White Paper

# Sound Localization and Non-perforated Screen Applications

A Q-SYS Direct View Screen Audio Solution

## Overview

Over the last ten years, there has been growing interest in using direct view emissive displays as an alternative to front projection for the image source in commercial cinema exhibition. There are many benefits to using these types of displays, including:

- Increased contrast ratio
- Increased brightness
- Eliminates the need for the projection booth, allowing more efficient and creative use of building square footage
- Image uniformity across the entire screen surface

Along with these potential benefits, there are several challenges for the delivery of the audio experience. Since direct view screens are not acoustically permeable, left, center, and right "screen channel" loudspeakers cannot be placed behind the screen. These loudspeakers must be positioned elsewhere; for example above, below, or to the sides of the screen. Some solutions position the loudspeakers in the seating area aimed toward the screen, reflecting sound back out to the audience. None of the currently proposed solutions are ideal; but then we must remember that even the practice of forcing sound through a porous or perforated screen is not ideal. As with any engineering problem, the solution is often a balance of trade-offs and compromises.

The primary goal is to deliver a sound experience that fully integrates with the visual one, to allow the moviegoer to undergo the "willing suspension of disbelief" that defines the cinematic experience.

A solution designed and tested by QSC engineers has produced a localization experience which closely approximates that of the traditional practice of behind-screen loudspeaker placement. The solution relies on the processing power of the Q-SYS platform to create a vertically-oriented virtual (or "phantom") image, simulating the effect of a sound source emanating from the same location as a traditional screen channel positioned behind a perforated screen.

## Background

In 1903, French inventor and cinema pioneer Leon Gaumont was granted patents for loudspeaker systems to go with his sound-on-disc talking films, which used one of Berliner's Gramophones, and he was reportedly the first to suggest placing loudspeakers behind the screen. His original concept for accurate localization went one step further, suggesting that loudspeakers should be hand carried behind the screen to follow the images on the screen – obviously an impractical solution, but one that indicates that accurate localization of sound to the image on screen was an early consideration in the history of cinema sound. "Sound porous screens", which most likely appeared around the same time as talking pictures in the late 1920s, made it practical to at least position loudspeakers behind the screen – which defined the localization experience that's been generally accepted as standard practice ever since.

Screen perforations affect both the visual and auditory experience. In the 1990s, AMC Theatres attempt to avoid the light loss and moiré effect caused by the perforations involved the use of a slightly curved, non-perforated "solid" screen, and loudspeakers were positioned above the screen. Trained listeners however found this configuration to be distracting, causing one to occasionally glance up to the top of the screen. In home applications, where listeners are located much closer to the image, listeners easily adjust to the disparity. Other distractions of the home viewing environment are far more detrimental to the "willing suspension of disbelief" than inaccurate localization of sound to image. But in a movie theatre, where the viewer is nearly 100% focused on the screen, accurate localization is critical to the experience.

Humans (and most other mammals) are much better able to detect the location of a sound in the horizontal plane because of the simple anatomical fact that our two ears are located on the sides of our heads. The phenomenon of interaural time differences (ITD), perceived by the ears and processed by the brain, provides the cues to accurately locate the sound in the horizontal plane. But ITDs have been found to be ineffective in allowing humans to localize in the vertical plane. As early as 1930, a study by Pratt published in the Journal of Experimental Psychology concluded that listeners were unable to accurately locate sound in the vertical plane when subjected to a series of sine wave "tones". However, they did note that when high frequency tones and low frequency tones were presented to listeners from sources at the exact same locations, listeners perceived the high frequency tones to originate "higher" than the low frequency tones, even when they came from the same location. Perceptual psychologists Roffler and Butler replicated this so-called "pitch-height" effect in 1968, leading to the conclusion the spectral content plays a role in the perception of localization of a sound source. In follow up studies, these researchers and several others have found that localization in the vertical plane is in fact possible as long as 1) the source signal is "complex" (includes multiple frequencies, 2) it includes frequencies above 7 kHz, and 3), the listener is able to use "pinnae cues" provided by the shape of the outer ear.

A series of studies published beginning in 2015 by researchers Wallis and Lee at the University of Huddersfield in the UK explore the relative contribution of inter-channel time differences (ICTD) and inter-channel level differences (ICLD) in vertical plane localization. These and other researchers have concluded that a number of mitigating factors including the "pitch-height" effect, time and level differences, and the frequency content of the source material all play a role on vertical localization. Wallis and Lee also note that "the research literature generally agrees that increases in ICLD between vertically arranged stereophonic loudspeakers will cause the resultant phantom image to be localized in a position biased toward the loudspeaker of greater amplitude."; i.e., the louder one. This essentially describes vertical amplitude panning, and is the premise behind the approach described in this whitepaper.

