NOISE PRIMER

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PREPARED FOR:
TDI NEW ENGLAND

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CONTENTS

Sound, as a physical quantity, has many characteristics, each with a manner of describing and measuring it. To inform readers of the physical characteristics of sound, and the variety of sound and sound level descriptors, RSG has compiled this primer of acoustical terms and descriptions. Included are:

1. A description of sound as a physical quantity;

2. How sound is described quantitatively over time and frequency; and

3. Different metrics that can be measured, with current sound level meter technology.

1.0   SOUND AS A WAVE

Sound is the rapid oscillation of particles in any medium. Using this definition, the sound we experience day-to-day is the rapid vibration of air that we can sense with our ears. However, sound can also propagate through solids such as steel, rock, or wood and through liquids such as water.

Through air, sound propagates as a compression wave. That is, sound travels as fluctuations of air pressure above and below the atmospheric pressure. Sound can also be described in terms of vibrating of air particles where, at certain points along the wave, air particles are compressed and, at other points, the air particles are spread out.

Figure 1 illustrates two ways of describing sound. The blue section at the bottom shows an example of a compression wave, with air particles represented in blue. The green at the top of the figure shows a transverse wave. A transverse wave is similar to a vibrating string. While sound does not physically propagate as a transverse wave, the transverse wave can be used to describe the two main properties of waves in general: amplitude and wavelength.
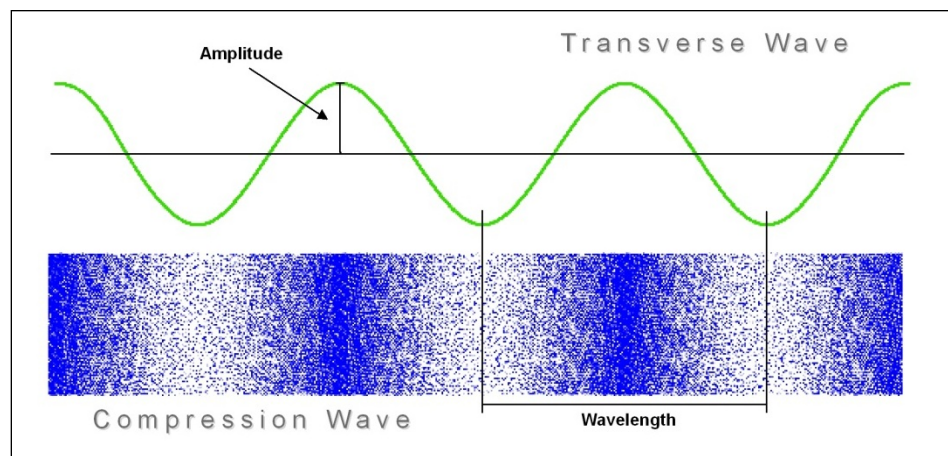

FIGURE 1: SOUND AS A WAVE

In reference to sound, amplitude is what we perceive as the sound pressure level or how loud a source is. The higher the amplitude of the sound wave, the louder it is. Physically, sound amplitude is a measure of the extent to which the air pressure, due to a sound wave, fluctuates above and below atmospheric pressure. In terms of the compression wave shown

in Figure 5, amplitude is expressed by how compressed or spread out the air particles are at the various points along the sound wave.

Wavelength is the distance between two maximum compression locations in a sound wave. One wavelength is one complete cycle of the sound wave. Wavelength is important because it is directly related to the frequency of the sound, which is what the human ear perceives as pitch. Sound with longer wavelengths are lower in frequency, and shorter wavelengths are higher in frequency. Frequency is dealt with in greater depth in Section 3.0.

2.0   SOUND PRESSURE LEVEL

The level of a sound is typically quantified by the pressure it exerts. The air pressures from sound that humans can hear range from 20 μPa to over 10,000,000 μPa. In order to scale the range down and better approximate the human perception of relative loudness, we use a logarithmic scale for sound pressure level. The unit used for the logarithmic scale is the decibel (dB).

The lower threshold of human hearing is 0 dB at 1000 Hz and the threshold of pain is around 130 dB. A typical conversation in a room is between 50 and 60 dBA ("dBA" indicates that these levels are A-weighted. A-weighting is discussed in Section 3.0).

