PROFESSIONAL

White Paper

JBL's Vertical Technology™: Achieving Optimum Line Array Performance Through Predictive Analysis, Unique Acoustic Elements and a Dedicated Loudspeaker System

October, 2003 – Audio Engineering Society Convention
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1. INTRODUCTION:

This White Paper introduces the principles of JBL's Vertical Technology™. This technology comprises a predictive tool, unique electroacoustical elements, and a family of multiway loudspeaker systems. These form JBL's VerTec™ system, a next-generation line array product first embodied in the Model VT4889 full-range system. VerTec users have access to a design program enabling systems to be arrayed *a priori* with the assurance that array performance will accurately meet the program's response estimations. In this paper we will:

A. Cover the basics of line array technology from its beginnings to the present;

B. Dispel much of the mystery surrounding line array technology;

C. Outline in detail the development of a full-range loudspeaker system and the computer software that optimizes arrays made up of these systems to produce a desired directional response.

2. WHAT IS A LINE ARRAY?

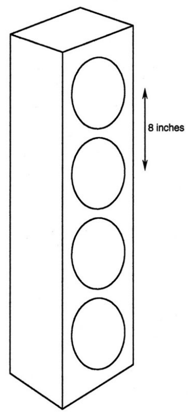
Line array loudspeakers date from the early days of acoustical research when it was observed that a simple vertical array of radiators produced increased directivity in the vertical plane.(1) Early commercial development is shown in Figures 1 through 3.

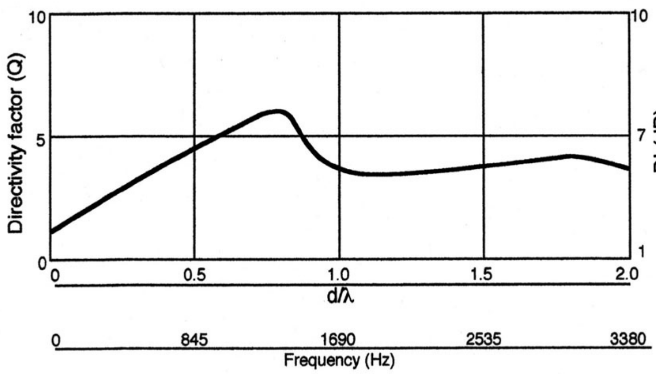
Figure 1A shows an array of four small drivers with a 200-mm (8-in.) center-to-center distance. Figure 1B shows the Q and DI (Directivity Index) of this short array. The DI increases up to that frequency where the response maintains a degree of useful directivity, but with the addition of mild off-axis lobes. The limiting frequency is where the inter-driver spacing is equal to the signal wavelength:

$f_{limiting}$ = (1130 x 12)/8 = 1690 Hz.

Horizontal directivity of the array is the same as that for a single driver. In addition to the height of the array, the center-to-center spacing of acoustic sources directly influences directionality of even the simplest line arrays.

Figure 1. A 4-element line array (A); directivity of 4-element array (B).





If we want increased vertical directivity we can use more drivers. Figure 2A and B show the effect of an 8-driver array with the same 200-mm (8-in) spacing. The array achieves very high directivity in the range up to the limiting frequency of 1690 Hz; however, above that frequency the off-axis lobing becomes very significant, and any directivity advantage drops off quickly.

It was soon discovered that *reducing* the length of the array at higher frequencies enabled it to hold its consistent coverage pattern with increasing frequency. Klepper & Steele (1963) devised a unique, low-cost way to accomplish the progressive truncation of the array length with increasing frequency through a gradual high frequency rolloff of the outer elements.(2) They employed carefully tapered wedges of fiberglass in front of the transducers to act as progressive acoustical low-pass filters.

Meanwhile, Hilliard (1970) was addressing aspects of motion picture sound with vertical columns of LF drivers. As his analysis tool he constructed arrays of small drivers and then scaled the results to give the response for 15-inch driver arrays.(3)

Overall, line arrays of the sort discussed here were excellent for speech or solo vocal purposes in moderate size rooms. Array theory was rarely if ever applied to high level music reinforcement, primarily because the available systems were physically small. Most commercial arrays, or “sound columns,” made use of 8-inch or smaller cone drivers and were clearly limited in their output capability.

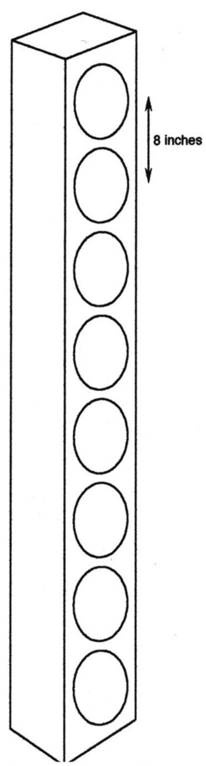


Figure 2A. An 8-element line array

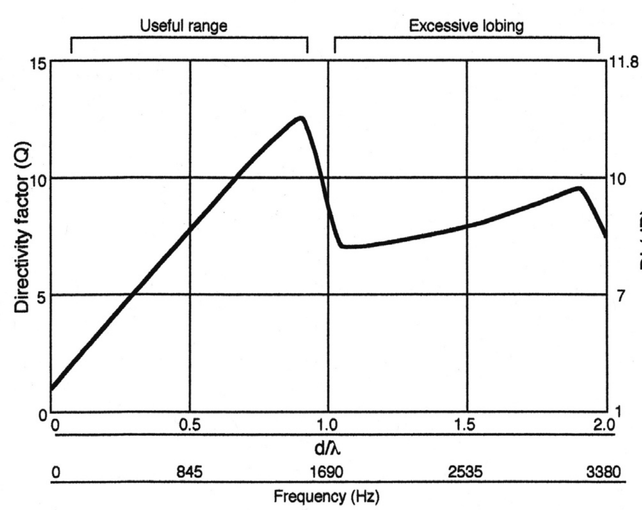


Figure 2B. Directivity of 8-element array (B).

