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Practical Considerations for Field Deployment of Modular Line Array Systems

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ABSTRACT
An emergent market trend during the past decade, modular line array systems are now being used for a wide variety of sound reinforcement applications. Variously referred to as line arrays, line-source arrays, curved arrays, curvi-linear arrays or vertical arrays, such articulating line array systems can offer performance results in the field that vary as widely as the applications to which they are applied. Regardless of the terminology used to describe the genre, such systems do typically provide relatively narrow vertical coverage patterns and increased apparent gain at distance when compared to more traditional, fan-shaped arrays.

These acoustical characteristics can be used to great benefit when the system is properly configured. At the same time, this class of device can present unique acoustical challenges for field deployment. Some of these challenges are influenced by the mechanical design of the individual modular line-array element and its suspension hardware. For instance, the size and shape of the individual enclosure, its acoustical capabilities, and the limitations of its suspension methods have a direct influence on what can, and cannot, be achieved when combining multiple elements in an arrayed system. With such systems, not only the high frequency section, but the entire full-range system performance must be considered.
To this end, relative merits of individual enclosure design attributes that influence overall system performance are discussed.

The availability of objective information regarding the usefulness of such systems when deployed in the field has not kept pace with the proliferation of commercially available product. However, information systems, including application notes and predictive software tools, are evolving to enable system users to reliably predict system array setup, projected coverage patterns, and average level in various parts of the intended audience area. A case-study approach is used to examine the practical aspects of deploying this type of sound reinforcement systems in performance spaces, and to review various design trade-offs encountered when using them in different venue types. While not a panacea, and not always suitable as a stand-alone sound reinforcement solution, it is shown that carefully-designed modular line array systems can be effectively deployed in both small and large venues if system limitations as well as advantages are understood.

INTRODUCTION

With the advent of the contemporary modular articulating line array system, sound reinforcement professionals have a potentially useful tool. Such systems have applications in the portable realm and for installed venue-specific system designs.

The popularity and market impact of such systems, available from several different equipment manufacturers in regions like Canada, England, France, Germany, Italy, the Netherlands, Spain and the United States, points to the need for practical and accessible information regarding the benefits and liabilities of using such systems. This requires an examination of how such systems are actually deployed under various circumstances, and an evaluation of their actual usefulness.

Studies have shown that the type and shape of an articulating line array system has considerable influence over the coverage pattern that may be expected in the listening area at various frequencies.[i] Advance modeling techniques and theoretical research can provide valuable insight into how such systems might perform in performance spaces. However, before a large-scale modular line array system can be effectively evaluated in the field, multiples of the actual enclosure to be used in the construction of such an array must be available for use.

A wide variety of individual enclosure design approaches are currently offered to system users. The results that can be obtained from combining these various enclosures into multi-box arrays of different sizes and shapes also vary. Some array performance results in the field will be judged by system users to be more useful than others.

With modular line array systems, the link between the design of an individual enclosure and the larger array made up of multiple boxes is more apparent to listeners than with traditional, fan-shaped arrays. This paper describes the various design tradeoffs and compromises that are encountered by the system designer, and details the field deployment of arrays of varying sizes comprising multiples of one specific enclosure design.

MODULAR LINE ARRAY ELEMENT DESIGN ISSUES

For a modular line array element to be useful in a wide variety of field applications, it must meet a number of design criteria. Portable systems will typically place a greater demand on the system designer than do enclosures for permanent installations, due to transportation, handling and flexible suspension issues. System designers are confronted with the need to balance acoustical performance expectations with several factors that include size, weight and enclosure shape.

In the design of modular line array elements, both mechanical and acoustical issues must be addressed, creating a dual-track design process that can challenge previous assumptions that may be based on experience with non-line array systems.

A primary design goal of the program which led to the practical results presented herein was to explore what could be accomplished with a “single-box” inventory (an array system based on multiples of only one type of enclosure). It was postulated that if the primary mechanical and acoustical design requirements for the creation of articulating line arrays could be rationalized in a single box design, then user inventories, handling issues and field deployment would all be simplified.

Therefore the enclosure design must be a hybrid of unique electro-acoustical and mechanical hardware solutions. While transport and setup issues are important to setup technicians, the acoustical results and audio performance of the package is vital. To achieve the desired acoustical results under actual-use conditions (outside the laboratory) demands that sound quality not suffer due to suspension or packaging issues. Complicating the matter is the issue of interference patterns and summation effects evidenced in line array systems.

