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Impact of free field inhomogenity on directivity measurements due to the measurement set-up

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Abstract

Measurements in an-echoic conditions are affected by the measurement set-up itself. The presence of grids, stands, turntables and the human body introduces reflections, diffraction, absorption and more changes to the ideally free field conditions. The impact of such equipment on directivity measurements is often neglected, and artifacts are are easily misinterpreted as features of the source directivity. In an an-echoic chamber several setups are compared with respect to changes in the measured directivity of a simplified musical instrument. The differences of the 1/r amplitude decay as well as the resulting directivity functions are presented and discussed.

Keywords: free field, reflections, directivity, set-up

1 INTRODUCTION

Measurements of musical instruments are often performed in an-echoic chambers to avoid any impact of reflections or other acoustic sources on sound recordings. Measurements of instrument directivity usually require complex set-ups including a turntable, a microphone array, excitation devices or a human player. These devices and the human body modify the transfer path between instrument and sensor/microphone due to superposition of reflected sound waves, diffraction or shadowing effects. Further deviations from ideal free field conditions are size and damping quality of the an-echoic chamber and its borders.

Depending on the size of the structures the effects depend on frequency. In earlier studies the impact of a music stand has been investigated [1, 2]. Whereas for frequencies that correspond to wavelengths that are much longer than the stand diameter the impact of the stand reflections can be neglected whereas the sound pressures from reflected waves of higher frequencies can be of same magnitude as the direct sound waves.

1.1 FUNDAMENTALS

At low frequencies and for omnidirectional sources the assumption of a point source radiation characteristics of a musical instrument is justified. For such a source the function of the sound pressure with respect to the distance r is defined as

$$p(t,r) = \frac{\hat{p}}{r} e^{j(\omega t - kr)}$$

with the peak value

$$\hat{p} = \frac{j\omega\rho_0\hat{Q}}{4\pi},$$

angular frequency ω, wave number k, density ρ_0 and volume velocity $\hat{Q}$. For each wave of unique frequency the amplitude decreases with distance according to the $\frac{1}{r}$ law.

Musical instruments that emit sound from one location only, i.e. a bell or one side of a vibrating plate, can be approximated by a point source when the dimensions of the opening or oscillating structure are small with respect to the wave length [3].

For higher frequency or larger dimensions of the sound exit the geometrical structure plays an important role for the estimation of the radiation characteristics [4]. For circular openings and membranes the assumption of a baffled piston can be used which exhibits a strong spatial variation of the pressure near field. For very high frequencies or large distance from the source ($kr \gg 1$) the assumption of a plane wave radiation is justified. In this case the amplitude of the sound wave does not follow the $\frac{1}{r}$ law but stays rather constant with respect to distance from the source.

If more than one relatively small opening exist the radiation can be approximated by a number of point sources that superpose taking account their relative amplitudes and phases. For only two openings a dipole source can be assumed, for higher numbers or complex geometries the radiation characteristic can be very complex and is difficult to predict [5, 6, 7].

2 METHODOLOGY

For a validation of the impact of the set-up two experiments have been performed. One series of measurements was used to test the validity of the $\frac{1}{r}$ law, the other one intended to quantify the room impact on FRF function during directivity measurements.

2.1 FRF OF A LOUDSPEAKER

In Figure 1 the loudspeaker position is shown with microphone array and turntable installed.

