White Paper for Filtered Direct Coupling in Audio

This white paper is a presentation of the basis, background and requirements for the practical execution of a filtered direct coupling system in high end audio. The purpose of filtered direct coupling is the management of mechanical energy within components commonly used in audio systems.

This paper will provide examples and concepts fundamentally supported by accepted physics and engineering principals while minimizing complex formulas. Theoretical assumptions have been intentionally avoided to the greatest extent possible.

The fundamentals supporting this paper are drawn from the First and Second Law of Thermodynamics particularly the propagation of longitudinal mechanical waves through air and solid materials having the properties of volume, length width, height and mass. To establish the efficacy of energy conversion, accepted physics calculations demonstrating energy conversion in known compounds will be presented.

To move the discussion forward in this presentation some assumptions are made to form groundwork including:

- Audio systems are composed of electronics
- The term electronics includes digital, analog, tube and solid state components
- Audio components are powered by electricity
- The term loudspeaker(s) refer to all embodiments common to the genre
- Loudspeakers contain elements which will be called drivers and drivers produce sound by acting mechanically on gasses
- Audio systems are composed of electronics and loudspeakers
- Audio systems are generally located in a space called a listening room
- A listening room has the properties of dimension and volume and is permeated by gasses commonly known as air.
- Sound is a longitudinal mechanical wave.
- The terms "sound", "vibration" and "mechanical energy" are interchangeable terms; these terms are behaviorally indistinguishable in audio.

Basis

The basis for filtered direct coupling as a vibration management system in audio is derivative of isolation system technology and the utilization of energy released by loudspeakers into the air. Loudspeakers are transmission towers and the drivers within them vibrating cones which convert electrical signals to sound. Sound is made by the in and out piston-like motion of the vibrating cones which compress gasses. The gasses in the air vibrate in sympathy to the cones and the molecular action of gasses on solids in the listening room becomes the energy source for filtered direct coupling. Sound is energy and energy in a listening room acts in predictable ways.

First, it is valuable to establish that there is indeed a formula for predicting the degree to which vibration can be converted from mechanical energy to heat through materials appropriate for the task. A sample calculation presented in support of US patent number 7,290,759 granted November 6, 2007 is shown below:

The problem that follows provides a sample calculation which identifies 6.14% transmissibility at 60Hz. Please note: Ancillary nomographs, definitions, assumptions and calulations were omitted for simplicity.

Solution:

Shape Factor:

Square: $sf = \frac{(L)}{(4)(t)} = \frac{1}{(4)(1.25)} = \frac{1}{5} = .2$

Static Deflection:

Compressive Modulus: $= \frac{Cs \text{ (See Fig. 1)}}{\text{(Assumed Percent Deflection)} / 100} = \frac{14.05}{(.2) / 100} = \frac{14.05}{.2} \Big/ 100$

$= \frac{7025}{100} = 70.25 \text{ psi}$

Compressive Modulus Corrected for Shape Factor:

$= (\text{Compressive Modulus})(1 + (2)(sf^2)) = (70.25)(1 + (2 \times .04)) = (70.25)(1.08)$

$= 75.87 \text{ psi}$

Static Deflection: $= \frac{(\text{Load Per Isolator})(t)}{(\text{Corrected Compressive Modulus})(\text{Area})} = \frac{(15)(1.25)}{(75.87)(1)} = \frac{18.75}{75.87} = .247"$

Percent Deflection: $= \frac{\text{Static Deflection}}{t} \times 100 = \frac{.247}{1.25} \times 100 = 19.76\%$

System Natural Frequency:

Assume a Natural Fequency of 9 Hz

Eod is Dynamic Compressive Modulus
K' is Compressive Stiffness
pi = 3.1416

Eod $= Gd \times 3$ (Gd is found in Figure 2 and is equal to 48.4 for this sample) $= 48.4 \times 3$

$= 145.2 \text{ psi}$

K' $= ((Eod)(1 + (2\,sf^2))) \times \frac{Area}{t} = ((145.2)(1.08)) \times \frac{1}{1.25}$

$= 156.816 \times .8 = 125.4528 \text{ lbs per inch}$

Natural Frequency $= \frac{1}{2(pi)} \times \sqrt{\frac{K' \times 386}{\text{Load per Isolator}}} = \frac{1}{6.2832} \times \sqrt{\frac{125.4538 \times 386}{15}}$

$= .1592 \times \sqrt{3228.31872} = .1592 \times 56.818 = 9.04 \text{ Hz}$

Transmissibility:

Tangent of Delta is @ Excitation Frequency found in figure 3.

