BS EN 1793-4:2015

BSI Standards Publication

Road traffic noise reducing devices — Test method for determining the acoustic performance

Part 4: Intrinsic characteristics — In situ values of sound diffraction

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National foreword

This British Standard is the UK implementation of EN 1793-4:2015.

The UK participation in its preparation was entrusted to Technical Committee B/509/6, Fences for the attenuation of noise.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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English Version

Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 4: Intrinsic characteristics - In situ values of sound diffraction

Dispositifs de réduction du bruit du trafic routier - Méthode d'essai pour la détermination des performances acoustiques - Partie 4: Caractéristiques intrinsèques - Valeurs in-situ de la diffraction acoustique

Lärmschutzvorrichtungen an Straßen - Prüfverfahren zur Bestimmung der akustischen Eigenschaften - Teil 4: Produktspezifische Merkmale - In-situ-Werte der Schallbeugung

This European Standard was approved by CEN on 13 December 2014.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

This document (EN 1793-4:2015) has been prepared by Technical Committee CEN/TC 226 “Road equipment”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2015 and conflicting national standards shall be withdrawn at the latest by September 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes CEN/TS 1793-4:2003.

The major changes compared to the previous published version are:

- the airborne sound insulation characteristics of the reference wall are specified in terms of the minimum values of the Sound Insulation Index, measured according to EN 1793-6, it needs to have;
- the sound absorbing characteristics of the reference wall are specified in terms of the minimum values of the sound absorption coefficient, measured according to EN ISO 354, it needs to have when lined on the source side with an absorptive flat layer of a single porous material;
- the sound source positions have been reduced from six to four and are now all obligatory;
- the microphone positions have been reduced from 12 to 10 and are now all obligatory;
- a “free-field” impulse response to be measured for each microphone position and therefore a geometrical spreading correction factor is no more needed in Formula (1);
- consideration of the measurement uncertainty has been added (see Clause 5 and Annex B);
- the summary of the test procedure (Clause 6) has been updated to reflect the changes compared to the previous published version.

This document should be read in conjunction with:

EN 1793-1, *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 1: Intrinsic characteristics of sound absorption under diffuse sound field conditions*

EN 1793-3, *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 3: Normalized traffic noise spectrum*

CEN/TS 1793-5, *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 5: Intrinsic characteristics — In situ values of sound reflection and airborne sound insulation.*

EN 1793-6, *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 6: Intrinsic characteristics – In situ values of airborne sound insulation under direct sound field conditions*

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

Part of the market of road traffic noise reducing devices is constituted of products to be added on the top of noise reducing devices and intended to contribute to sound attenuation acting primarily on the diffracted sound field. These products will be called added devices. This European Standard has been developed to specify a test method for determining the acoustic performance of added devices.

The test method can be applied *in situ*, i.e. where the traffic noise reducing devices and the added devices are installed. The method can be applied without damaging the traffic noise reducing devices or the added devices.

The method can be used to qualify products before the installation along roads as well as to verify the compliance of installed added devices to design specifications. Repeated application of the method can be used to verify the long term performance of added devices.

This method could be used to qualify added devices for other applications, e.g. to be installed along railways or nearby industrial sites. In this case, special care needs to be taken into account in considering the location of the noise sources and the single-number ratings should be calculated using an appropriate spectrum.

No other national or international standard exists about the subject of this European Standard.

1 Scope

This European Standard describes a test method for determining the intrinsic characteristics of sound diffraction of added devices installed on the top of traffic noise reducing devices. The test method prescribes measurements of the sound pressure level at several reference points near the top edge of a noise reducing device with and without the added device installed on its top. The effectiveness of the added device is calculated as the difference between the measured values with and without the added devices, correcting for any change in height (the method described gives the acoustic benefit over a simple barrier of the same height; however, in practice the added device can raise the height and this could provide additional screening depending on the source and receiver positions).

The test method is intended for the following applications:

- preliminary qualification, outdoors or indoors, of added devices to be installed on noise reducing devices;
- determination of sound diffraction index difference of added devices in actual use;
- comparison of design specifications with actual performance data after the completion of the construction work;
- verification of the long term performance of added devices (with a repeated application of the method);
- interactive design process of new products, including the formulation of installation manuals.

The test method can be applied both *in situ* and on samples purposely built to be tested using the method described here.

Results are expressed as a function of frequency, in one-third octave bands between 100 Hz and 5 kHz. If it is not possible to get valid measurements results over the whole frequency range indicated, the results shall be given in the restricted frequency range and the reasons of the restriction(s) shall be clearly reported. A single-number rating is calculated from frequency data.

