated in another laboratory, it is likely that discrepancies of two or three decibels will be found between the two calibrations at frequencies above 3000 cps. Only when different laboratories have worked out different systems to the point that they give reasonably good agreement can one expect that the calibrations are reliable. The National Bureau of Standards, the Bell Telephone Laboratories, and Harvard University are important calibration laboratories that have completed this cross-checking process using Western Electric Type 640AA Condenser Microphones in a coupler calibration. These microphones are used as primary standards to calibrate other microphones, and this type of microphone is regarded as the standard for accurate measurements. (Incidentally, this type of microphone can be used by means of an adaptor on the Type 1551-P1 Condenser Microphone System, but the microphone is difficult to obtain and is expensive.) In free-field calibration of a microphone using the W. E. Type 640AA as a standard, serious difficulty at high frequencies can occur, and only a few laboratories can provide satisfactory calibrations at present.

6.64 Comparison Tests Among Different Sound-Level Meters: When measurements are made on the same noise using two different sound-level meters, it is commonly found that the readings differ by a significant amount. The preceding material in this chapter should indicate most of the possible sources of discrepancy between the two. Differences in the microphone characteristics are usually the chief cause of this discrepancy. For example, if one sound-level meter uses a dynamic microphone and the other uses a Rochelle-salt microphone and if the noise contains strong low-frequency components, it is easily seen from the characteristics of Figure 6-10 that large differences can occur. When these effects are understood, most of the discrepancies are readily explained.

Another factor that can contribute to this discrepancy concerns the average level. For purposes of meeting certain tolerances the average level of an instrument made by one manufacturer may be set slightly differently from that made by another.

If the instruments are not operating properly or if standing waves are not averaged out, serious discrepancies can, of course, be expected.

In order to set an upper limit to these differences among sound-level meters, the *"American Standard for Sound Level Meters"*, Z24.3-1944, sets certain tolerances on the prescribed frequency characteristics. Representative values are as follows:

Frequency-cps	Tolerances-db
25	+6, —9.5
60	+3, —3
300 to 1100	+2, —2
2000	+3, —4
3000	+4, —5.5
5000	+5, —7.5
8000	+6, —9.5

6.7 OTHER AUXILIARY INSTRUMENTS

In addition to the regular instruments in the General Radio Sound-Measuring System, other instruments have been mentioned in Chapter IV as useful auxiliary equipment. The use of these instruments will now be discussed. The instruments to be discussed have a multiplicity of controls, which must be properly set in order to obtain useful information. It is wise, therefore, to become thoroughly familiar with the instruments, by using known signals for practice, before attempting to use them on a noise problem.

6.71 **Magnetic Tape Recorders:** A magnetic tape recorder is a useful and convenient instrument for obtaining a permanent record of a noise, as discussed in Chapter IV. When measurements are to be made on the recorded noise, a high-quality instrument must be used to insure accurate results. The recorder should have a flat frequency characteristic over a wide frequency range, low hum and noise level, low non-linear distortion, constant speed drive, and good mechanical construction, and it should be kept in good operating condition. A tape speed of 15 inches/second is recommended, since these required characteristics are more readily obtained and maintained at high tape speeds.

The frequency response controls on the tape recorder should generally be set and left at the position giving the most uniform response. Corrections should be made for any non-uniformity.

The gain of a magnetic tape recorder should be set, in general, according to the instructions supplied with the recorder. If an impact type of noise is to be recorded, however, it is usually desirable to set the gain 10 to 30 db lower than normal in order to avoid overloading the system on the peak of the impact. When possible, it is desirable to make a series of recordings of impact sounds at several different settings of the gain control.

6.711 **Reference Signal:** At the time the recording of a noise is made, a signal of known sound-pressure level should also be recorded for the same setting of recorder gain, so that the absolute level of the recorded noise may be determined. It is sometimes desirable to record this reference signal several times during the course of the recording. The Type 1552-A Sound-Level Calibrator can supply this signal. It should be used on the microphone that supplies the electrical signal to the recorder, and at the time of recording the signal, the background noise level should be kept as low as possible. The level of this reference signal can frequently be accurately determined on play-back even if the background noise is relatively high by using a narrow-band analyzer tuned to the calibrating frequency of 400 cps. Alternatively, the octave-band analyzer set to the 300-600 cps band can be used. When a narrow-band analyzer is used for this purpose, it is important to make certain that the fluctuations in speed (flutter) of the tape are sufficiently low and the band width of the analyzer sufficiently great that the signal is accurately measured. For example, if the flutter of the tape is 0.3% rms, the apparent recorded 400-cycle frequency will fluctuate over a total range of about 3.4 cycles.* The Type 760-B Sound Analyzer, when tuned to 400 cycles, is uniform in response to within 1 db of the peak value over a band of 4 cycles. Therefore its response will be satisfactory for measuring this 400-cycle signal with a flutter of 0.3%.

6.712 **Direct Connection of Microphone:** When a wide range of signal levels are to be recorded, or when analysis of the recorded noise is required, direct conection of the microphone output to the recorder is often desirable. This connection avoids the circuit noise that invariably must reduce the dynamic range when a sound-level meter is inserted between the microphone and the recorder amplifier. When the Type 1551-P1 Condenser Microphone System is used, the sound-level meter and the recorder can be connected in parallel using the two outputs provided on the case for the Type 1551-P1. When this is done, however, the combined impedance of the two connecting cables and the input circuit of the tape recorder should be kept as high as prac-

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* $2\sqrt{2} \times 0.003 \times 400$

tical. This usually means that short cables should be used. The effect on the measured sound level of adding the recorder circuit can usually be checked by noting the difference in measured noise level with and without the recorder plugged into the Type 1551-P1 power supply.

6.713 **Analysis of Recorded Noise:** When an analysis is to be made of the recorded noise, it is usually desirable to select a number of representative samples from the tape. The length selected should usually be equivalent to at least several seconds. Each of these lengths is then spliced into an endless loop, and each in turn is analyzed by playing back the loop continuously through the recorder and analyzing the output. If the absolute level needs to be known also, a sample of the recorded reference signal should be measured with the same control settings that are used for the noise samples.

If the recorded noise is sufficiently uniform with time, it is often simpler to make a long recording and analyze on playback directly without the use of a loop. An octave band analysis can be made directly even on short recordings by merely repeating the playback a few times. On each playback the level in one or more bands can usually be noted if the overall level is essentially constant with each playback.

The apparent convenience of merely recording the noise in the field and doing all subsequent measurements in the laboratory may lead one to assume that the field equipment should be limited to a magnetic tape recorder, a suitable microphone, and an acoustic calibrator. This assumption may be correct if the noise problem is already well understood. But in many situations it is desirable to analyze in the field to some extent to make certain that the desired data have been taken. Otherwise, subsequent analysis in the laboratory may show that the recordings are useless, because they do not contain the required information.

6.714 **Subjective Comparisons:** Magnetic tape recordings can be used for the subjective comparison of various noises. The direct subjective comparison of noises may be impractical in some instances because the noises are not available at the same place or at times that permit comparisons without long delays. When tape recordings are made of such noises, these recordings can be played back and compared with relative ease. These recordings may frequently be made of noise from a machine during different stages of work designed to quiet it, and then a subjective evaluation of the progress is possible. Binaural recordings seem to be more satisfactory for this comparison test than single channel recordings, because the noise seems to sound more realistic.

Whenever noise is recorded for the purpose of making a subjective comparison, it is desirable also to record a known acoustic reference signal. Then on playback the output level for each recording can be set to the proper level without relying on complete stability of recording gain characteristics for all the recordings.

6.72 **Graphic Level Recorder:** A graphic level recorder can be connected to the output of the sound-level meter or the octave-band analyzer to record the level of a noise as a function of time. The resulting description of the fluctuations in level is then more complete than that obtained by noting a few readings of the meter; and when observations over a long period are necessary, the recorder can be unattended for most of the time. A range of 40 or 50 db should ordinarily be used on the recorder.

6.721 **Input Connections:** If the input impedance of the recorder is less than 20,000 ohms, it is desirable to add enough series resistance at the output of the sound-level meter to bring it up to at least 20,000 ohms. If the gain of the recorder is adequate, even more series resistance should be added, up to a maximum of 100,000 ohms. The connection between the sound-level meter and the recorder should be made by means of a short, shielded line.

6.722 **Gain Setting:** When the level recorder is connected to the output of a Type 1551-A Sound-Level Meter, the gain of the recorder should usually be set so that a signal that is 0 db on the meter scale is recorded 20 db below the maximum level that can be recorded. This setting can be made by using either the 60-cycle calibrating signal or the signal from a Type 1552-A Sound-Level Calibrator. The level from these signals ordinarily produces a deflection of the meter different from 0 db, and the recorded level should be correspondingly different. For example, if the meter reads +4, the recorded level with this signal should be 16 db below the maximum level on the recorder.

Before the recorder is used, it is desirable to apply an acoustic reference signal to the sound-level meter and to observe the recorded level as the setting of the attenuator of the sound-level meter is changed. The minimum observable level will be determined by the background noise in the system, and the maximum level should be beyond full scale on the recorder provided both the recorder and the sound-level meter are in proper operating condition. Except near these two extremes the recorded level should shift by 10 db each time the attenuator setting is changed by 10 db. This check should serve to determine that stray pickup is sufficiently low and that the instruments are operating normally.

After this check has been made, the attenuator of the sound-level meter should be set so that the recorded signal will always be within the maximum range of the recorder; that is, the signal level should never exceed full scale on the meter of the sound-level meter by as much as 10 db.

If the acoustic signal is an impact type, such as that produced by punch presses or drop forges, the maximum indicated level on the sound-level meter should usually be kept below 0 db on the scale. Maintaining this lower level reduces the possibility of overloading the output amplifier in the sound-level meter.

6.723 **Chart Scales:** The recorder paper is usually divided so that the lines corresponding to 10 db intervals are accented. Then, when the recorder and sound-level meter have been set up by the steps given above, the top of the chart can be labeled as a sound-pressure level of 20 db higher than the sound-level meter attenuator setting. Successively lower 10 db intervals are then labeled, and any recorded level can be read off according to these labeled ordinates.

6.724 **Recording the Frequency Spectrum:** The graphic level recorder can also be used on the output of the Type 760-B Sound Analyzer to analyze the noise source by recording a curve of amplitude versus frequency. As the paper in the recorder is advanced, it is necessary to advance the tuning dial on the analyzer a corresponding amount. This synchronism is obtained either by a mechanical or an electrical link between the paper drive and a drive system for the analyzer. Some provisions for such linkages are incorporated in graphic level recorders, and if a large number of analyses are to be made, it is often worthwhile to prepare the necessary coupling system to achieve this synchronism. The manufacturers of the recorders should be consulted concerning the linkages available as well as for special recording papers marked for synchronized instruments.

6.73 **Cathode-Ray Oscillograph:** A cathode-ray oscillograph having a tube with a long persistence screen and a sweep range extending down to at least 2 seconds sweep time is the most useful type for acoustic measurements. A five-inch oscillograph tube is ordinarily used when the wave form is to be photographed. Otherwise, for field use, one of the smaller oscillographs is frequently more convenient.

6.731 **Connections and Adjustments:** The vertical-amplifier input terminals of the cathode-ray oscillograph should be connected to the output of the sound-level meter by means of a short, shielded cable. The controls on the oscillograph should usually be set as explained in the instruction booklet for the oscillograph. The gain of the vertical amplifier can be set in a number of ways. For those who are inexperienced, the following procedure may be found useful. A reference sine-wave signal should be applied to the sound-level meter, for example, the 60-cycle calibrating signal or the 400-cycle signal from the Type 1552-A Sound-Level Calibrator. Note the reading on the meter, and then adjust the vertical-amplifier gain to obtain a peak-to-peak (total vertical excursion) deflection according to the following schedule for a five-inch screen.

Meter reading db	Peak-to-peak deflection inches
0	1
1	1.12
2	1.26
3	1.41
4	1.5
5	1.78
6	2.0
7	2.24
8	2.51
9	2.82
10	3.16

The gain control on the oscillograph should not be changed after this setting has been made, and only the attenuator on the sound-level meter is used to adjust the gain when the noise signal is applied.

The attenuator on the sound-level meter should be set so that the maximum deflection produced by the noise signal is within the range shown on the above schedule. The decibel value corresponding to this deflection is then obtained from the above schedule. The equivalent sine-wave level is sometimes given as that decibel value plus the setting of the sound-level-meter attenuator. The *peak-to-peak* sound-pressure level for the noise is then that decibel value plus the sound-level meter attenuator setting plus 9 db. The 9 db is added because the original calibration is in terms of a sine wave, and the peak-to-peak value of a sine wave is 9 db higher than the r-m-s value used for the meter calibration. This difference between the peak-to-peak value as determined on an oscillograph and the value indicated on the meter will depend on the type of noise being measured. For most noises it will be in the range of 6 to 15 db, but for impact sounds it can be as high as 30 db.

6.732 **Wave Form Observations:** The oscillograph is also useful for observing the wave form of the noise. For example, on an impact sound it is usually most important to know the peak level reached by the noise, but it is also important to know how rapidly this level is reached and how rapidly the level decays after the peak.

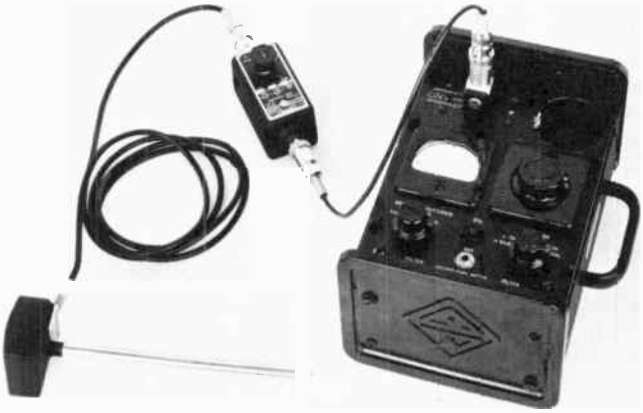


Figure 6-15.
The Type 759-P35 Vibration Pickup and Type 759-P36 Control Box used with the Type 1551-A Sound-Level Meter.

The time measurements that are required to determine this rate may be difficult, but a fairly good estimate can be made in many instances by selecting a sweep rate that displays the wave form with good separation of the rise and decay transient. Then this sweep can be calibrated by using a sine-wave signal of known frequency. Usually both of these displays should be photographed in order that suitable length measurements can be made. These length measurements are then related to amplitude and time by the calibration procedures suggested. An alternative timing signal can usually be put on the Z-axis (the beam intensity) as explained in the oscillograph instruction book. When it can be used, this timing system is usually more accurate than one that depends on sweep stability.

6.74 **Vibration Measuring Instruments:** Many air-borne sounds are produced as a result of the vibration of solid materials. The amplitude and spectrum of these sounds are determined in large part by the vibrating system, but the relations between the vibration and the resulting sound are so complicated that computing one from the other is not usually attempted. Vibration measuring equipment, nevertheless, can be of considerable help in solving some noise problems.

One class of these problems concerns reduction of the noise radiated by machinery, appliances, and other equipment. The vibration amplitude of the parts of the equipment can be measured, and in that way the parts that need most attention can usually be determined. The procedure for making these measurements is beyond the scope of this handbook, but information on making vibration measurements using the Type 759-P35 Vibration Pickup and Type 759-P36 Vibration Control Box as accessories for the Type 1551-A Sound-Level Meter or using the Type 761-A Vibration Meter is given in the General Radio booklet on vibration measurements.

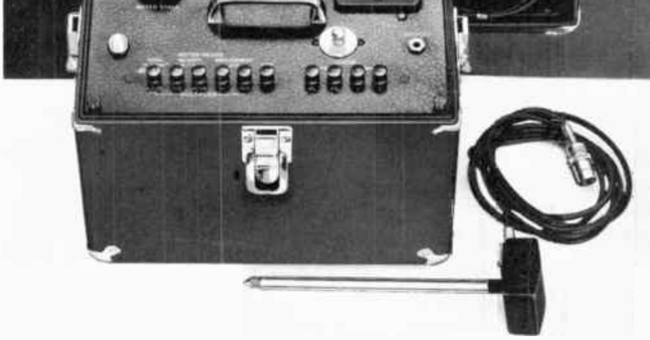


Figure 6-16.
The Type 761-A Vibration Meter.

Another noise measuring problem that can sometimes be solved by the use of a vibration pickup is the following. The noise output of nearly identical machines must sometimes be compared as a production control. Frequently, the background acoustic noise is so high that no satisfactory acoustic measurement can be made. In contrast, it is sometimes possible by suitable vibration mounts to keep background vibration from other sources down to a sufficiently low level so that the vibration of the machine itself can be satisfactorily measured. Then a study of the problem may show that some significant vibration measurements can be made that provide the essential information needed for a noise comparison of the machines.

6.75 **Earphones and Stethoscope:** A pair of high-quality earphones with tight-fitting earphone cushions is a useful accessory for noise measurements, and high-impedance dynamic or crystal-type phones are recommended. Good earphone cushions are essential to improve the low-frequency response and to help reduce the leakage of external noise under the earphone.

When a measurement system is being set up, the earphones should be plugged into the output of the sound-level meter. Then a listening test should be made to determine that the noise heard in the earphones is the same type of noise heard without the earphones. It is possible to detect trouble from microphonics (usually a ringing sound) or stray pickup in this fashion.

When the noise level is high, say, 90 db or higher, the leakage of external noise under the earphone may be sufficient to mask the sound from the earphones. Then the earphone cushions should be checked for tightness of fit. In addition the signal from the earphones can be increased by setting the attenuator of the sound-level meter to a value 10 db lower than that required for a satisfactory reading on the meter. This change of 10 db is usually not enough to overload the output, but a larger change should be avoided. It may also be desirable to have a long cord available so that it is possible to listen to the output of the earphones far from the noise source.

The earphones can also be used on the output of the analyzer to detect troubles from microphonics and stray pickup. In addition, a listening test may help one to determine which frequency bands contain the noise that is most objectionable in a given situation.

When the noise level is very high, the earphones on the sound-level meter may be useful in improving speech communication between observers during a measurement run. One observer wears the earphones, then the other observer shouts into the sound-level meter microphone. A definite improvement in speech communication usually results.

A similar procedure using a non-electrical, medical stethoscope is also possible. One observer has the ear tips in place, and the other speaks into the receiver of the stethoscope.

The stethoscope can also be useful for tracking down sources of noise on a machine, because with it the pickup of sound can be confined to a relatively small local area.

6.8 RECORD OF MEASUREMENTS

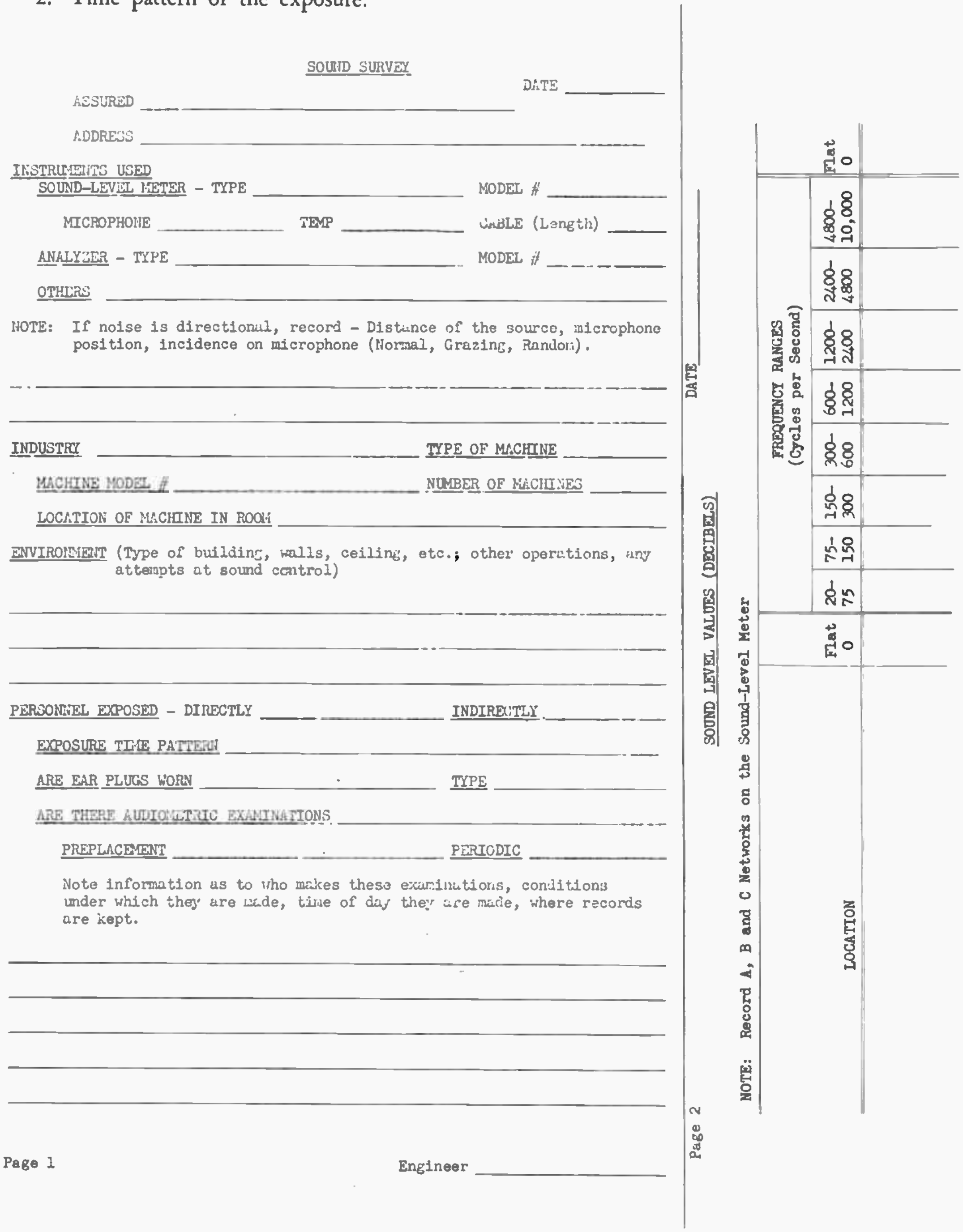
One important part of any measurement problem is obtaining sufficient data. The use of data sheets designed specifically for a noise problem helps to make sure that the desired data will be taken and recorded, and sample data sheets are shown in Figures 6-17a and 6-17b. The following list of important items may be found helpful in preparing data sheets of this type:

1. Description of space in which measurements were made.
    - Nature and dimensions of floor, walls, and ceiling.
    - Description and location of nearby objects and personnel.
2. Description of device under test (primary noise source).
    - Dimensions, name-plate data and other pertinent facts including speed and power rating.
    - Kinds of operations and operating conditions.
    - Location of device and type of mounting.
3. Description of secondary noise sources.
    - Location and types.
    - Kinds of operations.
4. Type and serial numbers on all microphones, sound-level meters and analyzers used.
    - Length and type of microphone cable.
5. Positions of observer.
6. Positions of microphone.
    - Direction of arrival of sound with respect to microphone orientation.
    - Tests of standing wave patterns and decay of sound level with distance.
7. Temperature of microphone.
8. Results of maintenance and calibration tests.
9. Weighting network and meter speed used.
10. Measured over-all and band levels at each microphone position.
    - Extent of meter fluctuation.
11. Background over-all and band levels at each microphone position.
    - Device under test not operating.
12. Cable and microphone corrections.
13. Date and time.

14. Name of observer.

When the measurement is being made to determine the extent of noise exposure of personnel, the following items are also of interest:

1. Personnel exposed—directly and indirectly
2. Time pattern of the exposure.
3. Attempts at noise control and personnel protection.
4. Audiometric examinations.
    Method of making examinations.
    Keeping of records.



SOUND SURVEY

DATE ____

ASSURED ____

ADDRESS ____

INSTRUMENTS USED

SOUND-LEVEL METER - TYPE ____ MODEL # ____

MICROPHONE ____ TEMP ____ CABLE (Length) ____

ANALYZER - TYPE ____ MODEL # ____

OTHERS ____

NOTE: If noise is directional, record - Distance of the source, microphone position, incidence on microphone (Normal, Grazing, Random).

INDUSTRY ____ TYPE OF MACHINE ____

MACHINE MODEL # ____ NUMBER OF MACHINES ____

LOCATION OF MACHINE IN ROOM ____

ENVIRONMENT (Type of building, walls, ceiling, etc.; other operations, any attempts at sound control)

PERSONNEL EXPOSED - DIRECTLY ____ INDIRECTLY ____

EXPOSURE TIME PATTERN ____

ARE EAR PLUGS WORN ____ TYPE ____

ARE THERE AUDIOMETRIC EXAMINATIONS ____

PREPLACEMENT ____ PERIODIC ____

Note information as to who makes these examinations, conditions under which they are made, time of day they are made, where records are kept.

Page 1

Engineer ____

DATE ____

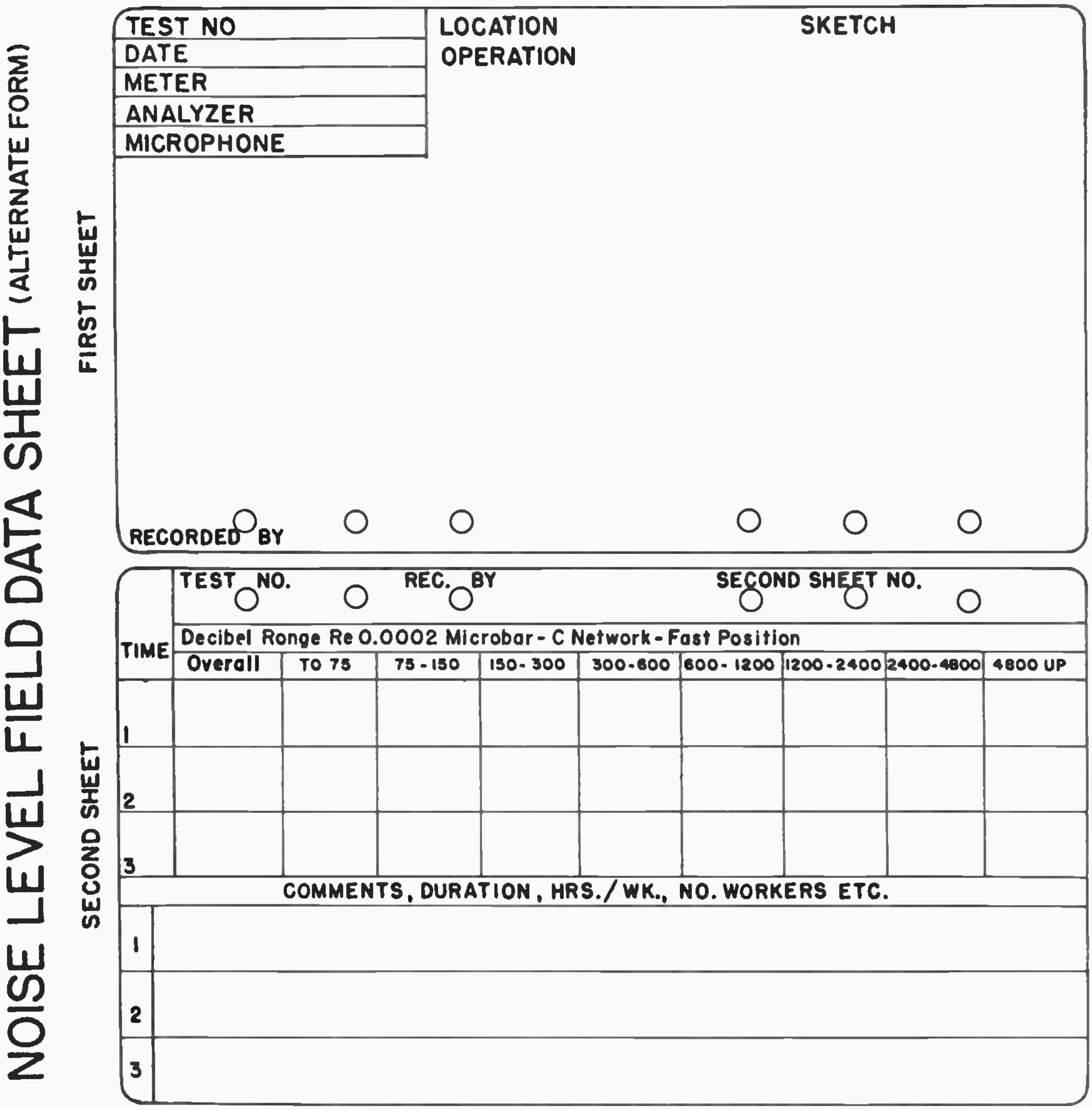
SOUND LEVEL VALUES (DECIBELS)

NOTE: Record A, B and C Networks on the Sound-Level Meter

LOCATION	Flat 0	FREQUENCY RANGES (Cycles per Second)								Flat 0
		20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-10,000	

Page 2

Figure 6-17a. A two-page sound-survey data sheet courtesy of Loss Prevention Department, Liberty Mutual Insurance Company.



