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Understanding Sound and Noise

Generation Propagation and Reduction

What is Sound and How Do We Hear It?

Noise is simply unwanted sound. So first we might want to look at sound and how it is generated. Sound is actually changing air pressure. That is, a generator of sound must move the air back and forth, creating "sound waves" that can be heard (presumably by humans). One way to picture this is to think of a large concert bass drum. When the mallet strikes the drum head, the head begins to move back and forth, or vibrate. As it does, it "pulls" some air in front of it towards itself, and then as the head moves out it pushes that same air away from it again. In doing so, the drum head creates small changes in air pressure that move (or propagate) through the air. These ripples in the air move out in all directions (though not always equally), eventually striking our eardrum. The human eardrum is like a very small drum head itself that can be moved by these minor changes in air pressure. As it moves back and forth, we perceive sound.

In the simple example above, we can imagine the bass drum head moving in and out, and we might be able to imagine the waves in the air moving towards us, eventually striking our own ear drum, which moves in harmony with the waves, and our brain "hears" the sound the bass drum made. In real life however, it can get somewhat more complex, even though following the same basic principles.

Frequency and Volume

The bass drum has a very low pitched sound. A flute may have a high-pitched sound. We perceive both differently because each one causes the air around them to vibrate differently. This is often referred to as frequency (or pitch) and is measured in Hertz. Essentially, the faster the air vibrates the higher the frequency. Conversely, the slower the air vibrates the lower the frequency. Different instruments and voices generate

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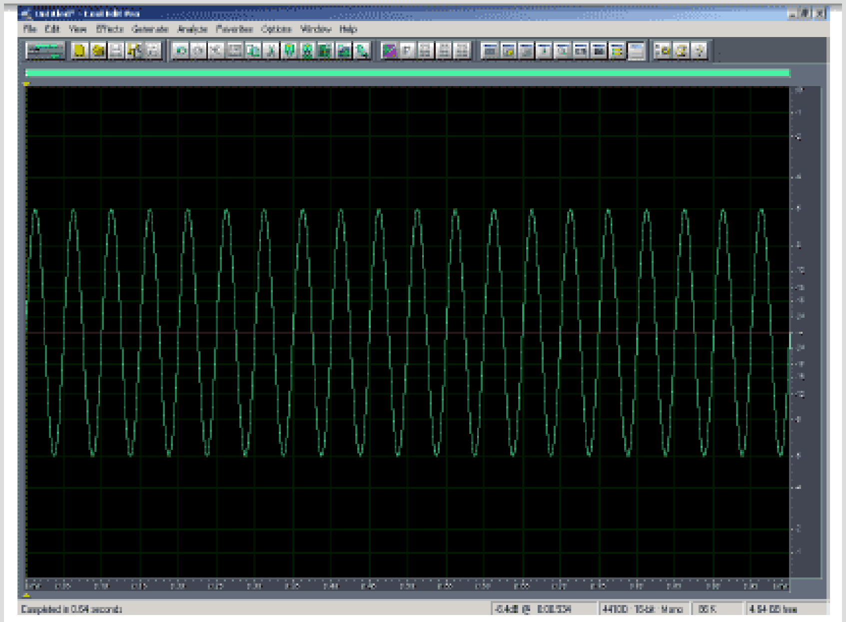
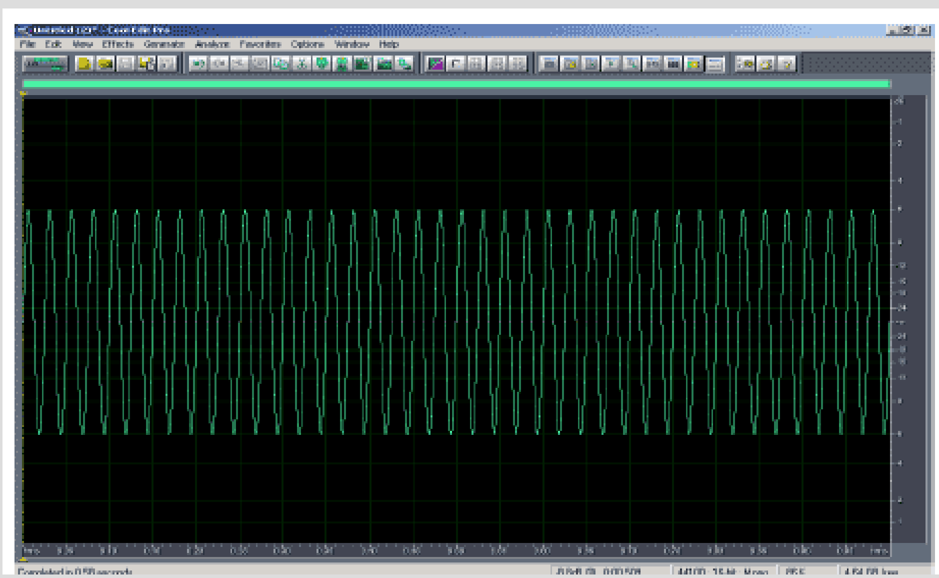
sounds at different frequencies.

