# EAW Research Brief

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Project #00-049-R-01 : Touring Line Array
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# Touring Line Array Technical Issues

## Divergence Shading
## Inverse-Square Law
## Integrated System Requirements

Touring line arrays (pardon the misnomer, since they are always curved) operate on the principle of divergence shading, which I'll define below. In preparation for developing a new touring line array system, it will be helpful to clearly understand the concept of divergence shading and how curved line arrays work. The acoustical requirements of the individual modules will then be clear, and the system we develop should work very much as we expect, - with as few surprises as possible.

To understand divergence shading, let's first look at the alternative; which is intensity shading.

**Intensity Shading**

Intensity shading refers to a source whose intensity varies over its surface. The output from a large source can be segmented to some extent - that is, the upper part of the source supplies sound to the upper part of the beam, while the lower part of the source supplies sound to the lower part of the beam. If the sound intensity emanating from the upper part is greater than the sound intensity emanating from the lower part, then an advantageous polar response results, with more sound energy directed to distant listeners than to near listeners.

Any time two sources are aimed in different directions and fed different levels, intensity shading is being employed. At high frequencies, it works very well. At low frequencies, the combined source has very little directionality. At intermediate frequencies, there is lobing and easily audible interference.

Intuitively, it is easy to see how the response in a particular direction depends strongly on the pressure at the normal point in a source wavefront (see Figure 1). However, the response is also strongly related to the variation in pressure along the wavefront. The discontinuities at the end of a line source produce interference that is closely tied to the location of the ends of the array. This is why amplitude shading of a KF750 rig (a true cylindrical-wavefront "line array") is so effective at improving the coherence below the rig. The sudden change in pressure at the top of the array is reduced by shading .

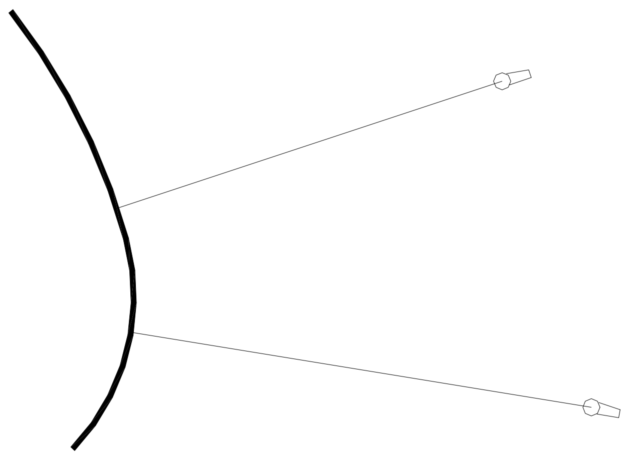

**Figure 1: Source Normal**

The derivative of pressure across any intensity-shaded source is, of course, non-zero. For instance, the pressure must increase rapidly toward the upper part of the source - if the long-throw part is to be sufficiently louder than the short-throw part. Consequently, the short-throw beam is "contaminated" by out-of-time arrivals from the lower edge of the long-throw source. This is analogous to the interference observed in the beam of a short-throw cabinet when the long-throw cabinet above it is turned up. In essence, there are signal paths that cross the normals to the intended wavefront.

## Divergence Shading

A superior method of achieving even SPL over distance is *divergence shading*. Literally speaking, *divergence* is the rate of increase of the area of the wavefront. At the surface of a relatively flat source, the area does not increase very fast - perhaps doubling in 20 ft. At the surface of a tightly curved source the area increases much faster - perhaps doubling in 2 ft.

With divergence shading, the pressure is kept constant throughout the source, and the curvature of the wavefront is varied. A flatter portion of the wavefront produces higher pressure at distance, and a tightly curved portion of wavefront produces lower pressure at distance. Referring to Figure 1 again, the upper microphone would detect higher sound pressure than the lower microphone. Furthermore, because the pressure is constant across the source, the rate-of-change of the pressure magnitude is very small. This results in relatively smooth frequency response.

Within limits, the SPL is directly related to the source curvature. If curvature is expressed as the change in normal angle per unit of height (i.e., 5 degrees splay per cabinet), then the pressure is inversely proportional to the square root of the curvature. Consequently, a system which seeks to obtain a 12 dB variation in pressure response (good for equal SPL over a 4:1 distance ratio) would need a 16:1 range of splay angles (for instance 2 degrees to 32 degrees). Realistically, though, the splay at the long-throw part of a line array would be very nearly zero. With a splay of zero degrees, the pressure can no longer be represented as a ratio (it would be infinite). However, modeling shows that flat-fronting part of an array does produce a relatively well-behaved frequency response.

Figure 2 is a family of curves representing the pressure on the axis of a 10-source array. The yellow (lowest-SPL) curve is for an array with 5 degrees splay between every source. The magenta curve has the center splay reduced to 0 degrees. The cyan reduces the 3 inner splays to 0 degrees, and the brown curve has the 5 inner splays reduced to 0 degrees. The effect is relatively broadband gain, consistent across frequency, with a graceful departure from ideal behavior at low frequencies. For this particular case, the gain resulting from flat-fronting is approximately 2 dB for each zero-splay - relative to a 5-degree per cabinet splay.

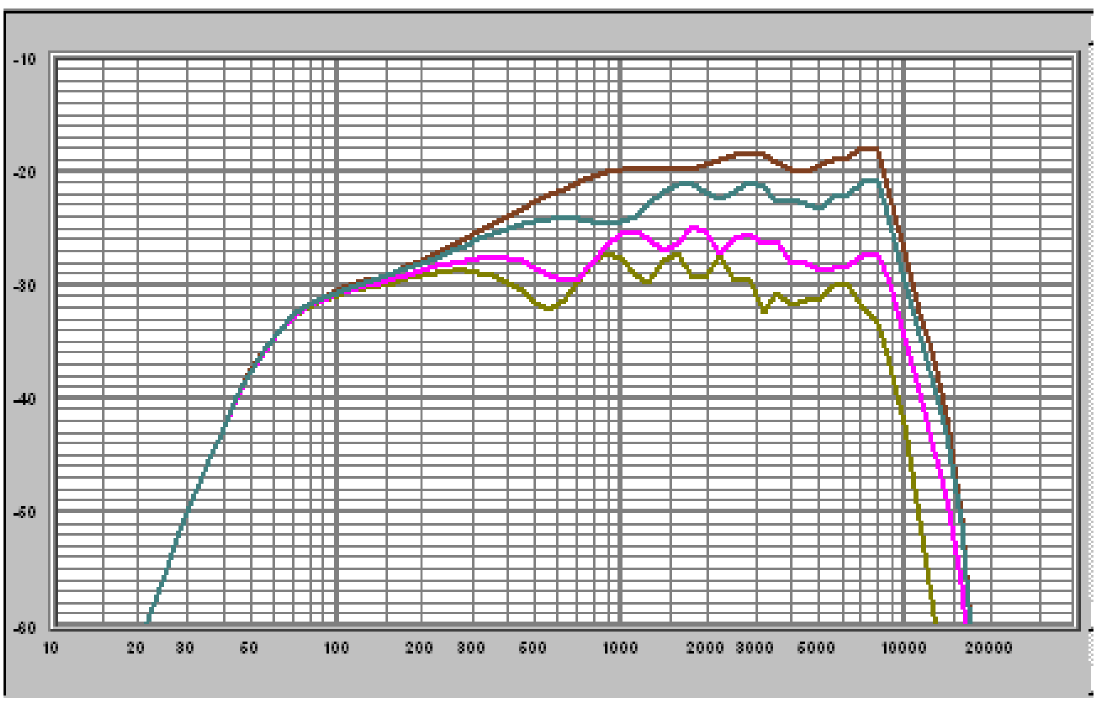


**Figure 2: Variation in length of flat section**

**Exemption from Inverse-Square Law**

Much has been made of the premise that the output from a line-array attenuates at a rate of 3dB per doubling of distance, rather than 6dB. The argument states that a line source produces a cylindrical wavefront (meaning it doesn't expand vertically). Consequently, the area of the wavefront varies proportionally to the distance from the source - rather than varying proportionally to the square of the distance (as does a spherical or conical wavefront). Sound pressure varies inversely to the square of the wavefront area - hence the pressure in a spherical wave varies inversely proportionate to the distance, and the pressure in a cylindrical wave varies inversely proportionate to the square root of the distance.

There are several problems with this line of reasoning. The most basic logical flaw is that a truly cylindrical wavefront would require the entire audience to be positioned within a vertical band no taller than the array. For the array to cover listeners above and below the array, there must be vertical dispersion - which means inverse-square law will be in effect. Obviously, a truly cylindrical wavefront would be of little use in the majority of venues - which is why line arrays are nearly always deployed in a curve.

Another logical flaw is that only an infinitely tall line can produce a true cylindrical wavefront. Cylindrical wavefronts are treated in academic texts within the context of parallel waveguides, in which solid walls prevent vertical dispersion from occurring. A line source of finite length will "act cylindrical" for some distance, after which vertical dispersion will occur. Unfortunately, the distance at which this occurs is frequency-dependent, so the frequency response will change shape significantly with distance.

Figure 3 shows the response at various distances on the axis of a 12ft line source. At 50 to 100 Hz, the wavefront "acts cylindrical" from 1 m to 2 m, but is essentially spherical beyond 2m. At 1 kHz, the wavefront "acts cylindrical" out to about 16 m. At 10 kHz, the wavefront acts cylindrical beyond 32 m, but its behavior beyond 32 m is somewhat obscured by air losses.

