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# ACOUSTICS 2012

## Influence of audience on propagation of sound at low frequencies

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At open-air festivals and large scale concerts subwoofers are often placed in a row in front of the stage. This arrangement provides even sound pressure level distribution over the audience area, but the audience itself often stands tightly packed in front of the stage. The sound waves from the subwoofers propagate therefore partly through the crowd and the propagation is strongly influenced by its density. An interesting effect that occurs is the reinforcement of lower frequencies at certain positions within the audience. This effect might be generated by interference of sound waves travelling partly through the audience and partly over the audience. The effect was shown by measurements, conducted at several rock concerts, and BEM-modelling. The paper presents measurement and simulation results.

## 1 Introduction

It's become common lately to use distributed arrays of subwoofers for large outdoor concerts or festivals. Subwoofers are placed in a row on the ground in front of the stage, and delays are used to control the directivity of the array. This technique helps to create an even sound pressure level distribution over the listening area, but it's not clear how the presence of the listeners influences the propagation of sound. Live sound engineers' opinions are different: some say the audience absorbs sound at low frequency, others, on the contrary, notice some increase of the sound pressure level. The paper aims to clarify the influence of audience on low frequency sound propagation.

## 2 Live Measurements

The first step to evaluate the influence of presence of audience on low frequency sound propagation is to compare the sound pressure level distribution in a venue with and without audience. The easiest way is to measure the frequency response on the middle axis of the sound system at different distances from the stage, first without and then with the audience present. The typical layout for this measurement is shown on figure 1. The PA-system consists of flown arrays of broad-band loudspeakers (so-called "tops") and ground stacks or a horizontal array of subwoofers. We are interested in the signal from the subwoofers on the ground since they produce the wave going through the audience.

At first measurement positions are marked on the centre line of the venue, usually with 5m steps. Then frequency responses of the subwoofers are measured after the sound-check in the empty venue with the system already set up for the show. This reference measurement is done with sweep signals; then the frequency responses of the subwoofers are measured at the same positions several times during the show, using program material as the measurement signal [1,2]. Then the sound pressure level decay with the distance from the stage is plotted in frequency bands and compared for empty and filled value.

As the next step the density of the audience has to be evaluated. This can be done only very roughly: at the beginning of each measurement a photograph of the audience is taken from the FOH-tower, then number of people is counted manually and divided by the area (also measured before the show). During one measurement the density stays almost constant, but it changes a lot with the distance: the crowd is much denser in front of the stage and becomes sparse at the last measurement position (fig.2). However, we take the average density as a parameter.

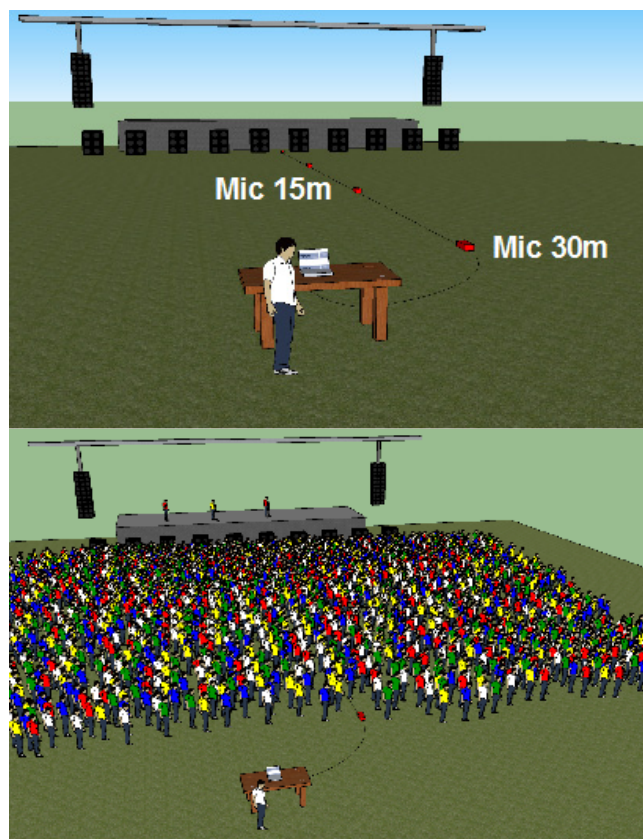


Figure 1: Typical layout for live measurements. Top: measurements in an empty venue, bottom: measurements in a full venue at the same positions.



Figure 2: Calculation of average density of audience.