Here is another example of frequency. In the diagram below, a 20Hz sound is shown for one second of time. Notice that during the one second of time we can count 20 complete cycles. The waveform shown is a simple sinusoidal wave, or sine wave for short.



Here we show a 40Hz sine wave. Note that there are twice as many complete cycles because the frequency (pitch) is twice as high as the 20Hz pitch. In music, this is also called an octave (as in this pitch is an octave higher than the last one).



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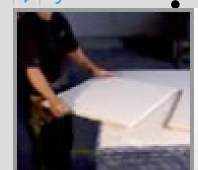

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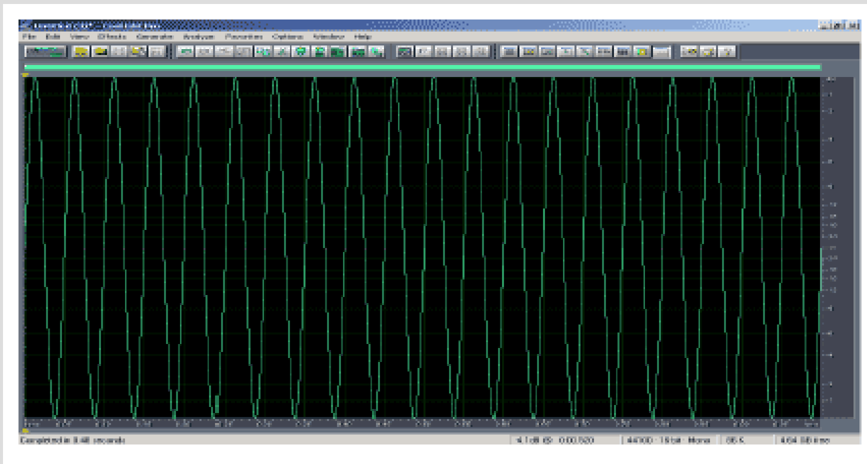
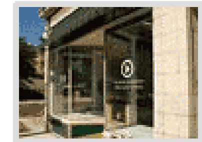
Now that we understand how sound is generated as well as a basic understanding of frequency, we need to understand loudness (or volume) of sounds. While frequency (pitch) is how fast the air pressure changes, loudness is determined by how much the air pressure changes. This can be illustrated in the example below.

Here is the same 20Hz sine wave we saw earlier, but this is now much louder. Note that the number of complete cycles is still 20 but highest points are higher and the lowest points are lower…thus creating larger swings in air pressure and a higher perceived volume, even though the frequency is exactly the same.



And again, we see a 20Hz wave, but this time it is obviously very soft. The high peaks are not very far away from the lowest peaks. In this way, we can depict small changes in air pressure (and thus a softer volume) even though the frequency is exactly the same.