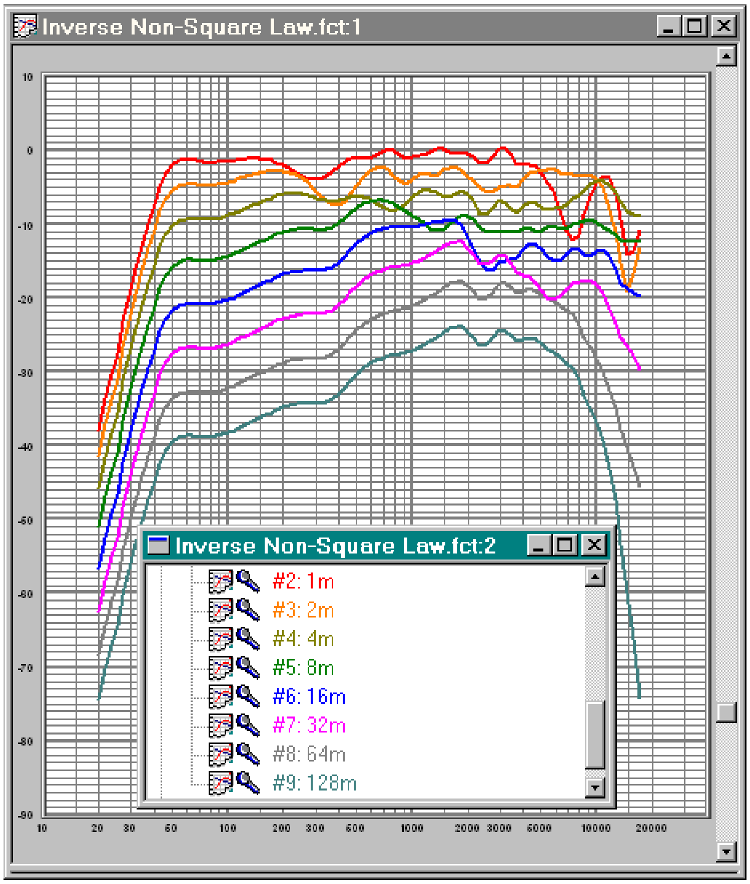


**Figure 3: Response vs. Distance On-Axis, 12 ft Line Source**

While academically interesting, this data is not very useful for sound systems. It is inconceivable that an entire audience would be located on the axis of a large line source. It is much more interesting to consider the response below the "cylinder", where the people are. Figure 4 shows the same source, with the microphones placed 15 ft below the bottom of the source.

Here, the family of response curves falls into an impressively tight group. If equalized flat, this could produce very consistent SPL out to about 64 m. The coherence is fairly low, as evidenced by the amount of  ripple in the curves. However, a bigger problem is that the SPL is extremely low.  The group runs at about -47dB (relative to a 1-m reference) from 5 kHz to 10 kHz, while the axial response at 64 m ran about -22 dB in the same frequency range. The cost of being outside the extremely narrow beam is 25 dB, in sensitivity.

In short, aside from being an academic novelty, the cylindrical wavefront argument has no practical value. To produce an array that covers an entire audience, we must design a curved array according to the principle of divergence shading. By designing the array as a continuous curve, flatter at the top and curving rapidly at the bottom, the coherence can be kept high, the coverage can be extremely consistent throughout the venue, and the efficiency can also be be very high.

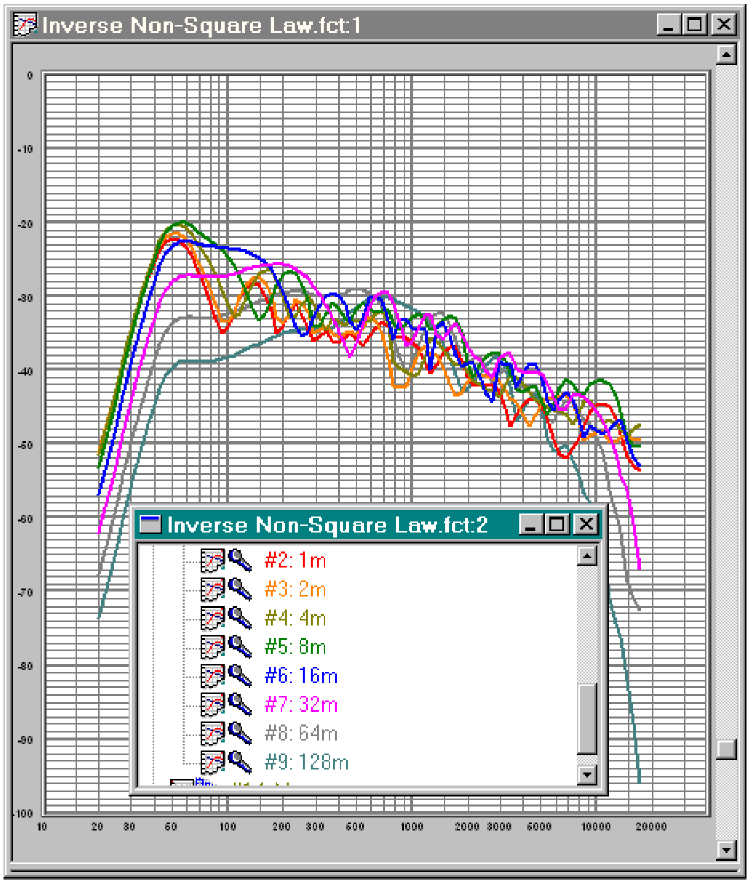


**Figure 4: 12 ft Line Source, 15 ft below Bottom of Source**

## Source Arc-Segments

It would seem that to create a "line-array" with a continuously varying curvature would require a special module for every segment of the array. However, within certain constraints, the technique is tolerant of mismatched source arc segments. Figure 5 shows the pressure response of a large arc-shaped source constructed of perfectly matched 5-degree arc segments - and then compares the result to that produced by arc segments twice as wide (10 degrees, rather than 5 degrees). The only effect is above 10 kHz, where two of the curves run about 6 dB low. This example is for an array of six 18"-high sources.

The lower-level curves in the second chart are actually on the axis of the individual horns. The curves on the seams exhibit higher pressure because the two overlapping patterns interfere constructively, resulting in a 6 dB increase relative to the axial level.

If the horns are designed to produce flat wavefronts, the effect is just the opposite. The high frequency response sags in the seams, because the individual horns do not have a wide enough pattern to fill the required angle. This is how the Vdosc system should work, if its horns actually perform as represented. It is one of the reasons why Vdosc cabinets are normally used in large multiples (8 or more cabinets), with very small splays (the other reason being a general lack of efficiency). It is also one of the reasons why the Vdosc system performs very poorly in the front rows. Physically, it cannot be splayed very much. Acoustically, it would produce very patchy response if it was splayed sufficiently to cover the expensive seats.

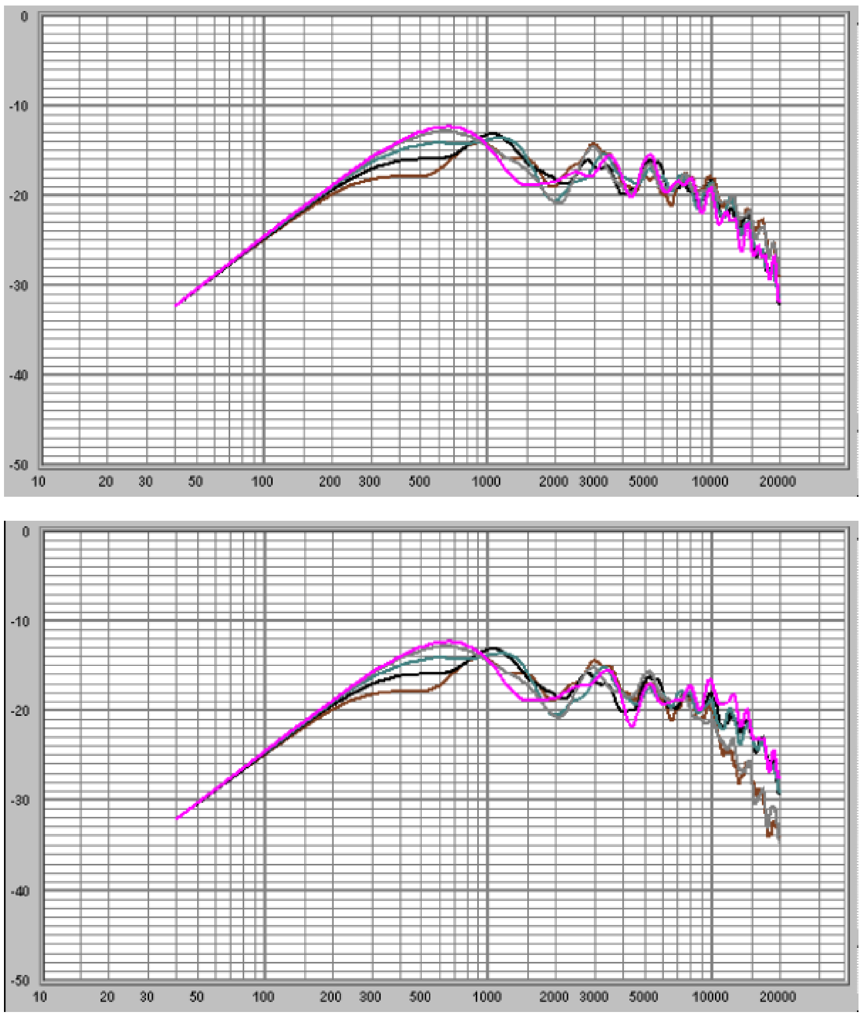


**Figure 5: Mismatched Arc Segments**

The horns in the KF860 represent the other extreme. The wavefronts they produce are 40 degree arcs, two-per-cabinet. It would seem, intuitively, that the high-frequency efficiency would be much lower with this approach. On the face of it, the individual horns have lower sensitivity, so one would expect the summation of the horns would be correspondingly lower. In practice, though, the average level is just as high as it is with matched arcs. The red curve in Figure 6 shows how an array of 40-degree segments sums, when arrayed with 5-degree splays. The average level is equal to the matched-arc case, but the response is much less smooth. Of course the cause of the response roughness is very apparent in the impulse response, where a distinct arrival from each individual source is clearly visible. The curves in Figure 6 are at a seam, so the 10-degree curve (blue) runs higher than the 5-degree curve (black), and the 0-degree curve (green) has failed to "fill the angle", leaving an octave-wide hole at 14 kHz.

