3D WAVEFRONT CONTROL

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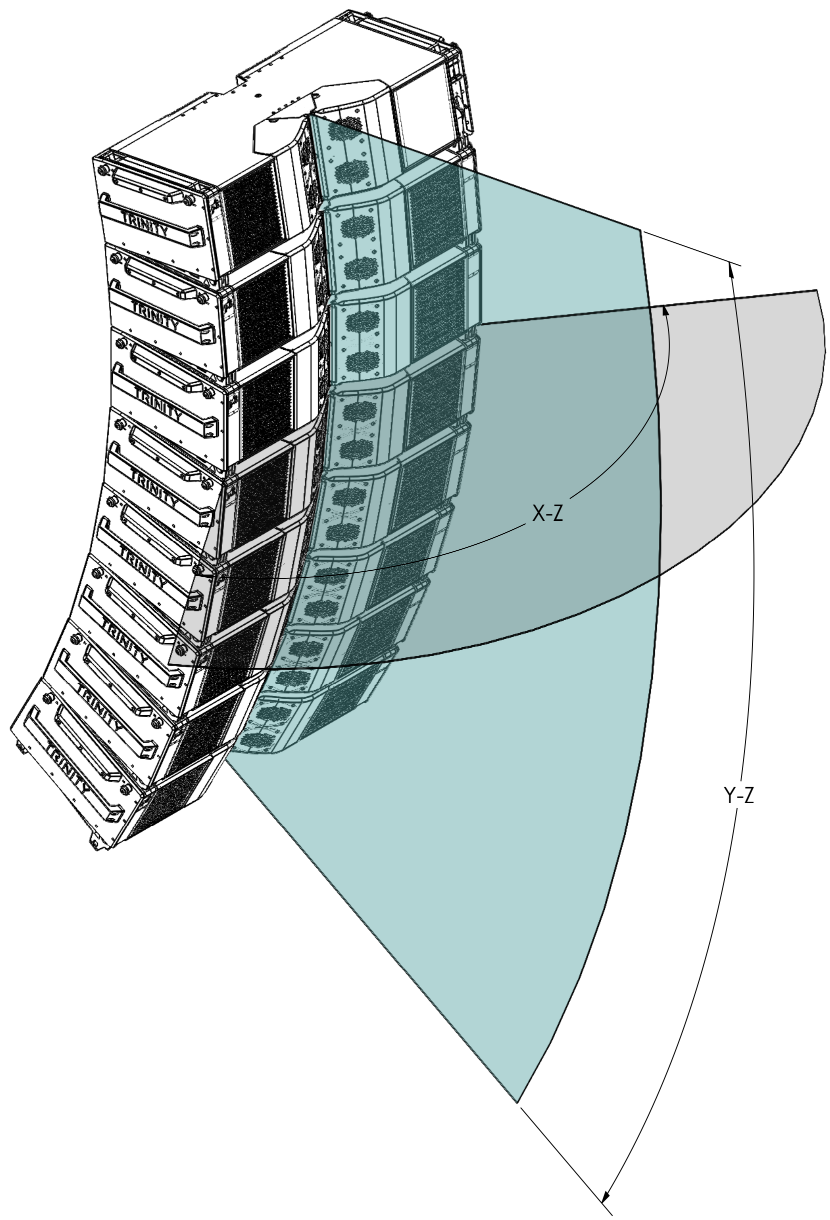

3D Wavefront Control

For the past two decades, innovation in loudspeaker design and application has been consistently linear compared to the exponential advancement in other technology-based industries. The professional audio industry, in general, has been doing things the same way since 1992, when L-Acoustics founder, Christian Heil, first introduced the line array to large format sound reproduction. Despite certain advancements (for example, with ergonomics, allowing systems to be flown more efficiently; with lighter weight, more powerful amplifiers and transducers making loudspeakers smaller and louder; and with cheaper digital signal processing (DSP) power, giving rise to digital steering technology and its noticeable tradeoffs), current technology continues to lack a key component—sound field control. Though venues come in different shapes and sizes, current control technology limits system designers and technicians to working with manual vertical field adjustability, while attempting to satisfy three-dimensional (i.e. vertical and horizontal) constraints. For example, the uppermost boxes in a line array very often require a narrow dispersion, while the middle and the bottom need to be progressively wider. This, combined with almost no ability to adapt to varying room width, avoid boundaries (such as walls), or reduce levels in adjacent areas or sound pressure level (SPL) sensitive areas, leaves even the most well-designed system lacking, simply because the right tools for the job are missing from the equation.

Often, the predictive simulation work done prior to an event becomes obsolete because of last-minute changes inherent in show business, such as having truss flown where the PA suspension points are supposed to be, or delay towers set up 10 meters further apart than anticipated, crowd barriers relocated, reduced audience size due to low ticket sales, incorrect rigging plots, or the many other possible factors that can arise beyond the audio supplier's control. What, then, if it's two hours until doors open? The truth is, we guess. We might guess incorrectly, but by then the band's sound check is 30 minutes away and there is no setup time left. With no time to re-hang an entire PA, technicians are forced to work with digital signal adjustments to compensate for inaccurate physical design, and this is an inadequate solution. To avoid this scenario, what is needed is real adaptability—not just in the vertical field but in all three dimensions, with the ability to effectively make changes, in real time, after the system is flown. This is not possible using loudspeakers with fixed polar directivity or that allow control only in the vertical plane, so PK Sound embarked on the search for a real solution. After years of research and development resulting in several ground breaking patents, PK Sound has succeeded in creating the world's first large format array – Trinity – which has variable remote control of directivity in all three dimensions.

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Behind the technology

The primary technology that allows for real-time 3D adjustments is 3D Wavefront control, which uses electronic actuators located in each loudspeaker module to physically control the horizontal and vertical directivity of the array by changing the shape of the array as well as the directivity of each individual module. The embedded systems in each module which control the actuation system are connected over an Ethernet network, allowing a computer with PK Sound's Kontrol software to remotely access the internal functions of each module and provide safety and DSP functions. Three-dimensional control of the sound field directivity is achieved through the combination of the two subsystems. The vertical dispersion is defined by assigning degree coordinates to each module, curving the array on the Y-Z plane. The horizontal plane is defined through assigning degree coordinates to the left and right sides on the X-Z plane, either asymmetrically or symmetrically. A combination of the horizontal and vertical coordinates allows adjustment of a three-dimensional wavefront that can be contoured to fit the intended listening area.