# The Q-SYS Solution

A test site in Buena Park, California was used in a collaborative effort with LG Electronics, Moving Image Technologies (MiT), and QSC. The room is approximately 83 feet long by 52 feet wide. A 15-meter LG Electronics LED screen was constructed and installed by MiT. The audio system was provided by the Q-SYS division of QSC, LLC.

Loudspeakers were placed above and below the LED screen as illustrated in Figure 1. In order to maintain a seamless sonic image, identical model loudspeakers were used. The model chosen for this room was the QSC AP-5152, a high-power 15-inch two-way design that can be operated either fully passive or in bi-amplified mode.

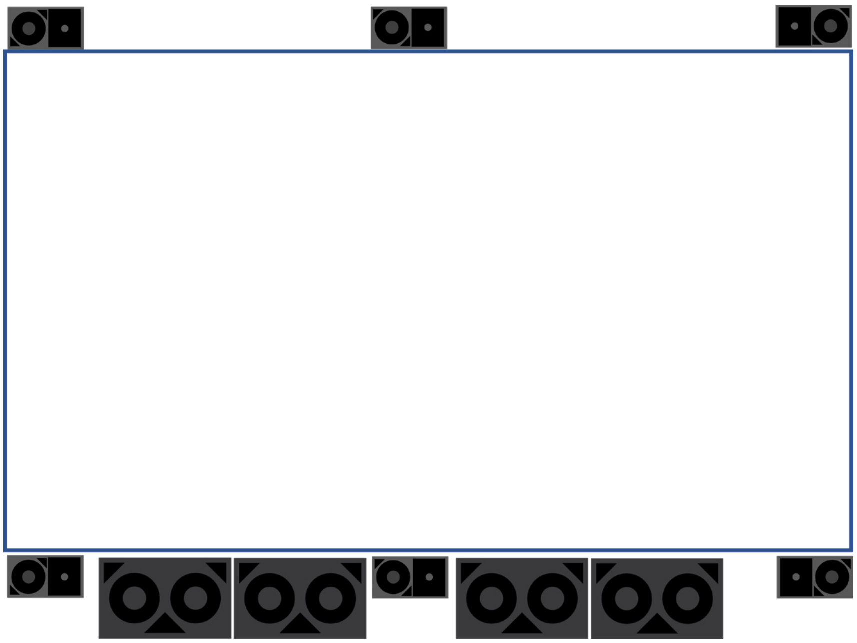

*Figure 1 - Loudspeaker configuration, showing three loudspeakers above and three loudspeakers below the screen, along with four dual 18-inch subwoofers on the floor.*

All screen channel loudspeakers were aimed following SMPTE standards at the Reference Listening Position (RLP) approximately two-thirds the distance from the screen to the last row of seating, as shown in Figure 2.

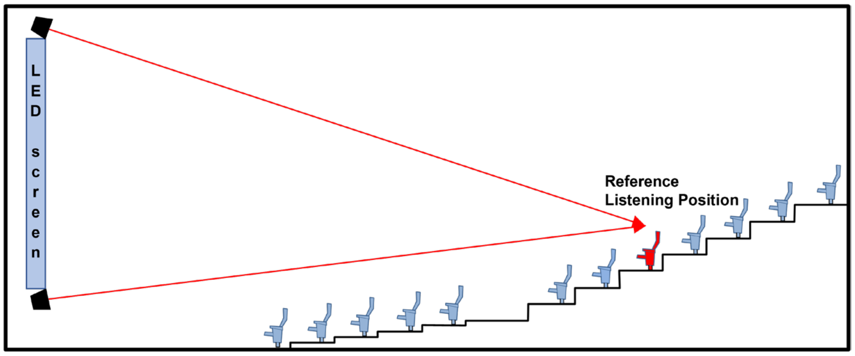


*Figure 2 - Elevation view showing Reference Listening Position and loudspeaker aiming.*

All loudspeaker signal processing and channel routing was accomplished using the Q-SYS platform. Q-SYS is a cloud-manageable audio, video and control platform built around a modern, standards-based IT architecture. Its control features are nearly limitless and can be used for virtually any audio-visual application. In this case, Q-SYS was used to control the IMB functions and lighting automation, as well as sound system configuration and signal processing including loudspeaker crossover, equalization, signal routing and delay, and matrix mixing.

The six above and below screen loudspeakers were configured in the Q-SYS matrix mixer to allow for amplitude panning and blending of the acoustic output. A special function of the Q-SYS matrix mixer component allows for two-dimensional panning between and among any input signal and output source. A GUI screen in the Q-SYS Designer software allows the user to visualize the physical locations of the sound sources (loudspeakers) as well as the relative output level at any location between sources (Figure 3).

