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Møller, Henrik

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A SYMPOSIUM ON

# PERCEPTION OF REPRODUCED SOUND

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EDITED BY  
SØREN BECH and  
O. JUHL PEDERSEN

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EDITORS  
SØREN BECH  
O. JUHL PEDERSEN

## LISTENING ROOMS FOR TEST OF LOUDSPEAKERS

Henrik Møller

Institute of Electronic Systems, Aalborg University  
Fredrik Bajersvej 7, DK-9220 Aalborg Ø, Denmark

### ABSTRACT

As an introduction to a discussion on planning, construction and testing of listening rooms, this paper summarizes the requirements given in five recommendations on the subject. Two documents describe rooms for quality assessment of loudspeakers, two describe control rooms to be used during recording, and one describes a listening room for final assessment of programme material. Major specifications of 7 Danish listening rooms are also given.

### 1. INTRODUCTION

Traditionally, loudspeaker performance has been described by means of objective measurements. The most widely used is the on-axis free-field frequency response, but several others appear in specifications, such as polar patterns at selected frequencies, power frequency response, on-axis free-field impulse response and harmonic distortion.

During the last one or two decades it has become common to use listening tests in the assessment of loudspeakers. There may be several reasons for this, one of them simply being lack of experimental facilities. Anechoic and reverberant rooms are necessary for the objective measurements, together with an extensive range of equipment. A reviewer at a popular High-Fidelity magazine will hardly have access to this, so what does he do? - He simply listens to the loudspeaker!

There are even better arguments for this than lack of equipment. The owner of the loudspeaker is going to use it in an ordinary living room and for reproduction of programme material, usually music. He is not going to listen to, for example, a swept sine, and he will not directly be able to detect and maybe not even appreciate a flat on-axis free-field frequency response or a specific polar pattern.

The scientific argument for listening tests is the uncertainty related to the assessment of objective data. Compared to other parts of a Hi-Fi system, the data of a loudspeaker are much more complex, one of the reasons being that the speaker creates a three-dimensional response. Furthermore, loudspeaker data tend to be much inferior to those of the other links in the Hi-Fi chain. Linear and unlinear distortion exist in loudspeakers that would never be accepted in for example a power amplifier. But what are the ideal data of a loudspeaker? - and what deviations from this can be tolerated? - These questions can never be answered without listening tests.

Just like most of the objective measurements, listening tests might be carried out in an anechoic room. However, the sound field will differ very much from that which would appear in a usual living room. In the living room, surfaces near the loudspeaker changes the acoustic loading and thus the acoustic output, early and later reflections are introduced, and a reverberation process takes place.

Obviously, a loudspeaker ought to be evaluated on basis of its performance in realistic acoustic surroundings. This demand could actually be made on objective as well as subjective data, but till now the argument has only been widely used in connection with subjective assessments. (Because the objective data will look even worse than they do now?).

When a loudspeaker is used in a normal living room, several properties of the room, the positions of the loudspeaker and listener etc. influence the sound field. Therefore, it is important that a test is carried out in a room that is representative for rooms in which the loudspeaker is going to be used. This paper deals with five recommendations which describe rooms intended for listening to reproduced programme material.

The IEC Technical Committee No. 29 has adopted a report on listening tests on loudspeakers including a description of a listening room representative of domestic listening rooms [1]. A DIN standard almost similar in scope has been issued by Deutsche Elektrotechnische Kommission [2]. The national broadcasting companies of the Nordic countries have issued two technical recommendations on listening rooms, one on control rooms [3] and one on a reference listening room [4]. Finally, Internationale Rundfunk- und Fernsehorganisation, OIRT has issued a recommendation on control rooms [5].

The aims of the rooms are slightly different. The IEC and the DIN rooms are meant for the assessment of loudspeakers, given the room and some programme material. The control rooms are used for changing the programme material (by mixing, equalizing etc.), given the room and a set of loudspeakers. The Nordic reference listening room is meant for final assessment of programme material. But in any case the overall goal is to simulate the acoustic experience of a listener in a living room.

Section 2 of this paper will give a brief introduction to each of the five documents. Section 3 contains a comparison of the demands to specific parameters of the room. Of course, due to space limitations the requirements can only be summarized here. For details please refer to the original documents.

A brief description of 7 Danish listening rooms will be given in Section 4, including a summary of their specifications. As this paper is intended as an introduction to a discussion, no discussion and no concluding remarks are included.

