THETA TECHNOLOGY by EAW COMMERCIAL

CONTROLLING DIRECTIVITY

SMS Series Loudspeakers

INTRODUCTION

Theta Technology™ is the application of highly sophisticated, electro-acoustic technologies developed by the EAW Engineering Department to small format loudspeakers for commercial public address (PA) and distributed audio system applications. The results are significant improvements in directionality, output levels, and sound quality over products of comparable size and price. Commercial audio applications include paging and background music systems for transportation stations, retail stores, offices, convention centers, sports venues, warehouses, and restaurants, as well as lower budget PA projects, including small auditoriums, theatres, and houses of worship. There are several challenges that need to be overcome when designing successful, commercial audio systems.

These typically include:
1. Projecting sound over large areas
2. Overcoming difficult acoustics
3. Providing high quality sound
4. Meeting tight budgets

This led to several design requirements focused on overcoming the above challenges:
1. Good directionality
2. Sonically superior, low cost drivers
3. Design configurations to produce coherent wavefronts
4. Small physical size
5. Low production costs
6. Fast, easy, foolproof installation methods

These requirements involved a high degree of interdependency whose sum led to an overall design methodology: Theta Technology.

DESIGN CHALLENGE DETAILS

The most important design criterion for Theta Technology centered on providing a solution to mitigate typical acoustic problems. Sound reflections off room surfaces can cause high levels of reverberation, delayed reflections, and echoes. All of these can impair intelligibility and degrade sound quality. The basic principle in reducing the effects of these acoustical problems is to direct loudspeaker sound only at the listeners and away from reflective room surfaces. Narrow projection patterns over a wide bandwidth are the usual solution. Until now, this kind of performance has been unavailable in small format, full-range, commercial loudspeakers. Even commercial paging horns, although specified as having narrow patterns, at best achieve them over very limited frequency ranges with low sound quality.

Typical designs for cost effective products for commercial applications consist of 1-way (single driver) or 2-way loudspeakers (low frequency and high frequency drivers). To achieve efficiency, horn loading is typically employed in both types of designs. Common 1-way loudspeakers are paging horns that, while efficient, have low sound quality. In addition, the directivity of their exponential horn flares varies considerably with frequency. Typical 2-way loudspeakers employ an HF (high frequency) horn that can provide good directivity. However, driver limitations typically limit the crossover point to a high frequency. This limits the frequency range where the loudspeaker has effective directivity.

Normally, a single, direct radiating LF (low frequency) device is used in 2-way designs having little directivity over most of its range. This means pattern control is limited by driver size, with larger drivers providing lower LF response but less directivity in the frequencies below the typical 2000 Hz to 3000 Hz crossover point.

In addition, efficiency drops off compared to the HF subsystem. In short, existing, commercial loudspeakers do not have the wider range directivity needed to effectively deal with adverse acoustical conditions.

In larger spaces, projection distances can be relatively long requiring loudspeakers be capable of high output. Coupled with the overriding low cost requirement this translated to high efficiency to keep amplifier power needs low. For example, even a 3 dB gain in sensitivity over other products could halve amplifier power requirements: a significant cost reduction.

Driver costs are a significant portion of product cost. To meet commercial budgets, drivers must be low cost, which has usually resulted in less than ideal sonic quality. Improving this situation required rethinking driver designs, both inherently and in context of the other design requirements. One of the benefits of Theta was the other design requirements ended up facilitating this task because of the way the drivers would be utilized. To overcome these design challenges, Theta technology would provide the directional control, output levels, and performance quality associated only with larger loudspeakers by utilizing similar design solutions normally only applied to larger products. While this concept is certainly straightforward, the only real difficulty that EAW Engineers faced the traditional obstacle that has limited the performance of low cost, small format, commercial loudspeakers.

This obstacle is quite easy to define: normally, directivity is closely related to loudspeaker size; make it bigger and it is easy to achieve better directivity; make it smaller and directivity suffers. Therefore, the key to Theta was to provide the desired wider range and better-controlled directivity while staying within the confines of small physical size and cost requirements for the intended applications.

Lastly, there was one additional but extremely important requirement that had to be satisfied: the high sound quality typical of every EAW Engineering design.

THETA SPECIFICS

The Theta concept would be initially applied to the SMS100, 200, and 400 families planned as 2-way products. There would be HF (high frequency) and LF (low frequency) subsystems for each loudspeaker, the three product families differentiated primarily by the LF compliment and thus LF capabilities. The intended applications lead EAW Engineers to design for three different beamwidths 90° x 90°, 90° x 40°, and 120° x 40°. Obviously, the most difficult challenge was achieving good performance for the radical 40° beamwidths in small format loudspeakers. However, even the 90° x 90° presented challenges in extending the pattern control to lower frequencies as well as providing both symmetrical and good directivity performance in both planes.

SOME HISTORY

Over the years, EAW Engineering has developed a number of evolutionary and revolutionary concepts dealing with loudspeaker directivity, coherency, efficiency, and sound quality to meet almost all imaginable application requirements. In describing these technologies, the focus will be on those elements of significance to Theta, which taken in sum, describe Theta.
While the mathematics and physics behind these technologies is beyond the scope of this article, these details, as related to directional performance, are discussed in the technical papers listed in the bibliography.

EAW'S ARRAY STEERING TECHNOLOGIES

Several of EAW's more advanced technologies have involved engineering arrays of drivers to precisely steer and shape a loudspeaker's or cluster's projection pattern to fit an audience area. These technologies were developed in response to specific application requirements from the smallest to largest venue, covering a range of program from low level speech to high level concerts.

There are many well-known advantages to using driver arrays to control projection patterns. They can be steered using electronic processing, can provide more output, and can be arranged to address both wide and narrow audience angles.

The usual focus when arraying multiple drivers, horns, or loudspeakers is to base the configuration on the shapes of the projection patterns meaning what you see on polar charts. For example, adjacent loudspeakers are often configured so the -6dB points in their polar patterns are just touching. PPST used a very different approach by basing the design on controlling the wavefront shapes within the projection pattern. By controlling the shape of the wavefront being emitted from each element in an array, their outputs can be combined to produce a single, coherent wavefront. This design approach uses a technique called "tessellation" to both model potential designs and to analyze measured results. Tessellation has been critical to achieving multiple-source coherency in the design of many EAW products. This complex technique is described in detail in the bibliographic sources.

Basically, tessellation, more simply called tiling, involves dividing the area of the aperture of a sound source into a grid of squares or tiles. The time, frequency, and intensity characteristics of the acoustical energy are determined for each tile in the grid pattern. By superpositioning the energies of all the grid squares, the shape of the entire wavefront emerges. This information is used to manipulate the energies across the grid plane to shape the wavefront so it combines with adjacent wavefronts in a coherent fashion. This manipulation is done through a combination of the physical design and configuration of the sound sources, whether it be a horn or an array of direct radiating drivers, and electronic manipulation, using either passive or active circuitry, the latter being analog or digital.