2.1 JBL'S EARLY LINE ARRAY SYSTEMS:

JBL developed a number of line array systems during the 1970s. The 4682, shown in Figure 3, is typical. Full power capability of the four 10" drivers, arranged in a vertical line format, was maintained at frequencies up to 2 kHz. At one-tenth its rated power, this system was capable of producing 96 dB SPL at a distance of 15.25 meters (50 ft).

JBL's early line array system products were based on the foundations of acoustical knowledge gained from decades of previous experimentation by sound reinforcement industry pioneers. This experience was applied for the benefit of professional users, and it led to the creation of new high-powered transducers able to take portable sound reinforcement systems to a new level of performance. Astute observers will be able to draw links between the Model 4682 system shown here and innovative tour sound products that emerged in the same time period.

At the core of JBL's Vertical Technology program is the recognition that the same line array physics established by industry pioneers, and evidenced in products like the Model 4682 line array system nearly 30 years ago, are applicable to modern, modular array elements and are thus scalable for use in larger-format systems.

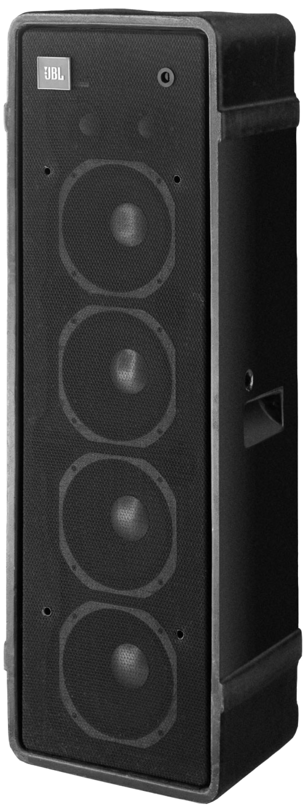


Figure 3. The JBL Model 4682 line array from the 1970s.

3. BASIC LINE ARRAY THEORY:

3.1 THE SUMMATION MODEL:

The arrays discussed so far can be easily analyzed, and their directional response can be determined using a discrete, or *summation*, model.

In this analytic approach, the array is broken down into component elements whose outputs are summed to produce the array's net response. The summation is taken to arrive at the array's response as it would be observed in the *far field* — the region in which inverse square law holds, with its characteristic falloff of 6 dB per doubling of distance.

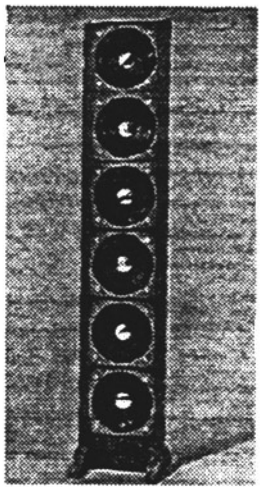
The far field begins at a distance that is proportional to the product of frequency and the square of the effective array length. At closer distances, we are in the near field, where the falloff with distance from a simple array does not follow inverse square law. Because it is an interference field, the changes in level with distance and/or angular displacement can be abrupt and unpredictable in the near field.

If we use the summation model and we assume that all elements are driven by the same signal, that the output amplitude and phase relationships are identical for all elements, and that the elements are all omnidirectional, then the directional response can be given by the following equation:

$$R(\alpha) = \frac{1}{n}\left|\frac{\sin\left(\frac{knd}{2}\sin\alpha\right)}{\frac{kd\sin\alpha}{2}}\right| \quad (1)$$

where *n* is the number of elements in the array and *d* is the spacing between them.[4,5] Let's use this relationship to determine the response of Hilliard's vertical array of 127 mm (5-in) drivers as shown in Figure 4A.

Figure 4A. Hilliard's 6-element line array of 5-inch drivers



Here, the number of elements is 6 and the spacing between them is 5 inches. Using the summation model equation we arrive at the polars shown at 4B for 500 Hz and 1 kHz. The 500 Hz polar shows a single, broad major lobe. This demonstrates good directivity at this frequency. The 1 kHz polar shows the formation of a narrower primary lobe with smaller secondary (off-axis) lobes.

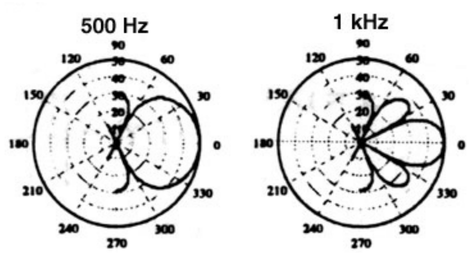


Figure 4B. Hilliard's polar response at 500 Hz and 1 kHz (B).

3.2 THE PRODUCT THEOREM — PERFORMANCE AT HIGHER FREQUENCIES:

The product theorem states that the response of an array can be obtained by multiplying its directional response by the response of a single element in the array.[6] This definition is shown graphically in Figure 5. The first product theorem allows us to make a better approximation of an array's directivity by multiplying the known directional characteristics of a non-simple source by the directional characteristics of an array of simple sources.

