There has been much discussion about what a line array is and does and there are a number of different approaches to its use. Line arrays are tools and certainly very effective ones when applied properly in the right settings, but they don't do everything quite as well as the marketing departments would have us believe.

This is an attempt to wade through all the different and often conflicting information and views. It is not meant to be absolutely comprehensive – we're just trying to understand this rapidly emerging phenomenon by comparing notes with designers, manufacturers and users. There's no looking for a "winner" or "the best", just doing as objective an information gathering process as we could. Bear in mind that some of the statements and views expressed are specific to their time – not so long ago, but things have and are developing and changing rapidly.

Line array speaker systems have very quickly become the hot commodity in sound reinforcement these days. Since the introduction in 1992 of the V-DOSC system from L'Acoustics as developed by Dr. Christian Heil, there have been many variations introduced by a number of manufacturers. At the turn of the Millenium there were other line array offerings from Apogee, Electro-Voice, JBL and Meyer. At last count there are now well over 30 different line array systems to choose from more than a dozen manufacturers which include, in addition to the manufacturers mentioned in the previous sentences, Martin, Altec, SLS, EAW, Claire Brothers, Jason Sound, Renkus-Heinz, McCauley, Adamson and DAS.

Why has this specific type of system quite literally exploded onto the concert scene – what makes it so special?

To answer that we need to look back at what was being done before.

Long Ago, Not So Far Away...

In the early days of sound systems there were a handful of manufacturers putting out smaller speaker systems suitable for speech and vocal reinforcement in moderately sized rooms. These were most typically sound columns such as the Shure Vocal Master which contained four or more 8" or smaller speakers mounted in a vertical column. The earliest products in this configuration date from the '50s and were used to increase speech intelligibility in reverberant environments. They were, in fact, line arrays.

They worked well enough for the high school dance in the gym, but their frequency responses extended only from about 100 Hz to 5 kHz. By the time you reached 10 kHz, they were probably down by more than 12dB. Also, they couldn't handle much power.

Most speakers of the time weren't line arrays at all. There were a few companies making "large format monitors" such as the Altec A7 Voice of the Theatre or the Electro-Voice Sentry IV that were modified for

Line Arrays

by
Don Barber
and
Jeff Berryman

concert use. When used at moderate levels, these boxes sounded remarkably good, especially if they were arranged properly. I went to some memorable concerts that sounded fine and some were even excellent; all done without line arrays.

The Beast That Grew

With the birth of rock and roll the musical content required more than just vocal reinforcement, Jim Marshall and Ampeg, amongst others, were providing larger instrument amplifiers powering big stacks of speakers, and crowds were getting bigger, starting to fill up arenas, stadiums and farmer's fields.

Many sound companies developed their own speaker systems using components from JBL, EV and others. Most of these components had been developed for cinema sound, where high efficiency was paramount – a 10-watt amplifier was considered quite powerful in early movie theatres. The most powerful of the proprietary designs were horn-loaded systems made up of component modules, and employed electronic crossovers to split the frequency band into two, three, or more separate low, mid and high ranges.

An important feature of the modular systems was that identical elements could be stacked vertically in line to narrow the vertical coverage and increase the throw of the system. This stacked modular approach was the first type of touring system based on array principles; you had a stack of bass bins, a stack of mid bins and a stack of horns. They coupled together quite efficiently and you could aim them where you wanted the sound to go. They were capable of sounding quite good, but getting the arrays stacked correctly was rather difficult. Good results were often a hit-and-miss affair.

Bear in mind (if you can imagine) that all of this work pre-dated laptop computers and DSP; measurement equipment was very simplistic by today's standards, not readily available for road use and quite expensive – there was no SIM or SMAART, and no digital delay or equalization.

A notable success of the pre-line-array era was the Martin system from Britain. Introduced in the early '70s, its components were the model 115 horn bass and the revolutionary "Philishave" mid-range horn – so named because of its rounded grille. The "revolutionary" aspect was horn loading its two 12" speakers with a phasing plug in front of each. The phasing plug had two important effects: first, it loaded the loudspeakers correctly, so that frequency response was maintained up to at least 1.2 kHz; second, it allowed the horn to have a smaller throat opening, thereby preventing mid-range beaming. The result was a system with relatively flat frequency response and even radiation pattern from about 250 Hz to 1.2 kHz. This put a lot of controlled and focused energy right in the drum and lower vocal range. Also, it allowed crossing over into high-mid horns at a higher frequency than had previously been possible. This greatly reduced distortion and increased the power handling and output capability of the high frequency devices. The Martin system was capable of sounding quite brilliant. Perhaps its most famous client was Supertramp, who was known for the sonic quality of their live shows.