Lobing issues can become critically important with varying array size and adjacent box splay angles. It is advantageous for the horizontal coverage pattern of both the individual modular element and the multi-box array to be consistent. It was therefore postulated that a good method to proceed with the design of the individual array element was to employ an axially symmetrical design. There are certain benefits to be realized from locating the high frequency element(s) on the centerline, between the low/mid frequency elements in an enclosure. This approach to solving lobing errors without having to employ complex corrections in the frequency-dividing network domain has been known for some time, and was previously described by D’Appolito.[ii]

Since an enclosure design that is axially symmetrical in the horizontal axis will simplify various digital signal-processing issues that inevitably come up when multiple modular enclosures are combined into line arrays, it is difficult to justify any design direction for a single enclosure that does not take this into account. With this fundamental issue resolved at the onset, system designers could proceed to evaluate the various compromises inherent in different mechanical and acoustical designs.

Mechanical Design Issues, Modular Line Array Elements

Election to take advantage of an axially symmetrical arrangement of transducers perhaps represents the most fundamental mechanical design decision. The shape of the enclosure also deserves careful consideration. For a number of reasons, wedge frustum (‘trapezoidal’) enclosures present an attractive design direction. These include both mechanical and acoustical reasons. Trapezoidal cabinets are convenient for physically building arrays, if destructive interference patterns can be minimized.[iii]

The polar patterns of arrayed loudspeaker systems are a direct result of their interference patterns. Thus some enclosure designs will offer better ‘arrayability’ characteristics than others.[iv] Since loudspeaker enclosures do not act independently of one another when multiples are combined in an array, it is critical that both acoustical and mechanical elements are considered when settling on the shape for modular elements to be used in a multi-box array. Many of the interference problems previously seen with early trapezoidal (non-line array) system enclosures can be addressed in a modular line array element through insightful acoustical design.

Acoustical Design Issues, Modular Line Array Elements

There is growing awareness that ‘line array technology’ for sound reinforcement is not a new concept. Research in the field dates back some sixty years and more. The high frequency section and the high frequency performance of such systems have historically received some measure of focus and investigation. Olson (1940)[v] and Beranek (1954)[vi] both described the results to be expected from line array systems. The systems examined were typically straight (non-articulating) arrays, and their directional response could be determined using a discrete, or summation model.[vii]

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

Fig. 1. : The discrete, or *summation,* model. Using this model to analyze such researchers’ work assumes *n* number of elements in the array and *d* as the spacing between them in the vertical axis.

Modern articulating line array systems differ in many ways from the early column-type loudspeakers described by researchers like Olson and Beranek. With contemporary systems being designed that behave more like a continuous ‘ribbon’, or uninterrupted line from top to bottom due to transducer and acoustical-element density, what is important is to determine the response of the continuous array in the far field, especially as it 'bends' or curves in the vertical axis. Here, the governing equation is:

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

Figure 2. : Determining the response of the continuous array in the far field (*kl/2* = *πl/λ*, where *l* is the array length).

Low Frequency Issues

It should be pointed out that such previous research literature describing line array technology was predominantly based on smaller, flat, non-curved column-type arrays intended for vocal-range use. It is therefore incumbent upon modern system designers to carefully consider not only the high- and mid-frequency properties of the system, but also to assess how low frequency sections of modular line array system elements contribute to the overall performance of multi-box arrays under different conditions.

A wealth of theoretical design literature is becoming available as proponents of various system design approaches seek to justify various directions taken. However, little documented research literature exists to allow the methodical consideration and review of the acoustical properties of full-bandwidth modular line array systems under actual-use conditions. Possibly for this reason, the understanding of low-frequency response characteristics of modular line array systems has lagged behind available information on high frequency performance.

There is adequate prior work available to assist in making decisions regarding the low frequency performance of arrays. The primary design decision for the low frequency section will center around the use of horn-loaded systems as opposed to sealed or vented-box designs.

The inter-relationship of cabinet volume, low frequency cutoff and efficiency must be carefully weighed. While some system designers may be tempted to explore horn-loading options for the low frequency section of a modular line array system, this design approach is not without its liabilities.

