WHITE PAPER

Addressing Sound Reproduction as a System-Wide Solution to Samsung's Onyx LED Cinema Screen Technology

ABSTRACT

Samsung's new, LED Cinema Screen technology—officially known as the Onyx—is poised to deliver a state-of-the-art cinematic experience to movie patrons. From a visual perspective, the new LED displays—available in 5- and 10-meter configurations—deliver unparalleled color, brightness, and contrast. With the technology's Ultra Contrast with TRUE black, viewers experience dramatically whiter whites and deep, true black. The system's High Dynamic Range (HDR) delivers unprecedented brightness, enabling the representation of a starry night sky, for example, in a manner never-before capable through traditional projection systems. Similarly, LED Cinema Screen technology provides vibrant color with never-before-experienced color accuracy. Equally notable, images exhibit perfect uniformity, free from optical distortion such as 'keystoning' caused by traditional projection systems when a projector is aligned non-perpendicularly to the screen.

These advances in visual excellence provided by the Samsung Onyx LED display, presented significant challenges in sound reproduction, due to the nature of the screen being solid. Unlike the customary placement used in traditional cinema, where the screen channel loudspeakers are placed directly behind the acoustically perforated screen, Samsung's Onyx Screen requires changes to traditional loudspeaker placement. From an acoustic standpoint, the traditional film screen is inherently flawed because placing a 'somewhat' acoustically transparent sheet of plastic in front of the screen channels negatively impacts their audio performance. For years, nonetheless, sound engineers have worked around these limitations to produce high-quality audio—because there was no better alternative. By contrast, an Onyx Screen is not acoustically permeable. Hence, the placement of screen channel loudspeakers must be handled very differently. This new approach to loudspeaker positioning and the considerations it entails provides a unique opportunity to overcome the acoustical restrictions of traditional setups and create sound that is pure and without impediment.

This document addresses the inherent challenges that Samsung's new LED Cinema Screen technology presents from an audio perspective and the process by which HARMAN's JBL Professional engineering team—working in tandem and as an integral part of Samsung—have addressed this new technology. This system level approach has produced innovation at multiple levels, including hardware (loudspeakers designed for the LED screen), DSP (Digital Signal Processing), and system EQ (equalization). The innovations documented here currently have no competition. They are the result of a concerted effort that only an organization of the size and scope of Samsung and HARMAN Professional (a Samsung company) can achieve.

UNDERSTANDING HOW THE BRAIN PROCESSES THE HORIZONTAL AND VERTICAL DIRECTION OF A SOUND SOURCE

The first and, perhaps, most obvious difference regarding loudspeaker positioning with Samsung's new LED Cinema Screen technology is the placement of the front channel loudspeakers. With the Onyx Screen, the screen channel loudspeakers are now positioned above the screen. To create the impression that the sound is coming from the front, which is what the audience expects and is accustomed to, the output of these loudspeakers needs to be 'de-elevated,' a process which unless addressed, can add additional and unwanted coloring of the sound.

[1] Research indicates that a universal de-elevation filter for an actual source at 25 degrees above the listener can create an apparent source de-elevated by about 13 degrees for male speech and by 10 degrees for female speech. De-elevation of the acoustic image of these elevated front channel loudspeakers is accomplished through DSP. To achieve this, however, an understanding of how the human brain processes both horizontal and vertical directionality is essential.

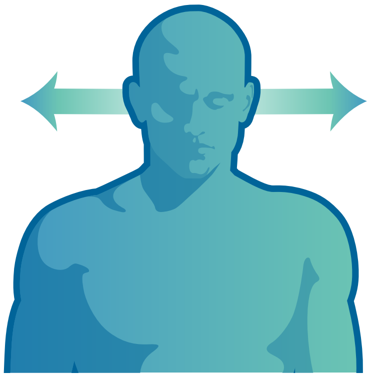

FIGURE 1

The first of these considerations is to understand a person's Head Related Transfer Function (HRTF) and how the human brain processes both the horizontal and vertical direction of a sound source (Figure 1). [2] Localization in the horizontal plane depends on the ITDs (time arrival to ears), ILDs (produced by head shadowing), and spectral changes caused by reflections and diffraction of the head, torso, and the shape of the ear. Localization in the median, or vertical, plane is different than in the horizontal plane since the signals available at both ears are almost identical.

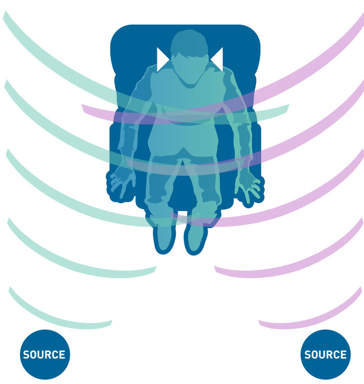

FIGURE 2

When processing the horizontal direction of a sound source, the brain compares differences in frequency, time, phase cancellation, etc., between both ears. As an acoustic image moves, the brain compares the differences to determine its location. The brain can process this information because there are two ears in the horizontal plane (Figure 2). The same is not true for the elevation of sound.

When processing the vertical placement of a sound source, the brain must use other techniques to determine its location as opposed to relying solely on the ears. In this case, the higher the trajectory, the more the forehead and upper ear lobe function to determine a source's location. A specific set of frequencies (1 kHz and above) are perceived with the forehead and upper ear lobe (Figure 3), relaying information that the sound source is located above.

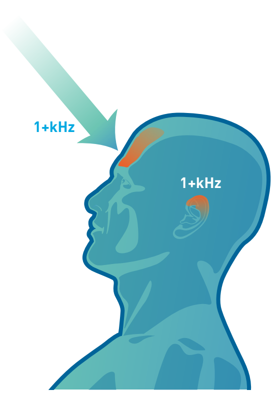

FIGURE 3

The lower the trajectory, the more important role the chest cavity (Figure 4) assumes in the process. Frequencies around 900 Hz are perceived in the chest cavity and provide further cues about the elevation of the sound source.

Using advanced Finite Impulse Response (FIR) filters for equalization, we can reduce specific high frequencies while increasing specific lower frequencies to 'de-elevate' the sound source's location. As mentioned previously, DSP is utilized to lower the acoustic image. As the perceived image source moves down the screen, the frequency response of the screen channels is modified.

These determinations were achieved by [3] a series of listening tests run across a panel of listeners. Nine of the listeners were considered trained, based on their performance in previous listening experiments, and all were measured for normal audiometric hearing. [4] In these sessions, listeners compared their individual 25-degree reference HRTF to a randomized treatment that could be either a de-elevation filter predicted to lower the audio to 0-degree, 10-degree, 20-degree, or the same 25-degree reference HRTF.

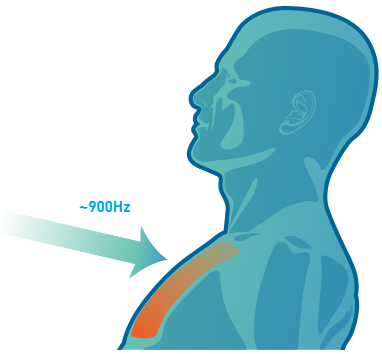

FIGURE 4

Please note that [5] this study was based on the physical characteristics of directional hearing included in the HRTF, but one must bear in mind that human sound perception in the median plane also relies on familiarity with the sounds and expectations. When it comes to cinema, most listeners are hearing the content for the first time and, as such, are not overly familiar with the content. Another point to emphasize is that to perceive elevation or de-elevation, the sounds should contain wideband and dense spectrum. Another issue is the spectral change introduced by the 'de-elevation' filters. This spectral change was reported by the listeners in the study. In informal listening It was also detected that the coloration introduced by the filters changed the sound quality to some extent. JBL engineering acknowledged these important observations and determined that more development was needed for this solution, which ultimately resulted in the introduction of the JBL CRF2 reflector horns.