EAW's pioneering steering technology, PPST (Phased Point Source Technology) was developed for the KF900 Series, an ultra high output, large-scale array used for large concerts as well as stadium-type installations. Steering involved a combination of the physical design of the array's individual elements, their configuration into an array, and the electronic processing for each element. The KF900's offspring, the DSA Series (Digitally Steered Arrays), are small line array loudspeakers using similar technology, but relying more heavily on electronic steering, the physical design of the array being fixed.

Unlike the electronically steered KF900 and DSA Series, EAW's KF730 and KF760 Series line array systems rely primarily on their physical design to steer and shape their projection patterns. This is done through a combination of the acoustical design of the individual subsystems in each loudspeaker as well as a curvature shape for the entire array. An important aspect of these designs, also being the most difficult design challenge, was to maintain the performance in the horizontal plane. The usual offaxis results for line arrays are that coherency is severely compromised because of the interference patterns from the multiplicity of sources. While the specifics are beyond the scope of this paper, the key concept was to apply multiple design solutions, the particular solution being a function of the sound wavelength. Again, the focus was to design the wavefront shapes from the individual bandpass elements in the array so that they would combine with other elements into a single, coherent wavefront over their operating ranges.

EAW's LS832 line array brought the classic, speech column loudspeaker up to date. The primary design approach was to use sophisticated frequency shading and all-pass filtering in the passive crossover design to integrate the multiple driver outputs. This sophisticated passive filtering, along with the physical configuration, maximized the pattern control benefits of a line array, but over a much wider operating range than possible for a classic, column loudspeaker.

EAW's CP Series was developed to surpass traditional, coaxial, ceiling loudspeaker designs. This was done using a multiple LF driver array to provide a wider range of beamwidth control and higher output. Using smaller multiple LF drivers provided far better reproduction of critical midrange frequencies while improving output capabilities and lowering distortion. The unique driver arrangement, where the HF horn flare incorporates the LF driver array, is designed to control the timing of the wavefronts to provide constructive summation within the nominal beamwidth. It also results in destructive summation outside the beamwidth, providing a significantly higher level of sound attenuation than that of a single LF driver.

Other seemingly more straightforward products, such as the SMS84 stage monitor, also use multiple drivers to control, shape, and extend the frequency range of its projection pattern. A hallmark of the SM84 is providing symmetrical horizontal and vertical projection patterns over a wide frequency range while providing a coherent wavefront throughout the projection pattern. In addition, typical stage monitor LF output requirements usually designs using 12-inch or 15-inch drivers that end up noticeably reducing vocal clarity. This is due to their well-known poor performance at the upper end of their operating ranges. By using several smaller LF drivers, the actual radiating surface area for the LF is larger than that of a 15-inch driver for strong LF performance. However, unlike a 15-inch driver, excellent transient and frequency response is maintained through the crossover region. As a result, the SM84 provides exceptional vocal clarity while providing the LF output levels required. In spite of its multiple LF sources, similar performance is maintained throughout its projection pattern. This is a result of careful attention to the physical spacing and angling of the drivers. This configuration shapes the overall LF wavefront to produce good signal coherency on and off-axis.

SERIOUS MULTIPLE DRIVER CHALLENGES

Multiple drivers can mean either those within a single bandpass or in adjacent bandpasses, such as HF and LF drivers. While there are clear advantages to using arrays of multiple drivers, without careful attention to their complex interactions, multiple drivers can cause serious performance problems, especially off-axis. On of the most critical aspects in designing using multiple drivers is to ensure the production of a coherent wavefront to provide good transient response and sonic clarity. The usual design approach for multiple drivers approach is to provide good magnitude and power summation. While optimizing these parameters can result in good looking frequency response curves and polar charts, the coherency of the overall wavefront may be severely compromised. The transient response will be poor and clarity compromised by so-called "smearing" - the result of multiple arrivals of the same signal over time.

The development of various types and combinations of solutions for these complex issues have provided EAW Engineers with a wealth of design possibilities for using multiple drivers within and between passbands. These solutions allow taking advantage of the benefits of using multiple drivers while mitigating destructive interference between them.

FCHART

One of the key factors that has allowed the development of these technologies is FChart. FChart is EAW's proprietary electroacoustical measurement, analysis, and modeling program written by EAW Engineers specifically for loudspeaker design engineering. The capabilities FChart offers provide EAW Engineers with detailed, in-depth looks at loudspeaker behaviors in both the frequency and time domains. It also allows precise and accurate modeling of driver and loudspeaker arrays. Rather than being based on textbook modeling of sources, FChart uses high resolution, complex data, (magnitude and phase responses) to accurately determine multiple source interactions in magnitude, frequency, and time in at any distance or angle.

One of FChart's tools is a balloon display that not only provides the shape of a loudspeaker's projection pattern, but the pattern as it appears projected on a surface (see Figure 2). This provides an extremely revealing look at a loudspeaker's energy distribution.

Another of FChart's tools was developed to design EAW's NT Series. This required a unique display and analysis of loudspeaker behaviors that could not be done with existing tools. This new tool is a spectrograph that produces a spectrogram that allows viewing and analyzing complex data to resolutions of fractions of a microsecond in time and a few Hz in frequency throughout the usable audio range. Among other things, this has proven an invaluable tool in designing crossover networks and equalization, whether passive or active.

The goal for the NT Series of loudspeakers was to design traditional format 12-inch and 15-inch format PA loudspeakers-ona-stick with the sound quality of recording studio monitors. PA loudspeakers invariably require horn loading. Unfortunately, otherwise well-behaved horn/driver combinations have certain built-in colorations and distortions. FChart's spectrograph allowed analyzing these adverse behaviors in ways that could isolate the specific problems that could be corrected using proprietary digital processing specifically designed for this purpose.

FChart's capabilities are not limited to engineering loudspeakers. Elements of FChart are at the core of EAW's public loudspeaker software used to determine array configurations and set signal processing for some of the products mentioned above: DSA, KF730 and KF760. The software programs use the actual, measured, complex data of the loudspeakers to determine the appropriate array design that meets the user's requirements. The complex data used by the software provides results that are accurate in magnitude, direction, frequency, and time.