NOISE LEVEL FIELD DATA SHEET (ALTERNATE FORM)

FIRST SHEET

TEST NO
DATE
METER
ANALYZER
MICROPHONE

LOCATION
OPERATION

SKETCH

RECORDED BY

SECOND SHEET

TEST NO.
REC. BY
SECOND SHEET NO.

Decibel Range Re 0.0002 Microbar - C Network - Fast Position

TIME	Overall	TO 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 UP
1									
2									
3									

COMMENTS, DURATION, HRS./WK., NO. WORKERS ETC.

1
2
3

Figure 6-17b. A noise-level field data sheet courtesy of Illinois Committee on Noise in Industry, sponsored by the Industrial Hygiene Unit, Factory Inspection Division, Illinois State Department of Labor.

6.9 A NOISE PROBLEM

In order to illustrate some of the procedures given in this chapter, this closing section will be an example of a noise problem.

An oil pump, used in a production setup to supply oil at high pressure to a number of hydraulic presses, was so noisy that the workmen objected to using it. This pump had been installed to speed up production with new presses, but the men preferred to use an earlier production method because it was not then necessary to use the noisy pump. The problem was to find out what should be done to make the noise less objectionable.

In this example, it was assumed that the pump itself could not be modified to reduce the noise, since correcting basic design faults would be a major problem. Errors in alignment or looseness of mounting, as the source of the high noise levels, however, should be taken into consideration. On that basis, the apparent procedure was to investigate these possibilities, to measure the noise produced by the machine, to measure the background noise level, and, then, to decide what recommendations should be made.

The following instruments were collected to take to the factory:

Type 1551-A Sound-Level Meter (with regular

Rochelle-salt microphone).

Type 1550-A Octave-Band Noise Analyzer.
Type 1555-A Sound-Survey Meter.
Type 760-B Sound Analyzer.
Type 759-P35 Vibration Pickup.
Type 759-P36 Control Box.
Pair of high-fidelity earphones.
Type 759-P21 Tripod and Extension Cable (these were not actually used).
Thermometer.
Two Sponge Rubber Pads.

Before going to the factory each instrument was given a maintenance check to see that it was operating properly, since it is easier to correct any faults at the home office than it is to correct them in a noisy factory where service facilities are limited. The procedure was as follows:

1. All equipment was turned on.
2. Batteries were checked.
3. The calibration cord was connected from the sound-level meter to the power line, and the calibration control was set.
4. The octave-band analyzer was connected to the sound-level meter, and with the 60-cycle signal from that instrument, its gain was set properly on the over-all band. The band switch was set to the first three bands to see that the expected behavior at 60 cycles was obtained.
5. The sound analyzer was connected to the sound-level meter, and the general procedure of Step 4 was repeated.
6. A Type 1552-A Sound-Level Calibrator and a suitable oscillator and voltmeter were used to check the over-all calibration of the sound-level meter. (It was not thought necessary to take along an acoustic calibrator and associated equipment for three reasons. First, it was expected that it would not be important to know the absolute level with high accuracy. Second, it would be relatively simple to recheck the calibration at the home office shortly after the test at the factory. Third, the equipment would be taken to the factory in an automobile so that all the instruments could be handled with care.)
7. The noise from a nearby noisy ventilator was measured with the octave-band analyzer to see that all the bands were operating properly.
8. The earphones were connected to the output of the sound-level meter. The attenuator was set at 90 db, the approximate expected level of measurement. Then the case of the instrument was gently tapped with one finger. Listening to the output indicated that the vacuum tubes were not particularly microphonic.

The instruments were taken in an automobile to the factory, where they were loaded on a rubber-tired cart and taken to the noisy pump on the ground floor. Incidentally, this type of cart is a convenient support for instruments when making measurements. At the pump, the obvious data were recorded. It was rated at 5 gallons per minute at 3000 PSI, and it was 6" long and 5½" in diameter with 7 knobs projecting from the outer cylinder. These knobs apparently corresponded to the seven cams of the pump. The pump was driven through a three-pronged flexible coupling by a 10-HP, 60-cycle, 1730-RPM, induction motor. This motor was air cooled. The oil storage and heat exchanger tank was about 25" long and 15" in diameter. These three main items, the pump, the motor, and the tank, as well as a mounting board, some gages and a line switch, were mounted on a 37"-square, heavy, steel base. Steel I-beams were welded underneath as a part of this base and these were securely bolted to the floor, which was a reinforced cement slab. Four heavy, brass, pipe lines were connected to the storage tank. Two of these were for water cooling, and the other two were for the oil. These lines ran directly to the heavy masonry wall nearby, and they were securely anchored in many places to the wall as they ran to the different presses.

The factory itself was of heavy reinforced concrete construction with no acoustic treatment. Numerous small machines, benches, storage racks, cartons, and other items were arranged in orderly fashion throughout the large factory space where this pump was located.

When the pump was turned on, it was clear why the men complained. It was very noisy. There were no obvious rattles from loose pieces, however, and there seemed to be no mounting troubles. The floor did not seem to be transmitting vibration, and this conclusion was verified later. The vibration in the oil lines could be felt by touch, but they did not seem to be an important source of noise. For example, a check using the Sound-Survey Meter carried along near the lines showed that the noise level dropped noticeably as one went away from the pump. The units mounted on the steel frame appeared to be the main source of noise, and listening nearby indicated that the pump itself was the major source.

A preliminary survey around and over the structure but some 5-feet away was made using the Sound-Survey Meter. As expected there was no obvious directional pattern, even with the A weighting.

The first measurement was made close to the pump. The microphone, only 16" from the pump shaft, was on the sound-level meter, which in turn was set on an empty cardboard packing case on the concrete floor. The octave-band analyzer was connected to the output of the sound-level meter. This first position was selected at this

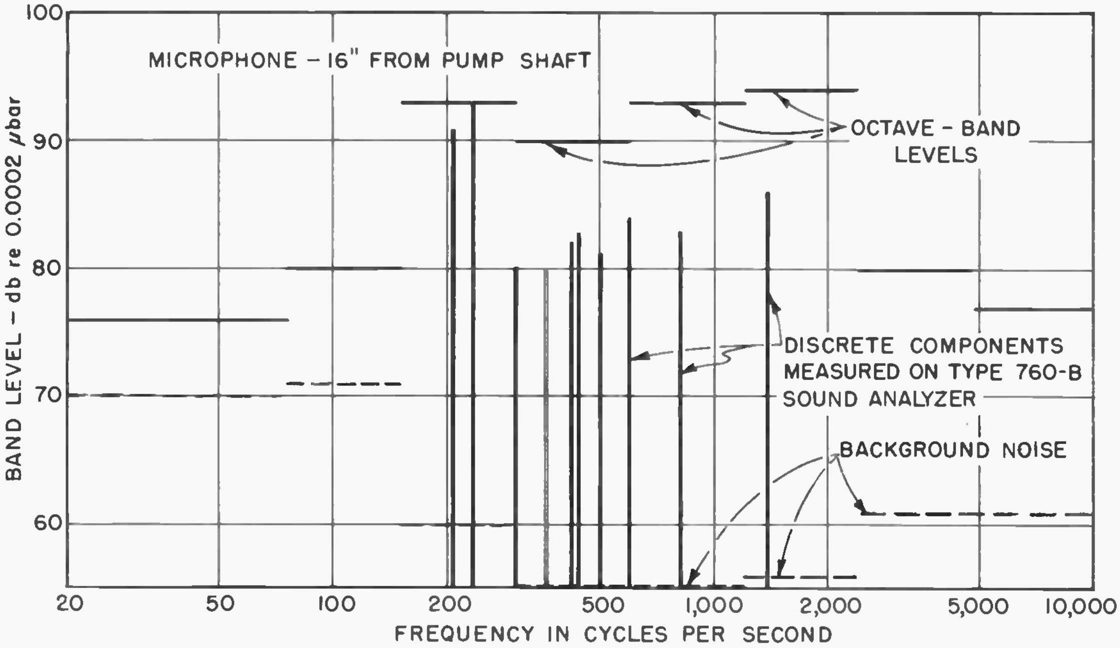


Figure 6-18. Frequency analysis of the noise produced by a pump. Levels measured with the octave-band analyzer are shown together with components measured on the Type 760-B Sound Analyzer. Background band levels are shown by horizontal dashed lines; solid horizontal lines represent pump noise plus background.

point to make certain that the background noise from other machines would not obscure any significant components.

The 60-cycle calibrating cord, connected to the power line, supplied the signal for setting the level of both the sound-level meter and the analyzer. With the pump turned on, the output from the analyzer was monitored by the pair of earphones. In the over-all position, there was no indication of microphonics in the noise heard from the earphones. Listening to the output of the various bands showed that the noise in the 600 to 1200 and 1200 to 2400 cps bands was the dominating part of the annoying, loud noise heard from the machine.

The complete analysis was made at this point as shown in the data sheet of Figure 6-18. Then the pump was turned off, and the background noise was analyzed. In all frequency bands but the lowest (20-75 cps), this background noise was so low that it could be neglected. It was obvious from this analysis that most of the noise was in the range from 150 to 2400 cps.

There were no apparent characteristic, pitched sounds in the noise heard from the machine, but it could be expected that some would be present. Just to make sure that something important would not be overlooked, an analysis of the noise was also made with the Type 760-B Sound Analyzer. The only discrete components (definite peaks in response as the analyzer was tuned) that were observed are listed on the data sheet. Of these components, the one at 205 cps was the basic pumping rate of seven times the rotational speed. A comparison of the levels from this analysis with that in octave-bands showed that most of the energy in the range from 150 to 600 cps was from discrete components, but above that the noise was generally unpitched.

The next step was to use a vibration test to find out if the mounting was satisfactory. The vibration pickup and control box were connected to the sound-level meter, and the sound analyzer was also used. Exploration with the pickup and the analyzer showed the following behavior. The pump itself was vibrating most strongly; the high-frequency components and the low-frequency ones were all present. The driving motor was not vibrating seriously. The storage tank vibrated most strongly at low frequencies. As the probe was moved about the mounting base toward the concrete floor the amplitude of motion decreased. At the floor the motion was insignificant. This vibration test confirmed that the mounting was not faulty.

The final measurements were octave-band analyses at a number of points 5 feet from the pump and one point 12 feet away. The results of these analyses are shown in the data sheet of Figure 6-19.

The nearest workmen were about 7 feet from the pump, so that the levels at 5 feet were nearly representative of the conditions they encountered. A comparison of the levels from the pump with the background data and with the speech-interference criteria given in the next chapter indicated that a 20-decibel reduction in noise level in the bands from 300 to 2400 cps would have been desirable.

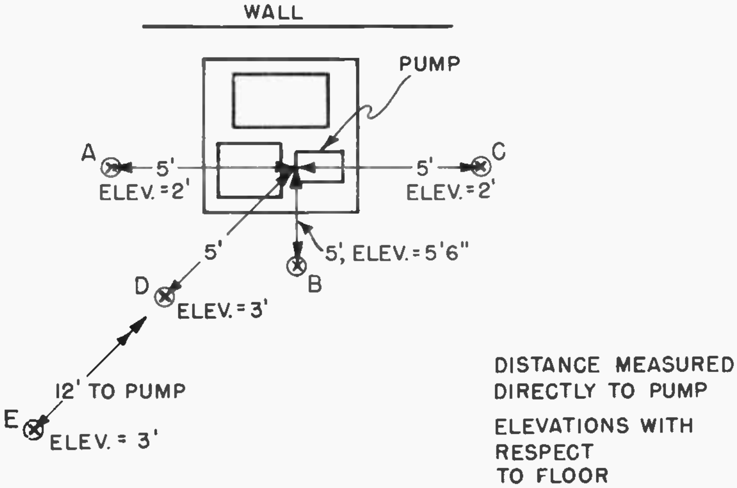
Therefore, as a solution to the problem, the following suggestions were made:

One possible solution is to use a different pump based on a principle of operation that produces less noise as a by-product.

Another possible solution is to enclose the whole pump in a tight housing with lined ducts for air ventilation. The housing should be treated on the inside with acoustically absorbing materials. The walls should not be resonant types, such as a single layer of plywood.

A third solution is to move the pump to another location outside the working area, and this solution was adopted. The pump was moved to a nearby boiler room.

What had been accomplished by these measurements? First, they had ruled out the possibility of a simple solution, such as isolating the whole structure by vibration mounts, putting flexible couplings in the pipe lines, or using acoustic baffles. Second, they provided the data needed for a preliminary design of a housing, so that its probable cost could be weighed against other possible solutions. In short, these measurements provided the necessary data for a decision by management.



MICROPHONE LOCATION	SOURCE	OVERALL	20 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 10000
A	Pump + Bkgd*	86	72-76	78	76	80	78	81	76	74
A	Bkgd	76-78	72-76	72	65	61	58	58	62	63
B	Pump + Bkgd	89	72-76	74-78	81	85-86	81-83	82-83	76	75
B	Bkgd	76	70-74	66	62	61	59	64	70	66
C	Pump + Bkgd	88	74-78	76-78	80	84	82	82-83	77-78	75
C	Bkgd	76-78	72-74	72-74	60	57	56	56	62	62
D	Pump + Bkgd	87-88	72-76	75-77	82	82	79	82	74	72
E	Pump + Bkgd	84-85	70-74	74	78	80	76	76	72	71

*Bkgd = Background

Figure 6-19. A diagram of the several positions used in making octave-band analyses of pump noise. Results obtained at the various locations are given in the table.

CHAPTER VII

LOUDNESS LEVEL, SPEECH INTERFERENCE, HEARING DAMAGE, AND NEIGHBORHOOD REACTION TO NOISE

7.1 INTRODUCTION

This section gives the specific details for calculating the loudness level and the speech-interference level of noise. It also gives some suggested methods for estimating, from measured octave-band levels, the possibilities of hearing loss as a result of exposure to certain noises and for estimating the reactions of people to noise in a residential area.

7.2 LOUDNESS LEVEL

The chart of Figure 7-1 has been prepared to simplify the calculation of loudness level from octave-band levels. The procedure is as follows:

1. The band level in db for each of the eight bands is related by means of the corresponding line chart of Figure 7-1 to a transfer value (t.v.). These transfer values are used for certain summing operations, and they have been empirically determined by using the Churcher-King equal-loudness contours and by using the psychoacoustic data obtained by Pollack for bands of noise.*
2. The total transfer value is then defined as the sum of the individual transfer values in the bands.
3. This total transfer value can be converted to loudness level in phons by the line chart for the 600-1200 cps band.

To illustrate this procedure, consider the following calculations using an analysis which was made of noise in a factory:

If the sound to be measured is a pure tone, a more accurate calculation of loudness level can be made by the method of Section 3.43.

For steady noises having a broad frequency spectrum, the calculated loudness level using the chart of Figure 7-1 agrees reasonably well with much psychoacoustic loudness-level data. But the calculated value is not to be considered accurate for intermittent sounds or impact sounds. For that reason some workers have proposed that this calculated value be considered as separate from loudness level and be given a new name. To avoid errors of interpretation, therefore, it is desirable to designate any loudness level obtained in the above fashion as a "computed loudness level."

If the measured levels are plotted on the chart of Figure 7-1, the relative positions of the points determine the relative contributions of the energy in the different bands to the total computed loudness level. These relative positions can then be used as one of the guides for deciding which regions of the frequency spectrum deserve most attention in a quieting problem.

7.3 SPEECH-INTERFERENCE LEVEL

The average of the band levels in db for the three octave bands, 600-1200, 1200-2400, and

Band	Over-all	20 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 10000
Level in db	88	76	77	82	82	79	82	74	72
Transfer value in each band		2.7	6.7	17	22	20	34	21	6.9

Total Transfer Value=130

Computed Loudness Level=103 phons

(This level is high compared to office or residential noises and it results from the high level of noise energy in the middle bands. Most of this noise came from an oil pump five feet from the microphone.)

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*L. L. Beranek, J. L. Marshall, A. L. Cudworth, and A. P. G. Peterson, "Calculation and Measurement of the Loudness of Sounds," *J. Acoust. Soc. Am.*, Vol. 23, May, 1951, pp. 261-269.

Job Test No. Date

Description

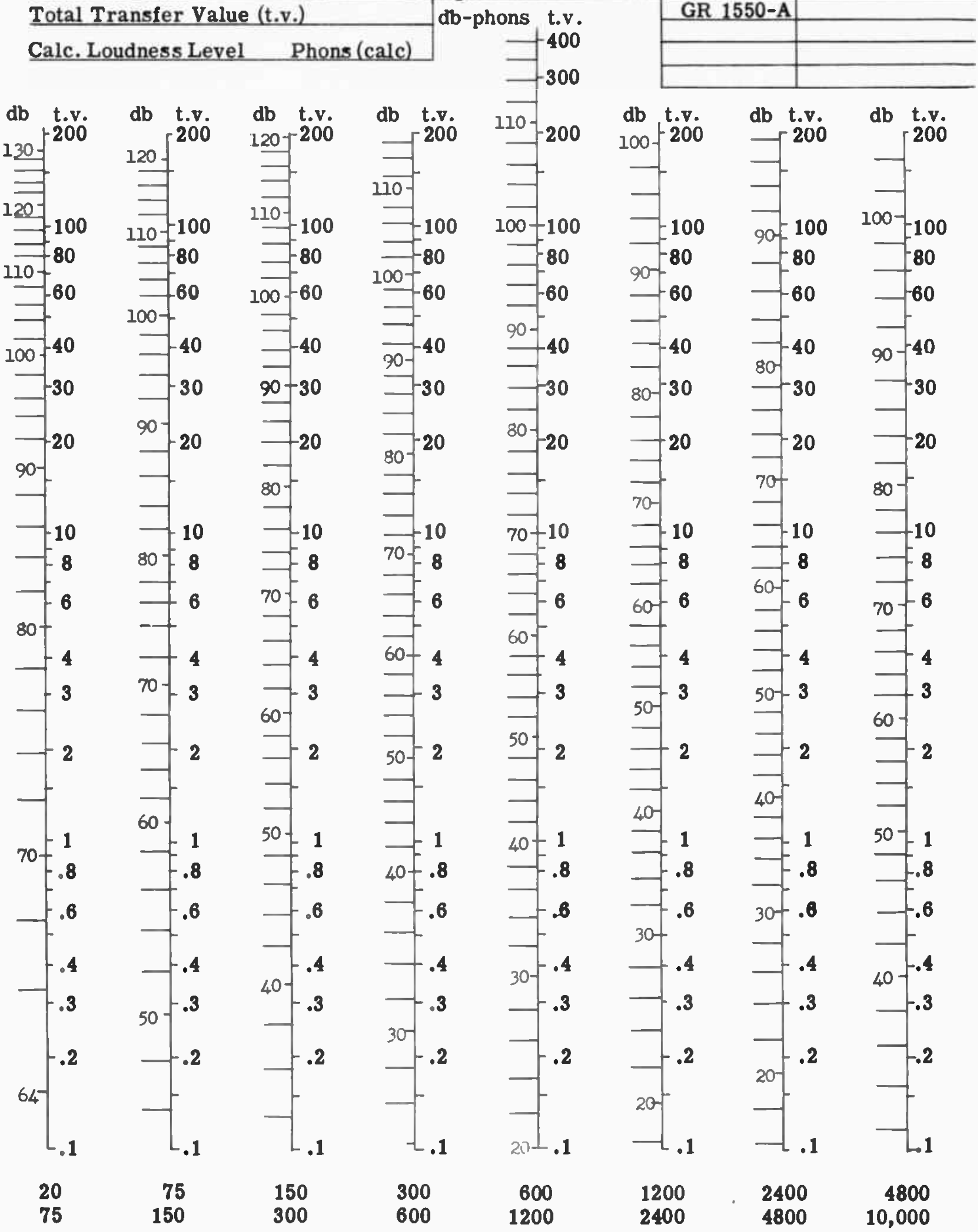
Observer

Over-all Level db Background db

Instruments	Serial No.
GR 1550-A	

Total Transfer Value (t.v.)

Calc. Loudness Level Phons (calc)



Frequency Bands (Random Incidence)

Figure 7-1. Chart for calculating loudness level from an octave-band analysis of a noise. The noise has been assumed to be coming at the listener from many directions (random incidence).

2400-4800 is called the speech-interference level. For example, in Section 7.2, the levels given in these bands for a factory noise are 79, 82, and 74 db, and the speech-interference level is then 78.3 db.

7.31 Speech Intelligibility: For satisfactory speech intelligibility using difficult speech material, maximum permissible values of speech-interference levels for men with average voice strengths are given in Table 7-I.

Table 7-I

Speech-interference levels (in db *re* 0.0002 microbar) should be less than the values given below in order to have reliable conversation at the distances and voice levels shown.

Distance (Feet)	Voice Level			
	Normal	Raised	Very Loud	Shouting
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61
24	37	43	49	55

It is assumed in forming this chart that there are no reflecting surfaces nearby, that the speaker is facing the listener, and that the spoken material is not already familiar to the listener. For example, the speech-interference level of 78.3 db, computed above, is high, and the chart indicates that shouting is usually necessary and that the two people must be closer to each other than two feet in order to be understood satisfactorily. If the words spoken are carefully selected, and limited in number, then, intelligible speech will be possible at greater distances.

If a number of conversations are to be held in the same reverberant room, the procedure is more complicated. This chart cannot be used on the basis of the background noise level before the conversations are in progress, because a given conversation will be subject to interference from the noise produced by all the other conversations. The general procedure for calculating a speech-interference level under those conditions has not been completely worked out.

7.32 Telephone Usability in Noisy Areas: The speech-interference level can also be used to predict the expected usability of a telephone under the given noise conditions. The following schedule has been found generally satisfactory, when the F-1 Western Electric handset is used for long-distance or suburban calls.

Speech-Interference Level	Telephone Use
less than 60 db	Satisfactory
60 to 75 db	Difficult
above 75 db	Impossible

For calls within a single exchange, the permissible speech-interference levels are 5 db greater than those shown in the table.

A suggested rating system for offices, based on a number of psychological and acoustical tests, is shown in Figure 7-2. The curves on this graph relate the measured speech-interference level of the background noise and the subjective rating of the noise ranging from "very quiet" to "intolerably loud." The two different rating curves illustrate that the environment influences the subjective rating. In order to be rated "noisy" the noise level must be appreciably higher in a large office than in a private office.

It can be expected that the probability of receiving complaints about noise will be high for subjective ratings above "Moderately Noisy" and low for levels that lead to a subjective rating below "Moderately Noisy". Furthermore, because of direct interference with transferring information, efficiency may be reduced for levels appreciably above the criterion points marked A and B.

Suggested criteria for noise control in terms of maximum permissible speech-interference level (SIL), measured when the room is not in use, are given in the following table:

Table 7-II. Criteria for Noise Control

Type of Room	Maximum Permissible SIL (measured when room is not in use)
Small Private Office	40
Conference Room for 20	30
Conference Room for 50	25
Movie Theatre	30
Theatres for Drama (500 seats, no amplification)	25
Coliseum for Sports Only (Amplification)	50
Concert Halls (No amplification)	20
Secretarial Offices (Typing)	55
Homes (Sleeping Areas)	25
Assembly Halls (No amplification)	25
School Rooms	25

The purpose of these criteria will be shown by the following example. Assume that we are to put a small conference room in a factory space. We measure the speech-interference level at that location and find it to be 64 db, whereas the suggested speech-interference level criterion for a small conference room is 30 db. The room must then be designed to attenuate the noise from the factory space by about 34 db in order to have a

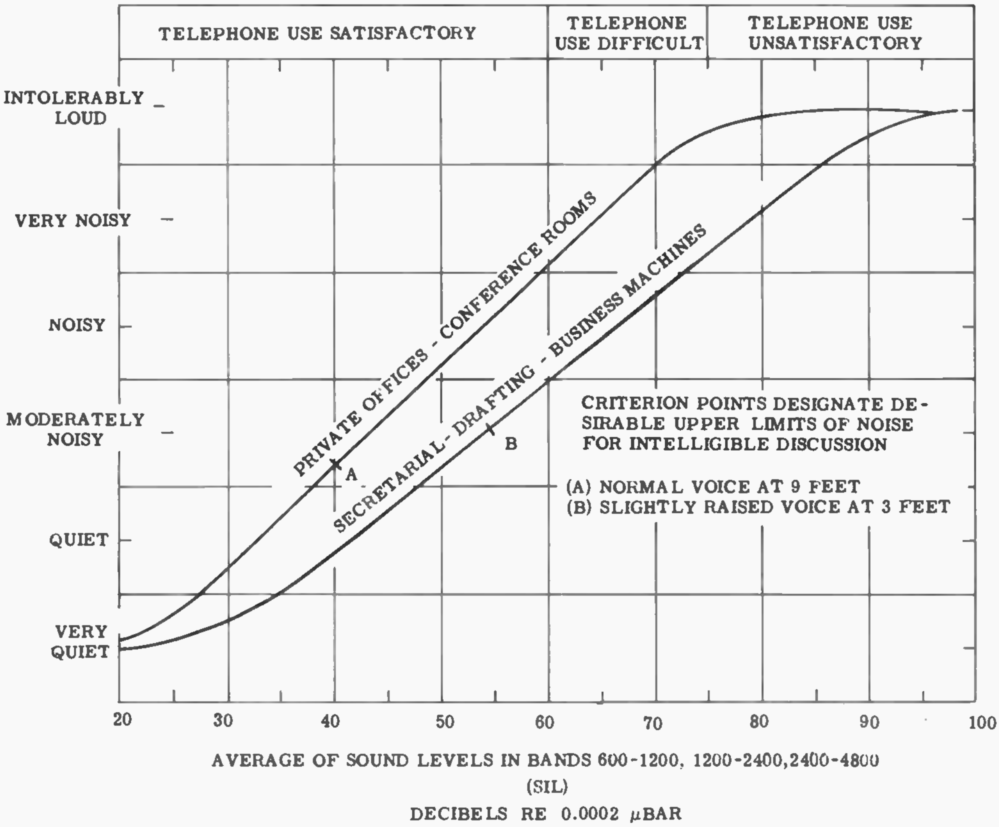


Figure 7-2. Rating chart for office noises. Data were determined by an octave-band analysis and correlated with subjective tests. (Courtesy Beranek and Newman.)

conference room that will be satisfactory as far as background noise level is concerned (such an attenuation is provided by a double-plastered, three- or four-inch thick stud wall, or by a hollow-tile wall plastered on one side).