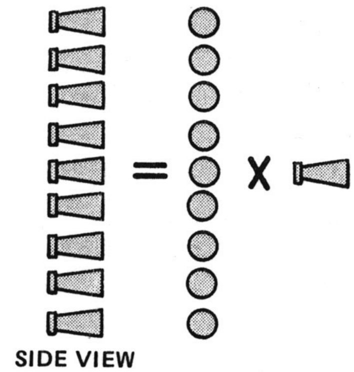


Figure 5. Graphical representation of the product theorem.

<u>Thus, if the individual driver beams at high frequencies, the net array response will be impacted by this same beaming.</u> This will be superimposed on the array response as determined by Equation 1.

4. LINE ARRAY THEORY USING THE INTEGRATION MODEL:

As long as we compose our line array of individual, discrete elements then equation (1) will give us the answers we need. However, it is important to note:

> <u>If we design new loudspeaker components that can be combined to form a continuous "ribbon" or line from top to bottom, we need a new mathematical model to describe it.</u>

Without burdening the reader with the rigors of the math involved, we'll go directly to the governing equation:

$$R(\alpha) = \frac{\sin\left(\frac{kl}{2}\sin\alpha\right)}{\frac{kl\sin\alpha}{2}}$$

(*kl/2* = p*l*/*λ*, where *l* is the array length) (2)

This equation enables us to determine the response of the continuous array in the far field.

Remember, the far field begins at that distance where we first notice that the fall-off in response follows inverse square law, diminishing 6 dB with each doubling of distance.

4.1 DECIBELS VERSUS DISTANCE

Figure 6 shows a continuous array 3 meters (10 feet) high, and we have indicated the distances at which the far field begins at 1 kHz and 10 kHz. Note that at 1 kHz the far field begins at 13 meters (43 feet), while at 10 kHz it begins at 130 meters (430 feet).

At high frequencies, the more disparate sources do not contribute coherently to the on-axis sources until a considerable distance from the array. This means that high frequencies will appear to have a farther "reach" than low frequencies when we listen to the array on-axis at large distances.

This comes as a simple consequence of basic physics and is not a result of any unique or advanced proprietary engineering.

When we consider the -6-dB beamwidth in the far field at high frequencies we can observe another phenomenon. In the example of Figure 6, the -6-dB beamwidth is only 0.8 degrees at 10 kHz. It is clear that only a small fraction of the audience will be in the zone where such performance could be appreciated.

This phenomenon has been presented and discussed in prior literature. Not so often discussed is the frequency-dependent nature of this effect and the varying coverage patterns that result. If we are to optimize the performance of a particular array used to cover a specific audience area, we must take all aspects of line array performance into account when constructing the array.

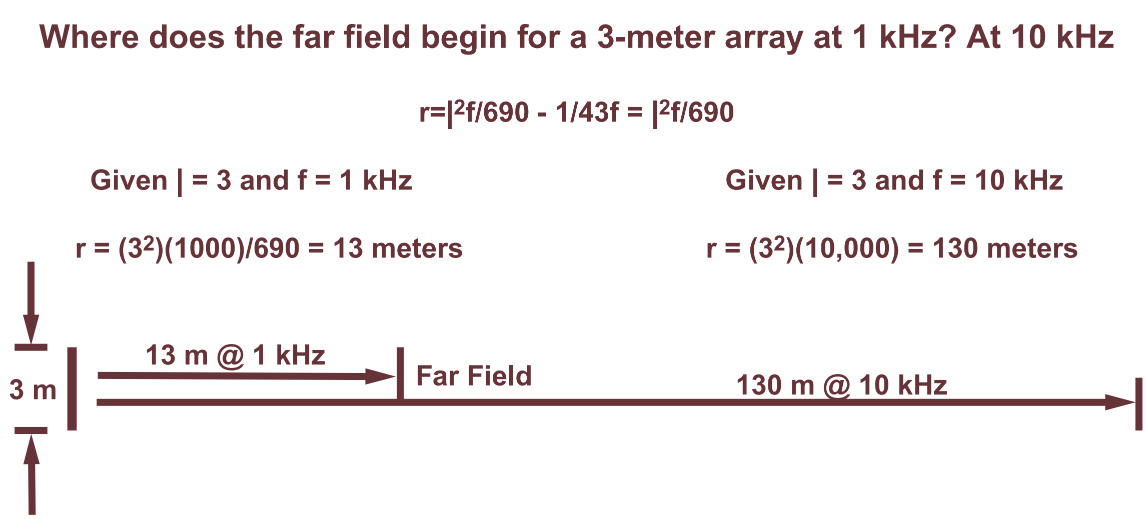


Figure 6: A far-field example. For a 3-meter array, the far field begins at 13 meters (43') for 1 kHz and at 130 meters (430') for 10 kHz.

5. NOT ALL ARRAYS ARE STRAIGHT:

If a line array is to be useful in large-scale sound reinforcement it must be capable of excellent coverage for all patrons. This normally requires that the vertical line array be articulated, or curved in the vertical plane.

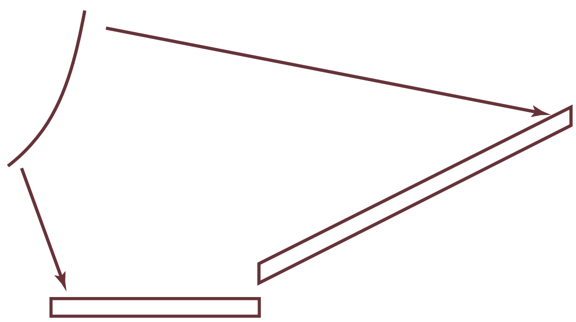


Figure 7. A curved array may be required for near and far coverage.

