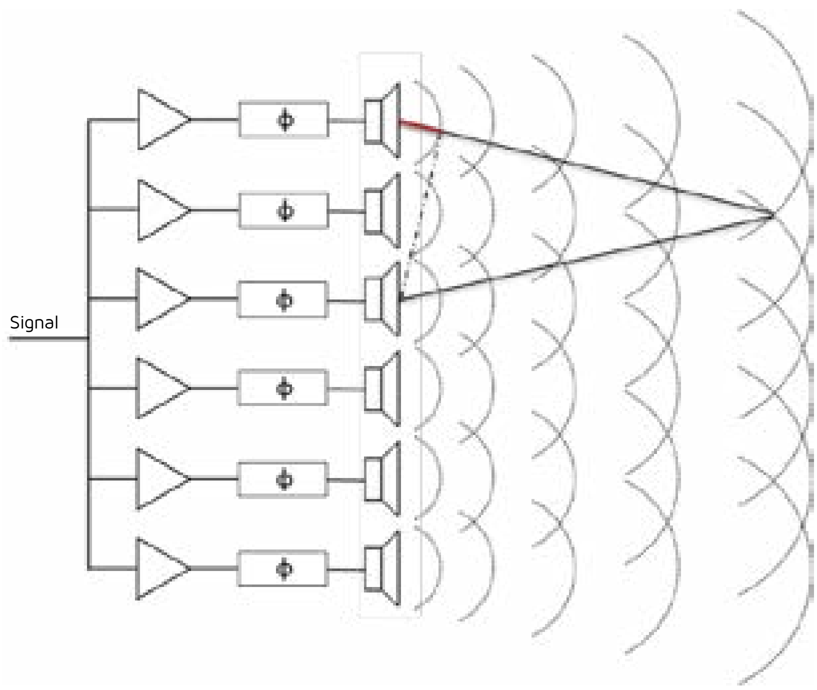
An Introduction to Electronic Beam Steering

The line array's introduction to the professional audio market in the 90s signaled a revolution for both live concert applications and installations. With a high directivity on the vertical plane, the line array's sound beam can be focused on the audience area, ensuring greater intelligibility in highly reverberant environments and enabling uniform coverage of distances much greater than those attainable with traditional sources. Given this high directivity, the position of the cluster and the orientation of the individual speakers of which it is comprised are extremely critical parameters. In most applications, it is necessary to adjust the angles of an array in order to obtain the typical "banana" profile to direct the sound beam down towards the audience area. An error in the height of the cluster or the angles between the various units may significantly affect the quality of the sound on the audience area. Moreover, once the array is installed, it is no longer possible to modify the characteristics of the dispersion.
It is here that the idea to digitally steer the sound beam generated by a line array was concieved.

Imagine a number of sound sources all driven by the same signal. At any point within the space, the acoustic waves emitted by each source will interfere constructively or destructively, depending on the phase difference at that point. The interaction's intensity, whether constructive or destructive, depends on the difference of the waves' amplitude. Therefore, if each source's signal phase and amplitude is controlled, it is possible to chose at which points we want the waves to sum and at which points we want the waves to cancel out each other. In other words, we can concentrate the sound energy in the space where it is needed, excluding areas that do not need to be affected by the sound beam.