7.4 HEARING DAMAGE FROM EXPOSURE TO NOISE*

As discussed in Sections 3.6 and 5.6, all noise ratings concerning the possibility of hearing damage are tentative at present. Many ratings have been suggested but so far no standards have gained acceptance, and all that can be done here is to indicate the order of magnitude of noise levels that are being considered as safe for lifetime exposures. More complete information is necessary before a widely acceptable rating can be given. In addition, general agreement must be reached on the answers to the following questions*:

"(1) What kind and amount of hearing loss constitutes a sufficient handicap to be considered undesirable? What role should presbycusis play in the setting of such a figure?

"(2) What percentage of the people exposed to industrial noise should a standard be designed to protect? In view of the large individual differences in susceptibility to noise exposure, should a noise standard be aimed at preventing hearing losses in 50 percent, 90 percent, or even 99 percent of the population?

"(3) How should noises be specified and exposures measured? Since different noises are apparently not equally effective in producing hearing losses, agreement must be reached on a standard specification of the spectral and temporal characteristics of the noise."

The noise-level ratings to be given here apply only to continuous exposure during a regular working day for a number of years and to steady noises, not to impact or impulsive sounds, such as gunfire. Impact sounds are more difficult to measure adequately (see Sections 6.34 and 7.73), and less information regarding hearing damage from impact sounds is available.

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*ASA Subcommittee Z24-X-2, "The Relations of Hearing Loss to Noise Exposure," American Standards Association, 70 East 45th Street, New York, 1954.

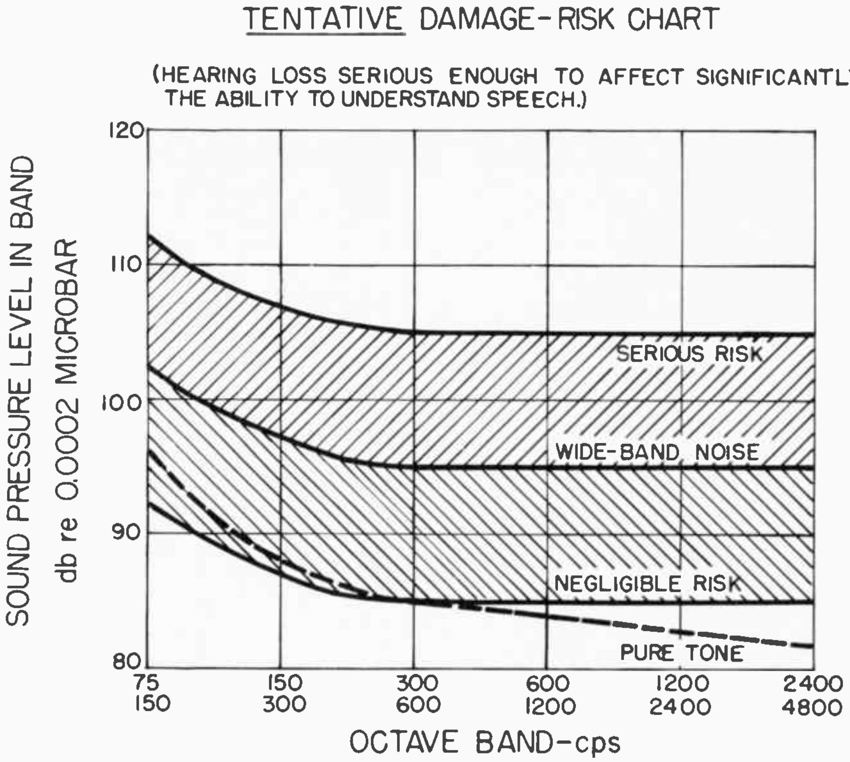

Figure 7-3. Tentative damage-risk chart. The ratings apply for continuous noise for exposure every working day for a lifetime and for suffering a loss in hearing serious enough to affect significantly the ability to understand speech. The zone of 20 db shown for "Wide-Band Noise" is to illustrate some of the uncertainty in this rating. A similar uncertainty applies to the "Pure Tone" curve.

The ratings are limited to continuous exposures, because evidence is given in the report* of the American Standards Association, Subcommittee Z24-X-2 that intermittent exposure results in less hearing loss than continuous exposure to the same type of noise, but the information is inadequate to show how this difference can be taken into account for a noise rating.

One suggested preliminary test is based on the reading with the B-weighting network of the Sound-Survey Meter or a sound-level meter, as follows: A reading above 100 db with B weighting indicates that the noise is probably unsafe for everyday exposures, at least for some people, and noise reduction or ear protection is necessary. Readings below 80 db indicate that there is probably no danger from the noise even if the noise is a pure tone.

When the reading with the B weighting is above 80 db, analysis is necessary, and an investigation should be made using the Type 1551 Sound-Level Meter and the Type 1550-A Octave-Band Analyzer. When this analysis is made, the tentative ratings shown in Figure 7-3† can be used.

For most factory noises the curve labeled "WIDE-BAND NOISE" should be used. When the sound is concentrated in a very narrow band, for example, a pure tone, the rating shown by the "PURE TONE" curve should be used.

The rating for "WIDE-BAND NOISE" is shown as a zone 20-db wide to illustrate some of the uncertainty involved in this rating. Thus, to insure that there would be negligible risk of suffering a loss in hearing serious enough to affect significantly the ability to understand speech, the noise levels should probably be lower than the lower limit of the zone shown in Fig. 7-3. This rating would apply for exposure during every working day for durations up to retirement.

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*ASA Subcommittee Z24-X-2, "The Relations of Hearing Loss to Noise Exposure," American Standards Association, 70 East 45th Street, New York, 1954.

†Adapted from Fig. 18.6 of W. A. Rosenblith and K. N. Stevens, *Handbook of Acoustic Noise Control.* Vol. II, *Noise and Man*, WADC Technical Report 52-204, (June, 1953), p. 219. That report is obtainable as PB111,274 from Office of Technical Services, U. S. Department of Commerce, Washington 25, D.C.

7.5 RESIDENTIAL NOISE LEVELS

Some factories, recreation halls, electrical substations, trucks, and airplanes are so noisy that they annoy people living near them. The reactions of those that are annoyed may range from mild remarks to legal action. Those that are responsible for the noise would, naturally, like to avoid the expense of court action; and, in many cases, in order to maintain the good will of the neighborhood, they are willing to put considerable effort into controlling the noise so as to avoid anything but mild annoyance.

In order to put this noise control on a systematic basis, a number of engineering groups have analyzed the experiences obtained in many different situations. They have found that reactions of annoyance cannot be successfully predicted on the basis of a single measurement, or even computed loudness ratings, but that many factors enter into the problem. In addition to the range of reactions to be expected from different individuals, some other factors are the following: The level and spectrum of the noise; whether or not there are strong, pure-tone components; the time pattern of the noise, including the rate of repetition and the actual time of occurrence during the day; and the general background noise level in the residential area affected. So far the data that is available is limited primarily to the reactions of people in residential areas of single-family houses surrounding industrial plants. We can expect that, because

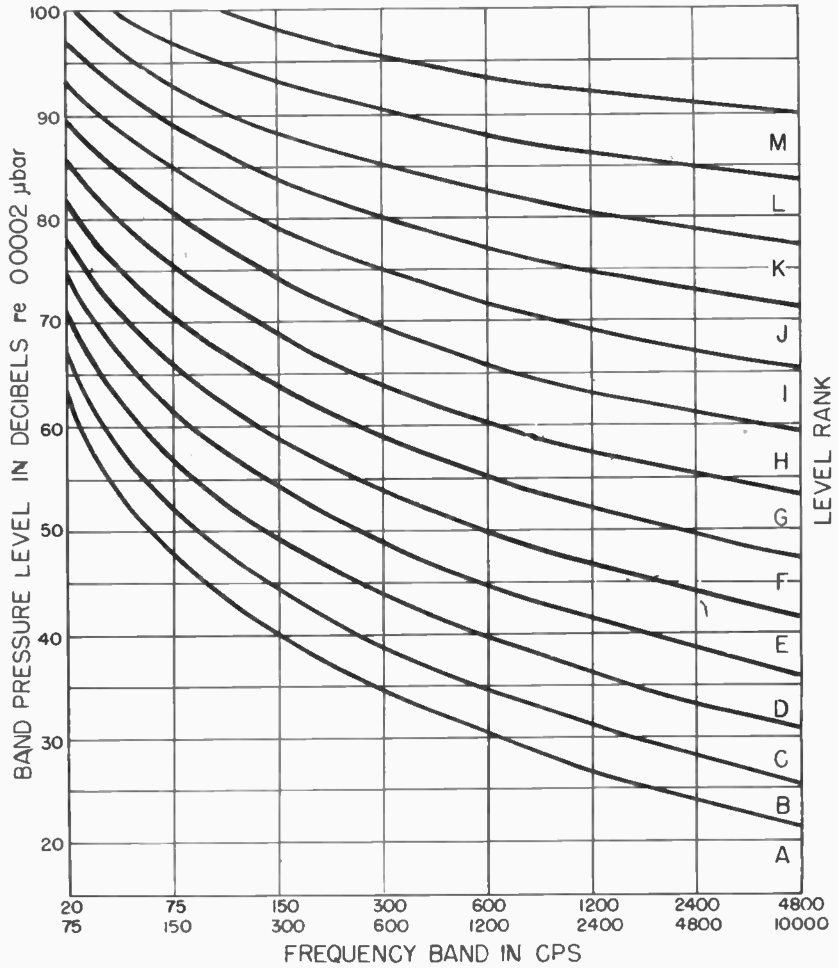

Figure 7-4. Set of curves for assigning a level rank to a residential noise. The octave-band levels of the noise are plotted on this chart. The highest of the alphabetically labeled zones into which any of the band levels penetrates is the level rank of the noise.

of the conditioning to noises that occur in multiple family dwellings, the reactions of the people there would be modified.

A tentative rating* for these residential noise problems is obtained in the following way: The octave-band noise levels are measured in the neighborhood. Under difficult circumstances such a measurement may require surveys for long periods of time, depending on the type of noise source and atmospheric conditions, particularly wind. These measured levels are then plotted on the chart of Fig. 7-4 to determine a "level rank."

For example, assume that the octave-band levels produced at night by a newly erected power substation at the nearest house in a suburban area are as follows:

Octave Band—cps	20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-10000
Band Level—db	30	48	47	38	34	28	22	22

Table 7-III

List of Correction Numbers to be Applied to Level Rank to Give Noise Rating

Influencing Factor	*Possible Conditions*	*Correction Number*
Noise Spectrum Character	Pure-tone components	+1
	Wide-band noise	0
Peak Factor	Impulsive	+1
	Not Impulsive	0
Repetitive Character (about one-half minute noise duration assumed)	Continuous exposures to one per minute	0
	10-60 exposures per hr.	—1
	1-10 " " "	—2
	4-20 " " day	—3
	1-4 " " "	—4
	1 " " "	—5
Background Noise	Very quiet suburban	+1
	Suburban	0
	Residential Urban	—1
	Urban near some industry	—2
	Area of heavy industry	—3
Time of Day	Nighttime	0
	Daytime only	—1
Adjustment to Exposure	No previous conditioning	0
	Considerable previous conditioning	—1
	Extreme conditioning	—2

When these levels are plotted on Figure 7-4, it is seen that, in this particular case, the level rank of the 150-300 cps band is the highest of any of the bands. The noise is then assigned that rank. The level rank of this assumed noise is then "C". This rank is then corrected by the numbers in Table 7-III, according to the factors listed. For the assumed noise the spectrum has strong pure-tone components (+1); it is a steady noise (0). not impulsive (0), in a suburban neighborhood (0), at nighttime as well as daytime (0), and we shall assume that this neighborhood has no previous conditioning to a noisy nighttime background (0). The net correction is then a shift upward of one level to a corrected "level rank" or noise rating of "D". Then from the chart of Fig. 7-5 we predict that the reaction to this noise will generally be mild complaints with a good possibility of some strong complaints. If there were many houses in a region of this noise level, the power company would probably try to reduce the noise level in order to avoid losing the good will of the neighborhood.

This rating system can also be handled in the opposite sequence. Thus, we could decide on the sort of response that we would be willing to have or to risk and proceed from that to the maximum allowable levels in each band.

Sometimes a noisy device is in a building where there are also bedrooms. The noise level produced by that device in the bedrooms should then be rated one rank higher than that given in Figure 7-4, since engineering experience indicates that the residents are less tolerant of noise generated within the same building.

The procedure given here is intended mainly as a guide. As more experience is obtained in this field of neighborhood noise problems, it can be expected that some revision of the numerical values will be found desirable.

*W. A. Rosenblith and K. N. Stevens, Op. cit., pp 181-200. L. L. Beranek, *Acoustics*, McGraw-Hill: New York, 1954, Part XXXII.

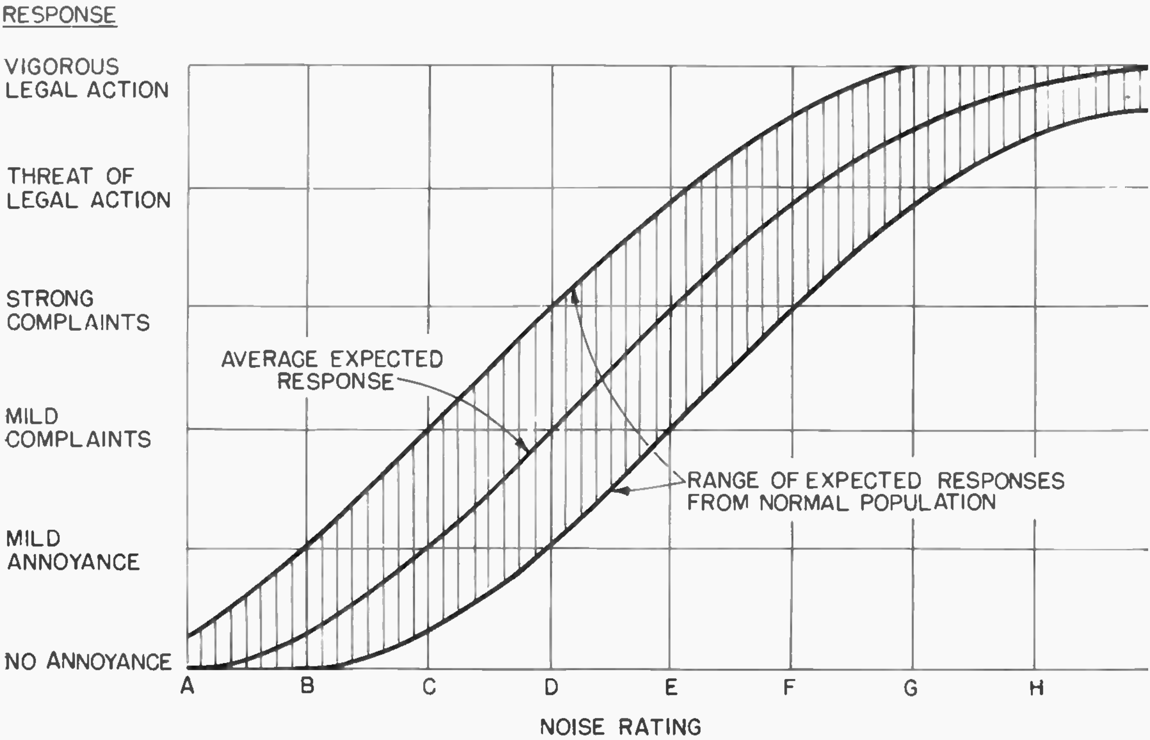

Figure 7-5. Relation between the noise rating and the expected response from the residents exposed to the noise.

CHAPTER VIII

NOISE SOURCE CHARACTERISTICS

8.1 INTRODUCTION

More and more apparatus is being rated for noise. This rating is usually intended to make possible the prediction of the noise level that the apparatus will produce when installed. In order for the rating to be adequate for this purpose, the total acoustic power radiated by the source and the acoustic directivity pattern of the source should be included as part of the rating. We shall explain in this chapter how the power and directivity can be determined; but first we shall discuss the limitations of the usual method of noise rating.

For example, an air compressor may be rated by the manufacturer as producing a noise level of 85 db at a distance of three feet. This level may have been obtained by taking the average of a few sound level readings three feet from the compressor. When it is installed and the level is measured, the new level may be, say, 90 db at three feet. Naturally, the purchaser feels that he should complain because the machine was incorrectly rated; perhaps, he returns the compressor, or he decides that he can no longer trust the manufacturer. Actually, the manufacturer may have been entirely correct in his noise measurements, but the rating was inadequate. The difference of 5 db may have been caused by incorrect installation, but usually such a difference is a result of the acoustic characteristics of the factory space. By the use of an adequate rating system and a knowledge of acoustic room characteristics, it would have been possible to predict this effect.

Another part of this same problem is the prediction of levels at places in the factory other than at the three-foot distance. For example, the nearest worker may be 20 feet away, and the level at a distance of 20 feet is then more important than at 3 feet. Again, a knowledge of the acoustic power radiated and the acoustic characteristics of the factory space will be needed to predict the probable level at this distance.

The procedure suggested here for determining the power and directivity is based on measuring the sound-pressure level at a number of points around the noise source. The technique for measuring sound-pressure level has already been discussed in Chapter VI. We shall discuss here the selection of the points at which the sound-pressure level is measured, the method of calculating the power and directivity, and the requirements on the characteristics of the space in which the measurement is to be made. We shall introduce this discussion by considering the behavior of noise sources under various conditions.

8.2 SOURCES IN FREE FIELD

8.21 Simple Source in Free Field:

8.211 Point Source: Any vibrating object will radiate sound into the air. The amount of sound radiated depends on (1) the amplitude of vibration of each vibrating part, (2) the area of each part, and (3) the time pattern of the vibrations, including the relative time pattern compared to that of the other parts.

The simplest form of source is spherical in shape and vibrates uniformly over its entire surface. We can think of this source as a round balloon with air in it. We periodically pump some more air into it and then let the same amount of air out. If the surface of the balloon then expanded and contracted uniformly, the balloon would be a simple, spherical source. This

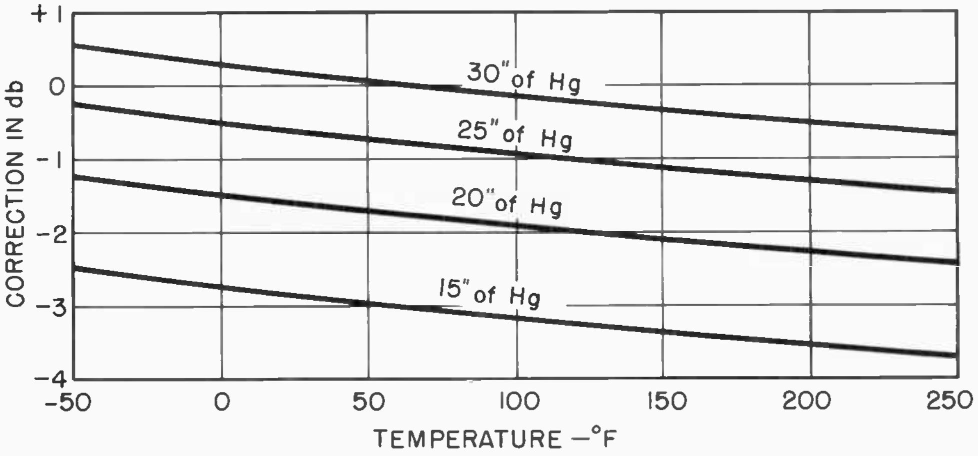

Figure 8-1. Corrections for temperature and barometric pressure to be applied when the equations relating power level (PWL) and sound-pressure level (SPL) are used. The correction is to be added to, if positive, or subtracted from, if negative, the sound-pressure level computed by the equation from the power level. If the power level is to be computed from a given sound-pressure level, the correction should be subtracted from, if positive, or added to, if negative, the given sound-pressure level before substituting the numerical value into the equation.

source radiates sound equally in all directions from an apparent center, which is the center of the balloon. It then is like a "point" source, insofar as sound radiation is concerned.

8.212 Free Field: If such a point (or spherical) source is in the air far from any other objects, including the ground, the sound-pressure produced by the source in every direction is the same at equal distances from the point source. Furthermore, the sound pressure decreases by a factor of two for each doubling of distance from the point. This change is usually expressed as a decrease in sound-pressure level of 6 decibels. The sound field produced under these idealized conditions is called a free field; because it is uniform, it is free from all bounding surfaces, and it is undisturbed by other sources of sound.

8.213 Power Level in Free Field: Under free-field conditions, a single measurement of the sound-pressure level at a known distance from a point source is enough to tell us all about the sound field radiated by the source. For example, we can then predict the level at any other point, since the sound-pressure varies inversely as the distance from the source. We can also compute the total sound power radiated by the point source. We shall do this calculation in terms of the power level *re* 10^{-13} watt *(PWL)* of the source (Section 2.1). Then the required relation to the sound-pressure level *(SPL)* is:

$$PWL = SPL + 20 \log r + 10.5 \text{ decibels}$$

where r is the distance in feet from the point source to the point where the sound-pressure level is measured. This relation is correct for a point source in a free field at normal room temperature and barometric pressure, that is, 68°F and 30 inches of mercury. At other temperatures and pressures it is necessary to apply the correction shown in the graph of Figure 8-1. This correction is usually unimportant.

As an example, suppose that we measured a sound-pressure level of 73.5 db *re* 0.0002 microbar at a distance of 20 feet from a point source. Then

$$PWL = 73.5 + 20 \log 20 + 10.5 = 110 \text{ db}$$
re 10^{-13} watt.

The value for 20 log r can be found from a table of logarithms or from the decibel tables in the Appendix, where the columns labeled as pressure ratios should be used for this distance.

The power level can be converted to actual acoustic power in watts as explained in Section 2.1. For the example above, the 110 db corresponds to an acoustic power of 0.01 watt.

Instead of calculating this level from the equation, we can use the straight line relation labeled "OPEN AIR" on the graph of Figure 8-3. This is a graph of the difference between the sound-pressure level and the power level as a function of the distance from the source. For example, at 20 feet this difference is shown to be 36.5 db. So that we have 73.5 + 36.5 = 110 db power level, as we also found above.

We can also use the equation or the graph to

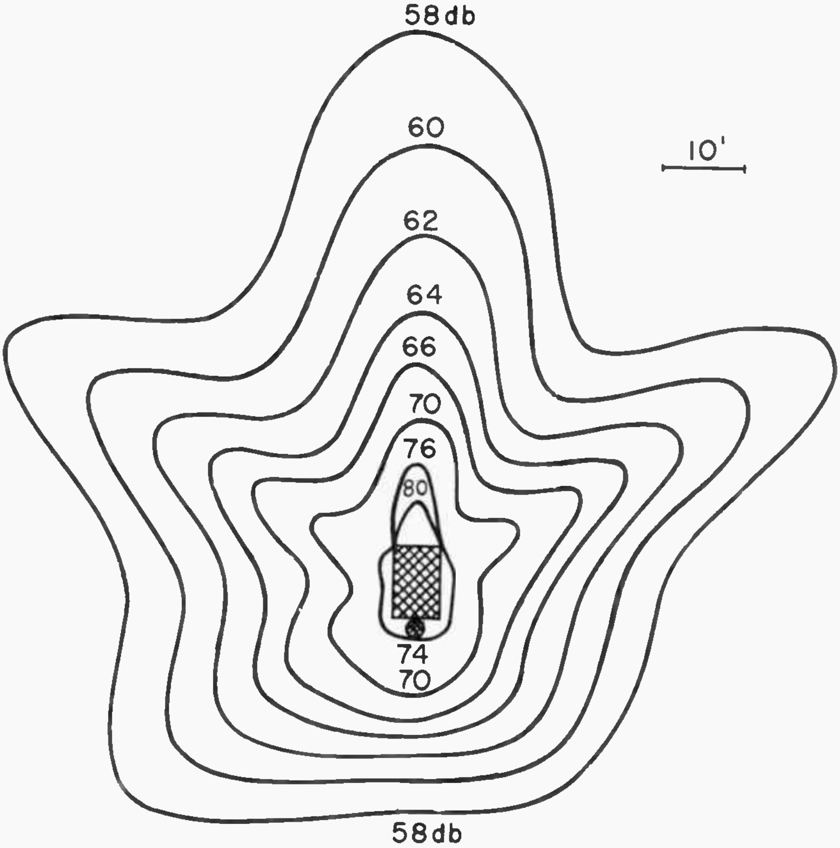

Figure 8-2. Contours of equal sound-pressure level around a large power-distribution transformer.

predict sound-pressure levels at any distance in the free field if we know the acoustic power radiated. Thus, this point source radiating .01 watt, corresponding to a power level of 110 db *re* 10^{-13} watt, produces a sound-pressure level of $110 - 30.5 = 79.5$ db *re* 0.0002 microbar at 10 feet from the source.

8.22 Directional Source in Free Field

8.221 Directional Source: In actual practice, most noise sources are not as simple as point sources. The sound is not usually radiated uniformly in all directions, either because the shape of the sound source is not spherical or because the amplitude and time phase of the vibrations of the different parts are not uniform or both. The net result is that more sound is radiated in some directions than in others.

8.222 Sound-Pressure Contours: In other words, the sound-pressure level is different in different directions for a given distance. As an example, let us observe the sound field surrounding a large 60-cycle power-distribution transformer, as shown in Figure 8-2. This figure shows contours around the transformer that correspond to the values of sound-pressure level marked on the contour. This source is obviously directional, since the contours are not circular, which would be the shape obtained if the sound-pressure level were independent of direction.

When such a directional sound source is far from any other objects, however, it behaves in some ways like a point source. For example, the sound-pressure level also decreases 6 decibels for each doubling of distance, provided we start our measurements at a distance away from the source that is several times the largest dimension of the source, and provided we move directly away from the source. For the example of the transformer in Figure 8-2 we see that, at distances greater than several times the length of the transformer, the contours are similar in shape and the levels decrease approximately 6 decibels for each doubling of distance. In actual practice this idealized behavior is upset by the effects of variations in terrain and the interference of nearby objects.

8.223 **Near Field and Far Field:** We can also see that at locations close to the transformer the sound level contours are different in shape from those at a distance. Furthermore, there is no apparent center from which one finds the 6 db drop for each doubling of distance. Consequently, this "near field" behavior can not readily be used to predict the behavior at a distance. The differences between the "near field" and "far field" can be described in part as follows. Assume we have a source in which one part moves outwardly while another moves inwardly and vice versa. The air pushed away by one part will then tend to move over to compensate for the decrease in air pressure at the inward moving part. If the air can move over quickly enough, there will be considerable motion of air between the two parts, without contributing much to radiation of sound away from the source. The time factor in this motion of air can be expressed as a relation between the distance to be covered and the wave length of the sound in air. The wave length, λ, in feet at normal temperature is as follows:

$$\lambda = \frac{1130}{f} \text{ feet}$$

where f is the frequency in cycles per second. Then, in order that the "near field" effect should not be very important, one should be at least one wave length away from the source. This dimension should be determined on the basis of the lowest frequency of interest. For the example of the 60-cycle transformer, the lowest frequency of sound is 120 cycles which corresponds to a wave length of about 10 feet.

Another factor that enters into the differences between the "near-field" and "far-field" behavior is the way the sound waves spread out from a source. The sound waves from a large source vary with distance differently from the way they vary when produced by a small source. But at a distance of several (3 to 4) times the size of the radiating source, "spherical spreading" is said to exist, and the behavior is then essentially independent of the size of the source.

8.224 **Measurement of Contours of Sound-Pressure Level:** When it is important to know both the characteristics of the near field and the far field, it is useful to make contour plots similar to those shown for the transformer. These contours should usually be made for each octave band, since the characteristics for the different frequency bands will be different.

