6.138, where the attenuation from the foam material extends from 1.8kHz to above 12kHz. The actual subjective differences are discussed in Section 6.50, Subjective Evaluation of Diffraction.

6.50 SUBJECTIVE EVALUATION OF DIFFRACTION.

Virtually all published loudspeaker diffraction information discusses either the mathematics of simulating diffraction[2, 4-9] or measurements of various diffraction scenarios[10]. However, the really important aspect of diffraction is not how it measures with a microphone or simulates in a computer, but how it subjectively affects what you hear. To my knowledge, no one has ever published any kind of controlled listening test to determine how hearable different aspects of cabinet diffraction can be perceived, despite the fact that both amateur and professional loudspeaker designers still spend considerable effort trying to eliminate the deleterious effects of measured diffraction.

Peter Kates concluded at the end of his diffraction paper titled "Loudspeaker Cabinet Diffraction effects"[2] that "reflections can cause frequency response irregularities of up to 4dB, accompanied by group delays of up to 0.5mS. These irregularities contribute to spectral coloration, confuse localization, and increase the apparent source width of the loudspeaker system." To what extent this is true apparently has never been determined in any kind of published subjective study.

Before undertaking this project, I contacted Sean Olive, the manager of the Subjective Evaluation R&D Group at Harman International (JBL, Infinity, Revel, and so on). Mr. Olive works for and with Dr. Floyd Toole, Vice President of the Acoustic Engineering Group at Harman International, and both of them have been working on the science of listening since their work at the NRC (National Research Council) in Canada. Certainly this group, whicb includes Floyd Toole, Sean Olive, and Alan Devantier, has contributed more to the science of subjective listening than any group I know of in the industry. When I asked Mr. Olive whether he was indeed aware of any published works on the subjective evaluation of various diffraction phenomena, be replied, after consulting with Dr. Toole, that neither he nor Floyd was aware of any available published information on the subject, so if there is, it doesn't seem to be showing up on anybody's radar. My apologies ahead of time if we missed someone's work.

As a result of this communication, I decided to design my own informal subjective diffraction study with the goal of eitber confirming or denying the existence of some of the conventional wisdom and wives' tales regarding the sonic effects of diffraction. Before beginning, I would first like to emphasize the informal nature of the following undertaking.

This was not a double-blinded ABX study using a large group of trained and untrained listeners that was followed up with some kind of statistical analysis to reinforce conclusions. Rather, this was just two very experienced loudspeaker industry professionals doing what we have successfully done for a living for a number of years: listen to loudspeakers and describe differences. The two professionals were myself and my business associate and voicing partner, Nancy Weiner, Vice President of Marketing for coNEXTion Systems Inc. (www.conextionsystems.com). Nancy and I together have voiced over 30 products for Atlantic Technology, coNEXTion Systems, and several other well-known loudspeaker manufacturers, all well reviewed by the major industry publications such as *Robb Report Home Entertainment, Home Theater Magazine, Stereophile Home Theater*, and *Sound and Vision*.

Comparative analysis of complete systems is a difficult task and has been well documented in the industry[11-19]. Just placing speakers in a room to compare them can be a daunting task[16,18]. I reported on a unique device for rapid A/B comparison of loudspeakers that was created by Dr. Toole's group at Harman called the "speaker shuffler" in an August 1999 issue of *Voice Coil*[20]. This device, described in detail in AES Preprint 4842[21], was built by a high-tech aerospace company for Harman and effectively could switch a pair of speakers for a listening test in 2–3 seconds while keeping the speakers in the exact acoustic space. This is *very* important, because placing even two speakers next to each other in a test can cause timbre differences due to room modes.

