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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

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THE NOISE PRIMER

PART III

THE DECIBEL—WHAT IS IT?

● IN SOUND MEASUREMENTS the results are expressed in decibels. The higher the number of decibels, the louder the sound. Zero decibels represent roughly the weakest sound which can be heard by a person with very good hearing. In practical noise measurements anything below 24 decibels can generally be considered so nearly inaudible as to be of no importance. In fact, except in unusually quiet locations, noises below 40 decibels may generally be disregarded.

From the strictly technical standpoint, a given number of decibels represents a ratio, since the decibel is a logarithmic unit. In terms of sound pressure the formula is

$$db = 20 \log_{10} \frac{E_2}{E_1} \qquad (1)$$

where E_1 and E_2 represent the two sound pressures being compared.[4] This applies only under conditions where the power is strictly proportional to the square of the pressure, which is generally

[4]This is the same formula that is used in electrical communications to compare two voltages operating at the same impedance levels.

Figure 4. Calibrating a Type 759-B Sound-Level Meter in the General Radio standardizing laboratory.

true for sound measurements in air.

In sound measurements decibels represent not merely ratios, but absolute levels, since a standard reference level has been agreed upon. This level is 0.002 dynes per square centimeter at 1000 cycles.[5] This reference level is approximately 16 db below the average threshold of hearing.[6]

Do Not Add Decibels

Since the decibel is essentially a logarithm, addition of decibels produces multiplication of sound pressures. For instance, increasing any sound level by 6 decibels is equivalent to doubling the sound pressure. Do not try, therefore, to add two sound levels together by ordinary addition. Sounds of a general and complex nature add approximately as the relative sound power involved. That is, two sounds of equal power, when added together, produce twice the power, which is $\sqrt{2}$ times (not twice) the sound pressure.

The Equation (1) for decibels expressed in terms of sound pressure represents a special case which is valid only because, under conditions generally encountered, the air has a constant impedance. The more fundamental equation is expressed directly in terms of power and is

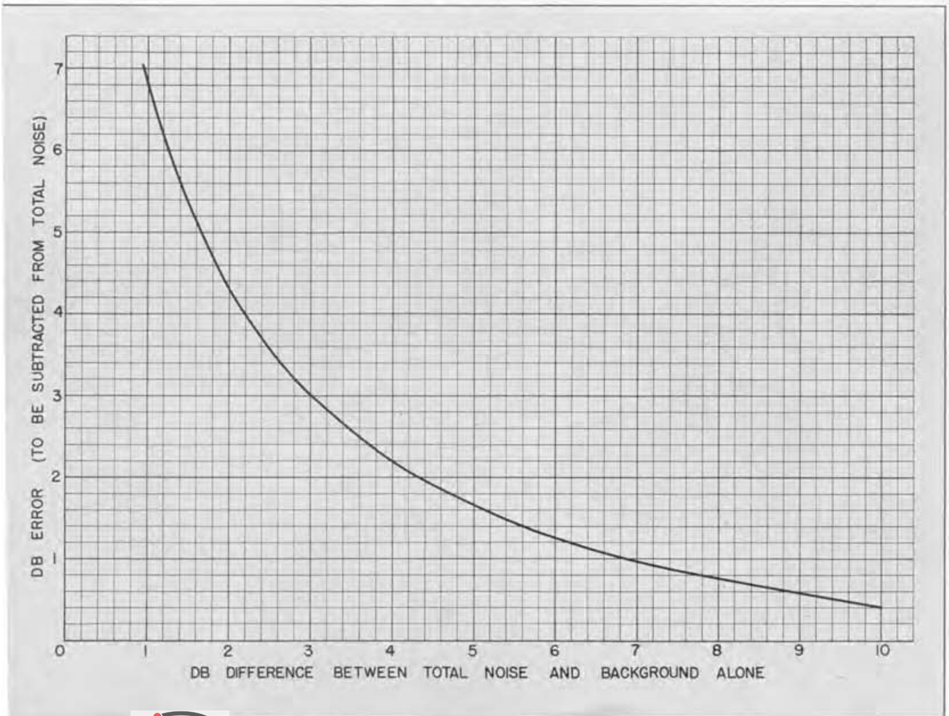
$$\text{db} = 10 \log_{10} \frac{P_2}{P_1} \qquad (2)$$

where P_1 and P_2 are the sound powers

[5]Sound-level meter microphones respond to sound pressure. 0.0002 dynes per square centimeter is the practical equivalent of 10^{-16} watts per square centimeter, as specified in the American Standards Association Bulletin Z24.3—1936.

[6]See Steinberg, Montgomery, and Gardiner, "Results of the World's Fair Hearing Tests," Journal of the Acoustical Society of America, Vol. XII, No. 2, pages 291–301, October, 1940.