Tangent of Delta $= .48085825$

Frequency Ratio $= \frac{\text{Excitation Frequency}}{\text{System Natural Frequency}} = \frac{60 \text{ Hz}}{9.04 \text{ Hz}} = 6.64$

Transmissibility $= \sqrt{\frac{1 + \text{Tangent of Delta}^2}{(1 - (\text{Frequency Ratio}^2)\left[\frac{\text{Gd @ Natural Frequency}}{\text{Gd @ Excitation Frequency}}\right]^2 + (\text{Tangent of Delta})^2}}$

$= \sqrt{\frac{1 + .48085825}{(1 - (44.04976)\left[\frac{48.4}{112}\right]^2 + (.23112)}} = \sqrt{\frac{1.4808}{190.219 + .23112}} = \sqrt{\frac{1.4808}{190.45}}$

$= .0614$

Percent Isolation $= (1 - \text{Transmissibility}) \times 100 = 1 - .0614 \times 100 =$ **93.86%**

Shape factor, compressive modulus, tangent of delta, compressive stiffness and transmissibility, hence isolation, are dynamically interrelated forces suggestive of the complexity of this discussion. But this is not important here. What is most important is the understanding that isolation and damping in high end audio require the measurable reduction of a mechanical disturbance transmitted into material(s) wherein the disturbance is converted to heat and thereby mitigated in conjunction with a lowering of natural frequency. To the point, vibration has to actually pass into something possessing definable attributes for energy to be diminished. Examples of accepted energy conversion media are springs, air bladders, and elastomers but there are others.

In the process of isolating components from mechanical forces it is common to use the downward force of the component's mass to compress the medium doing the energy conversion/work as vibration travels upward from the floor. Since it is important to ensure components are level, it is a general practice to position the component on a rigid board or substrate that pushes downward upon the conversion mechanism in conjunction with the mass of the component. The compressive force of the component and substrate form an actuator. As a side bar, non-compressible roller bearings generally convert vibration to work in the horizontal plane and, though not discussed here, are susceptible to the same forces of physics in the vertical plane as isolation systems.

Background

Keep in mind that vibration, mechanical energy and sound are interchangeable terms as noted at the outset. Somehow sound creates vibration in the floor and the walls and ceiling and vibration makes its way into audio components in the listening room. Something inherent to vibration degrades music and we want to stop this effect quickly and completely. We hang a lot of caveats off this charge, for example, we want dynamics, extension, air and the list goes on, just get rid of the bad stuff.

To get rid of the bad stuff, we use good physics. Dynamic elements like shape factor, dynamic compressive modulus, tangent of delta, compressive stiffness, transmissibility and isolation are supported by the First and Second Laws of Thermodynamics. These Laws are couched in Newtonian physics and were utilized by Einstein within the Third Law of Thermodynamics. Later, we will visit the Swedish school of quantum physics to validate the argument for filtered direct coupling. It is important to explore Thermodynamics and Quantum physics to cement our understanding of the way energy propagates in a listening room.

The First Law of Thermodynamics states that energy cannot be created or destroyed; it can however be converted from one form to another. Hence, the First Law specifically establishes the basis and context within which mechanical energy is converted to heat. Interestingly, great minds dating from the time of Galileo were unable to reason that heat energy and mechanical energy were related until James Prescott Joule bridged the intellectual gap. Audio systems utilize the First Law to convert various forms of electrical and mechanical energy to sound. These phenomena have been widely published and Filtered direct coupling operates within the same body of accepted science.

The Second Law asserts that energy tends to diffuse from a state of concentration to a state of dissipation. The Second Law of Thermodynamics is also known as the First Law of Cognitive Awareness.

Here are a series of straightforward thought problems illustrating what is meant. For example, what will happen if I walk into my living room and hold an open bottle of purple grape juice over my carpeting and slowly turn the bottle upside down until the open end is pointed directly downward? Let's try another, what will happen to me if I climb a ladder onto the roof of my 2-story house and step off the edge? Here's another, what music will come out of my loudspeakers if I turn on all of the components in my listening room and play the 2nd movement of Beethoven's 9th Symphony at a volume of 85dB measured from my listening chair? And finally, assuming my system is playing the 2nd movement of Beethoven's 9th Symphony at a volume of 85dB measured from my listening chair, would I hear anything at all if I got up and walked 10 feet directly forward and stood next to the rack supporting the CD player spinning the disc?

