Mr. Pablapa

LOUDSPEAKER BAFFLES: DRIVER LOCATION, SEPARATION, AND OTHER CONSIDERATIONS

6.10 SPL VARIATION DUE TO DRIVER BAFFLE LOCATION.

Loudspeaker front baffles provide a "launch" area for the wave front developed by a transducer. As was discussed in Chapter 5, enclosure (baffle) shape—be it rectangular, cylindrical, spherical, square, egg-shaped, etc.—can cause substantial variation in the measured SPL of the driver. In Section 5.10B, the effect of different locations was also discussed, but only from a limited perspective of the difference from the center of a baffle to the top of a baffle. The reality is that as woofers, midranges, and tweeters are mounted in different physical locations on a baffle, and as the distance from each baffle edge changes, the on- and off-axis SPL will be very different for each discrete location.

Where to locate a set of drivers on a new design has always been an unanswered question for speaker designers. Most manufacturers opt for the drivers centered on the baffle between the left and right sides of the speaker and usually build the array starting with the tweeter at the top of the baffle (or a woofer at the top if it's a woofer-tweeter-woofer design). Variations have been numerous and include such concepts as mirror-imaged drivers in which the tweeters are located close to the left for one channel of a stereo pair and on the right side of the cabinet for the other channel. Because this is such an open question to be answered when designing a loudspeaker, what is needed is a comprehensive set of examples that will give you some idea of what to expect when selecting a mounting location for a woofer, midrange, or tweeter. Using the virtual anechoic chamber provided in the LEAP 5 EnclosureShop software, I conducted an extensive study describing the consequence of the various possible mounting locations on different-size baffles. This is intended to serve as a guideline for this part of the loudspeaker design process.

This study of SPL variation vs. driver location is broken down into two parts: two-way loudspeaker SPL variations due to different driver mounting locations, and three-way midrange SPL variations due to different driver locations. Because the majority of loudspeakers built both by manufacturers and by amateur builders are standard rectangular types, and because trying to do baffle location variations for all the different possible enclosure shapes would be too exhaustive for the scope of this book, I consider only rectangular baffles.

A. Two-Way Baffle Woofer and Tweeter Location SPL Variation.

Because baffle size and driver diameter both affect the diffraction that causes SPL changes, this study includes four different baffle sizes and four different woofer diameters. The enclosures were modeled after enclosure volumes and dimensions of loudspeakers that were in production in 2005:

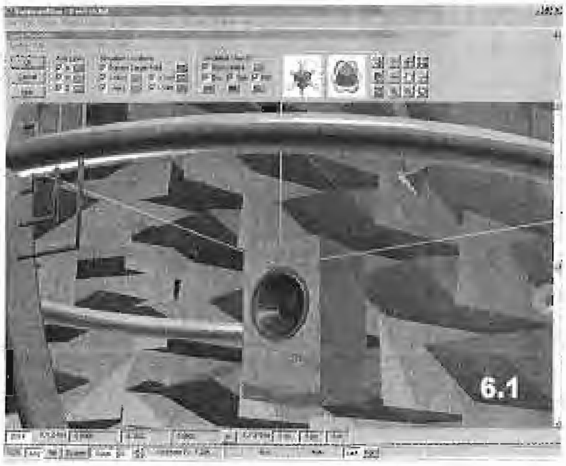
Woofer Diameter	Enclosure Dimensions (H × W × D)	Simulated Woofer
4.5″	8.75″ × 5.25″ × 5.5″	Peerless 830516
5.25″	10.75″ × 7.25″ × 8.5″	Vifa C13WG-19-08
6.5″	13.5″ × 8.75″ × 11.25″	Vifa P17WJ-00-08
8″	15.75″ × 10″ × 10.5″	Vifa P21WO-10-08

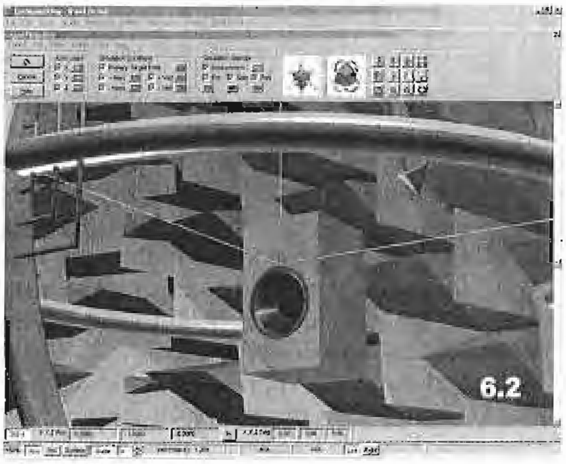
While the LEAP 5 EnclosureShop simulations are very good, they could not simulate the SPL anomalies that often occur in a tweeter's response and are caused by the reflections in a woofer or midrange cone. While there was no way to simulate this response affectation, if you care to know whether or not a particular response anomaly in a tweeter measurement is being caused by a reflection out of a woofer or midrange cone, cover the cone with a thin flat piece of cardboard and repeat the measurement. The question will be answered in the comparison.

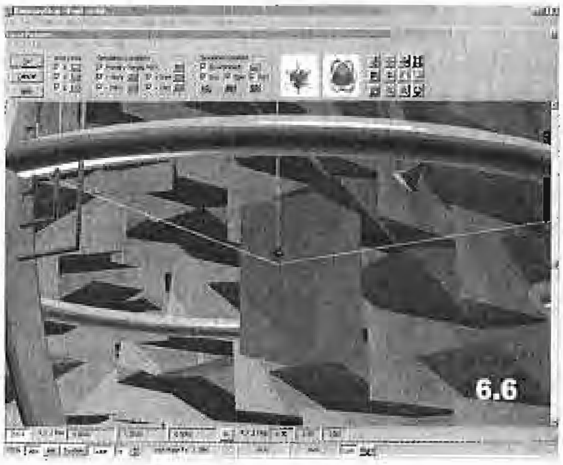
Because there are an infinite number of discrete baffle locations for any transducer, for the purposes of this study, I used just three different locations for the woofer and eight for the tweeter. These are pictured for the 8″ enclosure woofer SPL simulations in *Figs. 6.1–6.3* and for the 8″ enclosure tweeter SPL simulations in *Figs. 6.4–6.11*. These driver locations were relatively identical for all four different woofer and enclosure sizes.

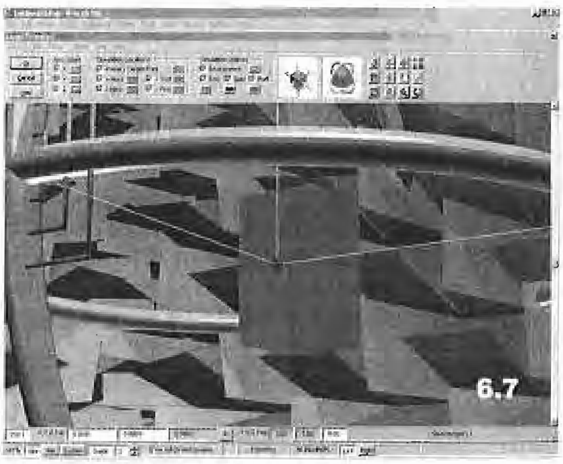
I determined the exact locations with both the woofer and tweeter mounted as close together as possible on the baffle and with the measurement axis placed between the two mounting positions. The three positions for the woofer are with the two drivers located such that the tweeter was at the top of the enclosure with enough clearance for a grille frame, with the two drivers located at the midpoint between the top and the bottom of the enclosure; the last position was with the woofer located at the bottom of the enclosure, again with enough practical clearance for a grille frame. Because contemporary rectangular cabinets tend to be just wide enough for the woofer and grille frame, there is no excess baffle space to study the left or right offset of a woofer, so this consideration is not part of this presentation. However, because tweeters can easily be offset to the left or right side of the enclosure, more variations can be considered.

If you look at the tweeter baffle locations in *Figs. 6.4–6.11*, you can see that this includes the same three locations as the woofer (the tweeter mounted just above the woofer with minimal spacing between the two drivers) down the center of the baffle, plus the same three locations with the tweeter offset to the far right, as far as possible while still maintaining some clearance for a grille. Also included is a tweeter mounting location for a WTW (woofer-tweeter-woofer) format with the tweeter located in the exact middle of the baffle plus the same center/middle position offset to the right. In this case of the WTW tweeter location, there is not sufficient room on the baffle for dual woofers, but you could easily use this baffle size for a dual woofer design by using the next smaller size woofers (dual 6.5″ on the 8″ baffle, dual 5.25″ on the 6.5″ baffle,









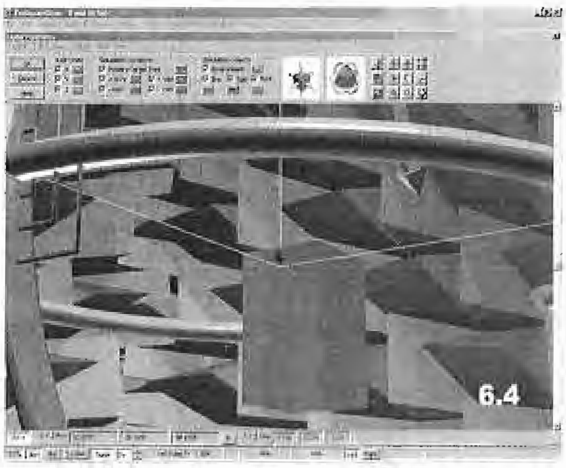


FIGURE 6.1: 8″ woofer top baffle location.

FIGURE 6.2: 8″ woofer mid baffle location.

FIGURE 6.3: 8″ woofer bottom baffle location.

FIGURE 6.4: 1″ tweeter top center baffle location.

FIGURE 6.5: 1″ tweeter mid center baffle location.

FIGURE 6.6: 1″ tweeter bottom center baffle location.

FIGURE 6.7: 1″ tweeter WTW center baffle location.

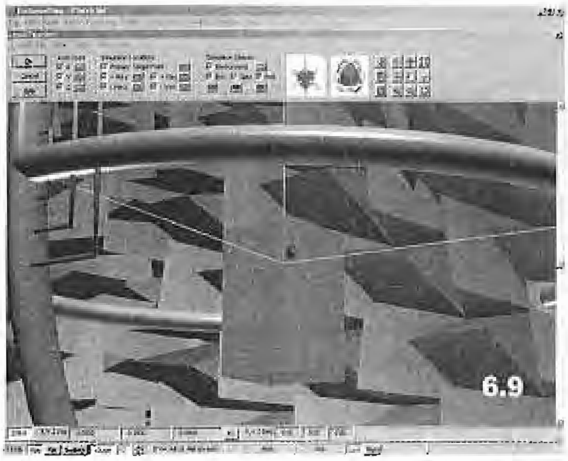
FIGURE 6.8: 1″ tweeter top offset baffle location.

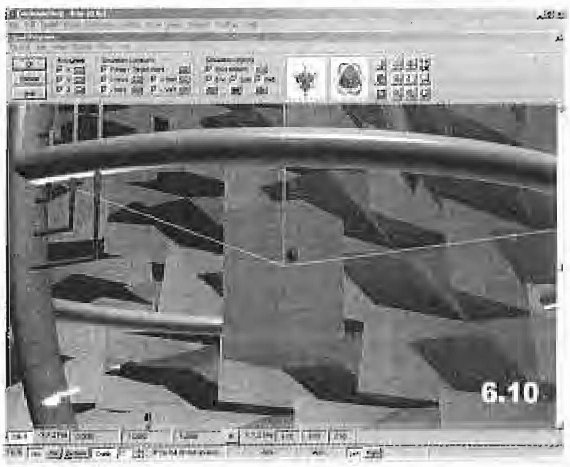
dual 4.5″ on the 5.25″ baffle, and dual 3″ on the 4.5″ baffle). For this reason, I included the middle tweeter position to provide tweeter data for possible dual woofer formats, albeit with a somewhat wider than normal baffle for that format.

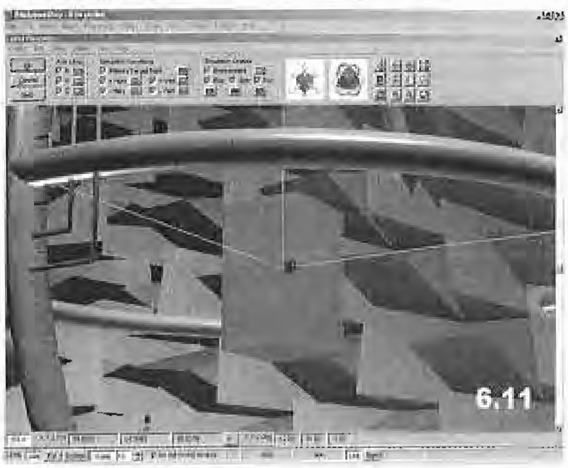
In order to fully understand what edge diffraction does to the driver response when measured with a microphone, you need to look at both the on-axis response as well as the horizontal and vertical polar responses. That said, the basic format for this diffraction study includes the following graphic information for each combination of baffle size and driver locations:

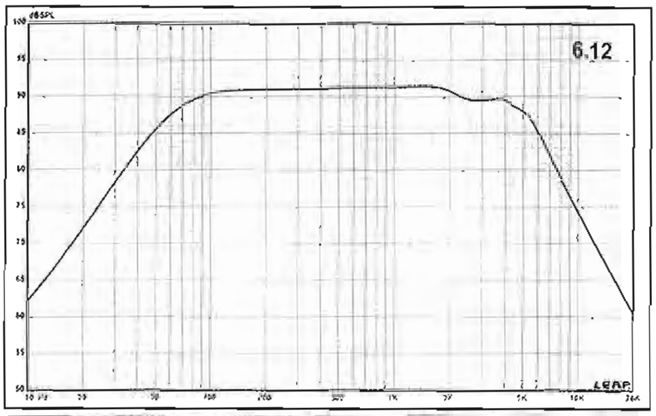
1. as a reference, the on-axis half-space response graph plus the half-space horizontal and vertical polar plots
2. a composite graph that compares the different anechoic on-axis response curves—one for the three woofer locations, one graph for four tweeter locations placed on the baffle centerline, and one graph for the four tweeter locations placed on the right side baffle location
3. individual on-axis and horizontal and vertical polar plots for each baffle location.

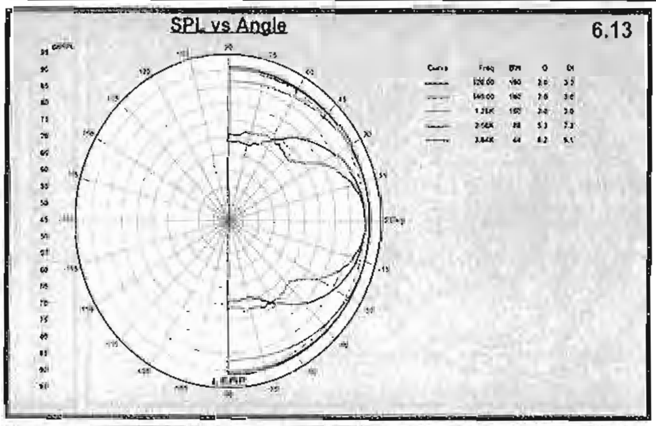
Given the number of baffle locations and enclosure examples, the number of graphs and plots required totals 168. Because the space required for this on the printed page is somewhat excessive (we are trying to keep this volume substantially smaller than Tolstoy's *War and Peace*!), you will find a mail-in coupon for receiving the data on CD-ROM that contains the complete graphic set for this entire diffraction study in full-color PDF format, along with some other useful information. While there are sim-

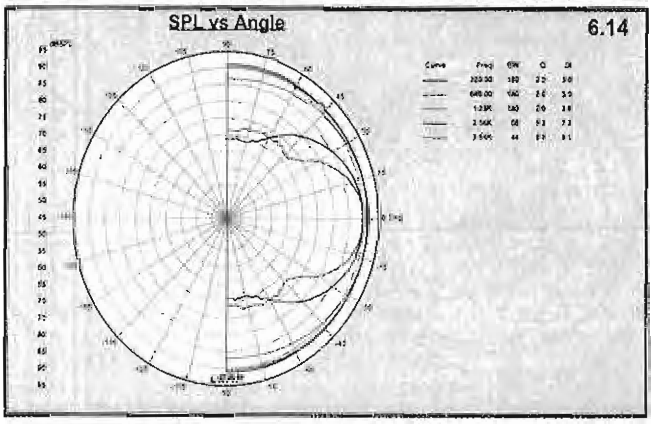












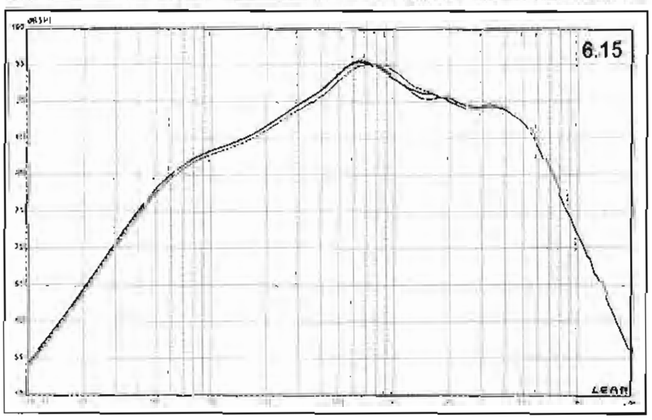


FIGURE 6.9: 1″ tweeter mid offset baffle location.

FIGURE 6.10: 1″ tweeter bottom offset baffle location.

FIGURE 6.11: 1″ tweeter WTW offset baffle location.

FIGURE 6.12: Frequency response of 8″ woofer mounted on an infinite baffle.

FIGURE 6.13: Horizontal polar plot for *Fig. 6.12* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.14: Vertical polar plot for *Fig. 6.12* (320Hz = solid, 640Hz = dash, 1.28kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.15: Comparison of 8″ woofer frequency response for all three center baffle locations (top = solid, mid = dash, bottom = dot).

ilarities in the effects of baffle location between the different enclosure sizes, the differences are much greater than you might expect, so as an exercise in overall understanding, you will find it very worthwhile to examine all the graphs and conclusions for each size enclosure. You will also find the polar plots much easier to read in color. That aside, data on the 8″ enclosure is provided in *Figs. 6.12–6.24* for the woofer locations and *Figs. 6.25-6.53* for the tweeter locations.

For the 8″ woofer example, start by examining *Figs. 6.12–6.14*. This is the half-space response of the woofer (mounted on an infinitely large baffle) on-axis and horizontal and vertical polar plots. As you can see, the response is mostly flat with a 2dB decrease in SPL in the octave from 2–4kHz, and the polar plots are identical and perfectly symmetrical. These plots are the result of having no edge diffraction or frequency-dependent-shaped baffle reflection to affect the single point microphone measurement.

The on-axis comparison graph of all three 8″ woofer baffle locations on the 15.75″ × 10″ baffle in *Fig. 6.15* shows the absolute SPL differences on-axis to be within a 1–1.5dB range. In terms of affecting the crossover from 2kHz and higher, the differenc-

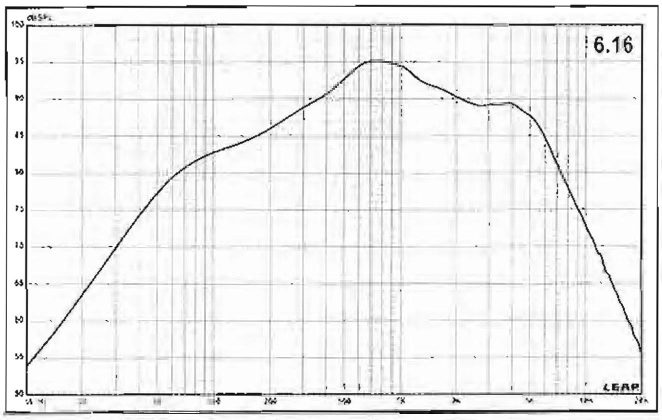


FIGURE 6.16: Frequency response for 8″ woofer at bottom baffle location.

