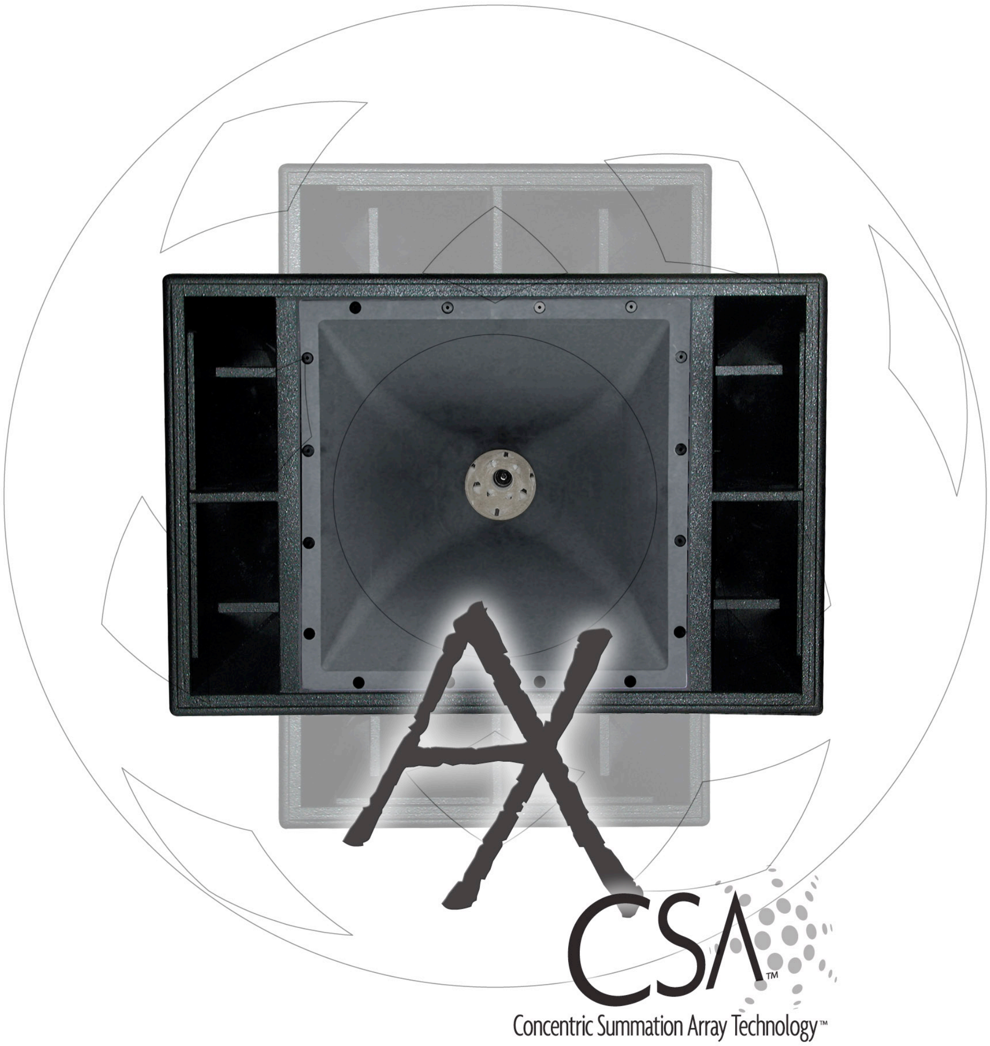


The **AX Series** and the Introduction of **CSA Technology**

A whitepaper by

EAW

Professional loudspeaker design attempts to optimize three parameters: size, weight and performance. Size and weight are often defined by the range of target applications: performance is optimized within these constraints. For instance, higher-output transducers with neodymium magnets enable the designer to provide higher SPL from a system of a given weight.

New horn designs and better transducer layout, both results of advanced modeling software, have produced single loudspeaker systems and array modules with better pattern control. However, the consistency and symmetry of off-axis response has changed little over the last decade or so. Most sound system designs attempt to cover the greatest number of listeners with the fewest number of loudspeaker systems: most of the listeners in these applications are off-axis. This paper will discuss the limitations of common loudspeaker designs and the problems they exhibit regarding off-axis response. Some existing solutions to these problems will also be presented, as well as a new approach.

Multi-way Loudspeaker Design Challenges

The physical design of full range, multi-way systems has changed little over the past three or four decades. Most designs, regardless of manufacturer, divide the audible spectrum into separate passbands, each of which has its own transducer. A common configuration is three passbands, reproduced by a combination of horn-loaded and direct radiating transducers. This driver complement, combined with active and/or passive electronic filtering, can provide almost three decades of bandwidth. Pattern control is optimized by the use of horns and/or by spacing between multiple transducers operating in the same passband. Ideally the loudspeaker system would exhibit the same pattern or beamwidth over the entire operating range. The large wavelengths of the lowest frequencies present a challenge, however, since they require horns, drivers and/or spacing of comparable dimensions in order to produce polars that are narrower than spherical. The designer is forced into a tradeoff between maximum horn size or transducer spacing, and minimum enclosure size and weight. Components must be positioned critically to utilize as much of the front surface of the loudspeaker as possible for the horns.

Geometry works against the designer. Low frequency transducers are, of necessity, large and, more importantly, round. These devices are usually mounted directly to the enclosure’s front baffle, which is generally smaller than a low frequency horn would be. Cutting a round hole in a rectangular baffle wastes frontal area that could otherwise be occupied by the rectangular horns needed for the upper frequencies. The image below shows how and where a standard loudspeaker front baffle layout wastes valuable space.

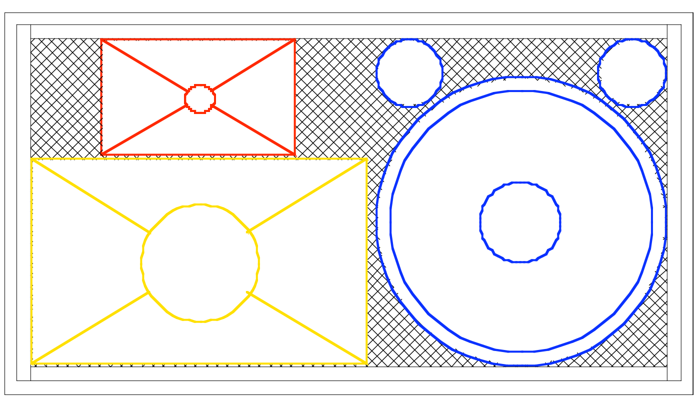


Figure 1 Schematic view of a common loudspeaker design's wasted baffle area and small horns.

In systems with separate mid frequency and high frequency devices, each requires its own horn. The designer is then forced into another tradeoff, this time between minimum enclosure size and effective pattern control at the lower crossover points of the horns. At least one dimension (height or width) of each horn for the mid and high frequencies often ends up smaller than ideal, sacrificing pattern control at the low end of its operating band in order to fit with the constraints of enclosure size. The lower limit of each horn's operating band is

$f_{min} = S \div (D \div 4)$

where

f_{min} is the lowest frequency at which the horn's polar pattern is narrower than a sphere,
S is 1129 feet/sec (nominal speed of sound) and D is the relevant dimension of the horn mouth (height for the vertical pattern, width for horizontal). The factor 4 expresses the fact that the horn will exhibit some degree of control over frequencies whose wavelengths are no longer than 4x the relevant dimension.

