Technical Notes Volume 1, Number 35

CBT Constant Beamwidth Technology^{TM}

Introduction

Column loudspeakers have become an important form factor for loudspeakers throughout the years. The tall and slender package fits nicely into a wide variety of architectural styles, and the columns provided performance characteristics that work nicely for certain application and room types.

Recently, column speakers have become more popular than ever, and an even more important element in the sound designer's toolbox for aesthetic reasons and the natural narrow vertical coverage. Large format line arrays have become increasingly common for large-scale sound reinforcement, and columns are a logical step-down in size from such line arrays. DSP technology and control interfaces have advanced to the point where powered column speakers having individual DSP processing for each driver and real-time remote control over the entire system is becoming economically feasible but still expensive. In addition, an appreciation of the importance of pattern control is expanding in the audio design community.

This paper explains JBL's Constant Beamwidth Technology^{TM}, which has been implemented in the CBT Series of non-powered line array column loudspeakers. These speakers solve many of the problems associated with traditional passive column speakers, as well as some issues present in powered columns, and in point-and-shoot loudspeakers. The end result is a line of affordable passive column speakers that provides constant directivity within narrow vertical coverage angles. They provide consistent frequency response regardless of distance or off-axis location within the listening zone, suppression of side lobes, switchable vertical coverage, asymmetrical vertical coverage for more uniform sound levels with in the room from front-to-back, and are practical for a wide variety of sound reinforcement projects.

History

The use of an array of loudspeakers to increase directivity can be dated back to the early era of public address systems in the 1930's. Increased directivity has long been known to improve intelligibility of sound systems. In the late 1950's and early 1960's there was an explosion in the use of column line arrays[1,2,3]. Designers sought to control the directivity with configuration and filtering techniques on line arrays of multiple transducers. The traditional thinking was that the directivity is directly related to the size of the array. Therefore to keep the directivity constant the effective size of the array would need to change with frequency. In the early 1970's the first true constant directivity devices in the form of horns were introduced. While a great leap forward for point and shoot systems they yielded less than ideal coverage when used as components in large arrays and were limited in bandwidth.

Early examples from Klepper and Steele[1] and Novak[2] show novel approaches for the time that include frequency tapering of the line and amplitude shading. The frequency shading attempts to use the outermost drivers to control directivity at the lowest frequencies and then moves the sound sources toward the center of the array as the response rises by low pass filtering the outer elements. This makes the apparent aperture or source size decrease with frequency which keeps the beam relatively constant in width with frequency. The authors of the early works acknowledged that the concept is challenged by the phase response of the filters which results in the sources not operating in phase at all frequencies, as would be desired, limiting the performance of the method. The idea is to make the effective size of the array a fixed ratio of the wavelength that it is producing.

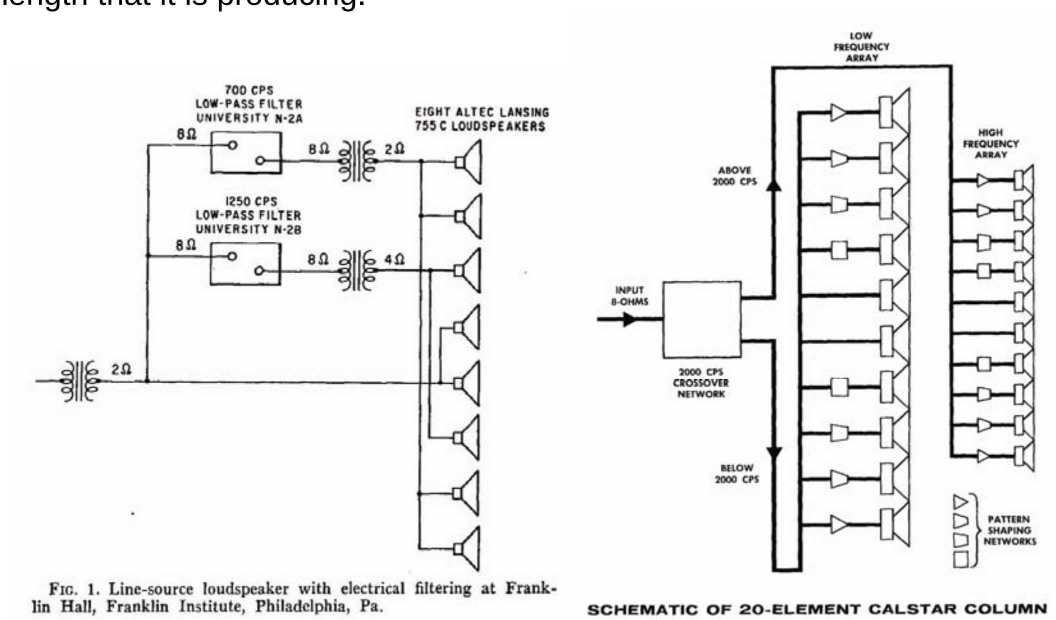


Figure 1. From Klepper and Steele[1] shows a simple network for improving directivity control and Novak[2] (on the right) shows more complex filtering

Klepper and Steele[1] also show the value of amplitude shading (reducing the output at the ends of the array) in improving dispersion and reducing side lobes.

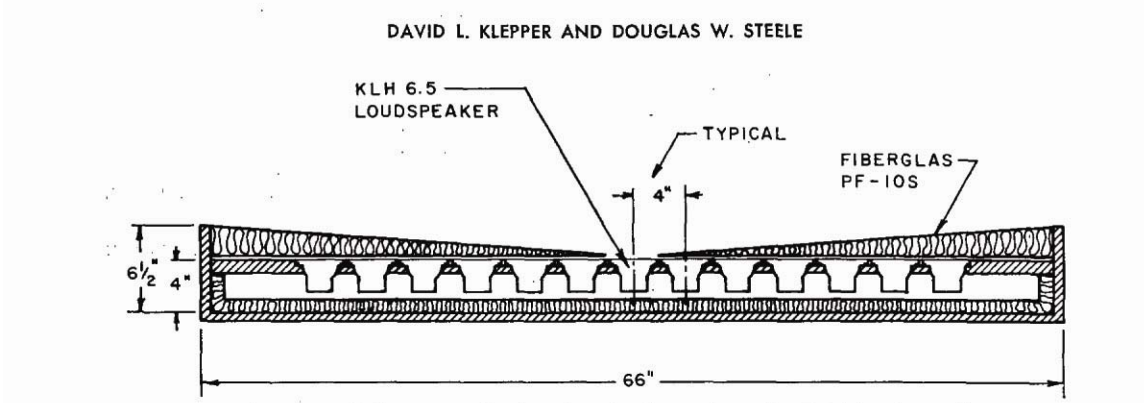


FIG. 4. Section through line-source loudspeaker (enclosure is made of ¾ in plywood).

Figure 2. From Klepper and Steele[1], a novel 'passive' approach to amplitude shading a line array with an absorbing medium.

In the 1980's, as designers began to use computers and imagine the use of digital delay for beamforming, further refinement of line array beamwidth control was demonstrated. Augspurger and Brawley[4] showed the computer modeling of a line array with delay and the use of a Bessel function for the amplitude shading.

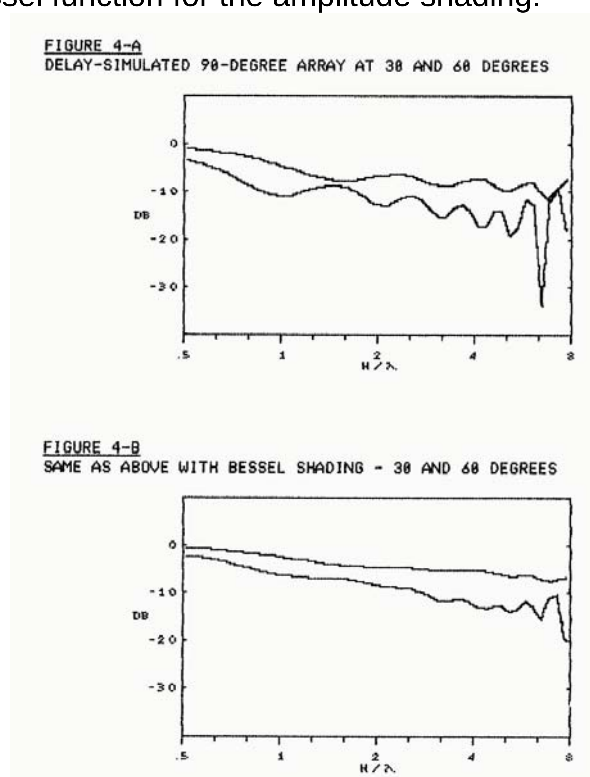


Figure 3. From Augspurger and Brawley[4] showing that relatively even coverage off axis can be obtained with delay and that with the addition of Bessel shading very smooth off axis behavior can be obtained.