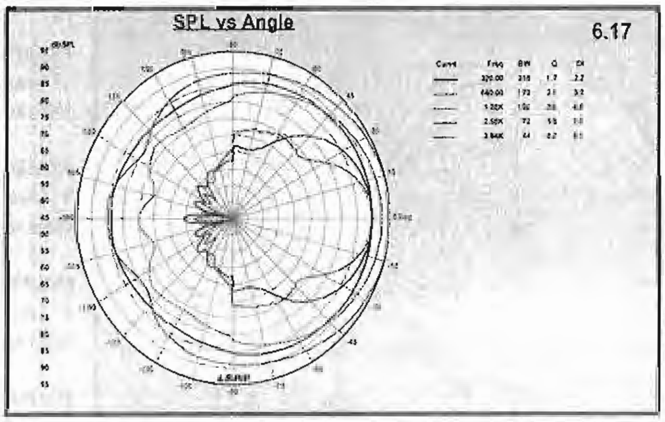


FIGURE 6.17: Horizontal polar plot for *Fig. 6.16* (320Hz = solid, 640Hz = dash, 1.28kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

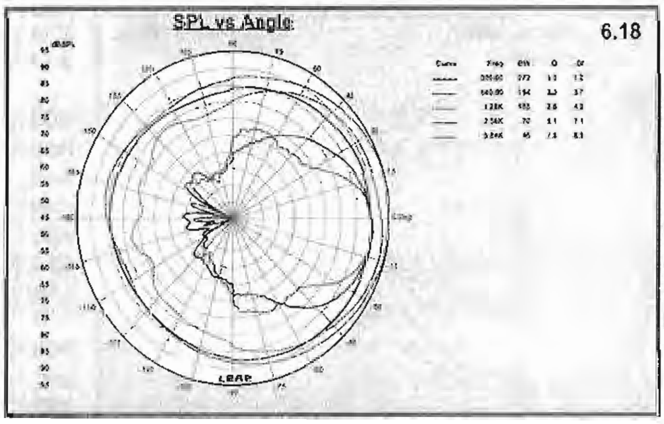


FIGURE 6.18: Vertical polar plot for *Fig. 6.16* (320Hz = solid, 640Hz = dash, 1.28kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.19: Frequency response for 8″ woofer at mid baffle location.

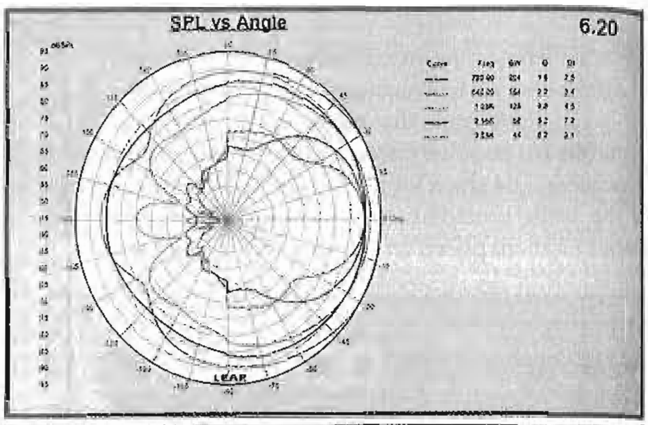


FIGURE 6.20: Horizontal polar plot for *Fig. 6.19* (320Hz = solid, 640Hz = dash, 1.28kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

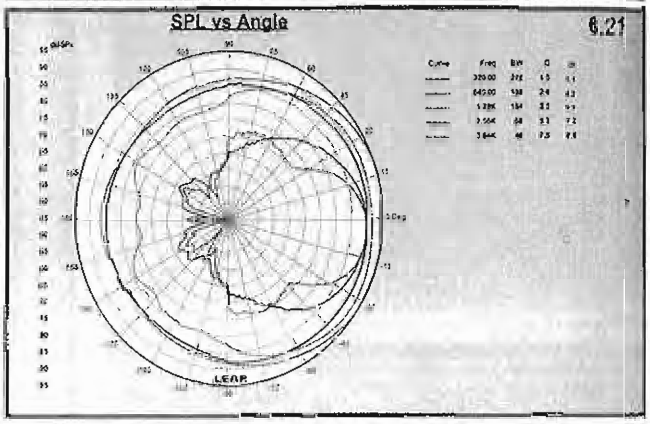


FIGURE 6.21: Vertical polar plot for *Fig. 6.19* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

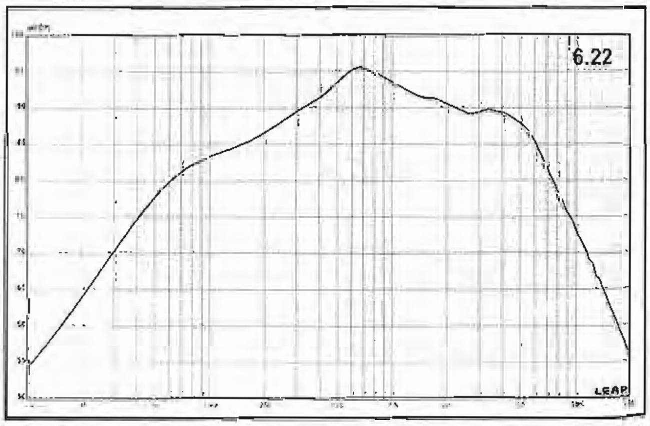


FIGURE 6.22: Frequency response for 8″ woofer at top baffle location.

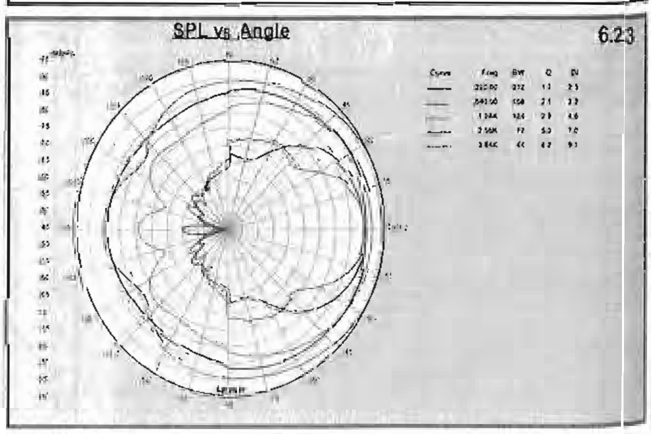


FIGURE 6.23: Horizontal polar plot for *Fig. 6.22* (320Hz = solid, 640Hz = dash, 1.28kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

es are not particularly significant. In terms of the horizontal polar plots (*Figs. 6.17, 6.20,* and *6.23*), any position on the baffle provides a symmetrical pattern, which means no "lobing" to one side or the other in the horizontal plane, so this is not an issue. Incidentally, the 8″ enclosure data is repeated on the CD-ROM and is much easier to read in color on a computer screen than the black and white graphic rendering on these pages. Baffle position does affect, however, the vertical polar response (*Figs. 6.18, 6.21,* and *6.24*) and causes some degree of frequency dependent lobing for each location.

As a generalization, frequencies above 3kHz, which ideally will be in the stopband of the low-pass filter section of a two-way crossover, are affected about the same for all three locations, which happens to be a downward tilt of about 6°. For the frequencies below 3kHz, the bottom position causes a 15° upward tilt, the middle position has some unevenness—but primarily does not cause any significant tilt (lobing)—and the top position causes a 15° downward tilt.

If you consider that non-coincident driver mounting of the tweeter above the woofer (both woofer and tweeter mounted on the baffle surface and the baffle oriented perpendicular to the floor and

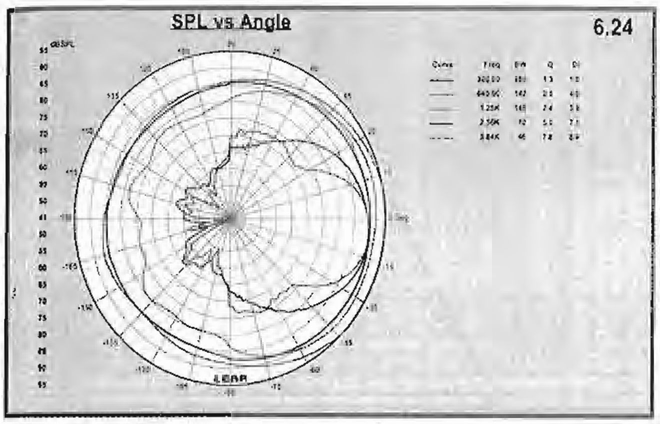
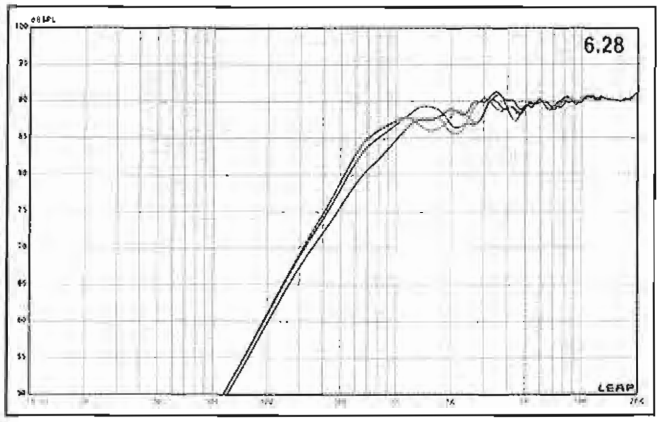


FIGURE 6.24: Vertical polar plot for *Fig. 6.22* (320Hz = solid, 640Hz = dash, 1.28kHz = dot, 2.56kHz = solid, 3.84kHz = dash).



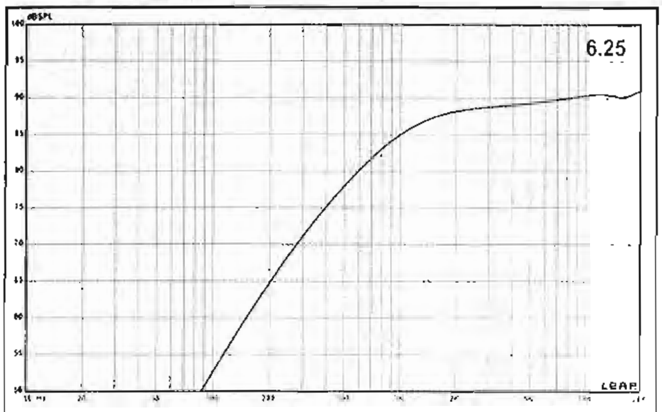
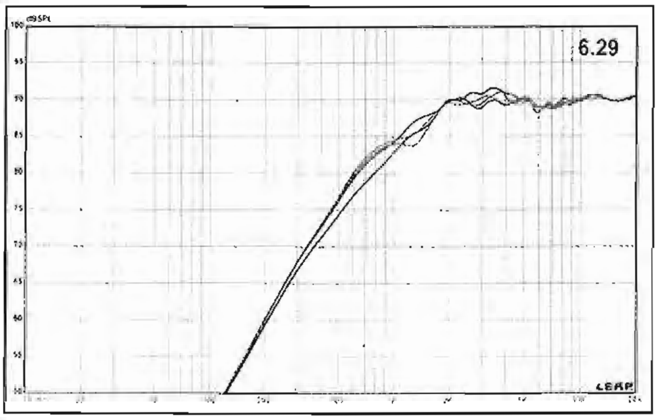


FIGURE 6.25: Frequency response of 1″ tweeter mounted on an infinite baffle.



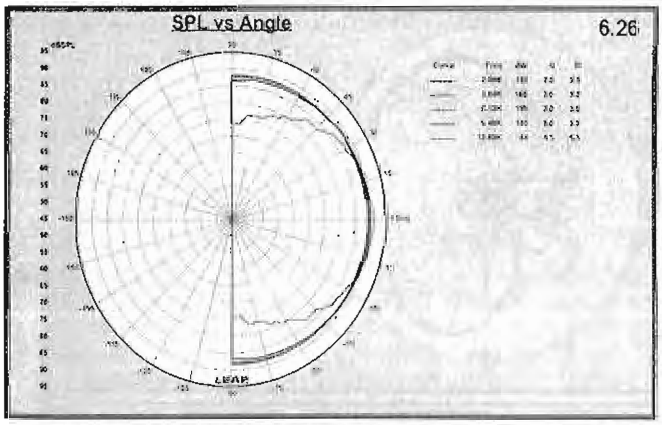
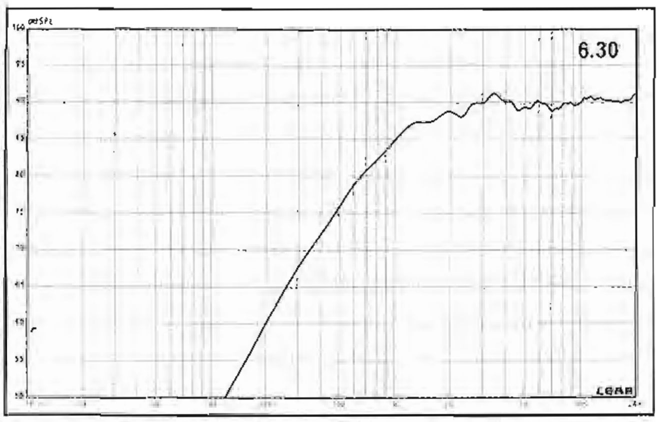


FIGURE 6.26: Horizontal polar plot for *Fig. 6.25* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).



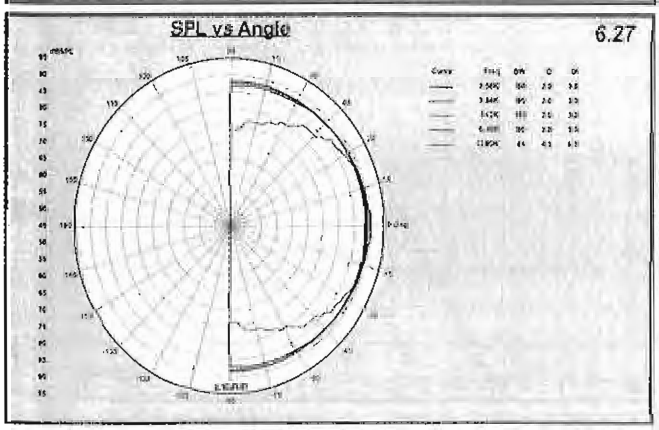


FIGURE 6.27: Vertical polar plot for *Fig. 6.25* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

FIGURE 6.28: Comparison of 1″ tweeter frequency response for all four center baffle locations (top = solid, mid = dash, bottom = dot, WTW = dash/dot).

FIGURE 6.29: Comparison of 1″ tweeter frequency response for all four offset baffle locations (top = solid, mid = dash, bottom = dot, WTW = dash/dot).

FIGURE 6.30: Frequency response for 1″ tweeter at top center baffle location

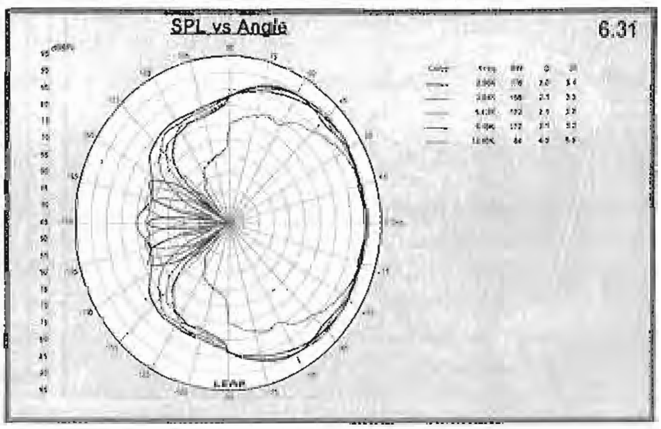


FIGURE 6.31: Horizontal polar plot for *Fig. 6.30* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

not tilted at an angle) causes a downward lobing (discussed in Chapter 7), then the top mounting position for the woofer will minimize the overall lobing and is the preferred mounting position that provides an overall more consistent vertical polar response for the system. If you mount the tweeter below the woofer, as the PSB Mini Stratus two-way (now out of production), the bottom mounting position for the woofer would make more sense, because the driver orientation would cause an upward vertical polar response tilt in the crossover region, and the baffle orientation of the woofer would also cause an upward tilt, again giving a more consistent vertical polar response for the system. This is important, as different types of lobing affect the perceived sound quality. The subjective perceived effect of lobing is discussed more in Section 6.20.

For the tweeter, you should again start by looking at the half-space on-axis response and the half-space horizontal and vertical polar plots in *Figs. 6.25–6.27*. As you can see, the response of this tweeter is relatively flat and the polar plots in either plane are totally symmetrical. There are two comparison on-axis plots given—one for the center baffle locations in *Fig. 6.28* and one for the offset positions in *Fig. 6.29*. This ±SPL data is quantified in *Table 6.1*.

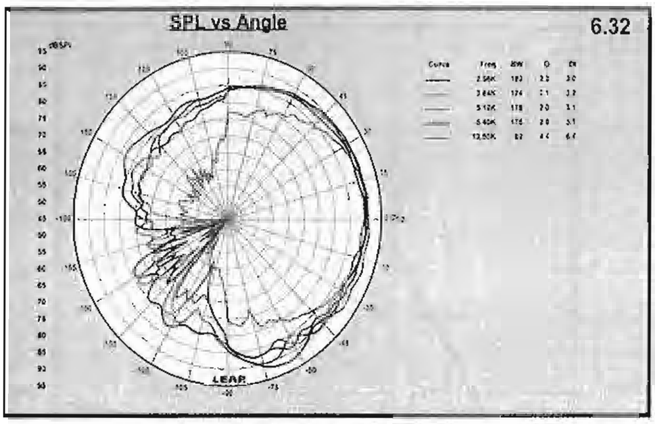


FIGURE 6.32: Vertical polar plot for *Fig. 6.30* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

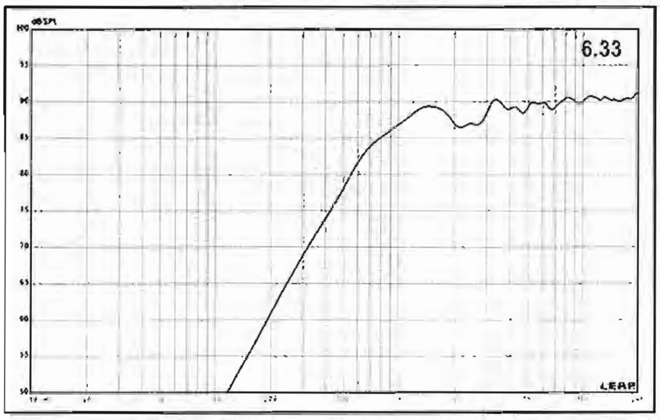


FIGURE 6.33: Frequency response for 1″ tweeter at mid center baffle location.

