CHAPTER FIVE

Mr. Pablapa

CABINET CONSTRUCTION: SHAPE AND DAMPING

5.10 ENCLOSURE SHAPE AND FREQUENCY RESPONSE.

The majority of low-frequency cabinets are rectangular in shape. This not only makes for reasonably aesthetic-looking loudspeakers/furniture, but is the easiest shape to construct for both amateur and manufacturer. The rectangular loudspeaker enclosure is, however, often judged less than optimal as a radiating surface because of edge diffraction issues and also less than optimal regarding internal standing wave modes.

A. The Olson Loudspeaker Enclosure Shape Study

Harry Olson's 1951 *JAES* article titled "Direct Radiator Loudspeaker Enclosures" is the classic work illustrating the effect of enclosure shape on cabinet diffraction. The article described a study done to determine the effect of different shapes on the frequency response of a speaker. Twelve shapes were used, which included a sphere, a hemisphere, a cylinder with the driver mounted in the end, a cylinder with the driver mounted on the curved surface, a cube, a rectangle, a cone (driver mounted in the tip), and double cone, a pyramid (the driver mounted in the tip), a double pyramid, a cube with beveled edges (the bevel equal to the width/height of the baffle), and a rectangle witb beveled edges (the bevel equal to the width of the baffle). A ⅞"driver was mounted on each enclosure and measured in an anechoic chamber. The results showed the different shapes provided anywhere from a nearly flat response to a constantly undulating one with a ±5dB variation. The various shapes and their associated on-axis curves reprinted from Mr. Olson's AES articles are shown in *Fig. 5.1*. A summation of the SPL variations from the various cabinet shapes that might be practically used in loudspeaker design follows:

Shape	Variation
Sphere	±0.5dB
Cube	±5dB
Beveled Cube	±1.5dB
Rectangle	±3dB
Beveled Rectangle	±1.5dB
Cylinder	±2dB

From this, it is obvious that an enclosure in the shape of a sphere gives the least amount of "ripple" in the response. While this is good news, the sphere is a somewhat difficult shape to manufacture and there have never been many examples to reach the market, a few exceptions being the Gallo Acoustics Micro, the Morel Soundspot, and the satellite speakers from Orb Audio. While Dr. Olson's is still the best study of its type, and indeed reveals much about enclosure shape and the resulting SPL, it has limitations in terms of both driver location vs. SPL, as well as not including some other enclosure shapes that have become popular over the years since 1951. This fact prompted me to undertake a second study in enclosure shape that takes up somewhat where Dr. Olson left off.

B. Olson's Enclosure Shape Study Extended

Since the publication of the 6th Edition of the *Loudspeaker Design Cookbook*, LinearX has released the Windows version of LEAP, LEAP 5. One of the many important new features of this software was the addition of a very powerful diffraction engine. The analysis mode for the box design part of LEAP 5, titled EnclosureShop, now includes what is literally an anechoic chamber in your computer. With the ability to accurately simulate up to 8th-order diffraction, LEAP 5 can quickly perform extensive diffraction analysis on a variety of shapes as well as be able to locate the transducer anywhere on the baffle surface, making this extended enclosure shape study much easier to undertake.

The shapes studied include some of tbe same ones done in Dr. Olson's original 1951 paper plus a few that weren't on Harry's list. Included in this 2005 study are a cube (15″ × 15″ × 15″), a beveled cube with 2″ bevel, a beveled cube with a 4″ bevel, a rectangle (18″ × 12″ × 9″), a beveled rectangle on four sides (Olson's was only beveled on three sides) with 2″ bevel, a beveled rectangle on four sides with 4″ bevel, a pyramid with the driver located on a facet (Olson's were located on the apex) (18″ height with 4″ width at top and 10″ width at the bottom), a cylinder (18″ height, 16″ diameter), a sphere (16″ diameter) and an egg-shaped enclosure (18″ height, 14″ diameter).

If you look at the shapes in *Fig. 5.1*, you will notice that the driver was located in the center of square-shaped types, the sphere, and the cylinder, and at different locations between the center and top of the enclosure on rectangles. I have also chosen to ignore the shapes in which the driver was located at the apex in this section because they are either not likely to be used as a commercial speaker enclosure or never have been to my knowledge. Because location of the driver on the baffle has such a strong effect on the response smoothness (this is investigated extensively in Chapter 6), I decided to include more than one driver location for each shape so as to better investigate the use of this shape for the different driver formats being used today.

Since Dr. Olson was trying to define the SPL response across the relevant frequency range, he designed a very special driver that had a response from below 100Hz to above 4kHz, but that had a power (combined off-axis) response that would not affect the results by "beaming" at the higher frequencies. The ⅞" cone driver he used was essentially a miniature woofer that could produce energy at 100Hz. Although Mr. Olson never published the absolute SPL of the unique device he designed for the study, you can assume that the SPL was very low so as not to cause the tweeter-sized woofer to overexcurse and distort at low frequencies. Since I did not have data available on that particular unique transducer, I instead substituted two drivers, a 2" wide range cone driver and a 1" dome tweeter. Between these two drivers, you can get a very good idea about what is happening with each of these enclosure shapes.

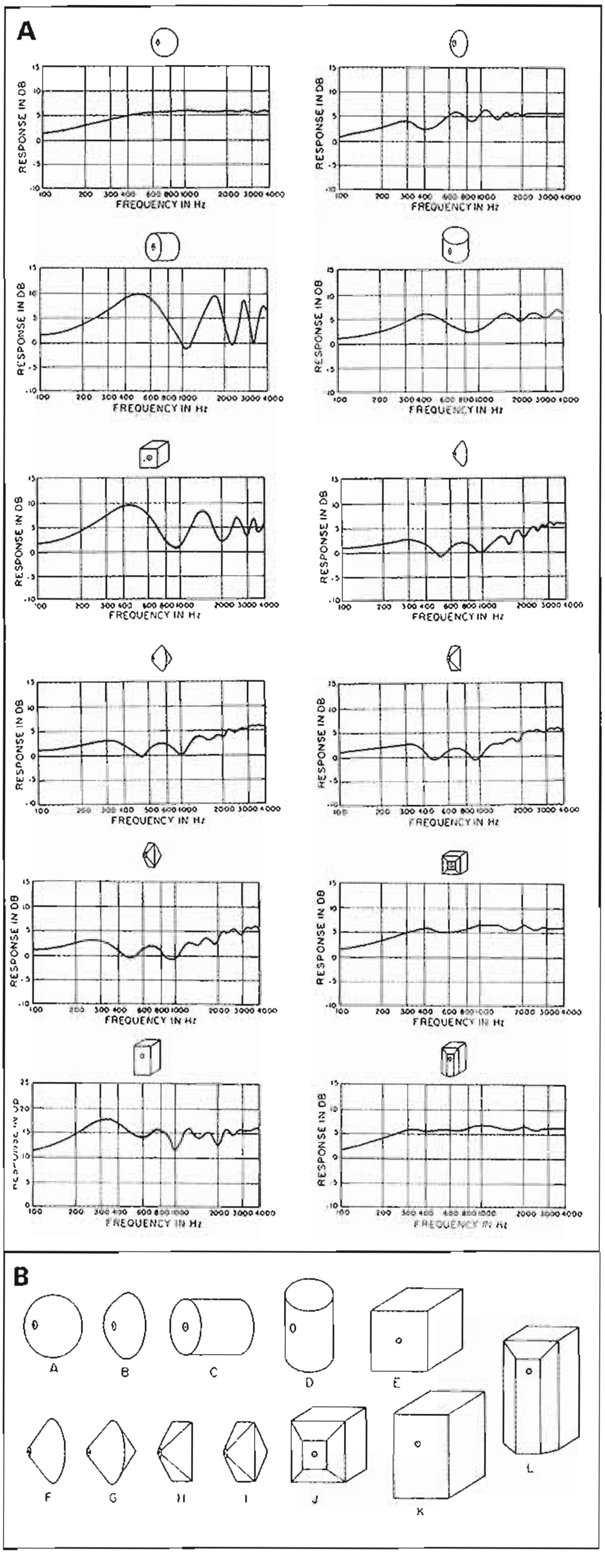


FIGURE 5.1A (right) and B (below). After Direct Radiator Loudspeaker Enclosures (Harry Olson, JAES, November 1951).

Each shape was used to produce four SPL curves, one curve for each of the two drivers at the two different baffle locations. The two locations were defined as mounting the simulated driver mid point in the center of the baffle for the one reference point, and the other location at the top of the baffle, centered between the right and left sides of the enclosure. The center position was used because many of the current woofer-tweeter-woofer (often referred to as the D'Appolito configuration for Dr. Joseph D'Appolito, who first published this design concept in *Speaker Builder* magazine) designs usually have a driver located at the center of the baffle. The second location at the top of the baffle was used because it is a typical location for tweeters. The exact location at the baffle top was roughly far enough from the baffle edge to allow for a grille frame to be installed.