While the simulation does not show constant directivity (which would yield flat parallel off axis curves) the paper shows that delay arcing of the speakers and Bessel amplitude shading provides a very useful solution. This approach would pave the way for the CBT concept.

Many analog approaches have been implemented over the years with limitations in performance. In recent years the method was improved upon by using zero phase shift digital FIR filters by Horbach and Keele[5]. They outline the expected performance of a log (driver spaced) array with new DSP filtering techniques. The system is very effective in controlling beamwidth. However this approach, like the earlier system, suffers from limited maximum high frequency output because the last octave is only being covered with two small drivers.

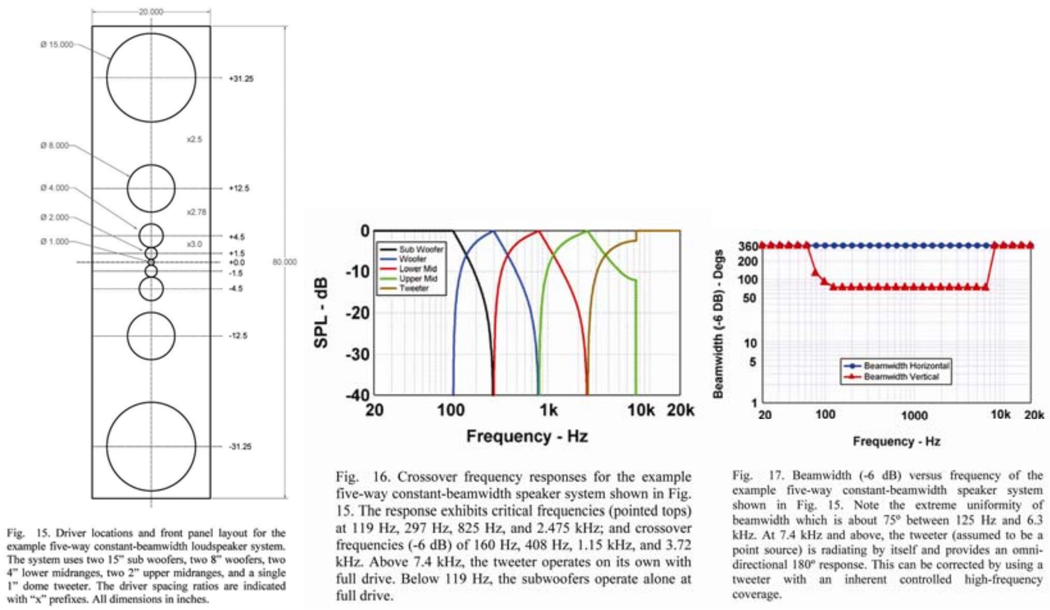
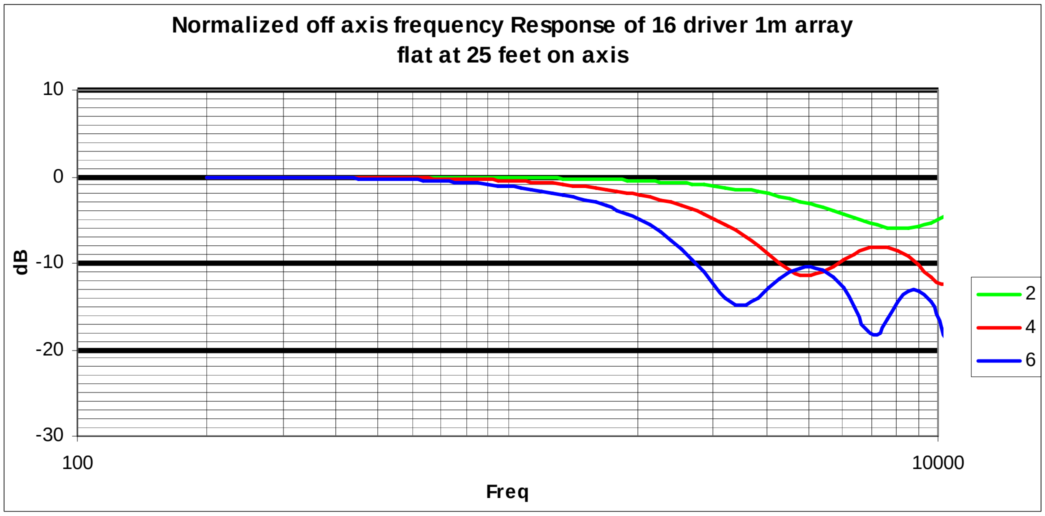


Figure 4. Figures (15, 16, 17) from Horbach and Keele[5], log array with zero phase shift Finite Impulse Response filters to achieve constant directivity.

Straight line arrays without any frequency shading or amplitude shading have found favor in the marketplace for some time. The property that is most often claimed is that they create cylindrical waves. While a line source of infinite length will create cylindrical waves, finite size arrays only create wave fronts resembling cylindrical waves over a narrow region in space and frequency. The region is defined by the height of the array. Simple superposition models of straight line arrays with discrete radiation elements work quite well to show the actual behavior of real finite line arrays. While purporting to create a 'wedge of sound' the array has a pattern than narrows constantly with frequency and is uneven. Additionally, the response changes with distance



Off axis response at 25 ft 2, 4 and 6 degrees off axis. Response changes radically within a very small forward beam.

Figure 5. The simulated on and off axis behavior of a finite straight line array of 16 elements 1m tall and the response at 6, 12 and 50 feet normalized to flat at 25 feet. The one axis response changes with distance.

The off axis response is very different even within a very narrow range (+/- 6 deg) and the primary forward beam gets extremely narrow at high frequencies. It is this narrowing that gives the array the sense that it is a laser beam of sound but in reality the beam is not constant in width or truly cylindrical. By examining the response and pattern at different points in space it can be seen that the array is different everywhere and in no way can purport to provide consistent sound within a defined 'wedge'.

The increasing high frequency output with distance (as the array becomes more coherent) is what gives the array the sense that it is projecting further and has a decrease with distance that is less than 6dB per doubling of distance. This is true at higher frequencies but is different at every frequency. At lower frequencies (where the wavelength is large compared to the size of the array) the level drops at 6dB per doubling of distance. The speaker simply gets brighter with distance. At some point the response will no longer change (when the far field is reached) and then all frequencies will drop off at 6 db per doubling of distance. Additionally the wavefront will then become spherical, not cylindrical, independent of frequency.

Straight line arrays of discrete sources will have severe side lobes.