The front baffle layout shown above creates significant off-axis asymmetries. These asymmetries generally exist around two acoustic crossover frequencies: one between the low frequency device and the horizontally adjacent midrange device and the other between the vertically adjacent midrange and high frequency devices. Polar plots of the system illustrated above will not be symmetrical – the response at –x degrees horizontally will not be the same as the response at +x degrees horizontally. This is the result of the physical spacing between these devices and the resultant difference in arrival times at the measurement point.

In addition to the asymmetries, off-axis response can never be ideal due to the physical spacing of the devices within the front of the loudspeaker, and their spatial offset from one another along the depth of the loudspeaker. Figure 2 below shows a top down view of the above system with circles representing the acoustic centers of the three devices. Additionally, a microphone is shown at an observation point in front of the loudspeaker. Although the illustration suggests an observation point immediately in front of the loudspeaker, the presented data is based on far-field distance. To better illustrate the effects, the data presented is of three point sources with the same orientation as the real sources.

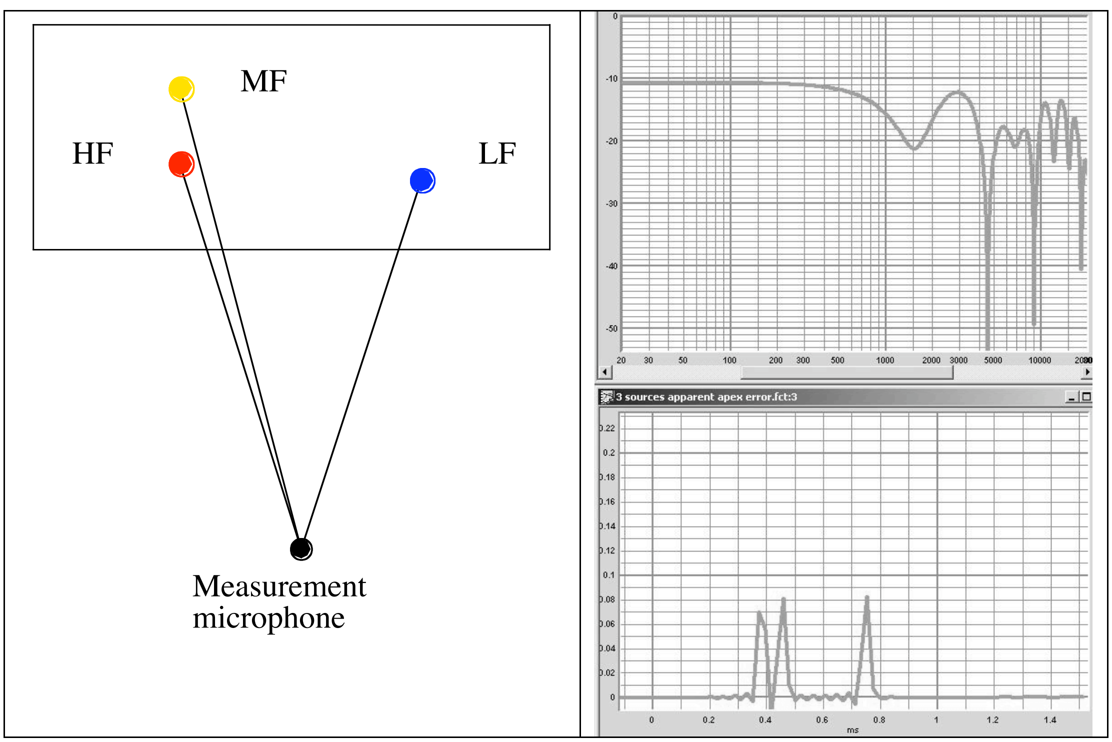


Figure 2 Magnitude response and impulse response of three point sources from farfield on axis, positioned as shown.

Here, on axis, each of the three sources contributes to the overall system response. However, since they are not temporally aligned, as shown from the three discrete arrivals in the impulse response, the magnitude response suffers from significant and numerous nulls.

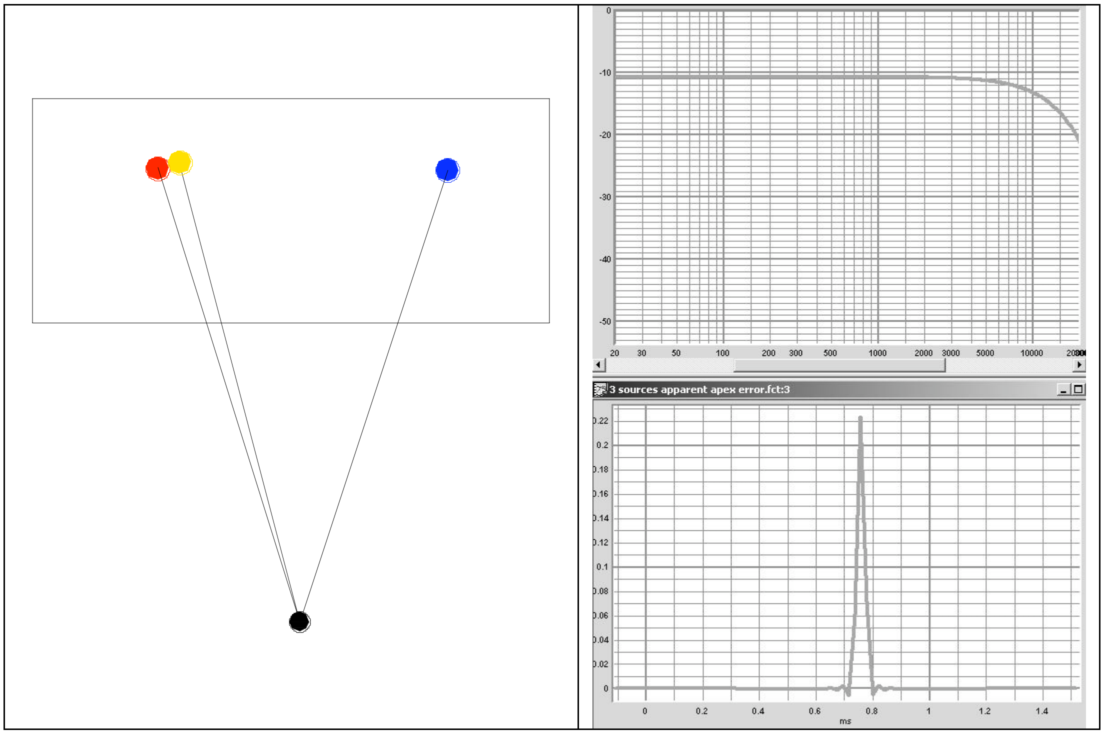


Figure 3 Magnitude response and impulse response of three point sources from farfield, on axis, delayed to apparent positions shown.

Using external electronic delay, the two devices with the earliest arrivals have been delayed to correspond with the arrival of the most distant source. The result is a single arrival as shown in the impulse response, and a smooth magnitude response. This is the result of each path length from the (apparent) source to the observation point being the same.

