Everywhere A Line

The RH line array blueprint

By Ralph Heinz

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There are several very practical reasons why line array loudspeaker systems have replaced horizontal arrays for many portable sound reinforcement applications. For a given performer, playing at the same volume in the same venue, a line array may be smaller, lighter, and easier to hang. It will probably occupy less truck space and require a smaller crew to rig/fly.

The new STLA line array from Renkus-Heinz.

In venues with the proper geometry, line arrays that are properly hung, aimed and curved can provide most of the audience with a very satisfying sonic experience.

But – is a "line array" a line source?

The quick answer is "sometimes." A line source is a line of equidistant drivers: the earliest products in this configuration date from the 1950s and were used to increase speech intelligibility in reverberant environments.

As has been well documented, a line source works by creating a very narrow vertical dispersion. At 0 degrees vertical dispersion, a "cylindrical wave" is generated. The cylindrical wave's energy decreases by 3 dB every time the distance from the source is doubled, whereas a spherical wave's energy drops by 6 dB per distance doubling.

There are two conditions for line source behavior. The first is that the line has to be at least four times as tall as the wavelength it is radiating for a vertical pattern that is a reasonable approximation of a plane wave.

A second requirement is that the sources on the line have to be less than 1/2 wavelength apart. This is the inverse of the first requirement. Olson[1] calculated in the 1940s that two adjacent sources radiate a spherical polar pattern (i.e. sum coherently) when they are less than 1/4 wavelength apart. Between 1/4 and 1/2-wavelength spacing the pattern narrows, but side lobes (interference patterns, caused by destructive interference) do not appear until the spacing is greater than 1/2 wavelength.

What does this mean in practice? Only very long line arrays can function as a line source at low frequencies, while only very short modules can couple at high frequencies. In the real world, the actual range of line source behavior is typically less than one octave. The answer to the question of whether a line array is a line source is "almost never." (For more about this topic, see *Live Sound* Senior Technical Editor John Murray's thorough discussion in the November 2004 issue.)

So – if it's not a line source, how does a line array work?

Line arrays are famous for their ability to provide even sound pressure levels from the front to the rear of the coverage area. To understand why, let's review some common practices in the design of sound systems using conventional horns and compression drivers.

The loudspeakers in a horizontal array are designed to cut a spherical wave front into pie-shaped sections of 60 degrees by 40 degrees, 90 degrees by 40 degrees or whatever the horn designer thinks will work well in a good range of venues.

If covering a relatively small area, even SPL from front to rear can be attained by aiming the center of the vertical pattern at the back row and the lower edge (the - 6 dB point) at the front row. With a high enough hang point, the loudspeakers can be aimed so that the distance from the horn to the front row was half the distance to the back row. Then the effect of the horn's dispersion control would balance the distance effects and SPL would be even from front to rear.

If architects would only build public venues to suit commonly available horn patterns, and keep them small enough so that one loudspeaker could cover each side of the audience, we would never need line arrays. Of course, this is not the case, with venues coming in all shapes and sizes.

A line array can deliver 18 dB to 24 dB more output than a single loudspeaker, and its vertical pattern can be shaped to the venue by varying the curvature of the array. Just like the properly aimed and located constant directivity horn, the correctly curved line array delivers equal power to equal areas of the audience.

This implies that as you get closer to the array, each module has to radiate into a larger included angle, so the splay angles between modules must increase as you move from the top to the bottom of the array. Therefore, in most venues, the array shape that produces consistent SPL from front to rear is the near-ubiquitous "J" shape.

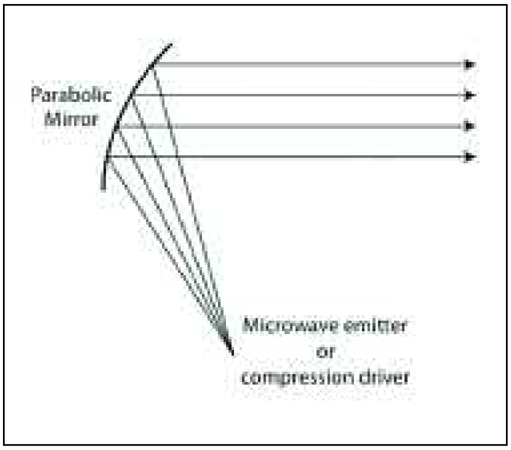

Figure 1: Whether for microwaves or sound, reflectors operate on a "ray" model.