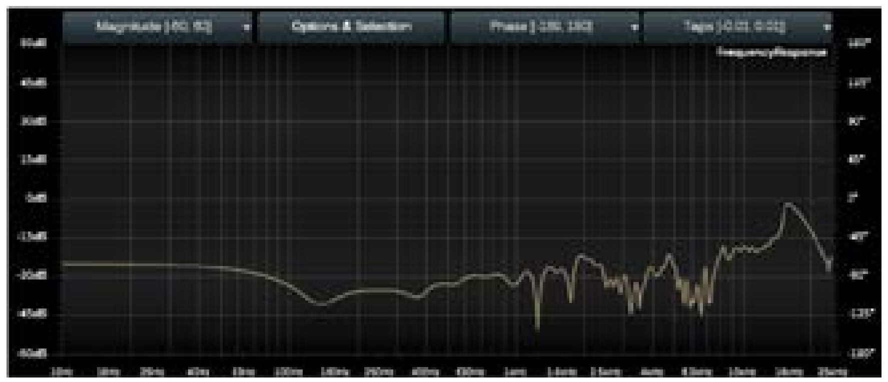
While this concept, identified as Electronic Beam Steering, might seem simple, it is actually very complex given that in space there are an infinite number of points where the waves interfere. In addition, the entire process is frequency dependent. Therefore, to obtain optimal results, it is necessary to manipulate each source's signal with a very high frequency resolution.

Electronic Beam Steering was initially implemented using the delay to vary the phase of the acoustic waves emitted by each line array element. The limitation of this approach is that the delay introduces a uniform delay at all frequencies and, therefore, does not allow the sound beam to be shaped independently at each frequency. This latter aspect is fundamental since the interaction between the acoustic waves emitted by each array element is a process that strongly depends on the frequency. Only by finely adjusting the phase and the amplitude of the signal frequency-by-frequency is it possible to obtain results of optimum steering, ensuring the same frequency response throughout the audience areas affected by the sound beam.

This is possible only if FIR filters are used instead of the delay or traditional filters. The FIR filters (Finite Impulse Response) digital filters are characterized by the fact that their impulse response has a finite duration. Because they are digital filters, the input and output signals are sequences of discrete values, called samples. Each sample x that enters the filter is multiplied by a given coefficient b and added to the previous M Samples entered in the filter each multiplied by an appropriate coefficient. In other words, the value y[n] of the sample outgoing from the filter at the time n is the weighted average of the last M samples entered in the filter.

$$y[n] = b_0 x[n] + b_1 x[n-1] + \cdots + b_M x[n-M] = \sum_{k=0}^{M} b_k \cdot x[n-k]$$

The values of the coefficients can be selected to obtain the desired transfer function, which can be that of a simple traditional filter (low pass, high pass, shelving etc.) or even much more complex.



FIR transfer function example

One of the properties that makes these filters ideal for electronic beam steering is that they can alter the signal phase at a given frequency without altering the amplitude, and vice versa. If we consider that each FIR filter has hundreds of adjustable coefficients, it is not hard to believe that using them will allow you to manipulate the amplitude and phase of a signal with an extremely accurate frequency resolution. Obviously, the calculation of the FIR coefficients is not done by hand, but rather by a powerful software that has the responsibility of optimizing these values to obtain the desired acoustic result.

For example, imagine a line array consisting of six KH2 elements each driven by a signal filtered by a FIR characterized by 400 coefficients. The software will have 6 x 400 = 2400 adjustable coefficients to ensure that the acoustic waves emitted by each line array element will interfere constructively in the audience area and interfere destructively where the sound pressure must be at a minimum i.e., the stage. Thanks to the very high number of coefficients in play, this steering process can be optimized frequency by frequency, ensuring optimal coverage throughout the entire audience area and reducing the noise pollution outside of this field.

The following examples demonstrate how this technology allows the end user to have full sound beam control, achieving results which are unattainable using the traditional approach to electronic beam steering.

