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A Ground Plane Measurement Comparison Between two Floor-Standing Loudspeaker Systems: A Conventional Three-Way Studio Monitor vs. A Ground-Plane Constant Beamwidth Transducer (CBT) Line Array

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ABSTRACT

This paper compares two different types of floor-standing loudspeaker systems. Both were measured over an acoustically reflective hard surface in a large space. The first is a high-performance conventional three-way 12"-woofer studio monitor and the second is a ground-plane circular-arc CBT line array loudspeaker. Measurements included direct-field frequency responses in front of the systems at 20 grid locations ranging over different distances/heights and response vs. distance at seated and standing heights. Horizontal off-axis and near-field responses were also gathered along with ceiling illumination responses at several launch angles. The measurements reveal that the CBT system has vastly more even coverage at all these locations compared to the three-way monitor and in addition eliminates the detrimental effects of floor bounce.

1. INTRODUCTION

1.1. General Comments

This paper compares the sound radiated by two different types of loudspeaker systems operated on an acoustically reflective ground plane.

The two systems compared are very different, one is a high-quality conventional three-way floor-standing studio monitor loudspeaker (the B&W Matrix 801 [1]) and the other is a circular-arc two-way ground-plane CBT line array loudspeaker [the CBT36k [2]].

1.2. Measurement Scenario

The measurement scenario consisted of gathering ground-plane direct-field frequency response

information at many different points in front of and to the sides of the systems.

1.3. Types of Measurements

The ground-plane measurements accomplished include:

- 1) Frequency response vs. height at different distances,
- 2) Frequency response vs. distance at seated and standing heights,
- 3) Off-axis horizontal frequency response,
- 4) Near-field frequency responses close to the array, and
- 5) Ceiling-directed frequency responses at several upward launch angles that illustrate the spectrum of acoustic energy aimed upward that contribute to the room's reverberant field.

1.4. Brief Overview of CBT Arrays

This section briefly describes CBT line array theory.

CBT or Constant Beamwidth Transducer theory is based on un-classified military under-water transducer research done in the late 1970s and early 80s and was applied to loudspeaker arrays by the author in a series of 12 AES technical papers between 2000 and 2016 [3-14]. CBT arrays provide wide-band extremely constant coverage and directivity behavior with virtually no side lobes.

1.5. Free-Standing CBT Line Arrays

As described in [3], a general CBT line array is formed by a continuous circular-arc acoustic source of arbitrary angle and size with special frequency-independent shading provided by a Legendre function. The shading controls the amplitude of the source as a function of its angle with the level maximum in the center and tapering off on either end of the arced source. The theory can be extended to discrete arrays of point sources like loudspeakers. Figure 1 illustrates a free-standing CBT circular-arc line array with frequency-independent Legendre shading.

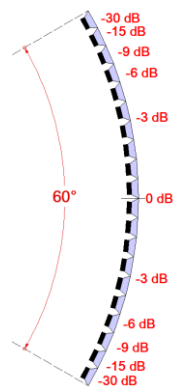


Fig. 1. Illustration of a free-standing (not a ground-plane) version of a discrete-source CBT 60° circular-arc loudspeaker line array with Legendre shading. The frequency-independent shading levels are maximum in the center of the array and tapers off towards the outside edges.

1.6. Ground-Plane CBT Line Arrays

A ground-plane CBT line array can be formed from a free-standing CBT line array by dividing the free-standing line array in half at its center and then lowering the resultant array down to a flat acoustically reflective surface [7].

When positioned close to the flat reflective surface the acoustic reflections essentially recreate the missing half of the array.

This paper compares a ground-plane version of the CBT array with a conventional three-way loudspeaker system, both measured over the ground-plane.

1.7. Measurement Scenario

Experimental measurements were gathered over an acoustically-reflective concrete floor in a large storage space. These measurements assessed the sound field generated by the systems when operated in a non-anechoic environment but when located over a reflective ground plane.

All frequency response curves were gathered with custom software written by the author based on Angelo Farina's log-sweep technique. The impulse responses were windowed with a 50 ms half-Hann window and all time-of-arrival offsets were compensated before converting to the frequency domain. All frequency response curves were smoothed with a 1/12th-octave filter.

2. DESCRIPTION OF CONVENTIONAL THREE-WAY LOUDSPEAKER SYSTEM

For comparative ground-plane frequency-response measurements, a high-quality three-way studio monitor was chosen: the B&W Matrix 801 Series 2 loudspeaker [1]. This system represented the pinnacle of conventional floor-standing loudspeaker systems circa 1988 and is held in high regard by all.

Fig. 2 shows photos and a side-view cross section of the system.

2.1. Brief Description

A three-way, reflex-loaded, floor-standing loudspeaker. Drive-units: 1" (26mm) tweeter, 5" (126mm) cone midrange unit, 12" (300mm) woofer. Crossover frequencies: 380 Hz and 3 kHz. Frequency response: 20Hz-20kHz \pm 2dB free-field. Sensitivity: 87dB/W/m.

2.2. Dimensions and Weight

Dimensions: 1 m x 0.43 m x 0.55m, HxWxD (39 11/16" x 17" x 22").