For indoors measurements see Annex A.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1793-3, *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 3: Normalized traffic noise spectrum*

EN 1793-6, *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 6: Intrinsic characteristics — In situ values of airborne sound insulation under direct sound field conditions*

EN 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*

EN ISO 354, *Acoustics — Measurement of sound absorption in a reverberation room (ISO 354)*

ISO/IEC Guide 98, *Guide to the expression of uncertainty in measurement (GUM)*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purpose of this document, the following terms and definitions apply.

3.1.1
structural elements
those elements whose primary function is to support or hold in place acoustic elements

3.1.2
acoustical elements
those elements whose primary function is to provide the acoustic performance of the device

3.1.3
noise barrier
noise reducing device which obstructs the direct transmission of airborne sound emanating from road traffic

3.1.4
added device
acoustic element added on the top of a noise reducing device and intended to contribute to sound attenuation acting primarily on the diffracted sound field

3.1.5
roadside exposure
use of the product as a noise reducing device installed alongside roads

3.1.6
sound diffraction index
result of a sound diffraction test whose components are described by the formula in 4.6

Note 1 to entry: The symbol for the sound diffraction index includes information on the setup used during the test: $DI_{x,refl}$ refers to measurements on a reflective reference wall. $DI_{x,abs}$ refers to measurements on an absorptive reference wall. $DI_{x,situ}$ refers to *in situ* measurements; where *x* is “0” when the added device is not on the top of the test construction and “ad” when the added device is on the top of the test construction (see 3.2).

3.1.7
sound diffraction index difference
difference between the results of sound diffraction tests on the same reference wall with and without an added device on the top, described by the formulae in 4.10

3.1.8
test construction
construction on which the added device is placed

Note 1 to entry: For *in situ* measurements the test construction is an installed noise reducing device; for qualification tests it is a reference wall (see 4.2).

3.1.9
reference plane of the test construction
vertical plane passing through the midpoint of the top edge of the construction (reference wall or installed noise reducing device) on which the added device has to be placed (see Figure 1, Figure 2, Figure 4, Figure 5 and Figure 8)

3.1.10
reference height of the test construction without the added device, $h_{ref,0}$
height of the highest point of the test construction in relation to the surrounding ground surface

Note 1 to entry: This highest point is not necessarily lying in the plane of longitudinal symmetry of the reference test construction, if this symmetry exists (Figure 1).

3.1.11
reference height of the test construction with the added device on the top, $h_{ref,add}$
height of the highest point of the added device installed on the test construction in relation to the surrounding ground surface

Note 1 to entry: This highest point is not necessarily lying in the plane of longitudinal symmetry of the reference test construction, if this symmetry exists (Figure 4).

3.1.12
free-field measurement for sound diffraction index measurements
measurement carried out placing the loudspeaker and the microphone as specified in 4.3, 4.4 and 4.5 without any obstacle, including the test construction with or without added device, between them (see for example Figure 7)

3.1.13
Adrienne temporal window
composite temporal window described in 4.8.5

3.1.14
background noise
noise coming from sources other than the source emitting the test signal

3.1.15
signal-to-noise ratio, S/N
difference in decibels between the level of the test signal and the level of the background noise at the moment of detection of the useful event (within the Adrienne temporal window)

3.1.16
impulse response
time signal at the output of a system when a Dirac function is applied to the input

Note 1 to entry: The Dirac function, also called δ function, is the mathematical idealisation of a signal infinitely short in time that carries a unit amount of energy

3.2 Symbols

For the purposes of this document, the following symbols and abbreviations apply.

Table 1 – Symbols and abbreviations

Symbol or abbreviation	Designation	Unit
α	Sound absorption coefficient measured according to EN ISO 354	-
DI_j	Sound diffraction index in the *j*-th one-third octave frequency band	dB
$DI_{0,refl}$	Sound diffraction index for the reflective reference wall without the added device	dB
$DI_{ad,refl}$	Sound diffraction index for the reflective reference wall with the added device	dB
$DI_{0,abs}$	Sound diffraction index for the absorptive reference wall without the added device	dB
$DI_{ad,abs}$	Sound diffraction index for the absorptive reference wall with the added device	dB

