

Outdoor Sound Propagation Primer

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Acoustics – An Overview

There are many factors that play a role in outdoor sound, from how sound propagates through the atmosphere to how people perceive different sounds, and what the background noise levels are. Each of these factors is important when computing siren contours for a new siren system. The following paper provides a brief overview of some of these key concepts.

Amplitude and Frequency of Sound

Amplitude is the measure of a sound's 'strength' and is generally measured using the logarithmic decibel scale, which uses the symbol dB. The 'd' is always written in lowercase to represent 'deci' for a factor of 10, and the 'B' is always written in uppercase in honor of Alexander Graham Bell, inventor of the telephone. 0 decibels (dB) is considered the threshold of human hearing. An increase of 10 dB is perceived as roughly twice as loud, and a level of 120 dB is at the threshold of pain.

Because of the logarithmic scale, addition of different sounds does *NOT* follow the expected arithmetic addition system where $2+2=4$. Instead, with decibels, if you add together a 60 dB signal with another 60 dB signal, the result is 63 dB, or $60 + 60 = 63$.

Frequency is another key element of an acoustic signal, and is measured in Hertz, which uses the symbol Hz, always with a capital 'H'. This is in honor of Heinrich Hertz, the first person to prove the existence of electromagnetic waves. One Hertz is defined as one cycle per second. Humans can hear sounds in a frequency range from about 20 Hz (a very low rumble) to 20,000 Hz (a high pitched whine). Middle C on a piano is at about 262 Hz. Our best hearing is centered around the frequencies most common in human voices, near 1,000 Hz. Because sound is so complex and has so many features, it is difficult to quantify a complex, time-varying signal with a single number. How does a sound at 20,000 Hz compare to a sound at 100 Hz? How can you define and compare the complex (and often annoying) noise levels in restaurants? The answer is that we have developed a method for computing single number metrics.

One common method for creating a single number metric is to apply a weighting factor to the frequencies within the complex acoustic signal. These weighting factors allow us to add up the energy from all frequencies into a single number by including a penalty (or gain) to certain frequencies to better represent human perception. The two most widely used weighting factors are the A-weighting, designated by dBA, and the C-weighting, designated by dBC. If no weighting is used, then all frequencies are combined equally, and the amplitude is designated simply by dB. Figure 1 is a graph showing both the A and C weighting factors used to compute dBA and dBC values.