Weight: 50 kg (110 lbs).

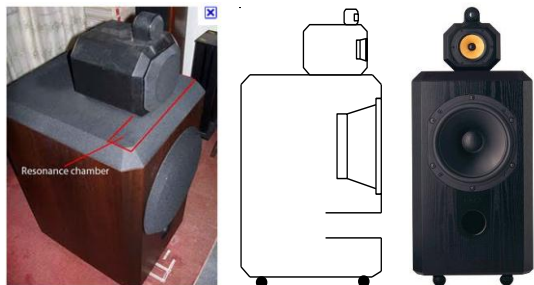


Fig. 2. Photos and depiction of the conventional three-way studio-monitor system, the B&W Matrix 801 Series 2 loudspeaker [1]. Left: Oblique view. Center: side view. Right: front view.

3. DESCRIPTION OF FLOOR-STANDING GROUND-PLANE CBT ARRAY

The CBT line array system measured for this comparison is a two-way 1.5 m (5 ft) tall 36° circular-arc ground-plane CBT system sold by Parts Express as a DIY loudspeaker kit [2].

3.1. Brief Description

A two-way floor standing circular-arc high-end loudspeaker line array. Each system contains 18 ea 3-1/2" full-range drivers used as mid woofers and 72 ea 3/4" diameter wide-band tweeters that are crossed over at 1 kHz.

Fig. 3 shows a photo and side-view cross section of the system, along with a front panel view with the five Legendre shading banks indicated. The shading attenuates the upper drivers with respect to the lower drivers.

The system is bi-amped and uses a DSP-based speaker EQ/processor along with two stereo power amplifiers. The system can be used down to 60 Hz without a separate subwoofer.

3.2. Dimensions and Weight

Dimensions: 1.5 m x 0.18 m x 0.63 m, HxWxD (61" x 7" x 25").

Weight: 25 kg (55 lbs)

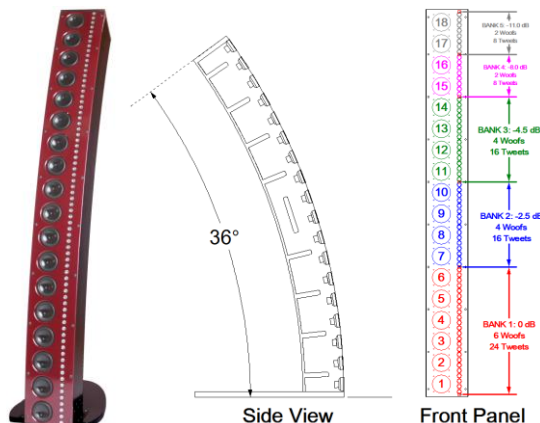


Fig. 3. Depictions of the floor-standing ground-plane CBT loudspeaker array. The system is the CBT36k kit system sold by Parts Express [2]. It houses 18 ea 3-1/2" full-range drivers and 72 ea 3/4" dome tweeters. Left: Oblique view. Center: side view. Right: front panel view showing the positions of the five CBT Legendre shading banks.

4. MEASUREMENTS

This section shows the results of the measurements outlined in Section 1.3.

4.1. Anechoic On-Axis Frequency Response of Conventional System

The conventional system's anechoic on-axis frequency response is shown in Fig. 4. This curve was not measured for this paper but was measured by the author for a loudspeaker review he did of the B&W 801 for *Audio Magazine* in 1990. It shows a commendably flat response over the complete audio band. It must be noted that the response was not measured over a reflective ground plane. It is a windowed pseudo-anechoic frequency response.

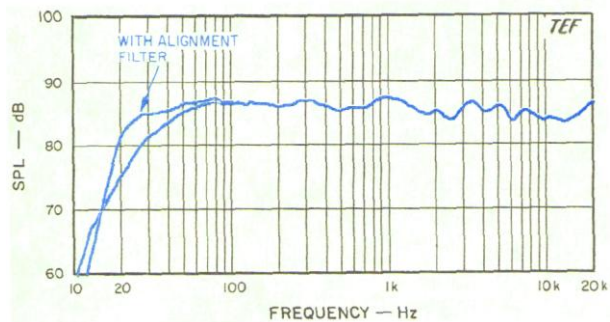


Fig. 4. On-axis 2.83 Vrms/1m anechoic frequency response of the conventional three-way system. This response was measured by the author in his 1990 loudspeaker review published in *Audio Magazine*.

4.2. Ground-Plane On-Axis Frequency Responses of Both Systems

The on-axis frequency responses of both systems were measured over the ground plane. Here, “on axis” means a frequency response measured at 1 m in front of the system at 1 m above the ground plane. It is noted that this height is essentially equal to the height of the tweeter in the conventional system. There is nothing magic about this location for the CBT array because its vertical coverage is so very even.

These two frequency responses are shown in Fig. 5. Note the floor-bounce dip exhibited by the conventional system at about 250 Hz. In contrast with this, the response of the CBT array is very flat and exhibits no floor-bounce effects whatsoever! The CBT array is specifically designed to operate over the ground plane.