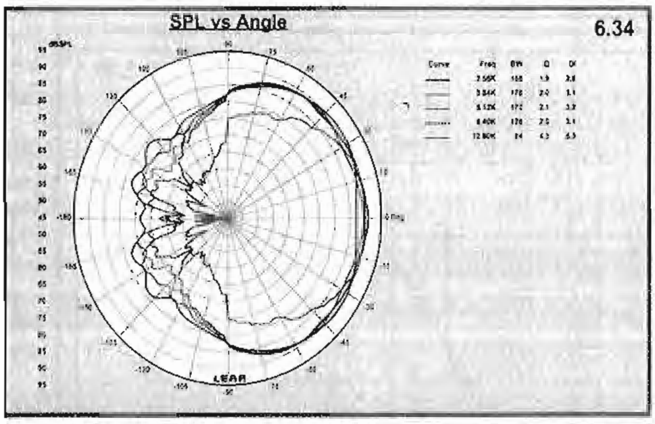


FIGURE 6.34: Horizontal polar plot for *Fig. 6.33* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

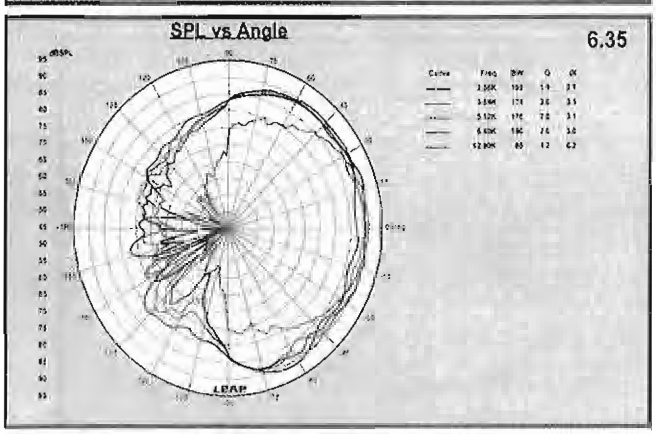


FIGURE 6.35: Vertical polar plot for *Fig. 6.33* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

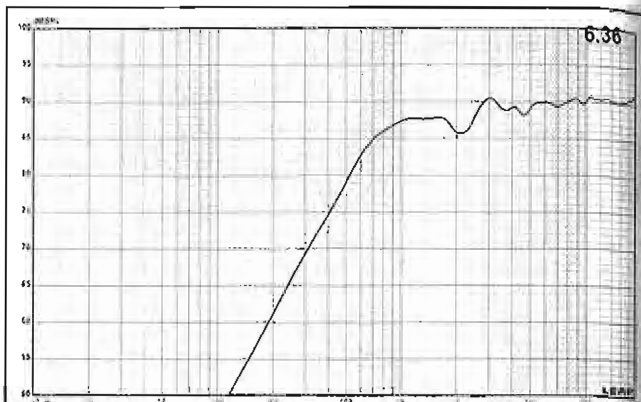


FIGURE 6.36: Frequency response for 1″ tweeter at bottom center baffle location.

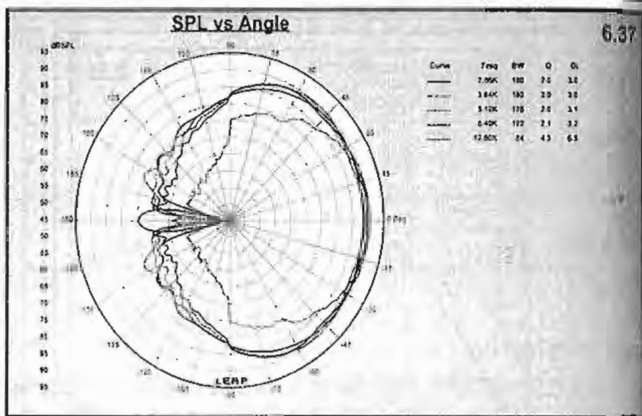


FIGURE 6.37: Horizontal polar plot for *Fig. 6.36* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

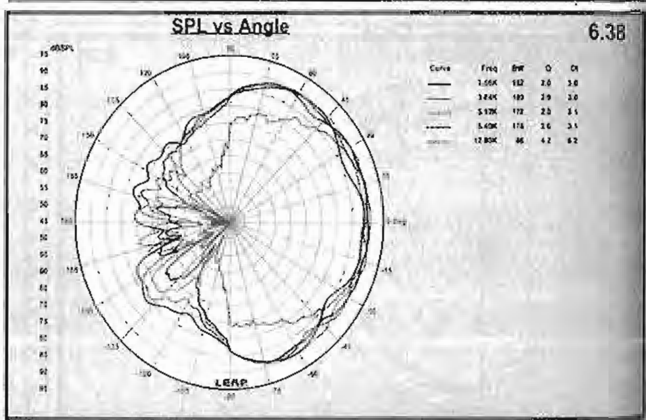


FIGURE 6.38: Vertical polar plot for *Fig. 6.36* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

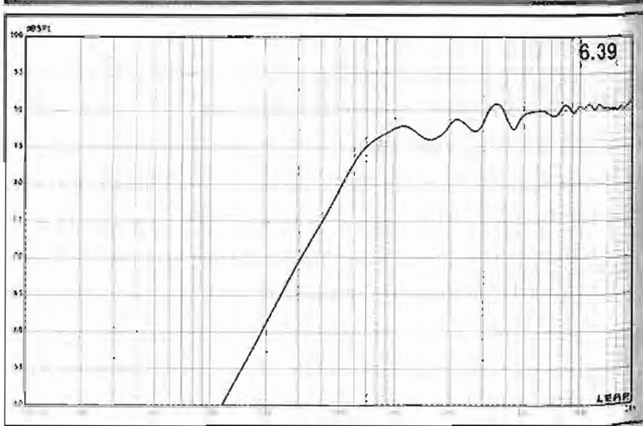


FIGURE 6.39: Frequency response of 1″ tweeter at the WTW center baffle location.

TABLE 6.1 Tweeter SPL Variations from 2kHz-10kHz for Different Baffle Locations (dB).

	Baffle Location			
	TOP	MID	BOTTOM	CENTER (WTW)
Center	1.57	1.89	2.41	1.87
Offset	1.51	1.04	1.17	1.11

From an on-axis single point microphone measurement standpoint, offsetting the tweeter to the far side of a baffle unquestionably results in a smoother response with less SPL variation on-axis, although it's not as significant as is often assumed, and the difference varies somewhat depending on the vertical placement (top, mid, bottom, or WTW). In the vertical polar plots (*Figs. 6.32, 6.35, 6.38, 6.41, 6.44, 6.47, 6.50,* and *6.53*), both center and offset, there is a small upward tilt for the top, mid, and bottom positions of 5, 4, and 3°, respectively, for the frequencies from 3.8kHz to 12.8kHz, while the WTW is centered on the 0 axis with no tilt. While the upward tilt for the top, mid, and bottom positions is not great, the symmetry of the tilt is somewhat better for the mid and bottom positions. Given that the top position was judged optimal for

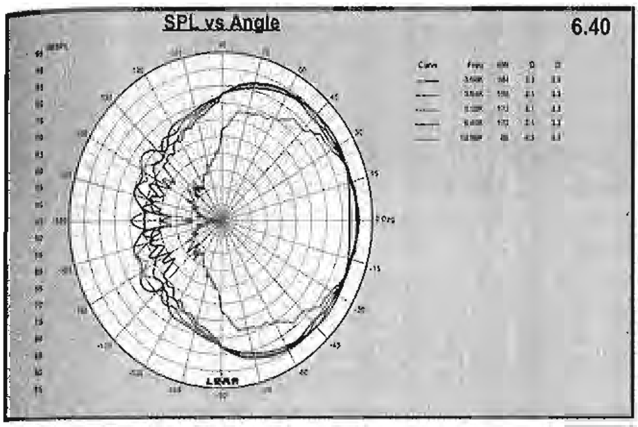


FIGURE 6.40: Horizontal polar plot for *Fig. 6.39* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

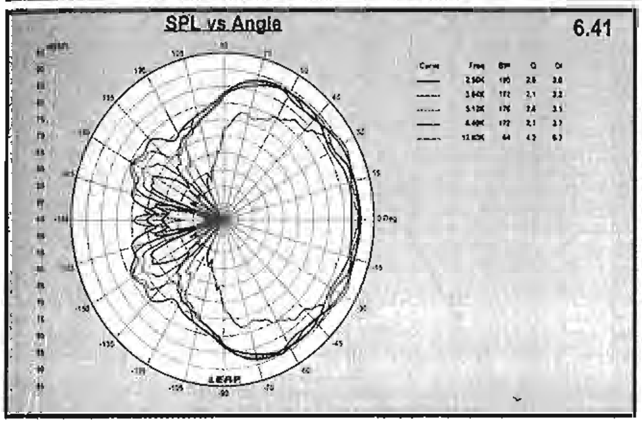


FIGURE 6.41: Vertical polar plot for *Fig. 6.39* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

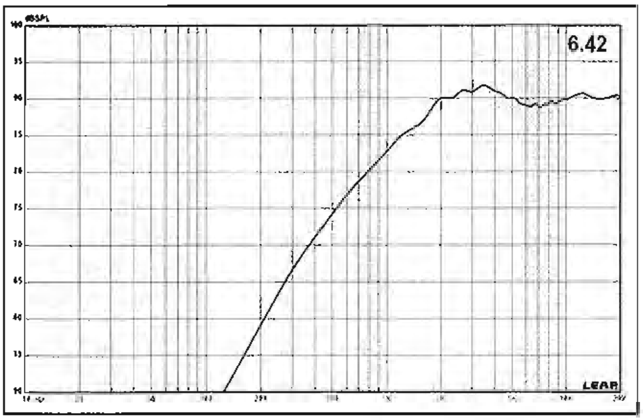


FIGURE 6.42: Frequency response for 1″ tweeter at top offset baffle location.

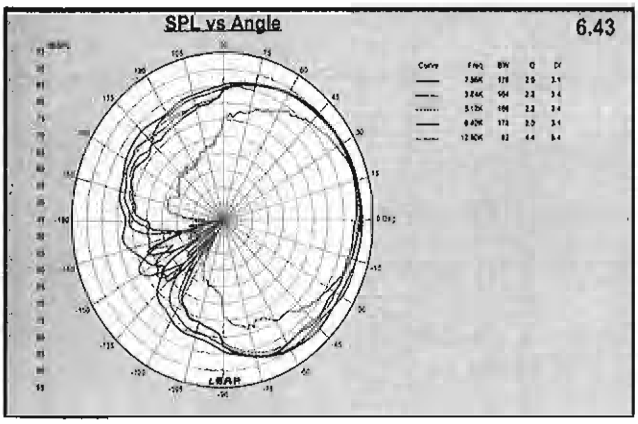


FIGURE 6.43: Horizontal polar plot for *Fig. 6.42* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

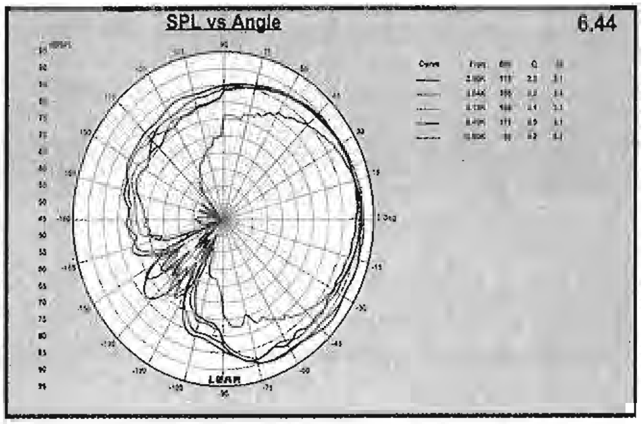


FIGURE 6.44: Vertical polar plot for *Fig. 6.42* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

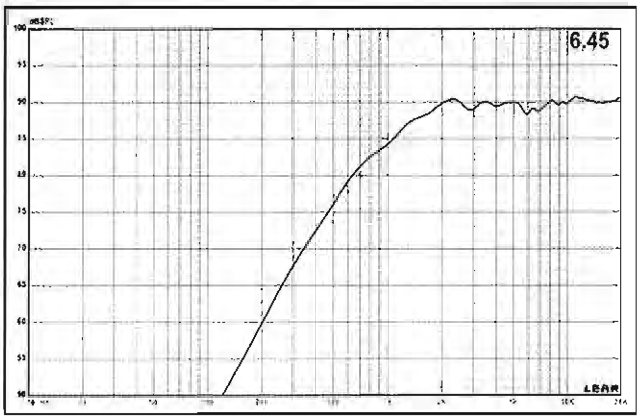


FIGURE 6.45: Frequency response for 1″ tweeter at mid offset baffle location.

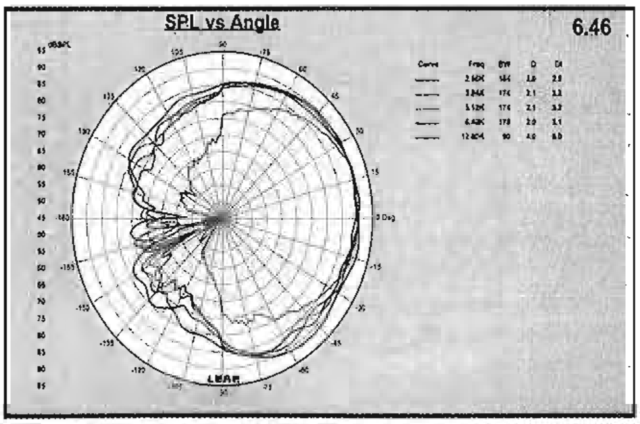


FIGURE 6.46: Horizontal polar plot for *Fig. 6.45* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

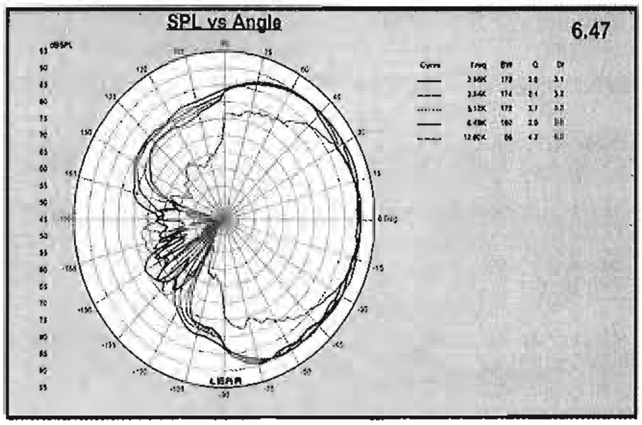


FIGURE 6.47: Vertical polar plot for *Fig. 6.45* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

the woofer, somewhere between what has been shown as the top and mid positions would likely be optimal from a system viewpoint, but I really don't believe that small changes such as this are extremely critical subjectively, so that the top position for both woofer and tweeter would still be a good choice. Another important observation regarding the WTW tweeter position is that the lack of lobing, coupled with the very symmetrical woofer and midrange lobing that you will see in sections 6.10B and 6.20, is undoubtedly at least one of the reasons the WTW D'Appolito format speaker has been so successful and tends to be subjectively well liked.

As far as the horizontal polar response of these different tweeter positions is concerned, like the woofer, all the center locations (*Figs. 6.31, 6.34, 6.37,* and *6.40*), whether mounted at the top, mid, bottom, or center (WTW) of the enclosure, have totally symmetrical profiles. However, if you consider all four offset tweeter positions (*Figs. 6.43, 6.46, 6.49,* and *6.52*), then the horizontal polar plots resemble the tweeter top vertical polar plots in terms of lobing. In this case the lobing is about a 15° tilt toward the side the tweeter is mounted on. Also important is that the amplitude spread at the various frequencies is more even on this side of the horizontal response.

In the '70s, mirror-imaged speakers were popular. "Mirror Image" meant that the tweeters were offset to the far side of the baffle, but on opposite sides for each stereo channel. The left channel speaker had the tweeter mounted on the right side of the baffle, and the right channel speaker had its tweeter mounted on the left side of the baffle. This at least was the preferred orientation, because by switching the location of the stereo pair, the tweeters would be on the outside instead of the inside.

From the various horizontal polar plots for the offset tweeters it becomes obvious why the inside orientation was the correct subjective choice. This way both horizontal polar responses tilt to the inside toward the center "sweet spot" listening position, with the added benefit of more consistent SPL and reportedly improved sonic imagery. This would also account for why non-mirror-image stereo and home theater LRs (Left/Right channels) are frequency canted to the inside listening area, because pointing the speaker at the listener is a similar function to the offset lobing pointing at the listener with mirror-image speakers, except there is an enhanced measured SPL consistency with the offset.

Tweeter offset to the baffle edge probably makes

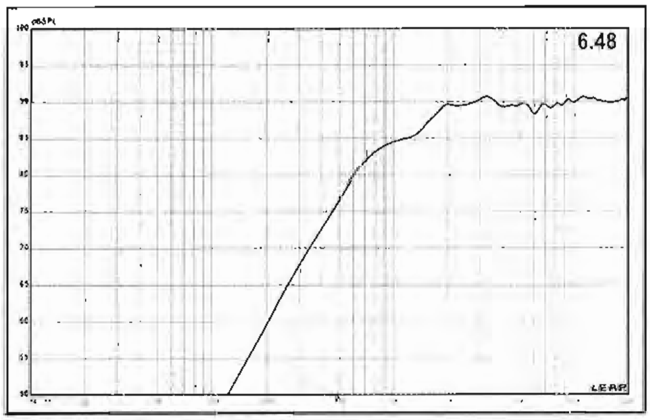


FIGURE 6.48: Frequency response for 1″ tweeter at bottom offset baffle location.

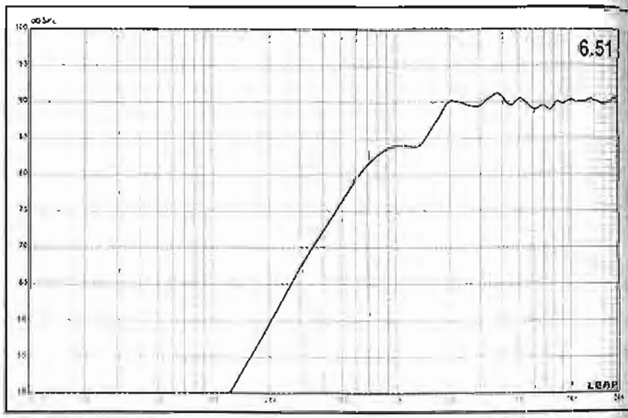


FIGURE 6.51: Frequency response of 1″ tweeter at the WTW offset baffle location.