TECHNOLOGY SUMMARY

As described in the technologies above, design solutions have included unique physical configurations, sophisticated passive crossover networks, complex horn designs, custom driver designs, and electronic processing, both passive and active. A combination of the these solutions was used to create Theta: state-of-the-art acoustical technology applied to low cost, small format, commercial loudspeakers. Also applied were EAW Engineering's years of experience in designing cost-effective loudspeakers for an extensive range of small to large applications. The result of this engineering is a new level of loudspeaker performance for applications where installations of only the most basic loudspeaker designs were possible. In adverse acoustical conditions, their lack of design sophistication usually resulted in less than acceptable performance at best. Theta technology is a significant improvement on that paradigm.
See the bibliography for a list of the AES (Audio Engineering Society) papers that provide details about some of the above technologies.

THETA APPLIED

The following discussion will point out some of the highly technical and detailed attention EAW Engineers applied to design the SMS products. It is a depth and breadth of engineering analysis and design one would only expect be applied to large, sophisticated PA loudspeakers, not low budget commercial products. However, EAW Engineers knew that only by applying the same sophisticated and advanced design techniques could they achieve their intended, break-though performance goals.

Depending on the particular model, these goals included:

1. Achieve wider than typical horizontal beamwidths to increase the minimum spacing between loudspeakers in a distributed system.
2. Achieve narrower than typical vertical beamwidths to avoid projecting sound into ceilings and other surfaces.
3. Maintain beamwidth consistency over as wide a frequency range as possible.
4. Provide high efficiency coupled with high power handling to maximize output.

Of course, these goals had to include optimized frequency response, coherency, and good sound quality on and off-axis.

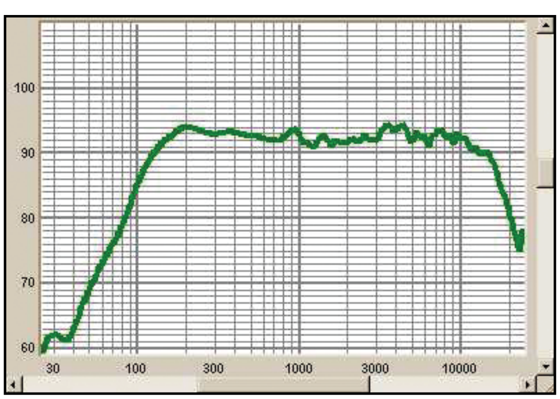
While all SMS100, SM200, and SMS400 models benefit in various ways from Theta technology, the SMS4990, SMS4940, and SMS4124 are good examples where a number of Theta technology solutions were applied.

PERFORMANCE COMPARISON

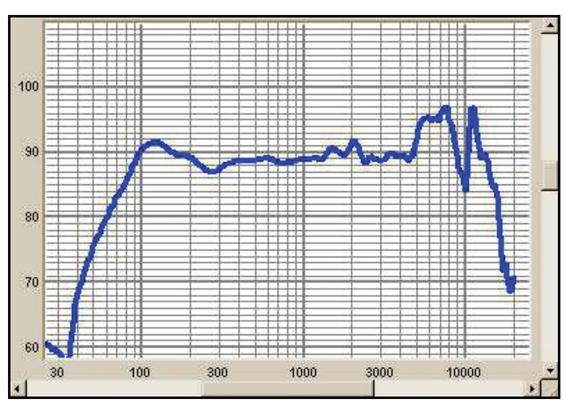
It is instructive to analyze the performance of the SMS4990 with Theta applied in comparison to a typical, 2-way, high quality, commercial loudspeaker. Both have 90° x 90° beamwidths, a pattern that is a fairly common pattern for small commercial loudspeakers. It is generally accepted it should be a fairly easy to achieve this wide pattern with good performance in smaller loudspeakers. The table shows that the two loudspeakers are comparable in size and driver compliment, the four 4 in SMS LF drivers equalling the cone area of the single 8 in driver. Figure 1 shows the on-axis frequency responses.

MODEL	LF SUBSYSTEM	HF SUBSYSTEM	DIMENSIONs (h x w x d)
SMS4990	4x4 in (4x100 mm)	1x1.3 in (1x32 mm)	16 in x 9.75 in x 11 in (406.4 mm x 254 mm x 279.4 mm)
Typical 90x90	1x8 in (1x200 mm)	1x1 in (1x25 mm)	15 in x 11 in x 8.6 in (380 mm x 280 mm x 220 mm)