THE JBL AUDIO SOLUTION—LOUDSPEAKERS SPECIFICALLY DESIGNED FOR THE LED CINEMA SCREEN ENVIRONMENT

As mentioned previously, Samsung's LED Cinema Screen requires the positioning of the screen channel loudspeakers to be above the screen. JBL offers two distinct loudspeaker systems for the front channel portion of the setup—depending upon whether the display environment is a 5- or 10-meter configuration. For the larger 10-meter rooms (the theater environment most movie patrons will find themselves in), JBL offers the 3733 Three-Way ScreenArray® Cinema Loudspeakers. This system consists of the JBL 3733 (Figure 5) front channel enclosures used in conjunction with the JBL CRF2 Reflector Horn (Figure 6) enclosures. For the smaller 5-meter display rooms (typical of a small private screening environment), JBL offers the C221 Two-Way ScreenArray® Cinema Loudspeaker (Figure 7) front channel enclosures, also used in tandem with the JBL CRF2 Reflector Horns. It should also be noted that, in addition to the C221, JBL 7-Series or other install loudspeakers can be deployed.

FIGURE 5

The JBL 3733 Three-Way ScreenArray® Cinema Loudspeaker is designed for critical sound reproduction. The 3733 uses the 4739 LF cabinet for increased low-frequency output, which incorporates dual 265H-2 380 mm (15-inch diameter), Differential Drive Edge-wound ribbon voice coil transducers. The High-Frequency portion of the 3733 utilizes Dual Dissimilar Arraying technology to shape the high-frequency coverage pattern for optimal use. JBL engineers have focused their research on improving the coverage patterns of all loudspeakers in cinemas to better match the geometry of a room with raked seating. This has led to the advent of "Sculpted Cinema Systems" from JBL.

FIGURE 6

Dual Dissimilar Arraying is a key component in creating coverage patterns appropriate for the individual location of the loudspeaker. Screen channel loudspeakers need a different coverage pattern than rear surrounds; however, both loudspeakers need to throw nearly the same distance. Dual Dissimilar Arraying is designed so that a screen channel can from their location, adequately be used to cover the entire audience area. JBL's C200 Series and the 3733 are screen channels that have incorporated this technology because the requirements of screen channels for the Samsung Onyx screen is very different due to the location (above the screen). The following images in Figures 8 - 11 show the coverage pattern that is created from Dual Dissimilar Arraying from 1kHz to 8kHz for the 3733.

FIGURE 7

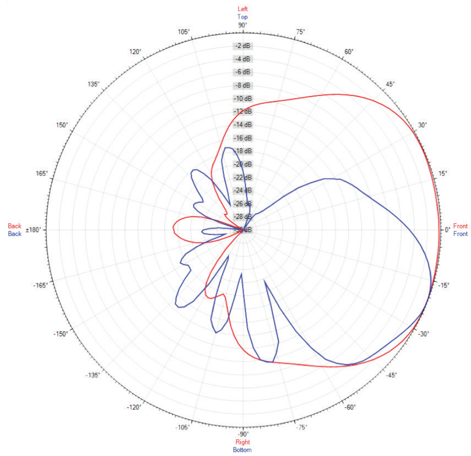

FIGURE 8A
(1KHZ COVERAGE) – POLAR PLOT

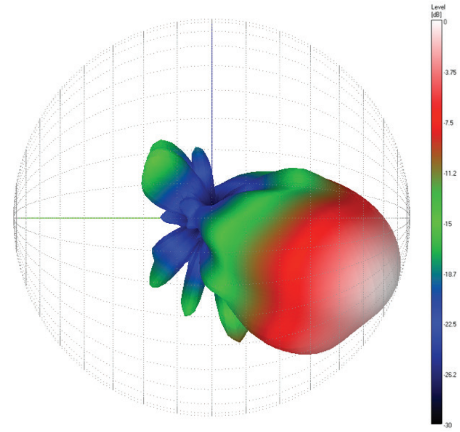

FIGURE 8B
(1KHZ COVERAGE) – BALLOON PLOT

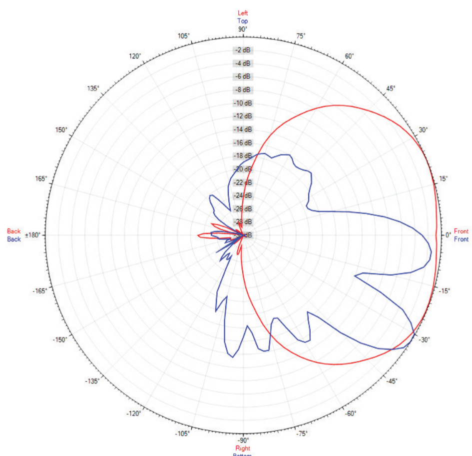

FIGURE 9
(2KHZ COVERAGE) - BALLOON

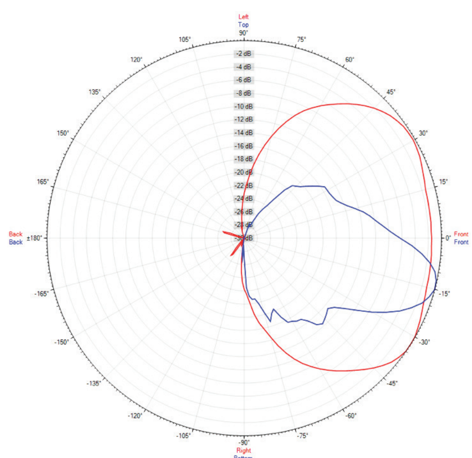

FIGURE10A
(4KHZ COVERAGE) POLAR PLOT

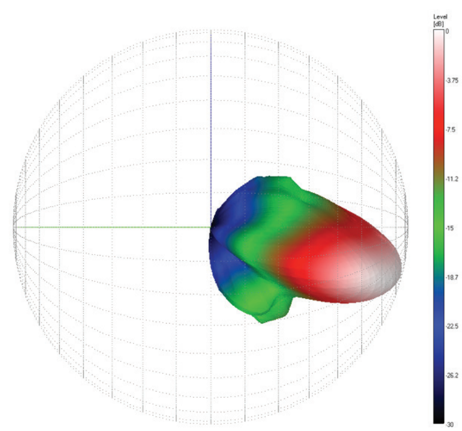

FIGURE 10B
(4KHZ COVERAGE) BALLOON

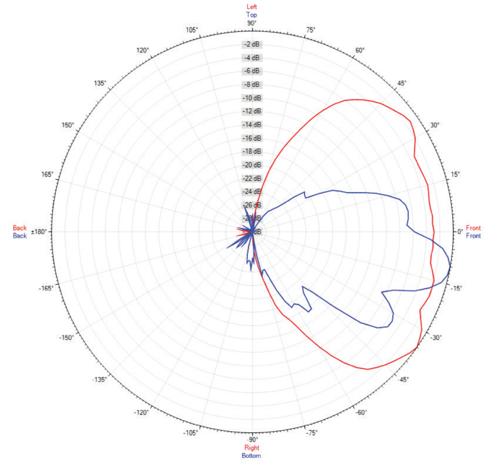

FIGURE 11A
(8KHZ COVERAGE) POLAR PLOT

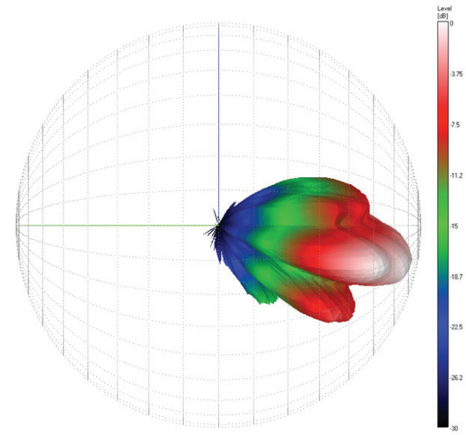

FIGURE 11B
(1KHZ COVERAGE) – BALLOON PLOT

In addition, the horn design improves the frequency response and lowers distortion at higher output. The 2415J-XP high-frequency drivers found in the 3733 are JBL's latest HF compression driver, designed to achieve higher output with lower harmonic distortion.

The JBL CRF2 Reflector Horns are mounted on the theater's side walls near the front of the room (Figure 12).

