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Large scale open air sound reinforcement in extreme atmospheric conditions

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ABSTRACT

Extreme atmospheric conditions have a profound effect on sound propagation. This paper presents two installations where this problem must be accounted for: the main stage of the Coachella Valley Music and Arts Festival and the Hollywood Bowl. The approach presented here combines an optimized sound system design combined with signal processing for partial compensation of remaining loss in selected areas.

1 Introduction

The main effect of atmospheric conditions on sound propagation is an over attenuation of high frequencies with respect to low frequencies that can exceed 80 dB at 15 kHz, 150m, 35°C and 15% humidity [1][2]. This effect, referred to as atmospheric absorption, tends to increase with frequency and distance. Atmospheric absorption is critical for large outdoor sound reinforcement systems that often require a very long throw distance.

We neglect here other known factors such as temperature gradient and wind. These factors are by nature difficult to predict and measure in a realistic setup and their effect on sound propagation remain a research topic especially for community noise prediction [3]. We want to explore here the effect of varying atmospheric conditions which are particularly severe for outdoor venues in contrast to indoor venues where air conditioning allows to moderate the variations.

In this paper, we first review the relation between atmospheric conditions and sound attenuation at high frequencies over than spreading losses. We then present L-Acoustics approach on electronic compensation of atmospheric absorption for Variable Curvature Line Sources. Next, we provide the result of simulations verifying the ability of this approach to offer a smooth distance dependent compensation. One important test case is the required discretization of the speaker elements at high frequency to smooth provide a smooth compensation and an intuitive control. Finally, we present two installations that present either varying or extreme atmospheric conditions: the main stage of the Coachella Valley Music and Arts festival and the Hollywood Bowl.

2 Atmospheric conditions impact on sound propagation

Atmospheric conditions have a major impact on sound propagation over large distances. Beside the well know broad band attenuation caused by spreading loss with distance (ex: 6 dB per doubling distance for a point source), the temperature, humidity, pressure and most important frequency have a significant influence on level attenuation. The resulting atmospheric absorption is described as an absorption coefficient expressed in dB per m.

Atmospheric absorption has an overall lowpass characteristic that tends to attenuate high frequencies in large proportions whereas lower frequencies are largely unaffected.
Figure 1 displays the averaged attenuation (8-kHz octave band) depending on temperature and humidity per the formulae of ISO 9613-1 1993 [1]. The attenuation in dB is given for 100 m and is directly proportional to distance. Therefore, the curves are linear shifted up and down for any bigger or smaller distances.
The curves have a double slope and exhibit a maximum for a temperature that highly depends on humidity. The minimum overall attenuation is even obtained with cold and dry conditions. Drier conditions tend to amplify the variations and shift the curve towards higher temperatures.
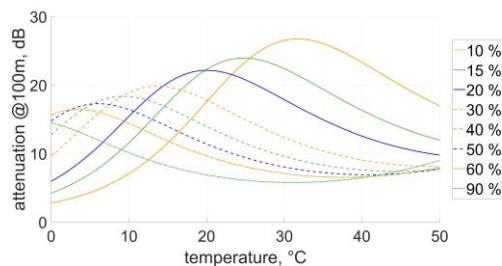

Figure 1. Atmospheric absorption in the 8-kHz octave band dependency on temperature and humidity (percentages given in the legend) for a pressure of 1 atm at 100 m distance.

Figure 2 displays the transfer function of atmospheric absorption at 100 m for worst case conditions of Figure 1. It shows that attenuation at

high frequencies can be extremely severe for hot and dry but also cold and humid conditions.
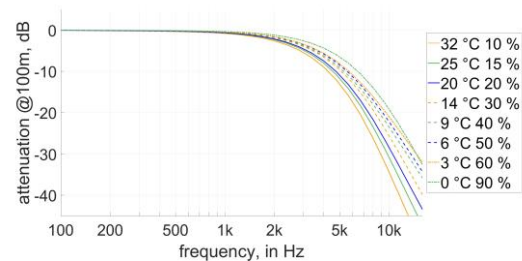

Figure 2. Atmospheric absorption for selected temperature and humidity for a pressure of 1 atm at 100 m, largest attenuation of Figure 1.

