NOISE MEASUREMENT
Revision A

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Introduction

Sound energy is typically measured in terms of a sound pressure level. This level is usually represented in terms of a decibel (dB) scale.

The sound pressure level (SPL) is calculated as

$$SPL = 20 \log\left[\frac{P}{P_{ref}}\right],$$

where

$$P_{ref} = 20\,\mu\text{Pa rms}$$

$$P_{ref} \approx 2.9(10^{-9}) \text{ psi rms} \quad \text{(English units)} \tag{1}$$

P is the root-mean-square sound pressure level in equation (1).

Further details regarding the basic sound pressure level calculation are given in Reference 1.

The sound pressure level can be calculated either for an entire acoustic spectrum or for a particular octave band.

There are many reasons for measuring sound. Acoustic fatigue of mechanical structures is an example. Concern for potential damage to human hearing is another.

The goal of the measurement determines the proper measurement technique. Most sound level meters have selectable weighting circuitry to accommodate the particular measurement needs.

Human Hearing

Note that the sensitivity of human hearing varies with frequency. Hearing is most sensitive to sounds between 2 kHz and 5 kHz. It is less sensitive at higher and lower frequencies. For example, an individual may "perceive" a 110 dB sound at 20 Hz to have the same "loudness" as a 70 dB signal at 1000 Hz.

Perceived loudness is a very subjective matter. Furthermore, it depends on an individual's age and health. A person who has been subjected to excessive noise from machinery, gunfire, or rock concerts may have diminished sensitivity, particularly at higher frequencies.

There are further complicating factors. The sensitivity of human hearing also varies with amplitude, duration, and other variables.

Weighting Networks

Scientists have thus come up with several scales to apply weighting factors to sound measurements. There are four common scales: linear, A, B, and C. These scales are implemented by circuitry in the sound level meter.

A linear network lets the acoustic signal pass through the circuitry without modification. This scale is appropriate for measurements where the acoustic fatigue of structures is the primary concern.

The A, B, and C scales are appropriate for measurements concerned with the effects on human hearing. The goal of the A, B, and C networks is to weight the signal in a manner which approximates an inverted equal loudness. The variation in hearing sensitivity with respect to amplitude necessitates these three weighting networks.

The A weighting network corresponds to low sound pressure levels.

The B weighting network corresponds to medium sound pressure levels.

The C weighting network corresponds to high sound pressure levels.

Of these three, the A network is the most commonly used.

The A, B, and C weights are displayed in Table 1 and in Figure 1. These factors assume a diffuse field, with random incidence. Furthermore, the weights are given in terms of one-third octave bands.

Weighting networks can be used to obtain data in the optimum format for a particular purpose. The technician or engineer who takes the measurements should take great care to note the network in the test report. For example, sound pressure levels measured via the A network are typically designated as dBA.

Loudness Level: Phons (L_N)

A phon is a subjective measure of loudness. It requires listeners to compare a 1000 Hz tone to the sound being rated.

Specifically, the number of phons is numerically equal to the sound pressure level in dB of a free sound wave of frequency 1000 Hz which is judged to be "as loud" as the sound being rated.

A 40 dB tone at 1000 Hz would equal 40 phons.

For simplicity, consider the human hearing threshold to be zero dB at 1000 Hz.

Loudness: Sones (N)

A sone is another subjective measure of loudness, which is related to the phon scale. A level of 1 sone is defined as a simple tone of frequency 1000 Hz that is 40 dB above a listener's hearing threshold. Thus, 1 sone is equal to 40 phons.

From Reference 2, the empirical relationship between sones N and phons L_N is

$$N = 0.046\left[10^{L_N / 30} \right] \tag{2}$$

Equivalent Sound Level (L_{eq})

The L_{eq} is the steady-sate sound that has the same level as the time-varying sound averaged in energy over the specified time interval. The mathematical formula for the interval t_1 to t_2 is

$$L_{eq} = 10 \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_o^{\,2}} \, dt \right] \tag{3}$$

where

$p_o = 20\,\mu\text{Pa rms}$

Equivalent Sound Level, A-weighted (L_{Aeq})

The L_{Aeq} is the steady-sate sound that has the same A-weighted level as the time-varying sound averaged in energy over the specified time interval.