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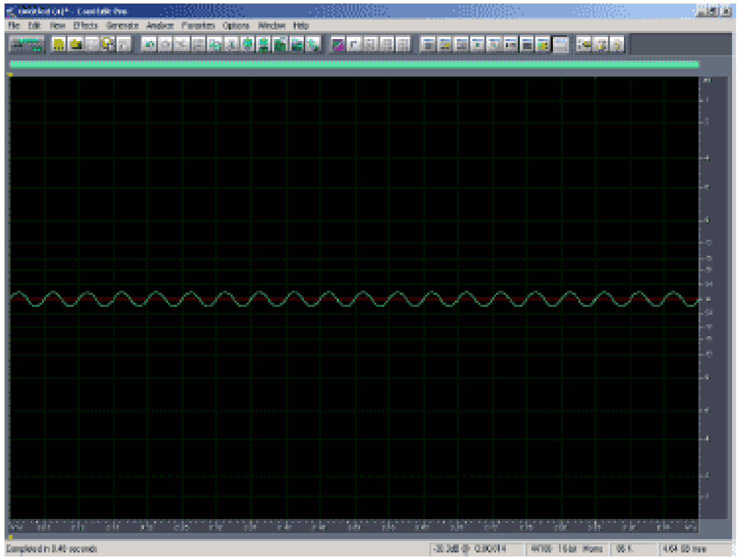


In real life, there are few things that generate single frequencies at a time. Even musical instruments have a fundamental tone, as well as "overtones". These "overtones" are frequencies that are generated in addition to the main frequency that is generated, and help us differentiate a violin from a flute, even if they are playing the same note. Moreover, other common objects, such as motors or engines generate a host of frequencies all at once with each moving part generating its own sound and adding it to the other sounds. The resulting sound is called a complex sound wave, and these make up virtually all of the sounds we hear.

- The important points of this section are:
- Sound is generated by changing air pressure
- The pitch is how fast the air pressure changes
- The volume is how much the air pressure changes
- Most sounds we hear are complex sine waves

What are Decibels?

The volume (or loudness) of a sound is measured in decibels (or dB). Think of it as the pressure (or energy) behind the volume. The general range of human hearing is from ~0dB to 120dB. A quiet library is about 30dB, while 120dB is considered the threshold of pain, where the ears begin to feel pain from the volume.

The following table shows some common generators of sound and their typical Decibel levels as well as OSHA exposure limits:

Maximum Exposure per day (OSHA)	Sound level	Decibel Level	Examples
	No Sound	0	Threshold of hearing… essentially no sound
		10	Breathing
		15	A sof t whisper in someone's ear.
	Very Quiet	20	Whisper, rustling leaves
		25	Recording Studio
		30	Quiet rural area, Very quiet library.
		40	Very Quiet Residence
		45	Typical neighborhood.
	Quiet	50	Quiet suburb, conversation at home, Private office
		60	Normal conversation (3-5 feet), sew ing machine, typewriter.
	Annoying	70	Freeway Traffic at 50 feet, vacuum cleaner
		75	Typical car interior on highway
	Loud	80	Garbage disposal, dishwasher, average factory, Telephone dialtone, Noisy office
16 hours		85	City Traffic (inside car).
8 hours		90	Power drill, shop tools, Busy urban street, diesel truck, food blender
6 hours		92	Clarinet, Oboe at 10 feet
4 hours		95	Subway train at 200 feet
3 hours		97	French Horn at 10 feet
2 hours	Very Loud	100	Jet takeoff 1000 feet, Outboard motor, farm tractor, garbage truck, Very heavy Traffic
1.5 hours		102	Motorcycle
1 hour		105	Power mower
		108	Home Theater (loud peaks)
0.5 hours		110	Chainsaw, pneumatic drill, typical rock concert, Steel Mill, riveting, auto horn at 3 feet
0.25 hours		115	Jackhammer
0 hours	Pain Threshold	120	Loud thunderclap, typical live rock music

