THE PA BIBLE

ADDITION NUMBER TWENTY
SO YOU WANT TO USE A LINE ARRAY?

Special note: EV's The PA Bible *and 19 "additions" were produced 1979-1997 by Electro-Voice engineers and technical marketing people. We still get requests for them. Initially intended to explain basic audio concepts to performing musicians, in order to improve their audio presentation, many issues were also of interest to permanent sound-system installers and designers. The tone was light and sometimes humorous. And there were no big formulas. Addition No. 20 marks the reintroduction of* The PA Bible*, in the spirit of the original. The new issues as well as the old are available on the Electro-Voice Web site in PDF format (www.electrovoice.com).*

Let us know what you think of the The PA Bible*. We have a long list of ideas for new subjects. Please send your own ideas and comments to pabible@us.telex.com.*

Jim Long, editor, May 2007

A LITTLE BIT ABOUT LINE ARRAYS AND THEIR HISTORY

The line array or "column loudspeaker"—most simply a long vertical stack of small cone loudspeakers—was very popular in the 1960's and 1970's. Such devices were touted as being able to throw sound to the rear of a room without "blasting out" those in the front.

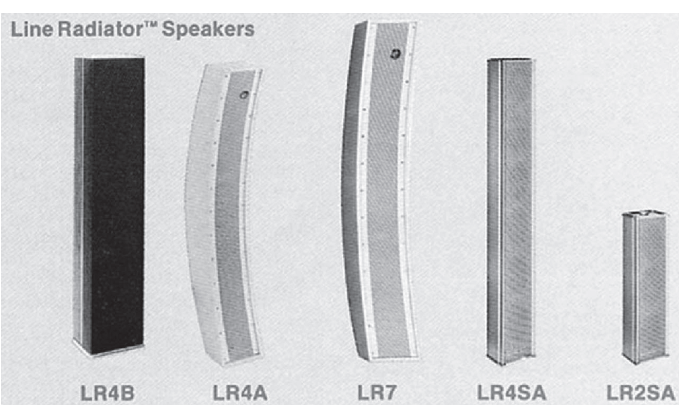

Figure 1. Various EV column loudspeakers circa 1970 (tallest unit is 5 ft high)

Most often containing small cone loudspeakers of, say, 4 inches in diameter, their low-frequency response and output ability were limited compared to the typical "pro sound" loudspeaker of today. As constant-directivity high-frequency horns with high-performance compression drivers came to dominate the industry in the mid 1970's and later (see additions 1, 6, 10 and 14), line arrays fell from favor. At least in part, this development was fueled by the desire for the higher sound pressure levels associated with the increasing popularity of rock-'n'-roll music, an interest which continues unabated today. Typical column speakers of the day, various EV Line Radiator™ systems, are shown in Figure 1.

In the 1990's, the line-array was reinvented as a high-output system for indoor and outdoor concerts and other high-energy live events. Instead of a stack of small loudspeakers in one box, the line array was comprised of separate modules, each a high-performance two- or three-way loudspeaker system. The modules are stacked to form the line array, typically with some curvature to the overall array to provide the most uniform sound levels from front to back in a venue. Figure 2 shows a typical modern concert-level line array. The 13-box array is about 15 ft high; the recommended minimum number of boxes for such an array is four (see "Are Line Arrays Ever Inappropriate?" section).

Figure 2. Typical large concert line array circa 2003 (13 boxes of EV XLC-127+ modules, about 15 ft high)

Today, concert-type line arrays have become popular in indoor venues, including auditoriums, performing arts centers and houses of worship that utilize contemporary music.