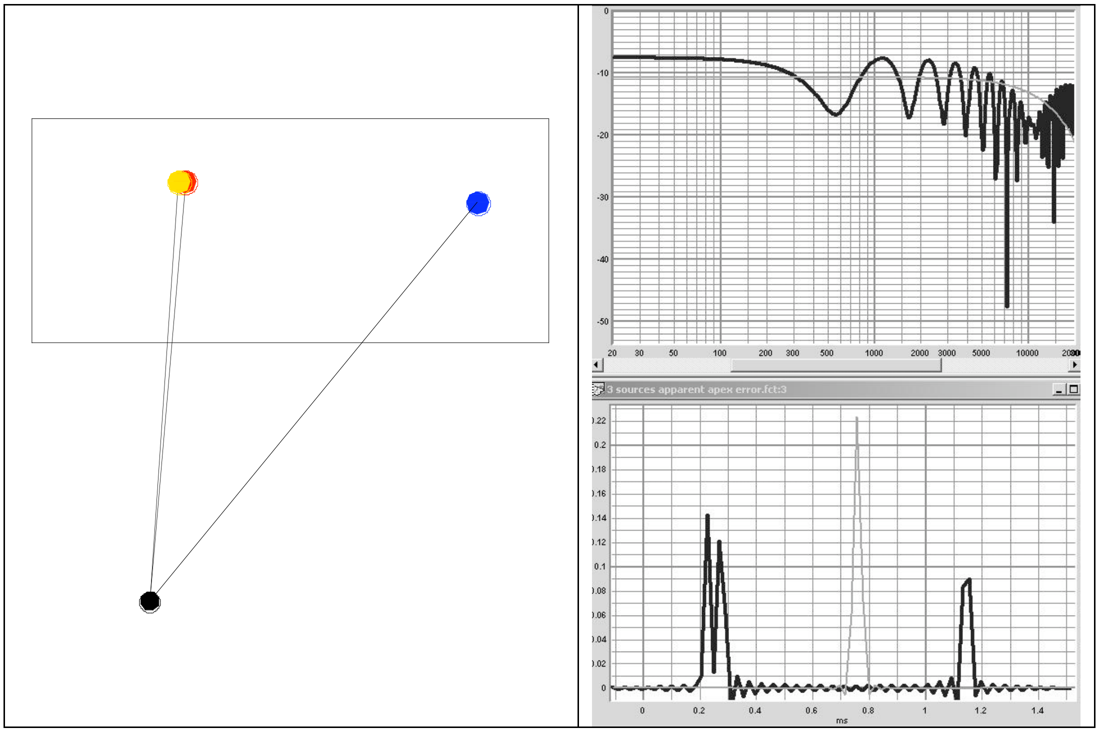


Figure 4 Magnitude response and impulse response of three point sources from farfield, 30 degrees off axis, delayed to apparent positions shown.

Off axis, the results are again problematic. The amount of delay required to achieve acceptable response must always determined along the path of observation. Therefore, the amount of delay required to temporally align three physically offset sources will change as the observation point changes. As shown in Figure 4, moving off axis has lengthened the path to the rightmost source, while shortening the paths to the two sources on the left. Using the same delays used in the on-axis measurement from Figure 3, the result is two early arrivals and one significantly delayed arrival. The delay values would need to change in order to align these sources at this observation point. This effect is known as apparent apex error. It should be noted that although frequency filtering of the three sources in the above examples would improve the overall magnitude response, the impulse responses would have the same characteristics. The late and early arrivals would still exist, reducing the system's apparent impact.

In order to improve the smoothness and symmetry of off-axis response, the devices must be positioned symmetrically, and with as little physical offset (in all three dimensions) as possible. Additionally, the horns should be as large as possible to achieve the desired pattern control at the lowest frequencies. The result is a system with better overall performance and better arraying characteristics.

Designs Using Conventional Transducers

Coaxial horns

Existing designs have had some success at meeting these criteria. EAW's KF750 arranges the three sources in a line. This locates all three acoustic centers along the axis that is normal to the front of the loudspeaker enclosure. The off axis response is symmetric in both the vertical and horizontal planes. As shown in Figure 5, this was accomplished by enlarging the mid frequency (MF) horn to occupy the entire front surface of the loudspeaker. Then, the high frequency (HF) horn was placed within it and the low frequency (LF) devices were mounted within the MF horn wall. The result is a compact system with improved off axis response and temporal coherency.

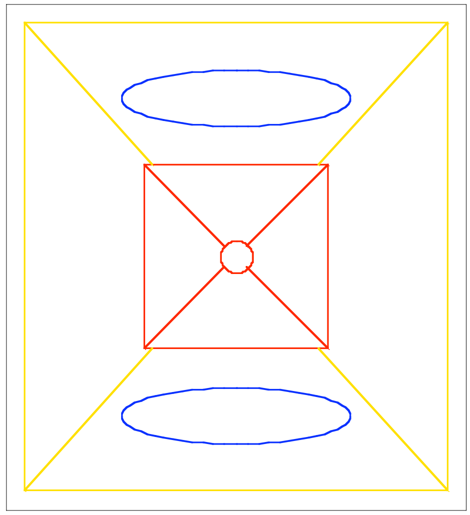


Figure 5 Schematic view of KF750 loudspeaker.

There are some problems and challenges with this implementation however. The HF horn mouth must remain small: neither width nor height can exceed the smallest wavelength produced by the MF device. Otherwise, the HF horn becomes a barrier to the MF source. Even if this criterion is met, this arrangement still creates some limitations. First, the MF horn mouth behaves as a ring radiator rather than a planar source. Polars collapse more rapidly at higher frequencies as shown in Figure 6.

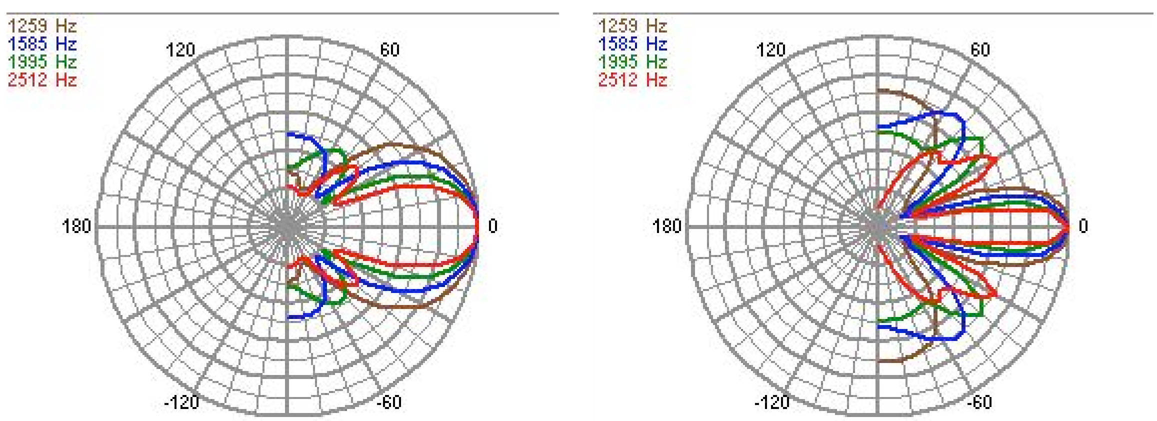


Figure 6 Left, polar response of a planar source. Right, polar response of a ring radiator of the same dimensions.