## 2. GENERAL DESCRIPTION OF THE DOCUMENTS

### 2.1 IEC Publication 268-13: Sound System Equipment; Part 13: IEC Report on Listening Tests of Loudspeakers [1]

This document gives recommendations for the setting up, performance and evaluation of listening tests on loudspeakers intended for domestic systems and environments. It includes rules for selecting the programme material, sound level setting, specifications for other equipment than the loudspeaker, experimental procedure, instructions, rating scales, statistical treatment etc. Below, reference will only be made to the parts describing physical properties of the room.

### 2.2 DIN 45 573 teil 4: Lautsprecher-Prüfverfahren. Hörtest. Paarvergleich [2]

The scope and field of application of this standard is similar to the above. It covers almost the same items, although the information given is a little less exhaustive.

### 2.3 Technical Recommendation N 12-A: Listening Conditions in Sound Control Rooms [3]

This recommendation sets up rules for rooms in which monitoring of programme sound is carried out, e. g. control rooms for radio, television and film recording. It gives rules not only to the room and to the positions of the loudspeakers and the listener, but also to the loudspeaker itself, equalizers, listening level etc. The loudspeakers are considered an integral part of the room, and there are requirements to their response in the room.

### 2.4 Technical Recommendation N 12-C: Reference Listening Room [4]

The field of application of this room differs slightly from that of N 12-A. The N 12-C room is designed for use with groups of listeners up to 10, and it is meant for technical-artistic assessment of the final programme material rather than for adjustments during recording. The recommendation mentions that the room may also be used to assess the performance of equipment, particularly loudspeakers, on the basis of listening tests. In questions

other than room dimensions, loudspeaker/listener positions and reverberation time, reference is made to N 12-A.

### 2.5 Empfehlung Nr. 86/1: OIRT Bezugs-Abhörräume [5]

Like the N 12-A this recommendation applies to control rooms. In addition to information about physical conditions in the room it sets up rules for the sound level setting.

## 3. COMPARISON OF DEMANDS TO SOME SELECTED PROPERTIES OF THE ROOMS

### 3.1 Room shape and dimensions

Normally a rectangular room with horizontal floor and ceiling is assumed. In the following,  $l$  denotes length,  $w$  width,  $h$  height and  $V$  volume. All documents specify symmetry about the stereo listening axis.

#### 3.1.1 IEC 268-13

Only a rectangular room is described. The dimensions should fulfil the following equations:

$$\begin{aligned} l &\geq 6.0 \text{ m} \\ w &\geq 3.5 \text{ m for monophonic listening} \\ w &\geq 4.0 \text{ m for stereophonic listening} \\ 2.3 \text{ m} &\leq h \leq 3.0 \text{ m} \\ 60 \text{ cubic metre} &\leq V \leq 110 \text{ cubic metre} \end{aligned}$$

Some more specific recommendations are given to describe an "international standard listening room" for use when the results are to have the widest possible application. This has the dimensions  $l = 6.7 \text{ m}$ ,  $w = 4.2 \text{ m}$  and  $h = 2.8 \text{ m}$  ( $V \approx 80$  cubic metre).

#### 3.1.2 DIN 45 573 teil 4

The following rules apply to the dimensions:

$$\begin{aligned} 1 &< l/w < 2 \\ h &= 2.75 \text{ m} \pm 0.25 \text{ m} \\ V &= 80 \text{ cubic metre} \pm 20 \text{ cubic metre} \end{aligned}$$

#### 3.1.3 N 12-A

A rectangular shape is recommended for practical reasons, but a trapezoidal shape is also suggested as being acoustically as good or even better. The dimensions should comply with the following:

$$\begin{aligned} 1.1 &\leq l/w \leq 1.7 \\ l \cdot w &= 35 \text{ m}^2 \pm 15 \text{ m}^2 \\ h &= 2.75 \text{ m} \pm 0.25 \text{ m} \end{aligned}$$

#### 3.1.4 N 12-C

More exact requirements on room shape have not been drawn up. The basic shape could, for example, be rectangular or slightly trapezoidal. A multicornered room, derived by "cutting" the

corners off a basic rectangular or trapezoidal room, may also be considered. Symmetry is required. In case of non-rectangular rooms the dimensions are average dimensions. The following restrictions are given:

$1.25 \leq l/w \leq 1.45$   
 $1.10 \leq w/h \leq 1.90$   
 $l/h \leq 1.90$  or  $l/h \geq 2.10$   
 $40 \text{ m}^2 \leq l \cdot w \leq 60 \text{ m}^2$ ,  $l \cdot w = 50 \text{ m}^2$  recommended

### 3.1.5 OIRT 86/1

A rectangular room is preferred, but a trapezoidal room is also accepted. The following equations should be fulfilled (in case of trapezoidal rooms mean values are used):

$1.25 \leq l/w \leq 1.45$   
 $1.10 \leq w/h \leq 1.90$   
 $l/h \leq 1.95$  or  $l/h \geq 2.05$   
 $90 \text{ cubic metre} \leq V \leq 120 \text{ cubic metre}$  (monophonic listening)  
 $120 \text{ cubic metre} \leq V \leq 150 \text{ cubic metre}$  (stereophonic listening)

## 3.2 Reverberation time

All five documents use the reverberation time measured in 1/3 octave bands. Three of them define a mean value  $T_m$  as the arithmetic mean of values obtained in a specified frequency range.

### 3.2.1 IEC 268-13

$T_m$  is defined for the frequency range 250 to 4000 Hz. It is required that  $0.3 \text{ s} \leq T_m \leq 0.6 \text{ s}$ . Individual deviations from  $T_m$  should be below  $0.25 \cdot T_m$  in the frequency range 250 to 4000 Hz. Outside this range larger tolerances are accepted (further specified).

Where the results of the listening tests are of more than regional or other specific interest, a  $T_m$  value of  $0.4 \text{ s} \pm 0.05 \text{ s}$  is recommended.

### 3.2.2 DIN 45 573 teil 4

For frequencies between 400 Hz and 10000 Hz, the reverberation time should be at least 0.2 s. The upper limit is 0.6 s at 400 Hz decreasing to 0.4 s at 10000 Hz. Within one octave, variations should be smaller than + 25% and - 20%. Larger values are specified below 400 Hz, and larger variation is accepted.

### 3.2.3 N 12-A

$T_m$  is defined for the frequency range 250 to 2000 Hz.  $T_m$  should not exceed 0.4 s, and a value of  $T_m \approx 0.3 \text{ s}$  is preferred.

Individual deviations from  $T_m$  should be below 0.075 s for frequencies between 250 and 2500 Hz, while larger tolerances are given outside this range (further specified).



3.2.4 N 12-C

$T_m$  is defined for the frequency range 200 to 2500 Hz. The recommended value of  $T_m$  is dependent on room size. A formula is given, but reference will here only be made to selected examples:

V = 100 cubic metre:  $0.23 \text{ s} \leq T_m \leq 0.33 \text{ s}$ , 0.28 s preferred  
 V = 150 cubic metre:  $0.27 \text{ s} \leq T_m \leq 0.37 \text{ s}$ , 0.32 s preferred  
 V = 200 cubic metre:  $0.30 \text{ s} \leq T_m \leq 0.40 \text{ s}$ , 0.35 s preferred

The preferred values are claimed to correspond to an average absorption coefficient of 0.33. Individual deviations from  $T_m$  should be below 0.05 s for the frequency range 200 to 10000 Hz. Differences between adjacent 1/3 octave bands should be below 0.05 s. Below 200 Hz larger tolerances are accepted (further specified).

3.2.5 OIRT 86/1

This document specifies a nominal reverberation time which should be between 0.25 s and 0.40 s. Individual deviations from the nominal value should be below 0.05 s in the frequency range 160 to 10000 Hz and below 0.1 s at lower frequencies

**3.3 Loudspeaker and listener positions**

All documents assume a symmetrical stereo set-up with the loudspeakers in one end of the room and the listener(s) in the other end or in the middle of the room. The relative positions between loudspeakers and listener(s) may be given by the stereo base (b), the perpendicular distance from a listener to the line connecting the two speakers (d), and the angle between the directions to the two speakers seen from the listener ( $\theta$ ). Not all documents use these terms, but for reasons of comparison, they will be used in the following. The two documents on control rooms [3, 5] specify a reference listening point (the position of the recording technicians head), while the other documents refer to a larger listening area (along the symmetri axis for stereo listening).

3.3.1 IEC 268-13

If the manufacturer of a loudspeaker gives guidelines for location, these should be followed. Otherwise, it is recommended that loudspeakers be auditioned in several different room locations. The loudspeaker should be mounted 1.25 m above the floor, facing the center of the listening area. The loudspeakers should be rendered invisible to the listener by an acoustically transparent screen separating the loudspeaker and listening areas (specifications given).