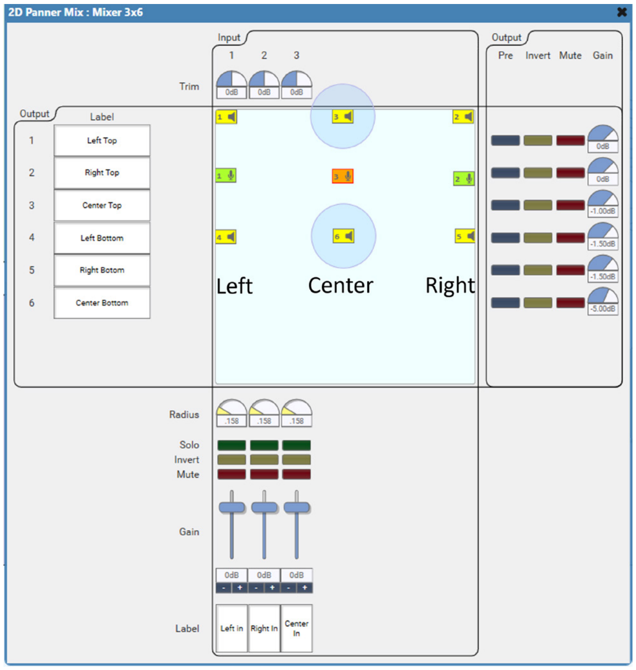


*Figure 3 - 2D Panner GUI in Q-SYS Designer software. The relative output level assigned to each loudspeaker is indicated by the size of the blue sphere around the loudspeaker location. The software graphical representations in the inputs appear as microphone icons – but in this case, the "inputs" are actually the Left, Center, and Right audio signals from the cinema playback server. The outputs are the actual loudspeakers. Moving the input icon on the screen changes the position and the size of the blue spheres, and thus the relative mix of signal to each upper and lower loudspeaker pair.*

In this way, an engineer positioned at the RLP can determine the optimal vertical pan between upper and lower loudspeakers that produce a perceived vertical phantom image that approximates the subjective localization of sound to the traditional loudspeaker aiming position, 5/8 to 2/3 screen height from the bottom of the screen.

While acoustical treatment near the screen is always highly recommended in every installation to control early reflections caused by floor bounce and side wall reflections, it is vitally critical in an application such as depicted here. Properly aimed loudspeakers installed at the top of the screen are likely to reflect significant energy from the ceiling; similarly, below screen loudspeakers will deliver energy to the floor surface directly below the screen, which could cause significant intelligibility problems if the floor is not heavily carpeted. For these reasons, screen channel loudspeakers with good directivity control are critical to the success of this type of application. Also, downward aiming of the rear wall surround loudspeakers is important, especially in smaller rooms, since the LED screen surface is highly acoustically reflective.

During system tuning, it was found that while the localization effect was good, it varied with the spectral content of the listening material. This is consistent with the "pitch-height effect" findings of Roffler and Butler, Barbour, Lee and others, where listeners noticed that during dialog, female voices were perceived "higher" in elevation than male voices, even though the pan position was constant. Using frequency shift, pink noise equalization, minimal delay, and subjective listening, it was possible to mitigate this disparity, which allowed all dialog to localize to the correct approximate position of the image on the screen.

# References

PRATT, C. C. (1930). "The Spatial Character of High and Low Tones," Journal of Experimental Psychology, 13, 278-285.

ROFFLER, S. K. (1967). "Sound Localization in the Vertical Plane," Doctoral dissertation, Univ. of Chicago.

ROFFLER, S. K., and BUTLER, R. A. (1968). "Factors that Influence the Localization of Sound in the Vertical Plane," Journal of the Acoustical Society of America, 43, 1255-1259.

BARBOUR, J., (2003). "Elevation Perception: Phantom Images in the Vertical Hemi-Sphere," presented at AES 24th International Conference on Multichannel Audio, June 26-28, 2003, Alberta Canada.

WALLIS, RORY and LEE, HYUNKOOK (2015). "The Effect of Interchannel Time Difference on Localization in Vertical Stereophony," Journal of the Audio Engineering Society, Vol. 63, No. 10.

WALLIS, RORY and LEE, HYUNKOOK (2017). "The Reduction of Vertical Interchannel Crosstalk: The Analysis of Localisation Thresholds for Natural Sound Sources," Applied Sciences, MDPI, vol. 7, 278.

Special thanks to Garrett Oliver/QSC, Frank Tees and Leo Enticknap/Moving Image Technologies, and Todd Best/LG Electronics for their roles in this project.