Pictures from LEAP 5 for each shape and baffle location can be seen in *Figs. 5.2* through *5.19* (these are for the tweeters only; however, the 2" full-range was placed in the exact same baffle locations). Because there is only a center position for a sphere- or egg-shaped box, only one baffle location was used for each of these two shapes. You will also notice that some of the shapes appear to be faceted; however, this is a necessary part of the technology employed in LEAP 5 that enables the software to analyze these shapes.

Before considering what each of these different-shaped cabinets does to alter the SPL of a driver, we need to establish some kind of reference with which to judge all the changes that can be observed. The choices would be to look at the driver mounted with no baffle in open air or mounted on an infinitely large baffle. Whatever any baffle does to a transducer's overall SPL, it will fall somewhere between these two extremes.

Figure 5.20 shows the 1" tweeter (solid curve) and 2" cone full-range (dashed curve) suspended in open air (anechoic) with no baffle, and *Fig. 5.21* depicts the response of the same two devices mounted on an infinitely large baffle, which is the same as saying they are being measured in half space (note, all data simulated at 2.83V/1m on-axis). As you can see, when mounted on an infinitely large baffle, the response is substantially flattened out and the anomalies become washed out by the full-range reflective nature of the baffle. As you go through the various examples, it will be helpful to keep these two extremes in mind.

Each of the different shapes except for the sphere and egg-shaped enclosure have four curves placed on two graphs, one graph for the 1" tweeter with the SPL generated at 2.83V/1m on-axis at both the top (dashed curve) center baffle location and the center middle baffle location (solid curve), and the same presentation for the 2" cone full-range driver in the second graph. The sphere and egg-shaped box have only one graph with both the 1" dome (solid curve) and 2" cone (dashed curve) on the same scale. This graphic series is depicted in *Figs. 5.22–5.39.* The data shown in *Tables 1* and *2* summarizes the ±SPL range for each of these. Because the tweeter begins to rolloff below 1.25kHz, its data was calculated in two ranges, 1kHz–10kHz and 2kHz–10kHz, and given in *Table 1.* The 2" full-range driver was examined from 500Hz to 10kHz, with the data displayed in *Table 2.*

Table 1. 1" Dome SPL dB Variations for Different Enclosure Shapes.

	1" Soft Dome 1kHz-10kHz		*1" Soft Dome 2kHz-10kHz*	
	Center	**Top**	**Center**	**Top**
Cube	4.73	3.29	1.99	1.15
Cube 2" Bev	3.33	2.77	3.33	1.32
Cube 4" Bev	2.54	2.65	2.54	0.92
Rectangle	3.09	2.22	1.64	1.84
Rect. 2" Bev	2.33	2.72	1.90	1.83
Rect. 4" Bev	3.05	3.89	1.71	1.38
Pyramid	1.76	2.78	1.49	1.18
Cylinder	2.82	2.60	0.81	0.78
Sphere	2.72	NA	1.11	NA
Egg	2.18	NA	0.55	NA

There are some general conclusions to be drawn from this. First, a word of caution, the SPL data for this type of study can vary substantially by the choice of dimensions, so no matter what, the best you can hope for is to observe some general trends. That said, the following can be concluded from these graphs:

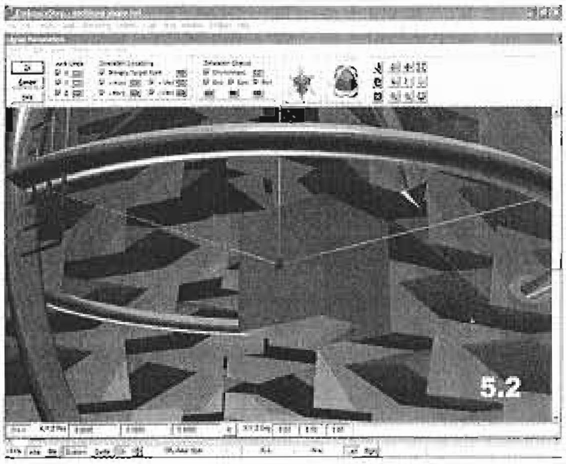
Table 2. 2" Full-Range SPL dB Variations for Different Enclosure Shapes.

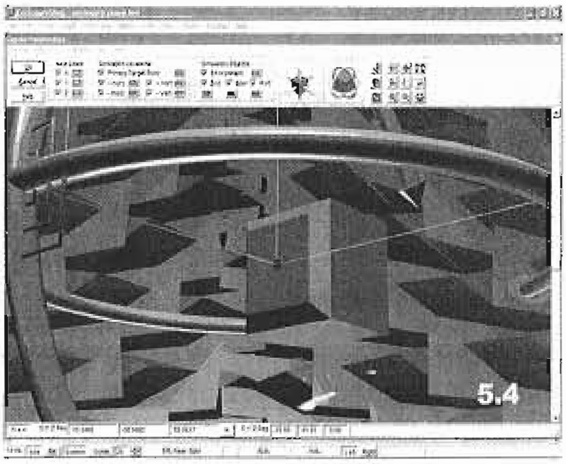
	2" Full-Range 500Hz-10kHz	
	Center	Top
Cube	4.35	2.22
Cube 2" Bev	3.22	1.92
Cube 4" Bev	2.82	1.20
Rectangle	3.03	2.26
Rect. 2" Bev	2.05	2.28
Rect. 4" Bev	1.13	1.60
Pyramid	2.71	2.30
Cylinder	1.29	1.15
Sphere	1.08	NA
Egg	1.51	NA

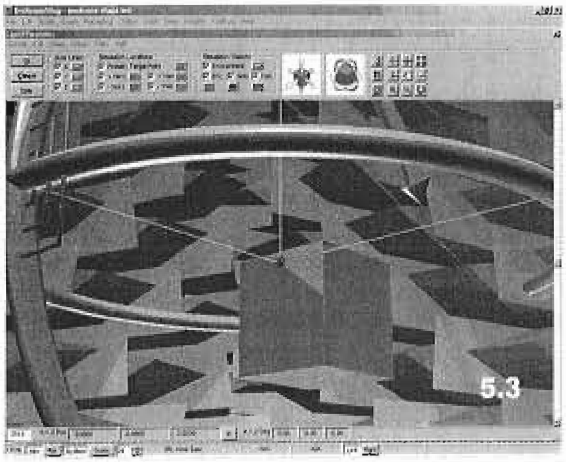
1. Cubes have the most SPL variation, followed by the standard rectangle, pyramid, egg shape, cylinder, and finally the sphere.

2. Beveled edges do decrease SPL variation, but it takes a substantial bevel to be really effective.

3. While a sphere may be the best performer in terms of minimal SPL variation, egg-shaped and cylinder-shaped enclosures are also quite good in this respect. You will notice a drawing in Chapter 6 of a cylindrical-shaped dual enclosure loudspeaker. This drawing is a representation of a loudspeaker I introduced with my first company, SRA (Speaker Research Associates) at CES (Consumer Electronics Show) in Las Vegas, 1978.







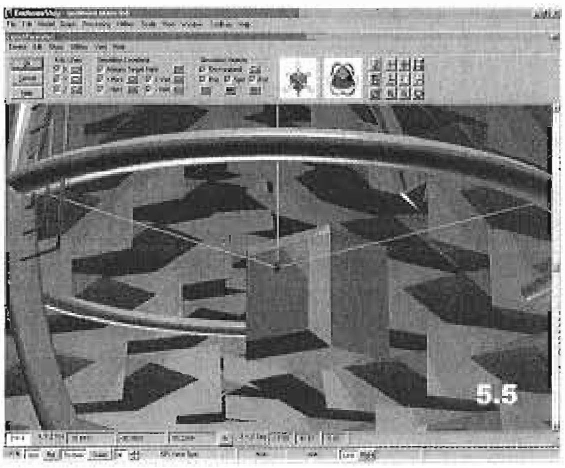


FIGURE 5.2: Cube Enclosure (driver center).

FIGURE 5.3: Cube Enclosure (driver top).

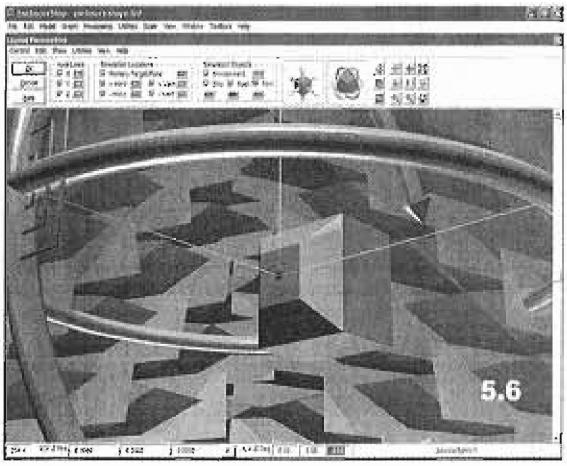
FIGURE 5.4: 2" Beveled Cube Enclosure (driver center).