Horns are actually less efficient in their use of enclosed volume when compared to direct-radiator systems. The superiority of the vented system over both a closed-box and horn system design has been previously described (Keele, 1976)[viii]. With the use of direct radiators in multiple arrays, efficiency increases roughly in proportion to the number of units used in the array.[ix]

As with the use of an axially symmetrical enclosure design, the choice of a vented low frequency section will typically result in fewer equalization demands to optimize enclosure, and array, performance. This is an important consideration if linear system power-band response is desired, today's digital signal processing capabilities notwithstanding.

It should also be noted that assumptions regarding the output efficiency advantage of horn systems typically assume the use of traditional (single gap, single voice coil) component transducers in the direct-radiating systems they are being compared to. The use of higher-output, dual-coil transducers available to the designers of the system described herein will afford a more than 3 dB greater maximum output over a single gap, single coil design.[x]

In addition, the use of neodymium as a magnet material within a well designed heat sink will yield a significant reduction in distortion, lower power compression, and lower inductance than a traditional single gap, single coil low frequency transducer. The overall benefits of such transducers to the design of a modular line array system element can further advantage the direct-radiating low frequency section when it is being compared to horn-loaded designs relying on more traditional components.

In preparing to review specific arrays deployed in the field, it is instructive to examine directivity characteristics to be expected from the low frequency section of a modular line array system.

The following chart assumes a baffle height of .5 m (19.5 in) for an individual line array element enclosure.

# Of Boxes	**Array Height**	**λ/4**	**λ/2**	**λ**	**3λ/2**
4	2 m	43 Hz	85 Hz	170 Hz	227 Hz
6	3 m	28 Hz	57 Hz	113 Hz	170 Hz
8	4 m	22 Hz	43 Hz	87 Hz	131 Hz
10	5 m	17 Hz	35 Hz	69 Hz	104 Hz
12	6 m	15 Hz	29 Hz	58 Hz	87 Hz
14	7 m	13 Hz	25 Hz	50 Hz	87 Hz
16	8 m	11 Hz	22 Hz	43 Hz	65 Hz
18	9 m	10 Hz	19 Hz	39 Hz	59 Hz

Figure 3. : Low Frequency Array Dimensions
(Where λ= wavelength)

For example, an 8-box array has a height of 4 meters (about 13 feet). At 87 Hz, relatively little directivity will be achievable. However, when that array size doubles to 16 boxes (with a height of 8 meters (about 26 feet), directivity at 43 Hz is now quite achievable (with a Directivity Index of 3.5 dB). The larger (16-box) array therefore can be expected to have the same directivity at 43 Hz that the smaller array has at 87 Hz, a full one octave lower.[xi]

What this means for the system user is that in typical field conditions the power response will be the inverse of the directivity. To achieve "flat" frequency response on-axis, the power response will be the inverse of the low-frequency array's directivity factor. Simply stated, the longer the array, the greater directivity will be at lower frequencies. Because of the line array summation effect, longer arrays can produce surprisingly large quantities of low-frequency energy. System users in the field can employ specific methods to predict and manage this effect, as we will see in the following case studies.

The VT4889: A Modular Line Array Element Design

Combining these various mechanical and acoustical design elements into a single enclosure, while seeking to offer users a flexible and useful array system in the field, led to the construction of the model VT4889.

This is a commercially available modular line array element manufactured in the United States. It is a 3-way active system, featuring a total of 9 (nine) component transducers in a relatively compact enclosure. Applications include live performances and special events in venues ranging from small to large. Upcoming case studies will detail some typical applications.

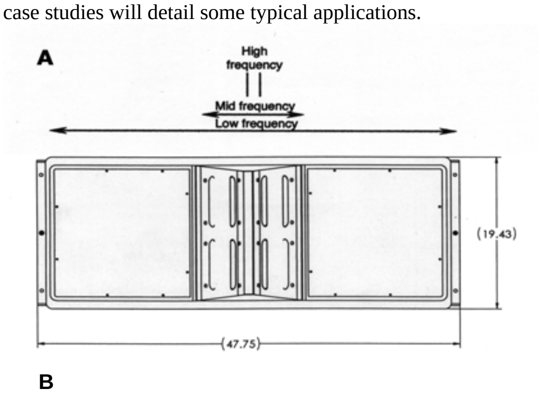

Figure 4. : Front (A) and side (B) views of the JBL VT4889

The decision to employ a wedge frustum box shape enables line arrays of varying length and with varying baffle splay angles to be constructed The axially-symmetrical design offers a very smooth horizontal polar pattern without overly complex signal processing requirements. This is a distinct advantage when combining multiple boxes in articulating line arrays.