Unfortunately, I really could not justify the $150,000 price tag of having my own "speaker shuffler" built for my office, so I came up with an extremely cost-effective alternative that only cost about $29! *Figure 6.139* shows a picture of my rapid A/B comparison fixture that will keep the speakers you are comparing in the exact same acoustic space and perform this task with an A/B switch time of less than 1 second. All you need are a couple of 24" diameter MDF (Medium Density Fiberboard) platters from Home Depot and an 11" lazy Susan bearing from Ace Hardware, two speaker stands, and a partner willing to rotate the platter while you are listening and switching the amplifier channels.

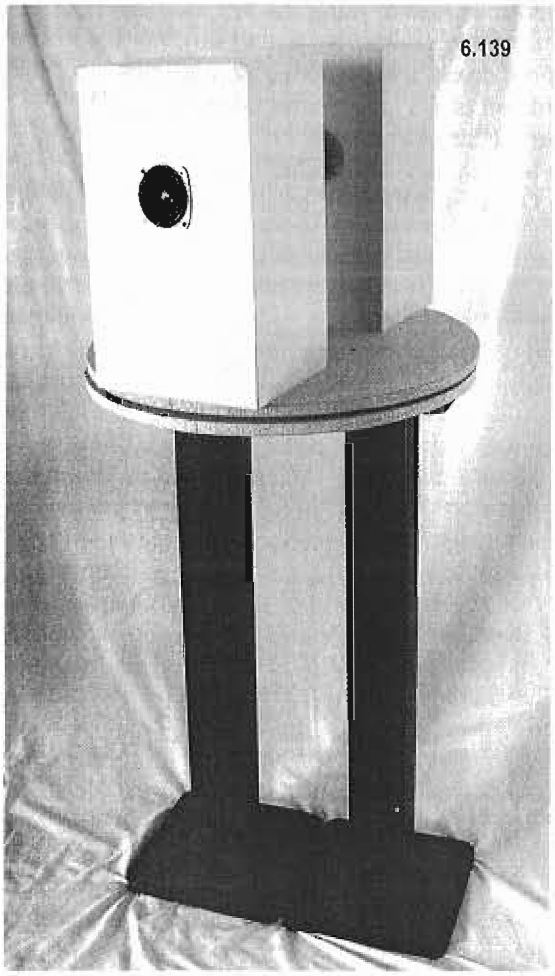
A total of five separate tests were performed to determine the subjective nature of the various aspects of diffraction.

Test #1—Tweeter Inset—the loudspeaker industry has spent probably millions of dollars recessing tweeters and other drivers over the years. The practice undoubtedly began because of measured differences in surface-mounted drivers and inset drivers, but also has probably continued as a cosmetic affectation that goes along with the ever-increasing industrial design aspect of loudspeaker manufacturing.

The test was simple: A/B compare two identical tweeters (Vifa DX25TG05-04 1" soft domes)—one inset flush with the baffle and the other surface mounted. I mounted both tweeters on the front baffle of a 15.75" × 10" × 8" enclosure and centered them 3" down from the top of the baffle. I used the LinearX LMS analyzer to take 2.83V/1m measurements of both examples with the on-axis comparison depicted in *Fig. 6.140* and the 30° off-axis curves shown in *Fig. 6.141* (both curves were of the exact same driver). The on-axis difference is rather substantial, but looking at the 30° off-axis curve comparison in *Fig. 6.141*, it's obvious that this is very much an on-axis phenomenon.

Test #2—Baffle Size—it's a generally accepted fact that smaller baffles sound different than larger baffles, but exactly what subjective characteristics each has should be revealing. For this test, and all the remaining tests for this study, I used a pair of closely matched 3″ full-range woofers (Tang Band model W3-594S). These have a frequency response from about 100Hz to beyond 10kHz, plus the off-axis performance of a relatively small diameter cone. I mounted one of the W3s in the 15.75″ × 10″ × 8″ enclosure baffle, 6″ from the top of the baffle and centered (vertically off-center from the middle of the baffle).