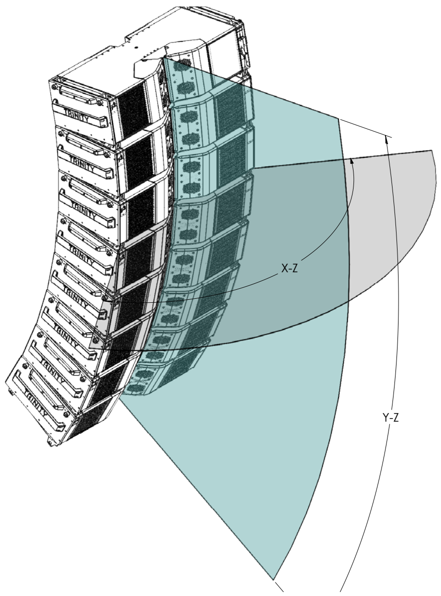

Figure 2 - 3D Wavefront Control

Adjustments to the vertical directivity of the array are accomplished through the rigging system where linear actuators located on both sides of every module are engaged, changing the inter-module angles. This allows the system to be remotely and continuously adjusted with 0.1° accuracy after the array has been flown. Due to the size of large arrays, a specifically designed rigging assembly was created through numerous finite element analysis (FEA) simulations to reduce the load on the actuators by a factor of four.

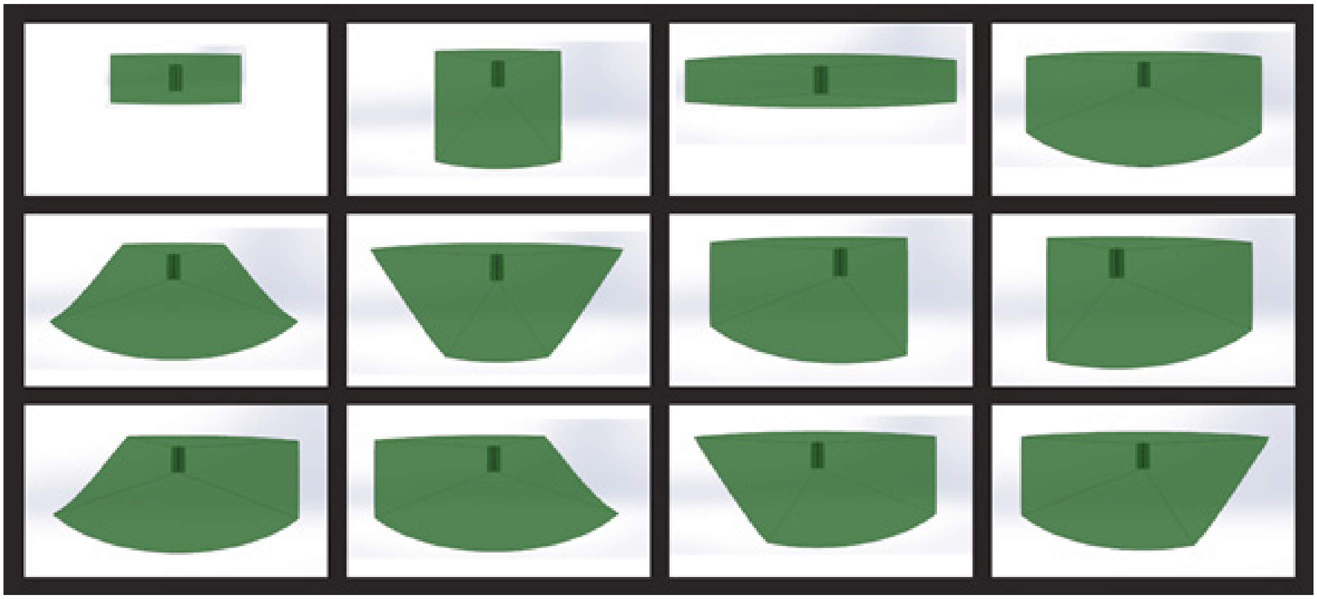

Figure 1 - 3D Wavefront Control Adjustable Sound Field

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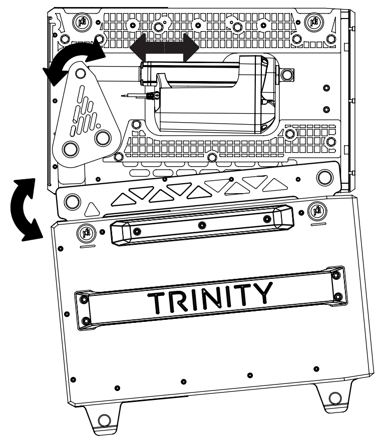

Figure 3 - Vertical Actuation System

The system is designed to transfer the majority of force through the rigging system instead of the actuators. This type of rigging system allows the array to be flown straight and then adjusted after it has been flown, drastically reducing the amount of time and number of people needed to set up the system.

Adjustment in the horizontal plane is achieved through actuation of a variable waveguide which controls the directivity of the mid and high frequency sections. The waveguide is capable of adjustment from 120° to 50° in 1° increments both symmetrically and asymmetrically. However, with this resolution the total amount of available angle combinations would be too great to efficiently manage, as would the loudspeaker data file to incorporate this number of directivity balloons. After over 205,000 individual measurements for 3D directivity, it was determined that 10° would be a sufficiently flexible, accurate increment, resulting in 25 possible combinations of symmetric and asymmetric angles.

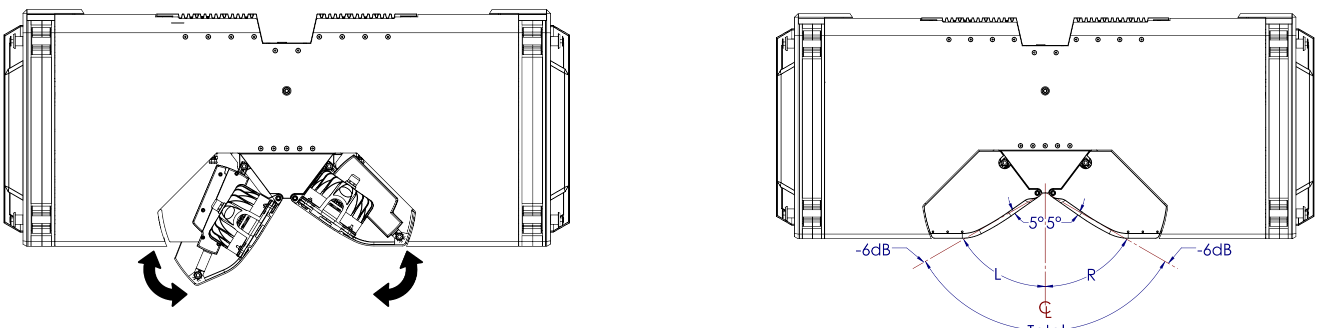

Figure 4- Horizontal Actuation System

SYMMETRIC	ASYMMETRIC L/R & R/L
120°	25–30° / 30–25°
100°	25–40° / 40–25°
80°	25–50° / 50–25°
60°	25–60° / 60–25°
50°	30–40° / 40–30°
	30–50° / 50–30°
	30–60° / 60–30°
	40–50° / 50–40°
	40–60° / 60–40°
	40–50° / 50–40°