Forsyth (which became EAW) had a single 9" mid-range device similar in concept to the Martin, and right here at home Select Concert Products with Hz Sound developed the LM 90 single 12" 90 x 60 horn.

These early horn systems were very efficient and sounded fine, but the different shapes and sizes of the modules meant that handling and truck packing were not easy.

In the early '80s, flying was the new thing; flying a modular system with its unusual shapes was not for the faint-hearted, so audio fashion moved to the all-in-one box. Such boxes, though easy to handle, could not accommodate the space required by low- and mid-frequency horns. The industry turned back to the less efficient but more compact direct radiators. Fortunately, newer speaker components were being purpose-designed and built for this new concert touring business. They were more efficient and handled more power – and power amplifiers were getting bigger, too.

The Claire Brothers S4 cabinet was perhaps the quintessential all-in-one box. It used JBL components – two18" woofers, four 10" mid-range speakers in a vertical column, two mid-range horns mounted one above the other, and a set of bullet tweeters. In the usual array configurations, the bass and mid-range loudspeakers formed primitive line arrays, but the higher frequency elements didn't. When large numbers of S4s were hung together in a "big black cloud," as it became known, you got a "wall of sound" that wasn't high on coherence or intelligibility but it was definitely rock and roll!

In Canada, Jason Sound offered the J60 system, an all horn-loaded, two-box system with separate subwoofers. Like the S4s, J60s used JBL components. Unlike the S4s, there was a separate mid-bass bin. The system's array qualities were similar to those of the S4s, but with somewhat higher undistorted per-box output.

As time went by, it became less and less necessary to build your own system, because loudspeaker manufacturers started making more appropriate products for concert touring. EAW, JBL, Meyer, Apogee and others offered various solutions. For most rental companies, scalability was an issue – you needed an inventory that could work in various venues from theatres and hotel ballrooms to arenas and stadiums. To meet this need, the manufacturers tended to offer "pie-shaped" boxes that you kept adding up to make bigger systems. Unfortunately, those boxes didn't always add up as well as the old stacks had.

A common problem of the older systems, both the proprietary designs and the later off-the-shelf products, was weak high-frequency response. Because the high-frequency elements of those systems were not properly arrayed, they didn't combine efficiently. The problem was made worse by the inherent high-frequency attenuation of air, which is quite large at distances of 200 feet or more. In large venues, with many of the old systems you weren't hearing much above 5 kHz. That covered the fundamental range of most instruments, but the sound was "dead", without harmonic overtones, sibilance, percussive attack or "air" quality. It was usually loud near the front and not so loud and clear near the back.

By the mid '80s, digital technology had matured enough to allow the use of delayed speakers to help recover high-frequency balance at distance, but using delay clusters was expensive and required more equipment, time, labour and truck space.

Enter The Line Array

1992 saw a dramatic change.

Dr. Christian Heil:
(www.l-acoustics.com)

"The need for more sound power to cover large audience areas in sound-reinforcement applications has required the use of multiple sound devices, typically configured in arrays or clusters in order to achieve the required SPL. Typically, trapezoidal horn-loaded loudspeakers are assembled in fan-shaped arrays according to the angles determined by the nominal horizontal and vertical coverage angles of each enclosure in an attempt to reduce coverage overlap, which results in destructive interference. However, since the directivity of the individual loudspeakers varies with frequency, the sound waves radiated by the arrayed loudspeakers varies with frequency, and do not couple coherently, resulting in interference that changes with both frequency and listener position.

"The result for most sound reinforcement systems is that the sound waves radiated by individual loudspeakers do not couple properly and interfere uncontrollably. This creates non-uniform coverage inconsistency in frequency response, poor intelligibility

and reduced overall sonic quality. The chaotic sound fields created by these interfering sound sources also wastes acoustic energy, thus requiring more total power than a single coherent source in achieving the same desired SPL.

"If we can construct a single sound source emanating from many speakers (which can then be separated for ease of handling and transport), then we have achieved the goal of providing a totally coherent, predictable wavefield. Line arrays have been regarded as the best approach to serve the diverse requirements of covering large audience fields. However, until now it has not been possible to make a line array operate properly because of:

1) the interference produced by multiple sound sources radiating over the same coverage area, and
2) an inability to achieve proper line array coupling in the high frequency range.

"An assembly of individual sound sources arrayed following a regular step distance on a planer or curved continuous surface is equivalent to a single sound source having the same dimensions as the total assembly if one or both of the following two conditions are fulfilled:

1) Frequency: The step (distance between the acoustic centres of individual sources) is smaller than half the wavelength over the operating bandwidth
2) Shape: The wavefronts generated by individual sources are planar and together fill at least 80 per cent of the total radiating surface.