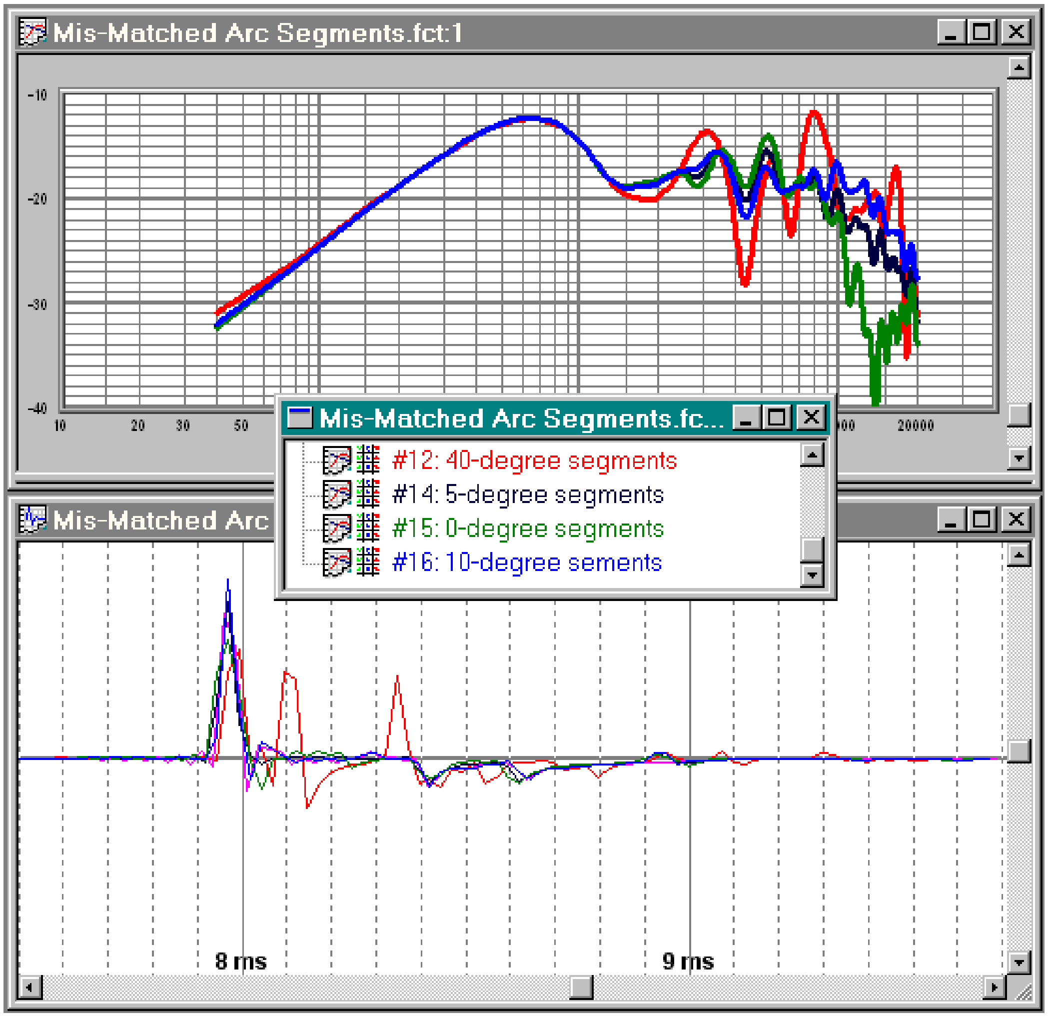


**Figure 6: Comparison of Source Arcs**

In short, the cost of massive overlap is a loss of coherency - not a loss of energy. A conservation of energy argument predicts this, because the total power radiated is the same in both cases - and the gross beam shape is the same (as defined by the overall array shape). The power integrated over the entire coverage area is the same, but the coherency suffers. The effect is least objectionable with large curved arrays, because there are many arrivals which show up at more-or-less random intervals - so the response lacks any deep & wide holes. Audibly, the effect is pleasant and spacious, but cannot be described as "high-resolution". Conversely, a horn which produces a perfectly flat wavefront is one of the least desirable configurations.

**Effect of Non-Contiguous Horn Mouths**

All of the example models shown so far have been simplified horn models with no gaps between them. Another important detail to explore is the effect of horn spacing. If the cabinet splays exceed the trapezoid angle, the fronts of the cabinets will separate. Also, the design of the new cabinets may not permit the high-frequency horn to fill the full height of the cabinet. This would be the case if the new system is based around a coaxial transducer, or if the depth of the horn is insufficient to allow the desired vertical coverage angle. In fact, there is always a gap amounting to at least two cabinet-wall thicknesses plus grille rails.

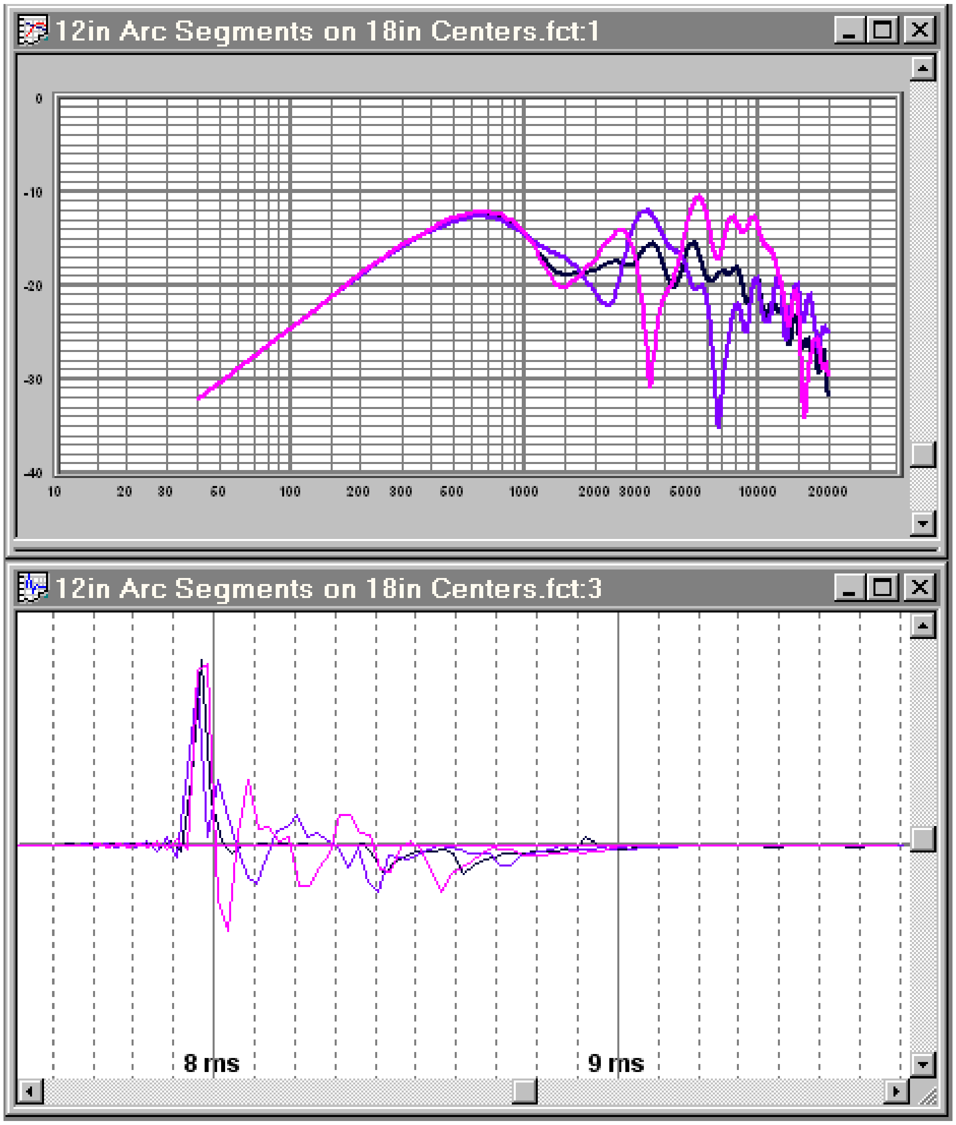


**Figure 7: Non-Contiguous Arc Segments, 12"/18"**

Figure 7 shows a comparison between matched 5-degree, 18" arcs and 5-degree, 12" arcs on 18" centers. The pink curve is on a seam, while the violet curve is on the axis of a horn. The black curve is the contiguous source. A loss of coherency is apparent from 2 kHz on up.