Table 1 - Horizontal Directivity Options

The need for sound field control in the horizontal plane

Rarely are venues exactly the same. The need for variable control in the horizontal plane would seem self-evident. There are currently two options for horizontal control. Manufacturers design multiple versions of loudspeakers, which are available in various fixed-directivity increments, in order to cover the intended listening areas. Therefore, the first option is to have many different loudspeaker models and combine them in different ways for each venue. This approach is inflexible and makes inefficient use of inventory, resulting in lower return on investment per loudspeaker. The second option is to try to use loudspeakers as available in a given inventory and make compromises with the sound field. The ideal solution goes beyond these: using loudspeakers with variable control of the sound field in the horizontal plane so that a single loudspeaker module can be used for a multitude of different, changing environments. This allows the loudspeaker to adapt to narrow or wide rooms, progressively tapered audience shapes and narrowing coverage requirements for long throw cabinets. It would allow avoidance of boundaries or SPL sensitive areas and improve combinations of multiple arrays to achieve wider coverage. Figure 5 shows a small sample of the vast number of diverse venue configurations, each with unique requirements for horizontal coverage.

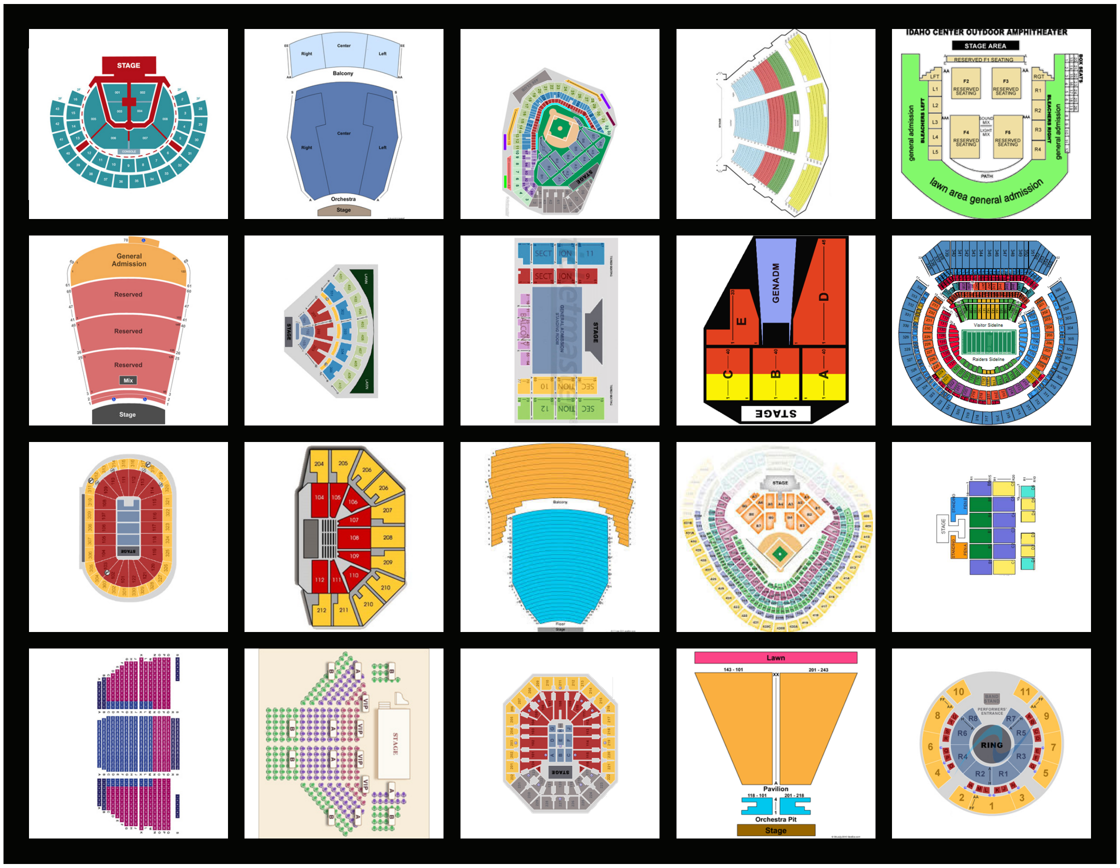

Figure 5 – Sample Variety of Venue Shapes

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Trinity provides 25 individual horizontal directivity options that can be arranged in any order in the array and fine-tuned on the fly to make meaningful changes. This flexibility allows users to change the horizontal directivity of the system to suit any number of audience configurations in a multitude of different venues. Figure 6 outlines the available directive options in each module.

