TECHNOLOGY OF THE ELECTRO-VOICE X-LINE ADVANCE LINE ARRAY LOUDSPEAKER SYSTEM

The Electro-Voice X-Line Advance line array loudspeaker system was designed from the ground up to be a technological leap forward from the tour-proven XLC line array system. By listening to many live sound professionals and gaining first hand insight into what works and what doesn't, Electro-Voice engineers were able to start with a clean slate and design the system to create a high efficiency, compact design that offers best in class sound quality and output.

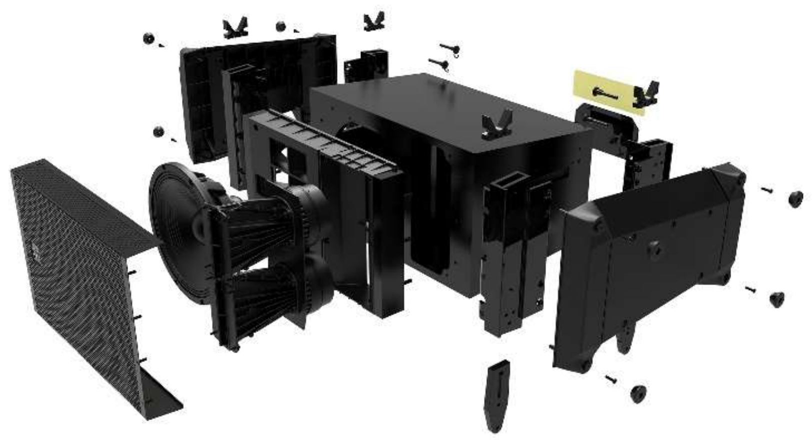

Figure 1: The components of the X1 and X2 line array elements (X2 shown).

CUSTOMER FOCUS

To start, EV brought in a large group of tour sound professionals, both users of EV products as well as users of competitive products. Several themes emerged regarding what customers and users wanted to be improved. Uniform sound coverage was critical, both side to side and front to back. Users wanted a more compact line array system, both for improvements in sight lines, as well as transportation efficiency. However, they also wanted the same or more SPL. They wanted to be able to suspend the entire array quickly and safely. They wanted a system based on a 12" woofer for low-frequency extension, high SPL, and impact.

It was also clear that two distinct performance levels were required. Some customers desired a "flagship" design with the highest maximum SPL possible. This design became the X2 system (Figure 1). Other customers were willing to sacrifice a little output for a design that was more value orientated, and they needed to drive three line array elements on a single amplifier channel. This design became the X1 system.

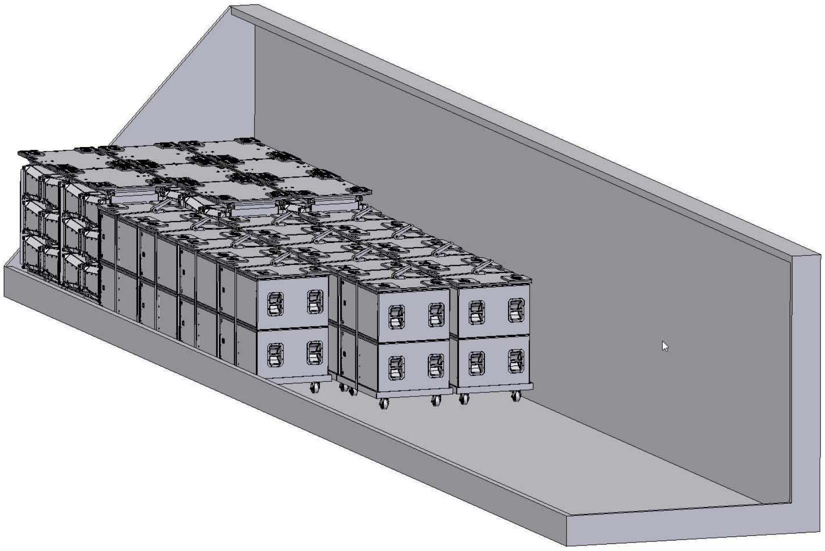

Figure 2: Analysis of a full size X1 or X2 line array within a 53 foot standard US trailer, which consists of 48 line array elements and 24 X12-128 subwoofers. The dollies are stackable if space allows.

FROM THE OUTSIDE IN

Given the customer requirements and a clean slate upon which to design the product, EV engineers set out to design a system which meets these requirements. EV engineers started with the truck pack requirements, analyzing the interior space of various vans and trailers globally to determine the optimum dolly size (Figure 2). From there, the optimum line array element size was determined. The focus on utilizing the most volume within the trailer or van truck ensures that the space is most efficiently utilized.

LOW FREQUENCY

In order to keep each line array element compact as possible, a two-way design was preferred. However, it is problematic to use a 12" direct radiating woofer up to the 1.6 kHz HF crossover point. A direct radiating 12" woofer does not behave like a line source above approximately 700 Hz in the vertical plane. Other two-way designs compensate for this by crossing over the HF compression drivers at a lower frequency, for example 1000 Hz. However, this is a compromise that adds distortion and thermal stress to the compression driver, and requires a larger waveguide for the compression driver in order to maintain the proper coverage at the lower crossover point. In addition to the problems in the vertical plane, a direct radiating 12" woofer does not maintain the proper beamwidth in the horizontal plane, which creates an uneven power response (Figure 3).

