International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R BS.2419-0

(04/2018)

Effect of microphone directivity regarding level calibration and equalization of advanced sound systems

BS Series

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International Telecommunication Union

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Electronic Publication
Geneva, 2018

REPORT ITU-R BS.2419-0

Effect of microphone directivity regarding level calibration and equalization of advanced sound systems

(Question ITU-R 62/6)

(2018)

Summary

This Report shows the results of two independently conducted studies regarding the influence of microphone directivity, for the level calibration of advanced sound systems within ITU-R BS.1116 compliant listening rooms. The procedures described here will provide additionally useful information for loudspeaker equalization to fulfil the operational room response limits.

Keywords

Microphone directivity, level calibration, listening room, loudspeaker equalization, operation room response, advanced sound system.

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1 Introduction

Recommendation ITU-R BS.1116-3 [1] – Methods for the subjective assessment of small impairments in audio systems, prescribes in § 8 (listening conditions) the loudspeaker level calibration (with a level tolerance of ±0.25 dB), measured with a broadband pink noise signal. Additionally, it outlines the operational room response tolerances in a frequency range from 50 Hz to 16 kHz.

Whilst the task is relatively straight forward for loudspeakers that retain consistent angles of incidence relative to the calibration microphone, for advanced loudspeaker systems additional elevation angles of incidence are introduced.

Microphones do not possess a perfect omnidirectional polar pattern at higher frequencies due to their physical sizes. This directionally dependent off-axis attenuation is likely to exceed recommended tolerance limits, as shown below, given the varying angles of incidence. Therefore, both microphone diameter size and orientation should be considered when conducting calibration measurements of advanced sound systems.

One solution may be to manually redirect the on-axis angle of incidence towards each loudspeaker used in the calibration procedure, for the highest fidelity measurement. This however is both time consuming for large systems such as the 9+10+3 (22.2) format and presents a not negligible possibility for human error. Another may be to produce an automated system thus eliminating human error, but would be cost inefficient and also introduces further equipment in the measurement spot which may impact the acoustic pathway. It is therefore desired to ascertain a solution which will overcome these complications that can be easily and reliably applied.

This ITU-R Report documents the findings of two evaluations using multiple microphone sizes and orientations and proposes filter based solutions for the calibration of advanced sound systems.

Contributions are split into two sub-sections for a detailed description of each approach.

2 First evaluation

2.1 Introduction

The following sections details a report investigating the effect of microphone size, orientation and distance on a loudspeaker calibration measurement, within two studio rooms, one of which conforming Recommendation ITU-R BS.1116. For more details see [2].

Microphone measurements were taken to reveal the high frequency attenuation of off-axis responses. The impact of this directivity is then observed for multiple angles within two listening rooms. An inverse filter is calculated to compensate for loudspeakers at specific off-axis elevation positions using two microphone sizes. The critical distance is calculated to justify this approach.

2.2 Microphone analysis

Four microphones (Table 1) were measured within an anechoic chamber to ascertain the directivity response of different off-axis angles (20°, 50°, 80°, 110°, 140°). As the loudspeaker does not possess a flat magnitude-frequency response and only relative differences are of interest, the on-axis (0° elevation) was employed as a reference and all other responses were normalized to this response.

TABLE 1

Technical data of measured microphones

Microphone #		**I**	**II**	**III**	**IV**
Diameter	(in)	1/2”	1/2”	1/4”	1/4”
	(cm)	1.27	1.27	0.63	0.63
Sound field type		free-	free-	free-	multi-field
Microphone manufacturer and type		Microtech Gefell MK221	NTi M2211	Microtech Gefell M373	Brüel & Kjær 4961

FIGURE 1

Frequency responses for (a) 1/2” mic I and (b) 1/4” mic IV.
All elevation responses are normalized to 0˚ on-axis response

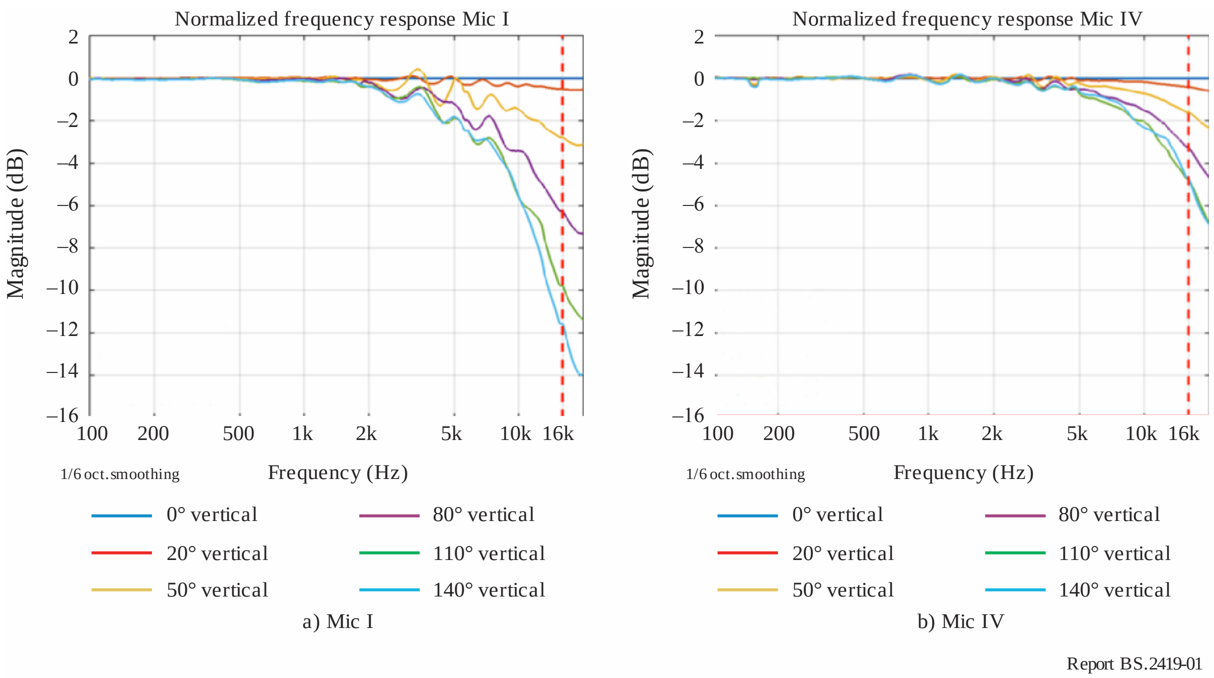
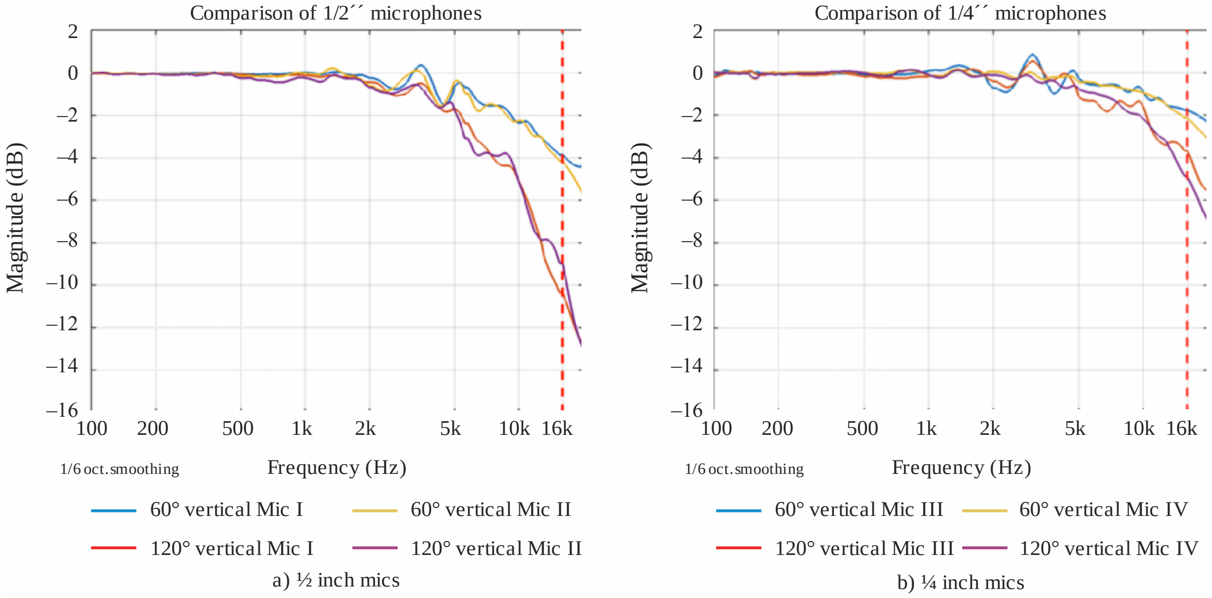


FIGURE 2

Comparison of frequency responses measured at 60° and 120°
for the two 1/2” microphones (a) and two 1/4” microphones (b)



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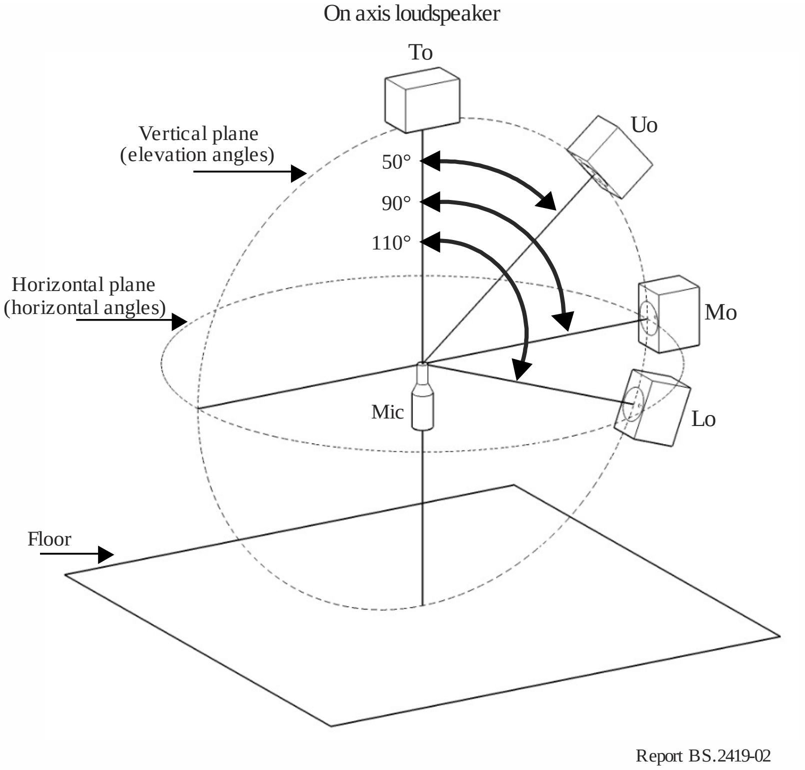
Results from Fig. 1 show that the greater the angle of incidence to the microphone, the greater the high frequency attenuation. In addition, Fig. 2 demonstrates that high frequency attenuation (measured at 60˚ and 120˚) is mainly dictated by the diameter of the microphone and elevation, and not so much upon the microphone manufacturer.