### 3 Live Measurements Results

On fig.3 measurement results for three different densities are shown:

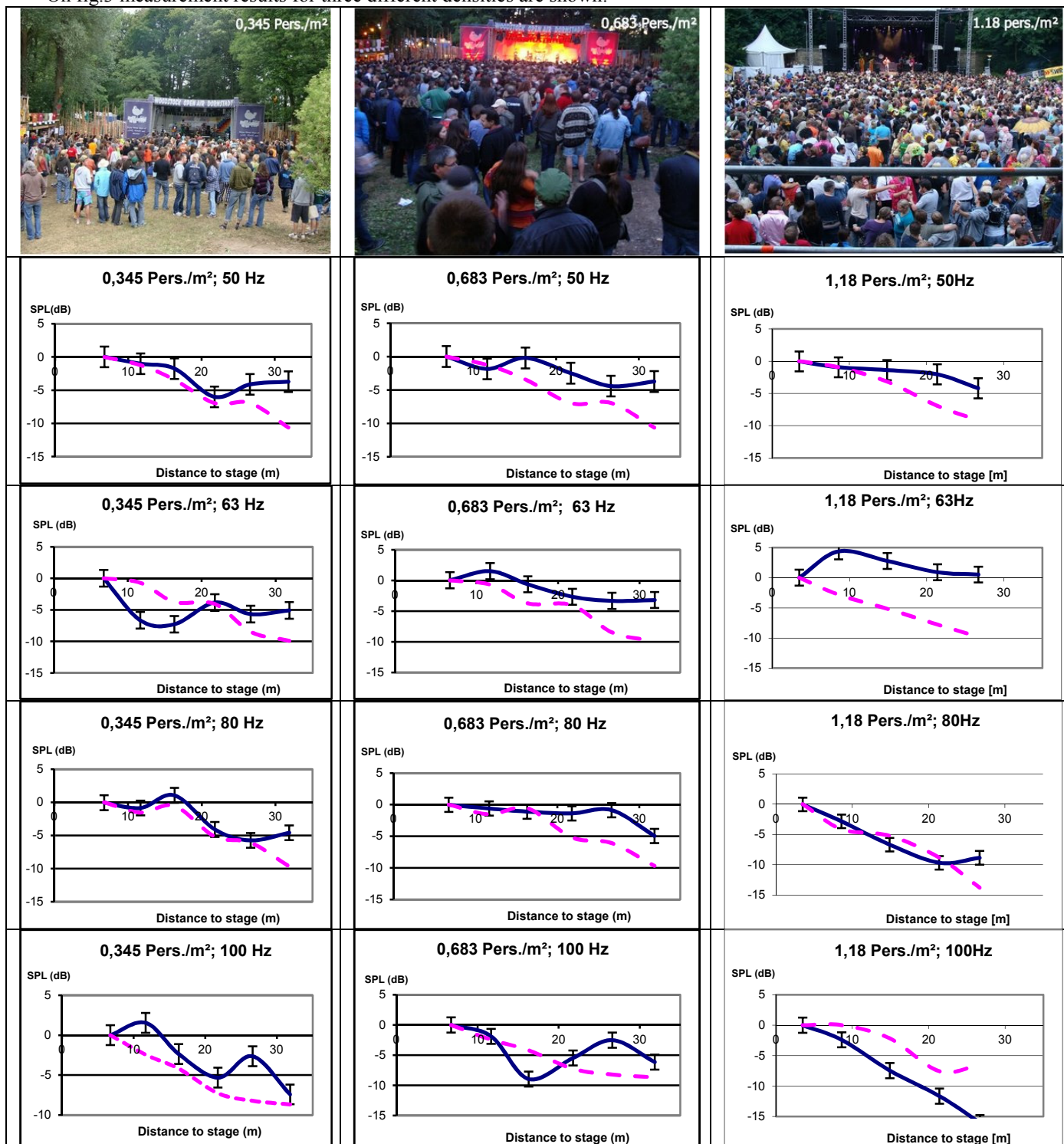


Figure 3: Live measurements results. Dotted line: empty venue, Solid line: filled venue

The uncertainty of the program material measurements was defined experimentally (the same measurement was repeated 30 times with different pieces of music, and then average and standard deviation were calculated). The uncertainty of the empty venue measurement lies within 0.5 dB and is therefore not shown.

Measurements were performed several times for different events and different densities of the crowd, and the result looks similar for most of the cases: **the decay of**

**the sound pressure level with the distance is less when the audience is present than in an empty venue.**

### 4 BEM-Simulation

In order to study multiple scattering on people as possible reason for the observed effect, a simplified model

of audience was constructed. People were modelled as hard cylinders with random radii of about 25cm and random heights about 170cm on reflective floor placed randomly within a certain audience area, with constant density. A point source was located near the floor 2 m before the audience (fig. 4). The Boundary Element Method was used for the simulation.