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APPLICATION EXAMPLES

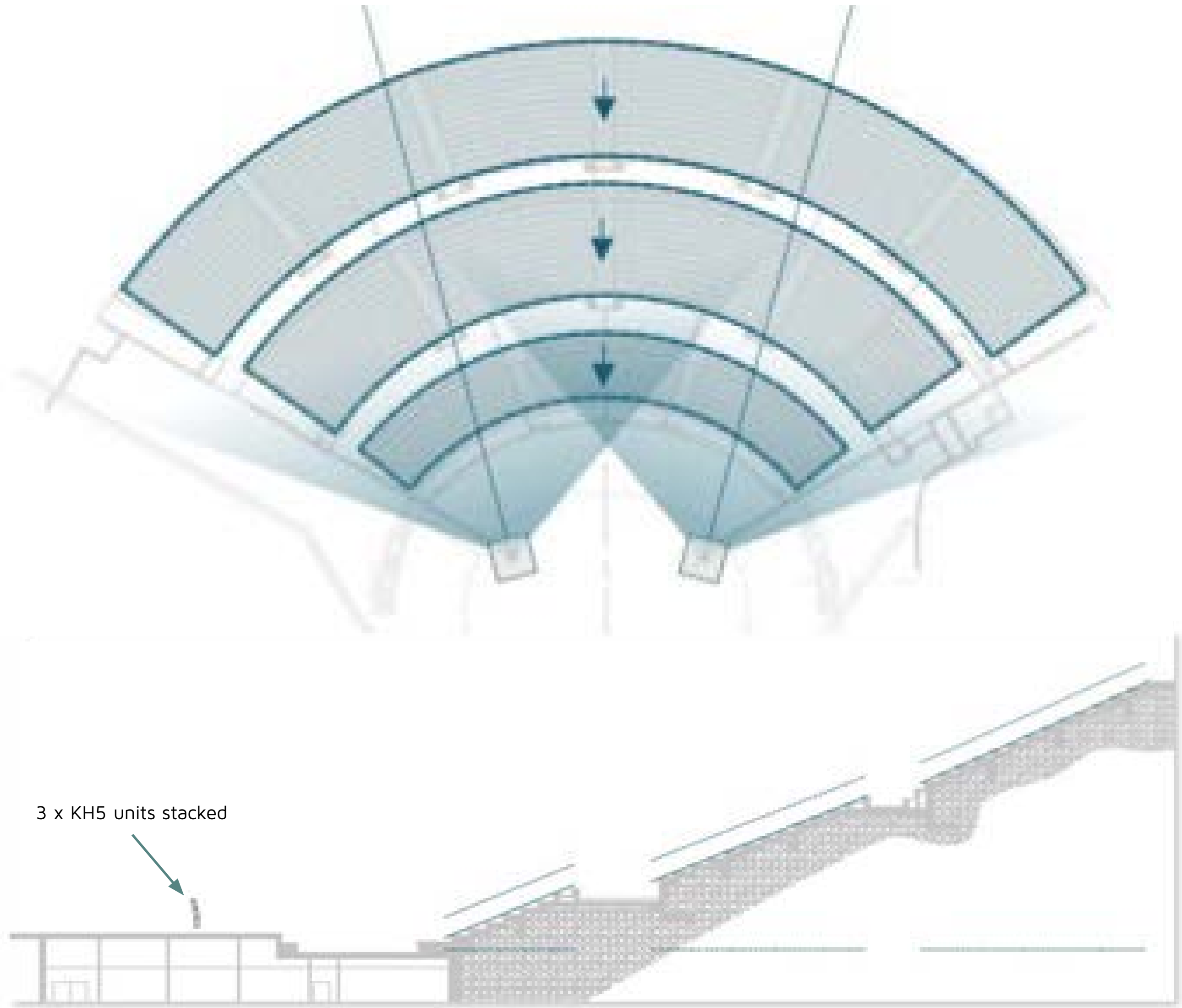
All examples shown have been created with EASE Focus acoustic simulation software. The simulations performed by the software are based on measured data at a very high resolution and are, therefore, totally representative of the actual behavior of the speaker.

EXAMPLE 1

In the following images it is possible to see a plan view and a sectional view of an amphitheater where an audio system consisting of two clusters of 3 KH5 speakers is installed.