$DI_{0,situ}$	Sound diffraction index for the *in situ* test construction without the added device	dB
$DI_{ad,situ}$	Sound diffraction index for the *in situ* test construction with the added device	dB
ΔDI_{refl}	Sound diffraction index difference for the test sample on the reflective reference wall	dB
ΔDI_{abs}	Sound diffraction index difference for the test sample on the absorbing reference wall	dB
ΔDI_{situ}	Sound diffraction index difference for the test sample on an situ test construction	dB
$DL_{\Delta DI,refl}$	Single-number rating of sound diffraction index difference for the test sample on the reflective reference wall	dB
$DL_{\Delta DI,abs}$	Single-number rating of sound diffraction index difference for the test sample on the absorbing reference wall	dB
$DL_{\Delta DI,situ}$	Single-number rating of sound diffraction index difference for the test sample on the *in situ* test construction	dB
δ_i	Any input quantity to allow for uncertainty estimates	-
Δf_j	Width of the *j*-th one-third octave frequency band	Hz
f	Frequency	Hz
F	Symbol of the Fourier transform	-
f_{min}	Low frequency limit of sound diffraction index measurements	Hz
f_s	Sample rate	Hz
f_{co}	Cut-off frequency of the anti-aliasing filter	Hz
h_B	Noise barrier height	m
h_{ref}	Reference height of the test construction	m
$h_{ref,0}$	Reference height of the test construction without the added device	m
$h_{ref,ad}$	Reference height of the test construction with the added device	m
$h_i\ (t)$	Incident reference component of the free-field impulse response	dB
$h_{d,k}(t)$	Diffracted component of the impulse response at the *k*-th measurement point	dB
j	Index of the *j*-th one-third octave frequency band (between 100 Hz and 5 kHz)	-
k	Coverage factor	-
k_f	Constant used for the anti-aliasing filter	-
L_b	Minimum length of the reference wall	m
L_d	Minimum length of the added device under test	m
n	Number of measurement points	-
SI	Sound Insulation Index measured according to EN 1793–6	dB
t	Time	s or ms
$T_{W,BH}$	Length of the Blackman-Harris trailing edge of the Adrienne temporal window	ms
$T_{W,ADR}$	Total length of the Adrienne temporal window	ms
u	Standard uncertainty	-

U	Expanded uncertainty	-
$w_{ik}(t)$	Time window (Adrienne temporal window) for the component of the free-field impulse response received at the *k*-th measurement point	-
$w_{t,k}(t)$	Time window (Adrienne temporal window) for the component of the impulse response diffracted by the top edge of the test construction and received at the k-th measurement point	-

4 Sound diffraction index difference measurements

4.1 General principle

The sound source emits a transient sound wave that travels toward the noise reducing device under test and is partly reflected, partly transmitted and partly diffracted by it. The microphone placed on the other side of the noise reducing device receives both the transmitted sound pressure wave travelling from the sound source through the noise reducing device and the sound pressure wave diffracted by the top edge of the noise reducing device under test (for the test to be meaningful the diffraction from the vertical edges of the test construction shall be sufficiently delayed in order to be outside the Adrienne temporal window). If the measurement is repeated without the added device and the test construction between the loudspeaker and the microphone, the direct free-field wave can be acquired. The power spectra of the direct and the top-edge diffracted components, corrected to take into account the path length difference of the two components, give the basis for calculating the sound diffraction index.

The final sound diffraction index shall be a weighted average of the diffraction indices measured at different points (see Figure 1, Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6).

When the test method is applied *in situ*, the measurement procedure and sound diffraction index calculation shall be carried out two times, with and without the added device placed on the test construction.

When the test method is applied on samples purposely built to be tested according to the present standard, the added device shall be subsequently placed on the top of two reference walls (reflective and absorptive), or of the same reference wall in two different configurations, (see 4.2) and the measurement procedure and sound diffraction index calculation shall be carried out for both walls, with and without the added device on the top.

The measurement shall take place in an essentially free field in the direct surroundings of the device, i.e. a field free from reflections coming from surfaces other than the surface of the device under test. For this reason, the acquisition of an impulse response having peaks as sharp as possible is recommended: in this way, the reflections coming from other surfaces than the tested device can be identified from their delay time and rejected.

4.2 Dimensions and specifications

4.2.1 Added devices

The added device shall have a minimum length L_d of 10 m. The reference wall shall have a minimum length L_b of 10 m and a minimum height of 4 m. The reference wall shall be vertical, flat and fixed firmly and without any air gaps on a supporting construction (foundation, floor etc.). The top surface of the supporting construction shall be level with the surrounding ground surface.

The maximum size of the added device measured perpendicularly from the reference plane either in the direction of the source or in the direction of the microphones shall not exceed a value of 1,0 m (see Figure 8).

4.2.2 Reference walls

Two versions of the reference wall shall be used in the tests:

A A reflective reference wall, constructed of homogeneous panels with a smooth surface finish. The wall shall be free of air leaks and shall have a thickness not greater than 0,20 m. The reference wall shall have the minimum values of Sound Insulation Index measured according to EN 1793-6 specified in Table 2, in order that the sound transmission through the reference wall is negligible.