You probably answered the questions as follows:

1) The grape juice will spill out onto the carpeting.
2) You will fall off the edge of your house and hit the ground.
3) The 2nd movement of Beethoven's 9th Symphony will come out of your loudspeakers.
4) Yes, you will hear the 2nd movement of Beethoven's 9th Symphony standing next to your rack. You might also astutely add that I would hear the same piece throughout my journey toward the rack and anyplace else I journeyed in the room.

You might be wondering why I am asking you questions with obvious answers. Obvious? How in the world did you come to these conclusions when you have never been in my house? How could you know these answers with any confidence without experiencing them first hand? Are you omniscient? Are you clairvoyant?

You know these answers because you have an unshakable cognitive belief that matter and energy conform to a uniformly observable and predictable set of rules to the extent you are absolutely positive the Laws that govern matter and energy in your home are exactly the same as those governing in mine. You know what will happen because you have experienced it in many ways over a lifetime. The Laws of Thermodynamics govern matter and energy in my home, your home, this planet and beyond.

As a final test of the 2nd Law of Thermodynamics, if I insist that in my home I can hold the empty bottle over the spilled grape juice and the puddle of grape juice will immediately flow back up into the bottle and stay there while I slowly screw the top back on, you would rightly think me a fool. If you were wrong, our world could not exist in its current form.

This is an extremely important point in our discussion of the behavior of energy in your listening room. Circling back to the example of the 2nd movement of Beethoven's' 9th Symphony playing at 85dB, if the sound you hear at the position of your listening chair can also be heard at the position of your rack and, by definition, any other position in your listening room simultaneously, then sound exists everywhere in the air of your listening room simultaneously. Since sound is mechanical energy and mechanical energy is vibration, through substitution, if sound

exists everywhere in your listening room simultaneously, then vibration exists everywhere in your listening room simultaneously.

Let's talk about Quantum Mechanics for a moment as this is very important. We are interested in the Copenhagen interpretation fathered by Niels Bohr which through popular expansion supposes matter and energy are not defined until they are observed. The example of light existing as both a particle and a wave until it is observed as one or the other is the classic proof of quantum behavior. The notion that light consists of discrete quantum particles was first postulated by Einstein who throughout his life rejected quantum physics as a complete description of the universe. Regardless, the example is accurate as are many other examples of the behavior of particles.

Popular culture likes to grab onto nuances of physics and popularize them into sweeping generalizations. Dr. Erwin Schrodinger devised a thought problem constructed to illuminate the shortcomings of Quantum superposition which has come to define quantum schools of thought. To be brief, Schrodinger imagined that the fate of a cat trapped in a sealed box with a diabolical death machine was dependent upon the discharge of a gamma particle from a Geiger counter also in the box. At any given moment, the gamma particle might or might not be discharged so at any given moment the cat might be dead and alive until we observed the cat. The subatomic structure of the cat might also be equal part alive and dead which could lead to a cat with a half dead and half living body. The act of observing the cat seals its fate one way or the other.

This is bizarre indeed, but expanding the dual-state nature of a subatomic particle to a large-scale superposition in the listening room, we could postulate that amplifiers are not turned on unless we observe them turned on. We could assert loudspeakers make no music in the above examples unless we hear it. We could assert that Beethoven's 9th playing at a volume of 85dB measured at the listening chair is playing at 0dB next to the rack until we actually get up and go to the rack and observe sound using our hearing faculties. We could further assert that music occurs only at the 1st layer of gas molecules next to our eardrums and in no other place in our listening room; the rest of our listening room is cloaked in silence <u>unless and until</u> we get up and observe a sound in a different area of the room.

Through the 1st Law of Cognitive Awareness (the 2nd Law of Thermodynamics) we know that matter and energy in audio systems act in predictable ways from one audio system to another. Quantum mechanics does NOT describe the behavior of energy and matter in a listening room. The reason is simple. Quantum mechanics can accurately predict randomness at the microscopic sub-atomic level, for example in particle physics. Quantum mechanics cannot, however, define behavior at the macroscopic level where molecules combine to form matter and matter forms complex usable devices like audio equipment which produce music. This is crucially important to remember! Here's why:

If sound is everywhere in the air of your listening room then every frequency you hear is vibrating your components at the same time you are hearing it. Therefore, based on the 2nd Law of Thermodynamics (1st Law of Cognitive Awareness), we know that energy propagates directly from your loudspeakers to the chassis of your components through the air and the air transfers vibration.