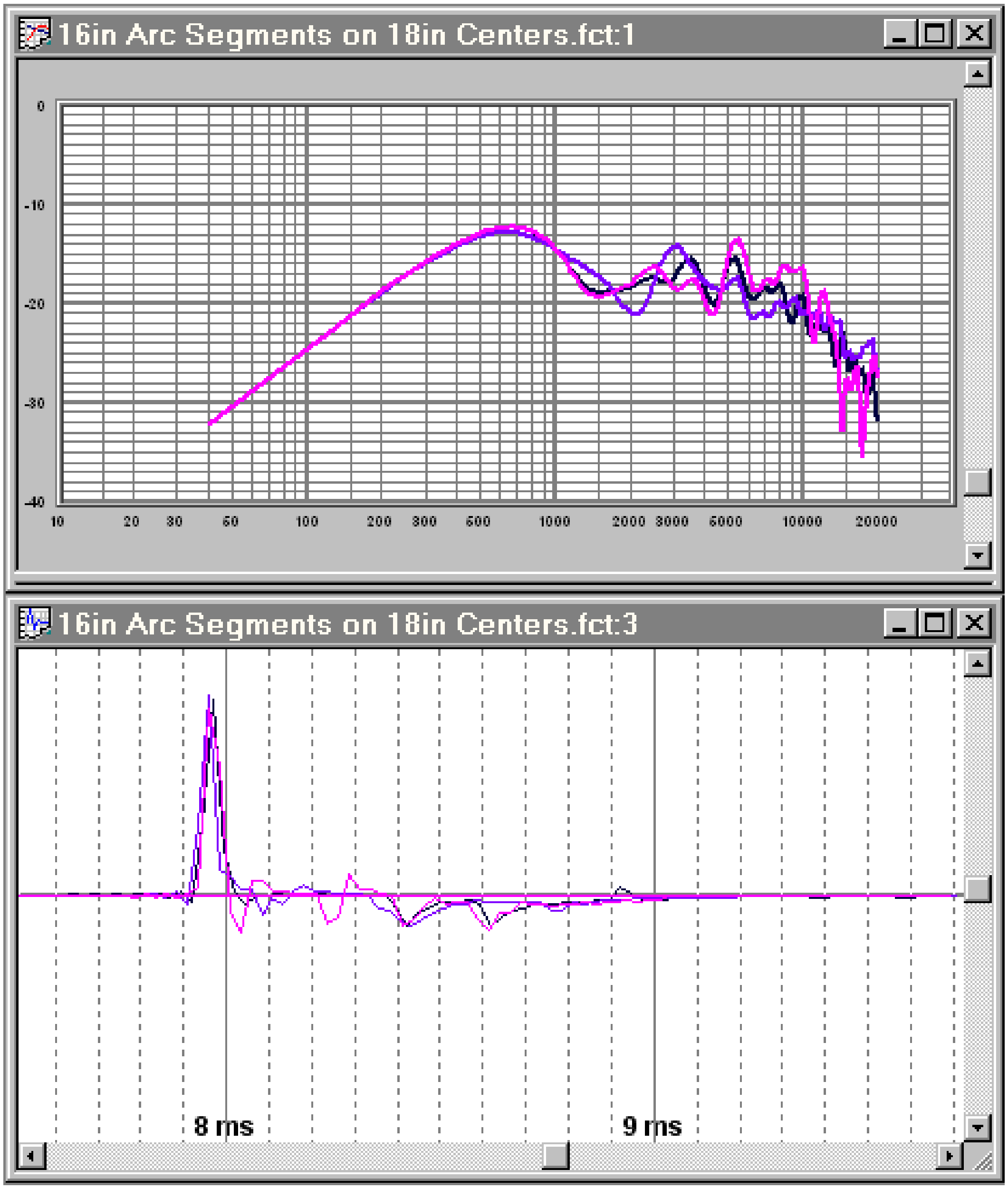


**Figure 8: Non-Contiguous Segments 16"/18"**

With 16" arc segments (about the minimum gap achievable), the result is much closer to the ideal - as evidenced in both the frequency response and impulse response views. This is shown in Figure 8.

The conclusion that can be drawn is that every effort should be made to fill as much of the vertical cabinet dimension as possible with the HF horn or horns.

**Optimum Arc Selections for an Integrated System**

The summation in the long-throw direction (perpendicular to the flat-front portion of the array) works well regardless of the particular selection of source arc. Consequently, the long-throw portion of the array should not be a strong consideration in the selection of source arcs. Instead, the source arcs should be selected on the basis of the curvature that addresses front-of-house (FOH).

In other words, for the prototypical venue, FOH will be located at a particular position relative to the upper-most seat. If we design a prototype source shape to fit the prototype venue, the portion directed at FOH will have a particular curvature. This becomes the standard source curvature for most of the cabinets in the array. As a result, the most coherent sound in the house should occur at FOH. At some lower angle, the horns must then trasition to a wider format, in order to obtain smooth coverage in the front fill region.

This line of reasoning dictates that an integrated system should have two basic cabinet types: a long-throw/FOH type, and a front-fill type. The front fill element is critical because one of the primary weaknesses of existing touring line arrays is that they lack an integrated front-fill element, and cannot be arrayed to point far enough down (except for KF860, which can be rigged to point the bottom cabinet straight down). The front-fill cabinet type should make use of a significantly overlapped horn design, to allow the greatest flexibility, and a slightly diffuse character (to avoid any complaints of "over-agressiveness in the front rows"). The long-throw/FOH type should provide an arc-shaped wavefront matched to the trapezoid angle. The cabinets facing FOH would be tight-packed, and the cabinets facing the farthest listener would be flat-fronted, or nearly so. According to the models, the cabinet can do everything required with just these two splay angles.

Figure 9 shows an example of a prototype venue (an arena with a single upper deck), illustrating the three regions of the array. At the top is a flat-front section. Below that is an arced section, the center of which is directed at FOH. At the bottom is a relatively small downfill section. Two possible approaches to breaking up the source into cabinets are illustrated in Figure 10.

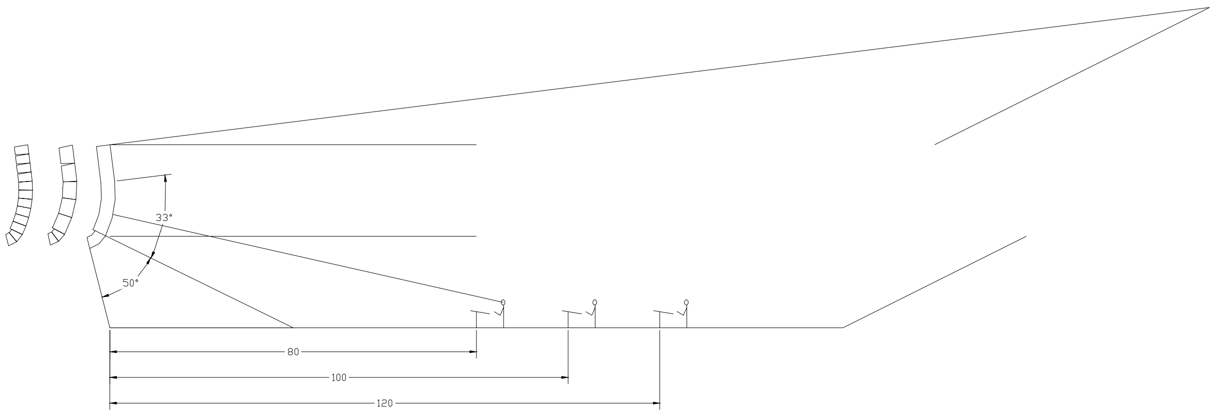


**Figure 9: Prototype Venue**

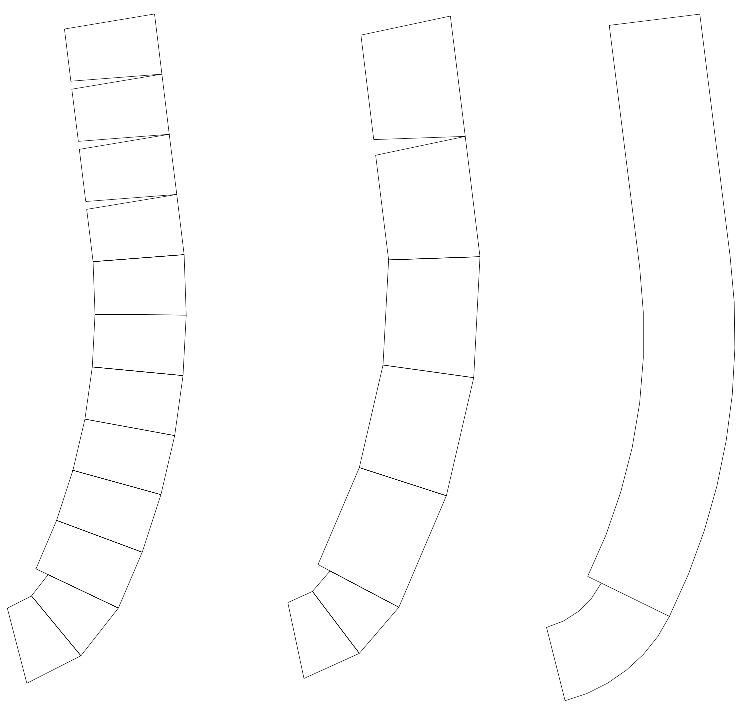

**Figure 10: Detail of Alternative Block Sizes**

The second array in Figure 10 was modeled with perfect arc sources, resulting in the family of curves shown in Figure 11. While the overall consistency is excellent, further examination revealed that the upper deck had poor high frequency coverage in its top and bottom rows. The flat, long-throw, section actually produces too tight of a beam. Much more consistent results were obtained with a slight arc (1/2 the splay angle of the main part of the array. These results are shown in Figure 12, and the array that produced them in Figure 13.