The conventional system was measured by applying an input voltage of 2.83 Vrms and the vertical axis is SPL calibrated. Also note that although the CBT array is an active system, its overall level was raised to roughly equal the SPL level of the conventional system.

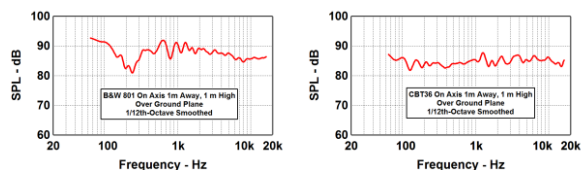


Fig. 5. Ground-plane on-axis measurements of frequency response. Left: conventional three-way system, Right: ground-plane CBT line array system. The test mic was located 1 m from the base of each system and 1 m above the acoustically reflective floor. Note the 250 Hz floor dip exhibited by the conventional system (left graph) and the absence of this effect in the CBT array response (right graph).

4.3. Ground-Plane Frequency Response vs. Height at Different Distances

The frequency response of both systems was measured over the ground plane at several heights and distances in a grid of locations which extended in height from 0 to 2 m at five locations and distance from 0.1 to 3 m at four locations. This made a total of 20 measurements.

To summarize, data was gathered at five vertical locations in front of the systems: 0.0, 0.5, 1.0, 1.5, and 2.0 m. Four distances in front of the systems were measured: 0.1, 1.0, 2.0, and 3.0 m. Note that the 0 m height is actually on the floor and the 2 m height is a distance significantly above the top of both systems. The distance measurements start at 0.1 m which is only

4” from the bottom front of the systems and is very close to each system.

4.3.1. Distance = 0.1 m

This subsection illustrates the frequency response of each system at five vertical locations at a distance of 0.1 m. Note that this distance is essentially directly in front of each system. Fig. 6 illustrates these vertical measurement locations for each system while Fig. 7 shows the results of the measurements.

Note additionally, that the conventional system *is not* designed to be listened to at locations this close to the system! As a result its response curves measured this close are extremely rough as evidenced by the curves shown on the left in the following Fig. 7. The 1 m height is essentially directly in front of the tweeter of the conventional system and as result its level is very high (top red curve on the left in Fig. 7). In contrast, the CBT array responses are extremely well behaved at this close distance!

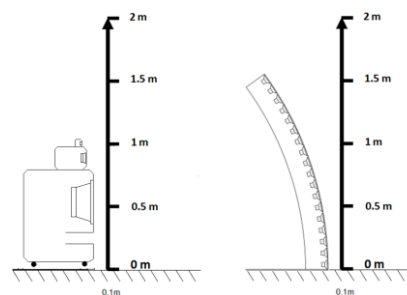


Fig. 6. Vertical test mic locations for ground-plane frequency response measurements at a distance of 0.1 m for the two systems. Left: conventional system. Right: CBT line array system. Note that 0.1 m (about 4”) is very close to the front edge of each system! Five vertical locations were chosen at increments of 0.5 m from 0 m (on the floor) up to 2 m above the top of each system.

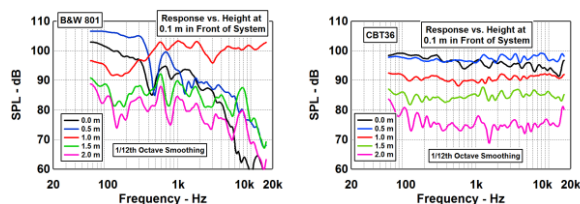


Fig. 7. Ground-plane frequency responses vs. height at a distance of 0.1 m. Left: conventional system. Right: CBT line array system. Note that at this very close distance, the very poor responses at each height exhibited by the conventional system compared to the nearly-perfect responses at each height for the CBT array.

4.3.2. Distance = 1 m

This subsection illustrates the frequency response of each system at five vertical locations at a distance of 1 m. Fig. 8 illustrates the vertical measurement locations for each system while Fig. 9 shows the results of the measurements. This distance is still quite close to the conventional system and its rough responses illustrate this (left graph, Fig. 9). The CBT array curves are still very uniform at 1 m (right graph, Fig. 9).

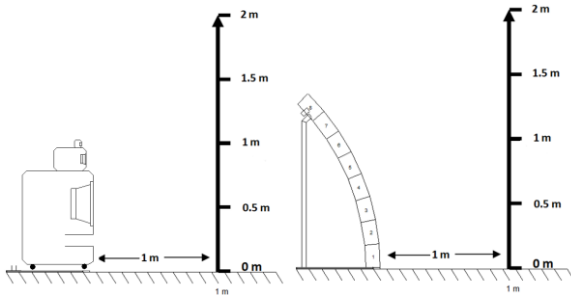


Fig. 8. Vertical test mic locations for ground-plane frequency response measurements at a distance of 1 m for the two systems. Left: conventional system. Right: CBT line array system. Refer to Fig. 6 for further test mic height details.

