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Electronic Bass Trap

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ABSTRACT

Bass traps, regardless of their effectiveness in abating bass acoustic coloration in a room have two, somewhat undesirable attributes: 1) large size and 2) lack of adaptability. An alternative to the use of bass traps, discussed in this paper, is *incorporating a properly devised, feedback control scheme into a powered subwoofer making the subwoofer to exhibit the same dynamics as that of a bass trap*. This patent pending [1], active coloration control solution which can be viewed as an '*electronic bass trap*' adds acoustic damping to the low-frequency modes of a room. In addition to a powered subwoofer, the electronic bass trap uses a microphone and an op-amp circuit. Numerical and experimental results indicate the effectiveness of the *electronic bass trap* in adding acoustic damping to the low-frequency standing wave(s) in a room.

1. INTRODUCTION

The listening experience is formed almost as much by the room acoustics as by the sound system. A primary reason for music, sounding muddy in rooms with small dimensions is the tendency for such rooms to have severe coloration[1] in the bass or upper low-frequency region. At certain frequencies the dimensions of a room are integer multiples of the wavelength of the tones corresponding to those frequencies. This causes the reflection of the wave from the opposing walls reinforce each other and establish standing waves between the walls. These frequencies are called resonant frequencies (known also as characteristic frequencies) of the room and their corresponding standing wave patterns are called mode shapes of the room. Coloration is a result of standing waves in a room. Smaller rooms have dimensions that favor standing waves (resonances) that are right in the fundamental range of some musical instruments as well as the sound track in many motion pictures.

The resonance frequencies and the corresponding mode shapes depend primarily on the shape and size of the

[1] Coloration is the result of standing waves or room resonances (modes). These are waves whose original oscillations are continuously reinforced by their own reflections.

room. For rooms with simple, parallel wall geometry the characteristic (resonant) frequencies and shape of the standing waves can be evaluated analytically. Finite element modal analysis can be used for modal characterization of the low-frequency acoustics of the rooms with complex geometry. Figure 1 depicts such a mode shape for a small room.

Using foam acoustical tiles, fiberglass, heavy drapery, thick carpets, and other absorptive materials can not solve bass coloration problems. While these materials are excellent absorbers at higher frequencies they become increasingly less effective below about 1000 Hz and totally ineffective at bass frequencies. Frequently, the overuse of foam tiles or fiberglass to cure a bad-sounding room actually aggravates the problem by severely reducing reverberation and results in a very dead-sounding room with a loss of the natural clarity of voice and instruments.

As stated above plush furniture and absorptive materials do not solve the low-frequency coloration problem in a room. Reactive absorbers, called bass traps[2], are commonly used as the most effective solution for treating the low-frequency standing waves. Helmholtz resonator (HR) is such a base trap. These resonators can be designed to absorb the energy of offending, low-frequency modes that cause coloration while at the same time reflect and diffuse the higher frequency modes contributing to a very natural sounding acoustical environment.

Unfortunately, bass traps are very large. For example, the frequency that a HR bass trap is tuned to, is inversely proportional to the square root of the cavity volume of the resonator. This makes the size of HRs objectionably large when they are tuned to low-frequencies. Another potential concern about using a bass trap is that when used for adding damping to an acoustic mode, a fair amount of energy dissipation should occur in that bass trap. It might not be easy to incorporate enough energy dissipation capability into a reactive bass trap, e.g., a HR, for it to be used effectively in such capacity. Such bass traps will split the mode they are tuned to, into two neighboring modes (phenomenon known as 'mode splitting') instead of adding damping to that mode. Tuning of a reactive bass trap, effectively, is difficult and once tuned to a particular mode, retuning it to another mode (e.g., taking it from one room to another room) without constructional/geometrical changes is not possible. And lastly, a tuned bass trap can only be tuned to a single frequency. When absorption at multiple resonant frequencies is required, a number of bass traps should be used. Most of the above-mentioned concerns hold true for a membrane type bass trap (known as membrane absorber). Moreover, while the first structural mode of membrane (commonly made of plywood or sheet rock, i.e., dry wall, mounted on 2×4 studs) is tuned to the coloring acoustic mode of the room and thus adds damping to that mode, the higher order modes of membrane vibration will couple with the acoustics of the room and create their own coloration problem.