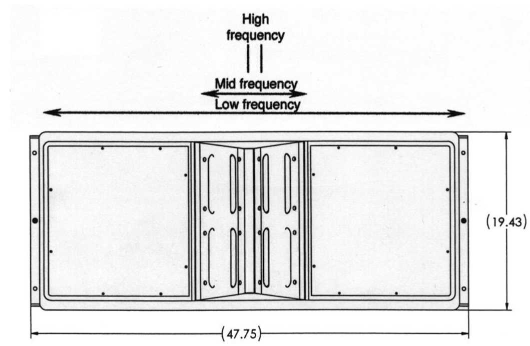
A typical coverage situation is shown in Figure 7. We can see intuitively that the far-throw coverage can be met by a relatively straight section of the array elements, while the near throw coverage will require some degree of curvature in order to provide uniformity of coverage over a wider vertical angle.

The VerTec solution to this design problem has been met through the design of a family of unique 3-way line array elements along with a Windows/Excel PC computer program, the JBL VerTec Line Array Calculator. This software tool is capable of estimating the response of an arbitrarily articulated vertical array of such elements.

Using this program a JBL VerTec system user can enter the vertical cross-section view of a performance space. The designer can then enter into the program various articulated vertical arrays and observe the net response on the seating areas. But first let's look at the new loudspeaker design required to integrate classical line array acoustics and the predictive software program into a useful, field-oriented sound reinforcement solution.

6. DETAILS OF THE JBL VT4889 SYSTEM:

Figure 8A shows a front view of the 3-



way 4889 system. The inner HF section consists of 3 in-line diffraction slots, each fed by the newly-designed 2435 compression driver. These in-line slots run from top to bottom and enable vertically stacked 4889 systems to provide a virtually continuous HF radiating segment from enclosure to adjacent enclosure.

A side view of the enclosure is shown at B, indicating the vertical relief angles on top and bottom sides that allow for articulation of adjacent enclosures.

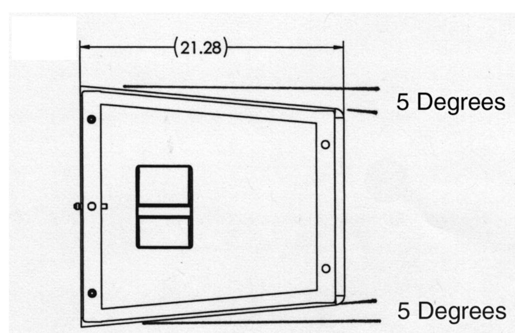


Figure 8B. Side view of the JBL VT4889 system.

Each frequency section should form a continuous virtual ribbon relative to its operating frequency range for the array to function properly. Gaps between cabinets should be minimized and remain constant for all splay angles between cabinets to prevent destructive interference at high frequencies.

Two MF sections flank the triple HF diffraction slot. Each of these contains two 200 mm (8-in) neodymium drivers with dual voice coils, working into compression slots located along the waveguide expansion of the HF section. On the outside are a pair of 380 mm (15-in) drivers. Crossover frequencies are roughly 200 Hz and 1.1 kHz with specific overlapping characteristics, so both LF and MF systems are effectively continuous radiators over their ranges of wavelength operation, resulting in a nested array of LF, MF and HF sections, as indicated at 8A.

Precise control of HF radiation in the proprietary waveguide is enabled by geometrical tapering of the path from each HF driver to the diffraction slot to ensure that there is no vertical beaming over the HF passband of the system.

Because of the close nesting of HF and MF elements, advanced acoustical and mechanical engineering was required. This included the waveguide boundaries that load the HF drivers and the compression loaded slots through which the MF drivers radiate.

A new Radiation Boundary Integrator (RBI™) was devised to allow the exit of HF acoustical energy past a boundary surface which is integral to MF radiation, making it virtually “invisible” to MF power radiation. This results in a smoother coverage pattern while reducing intermodulation distortion.

Figure 9 shows the horizontal polars for the VT4889 system. These indicate the effective horizontal coverage of a typical vertical array of the elements, and that response is largely independent of the vertical articulation of elements.

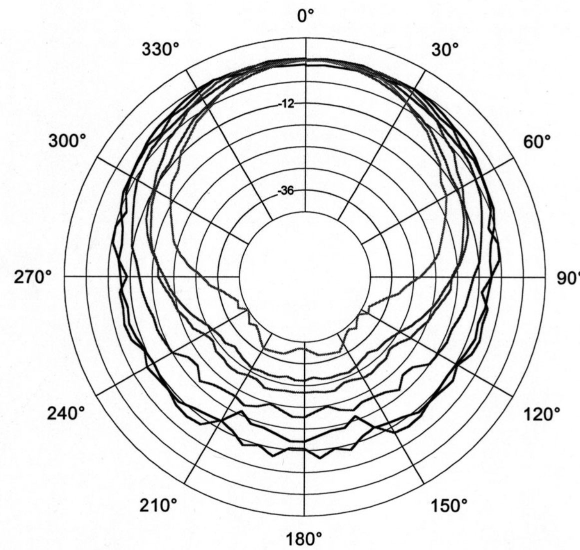


Figure 9. Horizontal polar response of a single JBL VT4889 system.

6.1 MECHANICAL DETAILS OF THE VT4889 SYSTEM:

We have seen in Section 4 that a continuous ribbon of sound with no gaps in the radiating surface is preferable, and in Section 5 we noted that arrays may need to be curved to adequately cover typical audience areas. The VerTec system enclosures have been designed to take maximum advantage of these two acoustical requirements.