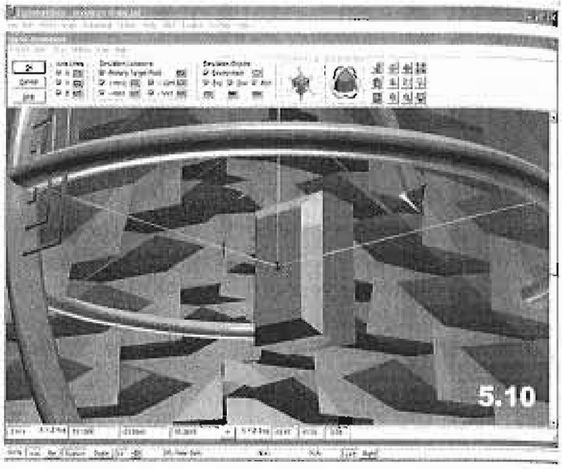
FIGURE 5.5: 2" Beveled Cube Enclosure (driver top).

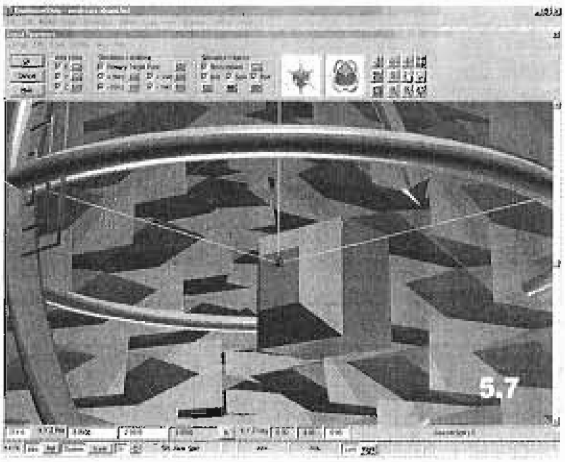
4. Pyramid-shaped enclosures are not appreciably better than rectangle box-type enclosures.

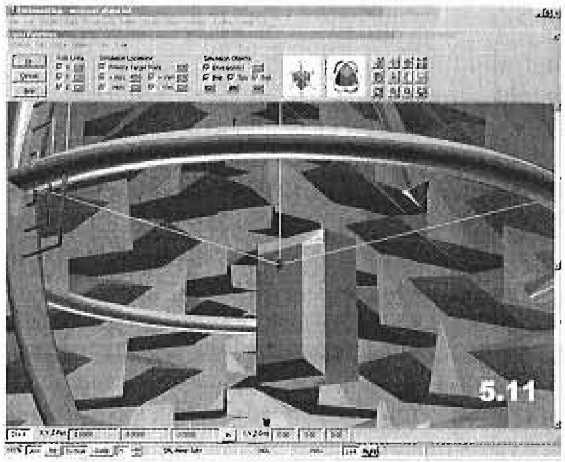
5. Drivers mounted near the top or bottom of an enclosure have substantially less SPL variation than drivers mounted in the center. This will be investigated in much greater detail in Chapter 6, including a subjective study of this type of diffraction phenomenon.

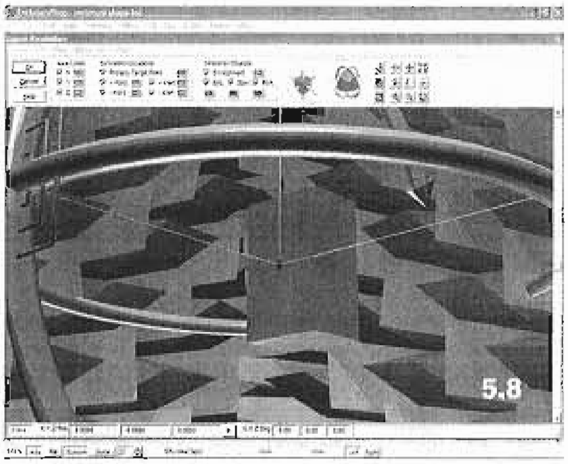
Besides the simulated data shown in this enclosure shape study, I also published an empirical look and the difference between standard enclosures

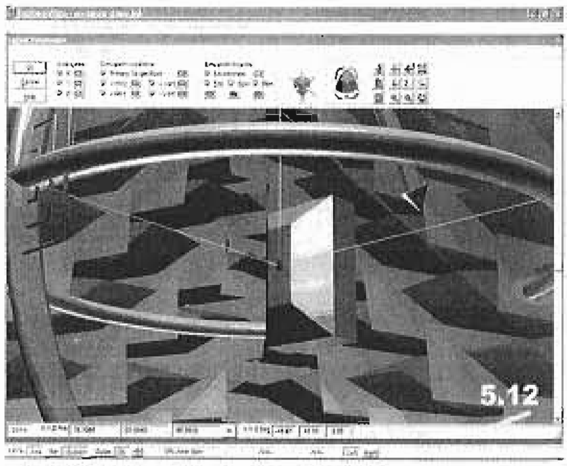


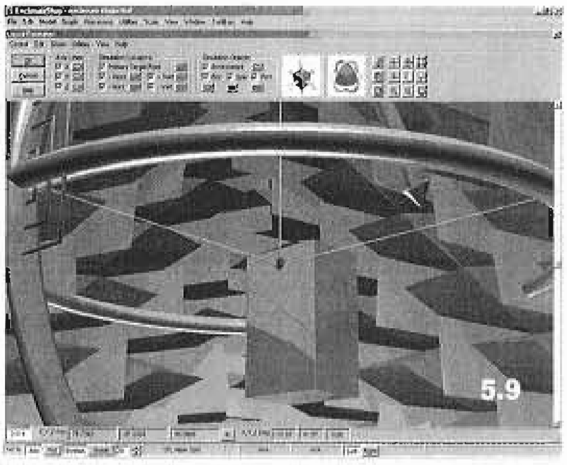












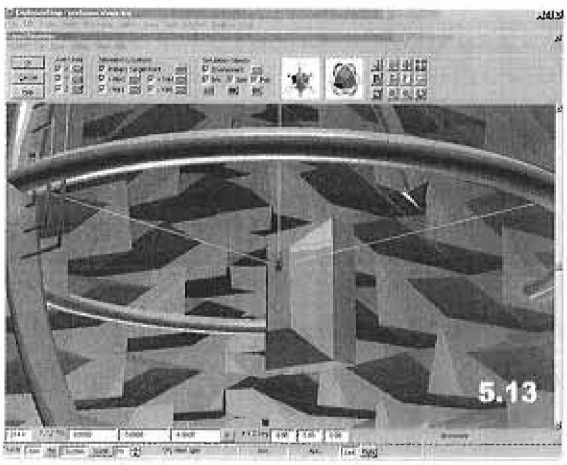


FIGURE 5.6: 4″ Beveled Cube Enclosure (driver center).

FIGURE 5.7: 4″ Beveled Cube Enclosure (driver top).

FIGURE 5.8: Rectangle Enclosure (driver center).

FIGURE 5.9: Rectangle Enclosure (driver top).

FIGURE 5.10: 2″ Beveled Rectangle Enclosure (driver center).

FIGURE 5.11: 2″ Beveled Rectangle Enclosure (driver top).

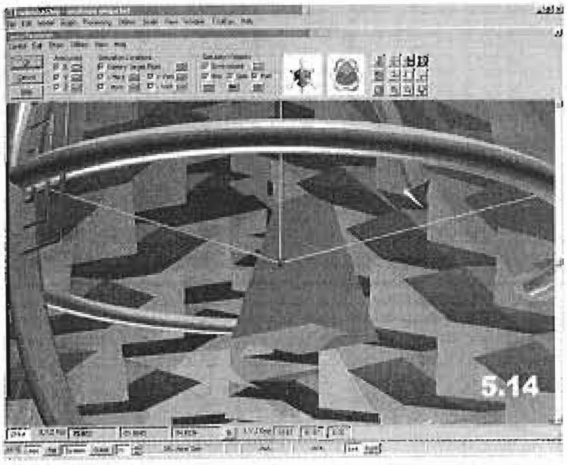
FIGURE 5.12: 4″ Beveled Rectangle Enclosure (driver center).

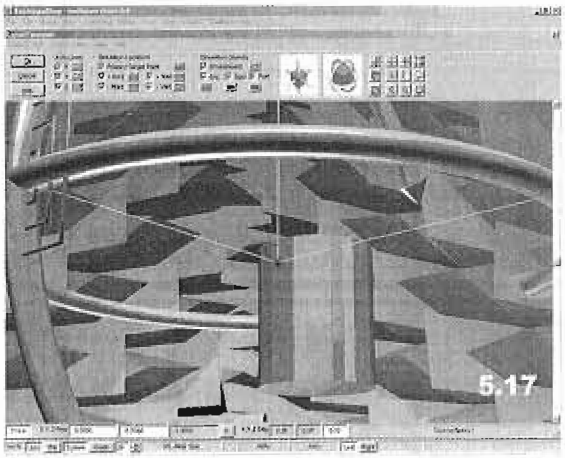
FIGURE 5.13: 4″ Beveled Rectangle Enclosure (driver top).