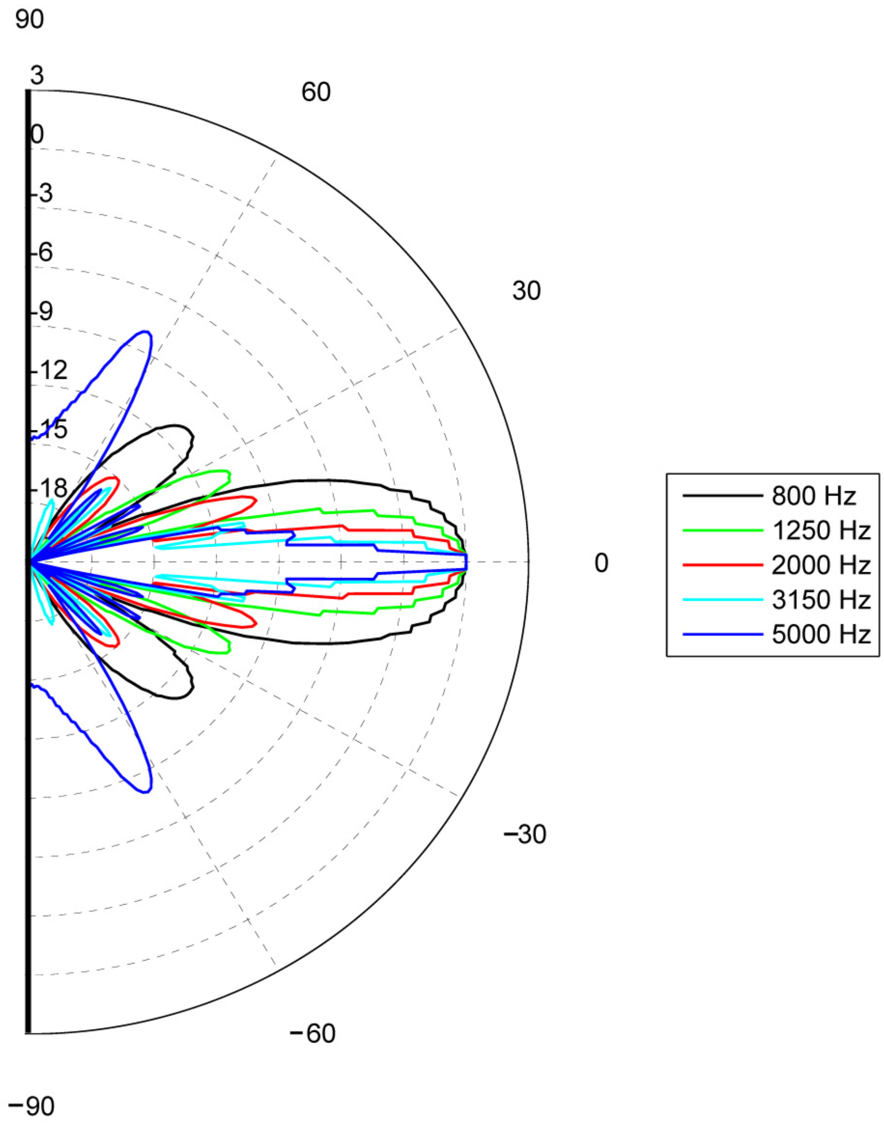


Figure 6. The measured vertical polar patterns from a popular straight line array of 1m in height with 12 discrete drivers. Side lobes can be seen as low as 800 Hz. The pattern continuously narrows with frequency and has clear lobes outside the main lobe.

Newer approaches, The CBT principle

In 2000 Don Keele[6] (the creator of JBL's BiRadial® constant directivity horns) started writing about the concept of a constant beamwidth device made up of discreet transducers that were all spaced equally and driven with full bandwidth. The concept was nicknamed CBT for "constant beamwidth transducer", but has taken on a broader meaning that JBL now refers to as Constant Beamwidth Technology™.

The idea is that a constant beamwidth array can be created by bending the array to a fixed arc and amplitude shading the drivers from inside to outside with a very specific mathematical expression (a Legendre function) that eliminates side lobes and creates a perfectly constant beamwidth that is 66% of the arc. In later publications Keele and Button[7] showed that time delay could be used instead of physical arcing to create the effective curvature. The concept can be applied to very wide bandwidth and is only limited by the size of the array and the spacing of the drivers.

The array's simulated farfield vertical above-ground-plane beamwidth (-6 dB) versus frequency is shown in the next figure. Compare this data with the data of the shaded physically-curved array of Fig. 57. The two curves are very close together, as expected.

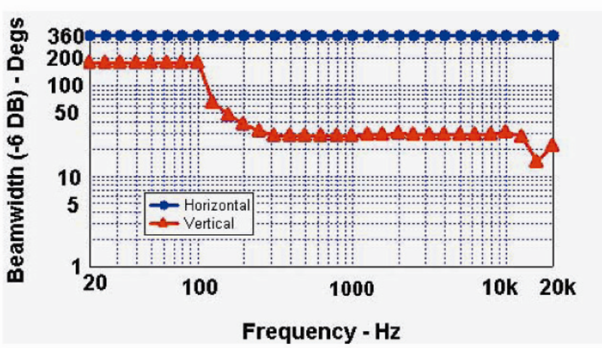


Fig. 80. Farfield above-ground-plane beamwidth (-6 dB) versus frequency for Legendre-shaded 50-point 1.25m-high 45° delay-curved straight-line source located on a ground plane (Fig. 79). Horizontal: blue circles. Vertical: red triangles.

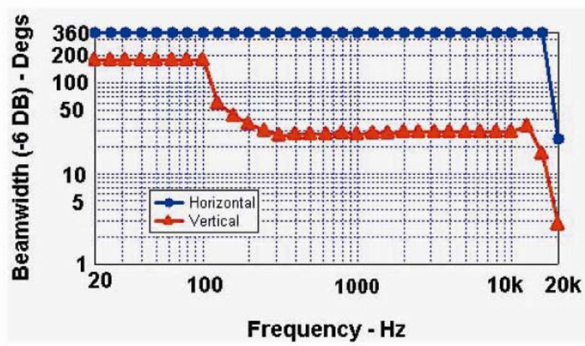


Fig. 57. Farfield above-ground-plane beamwidth (-6 dB) versus frequency for an Legendre-shaded 50-point 1.25m-high 45° curved-line source located on a ground plane (Fig. 56). Horizontal: blue circles. Vertical: red triangles. Note the extreme uniformity of vertical beamwidth with frequency.

Figure 7. Figures (80, 57) from Keele and Button[7] showing that a constant beam width array can be achieved by delay curving (80) or physical arcing (57) and Legendre shading.

The concepts, while simple, were a departure from the traditional approach of creating constant beamwidth by changing the apparent size of the sound source with frequency.

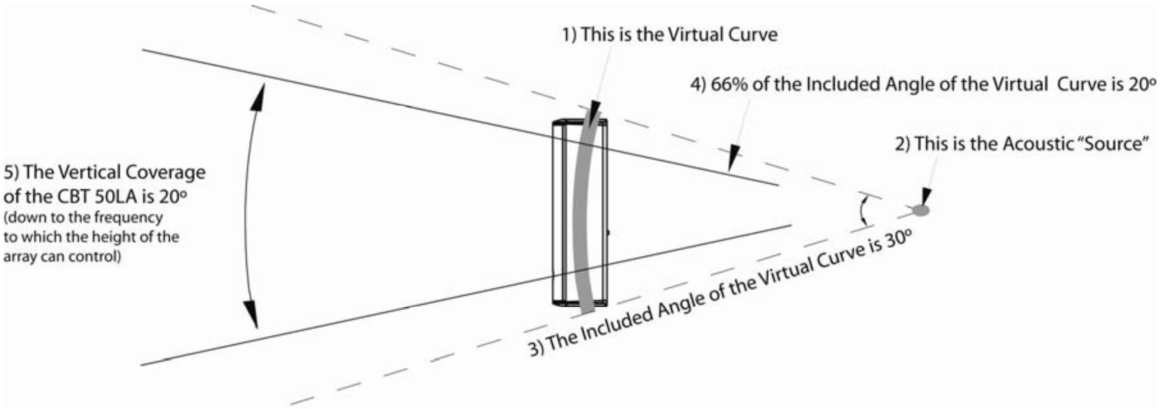


Figure 8. A virtual curved array can be achieved by bending it with time delay. The apparent point source is behind the array.

Implementing similar concepts has been done by many engineers using discrete amplifier channels and DSP to create the time delay. This method, while effective, is expensive and complex.

