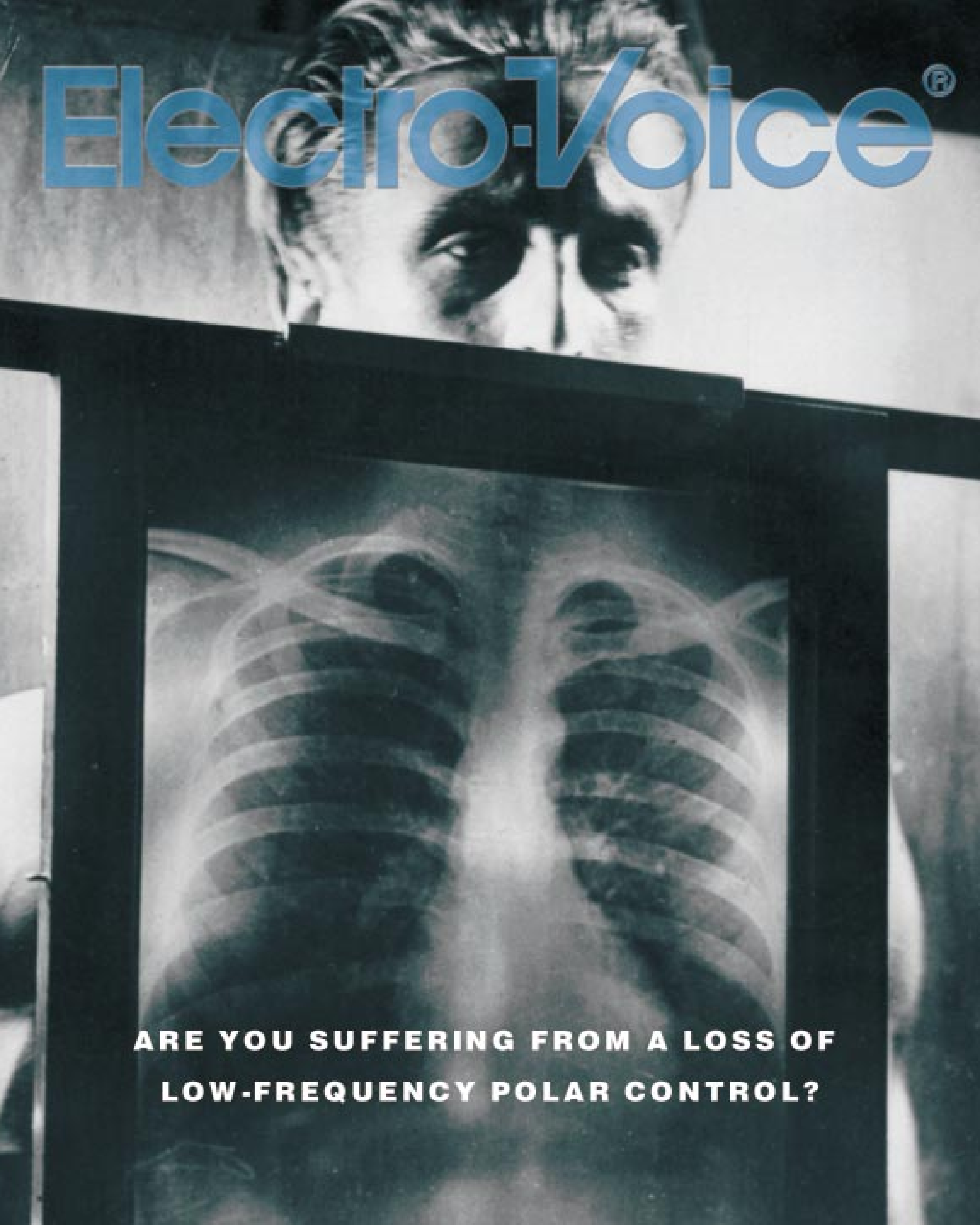
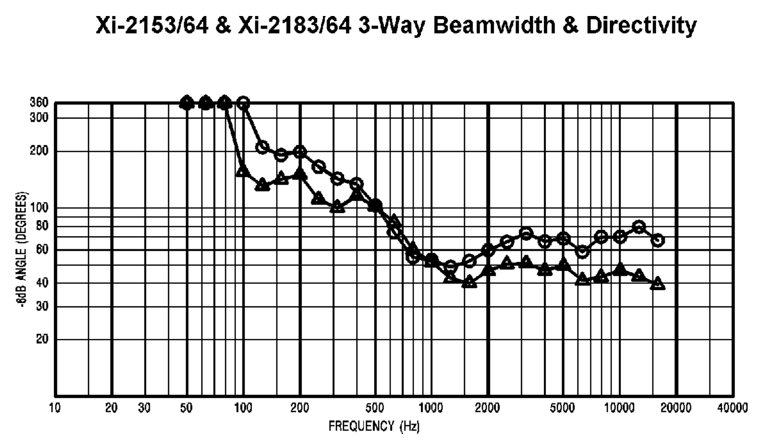
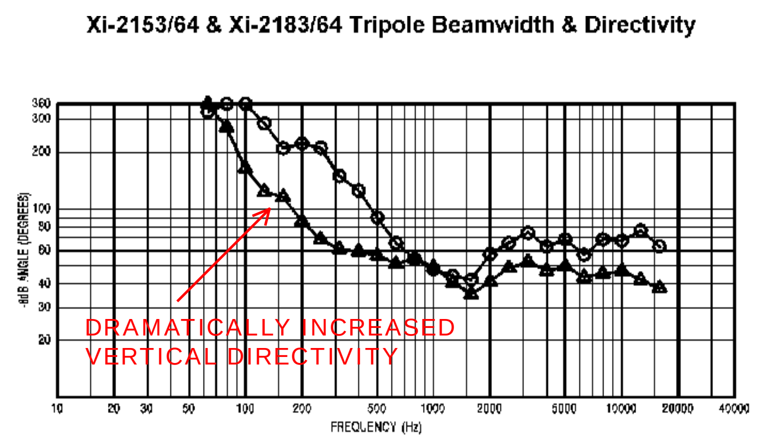

Electro-Voice®
ARE YOU SUFFERING FROM A LOSS OF
LOW-FREQUENCY POLAR CONTROL?

