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mbluergb0.2, 0.3, 0.8 morangergb1, 0.5, 0 mgreenrgb0.1, 0.4, 0.2 mredrgb0.5, 0, 0

Sound Systems Design and Engineering

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Part I
Loudspeakers

1 System Design Building Blocks

1.1 Decibel Math

The decibel (dB) involves the use of a logarithm to allow large differences and numbers to be written as conveniently small numbers. A decibel is a ratio between two pressure levels (ie. the measure of deviation of air at a certain point due to sound). These get big so quickly that logarithms quickly become necessary.

There are two definitions for decibels:

$$\mathrm{dB} = 10\log_{10}\left(\frac{A}{B}\right)$$
$$\mathrm{dB} = 20\log_{10}\left(\frac{A}{B}\right)$$

The first definition is in reference to power, the second in reference to voltage. In this class, we'll only work with the second one, as that's the one that is generally useful for sound. The first one is useful when talking about power amplifiers. For the future, we'll write log instead of $\log_{10}$ for the sake of simplicity.

A is the pressure value we want to measure, and B is the reference value. The reference value we use (B) is the quietest sound that it's possible to hear.

1.1.1 Logarithms (and their Applications)

A base-10 logarithm like we'll be using answers the question "what exponent does 10 need to be raised to to equal our value?" For example, $10^1 = 10$, so

$$\log(10) = 1$$

This asks the question "what exponent does 10 need to be raised to to equal 10," for which the answer is 1. Another example, $10^0 = 1$, so

$$\log(1) = 0$$

This asks the question "what expoent does 10 need to be raised to to equal 1," for which the answer is zero.

Logarithms convert multiplication into simple addition and division into simple subtraction. Written out, what this means is that we can write $\log(AB)$ instead as

$$\log(AB) = \log(A) + \log(B)$$

Similarly, we can also write $\log(A/B)$ as

$$\log\left(\frac{A}{B}\right) = \log(A) - \log(B)$$

There's another important thing to note about logarithms. If we measure the sound pressure level (SPL) at some point to be x dB, that means that we know

$$x = 20\log\left(\frac{A}{B}\right)$$

How do the number of decibels change for a sound twice as strong?

$$\begin{aligned}
20\log\left(2\frac{A}{B}\right) &= 20\log(2) + 20\log\left(\frac{A}{B}\right)\\
&= 20\log(2) + x\\
&= 20(.03) + x\\
&= 6\text{dB} + x\text{dB}
\end{aligned}$$

What this means is that any time we double the pressure of the sound, we're adding 6 dB.
Let's see what happens if we do this but we half it instead:

$$\begin{aligned}
20\log\left(\frac{1}{2}\frac{A}{B}\right) &= 20\log\left(\frac{A}{2B}\right)\\
&= 20\log\left(\frac{A}{B}\right) - 20\log(2)\\
&= x\text{dB} - 6\text{dB}
\end{aligned}$$

So, halving the pressure level means we subtract 6 dB.
One more example: what happens if we have an SPL ten times as large?

$$\begin{aligned}
20\log\left(10\frac{A}{B}\right) &= 20\log(10) + 20\log\left(\frac{A}{B}\right)\\
&= 20(1) + x\\
&= 20\text{dB} + x\text{dB}
\end{aligned}$$

This means that to get a sound with ten times the pressure, we have to add exactly 20 dB.

1.2 Inverse Square Law

As an introduction, the surface area of a sphere is

$$\text{Surface Area} = 4\pi r^2$$

where r is the radius of a sphere. Note that if we double the radius, there will be 4 times as much surface area.