Inside the enclosure was another smaller sealed enclosure, the same volume as the second W3 enclosure. This was done to keep the bottom end response of the two speakers as close as possible. The second and smaller enclosure measured 7″ × 4″ × 4″ and had the W3 mounted 3″ down from the top of the baffle and centered (see *Fig. 6.142* for a photograph



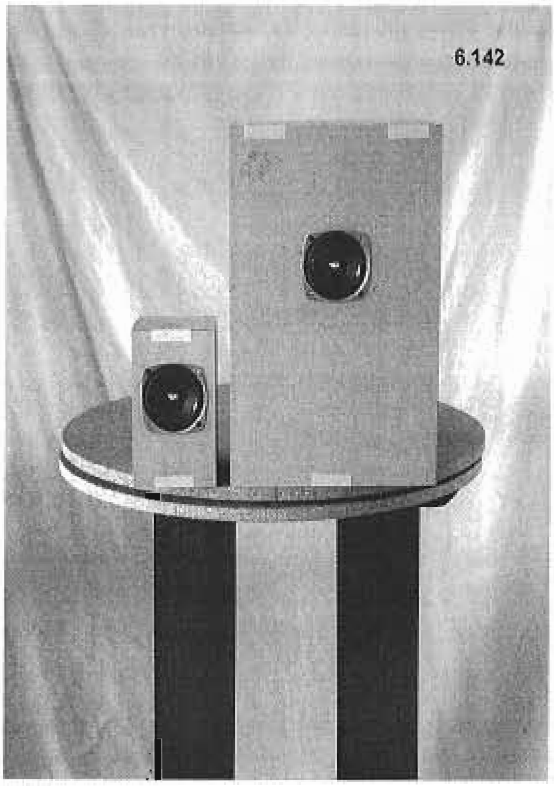


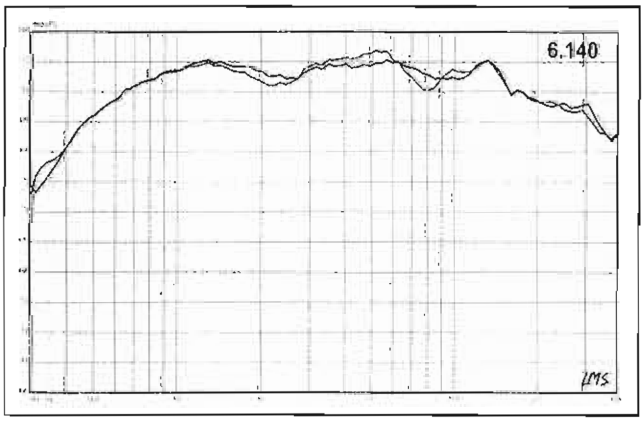
FIGURE 6.139: Picture of the rapid A/B comparison fixture.

FIGURE 6.140: On-axis frequency response comparison of an inset tweeter and a surface mounted tweeter (solid = inset, dash = surface mounted).

FIGURE 6.141: 30° off-axis frequency response comparison of an inset tweeter and a surface mounted tweeter (solid = inset, dash = surface mounted).

FIGURE 6.142: Relative size comparison of baffles used for diffraction subjective Test #2.

FIGURE 6.143: Test #2 on-axis frequency response comparison of driver mounted on small baffle and driver mounted on larger baffle (solid = larger baffle, dash = small).