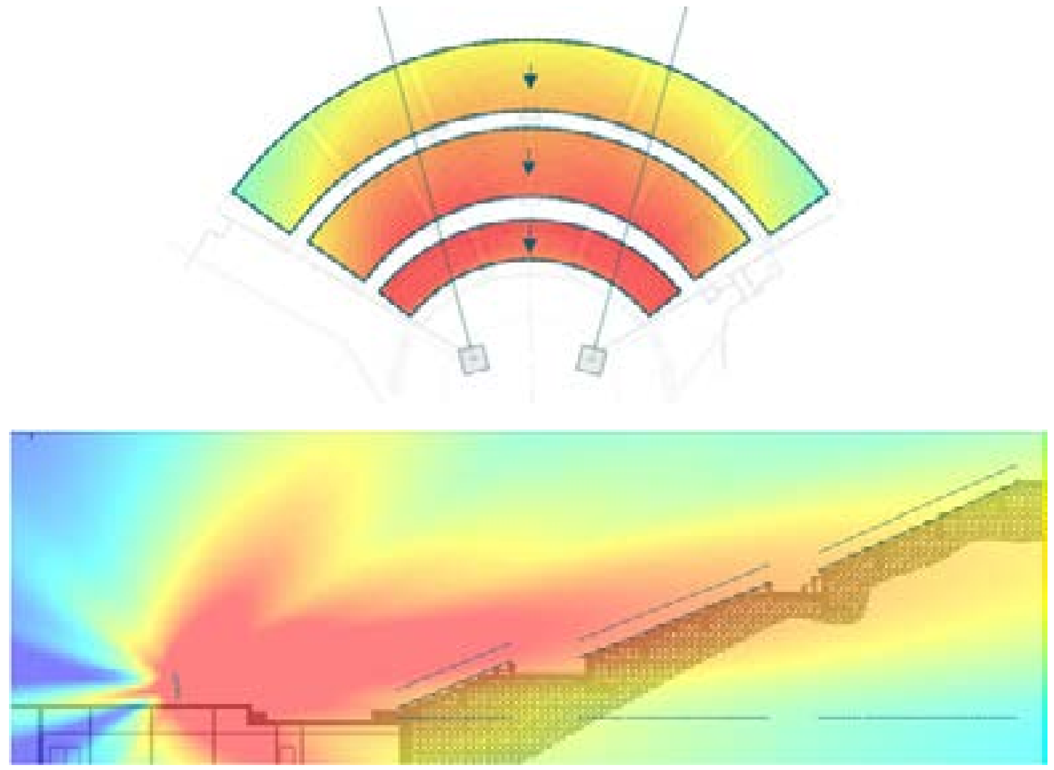
The speakers are placed on the stage and oriented appropriately to ensure optimal coverage of entire audience area.

The figures in the next pages demonstrate the simulation of the direct SPL in one octave band centered at 1000 Hz and 2000 Hz.

