Panel Damping Studies: Reducing Loudspeaker Enclosure Vibrations

Here's an extensive study to try to answer the age-old question: "How best to build a box to minimize vibrations?" **By Jim Moriyasu**

The design and construction of an enclosure is one of the most challenging tasks facing loudspeaker builders. What is the best way to construct an enclosure that is visually appealing yet acoustically inert? In the past, I have built enclosures out of particleboard, plywood, and medium density fiberboard (MDF). I've installed the odd brace or two and have applied various damping strategies to minimize the resonance of the open panels.

I used to think 1⁄16″ lead sheeting glued to a panel was the ultimate panel-damping treatment since it produced (apparently) favorable results when I rapped it with my knuckles. Still, I did not really know what design techniques, materials, or treatments were the most effective. However, the acquisition of an AMP ACH-01 accelerometer coupled with the impulse measurement capability of Liberty Audiosuite (Laud) and a good dose of curiosity led to this odyssey on panel vibrations.

RESONANCE MODES

According to theoretical analysis, panels can have multiple modes of vibration or resonance.[1] The primary mode is characterized as an in-and-out movement of the panel. The second mode can be visualized by dividing the panel in two vertically, for example, and imagining half the panel moves away while the other half moves forward. The third mode divides the panel in two horizontally.

The fourth mode divides the panel into thirds, and here the middle section moves forward as the other sections move backward. The fifth mode divides the panel into fourths and is characterized by two diagonally opposing quarters moving forward as the other two move backward. Higher modes are carried out by further subdivision of the panel.

TEST SETUP

In order to isolate the effect of various damping methods, I built a test box with a removable 14³⁄16″ panel, which is held in place during testing with eight toggle clamps (*Photo 1*). The panel is supported by a frame of ¾″ thick, one-inch-wide MDF. Thus, there is approximately a 12″ × 12″ square panel that is subject to vibration. A Peerless 831858 8″ woofer provides the excitation; it is vented to provide a low-frequency cutoff (f_3) of approximately 25Hz.

The enclosure has a volume of 1.4ft^3 and is built from ¾″ MDF with no internal bracing except for the frame that holds the test panel. The woofer is secured to the front baffle with 10⁄32 × 1″ hex-socket screws threaded into brass threaded inserts. I inserted a one-piece 1⁄32″ cork/neoprene gasket between the woofer and the front baffle to ensure an airtight seal, and also attached a one-piece 1⁄32″ neoprene sheet rubber gasket to the test cabinet to ensure an airtight seal for the test panel. I vertically positioned the enclosure on three spikes and placed it on a concrete floor.

I glued the accelerometer to a 1¾″ × 1⅛″ × ½″ acrylic block with cyanoacrylate glue and then affixed the block to the middle of the test panel with 1½″ wide double-sided general purpose carpet tape. I used a fresh piece of tape for each test, since it loses some effectiveness once it is removed (*Photo 2*).

I set the output of the Laud to 3.36mV RMS/√Hz, ~1.101Vpk and fed it to the NAD 2140 power amplifier that multiplies voltage by 15.35 times. I set the main in-level to 22.50dB, and set the window as wide as possible, 84.7ms, with a sample size of 16384 points and a sample rate of 48.0k.

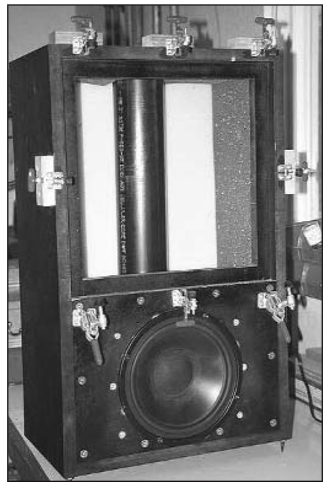

PHOTO 1: Test box showing the frame and toggle clamps for holding a test panel.

DIFFERENT MATERIALS

To see whether any material was superior, I started by examining particleboard, MDF, and plywood. The sound pressure level (SPL) chart for particleboard (*Fig. 1*) shows four resonance modes at 187.50Hz, 243.16Hz, 287.11Hz, and 383.79Hz. (Since the output is from an accelerometer it isn't sound pressure but it is useful to think of the vibrations as such, and thus I will refer to the converted impulse information as SPL output.) There are lesser modes at between 750Hz and 931Hz, which are about 10–20dB lower than the main four resonances. There seem to be some minor modes below 100Hz, but they don't appear to be a problem as indicated by the cumulative spectral decay (CSD) or waterfall chart (*Fig. 2*). The CSD shows that the resonance at 243.16Hz, though, takes well over 40ms to decay

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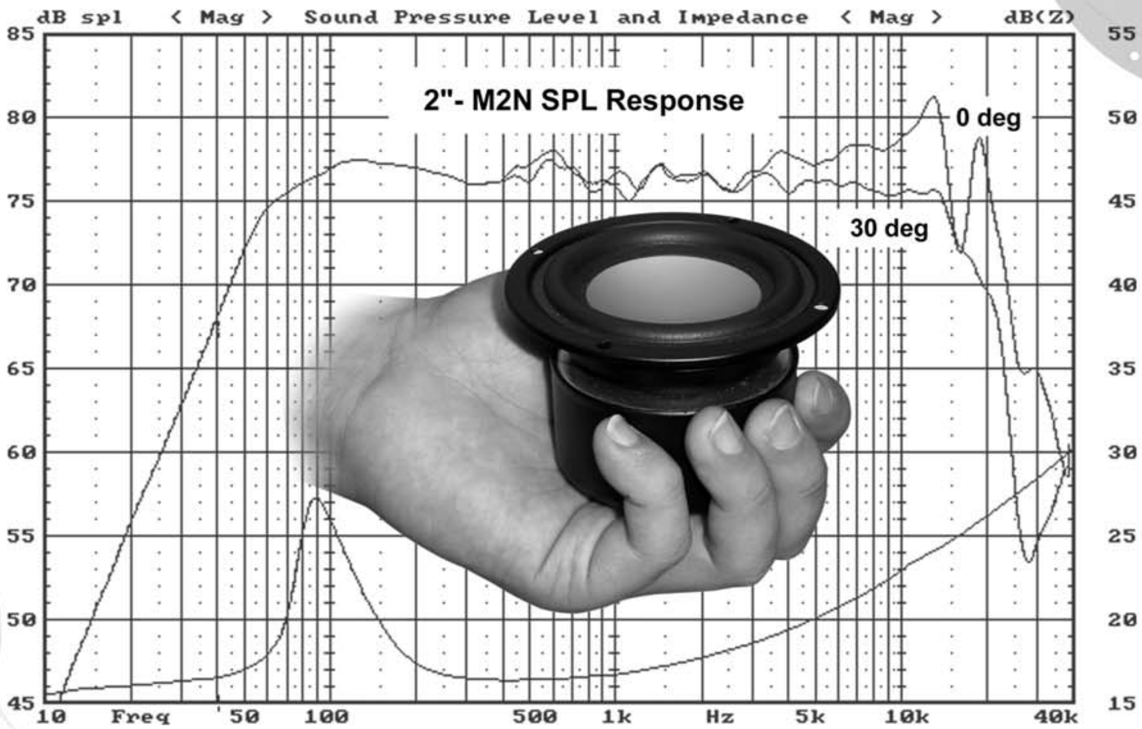

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SWANS SPEAKER a division of Hi-Vi RESEARCH or decline in level by more than 20dB, which suggests the second mode is the primary resonance mode of the panel.

MDF appears to behave similarly to particleboard (*Fig. 3*). The four resonance modes are at the same frequency, but peaks on the first three are 1–2dB lower. The waterfall chart (*Fig. 4*) shows no significant differences, either.