Two kinds of tests are suggested: monophonic tests, well suited to judgements of basic sound qualities and in which loudspeaker locations can be easily changed, and stereophonic tests that involve judgements of additional attributes of the reproduced sound, and in which loudspeaker locations are rigorously controlled.

For monophonic tests the speakers should be at least 1 m from the side walls and at least 0.7 m from the back wall. In stereophonic tests the distance to the sidewalls may be reduced to 0.5 m.

In stereophonic tests the following rules should be observed (d refers to the nearest listener):

$$\begin{aligned} b &\geq 2 \text{ m} \\ 0.8 &\leq d/b \leq 1.0 \quad (55^\circ \leq \theta \leq 65^\circ) \\ d &\geq 2 \text{ m} \end{aligned}$$

Several listening positions are suggested, for stereophonic tests all on the symmetri axis. If more than one listener participates at a time, all listeners should have a clear view at the speakers (progressive elevation of the seats from front to back is suggested). Positions closer to side walls than 0.4 m and closer to the back wall than 1.0 m should be avoided.

### 3.3.2 DIN 45 573 teil 4

The loudspeakers should be positioned according to their normal use, respecting possible indications from the manufacturer. The distance to the side walls should be at least 0.5 m.

For any of the listeners it is required that  $\theta \geq 45^\circ$ . All listeners should have a clear view at the speakers (progressive elevation of the seats from front to back is suggested). The loudspeakers should be hidden behind an acoustically transparent curtain.

### 3.3.3 N 12-A

The loudspeaker should be mounted at least 1.2 m above the floor, facing the listener and visible from the listening point. It should be placed at least 1 m from the sidewalls and ceiling, and at least 0.7 m from the wall behind the speaker. For good or even better results it is suggested to flushmount the speaker into the wall. Listeners should be at least 1 m from any wall.

The following rules should be observed:

$$\begin{aligned} 0.5 &\leq d/w \leq 0.6, \text{ or generally } d = 3 \text{ m} \pm 1 \text{ m} \\ \theta &= 60^\circ \pm 10^\circ \quad (d/b \approx 0.9 \pm 0.2) \\ &\text{(b is only given indirectly from these equations)} \end{aligned}$$

### 3.3.4 N 12 C

This document refers to N 12 A, except for the following to be observed:

$$\begin{aligned} 3.0 \text{ m} &\leq b \leq 4.5 \text{ m} \\ &\text{Reference listening point defined by } \theta = 60^\circ \end{aligned}$$

Acoustically transparent curtains may hide the loudspeakers (specifications given).

3.3.5 OIRT 86/1

The following rules are given:

$$3.0 \text{ m} \leq b \leq 4.5 \text{ m}$$

$$0.5 \leq d/b \leq 1.0 \quad (53^\circ \leq \theta \leq 90^\circ) \quad (\text{for small rooms})$$

$$0.5 \leq d/b \leq 1.5 \quad (37^\circ \leq \theta \leq 90^\circ) \quad (\text{for rooms intended for more than 5 listeners})$$

Reference listening point defined by  $\theta = 70^\circ$  ( $d/b \approx 0.7$ )

The speakers should be hidden behind an acoustically transparent curtain (specifications given) and be mounted not closer to any surface than 1 m.

### 3.4 Room surfaces

Only sparse and unsystematic information is given on this subject. N 12-A contains no demands except from that which follows from the requirements to the reverberation time.

In general it is stressed that absorption material should be distributed to all surfaces in the room in order to achieve a sufficiently diffuse reverberant sound field to avoid flutter echoes and other perceptible acoustic defects. The importance of stereo symmetry is also pointed out in this connection.

N 12-C and OIRT 86/1 mention that if resonating absorbers are used, these should be sufficiently damped (attenuation time shorter than room reverberation time).

IEC 268-13 asks for a ceiling that is mostly sound reflecting and a floor that is mostly carpeted. The wall behind the listeners should be absorbing.

The surfaces close to the speakers are very important for the sound field reaching the listener. IEC 268-13 specifies sound reflecting walls behind and immediately to the sides of the speakers. However, it also suggests movable absorbers that can acoustically damp these walls. A heavy drape suspended from a track near the perimeter of the room is useful. N 12-C sets up requirements to early reflections. Sound waves arriving less than 5 ms after the direct sound should be attenuated at least 10 dB (for frequencies  $\geq 250$  Hz).