It is possible to determine these contours by measurements at a large number of fixed stations around the noise source. Often, however, after the data have been taken in this fashion, it is found that the number of points is not adequate to give assurance of satisfactory interpolation. A preferred procedure is to set up the measuring equipment on a small cart. First, explore in a large circle around the source to find the directions of the maxima and minima. Then observe readings as the measuring station is moved radially away from the noise source. At each point where the level reaches a desired value, the corresponding distance on a steel tape laid out along the radial line is noted. A number of these readings should be taken along different directions. Many readings at relatively small intervals of sound-pressure level can be made in a short time when this procedure is possible.

8.225 **Directivity Factor:** When we are interested in sound-pressure levels beyond the immediate vicinity of the source, any sound can be treated as a point source provided we introduce a directivity factor. This factor takes into account the variation in sound-pressure level with direction to the source. This directivity factor, which is a function of direction and frequency, is usually labeled Q. It can be expressed as the ratio of two acoustic powers. One of these powers is that which would be radiated by a point source in order to produce the observed sound-pressure level in the specified direction. The other power is the total acoustic power radiated by the actual source.

8.226 **Sound-Pressure Level for a Directional Source:** When we know this directivity factor for the direction of interest, we can use it, in the earlier equation for a point source, as a multiplying factor on the power. Expressed in terms of level the new equation is as follows:

$$SPL = PWL + 10 \log Q - 20 \log r - 10.5 \text{ decibels}$$

This equation relates the power level of the source, the sound-pressure level in a given direction at a distance r feet from the source, and the directivity factor for that direction. (This equation is also subject to the minor corrections for temperature and pressure shown in Figure 8-1.)

For example, let us assume that an auto horn whose measured power level is 104 db is sounded. We are interested in the sound-pressure level at a distance of 20 feet in the horizontal plane of the horn, but at an angle of 20° from the principal axis of the horn. Along this direction of 20° from the axis the directivity factor is 5, say. Then we have

$$SPL = 104 + 10 \log 5 - 20 \log 20 - 10.5 = 74.5 \text{ decibels}$$

at 20 feet in the required direction.

8.3 SOUND SOURCE INDOORS

8.31 **Sound Source in a Room:** In most practical situations the problem is complicated by

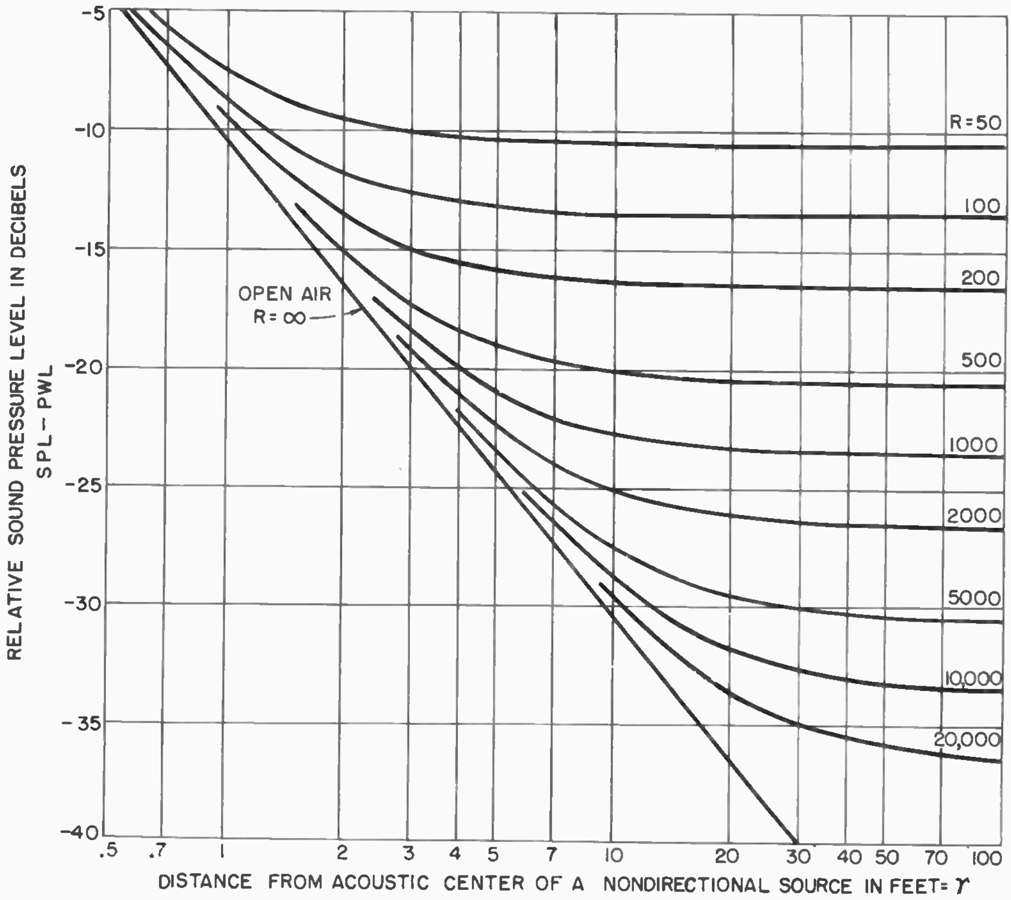

Figure 8-3. Chart showing the sound-pressure level, SPL, relative to the power level, PWL, for a non-directional source for different values of the room constant, R, as a function of the distance from the source.

additional effects of nearby walls and objects. In particular, when apparatus producing noise is used in a room, the walls, floor, and ceiling reflect the sound that strikes them. As discussed in Section 6.51 this reflected sound upsets the simple picture presented for the free field case; standing waves are produced, and the sound-pressure level is different from that expected from the free-field equations.

8.32 Standing Waves: In order to simplify the analysis of the effect of the room, we shall assume that enough measurements are made so that the standing wave can be averaged out. If the room is large and irregular and if the noise source radiates sound containing many frequency components, the standing wave is usually small, and the average is simply the average of the observed levels. When the sound-pressure level varies along a line from the source over ranges of more than 6 db, the average is taken to be 3 db below the frequently occurring peaks of sound-pressure level. As it will be seen shortly, this averaging may have to be done on a graph of sound-pressure level versus distance from the source. One practical method of doing this averaging while making the measurement is to suspend the microphone from a cable fastened to the ceiling and then to swing it in a circular path.

8.33 Sound-Pressure Level in Room: When this averaging process is introduced, we can obtain a relatively simple relation among the power level of the source, the average sound-pressure level, and the acoustic characteristics of the room. This relation is shown graphically in Figures 8-3 and 8-4, where Figure 8-3 applies to the non-directional or simple source or to a directional source in the direction having a directivity factor of 1 ($Q = 1$), and Figure 8-4 applies to the directions having the labeled values of directivity factor. In this relation it is assumed that the source is not near any of the surfaces of the room.

8.331 Room Constant: The symbol R on the curves is used for the room constant. At a given

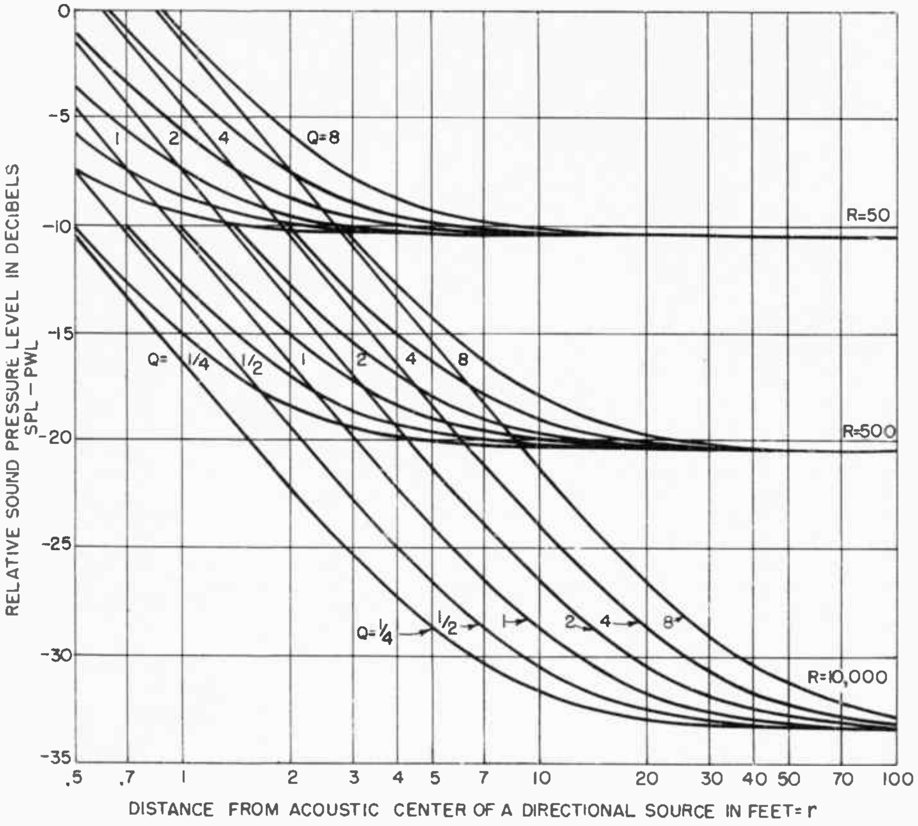

Figure 8-4. Chart showing the sound-pressure level, SPL, relative to the power level, PWL, for a directional source as a function of the distance from the source. The relation is shown for three different values of the room constant, R, and for six different values of the directivity factor Q.

frequency, the room constant is obtained from the following equation:

$$R = \frac{\alpha S}{1 - \alpha}$$

where S = the total area of the bounding surfaces of the room in square feet.
where α = average absorption coefficient of the surfaces of the room.*

Since most rooms are not uniform in surface conditions, the value for αS is obtained by adding together the absorption for the individual areas. Thus, for a simple example, we have most of the wall area and all of the ceiling treated with 900 square feet of acoustical material of a particular type that has a coefficient of absorption of 0.70 at 512 cps (one of the standard test frequencies). The rest of the walls are 300 square feet of lime plaster on wood lath ($\alpha = .061$). The floor is 400 square feet of concrete ($\alpha = .016$). The total absorption is then as follows: $\alpha S = 0.70 \times 900 + 0.061 \times 300 + .016 \times 400 = 655$ absorption units at 512 cps. If people and furniture are also present, the appropriate absorption units should be added to the room absorption to obtain the total absorption. The average value for the absorption coefficient is then obtained by dividing the total absorption by the total surface area. In the above example we have

$$\alpha = \frac{\alpha S}{S} = \frac{655}{1600} = .41$$

The corresponding room constant is

$$R = \frac{\alpha S}{1 - \alpha} = \frac{655}{1 - .41} = 1200 \text{ square feet}$$

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*Tables of values of absorption coefficients are given in books on architectural acoustics and in the references listed under acoustical materials in the bibliography at the end of this handbook.

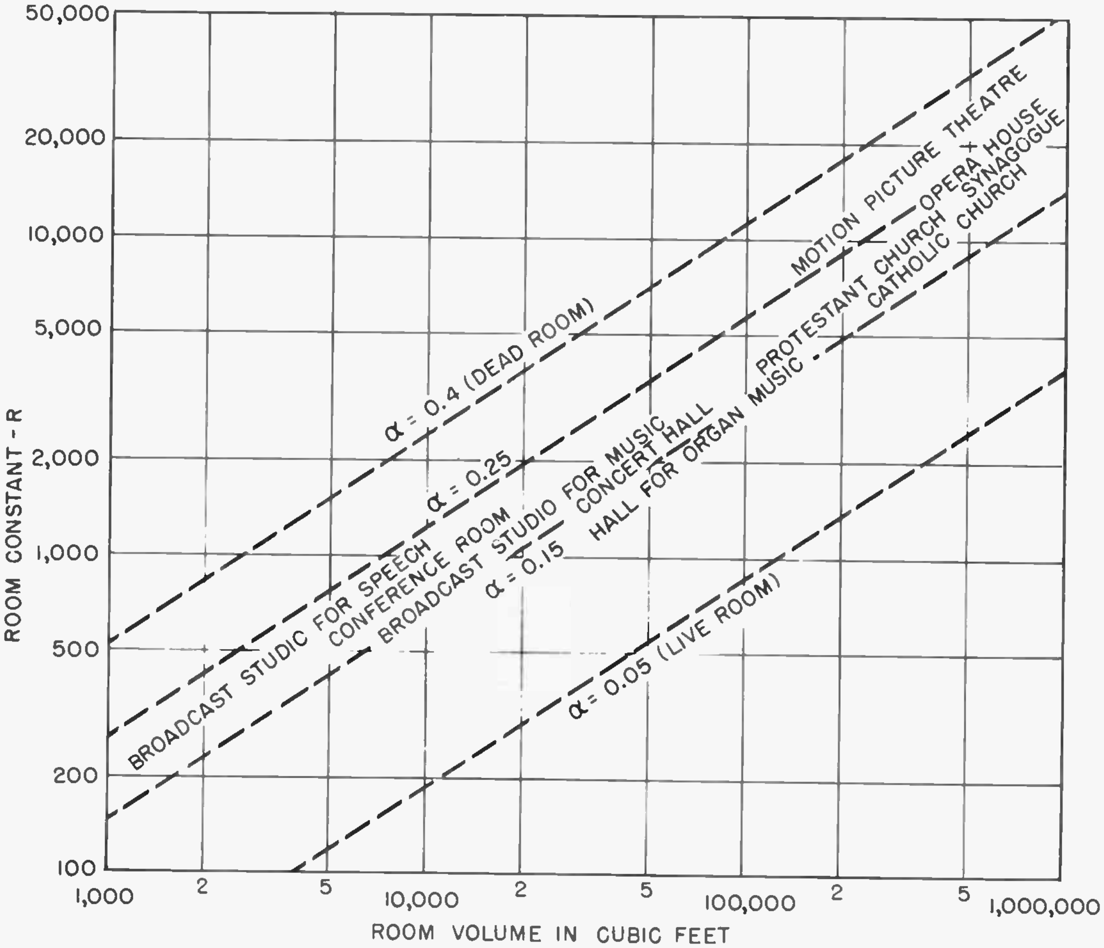


Figure 8-5. The relation between the room constant, R, and the volume of the room for four different values of the average absorption, α, in the room. For purposes of comparison, representative values of R for rooms used for various purposes are also shown. These values are indicated by placing the name at the level generally regarded as optimum acoustically for that class of service. Thus a broadcast studio used for music is usually designed to have a room constant of about 400 if it is as small as 5000 cubic feet or a room constant of about 5000 if it is as large as 100,000 cubic feet.

At frequencies above about 2000 cps, the sound absorption in the air in a very large room is often enough to affect the room constant appreciably. This absorption increases with frequency, and it is also a function of humidity. The absorption is a maximum at relative humidities in the range between 10 and 30 per cent. As an example of the extent of the effect, assume we have a room having a volume of 250,000 cubic feet. Then, at 6000 cps, air absorption alone could produce a room constant of up to about 10,000. Since the effective room constant thus produced varies approximately as the volume of the room, the effect in small, treated rooms is usually negligible.

8.332 Reverberant Field: The graphs of Figures 8-3 and 8-4 show that close to the source the sound-pressure level tends to vary with the distance from the source as it does outdoors under free-field conditions ($R = \infty$). But far from the source the sound-pressure level becomes independent of the directivity and the distance to the source. This region is called the reverberant field. Here the level is determined by the acoustic power radiated by the source and the acoustic characteristics of the room. The region over which the transition between the free-field behavior and the reverberant field occurs is determined by the directivity factor and the room constant.

The behavior in the reverberant-field region can be interpreted as follows: The boundaries of the room absorb all the acoustic energy radiated by the noise source. Then the average sound-pressure level near the walls is determined by the average absorption coefficient and the power level of the source. The relation is as follows:

$$SPL_R = PWL - 10 \log R + 6.5 \text{ db}$$

where SPL_R is the average sound-pressure level in the region where it is essentially independent of the distance to the source.

8.333 Sound-Pressure Level vs. Power Level in Room: The complete expression for the relation shown in Figures 8-3 and 8-4 is as follows:

$$SPL = \text{PWL} + 10 \log \left[\frac{Q}{4\pi r^2} + \frac{4}{R} \right] + 0.5 \text{ db}$$

In the derivation of the above formula it was assumed that the average absorption, α, was less than one-half, but when α approaches unity (complete absorption) the formula is again valid. This restriction on the range of α is of little practical concern, however, because in general only special measurement rooms have an average absorption greater than one-half. As implied previously, the equation was derived for sound fields in large, irregular rooms. (See Section 8.32)

8.4 MEASUREMENT PROCEDURE

The source characteristics are obtained by using the principles discussed in the previous sections of this chapter. In general, we need to be able to determine the following characteristics:

(1) The total sound power radiated by the source, as expressed by the power level, as a function of frequency.
(2) The directional characteristics of the source, as expressed by the directivity factor, as a function of direction and frequency.

8.41 Measurement Positions

8.411 Measurements Around the Source: If free-field conditions can be closely approximated, the power level and directivity can be calculated from the sound-pressure levels measured at a number of points. These measurements are made at points at equal distances from the source and all around the source. These points can be pictured as being on the surface of a hypothetical sphere surrounding the source. The radius of this sphere should be at least 3 to 4 times the largest dimension of the source; and, also, the radius should exceed the wave length that corresponds to the lowest noise frequency of interest.

Fundamentally, the sound-pressure level over the entire surface of this sphere should be explored. The practical procedure for approximating this exploration is to select a number of points on the sphere at which the basic measurement data is to be taken. Areas on the sphere are then associated with these points. These areas have the measuring points as their centers, and the extent of each area is determined by the nearness of the other measuring points. In the process of making the basic measurements, the variation in sound-pressure level over the associated areas should be determined by moving the microphone so that the full area is explored.

If the variations in sound-pressure level in any particular area are greater than 2 db, say, it is advisable to select a number of additional measuring points in that area. If, however, no attempt is being made to obtain an accurate picture of the directivity pattern, the extent of the variation in the area can be noted. Then, provided the variation in level is less than 6 db, the average level can be used as a representative value for the area.

8.412 Uniformly Distributed Measuring Points: The calculations for the radiated power are simplified if the basic measuring points are uniformly distributed on the surface of the sphere. Because of the nature of the geometrical pattern, however, only six such sets of points are possible. These six sets have 2, 4, 6, 8, 12, and 20 uniformly distributed points. The locations for the sets of 8, 12 and 20 points are shown in Figures 8-6, 8-7, and 8-8. A particular orientation of the points has been selected, and a different orientation may be found desirable for some particular applications. The areas associated with the 8, 12, and 20 points are regular spherical triangles, regular spherical pentagons, and regular spherical triangles, respectively.

8.413 Hemispherical Measurements: When the device to be tested is normally mounted on a concrete foundation or the ground, it is frequently desirable to test it when mounted that way. Then the sound-pressure level measurements should be made at points on a hypothetical hemisphere surrounding the source. The sets of points that lead to simple calculations of power level are now modified. A set of 4 points (one-half the set of 8) can be properly used, and a set of 6 points (which corresponds to the 12 for the sphere) can be used even though the set is not exactly uniformly distributed. A set of 12 can also be used, but then 4 of the set must be weighted by a factor of one-half (or, three db is subtracted from the level at these four points). (See Figure 8-8)

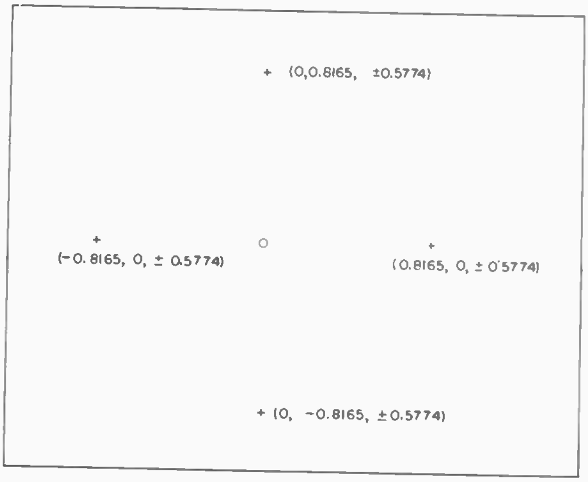


Figure 8-6.
Plan view of eight points uniformly distributed on a sphere of unit radius. Coordinates are given in terms of distances from center along three mutually perpendicular axes (x, y, z). The "±" sign refers to two points, one above the x-y reference plane and the other below. When measurements are to be made on a hemisphere, only the four points above the plane are used.

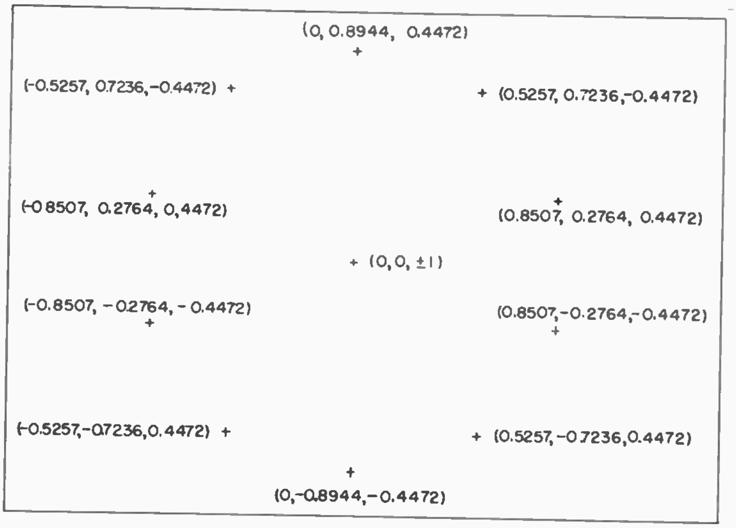


Figure 8-7.
Plan view of twelve points uniformly distributed on a sphere of unit radius. Coordinates are given as in the previous figure. When measurements are to be made on a hemisphere, only the six points above the x-y reference plane (positive values of z) are used.

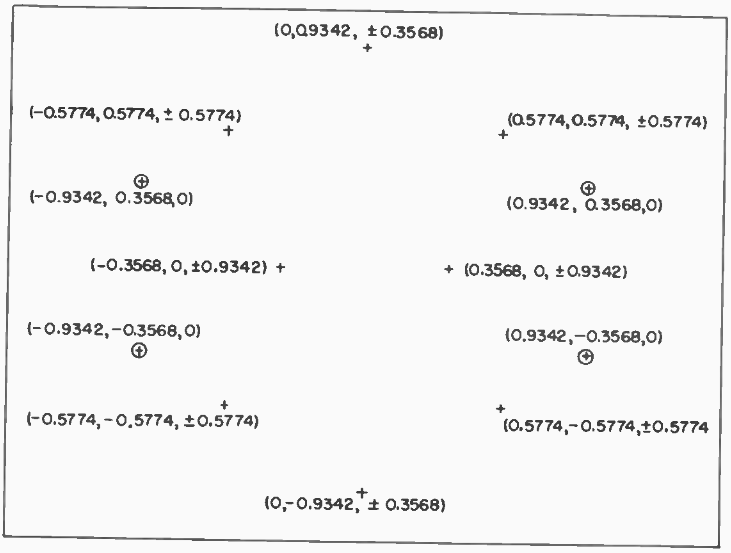


Figure 8-8.
Plan view of twenty points uniformly distributed on a sphere of unit radius. Coordinates are given as in Figure 8-6. When measurements are to be made on a hemisphere, twelve points are used, eight above the x-y reference plane and four in plane (z = 0, shown encircled). The four in the plane are weighted by a factor of ½ in power (see text).

When the hemisphere is used, the same procedure for calculating power level should be followed as described for the sphere in Section 8.42. But 3 decibels should be subtracted from the power level finally obtained, because the area of the hemisphere is just one-half that of the sphere.

8.42 Calculation of Power Level: If exploration shows that the basic set of points yield representative data, the calculations of power level and directivity factor can be made. For a uniformly distributed set of points, first, calculate the average level on a power basis. If the total range of sound-pressure levels is less than six decibels, a simple arithmetical average is usually adequate. The accurate method for any situation is as follows: Convert the decibel readings at each of the points of measurement to power ratios by using the tables in the Appendix. Add these power ratios. Convert back to a decibel level. Subtract a decibel value corresponding to a power ratio numerically equal to the number of levels used. (For 8, 12, and 20 readings, subtract 9, 10.8, and 13 db respectively.) The result is then the average level, which we shall call $\overline{SPL}$. Provided free-field conditions exist, the power level is then calculated from the equation.

$$PWL = \overline{SPL} + 20 \log r + 10.5 \text{ decibels}$$

where r is the radius in feet of the measuring sphere. As explained in Section 8.213, the sloping line labeled "OPEN AIR" in Figure 8-3 can alternatively be used for this calculation.

8.43 Calculation of Directivity Factor: After the average sound-pressure level, $\overline{SPL}$, has been determined, the directivity factor can also be calculated. If it is desired in a particular direction, the sound-pressure level on the measuring sphere corresponding to that direction, SPL_1, is measured. The difference between this particular level and the average level is called the directivity index, DI_1. Thus,

$$DI_1 = SPL_1 - \overline{SPL} \text{ decibels}$$

The directivity factor, Q, is obtained from the directivity index by converting the value in decibels into a power ratio by using the decibel tables in the Appendix. Thus, a directivity index of —2 decibels corresponds to a directivity factor of 0.63.

8.44 Effect of Room on Measurements: The space in which power level and directivity are to be determined must be carefully considered. Sometimes, the measurement can be made outdoors far from other objects. If the device under test is normally mounted on the ground, this outdoor measurement may be ideal, provided a location that is free from interfering objects and where the background noise level is sufficiently low can be used.

8.441 Requirements on Room Constant: If the measurement is to be made in a room, it should be a large room, and extensive acoustic treatment is usually necessary. Large acoustic absorption is particularly important if the directivity characteristics must be accurately determined. The graph of Figure 8-4 shows that for devices of moderate size, a room constant of over 20,000 is desirable. Even with the major part of the surfaces treated with good absorbing material, a room constant of this magnitude is obtained only in rooms having volumes of 100,000 cubic feet or more. (See Figure 8-5.) In order to obtain satisfactory results in smaller rooms, extraordinarily good acoustic treatment must be used. Many of these special measurement rooms have been built, and some of them have been described in the *Journal of the Acoustical Society of America.*

For most purposes, however, the situation is not so serious. Lack of adequate absorption in the room used for the measurements affects some aspects of the measurement more than it affects other aspects. For example, the greatest departure from free-field conditions is always observed in those directions where the least acoustic power is radiated, as a study of Figure 8-4 will indicate. Usually, an accurate measurement in those directions is not important, because their relative contributions to the total power radiated is not so much as for other directions. In addition, an approximate correction for the effects of the room can be made, as explained in Section 8.443.

The room constant need not be so large if only the acoustic power output is of interest. This situation exists if a noisy device is to be used in a large, reverberant room, and levels close to the source are not important. In order to make an accurate measurement of power in a room that is not heavily treated, however, it is necessary to know the room constant accurately.

Before any power measurement is attempted in a room, the room constant, R, which will be a function of frequency, should be calculated, as outlined previously in Section 8.331. Then the approximate effect of the room on the measurements can be judged from the curves of Figures 8-3 and 8-4. If the effect will be small, this calculated value can usually be used in making corrections for the effects as explained in Section 8.443. If the calculation shows that the departure from free-field conditions ($R=$) will be more than 2 or 3 db at the points of measurement, some consideration should be given to adding more acoustic treatment to the room.

