



# An Introduction to the Fundamentals of Acoustics

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# An Introduction to the Fundamentals of Acoustics

J. Paul Guyer, P.E., R.A.

## 1. INTRODUCTION

**1.1. THIS DISCUSSION** presents the basic quantities used to describe acoustical properties. For the purposes of the material contained in this document perceptible acoustical sensations can be generally classified into two broad categories, these are:

- **Sound.** A disturbance in an elastic medium resulting in an audible sensation. By definition, noise is “unwanted sound.”
- **Vibration.** A disturbance in a solid elastic medium which may produce a detectable motion.

**1.2. ALTHOUGH THIS DIFFERENTIATION** is useful in presenting acoustical concepts, in reality, sound and vibration are often interrelated. That is, sound is often the result of acoustical energy radiation from vibrating structures and, sound can force structures to vibrate. Acoustical energy can be completely characterized by the simultaneous determination of three qualities. These are:

- **Level or Magnitude.** This is a measure of the intensity of the acoustical energy.
- **Frequency or Spectral Content.** This is a description of an acoustical energy with respect to frequency composition.
- **Time or Temporal Variations.** This is a description of how the acoustical energy varies with respect to time.

**1.3. THE SUBSEQUENT MATERIAL** in this discussion defines the measurement parameters for each of these qualities that are used to evaluate sound and vibration.

**2. DECIBELS.** The basic unit of level in acoustics is the “decibel” (abbreviated dB). In acoustics, the term “level” is used to designate that the quantity is referred to some reference value, which is either stated or implied.

**2.1. DEFINITION AND USE.** The decibel (dB), as used in acoustics, is a unit expressing the ratio of two quantities that are proportional to power. The decibel level is equal to 10 times the common logarithm of the power ratio; or

$$\text{dB} = 10 \log \frac{P_1}{P_2} \quad (\text{eq 1})$$

In this equation,  $P_1$  is the absolute value of the power under evaluation and  $P_2$  is an absolute value of a power reference quantity with the same units. If the power  $P_2$  is the accepted standard reference value, the decibels are standardized to that reference value. In acoustics, the decibel is used to quantify sound pressure levels that people hear, sound power levels radiated by sound sources, the sound transmission loss through a wall, and in other uses, such as simply “a noise reduction of 15 dB” (a reduction relative to the original sound level condition). Decibels are always related to logarithms to the base 10, so the notation 10 is usually omitted. It is important to realize that the decibel is a dimensionless quantity (somewhat analogous to “percent”). Therefore, when using decibel levels, reference needs to be made to the quantity under evaluation and the reference level. It is also instructive to note that the decibel level is primarily determined by the magnitude of the absolute value of the power level. That is, if the magnitude of two different power levels differ by a factor of 100 then the decibel levels differ by 20 dB.

**2.2. DECIBEL ADDITION.** In many cases, cumulative effects of multiple acoustical sources must be evaluated. In this case the individual sound levels should be summed. Decibel levels are added logarithmically and not algebraically. For example, 70 dB plus 70 dB does not equal 140 dB, but only 73 dB. A very simple, but usually adequate, schedule for obtaining the sum of two decibel values is:

When two decibel values differ by	Add the following amount to the higher value
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	0 dB

When several decibel values to be added equation 2 should be used.

$$L_{\text{sum}} = 10 \log \left[ 10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + \dots + 10^{\frac{L_{pn}}{10}} \right] \quad (\text{eq 2})$$

In the special case where decibel levels of equal magnitudes are to be added, the cumulative level can be determined with equation 3.

$$L_{\text{sum}} = L_p + 10 \log(n) \quad (\text{eq 3})$$

where n is the number of sources, all with magnitude  $L_p$ .