All investigated microphones are round and therefore have physical rotation symmetry present around the main axis, in our setup the axis through microphone and loudspeaker T_0. The rotation symmetry is verified by calculating the difference between measured frequency responses at azimuth 0° and 90°, at vertical elevation angle of 90°. For frequencies lower as 16 kHz this symmetry below ±0.5 dB.

FIGURE 3

Elevation angles as seen in Table 2 typical for a 9+10+3 loudspeaker setup for an upright positioned measurement microphone



2.3 Elevation angle level influence

Besides the pure microphone properties, presented in the previous section, in this section the influence of the microphone directivity on a real sound level measurement in a studio room is investigated. Depending on the reverberation time of the room, the directivity of the loudspeaker and microphone used and the distance between them, the level measurement will be more in the direct field for some frequencies and more in the diffuse field for others. Therefore, the level difference resulting from the different microphone incidence angles is measured in two different studio rooms. A single loudspeaker position is used, while the microphone is tilted for each incidence angle accordingly. The microphone is always positioned in the listening sweet spot at 1.2 m height.

Table 2 presents the level differences between a 0° positioned loudspeaker in front of the microphone and three elevation angles. These three angles (50°, 90°, 110°) correspond to the angle between the upright microphone and the loudspeakers in the present 3D loudspeaker setup (see Fig. 3). The level drops with increase of the elevation angle. The magnitude loss for microphones of the same size is similar. Moreover, the room does not seem to have a big influence. The two studio rooms are described in more detail in [3].

TABLE 2

Broadband level differences (dB) between on-axis measurements and different elevation angles for two listening rooms and four microphones

Studio Room		**Mozart**			**Bach**		
RT60 (s)		0.36±0.05			0.34±0.15		
Volume (m^3)		300			102		
Distance (m)		2.78			2.03		
		Mic. elev. angle			Mic. elev. angle		
Mic. #	dia. (in)	50°	90°	110°	50°	90°	110°
I	1/2	0.7	1.2	1.5	0.5	1.0	1.2
II	1/2	0.6	1.1	1.3	0.4	0.7	1.1
III	1/4	0.3	0.6	0.8	0.3	0.5	0.8
IV	1/4	0.2	0.5	0.7	0.1	0.3	0.5

The measurement values are calculated out of the transfer functions, by averaging the difference values of the third-octave bands until 20 kHz. They are verified by the broadband values of an audio level meter using pink noise as excitation signal.

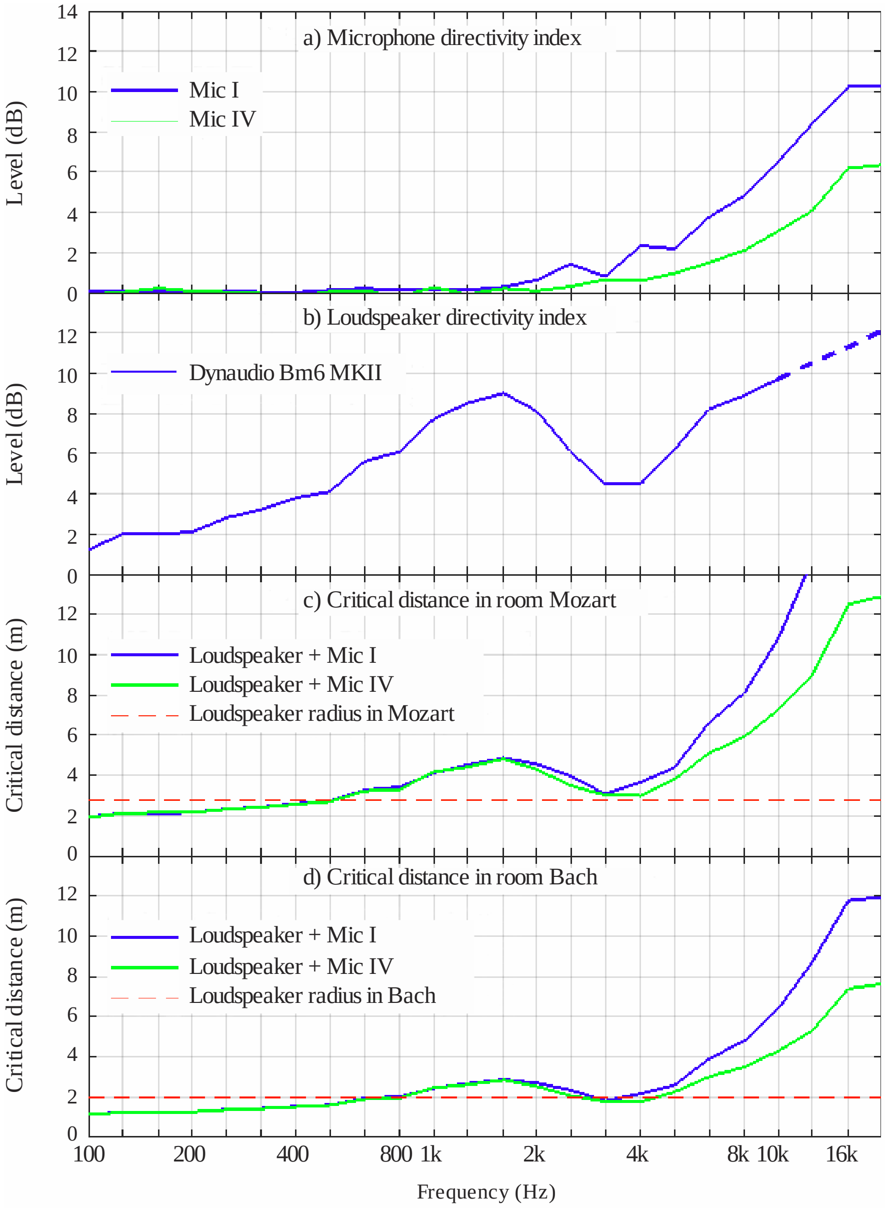
These measurements show clearly that the broadband level influence is microphone-angle and diameter dependent. Nearly none of the measured angled conditions fulfil the required accuracy of 0.25 dB.

2.4 Acoustic field analysis and apparent critical distances

In order to apply free-field corrections to a microphone for real room measurements, the pre-requisite is that the microphone placement must lie more within the direct field than in the diffuse-field. In other words, the loudspeaker to microphone distance is inside the apparent critical distance. The standard definition of critical distance includes the room properties and the source directivity. Here we take also the receiver directivity of the microphone into account and call it “apparent critical distance”. Taking the loudspeaker and microphone directivity into account, the apparent critical distance is highly frequency dependent. For the two investigated relatively dry studio rooms this distance reaches from 1.5 m for the low frequency up to 7-12 m at 16 kHz, dependent on the microphone diameter, Fig. 4. For the directivity calculation see [2]. With the given two loudspeaker radii of 2.0 and 2.8 m, most of the frequency range lies within the apparent critical distance.

FIGURE 4

a) Microphone directivity index (DI) for Mic I (1/2”) and Mic iV (1/4”);
b) DI for the used two-way loudspeaker Dynaudio BM6 MKII
(the values above 10 kHz are not calculated, but extrapolated);
c) apparent critical distances in studio room Mozart for the two different microphone diameters;
d) apparent critical distances in studio room Bach



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2.5 Angle compensation

The general microphone magnitude frequency can be described with a high frequency shelving filter. Therefore, the following section details the design of an inverse filter employed to compensate for such losses of an off-axis measurement.

The second-order shelving filters are defined by three parameters: gain G (dB), cut-off frequency F_c [Hz], and quality factor Q. The b and a parameters of the transfer function (1) are defined in equations (2) and (3) using [4], p. 53. The fitting is checked by the least squares method for each microphone diameter and different elevation angles.

$$H_{2\mathrm{nd}}(z) = \frac{b_0+b_1z^{-1}+b_2z^{-2}}{1+a_1z^{-1}+a_2z^{-2}} \tag{1}$$

$$a_1 = \frac{2(K^2-1)}{1+\sqrt{2}K+K^2}; \quad a_2 = \frac{1-\sqrt{2}K+K^2}{1+\sqrt{2}K+K^2} \tag{2}$$

$$b_0 = \frac{V_0+\sqrt{2V_0}K+K^2}{1+\sqrt{2}K+K^2}; \quad b_1 = \frac{2(K^2-V_0)}{1+\sqrt{2}K+K^2}; \quad b_2 = \frac{V_0-\sqrt{2V_0}K+K^2}{1+\sqrt{2}K+K^2}$$

$$K = \tan\left(\frac{\pi f_c}{f_s}\right) \; ; \; V_0 = 10^{G/20} \; ; f_s = 48 \text{ kHz} \tag{3}$$

The designed filters are presented in Figs 5 to 7.