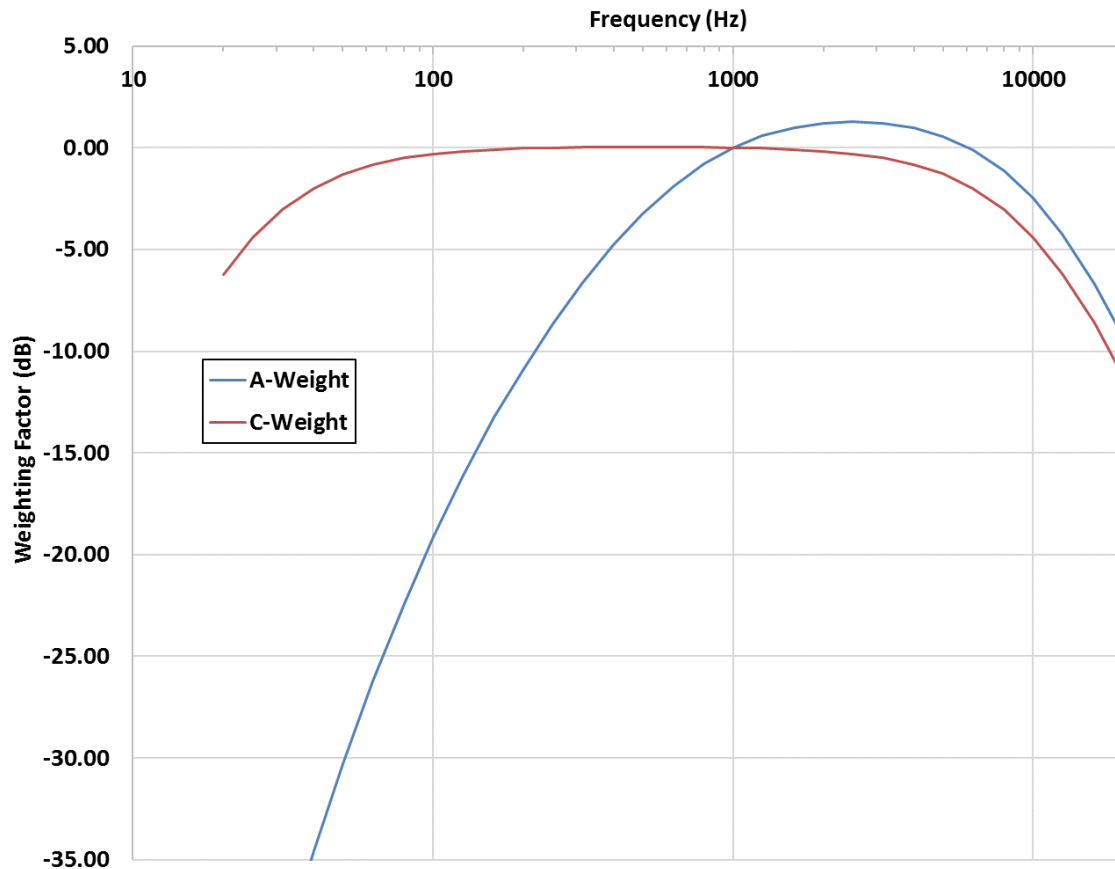


Figure 1. A and C frequency weighting.

The A-weighted factors, shown in blue in Figure 1, represents how the average human perceives sounds at normal, speaking amplitudes. We have the best hearing close to the human vocal range, from about 1,000 Hz to 5,000 Hz, and we tend to have poorer hearing at the very high and very low frequencies. A-weighted is the most commonly used metric when describing sound, with typical Sound Level Meters and phone apps providing the A-weighted levels.

The C-weighting factors, shown in red in Figure 1, represents how humans perceive high amplitude sound. If the sound we hear is loud, our ear responds differently than for quieter sounds. At higher amplitudes, people can hear frequencies between 100 Hz and 5,000 Hz at about the same level. This means that our ear responds better if the sound is louder –so music actually *does* sound better if it is played loud! For siren analysis, FEMA recommends using the C-weighting scale.

Audibility and Intelligibility

To determine if a sound signal is audible, there are several factors to consider. These include the background noise by the listener, the amplitude of the received sound, and the frequency content of both of these signals. As a general rule of thumb, if the sound of interest (like a

warning siren) is 10 dB above the background noise, it will be loud enough to be heard and noticed above that noise.

Intelligibility is a much more complex process – not only must the signal be above the background noise, it must be clear enough that individual syllables can be identified. There are a large number of confounding processes in outdoor sound propagation that can make this difficult. If there are any echoes, or if the signal is received from more than a single source, then the slight difference in the arrival times can mix the signals together, reducing intelligibility. This is a phenomenon known as multi-path reception. Also, as the sound travels through the air, small differences in the wind and air temperature, and bits of turbulence between the source and the receiver can also cause syllables to get garbled. Finally, the initial verbal message must be clearly spoken under optimal conditions. Under time-critical, stressful situations it can be difficult to have someone record a slow, clear message. Therefore, carefully crafted pre-recorded messages are a much better option if verbal messages are required.

Unfortunately, there are no reliable methods for computing these factors in an outdoor setting. Methods do exist to measure the intelligibility of an outdoor messaging system that is already in place. In these tests, a specially formulated acoustic signal is sent out through the messaging system and is measured at individual locations. These tests are typically conducted for closed systems such as at outdoor stadiums and are helpful in improving the intelligibility. However, these types of tests are poorly suited to a city-wide system as the measurements only provide single point measurement and do not provide an estimate over wide areas.