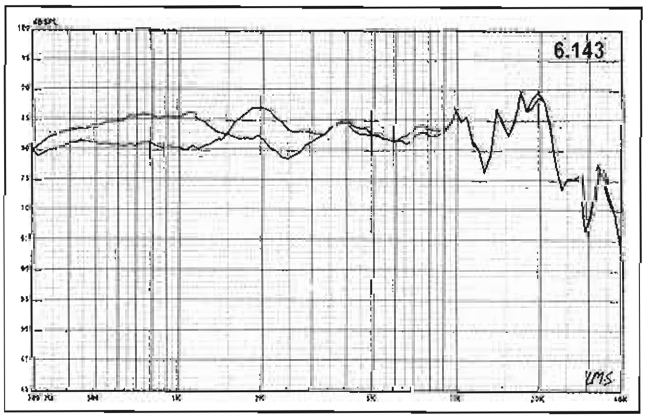
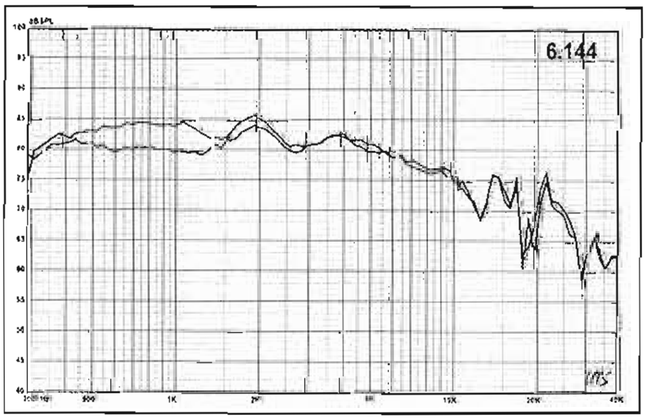


FIGURE 6.144: Test #2 30° off-axis frequency response comparison of driver mounted on small baffle and driver mounted on larger baffle (solid = larger baffle, dash = small).

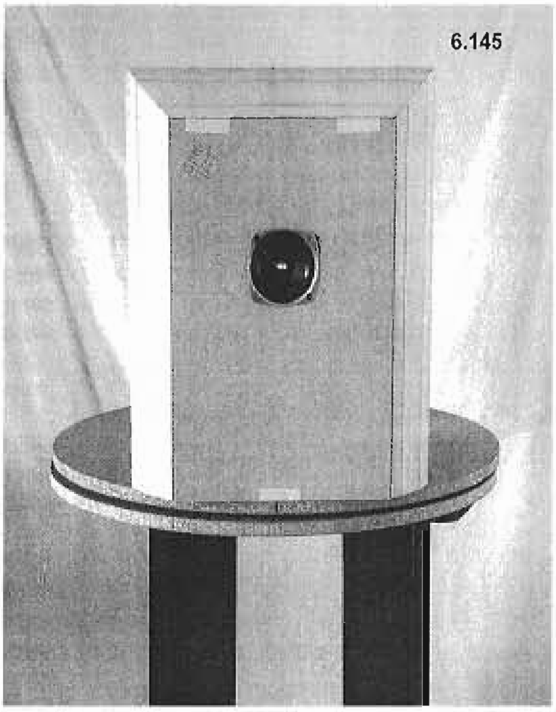


of both enclosures placed side by side with the drivers mounted).

Both small enclosures had 100% fill material, which in this case happened to be Acousta-Stuf, which is a good wide-range damping material for enclosure volumes. The W3s were A/B compared with the same driver height above the platter so that the perceived image location would be identical. Objective 2.83V/1m measurements of the 3" driver on the different size baffle are shown in *Fig. 6.143* for the on-axis response and *6.144* for the 30° off-axis response (both curves were of the exact same driver). The differences in this case were strong both on- and off-axis.

Test #3—Baffle Shape—Over the years manufacturers and amateur builders alike have produced cabinets designed to defeat edge diffraction with bevels anywhere from ¾" roundovers to large 3–6" straight, compound, and curved bevel shapes. Obviously, such exotic additions to plain rectangular enclosures are both time-consuming and expensive, although sometimes from an industrial design aspect, very attractive cosmetically. This test compared the standard 15.75" × 10" × 8" sharp-edged rectangular enclosure using the W3 driver in the same mounting position as Test #2 with the same enclosure, driver, and mounting position but with the addition of a 3" compound bevel (2" at a 45° angle and 1" at a 60° angle).