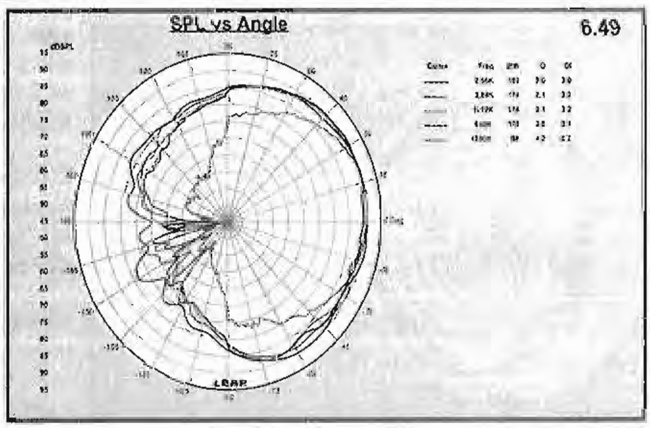


FIGURE 6.49: Horizontal polar plot for *Fig. 6.48* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

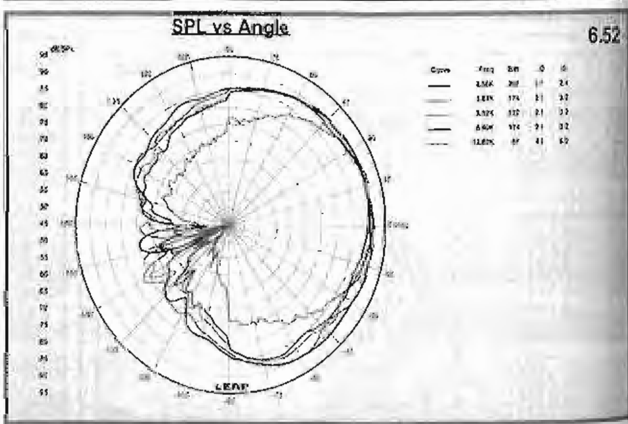


FIGURE 6.52: Horizontal polar plot for *Fig. 6.51* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

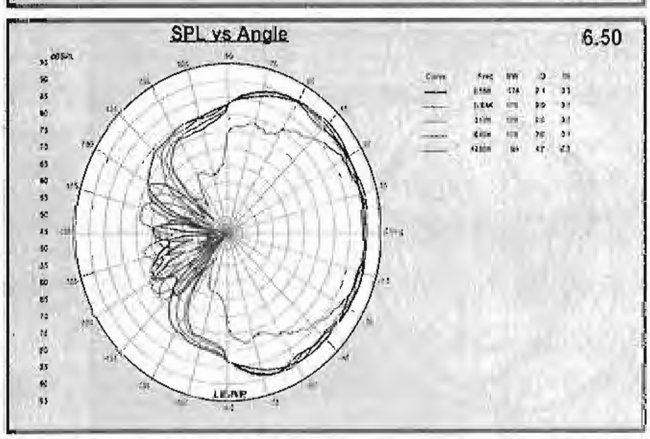


FIGURE 6.50: Vertical polar plot for *Fig. 6.48* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

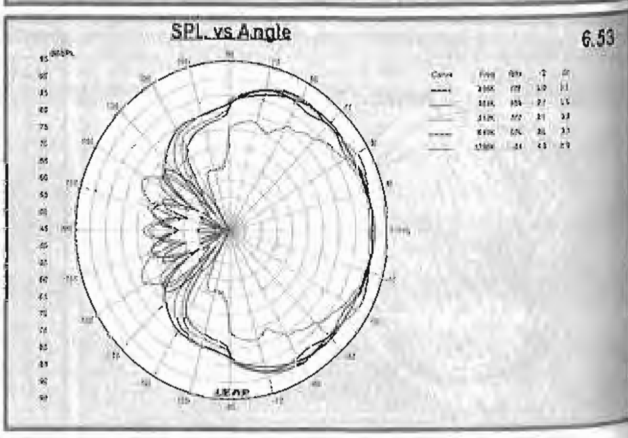
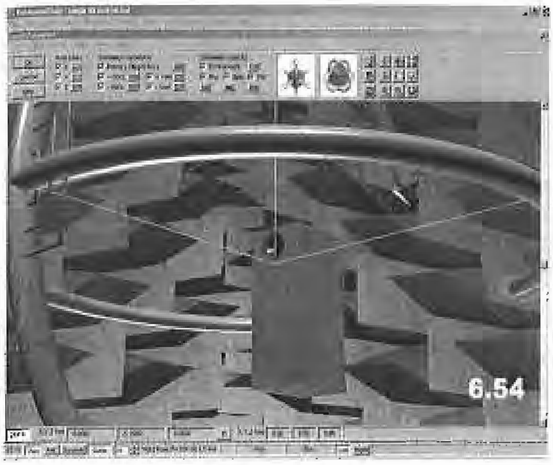
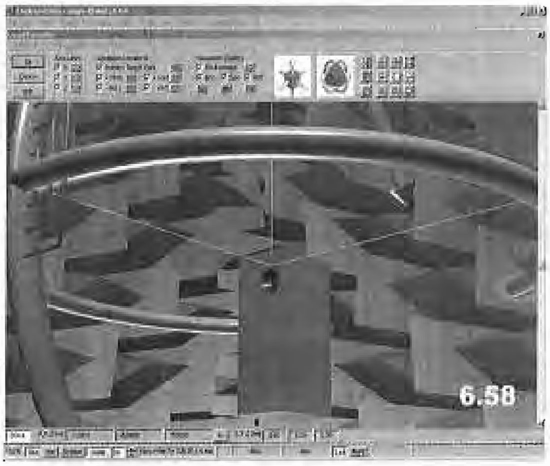


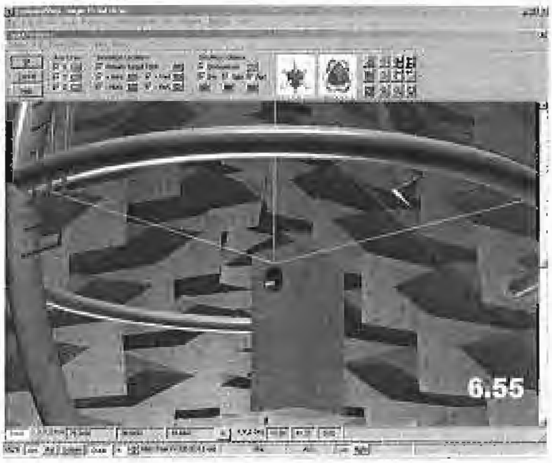
FIGURE 6.53: Vertical polar plot for *Fig. 6.51* (2.56kHz = solid, 3.84kHz = dash, 5.12kHz = dot, 6.40kHz = solid, 12.8kHz = dash).

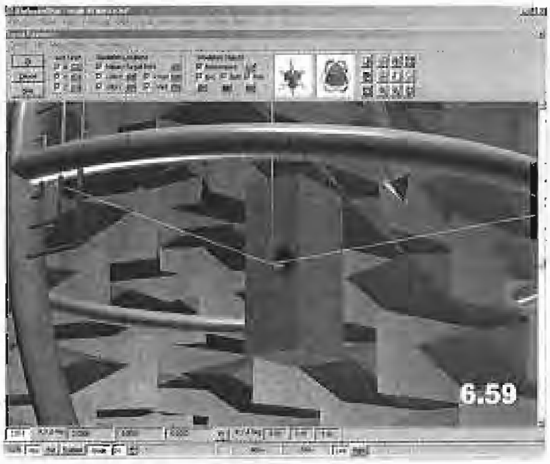
more sense with close-in listening positions in stereo than further back listening positions with home theater, especially with larger screens. The higher degree of ambient content at the more distant listening positions makes a symmetrical horizontal polar response more desirable. Of course, there is also the manufacturing issue of matching up left and right mirror offset channels, which makes such a practice more trouble than most manufacturers are willing to subject themselves to.

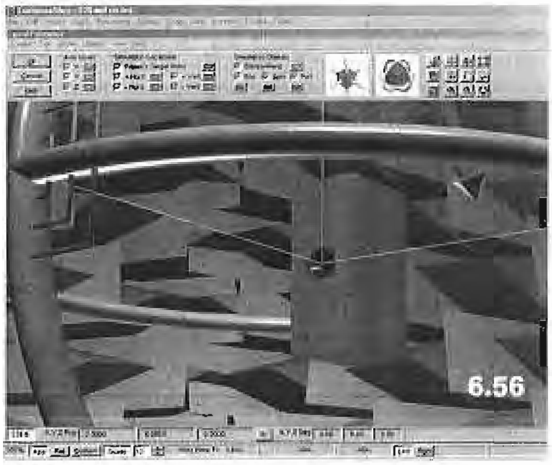
As a "guiding" principle, I think that keeping both vertical and horizontal polar responses as sym-











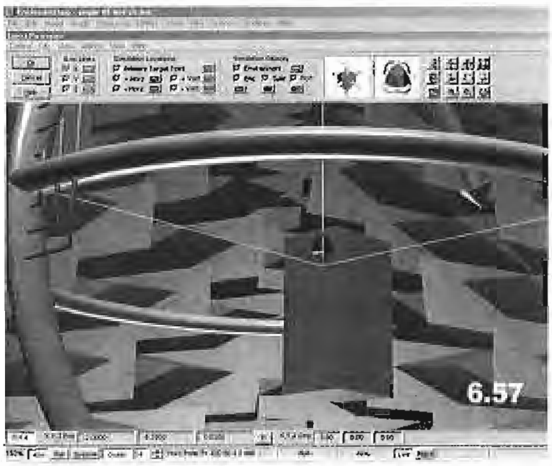


FIGURE 6.54: Single 4.5″ midrange top center baffle location.

FIGURE 6.55: Single 4.5″ midrange mid center baffle location.

FIGURE 6.56: Single 4.5″ midrange WTW center baffle location.

FIGURE 6.57: Single 4.5″ midrange top offset baffle location.

FIGURE 6.58: Single 4.5″ midrange mid offset baffle location.

FIGURE 6.59: Single 4.5″ midrange WTW offset baffle location.

FIGURE 6.60: Dual 5.25″ midrange top center baffle location.

FIGURE 6.61: Dual 5.25″ midrange WTW center baffle location.

metrical as possible results in a better subjective experience, which is at least one of the reasons I undertook this diffraction study. This, of course, runs contrary to some engineering personalities who maintain that home speakers should have some type of directivity. Controlled directivity is a standard practice for loudspeakers designed for use in large venues and is done to provide specific coverage patterns. Enhanced directivity loudspeakers are, however, the exception rather than the rule in speakers intended for small rooms.

B. Three-Way Midrange Location SPL Variation. Section 6.10A discussed SPL differences for woofers and tweeters in two-way systems located at different positions on a front baffle. This section will discuss the same information for midranges in three-way systems. I simulated two examples—a single 4.5″ midrange, and dual 5.25″ midranges—and chose the cabinet volumes and dimensions for this exercise from current production 2005 loudspeakers.

Midrange Diameter	Enclosure Dimensions (H × W × D)	Simulated Woofer
4.5″	20″ × 8.25″ × 10.5″	Peerless 830516
5.25″ (2)	32″ × 7.10″ × 10.5″	Vifa C13WG-19-08

I outlined six different positions for the 4.5″ midrange: three mounted on the baffle centerline and three offset to the right from those positions. These six baffle locations are depicted in *Figs. 6.54–6.59.* As you can see, the midrange was located in the center of the baffle (this is the same configuration as the production speaker with 6.5″ woofers mounted above and below this position), between the center and the top of the baffle (both 6.5″ woofers would be mounted below the midrange and a tweeter mounted above), and at the top of the baffle (both woofers at the bottom of the baffle and the tweeter mounted just below the midrange).

For the dual 5.25″ midrange format, only four positions are examined and are illustrated in *Figs. 6.60-6.63.* Only two basic positions are available for this format with this size enclosure. One configuration is with the tweeter mounted in the center of the baffle with one midrange mounted above and below and an 8″ woofer mounted at the top and bottom of the baffle (plus the offset variation). The other is with the midrange tweet-

FIGURE 6.62: Dual 5.25″ midrange top offset baffle location.

FIGURE 6.63: Dual 5.25″ midrange WTW offset baffle location.

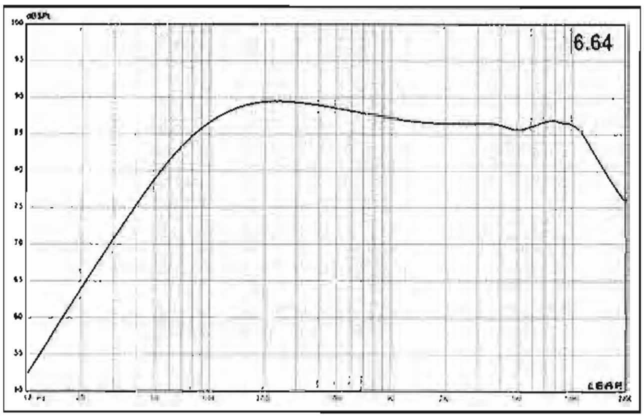


FIGURE 6.64: Frequency response of single 4.5″ midrange mounted on an infinite baffle.

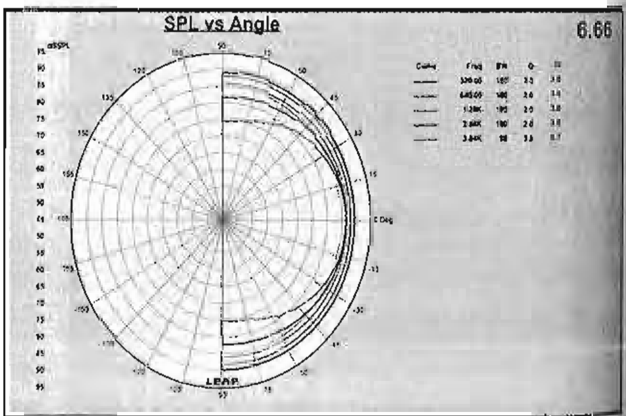


FIGURE 6.65: Horizontal polar plot for *Fig. 6.64* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

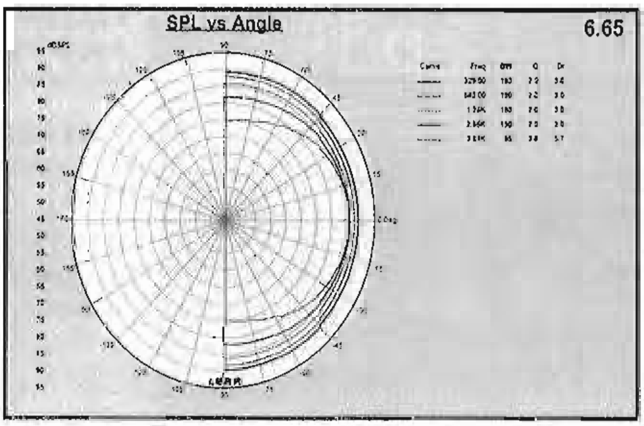


FIGURE 6.66: Vertical polar plot for *Fig. 6.64* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

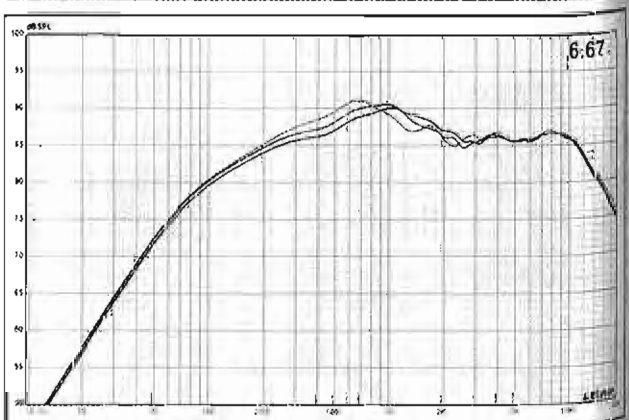


FIGURE 6.67: Comparison of single 4.5″ midrange frequency response for all three center baffle locations (top = solid, mid = dash, center = dot).

er MTM array located at the top of the baffle with two 8″ woofers located together at the bottom of the baffle. The graphic presentation for both three-way examples is similar to section 6.10A, as follows:

1. a set of reference graphs, on-axis half-space plus horizontal and vertical polar plots in half space

2. a composite graph that compares the different anechoic on-axis response curves, one for the three center 4.5″ single midrange locations, one for the three offset 4.5″ single midrange locations, plus one for the two dual 5.25″ midrange locations and one for the two 5.25″ midrange offset locations

3. individual on-axis and horizontal and vertical polar plots for each baffle location

As before, you should again start by looking at the half-space on-axis response and the half-space horizontal and vertical polar plots in *Figs. 6.64-6.66* for the single 4.5″ mid and in *Figs. 6.87-6.89* for the dual 5.25″ midrange format. Both midrange drivers have a smooth on-axis response, relatively flat for the dual 5.25″ set and with a somewhat declining SPL with increasing frequency for the single 4.5″. As with any half-space measurement, the horizontal and vertical polar plots are totally symmetrical, although you can see the cancellation effects and

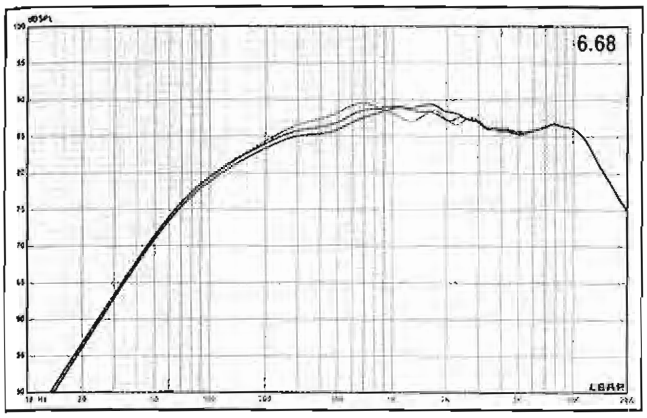


FIGURE 6.68: Comparison of single 4.5″ midrange frequency response for all three offset baffle locations (top = solid, mid = dash, center = dot).

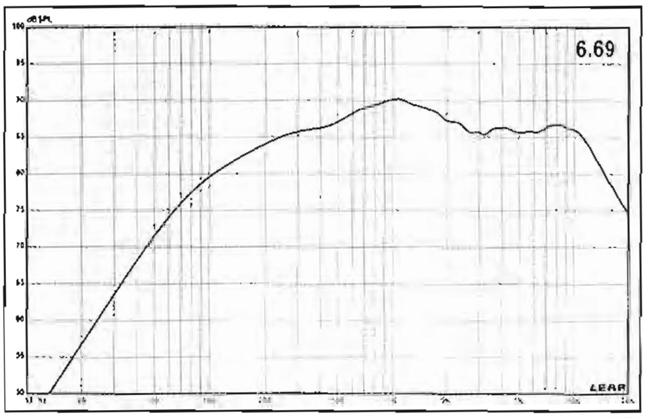


FIGURE 6.69: Frequency response for single 4.5″ midrange at top center baffle location.

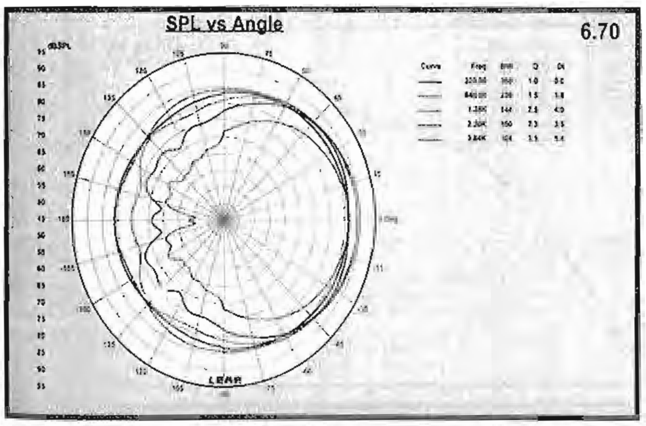


FIGURE 6.70: Horizontal polar plot for *Fig. 6.69* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

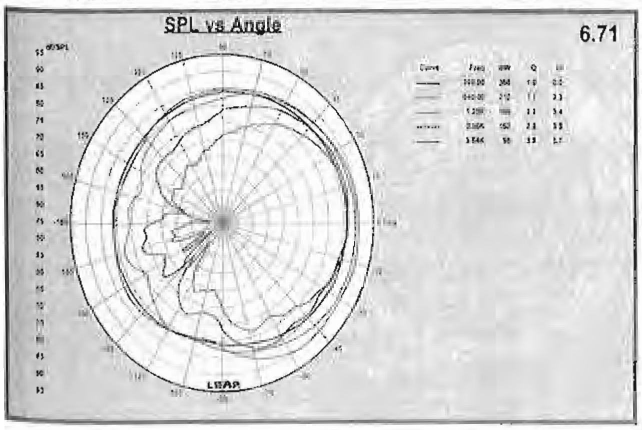


FIGURE 6.71: Vertical polar plot for *Fig. 6.69* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

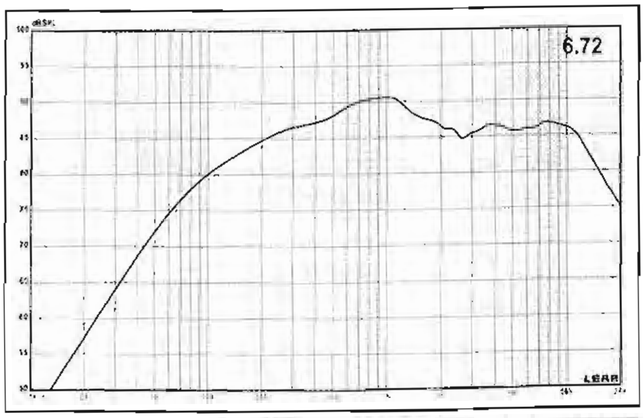


FIGURE 6.72: Frequency response for single 4.5″ midrange at mid center baffle location.