COMPARING COVERAGE OF CONVENTIONAL LOUDSPEAKERS TO THAT OF LINE ARRAYS

Conventional, non-line-array loudspeakers radiate sound spherically, in segments of a sphere, i.e., 90° x 40°, 60° x 40° or 40° x 20°, called "coverage patterns." A 90° x 40° pattern is typically known as a "short throw" pattern, 60° x 40° as "medium throw" and 40° x 20° as "long throw," because the narrower the pattern, the fewer reflective room surfaces are bombarded with sound, permitting such a pattern to "reach" farther into the venue. As you get farther away from a conventional, spherically radiating loudspeaker, the level of the direct field—the sound from the loudspeaker itself without the sound reflected from the many room surfaces—drops 6 dB every time the distance is doubled. This double-distance rule is called the "inverse-square law." Line arrays, appropriately configured, can reduce this drop off in level to 3 dB for every doubling of distance. This is obviously an attractive idea when the back of the room is a lot farther away than the front seats. (Most line arrays are curved in some fashion, producing a drop-off between 3 and 6 dB per doubling of distance.)

How Far Can a Conventional Loudspeaker Throw?

This is a good question to answer before deciding to use a line array. Figure 3 shows a simple side-view drawing representing a conventional loudspeaker with a 40° vertical coverage angle.

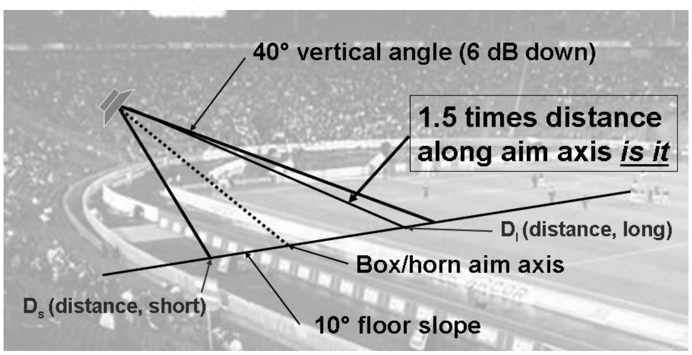

Figure 3. Side-view diagram of a conventional loudspeaker with a 40° vertical coverage pattern, showing the point beyond which coverage uniformity will be compromised (1.5 times the aiming axis distance)[1]

In the figure, the ratio of the long distance (D_L) to the short distance (D_S) is about 1.7, which can be rounded for practical purposes to 2. This is a good guideline for how far a single speaker can throw before some other help is needed in order to provide suitable direct-field sound-level uniformity: ±3 dB (ideal) up to a limit of about ±5 dB (acceptable under conditions of budget and/or architectural constraints).[1] How does uniform coverage result? When walking from the aiming axis (dotted line in Figure 3) toward the front, one finally reaches the 6-dB-down limit of the vertical coverage angle. However, this point is closer to the loudspeaker, so coverage is sufficiently uniform. As one moves toward the rear, not only does the sound level drop because of (1) approaching the upper limit of the vertical coverage angle but also (2) the listener is farther from the source. A loudspeaker with a wider vertical pattern would help, but eventually the level loss due to the inverse-square law will get us into trouble. Note: the most important octave bands for vocal intelligibility are the 2- and 4-kHz bands; the 8-kHz band is important for "sparkle."

1 Thanks to consultant and educator, Bob Coffeen, for the 1.5-times concept and comments on coverage uniformity.

Can Adding a "Long Throw" Element Help?

Adding a long-throw loudspeaker can extended the range of uniform sound levels. See Figure 4.

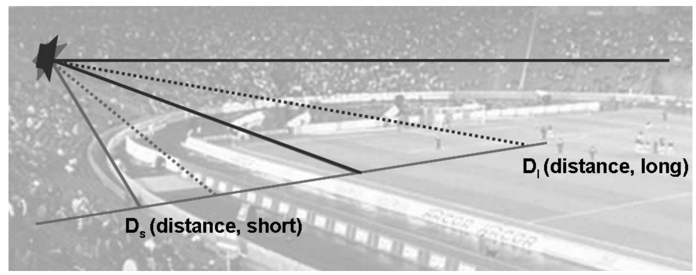

Figure 4. Side-view diagram as shown in Figure 3 but with a long-throw device (with 20° vertical angle) added.