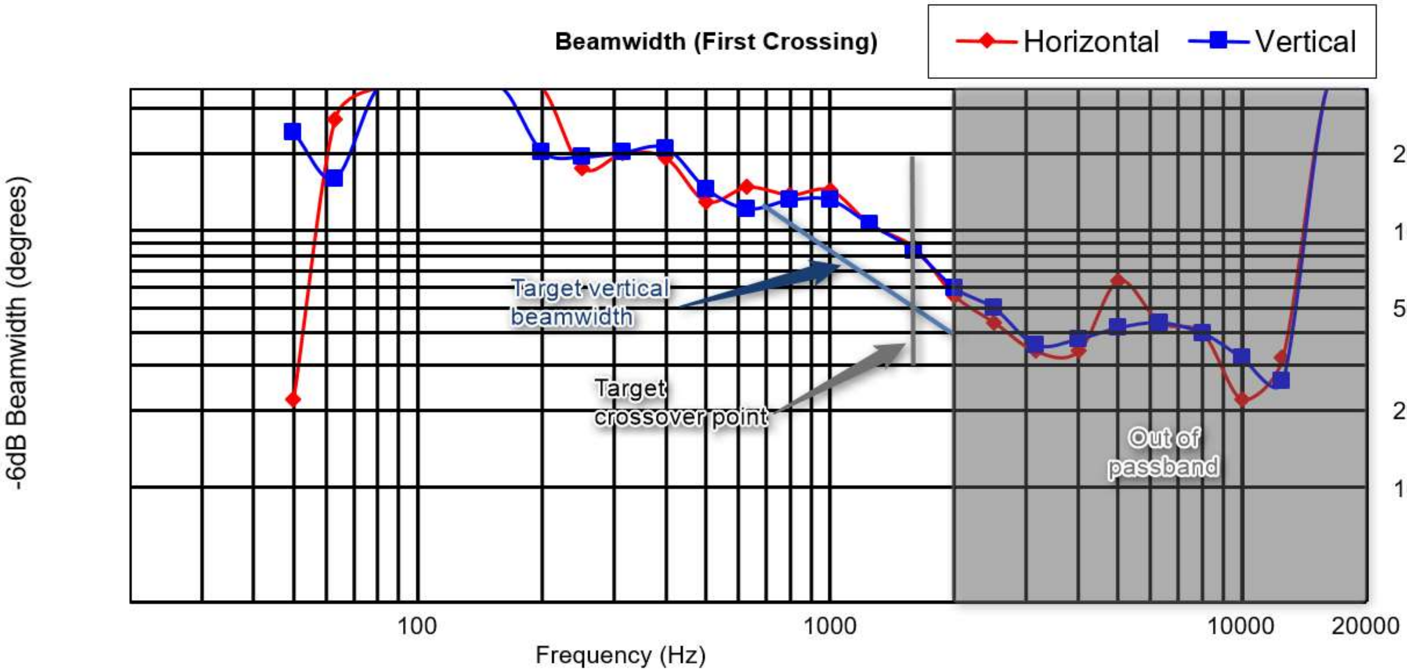

Figure 3: Beamwidth measurement of a direct radiating 12" woofer in the horizontal and vertical planes. The horizontal and vertical beamwidth are both 85° at the target crossover point, which is not desirable for a line array element. The solid blue line represents the target beamwidth response, shown for reference.

To solve this problem, the Mid Band Hydra (MBH) was designed. The patent pending MBH is a multi-aperture waveguide that applies EV's Hydra concept to midrange frequencies. The MBH works by converting the acoustic output of a single 12" woofer to two vertical columns of four apertures that are approximately 3" square (Figure 4). In the midrange frequencies, the MBH behaves as if it is an array of eight 3" phase-aligned woofers. This allows the MBH to widen the horizontal beamwidth from 1 kHz to 2 kHz, and to behave as a line source from 700 Hz to 2 kHz in the vertical plane (Figure 5). In effect, the beamwidth in each plane is much closer to the theoretical ideal for a line array element. In the lower frequencies, the MBH is effectively acoustically transparent, so each line array element maintains the same bass and mid-bass performance as a direct radiating 12" woofer.

Figure 4: The Mid Band Hydra (MBH) is a mid-frequency waveguide that consists of eight 3" apertures to control the horizontal and vertical beamwidth in the critical midrange frequencies.

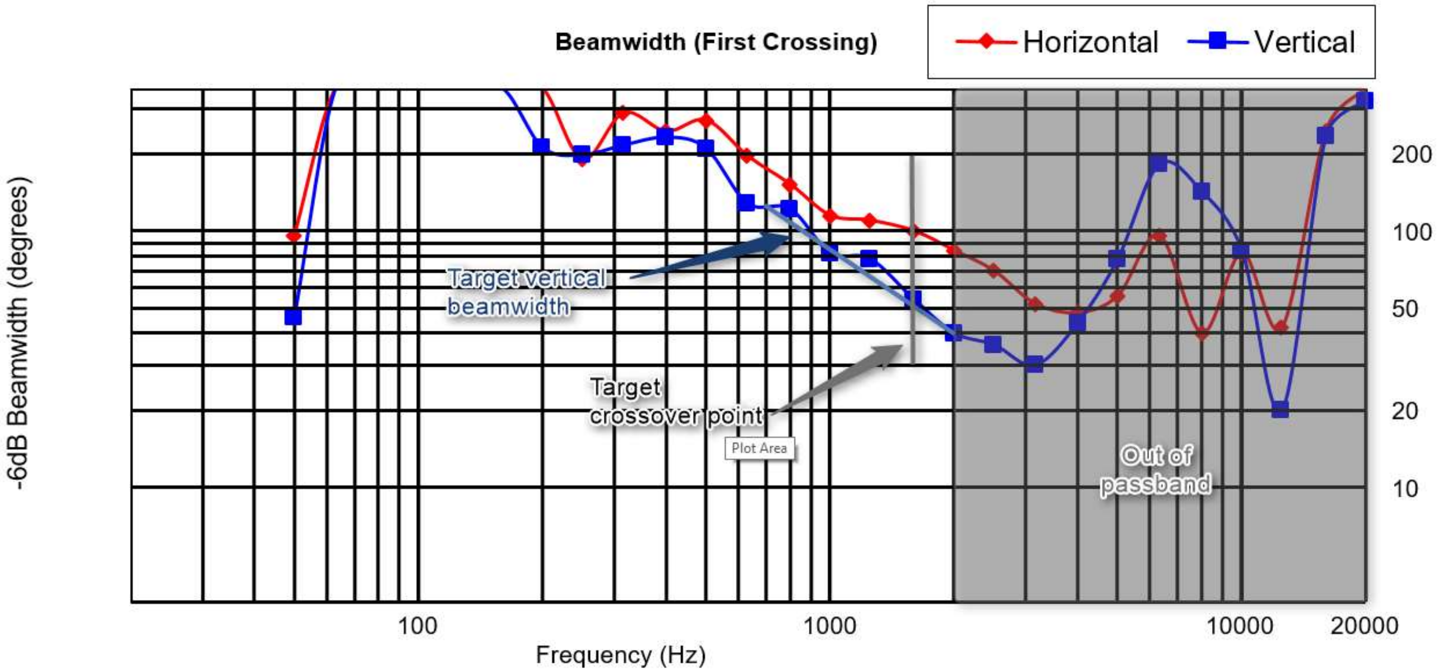

Figure 5: Beamwidth measurement in the horizontal and vertical planes of a 12" woofer with the MBH. The beamwidth in both planes is much closer to the target. The vertical beamwidth approximates an ideal line source from 700 Hz to 2 kHz, and the horizontal beamwidth is wider than a direct radiating woofer between 1 kHz and 2 kHz, allowing for a better power response and transition to the HF passband.