Hearing damage occurring		125	Pneumatic riveter at 4 feet
Ear drum distortion		130	Jet takeoff (300 feet), Noise level during a stock car race.
Permanent hearing damage		132	Very loud rock concert, 50 feet in f ront of speakers
		140	Gun muzzle blast
		140	Prop aircraft on takeoff , gun muzzle blast, aircraft carrier deck, jet engine at 100 feet
Ear drum rupture		150	Jet takeoff 75 feet
		155	Shot from a handgun (.38 or .44) at 1 foot
		160	Jet aircraft on Takeoff at 30 feet
Immediate death of tissue		180	Jet engine at 1 foot
		194	Loudest sound in air, air particle distortion (sonic boom)

Noise Propagation

Sound waves reflect off of other surfaces, so the sound coming from one source can easily fill every corner of a room by propagating out in all directions and by reflecting off of the surfaces in the room. So how does the sound get into one room from another above it?

The first thing to understand is that changes in air pressure not only move our eardrums back and forth, but also move other objects back and forth. For instance, if we were to make a wall out of cellophane, and stretch it from floor to ceiling in a doorway, sealing off all the airflow from one side to the other, do you think you could hear someone banging a bass drum on the other side? The answer is, of course you can, even though no air is flowing between the bass drum and you. That means that the bass drum vibrating generated rapid changes in air pressure (sound waves) that hit the cellophane, vibrating the cellophane in an almost identical fashion. The cellophane vibrating creates rapid changes in air pressure on your side (just as the bass drum would have directly done), which travel and hit your eardrum. Because the cellophane essentially reproduced the vibrations of the bass drum, you hear the bass drum, as if the cellophane were not there.

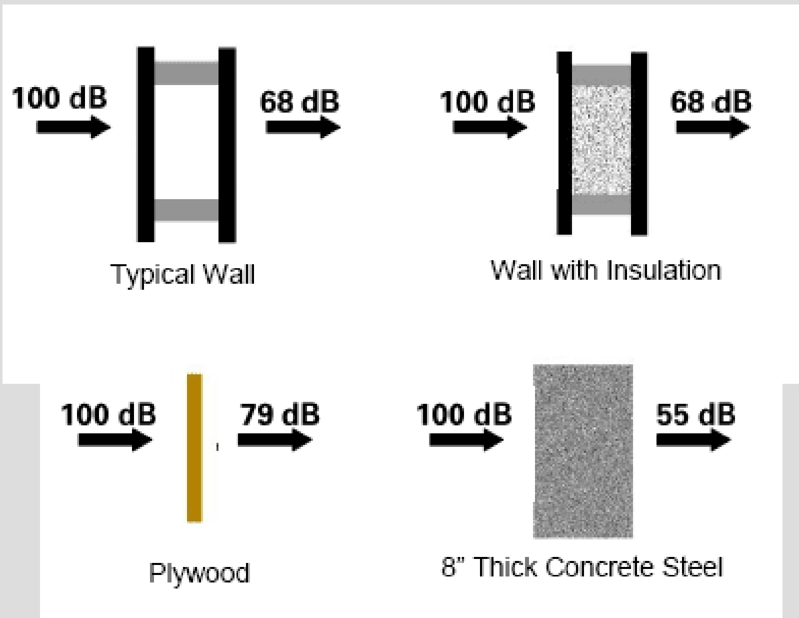
The cellophane can cause some distortions in the original sound. This occurs for many reasons. First of all, the cellophane has a certain mass that, like most materials, is larger than air. It requires more energy to move the cellophane back and forth than air, and that energy is dissipated as (or converted into) immeasurable amounts of heat energy.

Now, as we move farther away from any sound source, that sound generally gets softer. This is due to sound waves not only spreading out in every direction, but also the fact that the rapid changes in air pressure that make sound dissipate energy through the air, because even air has some mass. This loss of energy, through air, and more so through objects, causes the sound to get softer and thus, a lower dBA level.

In our cellophane example, we still hear the bass drum through the cellophane, but it should be a bit softer (due to the mass of the cellophane) than if we had no cellophane in the way.