FIGURE 1: Frequency Responses



SMS4990



Conventional Loudspeaker

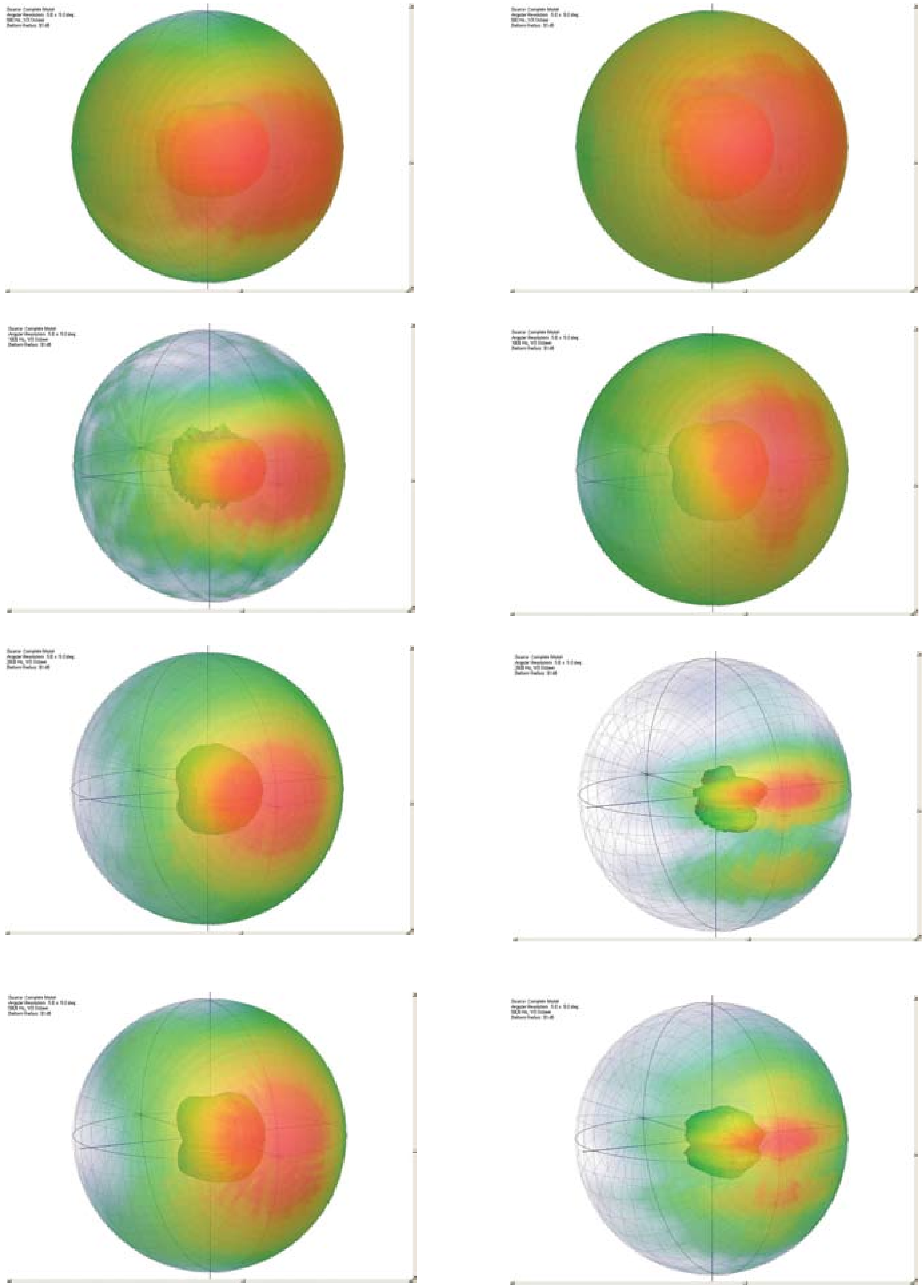
DIRECTIONAL / POLAR PERFORMANCE

Figure 2 dramatically shows the advantages of Theta technology over conventional loudspeaker designs. Shown are polar balloons for the SMS4990 and the conventional loudspeaker at representative, 1/3 octave frequency centers over the primary vocal range of 500 Hz to 5000 Hz. It is obvious that the directional performance for the SMS4990 far exceeds that of the typical loudspeaker. The SMS4990 maintains a similar shape and size for its projection pattern throughout this frequency range. By contrast, the typical design shows large variations in its directionality. It can also be readily seen that loudspeaker does not provide its rated 90° x 90° beamwidth.

While it is clear that the conventional loudspeaker may have better off-axis rejection in the 1000 Hz and 2500 Hz bands, the far more critical on-axis performance suffers significantly. It provides neither the rated beamwidths, evenness across the pattern, nor consistency from frequency band to frequency band. In addition, the primary projection lobes are not even on-axis. Another anomaly to note is that the performance above and below the 0° axis for the conventional loudspeaker is different, which will result in uneven vertical coverage. Unfortunately, this entire frequency range is critical to intelligibility. A comparisons of other frequency bands (not shown because of space considerations) show similar significant disparities in performance.

The poor performance from the conventional loudspeaker is fairly typical of single HF over LF driver configurations. Off-axis time arrival differences from the two drivers cause significant cancellations, breaks in the pattern, and shifting of the primary projection lobe. This mediocre performance stands in stark contrast to SMS's well-defined beamwidths, evenness across the pattern in every direction, symmetrical horizontal and vertical patterns, and consistent performance over the entire, critical vocal range. What is remarkable is that this kind of performance is normally found only in loudspeakers that are considerably larger and more expensive. However, providing this remarkable performance in such small loudspeakers is what Theta Technology is all about.

FIGURE 2: Polar Balloons 500 Hz, 1000 Hz, 2500 Hz, 5000 Hz



Left = SMS4990

Right = Conventional Loudspeaker

COHERENCY

One of the underlying criteria behind Theta was to provide a highly coherent wavefront within and beyond the loudspeaker's nominal beamwidths. A coherent wavefront provides the best reproduction and transient response by keeping all frequencies in the same time relationship as in the original signal. The two obvious challenges were doing this with multiple drivers within the LF passband and, as with the conventional loudspeaker, with both LF and HF drivers operating through the crossover region.

Even with single LF and HF drivers, their sounds will arrive at the listener at different points in time in many directions because of path length differences. Depending on the wavelengths, this can cause significant phase differences and wavefront coherency will suffer dramatically. The consequences can be seen in the balloon for the conventional loudspeaker in Figure 2 at 2500 Hz where these path length differences cause cancellations between the drivers. The result is the fragmented projection pattern as seen on the surface of the sphere.

IMPULSE RESPONSES

One way that EAWEngineers examine wavefront coherency is to look at the impulse responses, which show the loudspeakersmagnitude behavior over time. Figure 3 shows the impulse responses of an ideal point source as well as the SMS and the conventional loudspeakers at different microphone positions. The graphs show level vertically and time horizontally. For these graphs, differences in level are not significant. The left column of graphs are the impulse responses of an ideal, full-range, acoustical point source; the center column of graphs are the SMS loudspeaker; and the right column graphs are the conventional loudspeaker. In the top row graphs the microphone is at 30 degrees to the left and 30 degrees above the loudspeakers; in the second row of graphs, the microphone is on axis; in the third row graphs, the microphone is 30 degrees left and 30 degrees below the loudspeaker. It can be clearly seen that the SMS not only provides impulse responses that are not only much closer to the ideal, they do not change substantially with microphone position. Contrarily, the impulse response of the conventional loudspeaker varies considerably with microphone position. In the last row, the impulse from the conventional loudspeaker is extremely distorted having little resemblance to its on-axis impulse. For the SMS, even with its multiple LF and HF drivers, its impulse response is still excellent, even this far off axis.