In the X2 system, the MBH is paired to the DVN3125 (Figure 6), a new transducer created specifically for the X2 system. The woofer utilizes a highly optimized neodymium motor design that was created using magnetic finite element analysis. The woofer has both high sensitivity (101 dB 1W @ 1 m) and high power handling capability (500 W, per AES2-1984 standard) to achieve a high maximum SPL.

Figure 6: DVN3125 woofer.

Instead of designing a woofer with higher power handling, the focus for the DVN woofer was maximum mid-band sensitivity with the lowest amount of distortion. There are several benefits to this. First, it has a rising response over its operating bandwidth to balance the LF coupling of the line array that results in flat power response. Second, it produces a higher overall maximum SPL. Consider a common "off the shelf" woofer design that has a 96 dB sensitivity and a 1000 W power handling. The maximum SPL would be:

$$Maximum\ Calculated\ SPL = 96\ dB + (10 * \log(1000\ W)) = 126\ dB$$

Now consider the EV solution, which has a 101 dB sensitivity and 500 W power handling. The maximum SPL would be:

$$Maximum\ Calculated\ SPL = 101\ dB + (10 * log\ (500\ W)) = 128\ dB$$

Using half the power, the sensitivity difference still allows the DVN woofer to achieve a higher maximum SPL with less power compression and greater reliability.

In order to achieve the higher mid-band sensitivity, it is essential to lower the mass of the moving parts, as well as to design a highly efficient magnetic circuit. Many woofers that have neodymium motors use slug-style neodymium magnets. While this lowers the cost of the magnet, it is not possible to meet the high mid-band sensitivity target. The reason is because the slug must fit inside the voice coil. If the voice coil diameter is increased to accommodate a larger slug magnet, this increases the moving mass, which lowers the sensitivity. Instead of a slug magnet, EV engineers overcome this issue by using a larger ring magnet that is placed on the outside of the voice coil. This allows the magnet to be large enough to meet the sensitivity target, while not using a heavier voice coil.

The X1 system uses the SMX2121, a LF transducer with an optimized ceramic motor. This design is also high sensitivity, and includes a shorting ring for reduced distortion. The same design philosophy of the DVN3125 is used in the SMX2121 of a highly efficient motor with a light moving mass to achieve high mid band sensitivity (Figure 7).

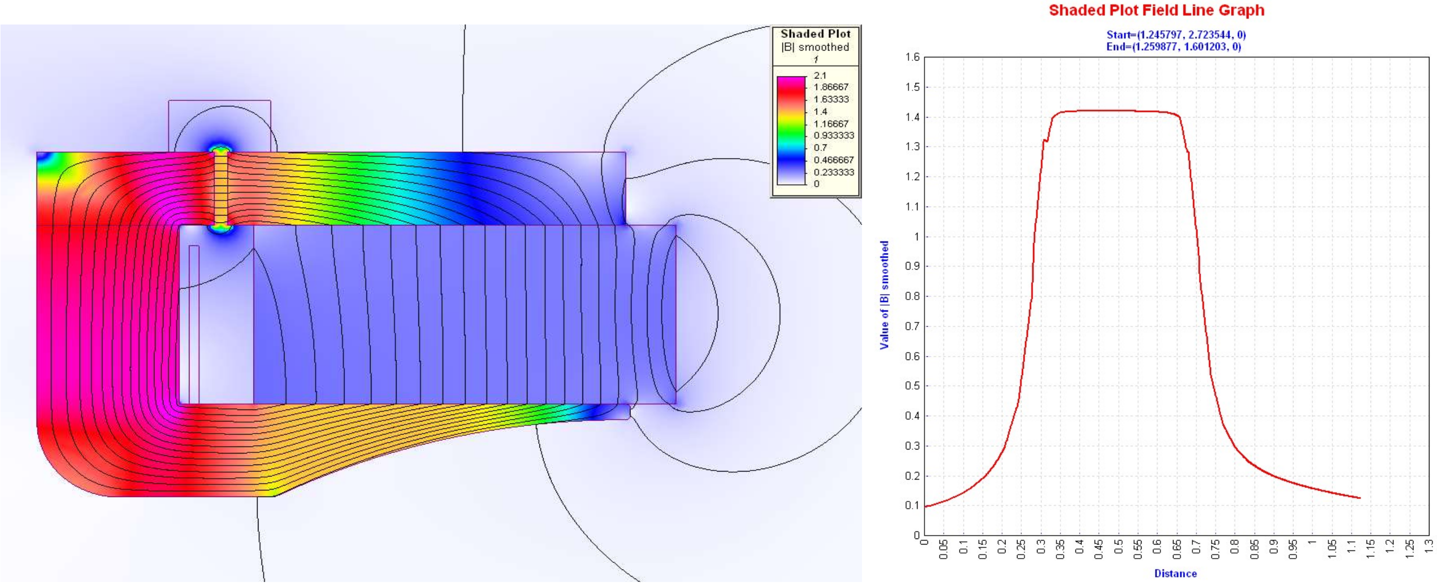

Figure 7: Simulation of the SMX2121 motor assembly. The left view shows the magnetic flux through a cross-section of the motor. The right view shows the nearly ideal symmetrical flux density within the gap.

Because of the small frontal area of the X1 and X2 systems, placing small ports in the front of the speaker would have yielded high port velocity, creating noises, distortion, and decreased LF output. This problem was solved by using a novel port design located on the sides of the X1 and X2, between the rigging frames. The large cross-sectional area produces low port velocity, which results in low noise and distortion. The ports also serve as concealed handles for each line array element, allowing for easy movement but maintaining a clean aesthetic. The ports face downward, so they are less likely to accumulate water than if the ports were placed on the front baffle.

By designing the woofer, port, and MBH concurrently and with a clean slate, EV engineers were able to optimize these components to each other. The geometry of the back side of the MBH closely matches that of the woofer cone, allowing tight spacing between the two. This smaller spacing maximizes the line array behavior and shifts any acoustic resonances out of the passband of the low-frequency section. The DSP presets (equalization and protection parameters) were designed in parallel with the MBH and woofers to ensure that the woofer does not contact the MBH due to over excursion of the cone during normal use. A rubber bumper is in place on the back side of the MBH to prevent damage if an excessive low-frequency boost is applied to the input of the system.