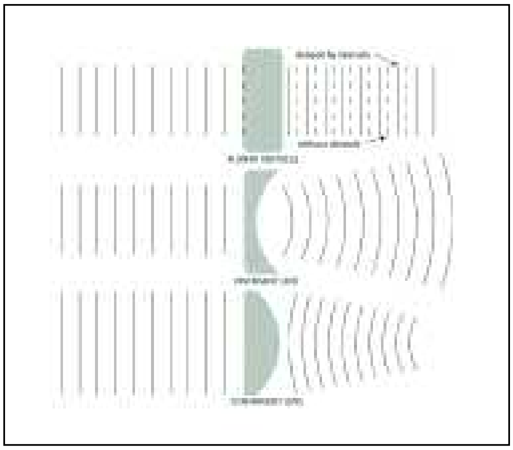
Figure 2: The effects of different lenses.

FUNCTIONAL REQUIREMENTS

When acoustic requirements for line source coupling and J-shaped arrays are combined with the practical benefits desired, the design goals for a line array module become clear:

- Full bandwidth.
- Axial symmetry so that left, right and center clusters behave identically.
- Driver selection and enclosure design such that all cone drivers are crossed over below the frequency at which acoustic centers are more than 1/2 wavelength apart.
- Flat or very narrow (less than 10 degrees) vertical pattern in the waveguide for frequencies above the point where acoustic centers are greater than 1/2 wavelength apart.
- Waveguide exit must occupy at least 80 percent of the height of the module in order to produce a "continuous" wavefront.
- Minimal size and weight for the available output.
- Simple, fast and reliable flying hardware; ditto cabling and signal routing.
- Array design software that makes accurate coverage predictions while facilitating the specification of array length, positioning, aiming and curvature.
- Where multiple drivers are used in a given frequency band, their horizontal spacing should be close enough to provide consistent dispersion across the operating band.

Over the past decade, a variety of new waveguides have been developed to enable a line array's output to be shaped by varying its curvature. These new approaches are broadly classified into four main types: ribbons, horns, reflectors and lenses.

The ribbon is subject to the same limitations as any other line source. A typical high-output ribbon is about 6 inches high and will be usable as a line source up to 4.5 kHz. Above that frequency the acoustic centers will be more than 1/2 wavelength apart and will generate side lobes due to destructive interference.

Conventional horns can be designed for relatively constant vertical pattern, but there are limitations imposed by geometry. Recall that the horn mouth has to occupy at least 80 degrees of the enclosure height. A 10-degree conical horn with a mouth opening of 12 inches (.3 meters) must be almost 5 feet 9 inches deep.

A second issue with conventional horns in conventional enclosures is the separation of acoustic centers. The acoustic center of a compression driver/horn combination is the compression driver's exit into the horn. For an array module with two 12-inch cones on the low end, a single 2.5-inch or 3-inch voice coil compression can produce more than enough high frequency energy to equal the output of the woofers.

But if we place a single compression driver and horn in an enclosure 15.5 inches high, the adjacent drivers will be about that far from each other, and cannot couple as a line source above 437 Hz. This is well below the compression driver's crossover point[2].

IN THE MICROWAVE?

Reflective waveguides have been long been in use – for microwaves, not audio. But it happens that the wavelengths of microwaves and sound waves are nearly the same. For instance, sound at 13.55 kHz travels through the air at 1129 feet per second, with a wavelength of 1 inch. Microwave radiation at 11.78 GHz travels at the speed of light (186,000 miles/second) and also has a wavelength of 1 inch.

Whether for microwaves or sound, reflectors operate on a "ray" model: the wavelength of the impinging energy is so short that all of it is reflected (**Figure 1**, previous page). The ray model is valid over a limited frequency range: lower frequencies with longer wavelengths will be refracted or diffracted when they encounter a boundary, instead of being reflected.