FIGURE 3: Impulse Responses

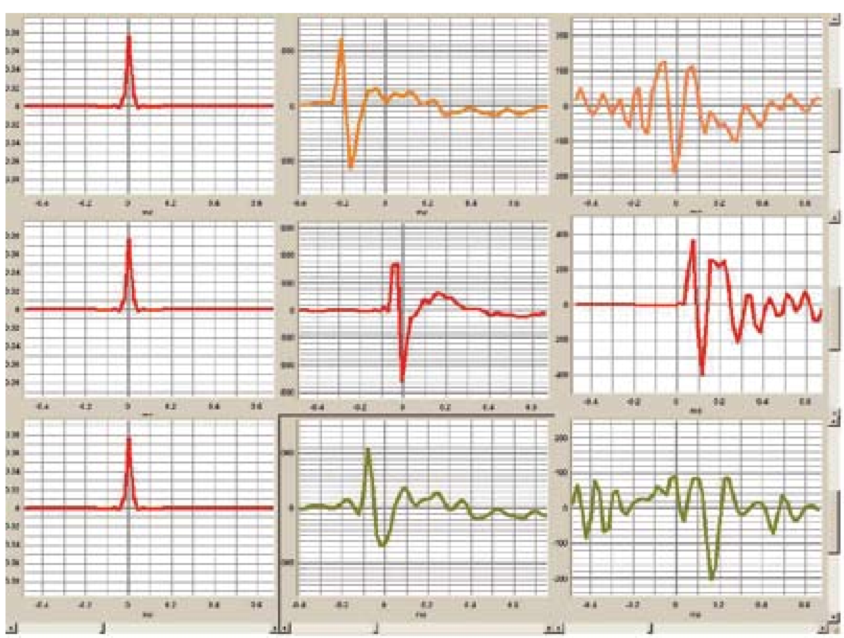
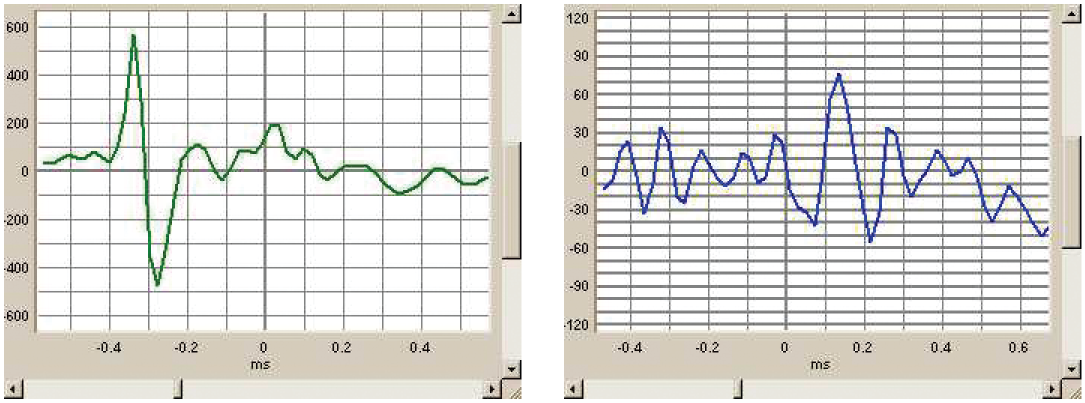


Figure 4 shows the impulse response well outside the nominal pattern at 60 degrees off axis and 60 degrees above the loudspeaker. The SMS still retains a clean impulse while that of the conventional loudspeaker is unrecognizable as an impulse.

FIGURE 4: Out-Of-Pattern Impulse Responses



SMS4990 Conventional Loudspeaker

SPECTROGRAMS

Spectrograms are another powerful design tool used in EAW's design process. The spectrograms show frequency on the vertical axis, time on the horizontal axis, and level by the color. The widening of the display is due to the fact the time window applied to the data widens with decreasing frequency. The information to the left of the peak, in this case located at time zero, is ignored, being an artifact of the the mathematics required for the spectrograph to process the data to produce the spectrogram. FChart's spectrograph was developed specifically to look at loudspeaker behaviors. spectrograph adjustments allow the spectrogram to display data over a range from very fine frequency to very fine time resolution. The spectrograms shown were taken between the two resolution extremes.

For comparison, Figure 5 shows the spectrograph of an ideal, point source loudspeaker.
FIGURE 5: Spectrogram of an Ideal Point Source

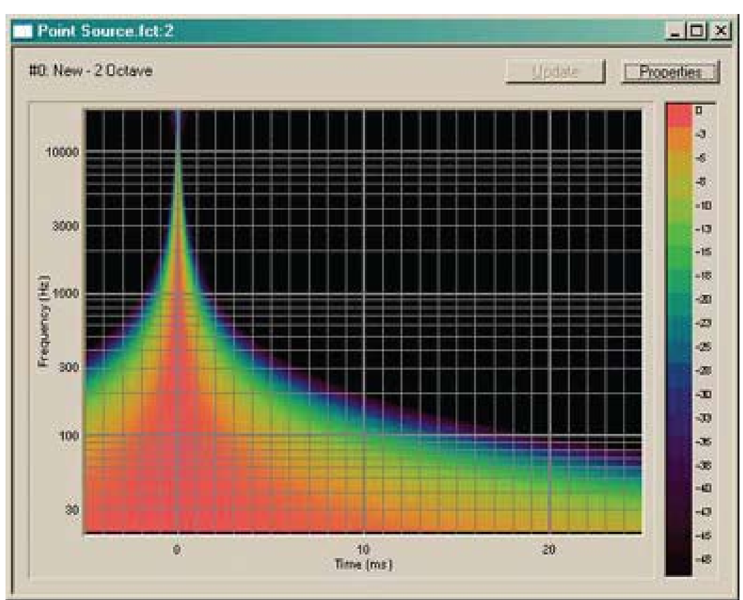
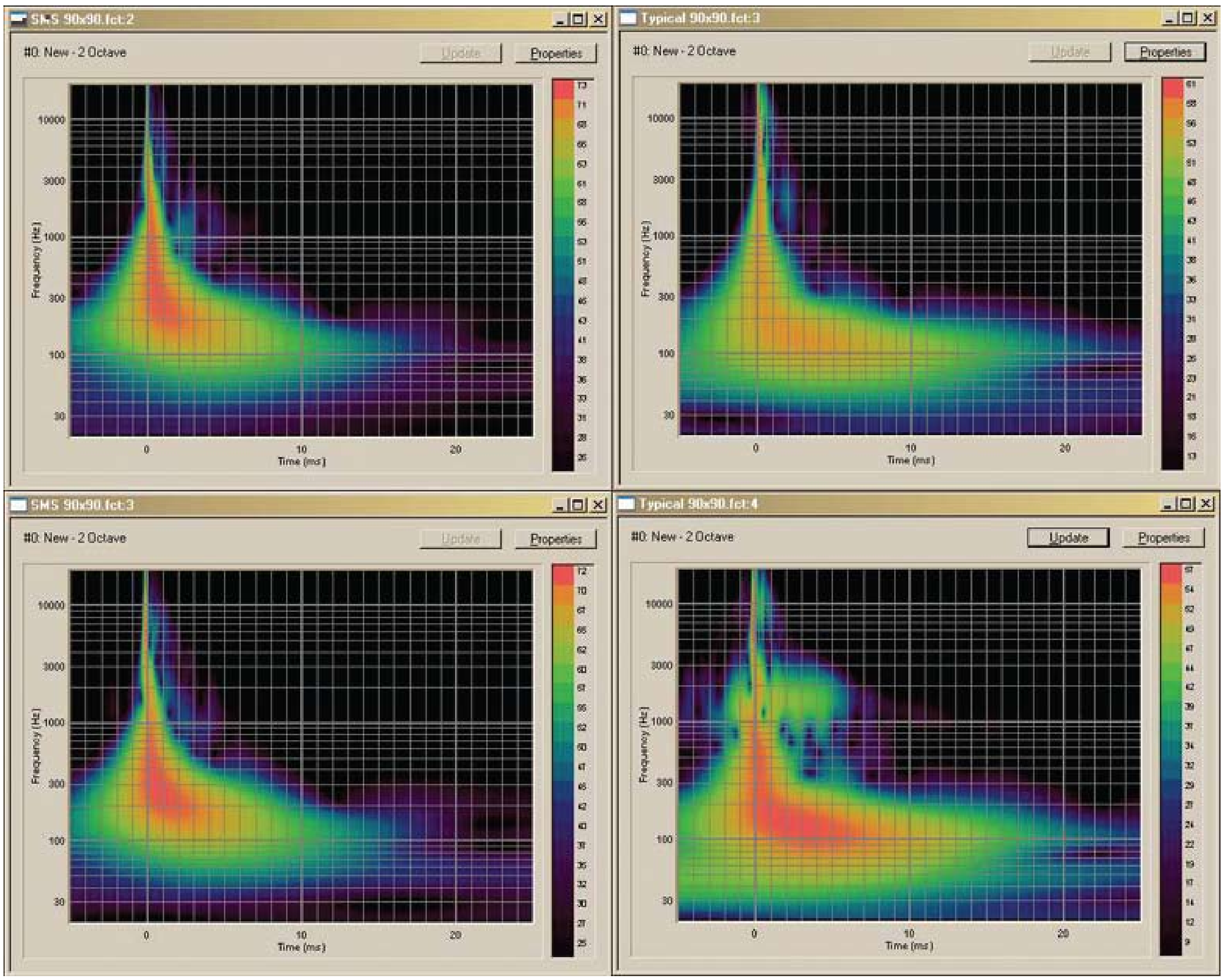