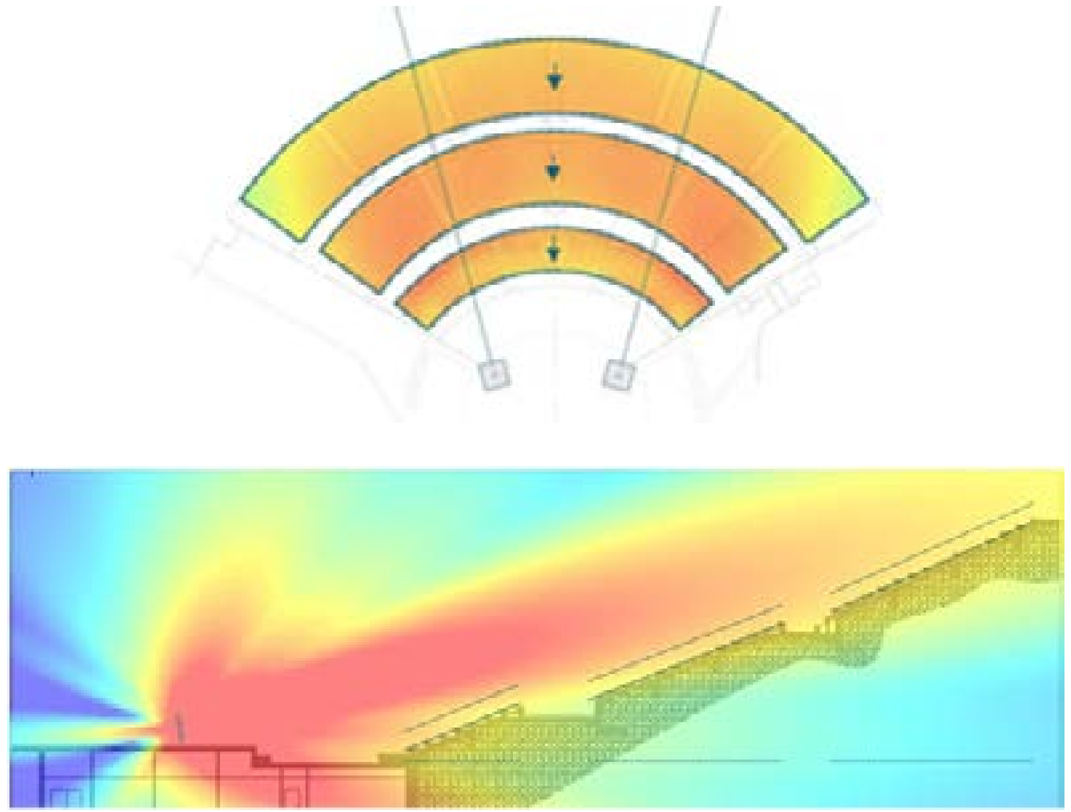


Plan view and sectional view of an amphitheater where two clusters of 3 KH5 are installed

1000 Hz



Electronic Beam Steering bypassed



Electronic Beam Steering active

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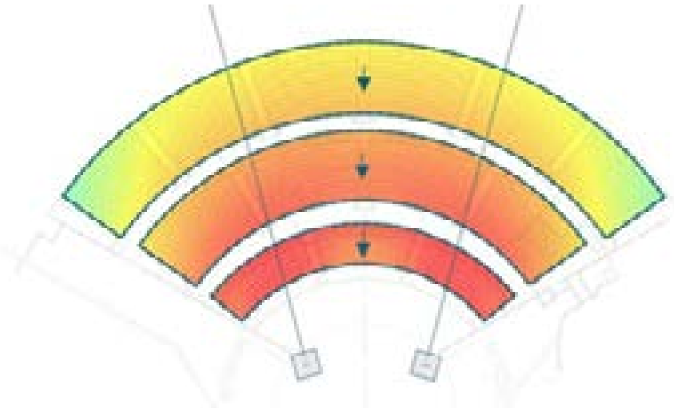
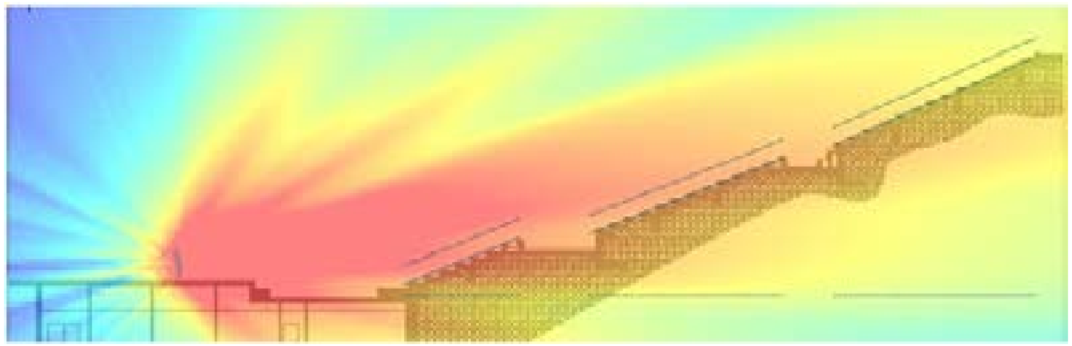
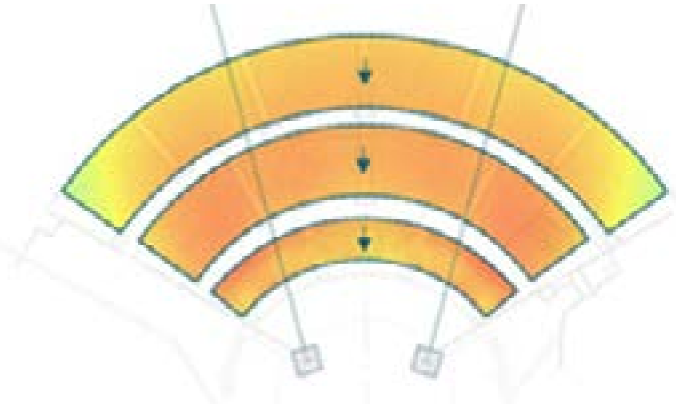
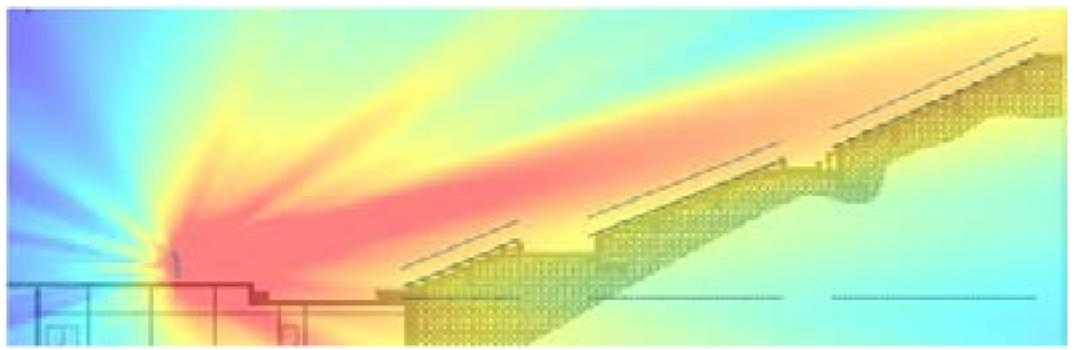
2000 Hz