Sound is difficult to describe in individual instantaneous measurements, which gives the sound pressure level at an exact moment in time. The level reading could be 62 dB, but a second later it could 57 dB. Sound pressure levels are constantly changing. It is for this reason that it makes sense to describe sound levels over time.

Take as an example, the sound levels measured over time shown in Figure 2. Instantaneous measurements are shown as a ragged grey line. The sound levels that occur over this time can be described verbally, but it is much easier to describe the recorded levels statistically. This is done using a variety of "levels" which are described below.

2.1 | LMIN AND LMAX

Lmin and Lmax are simply the minimum and maximum sound level, respectively, monitored over a period of time. Note that "maximum" is not the same as "peak". Peak levels have a different meaning, which is more applicable to sounds which can create hearing damage, which is not dealt with here.

2.2 | PERCENTILE SOUND LEVEL - LN

Ln is the sound level exceeded n percent of the time. This type of statistical sound level, also shown in Figure 2, gives us information about the distribution of sound levels. For example, the L10 is the sound level that is exceeded 10 percent of the time, while the L90 is the sound level exceeded 90 percent of the time. The L50 is the median and is exceeded half the time. The L90 is often described as the "residual" level, describing a condition when most short-term contaminating sources are removed.

2.3 | EQUIVALENT AVERAGE SOUND LEVEL - LEQ

One of the most common ways of describing noise levels is in terms of the continuous equivalent sound level (Leq). The Leq is the average of the sound pressure over an entire monitoring period and expressed as a decibel:

$$Leq_T = 10 * log_{10}\left(\frac{1}{T}\int_{\theta}^{T} p_A^2(t)dt \middle/ p_0^2\right)$$

where p_0^2 is is the squared instantaneous weighted sound pressure signal, as a function of elapsed time t, p_0 is the reference pressure of 20μPa, and T is the stated time interval.

The monitoring period, T, can be for any amount of time. It could be one second (Leq $_{1-sec}$), one hour (Leq$_{(1)}$), or 24 hours (Leq$_{(24)}$). Because Leq is a logarithmic function of the average pressure, loud and infrequent sounds have a greater effect on the resulting Leq than quieter and more frequent sounds. For example, in Figure 2, the L50 (median) is about 47 dB, but the Leq is 53 dB. Because it tends to weight the higher sound levels and is representative of sound that takes place over time, the Leq is the most commonly used descriptor in noise standards and regulations.
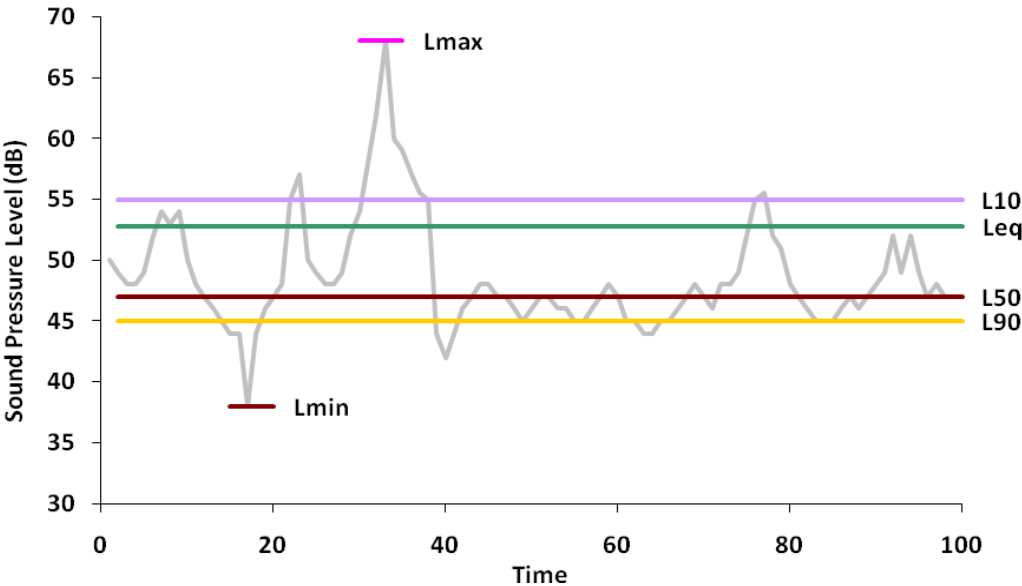

FIGURE 2: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

3.0 SPECTRAL SOUND LEVELS

As previously stated, frequency is inversely related to wavelength. The unit used for frequency is cycles per second or hertz (Hz). The relationship between wavelength and frequency is dependent on the speed of sound.

$$\lambda = \frac{c}{f}$$

where λ is wavelength, c is the speed of sound, and f is frequency.