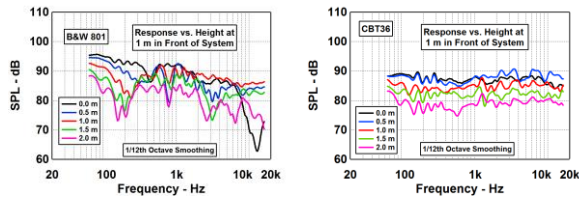


Fig. 9. Ground-plane frequency responses vs. height at a distance of 1 m. Left: conventional system. Right: CBT line array system. As before, the conventional system exhibits very poor response at all heights compared to the CBT line array system.

4.3.3. Distance = 2 m

This subsection illustrates the frequency response of each system at five vertical locations at a distance of 2 m. Fig. 10 illustrates these vertical measurement locations for each system while Fig. 11 shows the results of the measurements. At this farther distance, the conventional system's responses are starting to improve while the CBT array's responses are still quite uniform.

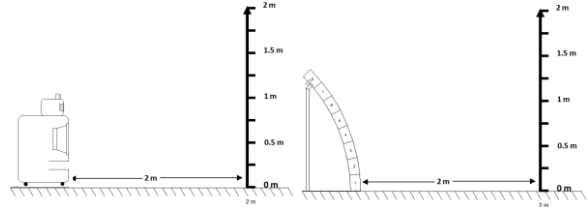


Fig. 10. Vertical test mic locations for ground-plane frequency response measurements at a distance of 2 m for the two systems. Left: conventional system. Right: CBT line array system. Refer to Fig. 6 for further test mic height details.

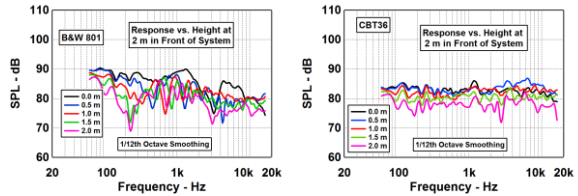


Fig. 11. Ground-plane frequency responses vs. height at a distance of 2 m. Left: conventional system. Right: CBT line array system. At this farther distance, the conventional system's response with height is improved but is still poor compared to the CBT line array system.

4.3.4. Distance = 3 m

This subsection illustrates the frequency response of each system at five vertical locations at the farthest distance measured of 3 m. Fig. 12 illustrates these vertical measurement locations for each system while Fig. 13 shows the results of the measurements.

At 3 m the family of responses of the conventional system are definitely much improved but are still quite rough and fit a relatively large envelope of about 20 dB (+/- 10 dB) from 100 Hz to 16 kHz (left Fig. 13). In contrast, the CBT array's responses are quite flat and well behaved and fit a much tighter envelope of about 10 dB (+/- 5 dB) over the same frequency range (right graph in Fig. 13).

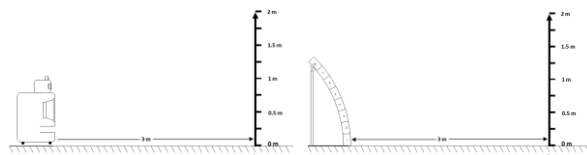


Fig. 12. Vertical test mic locations for ground-plane frequency response measurements at a distance of 3 m for the two systems. Left: conventional system. Right: CBT line array system. Refer to Fig. 6 for further test mic height details.

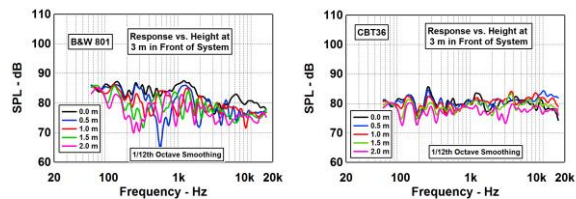


Fig. 13. Ground-plane frequency responses vs. height at a distance of 3 m. Left: conventional system. Right: CBT line array system. Even at this farthest measured distance of 3 m, the conventional system’s response with height is still inferior compared to the CBT line array system.

4.4. Frequency Response vs. Distance Comparing Conventional Three-Way System with CBT Array: Seated vs. Standing

This subsection illustrates the frequency response of both systems as a function of distance for both seated and standing listeners. These locations are important because they represent what a person hears at these locations when they are sitting down or standing up at these distances.

Data was gathered at two ear heights: Sitting: 1 m (40”) and Standing: 1.7 m (68”); at four distances in front of each system: 0.1, 1.0, 2.0, and 3.0 m. The seated responses are the same responses measured at 1 m high in the data gathered in Section 4.3 while the standing-height responses are from a new set of measurements.

4.4.1. Seated Listener

This subsection illustrates the frequency response of each system at four distances at an ear height of 1 m for a seated listener. Fig. 14 illustrates the measurement locations for a seated listener at each distance for each system while Fig. 15 shows the results of the measurements.

The conventional systems seated-height responses (left graph Fig. 15) illustrate the wide variation of its volume level from near to far. The 1 m height is roughly on axis of the tweeter and midrange and as a result, the level is very loud at the 0.1 m close distance. The conventional system’s level changes nearly 25 dB from near to far. This is in contrast to the CBT array’s responses which are much flatter and only drop by about 10 dB over the same distance range!



Fig. 14. Illustration of test mic locations for a seated listener at an ear height of 1 m for both systems. Left: conventional system. Right: CBT line array system. The mic locations spanned a distance of 3 m with four locations from 0.1 m to 3 m in steps of 1 m. The first location was very close to the front of each system at 0.1 m!