FIGURE 5

Filter-curve approximation for the 1/2” microphones at 50° angle

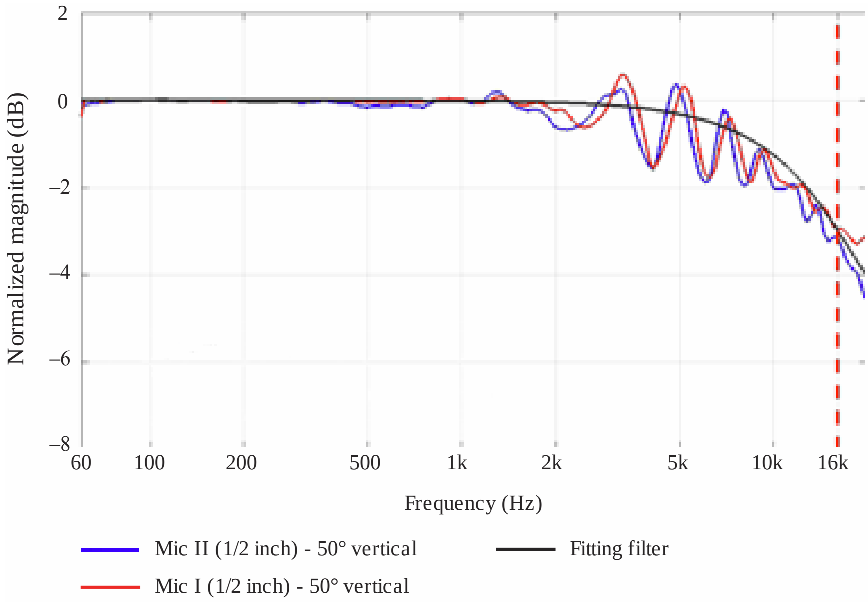

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FIGURE 6

Filter-curve approximation for the 1/4” microphones at 90° angle

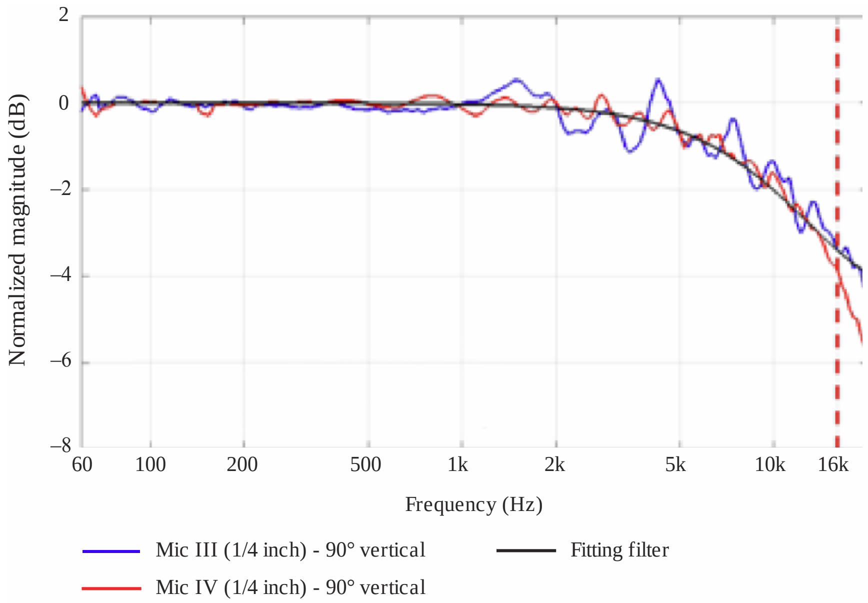

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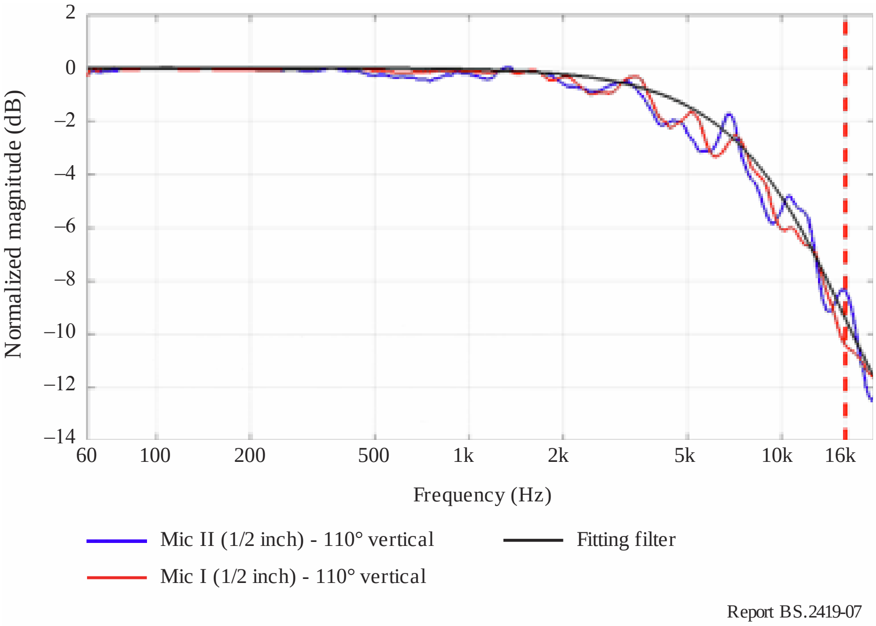
FIGURE 7

Filter-curve approximation for the 1/2” microphones at 110° angle



Measured level differences for the different angles in the rooms after the inverse-filter compensation are shown in Table 3. They are much smaller than the original errors in Table 2 and smaller than or very close to the requested high accuracy of Recommendation ITU-R BS.1116. The residual errors of the two different 1/4” microphones are nearly equal and very small. The residual errors of the two different 1/2” microphones using the same compensation filter are not exactly equal, but still smaller than the requested 0.25 dB.

These results indicate that compensation based on the microphone angle and diameter would be possible, regardless of the actually used microphone. Filters designed to compensate for a 1/2” and 1/4” microphone diameters for three difference angles are presented in Table 4. As values for frequency cut-off F_c (Hz) and quality factor Q remain a constant per microphone size, the only parameter which must be adjusted is the gain G (dB) with respect to the angle.

The level corrections for each third octave band provided by the correction filters in Table 4 can be seen in Table 5. The last line presents the broadband level corrections.

TABLE 3

Level differences [dB] after applying the compensation filter, dependent on angle, room and microphone

Studio Room		**Mozart**			**Bach**		
RT60 (s)		0.36±0.05			0.34±0.15		
Volume (m^3)		300			102		
Distance (m)		2.78			2.03		
		Mic. elev. angle			**Mic. elev. angle**		
Mic. #	dia. (in)	50°	90°	110°	50°	90°	110°
I	1/2	0.22	0.05	0.09	0.11	−0.02	−0.10
II	1/2	0.14	0.11	0.02	0.07	−0.20	−0.19
III	1/4	0.01	−0.08	−0.02	0.06	−0.04	0.07
IV	1/4	−0.04	−0.08	−0.08	−0.16	−0.26	−018

TABLE 4

Filter parameters for compensation filters

Diameter (inches)	**Angle (degrees)**	**F_c (kHz)**	**Q**	**G (dB)**
1/2	50	14.5	0.50	4.47
1/2	90	14.5	0.50	10.32
1/2	110	14.5	0.50	12.49
1/4	50	11.0	0.50	1.78
1/4	90	11.0	0.50	4.10
1/4	110	11.0	0.50	4.93

TABLE 5

Level corrections of compensation filters in third-octave bands, for three angles and two microphone diameters The last line presents the broadband level corrections

	Level correction (dB)					
	1/2" Mic angle			**1/4" Mic angle**		
f_T	50°	90°	110°	50°	90°	110°
200	0.00	0.00	0.00	0.00	0.00	0.00
250	0.00	0.00	0.00	0.00	0.00	0.00
315	0.00	0.00	0.01	0.00	0.00	0.00
400	0.00	0.01	0.01	0.00	0.00	0.01
500	0.00	0.01	0.02	0.00	0.01	0.01
630	0.01	0.02	0.02	0.00	0.01	0.01
800	0.01	0.03	0.04	0.01	0.02	0.02

TABLE 5 (*end*)

1k	0.01	0.04	0.06	0.01	0.03	0.04
1.25k	0.02	0.07	0.10	0.02	0.05	0.06
1.6k	0.03	0.11	0.16	0.03	0.07	0.09
2k	0.05	0.18	0.25	0.04	0.12	0.15
2.5k	0.08	0.28	0.39	0.07	0.18	0.23
3.15k	0.13	0.44	0.61	0.11	0.29	0.36
4k	0.21	0.69	0.95	0.17	0.44	0.56
5k	0.33	1.07	1.48	0.26	0.68	0.85
6.3k	0.52	1.66	2.25	0.40	1.01	1.26
8k	0.83	2.53	3.38	0.58	1.47	1.82
10k	1.30	3.78	4.94	0.83	2.05	2.53
12.5k	2.01	5.47	6.98	1.13	2.73	3.33
16k	2.99	7.56	9.41	1.45	3.41	4.13
20k	4.05	9.57	11.66	1.70	3.94	4.74
Total	**0.54**	**1.24**	**1.56**	**0.32**	**0.72**	**0.90**

2.6 Distance Dependency and Repeatability

For an investigation on the influence of the microphone-to-loudspeaker distance three distances are chosen: a) 1 m, b) listening distance in each room, and c) 4 m, see Fig. 8. The on-axis level of microphone I and the angle-compensated level of microphone I at 50° elevation are measured and their difference is calculated. The results shown in Table 6 indicate that these differences are not changing significantly over distance in either of the two different studio rooms.

