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: 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. Shading reduces the sudden change in pressure at the top of the array.

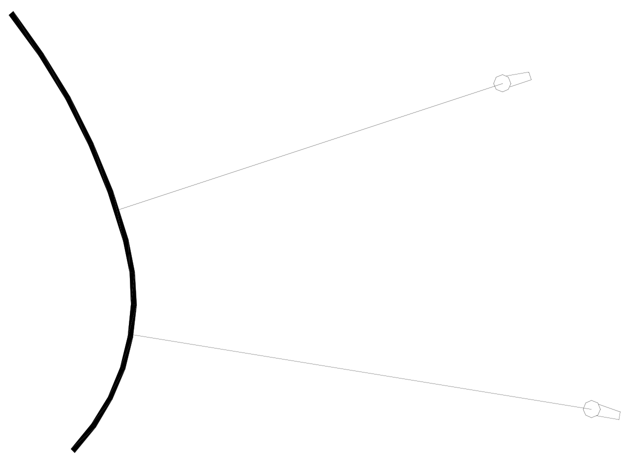


Figure 1: Source Normal

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, as long as the long-throw part is 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 wavefront area. 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 seeking 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, , 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.

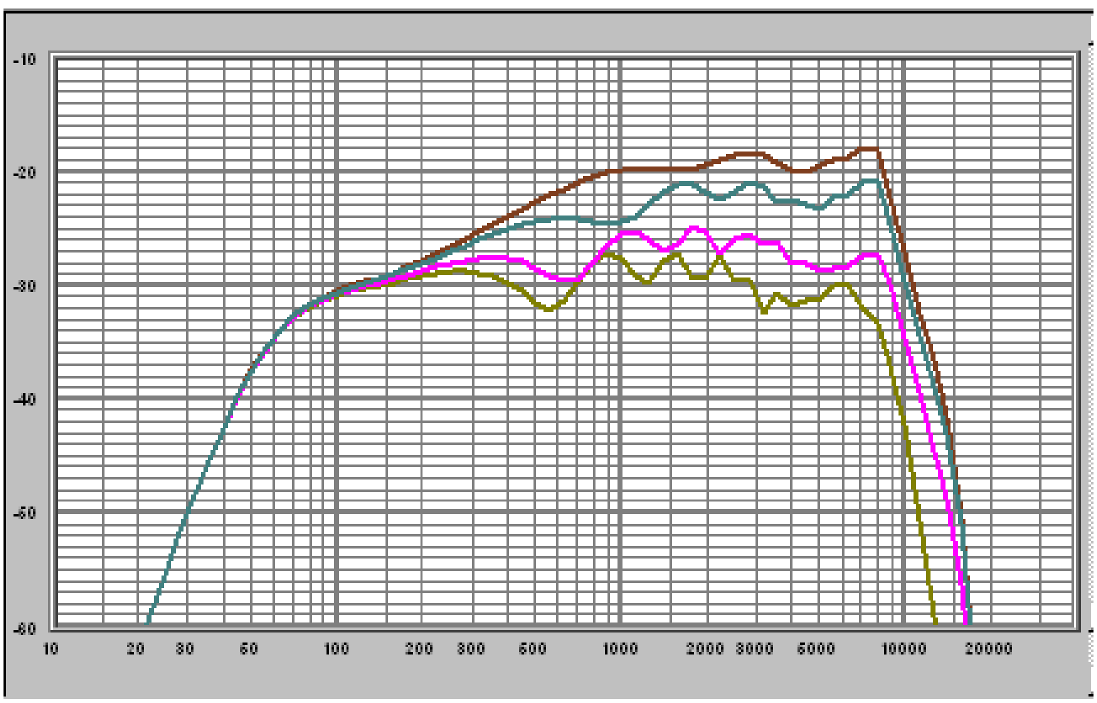


Figure 2: Variation in length of flat section

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 it, 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 where 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 12 ft line source. At 50 to 100 Hz, the wavefront may act cylindrical" from 1 m to 2 m, but it is essentially spherical beyond 2 m. 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.