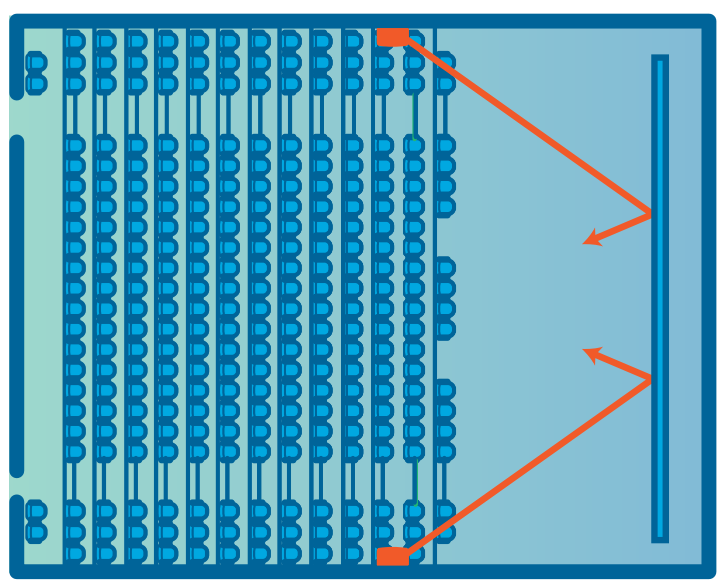

FIGURE 12

They are used to reflect high frequency content off the solid screen at the proper elevation. The CRF2 is designed to provide enough high frequency content at the correct elevation to enable the human brain to interpret dialogue as emanating from the proper, expected elevation. In addition, the CRF2 supplements the HF content that was lost in the de-elevation process. To maintain consistent tonal quality with the JBL 3733, the CRF2 utilizes the same JBL model 2415J-XP HF driver.

The 5m screen will be used for VIP Cinemas as well as post production and coloring facilities. For the smaller screen, it is critical to have a loudspeaker with a smaller footprint, for which JBL has plenty of options. With a compact footprint, the JBL C221 Two-Way ScreenArray® Cinema Loudspeaker features patent-pending Dual Dissimilar Arraying and Acoustic Aperture Technology, designed to provide uniform coverage and smooth, accurate sound reproduction throughout the room. The C221 has a depth of 12 inches (305mm), making it well-suited for small and medium multiplexes with space constraints.

THE SETUP:

Regardless of whether the loudspeaker setup uses the JBL 3733 Three-Way ScreenArray® Cinema Loudspeakers or the JBL C221 Two-Way ScreenArray® Cinema Loudspeakers for the front channel output, EQ processing is used to 'de-elevate' the sound for speakers above the screen. The ideal location of the screen channels is for Left/Right be located beside the screen and center channel to be located above the screen. Having all 3 screen channels above the screen is acceptable but not the ideal solution.. De-elevating the sound lowers its perceived output—thereby creating the impression that the sound is coming from behind the screen (Figure 13). It is important that this de-elevated sound still complies with the X-Curve, which since the early 1970s, has been the standard practice for movie sound production.

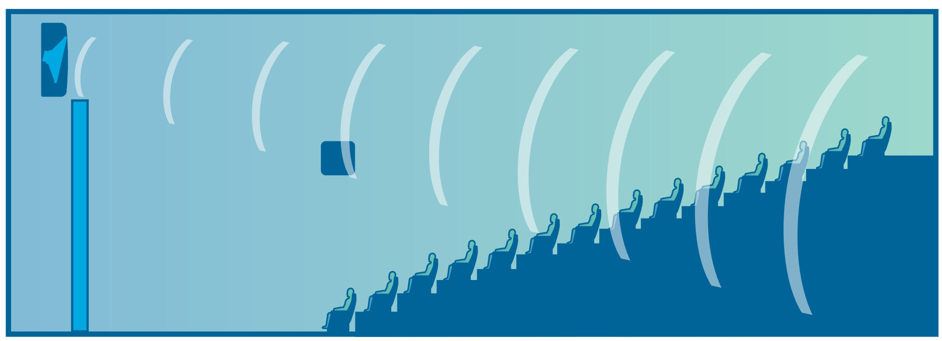

FIGURE 13

This is where the JBL CRF2 Reflector Horns come into play— to re-introduce high-frequency energy that was taken out in the 'de-elevation' process. With the CRF2 Reflector Horns mounted on the theater's side walls in reasonably-close proximity to the screen (Figure 12), their output is aimed at the front screen and reflected at the correct elevation, or acoustic height, to create an overall sonic impression that is coming from behind the screen (Figure 14).

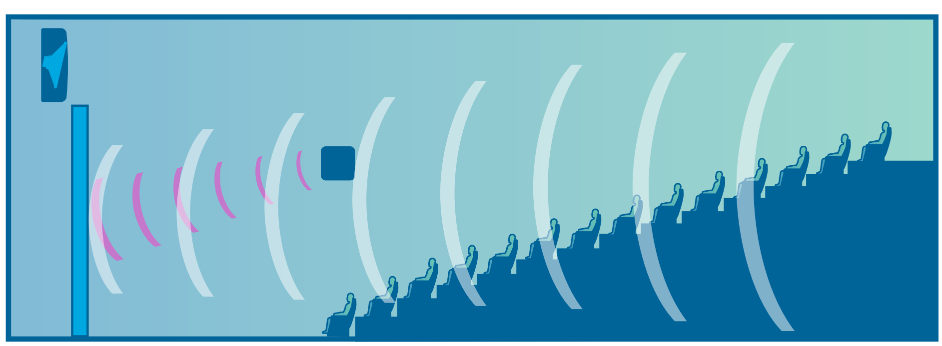

FIGURE 14

Together, the de-elevated output from the combination of either the JBL 3733 Three-Way ScreenArray® Cinema Loudspeakers or the JBL C221 Two-Way ScreenArray® Cinema Loudspeakers—and the output of the CRF2 Reflector Horns— reinforces the perception that the sound is approaching from behind the screen. It is important to note that the entire system (screen channels, subs, and surrounds) are time-delayed to the reflected HF output of the CRF2. The result then, is that the reflected HF output of the CRF2 and the output of the main screen channels—via either the JBL 3733 Three-Way ScreenArray® Cinema Loudspeakers or the JBL C221 Two-Way ScreenArray® Cinema Loudspeakers—are perfectly synchronized (Figure 15).