FIGURE 8

Distance measurement using on-axis and off-axis (50°) at three distances:
a) 1 m, b) listening distance for each room (room dependent – 2.78 m and 2.03 m) c) 4 m

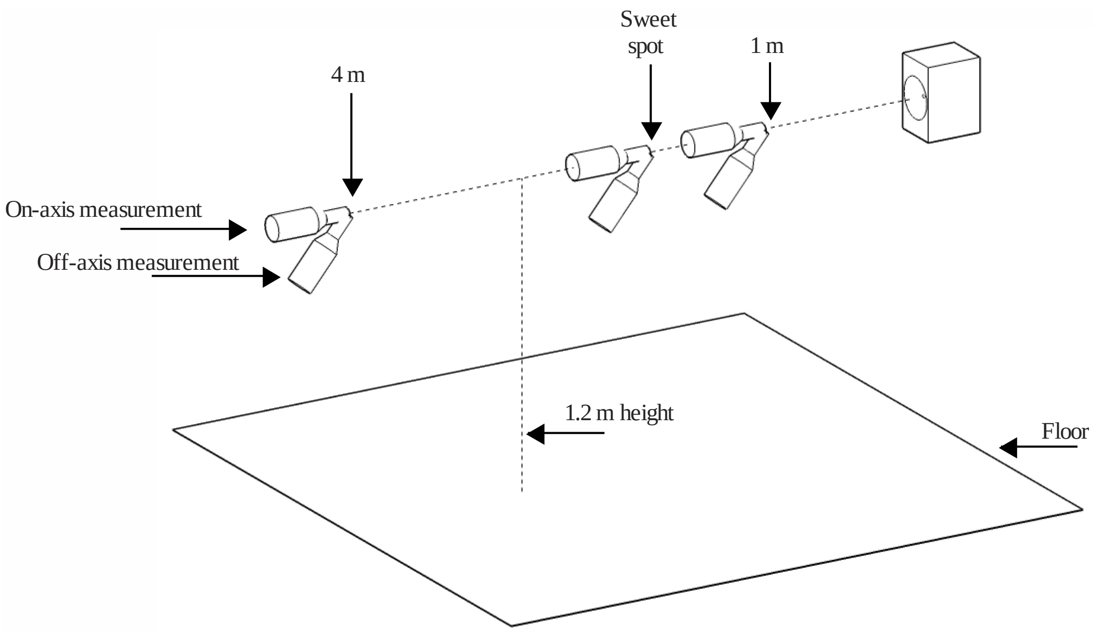


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TABLE 6

Distance dependent level differences of Mic. # 1 (1/2”), 0° – 50° (filter corrected) microphone orientation

Studio Room	Mozart			Bach		
Distance (m)	1.00	2.78	4.00	1.00	2.03	4.00
Difference (dB)	−0.32	−0.27	−0.20	−0.21	−0.13	0.14

The repeatability of the measurement setup was also tested, as the physical (re)positioning of the microphone can have an influence at high frequencies. In room ‘Mozart’, the reference angle (0°) and one off-angle case (110°) was measured five times. The equipment was mounted and dismounted each time. The worst standard deviation of the repeated level measurements is $\sigma = 0.15$ dB, still a very low value. This indicates that repeatability of the measurements is not a major issue.

2.7 Generalized filter approach

Since the proposed filters have fixed Fc and Q parameters, for each microphone size, it is possible to generalize the compensation filters for other elevation angles. A continuous fitting function for the different elevation angles θ is proposed by equation (4). The best fitting parameters are presented in Table 7. The function provides a very good approximation of the filter gains for angles until 120º elevation.

$$G(\theta) = \alpha\theta^2 e^{-0.0089\,\theta} \tag{4}$$

where:

θ: elevation angle

α: diameter dependent filter parameter (Table 7).

TABLE 7

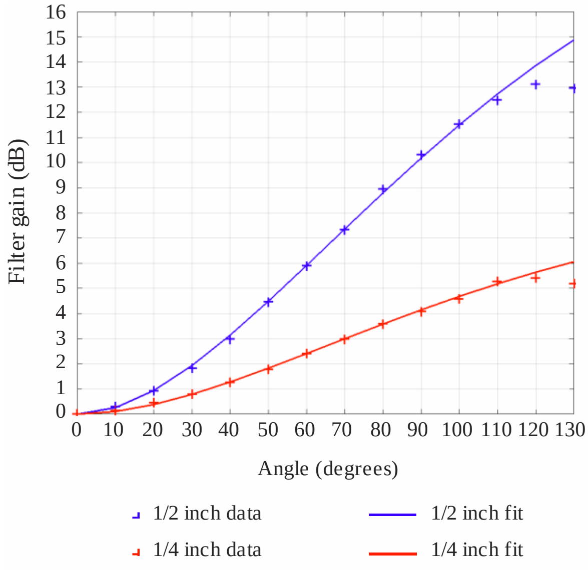
Microphone-diameter-dependent filter parameter α of equation (4)

Diameter (inches)	α
1/2	0.0028
1/4	0.00114

The gain values of the compensation filters for two microphone diameters are presented in Fig. 9 for 14 different elevation angles, along with a fitting curve between them.

FIGURE 9

Comparison between designed filter gain data and the fit provided by equation (4)



Using equation (4), the results seen in Table 4 (that only includes three angles of incidence) may be expanded to a range of 10°–120° allowing a loudspeaker to be off-axis at any angle to the calibration microphone. Table 8 displays calculations in 10° intervals for both microphone diameters in terms of filter gains (G_{filter}) and broadband level correction (G_{cor}).

The resulting compensation filters for a 1/2” microphone are graphically represented in Fig. 10.

Filter parameters are:

For 1/2” microphones: $F_c = 14.5\text{ kHz}$ and $Q = 0.5$

For 1/4” microphones: $F_c = 11.0\text{ kHz}$ and $Q = 0.5$.

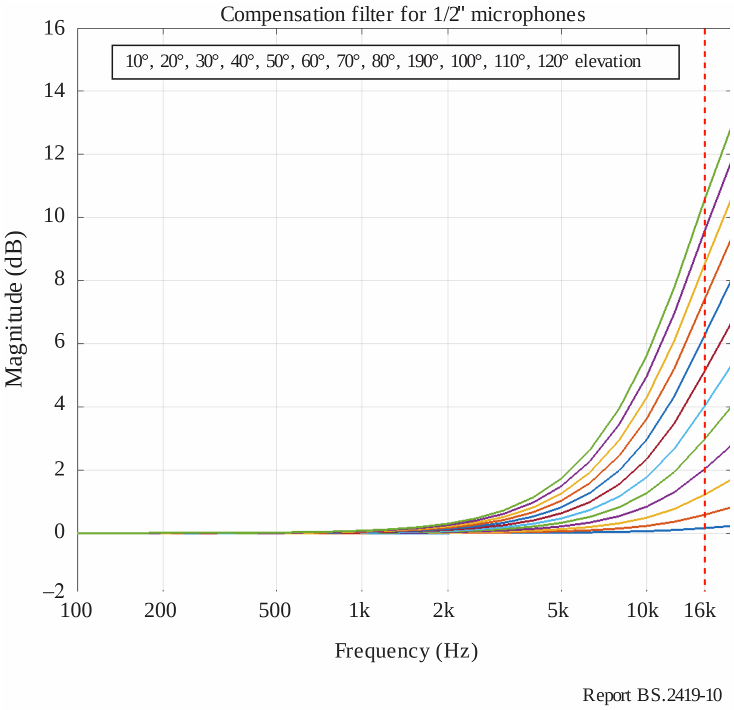
TABLE 8

Gain factor in terms of filter coefficients and correction level for compensation filters from 10° to 120°

Angle (degrees)	G_{filter} for 1/2” (dB)	G_{filter} for 1/4” (dB)	G_{cor} for 1/2” (dB)	G_{cor} for 1/4” (dB)
10	0.256	0.104	0.03	0.02
20	0.937	0.382	0.11	0.07
30	1.930	0.786	0.23	0.17
40	3.138	1.278	0.38	0.22
50	4.486	1.826	0.54	0.32
60	5.910	2.406	0.71	0.42
70	7.359	2.996	0.89	0.52
80	8.793	3.580	1.07	0.62
90	10.181	4.145	1.24	0.72
100	11.498	4.682	1.40	0.81
110	12.728	5.182	1.56	0.90
120	13.858	5.642	1.70	0.97

FIGURE 10

Compensation filters for 1/2” microphones and the elevation angles between 10° and 120°

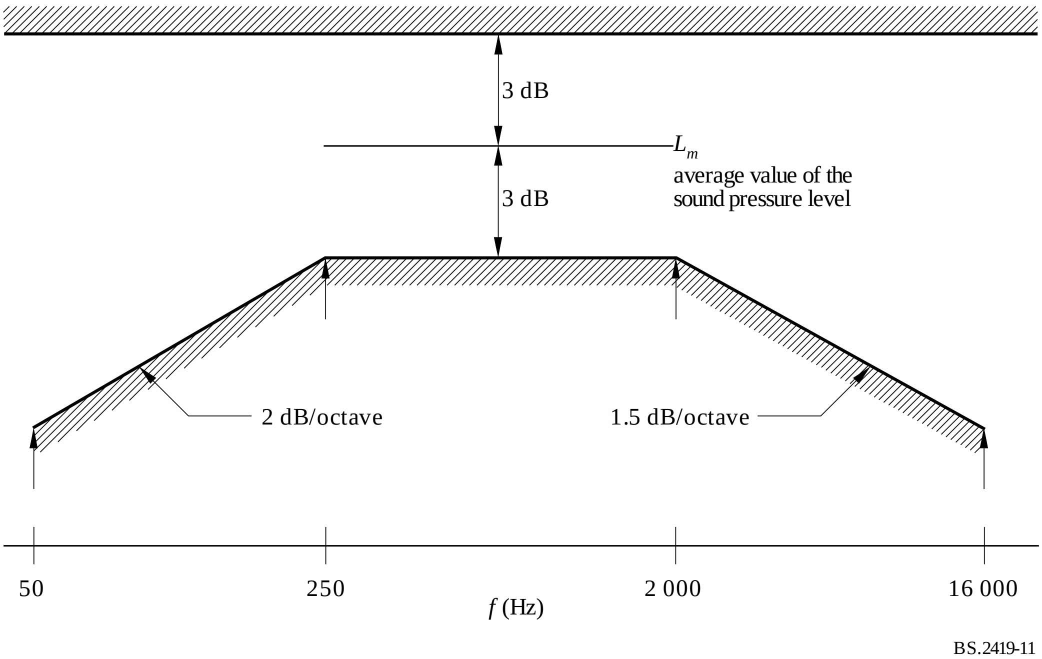


2.8 Frequency response equalization

From the previous frequency responses it is obvious that the angled microphone generates not only a calibration level error, but also a frequency error. The tolerance limits for the operational room responses of the loudspeakers in a studio room at 16 kHz is at −7.5 dB, see Fig. 11.