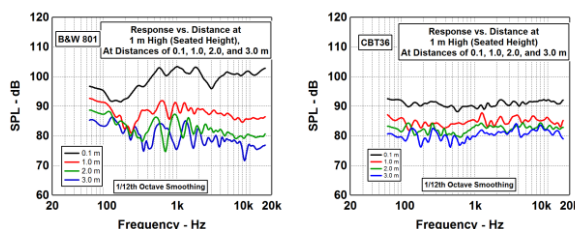


Fig. 15. Ground-plane frequency responses vs. distance for a seated listener at a height of 1 m. Left: conventional system. Right: CBT line array system. Note that this height roughly corresponds to the tweeter height of the conventional system. The CBT system responses are still much flatter than the conventional system at all these distances and further more only exhibits a drop of roughly 10 dB from near to far.

4.4.2. Standing Listener

This subsection illustrates the frequency response of each system at four distances at an ear height of 1.6 m (64”) for a standing listener. Fig. 16 illustrates the measurement locations for a standing listener at each distance for each system while Fig. 17 shows the results of the measurements.

At all these distances, the conventional system still exhibits rough responses and clearly shows the effects of floor bounce between 150 and 500 Hz (left graph Fig. 17). The conventional system still exhibits a significant drop in level from near to far for a standing listener and barely fits a wide envelope of nearly 20 dB (± 10 dB).

This is in contrast with the CBT array responses which are extremely flat and well behaved and fit a very close envelope of only about 8 dB (± 4 dB) from near to far. The volume level of the CBT array essentially does not change over this wide variation of distance!

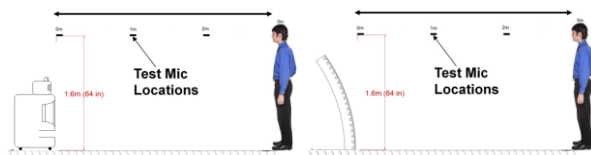


Fig. 16. Illustration of test mic locations for a standing listener at an ear height of 1.6 m (64 inches). Left: conventional system. Right: CBT line array system. The mic locations spanned a distance of 3 m with four locations from 0.1 m to 3 m in steps of 1 m. The first location was very close to the front of each system at 0.1 m!

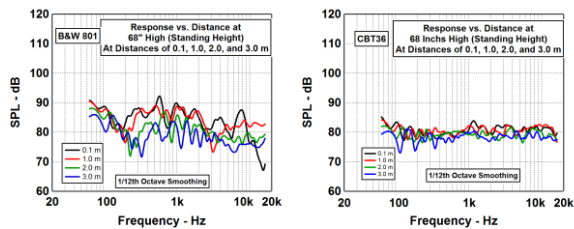


Fig. 17. Ground-plane frequency responses vs. distance for a standing listener at a height of 1 m. Left: conventional system. Right: CBT line array system. Note that this height is above the top of either system. The responses of the conventional system are still quite rough and exhibit a drop of nearly 20 dB from near to far. This is in contrast to the CBT line array system where the responses are all quite flat and exhibit essentially no drop from near to far!

4.5. Detailed Frequency Response vs. Distance of CBT Array: Seated vs. Standing

This subsection is somewhat similar to the previous section in that it shows frequency responses at different distances for seated and standing listeners. Here though, the measurements are only of the CBT line array and go into more response detail by adding additional measurement points between those analyzed in the previous section.

Previously, only four measurement points were chosen, in this section, three more locations are added making seven in all. This section emphasizes the performance of the CBT line array by illustrating its SPL vs. distance performance for seated and standing listeners.

Data was gathered at two ear heights: Sitting: 1 m (40”) and standing: 1.7 m (68”). Seven distances were chosen with increments of about 0.5 m: 0.1, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 m.

Fig. 18 illustrates the measurement locations for both the seated and standing listener at each distance while Fig. 19 shows the results of the measurements.

Note that the extreme uniformity and flatness of all these responses at both heights. The level drops only by about 10 dB near to far for the seated listener but essentially does not drop at all for the standing listener! This means that for a specific loudness in the rear of a listening space, the level does not get any louder as a standing listener walks up to the system. Conversely, for a specific level up close to the system, the level does not drop as a standing listener walks away from the system and goes to the rear of the listening space.

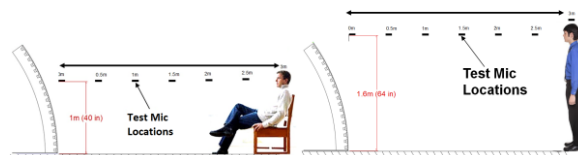


Fig. 18. Illustration of test mic locations for a seated (left) and standing listener (right) for the CBT line array system. Ear heights were 1 m seated and 1.6 m standing. The mic locations spanned a distance of 3 m with seven locations from 0.1 m to 3 m in steps of 0.5 m. The first location was very close to the front of the system at only 0.1 m (4”)!