The result of the highly optimized low-frequency section is a substantial increase in output over much of the passband compared to the previous generation XLC system (Figure 8).

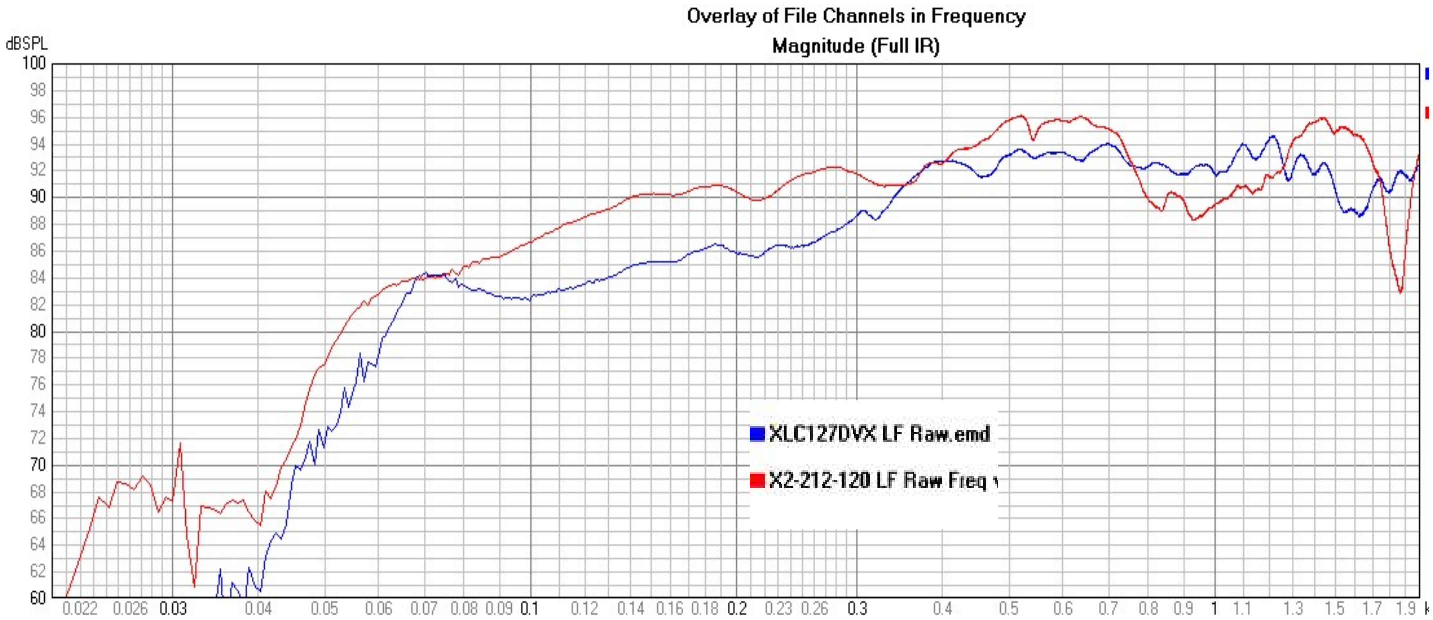

Figure 8: Comparison of X2 LF section (in red) and XLC LF section (in blue). The X2 has a 3-5 dB increase throughout much of the passband, as well as deeper bass response. Measurements were taken in EV's anechoic chamber, measured on axis at 10 ft. with a 4 V signal.

HIGH FREQUENCY

The X2 system uses dual ND6A compression drivers, which utilize 3" titanium diaphragms and neodymium motor systems (Figure 9). EV transducer engineers were able to make improvements over the already excellent performance of the existing ND6 (Figure 10) by designing a new phase plug and improving the diaphragm geometry. Since the diaphragm of the compression driver is also the suspension at the outer edge, the primary way to control the diaphragm motion is to adjust the geometry of the suspension. Geometric differences as little as .001" can have significant changes to the high-frequency performance of the compression driver. Since the tolerances on the diaphragm are very tight, it's not only important to have a great design, but also a precision manufacturing capability to hold these tight tolerances. EV designs and manufactures the X1 and X2 compression drivers in house, so all parts within the compression driver are closely controlled. Batches of titanium diaphragms are frequently laser scanned for dimensional tolerance and correlated to the acoustic performance once assembled, allowing manufacturing and transducer engineering to continuously improve upon the high-frequency performance of the compression driver. Because of these improvements, the ND6A has 3 dB of increased sensitivity above 10 kHz, and high-frequency extension up to 19 kHz. This is especially critical in a line array, as the compression drivers need to be very high sensitivity to compensate for air losses in longer throw applications, as well as balance the low-frequency coupling that occurs in line array systems. The more sensitivity that can be created by focusing on an efficient transducer and waveguide design, the less boost is required by DSP, which improves overall system sound quality, increases headroom in the amplifiers, and increases reliability.

Figure 9: Cutaway of ND6A compression driver with Pin Diffraction Hydra (PDH).