JBL has developed a Patent Pending method to mimic the performance of the digitally time delayed column array in a passive loudspeaker. The principal of operation starts with the premise that group delay that is flat with frequency is no different that digitally derived time delay. All passive [reactive] components have phase shift in degrees which can be expressed as group delay in time. The group delay of single passive components is not flat with frequency. However, networks of inductors and capacitors can be configured to have flat group delay over wide bandwidth. The drawback in many cases is that the group delay is very small. This turns out to be advantageous when developing the required delay to 'curve' a straight line array. The amount of delay required between each successive driver is small especially if the drivers are small.

In practice, digital-delay-derived CBT's require each delay line to be independently sent to each driver and the amount of delay must be quantized based on the sampling frequency. In a typical 48Khz system this is 20us in time or about 6mm distance. This limits the smoothness of the virtual curving of the array. In a passive CBT system the group delay can be 'tapped' off at points along a 'ladder' network. Each small amount of group delay between segments accumulates down the ladder. Because the amount of derived group delay is based on analog synthesis, and therefore continuously variable, the time quantization error is non existent. The CBT can also be thought of as a transmission line with delay and attenuation accumulating down the line. By appropriate design of the components in the group delay ladder network the right amount of delay to provide a smooth arc in time can be achieved. To complete the CBT principle the outward drivers must be amplitude shaded (attenuated) which is also realized through the network. Small amounts of delay and attenuation are accumulated down the network.

For the JBL CBT's a computer optimization was created to calculate the best component values for the network to achieve constant beamwidth.

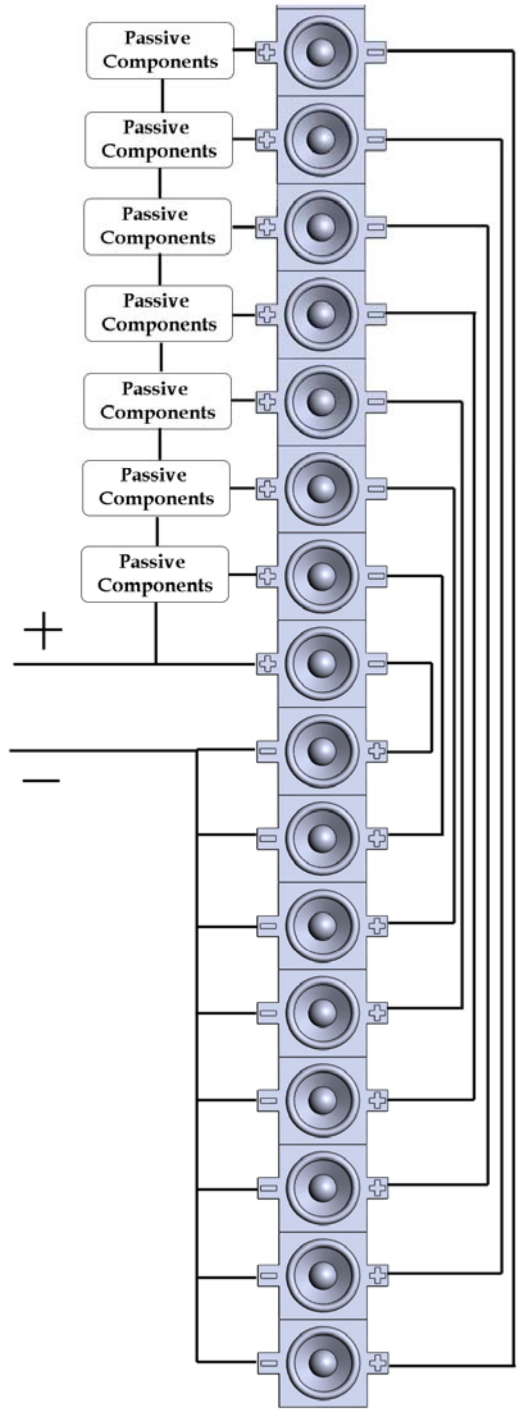
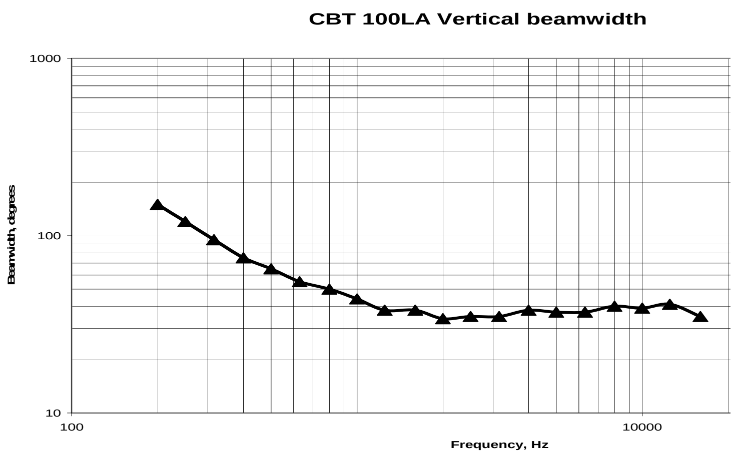


Figure 9. The passive CBT principle utilizing a ladder of passive components to create a delay line with increments of group delay to mimic the performance of a digital delay derived CBT array. The components chosen for a given arc can be changed to provide new arc if the pattern were required to change.

JBL introduces CBT passive line arrays CBT 50LA, CBT 100LA and CBT 70J.

The new JBL CBT systems incorporate a Patent Pending passive group delay network that provides time arcing along with amplitude shading that provides performance rivaling the digitally derived solution. The CBT's act much like a large constant directivity horn in the vertical direction with similar pattern control. This results in very consistent coverage when used in the broad setting and resembles the control of a large point and shoot system.



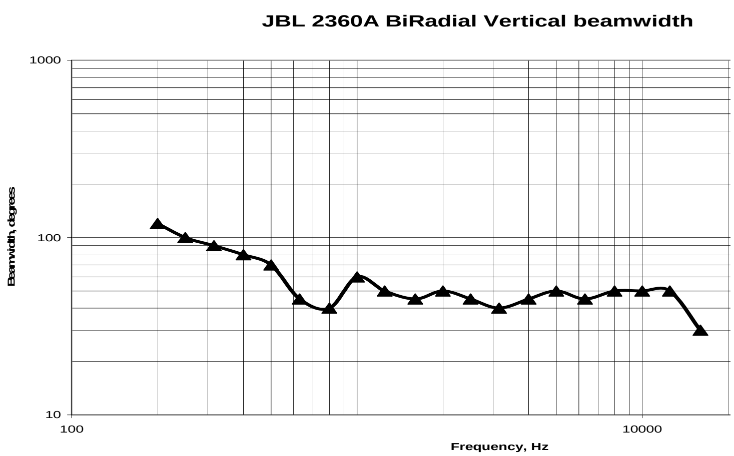
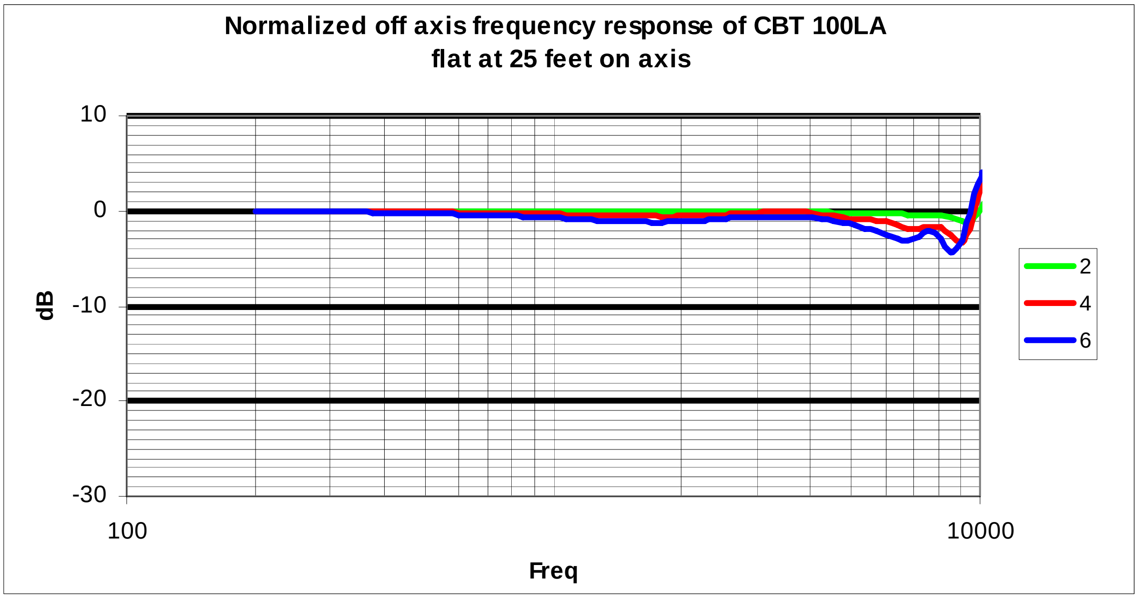