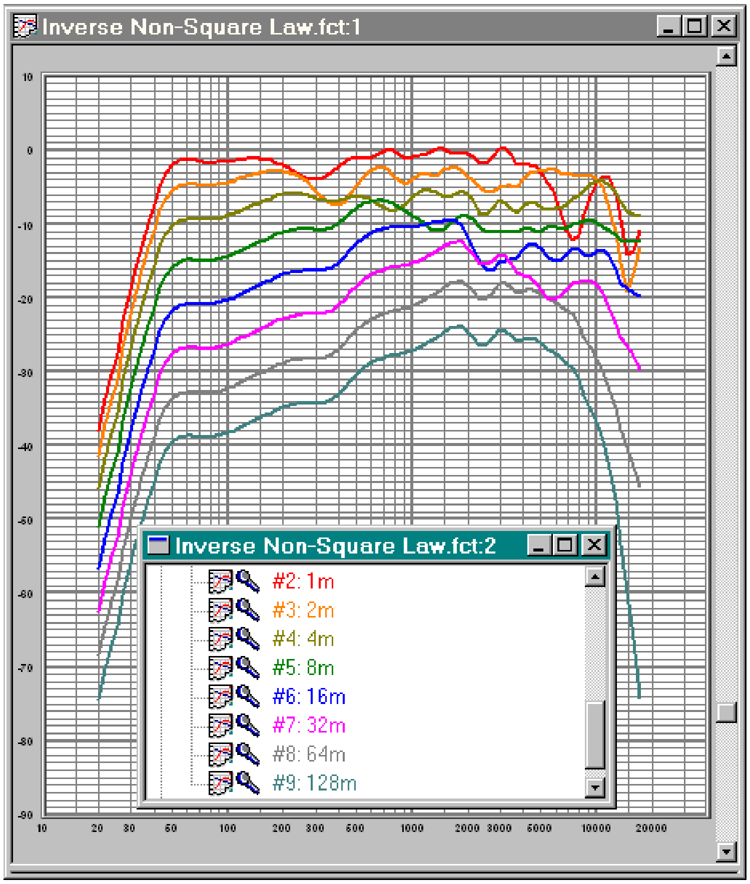


Figure 3: Response vs. Distance On-Axis, 12 ft Line Source

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 located. **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 1m 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 very high.

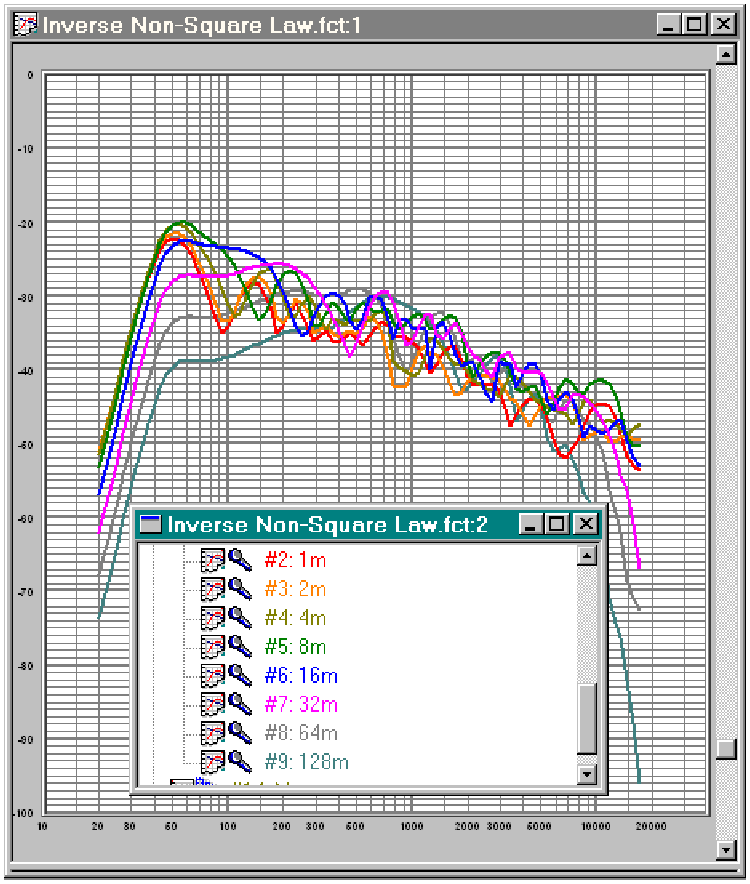


Figure 4: 12 ft Line Source, 15 ft below Bottom of Source

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. Systems designed this way perform very poorly in the front rows. Mechanically, they cannot be splayed very much. Acoustically, they would produce very patchy response if they were splayed sufficiently to cover the expensive seats.