The result is a design that works quite well for a high Q system, but cannot be implemented for lower Q systems since the MF collapses too rapidly off axis.

Side note – The KF850 and KF850z maximize the dimensions of the MF horn by placing the HF horn in front of the LF device. Because the LF wavelengths are so large, the HF horn does not present an obstacle. Although the MF horn's mouth size is increased by this design, the spatial separation between the HF and MF is not addressed.

Second, although the sources are arranged along the same axis, delay is still required to temporally align the sources along that axis as shown in Figure 7. Although not as severe, this source arrangement still suffers from apparent apex error at off-axis locations, as discussed above. When this configuration is used in high Q designs such as the KF750, the effect is generally not substantial until the observation point is outside the system's nominal coverage.

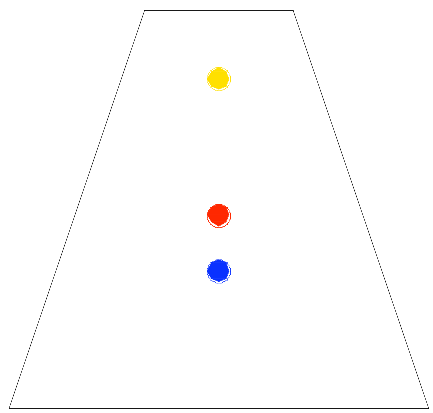


Figure 7 Temporal offset along axis still requires delay to align the sources in a KF750.

Midrange in the HF Horn Bell

The maximum horn mouth dimensions will be realized when a single horn occupies all or most of the enclosure's frontal area. One way to accomplish this is to mount two or four MF sources in the bell of a single horn which loads one or more HF compression drivers. The LF sources are mounted outside the horn. If the spacing of both the LF and MF devices is symmetrical on the horizontal plane, they will create acoustic origins that are aligned with the HF along the axis normal to the enclosure's front baffle. The vertical symmetry required for seamless integration in a line array is realized with this configuration. Horizontal symmetry is also preferred for even venue coverage, and is also realized in this configuration.

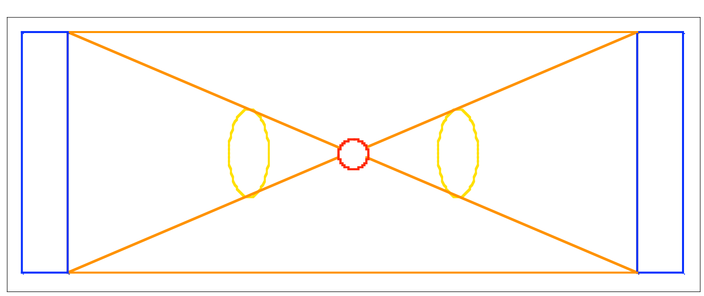


Figure 8 Schematic view of KF730/KF761 loudspeaker.

This design has its own set of limitations. The horizontal spacing between the MF devices, as well the delay required to align them to the HF device(s), again produces apparent apex error. In this particular case, the position and size of the MF devices were carefully chosen, and they are fired through an aperture designed specifically for this loudspeaker system. These design decisions eliminate anomalies within the loudspeaker's beamwidth. As in the KF750, the horizontal spacing of both the LF and MF devices improves rejection outside the system's nominal coverage angle. However, since the distance between these devices very nearly defines the system's beamwidth, the design is not adaptable to other horizontal coverage angles.

True Coaxial Design: A New Approach

If both MF and HF are radiated in common by a coaxial transducer, they can be loaded on a single horn. The size of the horn can be maximized and the polar pattern can be symmetrical both horizontally and vertically over a wide operating band.

However, this solution poses many engineering challenges. Coaxial transducers have generally been designed for use in two-way, full-range, low Q systems. They typically include a standard cone transducer (8", 10", 12" or 15"), with some modifications to allow a standard compression driver to be mounted on the back of the cone's motor structure and fire through its center. The usual modifications include hollowing out the cone's pole piece and shaping it to provide an initial horn bell for the compression driver. This waveguide section terminates at the end of the cone's former, where the cone itself becomes a continuation of the HF horn. In essence, the MF cone acts as a low Q conical waveguide for the HF. A second modification is the replacement of the solid dust cap typically found on cone transducers with a mesh dust cap. The mesh prevents airborne particles from entering the gaps in between the two voice coils and magnets, yet is acoustically transparent in the high frequency energy.

Limitations of the conventional coaxial transducer include:
Modulation of the HF when the device is used fullrange. Low frequency signals drive the cone to high excursions: since this cone is also acting as the main section of the HF waveguide, the high frequencies are modulated. A possible solution is to use the device as a part of a three-way system with a separate LF section.

Inherently low Q since the coaxial transducer cannot be loaded by a horn. There are two reasons for this, both related to the requirement for temporal coherence. The first is the need for a continually increasing flare rate. Classic horn design theory[i] states that the bell curvature angle should always increase along the path of the horn. As the figure below shows, simply loading a coaxial transducer onto a horn would break this rule. Initially the HF horn expands at an increasing rate through the pole piece and along the cone, but then the rate of expansion decreases at the base of the horn. It is intuitively obvious that this design would cause significant reflections off the horn walls, with the resulting multiple arrivals and attendant problems (side lobes and transient smearing).

[1] The theory underlying proper horn design is beyond the scope of this paper. See *Acoustics, Leo L. Beranek; Acoustical Engineering, Harry F, Olson* for an exposition.

