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The Source Directivity of a Dodecahedron Sound Source determined by Stepwise Rotation

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Summary

An omnidirectional sound source is commonly used in room acoustical measurements. The omnidirectional directivity is usually approached by placing 12 loudspeakers in a regular 12-face polyhedron, called a dodecahedron. In the ISO 3382-1 standard on the measurement of room acoustical parameters, limits are imposed on the maximum allowable deviation from omnidirectional directivity of the sound source. If this deviation approaches the limits, it is recommended to take a rotational average over at least three positions around the source. The average over three equal-angular positions in the horizontal plane of a dodecahedron sound source proves to be unreliable due to the particular geometry of the dodecahedron. In this research, the impact of the stepwise rotation method on the measured directivity deviation of a dodecahedron sound source is investigated. This is done by determining the maximum directivity deviation from rotation measurements over a whole number of equal-angular steps varying from 1 to 8. The measurements have been performed in a concert hall at 1, 5 and 18 meters distance using a standard dodecahedron loudspeaker, a turntable and stationary pseudorandom white noise. It was found that the maximum directivity deviation from average within the critical distance of a dodecahedron sound source is ± 2 dB, when determined from 3 equal-angular positions. Only when using 5, 7 or 8 equal-angular positions, the maximum directivity deviation is reduced to ± 0.5 dB at all distances.

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1. Introduction

For most room acoustic parameter measurements the use of an omnidirectional sound source is prescribed. According to the ISO 3382-1 standard [1] this sound source should be as close to omnidirectional as possible. The omnidirectionallity is usually approached by placing 12 loudspeakers in a regular 12-face polyhedron, called a dodecahedron or in a truncated version of a dodecahedron called an icosidodecahedron [5] (Figure 1). From earlier investigations it is found that the directivity deviation of a standard dodecahedron can cause large measurement errors depending on source-receiver distance, frequency band and averaged number of measurements [3][4][5][6][7][8], even though it meets the maximum allowable deviation from real omnidirectionality according to ISO-3382-1 [1] (Figure 2). If this deviation approaches the limits, it is recommended to take a rotational average over at least three positions around the source. The average over three equal-angular positions in the horizontal plane of a dodecahedron sound source proves to be still unreliable due to the particular

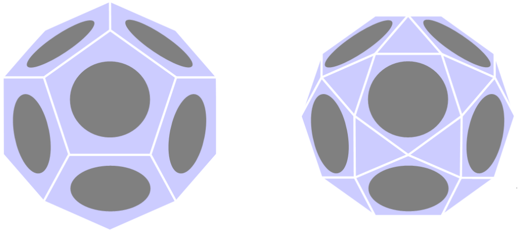

Figure 1. Dodecahedron versus icosidodecahedron.

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geometry of the dodecahedron. In this research, the impact of the stepwise rotation method on the measured directivity deviation of a dodecahedron sound source is investigated, by determining the maximum possible sound level deviation from rotation measurements over a whole number of equal-angular steps varying from 1 through 8.

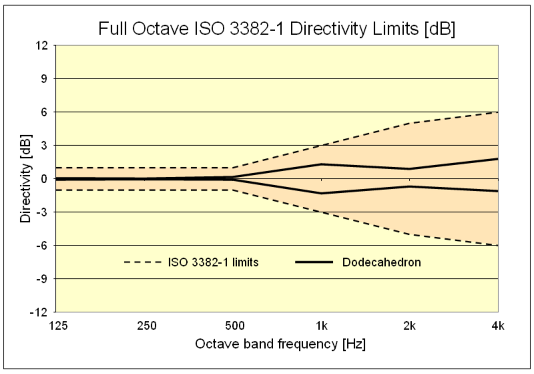

Figure 2. Maximum allowed directional deviation of an omniderectional sound source according to ISO 3382-1 (averaged over 'gliding' 30^o arcs in a free sound field).

2. Measurements

2.1 The dodecahedron sound source

The omnidirectional directivity of a sound source is commonly approached by placing 12 loudspeakers in a regular 12-face polyhedron, called a dodecahedron. Figure 3 shows the directivity polar plot of the used dodecahedron sound source (B&K 4292). For practical reasons this sound source has a truncated dodecahedral shape, called an icosidodecaheron. The diameter of the source is 0.39 m between two opposite triangular faces. The rotation axis passes through the center of two opposite triangular faces as shown in Figure 4 and Figure 5.