If the room effect is large, it is usually desirable, for accurate determinations of power, to

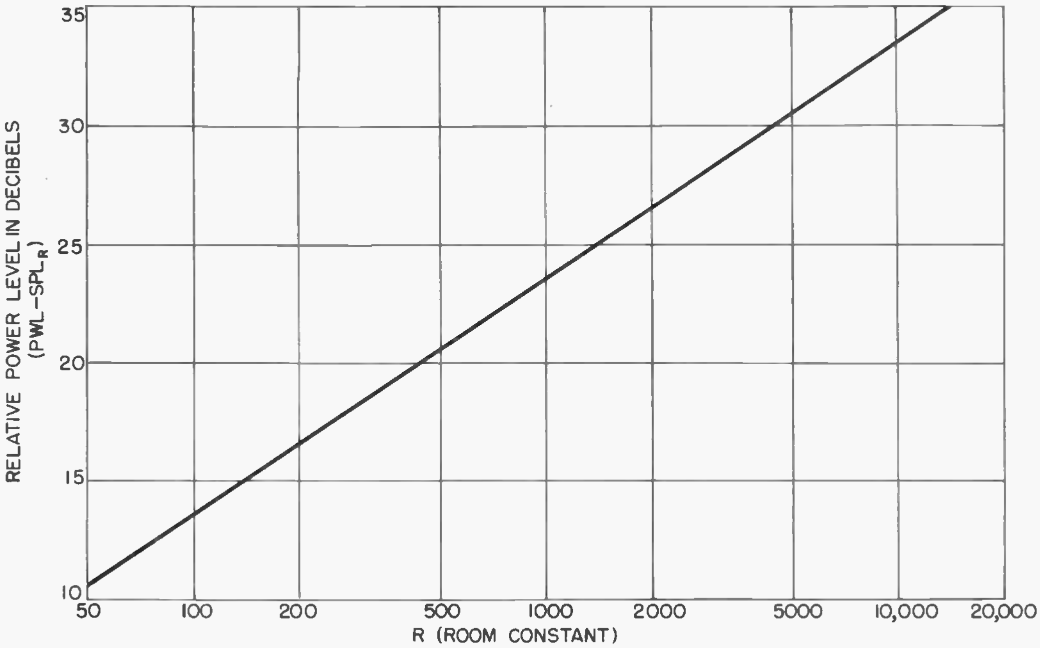


Figure 8-9. The power level (re 10^{-13} watt) of the source equals the sum of the measured sound-pressure level in the reverberant field and the ordinate corresponding to the room constant of the space in which the measurement was made.

make measurements to check the value of the room constant. One procedure for making this check requires the use of a small, non-directional source and consists of observing the rate of decay of sound-pressure level with distance from the source. Then the observed values are compared with the expected values of Figure 8-3.

8.442 Correction for Large Room Effect: If the room effect is so large that the measurements are made essentially in the reverberant field, the power level can be calculated from the equation given in Section 8.332, which is

$$PWL = SPL_R + 10 \log R - 6.5 \text{ db}$$

This relation is also shown on the graph of Figure 8-9, and this graph can be used for making the calculation. The value of R measured at the frequency or band of frequencies at which the sound-pressure level measurements were made should be used here.

Under idealized conditions the sound-pressure level in the reverberant field is independent of the position of the measurement, and then one measurement should be adequate. Actually, a number of measurements around the source should be made in the reverberant field. These measurements are then averaged as follows: If the range of values is less than 6 decibels, the average decibel value is taken. If the range is more than 6 decibels, a value 3 decibels below the maximum value is taken. If, however, the maximum value is unusually high compared to the other measurements, a further survey should be made to see whether or not it is so far out of line that it should be ignored. The averaged sound-pressure level is then used for SPL_R in the above equation.

The variations in level in the reverberant field are not a result of the directivity pattern of the source. As explained before, calculation of the directivity pattern from measurements made in the reverberant field is not possible.

8.443 Correction for Moderate Room Effect: If the expected difference between the measurements in a room and what would be obtained in a free field is less than about 5 db, the following method is suggested for correcting for the effect of the room.

The average sound-pressure level $\overline{SPL}$ is determined as described in Section 8.42. Then the approximate directivity factor is calculated for each measured point as if the measurements were made in a free field. Then the difference between free-field conditions and those for the given room constant are determined. This difference, $\Delta (SPL)$, is given by the equation

$$\Delta (SPL) = 10 \log \left[1 + \frac{16 \pi r^2}{QR} \right]$$

or the difference may be estimated from the graphs of Figures 8-3 and 8-4. The measured sound-pressure levels are corrected by using this difference to give an approximate equivalent free-field sound-pressure level. A new average is obtained by using these equivalent levels, and the process is repeated to obtain a better approximation. In each series of corrections it is important to note that the corrections are always applied to the measured sound-pressure levels. Usually only two series of these steps are necessary to arrive at a satisfactory set of corrected values. The final averaged equivalent free-field sound-pressure level, $(\overline{SPL})_{ff}$, is used in the equations of Section 8.42 to find the power level of the source. The directivity factor is also determined from the free-field equivalent levels by the method described in Section 8.43.

8.5 PREDICTING NOISE LEVELS

When we know the acoustic power level and the directivity pattern of a device, we can predict with fair accuracy the noise levels it will produce under a wide variety of conditions. The predictions are based on the principles discussed in Section 8.3.

If the noisy device is to be placed in a room, we must calculate the room constant (Section 8.331). Then we can use the equation of Section 8.333 or the graphs of Figure 8-3 and 8-4 for predicting the level. It should be noted, however, that these calculations assume that the room is large and irregular, and that the noise source is not close to any boundary of the room.

If the room is regular, with parallel walls and with few objects in the room, marked standing waves may occur. Then the actual level at a specific location may be quite different from the average level predicted by the equations. A very marked standing wave pattern may not be found, however. Often, there are many objects and irregularities in a room to diffuse the sound, and, the noisy device usually has many frequency components that help to smooth out the standing waves.

If the noise source is placed close to a room boundary, the levels near the source are somewhat different from those predicted by the methods of Section 8.3. This difference is a result of the effect of nearby large surfaces on the directivity pattern of the source. For example, a non-directional source mounted in the middle of a hard wall or floor has a directivity factor of 2; mounted in the middle of a corner, the factor is 4; and mounted in the corner at the floor or ceiling, the factor is 8. These simple examples should permit an estimate of the effects of the boundaries in many practical situations.

CHAPTER IX

NOISE CONTROL

9.1 INTRODUCTION

When the problem at hand is to reduce noise, we usually begin by measuring the noise spectrum to obtain the quantitative information that is helpful in doing something about the problem. We compare the measured noise levels with the acceptable levels, which are often estimated by using one of the criteria given in Chapter VII. The difference between these two levels is then the noise reduction necessary.

The next step is to find out how this noise reduction can be achieved most satisfactorily. A complete discussion of this problem is not possible in this handbook. But since many of those using this book are just beginning to work on noise problems, a few introductory statements on the subject will be made. Useful information on this subject will be found in books on architectural acoustics, in books on mechanical vibrations, in some books on acoustics in general, in some articles in the Journal of the Acoustical Society of America, and in some articles in various trade journals.

The general approach to noise reduction can be divided into two major parts as follows:

(1) Reduction of noise at its source.

(2) Reduction of noise level at the ear of the listener by changes in the path from the source.

9.2 CONTROL AT THE SOURCE

It is usually wise to see first if the noise can be reduced at the source. A different type of source might be selected. For example, a process might be changed so that parts are welded instead of riveted together. A source of different basic construction but of a similar type might be used. For example, a slower fan of many blades can sometimes be substituted for a high-speed two-bladed fan. Or, the construction of the particular source at hand might be modified, and this procedure will be discussed briefly.

When modification of a source is attempted, a decrease in the radiated power is usually the most important change that can be made. This reduction is usually achieved by reducing vibration amplitudes and by reducing the radiation of sound produced by the vibration. We can separate this problem into three sections as follows:

(1) Decrease the energy available for driving the vibrating system.

(2) Change the coupling between this energy and the acoustical radiating system.

(3) Change the structure that radiates the sound so that less is radiated.

In each of these sections it is usually helpful to track down the important sources of noise and the path of transmission by using frequency analysis of the sound and vibration. The effects of changes in the source, for example, speed, structure, and mounting, on the spectrum should also help in finding the important elements.

The sound energy may be reduced in a number of ways. If friction is the force producing the vibration, better lubrication may help to reduce it. But in some situations, adding friction or damping may absorb some of the energy in the vibration and thereby reduce it. Driven parts that fit poorly or that are badly worn may need correction or tightening. Usually, the speed of all parts should be kept as low as possible to achieve a low noise level. Air streams should be of low velocity to keep noise energy down. The use of structural materials, such as some plastics, with inherent vibration-damping qualities may be possible as another means of absorbing the energy.

Change in the coupling system frequently means the use of vibration isolation mounts. It may also mean decreased or even increased stiffness in some members transmitting the vibration. Or it may mean better fastening of some parts to massive, rigid members. Resonant structures are often troublesome coupling members. The resonance may be in the mechanical structure or in an air chamber. In either situation it is usually possible to shift the resonance by changes in the structure or to damp the resonance by adding absorbing material. Mufflers may be needed on exhaust or intake systems.

The changes in the radiating structure are often no more than reducing the external surface areas of the vibrating parts as much as possible. It may be posible to put holes in the radiating member to reduce the efficiency of radiation. Less stiffness of the part may help to reduce radiated sound by permitting sections to vibrate in different time patterns. Large surfaces near the vibrating parts should also be avoided, since these surfaces may increase the radiating efficiency of the vibrating parts.

Another possible way of modifying the source to improve the noise situation is to change the directivity pattern of the radiated sound. When streams of air or other gases come out of an opening, they radiate sound that may be highly directional at high frequencies. Changing the direction of flow can shift this pattern. It may be posible to direct it in such a way that noise in certain directions is considerably reduced.

9.3 CONTROL OF THE PATH OF SOUND

The control of the noise by changes in the path of the sound can be analyzed into three sections as follows:

(1) Change in relative position of source and listener.

(2) Change in acoustic environment.

(3) Introduction of attenuating structures between source and listener.

9.31 Changes in position: Increasing the distance between the noise source and the listener is often a practical method of noise control. Furthermore, merely rotating the source of noise may permit one to decrease the level if a change to a direction of low directivity factor is achieved. Both these procedures are effective only in the region where approximately free-field conditions exist. (See Section 8.33)

9.32 Change in Environment: The most obvious change that can be made in a room to reduce the noise level is to add acoustical absorbing material. A wide variety of commercial acoustical materials are available. These materials are often of great value in a noise reduction program, but the limitations of this treatment should be realized. These materials are mainly useful in the room where the noise originates, and there they help mainly to reduce the noise level at some distance from the source. The benefit that can be obtained by adding acoustic absorption can readily be estimated by the methods given in Section 8.33. The curves of Figure 8-3 show that at large distances a large reduction in level can be obtained by adding absorbing material if the room is originally "live." But at the same time not much reduction is obtained at a distance of 3 feet, say, which is a common distance between a machine and the operator's ear.

9.33 Attenuating Structures: A number of different types of attenuating structures are used for reducing the noise level for the listener. One of these is an ear defender, which may be an ear plug, waxed cotton, or earmuffs. Others are walls, barriers, and total enclosures. Almost any degree of reduction of air-borne sound can be achieved by a total enclosure or a combination of several enclosures. But as the required attenuation increases so does the complexity, weight, and cost. In addition, great care must be taken that the attenuation gained by the enclosure is not lost by sound transmission through a ventilating duct or by solid-borne vibration. Because of this possible flanking transmission in ventilating systems total enclosures frequently require carefully designed ventilating systems with ducts lined with absorbing material. These lined ducts are essentially mufflers for the air stream.

When a door is required in a total enclosure, it should be built with air-tight seals at all joints. A refrigerator-type door is usually satisfactory when it can be used. A total enclosure should also be lined at least on part of the inside walls with absorbing material. This lining helps to keep the noise at the walls of the enclosure at the lowest practical level.

A barrier is not as effective as a total enclosure, but it does help to shield high-frequency sound. Little attenuation of low-frequency sound is obtained unless the barriers are very large, and the attenuation of high-frequency sound is usually only a few decibels unless the opening that remains is relatively small. Here, too, absorbing material should cover the barrier to avoid exaggerating the level by reflections from the barrier.

9.34 Illustrative Example: In order to illustrate the possible noise reduction achieved by using vibration isolation, barriers, enclosures, and acoustic treatment, an example made up for the purpose is shown in a series of figures, Figures 9-1 to 9-8. We intend to show here only the general nature of the noise reduction obtainable as given by changes in the octave-band spectrum and the speech-interference level (Section 7.3). Actual results will vary in detail, and situations do occur where the results differ materially from those shown because of factors not considered here. But, in general, the noise reduction shown in the figures can be considered typical.

Figure 9-1 shows the octave-band analysis of the noise from the assumed machine. The speech-interference level is also shown. This machine is a noisy one with a spectrum that shows appreciable noise energy all over the audible range. All the noise measurements are assumed to be made in the relative position shown for the microphone designated M on the figures.

The use of vibration isolation mounts may be an important step in noise control. As shown in Figure 9-2, the initial result, however, is often only a moderate reduction of the low-frequency noise. The machine itself usually radiates most of the high-frequency noise directly to the air, and the amount radiated by the floor is small. A reduction in the vibration level at the floor only is then not important at high frequencies. At low frequencies, however, the machine may be too small to be effective in radiating sound, and then the floor may act as a sounding board to contribute materially to low-frequency sound radiation.

It is even possible to increase the noise as a result of the use of vibration mounts. This result is usually found when the stiffness of the mounting is of such a value that some vibration mode is exaggerated by resonance, but resonance can be avoided by proper design of the mounting. In the illustrative example it is assumed that the mounting is sufficiently soft that the basic vibration resonance of the machine on the mounting system is below 20 cps. In this particular example no significant change in the speech-interference level is shown as a result of the use of vibration isolation mounts alone.

The results shown in Figure 9-3 illustrate that a barrier is mainly effective at high frequencies, and there it produces only a moderate reduction in noise level.

The novice in this field sometimes assumes that the materials used for sound absorption can also be used alone for sound isolation. If we build an enclosure solely of these materials mounted on a light framework, we would typically find the result shown in Figure 9-4. Only at high frequencies do we have a noticeable reduction in level, and even there it is a small reduction.

A more satisfactory enclosure is built of more massive and rigid constructional materials. Assume that we enclose the machine by a well-sealed, heavy, plasterboard structure. Then we might observe the result shown in Figure 9-5. Here an appreciable reduction is obtained over the middle and high-frequency range. The enclosure is not as effective as it might be, however, because two important factors limit the reduction obtained. First, the vibration of the machine is carried by the supports to the floor and then to the whole enclosure. This vibration then may result in appreciable noise radiation. Second, the side walls of the enclosure absorb only a small percentage of the sound energy.

The addition of a suitable vibration isolation mounting will reduce the noise transmitted by solid-borne vibration. This effect is illustrated in Figure 9-6. Here we see a noticeable improvement over most of the audio spectrum.

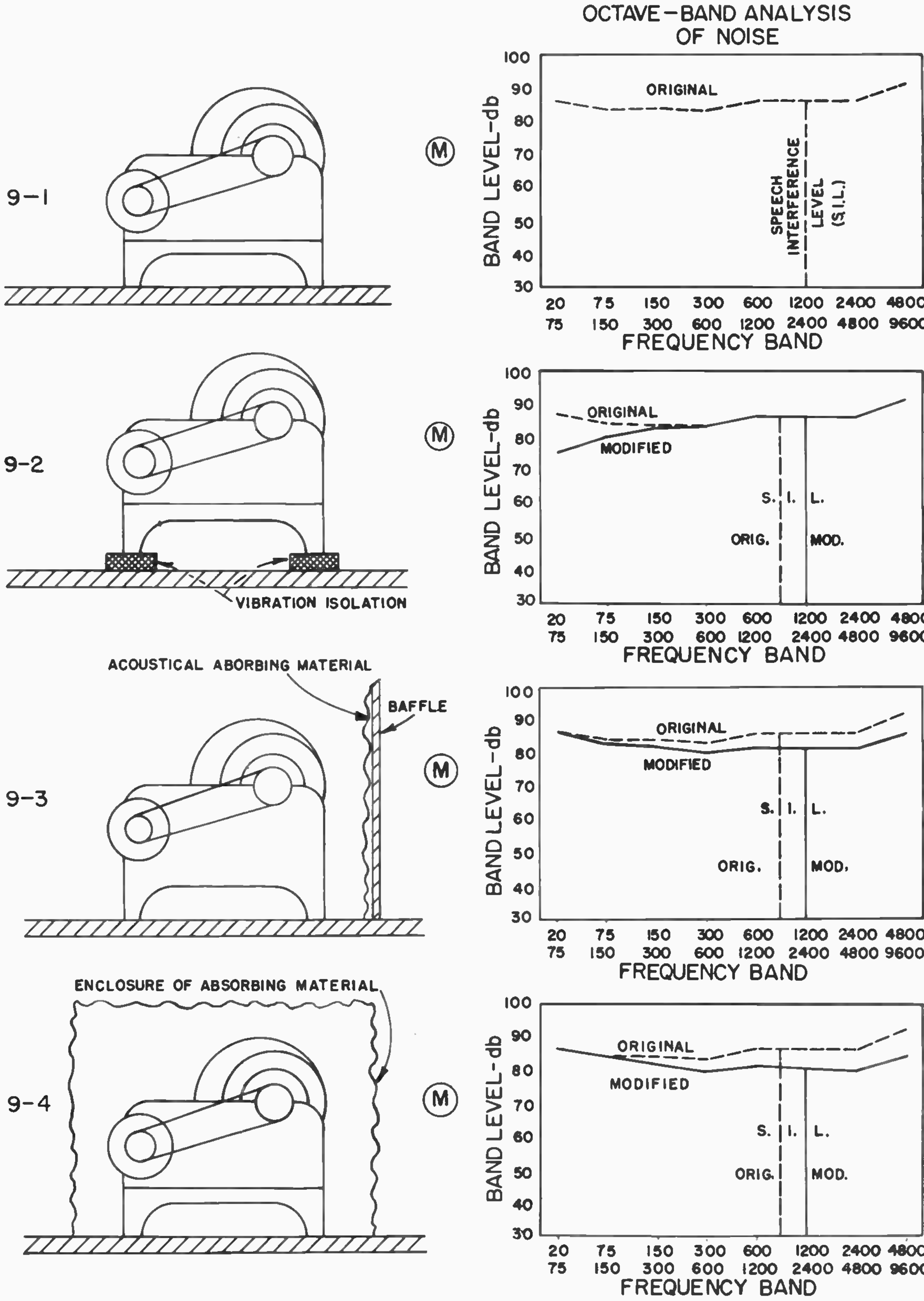
When the sound absorption within an enclosure is small, the noise energy from the machine produces a high level within the enclosure. Then the attenuation of the enclosure operates from this initial high level. The level within the enclosure can usually be reduced by adding some sound absorbing material within the enclosure, with the result that the level outside the enclosure is also reduced. This effect is shown in Figure 9-7, which should be compared with Figure 9-6.

If even more noise reduction is required than that obtained by the one enclosure, a second, lined, well-sealed enclosure can be built around the first. The first enclosure is supported within the second on soft, vibration mounts. Then a noise reduction of the magnitude shown in Figure 9-8 can be obtained.

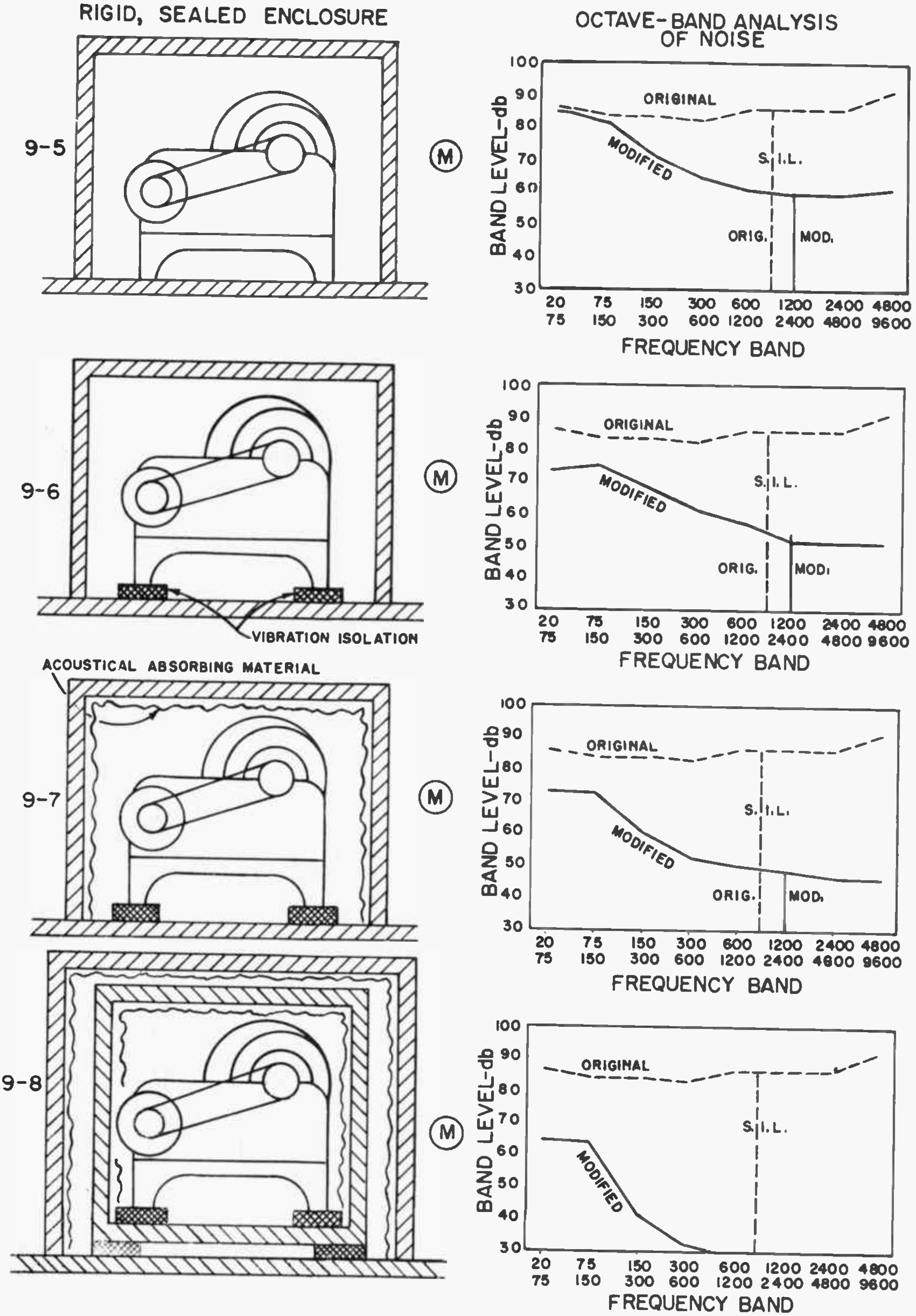
9.4 SUMMARY

The approach to a noise reduction problem can be summed up as follows:

(1) Consider the source.
   Can a quieter machine be substituted?
   Can the noise energy be reduced?
   Can a useful change be made in the directivity pattern?
   Are resilient mounts of any use here?
   Can a muffler be used?
(2) Consider the path from the source to the listener.
   Can the source or the listener be readily moved to reduce the level?
   Is acoustic treatment a useful solution?
   Should barriers be erected?
   Is a total enclosure required?



Figures 9-1 to 9-4. Examples to illustrate the possible noise reduction effects of some noise control measures.



Figures 9-5 to 9-8. Examples to illustrate the noise reduction possible by the use of enclosures.

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DEFINITIONS

This section on definitions includes most of the technical terms used in this handbook. Most of the definitions are taken from the American Standard Acoustical Terminology (Z24.1-1951), and those definitions are marked with an asterisk. Some of the others have been prepared especially for this handbook, and the remainder have been adapted from definitions in Beranek's *Acoustic Measurements* and the second volume of the *Handbook of Acoustic Noise Control*[†].

A number of these definitions are very technical in order to be precise. Some readers may then find it easier to refer to the discussion in the main text of this handbook for obtaining a general understanding of some of these terms.

Absorption Coefficient

Absorption coefficient for a surface is the ratio of the sound energy absorbed by a surface of a medium (or material) exposed to a sound field (or to sound radiation) to the sound energy incident on the surface. The stated values of this ratio are to hold for an infinite area of the surface. The conditions under which the measurements of the absorption coefficient are made are to be stated explicitly with all reported values.

Analyzer

An analyzer is a combination of a filter system and a system for indicating the relative energy which is passed through the filter system. The filter is usually adjustable so that the signal applied to the filter can be measured in terms of the relative energy passed through the filter as a function of the adjustment of the filter response-vs-frequency characteristic. This measurement is usually interpreted as giving the distribution of energy of the applied signal as a function of frequency.

Audiogram (Threshold Audiogram)*

An audiogram is a graph showing hearing loss, percent hearing loss, or percent hearing as a function of frequency.

Audiometer*

An audiometer is an instrument for measuring hearing acuity. Measurements may be made with speech signals, usually recorded, or with tone signals.

Note: Specifications for pure tone audiometer for general diagnostic purposes are covered by American Standard Specifications for Audiometers for General Diagnostic Purposes, Z24.5-1951, or the latest revision thereof approved by the American Standards Association, Incorporated.

Baffle*

A baffle is a shielding structure or partition used to increase the effective length of the external transmission path between two points in an acoustic system as, for example, between the front and back of an electroacoustic transducer.

Dead Room*

A dead room is a room which is characterized by an unusually large amount of sound absorption.

Decibel (db)

The decibel is a dimensionless unit for expressing the ratio of two powers. The number of decibels is 10 times the logarithm to the base 10 of the power ratio. With W_1 and W_2 designating two powers, or two intensities, and *n* the number of decibels corresponding to their ratio,

$$n \text{ (in db)} = 10 \log_{10} \frac{W_1}{W_2}$$

When the impedances are such that ratios of pressures are the square roots of the corresponding power ratios or intensity ratios, the number of decibels by which the corresponding powers or intensities differ is expressed by:

$$n = 20 \log_{10} \frac{P_1}{P_2}$$

where p_1/p_2 is the given pressure ratio.

Directivity Factor*

The directivity factor of a transducer used for sound emission is the ratio of the intensity of the radiated sound at a remote point in a free field on the principal axis to the average

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[†] W. A. Rosenblith and K. N. Stevens, Vol. II, *Noise and Man*, June, 1953, PB111274, WADC Technical Report 52-24, Office of Technical Services, U. S. Department of Commerce, Washington 25, D.C.

intensity of the sound transmitted through a sphere passing through the remote point and concentric with the transducer. The frequency must be stated.

Note 1: The point of observation must be sufficiently remote from the transducer for spherical divergence to exist.

Note 2: This definition may be extended to cover the case of finite frequency bands whose spectrum must be specified.

Directivity Index* (Directional Gain)
The directivity index of a transducer is an expression of the directivity factor in decibels, viz, 10 times the logarithm to the base 10 of the directivity factor.

Earphone (Receiver)*
An earphone is an electroacoustic transducer intended to be closely coupled acoustically to the ear.

Note: The term "receiver" should be avoided when there is risk of ambiguity.

Effective Sound Pressure (Root-Mean-Square Sound Pressure)*
The effective sound pressure at a point is the root-mean-square value of the instantaneous sound pressures, over a time interval at the point under consideration. In the case of periodic sound pressures, the interval must be an integral number of periods or an interval long compared to a period. In the case of non-periodic sound pressures, the interval should be long enough to make the value obtained essentially independent of small changes in the length of the interval.

Note: The term "effective sound pressure" is frequently shortened to "sound pressure."

Filter
A filter is a device for separating components of a signal on the basis of their frequency. It allows components in one or more frequency bands to pass relatively unattenuated, and it attenuates greatly components in other frequency bands.

Free Field*
A free field is a field (wave or potential) in a homogeneous, isotropic medium free from boundaries. In practice it is a field in which the effects of the boundaries are negligible over the region of interest.