**2.3. DECIBEL SUBTRACTION.** In some cases, it is necessary to subtract decibel levels. For example, if the cumulative level of several sources is known, what would the cumulative level be if one of the sources were reduced? Decibel subtraction is given by equation 4.

$$L_{\text{diff}} = 10 \log \left[ 10^{\frac{L_{p1}}{10}} - 10^{\frac{L_{p2}}{10}} \right] \quad (\text{eq 4})$$

**2.4. DECIBEL AVERAGING.** Strictly speaking decibels should be averaged logarithmically not arithmetically. Equation 5 should be used for decibel averaging.

$$L_{\text{avg}} = 10 \log \left[ \frac{10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + \dots + 10^{\frac{L_{pn}}{10}}}{n} \right] \quad (\text{eq 5})$$

**3. SOUND PRESSURE LEVEL ( $L_p$  or SPL).** The ear responds to sound pressure. Sound waves represent tiny oscillations of pressure just above and below atmospheric pressure. These pressure oscillations impinge on the ear, and sound is heard. A sound level meter is also sensitive to sound pressure.

**3.1. DEFINITION, SOUND PRESSURE LEVEL.** The sound pressure level (in decibels) is defined by:

$$L_p = 10 \log \left[ \left( \frac{p}{P_{\text{ref}}} \right)^2 \right] \quad (\text{eq 6})$$

Where  $p$  is the absolute level of the sound pressure and  $p_{ref}$  is the reference pressure. Unless otherwise stated the pressure,  $p$ , is the effective root mean square (rms) sound pressure. This equation is also written as:

$$L_p = 20 \log \left[ \left( \frac{p}{p_{ref}} \right) \right] \quad (\text{eq 7})$$

Although both formulas are correct, it is instructive to consider sound pressure level as the log of the pressure squared (eq 6). This is because when combining sound pressure levels, in almost all cases, it is the square of the pressure ratios (i.e.  $\{p/P_{ref}\}^2$ 's) that should be summed not the pressure ratios (i.e. not the  $\{p/P_{ref}\}$ 's). This is also true for sound pressure level subtraction and averaging.

**3.2. DEFINITION, REFERENCE PRESSURE.** Sound pressure level, expressed in decibels, is the logarithmic ratio of pressures where the reference pressure is 20 micropascal or 20 uPa (Pascal, the unit of pressure, equals 1 Newton/m<sup>2</sup>). This reference pressure represents approximately the faintest sound that can be heard by a young, sensitive, undamaged human ear when the sound occurs in the frequency region of maximum hearing sensitivity, about 1000 Hertz (Hz). A 20 uPa pressure is 0 dB on the sound pressure level scale. In the strictest sense, a sound pressure level should be stated completely, including the reference pressure base, such as “85 decibels relative to 20 uPa.” However, in normal practice and in this discussion, the reference pressure is omitted, but it is nevertheless implied.

**3.3. ABBREVIATIONS.** The abbreviation SPL is often used to represent sound pressure level, and the notation  $L_p$  is normally used in equations, both in this discussion and in the general acoustics literature.

**3.4. LIMITATIONS ON THE USE OF SOUND PRESSURE LEVELS.** Sound pressure levels can be used for evaluating the effects of sound with respect to sound level criteria. Sound pressure level data taken under certain installation conditions cannot be used to predict sound pressure levels under other installation conditions unless modifications are applied. Implicit in these modifications is a sound power level calculation.

**4. SOUND POWER LEVEL ( $L_w$  or PWL).** Sound power level is an absolute measure of the quantity of acoustical energy produced by a sound source. Sound power is not audible like sound pressure. However, they are related (see section 6). It is the manner in which the sound power is radiated and distributed that determines the sound pressure level at a specified location. The sound power level, when correctly determined, is an indication of the sound radiated by the

source and is independent of the room containing the source. The sound power level data can be used to compare sound data submittals more accurately and to estimate sound pressure levels for a variety of room conditions. Thus, there is technical need for the generally higher quality sound power level data.