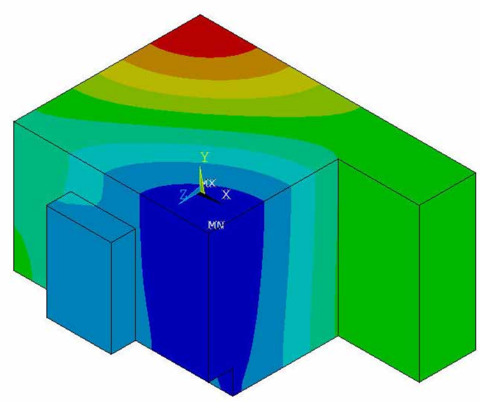

Figure 1 The 2nd standing wave of a room

2. ELECTRONIC BASS TRAP

An alternative to the use of bass traps is incorporating a properly designed, feedback control scheme into a powered subwoofer making the subwoofer to exhibit the same dynamics as that of a bass trap. This active, feedback coloration control solution which can be viewed as an '***electronic bass trap***' adds damping to the low-frequency acoustic mode(s) and smoothes out the magnitude of frequency response of the room. Figure 2 shows a schematic of *electronic bass trap* system. In terms of required hardware, in addition to a powered subwoofer, the *electronic bass trap* uses only a microphone, and an op-amp circuit. The microphone is

[2] Low-frequency absorbers that dissipate the energy of standing waves and the coloration they produce are called *bass traps*. There are many types of bass traps, some of which are intricate in design and construction. The most common ones are membrane absorbers and Helmholtz resonators. Tuning the fundamental frequency of these absorbers to an offending, coloring standing wave of the room helps dissipate the energy of that standing wave.

nearly-collocated with the subwoofer and the user needs not to be concerned about where to place it. The *electronic bass trap* can either be a stand-alone system or part of the existing sound system's subwoofer in a listening room.

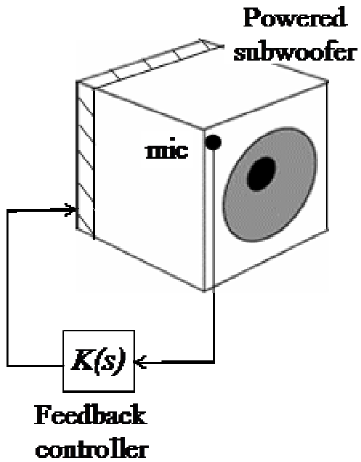

Figure 2 Schematic of *electronic bass trap* system

The feedback control scheme for *electronic bass trap* is realized by the op-amp circuit. The controller(s) can be tuned to a single (or multiple) resonant bass modes and abate sound coloration at that (those) resonant frequency (frequencies).

2.1. Acoustic Damping vs. Equalization

Contrary to the existing active bass treatment solutions based on *equalization* which just lower the level of excitation to the room at the offending frequencies, *electronic bass trap* truly adds acoustic damping to the room resulting in enhanced musical articulation over the frequency range of interest; this is evidenced by increased clarity of tone bursts played and less ringing when each burst was turned off. Besides, *electronic bass trap* can be used as an stand alone active bass trap, e.g., in a recording studio, whereas equalization-based systems can not.

3. EXPERIMENTAL EVALUATION RESULTS

A small room with parallel walls is used to evaluate how the patent pending, feedback controlled, active acoustic damping technology, *electronic bass trap* [1], abates the bass coloration corresponding to the first standing wave of the room which in turn enhances low-frequency musical articulation in that room. The room has the longest dimension (length) of 172 inches, with a dominant coloration due to the 38 Hz standing wave that shapes up along the length of the room. The *electronic bass trap* is tuned to add acoustic damping to the first low-frequency acoustic standing wave, i.e., the 38 Hz mode, of the room.

Figure 3 shows the frequency response functions of the room without and with the *electronic bass trap*. Clear from Figure 3, the *electronic bass trap*, which was tuned to the frequency of the first standing wave, has effectively reduced the coloration due to that mode. One can tune the controller to other standing waves or even to more than one standing wave and get similar results.