Day-Night Averaged Sound Level (L_{Adn})

The L_{Adn} is the 24-hour L_{Aeq} obtained after adding 10 dBA to the sound level from 10 p.m. to 7 a.m. (nighttime). This addition is made to account for increased annoyance due to noise during the night hours.

The L_{Adn} is also abbreviated as DNL.

Community Noise Equivalent Level (CNEL)

The CNEL is the 24-hour L_{Aeq} obtained after addition of 5 dBA to the sound levels from 7 p.m. to 10 p.m. (evening), and 10 dBA to the levels from 10 p.m. to 7 a.m. (nighttime).

Perceived Noise Level (PNL)

Per Reference 3, the PNL is a noise rating that has been used almost exclusively in aircraft noise assessment. PNL is computed from sound pressure levels measured in octave or one-third octave frequency bands. This rating is most accurate in estimating the perceived noisiness of broadband sounds of similar time duration which do not contain strong discrete frequency components. Currently it is used by the FAA and foreign governmental agencies in the noise certification process for all turbojet -- powered aircraft and large propeller-driven transports. The perceived noise level is expressed in decibels. These units translate the subjective linearly additive noisiness scale to a logarithmic dB scale, where an increase of 10 dB in PNL is equivalent to a doubling of its perceived noisiness.

Tone Corrected Perceived Noise Level (PNLT), PNdB.

Per Reference 3, the Tone Corrected Perceived Noise Level is the Perceived Noise Level adjusted to account for the presence of discrete frequency components. PNLT was developed to aid in prediction of perceived noisiness for aircraft flyovers and vehicle noise which contain pure tones, or have pronounced irregularities in their spectrum. The method for calculating PNLT adopted by the FAA involves calculation of the PNL of a sound and the addition of a tone correction based on the tonal frequency and the amount that the tone exceeds the noise in the adjacent one-third octave bands.

Sound Intensity (SIL) or (L_I)

Sound intensity is the acoustic power per unit area in the direction of propagation.

More precisely, the sound intensity is the average rate of energy flow through a unit area normal to the direction of propagation.

The fundamental units of sound intensity are watts per square meter (W/m^2).

A free field is a volume in which there are no reflections. Free field propagation is characterized by a 6 dB drop in the sound pressure level and in the intensity level for each doubling of distance. This is essentially the "inverse-square law."

Consider a point source which radiates sound in spherical manner in a free field. The intensity magnitude I is related to the sound power W by

$$|\,I\,| = \frac{W}{4\pi r^2} \tag{4}$$

where r is the radius.

The magnitude symbol on the left side of equation (4) is necessary because intensity is a actually a vector.

Note that the denominator in equation (4) is the surface area of a sphere

The sound intensity level (SIL) is measured in terms of decibels as

$$SIL = 10 \log \left[\frac{I}{I_{ref}} \right] \tag{5}$$

where

$$I_{ref} = \begin{cases} 1(10^{-12})\,\dfrac{W}{m^2} & \text{for air} \\ 6.7\,(10^{-19})\,\dfrac{W}{m^2} & \text{for water} \end{cases}$$

Note that the sound intensity level and the sound pressure level have approximately the same numerical value.

References

1. T. Irvine, The Acoustic Power Spectrum, Vibrationdata.com Publications, 1998.
2. Lawrence Kinsler et al, Fundamentals of Acoustics, Third Edition, Wiley, New York, 1982.
3. Aviation Noise Effects, Federal Aviation Administration, Washington D.C., 1985.

Table 1. Weighting Networks, One-Third Octave Bands			
Frequency (Hz)	A-weight (dB)	B-weight (dB)	C-weight (dB)
10	-70.4	-38.2	-14.3
12.5	-63.4	-33.2	-11.2
16	-56.7	-28.5	-8.5
20	-50.5	-24.2	-6.2
25	-44.7	-20.4	-4.4
31.5	-39.4	-17.1	-3.0
40	-34.6	-14.2	-2.0
50	-30.2	-11.6	-1.3
63	-26.2	-9.3	-0.8
80	-22.5	-7.4	-0.5
100	-19.1	-5.6	-0.3
125	-16.1	-4.4	-0.2
160	-13.4	-3.0	-0.1
200	-10.9	-2.0	0
250	-8.6	-1.3	0
315	-6.6	-0.8	0
400	-4.8	-0.5	0
500	-3.2	-0.3	0
630	-1.9	-0.1	0
800	-0.8	0	0
1000	0	0	0
1250	0.6	0	0
1600	1.0	0	-0.1
2000	1.2	-0.1	-0.2
2500	1.3	-0.2	-0.3
3150	1.2	-0.4	-0.5
4000	1.0	-0.7	-0.8
5000	0.5	-1.2	-1.3
6300	-0.1	-1.9	-2.0
8000	-1.1	-2.9	-3.0
10000	-2.5	-4.3	-4.4
12500	-4.3	-6.1	-6.2
16000	-6.6	-8.4	-8.5
20000	-9.3	-11.1	-11.2