Measuring only 1213 mm x 489 mm x 546 mm (47.75” W x 19.25” H x 21.4” D), each enclosure includes all required hanging and rigging hardware fittings to couple one box to another.
To make field handling easier and to enable systems users to create very large arrays, the individual box weight of the full-size VT4889 is only 72 kg (159 lb.),

despite a transducer complement that includes (2) 600-watt LF drivers, (4) 400-watt MF drivers, and (3) 100-watt large format HF compression drivers.

Due to the low individual weight of each array element, up to 18 VT4889 systems can be suspended from a single VT4889-AF hanging Array Frame, with a 7:1 design factor. The enclosure's compact size allows it to be stacked on-end, two-high in typical transport truck bodies with interior ceiling heights as low as 2438 mm (96 in).

7. CASE STUDIES:

With JBL's Vertical Technology, the horizontal coverage of an array is fixed (nominally 90°) and thus becomes a "constant" baseline on which the VerTec system engineer can build a well planned event or venue sound design. The primary tool is the software prediction program which enables the user to preview the expected results from the number of enclosures and their hinge-bar (vertical displacement) angles to achieve optimum coverage of the audience seating areas.

The VerTec Line Array Calculator, a software tool based on Microsoft Excel, allows the design engineer to select the number of array elements and individually adjust the splay angles between adjacent elements. The designer can specify up to three seating planes and determine the front-to-back distances as well as the slope of each plane, all relative to the location of the line array. The program then asks the user to select a frequency (one-third octave centers from 100 Hz to 20 kHz). When a frequency is selected the program calculates the vertical polar plot of the line array on 1-degree increments and indicates the front-to-back center-line coverage in dB on each of the three seating planes.

Through an intuitive process of entering, observing, and changing the angular relationships between adjacent elements, the designer can fairly rapidly arrive at a target directional function for any array of multiple enclosures. Additionally, useful mechanical information such as overall array weight, sizing and such is available to the system engineer.

Figures 10 through 12 show typical data produced by the design program, compared to actual field measurements of the same array that is depicted in the software.

Note that all field measurements were taken in a half-space groundplane environment, with the measurement microphone positioned at a distance of 20 meters.

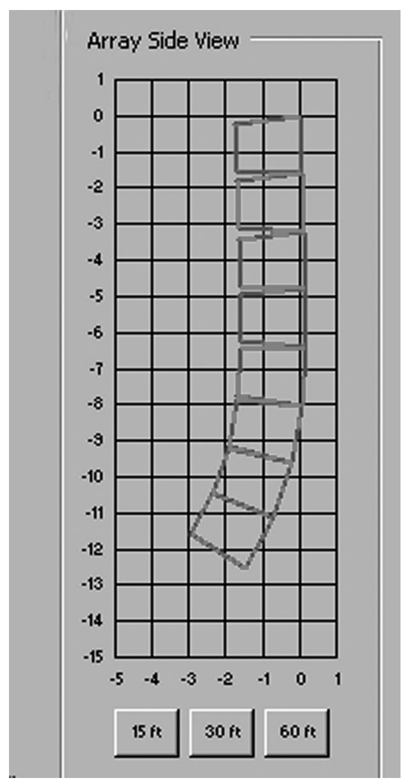
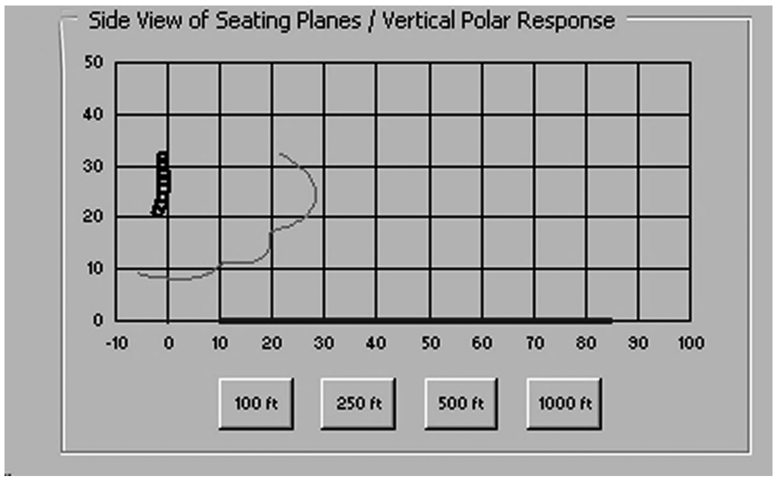
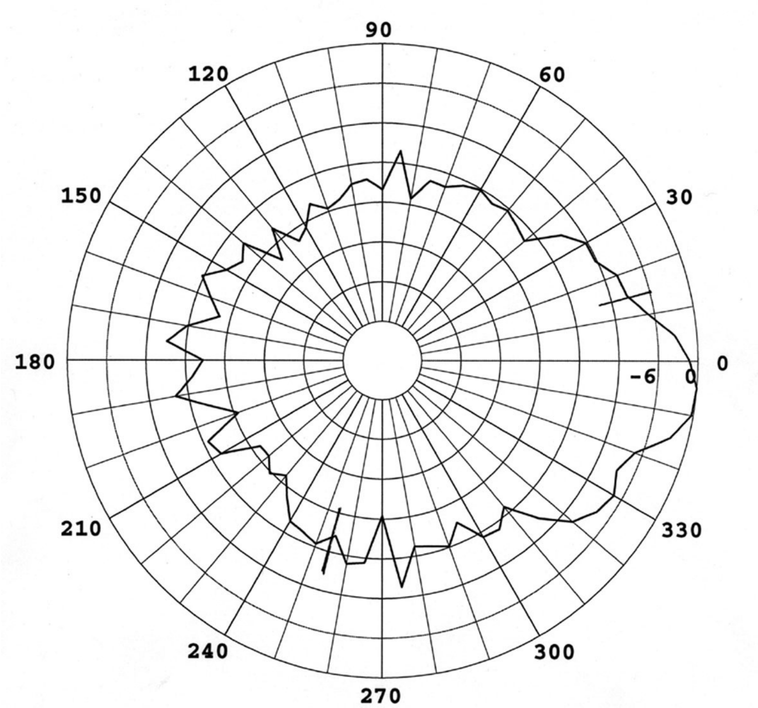


Figure 10A. Calculations vs. measurements. An 8-element array (A).