Now let's suppose we remove the cellophane from the doorway and close the door. The door has much more mass than the cellophane, and thus will dissipate more energy. Yes, the door itself will vibrate as the bass drum does, re-generating the bass drum sound on the other side. However, the loss through the door will be more than the cellophane.

The diagrams below demonstrate a variety of sound propagation through common materials and the amount of sound on 1 side versus the other:



Sound waves, like water, will find any leak to get through. Since air offers less resistance to sound than a piece of metal, much of the sound energy will exit any structure through air openings in the barriers. So, a 5-foot square 1" thick lead wall might reduce the noise traveling from 1 room to another. However, if there were three ½" holes for wires in the lead wall, the majority of sound will exit through those holes, reducing the effectiveness of the wall. Hence, the total system must be considered in any noise reduction problem.

Reducing Noise

When considering reducing noise in any system (from a lawnmower to a car to a machine to a home to an apartment), four major tradeoffs need to be considered. These are primarily weight, space, cost, and aesthetics. Given enough money, and unlimited weight and space, one could construct a 10-foot thick lead barrier, welded on all sides. Given the mass of this barrier, it would take considerable sound energy to make it vibrate, so the loss through it would be significant. This concept is called “mass loading”. The idea is to place extra mass between the noise source and you.

However, few places have an extra 10 feet to spare, let alone the cost (exceeding a few hundred thousand dollars) and the weight (exceeding 20 tons) to support a sound reducing method like the one mentioned above. Mass loading, while 200+ year old (technology wise), is not a very efficient method of dissipating noise and vibration, and most applications cannot afford the significant cost or weight it requires.

There are many examples of mass loaded materials for sound reduction including Mass Loaded Vinyl (typically at 1 pound per square foot) as well as Asphalt Based Mats.

Another method is by creating many surfaces for the sound to vibrate, each one having little loss, but in aggregate, absorbing a fair amount of sound. Closed-cell foams are popular for this, they are good for reducing sound WITHIN a room; however, they don’t do a good job of preventing noise from passing through them so they do not make good barriers. One can imagine the sound waves passing (and vibrating) each little cell of foam. There may be hundreds of cells that need to be vibrated before the sound has passed all the way through the material, thus causing a small amount of reduction, but a large amount of reduced reflections.

The newest technology in the noise-barrier field exploits the viscoelastic properties of some materials. By formulating special chemicals that are very viscoelastic, they can be deformed by sound waves, take time returning to normal, and within a range of temperatures and frequencies, reduce noise and vibration by 10-20dBA per layer or more. Think of a “Tempur-Pedic” mattress, which uses a viscoelastic foam material, it is deformed by weight and heat of your body when you lay on it, yet will return to its normal shape in 5-10 seconds after you get off of it. Viscoelastic materials work in a similar fashion. They are deformed by the sound wave but after awhile they return to their normal shape. In other words, viscoelastic materials dampen noise.

There are two ways to dampen sound with viscoelastic materials. Free (unconstrained) layer damping is one method and is the simplest way of introducing sound damping into a structure. The treatment consists of a layer of sound damping material bonded to the surface of the sound generating source or a sound barrier (such as metal or plastic). The coating moves with the sound barrier but due to its “noise absorbing” like qualities it helps to slowly dissipate sound wave energy. The material is low cost, low density (typically 1mm thick), and low weight.

The second method for dampening sound is through constrained layer viscoelastic damping. It is among the most efficient ways of introducing sound damping into a structure. This requires the viscoelastic material to be placed between 2 other rigid materials (such as metal, plastic, wood, drywall etc.). It must also have adhesive qualities to bond directly to both outer layers to work effectively.

QuietRock, a multi-layer laminated gypsum wall product from Serious Materials, Inc., is engineered around constrained layer viscoelastic damping. Because QuietRock simply hang it like standard drywall, it is eliminates the need for expensive, difficult and non standard sound isolation construction techniques. There are also materials (typically foams and fabrics) for sound absorption within a room. These work primarily by reducing reflections of sounds from surfaces (such as walls and ceilings). They do not stop sound from passing through them. Materials that work well for reducing reflections often are not very good at reducing sound transmission (through them). For instance, while some foams make excellent sound absorbers within a room, they don't make a very good sound barrier. Vinyl (mass loaded), makes a fine barrier, but a poor absorber. So the right material needs to be chosen for the right result.