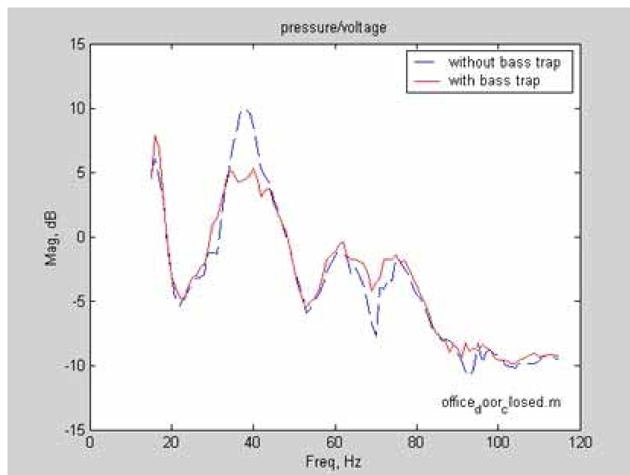

Figure 3 Frequency response functions of the room without and with the *electronic bass trap*

3.1. Low-frequency Musical Articulation Enhancement

Leveling the magnitude of the frequency response function in a listening room application can also be realized by equalization of the subwoofer. As stated earlier, equalization does so by just lowering the level excitation to the room at the offending frequencies, and as such does not affect the ringing and lingering of sound at those frequencies. As such, it can not be used in an application, such as a recording studio, with the intent of adding absorption to a low-frequency standing wave. Besides, equalization adds the undesirable phase delay, which the characteristics of the filtering, to the music. *Electronic bass trap* smooth out the magnitude of the frequency response by truly adding acoustic damping to the room and as such enhances the musical articulation of the room.

Musical articulation test[3] is used to evaluate the articulation of our test subject room, treated with the *electronic bass trap*. Twenty bursts of sinusoids covering the frequency range of 30-40 Hz with the frequency increment of 0.5 Hz are used to excite the room. The reason for the choice of this limited frequency range is that the first standing wave of the room, the one targeted for damping, lies in this frequency range. The duration of each burst is 0.25 sec followed by 0.25 sec of silence with the total test duration of 10 sec; see Figure 4. This signal is generated inside a computer and played, with the sampling frequency of 8 KHz, through an 18" subwoofer.

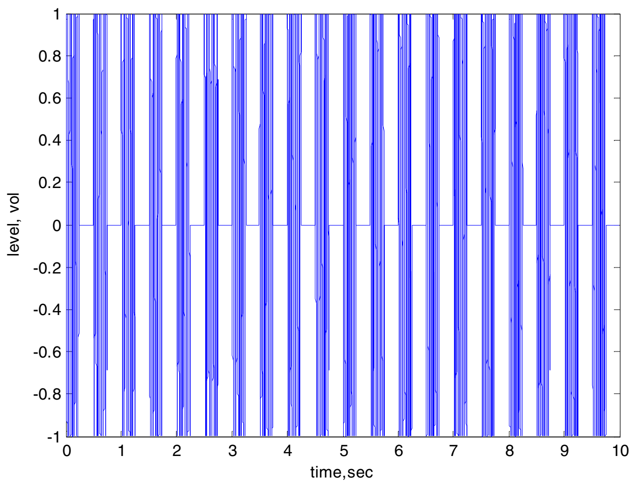

Figure 4 Input signal driving the speaker

A microphone located at the corner of the room is used for recording/evaluation. Provisions are made to be able to turn the *electronic bass trap* on or off and thus add damping to (by turning the system on) or not modify the acoustics of (by turning the system off) room. Figures 5 and 6 show the recording of the signal depicted in Figure 4, with the *electronic bass trap* 'on' and 'off'. Comparison of Figures 5 and 6 indicates that the addition of damping (*electronic bass trap* on) makes the pressure reading shown on Figure 6 to resembles the driving signal of Figure 4, more closely than the one without damping (Figure 5). Clearly the active, feedback controlled *electronic bass trap* enhanced the uniformity of level, as well as improved the articulation in the 30 to 40 Hz range. The articulation is evidenced by the increased clarity of tone bursts and less ringing when each burst is turned off.

[3] Musical articulation test, is proposed and popularized by Acoustic Sciences Corp (www.asc-hifi.com/about_asc.htm). The test is done by recording the playback of a selected set of tones designed to evaluate the way in which a loudspeaker or an acoustic treatment system performs in a listening room.