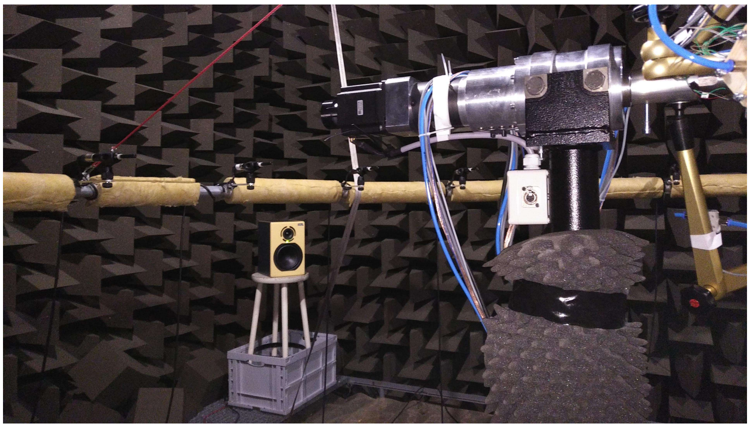
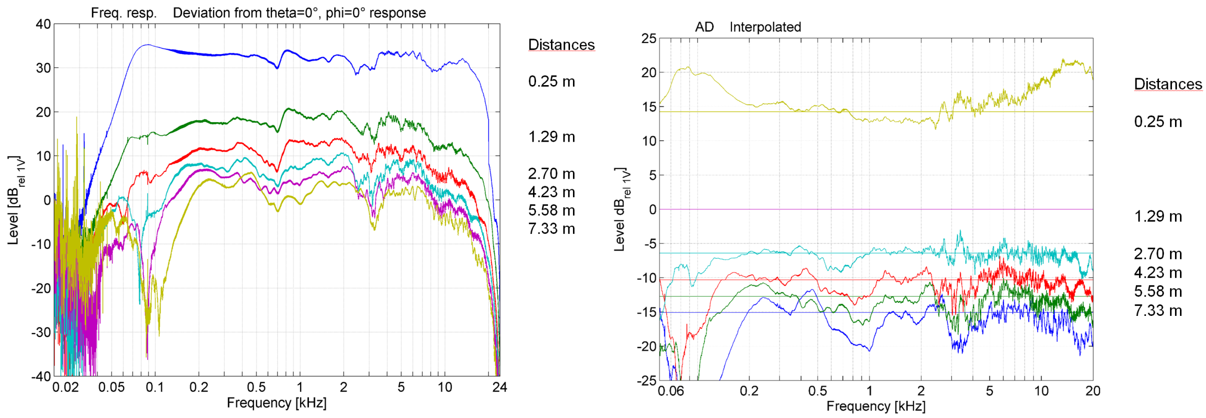


Figure 1. Set-up of loudspeaker in an-echoic chamber with turntable and microphone array.

2.1.1 Measurements

In Figures 2a and 2b the frequency response functions (FRFs) of a loudspeaker in an an-echoic chamber is shown. Figure 2a displays the FRFs measured in various distances, ranging from 25 cm to 7.33 m using the set-up shown in Figure 1. They seem to be rather similar but differ in some details. When the SPL is normalised to one measurement at 1.29 m distance the similarity of the functions is less obvious. In Figure 2b the calculated SPLs for the measured distances are added to the graphs.

This representation illustrates that the FRFs vary strongly at low frequencies below 200 Hz and also exhibit up to 5 dB variation throughout the whole frequency range. The level variation with distance below 200 Hz can be described as a low shelf filter for $r < 1.29m$ and a high-pass filter if increasing order for larger values of r.



(a) Overlay of FRFs without normalisation.

(b) FRFs normalised to the FRF in 1 m distance.

Figure 2. Measurement of a loudspeaker frequency response function in various distances.

2.2 DIRECTIVITY OF A TROMBONE BELL

In this experiment the directivity of a bell that was removed from a King Trombone Model 2104 4B was investigated using different set-ups of a Fouraudio ELF turntable, mounted in the an-echoic chamber of the OWL University of Applied Sciences and Arts. In all cases the bell was excited with swept sine signals emitted by a horn driver directly attached to the small end of the bell. These were the set-ups for the directivity measurements:

1. Bell without any other object than turntable and microphone
2. Bell as above with additional microphone array
3. Bell as above with additional mannequin

In Figure 3 the set-up with just the bell mounted on the turntable is shown. This set-up shall allow directivity measurements of the directivity with a minimum of artefacts. Due to the length of the bell it was mounted