Let's compress this tautology to "every frequency you hear is vibrating your components" and build the case for filtered direct coupling. We do this by looking at the mathematical elements of the 1st part of our original equation shown below. In the example, the amount of energy propagating upward from the floor resonating at 60Hz is greatly reduced using a common elastomer as the energy conversion material (springs, airbladders and rolling bearings not shown):

Shape Factor:

Square: $sf = \frac{(L)}{(4)(t)} = \frac{1}{(4)(1.25)} = \frac{1}{5} = .2$

Static Deflection:

Compressive Modulus: $= \frac{Cs}{(\text{Assumed Percent Deflection}) / 100} = \frac{14.05}{(.2) / 100} = \frac{14.05}{.2} \diagup 100$

$= \frac{7025}{} = 70.25 \text{ psi}$

Above, we see that the loaded area of dimensional energy conversion material is expressed as a ratio to its unloaded area and the stiffness of the material is expressed in pounds per square inch.

Below, stiffness is corrected for shape and expressed as deflection where downward force deforms the shape of the energy conversion material.

Compressive Modulus Corrected for Shape Factor:

$= (\text{Compressive Modulus})(1 + (2)(sf^2)) = (70.25)(1 + (2 \times .04)) = (70.25)(1.08)$

$= 75.87 \text{ psi}$

Static Deflection: $= \frac{(\text{Load Per Isolator})(t)}{(\text{Corrected Compressive Modulus})(\text{Area})} = \frac{(15)(1.25)}{(75.87)(1)} = \frac{18.75}{75.87} = .247"$

Percent Deflection: $= \frac{\text{Static Deflection}}{t} \times 100 = \frac{.247}{1.25} \times 100 = 19.76\%$

As stated at the outset, the component and the substrate upon which it rests exert a downward force upon the energy conversion material, thereby compressing the material by the force of its mass. The mass of the component deforming the shape of the material causes vibration propagating upward from the resonating mass to convert to heat within the material. The substrate must be level to be useful in audio.

The deficiency of isolation systems in the context of the audio reproduction is now apparent. The force of mass is "downward moving" which in turn converts energy that is "upward moving". True, vibration enters the isolation system from the floor and is abated prior to reaching the electronic component but, sound is airborne mechanical energy and every frequency you hear is directly vibrating your components through the air rendering downward looking isolation systems inadequate.

Active isolation systems may also afford less than optimal results when subjected to energy of broad bandwidth and the multiplicity of entry pathways inherent to a

listening room. One case in point is the piezzo-based Halcyonics Micro 40 active isolation system reviewed in Positive Feedback Online where the reviewer stated:

> *"…….At this point, I tried experimenting with the shelf material under the Micro 40. The original support for the preamp had been a three-inch thick granite machinist plate sitting on top of an equipment stand. The sound, though excellent, was a little more forward than I'm used to. I thought the granite was storing energy, so I replaced it with a one-inch thick plywood shelf and this improved the balance somewhat. It is interesting to note that I didn't have this issue when using the Micro 40 under source components. Although I like the clarity and overall system performance provided when using the Micro 40 under the preamp, I am not completely satisfied that the optimal system balance has yet been achieved. My experiments continue."* -Mike Wright, http://www.positive-feedback.com/Issue29/halcyonics.htm

Here we see the component resting upon the Micro 40 is affected by the material the Micro 40 rests upon. One suspects this active system follows the identical downward/upward isolation/energy paradigm consistent with Thermodynamic formulations within the "isolation" genre. Furthermore we suspect, as evidenced by the writer's experiences, certain molecular properties contained within the materials comprising the Micro 40 produce a weak diode effect impacting the performance of the system as a whole and, therefore, the performance of the component resting upon it. Placed in an environment where broad bandwidth energy is omnipresent, vibration circumvents a downward looking isolation system causing the component resting upon it to vibrate from mechanical energy transmitted though the air with deleterious effect. Additionally, piezzo-based systems can confuse canceling vibration with real vibration under the right circumstances and inadvertently create vibration. The final effect is of course, as we know now, determined by the molecular structure of the component and the weak diode effect of its feet.

A significant deficiency of "downward looking" isolation systems in audio applications can be overcome by designing a resting area predisposed to energy conversion. Correctly executed, the resting area of the isolation system can be made to produce a downward pulling motion on energy that otherwise stores inside the component. By carefully manipulating the elastic modulus of the resting area and/or adding an interface between the resting area and the component the flow of energy can be propagated downward so that as gases greatly excite the exterior metal surfaces of the component, energy flows into the more stable resting area as the component seeks equilibrium with the isolation system. This effectively reduces or eliminates the diode effect between the component and the isolation system.