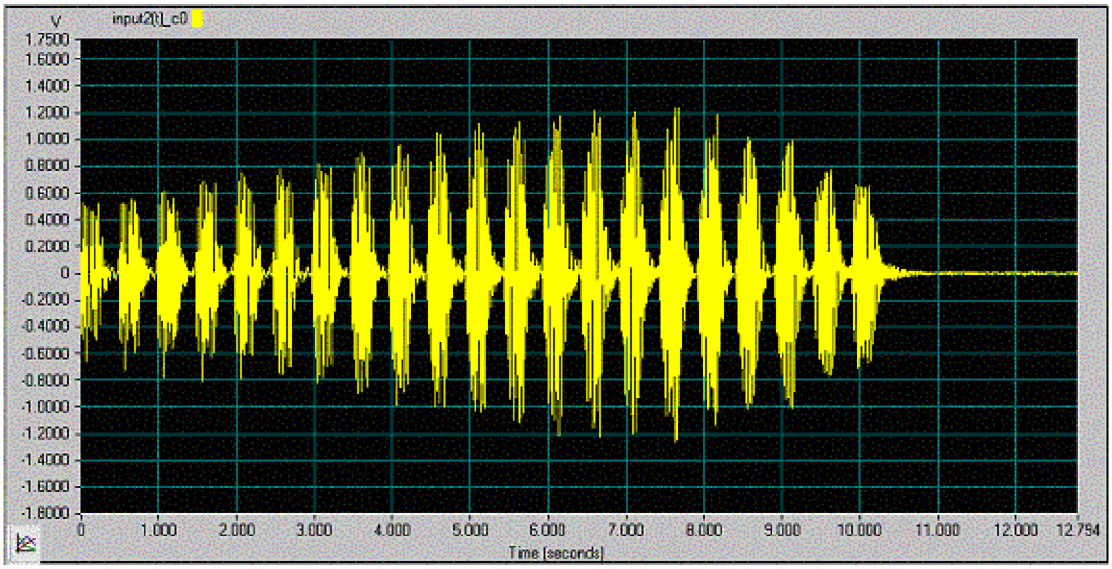

Figure 5 Pressure measured at the room corner with the *electronic bass trap* off