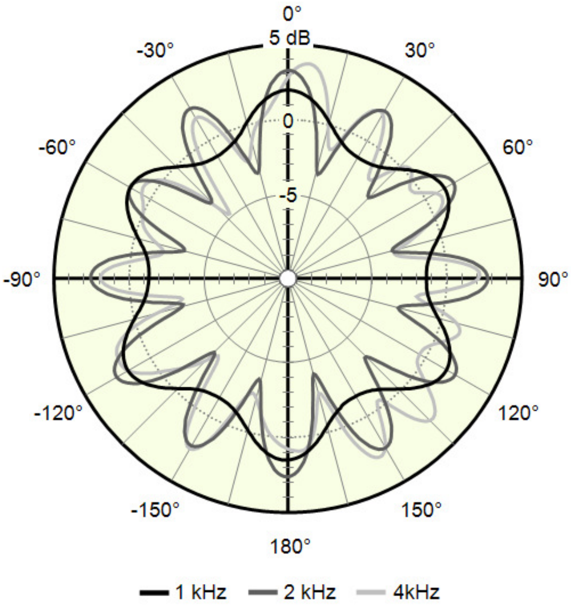

Figure 3. Horizontal directivity of the dodecahedron sound source measured in an anechoic room at a distance of 7 m using white octave band noise averaged over 5^o (gliding average time ≈ 1s).

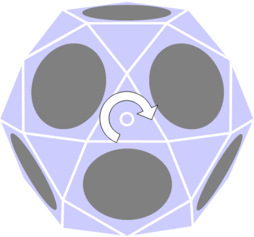

Figure 4. Top view of vertical rotation axis.

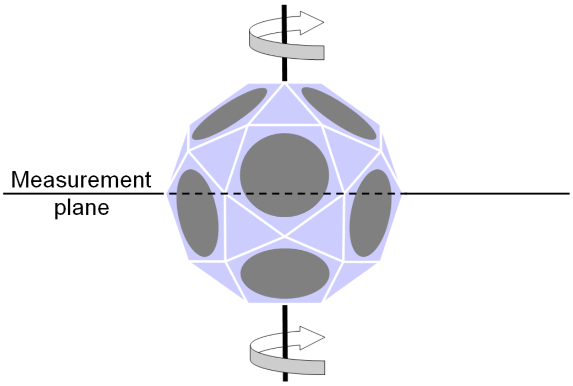

Figure 5. Side view of vertical rotation axis and horizontal measurement plane.

2.2 Measurement conditions

To evaluate the source directivity deviation of a dodecahedron sound source, measurements were carried out in the symphonic concert hall of "Muziekgebouw Frits Philips Eindhoven" with a volume of approx. 14,400 m^3, and reverberation time $T_{empty} \approx 2$ s. Figure 6 gives an impression of the hall and Figure 7 shows a schematic floorplan with the source position S at 2.45 m distance from the major axis of the hall, and the microphone positions P, R1 and R2, where P is in the near feald at 1 m from the centre of the sound source, R1 is at approx. 5 m from the source, which equals the critical distance, and R2 is in the diffuse field at approx. 18 m from the source. The room acoustical properties of this hall at the microphone positions are given in tables I to III, and obtained by averaging over eight 45^o stepwise rotation measurements. The sound source and the microphone were placed at a height of 1.5 m above the floor. During the measurements the stage and the hall were unoccupied. The decay range (INR) [9] exceeds 50 dB for all impulse responses measured with this setup.

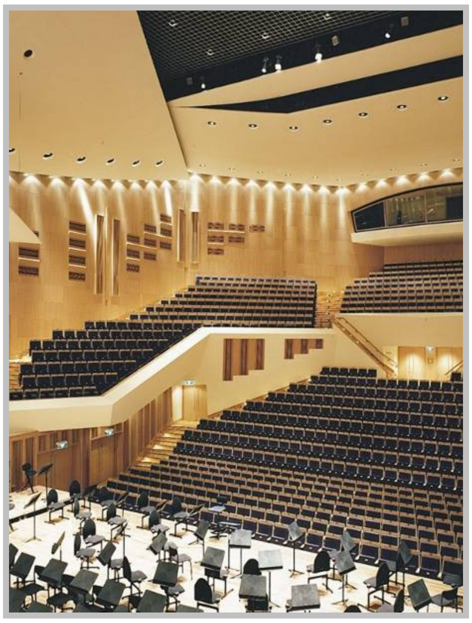

Figure 6. Impression of the concert hall.