It should be pointed out that the angular range of the computed polar plot consists only of the forward 120 degrees of the system's response; this range is marked off in the measured polar plots. It is clear that the program's estimates of polar response very closely match the measured data, consistent with the 5-degree resolution of the measurements.

An 8-element array is shown at A. The computed polar plot at 250 Hz is shown at B, along with the actual, measured 20-meter polar response at C.





Figures 10B & C. Calculations vs. measurements. Computed polar response at 250 Hz (B); measured polar response at 250 Hz (at 20 meters) (C).

Figure 11 shows corresponding computed and measured data at 1 kHz. The polar data produced by the design program are computed on one-degree increments, whereas the measured polar data are taken every 5 degrees.

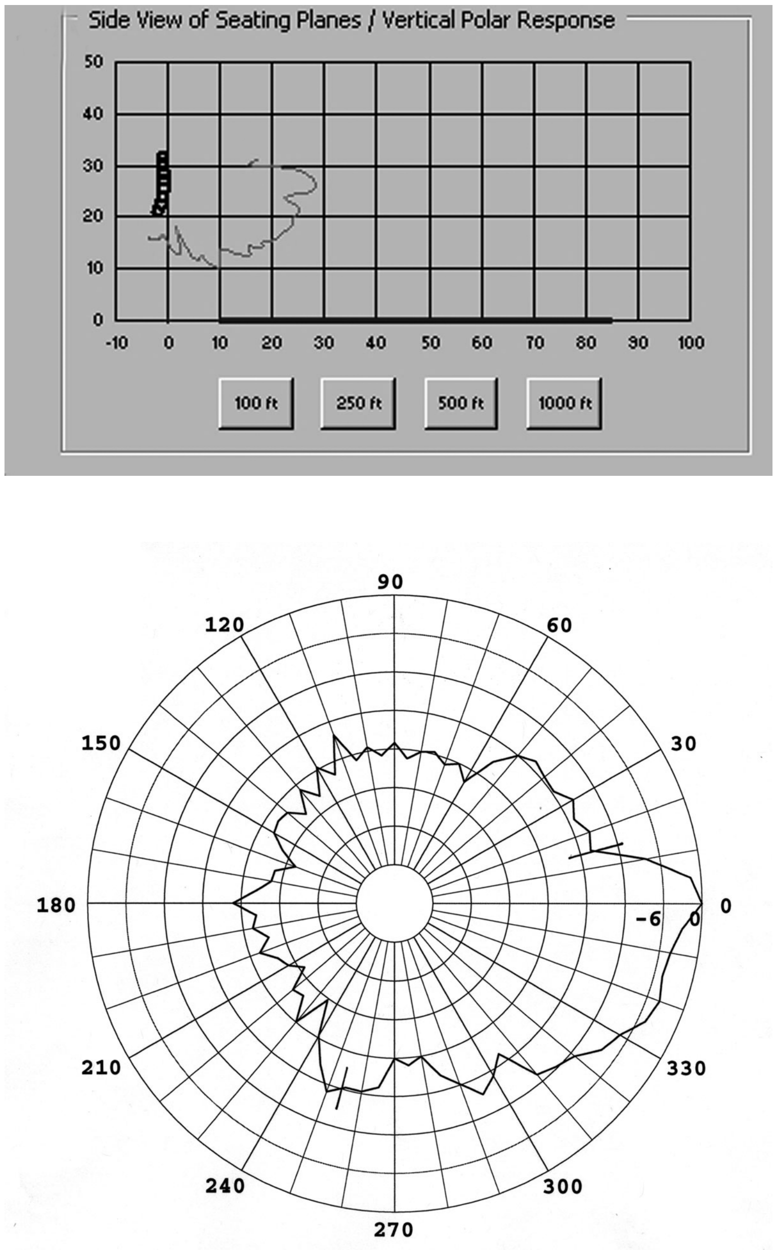


Figure 11. Calculations vs. measurements.
Computed polar response at 1 kHz (A); measured polar response at 1 kHz (at 20 meters) (B).

Figures 12A and 12B show corresponding data at 4 kHz.