Birch-faced seven-ply plywood shows more differences compared to MDF and particleboard. This is expected because it is stiffer than the other two. While the first three resonances are at the same frequency, the fourth is at 351.56Hz but is about 3–4dB lower. However, it now has two secondary modes at around 650Hz and 850Hz instead of the single broad mode between 750Hz and 931Hz. The CSD chart suggests a slightly longer decay time for the primary resonance mode at 287.11Hz (*Figs. 5* and *6*).

These results suggest none of the three materials tested to be significantly better than the other. However, since ¾″ MDF is the material of choice for the loudspeaker industry, I've chosen to concentrate the rest of this study on this particular material.

TRANSMISSION OF VIBRATIONS

I assumed that most of the vibration from the woofer is transmitted to the cabinet by contact or mechanical conduction. However, it occurred to me that some of the vibration is conducted through the air. To see how much of the vibration is transmitted by air, I stuffed the enclosure with 2 lb of Acousta-stuf. *Figure 7* shows

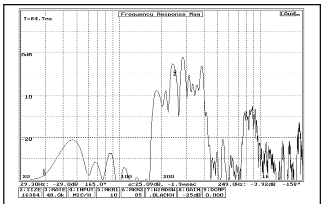

FIGURE 1: SPL of ¾″ particleboard without damping treatment.

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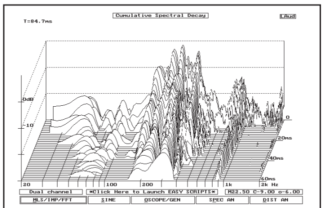

FIGURE 2: CSD of ¾″ particleboard without damping treatment.

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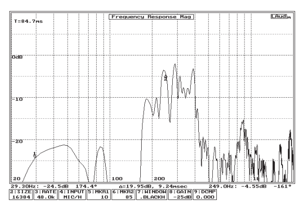

FIGURE 3: SPL of ¾″ MDF without damping treatment.

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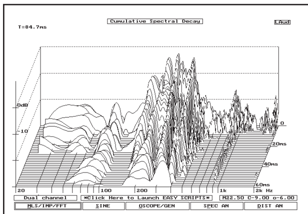

FIGURE 4: CSD of ¾″ MDF without damping treatment.

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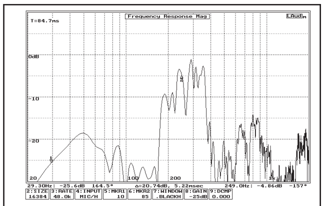

FIGURE 5: SPL of ¾″ birch-faced seven-ply plywood without damping treatment.

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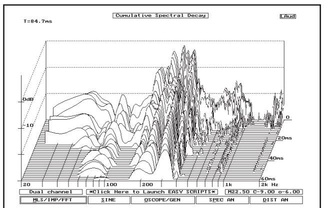

FIGURE 6: CSD of ¾″ birch-faced seven-ply plywood without damping treatment.

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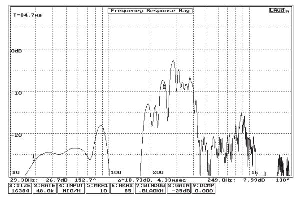

FIGURE 7: SPL of ¾″ MDF with enclosure stuffed with 2 lbs Acousta-Stuf.

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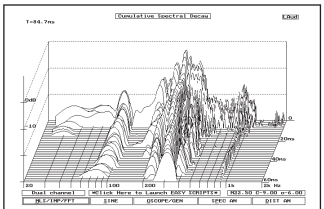

FIGURE 8: CSD of ¾″ MDF with enclosure stuffed with 2 lbs Acousta-Stuf.

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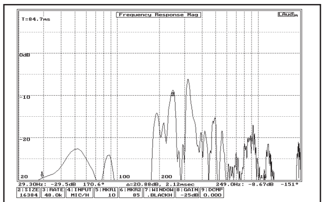

FIGURE 9: SPL of two layers of ¾″ MDF without damping treatment.

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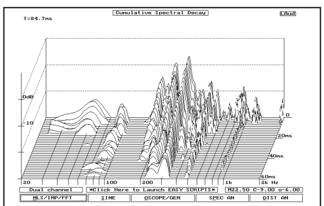

FIGURE 10: CSD of two layers of ¾″ MDF without damping treatment.

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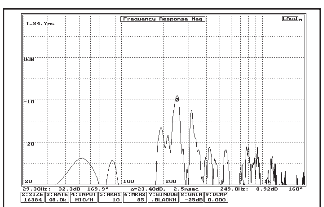

FIGURE 11: SPL of three layers of ¾″ MDF without damping treatment.

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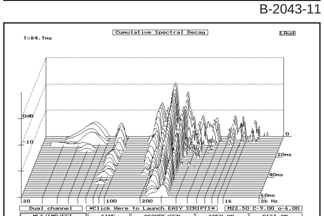

FIGURE 12: CSD of three layers of ¾″ MDF without damping treatment.

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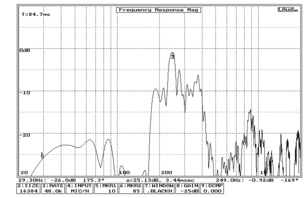

FIGURE 13: SPL of ¾″ MDF with 1/16″ BVD.

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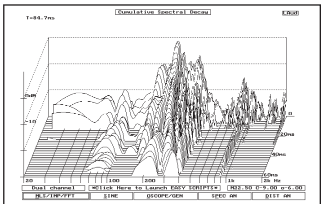

FIGURE 14: CSD of ¾″ MDF with 1/16″ BVD.

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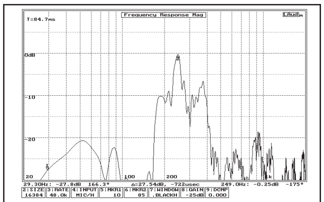

FIGURE 15: SPL of ¾″ MDF with Black Hole 5.

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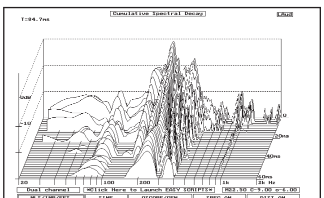

FIGURE 16: CSD of ¾″ MDF with Black Hole 5.

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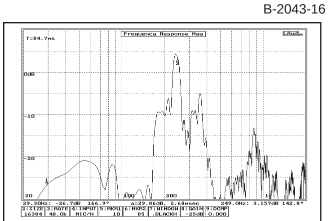

FIGURE 17: SPL of ¾″ MDF with Deflex subwoofer panel.

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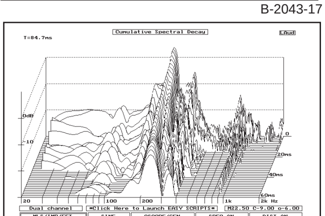

FIGURE 18: CSD of ¾″ MDF with Deflex subwoofer panel.

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a reduction in three of the four resonance peaks by 2–3dB. The waterfall chart (*Fig. 8*) confirms the modest improvement in decay.

This suggests that some of the panel vibration is transmitted by air with most of it caused by mechanical conduction. This would suggest that sealed box designs, which tend to have most of their enclosure volume filled with damping material, should be a little less affected by these resonances.

MULTIPLE LAYERS

One obvious approach to dealing with the panel resonance problem is to increase the panel thickness, making it stiffer but heavier. For example, kits from Zalytron, according to reviews in *Speaker Builder*, have cabinets built with a double layer of ¾″ MDF. The SPL chart in *Fig. 9* shows why this technique is popular; the first two modes are at the same frequency but are attenuated by 3–5dB compared to a single layer of MDF. The third mode is pushed up to 322.27Hz and is reduced by 4–5dB. The fourth mode is pushed out to 483.40Hz and is down more than 10dB. The CSD chart shows that decay time is approximately the same, however, as seen in *Fig. 10*.

