Noise and Hearing Conservation

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Printing Instructions

Appendix I:A. Physics of Sound

The physics of sound can be described in terms of the following:

Basic Qualities

TOP

Frequency

- The number of vibrations, or complete cycles, that take place in one second is the frequency (f).
- Frequency is measured in units of hertz (Hz).
  - One Hz = One cycle per second
- The frequency range of the human ear varies considerably among individuals.
- A young person with normal hearing will be able to perceive frequencies between approximately 20 and 20,000 Hz. With increasing age, the upper frequency limit tends to decrease.
- Frequencies around 2,000 Hz are the most important for understanding speech, while frequencies between 3,000 Hz and 4,000 Hz are the earliest to be affected by noise.

Wavelength

- The distance traveled by a sound wave during one sound pressure cycle is called the wavelength (l).
- A wavelength is usually measured in meters or feet.

Speed

- The speed (c) at which sound travels is determined primarily by the density and the compressibility of the medium through which it is traveling.
- Speed increases as the density of the medium increases and its compressibility decreases.

- Speed is typically measured in meters or feet per second.
- In air, the speed of sound is approximately 344 meters per second (1130 feet per second).
- In liquids and solids, the speed of sound is much higher.
  - For example, the speed of sound is about 1500 meters per sec in water and 5,000 meters per second in steel.

The **frequency**, **wavelength**, and **speed** of a sound wave are related by the following equation:

c = fl

c = speed of sound in meters per sec or feet per second
f = frequency in Hertz
l = wavelength in meters or feet

Decibel (dB)

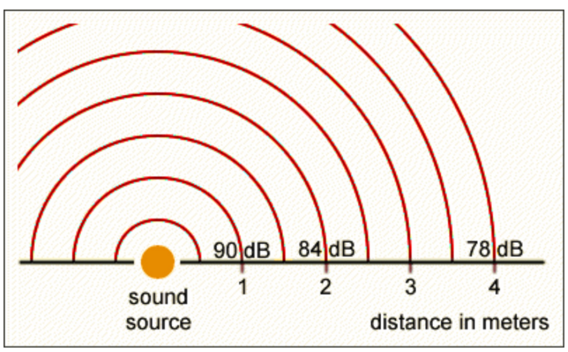
- In acoustics, decibel (dB) notation (App I:A-1) is used for measuring a variety of sound quantities.
- Any time a "sound level" or "sound pressure level" is referred to, decibel notation is implied.

Sound Fields **TOP**

Many noise control problems require a practical knowledge of the relationships between sound field, sound pressure, and sound power.

Free Field

- In a free field (no reflections), sound radiates into space from a source uniformly in all directions.
  - The sound pressure produced by the source is the same in every direction at equal distances from the point source.
  - The sound pressure level decreases 6 dB for each time the distance from the point source is doubled. This is a common way of expressing the inverse-square law in acoustics.



If a point source in a free field produces a sound pressure level of 90 dB at a distance of 1 meter, the sound pressure level at 2 meters is 84 dB, at 4 meters is 78 dB, and so forth.

- For certain tests, free field conditions are necessary (outdoor measurements are often impractical).
  - Some tests may need to be performed in special rooms, called free-field or anechoic chambers (echo-free), which have sound-absorbing walls, floors, and ceilings so that practically no sound is

reflected from them.

- Points of measurement are commonly referred to as far field and near field.

Reverberant Field

In many industrial situations, noise problems are complicated by the fact that noise is confined to a room. When sound-reflecting objects are introduced into the sound field, the wave picture changes completely because of the reflections (App I:A-2).

- Far from the source, unless the boundaries are very absorbing, the reflected sound dominates. This region is called the reverberant field.
- If the sound pressure levels in a reverberant field are uniform throughout the room, and the sound waves travel in all directions with equal probability, the sound is said to be diffuse.

In actual practice, perfectly free and reverberant sound fields rarely exist (in most cases, the sound fields are something in between).

Sound Propagation

TOP

The sound power level of a source is independent of the environment. However, the sound pressure level at some distance (r) from the source is dependant on that distance and the sound-absorbing characteristics of the environment.

