WHITE PAPER

QSC LEAF™
Length Equalized Acoustic Flares™
Waveguide Design

US patent 11,509,997

Introduction

One of the main attributes of line array loudspeaker systems is that they provide very controlled directivity in the vertical plane by behaving, effectively, as continuous line sources. This white paper describes the main objectives and challenges in designing the patented QSC LEAF™ (Length Equalized Acoustic Flares™) waveguide solutions.

Waveguides Design Objectives

Waveguides serve multiple functions, primarily directing sound waves emanating from one or more high-frequency driver(s) to produce a wave-front of a particular shape at their exit, typically an arc of a given curvature. In loudspeaker line array systems, it is a requirement that the sound outputs and the directivity of the different loudspeaker units sum coherently ("couple"), so that, as a whole, the complete system behaves as a single line source. Properly designed waveguides exhibit this coupling behavior when the individual wave-front shapes at the outputs of each waveguide element closely approximate the total desired wave-front shape of the entire array.

Waveguides act as an acoustic impedance adapter, more closely matching the high acoustic impedance at the compression driver's exit with the low impedance of the air in the surrounding environment. They improve drivers' efficiency and acoustic loading, allowing for a low crossover frequency between line arrays' high and low frequency transducers. Furthermore, since low-frequency transducers in line arrays are typically separated by a single box height, the output from these woofers radiates as discrete point sources when the wavelengths emitted become smaller than the distance between two adjacent boxes. As a result, unwanted coverage lobes waste significant acoustic energy and tend to produce undesirable effects such as feedback for performers on-stage behind the array. Lower crossover points lessen the potential for these lobes to appear.

Carefully designed waveguides also provide well-controlled directivity in the non-coupling plane – typically the horizontal one - achieving a coverage angle of choice, as determined by the waveguide design and product requirements.

The specific design objectives for the QSC LEAF™ waveguides were:

- To produce a coherent wave-front at the exit of the waveguide with a 12-degree arc angle in the coupling (vertical) plane, over a bandwidth extending from the crossover frequency to 20 kHz. The specific 12-degree arc angle was chosen to approximate a multitude of use case applications for typical line array deployments.
- To provide adequate acoustic loading to HF compression drivers in order to allow the use of 1500 Hz and 1200 Hz crossover frequencies for the LA108 and LA112 loudspeakers, respectively. These crossover frequencies were selected based on the measured distortion of the compression driver mounted in the waveguide around the desired crossover point, as well as the radiation pattern of the waveguide in the coupling (vertical) plane.
- To achieve an optimum coverage of 100 and 90 degrees in the non-coupling (horizontal) plane for the LA108 and LA112 loudspeakers, respectively.

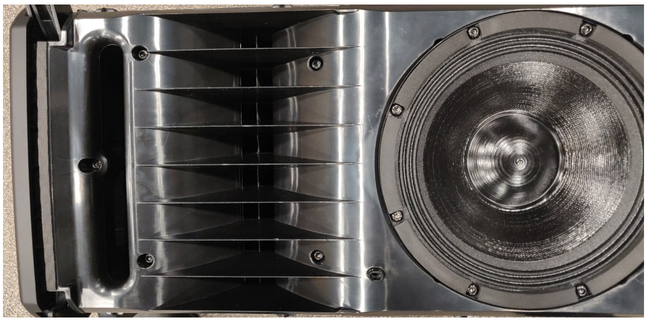

Figure 1. Close-up of the QSC LEAF™ waveguide in the LA108 active line array loudspeaker.

Waveguide Anatomy

The QSC LEAF™ waveguides consist of three sections that are illustrated in Figure 2 from the waveguide exit (mouth) to the compression driver exit (throat):

1. The **flares section** – sound waves expand within flares in the coupling (vertical) plane before summing at the exit of the waveguide along a 12-degree arc.
2. The **path-length equalization section** – sound paths are routed so that the sound waves in each channel are phase-aligned.
3. The **throat section** - sound waves are produced at the exit(s) of the compression driver(s).