Figures 11 and *12* show further gains from tripling the thickness: the first two resonance modes remain at the same frequency but are reduced by 5–6dB. The third mode is somewhere between 300–322Hz and is down more than 12dB. It isn't clear where the fourth mode is, but since the resonances above 400Hz are down by more than 20dB, they probably aren't much of a consequence. The CSD, though, still shows decay times re-

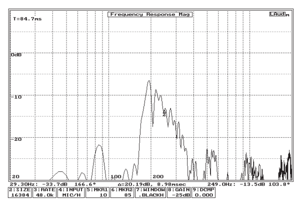

FIGURE 19: SPL of ¾″ MDF with 1″ sand-filled panel.

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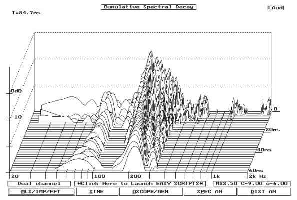

FIGURE 20: CSD of ¾″ MDF with 1″ sand-filled panel.

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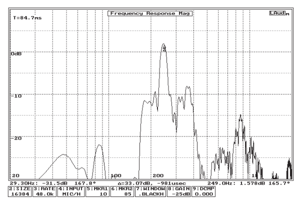

FIGURE 21: SPL of ¾″ MDF with 1⁄16″ lead sheet glued with contact cement.

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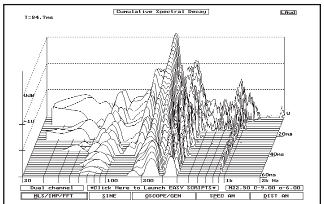

FIGURE 22: CSD of ¾″ MDF with 1⁄16″ lead sheet glued with contact cement.

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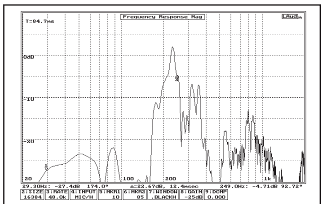

FIGURE 23: SPL of ¾″ MDF with 1⁄16″ lead sheet with ⅛″ Sorbothane.

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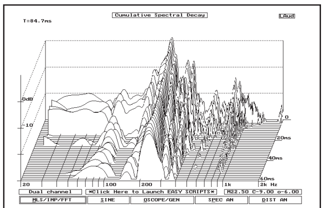

FIGURE 24: CSD of ¾″ MDF with 1⁄16″ lead sheet with ⅛″ Sorbothane.

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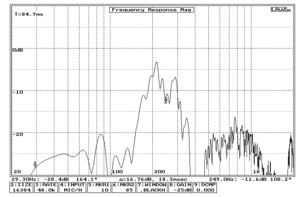

FIGURE 25: SPL of ¾″ MDF with 1⁄16″ lead sheet with ½″ Sorbothane.

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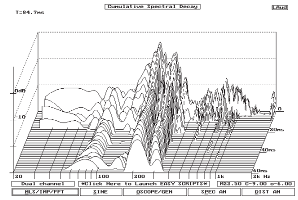

FIGURE 26: CSD of ¾″ MDF with 1⁄16″ lead sheet with ½″ Sorbothane.

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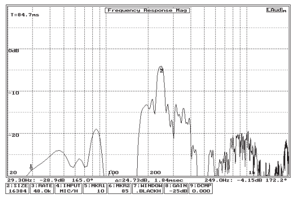

FIGURE 27: SPL of ¾″ MDF and ⅛″ Isodamp C-1002 and ¾″ MDF CLD panel.

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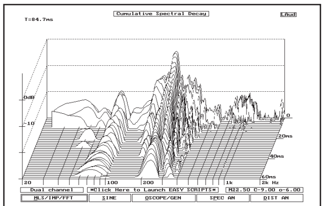

FIGURE 28: CSD of ¾″ MDF and ⅛″ Isodamp C-1002 and ¾″ MDF CLD panel.

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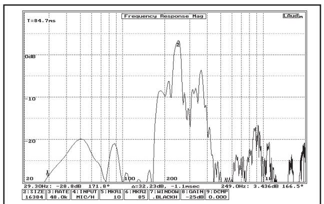

FIGURE 29: SPL of ¾″ MDF and ¼″ Isodamp C-1002 and ¼″ ACX plywood CLD panel.

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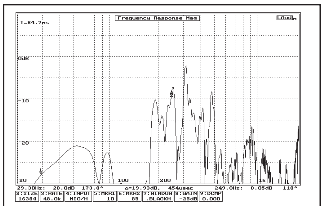

FIGURE 30: SPL of ¾″ MDF and ¼″ ACX plywood CLD panel.

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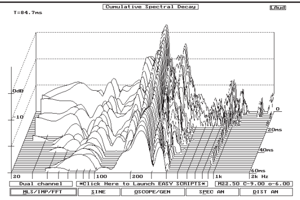

FIGURE 31: CSD of ¾″ MDF and ¼″ Isodamp C-1002 and ¼″ ACX plywood CLD panel.

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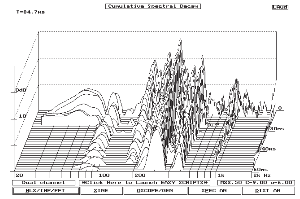

FIGURE 32: CSD of ¾″ MDF and ¼″ ACX plywood CLD panel.

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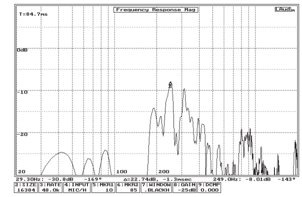

FIGURE 33: SPL of ¾″ MDF and North Creek soft glue and ¾″ MDF CLD panel.

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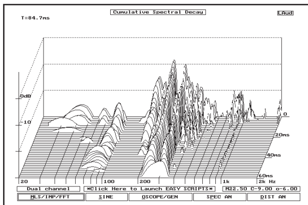

FIGURE 34: CSD of ¾″ MDF and North Creek soft glue and ¾″ MDF CLD panel.

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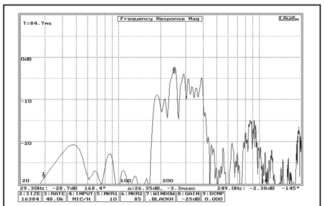

FIGURE 35: SPL of ½″ MDF and North Creek soft glue and ¼″ MDF CLD panel.

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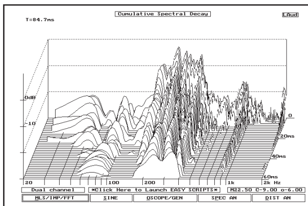

FIGURE 36: CSD of ½″ MDF and North Creek soft glue and ¼″ MDF CLD panel.

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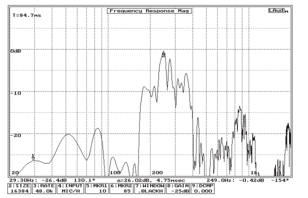

FIGURE 37: SPL of ½″ MDF and 1⁄16″ SBR rubber and ¼″ MDF CLD panel.

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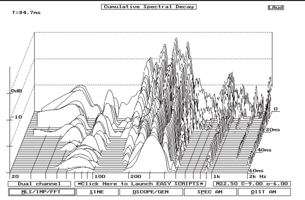

FIGURE 40: CSD of ½″ Apple-Ply and North Creek soft glue and ¼″ MDF CLD panel.

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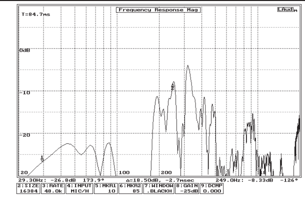

FIGURE 43: SPL of ½″ birch ply and North Creek soft glue and ½″ Baltic Birch CLD panel.