The aiming axis of the long-throw device becomes D_L, increasing the D_L/D_S ratio to 2.7, which can be rounded to 3. This is the guideline for how far a single array of loudspeakers can reach into a venue.

Extending the D_L/D_S Ratio beyond 3—Loudspeakers over the Audience

A common and effective way to improve coverage at the rear of a space when the D_L/D_S ratio exceeds 3 is to add loudspeakers over the audience. Figure 5 shows loudspeakers placed over a balcony.

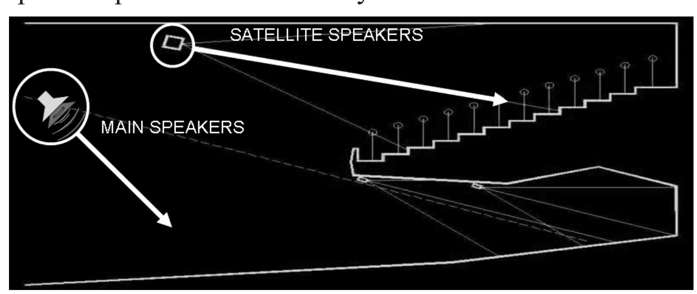

Figure 5. Room side view showing "satellite" loudspeakers over a balcony to compensate for a D_L/D_S ratio greater than 3.

This arrangement is an effective way to deal with D_L/D_S ratios greater than 3. The satellites are typically delayed so that they lag the main speakers by 5 to 10 milliseconds. Then, the so-called Haas effect makes the source seem to come from the front (desirable) even though the bulk of the direct field is coming from the satellites. However, adding satellites may not be architecturally or structurally possible. Outdoors provides other physical challenges; speaker "delay towers" are sometimes placed within the audience.

Extending the D_L/D_S Ratio beyond 3—Use a Line Array instead of Conventional Loudspeakers

Line arrays can provide uniform coverage in the face of D_L/D_S ratios greater than 60! Today, line arrays are accompanied by software that guides the user/designer in adjusting the curvature of the array (determined by the vertical splay angles between the box axes) and the drive level to each box—all in the service of producing uniform front-to-back sound levels. Figure 6 shows the coverage obtainable from a large, 14-box line array with a top trim height of 52 ft and a longest throw distance of about 350 ft.

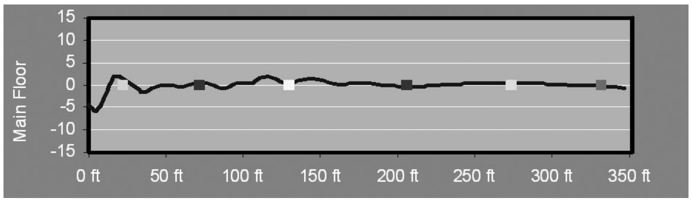

Figure 6. Typical line-array prediction software sound-level uniformity after optimization of array configuration (EV LAPS [Line Array Prediction Software]).

The black line shows coverage of close to ±3 dB from about 10 ft in front of the array to nearly 350 ft. (This coverage is predicted along the array's horizontal axis and in the octave band centered at 2.5 kHz, right in the middle of the voice-intelligibility bands.)

ARE LINE ARRAYS EVER INAPPROPRIATE?

The current popularity of concert-level line arrays sometimes gets them specified in places where they do not belong.

Line Arrays Are Typically Not Appropriate in Rooms with Low D_L/D_S Ratios

The room in Figure 7 has a main floor and balcony, with a D_L/D_S ratio of about 2.3. Covering the room with a line array is possible, but there is a wide vertical angle of nearly 90° to be covered. The maximum number of degrees that the vertical axes of line-array modules can be separated is limited to from about 3° to 10° (depending on model). For one "compact" line-array module, the EV XLC-127DVX, this limit is 8°. If the box axes are separated by any more than this, the ability of the array to function as a coherent source is compromised at very high frequencies, typically above 10 kHz. Very-high-frequency program material will be heard to drop "in and out" as the venue is traversed front to back. Thus, when the required vertical angle is high, the number of line-array modules is high, necessarily driving cost up and probably providing more sound-pressure-level capability than required.