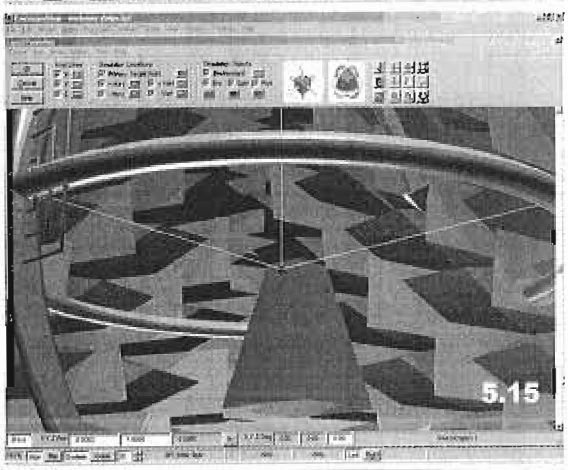
and a more exotic enclosure in *Voice Coil* magazine. The October 1990 issue featured a comparison between a rectangular-shaped enclosure and a flat baffled cylindrical shape, shown in *Figs. 5.40* and *5.41* (drivers were not inset on either enclosure). The flat-sided cylinder is manufactured by Cubicon, who makes geometric cardboard shapes for the furniture, display, and the speaker industry. The response differences shown in *Figs. 5.40* and *5.41* are not very dramatic for either the tweeter response or the woofer response (the woofer test was made without enclosure fill material, so part of the deviation is due to unsuppressed internal standing wave modes), but some deviation is apparent. The measurement was done with the MLSSA FFT analyzer and is windowed at 10mS, making the measurement essentially anechoic in nature. The data was moved from MLSSA into LEAP 4.0 to facilitate PostScript printout.

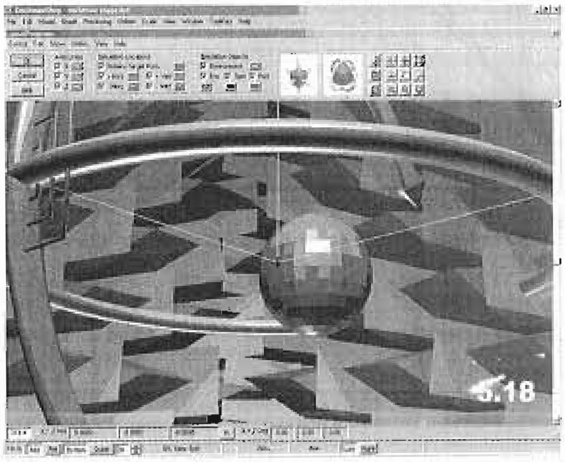
Since the anechoic measurement of these two different-shaped enclosures is so close using identical drivers, a subjective judgment of which shape "sounded" best in a room would be difficult. The final subjective response to any enclosure is influenced by the location of the speakers on the baffle and the way in which the various response variations in the driver combine with the variations caused by whatever enclosure diffraction effects are subjectively apparent in the listening environment. Although exotic enclosure shapes would seem intuitively to offer some of the best alternatives, the reality is that it isn't critically as important as has been claimed by some manufacturers. It remains true that some of the best reviewed and successfully marketed loudspeakers used simple rectangular shapes.

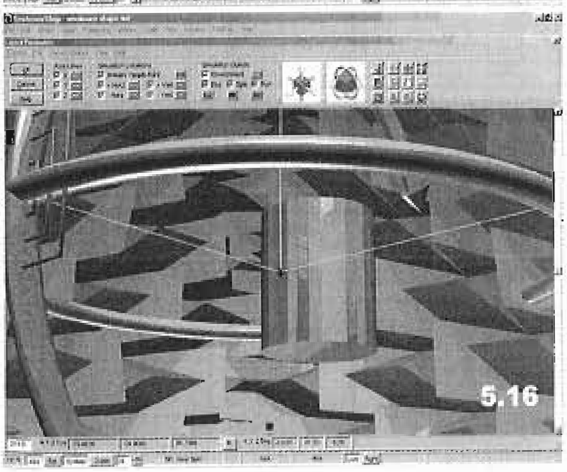
One thing that many loudspeaker companies have ignored over the years when designing off-wall loudspeaker enclosures is that loudspeakers are more than just sonic reproducers, but also a piece of furniture that will ultimately have to reside in someone's home. A good example of this is the Spica Angelus from the 1980s, a loudspeaker design optimized for minimal diffraction, but undoubtedly also with a very low WAF (Wife Acceptance Factor)











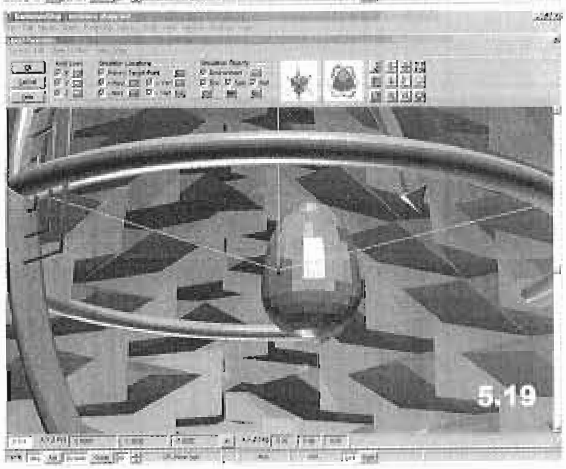


FIGURE 5.14: Pyramid Enclosure (driver center).

FIGURE 5.15: Pyramid Enclosure (driver top).

FIGURE 5.16: Cylinder Enclosure (driver center).

FIGURE 5.17: Cylinder Enclosure (driver top).

FIGURE 5.18: Sphere Enclosure (driver center).

FIGURE 5.19: Egg Enclosure (driver top).

because of its unusual shape. However, there is no question that diffraction is certainly measurable using a single point microphone measurement, but the implication is generally that this has a negative effect on sound quality.

All the data presented here and presented in Harry Olson's 1951 study of SPL variation and enclosure shape is done on-axis. If you think of baffles as being analogous to the reflector on a flashlight, then indeed, baffle diffraction is primarily an on-axis phenomenon that is diminished off-axis[1] and certainly somewhat swamped by the ambient field produced by placing the loudspeaker in a room. Although often thought of as strictly an on-axis event, the effect on the horizontal and vertical polar response is also relevant and will be further

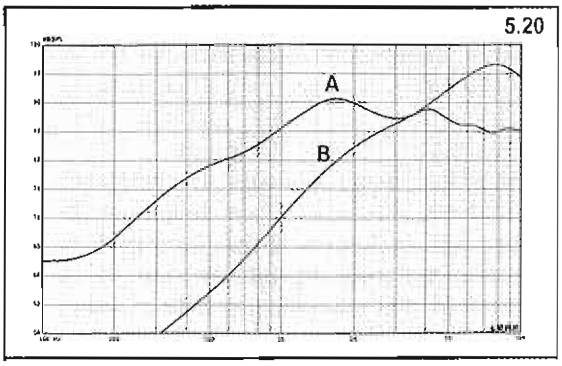


FIGURE 5.20: Frequency response of 2" cone woofer (A) and 1" dome tweeter (B) simulated with no baffle.

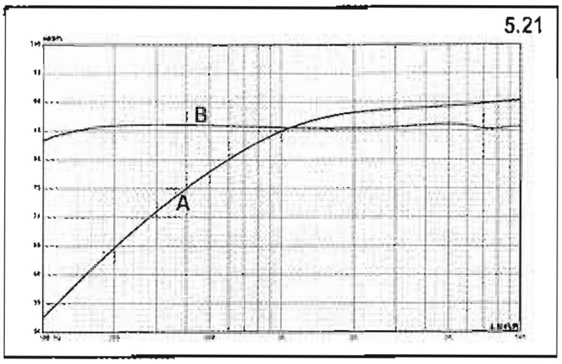


FIGURE 5.21: Frequency response of 2" cone woofer (B) and 1" dome tweeter (A) simulated with infinite baffle.

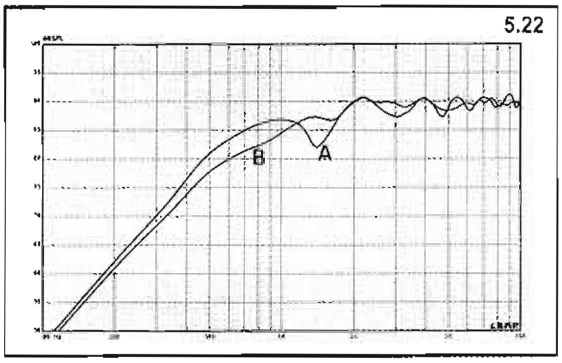


FIGURE 5.22: Frequency response for cube enclosure with 1" dome tweeter (A = tweeter mounted center; B = tweeter mounted top).