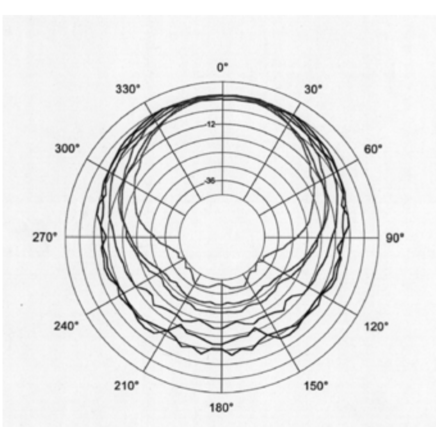

Figure 5. : Horizontal polar response of a single JBL VT4889 modular line array element.

With the primary acoustical and mechanical design characteristics of the individual enclosure settled on, the system design team then focused on multi-box combination issues. A number of controlled tests in both indoor and outdoor environments, including comparisons with other available systems, were conducted.

However, to definitively evaluate the viability of an enclosure design in the field requires setting up multiple boxes under various conditions. The field deployment of arrays in various venues using multiple VT4889 enclosures is described.

FIELD DEPLOYMENT : CASE STUDY INFORMATION

The following section details three specific events using modular line array systems. These events took place between February 2001 and February 2002. Each case study is based on a temporary installation of portable systems, relying on suspended arrays.

Details are provided on the venue, line array size and orientation. Discussion includes pre-show expectations of the event sound designer, details on additional speaker systems in use (if any) and anecdotal observations regarding results obtained.

Each of the examples provides an image of an array that was deployed, along with pre-event predictions of coverage for the venue's main (floor) seating plane and upper (balcony) seating plane(s) if applicable. This information is obtained from JBL's VerTec™ Line Array Calculator, an MSExcel-based software application that has been described in previous literature.[xii]

Array images shown depict the number of line array system elements under discussion for a particular event setup. Relative seating plane sound pressure level predictions (from front to rear of the seating area) are shown at 2kHz in each instance.

CASE STUDY #1: SMALL ARRAYS (800 PERSONS)

System and Venue Requirements

The system deployment shown here supported high-quality audio support for multi-track program and special effects playback and wireless dialogue microphones for a command performance by an internationally renowned acrobatic and theatrical troupe. An audience of approximately 800 persons (paying approximately EU 1,122 / US $1,000 per person) was seated at banquet tables. In this instance (a fund-raising benefit hosted by a state governor prior to an international championship winter sports event), each seat holder was considered to be a "VIP" (Very Important Person). Seating and the performance stage were set up 'in the round'.

Figure 6. : Small (4-box) Arrays, 360-Degree Coverage

Line Array System Setup

Suspended from the overhead box lighting truss were 4 (four) arrays of 4 (four) VT4889 enclosures, previously described. Each array was suspended from a corner of the box truss.

Each array was oriented downward at –15 degrees. All box splay angles were set at 10 degrees, the maximum available between adjacent boxes with this system due to their 5-degree angled enclosure sides.

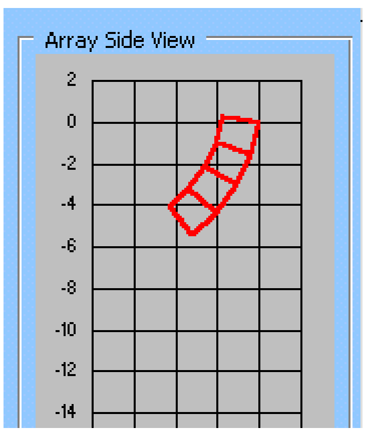

Figure 7. : Side view of 4-box VT4889 Array, 10-degree splay angles between baffles

Each VT4889 array has a nominal horizontal coverage angle of 90 degrees, but due to the exploded-cluster design format, additional fill boxes (comprising a compact 2-way system with 305mm woofer) were positioned midway between each of the four arrays on the side truss sections. Both sightlines for the acrobats and budgetary considerations suggested that the maximum number of modular line array system enclosures per array should be limited to 4 (four). Factory-supplied DSP file preset #4P1B (4 boxes, Constant Coverage baffle splay angle characteristics) was used.