Like reflectors, lenses have been used to control both microwaves and sound for decades. There are two types: the "obstacle array" and the "path length refractor." The obstacle array works exactly the same way a glass lens does when it focuses light: the obstacles (which can be spheres, discs, strips or irregular shapes, as long as they are small in relation to the frequencies involved) slow the sound as it passes through the lens. An obstacle array lens can produce a concave convergent, convex divergent or planar wave depending on its shape (**Figure 2**, previous page).

A piece of foam can provide the irregular shaped obstacles required for this type of lens. However, the particular material chosen will function only over a limited bandwidth.

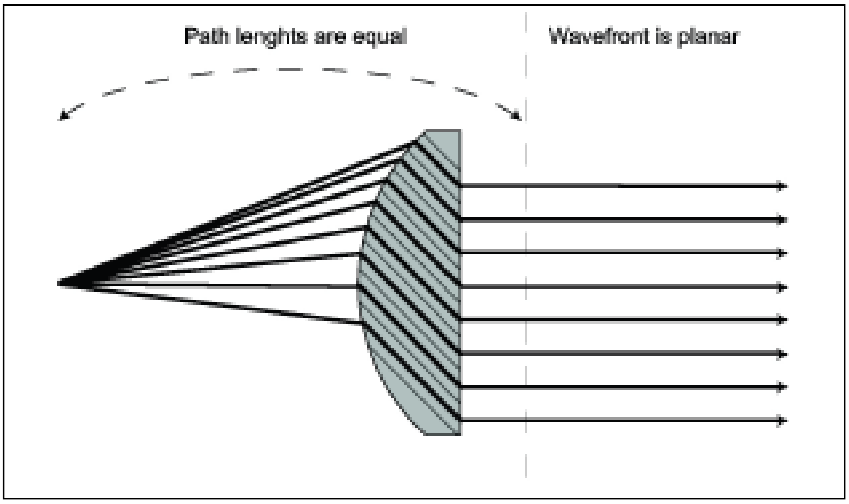

Figure 4: The path length refractor can generate planar wavefronts over a wide operating band.

Above a certain frequency, the material will absorb sound, converting the energy into internal motion and heat. Below another frequency, the irregular shapes will be too small to act as an obstacle array, and the sound will pass straight through no matter what shape is used. These frequencies are, of course, specific to individual materials.

The path length refractor uses plates (again with spacing that is small compared to the wavelengths in question) to force the sound to travel a greater distance than it would otherwise. Plates can be arranged in a zigzag pattern or simply slanted relative to the path of the sound to be refracted.

Although the slant lens looks as though it should be altering the direction of the sound, it does not. The added path length merely alters the arrival time of the pressure wave, not its direction.

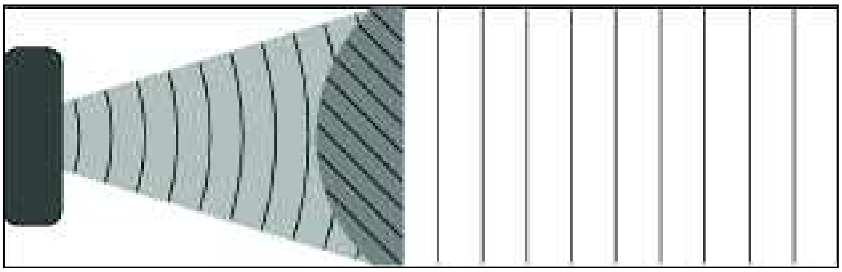

Figure 3: A look at the STLA waveguide.

In order to be able to produce a continuous, coherent wavefront that can be shaped by curving a vertical array, we need to radiate a more-or-less planar wavefront from an opening that is at least 80 percent of the enclosure height. Theory and measurement show that a wavefront whose curvature is less than 1/8 of a wavelength is effectively flat and will propagate as a plane wave.

CONTINUOUS WAVE FRONTS

What did all of this tell us as we set about designing the Renkus-Heinz (RH) STLA line array loudspeaker system? Let's start by looking at a schematic of the waveguide used in a STLA module (**Figure 3**).