Figure 6 shows spectrograms of two loudspeakers. The upper two spectrograms are the SMS4990 and the lower are the conventional loudspeaker. The spectrograms on the left were take on-axis and show both loudspeakers are quite well behaved (especially for lower cost loudspeakers). The spectrograms on the right are taken at 30 degrees off-axis and 20 degrees up, well within the nominal 90° x 90° degree beamwidths of both loudspeakers. It can be clearly seen that the SMS spectrogram remains quite similar at the off axis microphone position. However, the spectrogram for the conventional loudspeaker changes dramatically off-axis, showing a plume of excess energy smearing the signal over time in the critical 1000 Hz to 3000 Hz region.

FIGURE 6: Spectrograms 20 Hz to 20,000 Hz



SMS4990 Conventional Loudspeaker

This data shows that Theta technology provides a coherent wavefront both on and off axis. While the conventional loudspeaker provides good on-axis coherency, it loses coherency both within and beyond its nominal beamwidth. The loss of coherency means poor transient response, uneven frequency response, and resulting low quality off-axis performance. The conventional horn over single LF driver configuration results in very uneven vertical polar performance. The above exemplifies the kind of detailed analysis EAW Engineering applies to all loudspeaker designs.

The performance of small loudspeakers leaves a lot to be desired when trying to achieve higher directivities. As mentioned before larger physical size is usually needed to improve control, especially the consistency, of the projection pattern. However, Theta improves consistency without increasing size.

HOW THE RESULTS ARE ACHIEVED

LF Subsystem

To achieve their LF performance, the SMS400 and SMS200 loudspeakers draw heavily from the design of EAW's SM84. The SM84 is a stage monitor designed to overcome problems of dramatic frequency response changes as performers move side-to-side or up and downstage. In addition, there was the problem of vocal range clarity muddied by the typical 12-inch and 15-inch LF drivers used to achieve required LF levels. The use of a symmetrical driver layout as well as multiple, but smaller, LF drivers overcame both problems while actually increasing overall LF output capability. A precise driver layout as well as a unique horn and crossover design all contributed to achieving the design goals.

The SMS200s and SMS400s both mimic the SM84 in their LF driver configuration. An obvious advantage to this configuration is that it provides a symmetrical LF projection pattern in both the horizontal and vertical planes. However, equally important is the spacing and angling of the LF drivers. While both the spacing and mounting angles are critical to the beamwidth performance, they are also critical to the performance in other ways.

Spacing two sources within the same bandpass will result in a projection pattern that collapses with increasing frequency. This is due to what is called "doublet" radiation. Because there are four drivers, this doublet radiation can be made to work in two planes. The magic in the SM84 as well as the SMS products was to space and angle the four LF drivers in two planes in such a way that the collapsing beamwidth of this array in both directions complimented the beamwidth of the HF horn through the crossover region. At the same time, this array of multiple LF sources was to extend the useful beamwidth of the LF subsystem to a lower frequency while maintaining good off-axis coherency in the upper part of their operating range.

There are several other significant advantages to using multiple, smaller LF drivers over a singe larger LF driver. The most obvious is that smaller drivers have more extended HF bandwidth. This allows a smoother sonic transition to the HF subsystem. Large, single drivers are usually pushed beyond their optimum HF cutoffs in 2-way systems, resulting in muddied sound quality through the crossover region and reduced vocal clarity. The four, 4-inch drivers in the SMS400 products have the same cone radiating area as one 8-inch driver. However, because the SMS drivers are spaced, mutual coupling means the entire area bounded by the drivers effectively becomes the radiating area at the lowest frequencies. In this case, the radiating area is actually equivalent to that of a single 12-inch LF driver at lower frequencies. In addition, mutual coupling improves the LF efficiency, providing more output for a given input. The sum total of the power handling of the individual smaller drivers is significantly more than can be achieved for a single larger driver because of the multiple voice coils.

Using multiple LF drivers provide the SMS200 and SMS400 loudspeakers with extended LF response, lower distortion, higher LF sensitivity, higher sound quality in the critical crossover region, and higher maximum output capability.