Figure 3 shows corresponding wavelengths and frequencies for sound in air at 68°F. People can generally hear sounds at frequencies between 20 and 20,000 Hz (also designated as 20 kHz). As shown, wavelengths in the range of human hearing vary considerably from 56 feet at 20 Hz, to less than an inch at 20 kHz.

Sound below 20 Hz is known as infrasound. Sometimes, we can perceive frequencies below 20 Hz, but that is typically due to our sense of vibration rather than hearing or if the levels are very high. Infrasound wavelengths are very long, with sound at 1 Hz having a wavelength of just over 1,000 feet. Sound above 20 kHz is called ultrasound and is not perceptible by the human ear.
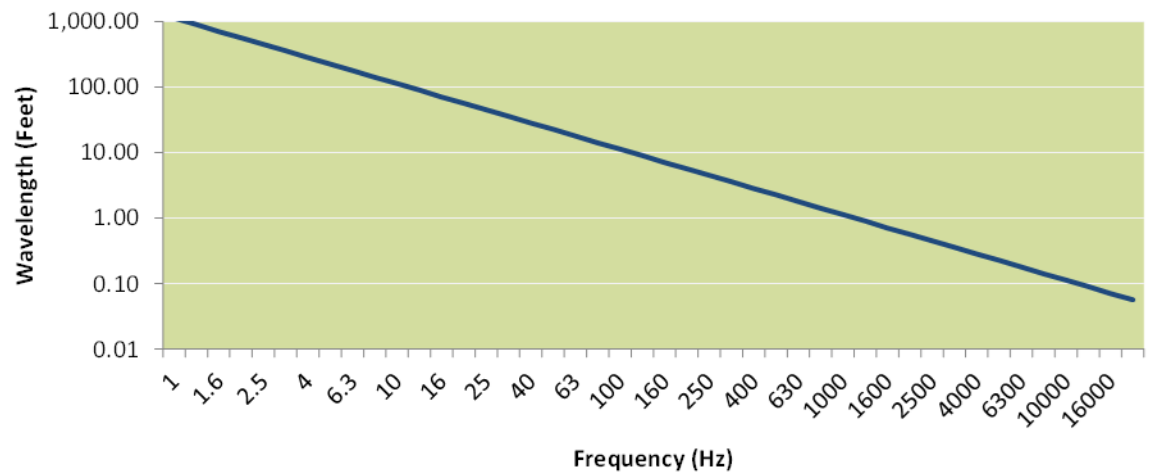

FIGURE 3: RELATIONSHIP BETWEEN FREQUENCY AND WAVELENGTH

Most sources are complex and composed of a wide range of frequencies at different sound levels. The range of frequencies and their corresponding sound levels is called a frequency spectrum.

Some sources are tonal, like the individual notes on a piano. Others are broadband, like fans. Human speech typically occurs between 200 Hz and 5 kHz.

3.1 | OCTAVE BANDS

For analysis purposes, sound is typically broken down into different frequency divisions, or bands. The most common division is the standard octave band. An octave is a band of frequencies whose lower frequency limit is half of the upper frequency limit. An octave-band is identified by its center frequency. As an example, the 500 Hz octave-band contains all frequencies between 360 Hz and 720 Hz. An octave higher would be twice this. That is, it would be centered at 1,000 Hz with a range between 720 and 1,440 Hz. The range of human hearing is divided into 10 standardized octave-bands: 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz, and 16 kHz. For analyses that require even further frequency detail, each octave-band is often broken down into parts, such as 1/3 octave-bands.