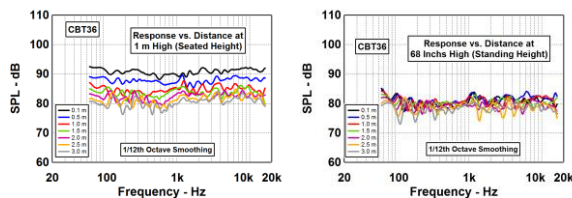


Fig. 19. CBT line array ground-plane frequency responses vs. distance for a sitting and standing listener. Left: seated listener. Right: standing listener. Note the uniformity of both sets of responses. The seated responses only drop about 10 dB over this wide distance range while the standing height responses essentially don’t drop at all, i.e. the level remains the same at all these locations!

4.6. Off-axis Horizontal Frequency Response of CBT Array

This subsection illustrates the horizontal off-axis behavior of the CBT line array. The off-axis response was measured at two locations: on the surface of the ground plane and at 1 m above the ground plane. Both were measured at a distance of 2 m in front of the bottom edge of the array.

Data was gathered at seven angles from 0° to 90° at increments of 15° and two heights of 0 m (on the ground plane) and 1 m (40”) over the ground plane. Data was measured on the side with tweeters closest to the edge of the enclosure.

Fig. 20 illustrates the test mic locations for both off-axis measurement locations while Fig. 21 shows the results of the measurements.

Question: why was the off-axis response measured on the floor? This is because the floor is actually the on-axis location for the equivalent free-standing CBT array that was cut in half to form the ground-plane CBT array.

The off-axis responses shown in Fig. 21 are all fairly well behaved at both heights. Some high-frequency rolloff is evident at 90 degs for the lower height. This presumably was due to the surface roughness of the concrete floor. Some midrange aberrations are also evident at 1 and 3 kHz possibly due to diffraction around the 0.18 m (7" wide) enclosure.

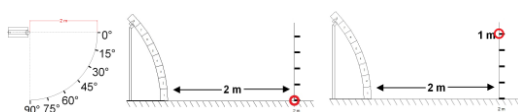


Fig. 20. Illustration of test mic locations for the off-axis horizontal response measurements of the CBT line array system. Left: the seven off-axis angular test mic locations. Center: mic located on the floor at 2 m. Right: mic located at a height of 1 m above the floor at a distance of 2 m. Mic locations are circled in red.

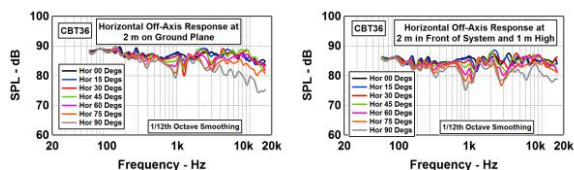


Fig. 21. CBT line array off-axis horizontal ground-plane frequency responses at two heights at a distance of 2 m: mic on the floor (left) and mic at 1 m above ground plane (right). Note response uniformity at both these heights.

4.7. Near-field Close-In Frequency Response of CBT Array

This section illustrates the frequency response uniformity at locations very close to the front surface of the CBT array.

Data was gathered on the CBT line array system at a height of 1 m; and several very-close distances of 0.05, 0.1, 0.2, and 0.4 m (2", 4", 8", and 16") from the front surface of the enclosure.

Fig. 22 illustrates the test mic locations for the close-in near-field measurements (left) and the results of the measurements (right).

All the responses are fairly flat and well behaved even at this close distance. This indicates that the CBT array would be a perfect near-field monitor even for listeners sitting directly in front of the loudspeaker!

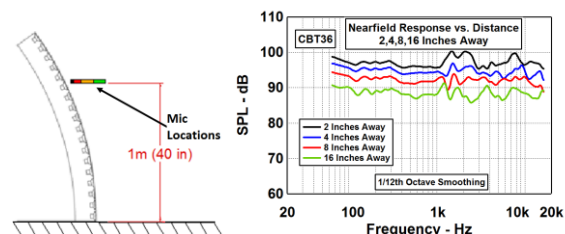


Fig. 22. Left: test mic locations for the close-in nearfield responses of the CBT line array system. The mic was very close to the array at a height of 1 m over the ground plane and spanned distances of 2", 4", 8", and 16" from the surface of the array. Right: Near-field frequency responses measured at the locations shown on the left. All are very well behaved, even the one 2" close!

4.8. Ceiling Coverage

This subsection illustrates the level and spectrum of the energy directed up towards the ceiling at several angles for both the conventional system and the CBT array system. The levels of the systems were adjusted for approximately equal SPL levels at 1 m in front of the systems. The energy reflected off the ceiling contributes to the reverberant field tonal characteristics in the room and influences the tonal quality heard by the listener at locations in front of the system.

If the energy spectrum launched towards the ceiling from a speaker is flat and well behaved, this contributes to a well-balanced reverberant room field and improved tonal characteristics heard by the listener.

Note that for every launch angle described in the following, the CBT array has much flatter and well-behaved energy directed towards the ceiling than the conventional system and has significantly less sound energy directed towards the ceiling in specific frequency bands.

These measurements assume operation in a room with a typical ceiling height of 2.4 m (8 ft).

All the data shown in this section are repeats of the frequency responses shown previously in Section 4.3 but reformatted to illustrate the points made in this section.