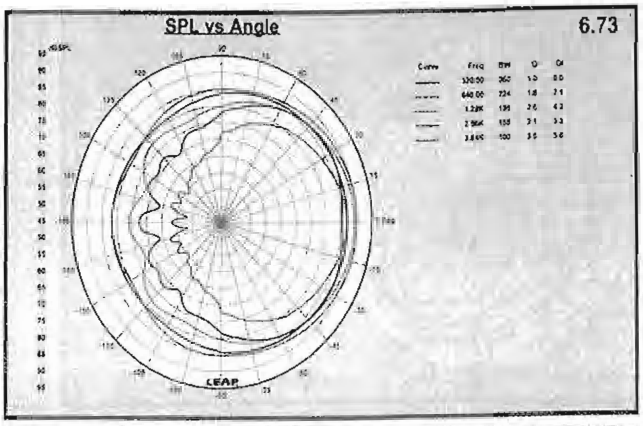


FIGURE 6.73: Horizontal polar plot for *Fig. 6.72* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

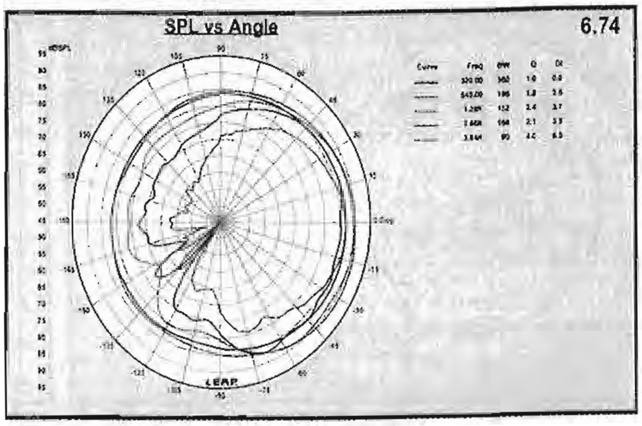


FIGURE 6.74: Vertical polar plot for *Fig. 6.73* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

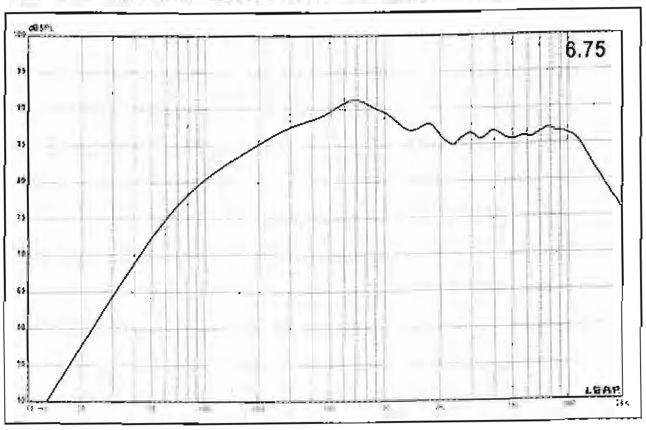


FIGURE 6.75: Frequency response for single 4.5″ midrange at WTW center baffle location.

resulting lobing of the dual 5.25″ midrange drivers in the vertical polar plot.

The on-axis comparison graph for the different centerline locations and the different offset locations are given in *Figs. 6.67–6.68* for the single 4.5″ midrange and in *Figs. 6.90–6.91* for the dual 5.25″ scenario. The ±SPL data for both the 4.5″ and 5.25″ drivers is quantified in *Tables 6.2* and *6.3*, respectively.

Table 6.2 Single 4.5″ SPL Variation from 500Hz-3kHz for Different Baffle Locations (dB).

	Baffle Location		
	TOP	MID	CENTER (WTW)
Center	2.30	2.95	3.07
Offset	1.69	1.07	1.45

Table 6.3 Dual 5.25″ SPL Variation from 500Hz-3kHz for Different Baffle Locations (dB).

	Baffle Location	
	TOP	CENTER (WTW)
Center	1.56	1.13
Offset	0.97	0.76

Results for the single 4.5″ midrange were very similar to the tweeter conclusions in Section 6.10A. Offsetting this midrange to the far side of a baffle unquestionably results in a smoother response with less SPL variation (see *Table 6.2* and *Figs. 6.67–6.68*), although, as before, not as significant as is often assumed. In the vertical polar plots (*Figs. 6.71, 6.74, 6.77, 6.80, 6.83,* and *6.86*), the baffle also tilts the response 5° upward for the placement at the top, about 3° upward for the mid location between the top and center, and no tilt at all with the midrange mounted in the center position. With no offset and the midrange located on the centerline of the baf-

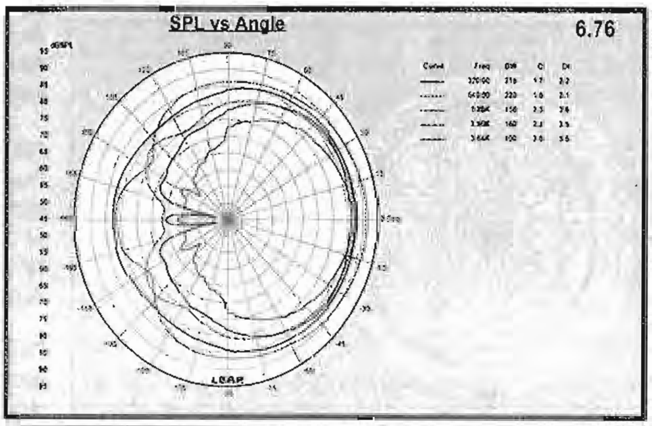


FIGURE 6.76: Horizontal polar plot for *Fig. 6.75* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

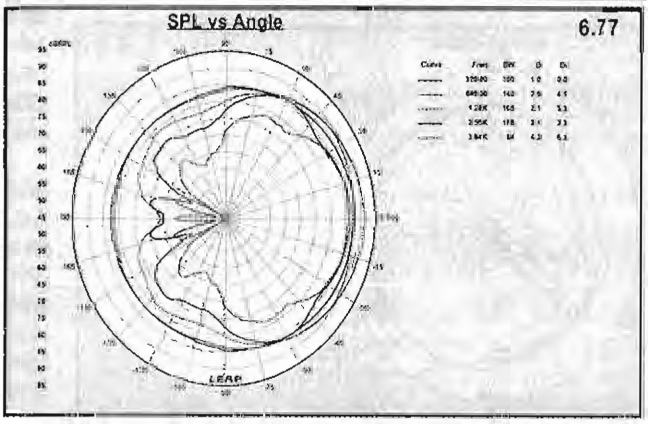


FIGURE 6.77: Vertical polar plot for *Fig. 6.75* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

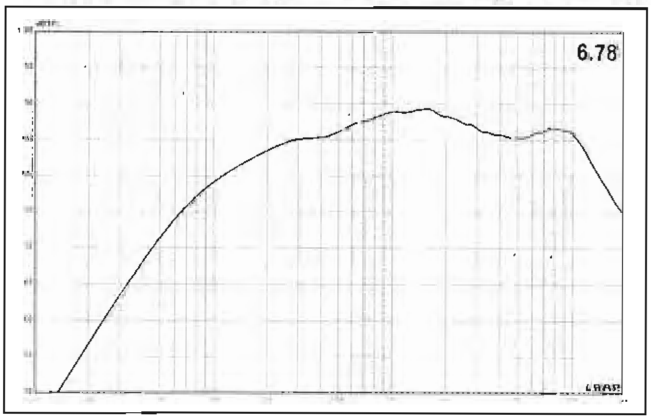


FIGURE 6.78: Frequency response for single 4.5″ midrange at top offset baffle location.

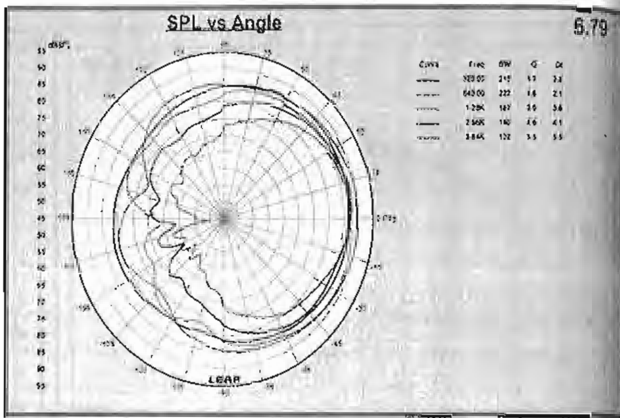


FIGURE 6.79: Horizontal polar plot for *Fig. 6.78* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

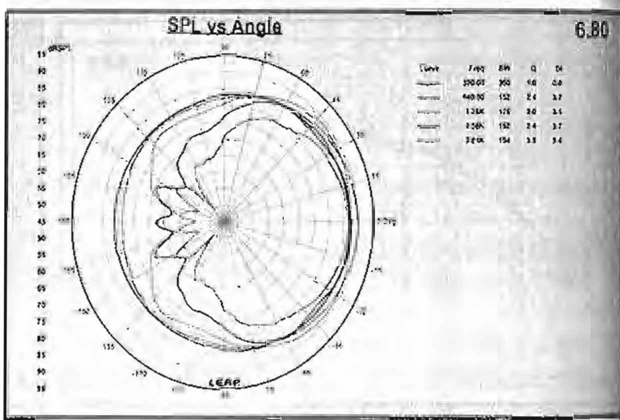


FIGURE 6.80: Vertical polar plot for *Fig. 6.78* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

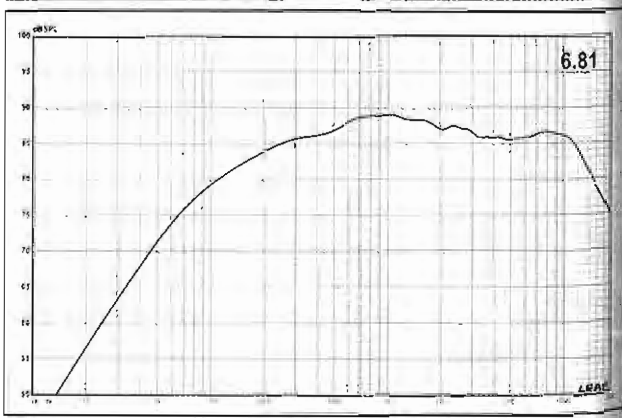


FIGURE 6.81: Frequency response for single 4.5″ midrange at mid offset baffle location.

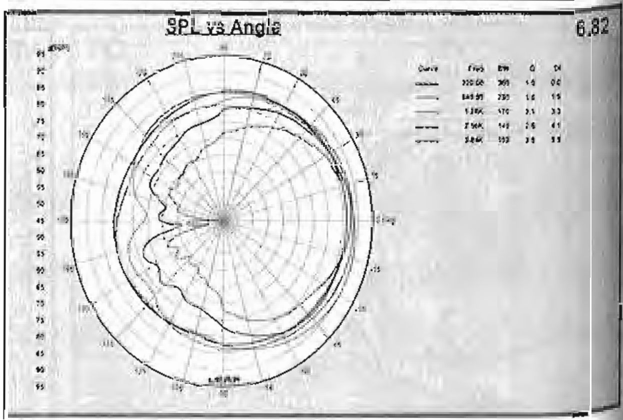


FIGURE 6.82: Horizontal polar plot for *Fig. 6.81* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

fle, all three locations have symmetrical horizontal polar plots (*Figs. 6.70, 6.73, 6.76*), again the same as the tweeter analysis in the previous section. The response change in the horizontal plane due to offset to the right side of the enclosure (*Figs. 6.79, 6.82,* and *6.85*) results in a 10–15° tilt toward the right side of the enclosure plus a tighter SPL spread on that side as well, again, very similar to the tweeter example.

Results for the 5.25″ dual midrange example were somewhat different, although the offset response given in *Table 6.3* (also see *Figs. 6.90–6.91*) also showed some small improvement over the center baffle location. In the vertical polar plots (*Figs. 6.94, 6.97, 6.100,* and *6.103*), the drivers located in the center of the baffle have a totally symmetrical response. When the two midranges are relocated to the top of the baffle, the response change is not extreme, but it also is not as symmetrical as the center location. Obviously, both locations exhibit a degree of cancellation due to the use of two sources operating in the same frequency range.

The offset location for the dual 5.25″ midranges resulted in less "tilt" toward the same side of the baffle they were located on—about 5° compared to 15° for the single 4.5″ midrange—but also ex-

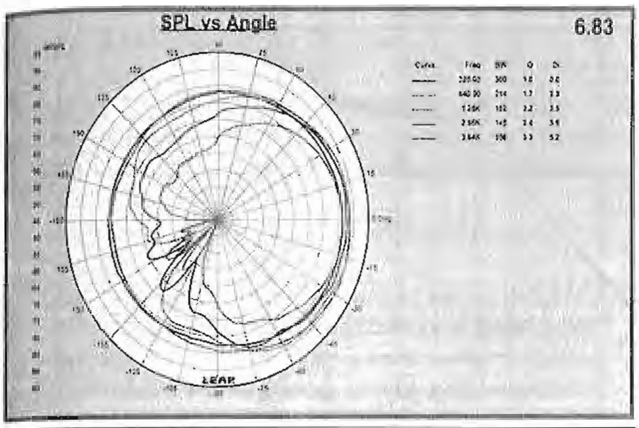
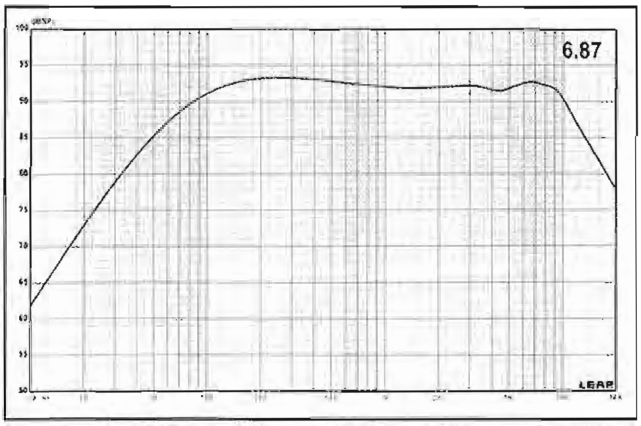


FIGURE 6.83: Vertical polar plot for *Fig. 6.81* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).



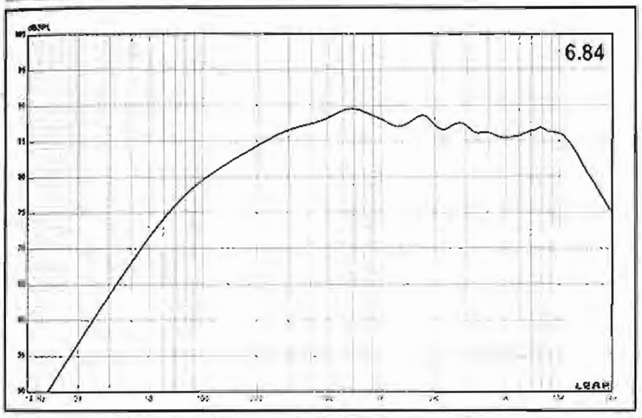
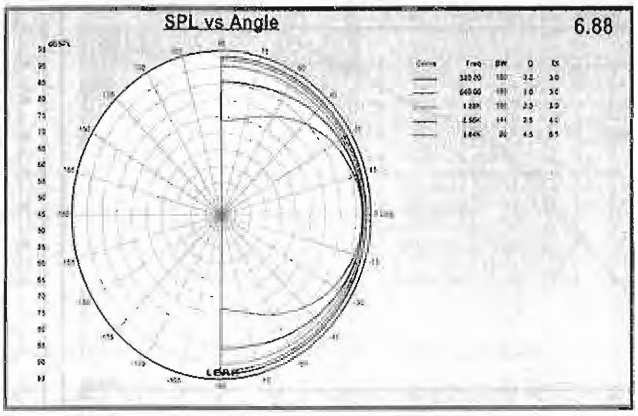


FIGURE 6.84: Frequency response for single 4.5″ midrange at WTW offset baffle location.



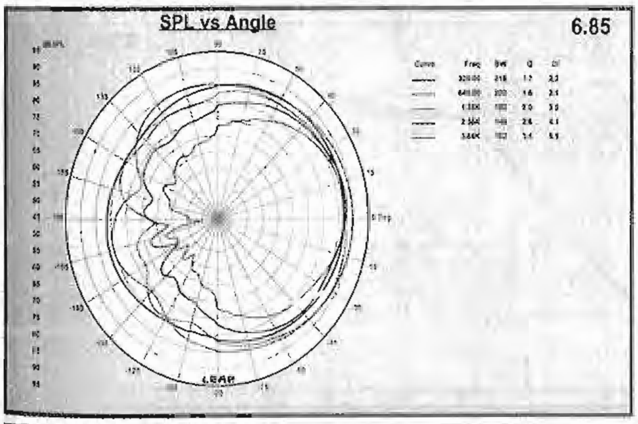
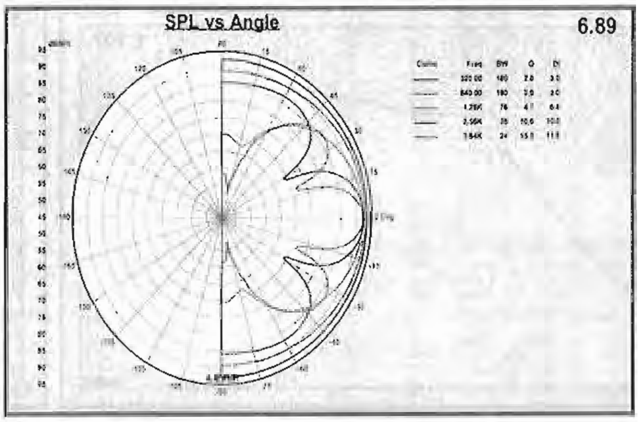


FIGURE 6.85: Horizontal polar plot for *Fig. 6.84* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).



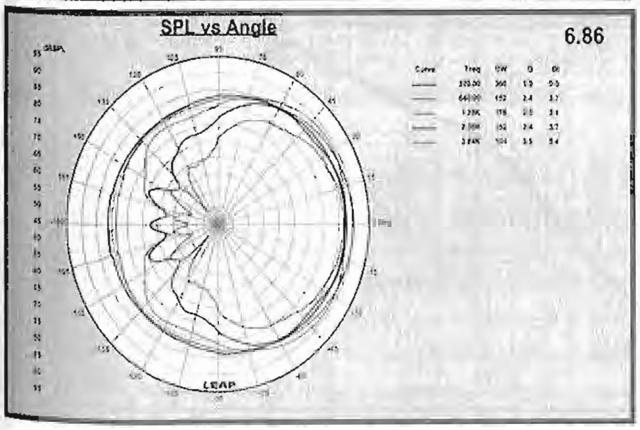


FIGURE 6.86: Vertical polar plot for *Fig. 6.84* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.87: Frequency response of dual 5.25″ midranges mounted on an infinite baffle.

FIGURE 6.88: Horizontal polar plot for *Fig. 6.87* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.89: Vertical polar plot for *Fig. 6.87* (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

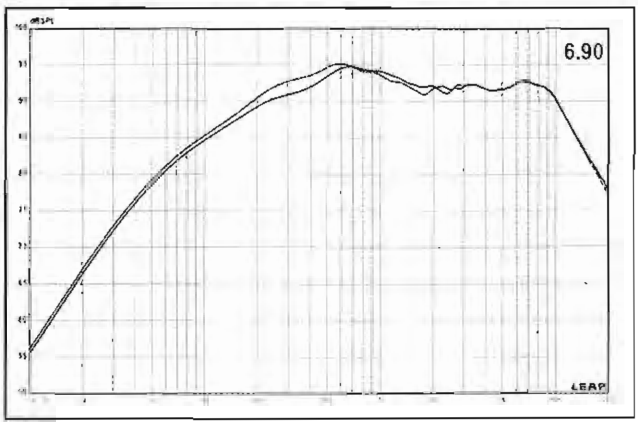


FIGURE 6.90: Comparison of dual 5.25″ midranges frequency response for both center baffle locations (top = solid, center = dash).

tems, and the second involves the design of horizontal WTW arrays used for center channel speakers in home theater systems.