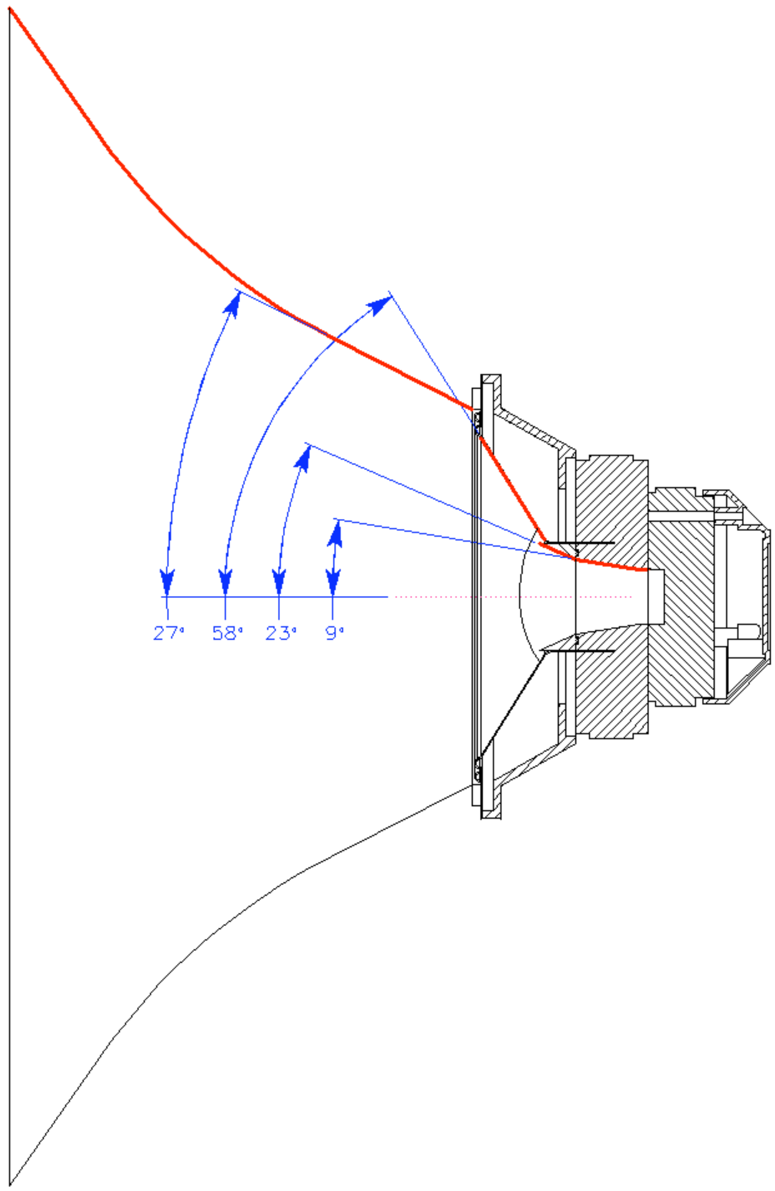


Figure 9 Cross-section view of a standard coaxial transducer mounted to a horn.

The second problem is related to the physical dimensions of the cone relative to the wavelengths of upper midrange frequencies. The cone moves as a piston, but the path length from the inside of the cone to the horn flare is longer than that from the circumference. At frequencies near the upper crossover limit, this difference is an appreciable fraction of a wavelength. Perhaps we should say “audible” rather than “appreciable.” The resulting uneven frequency response and smeared transients are rarely appreciated by the audience.

Horn-loaded coaxial transducer: design challenges

The goal is a common horn for both MF and HF, without multiple arrivals and interference issues. To eliminate these we must provide both constant expansion for the HF device, and a phase plug to load the MF device.

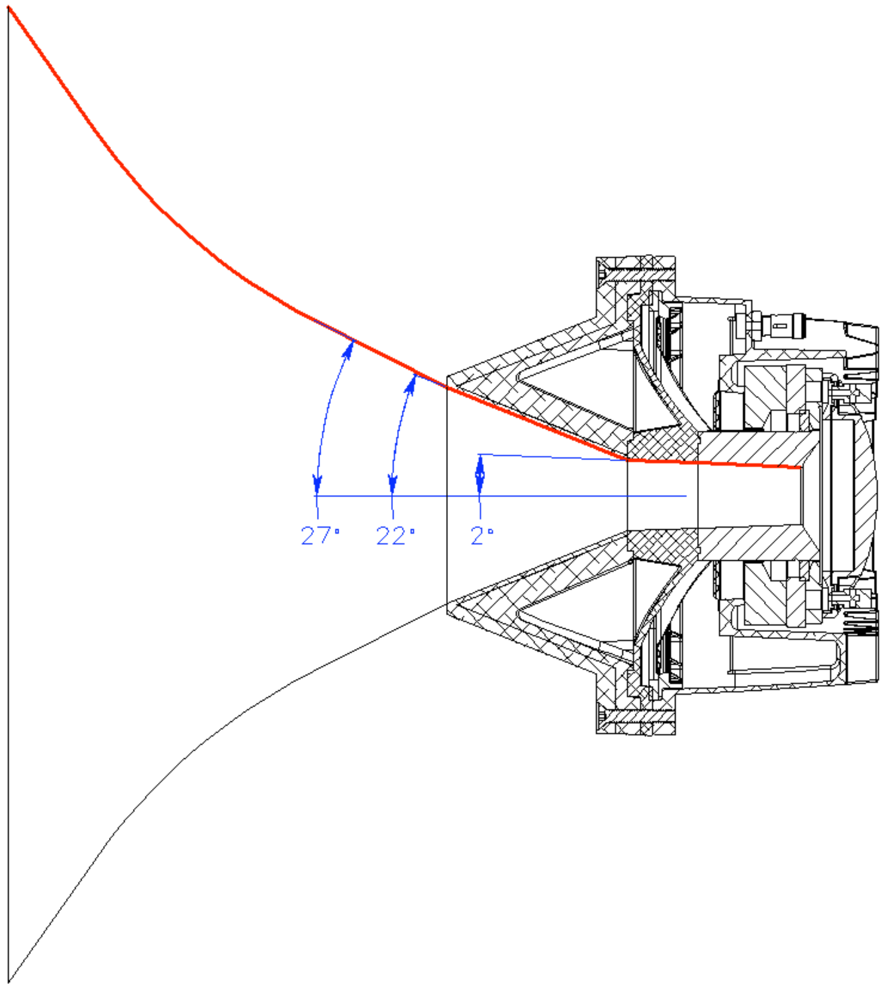


Figure 10 Cross section view of new coaxial transducer, phase plug, and horn bell loaded to a horn.

The chosen design integrates an acoustically "translucent" high frequency horn bell into the radial phase plug for the mid frequency device. This horn bell allows mid frequency energy to pass through unobstructed, while acting as a semi-permeable barrier for the high frequency energy.

The radial phase plug is a slight modification of the patented KF750 Radial Phase Plug™. It utilizes 10 slots instead of 6, but maintains asymmetry between the plan view and section view. A standard phase plug solves the temporal problems discussed earlier by creating a longer path length for energy from the central part of the cone in order to synchronize its arrival with the energy from the cone's circumference. The pistonic cone is thereby effectively changed into a ring radiator, causing the beamwidth to narrow at lower frequencies than it would without the phase plug. The Radial Phase Plug design properly corrects the temporal inconsistencies while maintaining the directional characteristics of a piston, allowing it to be used in lower Q systems.

As part of a coaxial transducer, the midrange cone lacks a dust cap and has a smaller diameter than that used in the KF750. Therefore less correction is required in order to provide coherent energy through the midrange. Additional information can be found in the whitepaper, "Acoustic Singularity."

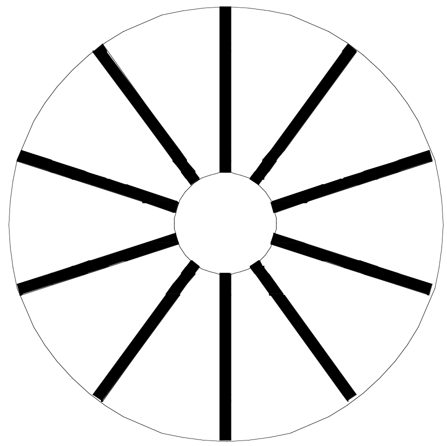


Figure 11 Schematic view of the implemented Radial Phase Plug slots.