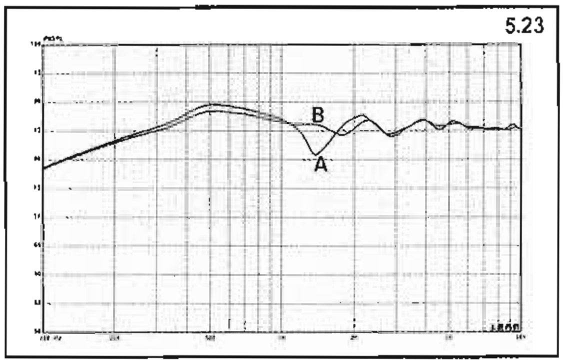


FIGURE 5.23: Frequency response for cube enclosure with 2" woofer (A = woofer mounted center; B = woofer mounted top).

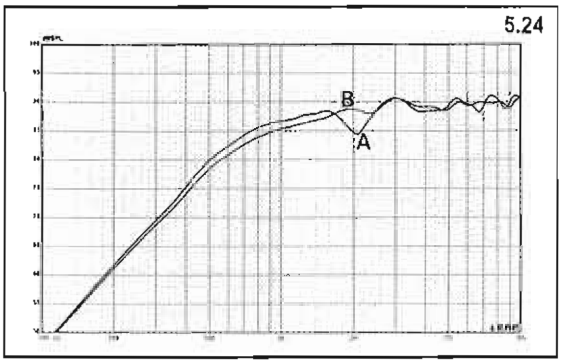


FIGURE 5.24: Frequency response for 2" beveled cube enclosure with 1" dome tweeter (A = tweeter mounted center; B = tweeter mounted top).

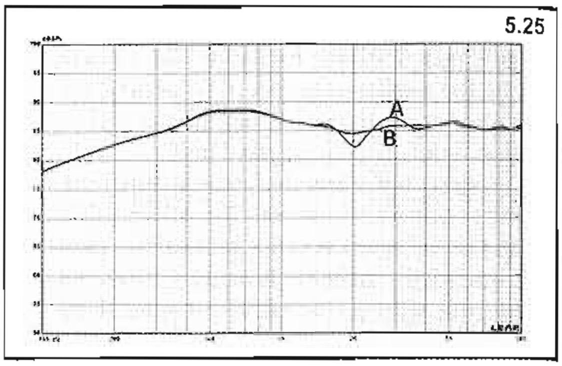


FIGURE 5.25: Frequency response for 2" beveled cube enclosure with 2" woofer (A = woofer mounted center; B = woofer mounted top).

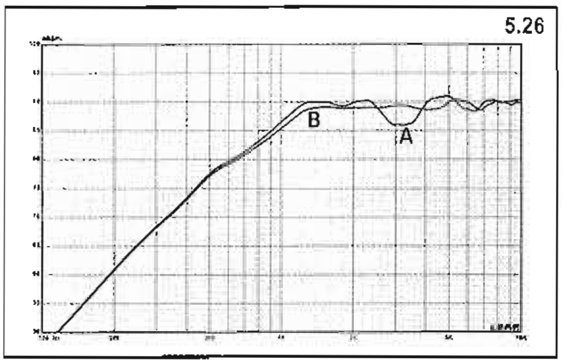


FIGURE 5.26: Frequency response for 4" beveled cube enclosure with 1" dome tweeter (A = tweeter mounted center; B = tweeter mounted top).

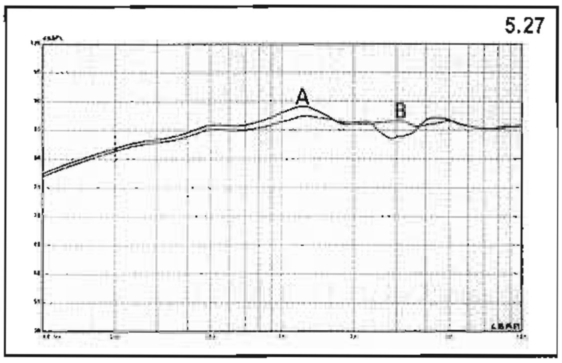


FIGURE 5.27: Frequency response for 4" beveled cube enclosure with 2" woofer (A = woofer mounted center; B = woofer mounted top).

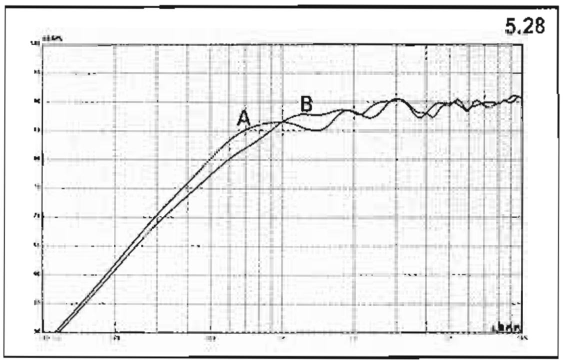


FIGURE 5.28: Frequency response for rectangle enclosure with 1" dome tweeter (A = tweeter mounted center; B = tweeter mounted top).

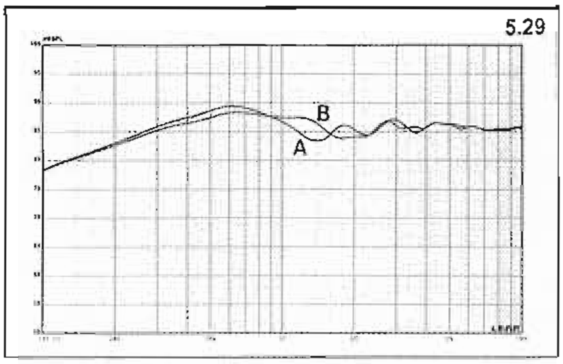
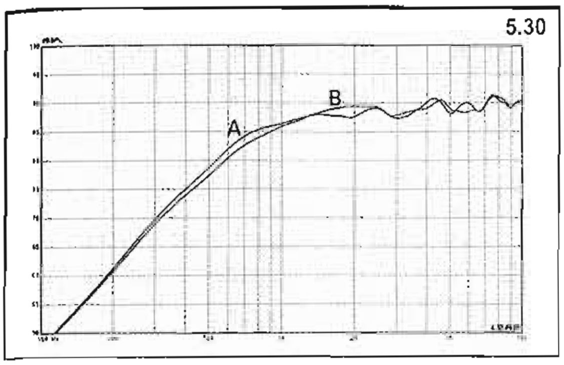


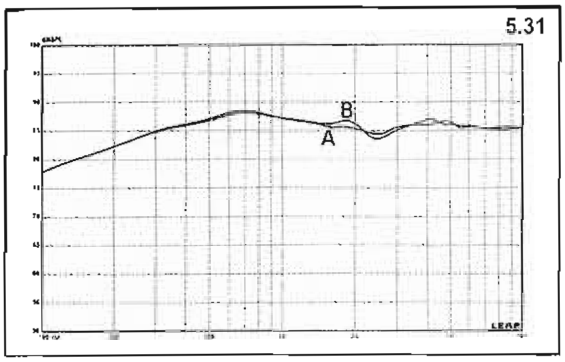
FIGURE 5.29: Frequency response for rectangle enclosure with 2" woofer (A = woofer mounted center; B = woofer mounted top).

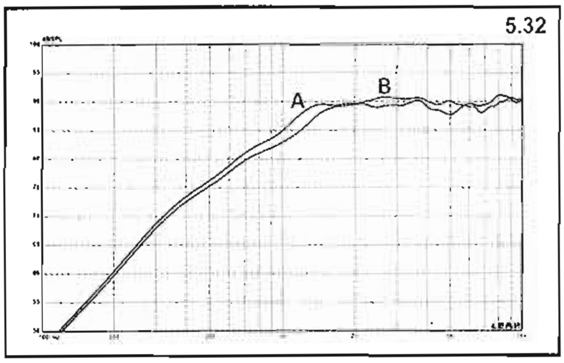
considered as this diffraction study continues in Chapter 6.

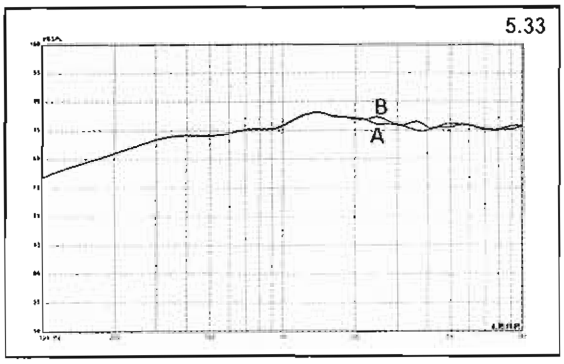
5.20 MIDRANGE ENCLOSURES.