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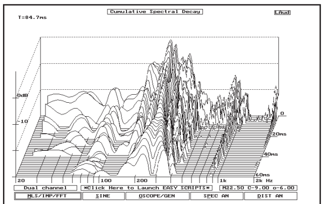

FIGURE 38: CSD of ½″ MDF and 1⁄16″ SBR rubber and ¼″ MDF CLD panel.

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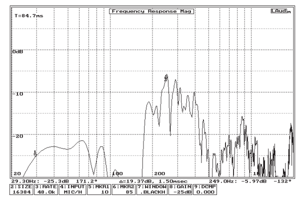

FIGURE 41: SPL of ½″ Baltic birch and North Creek soft glue and ½″ MDF CLD panel.

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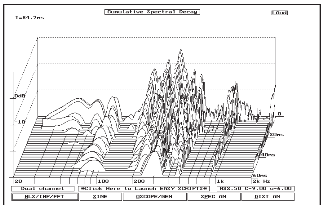

FIGURE 44: CSD of ½″ birch ply and North Creek soft glue and ½″ Baltic Birch CLD panel.

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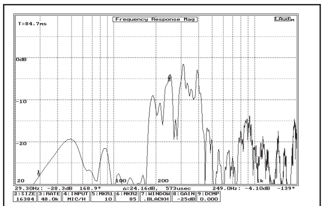

FIGURE 39: SPL of ½″ Apple-Ply and North Creek soft glue and ¼″ MDF CLD panel.

B-2043-39

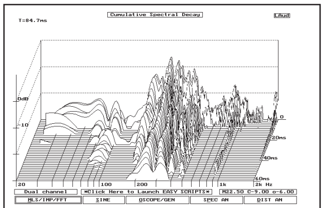

FIGURE 42: CSD of ½″ Baltic birch and North Creek soft glue and ½″ MDF CLD panel.

B-2043-42

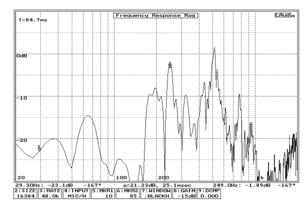

FIGURE 45: SPL of external cabinet with no brace.

B-2043-45

main quite long, at more than 40ms.

EXTENSIONAL DAMPING

This approach to panel damping applies damping material to one surface of the panel. It is also known as free-layer damping. I did an informal survey of past projects featured in *Speaker Builder*, and it seems that every builder has his/her favorite method or "recipe" for extensional damping.

For example, one project used a roofing compound, while another used a mixture of sand with yellow glue. British designers popularized the use of bituminous or tar-impregnated felt panels. In my college days in the '70s I ordered a kit from Falcon Acoustics that used such pads. Loudspeaker parts suppliers and auto sound dealers often sell an asphalt-based pad that has a self-adhesive layer. A good example of this type of material is BVD from Meniscus, which is sold in 1⁄16″ thickness.

Figure 13 shows that the first two modes remain at the same frequency but are actually 2–3dB higher! The third mode is reduced by about 7dB and the fourth mode by 3–4dB. The waterfall chart (*Fig. 14*) shows decay time for the primary mode to be extended compared to untreated ¾″ MDF.

Another material offered by suppliers is Black Hole 5, which is made up of five layers. The first is a high loss vibration damping material; the second is made of a ¼″ polyester urethane flexible open cell foam. The third layer is an ⅛″ barrier septum made of limp vinyl copolymer loaded with non-lead inorganic fillers; the fourth is 1″ polyester urethane foam; and the fifth is a thin diamond pattern embossing with polyurethane surface.

The SPL chart (*Fig. 15*) shows the first two resonances are about the same, while the third mode is reduced by 10dB, and the fourth mode by 3–4dB. The CSD chart in *Fig. 16* shows the long decay of the primary mode remains intact.

Another advertised damping material is Deflex from Spectra Dynamics. Their website states: “Made from an advanced polymer to reduce unwanted cabinet distortions to an absolute minimum. Deflex Panels control the energy, not absorb it, thus enhancing the performance of the system.”

I tested their subwoofer panel, which is larger than their other panels. This material is heavier than the previous two, and may be the cause of the increase in the

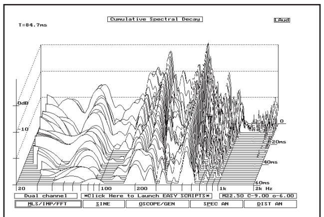

FIGURE 46: CSD of external cabinet with no brace.

B-2043-46

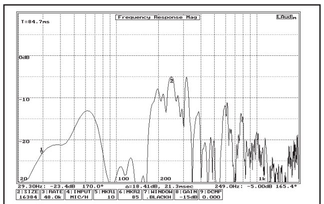

FIGURE 47: SPL of external cabinet with 1⅛″ hardwood dowel.

B-2043-47

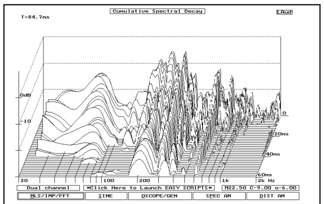

FIGURE 48: CSD of external cabinet with 1⅛″ hardwood dowel.

B-2043-48

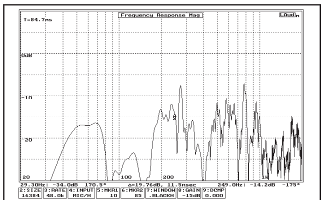

FIGURE 49: SPL of external cabinet with ¾″ × 2½ × 10½″ MDF brace.

B-2043-49

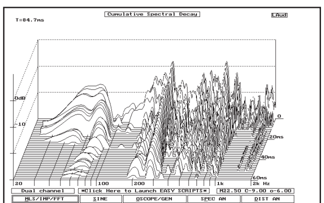

FIGURE 50: CSD of external cabinet with ¾″ × 2½ × 10½″ MDF brace.

B-2043-50

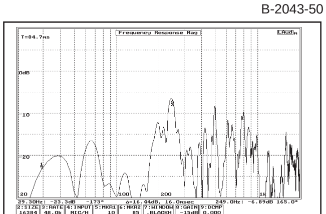

FIGURE 51: SPL of external cabinet with shelf brace with four windows and 1″ wide frames.

B-2043-51

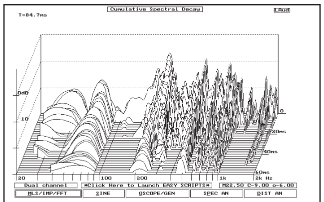

FIGURE 52: CSD of external cabinet with shelf brace with four windows and 1″ wide frames.

B-2043-52

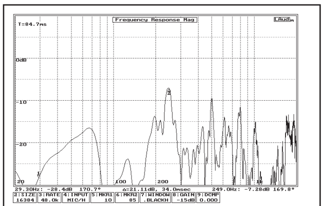

FIGURE 53: SPL of external cabinet with shelf brace with four ovals and 1″ wide frames.

B-2043-53

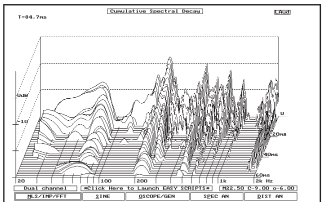

FIGURE 54: CSD of external cabinet with shelf brace with four ovals and 1″ wide frames.

B-2043-54

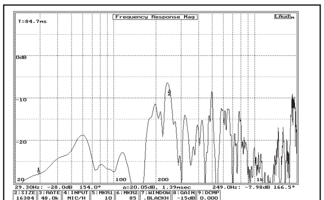

FIGURE 55: SPL of external cabinet with shelf brace with one big oval and 1″ wide sides.

B-2043-55

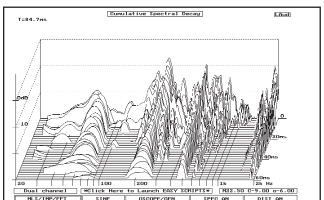

FIGURE 56: CSD of external cabinet with shelf brace with one big oval and 1″ wide sides.