An array of "very compact" line-array modules, such as the EV XLD281, would be at least 10 modules tall, compared to three horn-loaded three-way conventional systems, such as the EV Xi-1153A/64F, in an exploded horizontal array.

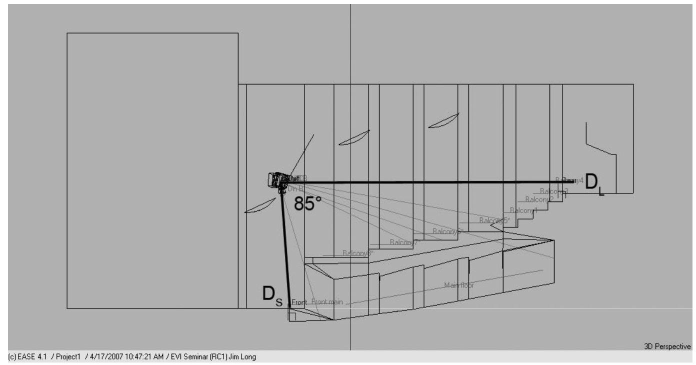

Figure 7. Side view of an auditorium where the D_L/D_S ratio of 2.3 is insufficient to justify a line array and the nearly 90° vertical coverage angle requires a very tall array of many boxes.[2]

Line Arrays Are Often Not Appropriate in Rooms with Height Constraints

An ideal (theoretical) line array is infinitely long, which of course is only a concept. Such an array would have the same "long throw" vertical directional characteristics at all frequencies. This ideal can only be approached in practice. For a practical array of a given length, as you go down in frequency the narrow vertical pattern eventually begins to widen and continues to widen with decreasing frequency. The frequency at which the pattern begins to widen can be called the "vertical directivity break frequency." Below the break frequency, the line array behaves more and more like a conventional loudspeaker.

How long a line array should be to hold its directional characteristics to a given frequency and what that frequency should be varies with whom you ask. A conservative view is that the overall array height must be four times the wavelength of the lowest frequency to which the desirable line-array directional characteristic is held. Wavelength is equal to the speed of sound divided by frequency:

$$\text{Wavelength (ft)} = \text{Speed of sound (ft/sec)/Frequency (Hz)},$$

where the speed of sound is 1,130 ft/sec. 1,000 Hz is a reasonable minimum frequency down to which the line characteristic should be held. Substituting 1,130 ft/sec and 1,000 Hz in the above equation gives:

$$\text{Wavelength (ft)} = 1{,}130 \text{ ft/sec} \div 1{,}000 \text{ Hz} = 1.13 \text{ ft.}$$

Four times 1.13 ft yields a minimum array height of about 4.5 ft. Holding the line array characteristic to 500 Hz (audibly desirable) doubles the array height to 9 ft.

The problem with high line-array vertical break frequencies is that the spectral distribution of program material—or sound quality—will not be constant from front to back

2 EASE model courtesy ASCOM, Inc., Wyoming, Michigan.

in a venue. Above the 1,000-Hz break frequency, the fall-off of sound level could follow (depending on specific configuration) the line-array's minimum 3 dB per doubling of distance as described on page 2 (great). Below 1,000 Hz, the array begins to behave like a conventional loudspeaker and eventually the sound-level fall-off is 6 dB per doubling of distance. *If the sound is nicely balanced up front, it will be "thin" (lacking in mid-bass and bass) and possibly unpleasant at the rear.*

For the above reason, line arrays more typically range from about 9 to 18 ft in height, with the 18-ft array providing (using the conservative "four times" rule noted above) a break frequency of 250 Hz. The 18-ft array has the advantage of providing very natural speech quality front to back.