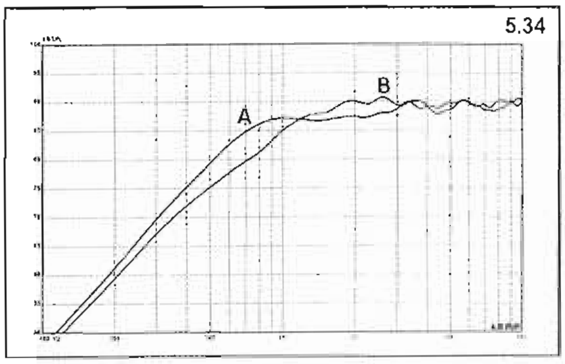
You will face two major considerations when configuring a midrange enclosure: the type of enclosure you will use, and how to minimize internal reflections. Your enclosure will be determined by the crossover frequency and network slope you have chosen. If the crosspoint is above 300Hz, if you have kept the driver resonance one to two octaves below the crosspoint (which would require a minimum midrange cavity resonance of 75–150Hz), and if you use a second-order or higher low-pass filter, the driver will not be operating significantly in its piston range and a simple sealed enclosure will be

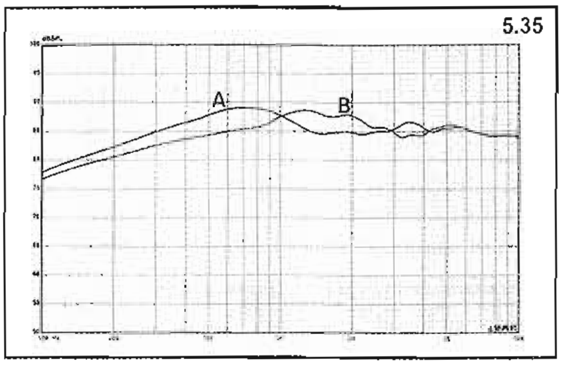


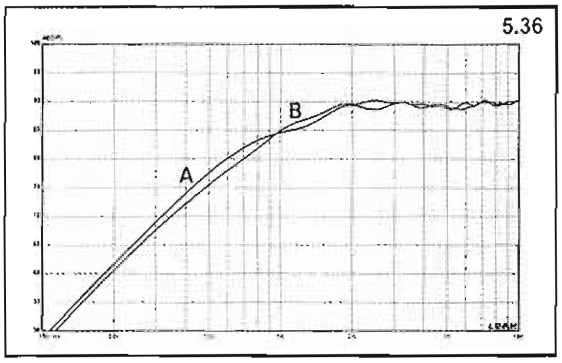


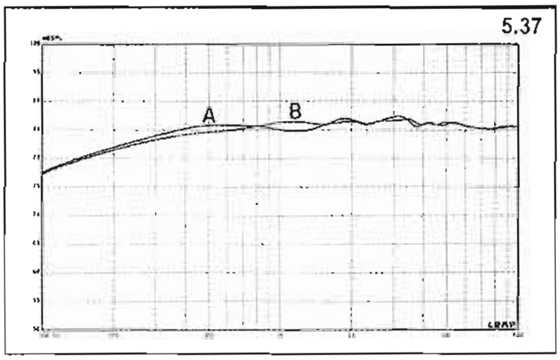


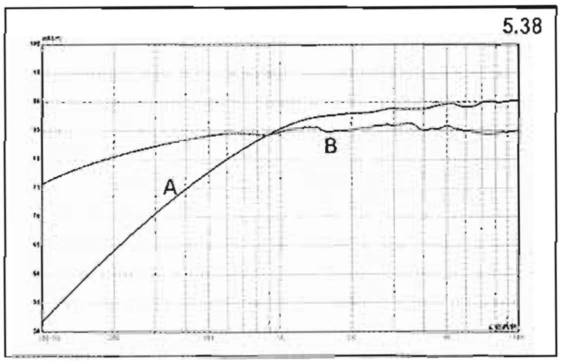












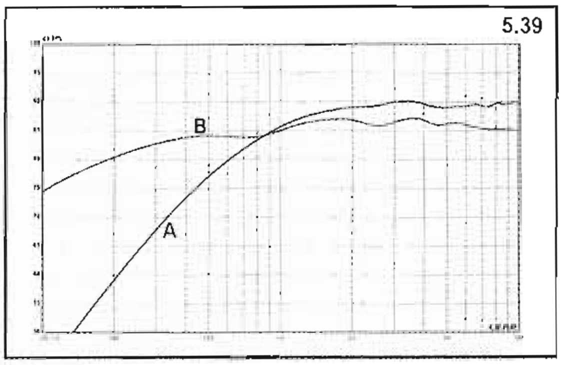


FIGURE 5.30: Frequency response for 2″ beveled rectangle enclosure with 1″ dome tweeter (A = tweeter mounted center; B = tweeter mounted top).

FIGURE 5.31: Frequency response for 2″ beveled rectangle enclosure with 2″ woofer (A = woofer mounted center; B = woofer mounted top).

FIGURE 5.32: Frequency response for 4″ beveled rectangle enclosure with 1″ dome tweeter (A = tweeter mounted center; B = tweeter mounted top).

FIGURE 5.33: Frequency response for 4″ beveled rectangle enclosure with 2″ woofer (A = woofer mounted center; B = woofer mounted top).

FIGURE 5.34: Frequency response for pyramid enclosure with 1″ dome tweeter (A = tweeter mounted center; B = tweeter mounted top).

FIGURE 5.35: Frequency response for pyramid enclosure with 2″ woofer (A = woofer mounted center; B = woofer mounted top).

FIGURE 5.36: Frequency response for cylinder enclosure with 1″ dome tweeter (A = tweeter mounted center; B = tweeter mounted top).

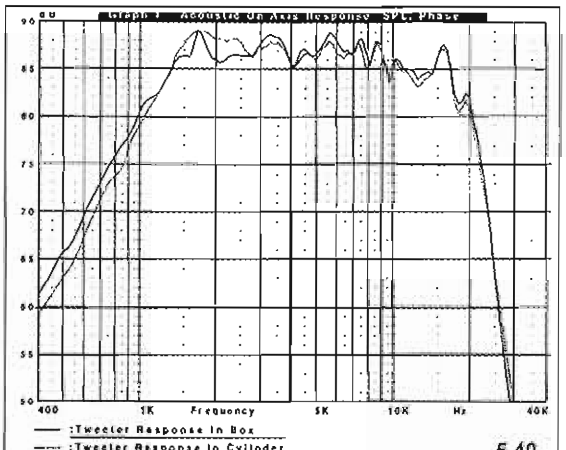
FIGURE 5.37: Frequency response for cylinder enclosure with 2″ woofer (A = woofer mounted center; B = woofer mounted top).

FIGURE 5.38: Frequency response for sphere enclosure (A = tweeter; B = 2″ woofer).

FIGURE 5.39: Frequency response for egg enclosure (A = tweeter; B = 2″ woofer).

adequate. If the crossover frequency is 100–300Hz (or lower than 450Hz using a first-order low-pass filter), the driver will be at least partially operating in its piston range, and will benefit from a properly optimized low-frequency enclosure (*Fig. 5.42*).

You can use a vented enclosure or trausmission-liue configuration if your driver resonance is at least two octaves below the crossover frequeucy. If your driver euclosure resonance can be only an octave or less from the crosspoint, a sealed enclosure, with its shallow rolloff, will cause less phase disturbance in the low-pass filter stopband (the region where filter attenuation takes place). In other words, if you cannot get an enclosure resonance from a TL or vented-type configuration at least two octaves below the crossover frequeucy, use a sealed enclosure. The benefits of using the TL and veuted enclosure include less rear reflection (in the case of the TL), and less midrange cone excursion, with less Doppler distortion (veuted).



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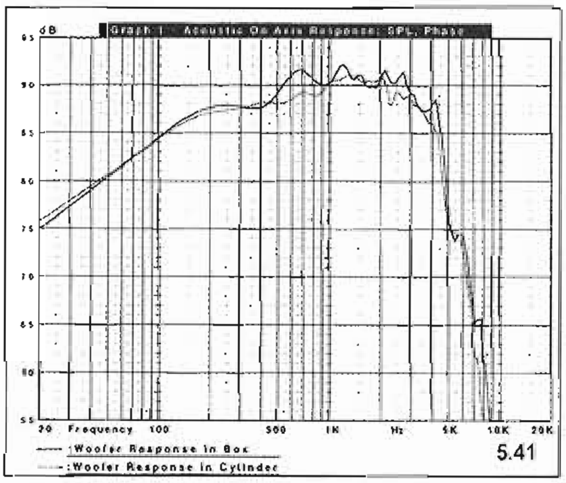


5.41

All types of midrange enclosures, except the TL, will benefit from an enclosure with non-parallel walls, because it will minimize reflections in the critical range of driver operation. In additiou, the proper use of fibrous damping material, such as fiberglass, Dacron, or long fiber wool, will go a long way to make for optimal midrange driver operation. The wall damping techniques described in Section 5.40 will be appropriate for midrange enclosures that are located separate from the woofer enclosure.

Last, and an often-overlooked option for midrange enclosures, is no enclosure at all, otherwise referred to as unbaffled mounting[2,3]. Probably the most popular example of an unbaffled midrange was the Dahlquist DQ-10 loudspeaker. The benefits include complete freedom from internal box reflections (critical to midrange drivers) and bipolar radiation in the mid-frequency range. You may find it somewhat surprising how low in frequency an unbaffled driver is able to perform.