Figure 10. The constant directivity capability of the CBT 100LA can be seen as compared to a large JBL BiRadial horn with even smoother and more consistent pattern control. The vertical pattern control of the CBT 100LA is nearly identical to the large cinema horn from the cinema industry standard JBL 4675.

Because the CBT's act more likes a constant directivity horn they have very consistent coverage off axis and with distance.



Off axis response at 25 ft 2, 4 and 6 degrees off axis. Unlike the straight array from figure 5 the CBT 100LA response is very consistent on and off axis.

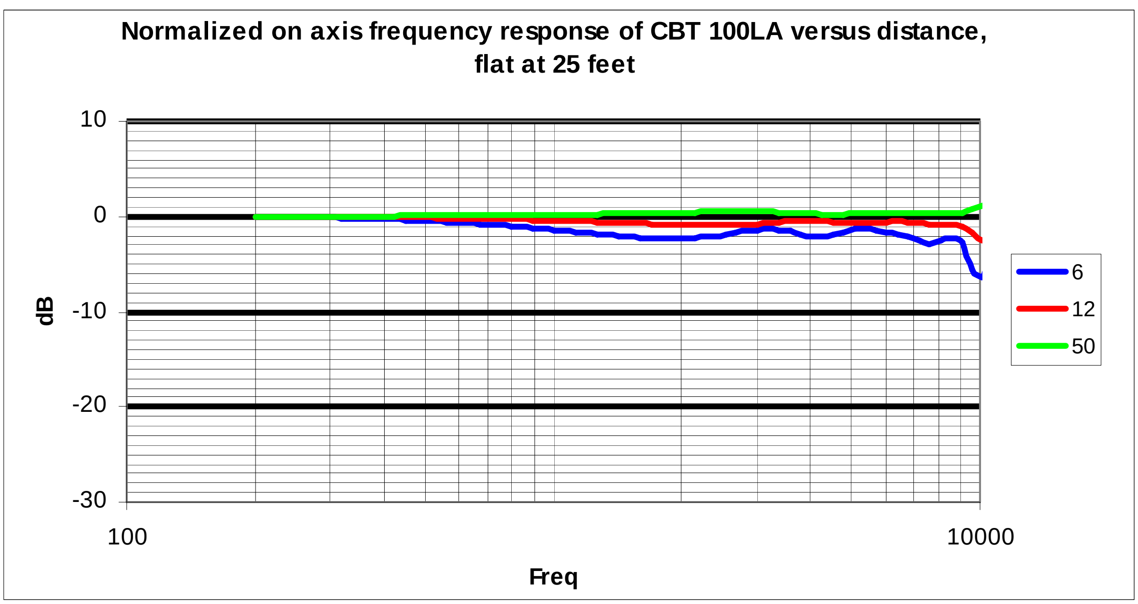


Figure 11. CBT 100LA response variation with distance is very consistent with distance as compared to straight array in figure 5.

The CBT 100LA also has virtually no side lobing in the critical midband frequencies unlike the earlier example of the straight array.

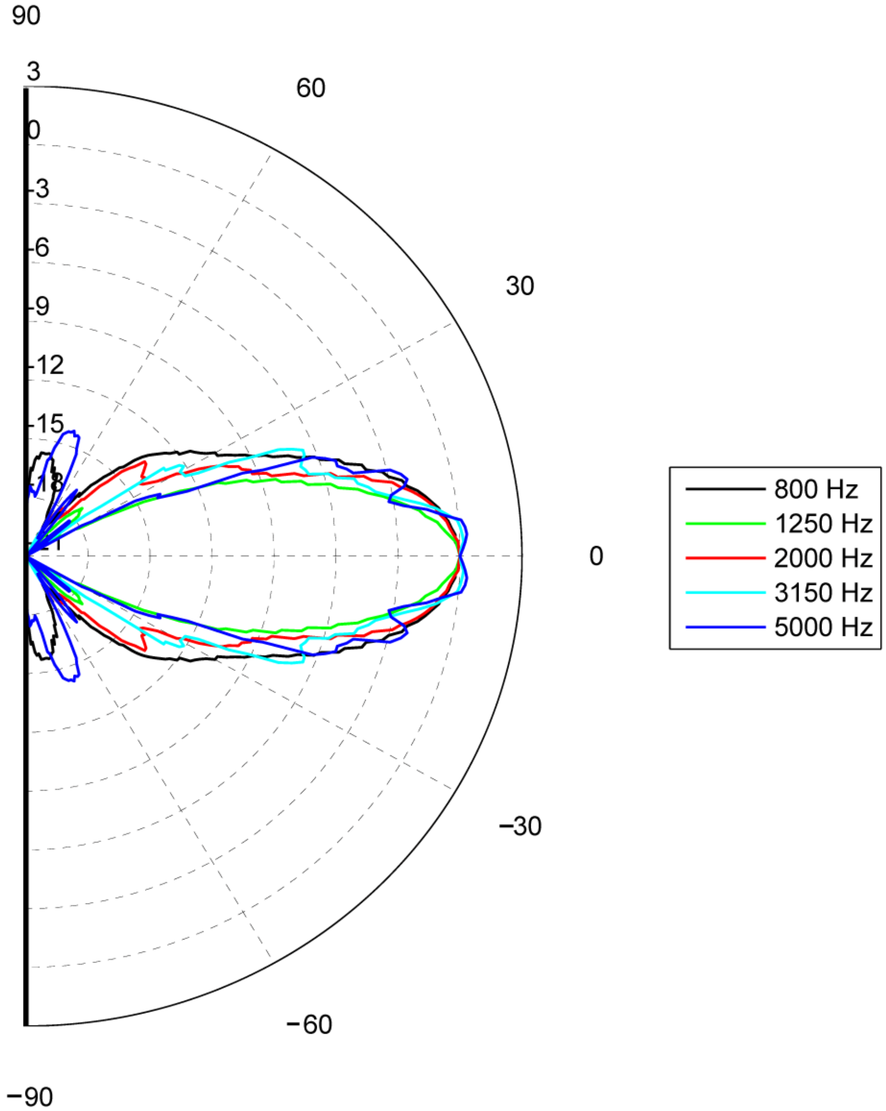
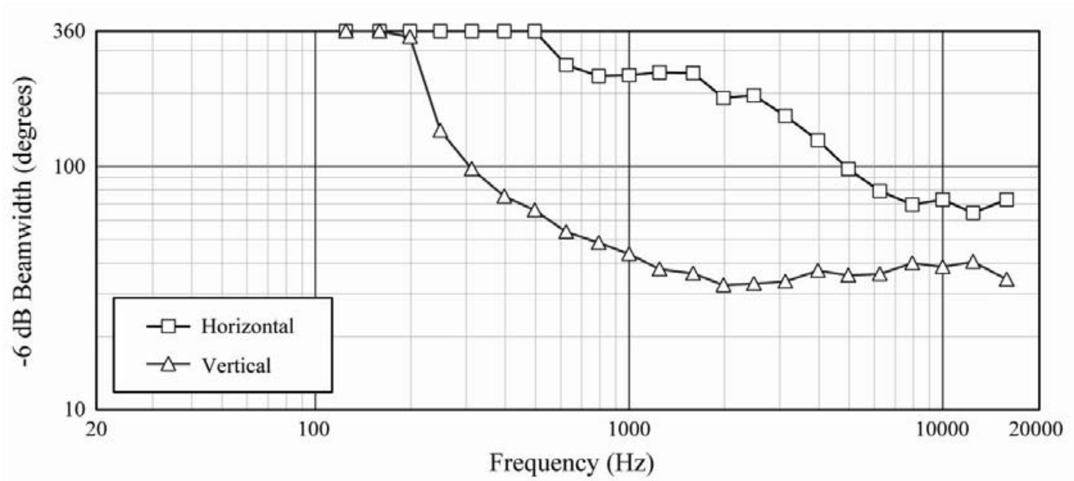


Figure 12. The measured polar patterns from a CBT 100 LA 1m in height. Compared with the straight array in figure 6, the pattern is very uniform with frequency with virtually no side lobes.