In contrast, Figure 3 displays the transfer function of atmospheric absorption at 100 m for best case conditions from Figure 1. This shows that drier conditions do not directly imply higher attenuation. Very low attenuation is observed for cold and dry conditions as well as hot and humid conditions.
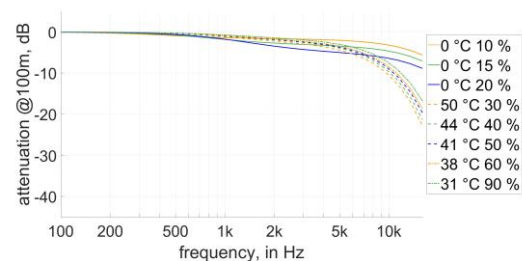

Figure 3. Atmospheric absorption for selected temperature and humidity for a pressure of 1 atm at 100 m, lowest attenuation of Figure 1.

We also show in Figure 4 the atmospheric absorption depending on altitude from 0 to 5000m, introducing a pressure drop from 101.33 kPa to 54.02 kPa [4]. We considered fixed temperatures and averaged values over a set of humidity. Similar curves are obtained for fixed temperature and averaged over humidity but are not displayed here.
We observe a change of maximum 2 dB on average for such a large pressure drop. Therefore, it can be assumed that altitude and pressure have a small impact on atmospheric absorption coefficients and

may be neglected for small variations of pressure and for locations not exactly at sea level.
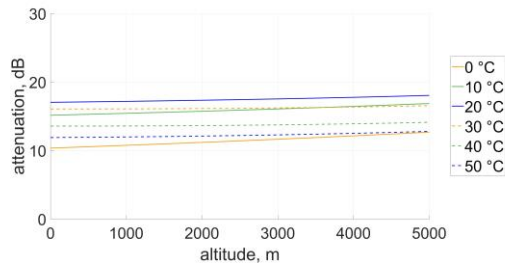

Figure 4. Attenuation due to atmospheric absorption for selected temperatures depending on altitude, averaged within 4 to 16 kHz and humidity (10%, 15%, 20%, 30%, 40%, 50%, 60%, 90%)

3 Air absorption compensation strategies

Air absorption compensation cannot be achieved with simple filtering techniques alone. As already mentioned, the absorption in dB is linearly increasing with distance therefore requiring distance dependent compensation.
Modern Variable Curvature Line Sources are built from speaker elements having a tight directivity in the vertical dimension at high frequencies. Their splay angles are tuned to target specific distances for each element. Therefore, a specific filter can be applied to each element to compensate for air absorption.

We define three zones of attenuation for the 8-kHz octave band:

- Small: attenuation below 6 dB, should be easy to compensate by electronic means;
- Moderate: attenuation between 6 and 12 dB, electronic compensation is still achievable but may constrain the available resources at high frequencies for the sound system;
- Severe: attenuation is above 12 dB, too much compensation needed, consider using delay speakers.

L-Acoustics' air compensation tool preserves the overall efficiency of the sound system while correcting for the most disturbing effects of air absorption. The frequency response of the filters is given in Figure 5 for different values of the tuning parameter G. The filters have linear phase to minimally affect the wave-front coherency.
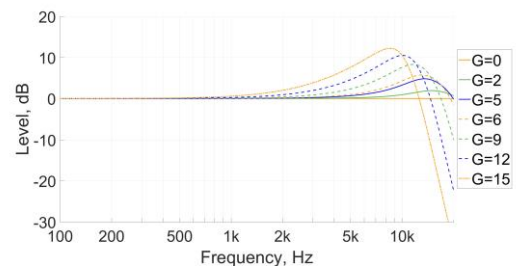

Figure 5. frequency response of air compensation tool of L-Acoustics depending on parameter G.