FIGURE 11

Operational room response limits in ITU-R BS.1116



With the demonstrated high frequency loss as a result of the microphone angling, this limit is rarely reached, only with the 1/2” mic for elevation ≥110°, see Fig. 6. However, if the loudspeaker already has a decrease in high frequencies then this further loss because of the microphone angling can make the frequency response measurement easily slip below the tolerance limit. Therefore, for frequency evaluation of the operational room responses of the loudspeakers the same compensating shelving filters should be applied as for the level correction. The corrected error increases with increasing elevation angle, see as an example Fig. 12, measured with Mic II.

In Table 1 and Table 2 the broadband level errors before and after applying the compensation filters for different elevation angles are presented. In the following Table 9 the gain correction at 16 kHz for the two microphone diameters are presented. These are the gains at the red dotted line in Fig. 10. This line represents the highest frequency where the operational room response of a loudspeaker is defined in Recommendation ITU-R BS.1116, see Fig. 11.

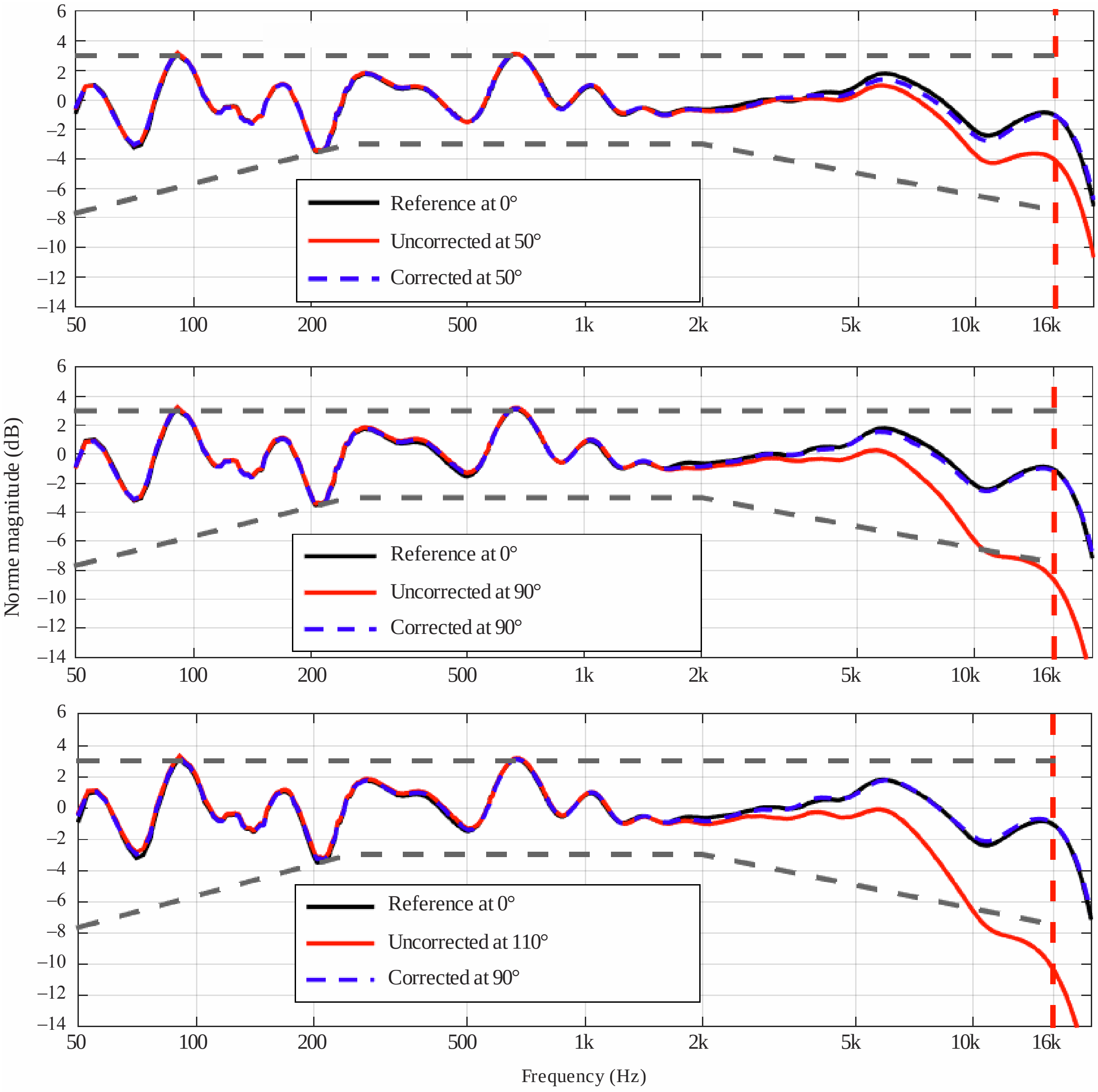
TABLE 9

Gain correction at 16 kHz for 1/2” and 1/4” microphone compensation filters

Angle (degrees)	10	20	30	40	50	60	70	80	90	100	110	120
1/2” (dB)	0.2	0.6	1.2	2.0	3.0	4.0	5.2	6.3	7.4	8.5	9.6	10.6
1/4” (dB)	0.1	0.3	0.6	1.0	1.5	2.0	2.5	3.0	3.4	3.9	4.4	4.8

FIGURE 12

Frequency correction of operational room responses of the centre loudspeaker in Mozart by applying shelving filters for Mic II at the elevation angles of 50°, 90° and 110°



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2.9 Summary 1

The proposed method can be used to compensate the non-ideal omnidirectional directivity pattern in the higher frequency range of 1/2” and 1/4” measurement microphones. The non-ideal directivity pattern causes angle dependent level differences in the calibration process of a 3D loudspeaker setup which are 1.2 dB for 1/2” microphones and 0.7 dB for 1/4” microphones under an elevation angle of 90° between loudspeaker and microphone main axis. With the compensation filters, these level differences can be reduced to values smaller than 0.25 dB. Furthermore, it is possible to equalize the frequency response of the microphone that varies with the entrance angle of the soundwave. The parameters of the compensation filters are dependent on the size of the diaphragm and the measurement angle, however not on the microphone type, manufacturer or listening room for the here tested setups. The method is necessary to fulfil Recommendation ITU-R BS.1116 in the calibration process of a 3D loudspeaker system when not adjusting the microphone to the direction of each loudspeaker. The compensation filters are valid for direct sound dominated frequency ranges (inside the apparent critical distance). This was proven for two studio listening rooms.

3 Second evaluation

3.1 Introduction

The following section documents the findings of measurements conducted using microphones with different diameters, positioned at different orientations and distances to ascertain the following:

– Dependence of a relationship between measurement error and orientation and size of the microphone.
– Dependence of a relationship between measurement error and orientation and distance to the loudspeaker.
– Relationship between the measurements error and tolerance of operational room response curve specified in Recommendation ITU-R BS.1116-3.

3.2 Microphone analysis

Three microphones were chosen for the measurements whose specifications are given in Table 10.

TABLE 10

Specifications of microphones used in the measurement

Name	Feature	Frequency response	Standards	Power
Microphone 1	1/2”, free-field	3.15 Hz to 40 kHz	IEC 61094-4 WS2F IEC 61672 Class 1 ANSI Type 2 & M	200 V external
Microphone 2	1/4”, free-field	4 Hz to 100 kHz	IEC 61094-4 WS3F	200 V external
Microphone 3	1/8”, pressure-field	6.5 Hz to 140 kHz	Not confirmed ※No IEC standards to specify 1/8 inch microphones could not be found.	200 V external

The measurements took place within an ITU-R BS.1116 compliant listening room using reproduction system H, (9+10+3 = 22.2) as specified in Recommendation ITU-R BS.2051 [5]. All loudspeakers have been calibrated using microphone 2 (Table 10), with the main on-axis direction pointed towards each measured loudspeaker, at a distance of 2.5 m in the middle layer. Measurements were made using pink noise at an SPL of 78 dBA, and operational room responses of 1/3rd octave bandwidth were analysed.

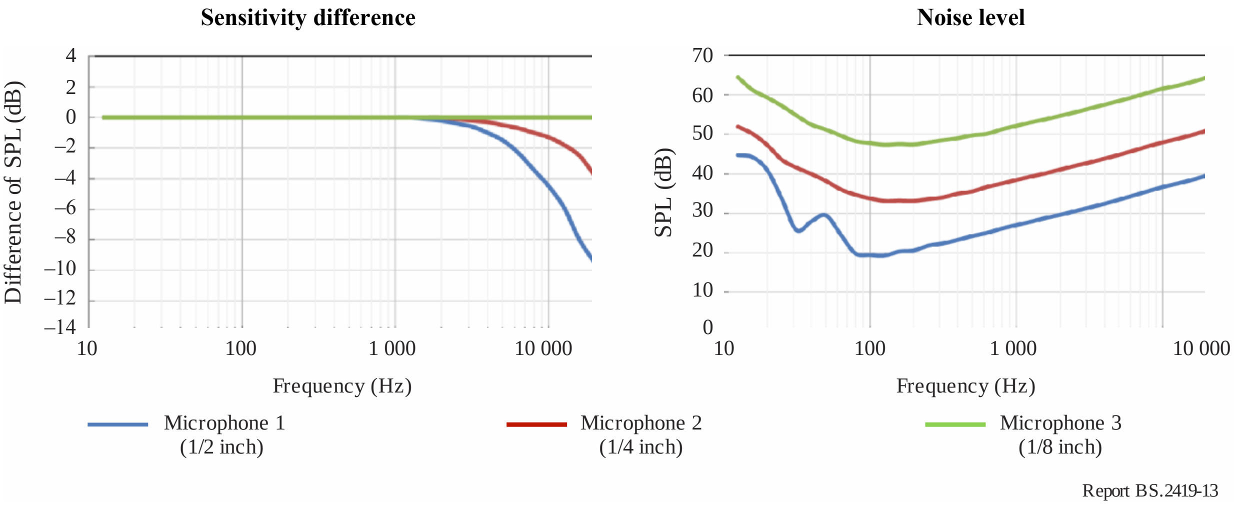
Directivity measurements taken on-axis 0° (front centre), and off-axis 90° (side left) were taken for all three microphones. The difference in sensitivity can be seen in Fig. 13a. Additionally, the inherent noise of the microphone (noise level equivalent in SPL) can be seen in Fig. 13b.