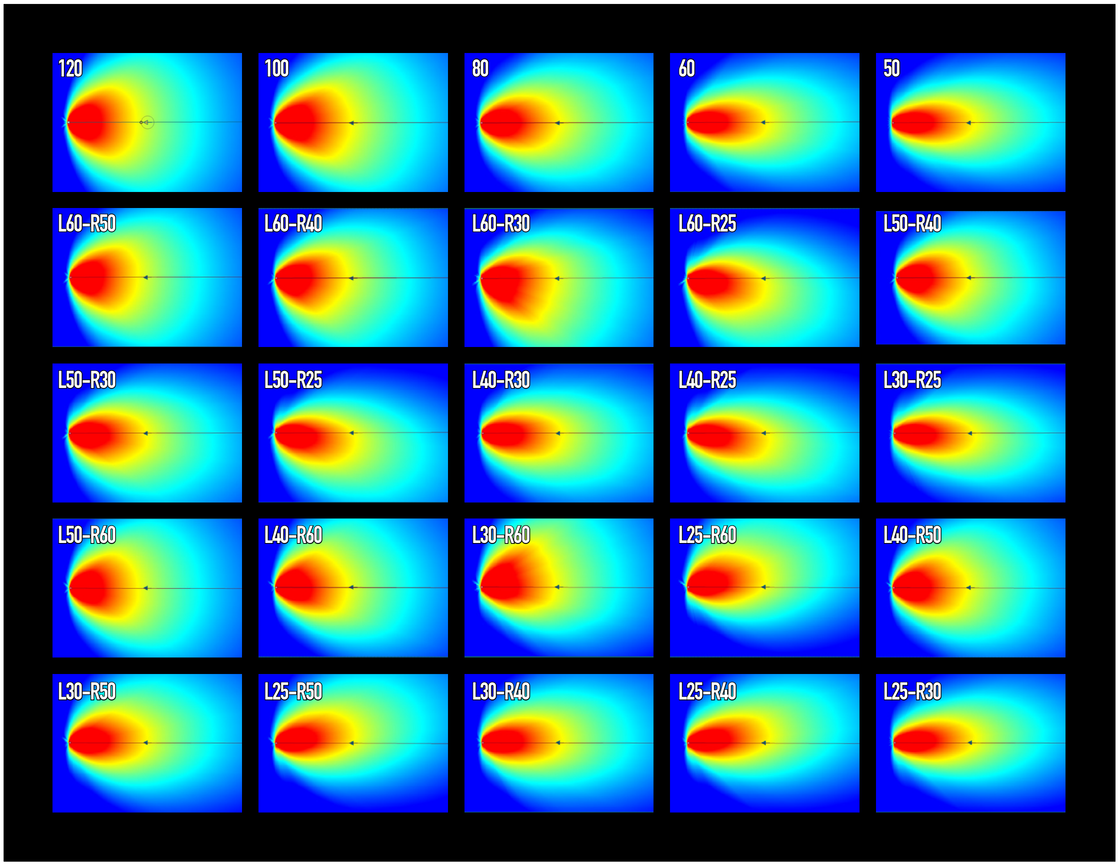

Figure 6 – Trinity Horizontal Directivity

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Reducing the noise floor

The ability to focus the sound field has far-reaching applications for noise floor reduction and improved sound quality in any venue with reflective boundaries near the audience. If we consider the simple example of a square room with a flat audience, we can quickly see the benefit of having modules with variable horizontal directivity. Figure 7 shows how we currently consider directivity when limited only to the vertical plane. With a traditional line array, one would assume we have good coverage of the venue.

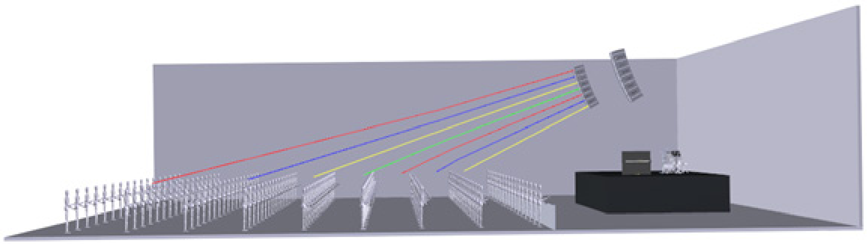

Figure 7 – Venue Side View

However, Figure 8 – the isometric view of the same setup – shows what is truly occurring. Traditional loudspeakers have fixed horizontal directivity; therefore, a significant portion of the sound field first collides with the walls, then reflects back onto the audience. This increases reverberation, excites the room and raises the noise floor, reducing sound quality and intelligibility.

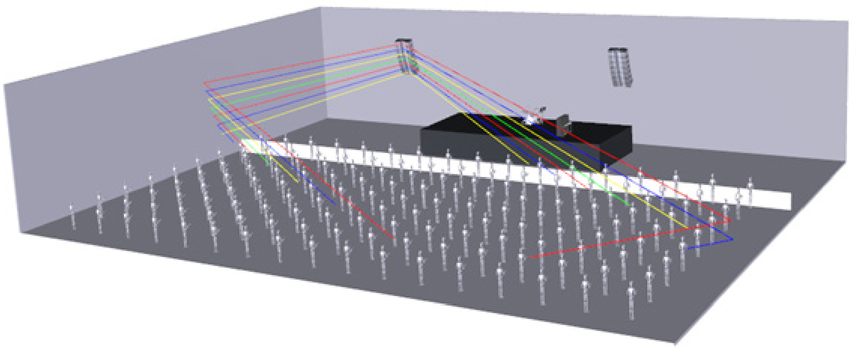

Figure 8 - Venue Isometric View

The human body is an extremely effective acoustic absorber – almost four times more absorptive, in fact, than a typical 4-inch absorber commonly used for sound treatment . The sound field should be focused on the audience to improve sound quality in the room by reducing spill onto reflective surfaces. In the case presented, as well as many other common situations, this requires that the top loudspeakers of an array have a narrow coverage, which gradually increases in width towards the bottom of the array.

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Figure 9 shows the system with variable horizontal control and a tapered horizontal coverage on the stage-right side. The sound field is directed not at the structure but at the intended audience zone which, being an absorptive surface, will increase sound quality and intelligibility across the venue.

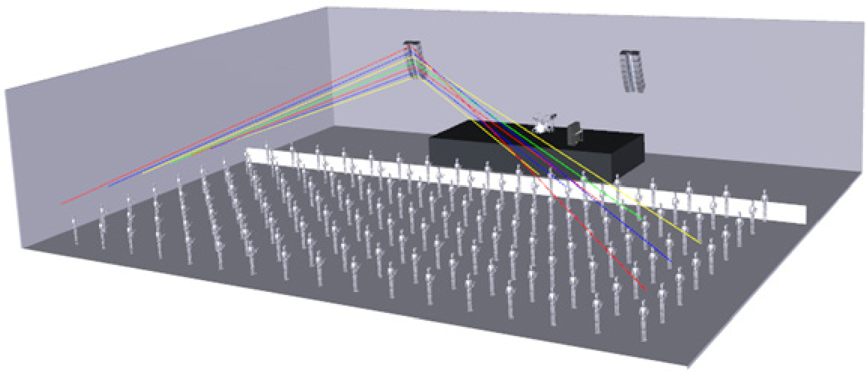

Figure 9 – Venue Isometric View w/variable directivity

Reduced noise pollution into adjacent areas

A second very common scenario is an outdoor show surrounded by residential areas with strict sound ordinances. Here, the goal is to reduce the level of the system as much as possible in every direction and contain the sound field to the audience alone. While there are products that claim to achieve this, they address only two dimensions (height and depth). There is no control over the width of the sound field toward the sides because the horizontal directivity of a standard loudspeaker is fixed.