**4.1. DEFINITION, SOUND POWER LEVEL.** The sound power level (in decibels) is defined by:

$$L_w = 10 \log \frac{P}{P_{\text{ref}}} \quad (\text{eq 8})$$

Where  $P$  is the absolute level of the sound power and  $P_{\text{ref}}$  is the reference power. Unless otherwise stated the power,  $P$ , is the effective root mean square (rms) sound power.

**4.2. DEFINITION, REFERENCE POWER.** Sound power level, expressed in decibels, is the logarithmic ratio of the sound power of a source in watts (W) relative to the sound power reference base of  $10^{-12}$  W. Before the US joined the ISO in acoustics terminology, the reference power in this country was  $10^{-13}$  W, so it is important in using old data (earlier than about 1963) to ascertain the power level base that was used. If the sound power level value is expressed in dB relative to  $10^{-13}$  W, it can be converted to dB relative to  $10^{-12}$  W, by subtracting 10 dB from the value. Special care must be used not to confuse decibels of sound pressure with decibels of sound power. It is often recommended that power level values always be followed by the notation “dB re 10<sup>-12</sup>W.” However, in this discussion this notation is omitted, although it will always be made clear when sound power levels are used.

**4.3. ABBREVIATIONS.** The abbreviation PWL is often used to represent sound power level, and the notation  $L_w$  normally used in equations involving power level. This custom is followed in the manual.

**4.4. LIMITATIONS OF SOUND POWER LEVEL DATA.** There are two notable limitations regarding sound power level data: Sound power cannot be measured directly but are calculated from sound pressure level data, and the directivity characteristics of a source are not necessarily determined when the sound power level data are obtained.

- **PWL Calculated, Not Measured.** Under the first of these limitations, accurate measurements and calculations are possible, but nevertheless there is no simple measuring instrument that reads directly the sound power level value. The procedures involve either comparative sound pressure level measurements between a so-called standard sound source and the source under test (i.e. the “substitution method”), or

very careful acoustic qualifications of the test room in which the sound pressure levels of the source are measured. Either of these procedures can be involved and requires quality equipment and knowledgeable personnel. However, when the measurements are carried out properly, the resulting sound power level data generally are more reliable than most ordinary sound pressure level data.

- **Loss of directionality characteristics.** Technically, the measurement of sound power level takes into account the fact that different amounts of sound radiate in different directions from the source, but when the measurements are made in a reverberant or semi-reverberant room, the actual directionality of the radiated sound is not obtained. If directivity data are to be obtained, measurements must be made either outdoors, in a totally anechoic chamber, or in a large open field to avoid any reflection that might distort the sound radiation pattern, or in a semi-anechoic chamber using special measurement techniques. This restriction applies to all sound power measurements.

## 5. SOUND INTENSITY

like sound power, is a scalar quantity. Sound intensity,  $I$ , relates sound power to sound pressure. Strictly speaking, sound intensity is the rate of sound energy through a unit area in a sound field. It is a vector quantity, having both a magnitude and direction. If the sound field is plane wave, it has both a magnitude and direction. Sound intensity is not directly measurable, but sound intensity can be measured indirectly.

### 5.1. DEFINITION, SOUND INTENSITY LEVEL

(decibels) is defined by:

$$L_i = 10 \log \frac{I}{I_{ref}} \quad (\text{eq 9})$$

Where  $I$  is the absolute level of the sound intensity and  $I_{ref}$  is the reference intensity. Unless otherwise stated the intensity,  $I$ , is the effective root mean square (rms) sound intensity.

**5.2. DEFINITION, REFERENCE INTENSITY.** Sound intensity level, expressed in decibels, is the logarithmic ratio of the sound intensity at a location, in watts/square meter ( $\text{W}/\text{m}^2$ ) relative to the sound power reference base of  $10^{-12} \text{ W}/\text{m}^2$ .

**5.3. NOTATION.** The abbreviation  $L_i$  is often used to represent sound intensity level. The use of  $IL$  as an abbreviation is not recommended since this is often the same abbreviation for "Insertion Loss" and can lead to confusion.