Further research using Fresnel light wave theory showed that:

3) The deviation from a flat wavefront must be less than 1/4 wavelength (others say 1/8th) at the highest operating frequency – this corresponds to less than 5 mm curvature at 16 kHz."

L'Acoustics invented the name "Wave Sculpture Technology" to describe their loudspeaker designs that met these three criteria, and patented their high frequency waveguide. Dr. Heil again:

"By satisfying WST criteria over the entire audio bandwidth, the engineer or designer is provided with a "single" loudspeaker with well-defined coverage and wavefront shape, thus allowing the geometrical distribution of energy to be precisely installed to match the geometry of the audience seating area."

As everyone now knows, the first L'Acoustics line array product was named V-DOSC. It was first used in Europe at large outdoor festivals. In such applications, with most of the audience in front of the stage and at a distance, a long line of V-DOSC boxes vertically coupling produces exceptional results. At a considerable distance from the stage, if you close your eyes, it sounds as if you are much closer than you actually are. When you open your eyes, they seem to be telling a different story from what your ears have been telling you. The high frequencies are clear because of the waveguide and the mid and bass energies have been focused along the vertical plane.

Coverage, clarity and output: Sounds ideal doesn't it? V-DOSC quickly became very popular. Mix engineers liked it because they had a virtual set of studio monitors in front of them; they were getting a much clearer focus that allowed for improved stereo imaging. They noted significant improvements in vocal intelligibility and overall dynamics. Also, because the coverage was relatively even, they were hearing the same sound the audience was hearing, at least in a good percentage of the seats.

Production managers liked the system because there was a very visually clean column of speakers requiring fewer rigging points, instead of the "big black cloud." This improved sight lines, which in turn freed up more unobstructed seats. The lore was that for the same band, playing at the same volume in the same venue, a line array speaker system would be smaller, lighter, and easier to hang, and would occupy less truck space and require a smaller crew.

V-DOSC "upped the bar" by introducing clarity and intelligibility that did not previously exist, particularly at farther distances. Coverage was improved and evened out considerably. Sight lines were improved, trucking and rigging were made more efficient, and time and money were saved. As one patent application put it, line arrays "ameliorated into insignificance" many of the problems and artifacts associated with large "clusters" of conventional loudspeakers.

Once the success of V-DOSC became evident, other manufacturers undertook to develop their own line arrays with their own waveguide solutions. The new approaches are broadly classified into four main types: ribbons, horns, reflectors, and lenses. (V-DOSC was patented, remember?).

Because it was the first, V-DOSC has been the obvious block to chip at. Questions have been raised about the efficiency of the front-loaded mid-range speakers, which don't couple much above 800 Hz; about cancellation between the midrange speakers, because they are spaced so apart on either side of the waveguide entrance; and about the effectiveness of the "V" as a high-frequency wave guide. Horn proponents have stated that the efficiencies of horn loading were lost:

"At the bass end, most current line arrays have adopted spaced direct radiators that have as much impact as a wet blanket in a fog... In the mid-range, cross-firing direct radiators lack both the efficiency and pattern control of properly designed horns."
- Martin Audio

Today, the field has expended and diversified. There are now available many different sizes of line array boxes with various rigging and packaging solutions. The field has matured, with marketing departments making all sorts of public claims, while in the background engineers are working to deepen their understanding of the technology, and improve it. For example:

"Each cabinet in a line array is not producing a 'slice of a cylindrical wave.' That is a marketing concept, not a scientific one."
-www.meyersound.com

"How loudspeakers interact with each other in an array is the hot topic in the industry at present. Whatever the hype says, the line array is not the Holy

Grail of loudspeaker design. It has always been around – it's only the current format that people are latching onto as 'new'. Unfortunately, this is a maximum BS area at present and simplistic claims are flying around. The current fashion for a particular horizontally formatted, one-box line array has led some manufacturers to bend acoustic rules and adopt some unacceptable compromises."

-Martin Audio EDGE, September 2001

Perfect Coverage?

In practice, using line arrays poses a number of challenges.

Most indoor applications don't require an open field of flat vertical coverage, all in front of the stage, and distant coverage is not necessarily the primary requirement. Ironically, line arrays can focus so well into the far field that what used to be a reverberant mush returning from the back of the hall can now be a very distinct slapback echo. Arenas, theatres, ballrooms and other venues of various sizes and shapes don't always conform to the wedge-shaped coverage patterns of line arrays.

In many venues, flying a single, long vertical line of speakers isn't possible. There may not be enough height or load capacity to hang enough speakers, or there may be seats right next to the stage, or under the stacks or along the sides or in balconies. Many situations don't need tight vertical coverage with a constant-width horizontal coverage. The horizontal and vertical coverage often need to be quite wide. (There are now several products that offer different horizontal coverage patterns, typically of 60, 90 and 120 degrees.)