Figure 13a highlights that the microphone with the smallest diameter (Mic 3 – 1/8” pressure-field mic) results in a consistently flat response from 20 Hz to 20 kHz irrespective of the angle of incidence. However, whilst this is useful for measurements of loudspeakers off-axis (at least up to 90°), Fig. 13b shows that the signal-to-noise ratio (SNR) is too large to accurately measure room response curves.

Microphones 1 and 2 yield a suitable SNR but possess a high frequency drop off analogous to that of a shelf filter EQ.

FIGURE 13

Dependence of sensitivity difference between 0° (front centre) and 90° (side left) of each measurement microphone (microphones 1, 2 and 3) and noise level of each microphone plotted for each 1/3 oct. band



3.3 Elevation angle level influence

In this section, the influence of the orientation of each microphone size is investigated for the operational room response of two loudspeakers. All loudspeakers are measured for three directional conditions of all microphones, to ascertain the level differences in microphone positioning.

Each measurement condition can be seen in Figs 14 to 16 along with a description of the measurements taken.

FIGURE 14

Measurement Condition 1: All loudspeakers of system H (only M+000, M+060 and T+000 are illustrated) were measured by measurement microphones 1, 2 and 3, whose main on-axis response was directed towards the overhead loudspeaker T+000

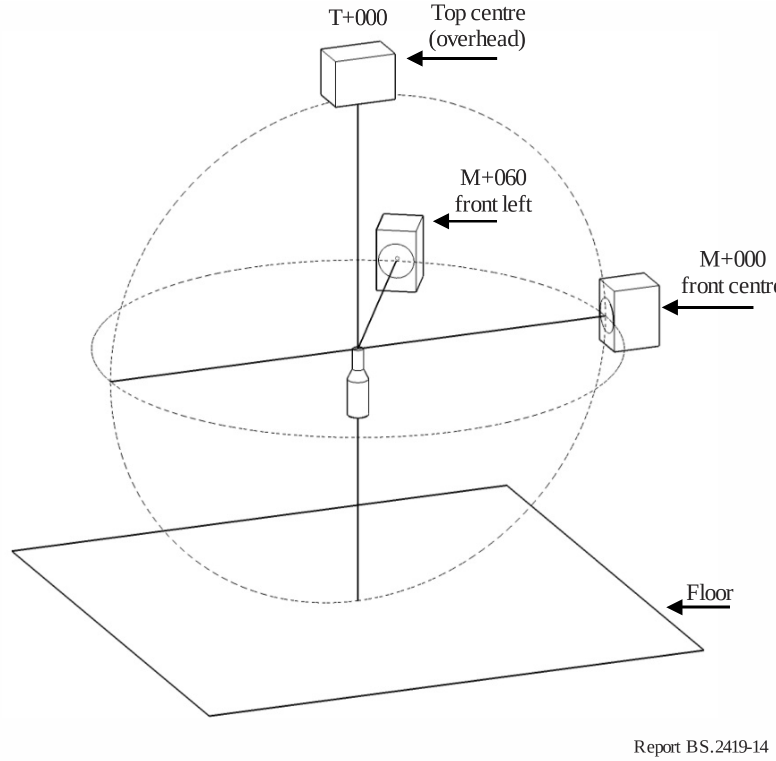


FIGURE 15

Measurement Condition 2: All loudspeakers of system H were measured by measurement microphones 1, 2 and 3, whose main on-axis response was directed at an elevated angle of +45° above loudspeaker M+000

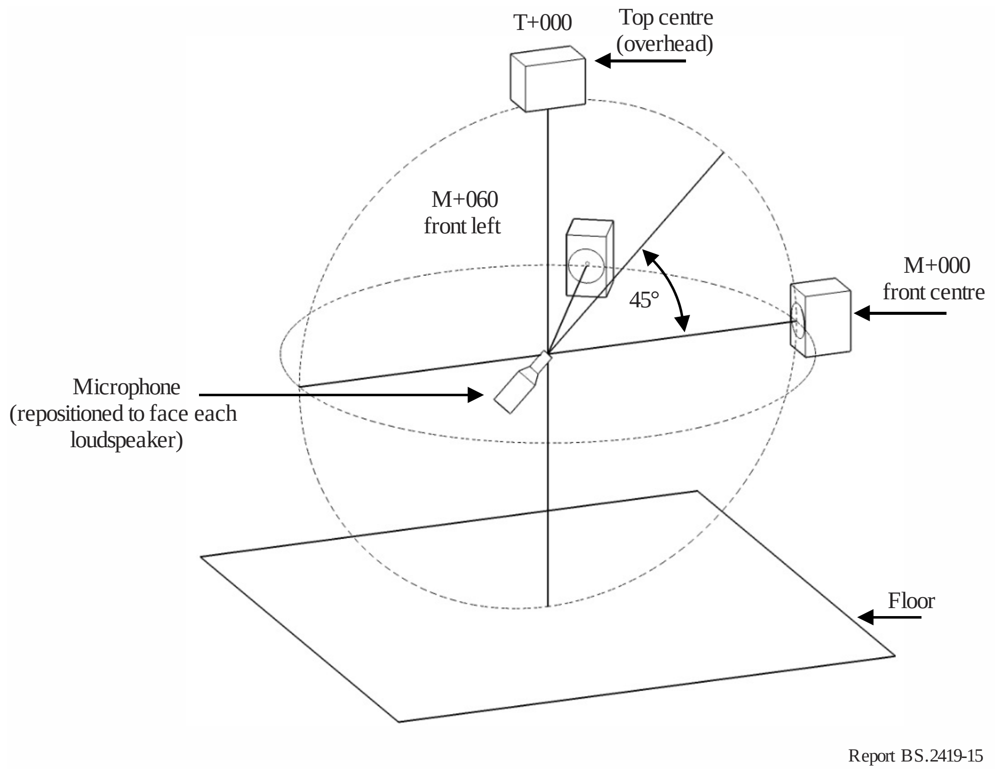
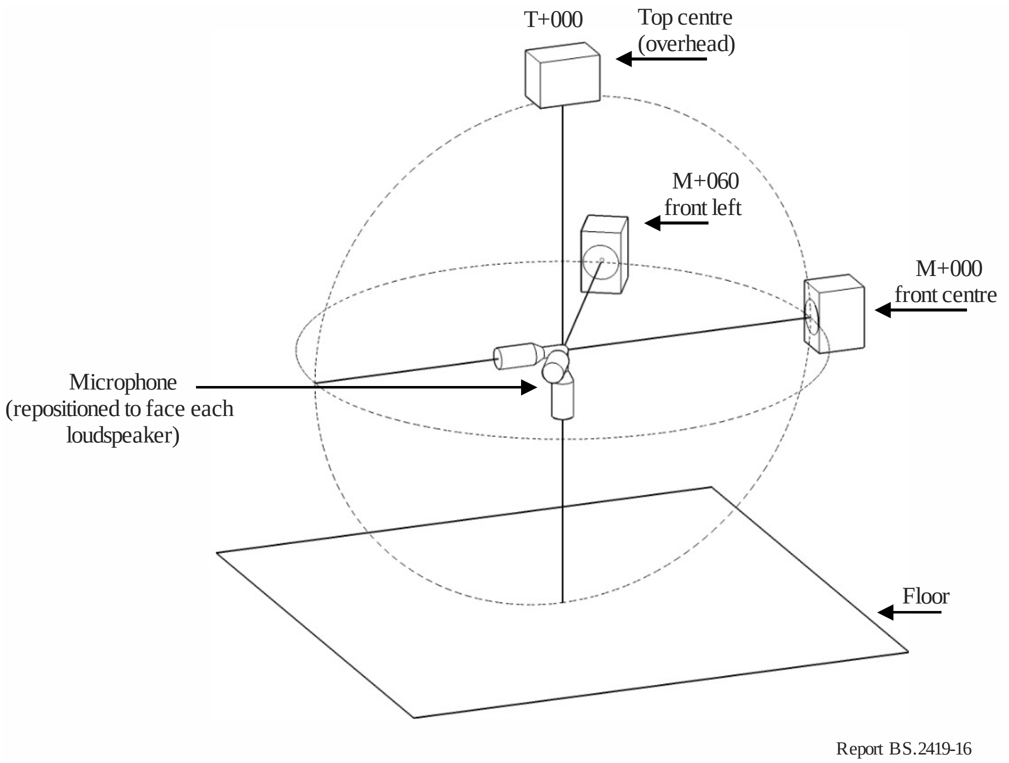


FIGURE 16

Measurement Condition 3: All loudspeakers of system H were measured by measurement microphones 1, 2 and 3, whose main on-axis response was adjusted to face each loudspeaker per measurement



The operational room responses provided by loudspeakers M+000 and M+060 are shown in Fig. 17. In these measurements, the angle between the microphones on-axis direction and the loudspeakers M+000 and M+060 remain the same for all measured conditions and are thus comparable. With respect to the microphones main on-axis direction the angle of incidence for loudspeaker M+000 and M+060 is:

– 90˚ (condition 1 as shown in Fig. 14)

– 45˚ and 69.3˚ (condition 2 as shown in Fig. 15)

– 0˚ (condition 3 as shown in Fig. 16).