Table 2 – Minimum values of the Sound Insulation Index of the reference wall, measured according to EN 1793–6, tolerance ± 0,5 dB

Octave centre frequency (Hz)	125	250	500	1000	2000	4000
SI (dB)	21,0	22,0	24,0	26,0	29,0	32,0

B An absorptive reference wall, constructed as mentioned under A, lined on the source side with an absorptive flat layer of a single porous material having the minimum values of sound absorption coefficient measured according to EN ISO 354 specified in Table 3.

Table 3 – Minimum values of the sound absorption coefficient for the absorptive treatment of the reference wall, measured in reverberation room, tolerance ± 0,05

Octave centre frequency (Hz)	125	250	500	1000	2000	4000
α	0,20	0,50	0,85	0,95	0,95	0,95

4.2.3 *In situ* tests

When applying the test method *in situ* on existing noise reducing devices, with the intention of obtaining results valid over the entire frequency range specified in 4.6, the test construction shall satisfy the requirements in 4.2.2.

If these requirements cannot be fulfilled by the existing noise reducing device, the obtained results shall only be valid over a restricted frequency range (see 4.8.7) and for the type of noise reducing device being tested.

4.3 Positions of the sound source

Two angles of incidence, 90° and 45°, shall be used (see Figure 2 and Figure 5).

For execution of the diffraction test at a right angle to the test construction the sound source shall be placed as follows (see Figure 1, Figure 2, Figure 4 and Figure 5):

- in the vertical plane containing the perpendicular bisector plane to the reference plane;
- horizontally: at 2 m distance from the reference plane of the test construction;
- vertically: in relation to the reference height h_{ref} of the test construction,

  for the source position S1: centre of the source 0,50 m lower than h_{ref};

  for the source position S2: centre of the source 0,15 m lower than h_{ref} ;
- oriented towards the microphone position M1 (see 4.4 and Figure 1 and Figure 3).

For execution of the diffraction test at an angle of 45° with the reference plane of the test construction the sound source shall be placed as follows (see Figure 2 and Figure 5):

- in a vertical plane that makes an angle of 45° with the reference plane of the test construction, passing through its mid-point;
- horizontally: at 2 m distance from the reference plane of the test construction;

- vertically in relation to the reference height h_{ref} of the test construction,

  for the source position S3: centre of the source 0,50 m lower than h_{ref};

  for the source position S4: centre of the source 0,15 m lower than h_{ref} ;

- oriented towards the microphone position M6 (see 4.4 and Figure 2 and Figure 3).

4.4 Position of the microphone(s)

For execution of the diffraction test at a right angle to the test construction the microphone(s) shall be placed as follows (see Figure 1, Figure 2, Figure 3, Figure 4, Figure 5 and Figure 6):

- in the vertical plane containing the perpendicular bisector plane to the reference plane;
- horizontally: at 2 m distance from the reference plane of the test construction;
- vertically in relation to the reference height h_{ref} of the test construction,

  for the microphone positions M1, M2, M3, M4 and M5:

  − microphone M1: 0,50 m higher;

  − microphone M2: 0,25 m higher;

  − microphone M3: equal to the reference height;

  − microphone M4: 0,25 m lower;

  − microphone M5: 0,50 m lower;

- making an angle in the horizontal plane so as to be oriented toward the sound source.

For execution of the diffraction test at an angle of 45° with the reference plane of the test construction the microphone(s) shall be placed as follows (see Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5):

- in a vertical plane that makes an angle of 45° with the reference plane of the test construction, passing through its mid-point;
- horizontally: at 2 m distance from the longitudinal axis of the test construction;
- vertically in relation to the reference height h_{ref} of the test construction,

  for the microphone positions M6, M7, M8, M9 and M10:

  − microphone M6: 0,50 m higher;

  − microphone M7: 0,25 m higher;

  − microphone M8: equal to the reference height;

  − microphone M9: 0,25 m lower.

  − microphone M10: 0,50 m lower.