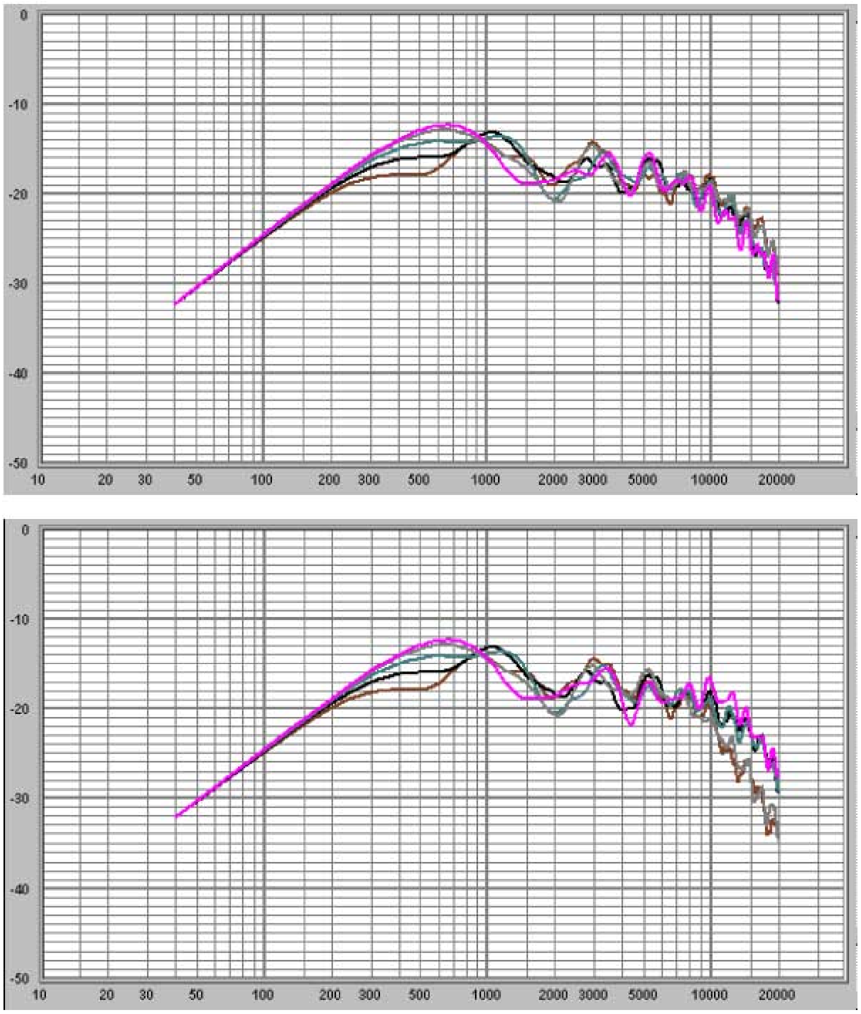


Figure 5: Mismatched Arc Segments

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.