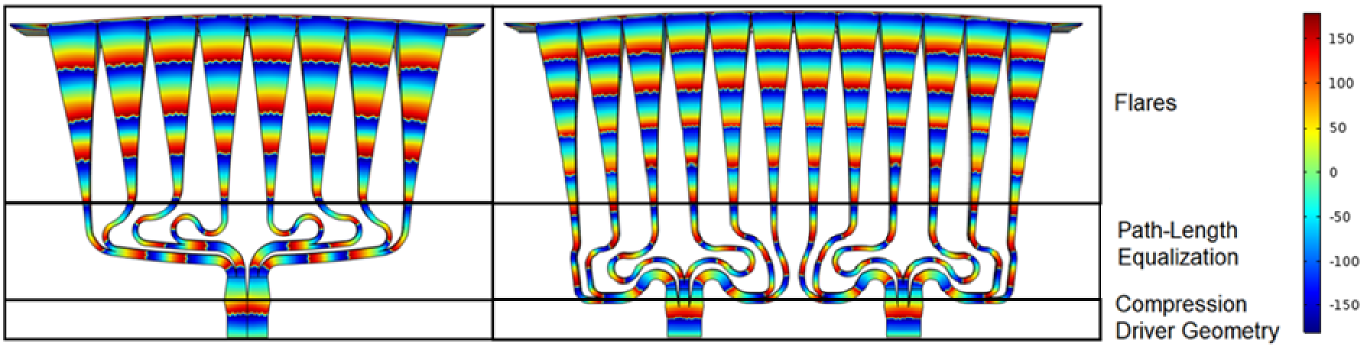

Figure 2. Phase analysis inside LA108 (left) and LA112 (right) waveguides at 15 kHz in a cross-section within the coupling plane.

The Flares Section

Producing a coherent wave-front at the mouth of the waveguide, as well as providing adequate low frequency loading to the compression driver(s), are both accomplished by designing the flares to be as long as possible. The deeper, or longer, the flares are, the better the acoustic loading at lower frequencies is, and the closer to parallel the side walls of each flare will be. Nearly parallel side-walls are desirable, as they will minimally bend the sound waves as they exit from the flares, allowing for better summation with the adjacent waves emanating from other flares. This results in superior high-frequency summation and waveguide projection.

Similarly, this elaborate design assists with the coupling between adjacent waveguides, ensuring that the physical distance between them is minimized. The specific flare expansion shapes were designed based on iterative 3D Finite Element Analysis (FEA) simulations in an attempt to strike an optimal balance between low frequency acoustic loading at the crossover point and the necessary dampening of resonances inside each channel within the operating bandwidth.

Throughout the flare section, the channels also expand in the non-coupling (horizontal) plane to produce the desired coverage patterns (Figure 3). This horn-like expansion shape was created using a variation of the method presented in the JAES paper "An Approach for the Optimization of 3D Loudspeaker Horns".

The Path-Length Equalization Section

Due to the compact size of the loudspeaker constraining the available space within the enclosure, maximizing the depth of the "flares" section was only made possible by minimizing the depth of the path-length equalization section. Such an optimization was achieved by curving each channel, in some cases in extreme ways, by implementing bends as large as 270 degrees.

These extreme bends are only acceptable when the width of each channel is small relative to the radius of curvature of the bend and the wavelength of the sound emitted in the channel.