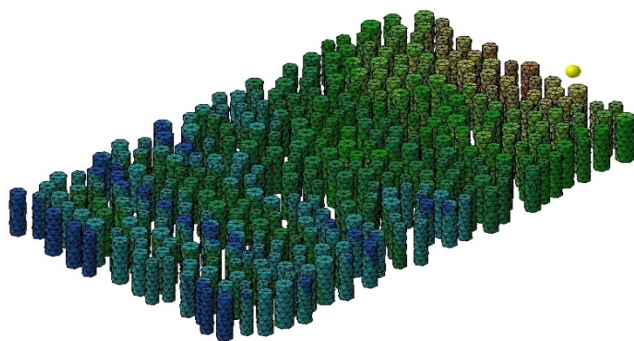


Figure 4: BEM-Simulation layout.

Sample simulation results are shown on fig.5

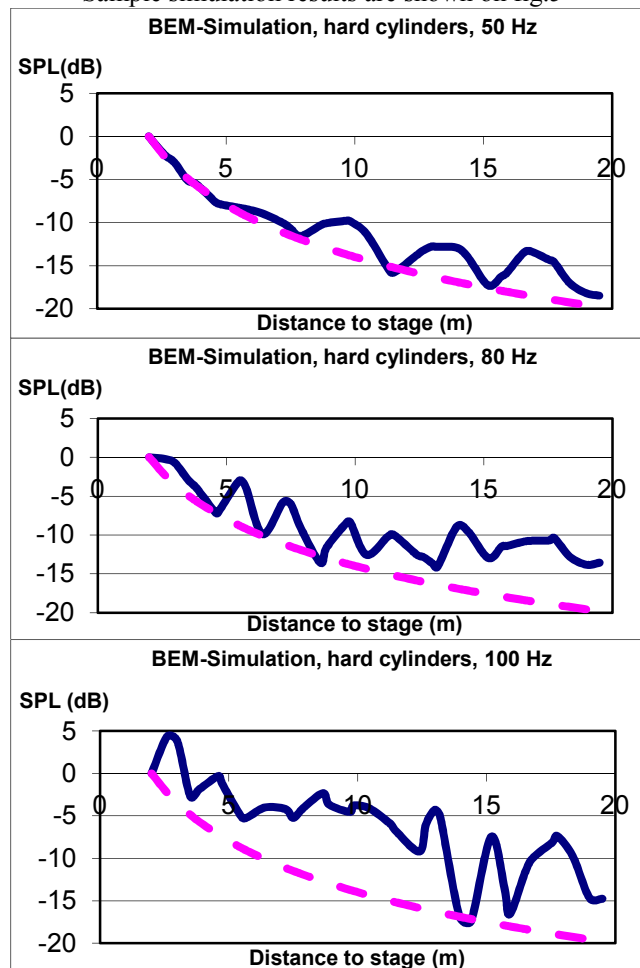


Figure 5: Sample simulation results. Dotted line: free field, solid line: sound propagation through a “crowd” of hard cylinders.

The simulation showed the same tendency as the live measurements: **the decay of sound pressure level with the distance from the source is less in the presence of obstacles than in free field.** Simulation also allows better space resolution: receivers can be located up to 50cm close to each other. The simulation therefore reveals an interference-like character of the field, which could not be

seen in the live measurement. The distance between maxima is equal to half of the wavelength (within the 50cm uncertainty: receivers can't be located inside the cylinders).

## 5 Discussion

Both live measurements and simulations show the same tendency: the decay of sound pressure level with the distance is less in the presence of audience than in free field and the effect seems to increase with the density of the crowd. However, it's very difficult to measure the effect quantitatively: a dedicated measurement session is difficult to arrange due to the large number of people to be involved, and live measurements contain huge uncertainties that can hardly be eliminated. Firstly, the exact measurement positions are hard to find in the presence of the audience, the error lies within 0.5m. Secondly, the sound engineer might change the setting of the system during the measurement (volume or EQ) if it is required for the show, and thirdly, the density of the crowd is not constant and hard to evaluate correctly.

The interference structure shown by the simulation might be caused by a reflection from the rear “boundary” of the crowd, or by a surface wave propagating on the surface of the crowd. That means, the cylinders (or the audience) forms a different medium with different impedance (probably bigger than the impedance of the air since the minimum at the rear boundary indicates soft boundary condition).

## 5 Conclusion

Both live measurements and simulations show the same tendency: the decay of sound pressure level with the distance is less in the presence of audience than in free field and the effects seem to increase with the density of the crowd. Simulation of audience as hard cylinders shows also an interference-like effect, which might be caused by reflection from the boundary between audience and air, or a surface wave propagating on the surface of the crowd.

## Acknowledgments

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