The Cure: EV X-Array Install™ Featuring Merlin™

Before treatment with X-Array Install™ and Merlin™



After one treatment with X-Array Install™ and Merlin™ — dramatically increased directivity at mid/low frequencies



The potent combination of the Electro-Voice X-Array Install™ systems and Merlin™ ISP-100 offers substantial increases in system intelligibility in reverberant spaces.

X-Array Install™

Merlin ISP-100

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Control of Lower-Midrange/Mid-Bass Directivity In Sound Reinforcement Loudspeakers Using Overlapping Techniques

Sound reinforcement loudspeaker systems must satisfy many performance criteria in order to provide not only high fidelity reproduction, but also a high degree of intelligibility. At first, it might seem that producing high fidelity and a high degree of intelligibility are one and the same. This would be true in a totally nonreflective environment. Outdoor applications approach this situation, but even outdoors, reflective surfaces such as adjacent buildings will produce significant degradation in intelligibility. The key point in this discussion is that even if a loudspeaker system were capable of perfect reproduction in a free-space nonreflective environment, perfect reproduction and intelligibility would be instantly degraded by the reflective surfaces in an enclosed, reverberant space.

In an enclosed space, the relationship between loudspeaker directivity and intelligibility is well documented. Consider two hypothetically perfect loudspeaker systems as discussed above, one that is quite directional (high Q) and one being nearly omnidirectional (low Q). A listener in a reverberant room would perceive two completely different levels of performance, even though both loudspeakers sound identical in a nonreflective environment. The clear advantage would be with the more directional source. Increasing or maintaining a higher level of directionality over a wider bandwidth will raise the ratio of direct-to-reflected energy, thereby increasing system intelligibility. The increase in directivity will have a larger effect on improving intelligibility as the reverberation time in the space increases.

It is quite simple to produce a device that is very directional over a limited frequency range. A horn's ability to control, or direct, a radiated pattern is one of the principle reasons horns still enjoy such widespread use. Unfortunately, any acoustical device begins loosing its ability to control its radiated energy when the radiated wavelengths become long compared to the dimensions of the device. For horns, this occurs when the wavelengths become long compared to the height or width of the horn mouth. Unfortunately, horn mouth size grows even larger for a given lower frequency limit, when the desired directivity is raised (higher Q).

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As an example, a horn-loaded speaker system is desired that will produce a uniform symmetrical pattern of 100° down to 200 Hz. For this situation, the required horn mouth size (or equivalent radiating area) would be 4.1 ft x 4.1 ft (16.8 ft^2). The resultant directional pattern would actually represent a very well controlled system. This is in contrast to a typical two-way sound reinforcement system consisting of a non-horn-loaded 15-inch woofer and high-frequency horn, which radiates essentially omnidirectional at 200 Hz. For an even narrower pattern of 60° down to 200 Hz, the horn's size and area would need to be a much larger, 6.9 ft x 6.9 ft (47.5 ft^2)!

Because human male vocal fundamentals extend to below 100 Hz, it is very important, for maximum intelligibility, that pattern control extend to below that frequency. Two effects occur in a sound reinforcement system to reduce vocal recognition. Primarily, low directivity control in the lower vocal range will produce a very poor ratio of direct-to-reflective energy. The higher the direct energy with respect to reflected energy, the higher the intelligibility. Secondly, in a live situation, poor directional control at lower frequencies will allow signals from the sound reinforcement system to reenter the live microphone directly from the PA system (with, of course, a delay associated with the spacing from the PA system to the open mic). The delayed signal will combine with the direct vocal signal and is now reradiated into the reverberant environment, further compounding an already difficult situation. This same energy can also produce feedback in the lower vocal range.

Current practice in performing arts centers, houses of worship and live entertainment venues is to use medium-format three-way horn-loaded systems. These high-performance systems offer excellent output capability, low distortion, and very linear response. Figure 1 illustrates the directivity verses frequency of systems typically used in these venues. As the frequency decreases, the wavelengths increase, and the radiated pattern is already 100° horizontal by 100° vertical at 500 Hz. At 200 Hz, the pattern is even greater, at 250° by 250° (the system shown is a horn-loaded mid-bass with mouth dimensions of 20 inches wide x 20 inches high). Increasing the vertical dimensions of the mid-bass horn mouth will improve vertical control. Unfortunately, the entire system of bass driver, mid-bass and high-frequency horns then grows correspondingly larger.