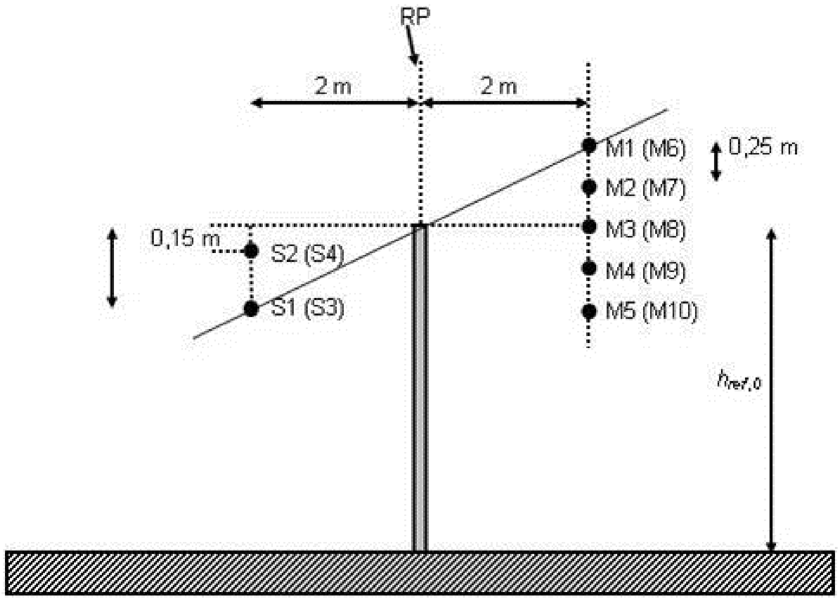
- making an angle in the horizontal plane so as to be oriented toward the sound source.

4.5 Free-field measurements

For each set of measurements done placing the sound source according to 4.3 (90° and 45°), a “free-field” impulse response shall be measured for each microphone position, keeping the sound source and the microphone positions with the same geometrical configuration of the set-up and without the reference wall or supporting barrier present (see for example Figure 7).

A whole set of measurements shall be carried out within 2 h. Otherwise a new free-field measurement shall be carried out.

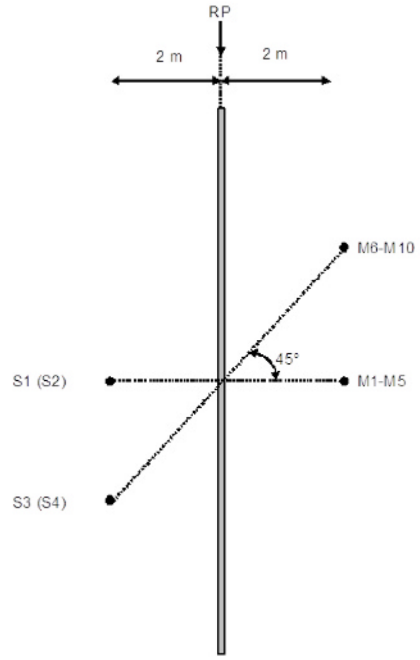
No obstacle shall be present within a distance of 3 m from the microphone(s).



Key

RP reference plane

Figure 1 — Source and microphone positions in a vertical cross section of the test construction without added device



Key

RP reference plane

Figure 2 — Source and microphone positions in a top view of the test construction without added device

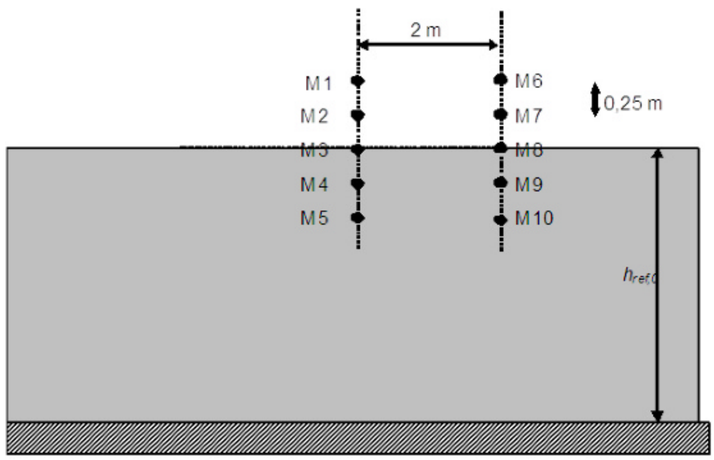
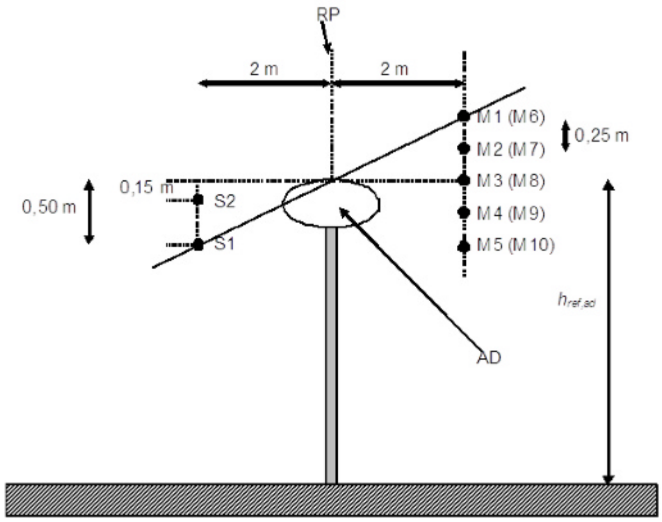