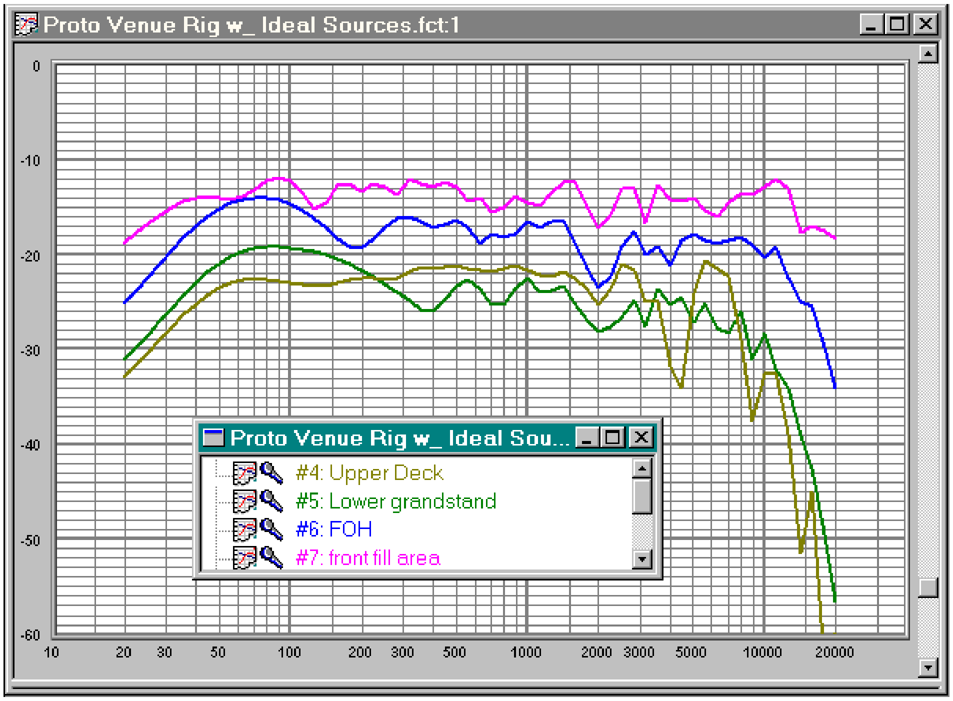


**Figure 11: Prototype Rig w/ Ideal Arc Sources, Flat Long Throw Section**

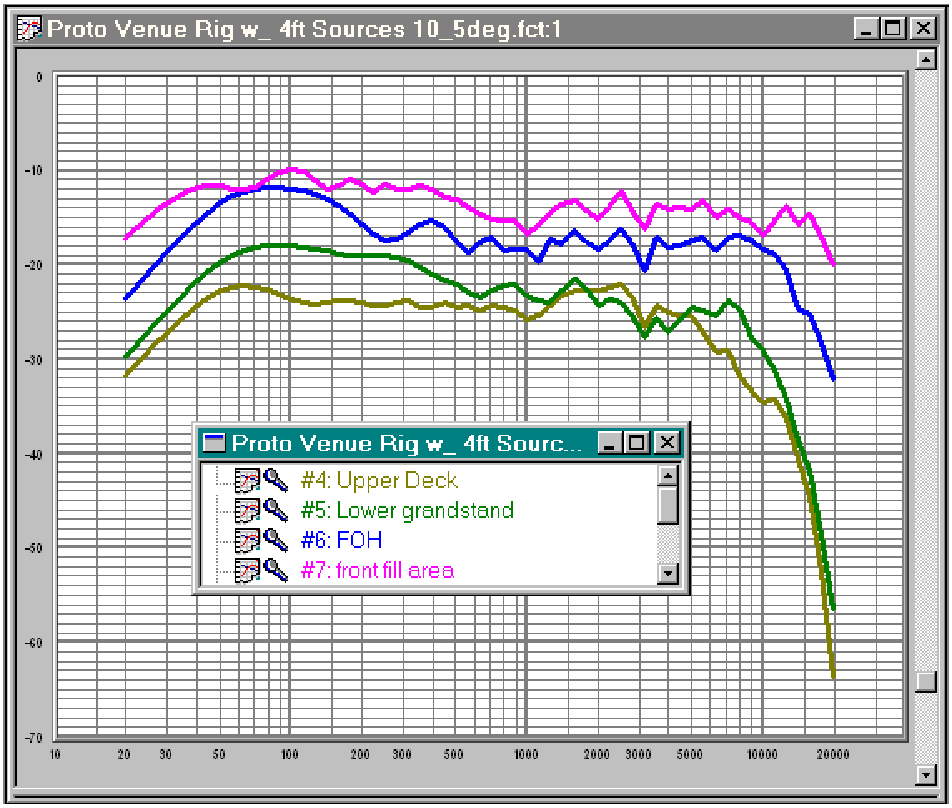


**Figure 12: Prototype Rig w/ 4ft Cabinets, Slight curve to long-throw**

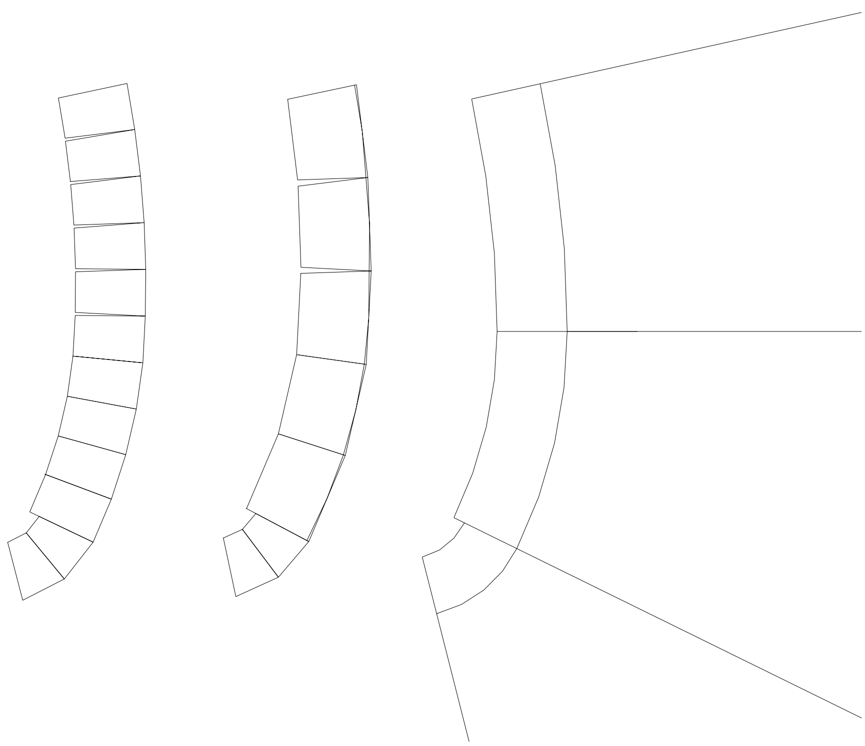

**Figure 13: Prototype Rig w/ Slightly Curved Long-Throw Section**

**Horizontal beams**

A curved line source cannot transition, horizontally, in the same fashion as a KF900 or KF750 column. While these arrays project a horizontal wedge, top-to-bottom, a curved line source projects a constant-beamwidth band. There will always be massive overlap below the arrays. Also, array columns cannot be tight-packed because the bottom-most cabinets pull back.

However, experience with the KF860 shows that a graceful transition is possible. VDosc arrays do not transition well, because their response is too ragged at the pattern edge. With a well-defined edge and a slightly wider-than-nominal beam (transition at -3dB, rather than -6dB), a satisfactory transition is very possible. If the off-stage array is shorter than the on-stage array, it is critical that the arrays are flown with the bottoms at the same height - not the tops. Otherwise, the arrays' relative arrival times will be different in the long-throw and downfill directions. This is an important issue, because it means a multiple column array cannot be hung from one bar, unless we devise some sort of spacer to lower the off-stage column.

In the frontfill region, the overlap is not as destructive as one might expect, because the listener is typically significantly closer to one stack than the other. In fact, the extremely wide pattern facing almost directly down can be an advantage. KF860 rigs can cover all the way to the center-stage lip, from the mains. The array can be configured so that the bottom-most cabinet faces almost straight down.

EAW TECHNICAL BRIEF
KF760 TECHNOLOGY OVERVIEW

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## INTRODUCTION

This brief is intended to provide insights into the technology and engineering design of the KF760 Series. Rather than addressing the complex engineering calculations and tests on which the KF760 design is based, this paper focuses primarily on the various electro-acoustical concepts employed. It describes how these concepts interrelate and function together to solve large array problems and achieve the desired overall performance.

## DESCRIPTION

The KF760 Series is engineered to be a touring system for use in arenas, large ballrooms, music pavilions, convention center exhibit halls, theaters, auditoriums, and flat field or amphitheater-style outdoor events. It is a scalable line array system that can be easily reconfigured for different size venues from theaters with fewer than 1,000 seats to large arenas. There are two models in the KF760 Series: The KF760 for short to long throw coverage and the KF761 for near field coverage.

Probably the most important feature of the KF760 Series is that, by design, it is an array system. While an individual KF760 or KF761 loudspeaker will certainly function by itself, the design performance of the KF760 Series is only achieved when the loudspeakers are used in arrays.

As an array system, the KF760 Series is designed to provide uniform SPL and frequency response, high resolution reproduction, and well-defined and predictable audience coverage. It is designed to do these things over the distances and coverage angles needed for most typical concert applications. The ultimate expression of the KF760 Series is producing a continuous, coherent wave front and similar dispersion pattern at all frequencies. One of the most important benefits of the KF760 Series design is that the signal processing, amplifier adjustments, and the physical set-up are greatly simplified compared to other line array technologies.

## LINE ARRAY THEORY AND PRACTICE

A major drawback to a line source (in practice, a line of sources) is that its acoustical behavior is highly frequency dependent for a given line length. Therefore, to provide consistent performance with frequency, techniques must be used to offset the behaviors. Given a fixed line length, classic line array theory and reality diverge very quickly once you have to reproduce more than a very limited frequency range.

For these reasons the KF760 uses a multi-design approach. In basic terms, a KF760 array is intended to:

1. operate as single source to any given listener at high frequencies.
2. operate as multi-cell device in the upper mid range.
3. operate as a single large horn at lower mid frequencies.
4. operate as a line source at low frequencies.
5. avoid complex signal processing and an unwieldy gain structure.

While the KF760 Series will be called a "line array", it is more accurately an array of loudspeakers in a line, and a curved one at that. It is designed to function as a true line array over a limited portion of its frequency range.

## INTENSITY SHADING

One major function of the KF760 Series is to provide a system that exhibits minimal SPL variations over distance. Normally, in order to achieve equal SPL from the near field to far throw, intensity shading is used to vary the output level of loudspeakers arranged in vertical columns according to the required projection distances. Typically, such arrays are curved top to bottom and often side to side so that the loudspeakers are aimed in the appropriate directions. Enclosures are normally splayed at the front causing physical separation of the array elements. This physical separation produces discontinuities in the vertical coverage and can cause severe off-axis side lobes as well. Because of the differences in output levels, intensity shading also invariably creates frequency response problems in the coverage seams between vertically adjacent enclosures. These output level differences also cause end of column effects that seriously degrade the performance below the array in the near field — right in the prime audience seating.