By controlling horizontal directivity, the Trinity system can focus the left and right of the sound field into the audience and avoid spill-over into adjacent areas. The following Ease Focus models (Figure 10 and 11) show an example of a simple target audience area (bounded by the solid black line) where Zone 1 and Zone 2 depict areas of desired reduction in the overall SPL in order to adhere to noise restrictions. The broadband SPL maps in Figures 10 and 11 compare two line arrays: 10 shows a standard array with fixed horizontal directivity; 11 shows a system with variable directivity demonstrating the reduction of SPL in the unwanted areas, increased SPL and greater consistency across the audience.

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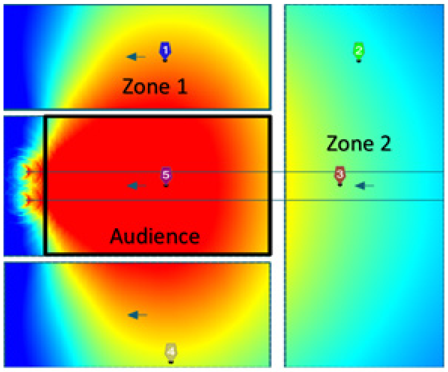

Figure 10 - Standard Line Array

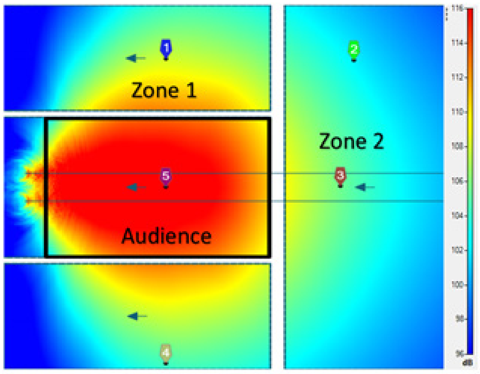

Figure 11 - 3D Wavefront Control

Table 2 below shows the A-weighted SPL difference at the five receiver locations, clearly illustrating the positive impact of 3D Wavefront control on SPL reduction in unwanted areas.

Where Figures 10 and 11 demonstrate control over the horizontal field, Figure 12 below demonstrates height and depth control. Properly designed line arrays already have effective control of the sound field in the vertical plane because of the very tight directivity in the high frequencies and natural off-axis cancellation in the lower frequencies. Therefore, vertical control is achieved by aiming the system with sufficient downward angle to ensure it does not extend past the far edge of the audience, splaying the vertical adjustment to evenly cover the target audience area, and applying the correct gain settings to the array. This technique, when combined with the horizontal control, achieves consistent vertical coverage while containing the sound field within the intended area.

	Receiver 1 (dBA)	Receiver 2 (dBA)	Receiver 3 (dBA)	Receiver 4 (dBA)	Receiver 5 (dBA)
Standard Line Array	115.2	104.9	108.3	110.7	116.3
3D Wavefront Control	106.1	101.0	106.2	104.5	118.5
Measured Difference	-9.1	-3.9	-2.1	-6.2	+2.3
Normalized Difference	-11.4	-6.2	-4.4	-8.5	0

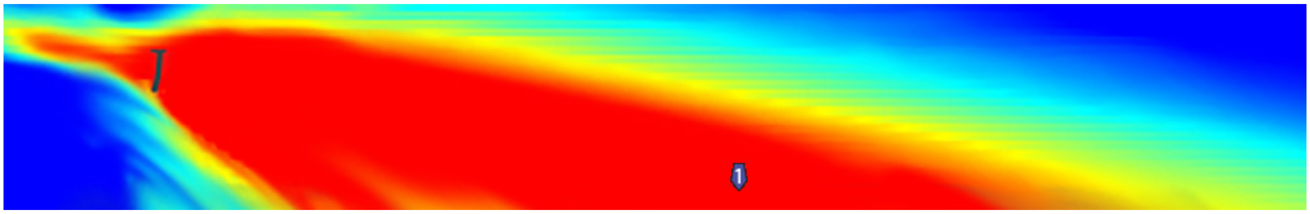

Figure 12 - Vertical Directivity Control

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Improved stereo image

Most sound systems have symmetrical directivity. However, loudspeaker direction is almost always perpendicular to the stage, which means a large portion of the audience does not receive an appreciable stereo image, shown in Figure 13. The effect is more dramatic with systems that have a fixed directivity of 80 degrees or less. Quite often the loudspeaker position can be too close to a boundary or the outside of the audience zone and usually, because of rigging constraints or aesthetics, the array is flown parallel to the room. By including asymmetrical coverage options, the outer edge of the sound field can be narrowed to avoid boundaries. Simultaneously, we can widen the inner coverage to provide a better stereo image for more of the audience, therefore improving the experience for a larger number of attendees, shown in Figure 14.

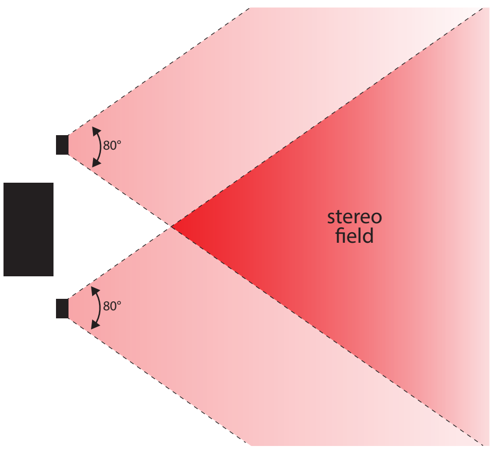

Figure 13 - Standard Symmetric Sound Field

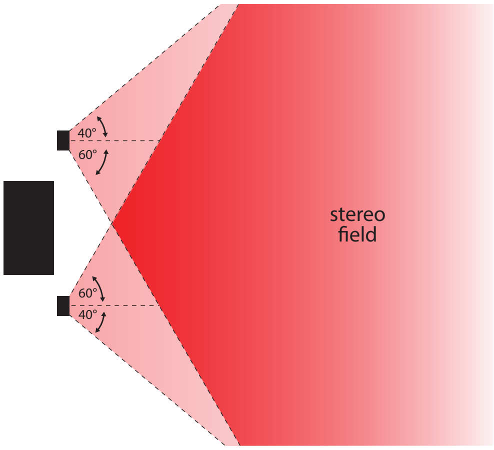

Figure 14 – Improved Stereo Sound Field

The advantage of increased sensitivity

As sound travels thought the air, a dampening effect causes a progressively increasing reduction of SPL at increasing frequency. In many cases, the uppermost enclosures in an array require additional high frequency output in order to overcome the effects of this attenuation. Simultaneously, these enclosures require more narrow directivity because of their projection distance. The effect becomes increasingly important above 25 meters. Figure 15 shows the sound attenuation effect from 25m to 100m.