Three upward launch angles of +87°, +45°, and +27° are illustrated. These angles were simply based on the

upward angles formed by the highest mic locations (2 m) and the bottom front edge of each cabinet at the three distances of 0.1, 1.0, and 2.0 m.

There is nothing magic about these angles or the associated images shown here, these are for illustration only. The spectrums shown for each angle are just simply the frequency responses measured previously at the highest 2 m test mic locations and roughly indicate the spectrum of the sound energy directed upwards towards the ceiling at each angle.

These three angles represent sound reflected off the ceiling for listeners located roughly: 1) directly in front of a system, 2) 2.5 m away, and 3) 4 m away.

Note that the following responses in this subsection are SPL calibrated and preserve relative levels between the two systems.

4.8.1. Spectrum at +87°

This location represents the sound energy directed up towards the ceiling immediately in front of a system and provides reflected coverage for listeners located roughly 1 m in front of a system.

Fig. 23 depicts the representative ceiling launch angles for the two systems while Fig. 24 shows the spectrums directed up towards the ceiling. In both figures, the conventional system is on the left and the CBT array is on the right.

At this close distance, the conventional system exhibits a very rough response directed towards the ceiling with a dramatically rolled off response above 2 kHz while the response of the CBT array is quite flat and well behaved.

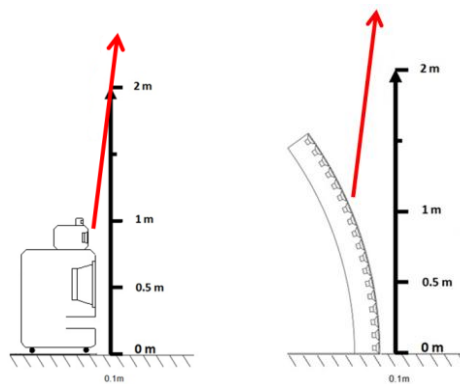


Fig. 23. Illustrations showing the approximate upward sound launch directions for each of the two systems for a launch angle of about +87°. Left: conventional system. Right: CBT line array system. This extreme upward launch direction illuminates the ceiling directly in front of the speakers.

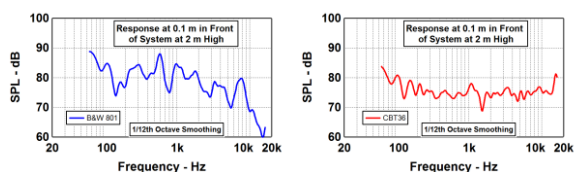


Fig. 24. Spectrum of sound launched upwards that illuminates the ceiling immediately in front of the systems. Left: conventional system. Right: CBT line array system. At this extreme upward angle, the spectrum of the conventional system is very rough and exhibits severe high-frequency rolloff. In contrast, the CBT array spectrum is quite flat and exhibits no high-frequency rolloff.

4.8.2. Spectrum at +45°

A 45° upward launch angle hits the ceiling about 1.5 m in front of the systems.

This location represents the sound energy directed towards the ceiling about 1.5 m away which provides reflected coverage for listeners located roughly 2.5 m in front of each system.

Fig. 25 depicts the representative ceiling launch angles for the two systems while Fig. 26 shows the spectrums directed up towards the ceiling. Left: conventional system. Right: CBT array.

As before, the conventional system's energy spectrum is quite rough with HF rolloff while the CBT array's spectrum is flat and well behaved.

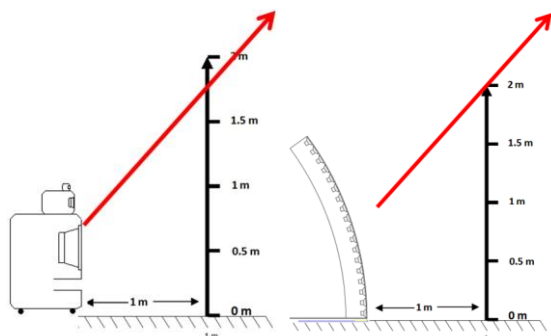


Fig. 25. Illustrations showing the approximate upward sound launch direction for each of the two systems for a launch angle of about +45°. Left: conventional system. Right: CBT line array system. This upward launch direction illuminates the ceiling farther away from the systems at about 1.5 m in front of the systems for a typical 2.4 m (8 ft) tall ceiling.

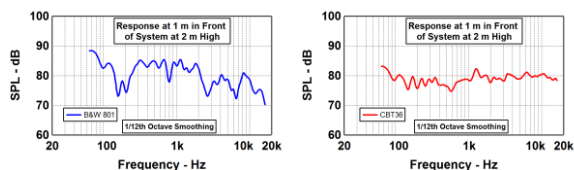


Fig. 26. Spectrum of sound launched upwards for a launch angle of +45° for both systems. This launch angle illuminates the ceiling at about 1.5 m in front of the system. Left: conventional system. Right: CBT line array system. At this launch angle towards the ceiling the spectrum radiated by the conventional system is still quite rough and exhibits significant high-frequency rolloff. This is in contrast to the CBT line array, which illuminates the ceiling with a balanced and flat spectrum.