Electronic Beam Steering bypassed





Electronic Beam Steering active

It is clear from the images that the activation of electronic beam steering leads to a clear improvement in the sound coverage of the audience area. The optimization of the FIR filter coefficients redistributes the energy so that, rather than being focused on the section closest to the system, it is distributed evenly over all areas of interest.

The most interesting thing to note is that the intervention of electronic beam steering on the sound energy dispersion is very different in the two bands taken into consideration.

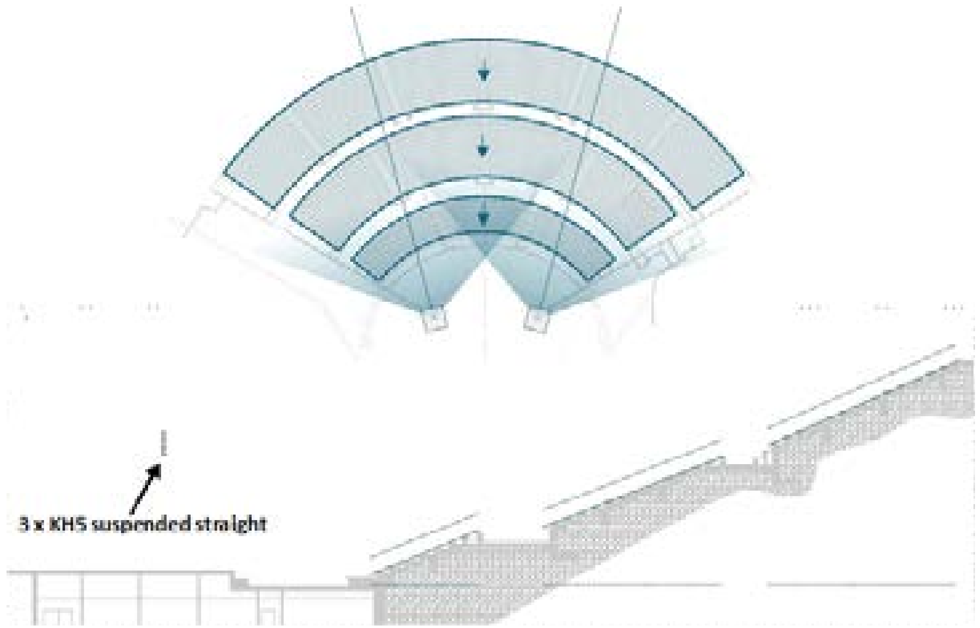
At 1000 Hz, the sound beam is not parallel to the audience area resulting in a higher sound pressure build up in the front rows compared to the section farther from the system. Since they are no longer on the same axis of the sound beam, the first rows lose the energy surplus that was there before the FIR filters were applied. The digital optimization, therefore, tends to bend the beam upwards, so as to effectively redistribute the energy.