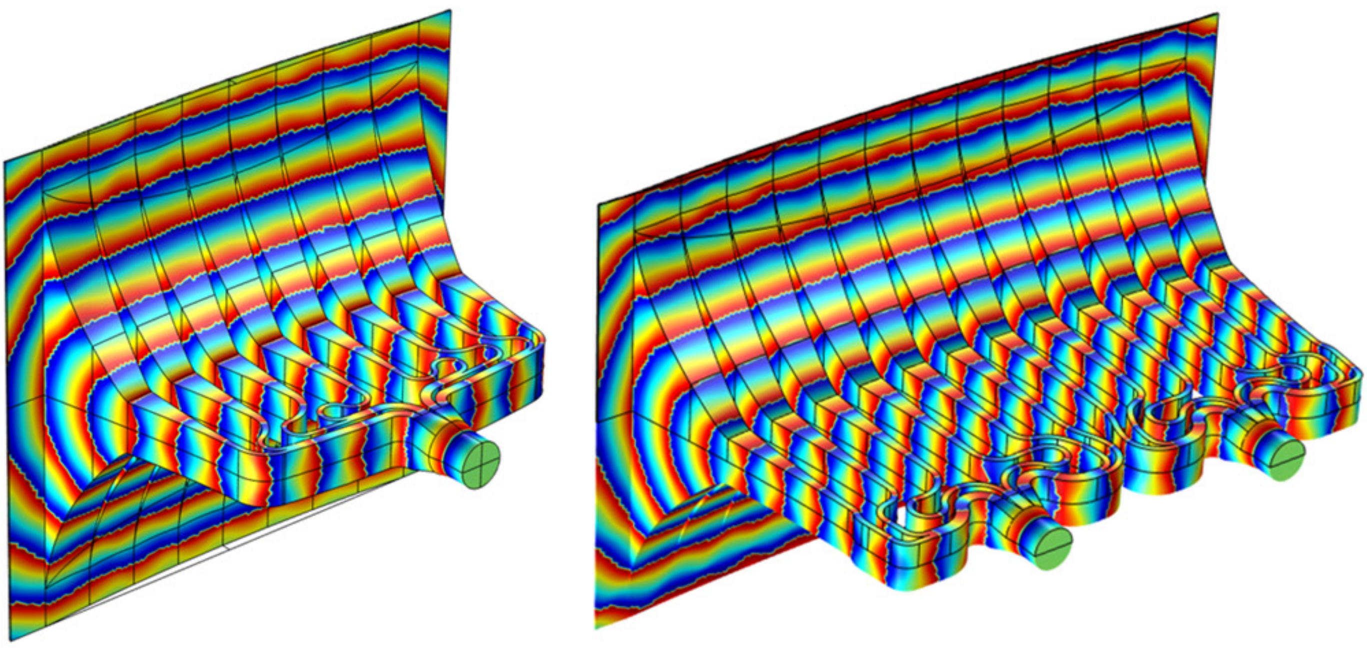

Figure 3. Isometric views depicting phase analysis within LA108 (left) and LA112 (right) waveguides at 15 kHz.

For example, if a very wide channel is curved abruptly, the wave traveling inside the channel will no longer be planar (fully perpendicular with the walls of the waveguide channel), since the portion of the wave traveling on the outside of the bend is delayed compared with the portion traveling on the inside. Such a design would display a phase mismatch as the wave enters its “flares” section (that would also be present at the exit of the flares), causing phase summation issues with other flares, therefore producing a non-coherent wave-front at the loudspeaker exit.

Furthermore, every time a bend is introduced in the channel design, the effective acoustic length of this channel changes, meaning that its physical length needs to be adjusted. Through careful iterative adjustments and FEA simulations, all the outputs of the path-length equalization section were phase-aligned, making sure, at the same time, that no bends would introduce any severe distortions to the global phase response.

The Throat Section

The throat section accomplishes the successful transition from the circular compression driver’s exit geometry to the sound channels of rectangular cross-section, by paying special attention to the conservation of the cross-sectional area as the cross-section shape is changing from circular to rectangular and the individual channels are being formed.

If a consistent cross-section area is not maintained along the throat section, an acoustic “low-pass” filter phenomenon will occur, resulting in the waveguide providing sub-optimal acoustic loading at high frequencies, typically above 8-10 kHz, depending on the severity of the cross-sectional area mismatch.

Waveguide Final Design Performance

Final FEA simulations of the acoustic coverage in the coupling (vertical) and non-coupling (horizontal) planes for the LA108 and LA112 loudspeakers’ waveguides are shown in Figure 4 and Figure 5 below.

Coverage simulations are calculated at a distance of 4 m (13 ft) for a waveguide mounted in an infinite baffle. For comparison purposes, analogous measurements performed in a standard IEC test baffle (that approximates an infinite baffle) are also presented.