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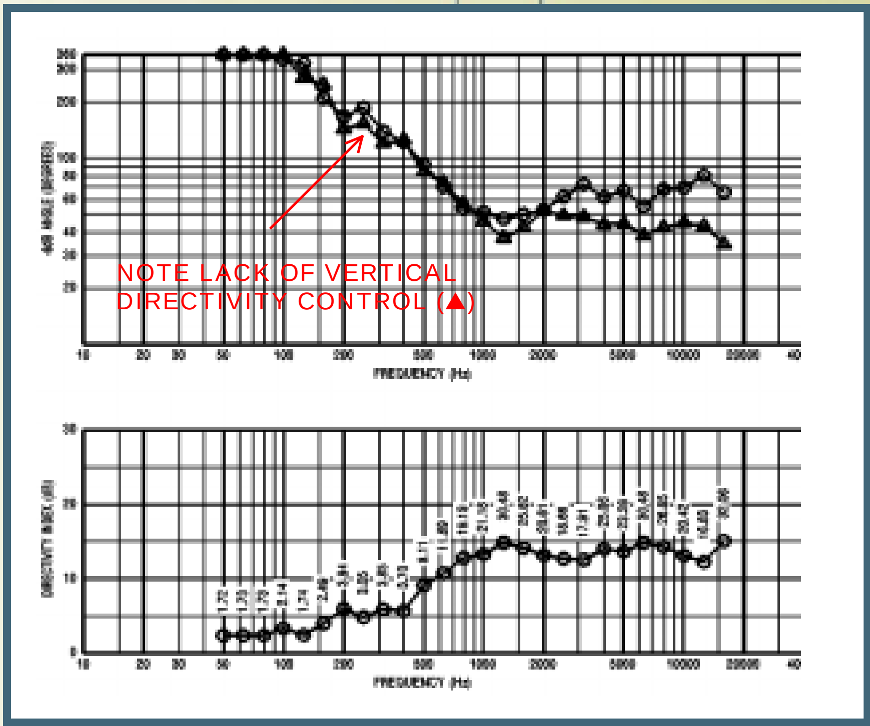

Figure 1:
Nonoverlapped Three-Way Shows Loss of Directivity Control in the Lower Midrange and Mid Bass

This frequently produces a system that has the advantage of improved directivity, but also has the disadvantage of being too large for the lines of sight or aesthetic considerations in the venue. Typically, a venue requires wide horizontal dispersion and a narrower vertical coverage that is limited to the audience only. Many popular venues require coverage in the horizontal plane of 80° to 120°, and vertical patterns of 60° to 40°. This restricted vertical pattern provides proper audience coverage and limits ceiling reflections, plus minimizes spill directed beneath the speaker toward the performing area.

Control of low-frequency vertical directivity can be accomplished through the use of vertical line arrays as well as large-format horns. *Figures 2 and 3* show two sources separated by 16 inches at frequencies of both 500 Hz *(Figure 2)* and 250 Hz *(Figure 3)*. Each device is an omnidirectional point source and the combination illustrates how interference effects between multiple devices can be used constructively. This constructive addition of radiated signals can be seen at 500 Hz where the combination of the two omnidirectional sources will produce the resultant vertical pattern of approximately 60°. *Figure 3* shows that the 16-inch spacing begins to exhibit significant pattern control at 250 Hz. A 6-dB improvement is seen at -90° and +90° (directly below and above the vertical system or array axis). For reference, *Figure 4* is a single omnidirectional source at 500 Hz.

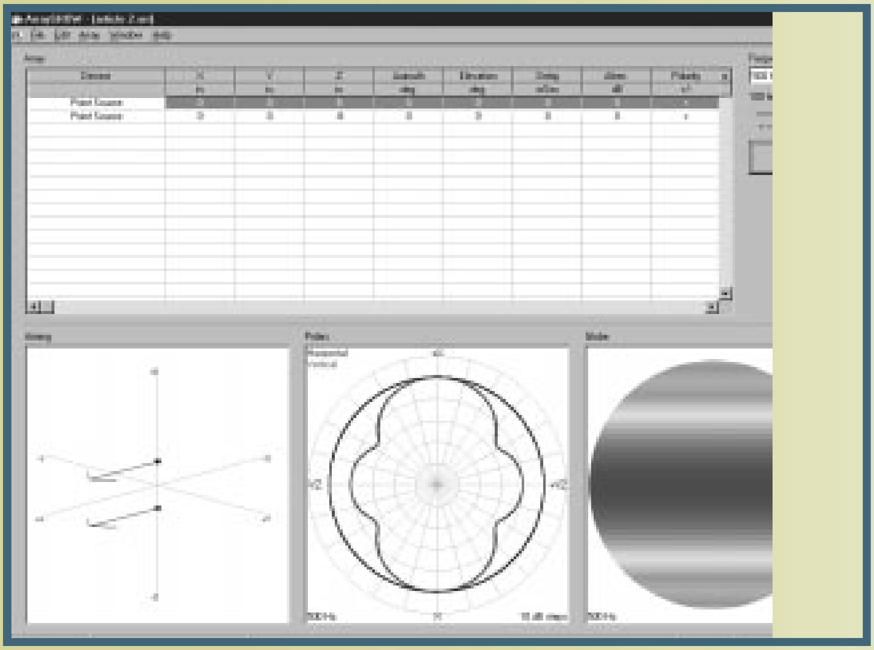

Figure 2:
Two-Element Line Array, Elements 16 Inches Apart—at 500 Hz, a High Degree of Directivity Control (vertical coverage angle of about 60°)