Additional information (App I:A-3) on sound propagation is also available.

Filtering

TOP

In order to properly represent the total noise of a source, it is usually necessary to break the noise down into its various frequency components. This is because:

- People react differently to low frequency and high frequency noises.
  - For the same sound pressure level, high frequency noise is much more disturbing and more capable of producing hearing loss than low frequency noise.
- Engineering solutions to reduce or to control noise are different for low frequency and high frequency noise.
  - Generally, low frequency noise is more difficult to control.

It is a conventional practice in acoustics to determine the frequency distribution of a noise by passing that noise successively through several different filters that separate the noise into 9 octaves on a frequency scale.

Frequency Bands

A frequency band is said to be an octave in width when its upper band-edge frequency (f_2) is twice the lower band-edge frequency (f_1):

$$f_2 = 2 f_1$$

Each *octave band* is named for the center frequency (geometric mean) of the band, calculated as follows:

$$f_c = (f_1 f_2)^{1/2}$$

f_c = center frequency
f_1 and f_2 are the lower and upper frequency band limits, respectively

The center, lower, and upper frequencies for the commonly used octave bands are listed in the following table:

Octave Band Filters (Frequencies in Hz)		
Lower Band Limit	Center Band (Geometric Mean)	Upper Band Limit
22	31.5	44
44	63	88
88	125	177
177	250	354
354	500	707
707	1,000	1,414
1,414	2,000	2,828
2,828	4,000	5,656
5,656	8,000	11,312

The width of the band being utilized (bandwidth) is equal to the upper band limit minus the lower band limit. *Note*: These filters are constant-percentage filters (their bandwidth is a fixed percent of the frequency at which the instrument is operating). Octave band filters have bandwidths that are 70.7 percent of the center frequency (this is easily seen in the 1,000 Hz band, as shown in the table above). For more detailed frequency analysis, the octaves can be divided into one-third octave bands.

- A one-third octave band is defined as a frequency band whose upper band-edge frequency (f_2) is the cube root of two times the lower band frequency (f_1):

$$f_2 = (2)^{1/3} f_1$$

Loudness **TOP**

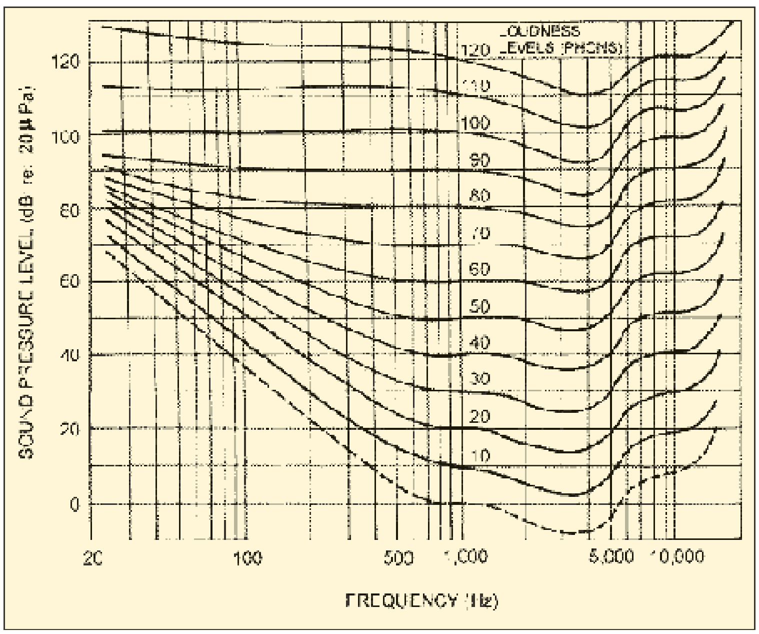
Loudness is the subjective human response to sound. It is dependent upon sound pressure (primarily) and frequency.

- The audible frequency range for young adults with good hearing is about 20 Hz to 20,000 Hz.
- The upper limit of frequency depends primarily on the condition of the person's hearing and on the intensity of the sound.
- The human ear is more sensitive to high-frequency sounds (2,000 to 8,000 Hz) than it is to low-frequency sounds.
- Most people lose sensitivity for the higher-frequency sounds as they

grow older.