Instead, at 2000 Hz the sound beam is already oriented in the right direction, so it does not need to be digitally bent. Rather, the digital optimization tends to reduce the angle of the vertical coverage so that the beam is better focused and can reach the back section of the audience with sufficient intensity.

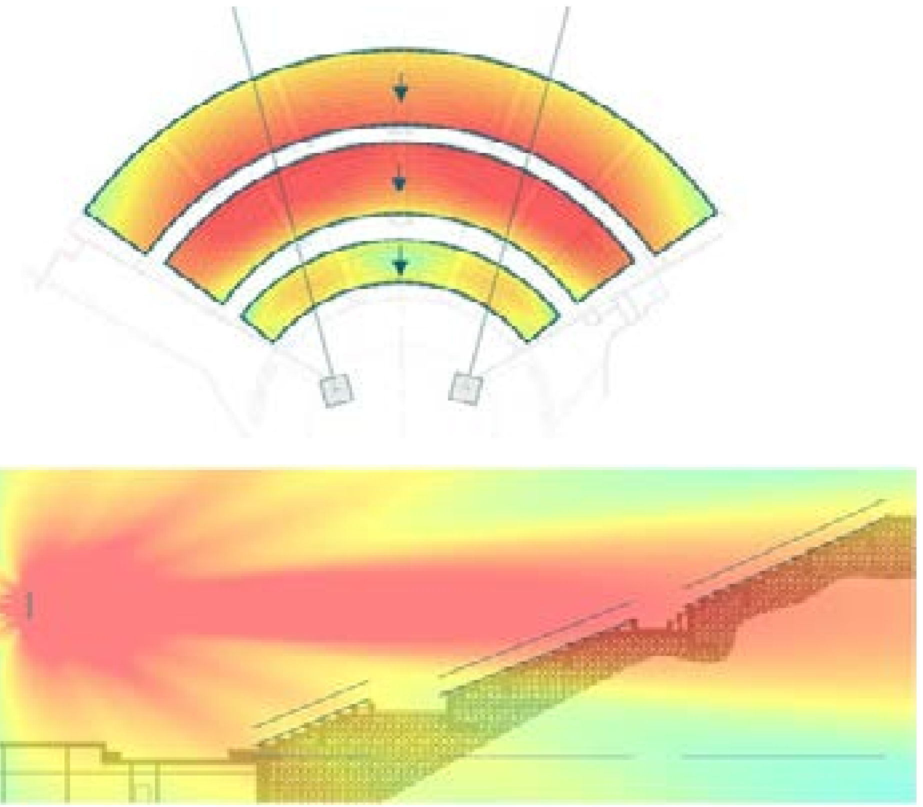
As explained above, only the use of FIR filters with a high number of coefficients can optimize the dispersion of the sound energy independently at each frequency. The application of a simple delay would not obtain the results shown in these examples.