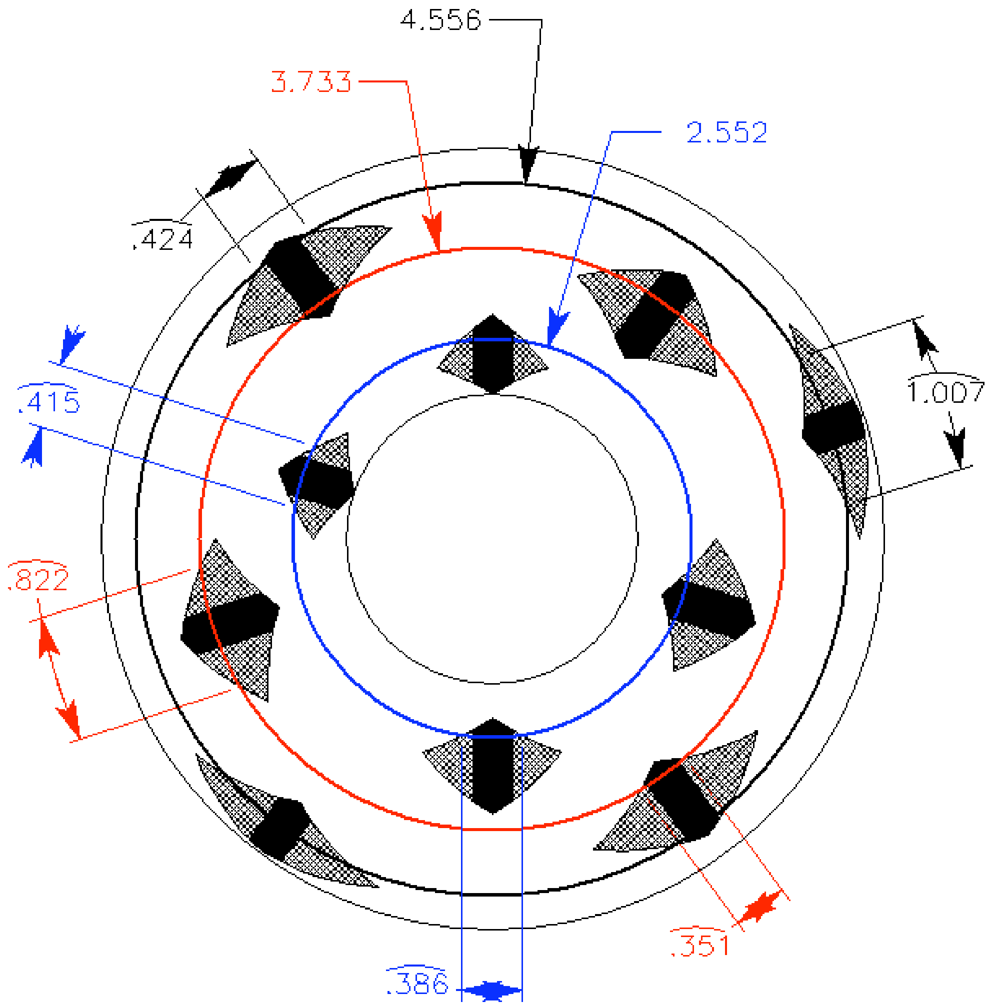
CSA™

Concentric Summation Array Technology

Because we have a phase plug in place of the traditional coaxial transducer's dust cap, we can use it for the initial section of the HF horn bell. The forward-facing section of the phase plug then requires a compromise between the configurations that would be ideal for the cone and the compression driver separately. For the mid range cone, the ideal configuration is a radial phase plug that is then loaded onto the horn without any barrier. For the compression driver, the ideal configuration is that it be loaded directly onto a solid horn bell. These two configurations are not perfectly compatible: the Radial Phase Plug design requires slots in the horn bell through which midrange frequencies can pass, but slots in the horn wall will "interrupt" the high frequency wavefront, acting as a mechanical high pass filter. A solid horn bell would obstruct the midrange frequencies and act as a mechanical low pass filter. Therefore, an optimum compromise design should minimize open area for the high frequencies while maximizing open area for the mid frequencies. This semi-permeable horn bell acts as a low pass filter to the mid frequency device and a high pass filter to the high frequency device. Therefore, the open area must be chosen appropriately in order to achieve raw responses from each device that can then be effectively electronically filtered for a smooth overall system response.

Furthermore, attention needs to be paid to the location of the open area in the horn. For the mid frequency, it needs to be evenly dispersed in order to achieve symmetric off-axis response. For the high frequency, the open area must be randomized, to avoid any large nulls at any particular frequency/wavelength (corresponding to specific locations along the path of the horn).

The chosen implementation (shown below) maintains an 80% solid horn wall for the high frequency, while providing randomized openings (one per phase plug slot) for the mid frequency. As the illustration shows, at any path length along the horn wall, the open area is 20%.



1st circle: D=2.552, C=8.017, Open=(0.386*2)+(0.415*2)=1.602, % Open=20
2nd circle: D=3.733, C=11.728, Open=(0.351*2)+(0.822*2)=2.346, % Open=20
3rd circle: D=4.556, C=14.313, Open=(0.424*2)+(1.007*2)=2.862, % Open=20

Figure 12 Schematic view of implemented horn bell and open area percentage calculations.