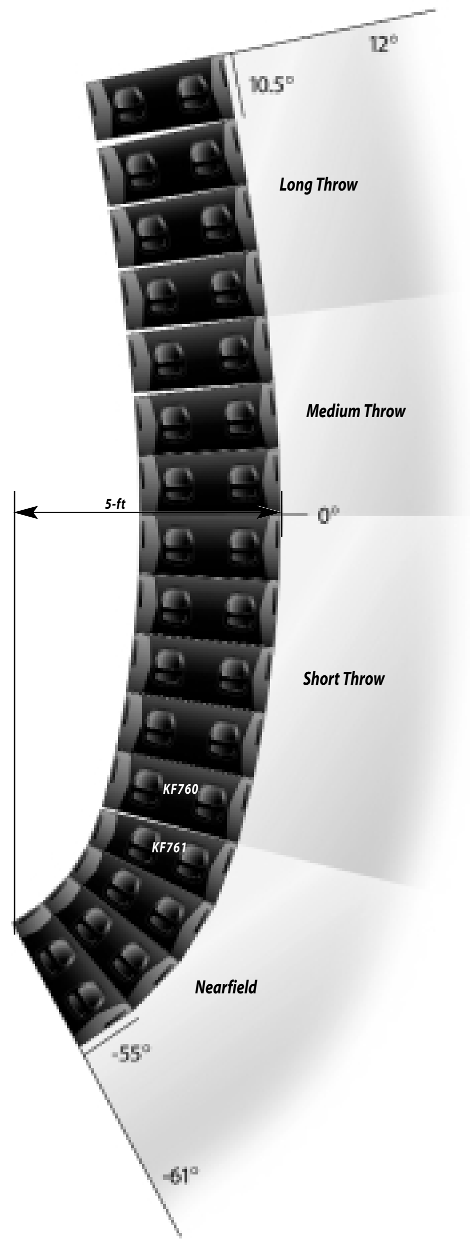


Figure 1

## INTENSITY SHADING VS. DIVERGENCE SHADING

Instead of intensity shading, the KF760 uses divergence shading to achieve equal SPL over distance. Using divergence shading, the input level is the same for all loudspeakers in the array. Instead of using loudspeaker level differences, the KF760 Series uses variations in the divergence or spread of the wave front, specifically in the vertical dispersion, to change the SPL depending on the required projection distance. This is primarily done by varying the curvature of the array, but also by using a combination of other appropriate acoustical techniques. One technique is akin to aiming more transducers at the furthest listeners then gradually changing to fewer transducers at listeners in the near field. Another is akin to using horns with narrower vertical patterns for long throw and horns with wider vertical patterns for short throw. Still others include the use of line source technology and the equivalent of multi-cell horns. Interestingly, line source technology is used contrary to its usual application in that it is applied at lower rather than higher frequencies.

As shown in Figure 1, in a properly configured KF760 array, a flat-fronted upper section focuses the most SPL within a given coverage area for long throw. Two lower sections, each with progressively more curvature, focus less SPL within a given coverage area for the medium throw and short throws. The most tightly curved section, comprised of KF761s, focuses even lower SPL within a given coverage area for the near field. The total vertical coverage in this example is 73°. The reduction in the SPL focused within a given coverage area from long to short distances provides a highly uniform SPL to the audience at all distances. Typically, the FOH position will be located in the medium or short throw areas.

## DIVERGENCE SHADING DESIGN

There are several critical parameters to achieving good performance using divergence shading. Without these design elements, discontinuities in both the frequency response and SPL occur. The application of these different design elements is highly frequency dependent, meaning each can function only over a limited frequency range. Therefore, great care was devoted to determine how to make them work in conjunction with each other to achieve the engineering goals.

1. The interaction between vertically adjacent enclosures must be minimized by reducing time arrival differences. This means there has to be both minimal spacing between individual transducers and essentially a continuous horn mouth from the top to the bottom of the array. At frequencies where this is not possible, coverage must be limited to a singular enclosure or transducer.
2. Where there is overlapping coverage from multiple transducers and their horns, their outputs must add coherently. At shorter wavelengths, transducers must be arranged so that their sound paths from vertically adjacent enclosures to any particular listener originate from a single point of geographic origin behind the enclosures. At longer wavelengths, adjacent horns must acoustically couple well to form a unified, coherent wave front.

3. All loudspeakers must work at the same input level to avoid complex and variable intensity, delay, or equalization settings in the signal processing.
4. At lower frequencies where the vertical dispersion pattern widens for each individual enclosure, the length of the array must provide the necessary columnar behavior to maintain vertical pattern control.
5. The rigging system must be engineered so the enclosures easily array in the correct curvatures needed for the projection distances.
6. The sonic character of the sound must be maintained for distances as close as around 15 feet to many hundreds of feet.

Properly executed, as it is with the KF760 Series, the result is consistent SPL and smooth frequency response throughout the near to far listening area. Using only two different loudspeaker models provides the capability to maintain the sonic character of the sound from the near field to furthest listening areas.

## OUTPUT LEVELS

Another major function of the KF760 Series is to provide sufficient output levels for high SPL live concerts in large venues.

A primary attribute of divergence shading is that high and uniform SPL are both provided while all loudspeakers in the array operate at the same input level. This is accomplished in a way that significantly simplifies the signal processing, amplification, and the physical setup by using familiar acoustical principles and techniques applied in unique ways and in appropriate combinations. These include using multiple transducers within each bandpass, horn loading, tightly focused dispersion patterns, wave front shaping, multiple enclosure coverage, line array effects, mutual coupling, and appropriate enclosure splays.

## ACHIEVING HIGH SPL

The use of transducers with high sensitivity and high power handling is a given for high output systems and the KF760 Series is no exception. Along with this, other techniques must be used to maximize SPL capabilities while maintaining uniform frequency response and dispersion.

A normal technique for increasing SPL output to reach the furthest listeners is to use multiple transducers, within a single loudspeaker and/or by using multiple loudspeakers. This effectively focuses more SPL within a given coverage area. However, a problem inherent in using multiple transducers and/or loudspeakers is that, because they must be physically separated, time arrival differences to the listeners can create dramatic frequency-specific cancellations, particularly at mid and high frequencies. Nonetheless, the KF760 design uses multiple transducers within each enclosure as well as using multiple enclosures aimed at the furthest listeners to achieve high SPL, but does so without these kinds of problems.

## OVERCOMING MULTIPLE SOURCE HIGH FREQUENCY ANOMOLIES

The worst-case condition in a properly configured KF760 array is the long throw section, where enclosures are normally arrayed "flat-fronted". With multiple enclosures covering the same listening area, sound waves reaching listeners are originating from multiple, physically separated transducers. To circumvent the resulting time arrival problems that would normally reduce coherency and cause cancellations, several techniques are used, depending on the frequency range involved.

## UPPER HIGH FREQUENCIES - >6 kHz

At the very highest frequencies, the geometry of the HF horn causes an intentional narrowing of the vertical pattern from each transducer. It actually has less vertical height than the enclosure face as the wave front leaves the enclosure. The sound waves are also shaped to produce a nearly, but not quite, flat wave front. This combination ensures that, even at long distances, a particular listener is primarily listening to the highest frequencies from only one, or at most, two HF transducers. A simple equalization boost compensates for the fact only one or two transducers might be providing the highest frequency information. The required EQ boost does not begin to overtax the transducers because of the low power requirements at these frequencies. This boost also incorporates compensation for HF air losses. In addition, the nearly flat wave front also helps reduce the HF loss over distance compared to a typical spherical wave front.

Although it could have been so shaped, the upper high frequency wave front is not perfectly flat-fronted by design. Given the 7 in / 180 mm spacing between the HF transducers, an absolutely flat wave front would have too narrow a beamwidth from each transducer, even at long distances, and thus create gaps in the vertical coverage. This would occur primarily in the "seam" between any two transducers. By providing a slightly arc-shaped wave front, these seams are substantially filled in. This requires HF horns that make an essentially continuous vertical horn mouth throughout the array. Essentially, the arc of the upper HF wave front is set to provide a slight scalloped effect between enclosures when they are flat fronted. The wave front transitions to a smooth continuous arc between enclosures when the curvature of the array is increased for shorter throws. Thus, this transition essentially eliminates overlapping coverage in the upper frequencies in the more critical medium to near field coverage areas.

The frequency and impulse responses of the HF section for two KF760s are shown in Figures 2 and 3. Figure 2 shows the results with the front of the enclosures splayed to achieve the desired vertical coverage. One curve was measured on axis of one enclosure and another on the seam between two enclosures. The third curve (the smoothest) is that of an "ideal" single curved source.

In Figure 2 the splay between the front of the enclosures causes time offsets in the impulses, resulting in severe anomalies in the frequency responses and in the "tail" of the impulse responses.

In Figure 3 the close agreement between the frequency response curves and virtual coincidence of the impulse responses shows the high coherency achieved in a KF760 array. The 2 enclosures are splayed but with tight-packed enclosure fronts, forming an essentially continuous horn mouth. Again the third curve is that of an "ideal" single curved source.

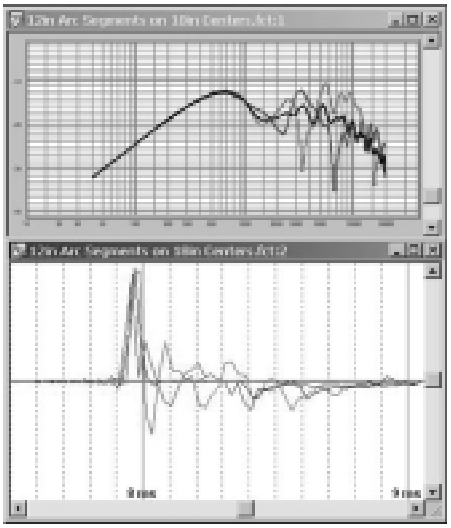

Figure 2

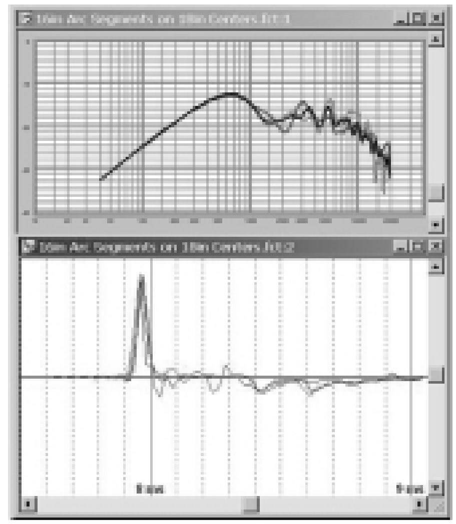

Figure 3

These four factors - pattern control, wave front shape, continuous horn mouths, and HF boost provide the appropriate SPL and high resolution sound at the uppermost frequencies for both longer and shorter projection distances.