With a fairly large baffle of one square meter, you can make a mid-woofer type driver operate down to 100Hz, with a 6dB octave rolloff from 100Hz to driver resonance[4]. Since power-handling capacity for this type of configuration is lowered if the driver is operating below 300Hz, you should provide minimal acoustic loading by affixing a small acoustic "blanket" over the rear of the driver. This can be the usual fibrous material or the felt type of acoustic material used in automobiles.

5.30 ENCLOSURE SHAPE AND STANDING WAVES.

Standing-wave modes within a rectangular enclosure can cause amplitude variations in driver respouse. The problem of standing-wave reflections into the driver cone is substantially eliminated by the use of damping materials such as those described in Chapter 1, Section 1.82. This is illustrated by the comparison of a rectangular enclosure with 100% fill aud without enclosure fill shown in *Fig. 5.43*. The respouse with the enclosure filled with sound-absorbing material has substantially less amplitude deviation than the empty enclosure. Because the

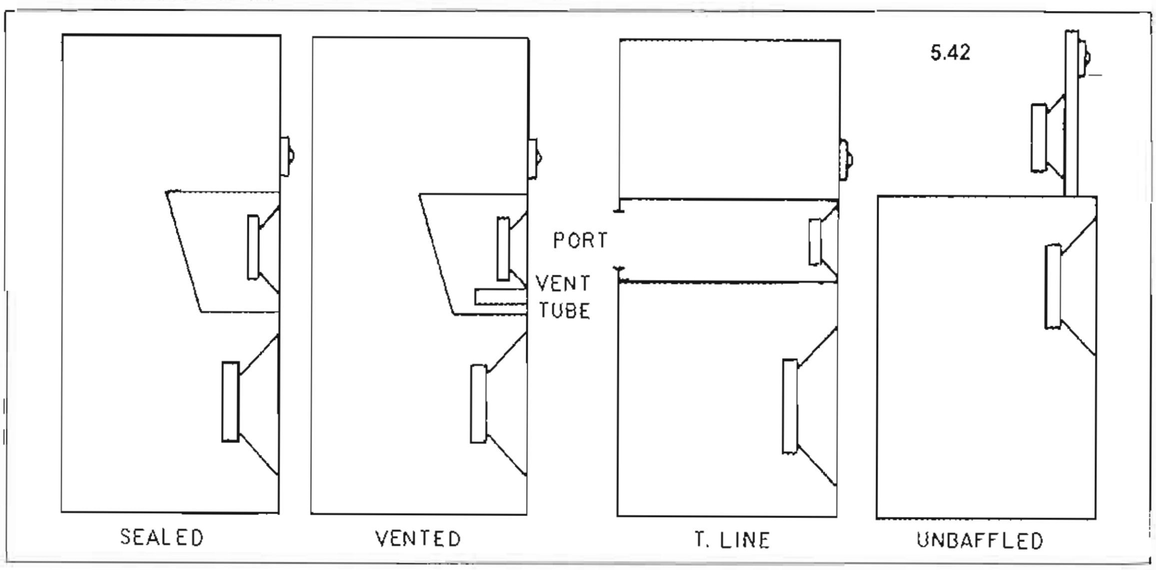
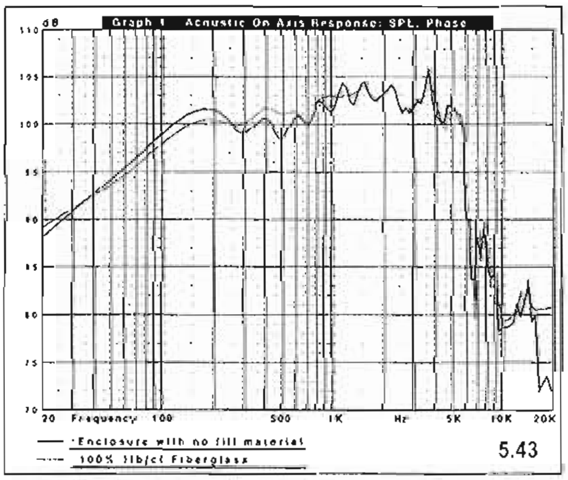


FIGURE 5.42: A variety of midrange enclosures.

inclusion of this type of material is so effective in damping standing-wave modes, any other considerations such as box shape and dimension ratios tend to be secondary. This applies especially to closed box designs which often use 100% fill with damping material. Vented boxes seldom have any greater than 50% fill so are somewhat more affected by box modes.

Standing waves in rectangular speaker enclosures are supposedly minimized by choosing appropriate ratios for box dimensions. These ratios usually coincide with ratios chosen to eliminate standing-wave modes in room environments. The most commonly quoted box dimension ratio is one suggested by Thiele, and also happens to be an artifact from the golden rule of architectural design dating back to the pyramids of Egypt[5]. The ratio of height/width/depth is given as 2.6/1.6/1. Other ratios have been suggested such as 2/1.44/1[6] and 1.59/1.26/1[7], but any improvement attributed to box dimension ratios will be a secondary effect as long as the enclosure is appropriately damped with absorbent material.

These ratios are still a good guideline (given the limitations of driver dimensions and layout) since it precludes making excessively long and narrow enclosures which can be prone to pipe resonances (which can, if necessary, be "broken" up by using internal reflecting baffle panels). Other types of enclosure shapes which have nonparallel sides, such as pentangle-shaped enclosures and enclosures with slanted front baffles, will have different and probably less pronounced standing-wave modes, but the



5.43

attraction is often more cosmetic than pragmatic.

Location of a low-frequency driver on the baffle also affects the severity of standing waves in an untreated enclosure. Locating the driver in the exact center and somewhere just below this point will minimize standing waves across the height and width (but not the depth) of the enclosure, according to one study[8]. The semi-cylindrical and cylindrical enclosure shapes will reduce standing waves across the depth of the enclosure and reduce the pressure response up to about 800Hz. This effect was determined by finite element analysis of unfilled enclosures, but will become less important when absorbent material is included.

In the example in *Fig. 5.41*, the difference between rectangular and cylindrical shapes is minimal even though the enclosures included absolutely no filling material. Rather than diffraction and standing-wave suppression, the real benefit is more cosmetic than anything, although the Cubicon cardboard tube does have good vibration damping qualities when compared to the same thickness of MDF (medium density fiberboard).

5.40 BOX DAMPING.

It is a well-established fact that typical veneered MDF and particleboard loudspeaker boxes resonate in conjunction with the woofer and radiate nearly as much sound pressure as the driver itself at certain frequencies[9]. The primary reason for the success of the Celestion SL-600 speaker (no longer in production) is the honeycomb aircraft aluminum enclosure which eliminates much of the coloration re-transmitted by most wood enclosures. A number of materials and techniques can be used to minimize enclosure vibration. This includes the choice of wall material, wall resonance damping material, bracing technique, driver mounting technique, and enclosure floor-coupling techniques.

A. Wall Materials

There are two basic schools of thought when it comes to choosing wall materials. One is the brute-force technique, which dictates the use of thick-walled high-density materials, such as 1" MDF in conjunction with extensive bracing and sometimes additional wall damping compounds. Speakers like those from Thiel Audio, Wilson Audio, and Aeriel

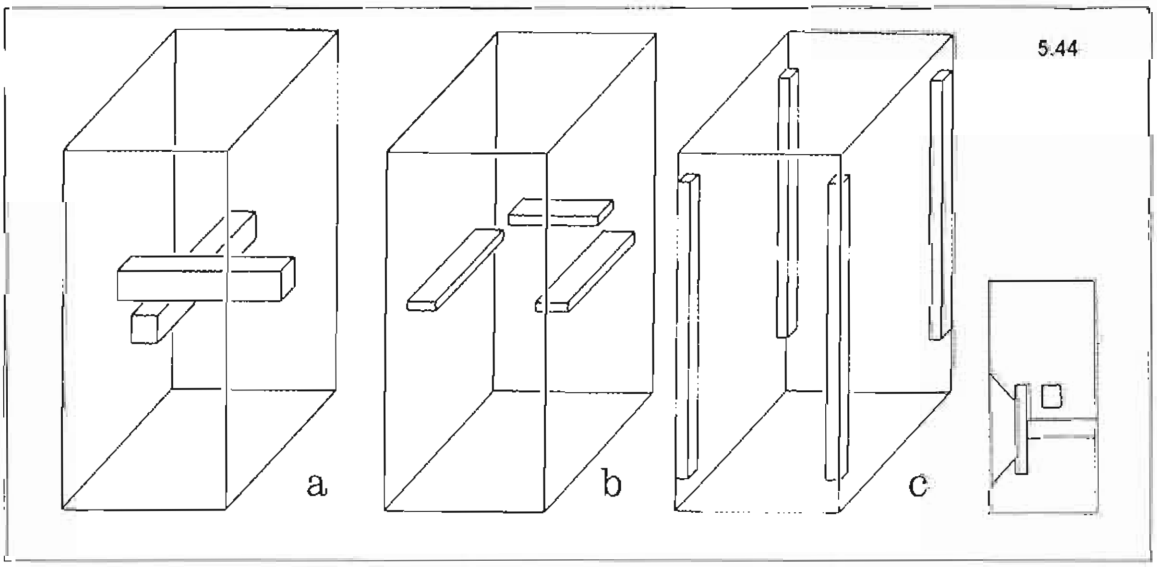


FIGURE 5.44: Cross brace (a), horizontal brace (b), and corner brace (c) for rectangular enclosure.