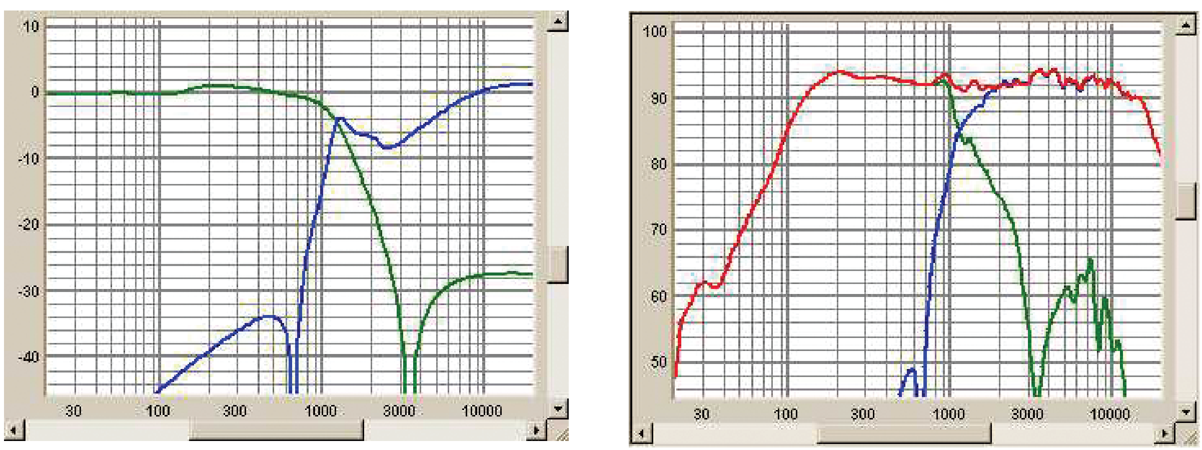
LF/HF Crossover

Figure 7 shows another, less-than-desirable aspect of the conventional loudspeaker's design. The crossover frequency region is centered around 3000 Hz. In this region, several anomalies can be seen such as lobing, inconsistent beamwidth, frequency response variations with direction, and poor impulse responses off axis. Using such a high crossover frequency, as is typical for small 2-way designs, can easily push LF drivers beyond their optimum usable upper limit. The most adverse problem is that crossovers in the 2000 Hz to 4000 Hz range are right in the middle of a critical region for speech intelligibility; not a good range in which to have performance problems such as the anomalies mentioned above.

One reason for these typically high crossover frequencies in small loudspeakers are the HF driver limitations, primarily a high resonant frequency. Near to and below this frequency the driver becomes essentially unusable due to power and sonic limitations. For the SMS loudspeakers a custom, high power HF driver was designed with a resonant frequency of about 200Hz. This meant that the crossover frequency could be lowered substantially to a frequency that was less critical for speech, that would work better in terms of providing consistent beamwidth where it matters most, and that would allow the LF drivers to be used well within their frequency capabilities. In addition, the extended high frequency response of the smaller LF drivers reduces the possibility of cone break-up distortion and beamwidth narrowing, enhancing sound quality through the crossover region.

The crossover networks designed for the SMS Series are the result of years of experience designing sophisticated passive crossover networks for high performance PA loudspeakers where consistent symmetrical polar performance is critical. They typically employ high order filters that compliment the driver responses and roll-offs. The responses of a typical SMS crossover in the left of Figure 7 easily show they are not “textbook” filters. However, the combined driver/crossover responses on the right show the textbook, symmetrical filtering one expects from a well-designed acoustical crossover.

FIGURE 7: SMS4990 Crossover Responses



Passive Crossover

Passive Crossover + Drivers

An important performance criteria is that the phase slope for the loudspeaker remains linear, not only through the crossover region but over the entire frequency range. The consequences of a non-linear phase can show up in the the crossover region. In Figure 2 it can be seen that the primary projection axis of the conventional loudspeaker is actually aimed upwards in the 2500 Hz and 5000 Hz balloons. In contrast the phase response through the SMS's crossover (1250 Hz) is linear, as seen in its 1000 Hz balloon where the main energy lobe is symmetrically centered on axis.

HF Subsystem

The HF subsystems for the 90° x 90° SMS models are conventional, albeit state-of-the art horn designs. This kind of wide pattern is the most common among small format loudspeakers because it is fairly easy to achieve. However desirable, small, full-range loudspeakers with specified narrower projection patterns, let alone ones that actually provide anything like the pattern control of larger loudspeakers are rare. The 120x40 and 90x40 SMS models change this by providing a 40 degree nominal beamwidth in a small loudspeaker that provides the type of pattern control expected only in much larger loudspeakers.

The 120° x 40° and 90° x 40° HF subsystems use multiple drivers. Like the LF subsystems, this increases both efficiency and power handling. Drawing on EAW's various steering technologies, the solution to creating a consistently narrow pattern over a wide bandwidth was a curved array of three HF drivers on a specially designed, curved horn. Nonetheless, this solution brought up the same challenges of projection pattern symmetry and consistency as well as wavefront coherency from multiple sources, especially given the short wavelengths involved at HF frequencies.

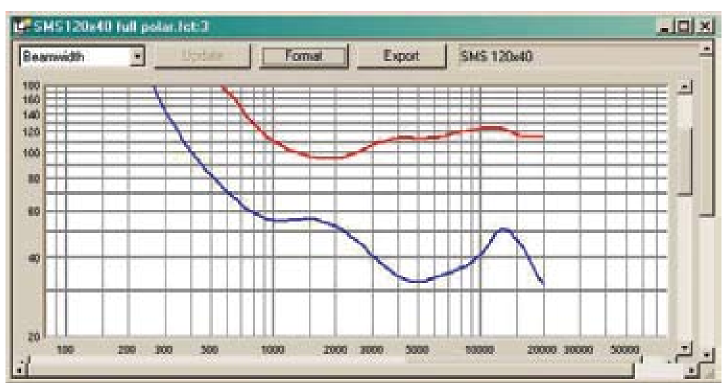
Because a practical, curved line source driver is not feasible, the challenge was to combine the outputs of multiple HF sources to behave as a single, longer, curved source. The HF drivers are configured as a multi-cell array that mimics the curved source behavior in the HF range achieved in the KF730 and KF760, but on a much smaller scale. This is accomplished primarily with the specially shaped throats and ovoid apertures for the individual drivers. These produce wavefronts from the individual "cells" shaped so that they combine coherently. The result is the three drivers produce a single, curved wavefront shaped appropriately for the single, shared horn flare. Additionally, the driver throats and their apertures provide the proper acoustical resistance for efficiently coupling the outputs of the drivers into the single horn flare.

An example of the detailed engineering applied this horn is a modification made during the design process to improve the HF projection pattern consistency. Contrary to what one might expect, the curvature of the HF horn does not match the curvature of the HF driver array. The curvature of the horn is actually shallower. The reason goes back to EAW's long history with wavefront shaping. It turns out that using classic horn design method to determine the horn flare for this design resulted in an inconsistent narrowing of the projection pattern in its lower frequency range. The cause was the horn curvature allowed energy from the outermost drivers to leave the horn too quickly in certain directions. This in turn distorted the wavefront shape in this frequency region. The solution was to increase the length of horn flare around the outermost drivers to increase their path lengths in the problem directions but without changing the overall dimensions of the horn. The resulting curvature of the overall horn throat is different than the curvature of the arc of drivers. This careful re-shaping of the horn provided a more uniform wavefront in time, improving the projection pattern consistency and coherency.

The most challenging products were the SMS with 120° x 40° and 90° x 40° beamwidths. Achieving the radical 40 degree beamwidth over a wide bandwidth would normally have required a large, long horn for a single driver. Instead, multiple drivers are used to create the horn-loaded, curved line source. Using a line source meant the HF subsystem would have an inherently narrow vertical pattern. The line length was made long enough to provide some directivity to below the crossover frequency without any horn loading. This reduced the difficulties in achieving such a narrow pattern using a small horn.

