Good Vibrations (Part 1)

The Basic Principles of Unwanted Vibrations

When we play back audio, we only want to hear sound waves created from the electro-mechanical vibrations produced by the loudspeaker. They are the result and intention of the artists. They are the original signals. These are good vibrations. However, for this article, we will focus on the basic principles of unwanted vibrations of audio playback environments.

By
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There are good vibrations, and there are bad vibrations. Everyone knows that, right? It turns out, not everybody does. At least not to the extent they should.

In the listening environment, there is much more than just the direct speaker-to-ear sound waves happening in the room. The construction materials and methods of the room, the dimensions and shape, even the furnishings can influence the direct sound waves. Some of these sound waves are desirable from a psychoacoustic point of view, but many, in fact most, are unwanted. They are new, unoriginal signals. They are bad vibrations.

When the driver in a loudspeaker moves, it pushes air molecules, which produce what we perceive as sound. Sound is vibration. Air is an elastic medium, which when pushed by the diaphragm of the loudspeaker, causes the particles to bump into the adjacent particles, after which, they return to their normal resting position. So, the particles don't actually travel across the room at approximately 1,130 feet per second, only the waves do. The action causes high and low pressures per unit area as the particles are displaced by compression and rarefaction. The action is a transfer of energy from one particle to the next.

Newton's Three Laws of Motion

Newton's three laws of motion may be stated as follows:

- Every object in a state of uniform motion will remain in that state of motion unless an external force acts on it.
- Force equals mass times acceleration [$f(t) = ma(t)$].
- For every action there is an equal and opposite reaction.

The first law, also called the law of inertia, was pioneered by Galileo. Before Galileo, people believed Aristotle's formulation that, wherever there is motion, there is an external force producing that motion.

The second law, $f(t) = ma(t)$, actually implies the first law, since when $f(t) = 0$ (no applied force), the acceleration $a(t)$ is zero, implying a constant velocity $v(t)$. The velocity is simply the integral with respect to time of $a(t) = \dot{v}(t)$.

Newton's third law implies conservation of momentum. It follows from the second law: When one object "pushes" a second object at some (massless) point of contact using an applied force, there must be an equal and opposite force from the second object that cancels the applied force. Otherwise, there would be a nonzero net force on a massless point which, by the second law, would accelerate the point of contact by an infinite amount.

In summary, Newton's laws come down to $f = ma$. Think of the enormous quantity of physical science has been developed, and continues to be developed, by applying this simple mathematical law to different physical situations.

Sound Waves

In a room, as sound waves are propagating out from the loudspeakers, they not only reach our ears, but they bombard into everything in their path until their energy is diminished via absorption. Absorption of sound energy is the conversion from sound energy to heat energy via friction of particles. Sound energy can also be reflected and transmitted. Transmission meaning sound energy being transferred from one medium to another (e.g., air to sheet rock to air). In our room, most of the sound waves traveling around are subjected to combinations of absorption, reflection and transmission.

Sound waves are pretty powerful and their interaction with the room can interfere with the direct sound more than most people realize. Sound waves can displace walls, cause cavities to resonate, or rattle and buzz the structure, all from a mid-fi stereo system not much louder than a normal conversation. Of course, if we extend the lower frequencies and boost the amplitude, we can increase these affects.

Loudspeaker designers and manufacturers put a lot of resources into the cabinet to control and prevent vibrations from introducing unwanted tonal colorations. Construction materials and methods are critical to the performance outcome. In general, the more you pay for the loudspeaker, the more of that money goes toward the loudspeaker enclosure to keep things under control. The cabinet's wall construction, bracing, damping, loading, fastening and driver mounting each play a role in the performance quality.

In addition, there is one more vital component that can impede the potential performance of the equipment and enjoyment factor for the listener—the speaker enclosure/platform coupling.

Most of us have experienced an audible subwoofer from a level above or below us, or even from the other end of the building. This is from the enclosure's vibrations being transmitted into the interconnected structure and is known as flanking (see **Figure 1**). Common construction techniques involve hard connections with no breaks. This is a noise control issue to be certain, but there are also sound quality issues being introduced.

Cabinet vibrations are coupled to the floor (or speaker stand, shelf, etc.), which in turn couples with the air, the rest of the structure, and pretty much everything contained in the room. Some people do not think that such vibrations contribute much. I would like you to think harder about that.

Experimenting With Vibration

DIY Vibration Experiment #1: Discover how much your speaker cabinets vibrate and can transmit vibrations to their resting platforms, etc.

Though speaker manufacturers may spend significant resources on anti-vibration elements for their cabinets, they still move. You may think that the speaker cabinet doesn't move and you may not feel it move to the touch, but even those made of concrete move.