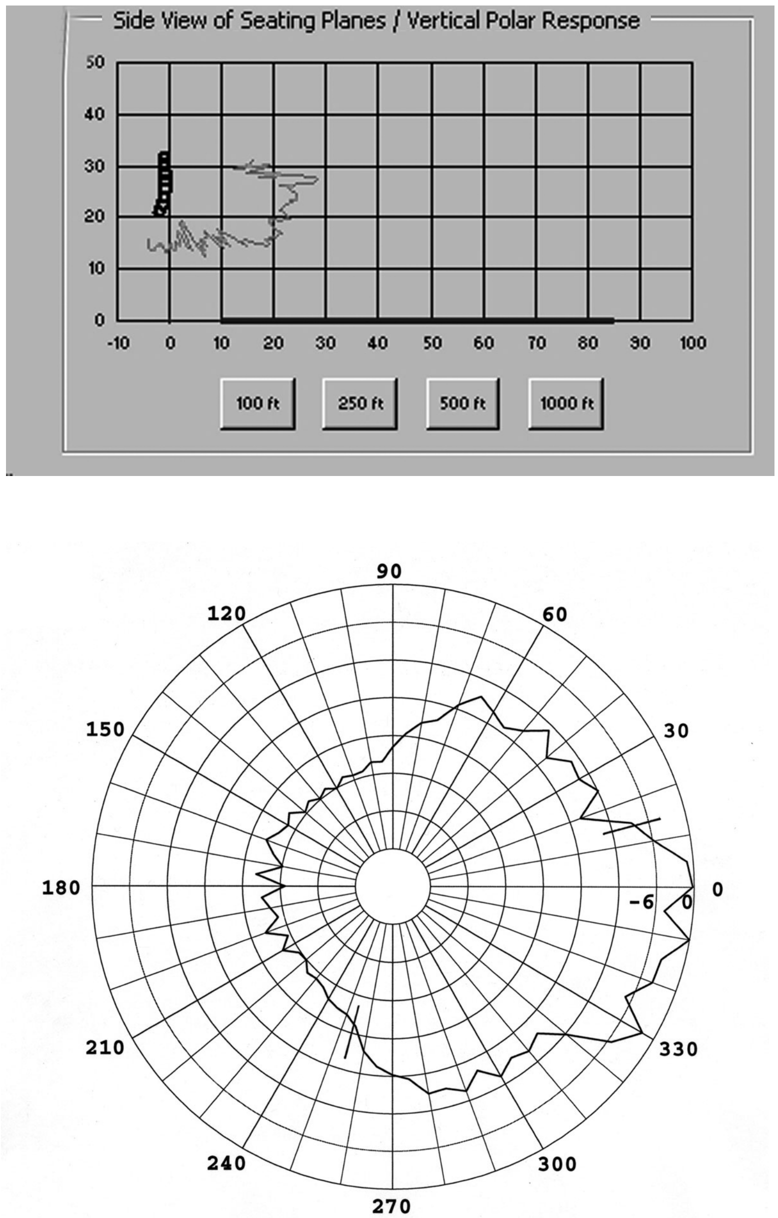


Figure 12. Calculations vs. measurements.
Computed polar response at 4 kHz (A); measured polar response at 4 kHz (at 20 meters) (B).