Figure 3 — Microphone positions in a vertical back view from receiver side of the test construction without added device

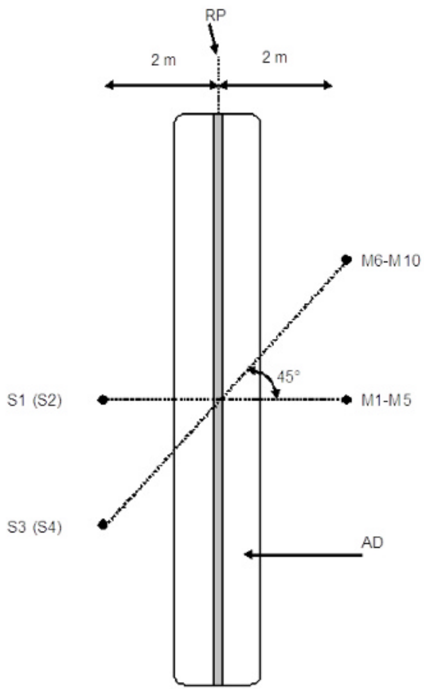


Key

RP reference plane

AD added device

Figure 4 — Source and microphone positions in a vertical cross section of the test construction with added device

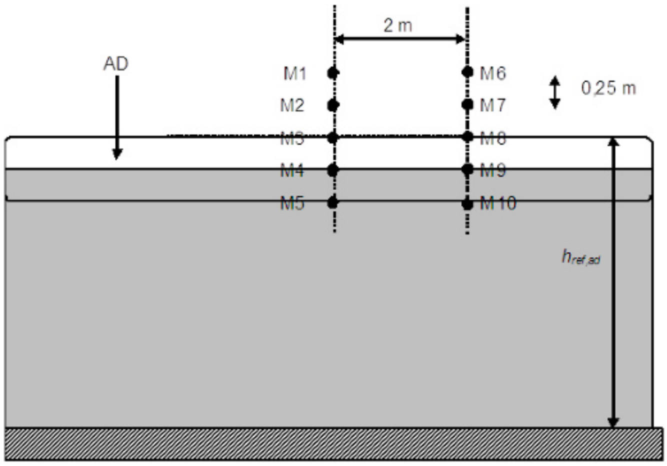


Key

RP reference plane

AD added device

Figure 5 — Source and microphone positions in a top view of the test construction with added device



Key

AD added device

Figure 6 — Microphone positions in a vertical back view from receiver side of the test construction with added device

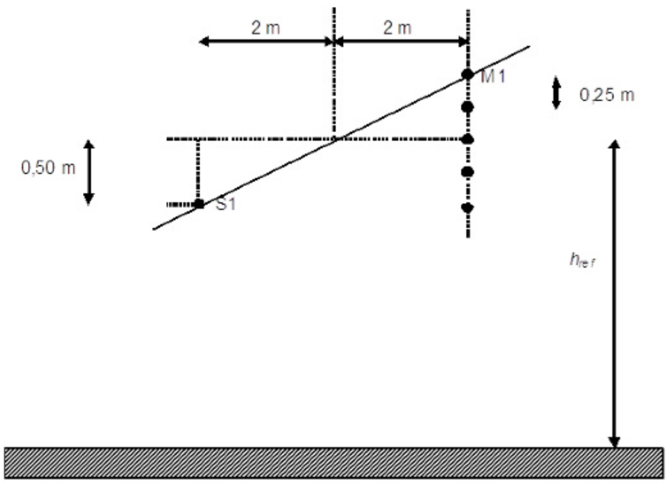
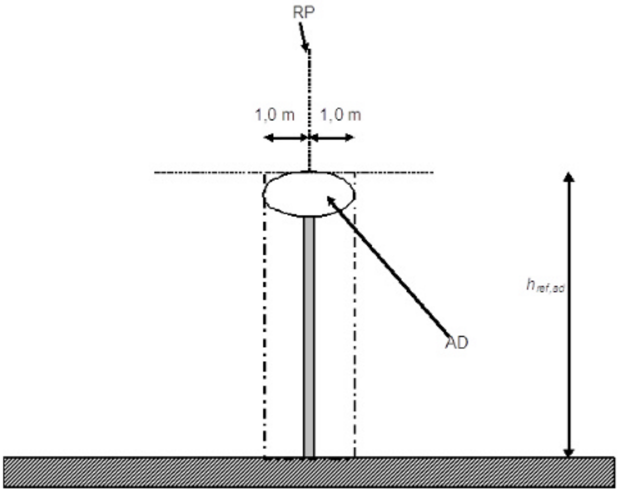