Figure 5. Error introduced in sound measurements by background noise (from L. E. Packard, "Background Noise Corrections in the Measurement of Machine Noise," General Radio *Experimenter*, Vol. XII, pp. 6, 7, Dec., 1937).



involved.[7] The standard zero reference level in terms of power is approximately 10^{-16} watts per square centimeter at 1000 cycles.

A slide rule, logarithm table, or, more conveniently, a decibel table (obtainable on request to the General Radio Company) is accordingly necessary for adding together sound levels expressed in decibels.

As an example, assume a sound of 50 decibels is to be added to one of 53 decibels. Looking in the decibel table, we find that the first represents a relative power ratio of 10^5, while the second represents a relative power ratio of 2×10^5. Adding these together, we get a total of 3×10^5, which is equivalent to 54.8 decibels.

A simple relation to remember is that doubling the sound power is about equal to an increase of 3 decibels, so that when equal sound levels are added together, regardless of their actual value, the resulting level is 3 decibels higher than that of the originals. Thus, 40 db + 40 db = 43 db, etc. If you add to a first sound a second which is 10 db lower in level (1/10 power) the resulting level is 0.4 db higher than the first sound alone, which is a negligible increase for most purposes.[8]

Background Noise

One of the most frequent applications involving the addition or subtraction of sound levels is the correction of readings for background noise. Ordinarily, of course, sound measurements should be made under conditions where the background noise level is negligible — that is, at least 10 db below the level being measured. However, this is not always possible, and the curve shown in Figure 5 is convenient in those cases. The horizontal scale of this chart represents the difference in sound-meter reading with and without the machine under test in operation. The vertical scale represents the number of db to be subtracted from the total reading (machine plus background noise) to obtain the noise level generated by the machine alone.

Loudness

It is generally assumed that the response of the ear to variations in sound intensity is logarithmic, but this is not strictly true. Figure 6 represents the actual relationship between the loudness as estimated by a large number of observers and loudness level. This curve shows loudness in L. U. (Loudness Units) plotted versus loudness level in phons.[9] Loudness level in phons is equivalent for most practical purposes to

[7] This is the exact equivalent of the electrical case, and the formula is the same as that which applies in general communications problems, where zero level is usually 1 milliwatt in a 600-ohm line.

[8] The exception to this would be when the two sounds were of markedly different character. This will be discussed in a later article.

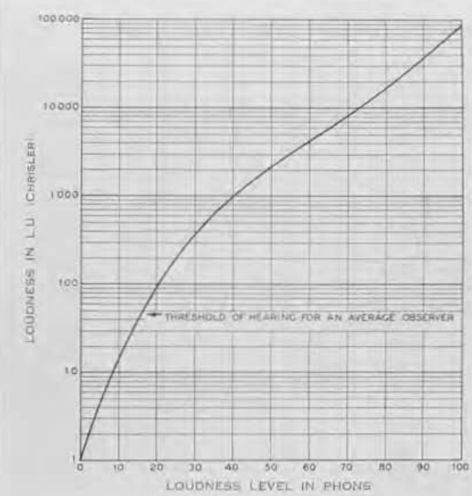


FIGURE 6. Relation between loudness level, from "American Standard for Noise Measurement," American Standards Association Bulletin Z24.2—1942.

sound level as measured by a sound-level meter, assuming that the meter has exactly the correct frequency response for the particular level being measured.

[3]A complete table of the function plotted in Figure 6 is given in the American Standards for Noise Measurement, A.S.A. Bulletin Z24.2—1942. This information is based upon the paper by Fletcher and Munson in the October, 1933, issue of the Journal of the Acoustical Society, referred to last month in Note 1.

In the strictest interpretation, loudness level in phons is measured by adjusting a 1000-cycle tone to exactly the same loudness as heard by the ear as the noise being measured, and then measuring the intensity of the 1000-cycle tone as with a sound-level meter. Loudness level and sound level correspond exactly, therefore, only for 1000-cycle tones.

As a practical matter, a sound-level meter, when the network corresponding most closely to the level being measured is used, provides readings closely approximating loudness level in phons. Phons and loudness units are seldom used in machinery noise problems, but do have some application in physiological and psychological work.

PART IV

HOW TO USE A SOUND-LEVEL METER

Operating Instructions

Manufacturers have tried to make sound-level meters as simple to operate as possible. The instruction sheets covering the actual mechanics of operating General Radio Company's Type 759-A and Type 759-B instruments are mounted in the covers. For those who may be unacquainted with the instruments, however, the following may be of interest.

A standard sound-level meter has, aside from various minor controls, three main controls and indicators which are used in taking the readings. The first of these is a knob generally marked "Weighting" and providing choice of any of three frequency characteristics shown in Figure 2 of last month's article. The second is a knob generally marked "Decibels," which shifts the sensitivity of the instrument in steps of 10 db. The third is an indicating meter calibrated over a range of approximately 16 db, which in effect interpolates between the readings of the decibels control. In operation the reading of the meter is added to that of the decibels control.