Can I Cheat a Bit? Some practitioners say that the length of the an array must be only two times—not four—the wavelength of the desired break frequency. Still, EV does not recommend a line array shorter than the 4.5 ft mentioned above, for a 1,000-Hz break frequency using the four-times rule. Four boxes of the EV XLC-127DVX "compact" line array modules are 57 in. tall; six boxes of the "very compact" XLD281 modules are 59 in. tall—both arrays approaching 5 ft in height, significantly higher than a typical large-format conventional system such as the EV Xi-1153A/64F (3 ft).

Practical Examples of Height Constraints

The room in Figure 7 (page 3) is one example of a height constraint. This mid-1980's auditorium opened with an array of high-frequency horns and separate low-frequency systems, a common approach of the day. All components were hidden from view by a grille about 22 ft wide and 4 ft high. This opening will not accommodate the short line arrays mentioned above, which in any case would have both a high, 1,000-Hz vertical break frequency and a vertical coverage angle far less than the required 85°.

Another example is shown in Figure 8, where the trim height for a line array is very low compared to the longest throw. The left and right line arrays that would cover the space uniformly would be very long and for many observers interfere with the video screens behind and/or next to them. For this church, conventional systems in an exploded horizontal array for the first half of the seating and delayed satellites serving the rear seating would be an appropriate approach that keeps all loudspeakers just above the ceiling beam structure and well out of sight.

Line Arrays May Not Be Right for Venues Where the Available Horizontal Coverage Angles Are Inappropriate

Initially conceived for "one-night stand" arena and stadium applications, concert-type line arrays were designed with wide horizontal coverage angles, i.e., 90° and 120°. These wide angles are overkill for some auditorium and church venues, spraying energy on the reflective side walls and reducing voice intelligibility. More recently, some manufacturers have offered an expanded choice of horizontal angles.

REBIRTH OF THE ONE-BOX LINE ARRAY

During the last several years, one-box line arrays have reappeared, often in boxes similar in size to the historical systems shown in Figure 1. Only brief comments follow.

Like their older brethren, output ability is limited compared to the concert-style arrays discussed above. Low frequencies and extreme high frequencies—or at least the desired line-array vertical directivity—are also lacking. These limitations make them most appropriate for speech. However, their tall, narrow shape complements vertical architectural elements, such as columns. The most technically advanced one-box arrays are "digitally steerable" in the vertical plane. It is possible to mount a box vertically while still directing the output where it needs to go.

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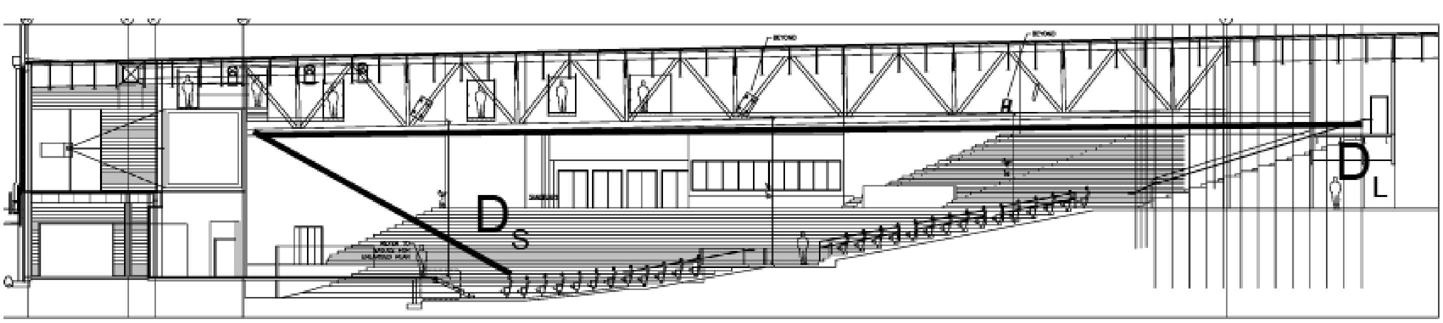

Figure 8. Side view of church in which the D_L/D_S ratio and the required vertical angle are appropriate for a line array but the array trim height and possible locations obstruct the view of the video screens from many seats (drawing courtesy Kirkegaard Associates, Chicago).