B-2043-56

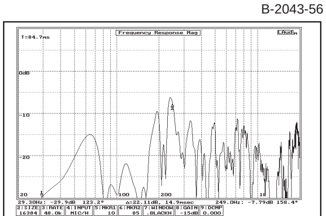

FIGURE 57: SPL of external cabinet with shelf brace with one big mahogany oval and 1″ wide sides.

B-2043-57

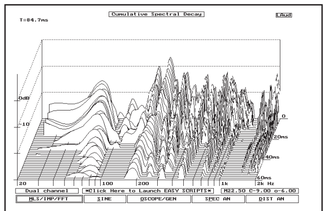

FIGURE 58: CSD of external cabinet with shelf brace with one big mahogany oval and 1″ wide sides.

B-2043-58

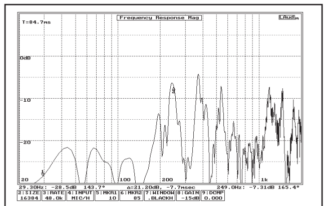

FIGURE 59: SPL of external cabinet with three shelf braces with one oval and 1″ wide sides.

B-2043-59

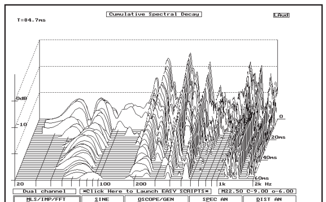

FIGURE 60: CSD of external cabinet with three shelf braces with one oval and 1″ wide sides.

B-2043-60

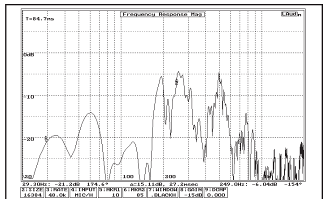

FIGURE 61: SPL of external cabinet with ¾″ SBR shelf brace with four circles and 1″ wide sides.

B-2043-61

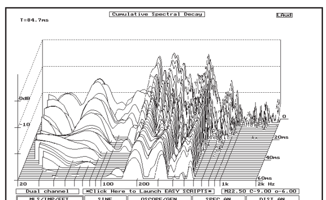

FIGURE 62: CSD of external cabinet with ¾″ SBR shelf brace with four circles and 1″ wide sides.

B-2043-62

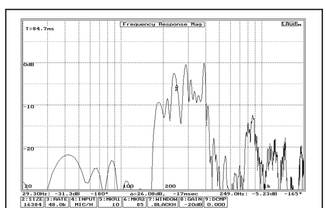

FIGURE 63: SPL of woofer with 1⁄32″ cork/neoprene gasket.

B-2043-63

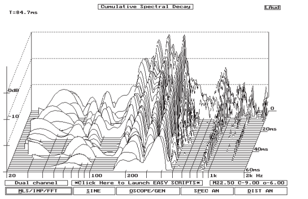

FIGURE 64: CSD of woofer with 1⁄32″ cork/neoprene gasket.

B-2043-64

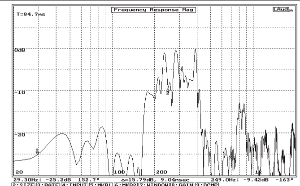

FIGURE 67: SPL of woofer with 1⁄16″ 30 durometer neoprene gasket.

B-2043-67

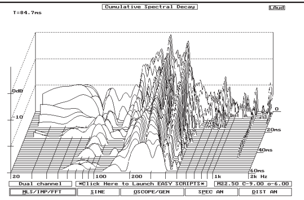

FIGURE 70: CSD of woofer with ¼″ 30 durometer neoprene gasket.

B-2043-70

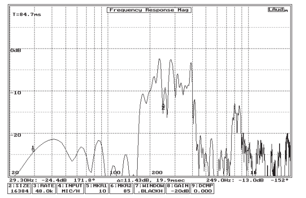

FIGURE 65: SPL of woofer with 1⁄8″ neoprene/EPDM/SBR foam gasket.

B-2043-65

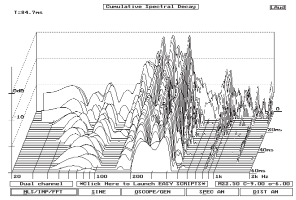

FIGURE 68: CSD of woofer with 1⁄16″ 30 durometer neoprene gasket.

B-2043-68

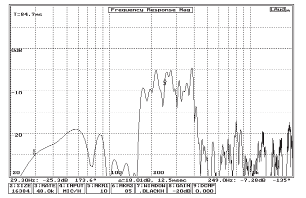

FIGURE 71: SPL of woofer with 1⁄16″ 30 durometer neoprene gasket and Wellnut.

B-2043-71

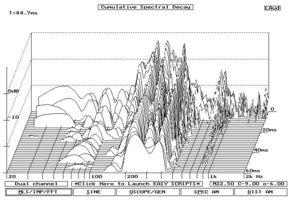

FIGURE 66: CSD of woofer with 1⁄8″ neoprene/EPDM/SBR foam gasket.

B-2043-66

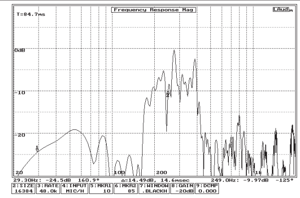

FIGURE 69: SPL of woofer with ¼″ 30 durometer neoprene gasket.

B-2043-69

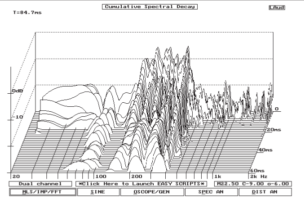

FIGURE 72: CSD of woofer with 1⁄16″ 30 durometer neoprene gasket and Wellnut.

B-2043-72

primary resonance mode by about 6–7dB (*Fig. 17*). The third mode is reduced more than 10dB, and the fourth mode by 3–4dB. The CSD chart (*Fig. 18*) shows the increased decay time of the primary mode with reduction of the third and fourth modes.

Next, I tested a sand-filled panel since it is considered to be a "classic" because of its apparent effectiveness. In this instance, I constructed this panel by applying 1″ of sand held in place with ¼″ MDF panels. You can see in *Fig. 19* that the first mode is actually about 4dB higher than untreated MDF. The primary mode is shifted to 222.66Hz and is down by about 2dB. The two other modes are significantly reduced by more than 10dB. A look at the CSD chart in *Fig. 20* shows the stubborn persistence of the primary resonance mode, however.

For the past several years, I considered lead sheeting to be the ultimate damping material because of its weight and used it in several designs. It seemed ideal because it was relatively cheap and available at the local roofing supply store and did not take up much space. And it seemed to do well on the knuckle rap test.

However, it now appears that the weight of 1⁄16″ lead sheeting can be a help and a hindrance. A look at the SPL chart (*Fig. 21*) shows the first mode is reduced by 1dB, but the second mode is raised by about 6dB. The third mode is down by 15dB and the fourth reduced by about 4dB. And, as you can see in *Fig. 22*, the CSD chart shows the persistence of the primary resonance mode.

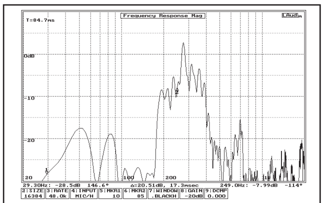

FIGURE 73: SPL of woofer panel on 1⁄16″ 30 durometer neoprene, 1⁄32″ cork/neoprene gasket.

B-2043-73

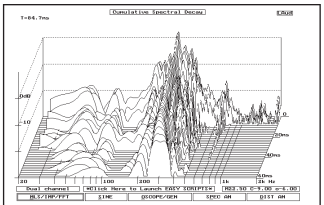

FIGURE 74: CSD of woofer panel on 1⁄16″ 30 durometer neoprene, 1⁄32″ cork/neoprene gasket.