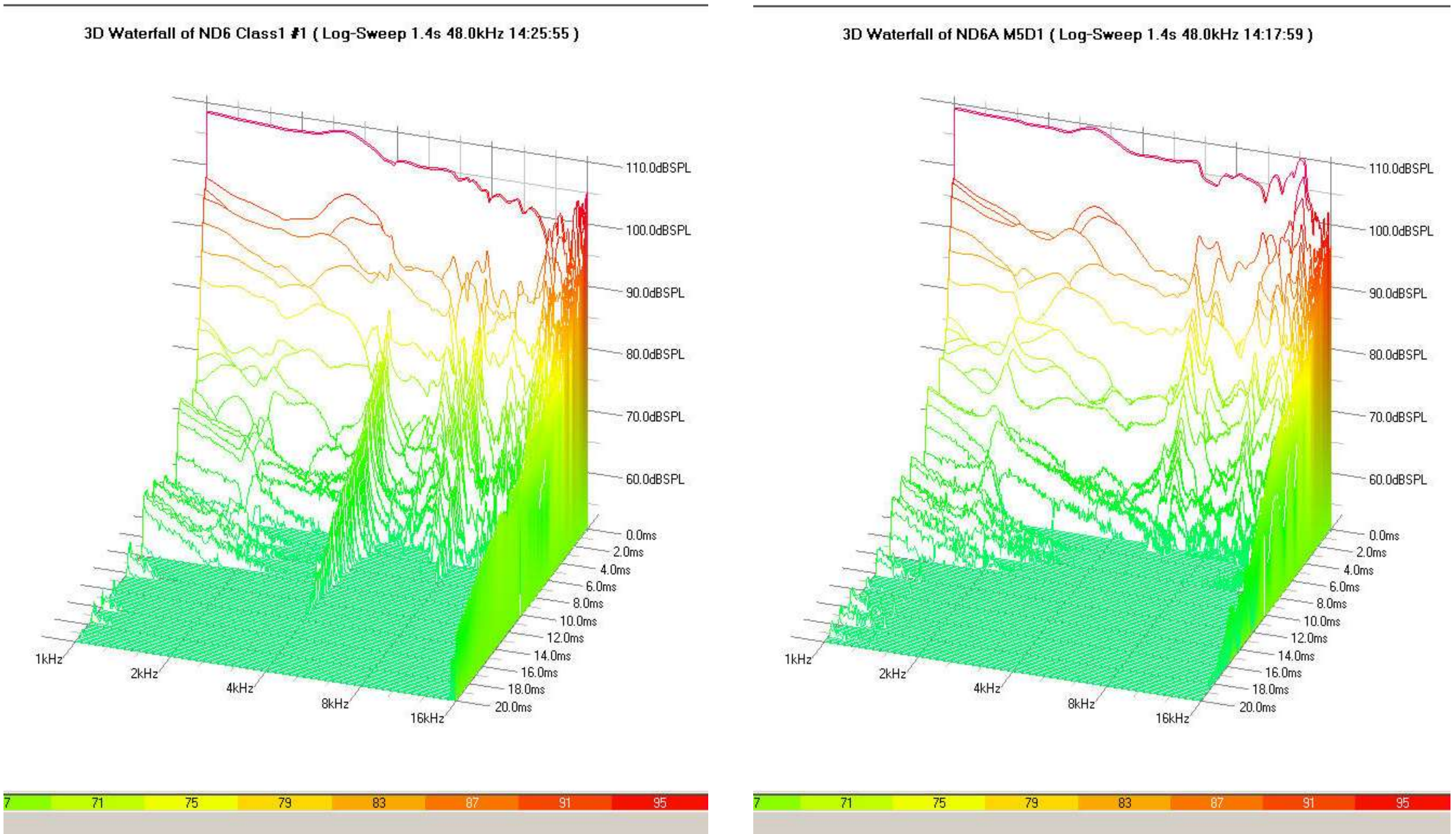

Figure 10: Waterfall measurement of ND6 compression driver (left), and the ND6A compression driver (right). The redesigned phase plug eliminates the resonances at 4 kHz and 8 kHz, leading to better sound quality.

One of the key requirements in a line array is to convert the spherical wavefront at the round exit of a compression driver to a planar wavefront at the rectangular horn throat entrance. Without a true phase-coherent planar wavefront, the interference between line array elements is too high, causing inconsistent sound coverage and poor sound quality. EV was one of the first brands to develop planar line-source waveguides for use in concert sound line arrays, developing the first device in the 1990s for use in the original X-Line system. Dubbed a "Hydra" for the way its internal vanes resembled the mythical creature of the same name, the Hydra uses vanes of different path lengths to convert the compression drivers' output to a planar line source. For the X2, EV engineers have designed the fourth-generation Pin Diffraction Hydra (PDH), which is a substantial improvement to the already excellent performance of the previous-generation designs. Instead of using vanes with different path lengths like previous generations, the new patent-pending PDH uses strategically placed pins directly in the path of the high-frequency wavefront (Figure 9). The pins diffract the sound waves within the Hydra to delay the wavefront more in the middle than on the ends. By the time the wavefront exits the PDH, it is a phase-coherent planar wavefront with uniform intensity that is very close to the theoretical ideal (Figure 11).

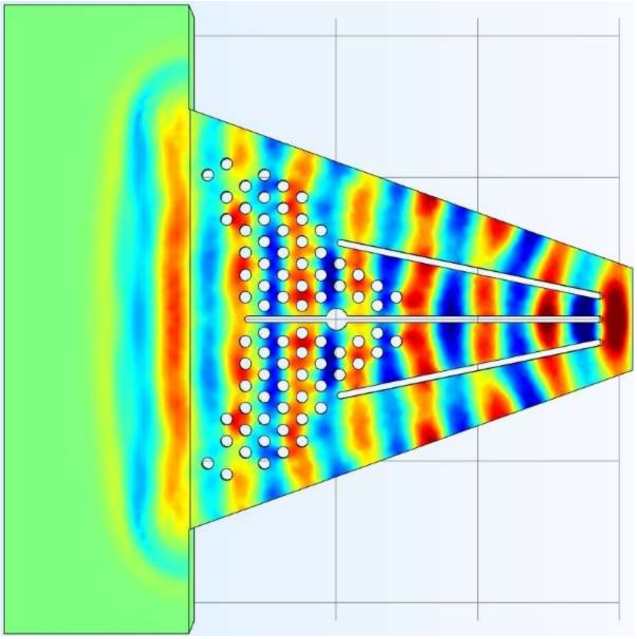

Figure 11: Wave propagation within the PDH. Red colors indicate high positive pressure and blue colors represent high negative pressure. The wavefront is spherical as it enters the PDH on the right, and becomes planar with uniform intensity as it exits the PDH on the left.

Figure 12: ND2R compression driver. The phase plug was redesigned to be an annular ring exit design.

Dual ND2R compression drivers are utilized in the X1 system, which have a 2" titanium diaphragm and neodymium motor system. The ND2R is also an improved design over the already great-sounding ND2 to improve the sound quality and high-frequency efficiency. The phase plug was completely redesigned to produce an annular ring exit design (Figure 12). Because of the annular ring exit design, a different Hydra design was required than the PDH. Called the WCH (Wavefront-shaping Circular Hydra), it was designed in parallel with the new annular ring exit phase plug (Figure 13). Instead of using pins to delay the wavefront in the middle, the WCH uses carefully adjusted curved acoustic paths to increase the pathlength, converting a spherical wavefront to a near ideal planar wavefront with uniform intensity.