Try striking a tuning fork and hold the end to the cabinet surface. Notice how the cabinet surface acts as a soundboard. The tuning fork becomes much louder because the cabinet is moving and pushing a greater volume of air. The amplitude will depend on the cabinet construction, but I'm sure it is much greater than the sound of the fork in free-air. The most common tuning fork is A440. That's of course, 440 Hz, midrange, and about the middle of the piano keyboard. You probably cannot see the tines move with the naked eye, and you can barely hear them vibrate un-aided. Especially difficult at the holding end where the energy is being transferred.

DIY Vibration Experiment #2: Discover how much your room vibrates and interferes with the direct

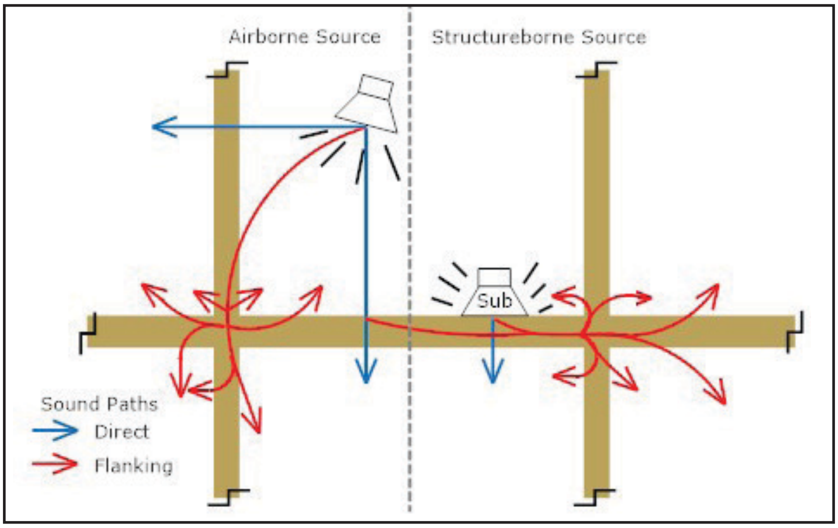

Figure 1: Depicting the difference between direct and flanking sound paths. In general, the effect of the structureborne flanking can be thought of as a point or line source (the force excites free bending waves in the panel to radiate sound) to the second radiating panel of the partition.

sound waves. Strike a tuning fork and place it on your walls, floor, ceiling, etc. These large surfaces are set into motion through the hard connections found in typical construction—the loudspeaker cabinet transfers vibrations to its stand, shelf, or floor causing the floor to vibrate, which is connected to the walls, which is connected to the ceiling. In fact the entire house is typically hard connected, which is why you can hear the subwoofer at the opposite end of the house, upstairs and downstairs. It is also why you can hear someone talking from the other side of the wall. In the listening room, the movements of these surfaces are acting as additional loudspeakers, adding to the original sound waves, later in time and from all around.

The tines of the tuning fork are barely audible until coupled to a hard plate (like the wall). It is impressive that the tiny tines can displace an entire wall even at say 440 Hz. Of course, lower frequencies will move the wall even more. However, the higher energy of lower frequencies is more difficult to diminish, which is why you can hear the subwoofer many rooms away through structure-borne vibrations.