B-2043-74

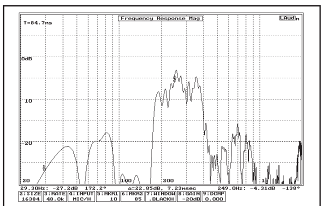

FIGURE 75: SPL of woofer panel on ¼″ 30 durometer neoprene, 1⁄32″ cork/neoprene gasket.

B-2043-75

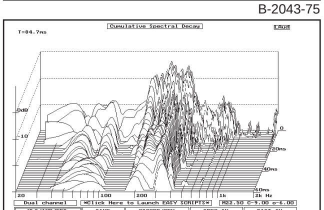

FIGURE 76: CSD of woofer panel on ¼″ 30 durometer neoprene, 1⁄32″ cork/neoprene gasket.

B-2043-76

Figures 23–26 show the results of bonding a layer of Sorbothane, a polyether-base polyurethane viscoelastic material, between the lead and the MDF. I had hoped the Sorbothane would help damp the vibrations. While the effect of the ½″ Sorbothane is better than the ⅛″ version, the CSD chart (*Fig. 26*) again illuminates the persistence of the primary resonance at 222.66Hz. I substituted solid neoprene rubber, foam neoprene rubber, and styrene-butadiene rubber sheets of varying thickness and hardness for Sorbothane; they produced similar but less satisfactory results.

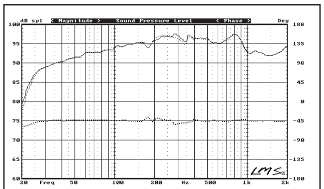

FIGURE 77: SPL comparison of ¾″ MDF and ¾″ MDF/sand-filled panel; difference curve raised by 75dB.

B-2043-77

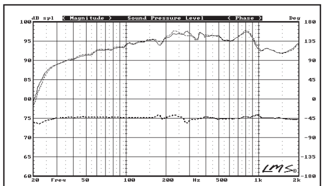

FIGURE 78: SPL comparison of ¾″ MDF and triple layer of ¾″ MDF; difference curve raised by 75dB.

B-2043-78

The difficulty of reducing this resonance suggests that most methods of extensional damping are capable of reducing secondary resonances but are ineffective when dealing with the primary resonance mode. In fact, most materials, because of their weight, appear to magnify the primary resonance. Apparently, this resonance behaves more like a weight suspended from a spring; increasing the weight increases the amplitude of the oscillation. The secondary modes may be easier to damp because their energy is distributed across a greater area.

CONSTRAINED LAYER DAMPING

Constrained layer damping (CLD) starts with extensional damping and improves it by bonding another panel to the damping material. The additional panel is called the constraining layer because it constrains the damping material. It is usually thinner than the panel being damped. Under excitation the panels move and slip thus causing a shearing force in the damping material. That is why this method is supposed to be more effective than extensional damping. You can find a more in-depth discussion on CLD at the EAR Specialty Composites website: www.earsc.com. Look under the engineering section for technical white papers. Also, a rather enlightening study on panel damping that was done by Nokia engineer Juha Backman[2] has an informative description of CLD.

I ordered samples of Isodamp C-1002, a vinyl thermoplastic produced by EAR Specialty Composites. It is used in the Sony SS-M9 loudspeaker, which was designed by Dan Anagnos and is covered by U.S. patent #5,949,033. Check it out at the United States Patent and Trademark Office: www.uspto.gov/.

The Sony speaker uses CLD for all of its exterior panels. The CLD panel comprises two 25mm panels with a 6.4mm constrained layer of Isodamp C-1002. Since the Sony speaker used two panels of similar thickness, I bonded a ⅛″ sheet of Isodamp C-1002 between two ¾″ MDF panels and tested it for resonances.

As you can see in *Fig. 27*, the primary resonance is increased by 4–5dB when compared to a double-thick layer of MDF (*Fig. 9*). The third mode is reduced by 7–8dB, but the fourth mode is higher by 3–5dB. The CSD chart (*Fig. 28*) shows the long decay of the primary mode as usual. Since this is similar to what results when lead sheeting or heavy extensional damping materials are

ABOUT DUROMETER SCALES

Durometer is the international standard for measuring the hardness of rubber, sponge rubber, plastic, and other nonmetallic materials. Very soft materials, such as gels and microcellular foam and sponge, are rated on the "Shore 00" scale. For example, chewing gum is about 20 durometer and a racquet ball about 35 durometer on this scale.

Rubber, soft plastic, polyurethane, leather, and felt are measured on the "Shore A" scale. For instance, a rubber band is about 40 durometer, car tires are about 50 durometer, and a shoe heel about 70 durometer on this scale.

Hard materials, such as hard rubber, rigid PVC, nylon, acrylic, polyurethane, and ABS, are rated on the "Shore D" scale. A bowling ball, for example, is about 55 durometer on this scale.

used, it appears the damping material and constrained layer are behaving more like extensional damping. This may be because the constraining layer is too heavy.

I also tested double ¾″ MDF panels with solid Neoprene (30 and 60 durometer hardness), styrene-butadiene rubber (75 durometer), vinyl, filled vinyl, and BVD to see whether the damping material was the problem. Results were very similar, but not as effective, when compared to the CLD panels with Isodamp C-1002. So, I then moved to examining a CLD panel constructed of ½″ MDF, ¼″ Isodamp C-1002, and ¼″ ACX plywood.

PHOTO 2: Test panel in place with ACH-01 accelerometer fastened with double-stick tape.

PHOTO 3: External cabinet with single large oval brace with 1″ frames.

Results are shown in *Fig. 29*. The first and fourth modes are the same, while the third resonance mode is reduced by about 12dB compared to untreated ¾″ MDF, but the primary resonance mode has increased by nearly 6dB. Compared to ¾″ MDF bonded to ¼″ ACX plywood (*Fig. 30*) the first mode is up by 2dB, the second (primary) mode has increased by 12dBm, the third mode is down by 5–10dB, but the fourth mode is shifted lower in frequency and is up by 5–6dB.

The CSD chart (*Fig. 31*) shows the prominent and long decay of the primary resonance. *Figure 32* shows the CSD chart for the MDF/ACX combination. Clearly, the weight of the damping material is a factor in these results.

In his study, Backman used a commercial plywood called Schauman Wisa-Phon S. It was described as two 9mm-plywood layers with a thin viscoelastic layer between them. I wasn't able to procure this material, so after some searching I decided to build panels with North Creek soft glue (NCSG) and Kapco bookbinding glue. Both glues are a white PVA that dries clear but remains flexible, and look like the glue that is used to keep a credit card in place when it is mailed. I also took a look at but did not test an Armstrong glue for wooden floors, which is another white PVA glue that remains flexible when dried.

As you can see in *Fig. 33*, the NCSG seems to be doing a modest job of damping two ¾″ MDF panels. The first two modes are unchanged, but the third mode is down by 3–

6dB, while the fourth is reduced more than 5dB. The CSD chart (*Fig. 34*) shows the decay times to be similar, however.

I then examined ways to make ¾″ CLD panels. In *Fig. 35*, ½″ MDF plus NCSG plus ¼″ MDF shows modest improvement compared to untreated ¾″ MDF. The first two modes are more or less the same, while the third and fourth modes are released by about 2dB. *Figure 36* shows a modest decrease in the decay time of the primary mode. *Figures 37* and *38* show the results of a CLD panel with a 1⁄16″ styrene-butadiene rubber layer.

In this case the first two modes are increased by about 2dB, probably because of the weight of the damping material, while third and fourth modes are reduced by 3–5dB. The CSD chart shows a slight increase in the decay time of the primary mode.