EXAMPLE 2

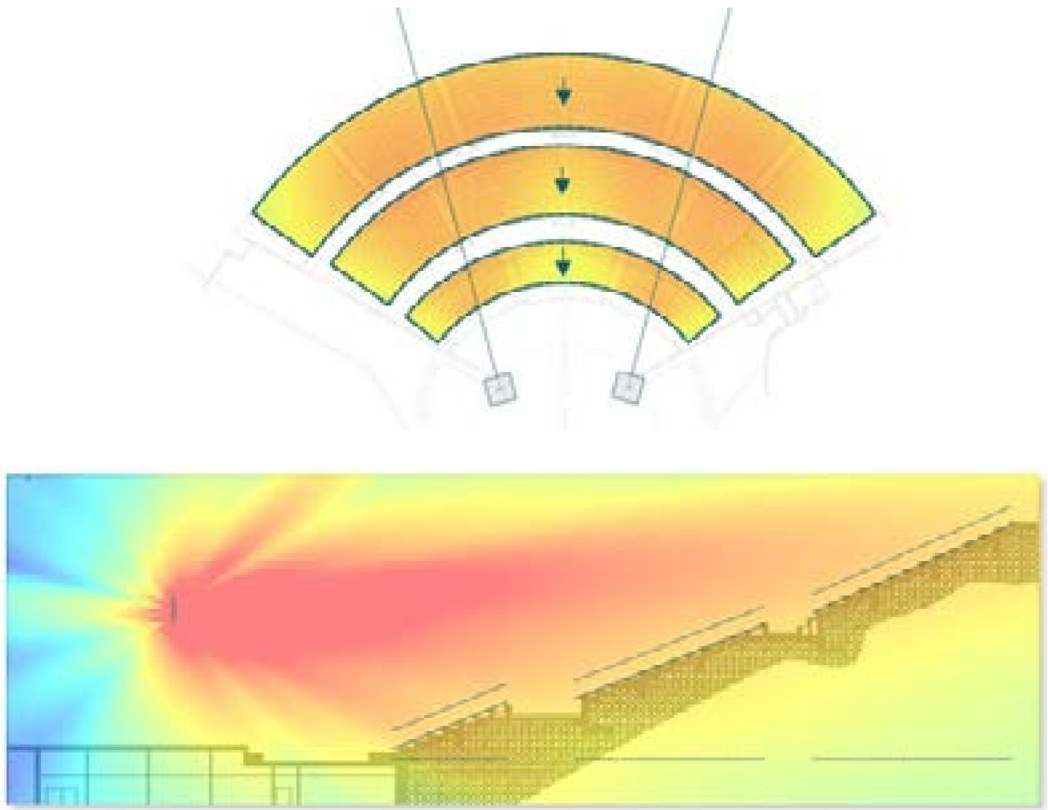
In the second example, two clusters comprised of three KH5 units are installed in the same amphitheater, but in a more extreme configuration. The clusters are suspended and left completely straight without any angle between the cabinets.



1000 Hz



Electronic Beam Steering bypassed



Electronic Beam Steering activ

As clearly shown, the ability to digitally adjust the sound coverage allows the suspension of a perfectly straight cluster to cover all areas of interest. The sound energy is redistributed evenly rather than building up along the array's axis.

In many applications where there are restrictions on the cluster placement, the ability to effectively cover the audience area without having to utilize the typical banana profile is big advantage of the system

CONCLUSION

The ability to digitally adjust the dispersion of a line array element not only ensures the same listening experience to all audience members but, at the same time, limits the noise pollution in the areas where the sound pressure must be kept at a minimum.
The use of FIR filters is the biggest advantage of our electronic beam steering technology since it provides extremely high frequency resolutions, which would not be possible using delays and traditional filters.
Electronic beam steering is an important component of K-array's Concert Series and Firenze Systems and, along with other important features such as premium materials and impeccable sound quality, puts K-array products on the forefront of cutting edge professional sound reinforcement.