The bevel-modified enclosure is depicted in *Fig. 6.145*. Objective 2.83V/1m measurements on-axis



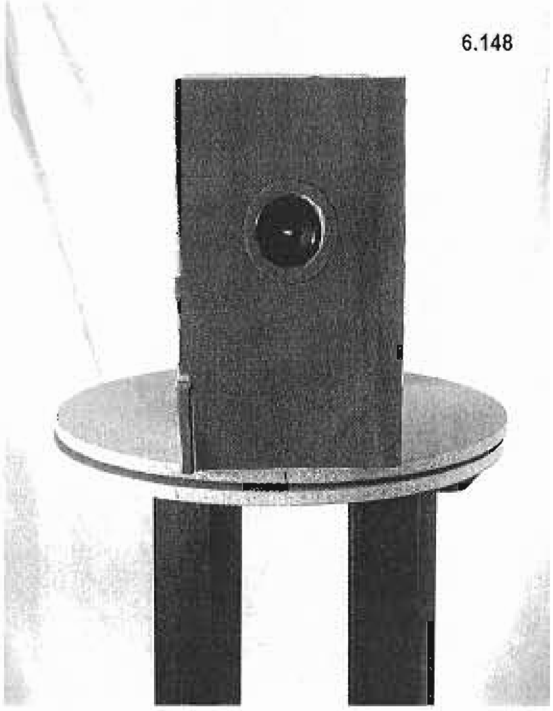
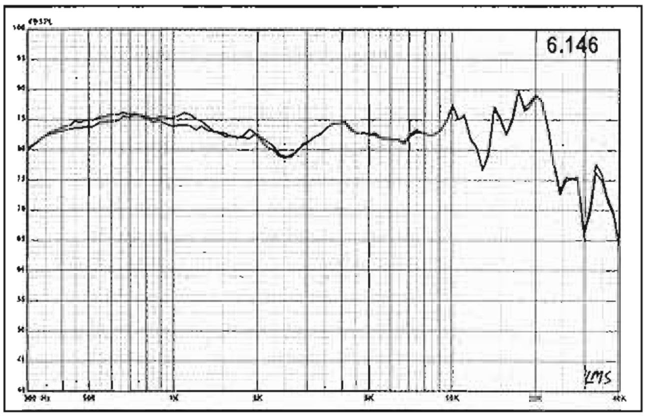


FIGURE 6.145: Picture of the compound beveled edge baffle for diffraction subjective Test #3.

FIGURE 6.146: Test #3 on-axis frequency response comparison of a compound beveled baffle and plain sharp edged baffle solid = plain baffle, dash = compound beveled baffle).

FIGURE 6.147: Test #3 30° off-axis frequency response comparison of a compound beveled baffle and plain sharp edged affle (solid = plain baffle, dash = compound beveled baffle).

FIGURE 6.148: Picture of)amed damped baffle for diffraction subjective Test #4.



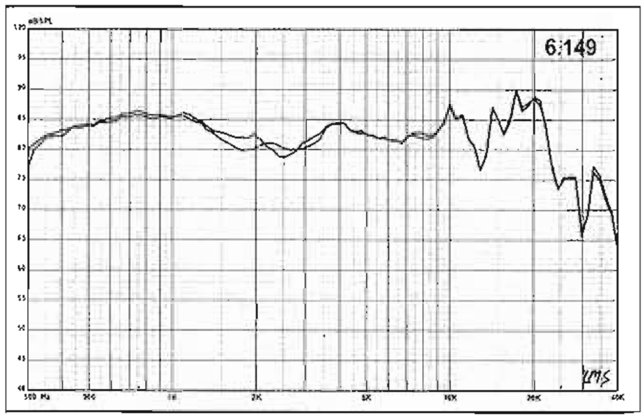
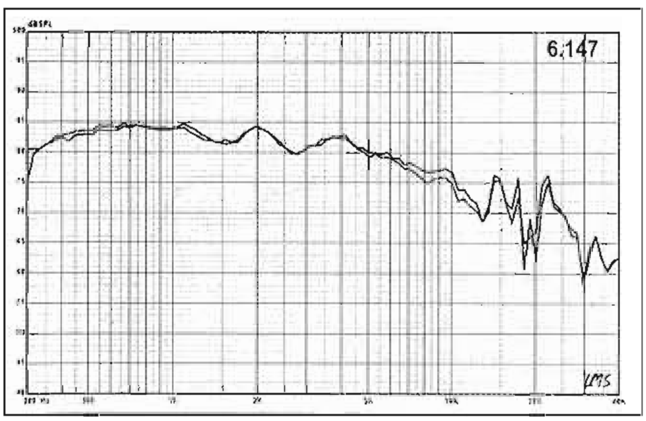