3.2 | FREQUENCY WEIGHTING

As previously mentioned, sound pressure levels are expressed in terms of decibels. Since the human ear is not sensitive to all frequencies equally, some frequencies, despite being the same decibel level, seem louder than others. For example, a 500 Hz tone at 80 dB sounds louder than a 63 Hz tone at 80 dB. For this reason, frequency weightings are applied to sound levels (Figure 4). The most common weighting scale used in environmental noise analysis is the A-weight, which more accurately represents the sensitivity of the human ear at low to moderate sound energy. An A-weighted sound level is usually denoted with the unit dBA or dB(A).

The C-weighting is often used for high-energy sounds such as explosions. It weights low frequency sounds more than the A-weighting. The Z-weighting is used to designate no weighting.

Recently, a new weighting has been proposed – the Ai weighting.[1] This is the A-weighted sound level with all sound above 1,250 Hz eliminated. This weighting is intended to be used to filter out biogenic sound that occurs at high frequencies, such as insects and birds.

4.0   SOUND LEVEL METER RESPONSE

As noted in Section 2.0, sound levels vary over time. In fact, the variation is so fast, that one would not be able to reliably read the level on a sound level meter. For that reason, the level shown on sound level meters is often subject to exponential time response, which dampens the reading showed on the meter display to make it readable.

There are three responses available on most sound level meters: slow, fast, and impulse. These levels are denoted as Ls, Lf, and Li, respectively. These may also be designated with a weighting, such as LAf for A-weighted fast –response level. Fast response has a time constant of 125 ms. This response is similar to the response of the human ear. The slow response has a time constant of 1 second. This is often used in environmental noise measurement in that it has a slow rise and fall time, which eliminates very short spikes in noise that are not related to the measurement. The impulse response has a very fast rise time of 35 ms and a slow decay time of 1.5 seconds. It is rarely used in environmental noise measurements, but can be used with other metrics to evaluate the impulsivity of a sound event.

Fast, slow, and impulse sound levels cannot be averaged, since they are not representative of the actual sound level over time – they are simply applied to the actual sound level to slow the meter reading. So, an integration of fast, slow, or impulse sound levels will not give an accurate representation of the energy average sound level over time. However, percentiles can be used when this is needed. A true energy average, or equivalent average sound level

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[1] Schomer Paul, D.; Slauch Ian, M.; Hessler George, F, "Proposed "Ai"-weighting; A weighting to remove insect noise from A-weighted field measurements", INTER-NOISE and NOISE-CON Congress and Conference Proceedings, InterNoise10, Lisbon PORTUGAL, pages 3543-4457 pp. 3991-4000(10).

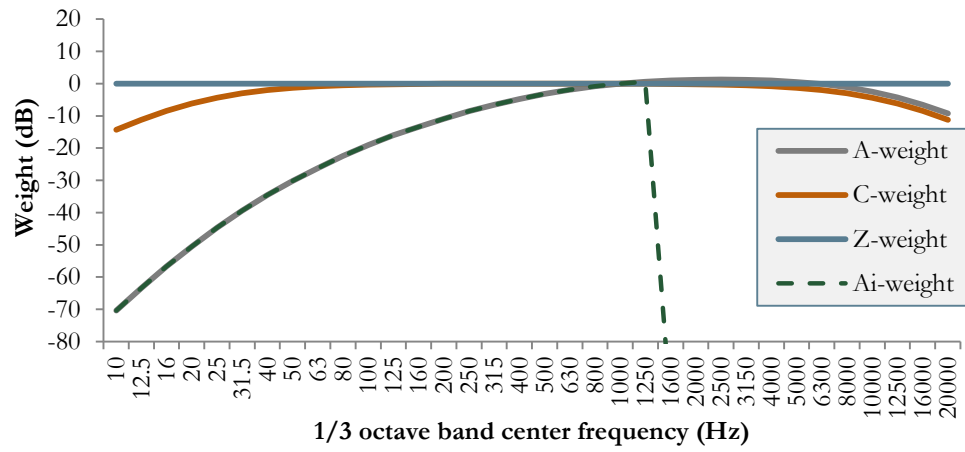can be calculated using the Leq metric, which is independent of the sound level meter response setting.

FIGURE 4: SOUND WEIGHTING SCHEMES