For line array coverage close to the stage, the usual practice is to curve the lower speakers of the array to form a "J" shape that directs sound down into the front rows. However, if you curve the array too much, the high frequency beams spread apart and the high-frequency coverage of the close rows gets "lined", as if it were light shining through a Venetian blind.

Another problem of curving line arrays is that at longer wavelengths the effect of the curve is lost. This can cause a narrow mid-bass lobe aimed at the middle and upper tiers of seating, with the sound firing over top of the nearer seats.

These issues have been well articulated by Meyer:

"In practice, gently curving a line array (no more than five degrees of splay among cabinets) can aid in covering a broader area. Radically curving line arrays, however, introduces problems. First, if the high-frequency section has the narrow vertical pattern that's required to make a straight array work, curving the array can produce hot spots and areas of poor high-frequency coverage. Second, while the curvature can spread high frequencies over a larger area, it does nothing to the low frequencies, which remain directional because the curvature is trivial at long wavelengths."

- www.meyersound.com

Horizontal Coverage Issues

In an arena, a forward-facing line array will cover the main seats in front of the stage within about a 90-degree horizontal angle, but in heavily-sold shows it will be necessary to cover seating to the side of the stage as well, and a second set of loudspeakers will be needed. Because the side seats are so close to the stage, the side-fill loudspeakers will need to cover quite a wide vertical angle. Ironically, this will require a very tall (read: expensive) array to cover perhaps 20 per cent of the seats.

When multiple line arrays are used, it is important to minimize interference between them. Bad interference will result in uneven tonal quality and poor intelligibility. L'Acoustics states that a second line array should be at least 25' away from the first. Spacing the arrays works because most people sitting in the area of overlap will hear the sound from the two stacks at different times – one then the other. This introduces an effect called "de-correlation", which means that the sounds of the two stacks don't get a chance to reinforce or cancel each other very strongly. The ear is fairly tolerant of de-correlated multiple sound sources, so negative perceptions of the overlap are minimized. However, the opposite approach is also common: the two systems are hung tight together, aimed carefully for minimal overlap, and appropriate delay and equalization are applied to minimize interference effects in the overlap area. This approach minimizes the size of the overlap area and maximizes correlation within that area.

Combination Solutions

Line arrays can be combined with other loudspeakers:

"...since linear waves pass through one another regardless of whether they are created by a direct radiator or a wave guide, it is possible to combine line array systems with other types of loudspeakers as long as their phase response matches that of the line array speakers. There is nothing special about the sound waves that line arrays create. They are merely the output of low-frequency cones, spaced using line array theory, and high-frequency waveguides. Therefore, skilled designers with the proper tools can flexibly integrate other compatible types of loudspeakers to cover short-throw areas."

-www.meyersound.com

Other Applications

The tight vertical pattern of a single speaker module can work as under-balcony and frontfills. Shorter arrays of smaller cabinets can work quite well as delay zones in distributed systems where bass pattern control is not always critical.

"Line array boxes "pack a lot more HF devices and mid-band transducers into a smaller space, creating a very high fidelity, high energy wavefront. Even in spaces where the "line array effect" is not necessary, where the throw distances may not be that extreme, the concentration of elements still offers a superior tonality and a more cohesive reproduction method, especially when handling the highly transient musical styles of dance and R&B."

-Ryan Finley, McCauley

Software

All modern line array products come with computer programs to predict vertical (and in some cases, horizontal) coverage. The more advanced programs are based on actual measured loudspeaker data. The simpler ones are based on simplified theoretical models. All of the programs allow entry of venue shape and size information. Some of them have 3D visualization capabilities, while others don't. Some of them have "automatic" modes that compute the optimum array configurations automatically, while others simply predict the performance of an array whose specifications you enter. A few of them predict the interaction of multiple arrays, but most of them just show you one array at a time. Some of them are suitable for concert touring use, where array design time is limited, but a few of them are intended for fixed installation design, where more elaborate models are required.

Few if any of the current programs predict the equalization that should be used with the array being modeled. This is a current development area.

Summary

Vertical line arrays work very well at focusing sound at a distance (long throw) with increased intelligibility and dynamic energy. It is possible to widen the vertical coverage into the mid-field area, but there will be a loss of high frequency energy. Fortunately, both of these areas benefit from an overall high frequency equalization boost - this compensates quite effectively for the mid-field energy loss and for the loss of high frequencies in air in the far field.

In arenas, line arrays don't always do a good job of covering near the stage, in front or to the sides. Sometimes "point source" systems carefully integrated into the line array coverage pattern may work better. ●

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