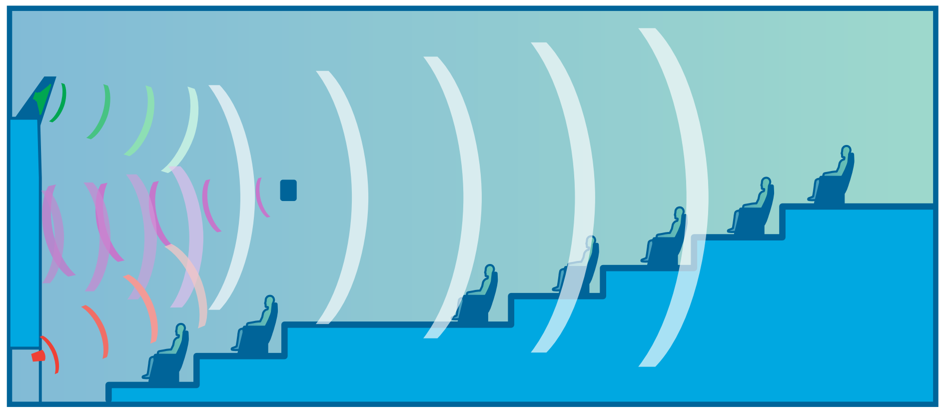

FIGURE 15

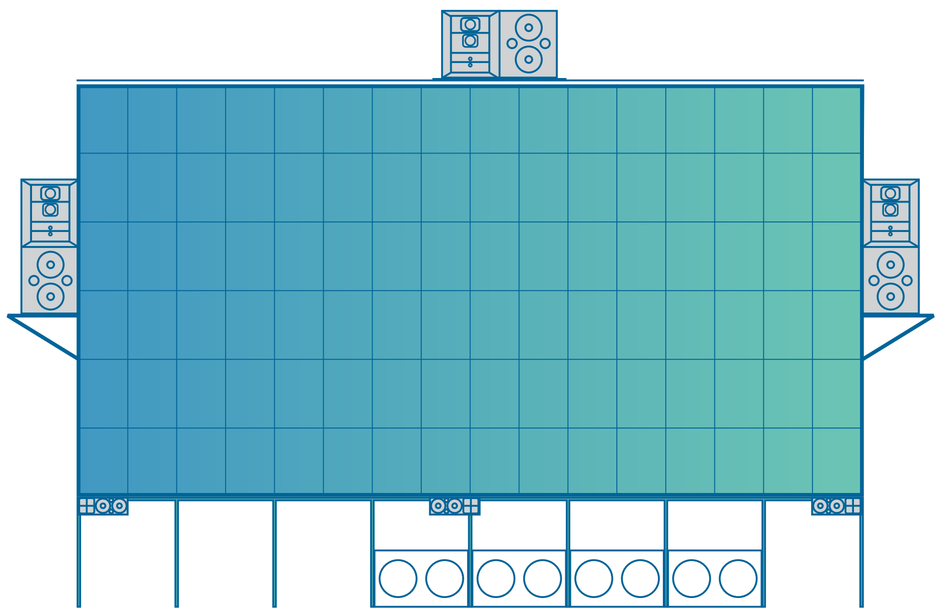

FIGURE 16

FILL SPEAKERS

As a complement to the screen arrays that are above the screen, three loudspeakers are also desirable under the screen for Left, Center, and Right Channels. These lower speakers are needed to supplement the high frequency content from the screen channels. The use of loudspeakers in this position is largely based on the geometry of the room, the coverage pattern of the 3733's, and the location of the first row seats. As the seating position is moved towards the screen, the use of the lower speakers becomes more critical. These speakers also help with the elevation of acoustic image. JBL AC28/26 loudspeakers are the preferred speakers for this location due to the 120 degree horizontal coverage pattern.

The tuning of these fill speakers is executed after the tuning of the main front speakers. To balance the frequency response, it is necessary to have a high pass filter set between 500Hz and 1kHz depending on each theatre and EQ filters (PEQ and FIR). Time alignment of these speakers are done in the first seating row, as their contribution is significant at this location. Beyond the first third of the room, the fill speakers contribution is less than 1dB, which is inaudible.

DIGITAL SIGNAL PROCESSING (DSP) ASSUMES AN INTEGRAL ROLE IN AUDIO MANAGEMENT

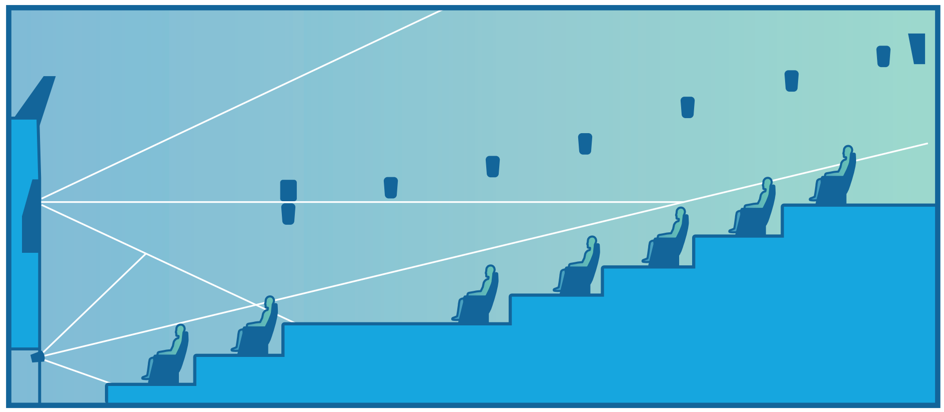

FIGURE 17

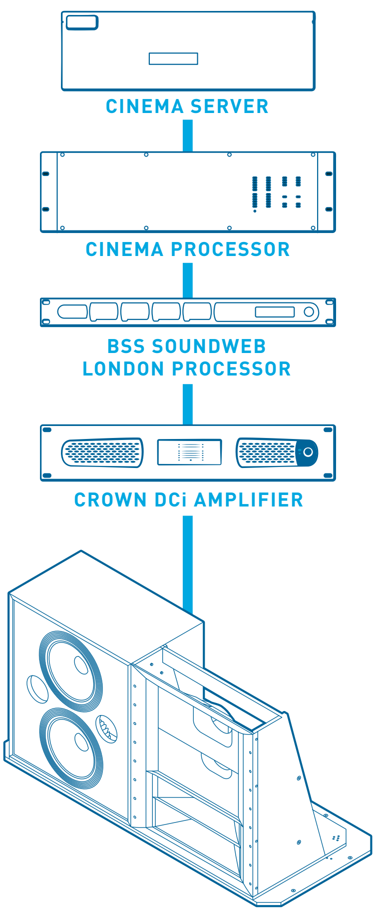

FIGURE 18

Due to the various changes in the positioning of the loudspeakers used with Samsung's Onyx Screen, DSP assumes an integral role in loudspeaker management. As part of this, it is important to understand the signal chain that constitutes JBL's audio solution for this new environment.

The first device in the signal chain (Figure 18) is the Cinema Server, which then feeds the Cinema Processor. From here, the next step in the chain is the BSS Soundweb London Processor, which is an open-architecture DSP platform that enables the use of advanced DSP and tuning capabilities. For this application, the BSS Soundweb London Processor can be configured with either an 8-channel analog card for input from the Cinema Processor or an 8-channel AES digital card for PCM audio directly from the server. The BSS Soundweb London Processor can be used instead of the cinema processor, but additional hardware requirements exist.

The output of the BSS Soundweb London Processor then feeds the Crown DCi power amplifiers. In the 10-meter Onyx Screen configuration, the output of the Crown DCi amps feeds the combination of the JBL 3733 Three-Way ScreenArray® Cinema Loudspeakers and the JBL CRF2 Reflector Horn. In the 5-meter Onyx Screen configuration, the Crown DCi amps feed the JBL C221 Two-Way ScreenArray® Cinema Loudspeakers and the JBL CRF2 Reflector Horn.

The process of 'de-elevation' from the front loudspeakers—now positioned above the screen as opposed to behind it—along with that of reflecting the high-frequency output of the CRF2 Reflector Horns off the screen requires considerable DSP to accomplish the sound delivery the audience expects. That, of course, is to hear the sound as though it is coming from the front of the theater. Anything less than this would be extremely disorienting.

Samsung and its HARMAN Professional audio team conducted extensive testing to determine optimum room response for the cinema environment. The challenges of implementing advanced DSP in the cinema are threefold. First, the time during which signal processing takes place must be minimal. Similarly, the process must achieve consistency from one room to another, and finally, the process of implementing DSP must be such that system integrators can manage the process in a timely fashion and without confusion. As with any audio application employing equalization, accurate measurements are essential to obtain the acoustical character of the audio system plus room interaction, or room response, as this is the underlying basis for any needed corrections to implement.

Samsung and HARMAN have developed advances in loudspeaker design (Dual Dissimilar Arraying) and DSP (De-elevation). These items address the critical nature of loudspeaker use and coverage. However, we needed to develop a system that enables consistent measurements and ease of use in setting DSP parameters. Therefore, Harman initiated development of a Moving Microphone Method for data acquisition and an FIR program to set final DSP.

INADEQUACIES IN STATIC MICROPHONE (SM) MEASUREMENTS

Standard equalization measurements [6] call for using 4 or 5 microphones positioned in a semi-random pattern—all at 0.45m above the seat backs. This configuration models a close to 2-dimensional plane hovering a set distance above the audience. In reality, the audience's ears are well inside the seat backs of most modern cinema seats, whereas this measurement plane largely avoids the acoustical boundary effects of the seat and does not properly model the appropriate room response perceived by the audience at all frequencies.

Since the static microphone positions (SM) share a common dimension to the floor and seats, they also have frequency response errors related to these dimensions not related to the ear positions. These boundary conditions will negatively influence the room response and skew the data set. It is well understood that a single SM position in the seating area will not properly characterize the room response perceived by the listener. First, there is no single position for the ears. With many body shapes and sizes, the statistical audience ear location is a 3-dimensional space. The goal, then, is to properly characterize the response for the entire room—for all audience members.