The current solution to overcome attenuation is simply to increase the high frequency (HF) output by increasing gain. While this approach can work, it requires extra high frequency drive units and power. More importantly, it has the negative impact of increasing the overall noise floor in the room due to additional unwanted boundary reflections. It will also increase noise pollution into adjacent areas.

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Alternatively, a variable waveguide enables increased sensitivity of the high frequency system by increasing directivity. By reducing the coverage angle from 120° to 60°, the radiating space of the waveguide is reduced by half, which provides an increase in sensitivity of 3dB, as shown in figure 16. This effect focuses the sound, keeping reverberation low while increasing the system's output capability. In order to achieve the same output increase in a traditional system with fixed directivity, either power would need to increase twofold or the number of HF drive units would need to double. Increasing the sensitivity of the system requires less HF drivers and achieves higher output while reducing power compression, stress on the transducers, and the weight of each module.

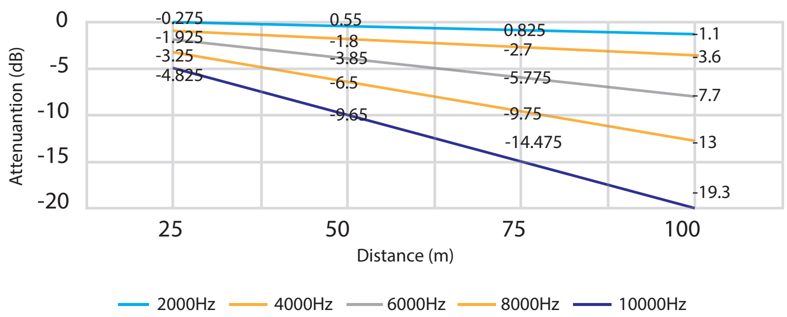

Figure 15 - Sound Attenuation vs Distance

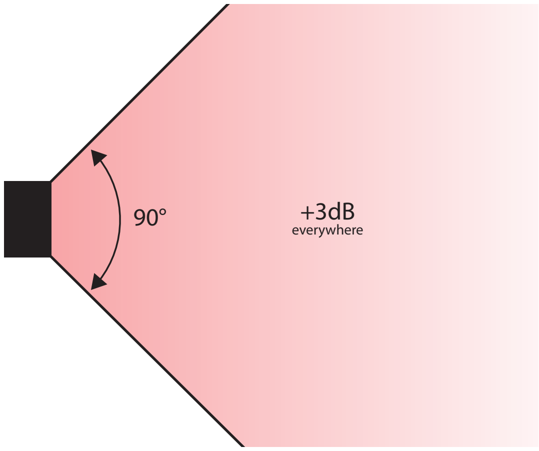

Figure 16 - Increased SPL via Gain

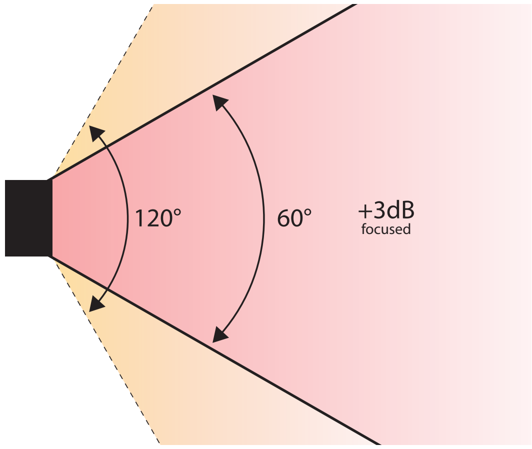

Figure 17 - Increased SPL via Directivity

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The advantage of 0.1° resolution

Manual rigging systems use a pre-defined number of holes in the rigging to adjust inter-cabinet angles. The vertical resolution possible in manual rigging systems is limited by the number of holes that represent each pre-defined angle. The less holes, the less precise the vertical resolution. For available angles between modules in a given line array, manual rigging systems have limitations in both accuracy and options because of the physical constraint of a limited amount of space for holes for quick release pins. A variable rigging system, however, has no such limitations. Vertical resolution can be set with 0.1° accuracy between the minimum and maximum vertical range.

By increasing accuracy of the loudspeaker array's vertical directivity we can more evenly cover the audience, especially at long distances. The goal of loudspeaker implementation should always be to have the system as perfectly aligned physically before adding any types of DSP manipulation. The two figures below show the difference between 0.5° and 0.1° of accuracy in the vertical plane. Notice by comparing Figures 18 and 19 how the incident angles are more consistently spaced across the audience from front to back.

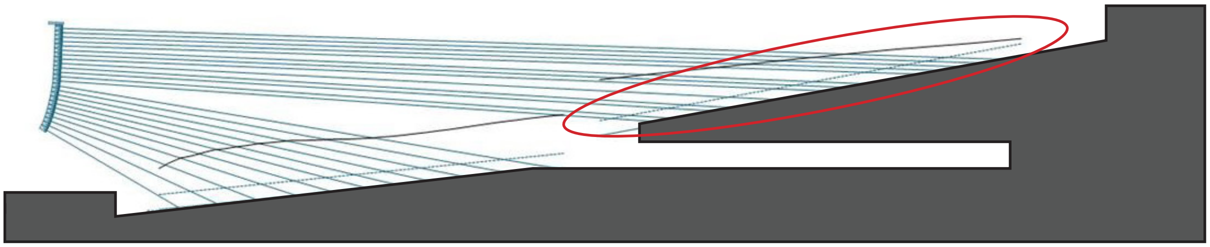

Figure 18 - 0.5° Vertical Resolution (inconsistent angular distribution)

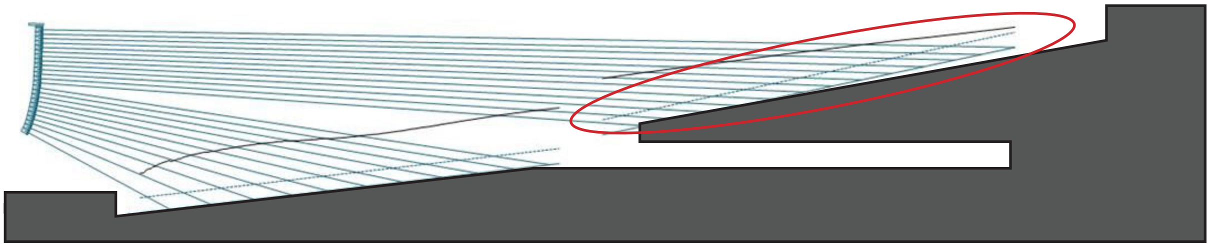

Figure 19 - 0.1° Vertical Resolution (smooth angular distribution)

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Remote control

Systems equipped with 3D Wavefront Control, can be adjusted remotely via PK Sound's Kontrol software from a computer. This application enables users to apply changes to the horizontal and vertical directivity of the array as well as DSP functions. Remote control adjustments can be made after the line array has been flown, in real time, by selecting individual or groups of modules and adjusting the inter-module or waveguide angles. The software also integrates safety features based on load calculations which limit the motion of the array to maintain specified safety factors.