Acoustics use this type of construction.

Another school suggests the use of moderately stiff and lighter thin-walled material such as ½"–¾" marine plywood with the application of heavy damping materials to achieve low-level coloration in the 100-500Hz region. The Leak Sandwich speaker built in the late 1960s used this type of construction. It was made from ½" plywood and damped with thick layers of roofing felt. Both formats seem to work and examples of both are found in the industry.

Constrained layer materials are another technique. Constrained layer construction board is made of two layers of MDF or similar material with a layer of wall resonance damping material sandwiched in between. This product is highly specialized and not generally available for amateur construction. An interesting alternative was suggested in a 3/89 *Speaker Builder* article[10] consisting of two layers of ¼" veneered plywood with two layers of ½" sheetrock sandwiched between, with each layer bonded with construction adhesive. Another constrained layer example came from a 4/82 *Speaker Builder* article[11], which suggested the use of sand-filled panels for wall material (originally proposed by G.A. Briggs, founder of the British Wharfedale Company).

The relatively poor damping of untreated MDF and the superior characteristics of constrained layer materials was quantitatively analyzed by Nokia engineer Juha Backman in a paper presented at the 101st AES Convention[12]. This study included both accelerometer measurements and nearfield cabinet measurements and clearly showed the superiority of constrained layer damping over extentional (external) damping.

B. Wall Resonance Damping Materials

If panel resonances are raised to a higher frequency, either by the choice of moderately stiff thin-walled material or by bracing, the higher frequency resonances can be damped by means of extensional damping compounds. Examples of these types of materials were discussed in previous issues of *Voice Coil*[13,14] and include two extremely effective products, Antiphon Type A-13 and EAR type CN-12. Antiphon Type A-13 is a bituminous felt/clay composite damping product. It is sold primarily to the automobile industry to damp resonance vibration in the roof panels of cars. It comes in 1⁄16" thick self-adhesive sheets. Two layers of this material applied to 50% or more of a cabinet's wall area is quite effective.

The EAR product is a graphite-filled vinyl product developed by EAR for the US Navy to damp hull vibration in nuclear submarines. It comes in 1⁄16"–¼"-thicknesses and is applied the same way as Antiphon and is likewise very effective. These materials are not as yet available to amateurs, but will likely be in the future. The cost of these products in quantity is from $1.60–$5/ft^2.

Less expensive alternatives are the use of multiple layers (4–6) of 30 lb. roofing felt stapled to the enclosure wall. The walls and inside of the front baffle should be 50–75% covered with the material and stapled in four corners and the center of each panel.

Liquid materials made for car undercoating have been applied in speakers, but the solvent-based products are likely to be hazardous to driver adhesives, surrounds, and cone materials. Another alternative is a 50/50 mix of sand and roofing cement, but the application is tedious and time consuming.

C. Bracing Techniques

Bracing effectively divides the wall into two quasi-independent panels, each having its own resonant frequency. The three basic bracing types are shown in *Fig. 5.44*. They are the horizontal, corner, and the cross-brace. The horizontal brace can be used to break up the enclosure resonance around the girth of the box.

Typical material used is ¾" × 2" lumber, although angle iron has been used in the same application. A variation, used in commercial manufacturing, is the shelf brace[15], which is a combination horizontal and cross-brace. The shelf brace is basically a solid panel which is attached to three or four sides of the enclosure and with large cutouts to allow for air flow within the box (*Fig. 5.45*).

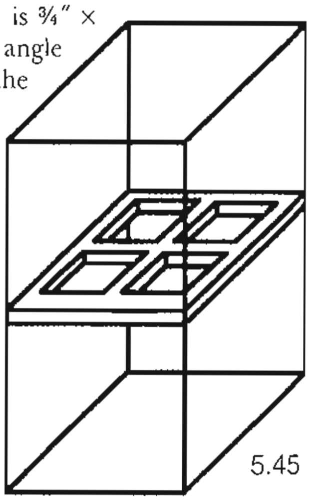


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FIGURE 5.45: Example of shelf brace.

The corner brace increases the mutual coupling of adjacent walls and helps dissipate energy. The

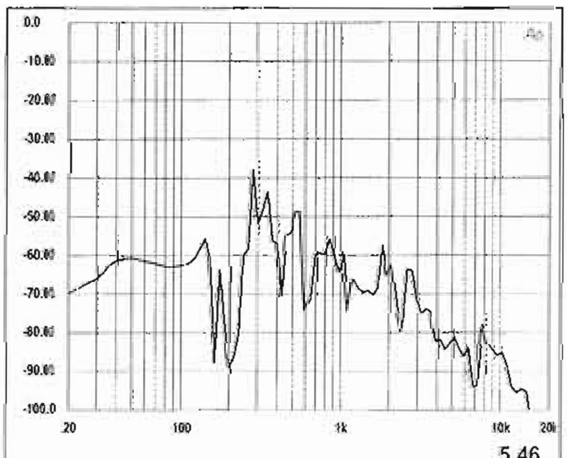

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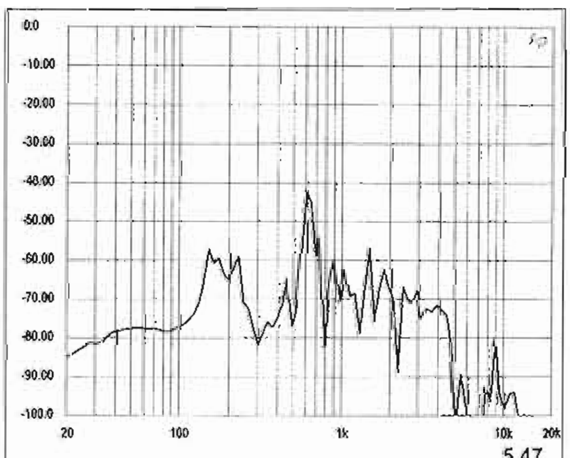
FIGURE 5.46: Accelerometer measurement of untreated 0.75" PB box.



5.47

FIGURE 5.47: Accelerometer measurement of damped and braced 1" MDF box.

cross-brace is used to connect opposite walls, left-to-right and front-to-back. Braces can be 2" × 2" lumber or large diameter dowels (1"–1.5"), which are stiff for the amount of enclosure space they occupy and can be used effectively. Cross-bracing placed in the center of a panel divides the resonance by two; however, staggering the brace so the two panel resonances are at different frequencies prevents their acoustic summation to some extent and spreads out the "noise" at a somewhat lower level[16].

D. Driver Mounting Techniques

Isolating the speaker frame's vibration has also been shown to be useful in lowering cabinet noise. A commercial product, Well-Nut Fasteners (USM Corp., Molly fastener division), works quite well in this technique. Well-Nuts are a rubber insert with a brass nut embedded in the base. This free-floating fastener is often used to damp vibration in electric motors and has the same effect with drivers. Well-Nuts also makes it easy to remove drivers without wearing out screw holes. Small rubber grommets located on the mounting screws or bolts have also been used[17] with some success. This plus an air-tight damping rubber, foam, or putty type gasket will help isolate driver vibration.

Another simple technique is to mount drivers with silicone adhesive. A ¼" bead of silicone placed on the driver mounting flange will provide an air-tight seal as well as a degree of vibration damping. The downside is the difficulty in removing the driver if it has been inset into the cabinet baffle.

E. Enclosure Floor Coupling

Floor-standing enclosures can transmit substantial vibration into the floor which in turn couples to the air. The fad for the last several years has been to use some type of metal spike to physically stabilize the speaker (usually three) to isolate it from the floor. While the spikes may provide some degree of isolation by limiting physical contact, they can be made even more effective by applying additional mass at the base. A new technique seen in the marketplace consists of providing some type of energy "sink" for the enclosure to rest upon. This takes the form of a heavy stone or marble platform which simply does not vibrate in any fashion and cannot transmit vibration to the floor.

A combination of all of these techniques can be quite effective in lowering the coloration caused by a vibrating enclosure. *Figures 5.46* and *5.47* show the results of an accelerometer measurement done on two enclosures, one ¾" particleboard enclosure (*Fig. 5.46*) and one 1" MDF enclosure with dowel cross-bracing and Antiphon Type A-13 extensional damping material (*Fig. 5.47*). The test was done with an Audio Precision System 1 sine wave sweep analyzer using a PVDF (polyvinylidene) accelerometer[18]. The PVDF accelerometer is not a calibrated unit, but the relative difference is apparent. Although the higher frequencies still persist, the level below 150Hz has been substantially attenuated. It is also apparent that some of the resonances have been shifted slightly higher, but not attenuated.

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