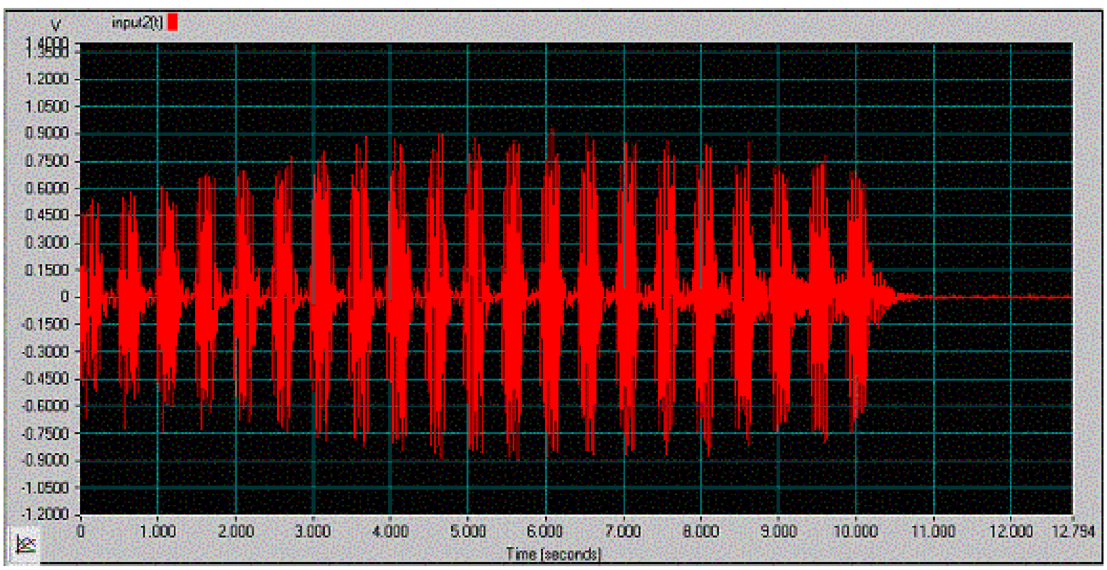

Figure 6 Pressure measured at the room corner with the *electronic bass trap* on

3.2. Vehicular Applications

Large vehicles, such as SUVs (Sport Utility Vehicles) and minivans are the size of a small room and thus exhibit bass acoustic coloration, known as *body boom,* the way a small room does [3]. In addition, the flexibility of the roof and walls as well as the structural dynamics of the tailgate on these vehicles contribute to this bass coloration problem through the vehicle's vibro-acoustic modes in the bass frequencies. Abating the boom noise by adding acoustic damping to the cabin is the more viable and less costly option than body changes. A modified version of the active feedback controlled acoustic damping technology [2] discussed in this paper is used to address the body boom problem in large vehicles. The modifications allows the feedback control system account for the vibro-acoustic nature of the acoustic enclosure.

A large SUV is used to demonstrate the effectiveness of the active, feedback-controlled sound absorption system. The vehicle exhibits a 30, 40, and 45 Hz vibro-acoustic modes due to tailgate, roof, and cavity first structural and acoustic modes, respectively. Under most driving conditions, these 3 resonances appear as one mode with the peak magnitude somewhat spread over the 20-45 Hz range.

The vehicle was driven over different road surfaces and with different speeds. The road excitation into the cabin vibro-acoustic system excites the boom noise which was damped/absorbed using the active system.

Figure 7 shows the scaled power spectrum of sound pressure measured at the driver's ear location, under different driving conditions, with and without the feedback controlled acoustic absorber. A road in a commercial/residential area (Shroyer[4] Ave.) and an interstate highway were used in the tests. The active, feedback controlled sound absorption system adds low-frequency absorption to the cabin and hence lowers the boominess of sound, is performing extremely effectively.

In addition to relieving the occupants from being exposed to the rumble of the cavity, abating the body boom in a large vehicle enhances the experience of listening to music in the vehicle.

[4] The road surface on Shroyer Ave. suffers from the typical wear and tear of a busy urban neighborhood. Its surface unevenness does not have any particular pattern and can be described as 'random'.

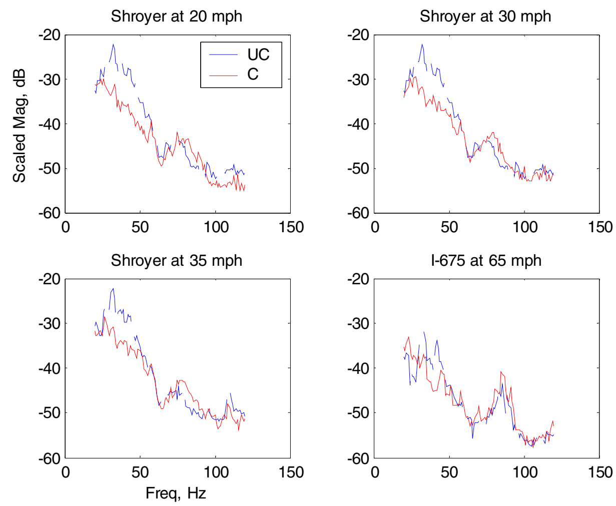

Figure 7 Power spectrums of sound pressure, under different driving conditions, with (blue/dashed line) and without (red/solid line) the electronic acoustic absorber

4. DYNAMIC SIGNAL ANALYSIS SOFTWARE TOOL

To assist users in experimental characterization of the bass acoustics of their recording/listening room, as well as tuning the *electronic bass trap* to that room a dynamic signal processing software tool is developed. This Windows software which has an intuitive and easy-to-use graphical user interface (GUI), uses the sound card of the computer to 1) play a random, controlled-frequency excitation via the subwoofer of the *electronic bass trap*, 2) collect the measured sound by the microphone built into the *electronic bass trap*, 3) calculate either frequency response function or power spectrum of the measured signal and 4) display the results. By saving the magnitude trace with the control loop open and overlaying on it the trace with the control loop closed while tuning in progress, the user can fine tune the controller to the target standing wave of the room.

Figure 8 depicts the screen shots of the GUI of the dynamic signal analysis code, being used to tune an *electronic bass trap* to our small test subject room, discussed earlier.