The pattern control techniques that have been borrowed from microwave research are useful for creating continuous high-frequency wave fronts, since the dispersion angle is independent of the path length from the driver to the waveguide exit, and therefore from the horn geometry. As a result, we believe that our Path Length Equalization Technology used in this device has a significant advantage over the other techniques illustrated in **Figure 1**, however.

Reflectors and obstacle arrays can be highly effective, but over a relatively narrow bandwidth: perhaps four octaves. This limitation is due to the transition from the "ray model" (reflection) to the "wave model" (refraction and diffraction) that occurs as wavelengths become long in relation to the reflector or the obstacles.

The path length refractor, however, can generate planar wavefronts over a wide operating band. When higher frequencies pass through the device, it operates on the "ray model," as seen in **Figure 4**.

What happens at lower frequencies, when the "wave model" takes over due to the longer wavelengths? The path length refractor lens then functions as a closely spaced array of diffraction slots.

This is where the RH CoEntrant design (patented) comes in, by integrating the output of a cone transducer and a compression driver into a single high output, wideband point source. Coupling these devices with RH Complex Conic horns has generated a number of highly effective horizontal array modules.

Specifically, the new CDT 1.5 CoEntrant driver has been developed for use in high output line array modules. It integrates a 6.5-inch carbon fiber cone with a 2.5-inch voice coil compression driver. The CDT1.5 can be crossed over as low as 350 Hz, allowing a properly designed waveguide to control dispersion over a frequency range of almost six octaves.

Because of its ability to function as a diffraction slot array at lower frequencies and as a path length refractor at higher frequencies, our Plane Wave Generator is able to control vertical dispersion over the entire operating bandwidth of the CDT1.5. A vertical array of these devices will produce a coherent wavefront from 350 Hz to 19 kHz.

As a result, the sound system design can shape the vertical dispersion of this wavefront by altering the splay angle between modules. As mentioned earlier, this is the key to adapting the array's output to a particular venue, in order to deliver consistent SPL from front to rear.

THEORY & CONFIRMATION

In the region below crossover from the waveguide into direct radiating cones, the "J" shape does tilt the main lobe downward and broaden the bottom edge, but this effect is only approximate. Control of dispersion is much more precise in the operating band of the waveguide. Assuming a good approximation of a continuous, coherent wavefront, the waveguide-directed output will closely follow the J curvature of the array, and output will be much more consistent from front to rear.

Theory suggests, and observation confirms, that for short lines the sound at the rear of the coverage area will be "thin," because higher frequencies will be projected more consistently than low frequencies. For longer lines the reverse is often true: there can be a narrow low frequency lobe that is aimed mainly at the upper tiers of seating, despite the tilting and broadening effect of a "J" curvature.

STLA line array modules cross over from a pair of 12-inch cones to the CDT1.5 CoEntrant Driver and Plane Wave Generator at 350 Hz. Since all frequencies above 350 Hz are being controlled by the waveguides, they will follow the array's curvature closely. This wideband coverage control generates the expected benefits: not only consistent SPL but consistent frequency response and timbral balance from the front to the rear of the audience area.

Line array modules should be symmetric on axis so that the same module can be used for left, right and center clusters. To reproduce the low frequencies, many line array modules use a pair of large cone drivers at the ends of the enclosure. This is an approximate and frequency-dependent pattern control technique, which depends on interference effects[3].

A side benefit (pun intended) of the CDT1.5 is that it allows the STLA's 12-inch woofers to be close together because there is no separate midrange section. The reduced horizontal spacing, combined with a low crossover point into the CDT1.5 CoEntrant Driver, enables the STLA to provide consistent horizontal dispersion over a full two decades: from 200 Hz to 20 kHz.

Not all audience areas are shaped in nice, neat rectangles, but many of them are. In this situation, it's useful to have different horizontal patterns for the top (long throw), middle (medium throw) and bottom (short throw) sections of the array.