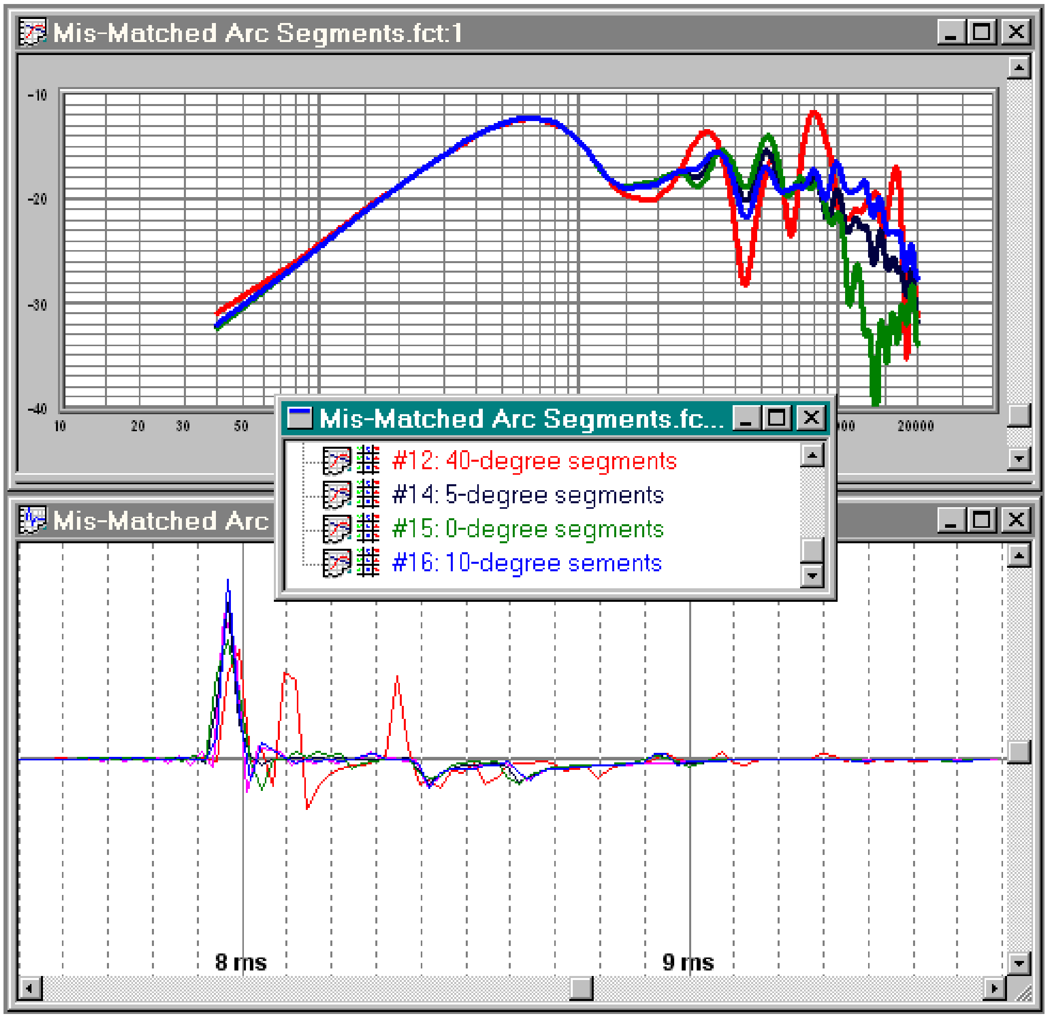


Figure 6: Comparison of Source Arcs

In short, the cost of massive overlap is a loss of coherency - not a loss of efficiency. A conservation of energy argument predicts this because the total power radiated is the same in both cases, while 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 since there are many arrivals showing up at more-or-less random intervals, therefore the response lacks any deep & wide holes. Audibly, the effect is pleasant and spacious, but cannot be described as "high resolution". Conversely, a horn producing 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 a thickness of at least two cabinet walls plus grille rails.