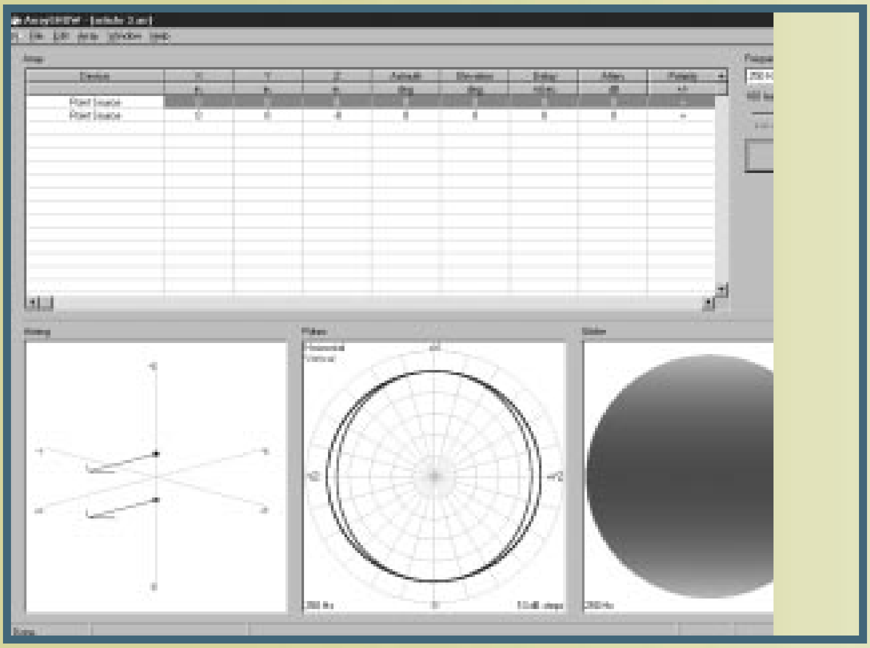

Figure 3:
Two-Element Line Array, Elements 16 Inches Apart—even at 250 Hz, Significant Pattern Control (6 dB of reduction at +90° and –90°)

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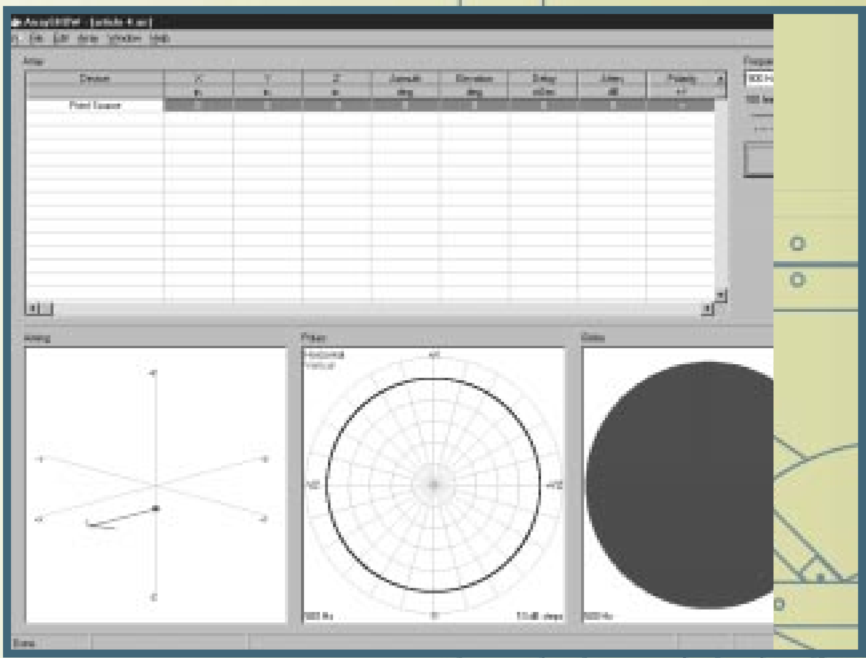

Figure 4:

Single Omnidirectional Source—

No Directivity Control

Additional sources can be used to produce further gains in directivity. *Figure 5* shows the results of three sources, each spaced 16 inches apart. Where the two-source array (*Figure 2*) produces a 60° pattern, three sources generate approximately a 45° pattern at 500 Hz. *Figure 6* shows a substantial gain in directivity over the two-element array shown in *Figure 3*. The three-element line array now produces a much tighter, 90° vertical control at 250 Hz. Most significantly, the SPL is now reduced by 15 dB above and below the system vertical axis (it should be noted that these line arrays have upper frequency limits and begin to lose good pattern control when the wavelengths are shorter than the device spacing). *Figure 7* illustrates an unusable situation where the wavelengths are shorter than the spacing.

Like a large-mouth horn, a vertical line array of sufficient dimensions can be used very successfully to extend directivity control and substantially improve overall intelligibility. An overlapped combination of bass and mid-bass drivers can also be used to produce a line array that will produce an “effective” radiating dimension to extend lower vocal directivity control. This technique of overlapping individual devices in such a manner will not only improve directional control but also make very effective use of the optimum performance of each device. The terms “dipole” and “tripole” are often used to describe two- and three-element line arrays in the current literature. Although these terms are not technically accurate, they both describe the systems and their results quite well.

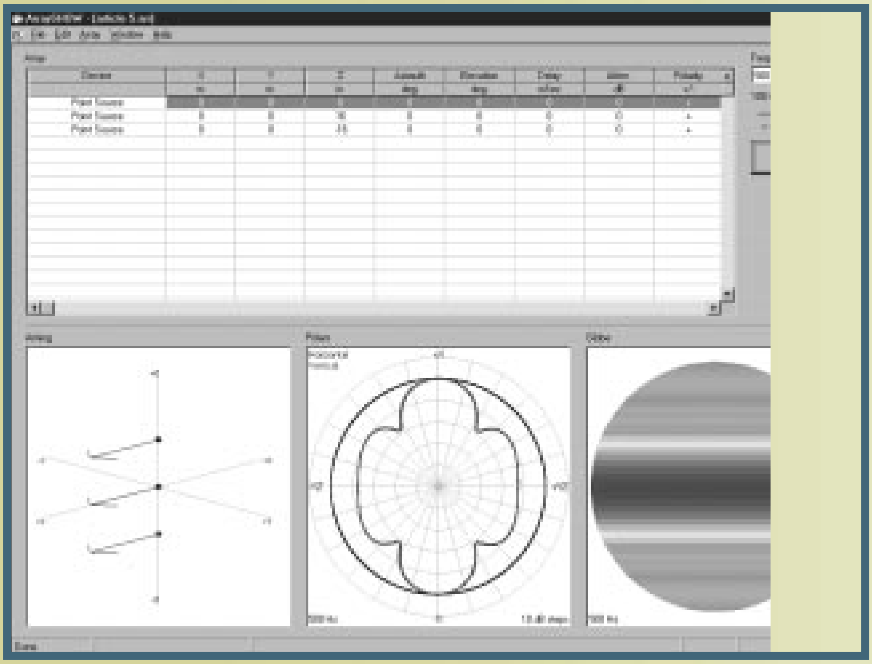

Figure 5:
Three-Element Line Array, Elements 16 Inches Apart—Three Sources Tighten the Vertical Coverage Angle to about 45° at 500 Hz (compare to Figure 2)