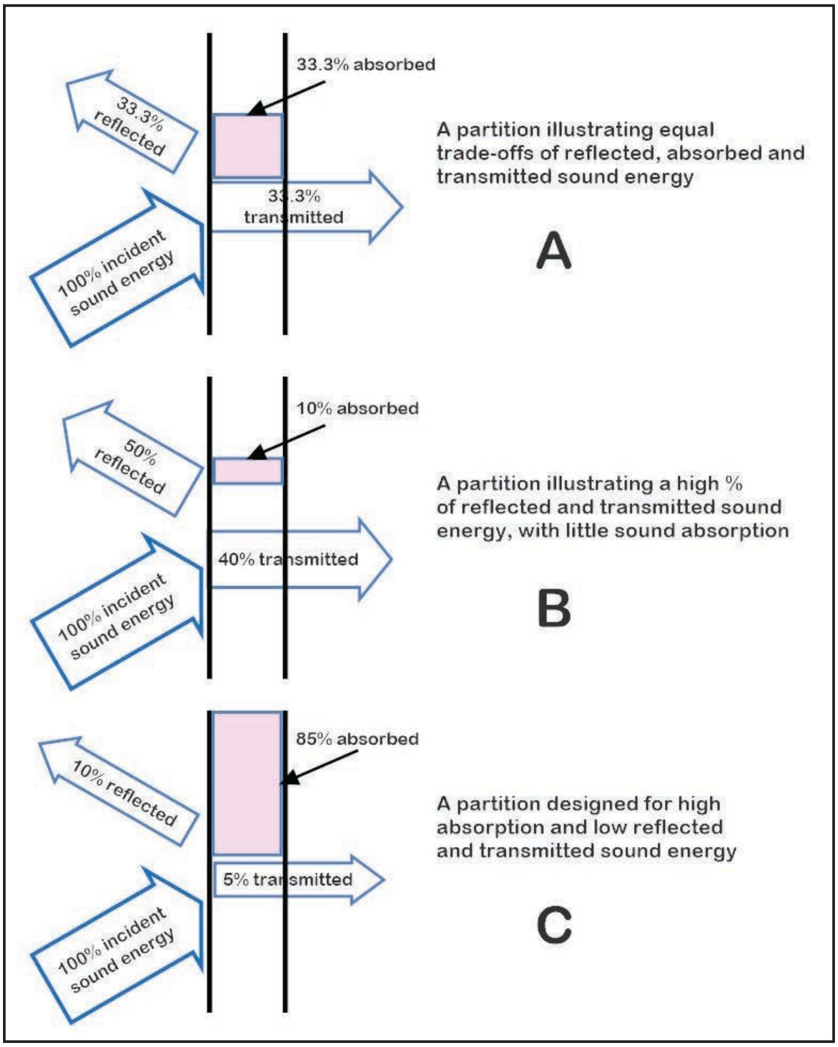

Figure 2: Illustrating how different types of partitions may reflect, absorb, and transmit sound energy

DIY Vibration Experiment #3: Lightly hit the skin (sheathing) of the wall between studs with your fist. The stud cavity produces a low boom, just like a big drum. In typical US construction, you're hearing about 70 Hz. This is a function of the surface mass of the skin and the thickness of the airspace. Whenever your music plays 70 Hz (which is probably most of the time), your walls sing along in sympathy. Not cool. This makes the room sound slow, muddy, and droning. In addition, such resonances occur later in time and duration than the original signal. This ringing is the cavity acting like a capacitor storing the energy and then releasing it later in time. This happens from the airborne sound waves impinging on the surface to be sure, but most of this excitement is generated from the mechanical structure-borne vibrations transmitted via the loudspeaker/platform interface.

When the bending sound waves form within the surface sheets of a wall, floor, or ceiling partition and coincide with the incident sound wave striking the panel, a resonance forms called "coincidence." It is quite typical in Transmission Loss (TL) curves to see a fairly narrow but major dip in the TL performance. The location and magnitude of this dip is primarily dependent on the density of the material, its modulus of elasticity, and the material thickness. For a given material such as drywall, the density and modulus of elasticity is constant, therefore, the driving factor is typically thickness.

There are a number of ways to reduce or shift the coincidence frequency. Elastomeric treatments work very well in this region. Introducing other materials and changing the thickness of the material reduces coincidence.

A common remedy is to change out thicker gypsum boards with the application of multiple thinner layers. As you can guess, gypsum wall board is a major player for most of the surface treatment of wall and ceiling partitions in the United States. The critical frequency for gypsum board can be calculated using the formula:

$$f_c \times t = 30.8$$

where "fc" is the critical frequency in Hertz and "t" is the thickness of the gypsum board in meters. For example, ½" or 13 mm gypsum has a coincidence frequency of 2,422 Hz.

Rooms are containers of sound. We cannot function comfortably without them, but they do create a lot of havoc on the music being reproduced.

We need them for noise control, both entering and exiting the space. They also help reinforce the sound energy. This is where the difficult balance of noise control and sound quality meet. We must control the first-order reflections to retain the original spatial and timbre qualities. We must also control the reverberation times to keep the original characteristics of dynamic range, articulation and low-level resolution. And, we must control the room mode distribution for linear bass response, etc. All of these room issues influence the final outcome we experience.

Vibrations and reflections are different principals. When airborne sound waves impinge on a surface, some of the energy is reflected, some absorbed (converted into heat energy), some is transmitted to the other side (see **Figure 2**), and some causes the surface to move and re-radiate back into the room. This part of the action is actually a new sound source. What is not represented in Figure 2 are cavity, panel, framing, and other resonances, which can contribute as new sources of sound energy. These can come from the shell of the room, and even furnishings in the room. We may also hear the structure become agitated and produce buzzes and rattles.

About the Author

Norman Varney is the owner of AV RoomService, an acoustic design company that also offers a few acoustical products. Having been in the noise control and sound quality industries for decades, he has earned awards for acoustical products and room designs while working for AV RoomService, Kinetics Noise Control, Owens Corning Science & Technology Center, and MIT. Norman has presented white papers to the industry and written articles on acoustics for numerous publications over the years, as well as participated in seminars and panel discussions. He is an active member of ASTM (Committee E-33 on Building and Environmental Acoustics), the Acoustic Society of America, the Institute of Noise Control Engineering, the Audio Engineering Society, the National Association of Music Merchants, CEDIA, and others.

We can think of the room as functioning much like an acoustic guitar:

- The room dimensions, like the dimensions of the guitar body, determine the modes that are reinforced.
- The shell construction of the room, like the guitar, act as a soundboard to amplify certain frequencies.

The difference is these attributes are for enhancement of the guitar, where as they are detriments to be controlled for the room. Imagine how much better the music might sound if all those unwanted vibrations did not exist.

In Part 2 of this article, we explore ways to solve these issues using various products that my company, AV RoomService, Ltd., has successfully developed when helping clients with their acoustic problems.