## 4. SOME DANISH LISTENING ROOMS

Below is given information on rooms intended for various listening tests. The list is not claimed to be complete. The data are given by the institutions running the rooms.

### 4.1 Laboratory of Acoustics, Technical University, Copenhagen

The room is built for the purpose of loudspeaker listening tests. The fulfilment of IEC 268-13 was aimed at. Except that the height is too large, due to the use of an old garage, this has been reached.

The dimensions are:  $l = 6.6$  m,  $w = 5.25$  m,  $h = 3.1$  m ( $V = 107$  cubic metre).

The reverberation time is  $0.4$  s with deviations  $\leq 0.02$  s at the  $1/3$  octave frequencies from  $160$  Hz to  $4000$  Hz. The decay curves show a smooth decay as evidence of a good diffuse sound field. The good low frequency characteristics have been obtained by means of membrane absorbers. The specifications for the reverberation time fulfil not only the general requirements of IEC 268-13, but also the stronger demands for "tests of more than regional or other specific interest".

The room is equipped with two free-standing vertical boards, reflective at one side and absorbing at the other. The reverberation time is not altered when these are moved in the room, but they can be used to change the reflection properties especially around the speakers or behind the listeners.

Some problems with asymmetry are reported, presumably due to an asymmetrically positioned large gate behind the listeners (remnant from the time, when the room served as a garage).

#### 4.2 Institute of Electronic Systems, Aalborg University

Also this room is built for the purpose of loudspeaker testing. The aim is to fulfil the requirements of IEC 268-13. At the time of printing the room is not completed, and only the data prescribed to the contractor can be given.

The dimensions are the following:  $l = 7.79$  m,  $w = 4.13$  m,  $h = 2.80$  m ( $V = 90$  cubic metre).

The requirements to the reverberation time are  $0.4$  s  $\pm 0.05$  s in the frequency range  $200$  to  $4000$  Hz,  $0.45$  s  $\pm 0.1$  s at  $160$  Hz,  $0.5$  s  $\pm 0.15$  s at  $125$  Hz and  $0.55$  s  $\pm 0.2$  s at  $100$  Hz.

One end-wall is furnished with a set of flush mounted loudspeakers that can be used as reference.

#### 4.3 Bang and Olufsen, Struer

The room is built for listening tests on loudspeakers. The dimensions are:  $l = 6.05$  m,  $w = 5.03$  m,  $h = 2.85$  m. Some minor asymmetry is introduced by a door and two windows.

$T_m = 0.37$  s for the frequency range  $250$  Hz to  $4000$  Hz. The reverberation time as a function of frequency shows large deviations at single frequencies below  $200$  Hz, and it shows a distinct decreasing tendency towards higher frequencies. Although the deviations are still within the limits of IEC 268-13, the room is under reconstruction, including a more exact adjustment of the reverberation time.

#### 4.4 Brüel and Kjær, Nærum.

The purpose of the room is quality auditioning of programme material, especially for assessment of microphone performance.

Dimensions are:  $l = 6.0$  m,  $w$  varies from 4.1 m to 4.4 m (slightly trapezoidal shaped, speakers at narrow end),  $h$  varies from 2.3 to 2.8 m (inclining roof, lowest in loudspeaker end),  $V = 65$  cubic metre.

Information on reverberation time not available at the time of printing. The room is equipped with a set of loudspeakers.

#### 4.5 Jamo, Glyngere

The room is intended to be used for listening tests on loudspeakers.

The dimensions are  $l = 8.0$  m,  $w = 5.0$  m,  $h = 2.5$  m ( $V = 100$  cubic metre).

In the frequency range 250 Hz to 4000 Hz the reverberation time ranges from 0.57 s at the low end to 0.33 at the high end. The average is well within the limits of IEC 268-13, but the variations are larger than accepted by this document.

#### 4.6 Rossing Electronic, Holbæk

Room for quality assessment of various electroacoustic equipment, including loudspeakers.

Dimensions:  $l = 6.8$  m, inclining roof,  $h$  ranges from 2.3 m to 3.35 m. No information on  $w$  at the time of printing.

For the frequency range 250 Hz to 4000 Hz the reverberation time ranges from 0.30 s to 0.41 s with  $T_m = 0.35$ . This fulfils the requirements of IEC 268-13.

#### 4.7 Ortofon, Copenhagen

No information received at the time of printing.

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