LOWER HIGH FREQUENCIES - 1 kHz to 6 kHz

At lower HF frequencies, the HF horn geometry gradually and proportionally broadens the vertical wave front for each HF transducer so that it emits from the entire vertical mouth area in each enclosure. The mouth of the MF horn actually becomes part of the HF horn, thus increasing its effective size at these longer wavelengths. The purpose is to transition the long throw array output from singular transducer coverage to multiple transducers in multiple enclosures to maintain high SPL in the lower HF frequency range. This is important as the power requirements in this frequency range increase, making achieving the necessary SPL from single transducers over long distances problematic.

Another problem in this range is that the sound wavelengths must be significantly longer than the time arrival differences between HF transducers to avoid destructive cancellations. This is achieved by the very close spacing of the transducers and providing an essentially continuous vertical horn mouth between enclosures. For example, a listener at 150 feet / 50 m on axis of one HF transducer at the top of one enclosure would experience a time arrival difference of only 0.04 milliseconds between it and the bottom HF transducer in an adjacent enclosure. At 4 kHz this is less than a 45° phase shift between the two transducers at the listener resulting in nearly coherent addition. In terms of sound pressure level, that phase shift results in about 1 dB less level than it would be with perfectly coherent addition — well within acceptable limits.

UPPER MID FREQUENCIES 500 Hz to 1 kHz

In the worst case, flat-front KF760 array section for long throw, the MF horns mouths are minimally spaced vertically allowing tight coupling of vertically adjacent horns. This enhances their summed output. In addition, even though the midrange transducers are more widely spaced in this frequency region, the wavelengths are significantly longer than the time arrival differences that occur from multiple transducers in vertically adjacent enclosures. This combination of things not only increases the SPL for long throw coverage, but it essentially eliminates destructive interference between multiple transducers in this frequency range.

SHORTER THROW DISTANCES >500 Hz

In the medium and short throw portions of a KF760 array, the splay at the rear of the enclosures is reduced from 3° to 1-1/2° or a tight pack. These splay angles produce a smooth but increasing front curvature in these portions of the array. In this way multiple enclosure coverage is reduced at shorter distances and becomes essentially singular at mid and high frequencies within distances less than 100 feet. This results in progressively less SPL within a given coverage area as one moves closer to the array. Transitioning to singular coverage also solves the potentially increasing problem of multiple transducer coverage. This problem is due to the geometry of the situation. As one moves closer to two or more sources separated by a fixed distance, the angle between the sources increases and would normally cause an increase in time arrival differences. This problem is largely mitigated using singular coverage at higher frequencies that transitions to multiple coverage but longer wavelengths at lower frequencies.

At distances less than about 70 feet, the near-field area, the KF761 is used to further reduce the SPL within a given coverage area by utilizing a much wider 12° vertical dispersion pattern which, given the enclosure size can be maintained to a lower frequency. Also when arrayed, the KF761s are configured with greater axial vertical splay angles. This results in audience areas receiving sound primarily from one enclosure at the closest distances to the furthest near-field distance. Like in the KF760, the high frequency section uses narrower dispersion to prevent the uppermost HF from causing interference between enclosures. At lower frequencies, the vertical dispersion appropriately changes with wavelength to continually provide a coherent wave front while maintaining the same SPL at all frequencies.

As frequency decreases in the midrange, the dispersion pattern of individual horns widens due to physical size limitations. However, for both the KF760 and KF761, the vertical continuity of the horn mouths and the wavelengths involved combine to reduce the vertical pattern as frequency decreases because of line source effects. Simply put, these two opposing effects essentially balance each other out.

## HIGH SPL SUMMARY

In a properly configured KF760 array, variations in the number of enclosures and transducers providing coverage is used along with other design attributes to smoothly vary the SPL for different throw distances within the overall coverage area. This carefully researched engineering design automatically ensures that each listener receives a similar SPL with negligible phase cancellation problems at all frequencies. A key element in achieving this is for all KF760s and KF761s in a KF760 array produce approximately the same SPL. This means amplifier sensitivities are normally set identically within each crossover passband for all KF760s and for all KF761s.

## KF760 HORIZONTAL COVERAGE

The KF760 model is designed with a nominal 80° horizontal dispersion pattern. This is sufficient for many applications with typical configurations that use left/right arrays. A significant attribute of the KF760 is that the frequency response is maintained well beyond its normal dispersion. In Figure 4, actual measurements of a KF760 array, taken at 110 ft / 33 m, show remarkable consistency to more than 60° off-axis, which corresponds to a 120° coverage angle. At this angle, the response is within +2.5 dB from below 125 Hz to 10 kHz including the dip seen at 750 Hz. Note that these are early prototype field measurements and that improvements have been made since that time.

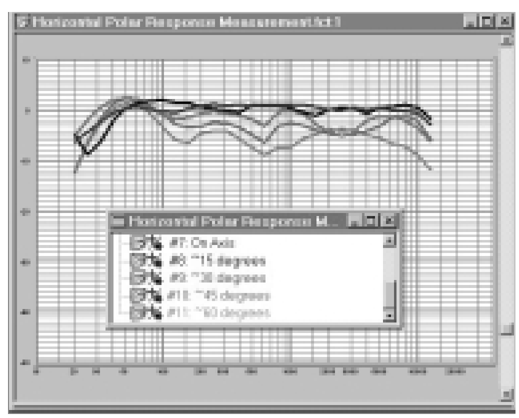

Figure 4

This performance is achieved using several techniques.

1. The horn mouths of the midrange sections for both the KF760 and KF761 are sufficiently wide to maintain a well-controlled and uniform horizontal dispersion pattern, particularly at the lower part of their frequency ranges.
2. Tight-packing the front of all enclosures provides a nearly continuous midrange horn mouth from top to bottom of an array. This eliminates the vertical side lobes that would normally occur between vertically displaced horn mouths.
3. The transition from the MF horn to the "dipole" LF section.

It is important to note that the off axis response in the entire range from below 125 Hz to over 10 kHz is attenuated by essentially the same overall amount for a given off-axis angle. This means that, unlike typical concert loudspeakers, the degree of overlap between arrays is not frequency dependent. This is especially important for the lower midrange where severe "build up" occurs with typical concert loudspeakers. This creates significant frequency response problems that to mitigate can require complex signal processing or difficult array positioning.

The horizontal coverage performance has several important consequences.

1. For audience areas well outside the nominal dispersion pattern excellent frequency response is maintained, albeit at reduced level. The smooth fall-off in level, which is essentially frequency independent, creates a "soft-shoulder" in the coverage that is entirely usable for many applications to eliminate the need for additional fill arrays.
2. If side fill arrays are required, as is the case with wrap-around arena audiences, a KF760 array can transition smoothly to a KF760 or KF750 side fill array, without having to physically separate them, usually simplifying the rigging. See Figure 5.
3. When using side fill arrays, the "soft shoulder" can be effectively used to expand the horizontal coverage. As shown in Figure 5 using a 10° "soft shoulder" allows the coverage of four KF760 arrays to extend some 280°. This is well beyond the 240° that normally would be assumed using the nominal 80° dispersion pattern.
4. With typical left/right arrays, there will be a smooth transition between them because of the lack of side lobes.

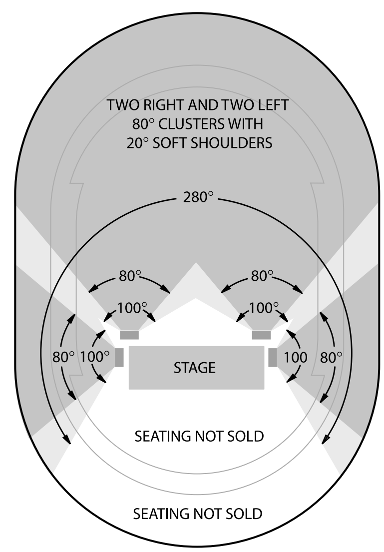


Figure 5

KF761 HORIZONTAL COVERAGE

The KF761 model has a wider nominal dispersion pattern of 100°. There are two reasons for this.

1. Along with its wider vertical dispersion, this reduces the SPL within a given coverage area compared to the longer throw KF760s, without the necessity of changing the input levels.
2. Given the short throw distances for which the KF761 is used, geometry dictates that a wider horizontal dispersion is needed to provide coverage for the same audience width as the longer throw KF760s.

## MID TO LOW FREQUENCY TRANSITION

Because of the longer wavelengths, maintaining pattern control commensurate with the higher frequencies through the mid to low frequency crossover is a problem area in typical loudspeaker arrays. Direct radiating low frequency drivers generally do not allow this kind control. Horn loading both the mid and low frequencies in this frequency range can work, but usually requires an unwieldy enclosure size.

One key to achieving a good mid to low frequency transition in the horizontal plane is having excellent pattern control to a low enough frequency for the mid frequency section. This is achieved in the KF760 Series simply by the large width of the mid frequency horn mouth (see Figure 6) that span almost the entire width of the enclosure. The other key is providing pattern control for the upper frequencies of the low frequency section. This is achieved in the KF760 Series with the spacing of the low frequency horn mouths in each enclosure (see Figure 6). Which operate similar to a dipole radiator. As such, the spacing chosen causes intentional off-axis phase cancellations that effectively provide attenuation proportional to the off-axis attenuation of the mid frequency horn. This maintains a smooth transition in the SPL through the crossover point throughout and beyond the nominal horizontal dispersion angle.

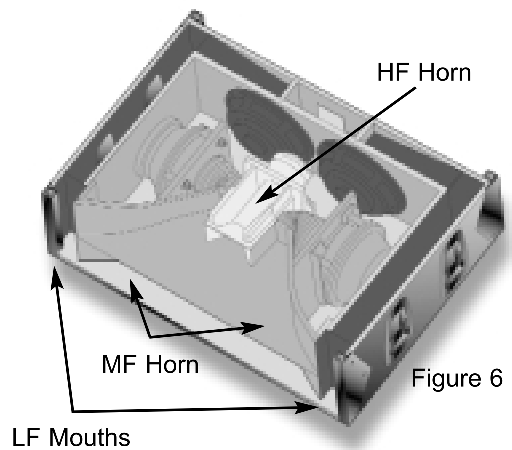

Figure 6

## LOW FREQUENCIES

Both the KF760 and KF761 have the same LF section that uses EAW's bent horn technology for the LF bandpass. This type of loading greatly increases the output efficiency of the LF section.