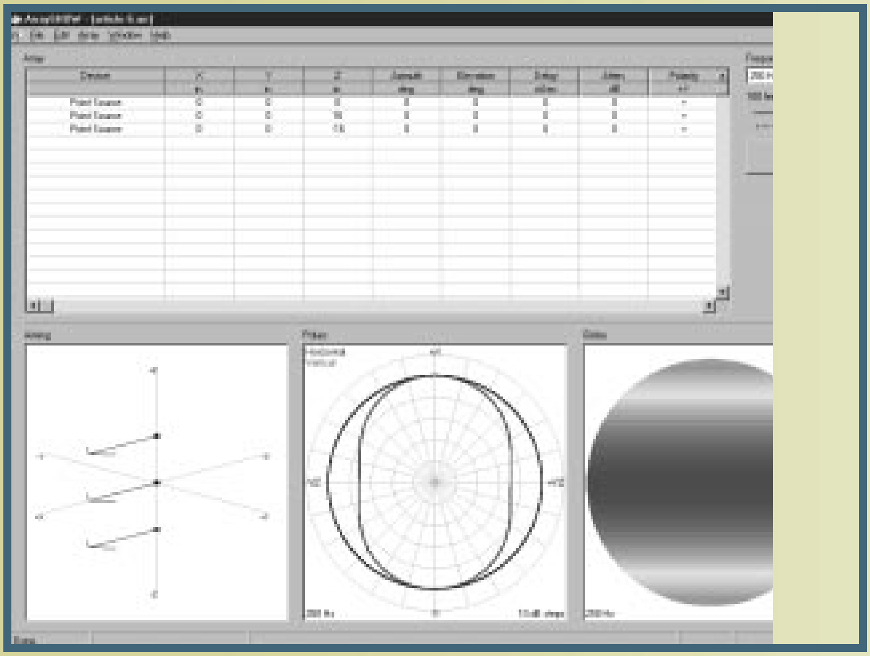

Figure 6:
Three-Element Line Array, Elements 16 Inches Apart—Tight Control Even at 250 Hz (15 dB of reduction at +90° and –90°) (compare to Figure 3)

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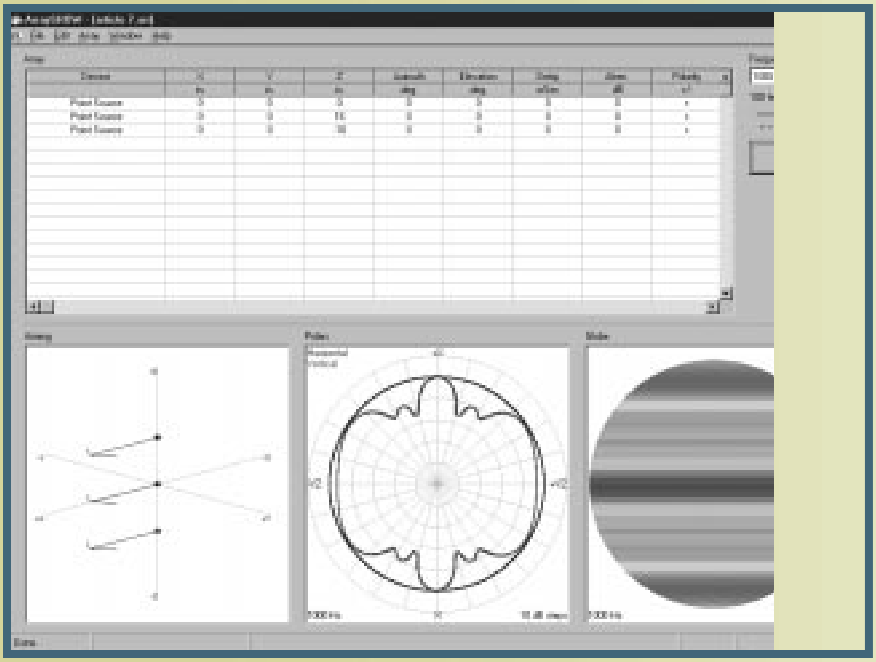

Figure 7:
Three-Element Line Array, Elements 16 Inches Apart—Good Pattern Control is Lost at 1,000 Hz (where wavelengths are shorter than element spacing)

A conventional “nonoverlapped” three-way system might comprise a bass section, a mid-bass section and a high-frequency section. A representative crossover diagram is shown in *Figure 8*. The crossover is a nonoverlapped, conventional design where the bass- to mid-bass crossover is at 125 Hz and the mid-bass to high-frequency crossover is at 1.7 kHz. *Figure 9* is the directivity versus frequency for such a system. This is very similar to *Figure 1*, and again illustrates how a mid-bass horn (or any device) looses its ability to control directivity when the wavelengths become longer than the radiating dimensions or area.