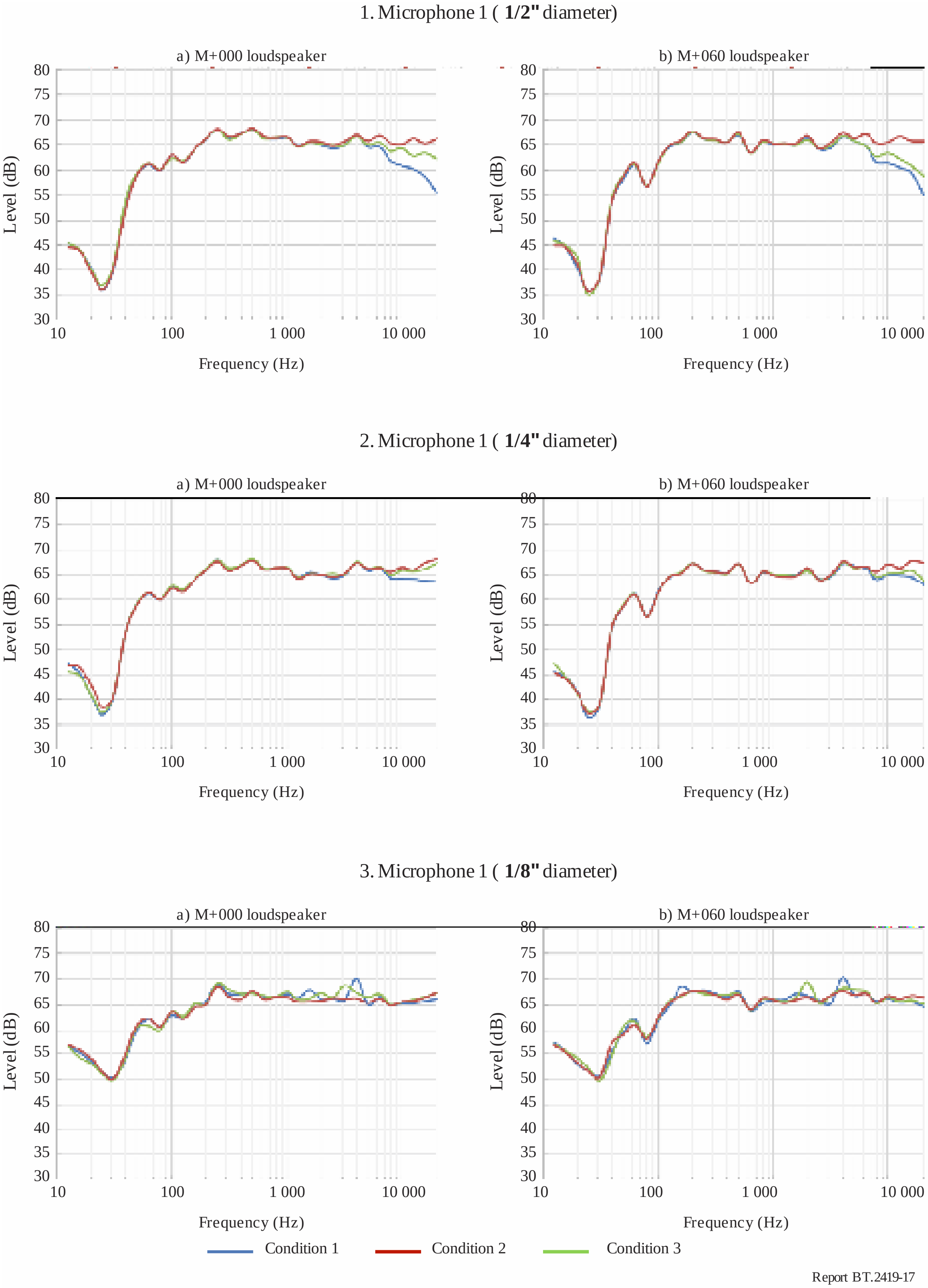
The results show that:

– The responses are similar between loudspeakers M+000 and M+060.

– The magnitude of directional measurement errors, particularly within the high frequency region (above 5 kHz), are dictated by the diameter of the microphone. The larger the diameter of the microphone, the steeper the attenuation.

Whilst microphone 3 produces minimal response errors, peaks may be observed at 2-4 kHz and may therefore be unreliable.

FIGURE 17


1. Microphone 1 (**1/2"** diameter)
a) M+000 loudspeaker
b) M+060 loudspeaker
2. Microphone 1 (**1/4"** diameter)
a) M+000 loudspeaker
b) M+060 loudspeaker
3. Microphone 1 (**1/8"** diameter)
a) M+000 loudspeaker
b) M+060 loudspeaker
Level (dB)
Frequency (Hz)
80
75
70
65
60
55
50
45
40
35
30
10
100
1 000
10 000
Condition 1
Condition 2
Condition 3
Report BT.2419-17

3.4 Influence of distance

The following section shows the impact of distance regarding an operation room response of a loudspeaker.

FIGURE 18

Directional Condition 1: The front centre loudspeaker was measured by the measurement microphone, whose main axis was directed toward the ceiling, 90° off-axis to the loudspeaker

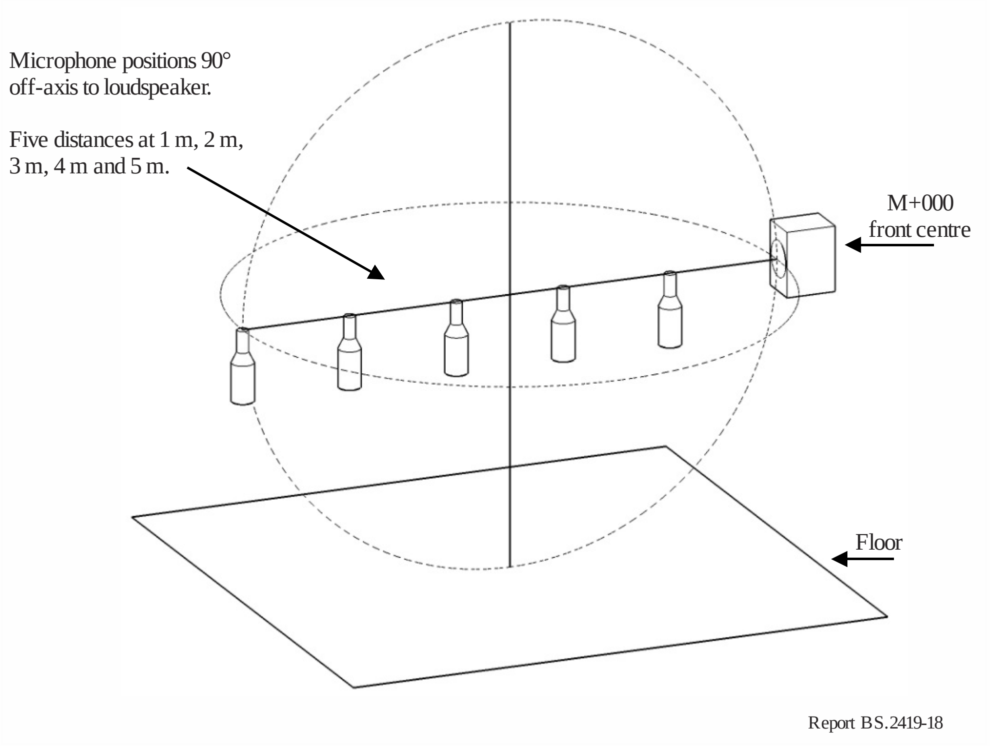
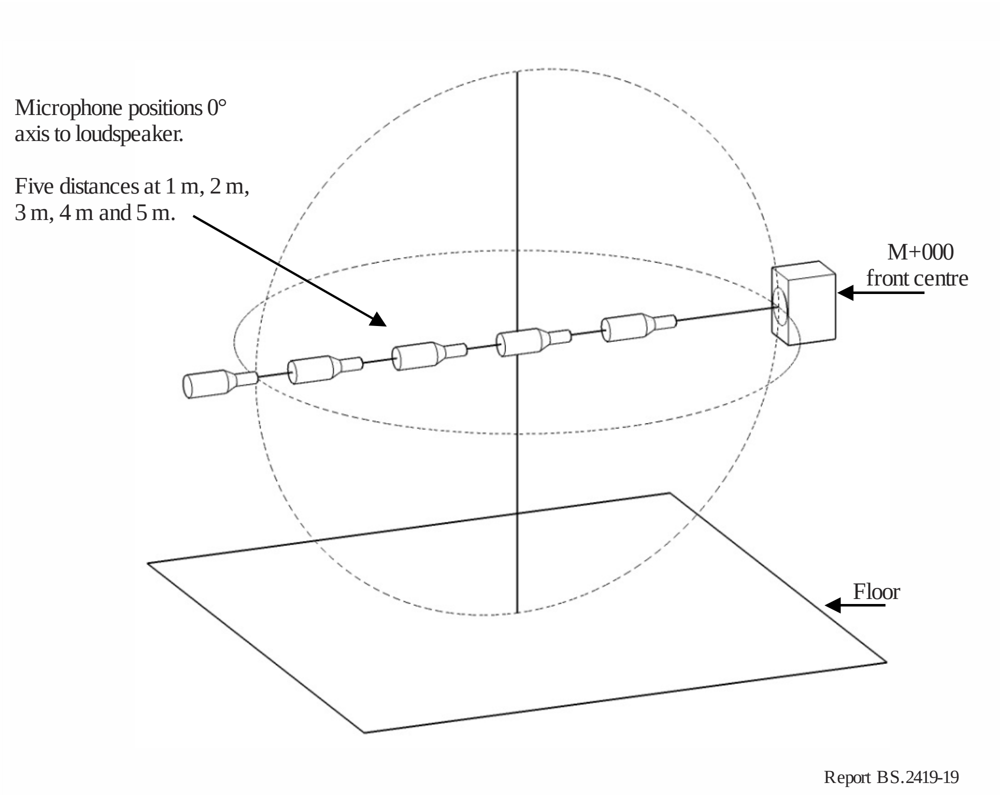


FIGURE 19

Directional Condition 2: The front centre loudspeaker was measured by the measurement microphone, whose main axis was directed toward the loudspeaker simulating 0° elevation