The traces on the figure are the magnitudes of the frequency response functions mapping the voltage driving the *electronic bass trap's* subwoofer to the pressure measured by the *electronic bass trap's* microphone. The red trace is with the control loop open, i.e., *electronic bass trap* off and black trace is for the control loop closed, i.e., *electronic bass trap* on.

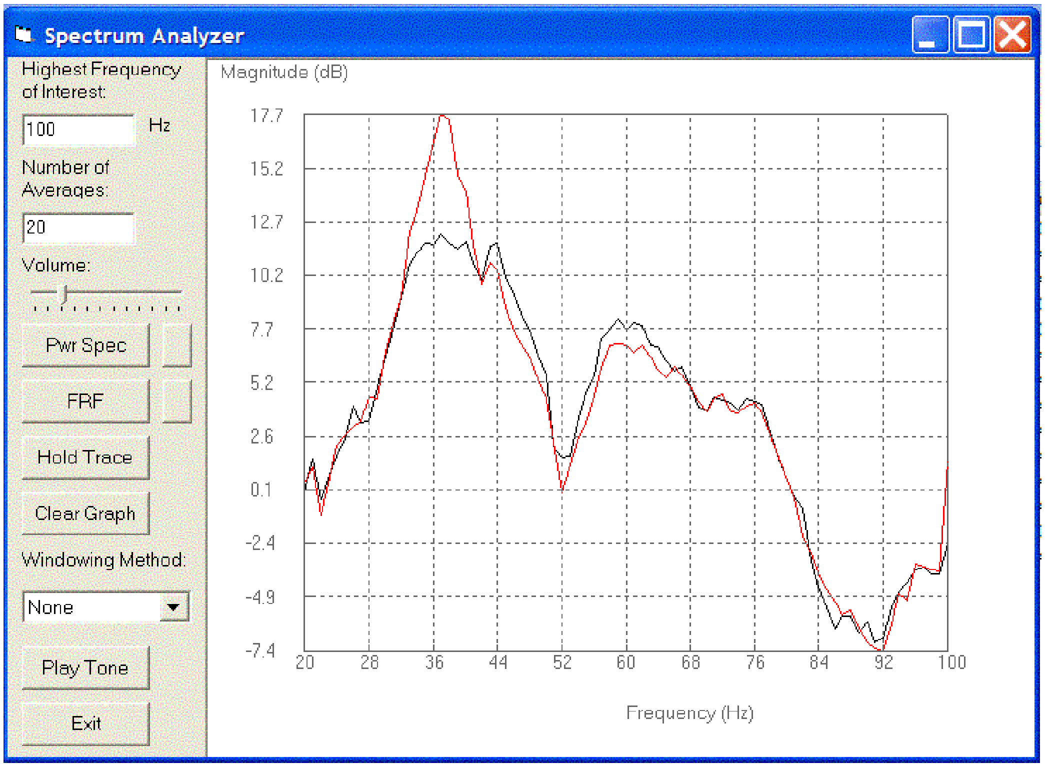

Figure 8 GUI of the dynamic signal analyzer software tool

5. SUMMARY

In a patent pending technology[1], the use of feedback control in conjunction with a subwoofer and a nearly-collocated microphone, dubbed *electronic acoustic trap*, in damping the low-frequency standing wave(s) in a closed space such as a listening room or a recording studio, is explored. The advantages of the closed-loop controlled acoustic damping system over the traditional passive acoustic absorbers are: ease of tunability to the target frequency(ies), tunability to multiple frequencies, and more importantly small size. Numerical and experimental results indicate the effectiveness of such *electronic bass trap* in adding damping to the low-frequency standing waves. Contrary to the existing active bass treatment solutions based on equalization which just lowers the level excitation to the room at the offending frequencies, *electronic bass trap* truly adds acoustic damping to the room resulting in enhanced musical articulation over the frequency range of interest.

Lastly, a dynamic signal processing software is developed to assist users, as a tool, in experimental characterization of the bass acoustics of their room and tuning the *electronic bass trap* to the room.

6. REFERENCES

[1] Kashani R., "Active Feedback-Controlled Silencer" U.S. Patent Application Serial No. 10/014,834 filed December 11, 2001

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[3] Kashani, R., and Orzekowski, J., "Acoustic Damping of Dodge Durango Cabin," Proceedings of the SAE Noise and Vibration Conf. Traverse City, MI; 2001