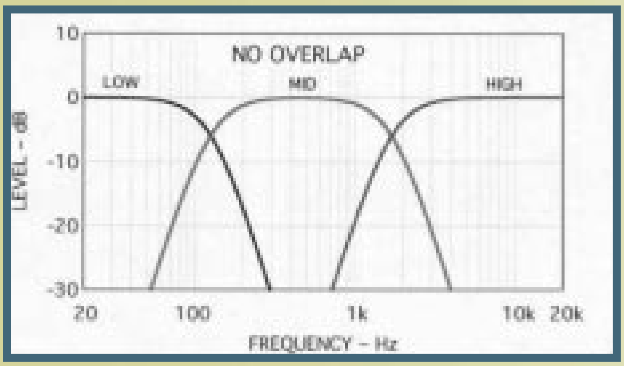

Figure 8:
Nonoverlapped Crossover

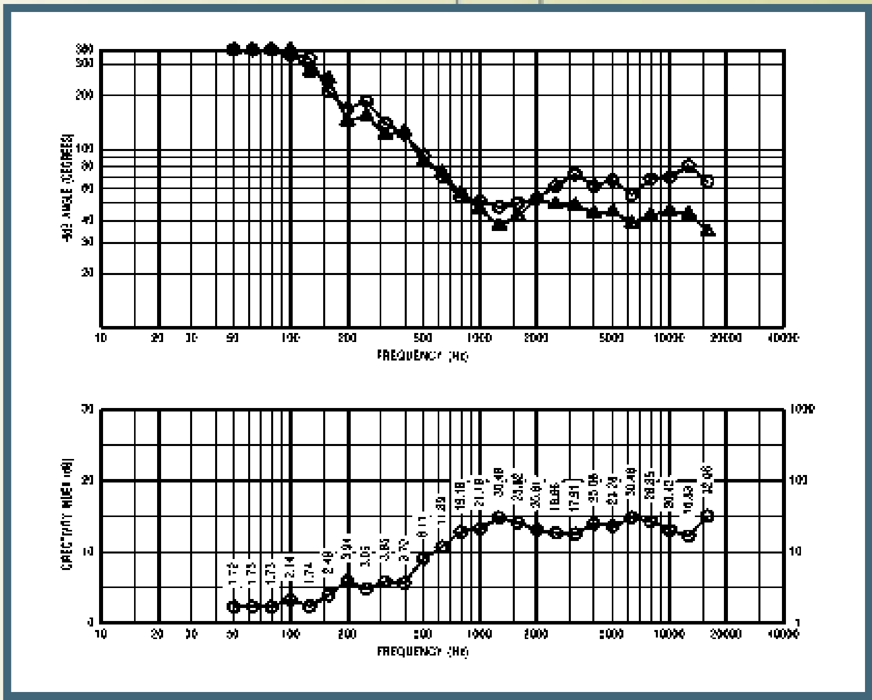

Figure 9:
Nonoverlapped Directivity vs. Frequency

A two-element line array (dipole) would have a crossover configuration similar to *Figure 10*. In this arrangement, the bass driver operates from 30 Hz to 540 Hz and overlaps the midrange section from 125 to 540 Hz. The 6-dB shelf between 125 Hz and 540 Hz is required so that the overlapped drivers sum acoustically to the same reference level as the rest of the system. The mid bass driver is operated between 125 Hz and 1.7 kHz. Above 1.7 kHz, the HF driver operates alone. The mid-bass section isn't extended below 125 Hz, because its power handling is much reduced in this range and its distortion is significantly higher.

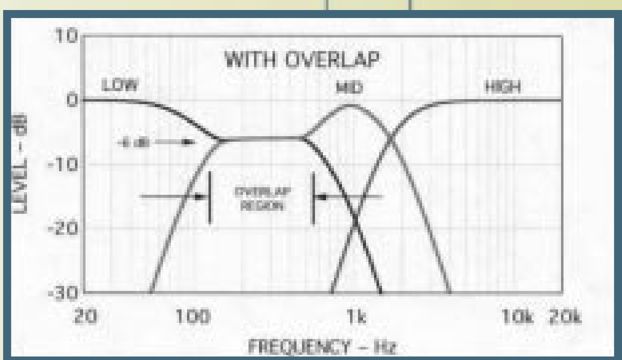

Figure 10:
Overlapped Crossover

The region of major interest in this example is between 125 Hz and 540 Hz, where the bass and mid-bass sections are overlapped and operate at equal and in-phase levels. This overlap significantly improves the lower mid-bass vertical coverage of the system. This is the area where the dipole/tripole line array will produce substantial intelligibility improvements. This is also the region where very carefully electronic processing must be implemented.

Almost any conventional digital crossover/loudspeaker management system can generate the response shapes seen in *Figure 10*. Unfortunately, the results may be much less than optimal because the acoustic outputs of the section sum incorrectly in the overlap region, due to crossover and driver phase shifts and delays. Crossovers and speakers exhibit nonconstant time delays, which vary with frequency and the steepness of their response roll-offs. The consequences of this variation of signal delay with frequency are polar response "tilts" or changes in direction. With the proper overlap filtering, *Figure 3* shows that the major polar lobe points directly ahead on axis, a very desirable situation. Signal delay can be used very successfully to tilt or aim polar patterns, but this tilt should be the same for all frequencies. If the overlap filtering is not implemented properly, the resultant polar pattern will tilt and not face straight ahead, and furthermore, the tilt angle will vary with frequency, quite undesirable!

Figure 11 is an example of two devices improperly overlapped. An excess delay of 1.5 msec in the mid bass with respect to the bass, due to the125-Hz crossover filter, causes an upward 30° tilt in the polar pattern which causes undesirable energy to be directed towards a reflective ceiling.

Fortunately a solution exists and can very effectively compensate for this polar tilting. Specific filter topologies (as implemented in the Merlin ISP-100 and applied to the X-Array Install™ family of products), can "re-aim" straight ahead the tilted major polar lobe that results from bad overlap conditions. The addition of frequency-selective phase and delay correction can produce the proper control necessary for both two-element and three-element arrays (arrays of more than three elements are certainly possible if proper spacing and bandwidth constraints are applied). It is important to restate the fact that many digital processors can perform the majority of functions necessary to produce line arrays, but without the required frequency-selective delays, the resultant response and polar patterns will be much less than optimal. Advanced processing systems, such as the Merlin ISP-100, can provide tunable frequency-selective delays, and as a result can compensate for the overlap-filter-generated polar tilting.