Note: The actual pressure impinging on an object (e.g., electro-acoustic transducer) placed in an otherwise free sound field will differ from the pressure which would exist at that point with the object removed, unless the acoustic impedance of the object matches the acoustic impedance of the medium.

Frequency (in cycles per second, or cps)
Frequency is the time rate of repetition of a periodic phenomenon. The frequency is the reciprocal of the period

Hearing Loss (Deafness)*
The hearing loss of an ear at a specified frequency is the ratio, expressed in decibels, of the threshold of audibility for that ear to the normal threshold. (See, also, American Standard Specification for Audiometers for General Diagnostic Purposes, Z24.5-1951, or the latest revision thereof approved by the American Standards Association, Incorporated.)

Live Room*
A live room is a room which is characterized by an unusually small amount of sound absorption.

Loudness*
Loudness is the intensive attribute of an auditory sensation, in terms of which sounds may be ordered on a scale extending from soft to loud.

Note: Loudness depends primarily upon the sound pressure of the stimulus, but it also depends upon the frequency and wave form of the stimulus.

Loudness Contours*
Loudness contours are curves which show the related values of sound pressure level and frequency required to produce a given loudness sensation for the typical listener.

Loudness Level*
The loudness level, in phons, of a sound is numerically equal to the sound pressure level in decibels, relative to 0.0002 microbar, of a simple tone of frequency 1000 cycles per second which is judged by the listeners to be equivalent in loudness.

Loudspeaker (Speaker)*
A loudspeaker is an electroacoustic transducer usually intended to radiate acoustic power effectively at a distance in air.

Note: The term "speaker" should be avoided when there is risk of ambiguity.

Masking*
Masking is the amount by which the threshold of audibility of a sound is raised by the presence of another (masking) sound. The unit customarily used is the decibel.

Mel*
The mel is a unit of pitch. By definition, a simple tone of frequency 1000 cycles per second, 40 decibels above a listener's threshold, produces a pitch of 1000 mels. The pitch of any sound that is judged by the listener to be n times that of a 1-mel tone is n mels.

Microbar, Dyne Per Square Centimeter*
A microbar is a unit of pressure commonly used in acoustics. One microbar is equal to 1 dyne per square centimeter.

Note: The term "bar" properly denotes a pressure of 10^6 dynes per square centimeter. Unfortunately, in acoustics the bar was used to mean 1 dyne per square centimeter. It is recommended, therefore, in respect to sound pressures that the less ambiguous terms "microbar" or "dyne per square centimeter" be used.

Microphone*

A microphone is an electroacoustic transducer which responds to sound waves and delivers essentially equivalent electric waves.

Minimum Audible Field

The minimum audible field is the threshold of audibility when the sound is presented to the listener as a freely traveling plane wave and the sound pressure in the plane progressive wave is measured at the position of the center of the listener's head before the listener enters the sound field.

Noise*

Noise is any undesired sound. By extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in any transmission channel or device.

Noise Level*

Noise level is the value of noise integrated over a specified frequency range with a specified frequency weighting and integration time. It is expressed in decibels relative to a specified reference.

Note: In air the acoustical noise level is usually measured with a sound-level meter (see American Standard Sound Level Meters for Measurement of Noise and Other Sounds, Z24.3-1944, or the latest revision thereof approved by the American Standards Association, Incorporated), and hence is the same as the sound level of the noise. For special purposes other measuring techniques are used and must be specified.

Octave*

An octave is the interval between two sounds having a basic frequency ratio of two. By extension, the octave is the interval between any two frequencies having the ratio 2:1.

Note: The interval, in octaves, between any two frequencies is the logarithm to the base two (or 3.322 times the logarithm to the base 10) of the frequency ratio.

Oscillation (Vibration)*

Oscillation is the variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than the reference.

Period (Primitive Period)*

The period of a periodic quantity is the smallest value of the increment of the independent variable for which the function repeats itself.

Phon*

The phon is the unit of loudness level. (See Loudness Level.)

Pitch*

Pitch is that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high, such as a musical scale.

Note 1: Pitch depends primarily upon the frequency of the sound stimulus, but it also depends upon the sound pressure and wave form of the stimulus.

Note 2: The pitch of a sound may be described by the frequency of that simple tone, having a specified sound pressure or loudness level, which seems to the average normal ear to produce the same pitch.

Point Source

See "Simple Sound Source."

Power Level

Power level is the ratio, expressed in decibels, of the total acoustic power (W) in watts to a reference power P_{ref}. Thus:

$$PWL = 10 \log_{10} (W/P_{ref})$$

P_{ref} is taken as a 1.0×10^{-13} watt in this handbook.

Presbycusis

Presbycusis is the condition of hearing loss specifically associated with old age.

Pressure Spectrum Level*

The pressure spectrum level of a sound at a specified frequency is the effective sound pressure level for the sound energy contained within a band 1 cycle per second wide, centered at the specified frequency. Ordinarily this has significance only for sound having a continuous distribution of energy within the frequency range under consideration. The reference pressure should be explicitly stated.

Pure Tone

See "Simple Tone."

Random Noise

Random noise is a noise whose instantaneous amplitudes as a function of time occur according to a normal (Gaussian) distribution curve.

Response*

The response of a device or system is a quantitative expression of the output as a function of the input under conditions which must be explicitly stated. The response characteristic, often presented graphically, gives the response as a function of some independent variable such as frequency or direction.

Note: Modifying phrases must be prefixed to the term "response" to indicate explicitly what measure of the output or of the input is being utilized.

Reverberation*

Reverberation is the persistence of sound at a given point after direct reception from the source has stopped.

Note: This may be due (a) (as in the case of rooms) to repeated reflections from a small number of boundaries or to the free decay of the normal modes of vibration that were excited by the sound source, (b) (as in the case of underwater sound in the ocean) to scattering from a large number of inhomogeneities in the medium or reflection from bounding surfaces.

Room Constant

Room constant is the name given to the expression $\alpha S/1-\alpha$, where S is the total area of the bounding surfaces of the room in square feet, and α is the average absorption coefficient of the absorption present in the room.

Sabin (Square Foot Unit of Absorption)*

A sabin is a measure of the sound absorption of a surface. It is the equivalent of 1 square foot of a perfectly absorptive surface.

Simple Sound Source*

A simple sound source is a source which radiates sound uniformly in all directions under free-field conditions.

Simple Tone (Pure Tone)*

(a) A simple tone is a sound wave, the instantaneous sound pressure of which is a simple sinusoidal function of the time.

(b) A simple tone is a sound sensation characterized by its singleness of pitch.

Sone*

The sone is a unit of loudness. By definition, a simple tone of frequency 1000 cycles per second, 40 decibels above a listener's threshold, produces a loudness of 1 sone. The loudness of any sound that is judged by the listener to be n times that of the 1-sone tone is n sones.

Note 1: A millisone is equal to 0.001 sone.

Note 2: The loudness scale is a relation between loudness and level above threshold for a particular listener. In presenting data relating loudness in sones to sound pressure level, or in averaging the loudness scales of several listeners, the thresholds (measured or assumed) should be specified.

Note 3: The term "loudness unit" has been used for the basic subdivision of a loudness scale based on group judgment on which a loudness level of 40 phons has a loudness of approximately 1000 loudness units. For example, see Figure 1 of American Standard for Noise Measurement, Z24.2-1942.

Sound*

A. Sound is an alteration in pressure, stress, particle displacement, particle velocity, etc., which is propagated in an elastic material, or the superposition of such propagated alterations.

B. Sound is also auditory sensation which is usually evoked by the alterations described above.

Note: In case of possible confusion, the term "sound wave" or "elastic wave" may be used for concept (a), and the term "sound sensation" for concept (b).

Sound Intensity (Specific Sound-Energy Flux) (Sound-Energy Flux Density)*

The sound intensity in a specified direction at a point is the average rate of sound energy transmitted in the specified direction through a unit area normal to this direction at the point considered. The commonly used unit is the erg per second per square centimeter, but sound intensity may also be expressed in watts per square centimeter.

Sound Level*

The sound level, at a point in a sound field, is the weighted sound pressure level determined in the manner specified in the American Standard Sound Level Meters for Measurement of Noise and Other Sounds, Z24.3-1944, or the latest revision thereof approved by the American Standards Association, Incorporated.

Note: The meter reading (in decibels) corresponds to a value of the sound pressure integrated over the audible frequency range with a specified frequency weighting and integration time.

Sound-Level Meter*

A sound-level meter is an instrument including a microphone, an amplifier, an output meter, and frequency weighting networks for the measurement of noise and sound levels in a specified manner; the measurements are intended to approximate the loudness level which would be obtained by the more elaborate ear balance method.

Note: Specifications for sound-level meters for measurement of noise and other sounds are given in American Standard Sound Level Meters for Measurement of Noise and Other Sounds, Z24.3-1944, or the latest revision thereof approved by the American Standards Association, Incorporated.

Sound Pressure Level*

The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure. The reference pressure shall be explicitly stated.

Note 1: The following reference pressures are in common use:

(a) 2 x 10^{-4} microbar
(b) 1 microbar

Reference pressure (a) has been in general use for measurements dealing with hearing and sound-level measurements in air and liquids, while (b) has gained widespread use for calibrations and many types of sound-level measurements in liquids.

[The reference pressure used in this handbook is 2 x 10^{-4} microbar.]

Note 2: It is to be noted that in many sound fields the sound pressure ratios are not the square roots of the corresponding power ratios and hence cannot be expressed in decibels in the strict sense; however, it is common practice to extend the use of the decibel to these cases.

Spectrum*

The spectrum of a wave is the distribution in frequency of the magnitudes (and sometimes phases) of the components of the wave. Spectrum also is used to signify a continuous range of frequencies, usually wide in extent, within which waves have some specified common characteristics, e.g., audio frequency spectrum, radio frequency spectrum, etc.

Speech Interference Level (SIL)

The speech interference level of a noise is the average, in decibels, of the sound pressure levels of the noise in the three octave bands of frequency 600-1200, 1200-2400 and 2400-4800 cps.

Standing Waves*

Standing waves are periodic waves having a fixed distribution in space which is the result of interference of progressive waves of the same frequency and kind. Such waves are characterized by the existence of nodes or partial nodes and antinodes that are fixed in space.

Threshold of Audibility (Threshold of Detectability)*

The threshold of audibility for a specified signal is the minimum effective sound pressure of the signal that is capable of evoking an auditory sensation in a specified fraction of the trials. The characteristics of the signal, the manner in which it is presented to the listener, and the point at which the sound pressure is measured must be specified.

Note 1: Unless otherwise indicated, the ambient noise reaching the ears is assumed to be negligible.

Note 2: The threshold may be expressed in decibels relative to 0.0002 microbar or to 1 microbar.

Note 3: Instead of the method of constant stimuli, which is implied by the phrase "a specified fraction of the trials," another psychophysical method (which should be specified) may be employed.

Threshold of Feeling (or Discomfort, Tickle, or Pain)*

The threshold of feeling (or discomfort, tickle, or pain) for a specified signal is the minimum effective sound pressure of that signal which, in a specified fraction of the trials, will stimulate the ear to a point at which there is the sensation of feeling (or discomfort, tickle, or pain).

Note 1: Characteristics of the signal and the measuring technique must be specified in every case.

Note 2: This threshold is customarily expressed in decibels relative to 0.0002 microbar or 1 microbar.

Tone*

(a) A tone is a sound wave capable of exciting an auditory sensation having pitch.

(b) A tone is a sound sensation having pitch.

Transducer*

A transducer is a device capable of being actuated by waves from one or more transmission systems or media and of supplying related waves to one or more other transmission systems or media.

Note: The waves in either input or output may be of the same or different types (e.g., electric, mechanical, or acoustic).

Transient Motion*

Transient motion is any motion which has not reached or has ceased to be a steady state.

Ultrasonics*

Ultrasonics is the general subject of sound in the frequency range above about 15 kilocycles per second.

Vibration

See "Oscillation."

White Noise

White noise is a noise whose spectrum is continuous and uniform as a function of frequency.

APPENDIX I Decibel Tables

APPENDIX II Catalog Section

DECIBEL CONVERSION TABLES

It is convenient in measurements and calculations on communications systems to express the ratio between any two amounts of electric or acoustic power in units on a logarithmic scale. The *decibel* (1/10th of the *bel*) on the briggsian or base-10 scale is in almost universal use for this purpose.

Table I and Table II on the following pages have been prepared to facilitate making conversions in either direction between the number of *decibels* and the corresponding power and pressure ratios.

Decibel—The number of decibels N_{db} corresponding to the ratio between two amounts of power P_1 and P_2 is

$$N_{db} = 10 \log_{10} \frac{P_1}{P_2} \qquad (1)$$

When two pressures E_1 and E_2 operate in the same or equal impedances,

$$N_{db} = 20 \log_{10} \frac{E_1}{E_2} \qquad (2)$$

TO FIND VALUES OUTSIDE THE RANGE OF CONVERSION TABLES

Values outside the range of either Table I or Table II on the following pages can be readily found with the help of the following simple rules:

TABLE I: DECIBELS TO PRESSURE AND POWER RATIOS

Number of decibels positive (+): Subtract +20 decibels successively from the given number of decibels until the remainder falls within range of Table I. *To find the pressure ratio,* multiply the corresponding value from the right-hand voltage-ratio column by 10 for each time you subtracted 20 db. *To find the power ratio,* multiply the corresponding value from the right-hand power-ratio column by 100 for each time you subtracted 20 db.

Example — *Given:* 49.2 db

49.2 db − 20 db − 20 db = 9.2 db

Pressure ratio: 9.2 db →

2.884 × 10 × 10 = 288.4

Power ratio: 9.2 db →

8.318 × 100 × 100 = 83180

Number of decibels negative (−): Add +20 decibels successively to the given number of decibels until the sum falls within the range of Table I. *For the pressure ratio,* divide the value from the left-hand pressure-ratio column by 10 for each time you added 20 db. *For the power ratio,* divide the value from the left-hand power-ratio column by 100 for each time you added 20 db.

Example — *Given:* −49.2 db

−49.2 db + 20 db + 20 db = −9.2 db

Pressure ratio: −9.2 db →

.3467 × 1/10 × 1/10 = .003467

Power ratio: −9.2 db →

.1202 × 1/100 × 1/100 = .00001202

TABLE II: PRESSURE RATIOS TO DECIBELS

For ratios smaller than those in table — Multiply the given ratio by 10 successively until the product can be found in the table. From the number of decibels thus found, subtract +20 decibels for each time you multiplied by 10.

Example—*Given:* Pressure ratio = .0131

.0131 × 10 = .131 × 10 = 1.31

From Table II, 1.31 →

2.345 db − 20 db − 20 db = −37.655 db

For ratios greater than those in table—Divide the given ratio by 10 successively until the remainder can be found in the table. To the number of decibels thus found, add +20 db for each time you divided by 10.

Example—*Given:* Pressure ratio = 712

712 × 1/10 = 71.2 × 1/10 = 7.12

From Table II, 7.12 →

17.050 db + 20 db + 20 db = 57.050 db

TABLE I

GIVEN: Decibels

TO FIND: Power and Pressure Ratios

TO ACCOUNT FOR THE SIGN OF THE DECIBEL

For positive (+) values of the decibel — Both pressure and power ratios are greater than unity. Use the two right-hand columns.

For negative (—) values of the decibel—Both pressure and power ratios are less than unity. Use the two left-hand columns.

Example—*Given:* ± 9.1 db. *Find:*

	Power Ratio	*Pressure Ratio*
+9.1 db	8.128	2.851
—9.1 db	0.1230	0.3508

← *—db+* →

Pressure Ratio	*Power Ratio*	*db*	*Pressure Ratio*	*Power Ratio*
1.0000	**1.0000**	**0**	**1.000**	**1.000**
.9886	.9772	.1	1.012	1.023
.9772	.9550	.2	1.023	1.047
.9661	.9333	.3	1.035	1.072
.9550	.9120	.4	1.047	1.096
.9441	.8913	.5	1.059	1.122
.9333	.8710	.6	1.072	1.148
.9226	.8511	.7	1.084	1.175
.9120	.8318	.8	1.096	1.202
.9016	.8128	.9	1.109	1.230
.8913	**.7943**	**1.0**	**1.122**	**1.259**
.8810	.7762	1.1	1.135	1.288
.8710	.7586	1.2	1.148	1.318
.8610	.7413	1.3	1.161	1.349
.8511	.7244	1.4	1.175	1.380
.8414	.7079	1.5	1.189	1.413
.8318	.6918	1.6	1.202	1.445
.8222	.6761	1.7	1.216	1.479
.8128	.6607	1.8	1.230	1.514
.8035	.6457	1.9	1.245	1.549
.7943	**.6310**	**2.0**	**1.259**	**1.585**
.7852	.6166	2.1	1.274	1.622
.7762	.6026	2.2	1.288	1.660
.7674	.5888	2.3	1.303	1.698
.7586	.5754	2.4	1.318	1.738
.7499	.5623	2.5	1.334	1.778
.7413	.5495	2.6	1.349	1.820
.7328	.5370	2.7	1.365	1.862
.7244	.5248	2.8	1.380	1.905
.7161	.5129	2.9	1.396	1.950
.7079	**.5012**	**3.0**	**1.413**	**1.995**
.6998	.4898	3.1	1.429	2.042
.6918	.4786	3.2	1.445	2.089
.6839	.4677	3.3	1.462	2.138
.6761	.4571	3.4	1.479	2.188
.6683	.4467	3.5	1.496	2.239
.6607	.4365	3.6	1.514	2.291
.6531	.4266	3.7	1.531	2.344
.6457	.4169	3.8	1.549	2.399
.6383	.4074	3.9	1.567	2.455
.6310	**.3981**	**4.0**	**1.585**	**2.512**
.6237	.3890	4.1	1.603	2.570
.6166	.3802	4.2	1.622	2.630
.6095	.3715	4.3	1.641	2.692
.6026	.3631	4.4	1.660	2.754
.5957	.3548	4.5	1.679	2.818
.5888	.3467	4.6	1.698	2.884
.5821	.3388	4.7	1.718	2.951
.5754	.3311	4.8	1.738	3.020
.5689	.3236	4.9	1.758	3.090
.5623	**.3162**	**5.0**	**1.778**	**3.162**
.5559	.3090	5.1	1.799	3.236
.5495	.3020	5.2	1.820	3.311
.5433	.2951	5.3	1.841	3.388
.5370	.2884	5.4	1.862	3.467
.5309	.2818	5.5	1.884	3.548
.5248	.2754	5.6	1.905	3.631
.5188	.2692	5.7	1.928	3.715
.5129	.2630	5.8	1.950	3.802
.5070	.2570	5.9	1.972	3.890
.5012	**.2512**	**6.0**	**1.995**	**3.981**
.4955	.2455	6.1	2.018	4.074
.4898	.2399	6.2	2.042	4.169
.4842	.2344	6.3	2.065	4.266
.4786	.2291	6.4	2.089	4.365
.4732	.2239	6.5	2.113	4.467
.4677	.2188	6.6	2.138	4.571
.4624	.2138	6.7	2.163	4.677
.4571	.2089	6.8	2.188	4.786
.4519	.2042	6.9	2.213	4.898
.4467	**.1995**	**7.0**	**2.239**	**5.012**
.4416	.1950	7.1	2.265	5.129
.4365	.1905	7.2	2.291	5.248
.4315	.1862	7.3	2.317	5.370
.4266	.1820	7.4	2.344	5.495
.4217	.1778	7.5	2.371	5.623
.4169	.1738	7.6	2.399	5.754
.4121	.1698	7.7	2.427	5.888
.4074	.1660	7.8	2.455	6.026
.4027	.1622	7.9	2.483	6.166
.3981	**.1585**	**8.0**	**2.512**	**6.310**
.3936	.1549	8.1	2.541	6.457
.3890	.1514	8.2	2.570	6.607
.3846	.1479	8.3	2.600	6.761
.3802	.1445	8.4	2.630	6.918
.3758	.1413	8.5	2.661	7.079
.3715	.1380	8.6	2.692	7.244
.3673	.1349	8.7	2.723	7.413
.3631	.1318	8.8	2.754	7.586
.3589	.1288	8.9	2.786	7.762
.3548	**.1259**	**9.0**	**2.818**	**7.943**
.3508	.1230	9.1	2.851	8.128
.3467	.1202	9.2	2.884	8.318
.3428	.1175	9.3	2.917	8.511
.3388	.1148	9.4	2.951	8.710
.3350	.1122	9.5	2.985	8.913
.3311	.1096	9.6	3.020	9.120
.3273	.1072	9.7	3.055	9.333
.3236	.1047	9.8	3.090	9.550
.3199	.1023	9.9	3.126	9.772

TABLE I (continued)

← −db+ →

Pressure Ratio	Power Ratio	db	Pressure Ratio	Power Ratio
.3162	.1000	10.0	3.162	10.000
.3126	.09772	10.1	3.199	10.23
.3090	.09550	10.2	3.236	10.47
.3055	.09333	10.3	3.273	10.72
.3020	.09120	10.4	3.311	10.96
.2985	.08913	10.5	3.350	11.22
.2951	.08710	10.6	3.388	11.48
.2917	.08511	10.7	3.428	11.75
.2884	.08318	10.8	3.467	12.02
.2851	.08128	10.9	3.508	12.30
.2818	.07943	11.0	3.548	12.59
.2786	.07762	11.1	3.589	12.88
.2754	.07586	11.2	3.631	13.18
.2723	.07413	11.3	3.673	13.49
.2692	.07244	11.4	3.715	13.80
.2661	.07079	11.5	3.758	14.13
.2630	.06918	11.6	3.802	14.45
.2600	.06761	11.7	3.846	14.79
.2570	.06607	11.8	3.890	15.14
.2541	.06457	11.9	3.936	15.49
.2512	.06310	12.0	3.981	15.85
.2483	.06166	12.1	4.027	16.22
.2455	.06026	12.2	4.074	16.60
.2427	.05888	12.3	4.121	16.98
.2399	.05754	12.4	4.169	17.38
.2371	.05623	12.5	4.217	17.78
.2344	.05495	12.6	4.266	18.20
.2317	.05370	12.7	4.315	18.62
.2291	.05248	12.8	4.365	19.05
.2265	.05129	12.9	4.416	19.50
.2239	.05012	13.0	4.467	19.95
.2213	.04898	13.1	4.519	20.42
.2188	.04786	13.2	4.571	20.89
.2163	.04677	13.3	4.624	21.38
.2138	.04571	13.4	4.677	21.88
.2113	.04467	13.5	4.732	22.39
.2089	.04365	13.6	4.786	22.91
.2065	.04266	13.7	4.842	23.44
.2042	.04169	13.8	4.898	23.99
.2018	.04074	13.9	4.955	24.55
.1995	.03981	14.0	5.012	25.12
.1972	.03890	14.1	5.070	25.70
.1950	.03802	14.2	5.129	26.30
.1928	.03715	14.3	5.188	26.92
.1905	.03631	14.4	5.248	27.54
.1884	.03548	14.5	5.309	28.18
.1862	.03467	14.6	5.370	28.84
.1841	.03388	14.7	5.433	29.51
.1820	.03311	14.8	5.495	30.20
.1799	.03236	14.9	5.559	30.90
.1778	.03162	15.0	5.623	31.62
.1758	.03090	15.1	5.689	32.36
.1738	.03020	15.2	5.754	33.11
.1718	.02951	15.3	5.821	33.88
.1698	.02884	15.4	5.888	34.67
.1679	.02818	15.5	5.957	35.48
.1660	.02754	15.6	6.026	36.31
.1641	.02692	15.7	6.095	37.15
.1622	.02630	15.8	6.166	38.02
.1603	.02570	15.9	6.237	38.90

← −db+ →

Pressure Ratio	Power Ratio	db	Pressure Ratio	Power Ratio
.1585	.02512	16.0	6.310	39.81
.1567	.02455	16.1	6.383	40.74
.1549	.02399	16.2	6.457	41.69
.1531	.02344	16.3	6.531	42.66
.1514	.02291	16.4	6.607	43.65
.1496	.02239	16.5	6.683	44.67
.1479	.02188	16.6	6.761	45.71
.1462	.02138	16.7	6.839	46.77
.1445	.02089	16.8	6.918	47.86
.1429	.02042	16.9	6.998	48.98
.1413	.01995	17.0	7.079	50.12
.1396	.01950	17.1	7.161	51.29
.1380	.01905	17.2	7.244	52.48
.1365	.01862	17.3	7.328	53.70
.1349	.01820	17.4	7.413	54.95
.1334	.01778	17.5	7.499	56.23
.1318	.01738	17.6	7.586	57.54
.1303	.01698	17.7	7.674	58.88
.1288	.01660	17.8	7.762	60.26
.1274	.01622	17.9	7.852	61.66
.1259	.01585	18.0	7.943	63.10
.1245	.01549	18.1	8.035	64.57
.1230	.01514	18.2	8.128	66.07
.1216	.01479	18.3	8.222	67.61
.1202	.01445	18.4	8.318	69.18
.1189	.01413	18.5	8.414	70.79
.1175	.01380	18.6	8.511	72.44
.1161	.01349	18.7	8.610	74.13
.1148	.01318	18.8	8.710	75.86
.1135	.01288	18.9	8.811	77.62
.1122	.01259	19.0	8.913	79.43
.1109	.01230	19.1	9.016	81.28
.1096	.01202	19.2	9.120	83.18
.1084	.01175	19.3	9.226	85.11
.1072	.01148	19.4	9.333	87.10
.1059	.01122	19.5	9.441	89.13
.1047	.01096	19.6	9.550	91.20
.1035	.01072	19.7	9.661	93.33
.1023	.01047	19.8	9.772	95.50
.1012	.01023	19.9	9.886	97.72
.1000	.01000	20.0	10.000	100.00

← −db+ →

Pressure Ratio	Power Ratio	db	Pressure Ratio	Power Ratio
3.162×10^{-1}	10^{-1}	10	3.162	10
10^{-1}	10^{-2}	20	10	10^{2}
3.162×10^{-2}	10^{-3}	30	3.162×10	10^{3}
10^{-2}	10^{-4}	40	10^{2}	10^{4}
3.162×10^{-3}	10^{-5}	50	3.162×10^{2}	10^{5}
10^{-3}	10^{-6}	60	10^{3}	10^{6}
3.162×10^{-4}	10^{-7}	70	3.162×10^{3}	10^{7}
10^{-4}	10^{-8}	80	10^{4}	10^{8}
3.162×10^{-5}	10^{-9}	90	3.162×10^{4}	10^{9}
10^{-5}	10^{-10}	100	10^{5}	10^{10}

To find ratios outside the range of this table, see page 96.

TABLE II

GIVEN: {Pressure} Ratio   TO FIND: Decibels

POWER RATIOS

To find the number of decibels corresponding to a given power ratio—Assume the given power ratio to be a pressure ratio and find the corresponding number of decibels from the table. The desired result is exactly one-half of the number of decibels thus found.