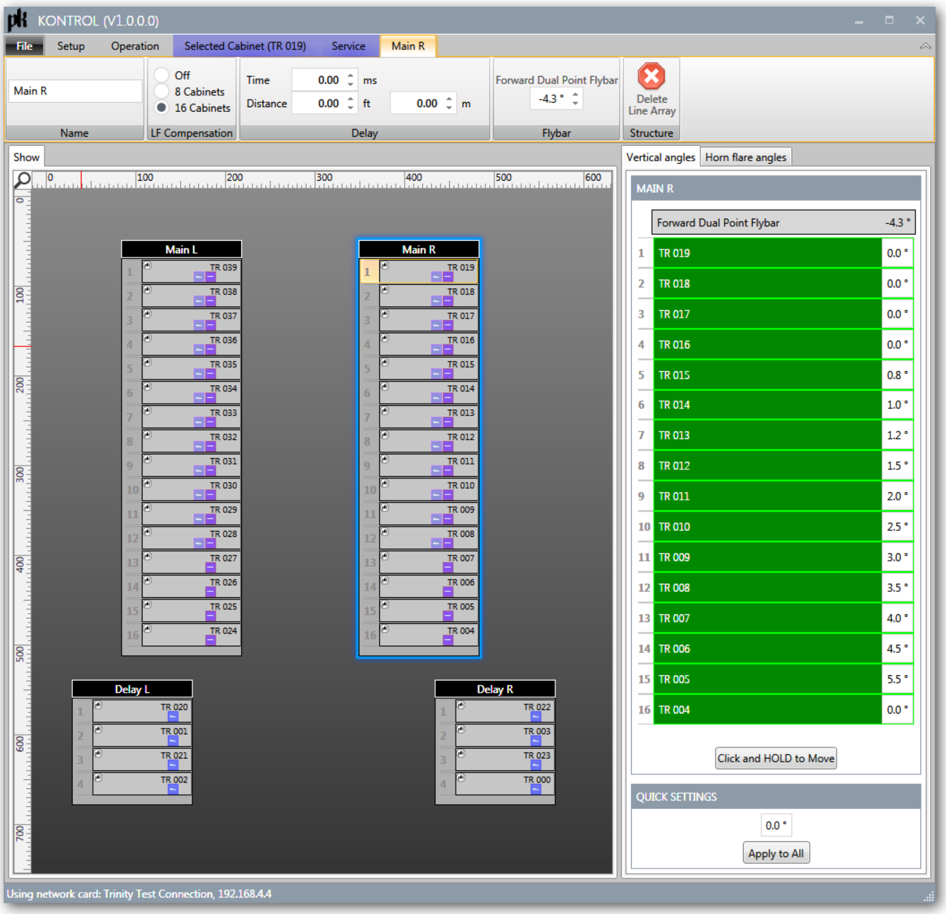

Figure 21 - Remote Software Application

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Real time adjustment

Systems equipped with 3D Wavefront control have the unique ability to adapt easily to different venues and changing conditions remotely. As noted earlier, it is not unusual to arrive at a venue after you have done predictive simulation, only to discover that the stage layout, rigging plot, or audience area has changed. It could also be an event where day to day the audience area changes or there are many more or less attendees than expected. Most engineers have encountered these problems. The ability to change the system in real time, remotely, provides tools to deal with each of these problems easily, in minutes. We can now widen, narrow, shorten or lengthen the sound field with a few simple clicks of a mouse in order to overcome the challenges of a constantly changing environment.

The variation in venue shapes and sizes is another issue. Even the same venue can be set up in a variety of different configurations. These changes most definitely have variability in the required three dimensional coverage, so having the ability to control only the vertical coverage of an array is insufficient. Venues are wide, narrow, offset, tall and short. They have tapered seating, balconies and audiences on the ground. Each of these configurations requires changes to the three dimensional directivity of the array.

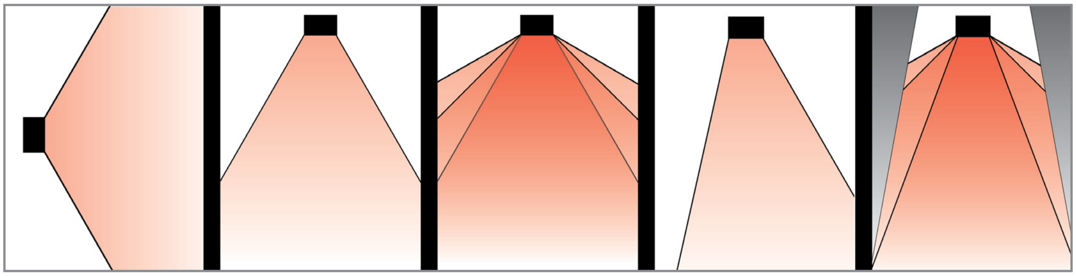

Figure 22 - Adjustable Directivity

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The advantage of flying the sound system straight

The ability to fly the loudspeaker array straight and then make the necessary angular adjustments has a number of direct benefits. It's faster, it's easier, it takes less people and it's safer. Because the rigging system is designed with a tapered, self-aligning assembly, the suspended boxes are lowered straight onto the next modules, the pins are inserted, and the array is lifted.

This eliminates cumbersome rigging links where fingers can be pinched, and there is no manual lifting of modules or attempts to curve the array under its own weight to insert pins in the correct hole. Thus, 24 modules can be suspended in significantly less time with increased safety and reduced complexity.