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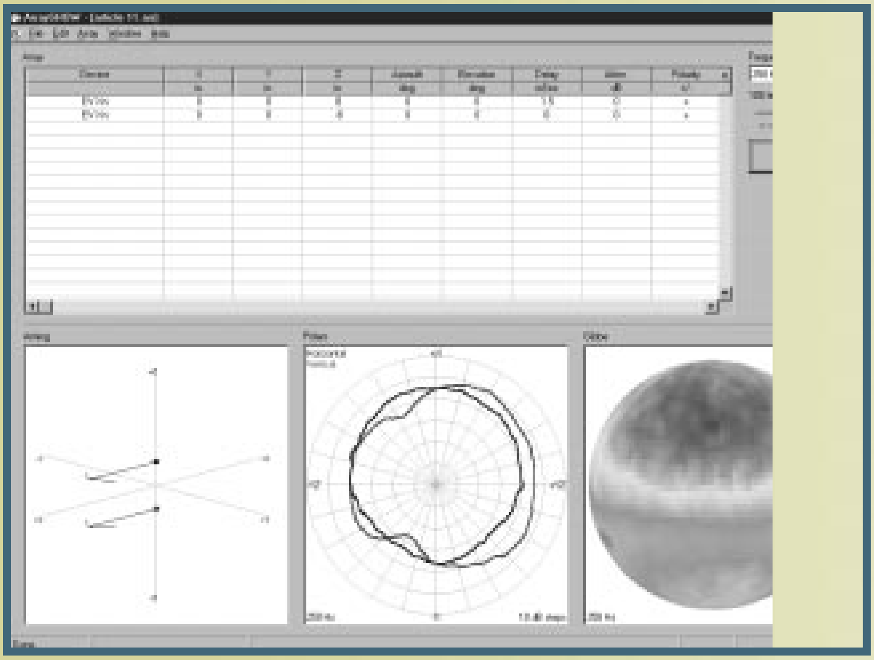

Figure 11:
Two-Element Line Array with Crossover Filter Delay—Note Unwanted Vertical Polar "Tilting"

Table 1 contrasts the directivity data of an Electro-Voice X-Array Install™ Xi-2153/64F, with an Xi-1183/64F and Xi-1153/64F. The Xi-2153/64F operates in an overlapped three-element line array configuration and the Xi-1153/64F is an overlapped two-element line array, while the Xi-2183F operates in a conventional nonoverlapped mode. Note that all systems are essentially the same except for different quantity of bass drivers. Both systems have exactly the same mid-bass and HF sections. *Table 1* clearly indicates the substantial increases in directivity and subsequent improvements in system intelligibility that the Xi-2153/64F and Xi-1153/64F provide. *Figures 12 and 13* demonstrate the data in *Table 1* (Xi-2153 and Xi-1153 directivity versus frequency). Proper processing of multi-element/ overlapped line arrays can result in very audible improvements in system performance. The increase in directivity (higher Q) and reduced vertical coverage greatly contributes to improved vocal intelligibility, which can easily be demonstrated particularly in reverberant spaces.

	1 kHz	800 Hz	630 Hz	500 Hz	400 Hz	315 Hz	250 Hz	200 Hz	160 Hz
Conventional three-way	50	55	70	100	130	150	160	170	210
Two-element line-array “dipole”	50	50	50	50	65	80	95	130	175
Three-element line-array “tripole”	50	50	50	55	60	60	70	85	120