Since increased weight seems to make the primary resonance mode worse, I then explored the use of high-grade plywood with the hope that a lighter and stiffer material would prove favorable. My favorite specialty lumberyard supplied me with ½″ nine-ply Baltic Birch and ½″ ApplePly, also a high-grade nine-ply product.

PHOTO 4: Woofer panel "floating" on ¼″ neoprene damping layer.

As you can see in *Fig. 39*, ½″ ApplePly with NCSG and ¼″ MDF produced mixed results when compared to ½″ MDF, NCSG, and ¼″ MDF. The first and fourth modes are unchanged, the second mode is down by 2dB, but the third is shifted slightly higher in frequency and increased by about 4dB. The CSD chart (*Fig. 40*) shows an increase in decay times for the major modes. A CLD panel composed of ½″ Baltic Birch, NCSG, and ½″ MDF showed good results for all four modes, however.

Compared to *Fig. 35*, all of the resonance modes in *Fig. 41* are down by 3–6dB. But, compared to double ¾″ MDF with NCSG (*Fig. 33*), modes are 2–6dB higher. The CSD chart (*Fig. 42*) shows a modest decrease in decay time of the primary mode.

Finally, a double layer of ½″ Baltic Birch with NCSG is shown in *Fig. 43*. Compared with *Fig. 35*, the ½″ MDF/NCSG/¼″ MDF sandwich, the Baltic Birch/NCSG sandwich has reduced the first two modes by 3–5dB and the fourth mode by about 10dB. The third mode, though, is pushed a little higher and is about the same level. The CSD chart (*Fig. 44*) shows a long decay for the third mode.

An examination of the various methods, multiple layers, extensional damping, and constrained layer damping suggests the following conclusions: Multiple layers can lower resonance peaks by 3–5dB and some by as much as 10dB; however, this benefit comes with the penalty of additional weight and bulk. This drawback dissuades most commercial manufacturers from employing this method. However, it is fine for do-it-yourselfers, and may be one reason why high-quality kits can produce better sound than a ready-made product. Decay times remain, however.

Most forms of extensional damping have mixed results, because they appear to only modestly reduce secondary modes but amplify the primary mode. The exception is the sand-filled panel, which is difficult to build, however. Constrained layer damping can be effective when you choose the right materials and damping materials. Double ¾″ layers of MDF and NCSG is a choice if size and weight aren't a factor.

If they are a concern, then I recommend double ½″ Baltic Birch with NCSG because it weighs nearly the same as a single layer of ¾″ MDF. In all cases, however, decay times of the resonances remain stubbornly high.

BRACING

Since it became apparent that both extensional and constrained layer damping were limited, I next turned my attention to bracing. After some thought, I devised an "external" cabinet that would allow the testing of various bracing schemes (*Photo 3*). The external cabinet is composed of two 12″ × 12″ side pieces of ¾″ MDF that I glued to the test panel and then connected with a 12″ × 10.5″ back piece. I then glued the bracing material to the test panel and the external cabinet, and installed the test panel with external cabinet for testing.

Direct comparisons with the previous tests are difficult because the external cabinet adds additional resonance modes and alters the previous modes. You can see this for a ¾″ MDF test panel with an external cabinet and without a brace in *Fig. 45*. There now appear to be two prominent modes instead of one; you can see this more clearly in the CSD chart (*Fig. 46*).

The first bracing test was with a 1⅛″ hardwood dowel, which is commonly available in three or four foot lengths from a hardware store. I glued it into place on the center of the test panel and the center of the back piece. Results with the dowel were mixed (*Fig. 47*).

Compared to the unbraced test panel the first mode is about the same, the second mode is reduced by 3dB, the third is up by 5dB. The prominent fifth mode is down by more than 10dB, however. The CSD chart in *Fig. 48* shows the impact of the increased third mode and the reduced fifth mode.

The second brace was a ¾″ × 2½″ × 10½″ piece of MDF that I glued to the center of the test panel, and glued the ends of the brace to the side pieces. As you can see in *Fig. 49*, it appears to be effective because it reduces the two major modes by 5–10dB, compared to the unbraced test panel, but is up just 2dB for one of the minor modes. The CSD chart in *Fig. 50* confirms its excellent performance.

The rest of the braces that I tested were all shelf braces; that is, they resemble shelves if you can imagine viewing the inside of the enclosure. They are not only glued to the test panel, but also to the sides and the back piece. I made most of them from ¾″ MDF, and they varied in the size, number, and shape of the holes in the shelf brace so as not to impede the flow of air within the enclosure.

The first of the shelf braces

looks like a window with panes. It includes four rectangular holes and 1″ wide frames around the "window" and the cross pieces. As you can see in *Fig. 51*, the shelf brace with four windows does a good job of lowering all of the major resonances by 5–10dB. The six minor resonances remain more or less the same. The CSD chart (*Fig. 52*) shows the reduction of the two prominent resonance modes.

The shelf brace with four oval holes also had 1″ wide frames, but the extra arch-shaped material from the oval shape added additional stiffness. *Figure 53* shows 1–3dB better reduction in peak modes compared to the shelf brace with four rectangular windows. The CSD chart (*Fig. 54*) also shows the modest improvement in the two major modes. This brace, however, is not quite as effective as the ¾″ × 2½″ × 10½″ piece of MDF. This is probably due to the frame being only 1″ wide.

While the shelf brace with four ovals or windows does very well, and could be improved by making the frame wider, there may be situations in which it would be impractical to use a brace that occupies or obstructs the central part of an enclosure. So I tested a shelf brace with a single large oval and 1″ frames. *Figure 55* shows the first mode is up by 2dB, the second by less than a dB, the third has increased by 7dB, while the others are about the same, compared to the shelf brace with four ovals. The CSD chart (*Fig. 56*) shows the modest increase in the first two modes.

The next shelf brace includes a single large oval and 1″ frame, but is made of mahogany lumber core plywood. I expected this material to be stiffer than MDF and do better; however, as *Fig. 57* shows, it produced 2–3dB increases in the first and third modes but was 4dB better on the fourth mode. The CSD chart (*Fig. 58*) shows the increase in those modes.

I then considered three shelf braces each with a single large oval but made with ¼″ MDF. I was hoping there might be some overall benefit to having more, but thinner, braces. I positioned the braces to divide the test panel into fourths. Compared to the shelf brace with four ovals, the three shelf braces with one oval made of ¼″ MDF was 1dB higher on the prominent second mode but more than 10dB up on the third mode, while the fourth was up by 3dB (*Fig. 59*). The CSD chart (*Fig. 60*) shows the increased prominence of the third and fourth modes.

Finally, I considered a resilient material, ¾″ styrene-butadiene rubber (75 durometer). This shelf brace had four circular holes, which produced 1″ frames. This material was a big disappointment (*Fig. 61*).

I thought it might be possible to dissipate some of the vibration with a nonrigid material. Compared to the shelf brace with four ovals, the first mode is up by 8dB while the others have increased by 2–4dB. The CSD chart (*Fig. 62*) shows the prominence of the first mode and the increase in the fourth mode decay time.

Apparently, bracing can reduce resonance modes by up to 5–10dB. As with multiple layers, bracing makes the panel stiffer and lowers the output of the resonance. Decay times of the resonances remain unchanged, however.

Oval or circular holes in shelf braces appear to be more effective than rectangular holes, as you would expect, because of the additional strength of the arch-shaped material. Single-hole shelf braces with side frames of 1–2½″ would be a good choice where internal space can't be compromised, such as when you must accommodate a port tube. Finally, it appears that MDF is an adequate bracing material, although you would expect stiffer materials such as plywood to do better.