FIGURE 6.149: Test #4 on-axis frequency response comparison of an undamped baffle and foam damped baffle (solid = plain baffle, dash = foam damped baffle).



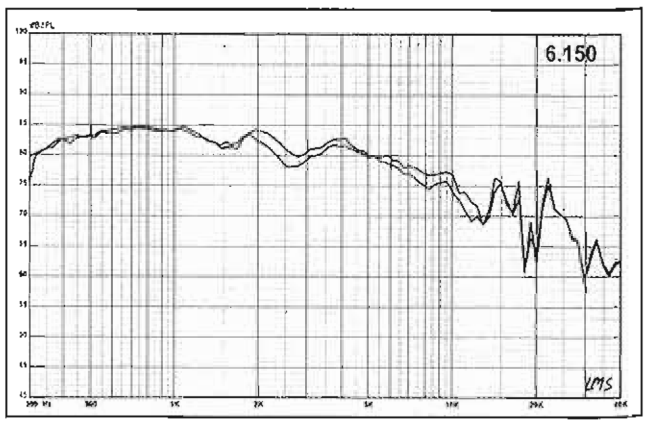


FIGURE 6.150: Test #4 30° off-axis frequency response comparison of an undamped baffle and foam damped baffle (solid = plain baffle, dash = foam damped baffle).

comparing the straight rectangular baffle with the compound beveled baffle are illustrated in *Fig. 6.146* with the 30° off-axis comparison shown in *Fig. 6.147* (both curves were of the exact same driver). Differences on-axis are primarily below 2.5kHz on-axis and extend to above 10kHz at 30° off-axis.

Test #4—Damped Baffle—the measurable effect of a damped baffle was discussed in Section 6.40, so this test was to confirm the subjective consequence of a foam-damped baffle. The test involved the same two enclosures, W3 drivers, and mounting positions as in Test # 3, but one baffle was 100% covered with the ¼" Soundcoat acoustic damping foam (*Fig. 6.148*). Objective 2.83V/1m measurements of the baffle with the foam and without the foam blanket are given in *Fig. 6.149* for the on-axis response, and *Fig. 6.150* for the 30° off-axis response (all curves produced with the exact same driver). Differences on-axis again are mostly below about 3kHz and extend to above 10kHz at 30° off-axis.

Test #5—Driver Baffle Location—The discussion and simulations in Section 6.10A and B were aimed at revealing measured SPL differences that occur when the same driver is located in different areas on a standard rectangular baffle. This listening test was designed to reveal the subjective differences that can be perceived from moving a driver to different locations on a baffle. Four locations were used—the middle and top of the baffle along the vertical centerline, and the same locations moved to the far right side of the baffle (*Fig. 6.151*). Objective 2.83V/1m measurements were made of the various baffle locations with the W3 full-range and are shown in *Fig. 6.152* for the on-axis response, and *6.153* for the 30° off-axis response. The SPL variations ranged up to 4dB, and were apparent on-axis out to about 3kHz and out to above 10kHz off-axis.

Testing required that the rapid A/B fixture be located 6′ from the nearest walls in a large 20 × 30 carpeted room with a vaulted ceiling, and oriented diagonally rather than parallel with the wall structures. Nancy and I took turns listening to each comparative test and used a simple 1–3 scale to evaluate the differences (note: this test was aimed only at establishing a level of perceptual difference between the two choices and not a preference). A score of 1 indicated that there was no discernible difference between the two choices. A score of 2 meant that the change was detectable, but not significant enough to matter. The highest score, 3, meant that the difference was both discernible and significant.