The maximum boost is limited to 12 dB around 8 kHz. Higher level boosts might damage the loudspeakers or would easily activate loudspeaker protection even at moderate input level. In either case, no efficient compensation can be achieved at high levels.

When higher boost would be required, either in relation to large throw distances or due to extreme air absorption, L-Acoustics recommends using delay speakers to cover further audience areas.
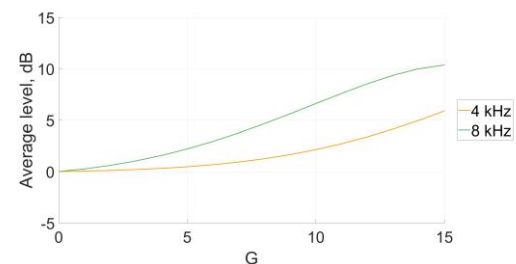

Figure 6. Averaged compensation level in the 4 and 8 kHz octave bands depending on G parameter

4 Spatial control with Variable Curvature Line Sources

We provide here simulations of a typical Variable Curvature Line Source used for long throw configurations. The purpose of this section is to verify the capabilities of the array to address precisely individual areas at high frequencies and therefore achieve atmospheric absorption compensation that linearly varies with distance.

The configuration we use consists of 16 L-Acoustics' K1[1] elements. It is displayed in Figure 7 along with the audience area under consideration. The speaker numbering used in the following defines the top element as 1 and the lower element as 16.
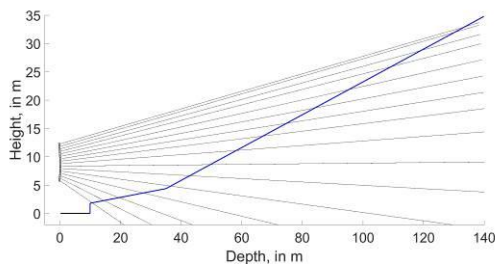
Figure 7. speaker configuration and audience area used for testing

The response of the loudspeaker array is simulated along the audience area every 25cm on axis (cutview) for relatively standard atmospheric conditions (20°C, 60% humidity). The calculation is performed in the frequency domain with 12 frequencies per octave and averaged in the 8-kHz octave band for each test position.

The response obtained with air compensation H_t is subtracted (in logarithmic scale) to the response H_{ref} obtained without air compensation (reference) obtaining H_{comp} that illustrates the effective impact of the compensation along the cutview.

We first test the impact of activating air compensation on 1 speaker element of the array only using the maximum value of 15.
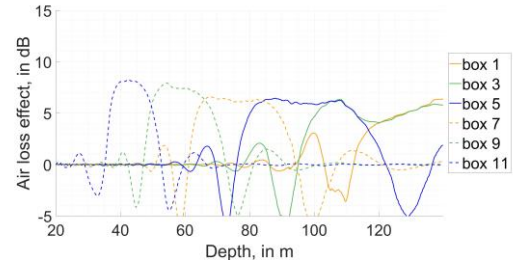
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[1] http://www.l-acoustics.com/products-loudspeaker-systems-63.html

Figure 8 effect of air compensation H_{comp} in the 8-kHz octave band activating 1 speaker element only with G=15, activated speaker element defined in legend.

Figure 8 shows the effect of air compensation H_{comp} in the 8-kHz octave band activating solely speakers individually. The controlled areas of speaker significantly overlap and do not provide the full amount of energy (target is 10.4 dB). Only at short distances, the overlap is reduced.
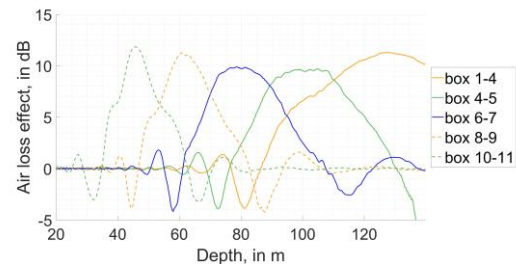
Figure 9. Effect of air compensation H_{comp} in the 8-kHz octave band activating groups of speaker elements with G=15, groups defined in legend.