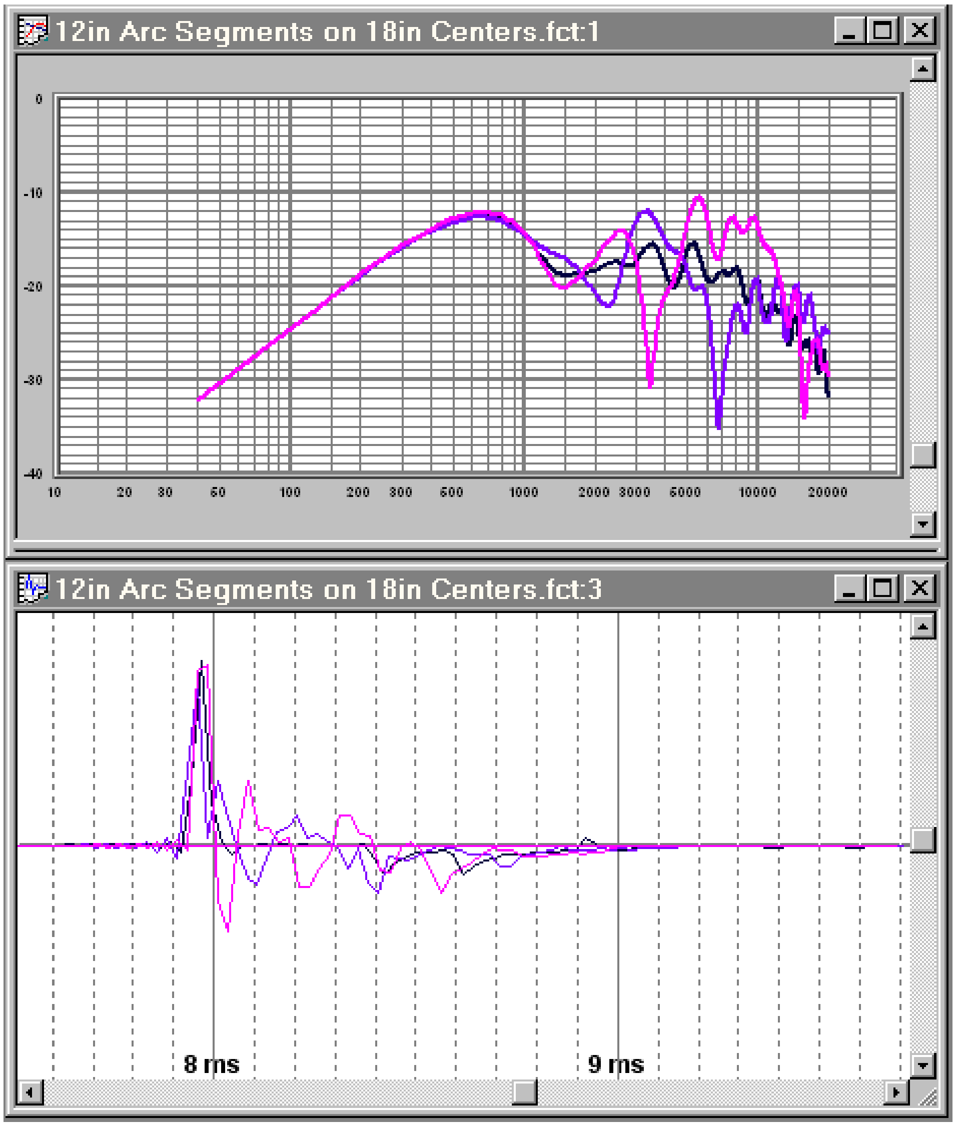
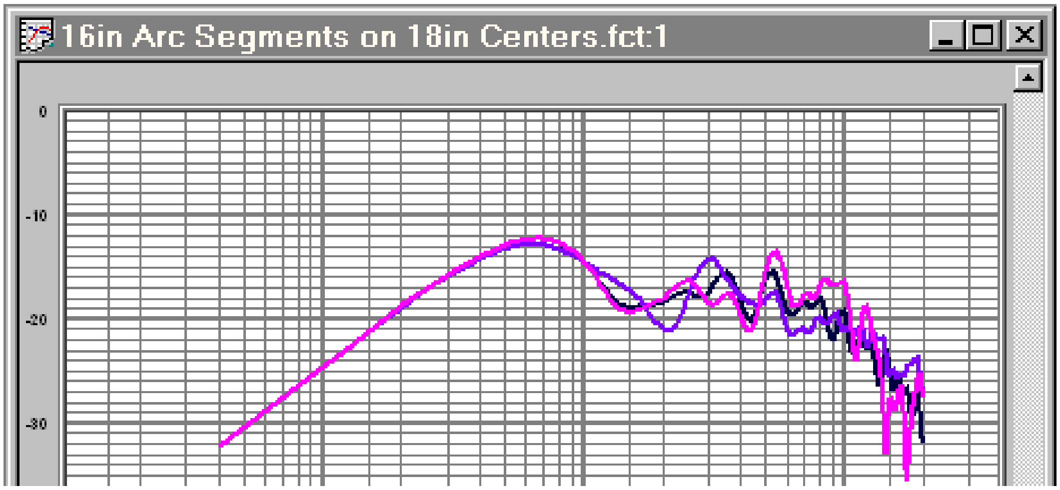


Figure 7: Non-Contiguous Arc Segments, 12"/18"

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.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