Figure 7 — Source and microphone positions for the free-field measurement in a vertical cross section (example given for source position S1 and microphone position M1)



Key

RP reference plane

AD added device

Figure 8 — Maximum horizontal dimension of the added device

4.6 Measured quantity

The expression used to compute the sound diffraction index DI for all loudspeaker locations and measuring frequencies, in one-third octave bands, is:

$$DI_j = -10\lg\left\{\sum_{k=1}^{n}\left[\frac{\int_{\Delta f_j}\left|\boldsymbol{F}\left[h_{dk}(t)w_{dk}(t)\right]\right|^2 df}{\int_{\Delta f_j}\left|\boldsymbol{F}\left[h_{ik}(t)w_{ik}(t)\right]\right|^2 df}\right]\right\} \quad (1)$$

where

$h_{ik}(t)$ is the component of the free-field impulse response received at the k-th measurement point ($k = 1\ldots n$);

$h_{dk}(t)$ is the component of the impulse response diffracted by the top edge of the test construction and received at the k-th measurement point ($k = 1\ldots n$);

$w_{ik}(t)$ is the time window (Adrienne temporal window) for the component of the free-field impulse response received at the k-th measurement point ($k = 1\ldots n$);

$w_{dk}(t)$ is the time window (Adrienne temporal window) for the component of the impulse response diffracted by the top edge of the test construction and received at the k-th measurement point ($k = 1\ldots n$);

F is the symbol of the Fourier transform;

j is the index of the one-third octave frequency bands (between 100 Hz and 5 kHz);

Δf_j is the width of the j-th one-third octave frequency band (between 100 Hz and 5 kHz);

$n = 10$ is the number of measurement points (microphone positions).

The sound diffraction index shall be calculated two times:

- for the test construction without added device;
- for the test construction with added device.

For each set of measurements, at least one free-field measurement shall be carried out, as described in 4.5.

4.7 Measuring equipment

4.7.1 Components of the measuring system

The measuring equipment shall comprise: an electro-acoustic system, consisting of an electrical signal generator, a power amplifier and a loudspeaker, one or more microphone(s) with their microphone amplifiers and a signal analyser capable of performing transformations between the time domain and the frequency domain.

NOTE Part of these devices can be integrated into a frequency analyser or a personal computer equipped with specific add-on board(s).

The essential components of the measuring system are shown in Figure 9.

The complete measuring system shall meet the requirements of at least a type 1 instrument in accordance with EN 61672-1, except for the microphone(s) which shall meet the requirements for type 2 and have a diameter of 1/2” maximum.

The measurement procedure here described is based on ratios of the power spectra of signals extracted from impulse responses sampled with the same equipment in the same place under the same conditions within a short time. Also, a high accuracy in measuring sound levels is not of interest here. Strict requirements on the absolute accuracy of the measurement chain are, therefore, not needed. Anyway, the requirement for a type 1 instrument is maintained for compatibility with other European Standards. The microphones should be sufficiently small and lightweight in order to be fixed on a frame to constitute a microphone array without moving.