THE MOVING MIC AVERAGE (MMA) ACHIEVES MORE ACCURATE RESULTS

The typical process of equalization with a Moving Mic Average (Figure 19) is to first measure the entire room for each loudspeaker [7]. This can be done by 2-row or single row measurements, repeating until all rows are measured, then averaged. In practice, this is the only time all rows are measured. The average is then differenced to the calibration row (or 2 rows) measurement. The inverse of this difference curve can now be applied to any future calibration row measurements revealing the room average from a single measurement. SMAART allows this function by applying a weighting curve.

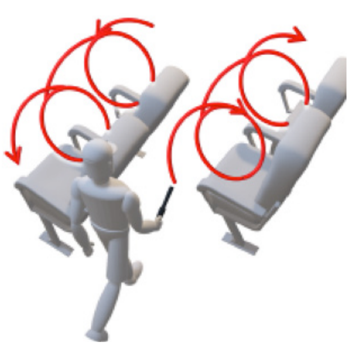

FIGURE 19

The MMA provides a significantly smoother overall curve, providing a better representation of the room response without boundary functions that are present with static microphone measurements. This smoothness is not only more accurate, but it is also more practical regarding equalization—particularly if the hardware only allows 1/3rd octave resolution.

It is important to understand that SMAART uses three averages per second when taking measurements. Therefore, many measurements are taken as the microphone moves through space. The process also averages-out boundary conditions that may be present in static microphone measurements. As the microphone moves over two rows through a 20 second period, 60 measurements get averaged together.

To summarize, the measurement first needs to incorporate a volume of space that shows not only the horizontal but also a vertical variation of acoustic response. The measurement needs to incorporate the seat as well because this will be the listener's position. The measurement needs to average out artifacts of boundary interactions as well as combining artifacts that obscure interactions between the correlated signals from multiple channels. Lastly, it is critical that the measurement provides consistent results that don't change with setup or a particular measurement position. Although it can be shown that a spatial average using a sufficient number of static microphones can meet these criteria, it becomes impractical in implementation because of the inordinate number of microphone positions required. The moving microphone method meets the requirements for consistent, accurate and relevant results while facilitating a simple and practical implementation.

PROCESSING THE COLLECTED ROOM MEASUREMENT INFORMATION

The Samsung Onyx screen audio solution uses a combination of Infinite Impulse Response (IIR) filters and Finite Impulse Response (FIR) filters. In general terms, these filters are used to make the necessary corrections for the room response, phase shift, and tuning (including weighting curves).

GENERAL NOTES:

- The first step in this process is to get each left/right channel pair to sound the same using Parametric EQ (PEQ). Since each loudspeaker will have an anechoic correction applied within the amplifiers, this usually takes a minimal amount of PEQ filters (4 or less) from 40Hz – 200Hz. This step is repeated for every channel pair (Left/Right, L/R Surrounds, L/R Surround Rears). Center channel PEQ's are set by themselves. In general, the response of all the screen channels should be nearly identical.
- Once the Left/Right channel pairs sound identical, FIR filters are used to precisely tune the loudspeaker response to the X-curve. This is based on the room response measurement taken with SMAART.

IIR Filters (parametric EQ): IIR filters have been used to adjust EQ in cinemas for many years. IIR filters can be either analog or digital. These filters can take the form of graphical EQs (typical in cinema) and Parametric EQs (typically only used in LFE in cinema). Graphical EQs are not very precise and impact a range of frequencies by the very nature of their limited frequency control and gain boost/cut. Additionally, the phase response of graphic EQs can be significant, which can introduce additional response issues. Parametric EQs are a step better than graphical EQs, as they can be far more accurate. Control of frequencies, Q, and Gain enables PEQs to be considerably more precise. Phase response for PEQs is still an issue; however, not as much of an issue as it is with GEQs. In IIR filters, phase response variation is inherent to the gain/boost/Q applied, so there is no control of the phase response. Further, DSP requirements are minimal with IIR filters, which makes these filters have a lower implementation cost.

- The image below (Figure 20) shows Left/Right Screen channels before adding any EQ other than the anechoic correction (speaker tuning).

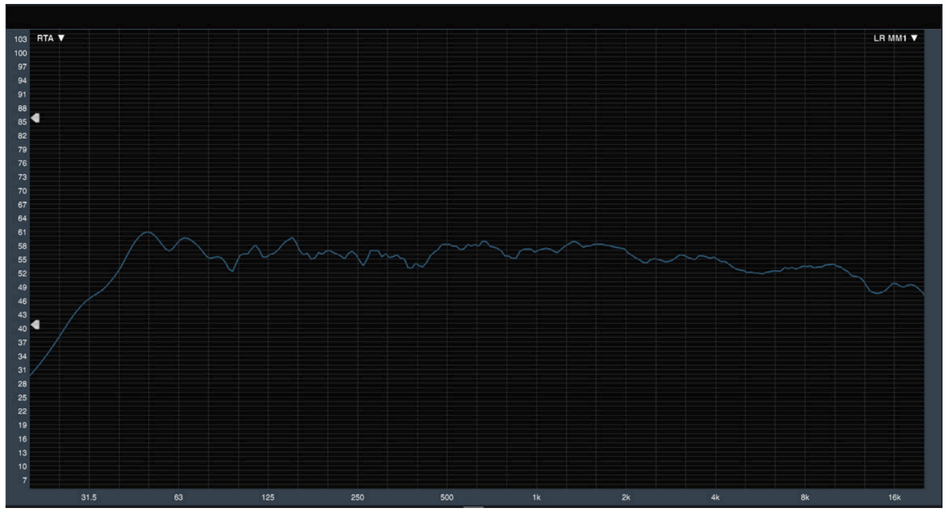

FIGURE 20

- A few PEQ's were added to adjust for some room correction. The image below (Figure 21) shows the room response after the addition of PEQ's. The blue line indicates the room without additional EQ, and the red line indicates the use of PEQ's. This is to compensate for the room interaction at a very basic level. Adjustments were made to frequencies from 63Hz – 1kHz.

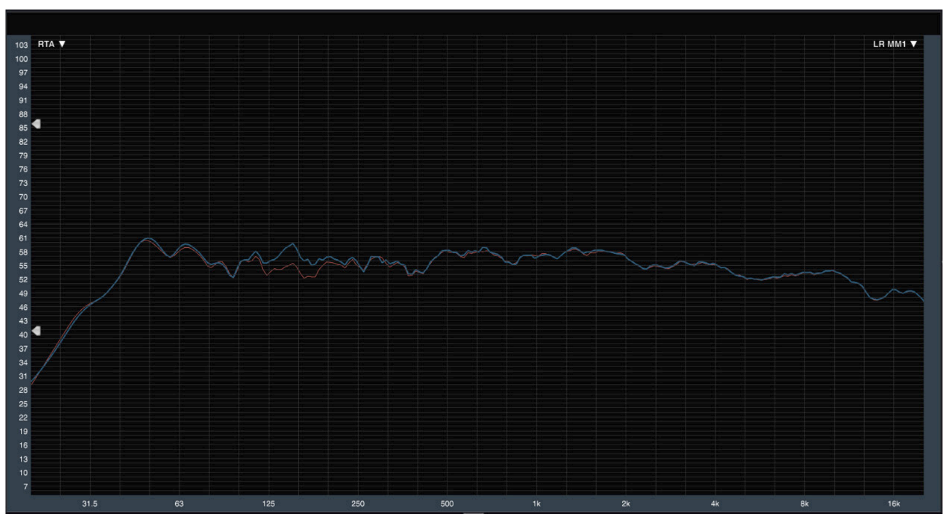

FIGURE 21

- Implementing PEQs is a good first step to correct for room interaction, especially in lower frequencies (from 40Hz – 200Hz). For the rest of the frequency spectrum, FIR filters are used because of their precision in frequency control and minimum phase characteristics.
- Also, note that the frequency response in the mid and high frequencies (1kHz – 20kHz) have a rougher response than desired which will be addressed with FIR filters.
    - FIR Filters can take significantly more DSP resources (computing power). However, they can be much more precise when establishing a desired room response and can now be quickly set. FIRs are only possible in the digital

domain, and as such, can create any frequency or phase response desired. FIRs in the Onyx room take 2048 taps per channel and impact frequencies ranging from 175 Hz to 20 kHz. FIR Filters are used to get a very precise frequency response to any curve weighting. For the Onyx system, the target is the X-Curve.