The inverse square law isn't just a sound thing—it's common between sound, gravitational pull, electric field strength, radiation, etc. If we have a point source that obeys the inverse square law (imagine, for example, a speaker in the air broadcasting sound equally in all directions), the intensity of a sound is inversly proportional to the distance from the source (as distance increases, intensity decreases, and visa-versa). Specifically, they're inversely proportional with a square relationship (hence the name). For example, if we move away from the source a distance of 2m, the intensity drops to 1/4 of what it was. This is because the sound is being projected in a sphere, and as we get farther away, the surface area is increasing, but the total sound pressure isn't increasing, so the sound has to spread out more to cover the area.

As an example. If a speaker 1 ft away from you has volume x. At 2 ft, it would have volume of $\frac{1}{4}x$. At 3 ft, $\frac{1}{9}x$. At 4 ft, $\frac{1}{16}x$. And so on. We get these numbers by squaring the distance and putting it on the bottom.

An important conclusion from this: if you're using surround sound (ie. sound from behind the audience), you'll get more even coverage if you put the speakers farther behind the audience. If the speakers are, for example, 1 ft behind the back of the audience, the volume even 6 feet away (one or 2 rows up) will be already $\frac{1}{36}$ the intensity since it's 6 times as far. On the other hand, if we put the speakers 12 ft away from the last audience member, the volume 6 feet away (one or 2 rows up) is only 1.5 times as far away, so it's only $\frac{4}{9}$ as quiet (if I'm doing my math right). This still isn't the best, but it's a lot better. We can also use vertical height to increase the distance from the audience without having to go as far back.

1.3 Reference Signals

1.3.1 Sine Waves

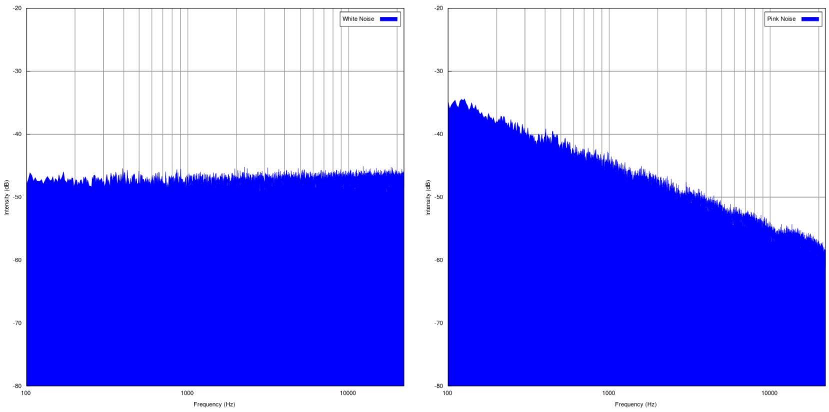
Sine waves are patterns of air pressure where the pressure in some direction can be modelled using a sine curve (very generally, this means that areas of high pressure happen at regular, predictable intervals at regular, predictable maximum intensities, and areas of low pressure similarly happen at regular, predictable intervals and with regular, predictable minimum intensities).

1.3.2 Fourier

Fourier found in the 1820s that any signal, no matter how complicated, can be written as the sume of sine waves at different amplitudes and at different phase relationships. Through Fourier analysis, we can convert from looking at a signal as a function of time, to looking at a signal as a function of frequency. Theoretically, we could totally replicate anything we hear or record with a sum of sine waves, but that would take literally tens of thousands of sine waves every moment, so it's hard.

1.3.3 Noise

There's two types of reference noise we use: white noise and pink noise. White noise has more audible high end than pink noise, and pink noise has more audible low-end. White noise has equal amplitude at every frquency. Pink noise takes white noise and applies a "pinking" filter, which takes away 3 dB per octave. There are more frequencies at a given octave at high frequencies, so in white noise, the high frequencies have much, much more energy, making them overpower the lower octaves. The goal with pink noise is to give us something that sounds like it's evenly distributed betwen notes. Here's the difference between white and pink noise (respectively) on a frequency spectrum:


White Noise
Pink Noise
Intensity (dB)
Frequency (Hz)
-20
-30
-40
-50
-60
-70
-80
100
1000
10000