Both the WCH and PDH terminate to either 120° or 90° waveguides. The 90° waveguide is designed for long-throw applications; the 120° waveguide is designed for shorter-throw applications. The waveguides were designed to have similar tonal characteristics, as well as the same physical depth to maintain the same time alignment. The 90° waveguides can be used in the top of the array to cover the audience further away; the 120° waveguides can be used at the bottom of the array to cover the closer audience.

FIR-DRIVE AND SYSTEM OPTIMIZATION

FIR-Drive is EV's unique hardware and software platform that allows EV engineers to create presets. Since EV designs and manufactures its loudspeakers, amplifiers, and processors in house, presets are created that are highly optimized to all components within the system. FIR-Drive is not just the hardware and software; it is also a development methodology that is used to create the presets. Because of this, only EV processing, amplifiers, and presets are recommended with X1 and X2. For more information on FIR-Drive, please visit www.electrovoice.com and search for "FIR-Drive."

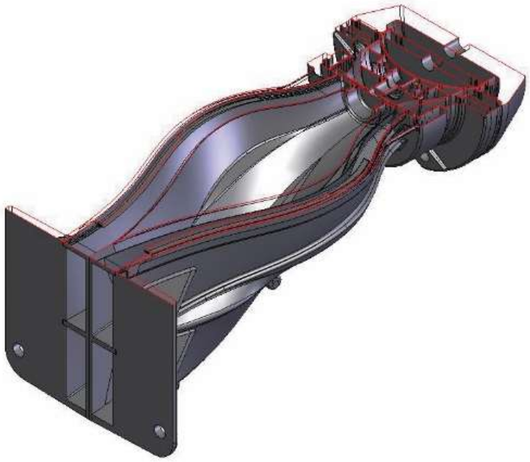

Figure 13: Cross-sectional view of the ND2R with the WCH. The pathlength of the middle acoustic paths are carefully extended and curved towards the sides to increase the pathlength, thereby time aligning with the top and bottom acoustic paths.

CROSSOVER AND EQUALIZATION

The X2 and X1 bi-amp configurations utilize FIR-Drive with "brick-wall" filters. Rather than be limited with typical IIR filters such as 12 dB/octave or 24 dB/octave, FIR filters allow for near infinite crossover slopes. EV's design philosophy is to use steep crossover slopes whenever possible, whether they are passive crossovers, or filters within DSP. The main benefit is that it limits the frequency range that is affected by both the low-frequency transducer and the high-frequency transducer. Whenever there are two physically separated transducers radiating sound at the same frequency, there will be acoustic interference (i.e., comb filtering) at various points off axis.

Figure 14 shows the acoustic performance of the X2 FIR-Drive brick-wall filter at 1.6 kHz. There are three measurements: the frequency response of the HF section only, the frequency response of the LF section only, and the summed frequency response of the system. At 30 dB down from the summed response, each section is effectively out of the passband, and not contributing to the output of the system. With brick-wall filters, the passband where both the HF section and LF section are contributing to the output is:

$$\frac{\ln\left(\frac{1750\ Hz}{1450\ Hz}\right)}{\ln(2)} = 0.271\ Octaves$$

This means that the crossover region is less than a third of an octave wide. A 24 dB/octave crossover such as a Butterworth or Linkwitz-Riley, by comparison, is over two octaves wide at -30 dB.

The crossover slope of the FIR brick-wall filter is theoretically infinite, but from a practical standpoint the acoustic crossover slope is approximately:

$$\frac{30\ dB}{0.271\ Octaves} = 110.7\ dB/Octave$$

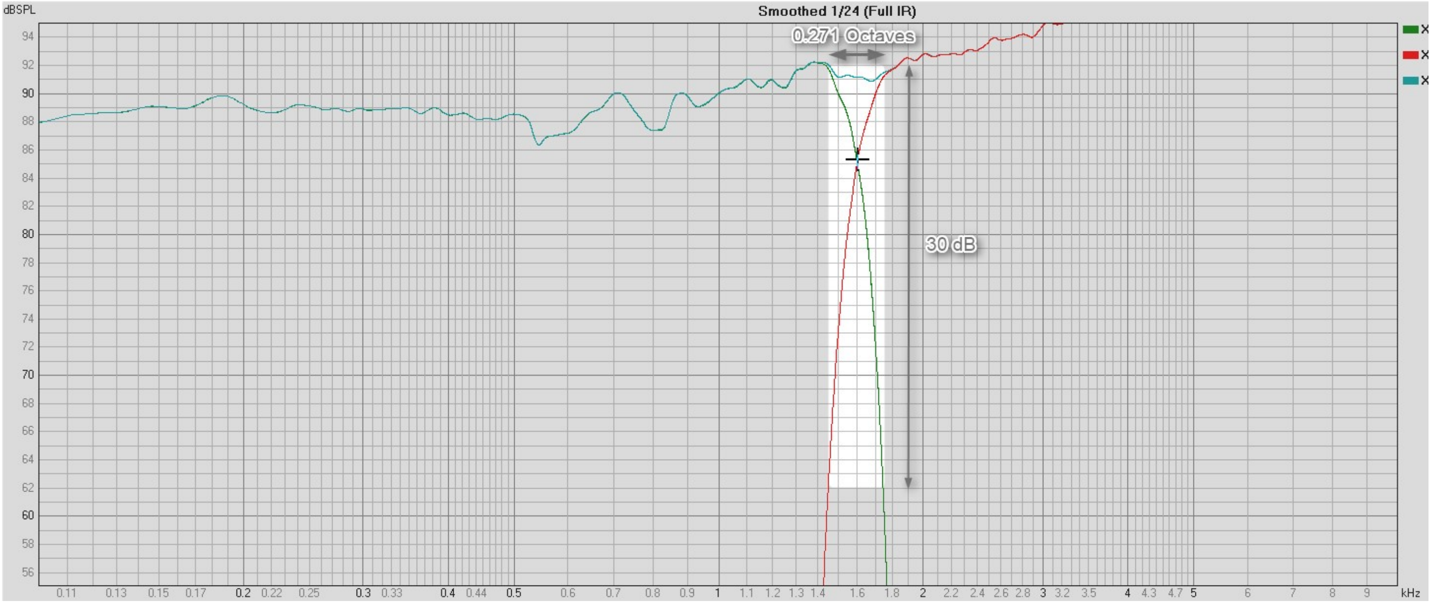

Figure 14: Close-up acoustic response of the crossover region of X2 line array element with FIR-Drive. The teal measurement is the summed system response, the green measurement is the LF response only, and the red is the HF response only.