- Compare the image below (Figure 22a) to the previous images. It is important to note that this response is after the implementation of the FIR. Note that the rough frequency response from 1kHz – 20kHz has been smoothed out with the FIR filter.

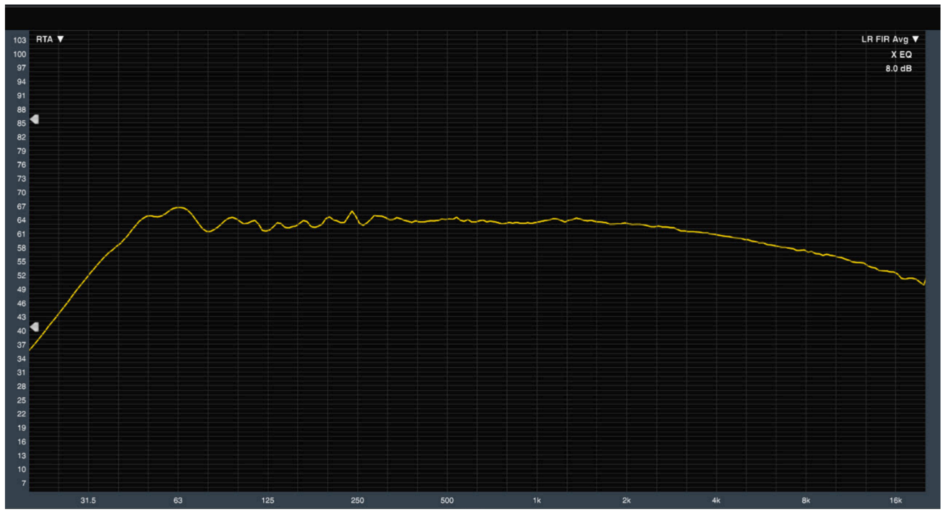

FIGURE 22A

- The response of each output is still tuned to the industry accepted X-Curve. FIRs are only used above 175 Hz. PEQs are used below this frequency range. The image below shows the same frequency response overlaid with the X-Curve.

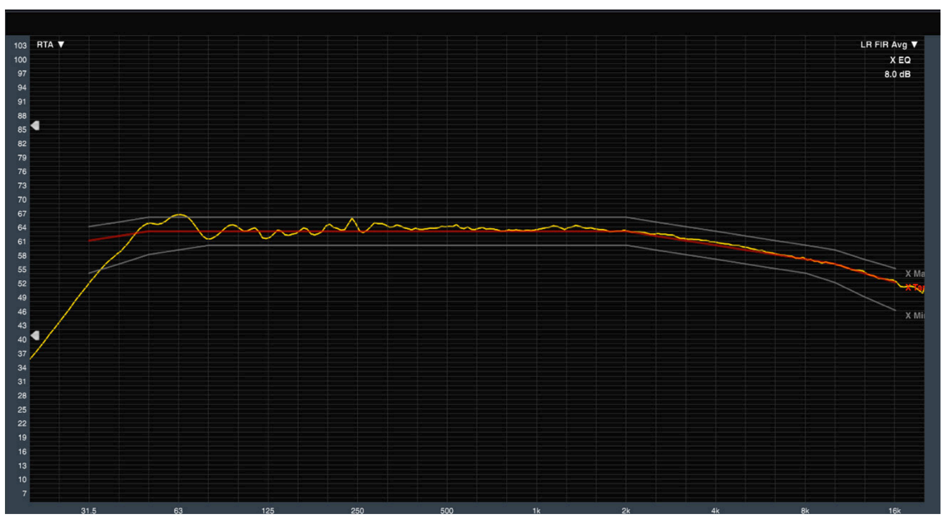

FIGURE 22B
(FREQUENCY RESPONSE W/X-CURVE)

- Note how close the frequency response is when compared to the X-curve is (+1.5 dB from 315Hz – 20kHz).
- All channels use FIR filters except for the LFE channel, which uses PEQs only.
- FIR filters are also used for the de-elevation process and the reflector horns due to the precise nature of the frequency response needed for these outputs.

SYSTEM PROCESSING EQUIPMENT

The hardware/software requirements used for tuning Onyx Screen theaters involve the combination of a SMAART audio and acoustical measurement and instrumentation rig along with the HiQnet Audio Architect software, which is used in conjunction with either the BSS BLU-806 Signal Processor with Digital Audio Bus and Dante or the BSS BLU-160 Signal Processor with Digital Audio Bus. Advanced knowledge of the SMAART system is essential to properly gauge Magnitude Response and Transfer Function (Figure 23). The Audio Architect template is supplied.

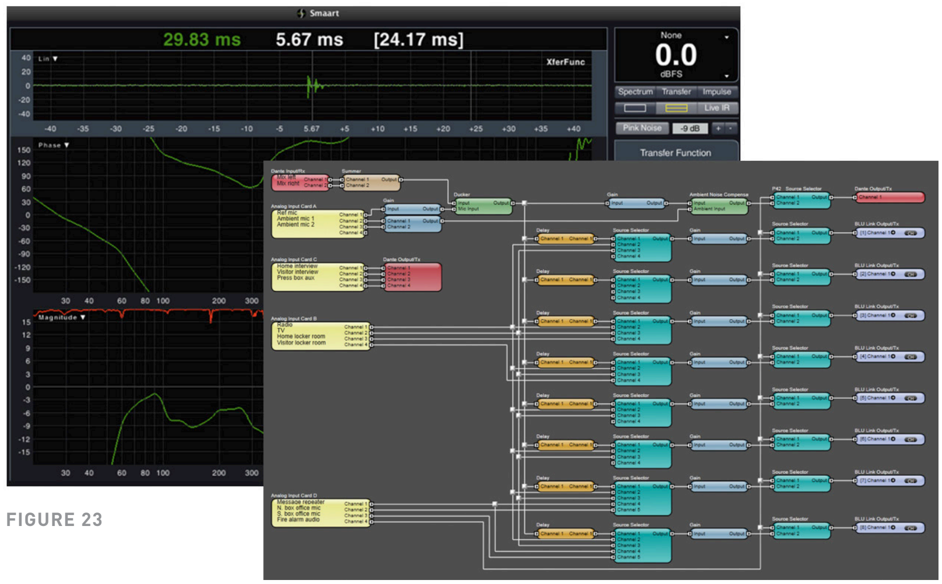

FIGURE 23

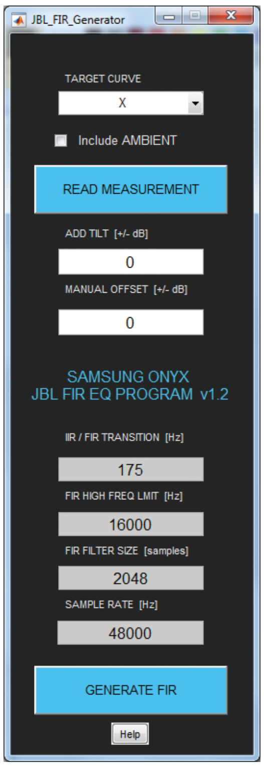

FIGURE 24

The process involves taking a ~20 sec measurement of room response by channel, after which the SMAART system data is loaded into an executable (.exe) file to produce the FIR filter. From here, the FIR filter is loaded into Audio Architect for use with the BSS BLU audio processors (Figure 24).

SCULPTED SURROUND—ENSURING OPTIMIZED SURROUND SOUND

To complete the Onyx Screen theater experience, one cannot ignore the necessity for the full, rich, evenly-deployed audio experience that only JBL's Sculpted Surround loudspeakers provide. Sculpted Surround ensures uniformity so that moviegoers experience sound the way a film's creators intended for 5.1 or 7.1 systems.

Every loudspeaker has a unique and complex acoustical radiation envelope shape [8]. This shape is important when trying to present uniform sound to a large area and when overcoming the attenuation of sound relating to the distance from the loudspeaker. In cinema terms, if the loudspeakers had no envelope shape, only the first few rows of seats would get good sound from the screen, and there would be no actual channel balance.