Other controls are generally provided for checking the calibration, changing the meter speed, etc.

Test Code

The American Institute of Electrical Engineers has formu-

Figure 7. Panel View of the General Radio Type 759-B Sound-Level Meter.

lated a test code covering certain standard methods of procedure particularly well adapted to the measurement of noises made by electrical machinery. The code is by no means complete and consequently does not apply in all cases, but it does form a basis for more specialized codes applying to individual applications.[10] In particular, it specifies standard test distances which can generally be followed in almost all cases. The standard test distances are 6 inches, 1 foot, and 3 feet. The distance should be measured between the nearest major surface of the machine under test and the microphone. When the microphone is mounted close to or on the sound-level meter case, that end of the case should face the sound source.

Microphone Placement

Remember that the sound-level meter measures sound pressure *at* the microphone, and that the sound pressure varies throughout a normal room and around a machine or other sound source. Microphone placement is probably the most important operation in the noise measurement procedure and about the only "trick" that has to be mastered by the beginner.

[10]A I.E.E. Test Code for Apparatus Noise Measurement, A.I.E.E. Bulletin No. 520, March, 1939, published by the American Institute of Electrical Engineers, 33 West 39th Street, New York, N.Y., price 30 cents. The test code is now being revised by the American Standards Association in collaboration with the A.I.E.E. Information on the revised code will be supplied as soon as it is available.

To measure with great accuracy the total noise output from a machine, it would be necessary to take an infinite number of measurements all around the machine and integrate the results. In actual practice measurements are made at equal intervals around a machine and at a fixed distance from it, the actual number of such measurements depending upon the complexity of the sound pattern and the importance of the results. Where extreme accuracy is not required, and particularly when the readings to be averaged are within a range of 10 decibels or so, a simple arithmetic average of the decibel readings is generally sufficient.

A more exact method involves converting the decibel readings to their corresponding relative power values, averaging these, and converting back to decibels. The procedure is similar to and involves the same equation as that previously described for the addition of sound levels, except that in this case the sum of the corresponding powers is divided by the number of readings to obtain an average, as shown in Table I, below.

This is the fairest way of comparing machines of different types or characteristics, but a simpler procedure can generally be used when comparing similar machines, as in production testing.

TABLE I

Microphone Position	*Decibels Sound Level*	*Relative Sound Power (Antilog 1/10 Sound Level)*
I	50	100,000
II	55	316,200
III	70	1,000,000
IV	55	316,200
		4)1,732,400 total
		433,100 average

$10 \log_{10} 433{,}100 = 56.4$ decibels.

A test position can be selected which gives a single reading that *varies* closely with the average noise as determined by the above method. This single test position is not necessarily one giving the *same* reading as the average. Usually it will be the position providing the *highest* reading.

This procedure may be modified in individual cases. For machines having a very pronounced noise pattern, two or more test positions providing fairly high readings might be used. On such machines, it is sometimes desirable, in order to get a better check on the total noise, to measure the level at these several maxima in the noise pattern and average the results, either arithmetically or according to relative power levels. This, of course, yields an average higher than the general average, and usually a more sensitive one. It provides a fair comparison only between similar machines. In comparing dissimilar machines, only a general average, taken with as many microphone positions as necessary, will be fair.

Choice of Weighting Curve

Aside from microphone placement, selection of the correct weighting curve is the next important factor in making noise measurements. Changing the weighting curve can produce variations in the results ranging from negligible differences in the medium and upper frequency range to variations of 20 or 30 decibels at low frequencies.

When all that is desired is knowledge of the sound level at the microphone, the problem is relatively simple. The following table shows the sound-level ranges and the weighting curve recommended:

Sound-Level Range	*Weighting Curve*
24- 55 db	A (40 db)
55- 85 db	B (70 db)
85-140 db	C (Equal response over entire range)

Strict use of this table will sometimes be impossible. For instance, a sound may read 54 decibels on the A characteristic and 56 decibels on the B, due to the greater weight given to low frequencies on the B curve. Similarly, although not so likely, a sound with a large amount of energy in the region of 2000 cycles might possibly read 56 db on the A curve and 54 db on the B. There is still, therefore, some judgment required in choosing the best curve to use under these conditions, but the following procedure is generally satisfactory. If the measurement is one of a series, most of which fall well within the range of a particular curve, this setting should be used for all measurements. If no such clear-cut distinction exists, it is desirable to record measurements made with both curves, noting, of course, the curve designation as well as the level. Where actual loudness is important, rather than mere changes in loudness or physical values, it is sometimes desirable to make measurements on both curves and average the results.