As we saw in the last section, various materials (such as concrete or gypsum) have a certain amount of sound transmission loss. This loss is mostly due to its mass. But what about adding some viscoelastic material, rather than mass? The results can be excellent.

For example, the diagram below represents standard 2" x 4" - 24" OC construction between two rooms. QuietRock is effective over both wood and metal standard studs.

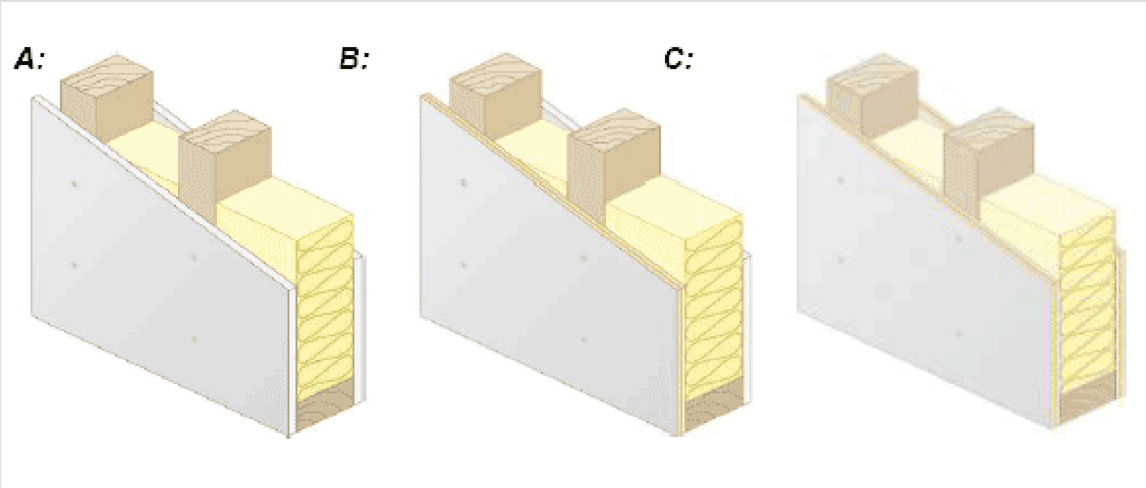


Figure 1: Three Scenarios

A. Represents existing/typical acoustical wall partition. Using 24" OC studs and R13 insulation, with one layer of gypsum on both sides, this wall has an average STC rating of 39.
B. Represents the same wall partition framing as in diagram a), but with QuietRock 525 as a replacement for the gypsum on one side. The STC rating is improved by 14dB over A, to 53.
C. Represents that same wall with QuietRock 525 as a replacement for the gypsum on both sides. The STC rating can be improved by 17dB over diagram A to STC 56.

The viscoelastic glue in QuietRock works by converting acoustic and vibrational energy into minute amounts of heat. This is very different than mass-loading or wall-fill techniques, and is easily achieved in existing construction at a low cost.

It is critical in every noise reducing application that all air gaps are filled. Otherwise, noise will always take the path of least resistance, which inevitably will be the air. In construction, a good acoustical sealant (one that never dries) is the best bet. Every wall seam must be completely airtight, between panels, and between floor and ceiling, as well as around wall outlets.

Conclusion

There are a variety of techniques to reduce noise and vibration in a variety of structures today. Every method relies on 1 of 2 principals, mass or viscoelasticity. Both methods can be effective, depending on how much material one would want to use. However, noise propagation is very complex, and even though materials are tested to absorb structural vibration it does not mean they will eliminate any particular noise problem. The more the source can be isolated with air-tight barriers treated with viscoelastic materials or mass-loaded techniques, the opportunity to meet your needs for quiet are enhanced.

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