Sound Propagation

Sound can be defined as small fluctuations in air pressure that move, or propagate, from the source to a receiver. As the sound propagates through the air, it is altered in many different ways. Things that impact sound propagation are spherical spreading, atmospheric absorption of the sound, atmospheric refraction, diffraction by terrain, and ground reflections.

Spherical Spreading

As sound leaves the source it moves out in all directions, expanding like a bubble. As it expands the sound level decreases. This is an intuitive fact we all understand – the farther you are from a sound source, the quieter the received sound. The mathematics state that the sound level is reduced by 6 dB for every doubling of distance between the source and the receiver. This is why it is not enough to say how loud a source it – you must state at what distance it was measured. For example, just saying a lawnmower is 90 dBA is not enough. Was that measured one foot away or 100 feet away? The difference between a measurement at one foot and 100 feet is 40 dB!

Atmospheric Absorption

As sound travels through the air, some of the sound energy gets absorbed by the air. How much energy gets absorbed depends on the temperature and humidity of the air, and the frequency

of the sound. This is a complex relationship, but in general, high-frequency sounds get absorbed more than low-frequency sounds. This is why you can often hear a distant road as a low rumble – the low-frequency sounds make it to you, but the high-frequency sounds get absorbed by the air.

Atmospheric Refraction

Atmospheric refraction is a complex process by which sound can bend, caused by vertical variations in the wind speed and temperature. This is caused by changes in the speed of sound with altitude. The speed of sound is affected by the air temperature, with sound traveling faster in warmer air, and sound that travels downwind travels faster than sound that travels upwind.

It is the variations of temperature and wind speed with altitude that cause refraction. Take, for example, a thermal inversion. This is a condition, typical in early mornings before the sun has a chance to warm the ground, where the air is cooler close to the ground and gets warmer at higher altitudes. Fog and low laying clouds are often evident during an inversion. During an inversion, the sound at altitude travels faster (because of the warmer air) than the sound at lower altitudes. The result is that the sound is ‘bent’ downward. This is similar to sound traveling downwind. Figure 2 shows a representation of how sound travels during an inversion.

Inversion conditions allow sound to travel farther. In some situations, the sound can even ‘bounce’ along the ground, and travel over barriers. One example people may be familiar with involves highway noise barriers. Residents living behind a barrier will say that sometimes they cannot hear the road, and sometimes it seems like the road is right next door. The difference is that, under inversion conditions, the sound can actually bypass the barrier completely!

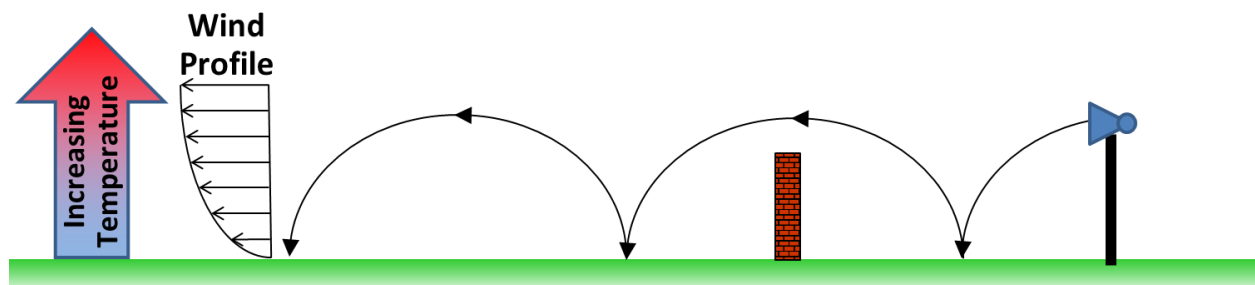


Figure 2 Sound propagation during an inversion, or downwind propagation.

The opposite of an inversion is called a thermal lapse. This occurs after the sun has had a chance to warm the ground, and the air close to the ground is warmer than the air at altitude. This is typical of sunny afternoons, with high altitude clouds. When there is a thermal lapse the sound travels faster along the ground (with the warmer air) and slower at altitude. The result is that the sound tends to ‘bend’ upward. The same effect is achieved if sound has to travel upwind. This type of atmospheric refraction can result in a shadow-zone – a region where sound has difficulty entering because it has been bent up and away from the ground.