At the end of each test using the rapid A/B device, we then placed the two test speakers side by side and A/B-compared the two speakers a few times in this orientation and then reversed positions and repeated the procedure. It is interesting to note that with the really large amount of comparative listening and voicing we have done together using two samples in mono placed side by side in the same location as just described, we both found the high-speed A/B device to be very useful, but almost too slow. Acoustic memory is so brief that instantaneous comparison is almost a requirement to differentiate between two sonic choices. The 0.5–1 second delay that it took to rotate the speakers into place was barely fast enough for either of us to feel totally comfortable, which is the reason we did the side-by-side comparison at the end of each test. However, at the end of each separate test, we also took the time to discuss what we each had heard and summarized these details.

The results were very interesting, but not unexpected.

Test #1—neither of us was able to distinguish any difference between the inset or the surface-mounted tweeter dome. Given the highly directional nature of the objective measurements, it is not surprising that this was the result. It is possible that the result could be different with a multi-way speaker with the woofer frames surface-mounted or recessed, but I tend to

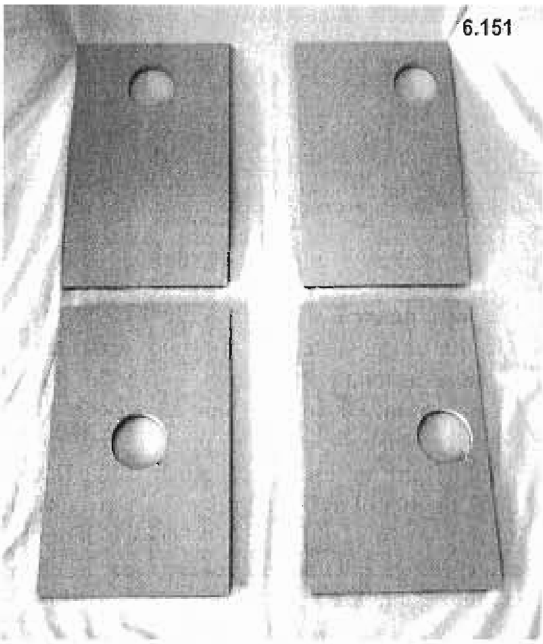


FIGURE 6.151: Baffle locations for subjective diffraction Test #5.

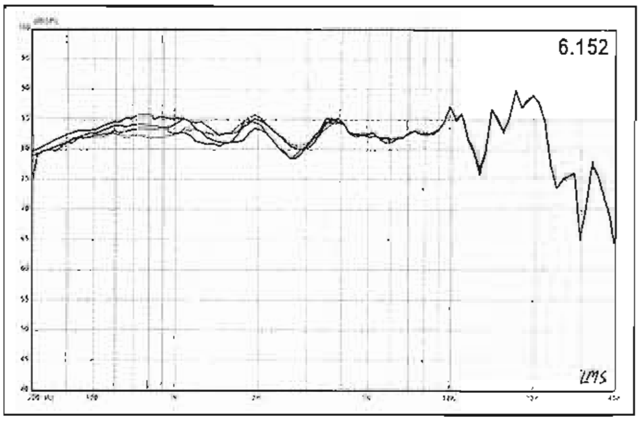


FIGURE 6.152: Test #5 on-axis frequency response comparison of different baffle locations (solid = center location, dot = top offset location, dash = top center location, dash/dot/dot = center offset location).