A. 2.5-Way WTW vs. Full-Range 2-Way WTW.

Over the last several years I have heard criticism leveled at the use of full-range two-way WTW speaker formats in home theater with the suggestion that 2.5-way formats are superior. A 2.5-way speaker has two woofers like a regular WTW format, but instead of crossing both of them over at the same frequency to blend with a tweeter, one woofer uses a low-pass filter set over an octave or so lower in frequency, while the other is crossed normally with the tweeter. The concept being promoted is that the 2.5-way format will reduce the "undesirable" interference (lobing) due to the separation between the two woofers that are both operating together with the tweeter. The claim is that by reducing the lobing, the resulting 2.5-way format will produce a subjectively superior-sounding loudspeaker.

Fortunately, the occasion came up in the last year (sometime in 2004) for me to compare the exact same loudspeaker (cabinet and driver set) opti-

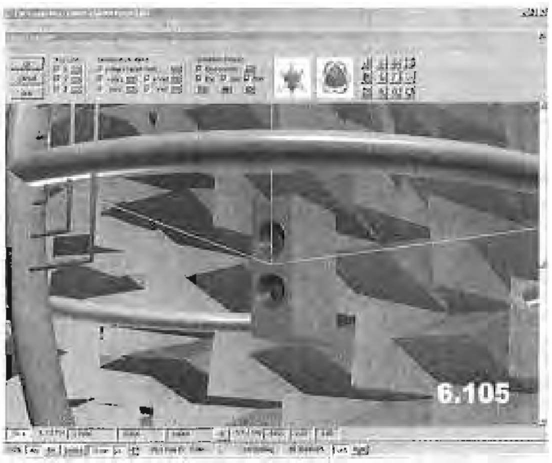
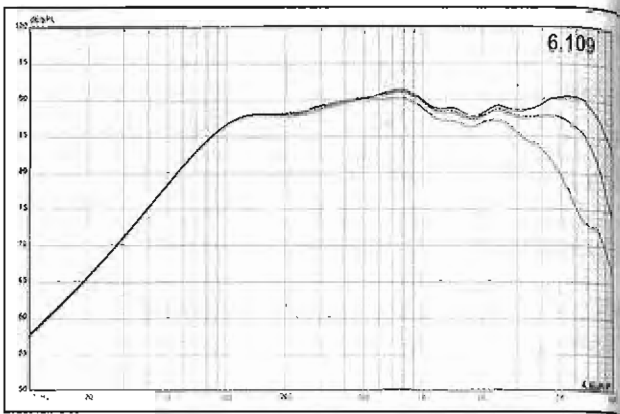
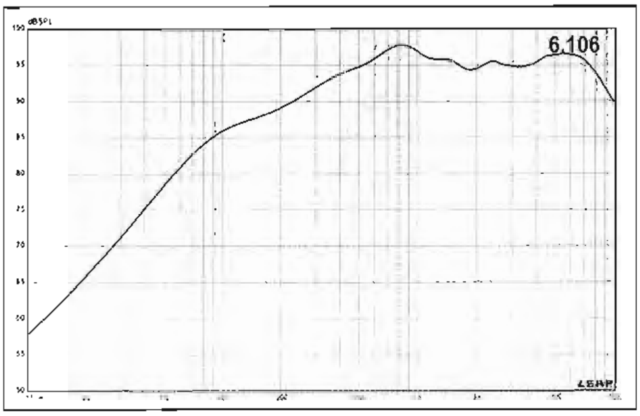
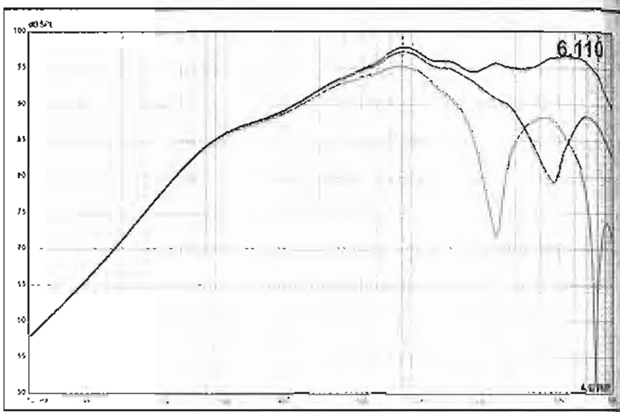
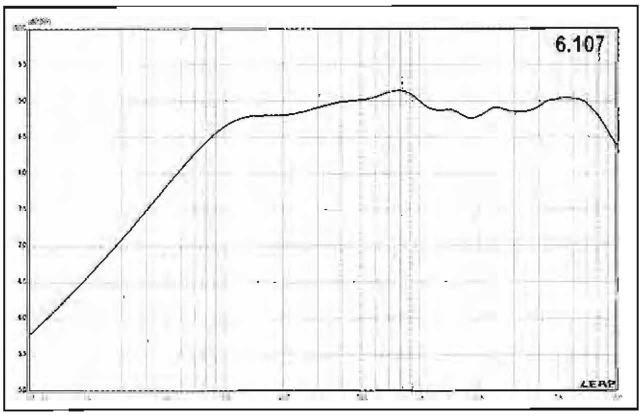


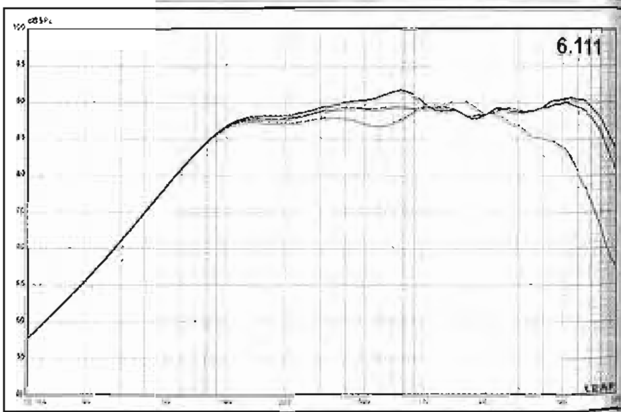
FIGURE 6.105: Drive layout for 2.5-Way vs. WTW.

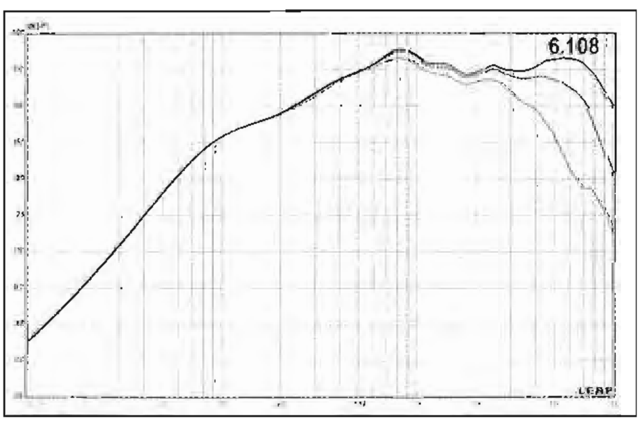












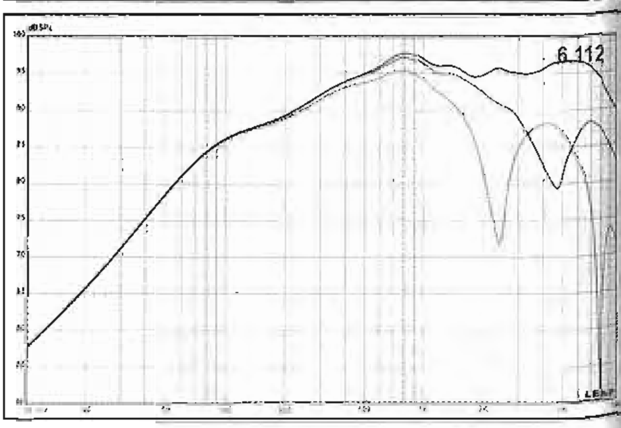


FIGURE 6.106: WTW on-axis response.

FIGURE 6.107: 2.5-Way (network on single woofer) on-axis response.

FIGURE 6.108: WTW horizontal on- and off-axis (solid = 0°, dot = 15°, dash = 30°).

FIGURE 6.109: 2.5-way horizontal on- and off-axis (solid = 0°, dot = 15°, dash = 30°).

FIGURE 6.110: WTW vertical on- and off-axis (solid = 0°, dot = +15°, dash = + 30°).

FIGURE 6.111: 2.5-way vertical on- and off-axis (solid = 0°, dot = +15°, dash = + 30°).

FIGURE 6.112: WTW vertical on- and off-axis (solid = 0°, dot = -15°, dash = - 30°).

mized for a full-range WTW and the same speaker optimized as a 2.5-way. This gave me the opportunity to very critically compare the 2.5-way incarnation side by side with the same drivers in a full-range D'Appolito format. My observation was that although the timbre of both formats was very similar, the 2.5-way lacked the perceived image depth of the standard WTW format (this was a mono A/B test—for more on this, see Chapter 7.90, Loudspeaker Voicing). What follows explains the subjective difference using LEAP 5 simulations and offers some more guidance in terms of the optimal polar response in a loudspeaker.

Figure 6.105 gives the cabinet and driver setup that was configured in LEAP 5 EnclosureShop. What you see in the illustration is a dual 6.5″ speaker with the woofers spaced at the distance required to fit a small faceplate neodymium tweeter between them. Because of the methodology employed in LEAP 5 that allows you to add passive filter sections for diffraction analysis, the only network employed in the simulations was the low-pass on the single woofer in the 2.5-way example, so both the full-range WTW and the 2.5-way do not have a crossover at the tweeter crossover frequency.

The full-range WTW woofer example (without any crossover) and the 2.5-way (with a bottom woofer 1.5kHz LP filter) analysis resulted in the production of an on-axis curve, a 30° off-axis curve in both the horizontal and vertical planes, and both horizontal and vertical polar plots for each example. Because no crossover was used in conjunction with the WTW example, you see the woofer "step" response (this will be discussed in Section 6.30), but the overall response above the "step" is identical to the 2.5-way. Curves for the full-range WTW woofers and the 2.5-way examples are as follows:

	WTW	2.5-way
On-axis	6.106	6.107
On-axis, 15° H, 30° H	6.108	6.109
On-axis, +15° V, +30° V	6.110	6.111
On-axis, −15° V, −30° V	6.112	6.113
Vertical polar plot	6.114	6.115

When examining these two curve sets, you see that the horizontal on- and off-axis (*Figs. 6.108* and *6.109*) curves are very symmetrical for both formats. However, if you compare the vertical off-axis curves both up (+) and down (−) from the measurement axis, the pair of graphs for the WTW woofers is identical (*Figs. 6.110* and *6.112*), but for the 2.5-way (*Figs. 6.111* and *6.113*), definitely not at all symmetrical. This is to be expected when one woofer is below the other and playing in a different frequency range. This is confirmed by comparing the vertical polar plots in *Figs. 6.114* and *6.115*.

While the 2.5-way speaker does not have the lobing that is typical of the full-range WTW, its vertical response is very asymmetrical. My conclusion is that having a radiating field that is symmetrical, lobing or not, sounds better than an asymmetrical radiat-

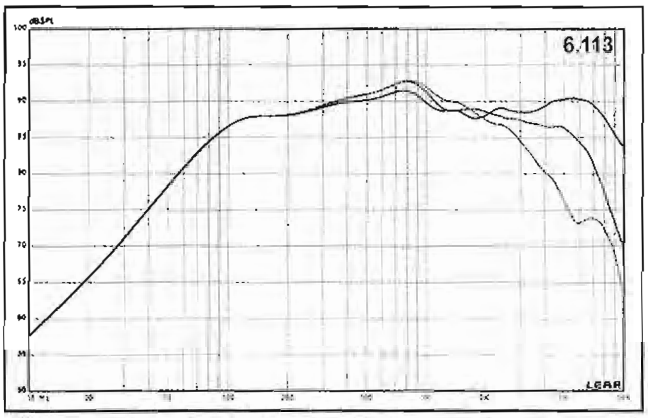


FIGURE 6.113: 2.5-way vertical on- and off-axis (solid = 0°, dot = -15°, dash = - 30°).

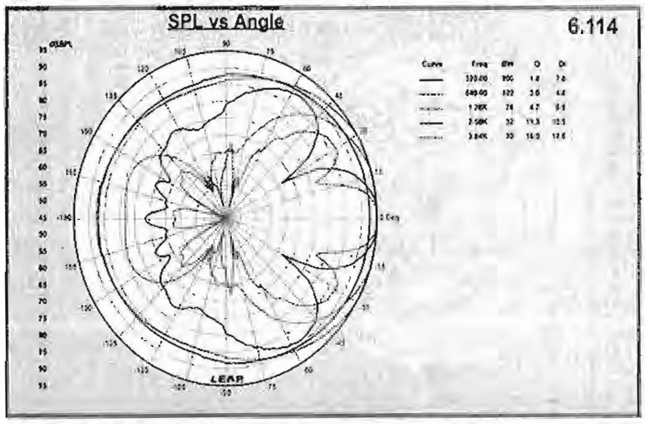


FIGURE 6.114: Vertical polar plot for WTW (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

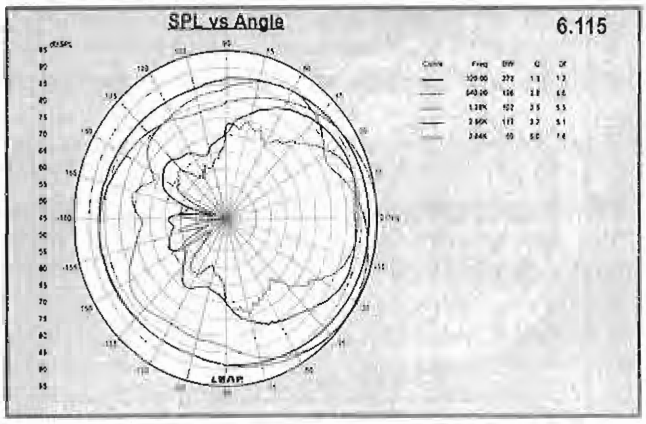


FIGURE 6.115: Vertical polar plot for 2.5-way (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

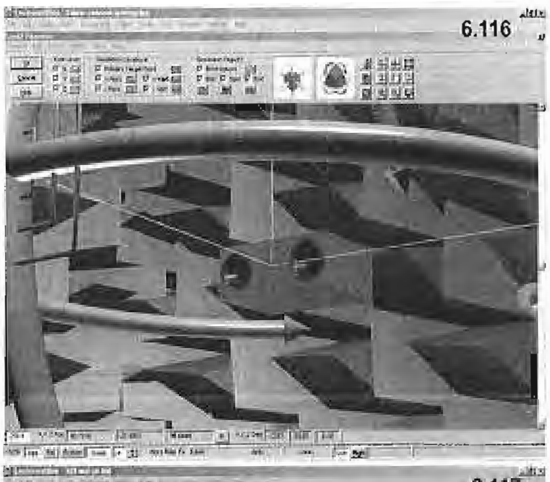


FIGURE 6.116: Center channel dual woofer layout with wide spacing.

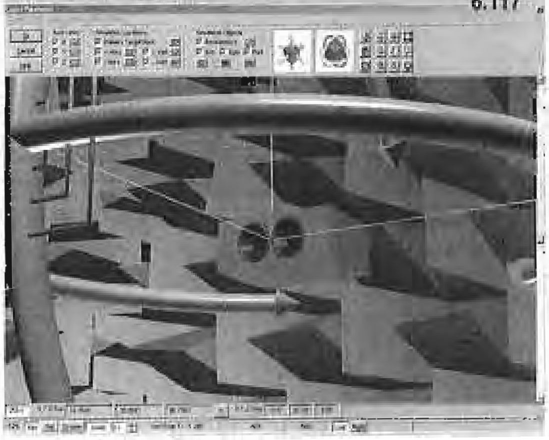
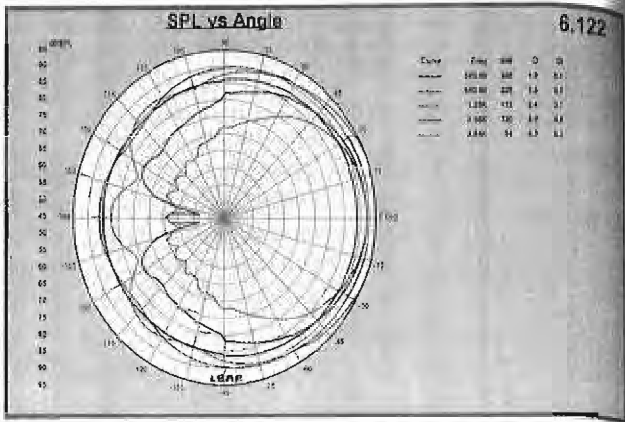


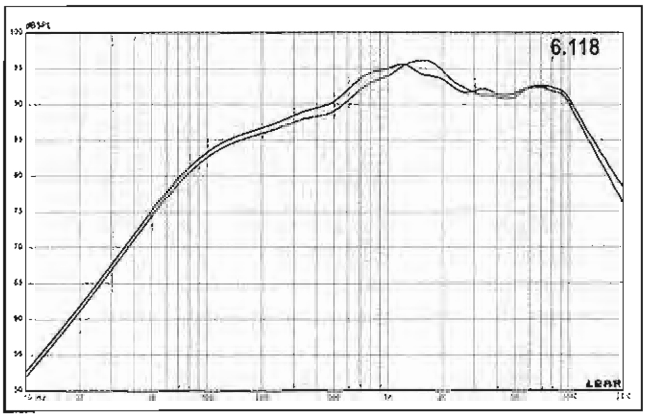
FIGURE 6.117: Center channel dual woofer layout with close spacing.

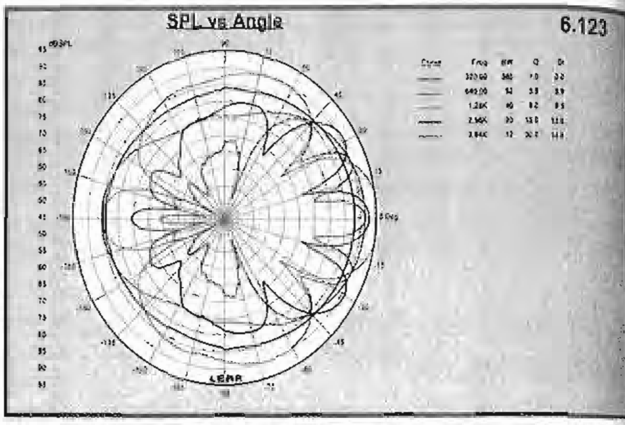
ing field, and this is the reason the full-range WTW gave a better sense of ambience in a room than the 2.5-way speaker did.

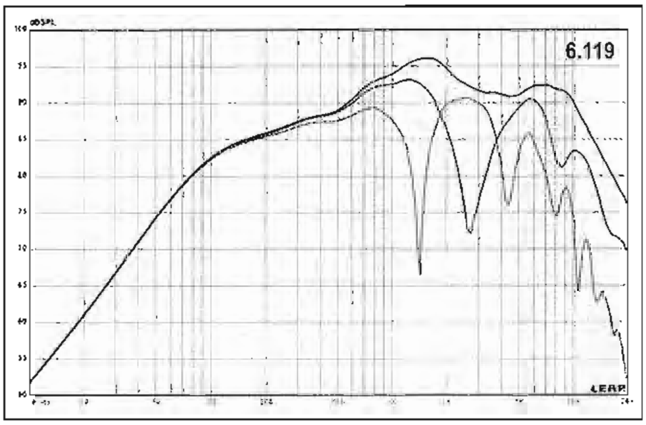
B. Woofer Spacing for 2-Way WTW Center Channel Speakers.