X1 PASSIVE CROSSOVER

The X1 line array elements can be set up for bi-amp operation, or they can be operated with a passive crossover for use with a single amplifier channel. The passive crossover network in the X1 is designed around an eighth-order topology with HF driver protection, shelving, and PEQ equalization built-in (Figure 15). When combined with the acoustic roll-off of the transducers, this topology produces effective acoustical crossover slopes approaching 96 dB per octave through the same 1.6 kHz crossover point that is utilized in the X2 brick-wall filters. The crossover utilizes heavy-gauge copper coils to keep insertion loss to a minimum (<0.5 dB). The crossover also uses high-grade, 300 V metallized polyester film capacitors, instead of lower cost (but less reliable) electrolytic capacitors. The crossover has been designed to have a 6Ω minimum impedance (at 145 Hz), allowing for up to three passive X1 elements to be operated from a single amplifier channel, assuming that the amplifier channel is stable driving a 2Ω load. Utilizing the X1 passive crossover allows the system to be driven with half the amplifiers that would be required for a bi-amplified system, which can lead to substantial system cost savings.

Figure 15: X1 passive crossover. Shown on top of an X1 for size reference.

LIMITERS

FIR-Drive uses two limiters to protect the system, the Peak Anticipation limiter (PA limiter) and the Thermal Energy Management and Protection limiter (TEMP limiter).

The PA limiter is designed to protect the transducers from instantaneous peak voltages that can cause over excursion, which eventually leads to mechanical failure of the transducers. Not all limiters are equal. EV engineers have spent years developing and optimizing the PA limiter, using a combination of double blind listening tests, electrical measurements, and real world abuse testing. The PA limiter is a low-latency "look ahead" limiter, which means that the DSP samples the signal prior to applying any processing. This prevents the signal from overshooting the limiter (Figure 16).

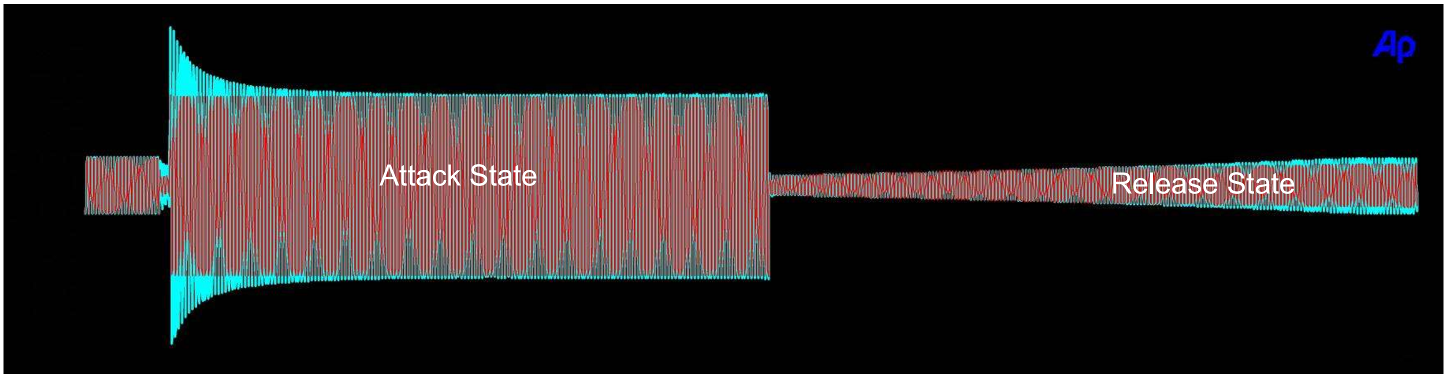

Figure 16: PA limiter (red) vs. a conventional limiter (cyan). Conventional limiters allow instantaneous peaks beyond the limiter threshold, which can lead to amplifier clipping and transducer mechanical failures. By using a low latency look ahead limiter, the PA limiter does not allow instantaneous peaks beyond the limiter threshold.

Voltage at the transducer terminal is more important to examine than peak power handling of each transducer when designing peak limiters. "Wattage," especially when dealing with transducers that have an impedance that varies with frequency, is a dubious term that isn't useful to engineers when designing limiter parameters. The DVN woofer used in X2, for example, is 500 W per the industry standard AES2-1984 power test. Since the AES noise test has a 6 dB crest factor, the peak power is rated at 2000 W. However, this peak power handling rating isn't relevant to the proper optimization of the system. EV engineers instead examine the instantaneous peak voltage the transducer can handle long term without mechanical failure, using a variety of proprietary test signals and real-world program material. If one were to try and convert the instantaneous peak voltage back to a peak power handling rating, they would find that it is higher than the AES rating would indicate.

It's also important to examine the peak voltage capability of the amplifier when developing the PA limiter. EV engineers examine the output of the recommended TG-7 amplifier in a variety of mains and loading conditions. Even under worst case conditions, the PA limiter threshold is set slightly below the peak voltage capability of the amplifier, which prevents the amplifier from clipping or going into its own protection. This is highly optimized as it allows a small amount of headroom within the system before the amplifier protection activates.