The following results of experiments designed to determine the response of the human ear to sound were reported by Fletcher and Munson in 1933:

- A reference tone and a test tone were presented alternately to the test subjects (young men), who were asked to adjust the level of the test tone until it sounded as loud as the reference tone (1,000 Hz).
- The results of these experiments yielded the familiar Fletcher-Munson, or "equal-loudness," contours.
  - These contours represent the sound pressure level necessary at each frequency to produce the same loudness response in the average listener.
  - The non-linearity of the ear's response is represented by the changing contour shapes as the sound pressure level is increased (a phenomenon that is particularly noticeable at low frequencies).
  - The lower, dashed curve indicates the threshold of hearing, and represents the sound pressure level necessary to trigger the sensation of hearing in the average listener.
    - The actual threshold may vary as much as ±10 decibels among healthy individuals.



Sound Pressure Weighting	TOP

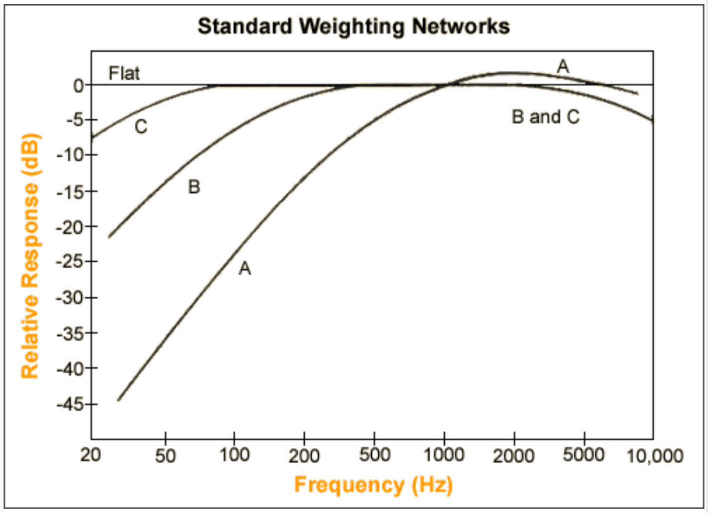
Various acoustical measuring instruments employ frequency-selective weighting filters. By definition, a weighted-frequency scale is simply a series of correction factors that are applied to sound pressure levels as a function of frequency.

Octave-Band Correction Factors for Weighting Networks Commonly Used in Noise Measurements

Octave-Band Center Frequency	A-Weighting (dB)	B-Weighting (dB)	C- Weighting (dB)
31.5	-39.4	-17.1	-3.0

63	-26.2	-9.3	-0.8
125	-16.1	-4.2	-0.2
250	-8.6	-1.3	0
500	-3.2	-0.3	0
1,000	0	0	0
2,000	+1.2	-0.1	-0.2
4,000	+1.0	-0.7	-0.8
8,000	+1.1	-2.9	-3.0

The most common weighting networks are designated A, B, and C. They were designed to approximate the equal-loudness contours at:



- Low sound pressure levels for the A-network (App I:A-4),
- Medium sound pressure levels for the B-network, and
- High levels for the C-network.

By using these weighting networks, the measuring instrument is able to respond to some frequencies more than others.

- The very low frequencies are attenuated:
  - Greatly by the A-network,
  - Moderately by the B-network, and
  - Minimally by the C-network
    - **Example:** If the measured sound level of a noise is much higher on C-weighting than on A-weighting, much of the noise energy is probably low frequency.
- It has been found that the A-network gives a better estimation of the threat to human hearing than the other networks. The A-network is required by OSHA for measuring noise in the workplace and is widely used in describing occupational and environmental noise.
- The C-network is sometimes used in conjunction with the A-network to determine if a sound is predominantly low-frequency in nature.
  - To perform this evaluation, A-network and C-network readings are obtained simultaneously for a given noise source.
  - If the noise has significant low-frequency components, the C reading will be higher than the A. If it does not, the two readings will be similar.
  - C-network readings are also necessary when determining the amount of attenuation from hearing protection.

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