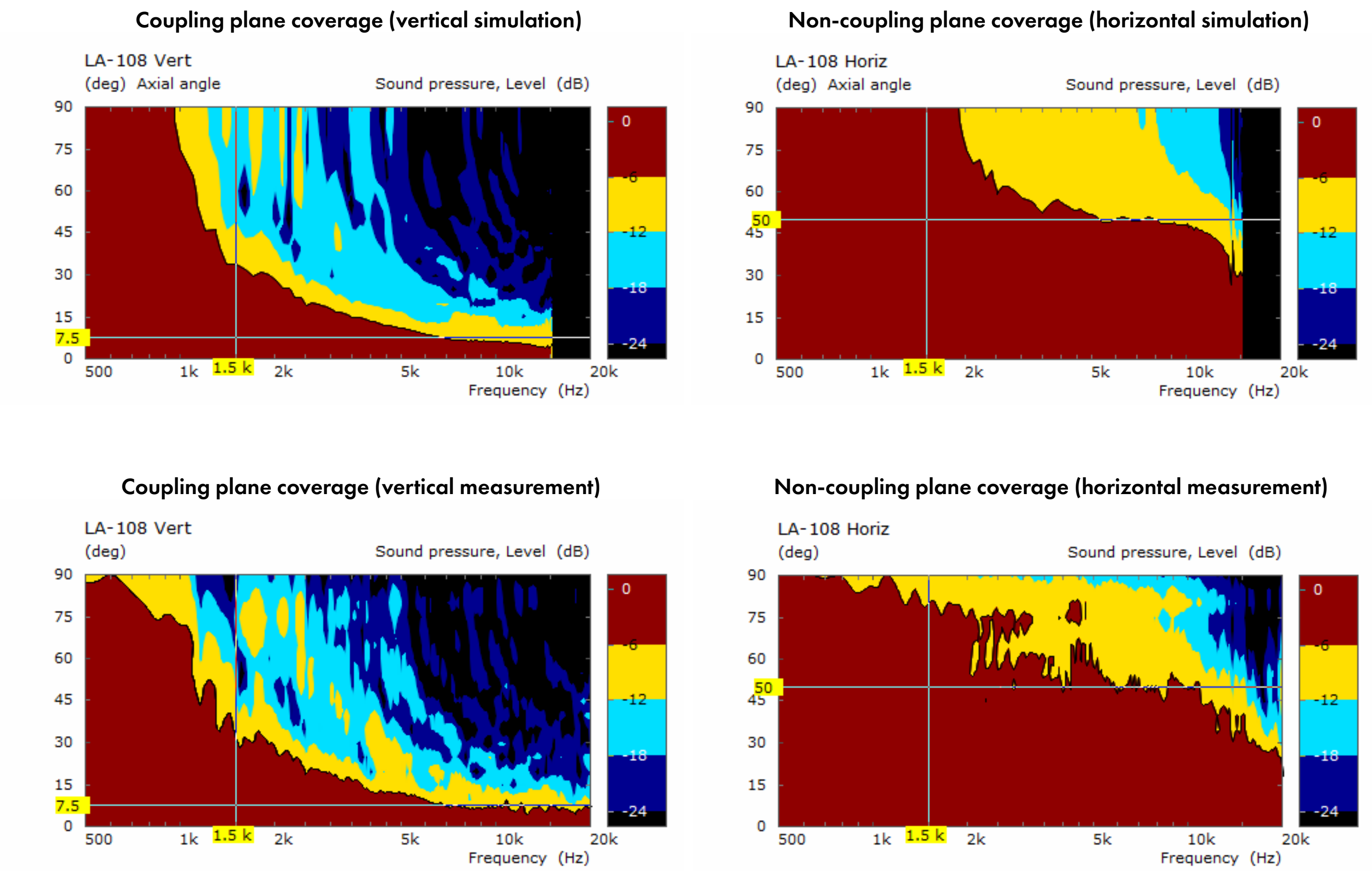

Figure 4. Simulated and measured coverage contour plots of the LA108 loudspeaker’s waveguide at a distance of 4 m (13 ft).