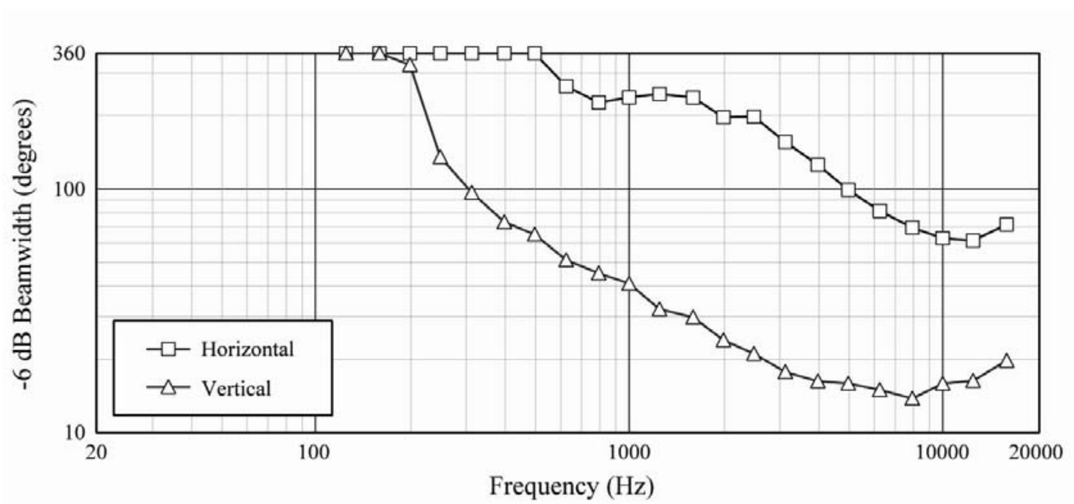
Switchable pattern control

JBL has made the pattern adjustable to broad and narrow settings with the flip of a switch. There are no software upgrades and complicated computer interfaces to bother with. The CBT 100LA and CBT 70J have a conveniently located pattern switch that can easily be adjusted before or after the speaker has been mounted.

The pattern of passive steered arrays can be changed by changing the components to change the amount of group delay. The CBT speakers have two vertical patterns that are described as broad and narrow. The narrow pattern provides high directivity without the continual narrowing of a traditional straight array. This gives the positive benefits of the line array (high directivity, good intelligibility) without the uneven coverage.



The broad vertical coverage beamwidth of the CBT 100 LA



The narrow vertical coverage beamwidth of the CBT 100LA.

Figure 13. CBT 100 LA beamwidth plot in the two switchable patterns.

In the narrow setting the systems act more like a highly directional column speaker but without the exaggerated narrowing at very high frequencies and the out of coverage lobing found in the midband.

Adjustable voicing

The handy point-and-shoot CBT 50LA, CBT 100LA and CBT 70J also incorporate an EQ switch to add midrange boost for presence in speech systems. This boost is achieved by removing a notch filter which flattens the response in the music mode. As a result, the sensitivity in the midrange is increased and so is the maximum SPL that can be achieved in this range by as much as 5dB.

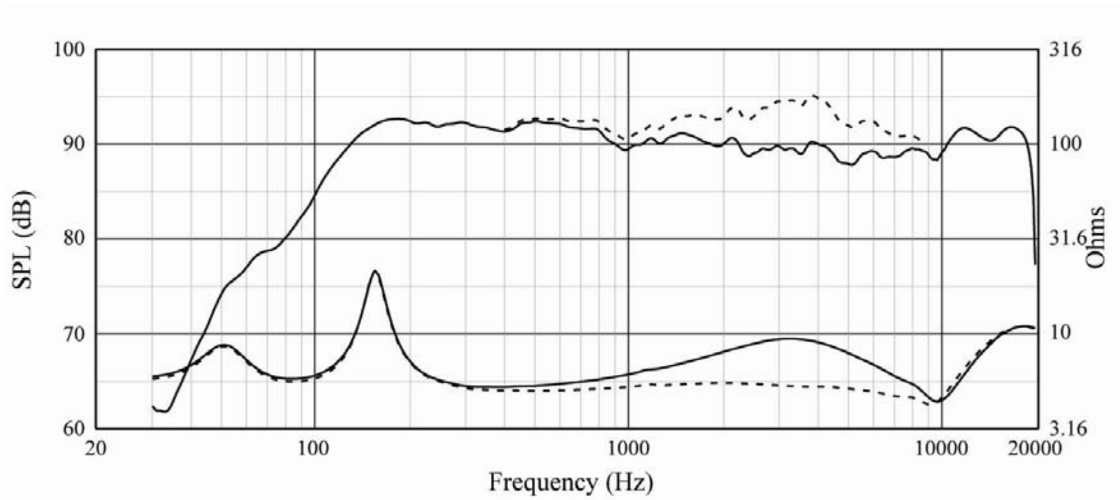


Figure 14. The CBT 100LA frequency response in Music (solid) and Speech (dotted)

JBL introduces a CBT with downfill capability.

The CBT 70J has an asymmetrical down curvature (J shape) to provide downfill for applications that have a requirement for close coverage as well as a long-throw need. The CBT 70J is a short throw and long throw system all in one.