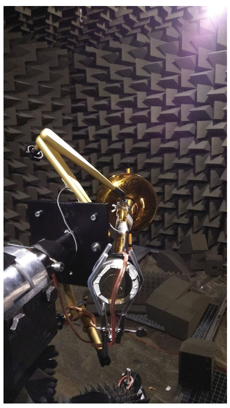
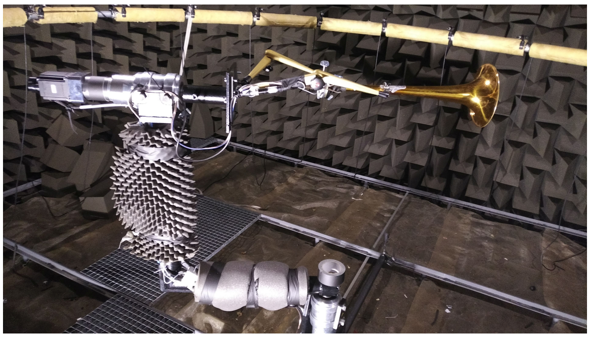
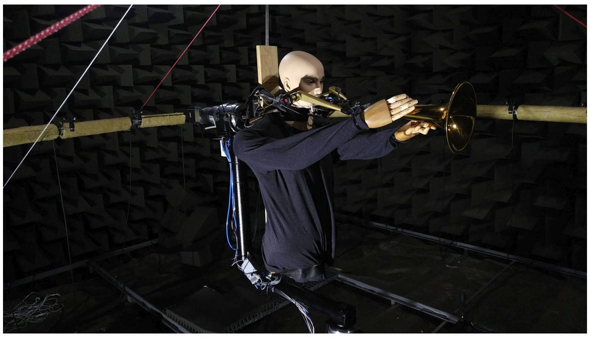


Figure 3. Directivity measurement set-up of trombone bell with neither mannequin nor microphone array

slightly off-axis with respect to the vertical axis of the turntable. In the second set-up shown in Figure 4a a 24 channel microphone array was installed in the an-echoic chamber. It is used for simultaneous assessment



(a) Directivity measurement set-up without mannequin but with microphone array



(b) Directivity measurement set-up with mannequin and microphone array

Figure 4. Directivity measurement of a trombone bell with and without a mannequin

of the sound radiated in the horizontal plane. The array was not used as a sensor in this investigation but rather as an obstacle which potentially introduced artefacts to the measurements. In the last set-up a mannequin was attached to the bell that was turned together with the bell for all measurements. It shall mimic the acoustic effect of a human player with respect to diffraction and absorption of sound from the bell. This set-up is shown in Figure 4b.

2.2.1 Results

A comparison of measurements of the set-up with mannequin in horizontal direction and 12 different values of vertical orientation is shown in Figure 5. The variation of the vertical angle of the mannequin and the bell

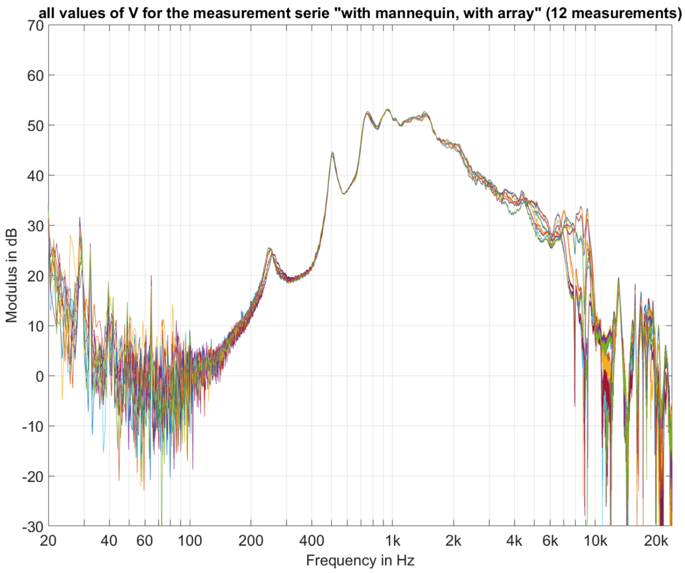


Figure 5. Frequency response function between horn driver and recording microphone for 0° horizontal and varied vertical angle of the instrument with mannequin attached