TRADITIONAL SURROUND SOUND 5.1 / 7.1 SYSTEMS

For years, cinema surround coverage was distributed by a single array of loudspeakers, evenly spaced around the perimeter of the theater. Each loudspeaker only needed to cover a small portion of the audience. The evolution of surround formats, however, requires a more sophisticated approach. Most surround speakers are not designed to work with stadium seating. Typical surround loudspeakers that are not adjusted for the inclined rake in theaters can create a buildup and uneven distribution of surround information. As a result, moviegoers may have vastly different surround sound experiences in the same

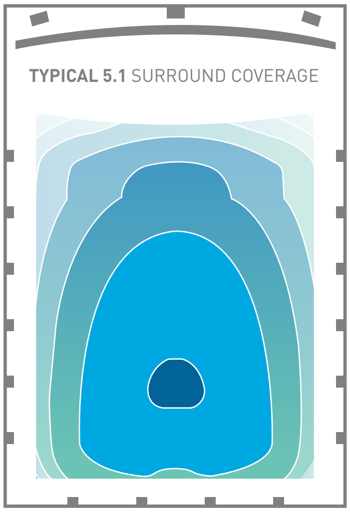

FIGURE 25

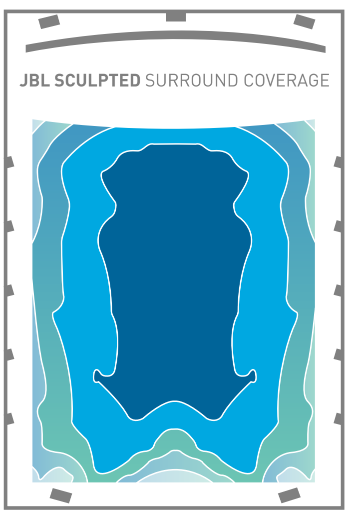

FIGURE 26

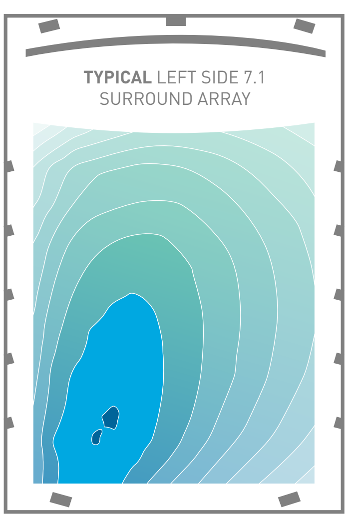

FIGURE 27

room, since different locations in the room demand a different envelope shape (Figure 24). As an example, a rear surround sees different room geometry than a side surround. When the ceiling and screen locations are factored in, there are at least four distinct patterns necessary for uniform surround coverage in the immersive formats, and at least two for 7.1 or 5.1.

The shortcomings of the traditional 5.1 or 7.1 surround sound system typically include:

- Rearward bias
- Poor coverage
- Strong forward cueing for side content
- A reduced atmospheric audio experience
- Only a small section of the audience hears the front/rear loudspeakers as represented by the darkest color on the graph. There may be as many as three zones in the theater with distinctly different experiences

THE SCULPTED SURROUND 5.1 / 7.1 SYSTEM

By contrast, a Sculpted Surround system (Figure 24) evenly deploys sound throughout the room by accommodating inclined seating. Benefits of the Sculpted Surround system include:

- All seats receive the same signal strength from each loudspeaker
- Speaker directivity and tilting eliminates hotspots and rearward bias
- Moviegoers experience broadened sound coverage
- The sound radiation pattern complements the screen channels
- The coverage area of the surrounds is more balanced and even
- Sculpted Surround can potentially reduce the number of loudspeakers required

The contemporary cinema-style stadium seating arrangement with its inclined rake has forced several considerations now addressed by the Sculpted Surround 5.1 / 7.1 system and its more sophisticated approach. [9] Surrounds must now operate in much smaller groups, or even solo, meaning that each surround must be able to cover much, if not all, of the room.

It is important to design the audio experience to track with the visual experience. In layman's terms, the best visual seats should also be the best audio seats. Coupled [10] with the fact that screen channel content is of greatest importance, the screen channel plot can easily be regarded as the reference target for the surround plots as we begin looking at the newer formats.

The contour map [11] below (Figure 26) shows coverage of the 7.1 left side surrounds, with seven loudspeakers in this model. One can immediately see a strong bias towards the rear.

Noting that the right side mapping will be a mirror image of the left, a box is drawn in the area where the surrounds are in left/right balance, and also in balance with the screen channels.

Please note that, compared to a 7.1 environment, 5.1 performs worse because half of the rear loudspeakers are grouped with their associated side arrays, making the rear bias even stronger and collapsing the balance area even further. Meticulous level adjustments with the loudspeakers can improve this slightly, but two fundamental issues remain: incorrect loudspeaker pattern and improper orientation in relation to the seating plane.

Seating plane orientation is best described by the graphic below (Figure 25), which shows loudspeaker pattern orientation from a side surround position to the audience. The goal

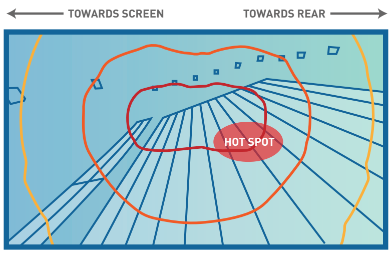

FIGURE 28: How a side surround 'sees' the audience. The yellow, orange, and red lines represent the 3, 6, 9 dB pattern lines of the loudspeaker. Stadium seating creates a 'hot' spot—shown by the red ellipse—where the loudspeaker energy is strong, and the audience is close.

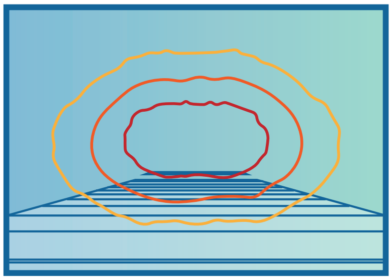

FIGURE 29: How a typical rear surround 'sees' the audience.

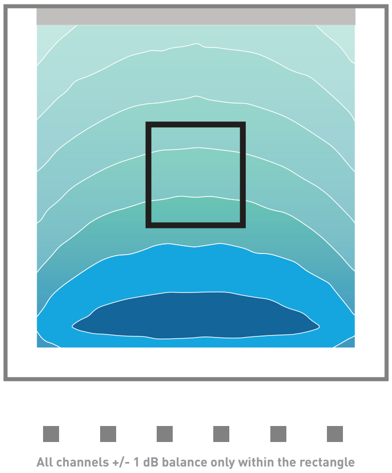

FIGURE 30

FIGURE 31

is for the intense (dark blue contour) energy to be directed to the most distant seats. With horizontally oriented loudspeakers presenting to an angled seating plane, there is a natural 'hot' spot created on the rear side of the pattern where the seating plane approaches the height of the loudspeaker. Explained a different way—audience distance from the rear side of the red contour is much closer than the audience on the forward side of the red contour. Since all of the loudspeakers experience this phenomenon, a rear bias is created in the coverage.

Analysis [12] of 7.1 rear surrounds (Figure 28) reveals a more difficult coverage requirement. The primary room-related parameter a cinema loudspeaker must compensate for is attenuation due to distance. The contour map below shows this for a 7.1 left rear array and demonstrates the 16 dB difference between front and rear rows. To further complicate the issue, this happens in a fairly small angle from the loudspeakers' perspective. The graphic below shows how a typical loudspeaker coverage pattern presents in this arrangement. The audience does not experience the most intense energy, so it stands to reason that it's not the correct pattern for this application.

Figure 30 shows the resulting coverage map of a 7.1 rear surround array. It has a severe rearward bias and a 7 dB differential between the front seats and rear seats. In this example, the front half of the theater receives no intelligible rear content. Also, there is a 4 dB differential between the rear row and calibration row. Evaluating the +/-1 dB channel balance for all loudspeakers is now restricted to the box shown, which represents approximately a mere 7% of the audience!

JBL's legendary engineering team [13] embarked on an exhaustive research and development journey to combat this issue, and the result is the JBL 9350 Configurable Pattern Surround loudspeaker (Figure 31).