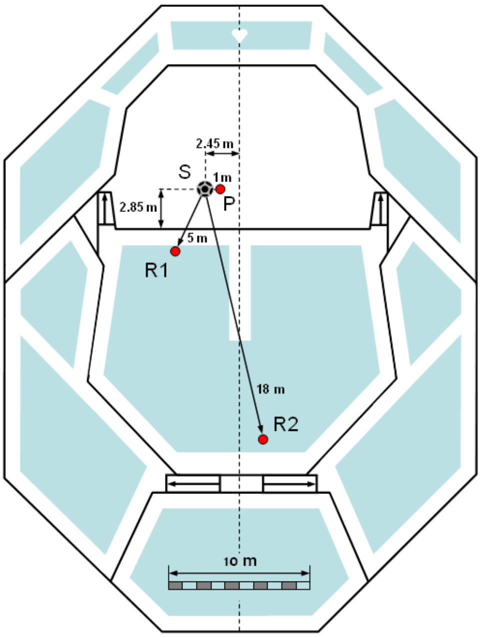

Figure 7. Floor plan with source (S) and receiver (P and R) positions.

Table I: Acoustic parameter values measured on position **P**, according to ISO 3382-1

Room acoustic parameter	Octave band [Hz]			
	500	1k	2k	4k
Strength G [dB]	21.0	20.9	19.6	20.0
Early Support ST_{early} [dB]	-16.3	-15.8	-14.2	-14.1
Late Support ST_{late} [dB]	-14.8	-15.1	-13.6	-14.9

Table II: Acoustic parameter values measured on position **R1**, according to ISO 3382-1

Room acoustic parameter	Octave band [Hz]			
	500	1k	2k	4k
Strength G [dB]	10.0	9.6	10.4	10.4
Reverberation Time T_{30} [s]	2.1	2.2	2.2	1.8
Clarity C_{80} [dB]	4.0	2.9	3.2	4.5

Table III: Acoustic parameter values measured on position **R2**, according to ISO 3382-1

Room acoustic parameter	Octave band [Hz]			
	500	1k	2k	4k
Strength G [dB]	5.8	6.6	6.2	5.1
Reverberation Time T_{30} [s]	2.2	2.2	2.2	1.9
Clarity C_{80} [dB]	-2.3	-1.3	-2.0	-1.6

2.3 Measurement procedure

Three full rotation measurements were performed using stationary pseudorandom white noise, a dodecahedron sound source on a turntable with a continuous rotation speed of 360^{o}/80s and just one microphone per position.

2.4 Measurement equipment

The measurement equipment consisted of the following components:

- *power amplifier:* (Acoustics Engineering - Amphion);
- *sound source:* dodecahedron (Bruël & Kjær - Type 4292);
- *turntable:* 80 s for one rotation (Bruël & Kjær - Type 2305);
- *microphone:* ½” omnidirectional ICP (Bruël & Kjær Type 4189);
- *sound device:* USB audio device (Acoustics Engineering - Triton);
- *software:* DIRAC 5.0 (Bruël & Kjær /Acoustics Engineering - Type 7841).

3. Results

The maximum possible sound directivity deviation was calculated as a function of the number of equal-angular positions around the sound source in the horizontal plane for any starting point t_0 according to the following formula:

$$D_{\max} = \left| 10\lg \frac{\dfrac{1}{N}\displaystyle\sum_{n=0}^{N-1}\left(\dfrac{1}{T_0}\displaystyle\int_{t_0-\frac{1}{2}T_0}^{t_0+\frac{1}{2}T_0} p^2\!\left(t_0+\dfrac{n}{N}t_{rot}\right)dt\right)}{\dfrac{1}{t_{rot}}\displaystyle\int_0^{t_{rot}} p^2(t)\,dt} \right|_{\text{max over } t_0} \quad [\text{dB}]\ (1)$$

Where:

$D_{\max}$ = maximum directivity deviation [dB] over all reference angles
N = number of equal-angular steps = 1 through 8
T_0 = gliding average time = 1s
t_0 = measurement starting point
t_{rot} = rotation time of the turntable = 80 s

Using the results of three rotation measurements (see Figure 7: S-P, S-R1 and S-R2) the impact of the stepwise rotation method on the measured directivity deviation of a dodecahedron sound source has been determined. This is done by calculating the maximum possible directivity deviation from rotation measurements over a whole number of equal-angular steps varying from 1 to 8 as depicted in Figure 8. Calculated values are presented in Figures 9 to 11 for the 1, 2 and 4 kHz octave bands only, because the directivity for the lower bands deviates negligibly from omnidirectionality (see Figure 2). Figures 9 to 11 show the maximum possible sound directivity deviation as a function of the number of equal-angular steps at equal distance around the sound source in the horizontal plane, for every possible sound source orientation starting point. Figure 9 shows the maximum source directivity deviation for measurements in the near field of a dodecahedron sound source, while Figures 10 and 11 show the maximum directivity deviation for measurements at the critical distance and in the diffuse field respectively.