Venue-Specific Configuration

Bearing in mind that the 4-box array suspended in this venue (each with a total baffle height of 2 meters) would not offer much effective directivity control below 170 Hz, the high pass filters in the line array system drive electronics were set relatively high. The event sound designer specified one double-457mm subwoofer enclosure per quadrant for a total of 4 (four) units to supplement low frequency performance in the venue. Imaging between the various parts of the system was managed through proper application of signal-delay techniques for various loudspeaker groups. Accurate signal alignment of a sound system to the source (stage performance) can greatly enhance the audience's listening experience. This is especially important in smaller venues and in the first 30-40 meters of audience area in larger venues.[xiii]

Each VT4889 array has a nominal horizontal coverage angle of 90 degrees, but due to the exploded-cluster design format, additional fill boxes (comprising a compact 2-way system with 305mm woofer) were positioned midway between each of the four arrays on truss sections. Despite the maximum 10-degree splay angles, the 4-box array prediction showed an anticipated reduction of optimum coverage in the first 6 meters of the seating area.

Accordingly, the event sound designer positioned 12 (twelve) compact fill speakers, each with 203 mm woofers, on the stage lip to provide quality sound reinforcement with near-field imaging characteristics. This system comprised 3 (three) units per quadrant.

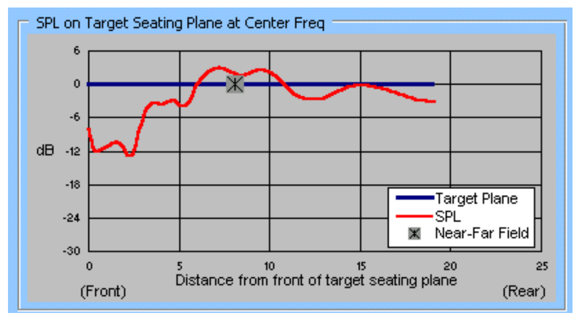

Figure 8. : Predicted SPL on 2k Hz center frequency. Front seating rows at left.

Results: Anecdotal References

System users and event producer alike reported consistent coverage and adequate dynamic range throughout the listening area for both speech and full-bandwidth musical program material. No howling or feedback problems were observed with dialogue microphones despite the central stage location and performers in motion.

CASE STUDY #2: MIDSIZE ARRAYS (2,800 PERSONS)

System & Venue Requirements

The system deployment shown here comprised a pair of arrays set up in left/right format on a traditional proscenium stage. The venue accommodated approximately 2,800 persons.

An event series served a wide variety of productions ranging from musical theater performances and rock concerts to multi-media presentations for business meetings. A high, steep balcony comprised approximately 45% of the available seats.

Figure #9. : Left/Right VT4889 Arrays in Proscenium Stage Theater (pair of 8-box arrays)

Two arrays of 8 (eight) VT4889 enclosures each were positioned at a +10-degree angle to accommodate both forward seating rows and upper balcony areas. A progressive type array was selected with baffle splay angles of 0,2,4,4,6,8,10 degrees.

Factory preset #8P1B (eight box array, progressive baffle splay angles) was employed. High pass filter settings varied with event and musical program type, depending upon low frequency characteristics desired for the production.

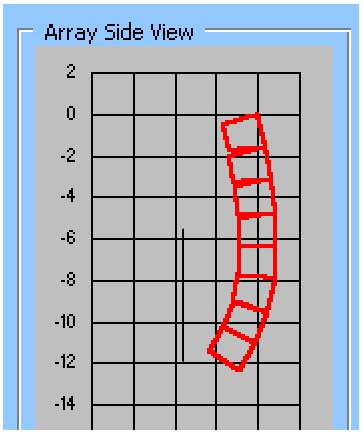

Figure #10. : Side View of 8-Box VT4889 Array, configured as a progessive line array

Venue-Specific Configuration

System technicians positioned 4 (four) double-457 mm subwoofer enclosures at the far left and right corners of the proscenium stage area, for a total of 8 (eight). While an additional central cluster was available, it was typically not required and nearly all productions relied on only the main left/right arrays.

Advance predictions showed that acceptable coverage in the forward rows (± 3 dB throughout the vocal region) could be expected without the use of compact auxiliary front fill units. Due to the facility manager's desire to keep a visually clean stage front area, such units would rarely be allowed for typical events in the venue.