WEIGHTING NETWORKS FOR THE SOUND LEVEL METER
FOR A DIFFUSE-FIELD (RANDOM INCIDENCE)

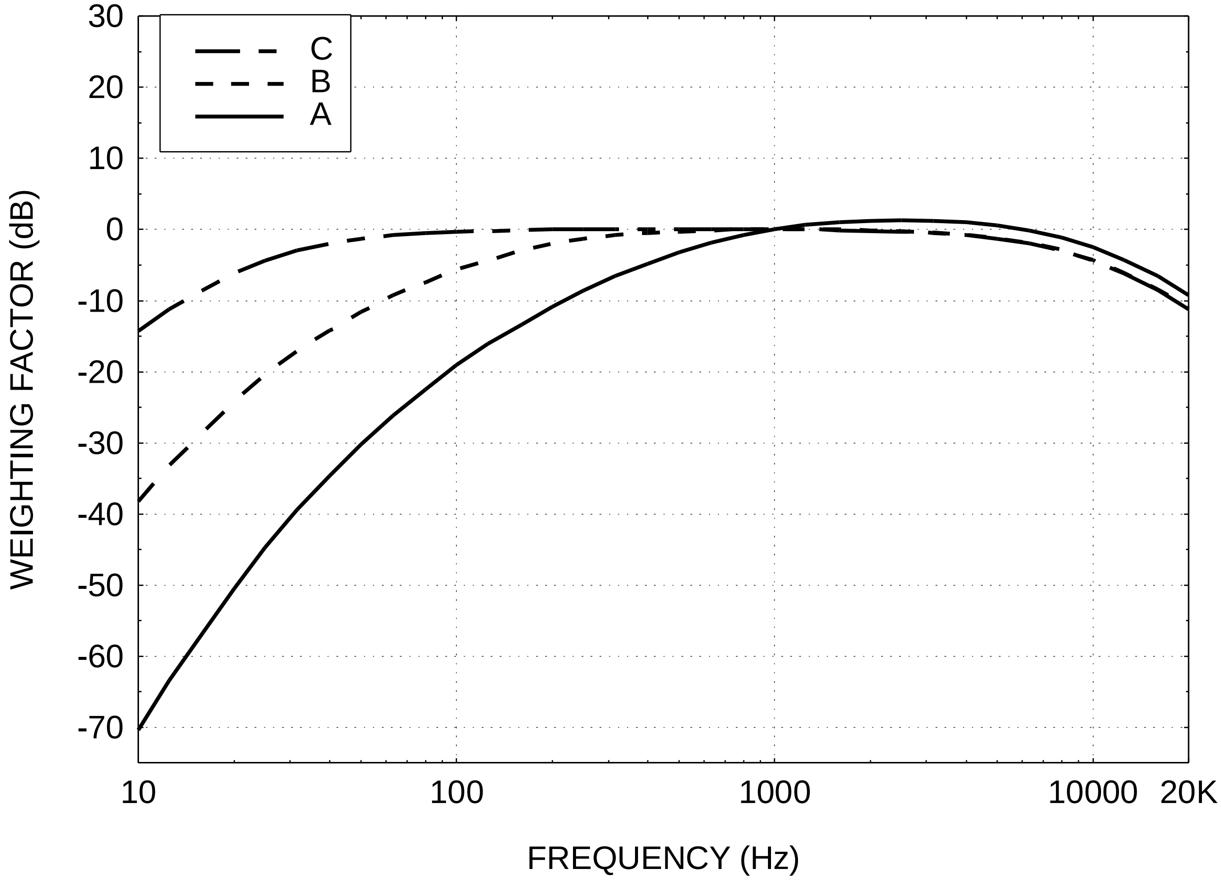

Figure 1.