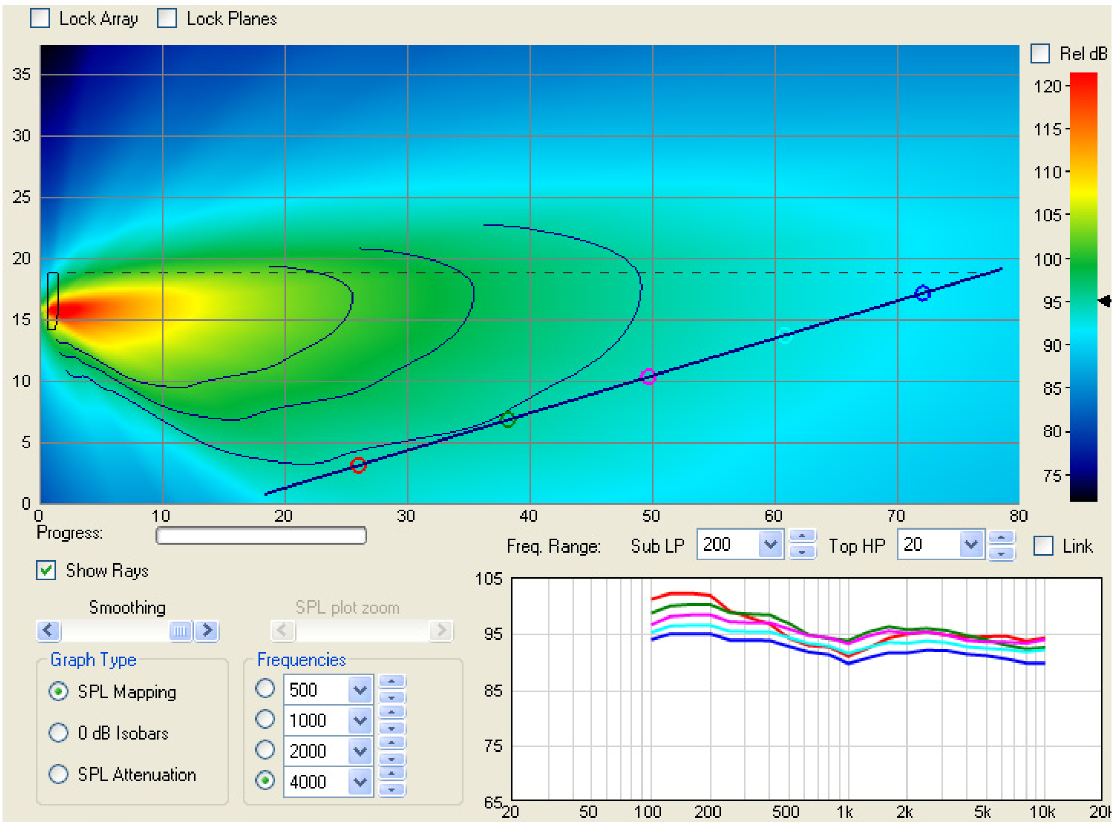
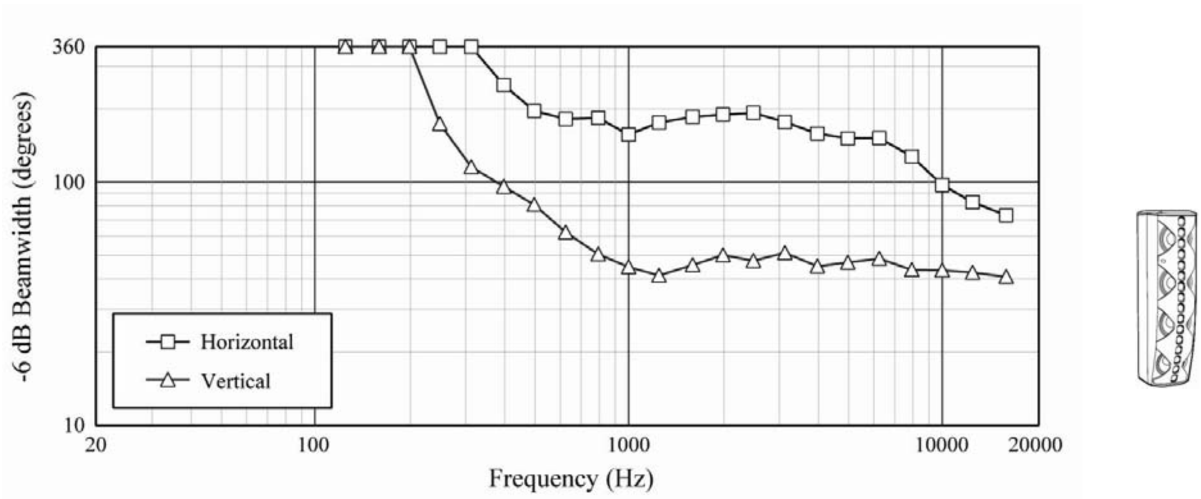


Figure 15. CBT 70J has tighter pattern control above the speaker and broad downfill capability below. The CBT 70J has excellent front to back evenness of coverage. Note response variation (in lower right corner) from front to back is only 5dB from 500 Hz and above. (From CBT calculator). The frequency response at 5 evenly spaced locations is clearly indicated with color coding.

The downfill is achieved through a slight downward curvature of the array. It is a hybrid of the delay beam forming and physical arcing. Beam forming (even with digital delay) has limitations due the directivity of the drivers themselves. Physical arcing helps provide constant coverage angles to higher frequencies.

Extending the pattern control

The low frequency pattern control and LF extension of the CBT 70J can be further extended by adding the CBT 70JE. The added bass extension module lowers the pattern control (± 10 degrees) from 800 Hz to 400 Hz for demanding high reverberant application. The usable lower frequency limit is extended from 60Hz to 45hz. The CBT 70J is also fitted with a conveniently located pattern and EQ switch that can be adjusted after installation.



CBT 70J has controlled vertical beamwidth control down to 800 Hz

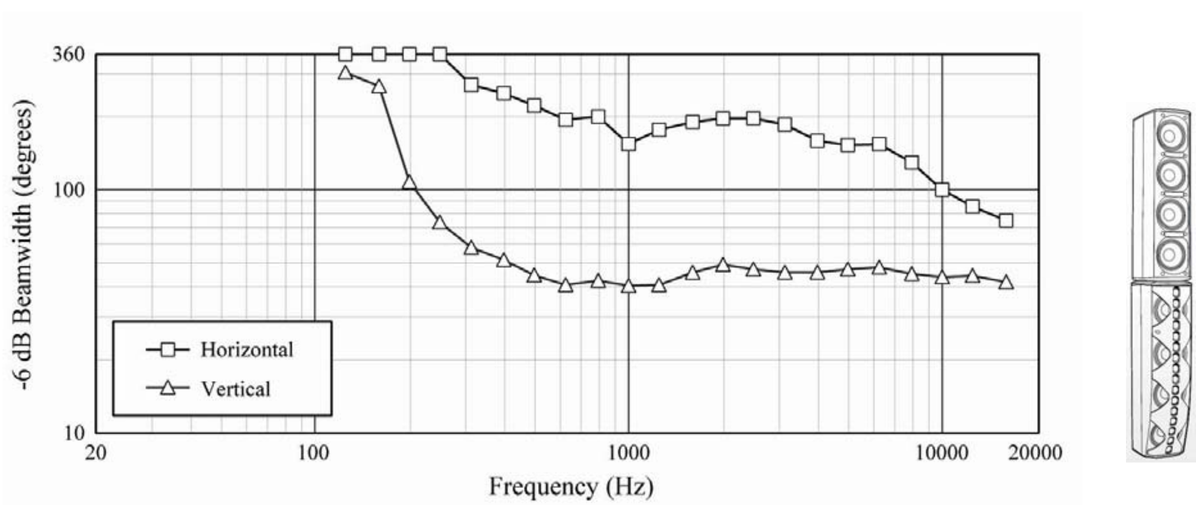


Figure 16. Beamwidth plots for the CBT 70J without and with the added CBT 70JE extension box. CBT 70J with CBT 70JE added has vertical beamwidth control down to 400 Hz.

The CBT70J and 70JE system have good low frequency pattern control but also have substantial side lobe suppression at frequencies well below the specified pattern of control (+/- 10 deg).

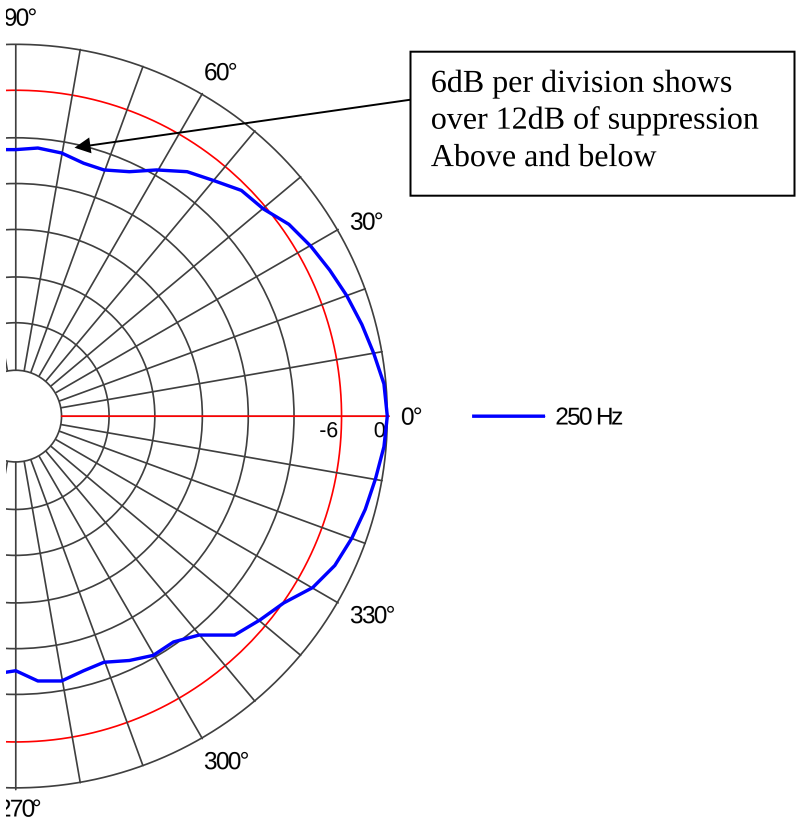


Figure 17. The vertical polar of the CBT J and CBT 70JE coupled together at 250 Hz. Even though the pair is specified as having pattern control down to 400 Hz there is still well over 12dB of suppression above and below the array at 250 Hz.