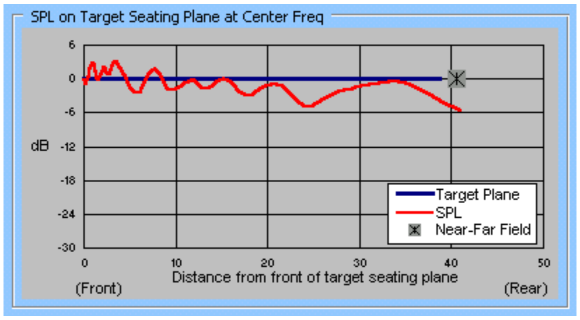

Figure #11. : Predicted SPL on main floor seating plane at 2K Hz center frequency.

Note that the particular array format selected for the venue allows for somewhat of a gradual reduction in average level across the seating plane moving toward the rear of the facility (right end of the line predicting SPL in the main floor back row at a center frequency of 2k Hz). This aspect of the arrays' acoustical characteristics complemented the venue architecture. An overhead balcony edge was positioned at roughly the same point on the seating plane as the level reduction that can be observed in the prediction. This helped mitigate the harsh-sounding reflective buildup in the vocal region that can be experienced beneath balconies in such venues with plaster ceilings.

The next graphic shows the predicted SPL from the same array on the balcony seating plane, also at a center frequency of 2k Hz.

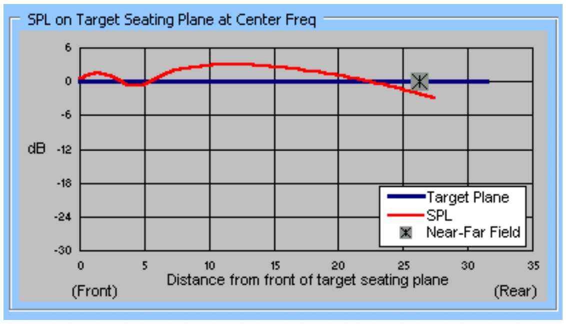

Figure #12. : Predicted SPL on balcony seating plane, 2 kHz

Results: Anecdotal References

Sound system operators and event producers provided positive comments on a regular basis regarding system coverage, fidelity and dynamic range. Without reconfiguration, the system arrays as positioned served a widely diverse event series, from dance performances to religious music productions to hard-rock concerts. Considerable low frequency energy was available.

CASE STUDY #3: LARGE ARRAYS (6,500 PERSONS)

This system deployment was a televised awards show staged in a multi-purpose sports arena. TV camera locations caused arrays to be set at a relatively high distance above the floor. Program material included celebrity presenters, audio/video playback and pop music. Producers sought full-bandwidth sound reinforcement with highly accurate speech and live and recorded music reproduction at all seats for this premier entertainment production.

Figure #13. : VT4889 triple-array setup for asymmetrical seating area in multi-purpose sports arena.

Line Array Setup

3 (three) VT4889 arrays were suspended above the level of the temporary lighting equipment trusses, angled downwards to a main floor and reaching gently sloping side seating areas. An A/B/C array format covered the asymmetrical seating area. Array ‘A’ (house left) comprised an 8 (eight) box array, configured as a modified constant curved array with baffle splay angle settings of 6-6-6-6-6-7-8 degrees. Arrays ‘B’ (house center) and ‘C’ (house right) included 10 (ten) boxes, configured as progressive arrays, with baffle splay angles of 1-2-4-4-4-4-4-6-7 degrees). Signal-processing preset #12FP1B (10 to 12 boxes, Constant curvature, Far coverage, J-shape/Progressive splay angle settings) was used.

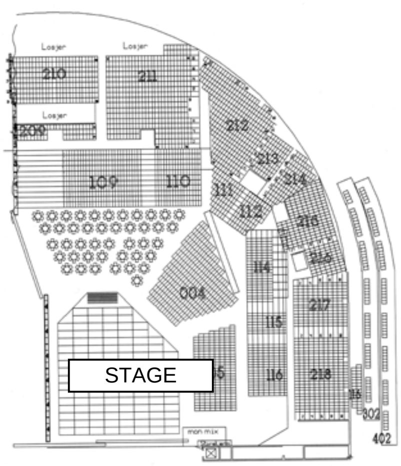

Figure #14. : Asymmetrical seating area, sports venue

Venue-Specific Configuration

Each of the three arrays directly faced one of the three main seating areas in the asymmetrical listening space. Full-bandwidth sound was available from the main arrays, with effective directivity control to 69 Hz available from the 10 (ten) boxes, which in total defined a baffle height of 5 (five) meters. The sound designer specified 12 (twelve) double-457 mm subwoofer enclosures, positioned beneath the stage so as to hidden from view.