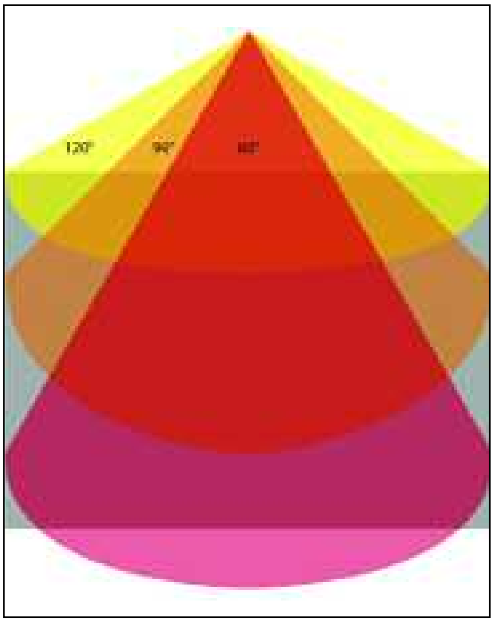

Figure 5: Wider at the bottom? Useful for handling the edges of the coverage area.

Figure 5 shows how wider horizontal dispersion at the bottom of the array helps cover the edges of the audience. With a single horizontal pattern we would have to choose between leaving the sides of the front rows in acoustical "shadow" or bouncing excessive energy off the side walls, thereby creating a large reverberant field and degrading the intelligibility and clarity of the sound in the audience area.

Because the PWG is not a conventional horn we can make the mouth of the device a diffraction slot. The width of the horizontal coverage can then be varied by replacing part of the front baffle. This can be done at the factory, in the rental warehouse or even at the venue itself: the procedure is simply removing and replacing a few screws.

PRACTICAL CONSIDERATIONS

The vertical pattern control technique is a "path length refractor" type of acoustic lens, which has a wide operating band. This technique complements the wideband point source CDT1.5 drivers effectively to control both midrange and high frequencies. We believe that waveguide control (as opposed to line source control, horizontal spacing or other fixed-geometry, dimension-dependent techniques) of both midrange and high frequencies maximizes the usefulness of the adaptable "J" curved vertical array.

Narrow horizontal spacing between woofers and a low crossover point to the CDT1.5 provide consistent horizontal pattern control from 200 Hz to 18 kHz. The horizontal waveguide for the midrange and high frequencies can be altered in the field: this allows the entire array to produce a closer approximation of a rectangular coverage pattern, which is very useful for many audience areas.

The STLA line array module is a fully integrated system that incorporates a Class-D digital tri-amplifier with comprehensive onboard loudspeaker management processing. This makes for a simpler setup process, and a sound system that is smaller and lighter overall, since the amplifier and processor racks are eliminated, and signal connections are made with line-level XLR cables instead of heavy-gauge speaker wire.

Class-D amplifiers are highly efficient, generating maximum acoustic power from the available electrical power. Their high efficiency means less energy is wasted as heat, so fan cooling is not required. Digital amplification is also light in weight and has another important advantage in a line array module: it is light weight.

STLA/RHANG hardware is designed to make array setup efficient and safe. Each module includes two 5/8 inch metal tie bars and two quick-release pins. The holes in the tie bars allow adjacent cabinets to be hung with 0-degree, 2.5-degree or 5-degree splay angles. The fly bar will support up to twelve-deep arrays.

STLA dollies can hold four cabinets and because the stack is less than six feet tall, groups of four can be rolled on and off the truck, attached to the fly bar or to another group of cabinets, and flown. The dolly wheels can be locked, allowing the dolly to function as a stage-stack or ground-stack platform.

Finally, AimWare helps simplify the design of STLA arrays by allowing the designer to input a section view of the venue and experiment with different array trim heights, aiming angles and curvatures. The software predicts the results and can output the array as a file for import into EASE 4.0 and higher. ■

Ralph Heinz *is vice president and head of engineering for Renkus-Heinz. Reach him at Ralph@renkus-heinz.com.*

References

1) Olson, H., *Acoustical Engineering, Professional Audio Journals*, 1991.

2) For more on the acoustic centers of conventional horn/driver HF devices and their behavior in arrays, please consult the Renkus-Heinz White Paper on the TRue Array Principle.

3) Olson, H., *Acoustical Engineering, Professional Audio Journals*, 1991.