Example—*Given:* a power ratio of 3.41. *Find:* 3.41 in the table:

3.41→10.655 db × ½ = 5.328 db

Pressure Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.0	.000	.086	.172	.257	.341	.424	.506	.588	.668	.749
1.1	.828	.906	.984	1.062	1.138	1.214	1.289	1.364	1.438	1.511
1.2	1.584	1.656	1.727	1.798	1.868	1.938	2.007	2.076	2.144	2.212
1.3	2.279	2.345	2.411	2.477	2.542	2.607	2.671	2.734	2.798	2.860
1.4	2.923	2.984	3.046	3.107	3.167	3.227	3.287	3.346	3.405	3.464
1.5	3.522	3.580	3.637	3.694	3.750	3.807	3.862	3.918	3.973	4.028
1.6	4.082	4.137	4.190	4.244	4.297	4.350	4.402	4.454	4.506	4.558
1.7	4.609	4.660	4.711	4.761	4.811	4.861	4.910	4.959	5.008	5.057
1.8	5.105	5.154	5.201	5.249	5.296	5.343	5.390	5.437	5.483	5.529
1.9	5.575	5.621	5.666	5.711	5.756	5.801	5.845	5.889	5.933	5.977
2.0	6.021	6.064	6.107	6.150	6.193	6.235	6.277	6.319	6.361	6.403
2.1	6.444	6.486	6.527	6.568	6.608	6.649	6.689	6.729	6.769	6.809
2.2	6.848	6.888	6.927	6.966	7.008	7.044	7.082	7.121	7.159	7.197
2.3	7.235	7.272	7.310	7.347	7.384	7.421	7.458	7.495	7.532	7.568
2.4	7.604	7.640	7.676	7.712	7.748	7.783	7.819	7.854	7.889	7.924
2.5	7.959	7.993	8.028	8.062	8.097	8.131	8.165	8.199	8.232	8.266
2.6	8.299	8.333	8.366	8.399	8.432	8.465	8.498	8.530	8.563	8.595
2.7	8.627	8.659	8.691	8.723	8.755	8.787	8.818	8.850	8.881	8.912
2.8	8.943	8.974	9.005	9.036	9.066	9.097	9.127	9.158	9.188	9.218
2.9	9.248	9.278	9.308	9.337	9.367	9.396	9.426	9.455	9.484	9.513
3.0	9.542	9.571	9.600	9.629	9.657	9.686	9.714	9.743	9.771	9.799
3.1	9.827	9.855	9.883	9.911	9.939	9.966	9.994	10.021	10.049	10.076
3.2	10.103	10.130	10.157	10.184	10.211	10.238	10.264	10.291	10.317	10.344
3.3	10.370	10.397	10.423	10.449	10.475	10.501	10.527	10.553	10.578	10.604
3.4	10.630	10.655	10.681	10.706	10.731	10.756	10.782	10.807	10.832	10.857
3.5	10.881	10.906	10.931	10.955	10.980	11.005	11.029	11.053	11.078	11.102
3.6	11.126	11.150	11.174	11.198	11.222	11.246	11.270	11.293	11.317	11.341
3.7	11.364	11.387	11.411	11.434	11.457	11.481	11.504	11.527	11.550	11.573
3.8	11.596	11.618	11.641	11.664	11.687	11.709	11.732	11.754	11.777	11.799
3.9	11.821	11.844	11.866	11.888	11.910	11.932	11.954	11.976	11.998	12.019
4.0	12.041	12.063	12.085	12.106	12.128	12.149	12.171	12.192	12.213	12.234
4.1	12.256	12.277	12.298	12.319	12.340	12.361	12.382	12.403	12.424	12.444
4.2	12.465	12.486	12.506	12.527	12.547	12.568	12.588	12.609	12.629	12.649
4.3	12.669	12.690	12.710	12.730	12.750	12.770	12.790	12.810	12.829	12.849
4.4	12.869	12.889	12.908	12.928	12.948	12.967	12.987	13.006	13.026	13.045
4.5	13.064	13.084	13.103	13.122	13.141	13.160	13.179	13.198	13.217	13.236
4.6	13.255	13.274	13.293	13.312	13.330	13.349	13.368	13.386	13.405	13.423
4.7	13.442	13.460	13.479	13.497	13.516	13.534	13.552	13.570	13.589	13.607
4.8	13.625	13.643	13.661	13.679	13.697	13.715	13.733	13.751	13.768	13.786
4.9	13.804	13.822	13.839	13.857	13.875	13.892	13.910	13.927	13.945	13.962
5.0	13.979	13.997	14.014	14.031	14.049	14.066	14.083	14.100	14.117	14.134
5.1	14.151	14.168	14.185	14.202	14.219	14.236	14.253	14.270	14.287	14.303
5.2	14.320	14.337	14.353	14.370	14.387	14.403	14.420	14.436	14.453	14.469
5.3	14.486	14.502	14.518	14.535	14.551	14.567	14.583	14.599	14.616	14.632
5.4	14.648	14.664	14.680	14.696	14.712	14.728	14.744	14.760	14.776	14.791
5.5	14.807	14.823	14.839	14.855	14.870	14.886	14.902	14.917	14.933	14.948
5.6	14.964	14.979	14.995	15.010	15.026	15.041	15.056	15.072	15.087	15.102
5.7	15.117	15.133	15.148	15.163	15.178	15.193	15.208	15.224	15.239	15.254
5.8	15.269	15.284	15.298	15.313	15.328	15.343	15.358	15.373	15.388	15.402
5.9	15.417	15.432	15.446	15.461	15.476	15.490	15.505	15.519	15.534	15.549

TABLE II (continued)

Pressure Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
6.0	**15.563**	**15.577**	**15.592**	**15.606**	**15.621**	**15.635**	**15.649**	**15.664**	**15.678**	**15.692**
6.1	15.707	15.721	15.735	15.749	15.763	15.778	15.792	15.806	15.820	15.834
6.2	15.848	15.862	15.876	15.890	15.904	15.918	15.931	15.945	15.959	15.973
6.3	15.987	16.001	16.014	16.028	16.042	16.055	16.069	16.083	16.096	16.110
6.4	16.124	16.137	16.151	16.164	16.178	16.191	16.205	16.218	16.232	16.245
6.5	16.258	16.272	16.285	16.298	16.312	16.325	16.338	16.351	16.365	16.378
6.6	16.391	16.404	16.417	16.430	16.443	16.456	16.469	16.483	16.496	16.509
6.7	16.521	16.534	16.547	16.560	16.573	16.586	16.599	16.612	16.625	16.637
6.8	16.650	16.663	16.676	16.688	16.701	16.714	16.726	16.739	16.752	16.764
6.9	16.777	16.790	16.802	16.815	16.827	16.840	16.852	16.865	16.877	16.890
7.0	**16.902**	**16.914**	**16.927**	**16.939**	**16.951**	**16.964**	**16.976**	**16.988**	**17.001**	**17.013**
7.1	17.025	17.037	17.050	17.062	17.074	17.086	17.098	17.110	17.122	17.135
7.2	17.147	17.159	17.171	17.183	17.195	17.207	17.219	17.231	17.243	17.255
7.3	17.266	17.278	17.290	17.302	17.314	17.326	17.338	17.349	17.361	17.373
7.4	17.385	17.396	17.408	17.420	17.431	17.443	17.455	17.466	17.478	17.490
7.5	17.501	17.513	17.524	17.536	17.547	17.559	17.570	17.582	17.593	17.605
7.6	17.616	17.628	17.639	17.650	17.662	17.673	17.685	17.696	17.707	17.719
7.7	17.730	17.741	17.752	17.764	17.775	17.786	17.797	17.808	17.820	17.831
7.8	17.842	17.853	17.864	17.875	17.886	17.897	17.908	17.919	17.931	17.942
7.9	17.953	17.964	17.975	17.985	17.996	18.007	18.018	18.029	18.040	18.051
8.0	**18.062**	**18.073**	**18.083**	**18.094**	**18.105**	**18.116**	**18.127**	**18.137**	**18.148**	**18.159**
8.1	18.170	18.180	18.191	18.202	18.212	18.223	18.234	18.244	18.255	18.266
8.2	18.276	18.287	18.297	18.308	18.319	18.329	18.340	18.350	18.361	18.371
8.3	18.382	18.392	18.402	18.413	18.423	18.434	18.444	18.455	18.465	18.475
8.4	18.486	18.496	18.506	18.517	18.527	18.537	18.547	18.558	18.568	18.578
8.5	18.588	18.599	18.609	18.619	18.629	18.639	18.649	18.660	18.670	18.680
8.6	18.690	18.700	18.710	18.720	18.730	18.740	18.750	18.760	18.770	18.780
8.7	18.790	18.800	18.810	18.820	18.830	18.840	18.850	18.860	18.870	18.880
8.8	18.890	18.900	18.909	18.919	18.929	18.939	18.949	18.958	18.968	18.978
8.9	18.988	18.998	19.007	19.017	19.027	19.036	19.046	19.056	19.066	19.075
9.0	**19.085**	**19.094**	**19.104**	**19.114**	**19.123**	**19.133**	**19.143**	**19.152**	**19.162**	**19.171**
9.1	19.181	19.190	19.200	19.209	19.219	19.228	19.238	19.247	19.257	19.266
9.2	19.276	19.285	19.295	19.304	19.313	19.323	19.332	19.342	19.351	19.360
9.3	19.370	19.379	19.388	19.398	19.407	19.416	19.426	19.435	19.444	19.453
9.4	19.463	19.472	19.481	19.490	19.499	19.509	19.518	19.527	19.536	19.545
9.5	19.554	19.564	19.573	19.582	19.591	19.600	19.609	19.618	19.627	19.636
9.6	19.645	19.654	19.664	19.673	19.682	19.691	19.700	19.709	19.718	19.726
9.7	19.735	19.744	19.753	19.762	19.771	19.780	19.789	19.798	19.807	19.816
9.8	19.825	19.833	19.842	19.851	19.860	19.869	19.878	19.886	19.895	19.904
9.9	19.913	19.921	19.930	19.939	19.948	19.956	19.965	19.974	19.983	19.991

Pressure Ratio	0	1	2	3	4	5	6	7	8	9
10	**20.000**	**20.828**	**21.584**	**22.279**	**22.923**	**23.522**	**24.082**	**24.609**	**25.105**	**25.575**
20	26.021	26.444	26.848	27.235	27.604	27.959	28.299	28.627	28.943	29.248
30	29.542	29.827	30.103	30.370	30.630	30.881	31.126	31.364	31.596	31.821
40	32.041	32.256	32.465	32.669	32.869	33.064	33.255	33.442	33.625	33.804
50	33.979	34.151	34.320	34.486	34.648	34.807	34.964	35.117	35.269	35.417
60	35.563	35.707	35.848	35.987	36.124	36.258	36.391	36.521	36.650	36.777
70	36.902	37.025	37.147	37.266	37.385	37.501	37.616	37.730	37.842	37.953
80	38.062	38.170	38.276	38.382	38.486	38.588	38.690	38.790	38.890	38.988
90	39.085	39.181	39.276	39.370	39.463	39.554	39.645	39.735	39.825	39.913
100	**40.000**	—	—	—	—	—	—	—	—	—

To find ratios outside the range of this table, see page 96.

TYPE 1551-A SOUND-LEVEL METER

USES: The Type 1551-A Sound-Level Meter is a new instrument, of advanced design, for the general measurement of sound fields. It is ideally suited to the sound-measuring problems of commerce and industry. Manufacturers of machines and appliances use it for measuring product noise both in the development laboratory and in production. For such plants, it provides a means of establishing noise standards, of accepting or rejecting products on the basis of noise tests, and of analyzing and correcting trouble in the rejected units.

Acoustical engineers also use the sound-level meter for determining noise levels from engines, machinery, and other equipment, and for investigating the acoustical properties of buildings, structures, and materials.

Industrial hygienists and psychologists use it in surveys of the psychological and physiological effects of noise and for the establishment of acceptable noise levels and the determination of satisfactory noise environments in factories and offices.

Accessory equipment, such as frequency analyzers, graphic-level recorders, and magnetic-tape recorders can be operated from the output of the Sound-Level Meter.

It is also suitable for use as a portable amplifier for laboratory standard microphones, and, with a high-fidelity microphone, for measurements on high-fidelity sound systems.

Although the low-cost crystal microphone supplied with the Type 1551-A Sound-Level Meter is satisfactory for the majority of applications, special microphones can be used to full advantage. Among these are the Type 1551-P1 Condenser Microphone System for high-fidelity work, the Western Electric 640-AA where a reproducible standard is desired, and the Type 759-P25 Dynamic Microphone Assembly for use with a long cable.

DESCRIPTION: The Type 1551-A Sound-Level Meter is an accurate, portable, low-priced meter for reading, in terms of a standard reference level, the sound level at its microphone.

It consists of a non-directional microphone, an amplifier, a calibrated attenuator, and an indicating meter.

The complete instrument, including batteries, is mounted in an aluminum case with an easily removed cover over the panel. The microphone is mounted on a bracket and folds down into a panel recess when not in use. In this storage position of the microphone, batteries are automatically turned off. An a-c power supply unit is available.

FEATURES: ➔ Small, compact, and easily portable — weighs only 11 pounds with batteries.
➔ Simple to operate.
➔ Meets all standards of the American Standards Association, the American Institute of Electrical Engineers, and the Acoustical Society of America.
➔ Separate output systems for panel meter and output terminals. When a sound analyzer is used, meter can be used for monitoring.
➔ Two-speed meter movement permits measurement of either steady or fluctuating sounds.
➔ Wide range — from 24 to 140 db.
➔ Sub-miniature tubes in negative feedback amplifier circuits provide excellent stability.
➔ Batteries are readily available.
➔ Amplifiers and panel meter have wide frequency response, 20 cycles to 20 kilocycles.
➔ Low internal noise level.
➔ Internal calibration system for standardizing amplifier gain.

SPECIFICATIONS

Sound-Level Range: From 24 db to 140 db above the standard sound pressure reference level of 0.0002 microbar (a pressure of 0.0002 dyne per square centimeter) at 1000 cycles.

Frequency Characteristics: Any one of 4 response characteristics can be selected by means of a panel switch. The first and second of these are, respectively, the 40 and 70 db equal-loudness contours in accordance with the current standard specified by the American Standards Association. The third frequency response characteristic gives a substantially equal response to all frequencies within the range of the instrument and its microphone. This characteristic is used when measuring extremely high sound levels, when measuring sound pressures, or when using the instrument with the Type 760-B Sound Analyzer, the Type 736-A Wave Analyzer, or the Type 1550-A Octave-Band Noise Analyzer. The fourth frequency response characteristic provides an amplifier which has essentially flat response from 20 cycles to 20 kilocycles, so that full use can be made of extremely wide range microphones such as the W.E. 640-AA or the Type 1551-P1 Condenser Microphone System.

Microphone: The microphone is of the Rochelle-salt, crystal-diaphragm type with an essentially non-directional response characteristic. Condenser and dynamic microphones are available as accessories.

Sound-Level Indication: The sound level is indicated by the sum of the readings of the meter and an attenuator. The meter has a range of 16 db, and the attenuator has a range of 100 db in 10 db steps.

Output Terminals: A jack is provided, which supplies an output of 1 volt across 20,000 ohms when the panel meter reads full scale. This output is suitable for use with the Type 760-B Sound Analyzer, the Type 736-A Wave Analyzer, the Type 1550-A Octave-Band Noise Analyzer, a graphic level recorder, or a magnetic tape recorder.

A SLOW-FAST switch makes available two meter speeds. With the control switch in the FAST position the ballistic characteristics of the meter simulate those of the human ear and agree with the current standards of the American Standards Association. In the SLOW position, the meter is heavily damped for observing the average level of rapidly fluctuating sounds.

Calibration: A means is provided for standardizing the sensitivity of the instrument in terms of any a-c power line of approximately 115 volts.

The absolute level of all microphones is checked at several frequencies against a standard microphone, whose calibration is periodically checked by the National Bureau of Standards.

Type 1552-A Sound-Level Calibrator (page 15) is available for making periodic checks on the over-all calibration, including microphone.

Accuracy: The frequency response curves A, B, and C of the Type 1551-A Sound-Level Meter fall within the tolerances specified by the current ASA standards. When the amplifier sensitivity is standardized, the absolute accuracy of sound-level measurements is within ±1 decibel for average machinery noises in accordance with the ASA standards.

Temperature and Humidity Effects: Readings are independent (within 1 db) of temperature and humidity over the ranges of room conditions normally encountered.

Batteries: Two $1\frac{1}{2}$-volt size-D flashlight cells (Eveready 950 or equivalent); one Eveready 467 B battery or equivalent. Batteries are supplied. The Type 1262-A A-C Power Supply is available if a-c operation is desired. (See price table below.)

Tubes: Four CK-512-AX and three CK-533-AX are required. A complete set is supplied with the instrument.

Accessories Supplied: Power Cord (for calibration check), telephone plug.

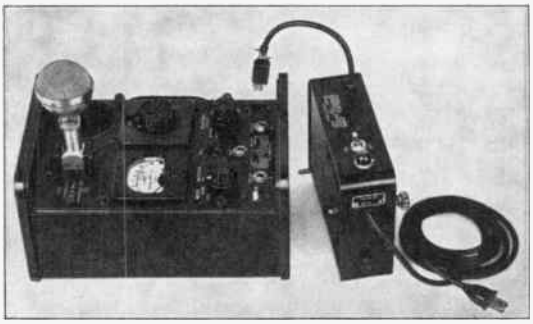
Other Accessories Available: See pages 12 to 15.

Case: Shielded carrying case of aluminum construction.

Dimensions: The over-all dimensions are approximately (height) $6\frac{5}{8}$ x (length) $10\frac{13}{16}$ x (width) $8\frac{7}{8}$ inches.

Net Weight: 11 pounds, with batteries.

TYPE 1262-A POWER SUPPLY



The sound-level meter is supplied with batteries. For a-c operation the Type 1262-A Power Supply attaches to the sound-level meter cabinet, as shown above. Input is 105 to 125 volts, 50 to 60 cycles, 2 watts.

Type		*Code Word*	*Price*
1551-A	**Sound-Level Meter**	MIMIC	**$360.00**
1262-A	**Power Supply**	MANLY	**75.00**

(Licensed under patents of the American Telephone and Telegraph Company)

TYPE 1555-A SOUND-SURVEY METER

USES: This pocket-size, inexpensive, sound-survey meter, of good accuracy, is designed for the many applications where the nature of the measurements does not require the accuracy of the Type 1551-A Sound-Level Meter. The Type 1555-A Sound-Survey Meter is well suited to a wide variety of general survey measurements, many of which are economically practical only with a low-cost meter.

This handy, versatile device can be used for checking the level of reproduced sound from theatre systems, public-address systems, and other sound systems; and, on high-fidelity sound systems, for determining the response characteristics through the cross-over point and for measuring the dynamic range. It is also useful for checking levels at rehearsals and in speech and singing classes; for determining an acoustic reference level when recording; for preliminary field surveys by sales engineers for acoustical materials; for acoustic experiments in physics classes; for measuring the sine-wave response characteristics of loudspeakers and rooms; for preliminary surveys to determine noise levels in homes, offices, factories, and other buildings, in streets and subways, and in vehicles; for determining levels from appliances, machinery, and office equipment; and for preliminary checks of noise levels for estimating the possible long-time effect on hearing of operating personnel.

When compliance with noise test codes is required or when analysis of the noise is desired, or both, the Type 1551-A Sound-Level Meter and its accessory instruments are recommended.

DESCRIPTION: The Type 1555-A Sound-Survey Meter indicates the level of noise and other sounds in terms of a standard reference level. It consists of a non-directional microphone, a calibrated attenuator, an amplifier, and an indicating meter. The amplifier uses subminiature tubes in a negative feedback circuit.

The entire assembly, including microphone and batteries, is mounted in a simple, two-piece, aluminum case. The controls for the attenuator and the weighting network selector are finger-tip-control discs.

FEATURES: ➤ Small enough to fit in trousers pocket. 6 x 3⅛ x 2½ inches, over-all.

➤ Weighs only 1 pound, 14 ounces with batteries.

➤ Indicating meter is conveniently located and easily read.

➤ Only two controls, both on face of instrument.

➤ Can be used when set on a bench or table, when mounted on tripod or when held in hand.

➤ Miniature in size, yet it uses standard and well-tested components.

➤ Meter can be read for either horizontal or vertical orientation of microphone.

SPECIFICATIONS

Range: From 40 db to 136 db above the standard sound-pressure reference level of 0.0002 μbar.

Frequency Characteristic: Three different frequency characteristics can be selected by the main control switch. In the *C* and *C* +30 db weighting positions substantially equal response to all frequencies between 40 and 8000 cps is obtained. This characteristic is ordinarily used for all levels above 85 db.

The *B* weighting position is used for levels between 55 and 85 db. Its response follows the 70 db contour established as the standard of weighting for sound-level meters. The *A* weighting position is usually used for levels between 40 and 55 db. Its response follows approximately the 40-db contour established for sound-level meter weighting. In addition to providing means for making the usual weighted level measurement, these characteristics permit one to estimate, by comparative measurements with different weighting characteristics, the relative importance of low-frequency components in the sound being measured.

Microphone: The crystal diaphragm-type microphone cartridge is mounted at the top of the instrument. Proximity of microphone to tube grid reduces the temperature coefficient to the order of 0.03 db per degree F.

Meter and Attenuator: For levels below 100 db the noise level is given by the sum of the readings of the meter and attenuator.

For levels above 100 db the main control switch is set to "*C* +30 db." Then the noise level is given by the sum of the readings of the attenuator and the meter plus 30 db.

The ballistic characteristics of the rectifier-type meter are similar to those for standard sound-level meters.

Stability: The amplifier and level indicator are stabilized by feedback. The change in gain with battery voltages is thereby reduced to moderate values.

The behavior of the instrument is not noticeably affected by temperature and humidity over the ranges of room conditions normally encountered. The maximum safe operating temperature is 115° F. Temperatures above 130° F will permanently damage the Rochelle-salt crystal in the microphone cartridge.

Accuracy: The gain of the amplifier is set initially so that the sensitivity of the instrument is correct at 1000 cps within ±1 db. The *B* and *C* frequency characteristics are essentially within the tolerances allowed by the American Standards Association specification on Sound-Level Meters. The *A* frequency characteristic is similar to that required by the ASA specification, but it provides only the low-frequency roll-off below 1000 cps.

When the *B* and *C* weighting are used, the reading of this meter, for almost all types of sounds, agrees with that of a meter meeting the ASA specification on sound-level meters to within the tolerances allowed by the standard but increased by 1 db.

Batteries: One $1\frac{1}{2}$-volt size-C flashlight battery (Eveready 935 or equivalent) and one 30-volt hearing-aid battery (Eveready 413E or equivalent) are supplied.

Tubes: Two CK-512-AX and two CK-533-AX tubes are supplied.

Cabinet: Aluminum, finished in organic black with standard ¼-20 threaded mount for tripod. Leather carrying case is available, see price list below.

Dimensions: 6 x $3\frac{1}{8}$ x $2\frac{1}{2}$ inches, over-all.

Net Weight: 1 pound, 14 ounces, with batteries.

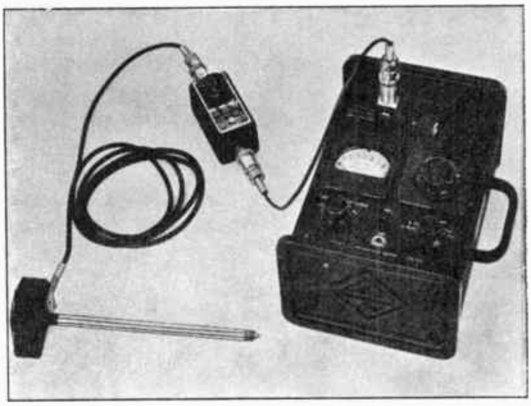
Type		*Code Word*	*Price*
1555-A	**Sound-Survey Meter**	MISER	**$135.00**
	Set of Replacement Batteries	MISERADBAT	**1.53**
1555-P1	**Case**	CASER	**10.00**

PATENT NOTICE. See Note 1, page vi.

STANDARD ACCESSORIES FOR THE TYPE 1551-A SOUND-LEVEL METER

The following accessories are available for use with the Type 1551-A Sound-Level Meter to increase its field of application and to adapt it for specialized types of measurement. Many of these accessories can also be used with the older Type 759-B Sound-Level Meter.

VIBRATION PICKUP AND CONTROL BOX



The vibration pickup and control box plug into the sound-level meter in place of the microphone, as shown in the photograph above.

The Type 759-P35 Pickup and Type 759-P36 Control Box have been designed for use with General Radio Sound-Level Meters.

The Type 759-P35 Vibration Pickup is an inertia-operated crystal device which generates a voltage proportional to the acceleration of the vibrating body. By means of integrating networks in the control box, voltages proportional to velocity and displacement can also be delivered to the sound-level meter. The desired response is selected by means of a three-point switch on the control box.

The low-frequency response of the sound-level meter is sufficiently good to permit vibration measurements at frequencies down to 20 cycles. Such measurements include the fundamental and harmonic frequency vibrations of machines rotating at 1200 rpm or higher, as well as many structural resonances.

SPECIFICATIONS

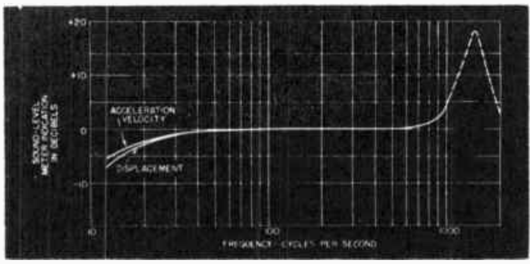
Calibration: The db readings of the sound-level meter can be converted into absolute values of displacement, velocity, or acceleration by means of calibration data.

Range: The range of measurement of the pickup and control box when used with the Type 1551-A or the Type 759-B Sound-Level Meter is approximately as follows:

R-m-s Displacement — 30 micro-inches (minimum).

R-m-s Velocity — 1000 micro-inches per second (mini-

Over-all frequency response characteristic of the vibration pickup, control box, and sound-level meter for constant applied acceleration, velocity and displacement, respectively.



mum). The upper limit of velocity and displacement measurements is dependent on the frequency and is determined by the maximum acceleration permissible before non-linearity occurs (10 g).

R-m-s Acceleration — 0.3 to 3900 in./sec/sec (10 g).

Frequency Characteristic: See plot. For frequencies below 20 cycles the Type 761-A Vibration Meter should be used.

Mounting: Both control box and pickup are housed in metal containers, finished in black lacquer.

Net Weight: Type 759-P35 Vibration Pickup, 8 ounces (pickup only); pickup plus 7-foot cable and tips, 1 pound; Type 759-P36 Control Box, 1 pound, 13 ounces.

Type		*Code Word*	*Price*
759-P35	**Vibration Pickup**	NOSEY	**$40.00**
759-P36	**Control Box .....**	NANNY	**50.00**

DYNAMIC MICROPHONE ASSEMBLY

For some measurements, particularly where a long cable must be used between microphone and meter, or where large ranges of temperature and humidity are encountered, a dynamic microphone is preferable. The Type 759-P25 Dynamic Microphone Assembly includes, in addition to the microphone, a 25-foot cable, an input transformer, and a tripod. The transformer plugs into the Sound-Level Meter in place of the standard microphone, and the microphone cable plugs into the transformer.

SPECIFICATIONS

Frequency Response: When the sound-level meter and dynamic microphone are adjusted to the correct level, the combination will meet the ASA specifications above 40 cycles. The procedure for making this adjustment is described in the instruction book. Typical response curves are shown below.

Sensitivity: Open-circuit output of typical microphone is 90 db below one volt per microbar, and of microphone plus transformer is 60 db below one volt per microbar. This sensitivity is satisfactory for use with both the Type 1551-A and the Type 759-B Sound-Level Meters.

Direct Use with Analyzers: This microphone assembly is suitable for supplying a signal directly to the Type 1550-A Octave-Band Noise Analyzer and the Type 760-B Sound Analyzer provided the level of the measured components is above 70 db (re 0.0002 μbar). (A Type 1552-A Sound-Level Calibrator is then necessary to obtain absolute level.)

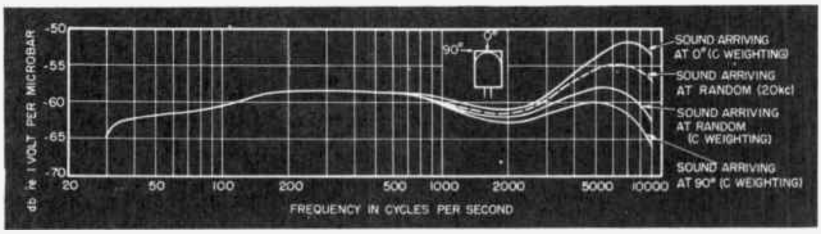
Calibration: Output level is checked in our laboratories at several frequencies against a standard microphone that is calibrated periodically by the National Bureau of Standards. The level at 400 cycles is supplied.