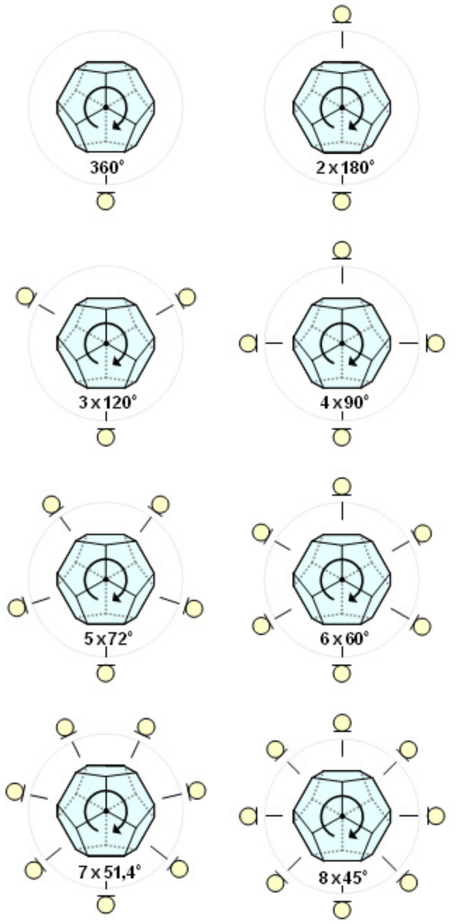

Figure 8. Determining the maximum directivity deviation of a dodecahedron sound source by averaging over 1 through 8 equal-angular step measurements.

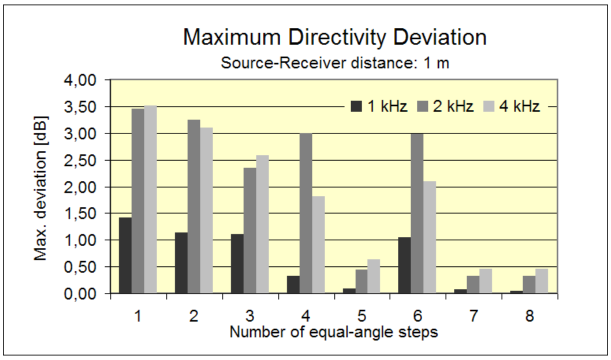

Figure 9. Maximum dodecahedron sound source directivity deviation for receiver position **P**, with source-receiver distance of 1 m (direct/near field).

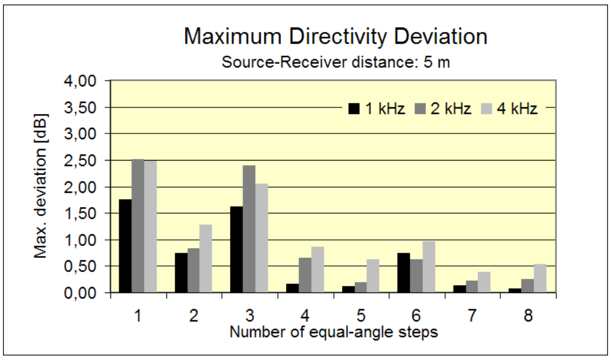

Figure 10. Maximum dodecahedron sound source directivity deviation for receiver position **R1**, with source-receiver distance of 5 m (critical distance).

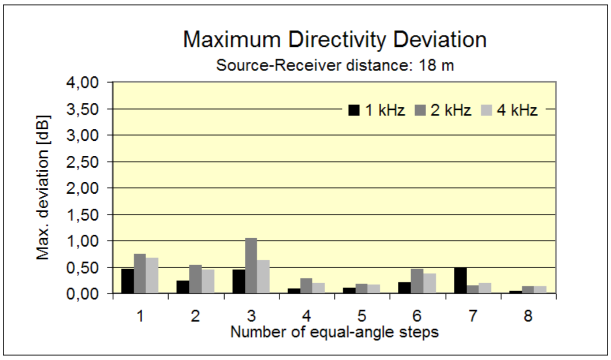

Figure 11. Maximum dodecahedron sound source directivity deviation for receiver position **R2**, with source-receiver distance of 18 m (diffuse field).

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4. Conclusions

Starting from a standard dodecahedron sound source in a concert hall, the following can be concluded:

- The source directivity can deviate more than 2 dB from average, when determined from 1 single position or 3 equal-angular positions in the horizontal plane (ISO 3382-1) within the critical distance.
- When averaged over 5, 7 or 8 equal-angular positions, the directivity deviation is reduced to a maximum of ± 0.5 dB at any source-receiver distance.
- In general: results suggest that a number of 5 equal-angular steps (instead of ‘at least 3') should be used to measure accurate sound level related room acoustic parameters

5. Further research

Further investigation is needed to validate this result for all types of room acoustic parameters for both audience and stage area according to ISO 3382-1.

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