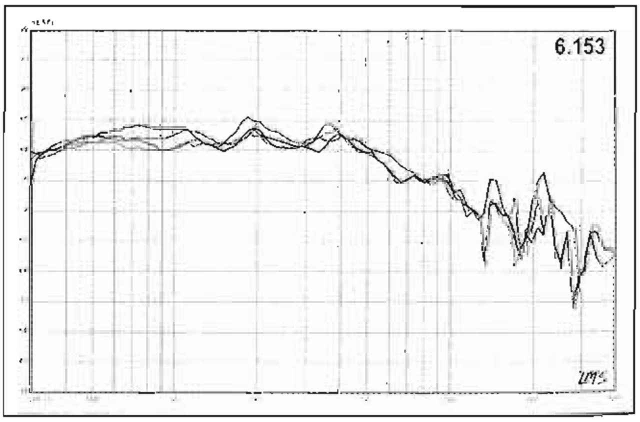


FIGURE 6.153: Test #5 30° off-axis frequency response comparison of different baffle locations (solid = center location, dot = top offset location, dash = top center location, dash/dot/dot = center offset location).

doubt it. The primary reason for recessing drivers would seem to be more cosmetic than acoustic.

Test #2—the large vs. small baffle test received a 3 from both of us: definitely discernible and significant. We both believe the larger baffle had more warmth, but definitely less detail and tending toward "muddy." The small baffle speaker had less "warmth," probably because there is less low-frequency reinforcement and low-frequency (approximately 50–200Hz) emphasis. We both believe that there was a significant impression of increased detail with the small baffle. It's no secret that small baffles have much more pinpoint imaging in stereo than larger baffles, but the increased detail is certainly a function of less reflection and delay, which are consequences of a comparatively small baffle area.

Test #3—the results of comparing a sharp edge baffle to a large beveled edge baffle was somewhat unexpected. We both rated it a 3, definitely detectable and significant, but neither of us believe it was so much an improvement as just a difference. The sharp edge, often criticized for all the diffraction it produces, actually seemed more "live." Nancy described it as having more "room tone" from the recording.

We also noticed that the large beveled edge made the image (listening in mono) seem larger and more spacious, but again somewhat dulled by comparison. Obviously, there have been many extremely well-reviewed and popular loudspeakers built from the lowly rectangular cabinet, and, frankly, neither of us thought that this was a serious handicap. As far as the large bevel goes, it definitely changes things, but for better or for worse I think is a matter of opinion.

Test #4—since I have used damped baffle configurations on numerous occasions over these years in my design work, I pretty much expected the results of this test. We both gave this a resounding score of 3, definitely discernible and very significant. The foamed damped baffle really made the driver sound smoother, less edgy, and increased the sense of detail in the music. Nancy noted it seemed to bring out the midrange more. Her perception was likely due to less high-frequency delayed reflection, and the decreased high-frequency "hash" would have the effect of making the midrange seem more pronounced.

Test #5—four A/B comparisons in terms of baffle placement were done for this test as follows:

a. top center compared to middle center
b. middle center compared to top right
c. middle center compared to middle right
d. top center compared to top right

Mounting location comparison (a) rated a score of 3 from both of us, definitely detectable and significant. The center baffle position had more perceived "warmth," but the top position had a more "open and airy" quality, undoubtedly caused by the asymmetrical vertical polar response and the slight upward tilt of the polar pattern. Mounting location comparison (b) rated a 3 as well, but seemed less prominent an effect than (a). Comparisons (c) and (d) both rated a 2, were discernible, but did not impress either Nancy or me as being very significant.

Diffraction has always seemed to me as being touted as more of a "boogie man" than reality would indicate. I have frequently commented when asked about the importance of diffraction that "the diffraction caused by cabinet edges and baffle protrusions is probably at least as hearable as the diffraction caused by the vase your wife or girlfriend put on top of your speaker, which is to say, not at all." While this may not be far from true, the benefit from damping a front baffle is still a very real and important tool for increasing the quality of the subjective listening experience, but at the same time does not mean the undamped baffles are so objectionable as to be unusable. Ultimately, it is an eclectic combination of driver timbre, driver placement, sharp or beveled edges, different baffle areas, crossover and enclosure low-frequency design, the degree of baffle damping and the room interface that describe the subjective experience.

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