The advantage of flying the sound system straight can be illustrated by the following simple rigging steps:

1. Install rigging arm
2. Lift modules and remove cart
3. Lower and connect next four modules
4. Repeat until desired number of modules are connected

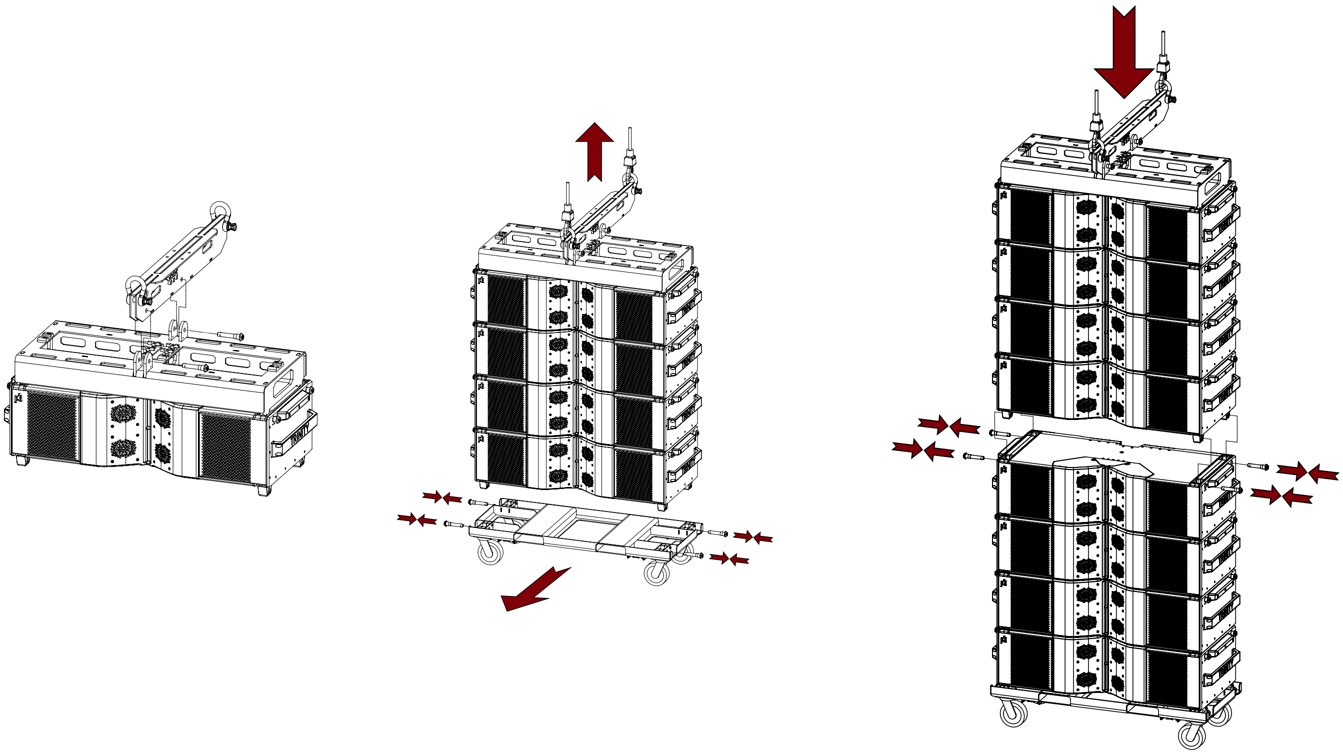

Figure 23 - Rigging Instructions

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Simple and practical use

An interesting advantage to systems that physically move in order to control the sound field is that any change made is visible, thus users can intuitively see how changes will affect the sound field. As with a normal loudspeaker, the direction a module points is generally the path along which the sound will travel. To change the sound field, the module moves; there is no mystical computer processing happening in the background, where users really don't know what's going on or to what extent the source signal is being manipulated to achieve the desired result. It's deceptively simple, but by following the centerline of the module and the angle of the waveguide the user can see and hear fairly closely the directivity of the sound field.

Figure 24 - Local Module Control

Secondly, whether we like to admit it or not, engineers will eventually encounter situations in which there is simply not enough time to hook up the computer network, let alone spend time plotting the venue to achieve good results. In this case, the system can work using a point-and-shoot approach by simply flying the array and using the local control on the back of each module (shown in Figure 24) to set both the horizontal and vertical angles. Because the system is intuitive and users can see in real time any changes made, a suitable setup can be achieved within a few minutes. More importantly, necessary changes can be made quickly and efficiently. Although this is certainly not the recommended way to deploy any system, the touring world can be unpredictable, and it is advantageous to have this additional capability to perform on-the-fly adjustments.

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Reduction of DSP manipulation to achieve results.

One of the first fundamental rules taught to audiophiles and audio engineers is: the less manipulation of the source signal the better. A pure unaltered signal accurately transferred from the artist to our ear should be the goal. With today's access to technology, we have a vast array of complex tools to solve problems. For engineers, it's easy to forget the basics in favour of a complex new approach. When designing a loudspeaker system the physical design must first provide a solid and transparent foundation that allows music the be reproduced without coloration. Loudspeaker acoustic engineering design is a painstaking process of enclosure design, transducer selection, and thousands of hours of A/B comparisons, both by measurement and by ear. Spending a significant amount of time getting basic attributes of the physical design correct – before trying to digitally "fix" a problem– leads to a better experience with less acoustic compromise.

When PK Sound set out to meet the challenge of achieving variable three-dimensional control of the sound field, the same principle was applied: maintaining a simple, intuitive design philosophy. By the inherent nature of its design a line array is already a set of complex phase, gain, and delay interactions between a large number of drivers. Instead of relying on complex DSP algorithms that exacerbate these complex interactions, PK chose to improve and automate the proven approach of physically aiming the speaker, providing greater adjustability and higher precision with the ability to remotely control it from a laptop. This approach dramatically improves sound quality when compared to systems that use beam steering to manipulate the source signal and aim the sound. Where digital steering sacrifices efficiency and output for the ability to steer the sound, 3D Wavefront Control increases sensitivity and therefore output by more precisely focusing the sound.

Conclusion

Not all venues are created equal. In order to address the multi-faceted challenges of varying venue dimensions, the industry needs a loudspeaker that permits control of directivity in both the vertical and horizontal planes. 3D Wavefront control is the first technology to address this need flexibly and remotely, allowing users to adjust a system to a room in three dimensions and make meaningful decisions that positively impact the sound quality in any given location. It does so without the need for drastic DSP manipulation while increasing coherency and output. 3D Wavefront control allows the user to focus sound where it is intended, reduces reflections, and avoids spill into adjacent areas. It dramatically improves the engineer's toolkit, is simple and effective for reducing setup times, and improves the experience of the entire audience.

CANADIAN OFFICE • 403.452.6004
BAY 133 – 2634 45 AVE SE, CALGARY ALBERTA, T2B 3M1

WWW.PKSOUND.CA

US OFFICE • 415.845.0132
2919 WHIPPLE RD. UNION CITY CA, USA. 94587