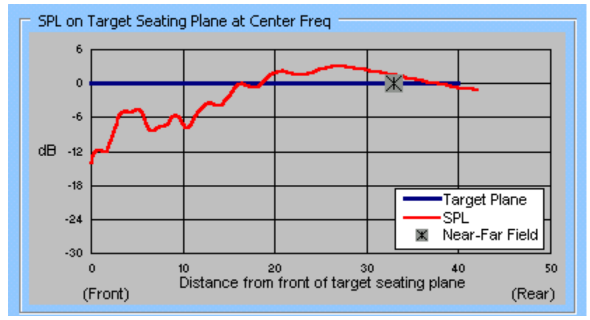

Figure #15. : Predicted SPL on main floor seating plane at 2k Hz center frequency, in venue with very high suspended arrays.

With the first seating rows beginning at a distance of 6 meters from the front edge of the stage, an auxiliary front fill system was employed. This comprised a group of 10 (ten) evenly spaced compact two-way enclosures fitted with 254 mm woofers. These units, correctly signal-aligned and level-balanced to the main overhead line array systems, were used to assist in providing smooth, coherent coverage from front to back in all seating areas.

Results: Anecdotal References

The event production team and sound system operators were reportedly satisfied with the response and dispersion of the system throughout this challenging venue. Listeners moving from the highest seat in one top corner to the opposite top corner reported no noticeable changes in sound quality, imaging or tonal balance.

CONCLUSIONS

The performance of modular line array systems is dependent upon design characteristics of the individual enclosures used to construct multi-box arrays. Acoustical and mechanical design issues must be addressed in the modular enclosure if the array is to be useful, and for optimum system performance to be realized.

The use of wedge frustum (trapezoidal) enclosures, an axially symmetrical design format, and a direct-radiating low frequency section in the enclosure each offer array performance advantages. When such enclosures are combined into arrays, the system can offer predictable and consistent performance characteristics with only a single type of enclosure being used to construct the array.

Low frequency directivity of various arrays can be predicted and integrated into overall event system designs through the use of high pass filters and auxiliary subwoofer units as desired to match event program material. Close seating areas not served by suspended line arrays can be adequately covered with compact fill speaker systems. Both subwoofers and auxiliary fill systems are used to best advantage when proper attention is paid to signal alignment of these support systems with the primary line arrays.

Assuming a viable design for the enclosure and its proper integration into a multi-box system, successful field deployments of line arrays are being realized, ranging in size from small to large systems, for a variety of venues and events. One such enclosure design has been profiled and case studies discussed.

PREDICTIONS

It is anticipated that derivatives of such an enclosure design can be constructed that take the same fundamental acoustical and mechanical design principles and scale them up to construct larger enclosures employing 457 mm (18 inch) woofers. Commercially available examples of such larger array elements, however, are likely to be determined by market preferences to be impractical and not as useful due to size and bulk.

It is more likely that modular line array systems will proliferate taking the acoustical principles described herein, including axially symmetrical trapezoidal enclosures and direct-radiating low frequency sections, and scale them down. These could include designs based on common component transducer sizes, 305 mm (12 inch) and 203 mm (8 inch) woofers for example.

Additional future developments in the field will likely include self-powered modular line array systems with integrated digital signal processing. As the varying needs of event sound designers and system operators for wide-ranging field applications come to be better understood by sound system development engineers and researchers, the global sound reinforcement industry can look forward to refinements in line array technology more closely linked to specific needs of system users.

ACKNOWLEDGMENTS

The author would like to express his thanks to Stuart Morch-Kerrison of Audio One (Norway), Eric Williams of Flag Systems (California, USA) and John Phillips and Noah Bard of Rocky Mountain Audio–Visual (Idaho, USA) for sharing information about events featuring line arrays. Thanks are also due to Raul Gonzalez for field information gathered under various circumstances, often while subjected to sleep deprivation, stagehand coffee breaks and marginal catering.

In addition, acknowledgment is made of the growing number of portable system technicians and soundmixers providing valuable insight about practical aspects of field deployment of line arrays systems, and who are broadening the industry's perspective.

Such perspective is crucial to comprehending evolving expectations in the portable systems industry, characterized as a rapidly changing marketplace. This is due in no small part to a growing understanding of the actual performance characteristics of this genre, which is displacing other system formats.

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