RDA Tech Corner: Acoustics 101 – Sound Wave Properties and Propagation

Part 1: Properties of a Sound Wave

Hello and welcome to the RDA Tech Corner. In this column we will discuss sound waves and how they travel. I know we are all familiar with sound waves, but sometimes it's good to refresh the basics of sound propagation and travel and what happens when sound waves encounter obstacles and walls.

Sound waves in air are known as longitudinal waves, which means the energy travels parallel to the direction the wave travels in the medium, in this case the medium being the air around us. While we are used to visualizing sound waves as a sine wave, it is more accurate to think of sound waves as a series of compressions and rarefactions travelling outward from the source. A compression is when the air molecules get squeezed together, a rarefaction is when they spread back out. This squeezing and spreading happens as the energy travels and how many times it happens per second is the frequency of the wave, measured in Hertz, where 1 Hertz is one full cycle per second. It is important to note that it is the energy that is travelling and not the air molecules themselves. They are vibrating and moving within a very small space, but the molecules that impinge upon your eardrum are not the same molecules being excited by a speaker 6 feet away.

As a side note, Hertz is named for Heinrich Rudolf Hertz (1857-1894), a German physicist who first proved the existence of electromagnetic waves. In 1930 the IEC established Hertz (Hz) as the unit of measure for the number of times a repeated event occurs in one second in honor of the physicist.

In the case of the sound wave, if we measure from the beginning of one compression, through the rarefaction and to the beginning of the next compression, we have one cycle of the wave. As stated, the number of times this happens in one second is the frequency, and the distance covered in this period is the wavelength, which we represent with the Greek letter lambda (λ). In addition, the difference in pressure these compressions and rarefactions have compared to the still air around them gives us the amplitude of the wave. This amplitude is measured in decibels of sound pressure level, or dBSPL. Putting this all together, the frequency of the wave (*f*) is what we perceive as the pitch of the wave, the amplitude of the wave is what we perceive as the volume of the wave (dBSPL) and the distance travelled in one period gives us the wavelength (λ).

Let's examine these properties in a little more detail. In the case of frequency, we perceive this as the pitch of the sound wave, and humans are generally able to perceive pitch in the range of 20 Hz (low frequency) to 20,000 Hz. (high frequency) It is common practice to abbreviate larger numbers like 20,000 Hz as 20 kHz, or Kilohertz, with the prefix Kilo being equal to 1000. If we break this down into musical terms, this is a 10 octave range. A doubling of frequency from say 1 kHz to 2 kHz is a span of one octave. We describe this range in terms of octave centers, ie. the center frequency of a given octave. Therefore, we start at 31.5 Hz for the first octave, and double the numbers from there, with a little fudge at the bottom between the second and third octaves. (Slight rounding errors in the math result in the discrepancy between 63 Hz and 125 Hz.) Here are the 10 octave centers:

31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, 8 kHz, 16 kHz. You may recognize these numbers from a 10 band graphic equalizer, or every third slider on a 1/3 octave graphic equalizer. Given that a piano with 88 keys only spans a 7 ¼ octave range, it is clear the human ear is a rather fantastic instrument.

Looking at wavelength, or λ, we get a little more insight into what differentiates low frequency waves from high frequency waves. In order to calculate wavelength we need to know two other terms, the speed of sound in air and what frequency we are working with. The speed of sound in air at 70° Fahrenheit is 1,130 feet per second. Think of this as a constant. While it is true that colder air will cause sound to slow down, and it will also be affected by pressure, the differences are small enough to be ignored in most calculations. Using these values, we can apply the formula **$\lambda = c / f$**. Where **λ** is wavelength, **c** is the speed of sound and **f** is the frequency of the wavelength we are calculating. Let's look at a 100 Hz wave to determine it's wavelength:

$\lambda = c / f$

where c = 1,130 ft. / second,

f = 100 Hz or cycles / second,

we can calculate 1,130 ÷ 100 = 11.3.

The seconds cancel out in the equation, and we are left with 11.3 feet per cycle. A rather large number. Let's look at another frequency, 1000 Hz. Applying the same formula we get 1.13 feet / cycle. Quite a bit smaller. Taking this one step further, looking at 10 kHz, we get a λ of 0.113 feet, or just under 1.4 inches. From these calculations you can determine that wavelength is inversely proportional to frequency, ie. as frequently increases, wavelength decreases.

In terms of amplitude, there are two terms to consider, Sound Intensity Level (SIL) and Sound Pressure Level (SPL). Remember the amplitude of a sound wave is defined as the difference between the pressure of the sound wave and the still air around it. For a Sound Intensity measurement there are two factors involved: the pressure of the sound wave and the particle velocity of the air molecules. As this particle velocity is difficult to measure, and the human ear behaves more closely to a Sound Pressure measurement, I'll focus on the SPL measurements. Microphones respond to changes in the air pressure, which is then converted to ac voltage. Whether it is a pressure microphone (typically omnidirectional) or pressure gradient microphone (cardioid to figure eight and everything in between) it is the pressure changes in the air that move the diaphragm and create an output that we can measure. We measure this voltage and by using a logarithmic scale we determine the decibels of Sound Pressure Level (dBSPL). This scale is used to more closely track the way we hear, as the range of human hearing is quite large, with the range between the quietest sound we can detect to the loudest sound we can tolerate being nearly $1{:}1\mathrm{x}10^{12}$. That's a 1 with 12 zeroes behind it! Hence the logarithmic scale, as dealing with numbers this large is unwieldy otherwise. I'll discuss logarithms and decibels in another column, but for now know it is used to make measurements more manageable when dealing with a ca. 120 dB dynamic range of the human ear.

To sum up, sound waves in air are longitudinal waves, with the properties of frequency, wavelength, and amplitude. Knowledge of these properties will help with an understanding of how sound waves interact with the environment. In the next column we will look at sound in a room, and how the wavelength determines it’s behavior, along with other common room acoustics.