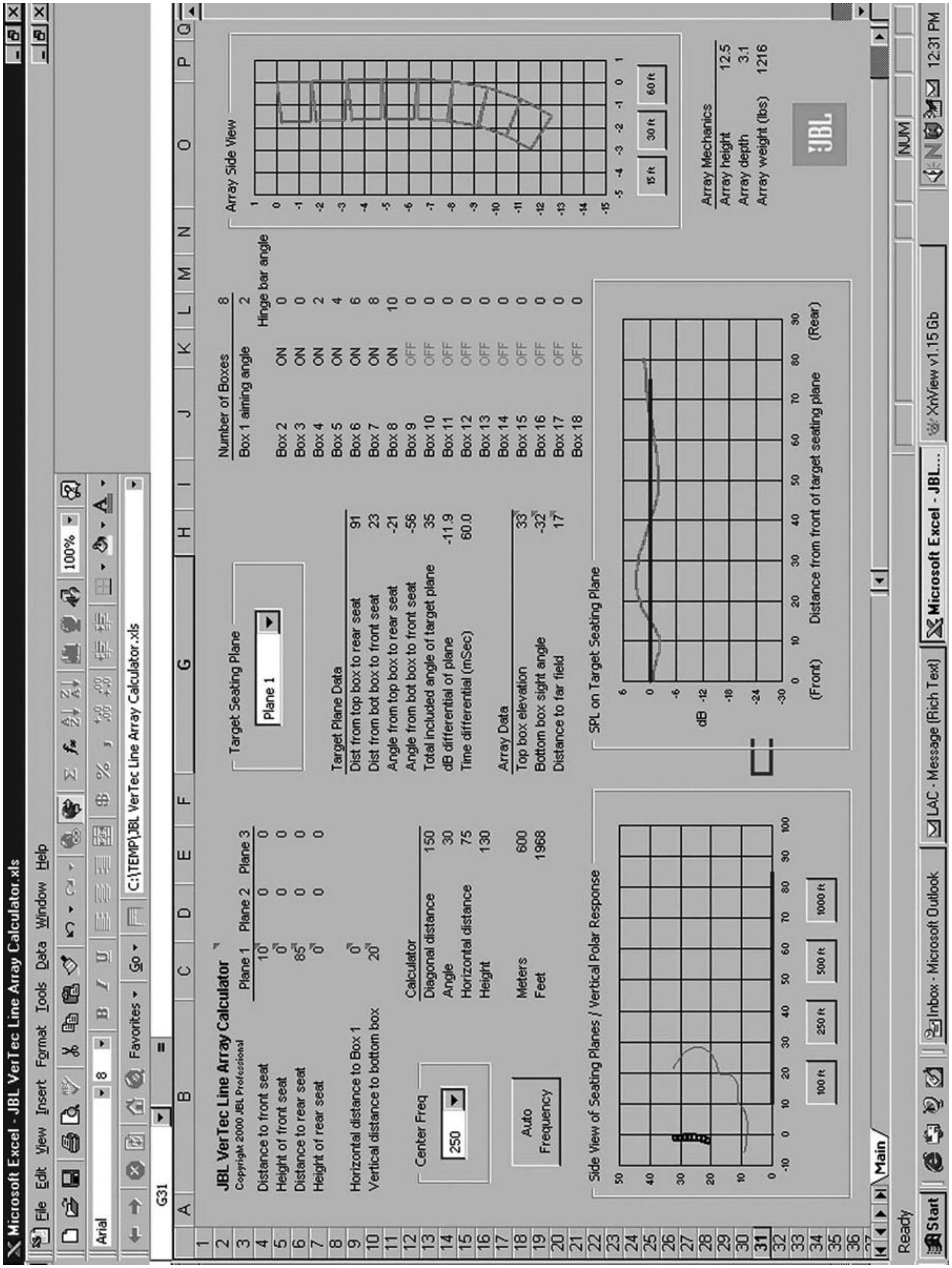


Figure 13. JBL VerTec line array calculator: Full computer display.

In order to give the reader an idea of the full scope of the VerTec Line Array Calculator design program, Figure 13 illustrates a full-screen view of the program, showing mechanical details of the array, effective polar data, and uniformity of coverage on any selected seating plane.

Note an array of eight (8) full-size VT4889 enclosures has been selected, with an array aiming angle ('Box 1') of 2 degrees downtilt, with individual box aiming angles set at 0, 0, 2, 4, 6, 8 and 10. The graphic figure at the lower center of the display shows the predicted sound pressure level of the array at 250 Hz, from the first to last seating rows. *Array design, splay angles and performance results will vary when the mid-size VT4888 or compact VT4887 multi-way line array element are used.*

CONCLUSIONS

The introduction of JBL's Vertical Technology has taken the mystery and mythology out of line arrays. It has been shown that classical array acoustics which were used to create first-generation line array systems more than 50 years ago still hold true today, and that the same mathematical concepts explained by classical acoustical researchers like Beranek, Olson and Hilliard can be scaled up to create higher-powered line array systems capable of serving the sound reinforcement needs for both voice and music in even the largest of performance venues.

JBL's VerTec line array systems, with their unique suspension hardware system, provide a continuous baffle surface and can be configured into straight-line arrays, uniformly and non-uniformly curved arc arrays, progressive spiral, and J-form arrays. They are representative of the dramatic evolution of the original compact 'speaker column' that was first explored by such early practitioners. Such flexible, full-bandwidth arrays offer a powerful new set of tools for the sound reinforcement industry.(7)

One of the most significant things to comprehend is that, regardless of origin or manufacturer, when modular elements are combined into a line array, the observer should not, and indeed cannot, expect the axial directivity of the larger array to behave as if it were simply a composite stack of linear soundpaths, or 'laser-like' box angles. The observer will come to understand that the array's performance should be evaluated holistically, rather than from the point of view of discrete array elements.

In effect, the performance of a modular line array, regardless of element size and the number included in the array, will be influenced by the acoustical characteristics and capabilities of each individual enclosure. Assuming a viable design for the individual enclosure, successful field deployments of line array systems can now be realized, ranging in size from small to large systems for a variety of venues and events.(8)

The expectations of audiences and sound engineers alike have changed greatly since the early days of acoustical research. New line array system tools are now available to meet those expectations of clear, articulate sound with higher system output and greater dynamic headroom potential. With the application of JBL's Vertical Technology, the VerTec system gives modern system designers and operators that capability.

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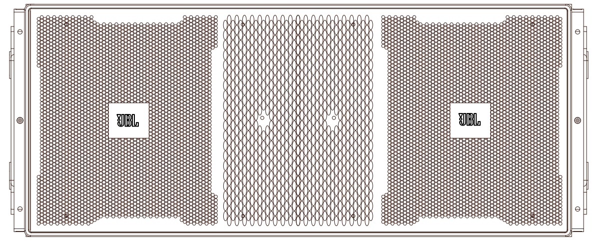
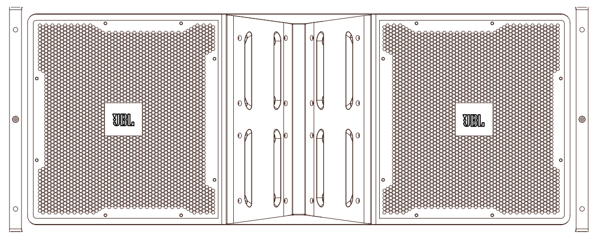
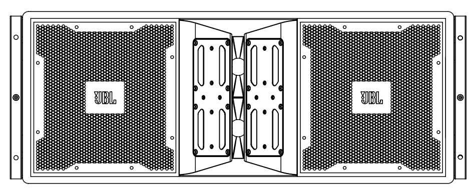
VT4880
(Full-size arrayable subwoofer)



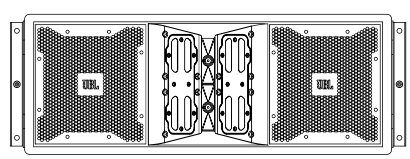
VT4889
(Full-size 3-way line array element)



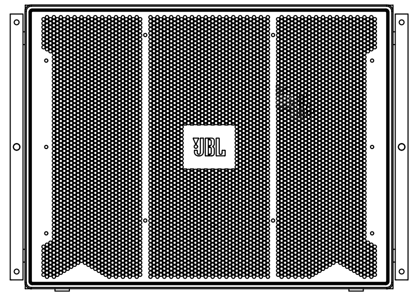
VT4888
(Midsize 3-way line array element)



VT4887
(Compact bi-amplified 3-way line array element)



VT4881
(Compact arrayable subwoofer)



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