Always record the weighting curve designation as well as the decibel values.

Noise at Distance

It is not always the sound level at the microphone which is important, but rather the annoyance which the noise will produce at some distance. Under these conditions the choice of the weighting curve should be based upon the level at the point where the annoyance exists, although measurements may actually be made close to the machine as a matter of convenience.

For instance, assume the problem is to quiet an airplane motor test chamber so that, with an engine running under test at full speed, neighbors some distance away will not be disturbed by the noise. Assume that at the neighbors' homes the sound has a level below 55 decibels. Measurements made on the test chamber, therefore, even though they may be made close by as a matter of convenience and at a level considerably above 55 decibels, should be made on the A (40 db) characteristic. The measurements then will be a much better indication of the value of any quieting procedure than if they were made with the B or the C characteristic, since the meter will be operating with a frequency response more nearly duplicating that of the ears of the neighbors under the actual listening conditions.

Physical Measurements

Wherever actual physical measurements of sound pressure are desired, or where the sound meter is to be used with an analyzer, it is generally desirable to use the C characteristic, which provides substantially equal response over the audio-frequency range. Reasons for this will be discussed in a later article.

— H. H. Scott

IF YOU MUST TELEPHONE

● **WHEN YOU COMMUNICATE** with us on business or technical matters, letters are by far the most satisfactory method. They make a permanent record and allow time to prepare a well organized and complete reply. The next best method is to telegraph. This method still gives the permanent record, but it is usually less complete than a letter can be.

If, however, the requirement is too urgent to permit the use of slower methods, and telephoning is essential, it is highly desirable to have your call routed to the proper person with a minimum of delay. Naturally, with the hundreds of active orders handled every day, no one person in our organization can know all the answers, but the following list indicates those who are likely to be best informed on the various subjects. When in doubt, ask our operators.

To determine the delivery status of orders already placed:

Mr. H. P. Hokanson — Extension 25

To check matters of credit:

Mr. C. E. Hills, Jr. — Extension 50

To inquire about probable delivery and prices of equipment under consideration, but not ordered:

Mr. M. T. Smith — Extension 30
Mr. I. G. Easton — Extension 94

To inquire about matters pertaining to maintenance and repair:

Mr. H. H. Dawes — Extension 24
Mr. K. Adams — Extension 79

It must be emphasized that it takes time to check up on the myriad details that may be associated with an order — with luck, it may be only a few minutes, but it often takes much longer.

USE OUR DISTRICT OFFICES

● **MANY OF OUR CUSTOMERS** know that the General Radio Company maintains branch engineering offices in New York City and Los Angeles, California. This fact may have been overlooked by others recently transferred to these areas.

These offices have been established

primarily for the convenience of our customers in the regions served. Each office is in the charge of a member of our Cambridge engineering staff, who is prepared to furnish technical data regarding the instruments which we manufacture and to recommend uses and applications. Much information which ordinarily would be transmitted to the customer in letter form is available by telephone in the New York City and Los Angeles areas.

Every effort is made to keep the District Office engineers fully informed of the current delivery situation of all of the many catalog items which we manufacture. It is often possible for these offices to suggest satisfactory alternative arrangements of test equipment on which the shortest delivery can be realized.

A limited stock of general catalogs and bulletins relating to special instruments is maintained at these offices and will be forwarded upon request.

Under present conditions it is difficult to keep the District Office engineers fully informed of the status of the many orders placed with us. The delivery information on file at these offices is sufficient so that a valid estimate of the delivery on a new inquiry can be made on the basis of a high priority rating. If, however, you wish specific delivery information on an order which has been placed with us for some time, our District Offices will obtain the data you require from our factory, and will see that the report reaches you in the minimum possible time.

Service difficulties cannot usually be handled in the field or at the District Offices. However, our District Office engineer will be glad to consult with you regarding any trouble which might occur. He may be able to suggest minor adjustments and repairs that you can make in your own plant with the help of our Service and Maintenance Notes, and will make arrangements for service work to be done at our factory when required.

The engineer in charge of our New York Office, at 90 West Street, is Mr. L. E. Packard. Mr. Packard may be reached by telephone at COurtlandt 7-0850. Mr. Frederick Ireland of our engineering staff is located at our office at 1000 North Seward Street, Los Angeles, California. He may be reached at Hollywood 6321.

SERVICE DEPARTMENT NOTES

ERRATA

● THE FOLLOWING ERRORS have been noted in service information published in recent issues of the *Experimenter*.

November, 1942:

In the article entitled "Orders for Replacement Parts," the plug listed as Type 2173, page 8, should have been 2713.

January, 1943:

In the list of substitute batteries for Type 814-AM Amplifier, page 7, for "any 115-volt flashlight cell," read "any 1.5-volt flashlight cell."

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