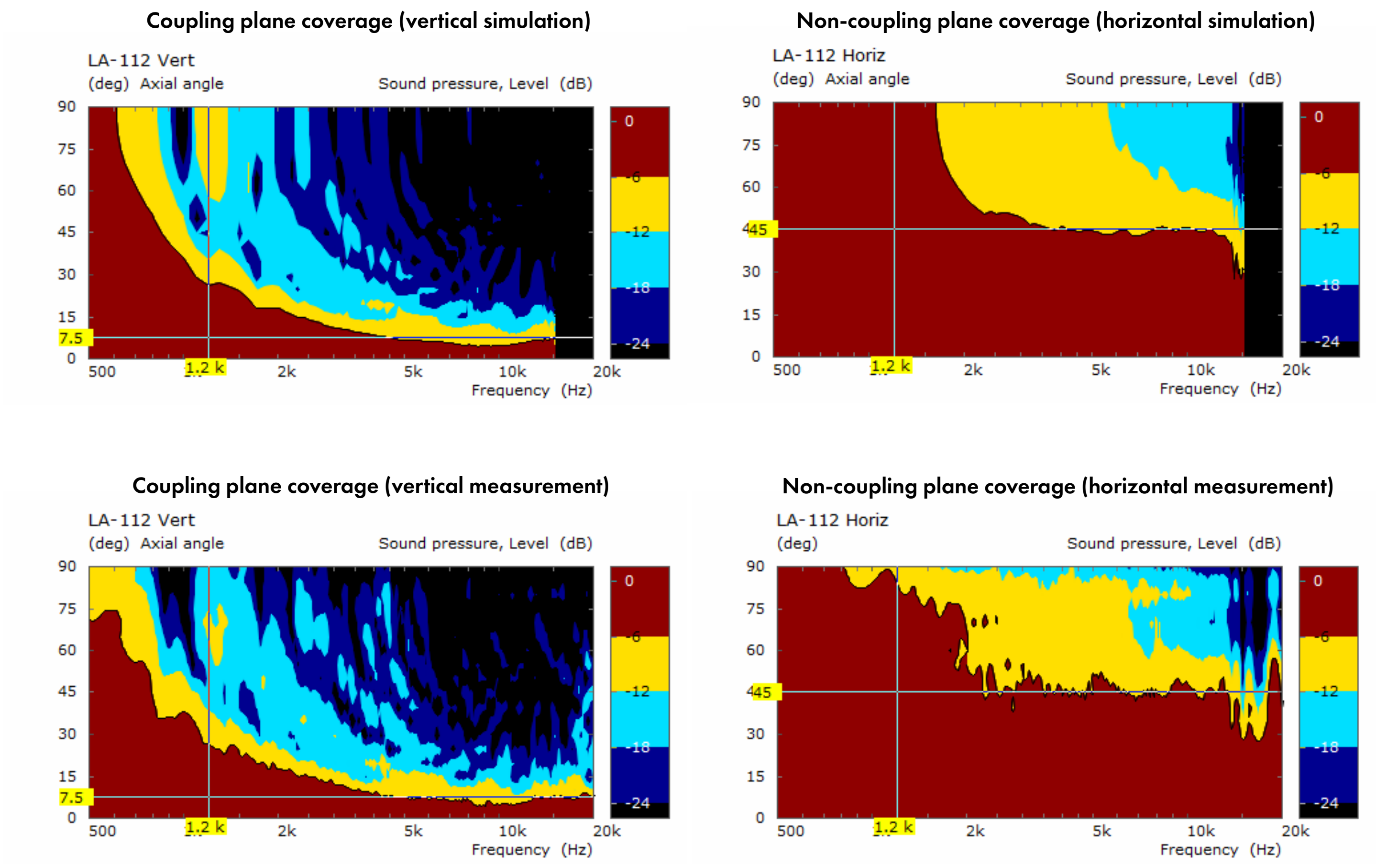

Figure 5. Simulated and measured coverage contour plots of the LA112 loudspeaker's waveguide at a distance of 4 m (13 ft).

Conclusion

This white paper has presented some of the general design principles that were followed when designing the QSC LEAF™ waveguides found in the LA108 and LA112 active line array loudspeakers.

These waveguides provide efficient acoustic loading at the crossover point with a minimum of resonances and create coherent wave fronts at the loudspeaker's exit across a wide range of frequencies. They also couple very well with adjacent waveguides, and provide wide and consistent coverage in the non-coupling (horizontal) direction.

LA108 LA112

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