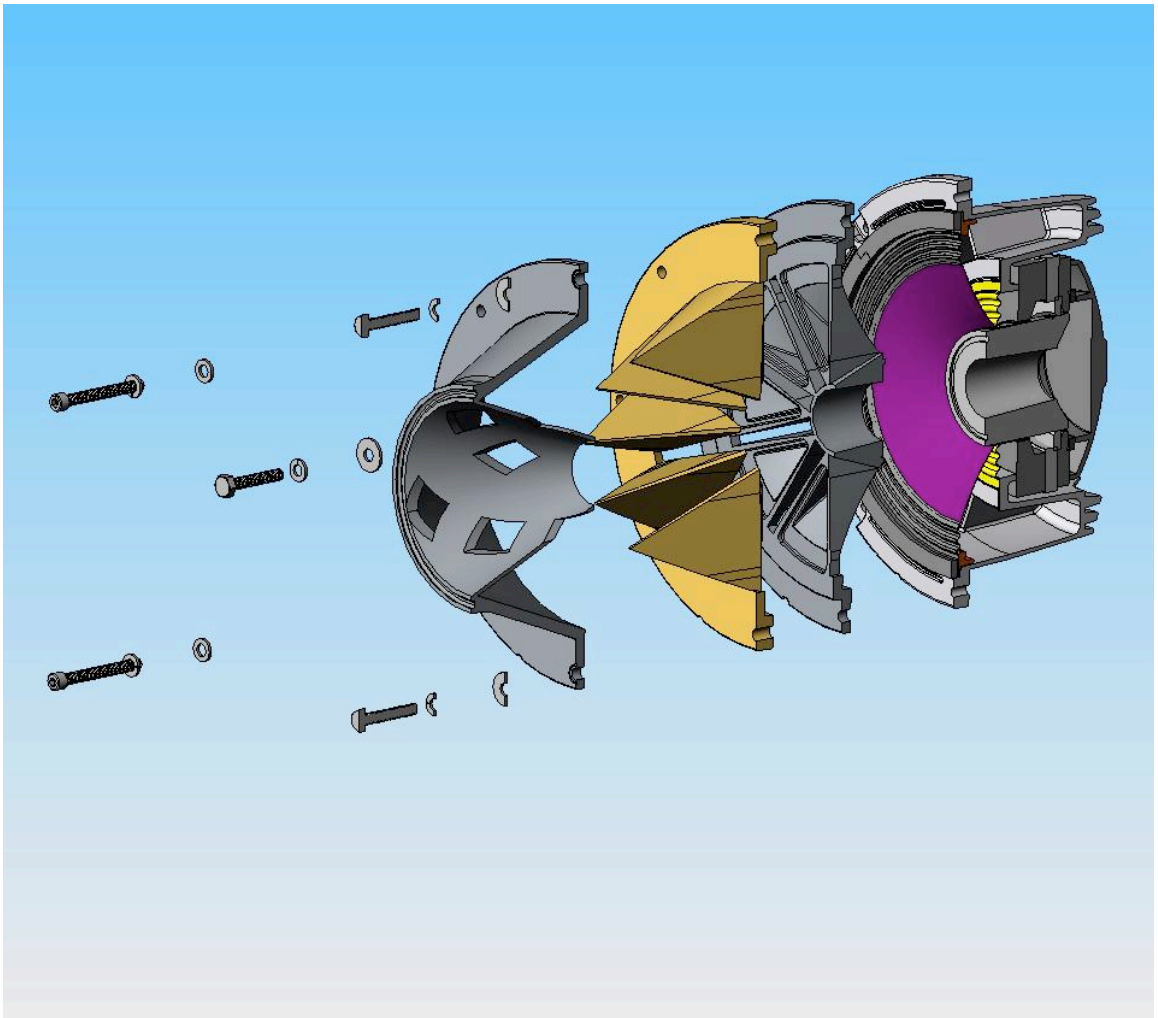
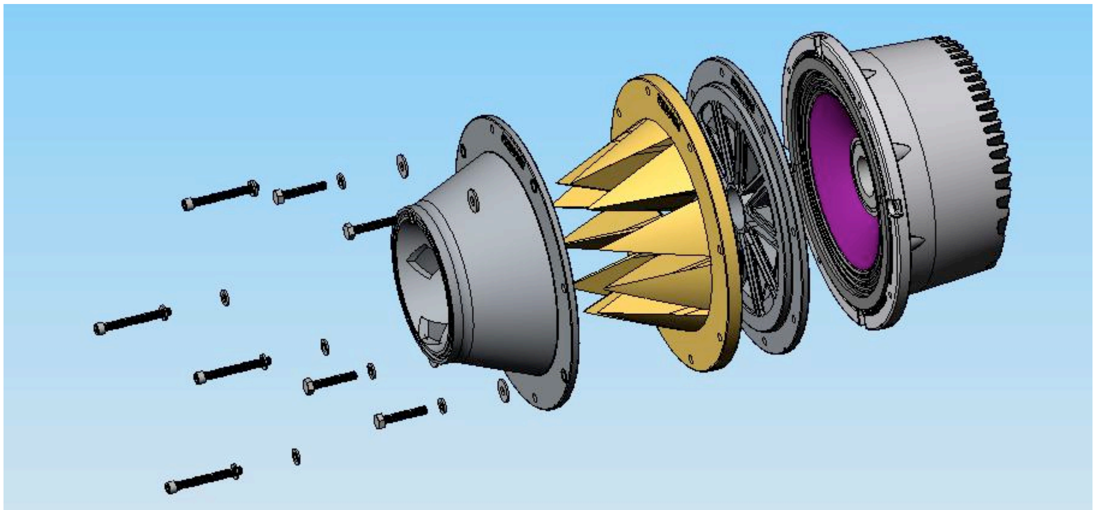


Figure 13 Exploded 3-D cross section of coaxial assembly.

The AX Series

The new AX series uses a newly-designed MF/HF coaxial transducer, loaded onto a common horn via the phase plug described above. The coaxial transducer is composed of a high efficiency 2.5-inch voice coil, 8-inch cone midrange in a sealed chassis and a 2.5-inch voice coil, 1.4-inch exit compression driver. The midrange and compression driver share a common neodymium magnet, significantly reducing weight. This common magnet also allows us to minimize the distance between the voice coils of the MF and HF devices, and by extension their acoustic origins. The sealed midrange chassis is made of aluminum and acts as a heat sink for the entire assembly. The exit of the mid frequency phase plug is just over 4 inches in diameter, allowing wider coverage angles at the upper range of the mid frequencies.



Another exploded view of the coaxial MF/HF device

To reproduce low frequencies, a pair of spaced 12-inch low frequency transducers is used. This combination of drivers and their orientation within the enclosure creates a loudspeaker that has a symmetric pattern horizontally and vertically. The system is a true triaxial design, since the pair of spaced 12-inch low frequency transducers creates an acoustic origin along the axis of the mid and high frequency components. The spaced 12-inch woofers provide better pattern control than systems of similar size that utilize single direct radiating transducers. The large mid/high horn provides pattern control throughout the entire bandwidth of the mid/high device.

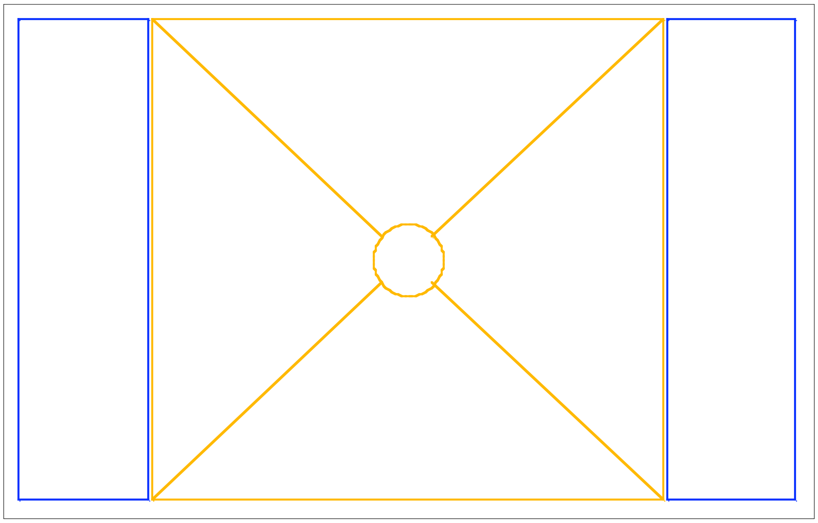
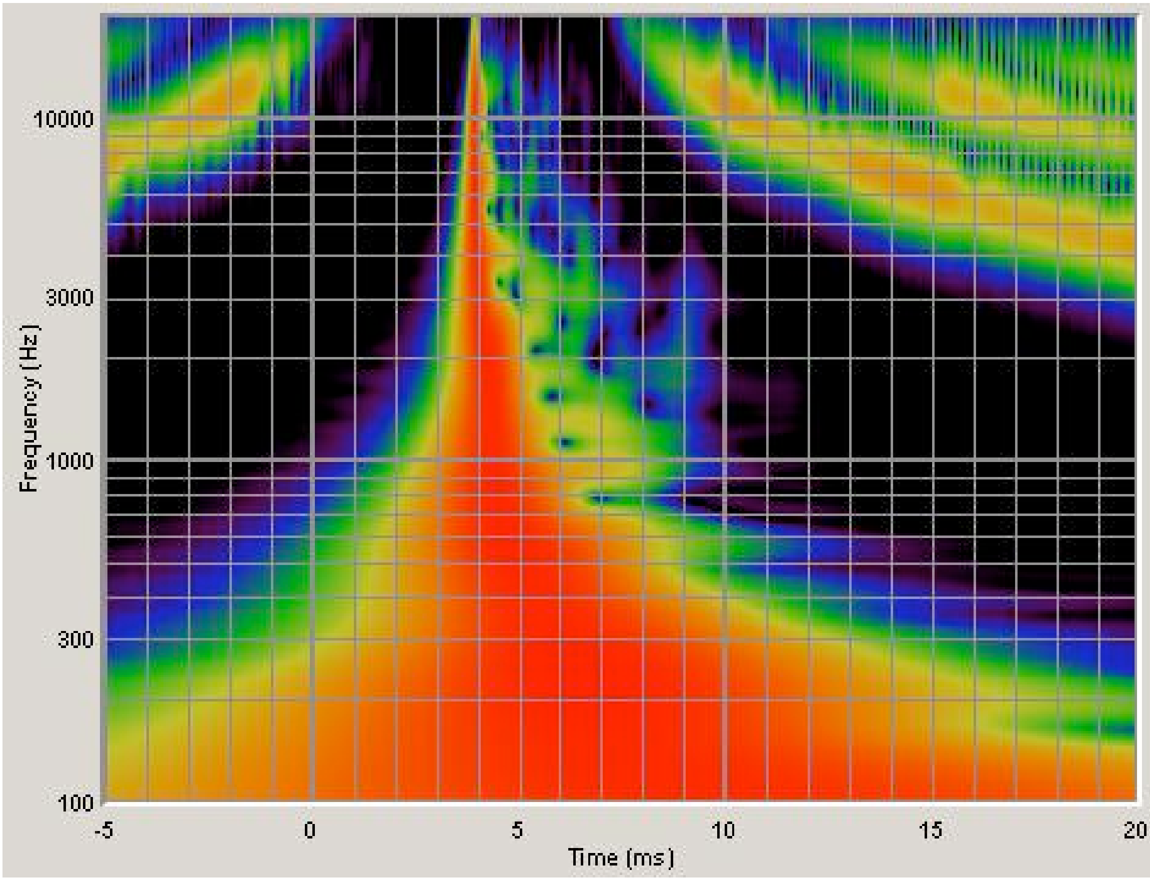