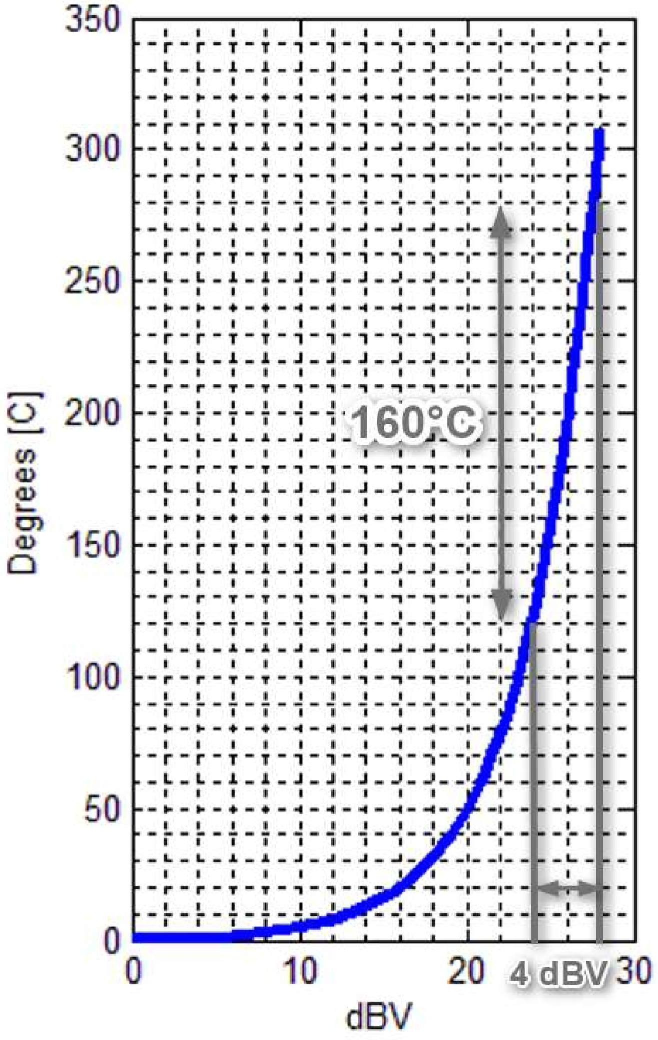

Figure 17: Voice coil temperature rise vs. applied voltage to a transducer. In this transducer, a voltage increase of just 4 dBV causes a 160°C temperature rise in the voice coil.

While the PA limiter works to prevent mechanical failure of the transducers, the TEMP limiter works to prevent thermal failure in the transducers. Thermal failure occurs when the voice coil exceeds its temperature limitations, and the adhesives and insulation within the voice coil assembly begin to break down. Similar to the PA limiter, the continuous power handling of the transducers at which this occurs is not relevant to the design. The temperature of the voice coil is what really matters. During the development of the TEMP limiter, each transducer in X-Line Advance has been measured to create a mathematical model of how the transducer heats up over time. Once the mathematical model is created, the DSP can predict how hot the voice coil is, based on the signal that has been sent to it.

Small changes in signal can have dramatic differences in voice coil temperature. Just a 4 dBV increase in the signal to the transducer may raise the voice coil temperature 160°C (Figure 17). This may be the difference between the transducer surviving, or bad sound and costly repairs. For more information on the TEMP limiter, please visit www.electrovoice.com and search for “TEMP limiter.”

SYSTEM ABUSE TESTING

Both the TEMP and PA limiter have been abuse-tested extensively during the development of the X-Line Advance system. In addition to using the industry standard tests such as AES noise tests, over the last 25 years EV engineers have developed proprietary tests that better mimic the real-world conditions that the X-Line Advance system is likely to experience. The final test is an EV-proprietary 1000-hour music abuse test, using production components and presets. Each passband within the system is driven up to 6 dB past where the PA limiter or TEMP limiter would activate. The test is then run continuously for 1000 hours without stopping. It stresses all components with sustained mechanical vibration and thermal load, including the amplifiers and transducers. If any weak points within the entire system are detected during this test, they are improved upon and the test is rerun. In the case of X-Line Advance, an entire array of elements was tested simultaneously to take into account any potential heat buildup within the array, as well as to test a population of components. X-Line Advance has accumulated well over 10,000 hours of total abuse testing prior to shipping to customers. While this can take months, once completed successfully there is a high degree of confidence that the system will last for many years in the field.

LISTENING TESTS

The ultimate goal of all the technology within the X-Line Advance system is to make the system sound good. EV engineers spend hundreds of hours in testing full arrays in both indoor venues as well as outdoor spaces to ensure all the presets sound well with each other and that the acoustic predictions are accurate (Figure 18).

Figure 18: Testing X2 line array with the X12-125F in cardioid configuration. The cardioid presets are designed to sound the same as the standard presets on axis.

X-Line Advance has a full set of presets for a variety of array configurations. There are presets that are optimized for both the 90° version and the 120° version. Both presets are tuned to sound the same, so that one array can use a combination of both waveguide patterns if the application calls for it. There are presets that include both the X12-128 and the X12-125F subwoofers in the same array. Since the X1 system can be configured for passive or bi-amp operation, there are presets for both. The X1 passive preset still uses FIR-Drive for equalization and limiters, so it sounds very much like the bi-amp version, as well as the X2 with FIR-Drive.

RIGGING

X-Line Advance features an all new suspension concept called the Integrated Rigging System (IRS). IRS allows for quicker and easier suspension of the array at the venue, in part because of its captive twist lock pins that automatically align with the link bars from the line array element above. IRS allows the array to be flown in tension, or in compression using the pull up grid. The IRS is capable of suspending up to 24 elements per array and is designed to work in conjunction with LAPS to ensure that the array is suspended safely.

EV takes the design and structural testing of suspension components very seriously. During development, EV engineers use mechanical simulation software to determine the yield point of every structural component within the array. To confirm the simulations, all components are tested on EV's pull test machine, a device that can apply and measure up to 20,000 lbs. of force (Figure 19). Multiple components are tested at various angles to determine the yield and ultimate failure as a function of load angle. The results are compared against the simulations. The actual test data is used to define the structural ratings. After the component level simulations are performed, many configurations of full arrays are simulated to determine the maximum amount of elements that can be safely suspended for a specific configuration. From these simulations, calculations are developed and built into the Line Array Prediction Software (LAPS) to evaluate the safety of any array designed by a user. Many engineering hours have been spent on simulations and testing to make sure that X-Line Advance line arrays are absolutely safe in all recommended configurations.

Figure 19: Structural testing of the X12-125F subwoofer system. All structural components are extensively tested on EV's pull test machine to ensure safe overhead suspension.

LAPS

EV's Line Array Prediction Software (LAPS) is an acoustics prediction software package that has been designed specifically for EV's line array products. It has been extensively updated to include X-Line Advance array predictions, as well as other updated features such as cardioid subwoofer arrays. LAPS runs off of a MS Excel GUI for ease of use and functionality on a variety of systems. However, the simulation engine is based on a powerful MATLAB platform. LAPS will not only predict the acoustic performance within the venue, but will also make sure that the array will be suspended safely, by informing the user if a particular array meets the desired safety factor. LAPS will even pick the correct presets to use based on the array configurations within the venue, reducing the risk of using incorrect presets. During the array testing, LAPS predictions were confirmed with measurements and listening tests to double check for accuracy.

CONCLUSION

The X-Line Advance line array system is a culmination of EV's years of experience in designing best in class line array systems, and represents EV's continuing commitment to the concert sound market. Thousands of engineering hours have gone into the research and development of X-Line Advance to ensure that the system has great sound and will be reliable for many years in touring and install applications.