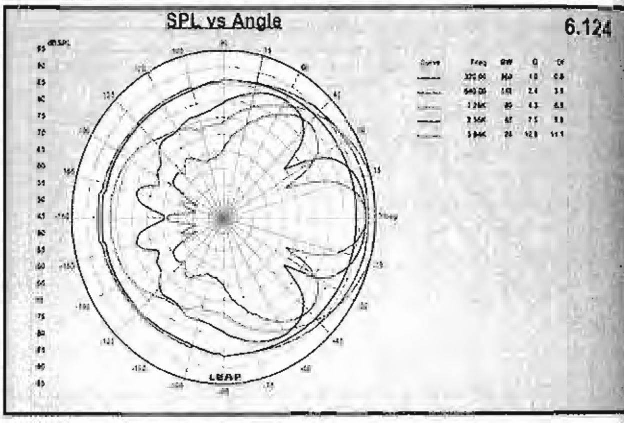
While three-way center channel speakers that have vertical MTM arrays with the same acoustic polarity as their accompanying LR speakers are by far one of the best solutions for home theater, the majority of center channel loudspeakers are 2-way horizontal aspect ratio dual woofer WTW arrays. If you survey the variety of the horizontal

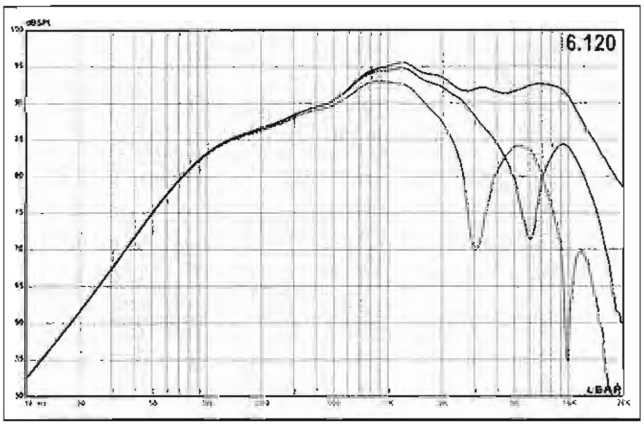


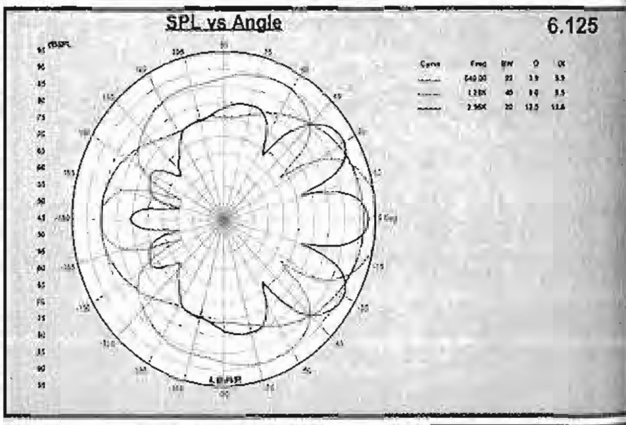


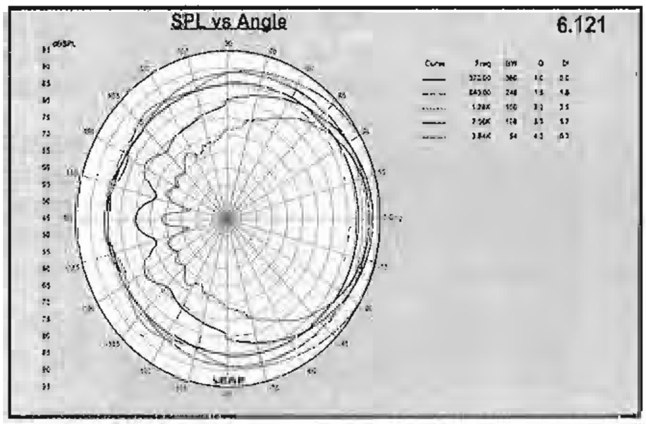












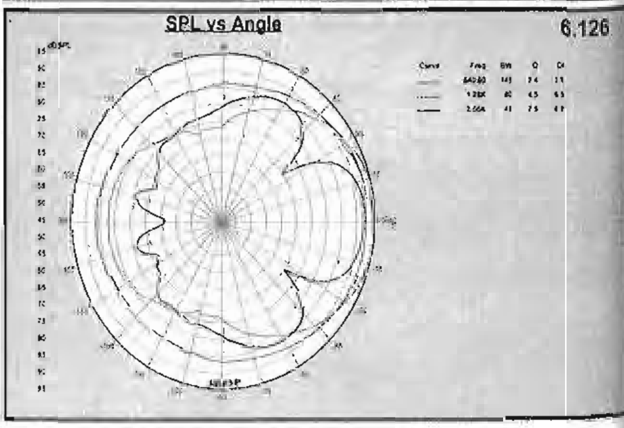


FIGURE 6.118: Frequency response comparison of on-axis close and wide spaced center channels (solid = close spaced woofers, dash = wide spaced woofers).

FIGURE 6.119: On- and off-axis horizontal frequency response for wide spaced woofers (solid = 0°, dot = 15°, dash = 30°).

FIGURE 6.120: On- and off-axis horizontal frequency response for close spaced woofers (solid = 0°, dot = 15°, dash = 30°).

FIGURE 6.121: Vertical polar plot for wide spaced woofers (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.122: Vertical polar plot for close spaced woofers (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.123: Horizontal polar plot for wide spaced woofers (320Hz = solid, 640Hz =dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.124: Horizontal polar plot for close spaced woofers (320Hz = solid, 640Hz = dash, 1.25kHz = dot, 2.56kHz = solid, 3.84kHz = dash).

FIGURE 6.125: Horizontal polar plot for wide spaced woofers (640Hz = dash, 1.25kHz = dot, 2.56kHz = solid).

cabinet dual woofer center channel speakers being offered by the loudspeaker industry, you will notice that spacing between the woofers varies considerably from very close and nearly touching to spread apart at a considerable distance that can be as much as 5-8″ from cabinet center for each woofer. The consequence of wider spacing between the dual woofers is more complex lobing in the horizontal response of the speaker and can be avoided.

Figures 6.116 and *6.117* depict two horizontal center channel scenarios for a speaker with 5.25″ woofers, one with wide spaced woofers each mounted 5″ from the cabinet center, and the other with the two woofers nearly touching. For the speaker in *Fig. 6.117*, the tweeter would be mounted either at the top or bottom of the baffle, on the centerline where the two woofers are mounted. Generally, this requires the use of a small footprint neodymium type dome tweeter. Graphic data for the comparative analysis of these two center channel formats is as follows:

	Wide Spaced	Close Spaced
On-axis for both cabinets	6.118	
On-axis, Horizontal 15, 30°	6.119	6.120
Vertical Polar Plots	6.121	6.122
Horizontal Polar Plots	6.123	6.124
3 Freq. Horizontal Polar Plots	6.125	6.126

As you can see in *Fig. 6.118*, the on-axis response is somewhat different due to the spacing, but nothing that would indicate any kind of SPL problem. Also, in the two vertical polar plots in *Figs. 6.121* and *6.122*, there is no indication of a problem, as these are nearly identical. However, when you look at the horizontal on- and off-axis curves in Figs. *6.119* and *6.120*, it is obvious that the complexity of the off-axis cancellation nulls is much greater for the wide-spaced dual woofer example. However, with a 3kHz low-pass network, it doesn't really look like all that much of an issue.

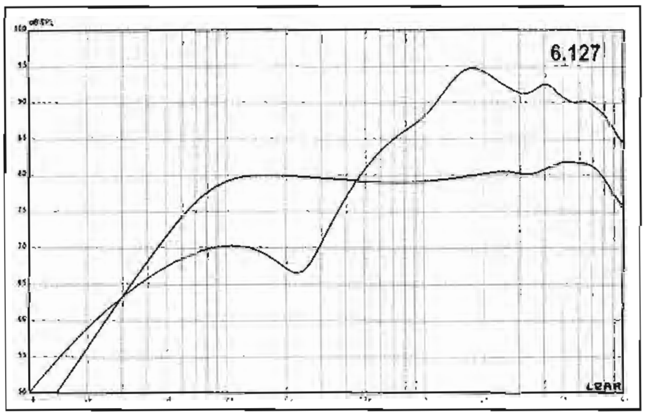
If you now look at the two horizontal polar plots in *Figs. 6.123* and *6.124*, you can get a better feel for what is going on. *Figures 6.125* and *6.126* are the same polar plots as *Figs. 6.123* and *6.124*, but are somewhat easier to read and only display the 640Hz, 1.28kHz, and 2.56kHz frequency bands. The idea is that the closer-spaced woofers will give a more even coverage pattern across your listening audience, especially if they are fairly close to the screen and the speakers.

6.30 RESPONSE VARIATION DUE TO BAFFLE AREA (STEP RESPONSE).

Chapter 5, Cabinet Design: Shape and Damping, discussed the effect that different baffle shapes have on the SPL of a woofer, midrange, or tweeter. However, while exotic shapes are interesting, the fact remains that the majority of loudspeakers both currently and historically are built from simple rectangular boxes. The analogy of a baffle in anechoic space is similar to a flashlight reflector, except that the wavelength of light is at just one frequency (well, actually it's a grouping of wavelengths between 400–800nm), while the bandwidth of a loudspeaker relevant to typical baffle areas is actually quite wide. As the area of a loudspeaker baffle increases, it will offer more and more reinforcement to the very lowest frequencies right up to the point where the baffle becomes infinitely large and reinforces all frequencies from 1Hz to the upper limit of the audio spectrum. Step response is often used to describe this phenomenon, the step being the upper frequency at which the baffle supplies even reinforcement for all frequencies at that frequency and higher.

The example that was simulated in LEAP 5 EnclosureShop to demonstrate the overall SPL changes that occur with increasing total baffle area incorporates a 6.5″ driver. The extremes for any baffle-related response change, as discussed in Chapter 5, are from the speaker being mounted with no baffle in open air to the speaker being mounted on an infinitely large baffle, or half-space. For the 6.5″ example, the simulation curves for these two extremes are given in *Fig. 6.127*. Any realizable baffle response will fall somewhere between these two curves.

The simulation started with the 6.5″ woofer loaded into a small enclosure with a baffle that measured 9.25″ high by 6″ wide, just wide enough for the example driver to fit (*Fig. 6.128*). Keeping the



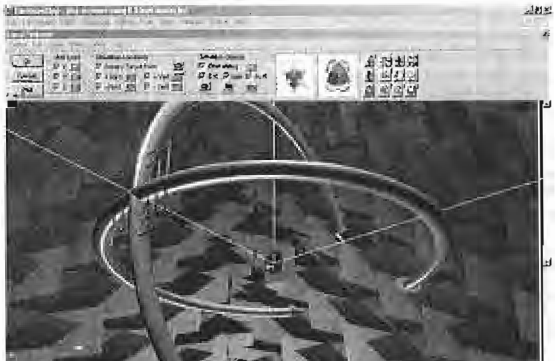


FIGURE 6.126: (*see previous page*) Horizontal polar plot for close spaced woofers (640Hz = dash, 1.25kHz = dot, 2.56kHz = solid).

FIGURE 6.127: Frequency response comparison of 6.5″ woofer with no baffle and with infinite baffle (solid = infinite baffle response, dash = no baffle response).

FIGURE 6.128: Smallest baffle layout for step response.

FIGURE 6.129: Largest baffle layout for step response.

aspect ratio (the ratio of height to width) the same, I increased the baffle width in 1″ increments from 6″ to 12″, and then from 12″ to 20″ in 2″ increments, plus added a final monster baffle that measured 60.6″ × 40″ (*Fig. 6.129*).

I programmed all the various baffle sizes into LEAP 5 and performed on-axis 2.83V/1m simulations for all 13 baffle sizes. The results are shown in *Figs. 6.130–6.133*. The series of graph curves begins with all of the SPL curves displayed simultaneously along with the reference half-space infinitely large baffle curve (*Fig. 6.130*). While this many curves on one graph are difficult to read, you can definitely see the emerging pattern. As the baffle mutates from a 6″ width to a 40″ width, two major features are apparent.

First, the peak at 1.1kHz in the 6″ wide baffle curve decreases in frequency as the baffle area increases. Next, the amplitude of the 100Hz corner frequency of the high-pass rolloff of this driver gradually increases from 70dB for the smallest baffle area to 83dB for the largest baffle area. Looking at *Fig. 6.131*, which represents the baffle widths from 6″ to 12″ in 1″ increments, the 1.1kHz peaking in the 6″ wide baffle not only decreases in frequency as the baffle area increases, but the peak also decreases somewhat in amplitude in this series.

The group of curves in *Fig. 6.132* shows the progression from 12″ wide to 20″ wide in 2″ increments, again showing an inverse relationship with the peaking in the response decreasing in frequency as area increases, but this time a small increase in amplitude occurs as the area increases. This SPL pattern is somewhat easier to see in *Fig. 6.133*, where the graph has three curves starting at a 10″ baffle width, doubling to 20″ and then 40″. *Figure 6.134* compares the largest 40″ wide baffle with a half-space measurement of the driver, showing that this process is definitely mutating to half-space.

This raises an interesting issue about which design format is subjectively superior: a loudspeaker in an off-wall cabinet with some kind of defined baffle area and shape, or an in-wall speaker with comparatively large baffle area the size of a house wall. Over the years I have designed a number of in-wall products for various companies including M&K Sound, Parasound, Posh Audio, coNEXTion, and a THX Ultra in-wall for Atlantic Technology, as well as a rather large number of off-wall speakers.

In a 2005 interview by Brent Butterworth in *Robb Report Home Entertainment* magazine[1], I was asked the question of which worked best, in-wall or off-

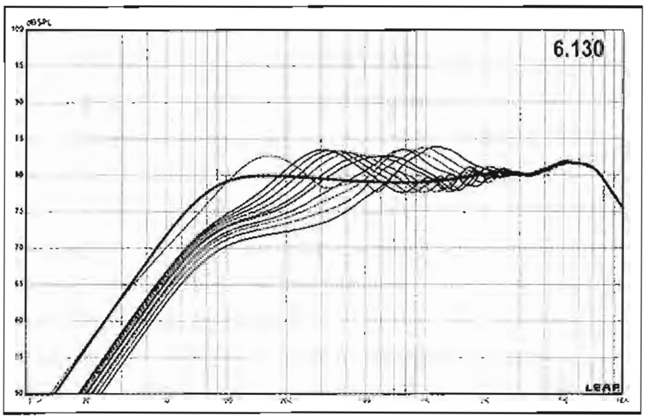


FIGURE 6.130: On-axis requency response comparison of all 12 baffle sizes with infinite baffle base curve (thick solid = infinite baffle response).

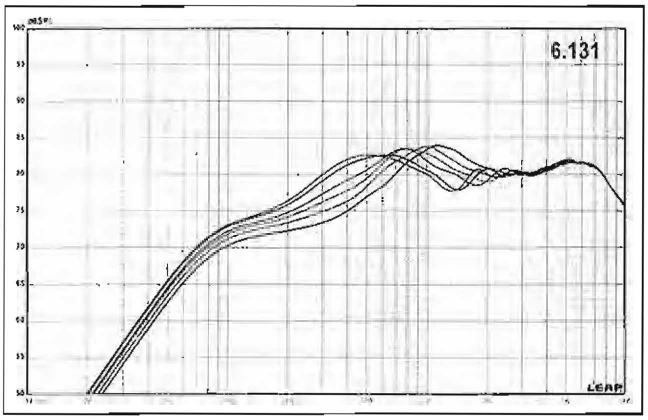
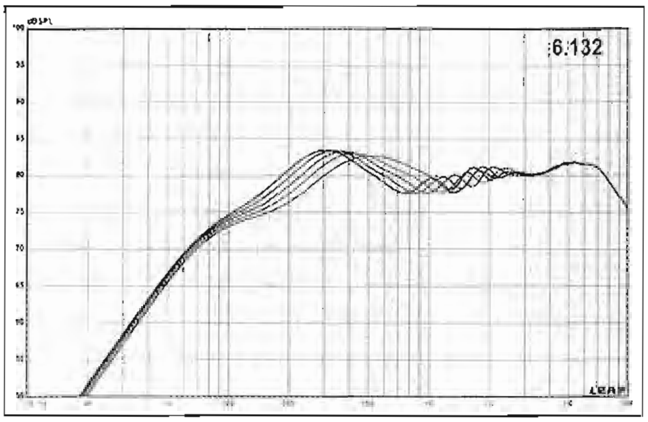


FIGURE 6.131: On-axis requency response comparison of seven baffle sizes in 1″ incre- nents from 6″ wide to 12″ wide.



IGURE 6.132: On-axis frequency re- ponse comparison five baffle sizes in ″ increments from 12″ wide to 20″ wide.

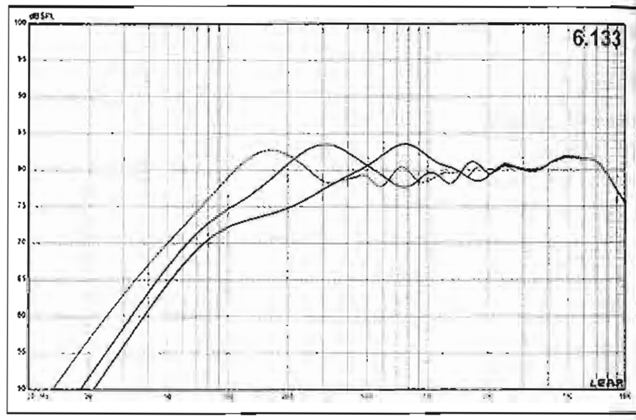


FIGURE 6.133: On-axis frequency response compari- son of three baffle sizes, 10″ wide, 20″ wide, and 40″ wide (solid = 10″ vide baffle, dash = 0″ wide baffle, dot = 40″ wide baffle).

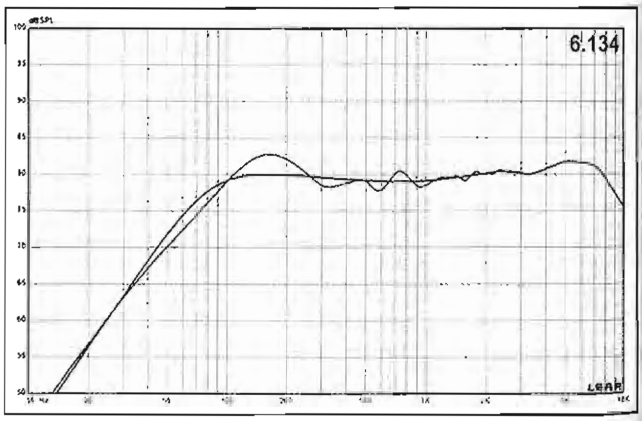
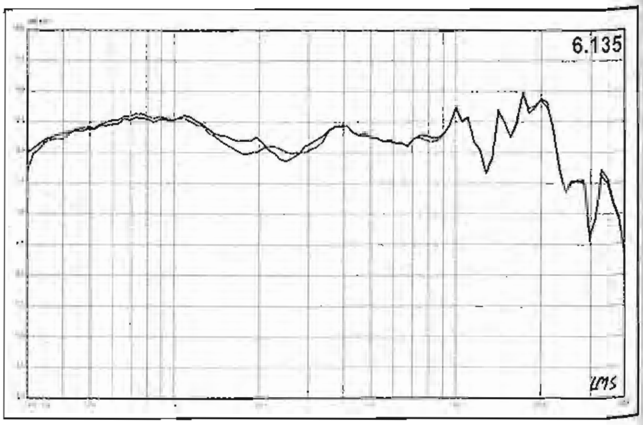


FIGURE 6.134: On-axis frequency esponse compari- son of the largest baffle size with the infinite baffle response (solid = nfinite baffle, dash = 40″ wide baffle).



IGURE 6.135: On-axis frequency re- ponse comparison of an undamped nd a foam damped baffle (solid = no surface damping on baffle, dash = am damped baffle surface).

wall speakers. Because Mr. Butterworth has been measuring and reviewing home theater loudspeakers for a number of years, first in *Home Theater* magazine, and then for *Robb Report*, he has had the opportunity to observe the loudspeaker industry trend of home theater speakers being placed physically out of sight in a home theater, as they are in a real commercial theater. Rather than have the LCR (Left, Center, Right), surrounds, subwoofer, and rear channels all sitting on the floor (or placed on speaker stands) away from the walls or even mounted on the walls, many installations have speakers that are hidden behind curtains, behind grilles in home entertainment centers, mounted in the wall, or mounted in the ceiling. Chapters 5 and 6 have spent much effort defining the SPL modification that a discrete baffle has on the response of a speaker, but also made it apparent that the larger the baffle, the more even and smooth a response the drivers will be able to produce.