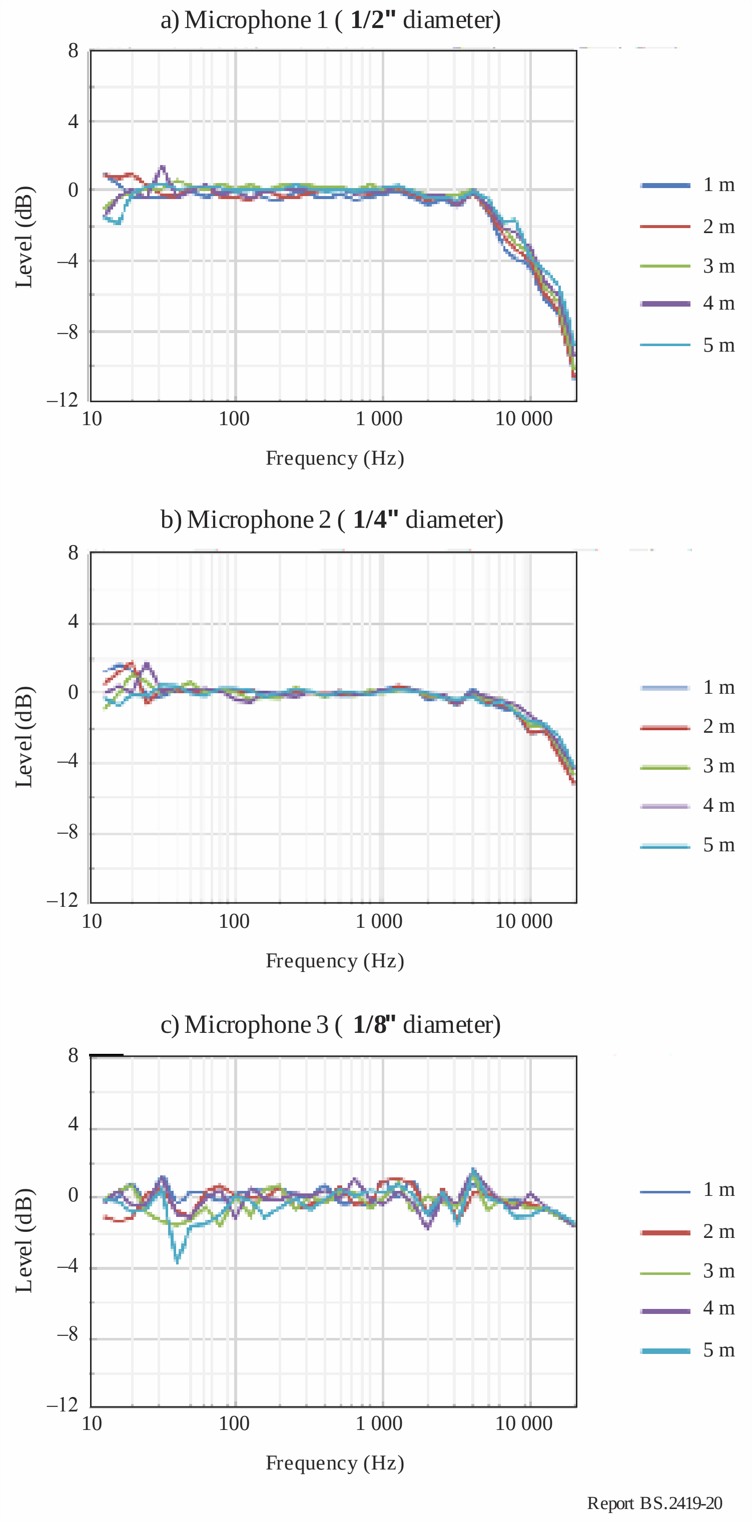
For this, measurements were taken at five distances from the centre loudspeaker 1 m-5 m, in intervals of 1 m. The measurements were conducted two times for each microphone, placed 90° off-axis (facing upright) and on-axis (0°) with respect to the loudspeaker (Figs 18 and 19 respectively). SPL levels were adjusted to the same level for each measurement distance.

The difference between the measurements taken on- and off-axis for each distance and microphone can be seen in Fig. 20.

Results show that the difference in distance does not yield a significant change in levels and that the main difference is provided by the use of varying microphone diameters.

FIGURE 20

Difference between room response of directional condition 1 and that of directional condition 2 measured by three microphones placed at five distances (1 to 5 m from the loudspeaker)



3.5 Relationship between tolerance of room response specified in Recommendation ITU-R BS.1116 and measurement error

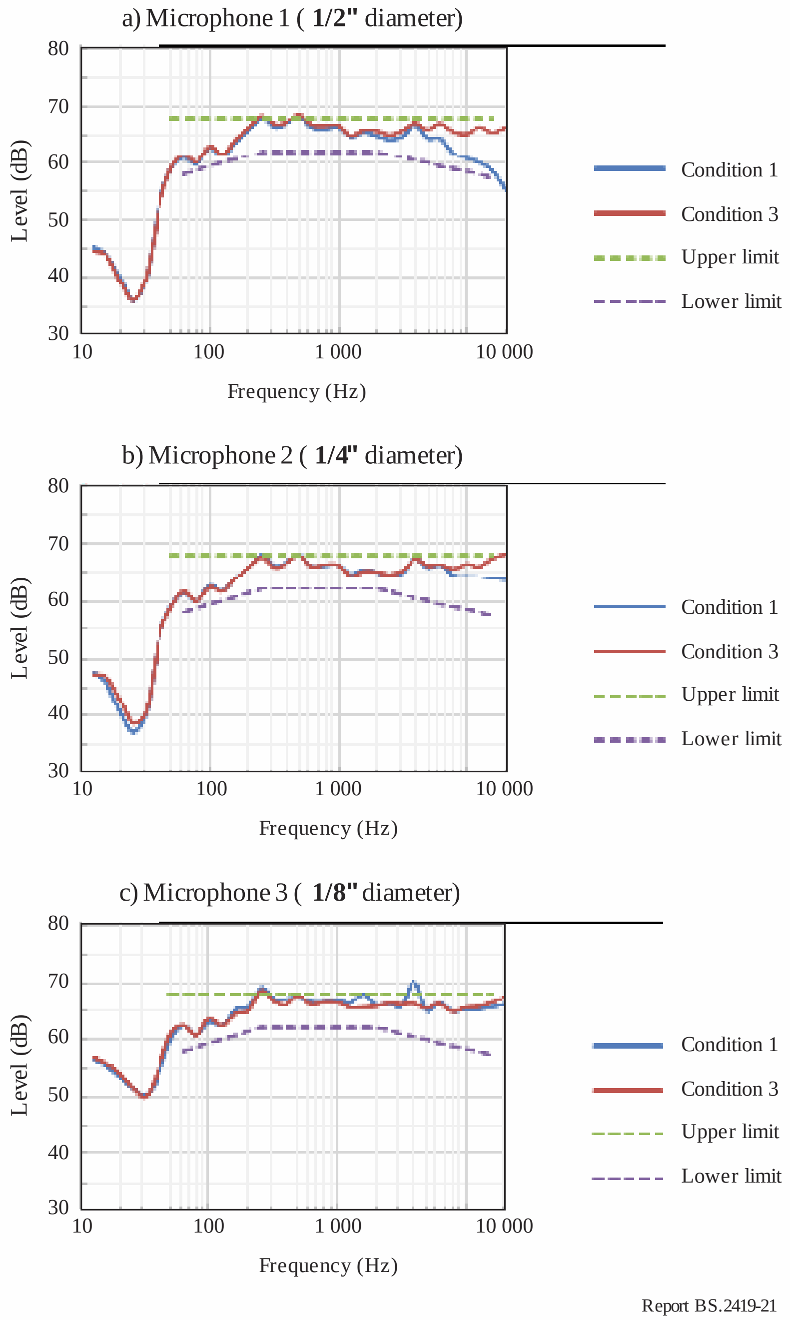
The tolerance for operational room response curves specified in Recommendation ITU-R BS.1116 and the room responses measured by microphones 1 to 3 are shown in Fig. 21. The target level for each 1/3 octave band is 65 dB.

The room responses of microphones 1 and 2 are within the tolerance. However, if the room response is adjusted using the microphone 1 (1/2 inch) with directional condition 1 (the axis of the microphone is directed toward one direction such as the ceiling), the actual room responses in high-frequency bands will exceed the tolerance levels. Therefore, it is reasonable that the directional sensitivity of the measurement microphone is considered. A reasonable method is to direct the measurement microphone toward each measured loudspeaker. If the measurement microphone is directed toward the ceiling or any other direction, the measured response should be electrically adjusted using the directional specifications of the measurement microphone.

Microphone 3 (1/8 inch) is not free-field type. It is difficult to ensure a satisfactory *S*/*N* ratio, because its noise level is very high. Microphone 3 generates some local peaks in high-frequency bands. Therefore, it is not appropriate for use as a measurement microphone.

FIGURE 21

Relationship between tolerance of room response specified in Recommendation ITU-R BS.1116 and room responses measured by three types of microphone with two directional conditions



3.6 Summary 2

Measurement microphones 1 (1/2 inch) and 2 (1/4 inch) specified in IEC 61094-4 showed good performance. However, measurement errors, which depended on the direction of the microphone, were significant, particularly when the size of the microphone was 1/2 inch. Care should be taken in the selection of the measurement microphone and its orientation when room responses are measured. In particular, in the case of an advanced sound system, the effect of the orientation of the measurement microphone should be adjusted, for instance, by directing the measurement microphone toward each measured loudspeaker. Otherwise, the measurement microphone should be directed toward the ceiling and the measurement result should be adjusted using the frequency response of the measurement microphone. This method requires the free-field response of the microphone for each elevation angle.

4 References

[1] Recommendation ITU-R BS.1116-3 – Methods for the Subjective Assessment of Small Impairments in Audio Systems.

[2] Silzle, A., *et al.*, *The Influence of Microphone Directivity on the Level Calibration and Equalization of 3D Loudspeakers Setups*. 29th Tonmeistertagung – VDT International Convention. 2016. Cologne, Germany.

[3] Silzle, A., *et al.*, *Vision and Technique behind the New Studios and Listening Rooms of the Fraunhofer IIS Audio Laboratory*. 126th AES Convention. 2009. Munich, Germany, preprint #7672.

[4] Zölzer, U., DAFX: Digital Audio Effects. 2002, John Wiley & Sons, New York.

[5] Recommendation ITU-R BS.2051-0 – Advanced Sound System for Programme Production.