Figure 14 Schematic view of AX3 series loudspeaker.

The enclosure is a dual trapezoidal design, allowing arrays to be easily constructed in either the horizontal or vertical orientation. Behavior is optimized in either orientation because of the symmetrical arrangement of the drivers.



The spectrograph above shows amplitude (color) vs. frequency and time for the AX Series.

The spectrograph above shows the on-axis impulse response for an AX Series loudspeaker. The operation of Concentric Summation Array Technology is clearly visible in the single wideband impulse. This is apparent to the listener as greater transient impact.

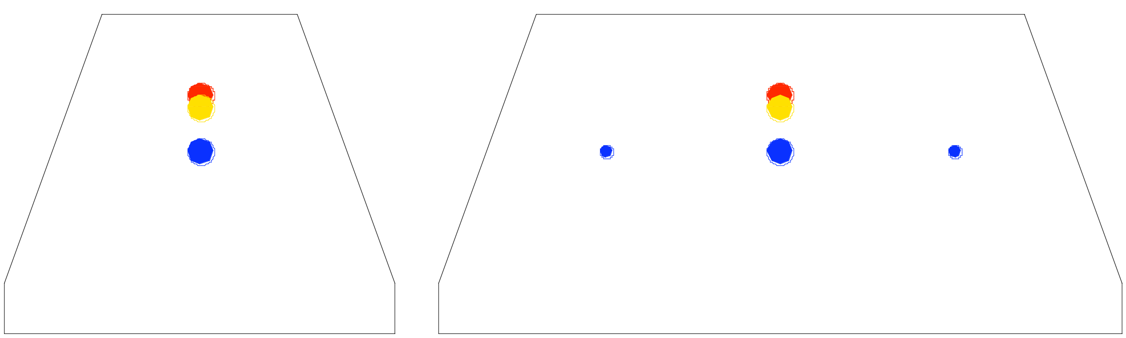
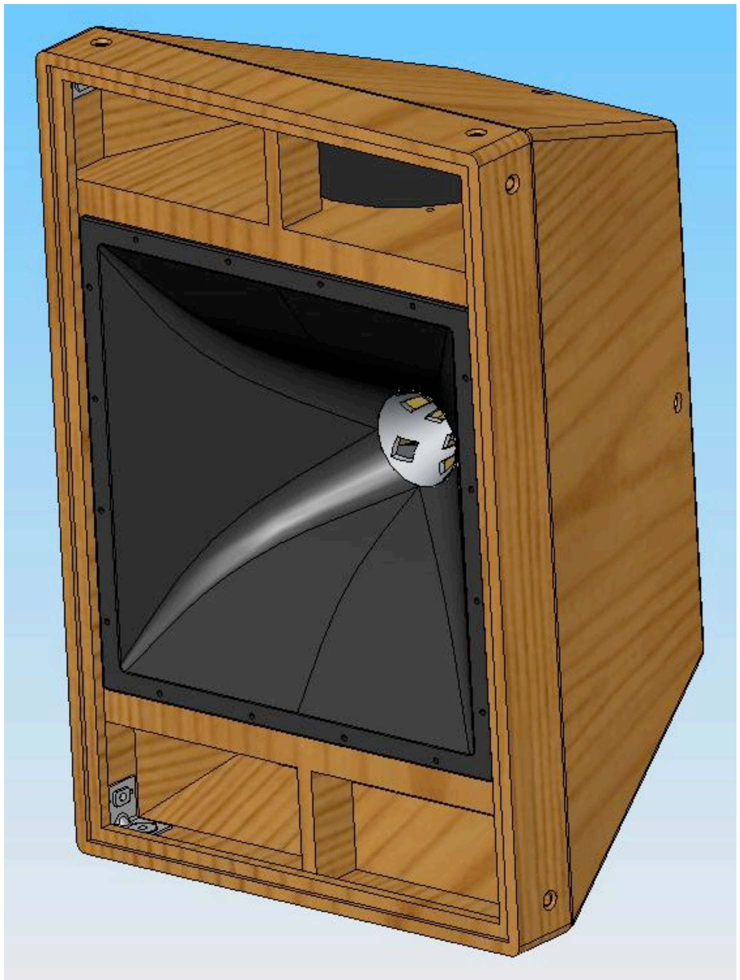


Figure 15 Small distance between the MF and HF, as well as the close proximity of the LF transducers, requires little or no delay for temporal alignment. Top and side views.

Since all three sources are closely aligned, the apparent apex error is minimized. Amplitude response of this system will be symmetrical vertically and horizontally. Measurements off axis should be as flat as those taken on axis.



Applications & Benefits

AX Series loudspeaker systems include horn patterns from 45° x 45° to 90° x 60°. To maintain coverage symmetry and consistency over the widest possible operating band, the entire enclosure can be arrayed either horizontally or vertically: this maintains the proper relationship between the polar patterns of the various frequency bands. The AX Series offers the sound system designer a versatile set of arrayable modules that can provide the required "horsepower" for high-SPL output in larger venues. The triaxial design eliminates many of the problems associated with multi-loudspeaker arrays.

Each side of the enclosure has three 3/8" threaded mounting points for easy suspension. Four 3/8" threaded points are provided on the back surface for pullback. Full-range or bi-amp powering modes allow for a minimal inventory of amplifiers.

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