Table 1:
Comparison – Overlapped vs. Nonoverlapped

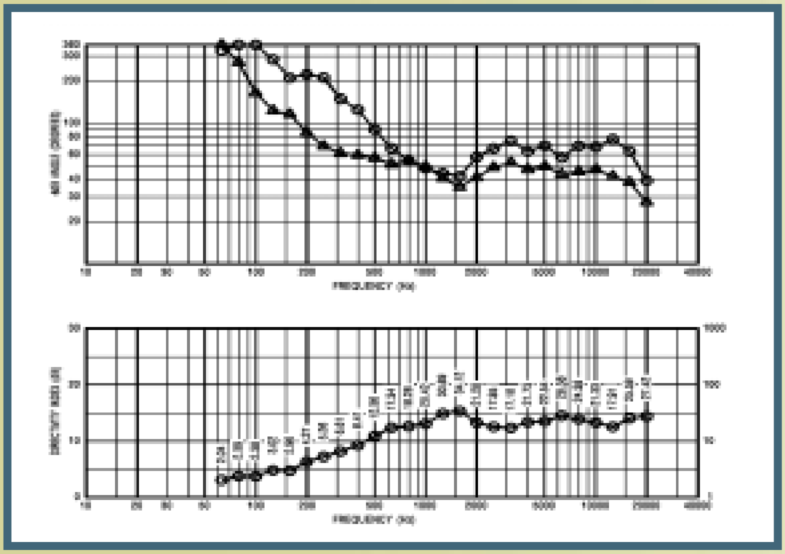

Figure 12:
Directivity vs. Frequency – Three-Element Line Array

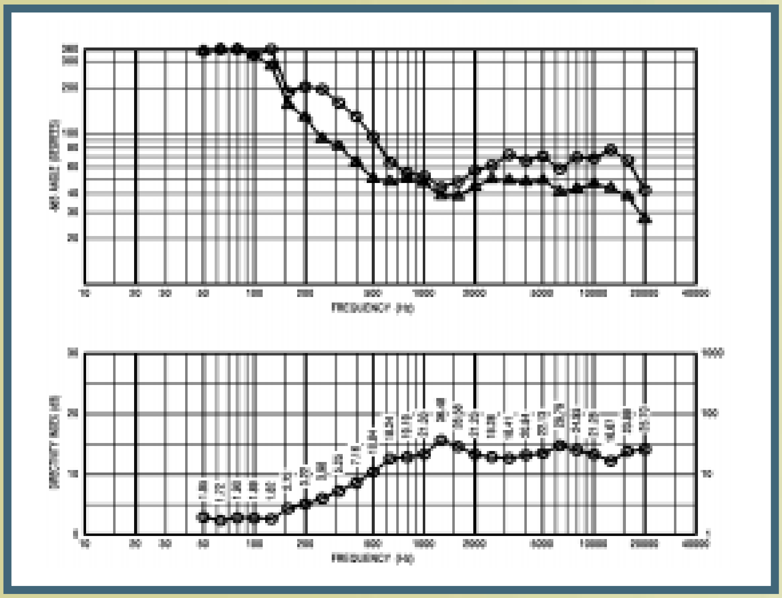

Figure 13:
Directivity vs. Frequency – Two-Element Line Array

The Entire X-Array Install™ Line at a Glance

Model	Description	Coverage Angle (h x v)	Frequency Response	Overall Dimensions (hwd)
Xi-1122/85F	12-inch two-way	80° x 55°	60-20,000 Hz	23.0 in. x 14.8/7.8 in. x 14.0 in.
Xi-1123/96F	12-inch three-way ***"dipole configurable"***	90° x 60°	60-20,000 Hz	31.4 in. x 17.8/12.5 in. x 18.2 in.
Xi-1152/64F	15-inch two-way	60° x 40°	50-20,000 Hz	29.9 in. x 17.8/9.8 in. x 16.3 in.
Xi-1152/94F	15-inch two-way	90° x 40°	50-20,000 Hz	29.9 in. x 17.8/9.8 in. x 16.3 in.
Xi-1153/64F	15-inch three-way ***"dipole configurable"***	60° x 40°	48-20,000 Hz	36.0 in. x 23.1/13.9 in. x 29.9 in.
Xi-1183/64F	18-inch three-way	60° x 40°	48-20,000 Hz	36.0 in. x 23.1/13.9 in. x 29.9 in.
Xi-1191 Xi-1191F	18-inch subwoofer	Essentially omnidirectional	37-160 Hz (normal) 28-160 Hz (step-down)	36.0 in. x 23.7/13.9 in. x 29.9 in.
Xi-2123/96F	Dual 12-inch three-way, ***"tripole configurable"***	90° x 60°	60-20,000 Hz	39.7 in. x 17.8/12.5 in. x 18.2 in.
Xi-2153/64F	Dual 15-inch three-way, ***"tripole configurable"***	60° x 40°	45-20,000 Hz	48.0 in. x 23.1/13.9 in. x 29.9 in.
Xi-2183/64F	Dual 18-inch three-way	60° x 40°	45-20,000 Hz	48.0 in. x 23.1/13.9 in. x 29.9 in.

All models in black painted trapezoidal enclosures. "F" suffix indicates L-track hanging hardware on enclosure top and bottom.

These helpful X-Array Install™ and Merlin ISP-100 tools can be ordered through Electro-Voice customer service at 616/695-6831 or 800/685-6386:

X-array Install™ brochure
part#535036-9901

ArraySHOW™ CD
part#535290

Pro Sound Facts No. 17
part #535214

X-array Install™ engineering data sheets

Special Applications Merlin ISP-100 and Electro-Voice X-array Install™
part #535297

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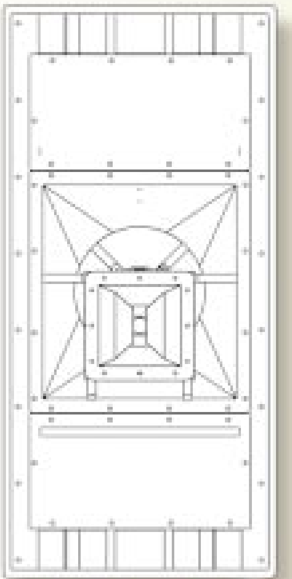
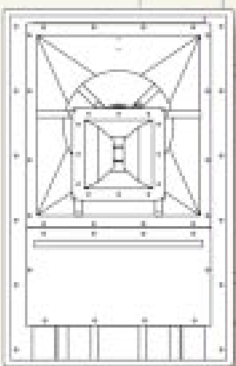
X-Array Install™

EV

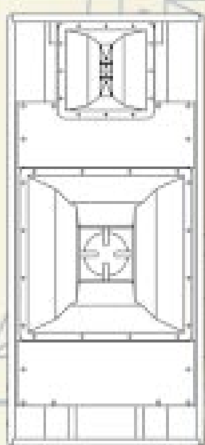
Electro-Voice Products that Make Overlapped Arrays



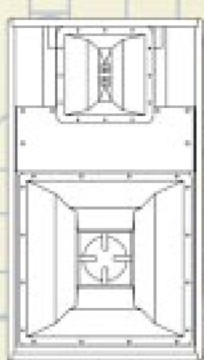
Xi-2153/64F



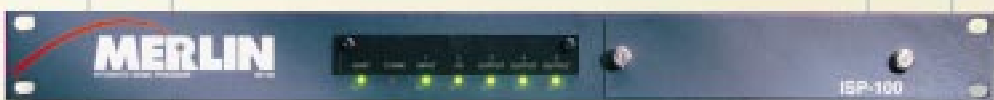
Xi-1153/64F



Xi-2123/96F



Xi-1123/96F



ISP-100

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