Therefore, lapse conditions are poor for long-range sound propagation. A thermal lapse can be seen graphically in Figure 3.

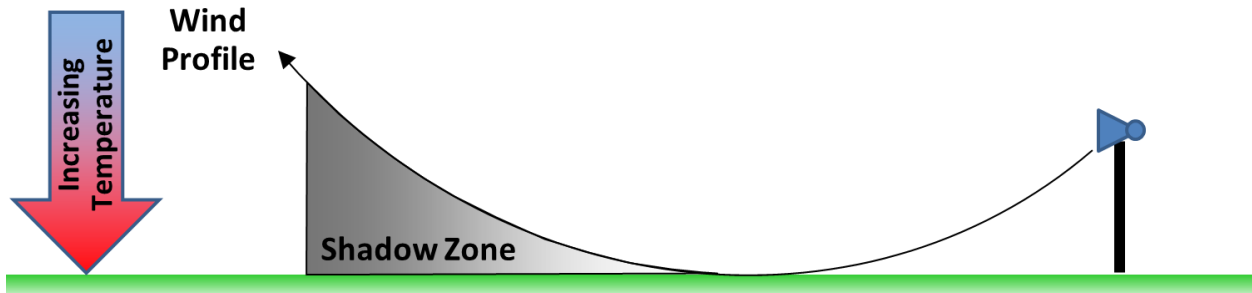


Figure 3. Sound propagation during an inversion, or upwind propagation.

Diffraction

Diffraction is the process by which sound bends and flows around obstacles. We are all familiar with this phenomena – stepping around a corner of a building does not mean that sounds can no longer reach you – they just quickly become quieter. The process of diffraction is complex, but the general principle is fairly simple. Sound can bend around objects that are about the same size as the acoustic wavelength. As a rule of thumb, sound that has a frequency of 100 Hz has a wavelength of 10 feet, a frequency of 1,000 Hz has a wavelength of 1 foot, and a frequency of 10,000 Hz has a wavelength of 0.1 feet.

Because of this process, low-frequency sound waves (with longer wavelengths) tend to move around objects larger objects. High-frequency sounds have shorter wavelengths, and so tend to get blocked by the objects. For example, any object that is about 1 foot in size or larger will have a strong impact on sound of 1,000 Hz or higher in frequency. The object’s size is the same as the wavelength. The result is that low-frequency sound can effectively move around large objects such as buildings and terrain. Figure 4 has a representation of diffraction of a siren signal around terrain.

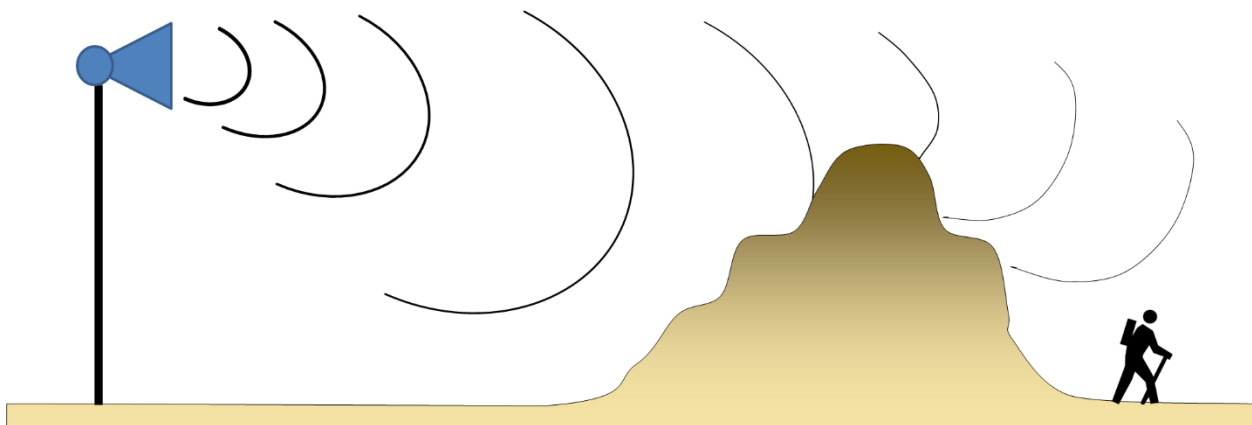


Figure 4. A representation of diffraction of sound around terrain.