should not have any impact on the measurement in an ideal an-echoic environment since due to symmetry considerations all potential contributions of the turning sound source and the mannequin should be the same on axis, disregard the orientation in space.

However, in Figure 5 differences between the FRFs can be observed in the low frequency range below 200 Hz and in the high frequency range above 4 kHz. In the medium range the deviation is rather small.

Another comparison of measurements of the set-up without any obstacle, with the microphone ring, and with an additional mannequin inside the room is shown in Figure 6. As for the previous measurements, the variation

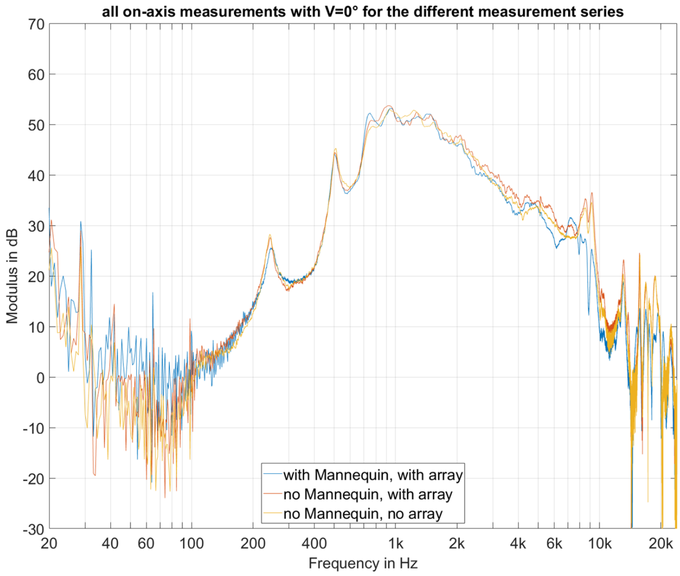


Figure 6. Frequency response functions in 0° vertical and 0° horizontal direction between horn driver and recording microphone for varied configurations of the room and instrument set-ups

of the FRFs is rather small for the frequency range from 200 Hz to 2 kHz. At higher frequencies the mannequin seems to introduce a small level drop up to 7 kHz and more serious level fluctuations for higher frequencies.

3 CONCLUSIONS

From the investigations using FRF measurements of a loudspeaker in an an-echoic chamber the effect of the near field and proximity of the loudspeaker to the walls could be observed. Contrary to the assumption of a point source the sound pressure only approximately followed the $\frac{1}{r}$ law. For low frequencies the lack of room absorption at the walls could explain the level increase with smaller distances: the hard walls of the not anymore an-echoic chamber would increase the SPL near the edge where the loudspeaker was placed. However, the level decay with increasing distance would not be explained with this effect.

The investigations of the FRFs have shown that the presence of obstacles in a room such as microphone arrays or a model of the human body have a small effect on FRF measurements for on-axis measurements. At higher frequencies, however, larger deviations occur that can be attributed to the presence of obstacles in the room. In case of the microphone array the effect seems to be very small, probably the attempts to reduce reflections of the array were not in vain. Measurements with a mannequin revealed larger deviations in SPL at frequencies that correspond to wavelengths of similar order as the mannequin's variation in geometry.

A more detailed investigation of the radiation patterns is planned in the future. A problem to be solved is the transformation of the acoustic centre and axis of rotation for the different set-ups. Due to the change of the opening and axis of the bell with respect to the turntable axes these transformations are needed to avoid artefacts in the radiation pattern calculation.

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