Figure 9 shows the effect of air compensation H_{comp} in the 8-kHz octave band activating groups of speakers, using a larger amount of speaker elements when targeting larger distances. The groups have a more limited overlap and can restore the full amount of gain at the target distance.

Therefore, speaker elements not only could but also should be connected in parallel for more direct control of the atmospheric absorption compensation at a target distance.

We display in Figure 11 the air compensation effect H_{comp} obtained using air compensation settings of

Figure 10 for three different configurations in the 8-kHz octave band. The "Sparse" configuration corresponds to settings that provide best results at nominal atmospheric conditions (20°C, 60% humidity). The "1amp per box" configuration is a smoothed version of the "Sparse" configuration where different settings could be set for each speaker element independently.
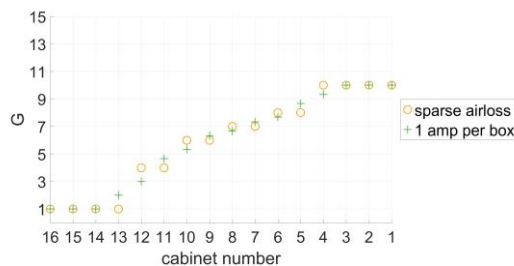

Figure 10. Air compensation test configurations with corresponding G values for each speaker element.
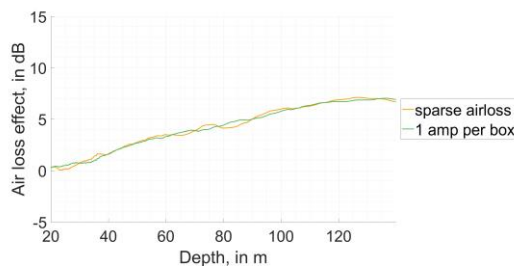

Figure 11. Effect of air compensation H_{comp} for configurations of Figure 10, averaged over 8 kHz octave.

Figure 11 shows that a smooth control of air compensation over distance can be realized without requiring a fully independent control on each speaker element.

5 Coachella Valley Music and Arts festival main stage

The Coachella festival is a perfect case of extreme atmospheric conditions. It is an annual festival that is held in Inland Empire's Coachella Valley, in the California Desert, during the month of April. Average temperature is 30°C with 30% humidity during the day but can exceed 40°C and down to

10% humidity. At night, the temperature can reduce to 10°C with remaining dry conditions.

Referring to Figure 1, this corresponds to largely varying amount of air absorption from almost extreme conditions (red plain curve in Figure 2) to limited absorption at night.

Figure 12 Main stage at the Coachella Valley Music and Arts Festival

In 2017, the mainstage was sized for greater than 120,000 people with coverage of an area of 70,000 m². The throw is over 280m to the back and the width is 250m.

The proposed design of main left/right system is using 8*K1SB, 12*K1 and 4*K2 for down-fill. It is complemented by 12*K2 as side fill.

10 delay towers are used within the audience area in rows of 4 then 3 at -60m, 0, and 60m. The first row is located only 50 m away from the stage, the second at 110 m and the third at 170 m.

A moderate amount of air compensation is applied on speaker elements targeting larger distances but never exceeds a G factor of 8.

This configuration avoids targeting too large distances where high frequency attenuation might just be prohibitive during day time.

6 Hollywood Bowl

The Hollywood Bowl is a large scale open air amphitheater with 17500 seats capacity. It is home of the Los Angeles philharmonic orchestra during the summer outdoor season and hosts more than 110 performances of pop and classical music from April to November every year.

Figure 13 Hollywood Bowl stage and sound system

In this installation, there is no possibility to use delay speakers and the throw distance ranges from 10 up to 130 m. The 2 main arrays comprise each 4*K1-SB, 16*K1 and 4*KARA as downfill. The central cluster array consists of 8*KARA.

Two different configurations are used as front-fill. Either 8 single KARA along the stage for rock and pop shows or 12*5XT as lower profile option, mainly used for classical applications.