While it might be tempting to either conclude that in-wall baffles are superior for this reason, or, to the contrary, adapt an elitist attitude that in-wall speakers are inherently inferior (it's only been since perhaps the year 2000 that really high-end in-wall speakers have appeared on the market, and prior to that they were mostly distributed audio speakers intended for a muzak scenario, totally repugnant to any self-respecting audiophile), the truth is that neither of these would be correct. My answer to Brent's insightful question is that you can take any given set of drivers and make them sound musical in either design format, in-wall or off-wall; it's just a matter of design criteria. Each platform provides a launch vehicle for a wave front, and the fact remains that you have several choices on how to get sound into a room. In my experience as a loudspeaker design consultant, you can easily make all of these formats (on-wall, off-wall, in-wall, or in-ceiling) work extremely well.

6.40 BAFFLE DAMPING.

All baffles reflect sound. As the initial wave-front propagates from the driver diaphragm, it travels over the surface of the baffle, and part of the energy is reflected and some diffracted off edges and protrusions. All of these incidental aspects of the composite wave front unavoidably involve some small time delay (up to 0.5mS[2]) compared to the initial wave front emanating from the driver diaphragm. This acoustic "clutter" tends to smear the sonic detail and muddy your subjective musical perception.

As a consequence, much effort over the years has gone into limiting this problematic consequence. Various ideas have been patented and incorporated for this purpose, but the two basic approaches are to either scatter the reflective energy in all directions, or to damp it as much as possible. B&W has used plastic baffles with a 3-D surface composed of hundreds of tiny pyramids that were supposed to scatter reflective energy, and numerous speaker designers, including models from Cizek and SRA (my first company) in the mid to late 1970s, have used die cut sheets of acoustic foam to cover all or part of a baffle.

The measured differences between an undamped and damped baffle can range from fairly impressive to not particularly significant, depending on the type and amount of material[3]. The on-axis curves shown in *Fig. 6.135* are for a 15.75" × 10" × 8" enclosure with a 3" full-range (the driver mounted about 3" down from the top of the baffle and centered) both with and without a ¼" thick foam-damping material covering the entire surface of the baffle up to the edges of the driver. The material was a specialized acoustic foam-damping product that came from Soundcoat, an OEM noise-control manufacturer.

As you can see, the primary damping effect occurred between 1kHz and 3.5kHz for this particular material; however, if you look at the on-axis CSD (Cumulative Spectral Decay) plots done with a CLIO MLS analyzer in *Figs. 6.136–6.137*, you can also see decay differences that occur at different parts of the bandwidth (see *Fig. 6.136* for the waterfall plot without foam material on the baffle and *Fig. 6.137* for the waterfall plot with the Soundcoat foam attached). This changes significantly off-axis, as seen in the 30° off-axis curve comparison in *Fig.*

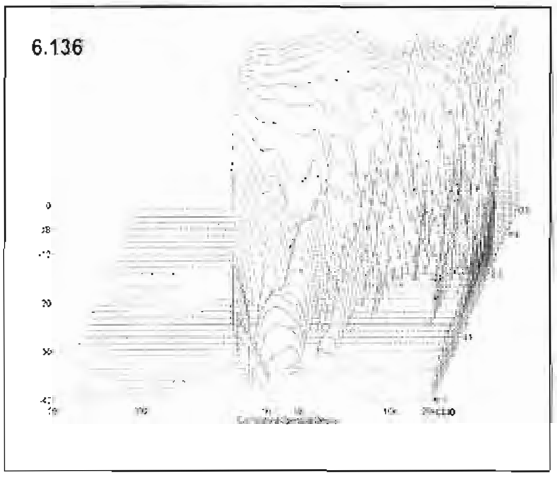


FIGURE 6.136: CLIO CSD plot of undamped baffle.

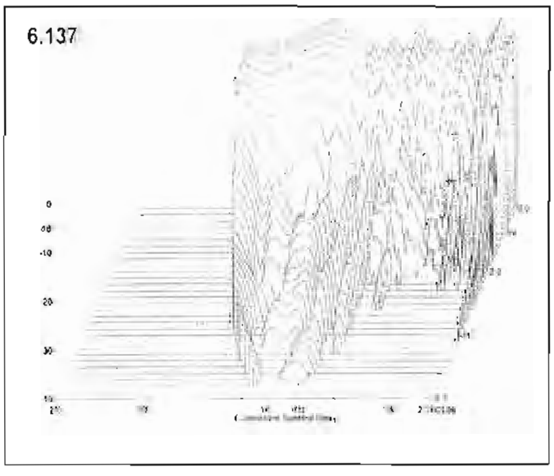


FIGURE 6.137: CLIO CSD plot of foam damped baffle.

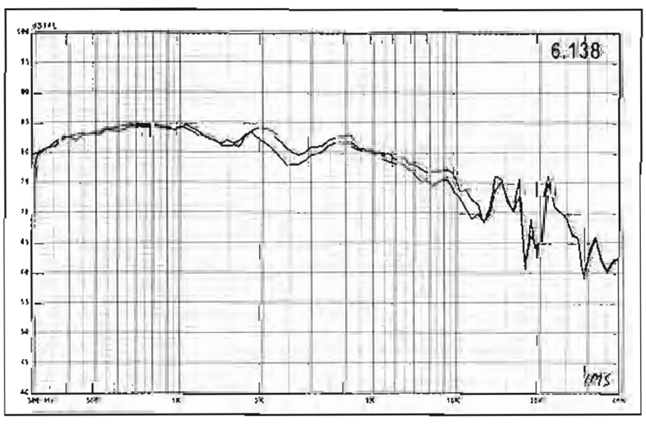


FIGURE 6.138: 30° off-axis frequency response comparison of an undamped and a foam damped baffle (solid = no surface damping on baffle, dash = foam damped baffle surface).

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.

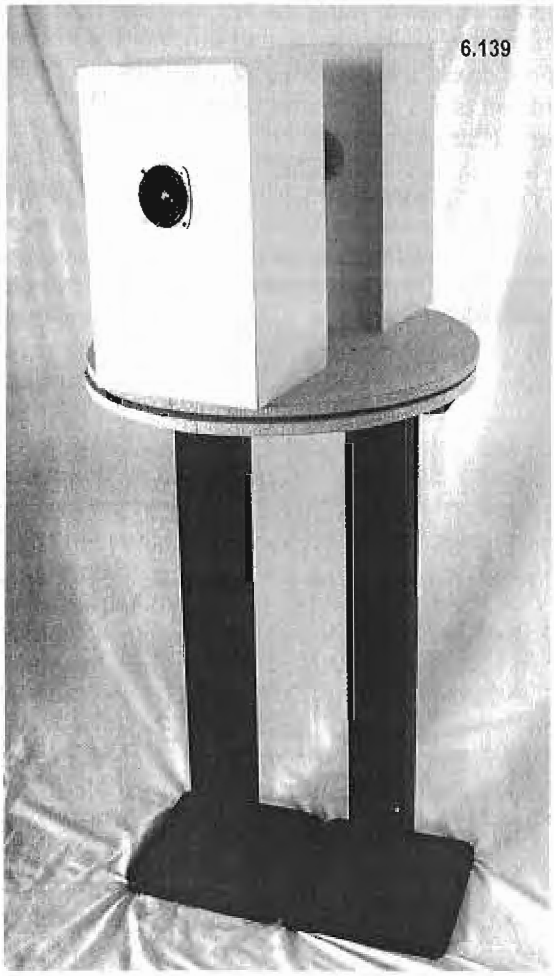
A total of five separate tests were performed to determine the subjective nature of the various aspects of diffraction.

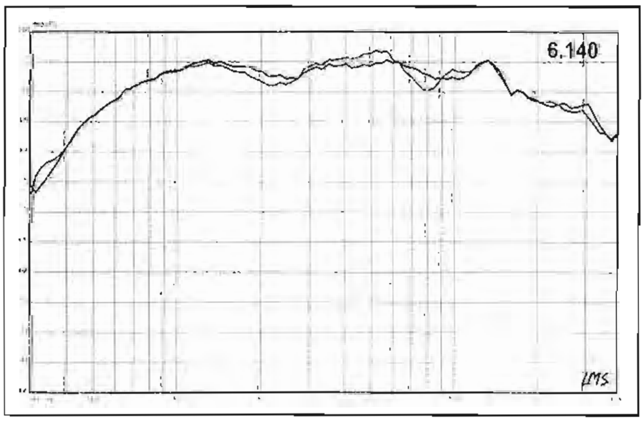
Test #1—Tweeter Inset—the loudspeaker industry has spent probably millions of dollars recessing tweeters and other drivers over the years. The practice undoubtedly began because of measured differences in surface-mounted drivers and inset drivers, but also has probably continued as a cosmetic affectation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

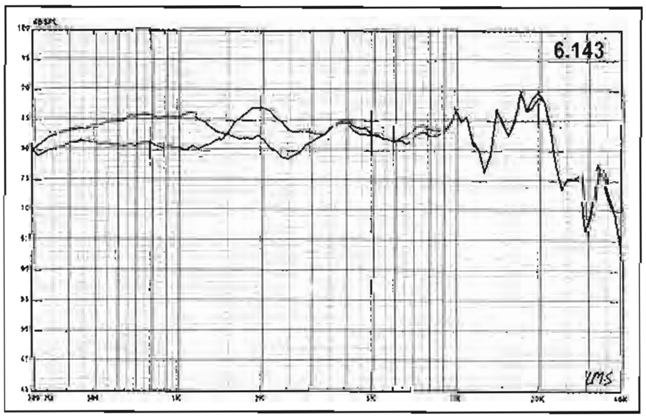
The test was simple: A/B compare two identical tweeters (Vifa DX25TG05-04 1" soft domes)—one inset flush with the baffle and the other surface mounted. I mounted both tweeters on the front baffle of a 15.75" × 10" × 8" enclosure and centered them 3" down from the top of the baffle. I used the LinearX 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







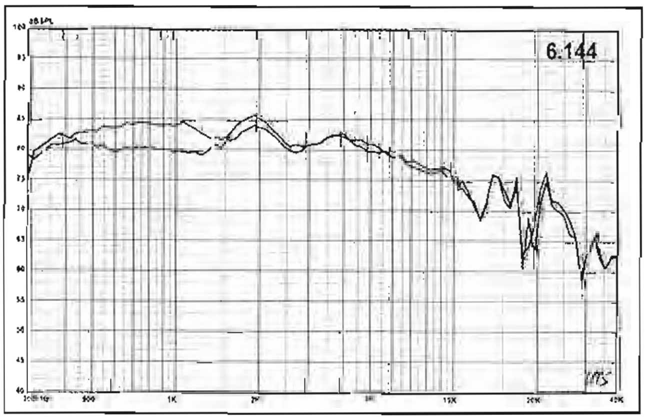


FIGURE 6.139: Picture of the rapid A/B comparison fixture.

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

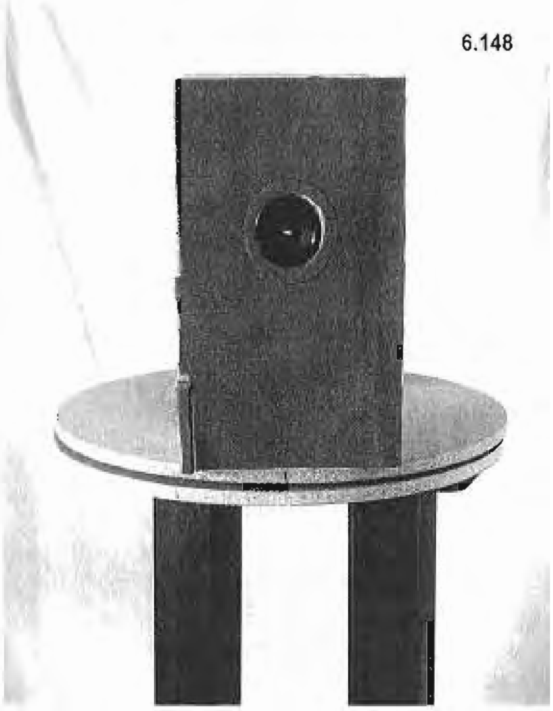
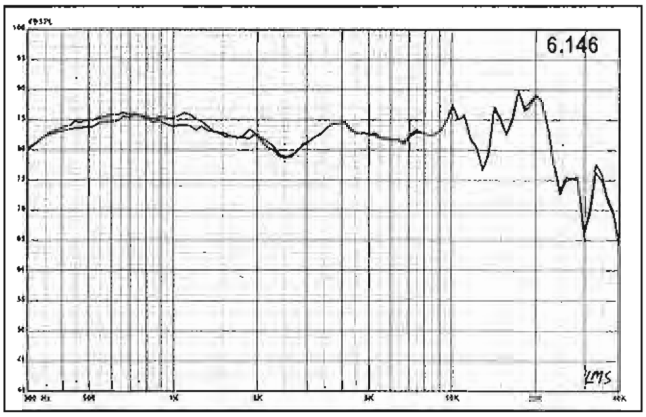


FIGURE 6.145: Picture of the compound beveled edge baffle for diffraction subjective Test #3.

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.



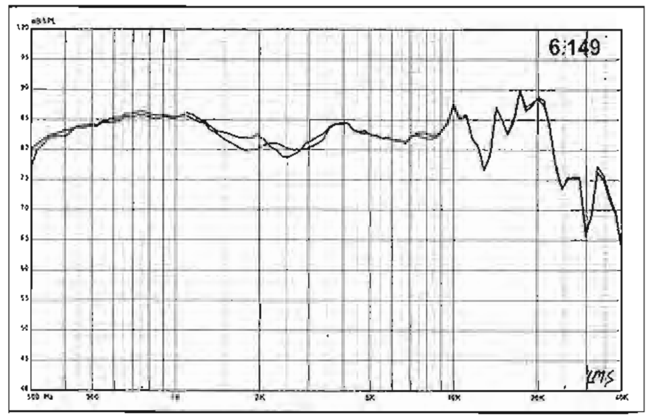
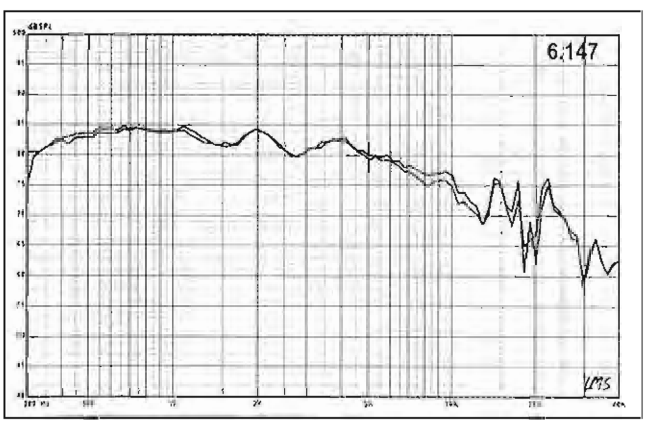


FIGURE 6.149: Test #4 on-axis frequency response comparison of an undamped baffle and foam damped baffle (solid = plain baffle, dash = foam damped baffle).



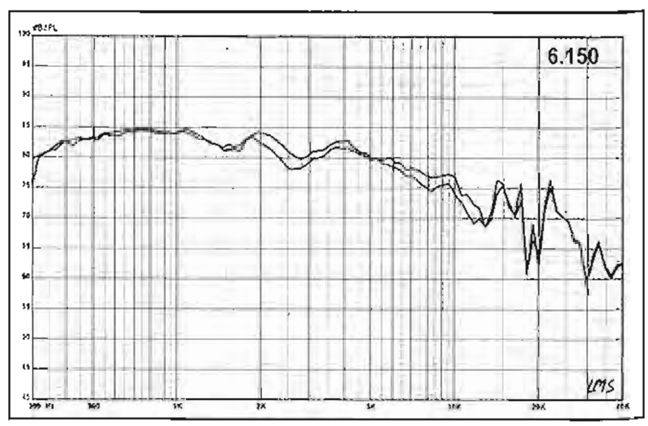


FIGURE 6.150: Test #4 30° off-axis frequency response comparison of an undamped baffle and foam damped baffle (solid = plain baffle, dash = foam damped baffle).

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, bnt I tend to

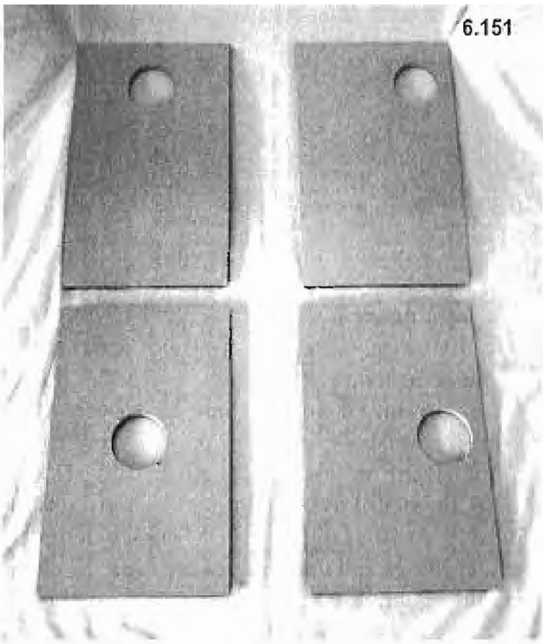


FIGURE 6.151: Baffle locations for subjective diffraction Test #5.

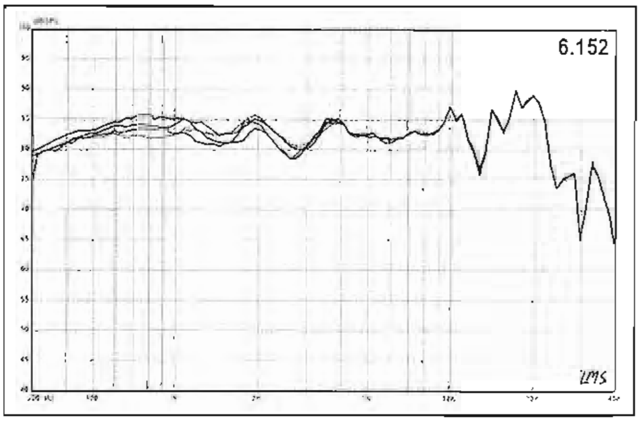


FIGURE 6.152: Test #5 on-axis frequency response comparison of different baffle locations (solid = center location, dot = top offset location, dash = top center location, dash/dot/dot = center offset location).

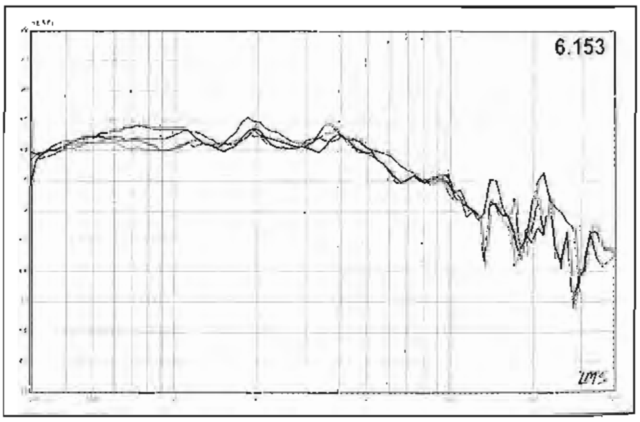


FIGURE 6.153: Test #5 30° off-axis frequency response comparison of different baffle locations (solid = center location, dot = top offset location, dash = top center location, dash/dot/dot = center offset location).

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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