4.8.3. Spectrum at +27°

A 27° upward launch angle hits the ceiling much farther away at about 2.5 m in front of the systems. This provides ceiling reflected energy for listeners located about 4 m away.

Fig. 27 depicts the representative ceiling launch angles for the two systems while Fig. 28 shows the spectrums directed up towards the ceiling. Left: conventional system. Right: CBT array.

As with the previous comments in this sub section, the conventional system’s ceiling energy spectrum is still very rough while the CBT arrays spectrum is extremely well behaved and flat.

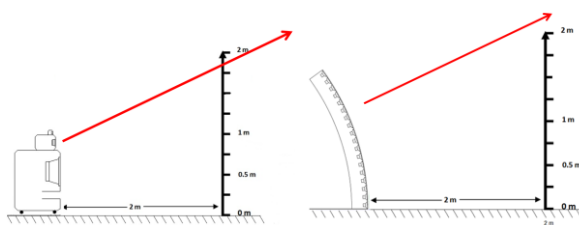


Fig. 27. Illustrations showing the approximate upward sound launch direction for each of the two systems for a launch angle of about +27°. Left: conventional system. Right: CBT line array system. This upward launch direction illuminates the ceiling much farther away from the systems at about 3 m in front of the systems for a typical 2.4 m (8 ft) tall ceiling.

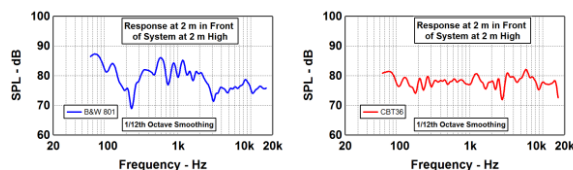


Fig. 28. Spectrum of sound launched upwards at an angle of about +27° that illuminates the ceiling roughly 3 m from the front of the systems. Left: conventional system. Right: CBT line array system. As before, the spectrum radiated by the conventional system is very rough while the CBT array system’s radiation is much smoother with a flat and extended spectrum.

4.9. General Measurement Observations

- The CBT array exhibits extremely even and well-behaved frequency response over the floor compared to the conventional system. No floor bounce aberrations are exhibited!
- At all distances and heights, the conventional system exhibits rough and uneven frequency responses compared to the CBT array system.
- At seated and standing heights, the CBT array exhibits much more uniform and flat frequency responses compared to the conventional system.
- At both seated and standing heights, the CBT array exhibits much less variation of level with distance only dropping 10 dB from near to far for a seated listener and not dropping at all for a standing listener.
- At standing height, the volume and frequency response of the CBT array hardly changes over a very wide distance range of 0.1 m to 3 m (4 in to 10 ft). It’s level doesn’t drop off as you walk away from the system or get louder as you walk up to the system!

- The horizontal off-axis frequency response of the CBT array is quite well behaved and extended out to $\pm 90^\circ$ from on axis.
- The CBT array exhibits well-behaved and flat frequency responses close to the front surface of the array, which makes it a perfect near-field monitor for persons listening close to the array!
- The CBT array illuminates the ceiling with less energy and a much flatter response compared to the conventional system when they are adjusted for equal direct-field levels at 1 m in front of the systems. This is also true for sound radiated towards the sidewalls and reflected back into the room. These characteristics contribute to an even and well-balanced reverberant sound field in the listening room.

5. CONCLUSIONS

5.1. Great Sound Everywhere!

The following rather humorous illustration shows all the locations that the CBT line array system provides well-behaved direct-sound coverage. Points from very near the system to points far away and points near the floor to points above the system are covered very evenly. Even the mouse Ratatouille and the dog Nipper near the floor hear excellent sound along with the listener standing on the stool with his head way above the top of the CBT system!



5.2. Overall Conclusions

This paper compared the over-the-ground-plane sound radiated by a high-quality conventional three-way loudspeaker system and a circular-arc two-way ground-plane CBT line array. The conventional system was the

floor-standing B&W Matrix 801 Series 2 studio-monitor loudspeaker [1] while the CBT array was the CBT36k system sold by Parts Express [2].

Various measurements were accomplished including direct-field frequency responses in front of the systems at 20 grid locations, response vs. distance for seated and standing listeners, horizontal off-axis responses, nearfield frequency responses close to the surface of the array, and ceiling illumination responses at several launch angles.

The measurement results show the clear superiority of the sound coverage provided by the CBT array when compared to the conventional floor-standing loudspeaker system. When measured over the ground plane, the conventional system's frequency response is very rough and uneven, and exhibits the clear effects of floor bounce. In contrast with this, the coverage of the ground-plane CBT array is extremely even at all locations in front the system from points near and far, up and down, and to the sides.

The coverage of the CBT array is very good even at points on the floor near the front of the system up to locations over the top of the system at distances from near and far.

One unique characteristic of the CBT array is its capability to provide equal volume levels for standing listeners from locations very close to the system to locations 3 - 4 m away. This is a very easy feature to demonstrate. This means that for a specific loudness in the rear of a room, it does not get any louder as you walk up to the system or drop off as you walk away!

6. REFERENCES

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