This is exactly the purpose of the resting area used in the Black Label series of isolation systems by Critical Mass Systems and, in fact, is a trickle-up technology implemented in Critical Mass Systems Filtered Direct Coupling systems with greater precision.

Requirements for the Practical Execution of Filtered direct coupling

"Advancement often emanates from solutions derived from the elucidation of the previously ignored obvious."

It is worth repeating that vibrating cones inside transmission towers (loudspeakers) directly couple vibrating gasses to the rack, the filter and the component. In audio, energy propagates directly upward from the floor, and passively and directly into the rack and the component from the air. Vibration generated inside components is problematic, but filtered direct coupling provides for the unconstrained, multi-directional propagation of mechanical energy through equivalent compositional pathways mitigated by a complex filter that encompasses all sources of mechanical disturbances. This all-inclusive paradigm is a shift from classical constructs.

Filtered direct coupling is derived from wave propagation and thermodynamic energy conversion. The first requirement for the practical execution of filtered direct coupling is an adult understanding that quantum mechanical ideas about vibration are incorrect. Vibration is everywhere in the listening room the moment loudspeakers produce sound. Additionally, belief in the existence of an absolute mechanical diode in a listening room must be discarded. Variable phase incoherent energy fields are present on both sides of the diode which creates a push-pull motion as equilibrium is by no means reached. This was touched upon in the previous section.

To elucidate, the fundamental property of a diode is its tendency to conduct electric current in only one direction (forward) and not at all in the opposite direction (reverse). Diodes are used to achieve limiting, regulation, switching and stabilization, etc.

Audio accessories referred to as "tweaks" are weak diodes that cause as many problems as they solve. The efficacy of these products is not important. What is important is that the use of anything intended to be a mechanical diode is generally antithetical to filtered direct coupling. This extends beyond the use of cones or spikes to all materials used to formulate the rack, shelf, filter and resting area of any device placed underneath an audio component.

In order to mitigate the effects of the steady state of excitation in the air and in the floor of the listening room as well as the rack itself, there needs to be an unabated flow of energy in all directions. The use of any surface or device meant to reflect or otherwise block the flow of energy causes audible problems which must be otherwise overcome.

Consider how very different this approach is compared to isolation systems which are generally box enclosures consisting of (from the bottom to the top) feet which are weak diodes, a base, exterior walls enclosing the isolation system and a resting area that generally reflects energy upward due to its requisite stiffness. These boxes are placed or mounted onto racks or the floor. Now, we see box-structured isolation systems as self-contained downward looking energy transmission breakers which offer a solution contrary to the pervasive, all encompassing energy field in a listening room. Energy easily finds a way around and through these systems.

The great simplicity of the filtered direct coupling concept lays the groundwork for the possibility of an effective solution. Rather than viewing vibration as a randomly occurring event, we view the listening room as a unified field. What is only required then is a multi-directional filter which converts energy as energy passes through it in an amount that allows for the full development of leading edge transients across the

audible spectrum and into both extremes without overshoot or curtailment. This is exactly the purpose of the filter and the sum of what it accomplishes. Based upon what we know about sound fields, the filter provides a multi-directional albeit precisely regulated pathway between the air, the component, the rack, the floor; forward, backward and again.

Summary

Perhaps, it is due to years of focus on advancements in loudspeaker technology and digital and analog components that awareness of the energy components produce remains less understood. You can point to a loudspeaker. You can hold a component. You can flip a switch. You can turn a knob. You can plug in a cable. You CANNOT, however, see sound and sound, vibration, is everywhere the moment loudspeakers make a sound.

The complexity of the sound field in a listening room and the fact that it is invisible makes it too difficult to assign attributes to sound; mechanical energy; vibration. We blindly think what we hear is solely a result of electrical interactions between things we can see. Sound; vibration; mechanical energy is unseen and perceived as something of a quantum mechanical manifestation; something that "may or may not be". Indifference to that which cannot be observed perpetuates ignorance.

The purpose of this white paper is to establish the basis for filtered direct coupling criteria which, in the process, requires an understanding that a listening room is a charged energy field. It should be obvious that the air, the component, the rack, the floor, etc pass energy in all directions to reach equilibrium as loudspeakers produce prodigious amounts of variable wavelength energy. It should also be obvious that the only way to address this condition is to include all of the elements in the solution; exclude nothing. To this end the component, the air, the floor, the rack etc, must be directly coupled through a filter with the least possible resistance; everything passes through the filter.