The mouths of the low frequency horns are vertical rectangular slots on each side of the enclosure front (see Figure 6). When arrayed this creates two continuous vertical slots on either side of the front of the array. In the vertical plane the output from these slots add coherently to extend the low frequency response. This is readily evidenced by the -3 dB LF roll-off points. While a single enclosure has a -3 dB point at 80 Hz, a four enclosure array (the minimum required) has a -3dB point at 60 Hz, and an eight enclosure array (a typical array size) has a -3dB point at 40 Hz. Within the nominal dispersion angle in the horizontal plane, the left/right spacing of the LF slots in comparison to the wavelengths reproduced allows nearly coherent addition.

Given the typical length of most KF760 arrays, these slots also create a true line array for the low frequencies that provides vertical pattern control to below 100 Hz. This prevents excessive low frequencies near to and almost under the array while focusing more energy to the longer throws. Compared to traditional systems, this helps maintain the frequency response over varying distance to very low frequencies. Again, this is achieved with the physical design rather than complex signal processing. These design elements provide the prodigious LF output and pattern control required to match those of the MF and HF sections.

## ADDING SUBWOOFERS

Although virtually any type of subwoofers can be used with a KF760 array, KF940 SuperSub™ Bent Bass Horn Subwoofers are recommended for the following reasons.

1. The output capabilities are an appropriate match for the KF760 with a one to one ratio. Note: This is based on using a minimum of four KF940s.
2. The sonic character is a natural extension of a KF760 array's low frequencies.
3. The output to size ratio is in keeping with the KF760 Series in terms of the physical space required both in use and for transport.
4. The "throw" capabilities are complementary to a KF760 array.

## ELECTRONIC SIGNAL PROCESSING

The KF760 and KF761 are tri-amplified loudspeakers making their frequency responses dependent on electronic crossovers along with any equalization needed for the particular transducers used. These basic signal processor settings are normally pre-programmed and rarely need adjustment. The crossover and basic equalization required for the KF760 and KF761 are, of necessity, different because their electro-acoustic designs and their applications are distinctly different.

## SIGNAL PROCESSING VS. THROW DISTANCE

There are distance related, sound propagation realities that are addressed by the preset signal processing. A consequence of being in the near field (<70 feet) of loudspeakers is that a flat frequency response tends to be perceived as "aggressive" in the higher frequencies. However, at longer distances there a natural attenuation of higher frequencies due to air absorption that increases both with frequency and with distance. Another less understood phenomena concerns the perception of a loss of "warmth" with line arrays of all types at longer distances. This translates into an apparent loss of power generally in the 100 Hz to 500 Hz range. Fortunately, these anomalies can be easily corrected with standard signal processing.

DISTANCE-BASED PROCESSING

The distance-based frequency response modifications are straightforward. In addition to the inherent frequency response properties of the KF761s used for near-field coverage, the higher frequencies are further attenuated using a gentle roll-off to counteract the perception of an overly aggressive high frequency response. For all KF760s, the frequency response is modified to correct for the apparent loss of warmth that is associated specifically with line arrays beyond the near field. For a KF760 long throw section, a high frequency boost is applied to compensate for high frequency air losses. As these anomalies in frequency response are primarily a function of distance, they change very little from situation to situation and rarely need adjustment.

MINIMAL SIGNAL PROCESSING REQUIRED

Surprisingly, a full KF760 line array needs only eight signal processing channels, as shown in Figure 7, to fulfill all basic signal processing requirements, including crossover, preset equalization, distance-based frequency response modifications, and subwoofer processing.

1. Three channels for tri-amplifying the KF761s.
2. Three channels for tri-amplifying the KF760s.
3. One channel for separate HF equalization in a KF760 long throw section.
4. One channel for subwoofers.

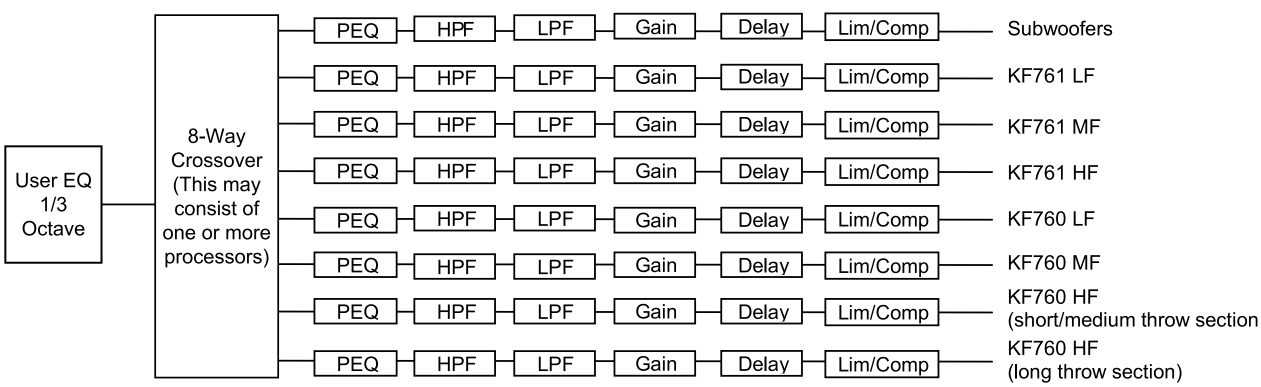


Figure 7

This 8 output configuration can be accomplished with one loudspeaker processor that can be configured for 1 input x 8 outputs, such as EAW's MX8750. If a system is used monophonically, one processor can serve any number of KF760 arrays.

## USER EQUALIZATION

Normally, the only user adjustable signal processing needed is straightforward 1/3 octave equalization. This is to correct for frequency response anomalies specific to a particular acoustical situation, type of program, or simply to satisfy a particular mixing engineer's taste in frequency balance. An important benefit of the KF760 Series technology is that, by inherently maintaining the sonic character throughout the audience, user equalization will affect the frequency balance in all areas of the audience in the same way.

## SIGNAL DELAY

Signal delays in a KF760 Series array are used only for time aligning transducers in the enclosures and for time aligning subwoofers to the array. Transducer alignment delays are the same for all KF760s and for all KF761s. Signal delays are sometimes used between enclosures or sections of an array for "steering purposes". In a KF760 Series array, this is not necessary.

## PHYSICAL SET-UP

There are only 3 splay angles engineered into the rigging for the KF760s. These are set by changing the splay between the rear of the enclosures rather than the front. This means that the fronts of all enclosures are always tight-packed. For larger venues, all three splay angles would normally be used. For throw distances less than 150 feet, only one or two splay angles are normally used. This greatly simplifies the physical setup.

The KF761s, when used with the KF760s, are normally tight-packed tops to bottoms. Used by themselves the KF761s have two other splay angles available to adjust their coverage for smaller venues. Like the KF760s, the splay of the KF761s is set by changing the angle between the rear rather than the front of the enclosures.

## RIGGING METHODOLOGY

The caster pallet designed for the KF760 Series can normally transport a stack of up to four enclosures. The pallet automatically provides a staging platform for any array to add or remove a pre-rigged assembly of up to four enclosures at one time.

The fly-bar designed by EAW specifically for the KF760 Series, is fully modular allowing considerable versatility for flying a KF760 Series array. The fly-bar can be set up in several different configurations depending on the particular rigging situation and/or pullback requirements. The fly-bar is made of heat-treated, structural steel with a working load capacity well in excess of typical array requirements.

Once the top enclosure of an array is rigged to the fly-bar, the KF760 is rigged in traditional manner by lifting an enclosure and attaching an additional one underneath, initially inter-connecting only the two front suspension points on each enclosure. Using the now-connected front points as a hinged support, the rear of an enclosure is then easily lifted to the one above and attached using the two rear suspension points. The desired rear splay angle is set with this step. Using pre-rigged assemblies on their caster pallets, up to four enclosures can essentially be rigged to and removed from an array at one time. Once this process is completed, along with connecting the loudspeaker cabling, the entire array is flown to its trim height.

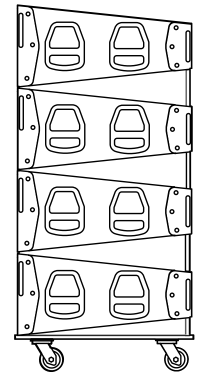
Figure 8

A set of four KF761s is shown on a caster pallet in Figure 8, ready for rigging or transport. In this case, the rear suspension points that determine the rear splay are fully extended to achieve the smallest footprint for transport and a flat surface for decking a truck. The enclosures are locked together and to the pallet by their connecting pins. In this way, the connecting pins are designed to stay attached to the enclosures when transporting thus eliminating any separate loose parts. This also makes them available for rigging an array exactly when and where they are needed.

SUMMARY

The KF760 Series is engineered to provide uniform SPL, frequency response, and sonic character to all audience areas. Remarkably, this is achieved with extraordinary simplicity in both the physical set-up and signal processing:

1. KF760s require at most 3 splay angles set at the rear of the enclosures to achieve the desired vertical coverage.
2. KF761s provide down fill to directly under a KF760 array and are all tight-packed for this purpose.
3. There are no "loose parts" because connecting pins normally stay with the enclosures for transport.
4. Minimal stage area is required to set up and fly a KF760 array.
5. The horizontal coverage of a KF760 array provides excellent performance well beyond the nominal ±40° dispersion, sometimes eliminating the need for side fills
6. The horizontal performance of a KF760 provides excellent acoustic integration between left/right main arrays and side fill arrays, simplifying rigging requirements and signal processing.
7. Signal processing is simplified to the point that only up to 8 outputs are needed for an entire array of tri-amplified KF760s, KF761s, and subwoofers.
8. All amplifiers within each crossover passband are set at the same sensitivity.
9. Minimal equalization is used for the transducers and this is normally preset for all applications.
10. Array signal processing uses distance related equalization issues and this is normally preset for all applications.
11. Signal delay is used only for transducer alignment within enclosures and this is preset for all applications.
12. Typically, only standard 1/3 octave equalization is required for user adjustments for specific venues or events.