Maximum Safe Sound Pressure Level: Sound pressure levels above 140 db can damage the microphone.

Cable Correction: No correction is necessary for the 25-foot cable supplied or the Type 759-P22 100-foot cable.

Net Weight: 4⅝ pounds.

(B) Microphone and transformer plug into the sound-level meter as shown above.



Typical response curves of Type 1551-A Sound-Level Meter with Type 759-P25 Dynamic Microphone and Accessories.

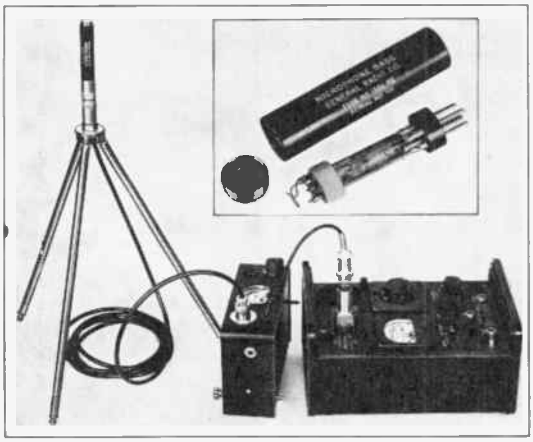
Type		*Code Word*	*Price*
759-P25	**Dynamic Microphone Assembly......**	NABOR	**$150.00**
759-P22	**Extra 100-foot cable...............**	NASAL	**30.00**

TRIPOD AND EXTENSION CABLE

For measurements where the microphone must be located at a distance from the meter, the Type 759-P25 Dynamic Microphone is recommended (see above). However, a 25-foot extension cable and tripod for mounting the Rochelle-salt crystal microphone can be supplied. With this cable a correction curve is furnished, giving the cable correction as a function of temperature of the microphone.

Type		*Code Word*	*Price*
759-P21	**Tripod and Extension Cable.........**	KIMBO	**$18.50**

TYPE 1551-P1 CONDENSER MICROPHONE SYSTEM



View of the condenser microphone system and sound-level meter, showing how power-supply assembly attaches to sound-level meter cabinet. Inset shows microphone, preamplifier and base, disassembled.

The Type 1551-P1 Condenser Microphone System is designed for use with the Type 1551-A Sound-Level Meter. When the sound to be measured covers a wide frequency range or has much energy above 5 kc, the Condenser Microphone System is a better pickup for the Sound-Level Meter than either crystal or dynamic microphones. For high sound levels the Condenser Microphone System can be connected directly to an analyzer.

The condenser microphone (Altec 21-Type) mounts on a small cylindrical base, which houses a subminiature pre-amplifier tube. A battery operated power supply, which can be fastened to the end frame of the Sound-Level Meter, provides filament and plate power for the pre-amplifier and polarizing voltage for the microphone. A 10-foot extension cable, a tripod, a calibration adaptor, and a leather carrying case are supplied.

SPECIFICATIONS

Frequency Response: Useful range of the Type 1551-A Sound-Level Meter with Type 1551-P1 Condenser Microphone System is 20 cycles to 15 kilocycles. Typical frequency response curves are shown below.

Calibration: The output level of the microphone system is measured at several frequencies against a standard microphone that is calibrated periodically by the National Bureau of Standards. The measured level at 400 cycles is supplied. A Calibration Adaptor is provided for use with the Type 1552-A Sound-Level Calibrator.

Direct Use with Analyzers: This microphone assembly is suitable for supplying a signal directly to the Type 1550-A Octave-Band Noise Analyzer and the Type 760-B Sound Analyzer provided the level of the measured components is above 70 db (re 0.0002 μbar). (A Type 1552-A Sound-Level Calibrator is then necessary to obtain absolute level.)

Maximum Sound-Pressure Level: At levels above 140 db the output of the microphone becomes non-linear. For levels up to 180 db the Altec Type 21-BR-200 can be used in place of the one supplied. (The Type 21-BR-200 is not furnished as part of the Type 1551-P1.)

Cable Correction: No correction is necessary for the 10-foot cable supplied.

Internal Noise Level: Under normal conditions the noise level of the Type 1551-P1 Condenser Microphone System is low enough to permit satisfactory measurements of sound-pressure levels as low as 50 db (re 0.0002 μbar).

Output Terminals: A short flexible output cable on the power unit plugs into the microphone socket of the Type 1551-A Sound-Level Meter in place of the standard crystal microphone. In addition, a jack located on the side of the power supply provides a direct connection to the Type 760-B Sound Analyzer or the Type 1550-A Octave-Band Noise Analyzer.

Batteries: One 1½-volt size-D flashlight cell (Eveready 950 or equivalent) and one 300-volt B battery (Eveready 493 or Burgess V-200) are supplied.

Tubes: One Raytheon Type CK-512-AX is supplied in the Type 1551-P1-25 Microphone Base.

Mounting: Microphone on microphone base plugs into one end of 10-foot cable, which has fitting to mount on the tripod. Other end of 10-foot cable connects to power supply unit which fastens to the end frame of the Sound-Level Meter.

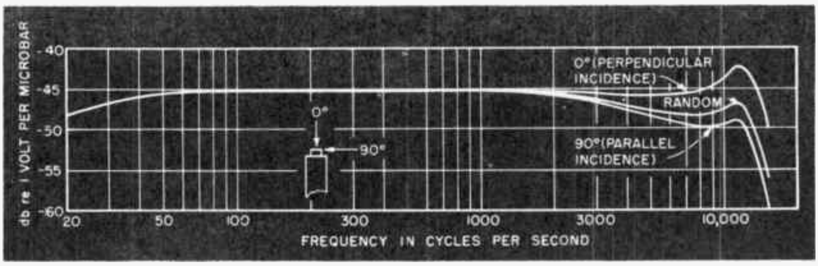
Dimensions: Microphone — (diameter) ⅝ x (length) $2\frac{1}{64}$ inches; Microphone Base — (diameter) ¾ x (length) 3 inches; Power Supply — (height) 7 x (length) 3¼ x (width) 7½ inches.

Leather carrying case with compartment for microphone and microphone base, power supply, 10-foot cable, and calibration adaptor has over-all outside dimensions of approximately (height) 7 x (length) 5½ x (width) 8½ inches.

Net Weight: Altec Microphone, less than ½ oz.
Microphone and Base, 1.2 oz.
Power Supply, 3 lbs. 11 oz.
Complete System in Carrying Case, 7 lbs. 6 oz.

Type		*Code Word*	*Price*
1551-P1	**Condenser Microphone System**	NONAL	**$260.00**

(Note: The Type 1551-P1 can be used with the older Type 759 Sound Level Meters within the frequency limits of the Type 759.)



Typical response characteristics for the Type 1551-A Sound-Level Meter and the Type 1551-P1 Condenser Microphone System.

TYPE 1552-A SOUND-LEVEL CALIBRATOR

USES: The Sound-Level Calibrator provides a means of making an over-all acoustic check of the Sound-Level Meter calibration, including the microphone. It can be used to calibrate the Type 1551-A, Type 759-B, and Type 759-A Sound-Level Meters; the Type 1551-P1 Condenser Microphone System; as well as other instruments that use the 9898-type, the BR2S-type or the Type 759-P25 (633A) microphones.

In conjunction with the internal calibration check on electrical circuits that is provided in the Sound-Level Meter the Sound-Level Calibrator makes it possible to detect and to evaluate any long-period change in over-all sensitivity and to locate it either in the microphone or the electrical circuits. Such a check is invaluable where a series of measurements are to be taken over a long period, or where several meters are to be intercompared.

This calibrator can also be used to make acoustic checks on the Type 1555-A Sound-Survey Meter, which has a built-in microphone, and to calibrate the Type 1550-A Octave-Band Noise Analyzer or the Type 760-B Sound Analyzer when it is used directly with dynamic microphone input or directly with the Type 1551-P1 Condenser Microphone System. It can also be used to supply an acoustic reference level for magnetic tape recorders, graphic level recorders, and oscillographs provided the signal for these instruments is supplied by one of the microphones mentioned above.

DESCRIPTION: The calibrator consists of a small, stabilized, and rugged loudspeaker, mounted in an enclosure which fits over the microphone of the Sound-Level Meter. The enclosure is so designed that the speaker is always located at the correct distance from the microphone diaphragm. A standard 400-cycle voltage is required to operate the calibrator (see specifications below).

SPECIFICATIONS

Input: 2.0 volts, 400 cycles; total harmonics must not exceed 5%.

Output: When in position on the 9898-type microphone used on Types 1551-A and 759-B Sound-Level Meters, the calibrator produces a sound pressure of 85 ±1 db (above a reference level of 0.0002 microbar) at the microphone diaphragm for rated input as specified above.

Terminals: Input terminals are Type 938-W Binding Posts.

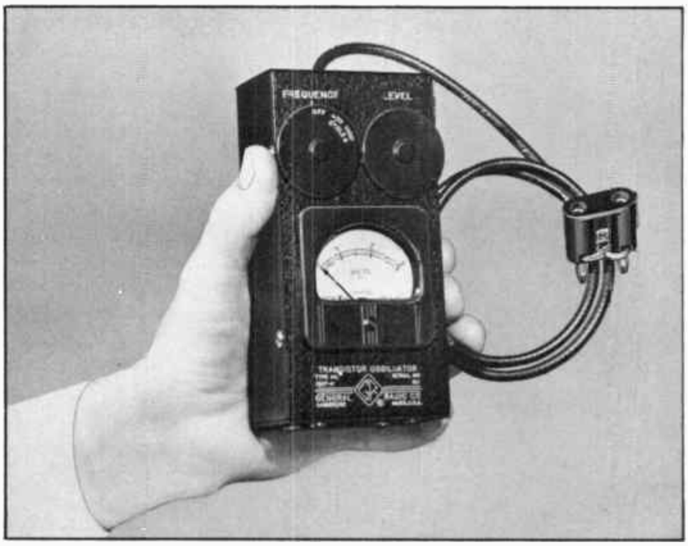
Accessories Required: 400-cycle source, with output control and voltmeter. The Type 1307-A Transistor Oscillator, (a battery-operated device that includes all these elements) is recommended (see page 153). The Type 1214-A Unit Oscillator (a-c operated, see page 164) is also satisfactory. For use with this oscillator, which includes an output control, the voltmeter can be a Weston, Model 301, 0–3 volt, rectifier type, a-c voltmeter, 2000 ohms per volt. A vacuum-tube voltmeter, such as the Type 1803-A (page 184) can also be used.

Dimensions: (Length) 4½ x (diameter) 2½ inches, over-all.

Net Weight: 12 ounces.

Type		*Code Word*	*Price*
1552-A	**Sound-Level Calibrator**............	NATTY	**$45.00**
1307-A	**Transistor Oscillator**...............	OMEGA	**88.00**

TYPE 1307-A TRANSISTOR OSCILLATOR



USES: The Type 1307-A Transistor Oscillator is a convenient battery-operated source for the Type 1552-A Sound-Level Calibrator (see page 15). Because it is so easy to carry and use at any location, it is also useful in continuity checks of audio systems, in setting operating levels, in checking the sensitivity of oscillographs, and in making other preliminary calibrations of electronic systems. In addition, it is a convenient power source for bridge measurements at 400 and 1000 cycles.

DESCRIPTION: The Type 1307-A Transistor Oscillator uses a P-N-P junction-type transistor. The oscillator uses the Hartley circuit. The inductor of the tuned circuit contains an additional winding for supplying the output load, and a rectifier-type voltmeter is connected across this winding to indicate the voltage at the output terminals.

FEATURES:

- ➔ Small and compact; easily carried in pocket.
- ➔ Battery operated.
- ➔ Meter indicates output voltage.
- ➔ Fits Type 1555-P1 carrying case.

SPECIFICATIONS

Frequency: 400 and 1000 cycles accurate to ±3% at 2 volts output into a 600-ohm resistive load. The frequency decreases slightly with increase in output level. A reactive load will shift the frequency, since the load is coupled directly into the tuned circuit.

Output: Adjustable. Maximum output is at least 2 volts across 600-ohm load.

Distortion: Less than 5% at 400 c and at 2 volts across 600-ohm load. It may be slightly higher at 1000 c.

Voltmeter: 3 volts full scale, calibrated directly in volts at the output terminals.

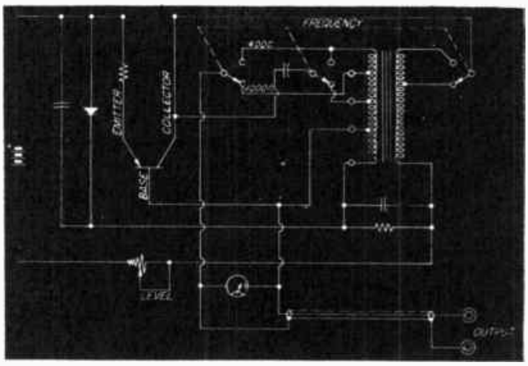
Output Circuit: The output cable is terminated in a 274-MB double plug. No connection is made to the case.

Batteries: Three mercury A batteries (Mallory RM-1 or equivalent) are supplied.

Transistor: One P-N-P junction transistor (Raytheon Type 721 or equivalent) is supplied.

Case: Aluminum, black finish.

Carrying Case: A leather case with straps is available, Type 1555-P1.

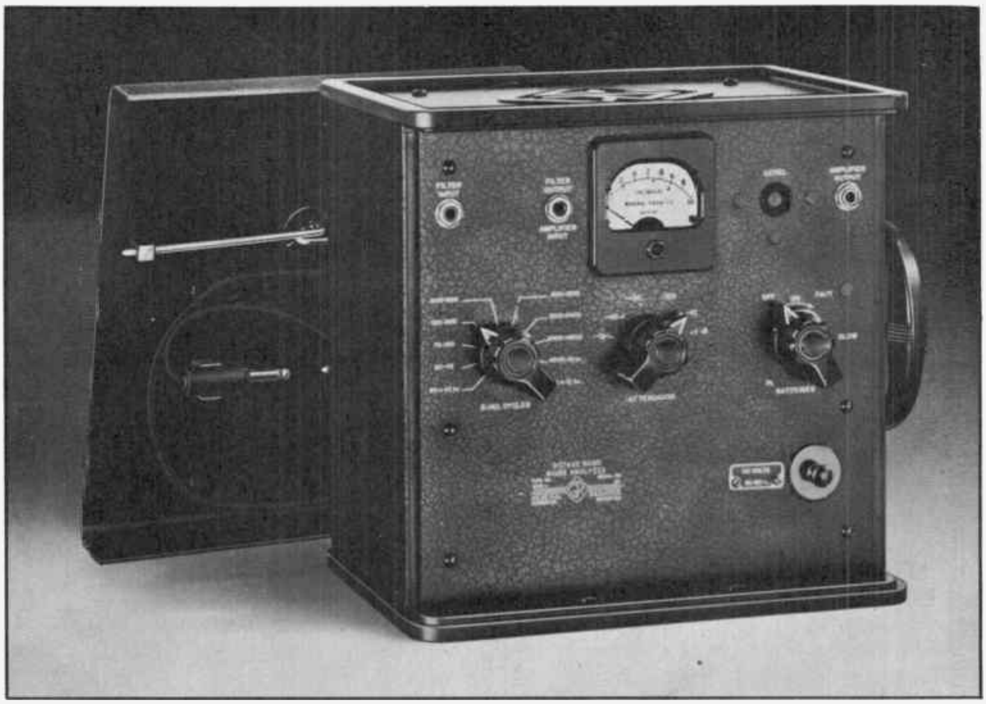


Dimensions: 6 x 3⅛ x 2½ inches, over-all but excluding output cable.

Net Weight: 1 pound, 14 ounces, with batteries.

Type		*Code Word*	*Price*
1307-A	**Transistor Oscillator**	OMEGA	**$88.00**
1555-P1	**Leather Carrying Case**	CASER	**10.00**

TYPE 1550-A OCTAVE-BAND NOISE ANALYZER



USES: The Octave-Band Noise Analyzer makes possible the simple and rapid analysis of noises having complex spectra. Operating from the output of a sound-level meter (page 9), it is more convenient than the Sound Analyzer for those applications where a knowledge of the individual frequency components is not required; and, in addition, is particularly suited for noise measurements on aircraft, vehicles, and machinery, for the analysis of office noise, where speech interference level is the significant factor and for determination of the possible damaging effects of noise on hearing. Another important application is in determining the acoustical characteristics of rooms. It is particularly valuable in production testing and for noise-level acceptance tests.

DESCRIPTION: The analyzer consists of a set of band-pass filters with selection by means of a rotary switch, followed by an attenuator and an amplifier, which drives both an indicating meter and a monitoring output.

The filter is isolated by a resistance pad, which makes the filter characteristics independent of the source, provided the source impedance either is small compared to the 20,000-ohm analyzer impedance or is constant over the audio-frequency range.

FEATURES: ➔ Small, compact, lightweight.

➔ Excellent attenuation characteristics.

➔ Monitoring output is provided.

➔ Meets A.S.A. standards.

➔ Operates from output of the Type 1551-A or the Type 759-B Sound-Level Meter as well as other sound-level meters with outputs adequately free from noise and distortion.

➔ Can be used directly with microphone for high sound levels.

➔ Amplifier input jack permits amplifier to be used alone.

➔ A-C power supply can be substituted for batteries for laboratory use.

SPECIFICATIONS

Range: 20 cycles to 10,000 cycles in 8 bands,

20 c to 75 c (low pass)
75 c to 150 c
150 c to 300 c
300 c to 600 c
600 c to 1200 c
1200 c to 2400 c
2400 c to 4800 c
4800 c to 10,000 (high pass)

In addition, a band with a flat characteristic from 20 c to 10 kc is available at two switch positions for convenience in calibration against the sound-level meter.

Input Level: Between 1 and 10 volts for normal range. Levels below one volt reduce the range of reading; those higher than 10 volts overload the filters.

Input Impedance: 20,000 ohms. Input is isolated by a resistance pad, so that performance is independent of source if source impedance is constant over audio range or is small compared to 20,000 ohms.

Source: Sound-level meter supplying analyzer input must have low hum, low internal noise, and low distortion. The Type 1551-A or the Type 759-B Sound-Level Meter is recommended.

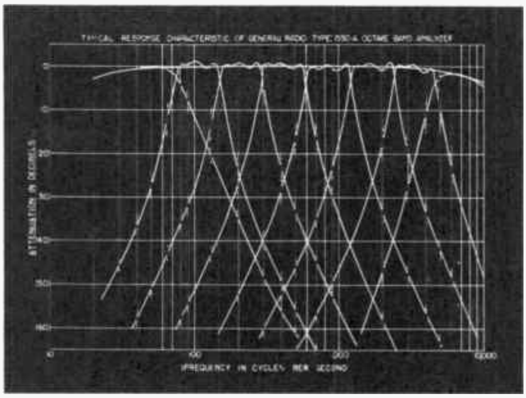
Direct Use with Microphone: The Type 1551-P1 Condenser Microphone System can be used if the band levels exceed 60 db, or the Type 759-P25 Dynamic Microphone Assembly can be used if the band levels exceed 70 db (re 0.0002 μbar). A Type 1550-P1 Microphone Adaptor Plug is required with the Type 759-P25 Dynamic Microphone Assembly.

Level Indication: Meter calibrated in decibels from −6 to +10 db; attenuator covers 50 db in 10 db steps. Level is sum of meter and attenuator readings.

Attenuation: Except for the lowest and highest bands, at least 30-db attenuation is obtained at one-half the lower nominal cut-off frequency and twice the upper nominal cut-off frequency; at least 50-db attenuation is obtained at one-fourth the lower nominal cut-off frequency and at four times the upper nominal cut-off frequency. The 75-cycle low-pass filter has at least 30-db attenuation at 200 c and 50 db at 400 cycles. The 4800-cycle high-pass filter has at least 30-db attenuation at 2400 cycles and 50 db at 1200 cycles.

Tubes: Three 1U4 and one 1T4, all furnished.

Power Supply: Battery, Burgess 6TA60. Battery is included in price. For a-c operation, Type 1261-A Power Supply (page 101) fits battery compartment.



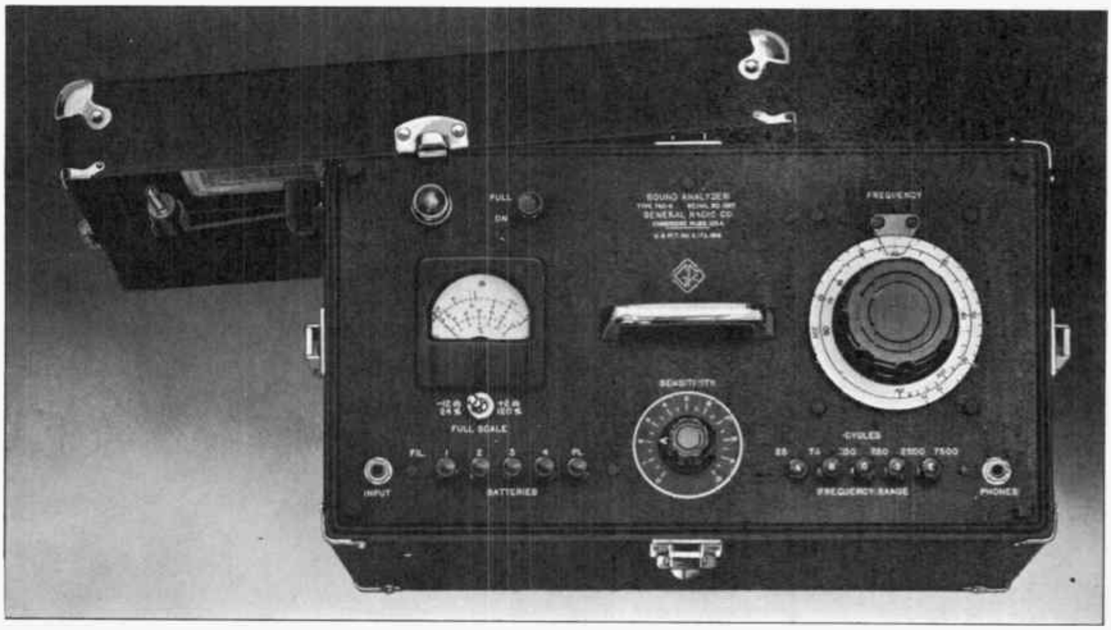
Accessories Supplied: Shielded cable and plug assembly for connecting analyzer to sound-level meter.

Dimensions: (Width) 11⅝ x (height) 12$\frac{9}{16}$ x (depth) 9 inches, over-all.

Net Weight: 27 pounds including battery.

Type		*Code Word*	*Price*
1550-A	**Octave-Band Noise Analyzer**	ABEAM	**$535.00**
	Replacement Battery for above	ABEAMADBAT	**5.79**
1550-P1	**Microphone Adaptor Plug**	MATOR	**4.00**
1261-A	**Power Supply**	NUTTY	**128.00**

TYPE 760-B SOUND ANALYZER



USES: This instrument has been designed particularly for analyzing the noises produced by electrical and mechanical equipment, such as airplane and automobile engines, industrial machinery, and household appliances. It operates from the output of the Sound-Level

Meter and measures the amplitude of each individual frequency component, or pitch, in the noise. This information is valuable in tracing and locating the sources of noise.

In the electrical laboratory, the Sound Analyzer can be used as a harmonic analyzer and as a selective bridge balance indicator.

DESCRIPTION: The circuit is that of a three-stage degenerative selective amplifier having a bandwidth that is a constant percentage of the operating frequency, followed by a voltmeter. The frequency to which the amplifier is tuned is indicated by a single dial and push-button multiplier. The amplitude of the selected component is indicated directly on the meter scale.

FEATURES: ➔ External magnetic fields do not affect readings.

➔ Constant-percentage bandwidth is an advantage for measurements on machines whose speeds fluctuate.

➔ Dial can be rotated continuously in either direction, so that the analyzer can be adapted for automatic recording.

SPECIFICATIONS

Frequency Range: From 25 to 7500 cycles per second, direct reading. This total range is covered in five complete turns of the tuning knob, the ranges on the various dial rotations being 25 to 75, 75 to 250, 250 to 750, 750 to 2500, and 2500 to 7500 cycles. A push-button switch allows immediate change of the main control to any one of these ranges.

Frequency Calibration Accuracy: ±1.5% of the frequency to which the dial is set or ±1.5 cycles per second, whichever is the larger.

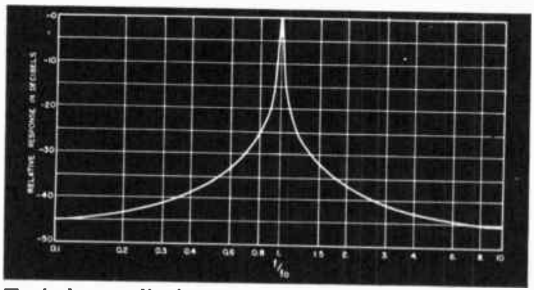
Input Voltage Range: 1 millivolt to 10 volts for usable indications. The meter scale is calibrated for reading directly component tones down to 1% of the sound pressure (or voltage) of the fundamental or loudest component. Hence the input voltage at the loudest component or fundamental should be 0.1 volt or higher.

Input Impedance: Between 20,000 and 30,000 ohms, depending upon the setting of the sensitivity control. A blocking capacitor is in series with the input.

Frequency Response: Flat within ±2 db over the entire range. At points where two ranges overlap, the sensitivity is the same on either range, within ±1 db.

Band Width: Relative attenuation is 3 db at 1% off the peak to which the analyzer is tuned.

Direct Use with Microphone: The Type 1551-P1 Condenser Microphone System can be used if the component levels exceed 60 db, or the Type 759-P25 Dynamic Microphone Assembly can be used if the component levels exceed 70 db (re 0.0002 μbar). A Type 1550-P1 Microphone Adaptor Plug is required with the dynamic microphone.



Typical normalized response curve for the Type 760-B.

Temperature and Humidity Effects: Under very severe conditions of temperature and humidity slight shifts in calibration, sensitivity, and bandwidth may occur.

Meter: The indicating meter is calibrated in two ranges. For convenience in use the meter scale is calibrated with the 0 located 2 db below full scale on the meter, so that actual meter scales are +2 to −30 db and −12 to −40 db. Auxiliary percentage ranges of 0 to 120% and 0 to 24% are provided.

Output: A jack is provided on the panel for plugging in a pair of head telephones, in order to listen to the actual component of the sound to which the instrument is tuned. This is also useful when the analyzer is used as a bridge-balance indicator.

Tubes: Three 1L4-type and one 1U4-type are used, together with a neon pilot light (NE-48). All are supplied.

Batteries: The batteries required are four Burgess No. 2FBP 1.5-volt batteries, or the equivalent, and three Burgess No. Z30NX 45-volt batteries, or the equivalent. A battery compartment is provided in the case of the analyzer. Batteries are supplied with instrument.

Accessories Supplied: A shielded cable-and-plug assembly for connecting the analyzer to the sound-level meter.

Case: Shielded carrying case of airplane-luggage construction.

Dimensions: (Length) 18 x (width) 10 x (height) 11½ inches, over-all.

Net Weight: 36½ pounds, with batteries.

Type		*Code Word*	*Price*
760-B	**Sound Analyzer**	ATTAR	**$520.00**
Set of Replacement Batteries for above		ATTARADBAT	**12.02**
1550-P1	**Microphone Adaptor Plug**	MATOR	**4.00**

U. S. Patent No. 2,173,426.

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