Ground Reflection

One surprising fact some people don't know is that as sound leaves a source it travels to the receiver along two paths. One path goes directly from the source to the receiver, while the other reflects off of the ground before going to the receiver. These two paths combine at the receiver, summing up to the received sound level. Because one path reflects off of the ground, the properties of the ground are important to the received sound. The porosity of the ground is a strong indicator of its acoustic properties. Ground that is highly porous, such as grass, sand, and forest leaf litter, is considered acoustically soft. This type of ground absorbs some of the acoustic energy, reducing the received sound. Similarly, non-porous ground types such as water or concrete are considered acoustically hard and reflect the more sound, allowing more to reach the receiver. Figure 5 has a representation of the process of ground reflections.

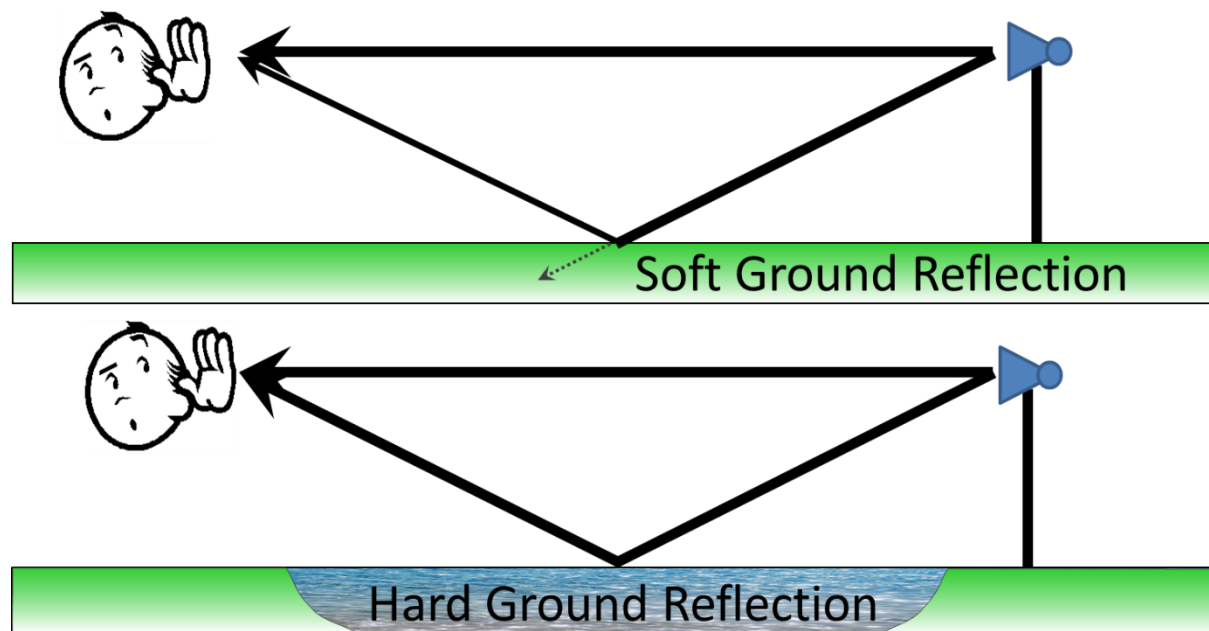


Figure 5. Representation of ground reflections for soft and hard ground.