The 9350 is a configurable pattern loudspeaker, featuring multiple patent-pending technologies that deliver unprecedented performance, far surpassing any other product in this market. Using a unique combination of waveguide and line array techniques named Dual Dissimilar Arraying, two distinctly different waveguides are used in tandem to sculpt a combination pattern to match the requirements of the room's geometry. By utilizing electronic filtering, the coverage pattern possibilities are virtually infinite. The standard 9350 features both a side surround and rear surround pattern. This may sound like it would require sophisticated DSP, multiple amplifiers, and an extreme price tag, but the 9350 is a passive loudspeaker with one amplifier connection and a simple selector switch at the input terminals to configure the coverage pattern. In other words, it's efficient and affordable.

In more specific terms, the 9350 is a dual HF two-way with a waveguide and an LF section that includes 15-inch woofer. The unique 'acoustic divider' waveguide (patent pending) on the woofer provides directivity and crossover performance closer to a 3-way system, and the powerful 15-inch neodymium woofer uses legendary JBL Differential Drive technology for an impactful low-frequency extension. The 9350 rivals screen channels in sonic performance and dynamics. With the 15" driver, this unit can achieve higher output at lower frequencies, thus eliminating the need for surround bass management.

JBL 9300 JBL 9310

FIGURE 32

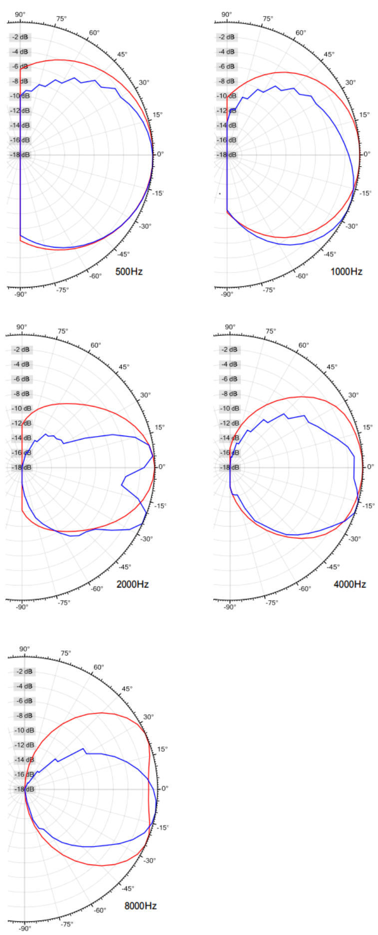

FIGURE 33: JBL 9300 Coverage.
1 Oct avg polar plots
VER=blue, HOR=red.
Note: HOR not in audience area

ADDITIONAL JBL CINEMA SURROUND LOUDSPEAKER SOLUTIONS: THE 9300 AND 9310

Digital cinema and the new audio formats require surrounds to operate in much smaller groupings and even singularly. Now more than ever, surrounds must possess engineered coverage patterns and improved output dynamics. JBL's extensive research efforts to analyze these new requirements and then to design a completely new surround loudspeaker resulted in the groundbreaking 9300 series. The horns developed specifically for the 9300 and 9310 (Figure 32) provide studio quality performance yet offer pattern control that's tailored to multiplex theater geometries. The 9300 horns map to a theater more consistently and accurately than ever before. Integral to their design is a wave shaping vane which distributes acoustic energy in proper proportion to the room. This technique provides a wavefront that is sculpted to the room geometry and provides very precise mapping capability. This shaping also allows the loudspeaker to naturally orient to the wall while directing the acoustic energy to the seats.

Key features of the JBL 9300 Cinema Surround Loudspeaker include its 250-watt power handling capability and a high-frequency horn that integrates JBL Image Control Technology for precise pattern control. Three separate horizontal mounting planes at 15-degree angles for specific positioning improve coverage while input terminals on top of the cabinet facilitate easy access. The 9300 utilizes a lightweight, rigid molded enclosure and the loudspeaker delivers uniform asymmetric 60-degree vertical coverage and 110-degree horizontal coverage.

JBL's 9310 Cinema Surround Loudspeaker offers 350-watt power handling capability and a high-frequency horn that features JBL Image Control Technology and Wave Shaping Vane for precise pattern control. There are three separate horizontal mounting planes at 15-degree angles for specific positioning to improve coverage and input terminals on top of the cabinet provide easy access. Like the 9300, the 9310 utilizes a lightweight, rigid molded enclosure and the loudspeaker delivers uniform asymmetric 60-degree vertical coverage and 110-degree horizontal coverage.

JBL CINEMA LFE

The use of low frequencies in cinema is a very important driver of the cinematic experience. Rich, powerful and well-controlled low frequencies can greatly increase the perceived quality of the cinema. Film soundtracks can be more transient and non-linear than can be addressed by typical music playback systems; therefore, the sound system and its products must be chosen to deliver high output low-frequency sound without distortion. The objective of the subwoofer in cinema is to move as much air as possible. This is critical when the subwoofer needs to deliver peak output at some of the most emotional "big moments" of a movie. For subwoofers, the "big moment" translates into the ability to deliver a physical impact that is equal to the audible level of the subwoofer. A visual explosion on screen needs to be felt as much as be heard.

The ability to deliver impact as well as high volume directly correlates with the volume of air that is moved by the subwoofer and the more surface area of a subwoofer cone, the more volume of air that can be moved. The subwoofers used for the Onyx screens include driver technology to increase output while maintaining linear reproduction of the soundtrack. JBL's 5628 subwoofer includes Differential Drive® woofers featuring Vented Gap Cooling™ technology with ultra long excursion of the drivers. Typical cinema's that have a 10m or 14m screen uses 1- dual 18" subwoofer. In the Onyx system, a minimum of two 5628 subwoofers are specified (four 5628 subwoofers are the specified standard configuration) to ensure that there is plenty of headroom to deliver both the impact and audible content that viewers come to expect in premium cinemas.

The subwoofers should be spaced as close together as possible to deliver as much impact as possible. In the Onyx system, this will largely depend on the construction of the screen frame. Figure 34 shows the best configuration for subwoofers. It is important to note that this configuration is set slightly off center of the screen, but the subwoofers are grouped very close together.

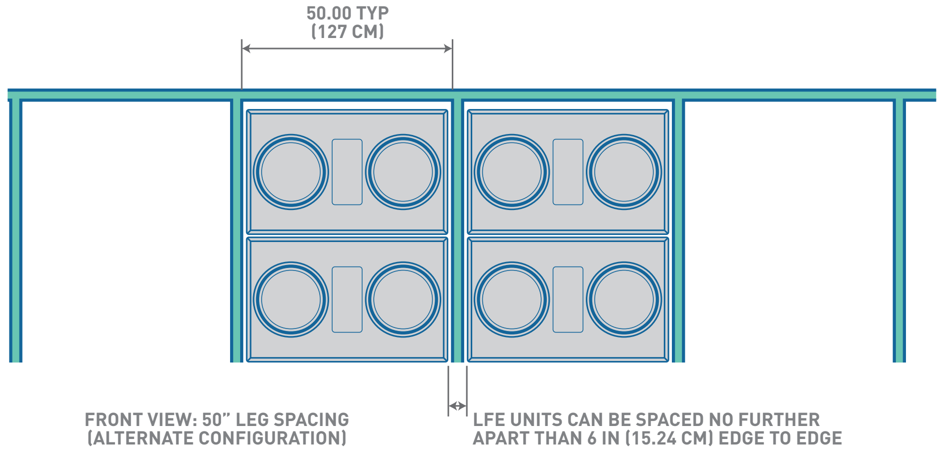

FIGURE 34

Other configuration can be considered based on the frame construction, however, this configuration is considered optimum.

SUMMATION

Samsung's Onyx LED Cinema Screen technology is poised to revolutionize the movie-going experience. The visuals are designed to provide vivid imagery that conventional projection systems simply cannot match. By working closely with Samsung, JBL's loudspeaker engineering prowess takes the audible side of the movie experience and elevates it to an entirely new level. The result is a theatrical experience that is second to none.

JBL's leadership in loudspeaker design and engineering is ready to provide a flawless surround sound experience to every seat in the theater. To learn more, we invite you to learn more about our complete solutions for the cinematic experience at http://www.jblpro.com/www/products/cinema-market/

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[11] Balanced Surround Coverage for Professional Cinema – JBL Professional, 2017 HARMAN International Industries, Incorporated. Page 3.

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