Low diffraction baffle designs

All of the CBT's incorporate very low diffraction baffles optimized with the latest 3D computer optimization programs and verified with JBL full spherical frequency response data acquisition system. The sculpted shapes of the driver interfaces insure reflection free propagation. This ensures the on an off axis response have no irregularities and that the benefits of the CBT principle are not compromised.

The unique shape of the tweeter baffle in the CBT 70J's provides a continuously changing boundary condition while providing transparency for the low frequency drivers. The 70J 2-way system also incorporates a co-linear co-axial design for proper driver alignment in all directions.

CBT 100LA **CBT 70J**

Figure 18. Low diffraction baffles of CBT 100LA and 70J

Purpose designed transducers

JBL has long been a leader in developing it's own transducer for use in JBL systems. The CBT's employ JBL designed transducers specifically optimized for the CBT application. The CBT 50LA and CBT 100 LA have requirements not normally found in off the shelf drivers. To operate full range the driver must have a very low resonance and be able to reproduce the highest frequencies all with very high efficiency. For use in line arrays the driver must have a rising frequency response as the low frequencies will couple better than the high frequencies when arrayed which flattens out the rising response as more drivers are added. All the drivers in the CBT's have dual Neodymium magnets and the 2" driver found in the CBT 50LA and CBT 100LA has a copper sheathed pole piece to maximize the rising response character and a low resonance of just 100Hz with useful response down to 80Hz in the tuned CBT 50LA and 100LA enclosures. All of the CBT drivers have very high motor strength and minimum moving mass for maximum efficiency. The low frequency drivers in the CBT 70J and 70JE take design elements from their concert sound cousins, resulting in very high output, reliability and weather resistance. The tweeters also draw on time proven design principles to provide the highest level of durability while maintaining the highest fidelity.

Putting it all together

One of the clearest ways of seeing the advantages of the CBT's is when comparing the frequency response a straight line array of a traditional design with the CBT just off the centerline.

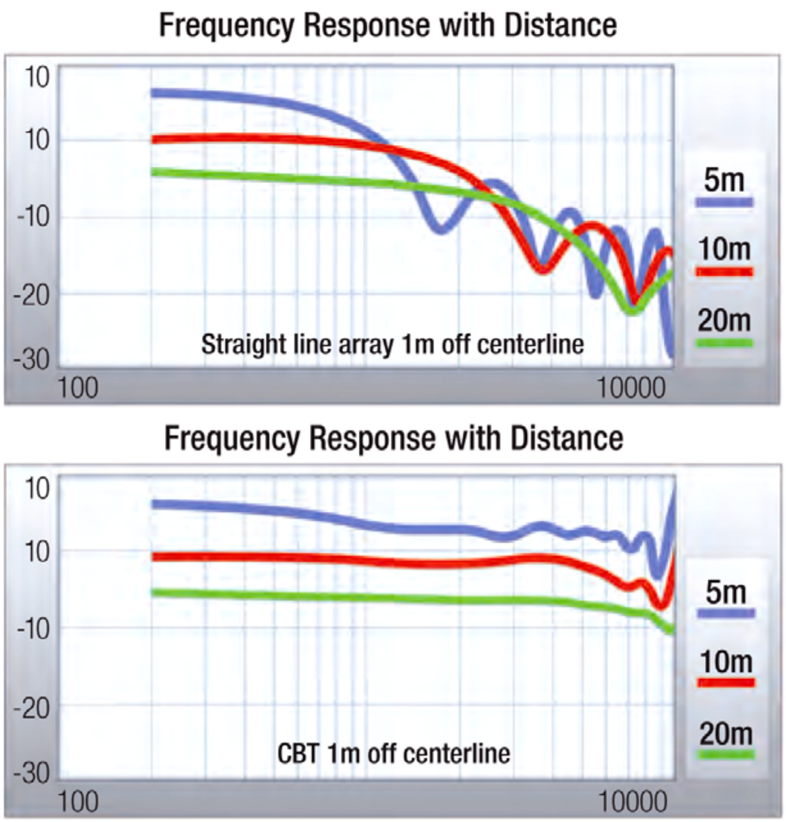


Figure 19. The simulated response of a 1m straight line array and JBL CBT 100LA with the microphone just 1m off the centerline of the speaker.

The response is shown at several different distances and has been normalized to the on axis response for the sake of comparison. The comparison shows that the straight line array is different at every position while the CBT maintains very uniform response. It is clear from this examination that the straight array does not really provide coverage in the proposed wedge defined by the height of the array and that a CBT will provide very even coverage off axis and with distance.

The CBT solution

The end result is the CBT Series of Line Array Column Loudspeakers. Constant Beamwidth Technology solves many of the problems associated with traditional passive column speakers, as well as some issues present in powered columns and in point-and-shoot speakers.

A specific coverage angle is locked in over a very wide bandwidth, providing both constant directivity and consistent power response. Within the coverage area, the CBT models deliver consistent coverage and uniform frequency response so that all listeners hear the same mix of sound. The CBT models combine narrow vertical coverage with constant directivity coverage of the listening space. They provide consistent frequency response regardless of distance and off-axis position within the specified listening zone. Side lobes outside the coverage area are substantially suppressed.

CBT allows selection of the vertical coverage angle via switching of component values in the passive network. The useful frequency response of the CBT 50LA and 100LA extends down to 80 Hz (-10 dB), making them practical for music as well as speech.

A voicing selection switch allows either a flat frequency response in the Music position or a presence peak in the midrange for higher intelligibility in the Speech position. Becasue the midrange peak comes from increased sensitivity, he speech position also increases the maximum SPL output of the speaker by as much as 5 dB in the midrange.

In addition to these performance benefits from the CBT design, the model CBT 70J provides additional features. CBT 70J's asymmetrical vertical coverage sends a higher, more concentrated, sound level in the direction of the far area of the room and a lower, more spread out, sound level in the direction of the near area of the room. This provides a more uniform SPL coverage of the room from front-to-back.

The CBT 70J's baffle design provides low-diffraction which allows for a smoother frequency response. The coaxial configuration decreases discontinuities in the crossover region and further reduces disparities off-axis.

The CBT 70JE extension cabinet for the CBT 70J, consisting of a duplicate of the CBT 70J's LF section, couples to the end of the CBT 70J to double the height of the array. While the 70J provides extremely consistent pattern control, broadening by just 10 degrees by 800 Hz (and with significant pattern control well below that frequency), the CBT 70J+70JE combination array moves the 10-degree broadening point down to 400 Hz, while still providing 12 dB of suppression below the array at 250 Hz.

The CBT Series has brought a wide collection of performance features that had not been available anywhere in passive loudspeakers. These performance features of the CBT models provide a considerable degree of versatility, allowing the CBT Series models to excel in a very broad range of applications, including performance spaces, transit centers, lecture halls, board/meeting rooms, retail stores, houses of worship, courtrooms, theme parks, lobbies, cinemas, and other applications requiring speakers with discrete appearance, excellent sound and superb pattern control.

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