Siren Sound Output

Siren manufacturers all want to sell their products, and they compete with one another to sell the best product at the best price. Unfortunately, when they provide the specifications on their sirens, it can be difficult to be certain how two different manufacturers sirens actually compare in terms of sound output in real-world applications. Fortunately, there is an American National Standards Institute method for measuring sirens so that they can all be on an even playing field. The standard is ANSI S12.14¹, and describes the measurement process in detail.

¹ ANSI S12.14 – Methods for the Field Measurement of the Sound Output of Audible Public Warning Devices Installed at Fixed Locations – 1992, reaffirmed 2002.

The basic concept is to measure the siren at the same height as the center of the siren stack, at a distance of 100 feet. This should be over roughly flat and level ground (see Figure 6). The measurement should include the frequency content of the siren, and the final report should include the maximum sound level measured and the average sound level measured. Having this data allows a direct comparison between different siren manufacturers products. Acoustic Analytics always recommends testing at least 10% of new sirens installed in a system to ensure they are able to produce their rated (and paid for!) sound level.

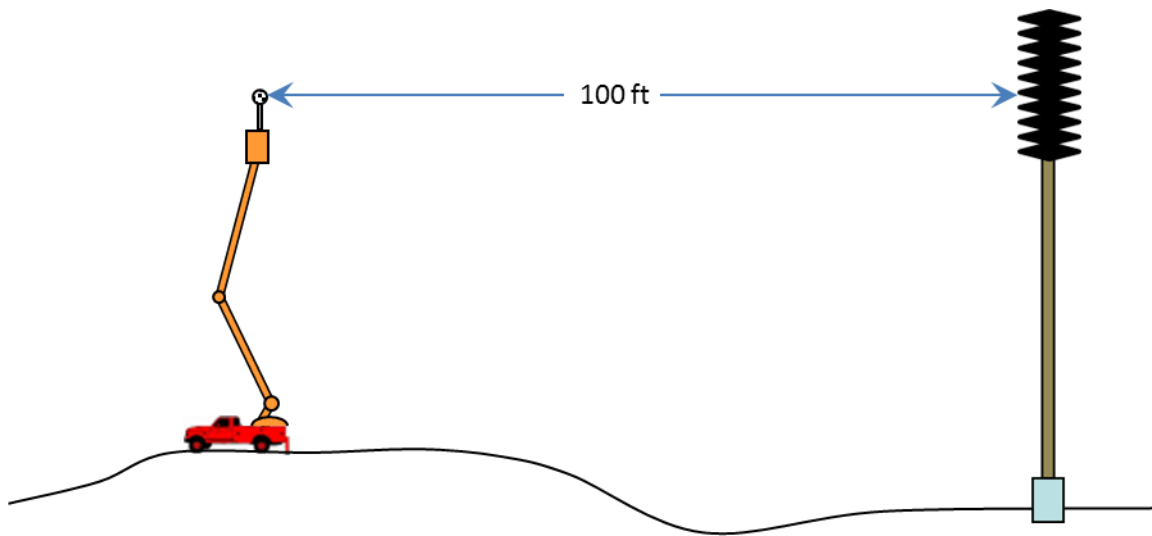


Figure 6. Representation of an ANSI S12.14 siren measurement.

One topic that is important to understand is how the results from these tests are reported. There are three main terms that are commonly used – peak, maximum, and average. The peak level is the single highest sample from a test. For a measurement device that samples data at 44 kHz (which is typical), this means that the peak value is the single highest 0.00002 seconds of sound during the entire test. This is sometimes reported as the rated output of a siren but is not a level that translates into human perception. The maximum level is the single highest 1-second sample. While this level is detectable by humans, it does not represent an alerting tone. The maximum is often at least 6 decibels lower than the peak level but is still not a good representation of how a siren will work to alert the public. Finally, the average sound level is computed from an entire siren test (from 20 seconds to 3 minutes depending on how the siren operates). This is often 2 to 3 decibels lower than the maximum. This is the level that is recommended by Acoustic Analytics for determining the output of a siren system. Both the maximum and the average sound level should be reported as part of the ANSI S12.14 test.