A compact outfill system of 4*ARCSII constant curvature line source is used on either side of the stage. The system is complemented by 10 SB28 subwoofers per side.
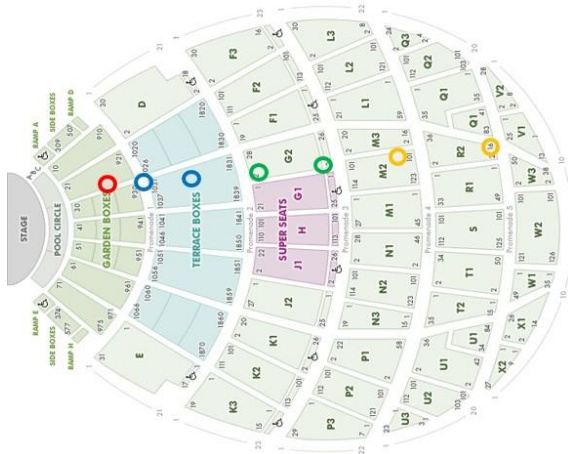

Figure 14 Hollywood Bowl floor plan and measurement positions

Atmospheric conditions are very different during day (hot and dry, typically up to 30°C and less than 20% humidity) and at night when the performance starts (mild and more humid, 15-20°C and about 45-60% humidity).

The challenge is therefore to tune the sound system during day-time anticipating conditions during night time operation. L-Acoustics' Soundvision provide the designer tools to simulate the sound system performance under show time atmospheric conditions and preadjust G values.

During the tuning/measurement phase, it is then recommended to use a target curve that anticipates the difference in air absorption between the actual atmospheric conditions and the expected atmospheric conditions at show time according to measurement distance from the main system.

Another important consideration is the location of the guest FOH (Front Of House) mixing position. To provide a consistent impression between day time sound check and night time show, it is very important to locate the FOH position at a relatively small distance from the stage that would be minimally affected by atmospheric conditions. In the case of the Hollywood Bowl, the guest FOH mixing position is located around the first blue marker of Figure 14 at a relatively small distance from the main system that is little affected by atmospheric condition variations.
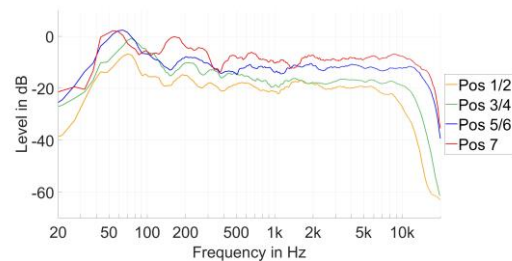

Figure 15: frequency responses (third octave smoothing) of the sound system during night time operation (22°C, 48% humidity). Measurement positions per colored markers in Figure 14 .

Figure 15 shows the frequency response of the sound system measured along the axis of the right main array at night time. A relatively flat frequency response in mid and highs can be obtained up to about 10 kHz despite the very large distance (~100 m for the yellow curve of pos 1 and 2).

7 Conclusions and discussion

We provided a deep review of the influence of atmospheric conditions on high frequency attenuation over distance presenting frequency dependent attenuation for the extreme cases (smallest and biggest for given humidity).

The electronic compensation of this atmospheric absorption should remain within reasonable boundaries to avoid audible artefacts from limiters and/or deteriorate the high frequency drivers. The L-Acoustics air compensation tool has been designed to limit the impact on resources while providing a simple yet efficient tool.

The combination of this tool with modern Variable Curvature Line Sources enable a precise control of the compensation over distance without requiring a high discretization of the high frequency channels along the array. Grouping even allows for an intuitive energy transfer from the array to the audience. This simplifies the tuning of the electronic compensation while still providing a smooth compensation curve over distance.

L-Acoustics' Soundvision software is a primary resource for estimating the effect of atmospheric absorption in the design phase and decide on the need of implementing a delay system as well as define the best transition between the main and the delay systems.

References

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