Thus, a well-designed enclosure should feature extensive bracing. That is, every panel should be braced; and, if possible, double-braced by dividing the panel into fourths. Bracing is another reason why you can produce a homemade loudspeaker to outperform a store-bought one, since extensive bracing adds to the complexity, cost, and weight of an enclosure.

WOOFER ISOLATION

As demonstrated earlier, much of the vibration is caused by mechanical conduction. So finding a way to reduce the transmission of vibration from the driver to the baffle could prove effective. I started by examining the gasket that is used to ensure an airtight seal between the driver and the baffle.

One of the more common methods of sealing the woofer/baffle joint is to use foam tape, which is often available as window weather stripping at the local hardware store or is sold by various loudspeaker parts suppliers. It seems effective, but I've never believed it to be satisfactory.

So instead, I've developed the practice of cutting gaskets from 1⁄32″ neoprene (60 durometer) and, lately, 1⁄32″ cork/neoprene. These materials are available at McMaster-Carr, an industrial supply firm. Their website is: http://www.mcmaster.com/. I used to draw circles with a compass and then use scissors or a hobby knife to cut the gasket, but now I prefer to use a low-cost gasket cutter with a disposable blade. The gaskets were roughly ¾ of an inch wide.

In *Figs. 63* and *64* you see the familiar resonance peaks and long decay of the test panel with a 1⁄32″ cork/neoprene gasket. In *Fig. 65* the results of using a foam gasket made of 1⁄8″ neoprene/EPDM/SBR foam rubber are shown. Compared to the 1⁄32″ cork/neoprene control gasket, the first resonance mode is down by 2dB, while the second mode is moved slightly lower in frequency. The third mode is down by 3dB, and the fourth is off by about 4dB. The CSD chart (*Fig. 66*) shows an extension in decay time.

So results are mixed to modestly better for this type of material. This material does compress a fair amount; it seems to end up being about 1⁄32″ once the screws are hand-tightened.

The next gasket material was 1⁄16″ neoprene with a hardness of 30 durometer. This material appears to be similar to what is used for bicycle inner tubes. *Figure 67* shows the first mode is down by about 1dB, but the second has risen by about 2dB; the higher two modes are unchanged. Also, the mode at 80Hz is up by more than 5dB. The CSD chart (*Fig. 68*) confirms the longer decay times due to the higher levels.

A ¼″ thick 30 durometer neoprene gasket produces mixed results (*Fig. 69*). Here the first mode is lowered by 2dB, the second mode is lower in frequency and is reduced by 2dB, the third mode is unchanged, and the fourth is off by 2dB. *Figure 70* shows the still prolonged decay of the third mode.

So, it appears that a gasket made of some resilient material and of some thickness can modestly reduce these troublesome vibrations. One reason why the vibration reduction is so modest may be because the driver is transmitting vibrations through the fastening screws, which are directly connected to threaded inserts embedded in the baffle.

In his excellent *Loudspeaker Recipes* book, Vance Dickason uses Wellnuts, a brand of rubber-insulated rivet nuts, to secure the drivers and reduce the transmission of vibration. These fasteners have a rubber body with a nut at one end, which is inserted through a hole. As the nut is tightened the rubber expands to keep the fastener from being withdrawn.

In this instance, I tested a Wellnut that is 1 1⁄16″ long and ⅜″ in diameter and that uses a 10/32 screw. Since the Wellnut has a 1⁄16″ flange, I used it in conjunction with the 1⁄16″ 30 durometer neoprene gasket. *Figure 71* shows this combination did not lower the first mode, trimmed the second mode by 2dB, and lowered the third and fourth by 4.5–5dB. The CSD chart (*Fig. 72*) shows a corresponding reduction in decay times and a slight breakdown of the ridges in the third mode.

Because it appears that fasteners help to transmit vibrations to the panel, it occurred to me that a way to isolate the woofer baffle might prove more effective than rubber-insulated rivet nuts. So, I constructed a sandwich panel with the damping material glued between two ¾″ MDF panels (*Photo 4*).

The bottom ¾″ MDF panel is fastened to the woofer baffle with machine screws and threaded inserts. The woofer is attached to the top panel with ¾″ wood screws that do not penetrate the damping material or the bottom panel. Thus, the panel the woofer is attached to is "floating" or isolated from the rest of the enclosure by the damping material.

The first test was with 1⁄16″ 30 durometer neoprene. In *Fig. 73* it produced mixed results with a shift in mode frequencies, a reduction in some modes, and a significant increase in one mode (*Fig. 73*). The CSD chart (*Fig. 74*) shows the increased decay time of the prominent mode but reduced decay times for the higher modes.

With a ¼″ thick layer of 30 durometer neoprene, results were improved (*Fig. 75*). Again, the higher modes were reduced the most while the first is up a dB and the second is down a dB. The CSD chart (*Fig. 76*) shows the first-mode ridge to be intact but the others are less defined. Compared to the woofer fastened with Wellnuts and a 1⁄16″ 30 durometer neoprene gasket, this particular combination appears to have a slight edge in reduced decay times and slightly less prominent ridges in the CSD chart.

SOUND PRESSURE LEVEL MEASUREMENTS

All of the preceding commentary would be meaningless, of course, if these resonances had no effect on the sound we hear from a loudspeaker. Are these resonances audible? The following SPL measurements appear to definitely indicate their presence (*Fig. 77*). These are one-meter ground-plane sweeps of the test box with a ¾″ MDF panel (solid line) compared with a ¾″ MDF/sand-filled panel (dotted line).

The line at 75dB is the difference between the two curves raised by 75dB. Clearly, there are up to 1dB differences in the SPL between 150 to 400Hz and a little something between 900 and 1000Hz which coincides with the resonance modes in the ¾″ MDF panel. *Figure 78* shows the difference between ¾″ MDF and a test panel with a triple layer of MDF. Again, there are differences of up to a dB or more.

While a 1dB difference seems negligible, it is actually quite significant, indicating that the resonances are nearly as loud as the driver. A similar finding was reported by Barlow[3] who determined that the output of certain resonances approached the level achieved by the driver. This is also referenced by Colloms.[4]

These differences could easily be more than 1dB compared to a well-built enclosure, because the area of the test panel is less than a quarter of the entire enclosure. This notion is made credible by Backman's study[2], which primarily used front and rear SPL measurements of a 6½″ woofer in enclosures made from various materials. His study showed 1–2dB differences for front SPL readings between an enclosure built entirely with CLD panels compared with one made of untreated MDF. Rear SPL measurements showed the CLD enclosure to have SPL peaks that were 10–20dB lower than the MDF enclosure!

If panel-induced resonances are nearly as loud as the driver, then they must have a detrimental effect on the subjective sound of a loudspeaker. You can, without a doubt, hear these resonances in a poorly constructed enclosure.

CONCLUSION

When I started this odyssey more than a year ago, I discussed some of the initial results on extensional damping with my mentor, Vance Dickason. He politely suggested I was making a Don Quixote-like attempt to solve the loudspeaker enclosure vibration problem with that particular method. He was right, of course, because this study shows that the primary resonance seems invincible to any form of extensional damping layer. And, he was probably suggesting that multiple solutions would be required to solve the problem and that even these would only moderately attenuate resonances rather than eliminate them. Again, he was right.

This study suggests a well-built enclosure should incorporate CLD or multiple-thickness panels, extensive bracing, and some method of isolating the woofer from the enclosure. The use of rubber-insulated rivet nuts and a thick gasket might be appropriate for some designs; a "floating" woofer panel might work with a stepped front baffle approach for others.

This study, while finished for the present, resembles an unfinished book. It would have been wonderful to devise some sure-fire method, some "killer app" to kill those persistent resonance modes. Doing so might someday win someone a Nobel Prize.

For the time being, however, we are stuck with compromises. Therefore, I remain open to suggestions, criticisms, and new ideas on this subject. Please e-mail me at: jimbo@maui.net. ❖

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