The excellent results are shown in Figure 8. It is especially notable that good vertical pattern control is maintained down to almost 300 Hz.This is remarkable considering the small size of the loudspeaker compared with the typical size of loudspeaker normally needed to achieve this level of pattern control.

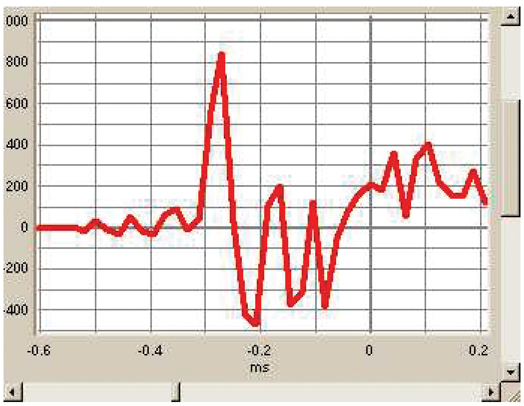
FIGURE 8 - SMS4124 Beamwidths



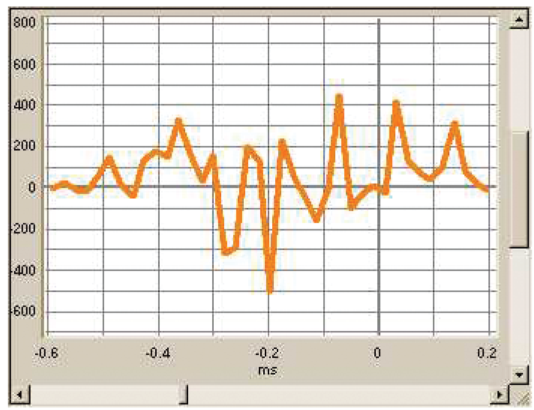
Red = Hoizontal Blue = Vertical

Another old simple, but effective technique of "barn doors" is used at the ends of the HF horn to physically block some of the higher frequency energy from being projected beyond the desired pattern. However, this solution had to be implemented carefully to avoid, among other things, reflections from these surfaces interfering with the sound within the desired beamwidth. The doors intentionally end sharply. This discontinuity in the horn flare causes destructive interference outside the nominal beamwidth. This is done to provide a much sharper energy cutoff outside the nominal beamwidth and produce a much betterdefined projection pattern. Both of these attributes are critical to making narrow projection patterns work effectively. Impulse responses are shown in Figure 9 at 20 degrees off-axis (left) compared to that at 30 degrees off-axis. The impulse is quite good, showing excellent wavefront coherency at the edge of the nominal vertical beamwidth. However, at 30 degrees, the desired severe deterioration is seen where the impulse is quite unrecognizable.

FIGURE 9: SMS4124 Impulses Responses, Vertical Plane



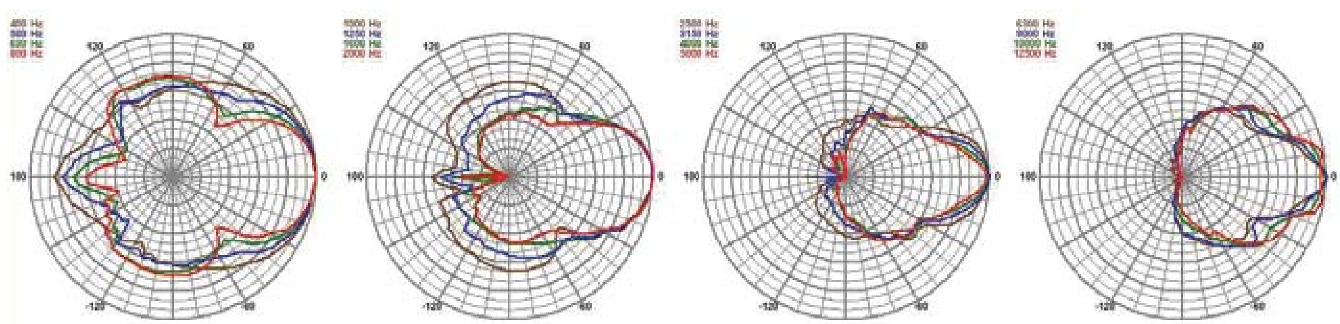
20° Off-Axis



30° Off-Axis

This result of these design details is shown in Figure 10. The polar charts show the desired, sharp out-of-beamwidth rejection as well as the maintenance of good pattern control well below the crossover point down to the 400 Hz band. In this case, the luxury of maintaining coherency and thus sound quality beyond the nominal beamwidth was sacrificed in favor of providing a more effective narrow pattern that is well-defined, consistent with frequency, and with sharp attenuation outside the nominal beamwidth.

FIGURE 10 - SMS4124 Vertical 1/3 Octave Polar Charts



400 Hz to 5000 Hz

THE SOUND QUALITY

Starting with the earliest prototype and continuing through the entire design process, EAW subjects its loudspeaker designs to exhaustive listening tests by expert listeners from both inside and outside the company. “Expert” means listeners experienced in evaluating loudspeaker performance for its applications, rather than according to any simplistic or arbitrary “accuracy” or “quality” convention. While sound quality is always an important issue, others are equally important, including directional performance, maximum usable output levels, voicing, and program dependent performance. The SMS loudspeakers were subjected to exhaustive listening tests for application suitability.

An example of application-specific, program dependent performance can be illustrated in EAW’s development of the Avalon Series. This loudspeaker series was engineered specifically for reproducing modern dance music in a variety of different architectural environments. For this reason, well-known DJs were primary experts among the listening panels. Among other things, the music’s unique spectral content led to unique voicing and power handling requirements which conventional loudspeaker designs simply could not fulfill.

SUMMARY

Theta Technology involves the application of the sophisticated pattern control solutions developed by EAW Engineering for a variety of products from large prfessional loudspeakers to low-cost, small format, commercial loudspeakers. First applied to the SMS Series of loudspeakers, Theta involves subjecting each loudspeaker design to the same, rigorous, and exhaustive design process normally expected only for premium products. As such, all the solutions EAW has developed to solve complex loudspeaker design problems come into play, as do strict criteria for their proper implementation and performance. As it turns out, most of these solutions can be cost-effectively implemented to provide significantly improved performance compared to existing commercial products. Thus, as well as being the heart of the new SMS products, Theta technology will be applied to future products equally effectively.

It is said that there are three ways you can specify any engineering project. However, you only get a choice of two.

1. Fast
2. Cost effective
3. Better

In the case of Theta, it is the last two that apply. That’s the only way EAW knows how to design loudspeakers: taking the time to engineer the best performance possible within the product’s market constraints.

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** A copy of any of the above papers can be provided by EAW on request.*