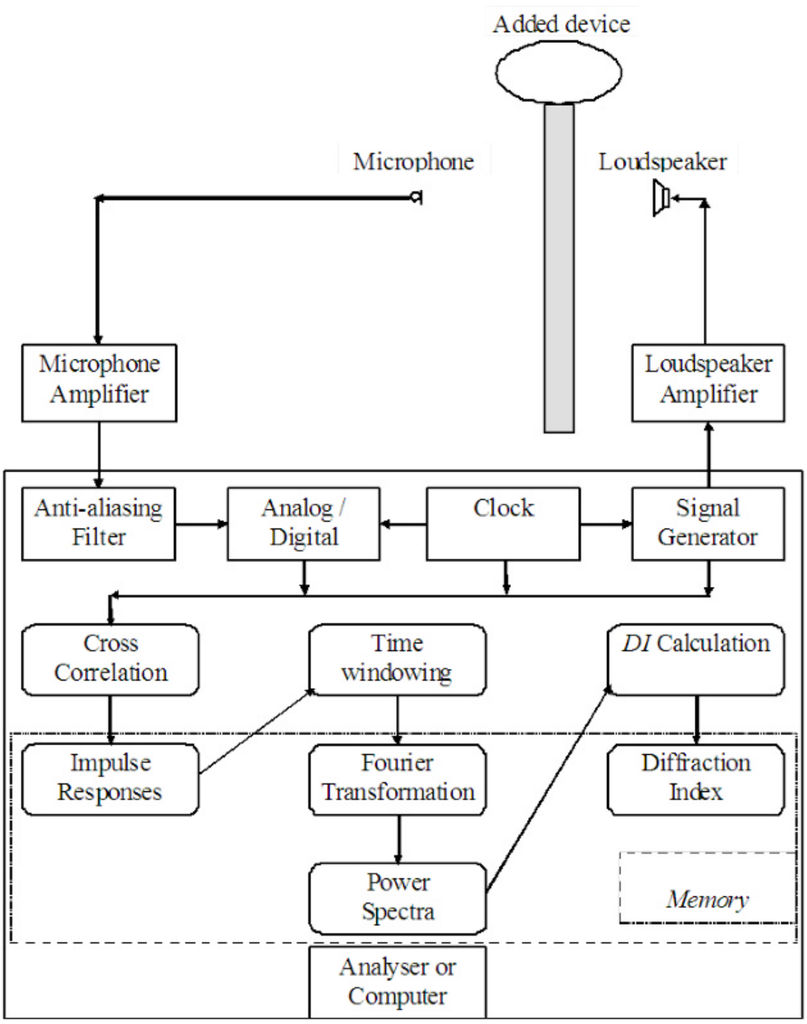


Figure 9 — Sketch representing the essential components of the measuring system

4.7.2 Sound source

The electro-acoustic sound source shall meet the following characteristics:

- have a single loudspeaker driver;
- be constructed without any port, e.g. to enhance low frequency response;
- be constructed without any electrically active or passive components (such as crossovers) which can affect the frequency response of the whole system;
- have a smooth frequency response without sharp irregularities throughout the measurement frequency range, resulting in an impulse response under free-field conditions with a length not greater than 3 ms.

NOTE As the sound diffraction index is calculated from the ratio of energetic quantities extracted from impulse responses taken using the same loudspeaker-microphone assembly within a short time period, the characteristics of the loudspeaker frequency response are not critical, provided a good quality loudspeaker meeting the above prescriptions is used.

All the measurements (diffraction and free-field) shall be made with the same amplification gain.

4.7.3 Test signal

The electro-acoustic source shall receive an input electrical signal which is deterministic and exactly repeatable. The input signal shall be set in order to avoid any nonlinearity of the loudspeaker.

The *S/N* ratio is improved by repeating the same test signal and synchronously averaging the microphone response. At least 16 averages shall be kept.

This European Standard recommends the use of a MLS signal as test signal. A different test signal may be used, e.g. sine sweep, if results can be shown to be exactly the same. This means that it shall be clearly demonstrated that:

— the generation of the test signal is deterministic and exactly repeatable;

— impulse responses are accurately sampled (without distortion) on the whole frequency range of interest (one-third octave bands between 100 Hz and 5 kHz);

— the test method maintains a good background noise immunity, i.e. the effective *S/N* ratio can be made higher than 10 dB on the whole frequency range of interest within a short measurement time (no more than 5 min per impulse response);

— the sample rate can be chosen high enough to allow an accurate correction of possible time shifts in the impulse responses between the measurement in front of the sample and the free-field measurement due to temperature changes;

— the test signal is easy-to-use, i.e. it can be conveniently generated and fed to the sound source using only equipment which is available on the market.

4.8 Data processing

4.8.1 Calibration

The measurement procedure here described is based on ratios of the power spectra of signals extracted from impulse responses sampled with the same equipment in the same place under the same conditions. An absolute calibration of the measurement chain with regard to the sound pressure level is therefore not needed. It is anyway recommended to check the correct functioning of the measurement chain from the beginning to the end of measurements.

4.8.2 Sample rate

The frequency at which the microphone response is sampled depends on the specified upper frequency limit of the measurement and on the anti-aliasing filter type and characteristics.

The sample rate f_s shall have a value greater than 43 kHz.

NOTE Although the signal is already unambiguously defined when the Nyquist criterion is met, higher sample rates facilitate a better reproduction of the signal. With the prescribed sample rates errors can be detected and corrected more easily, such as time shifts in the impulse responses between the measurements on the sample and the free-field measurement due to temperature changes.

The sample rate shall be equal to the clock rate of the signal generator.

The cut-off frequency of the anti-aliasing filter, f_{co}, shall have a value:

$$f_{co} \leq k f_s \qquad (2)$$

where k = 1/3 for the Chebyshev filter and k = 1/4 for the Butterworth and Bessel filters.

For each measurement, the sample rate, the type and the characteristics of the anti-aliasing filter shall be clearly stated in each test report.

4.8.3 Background noise

The effective signal-to-noise ratio *S/N*, taking into account sample averaging, shall be greater than 10 dB over the frequency range of measurements.

NOTE Coherent detection techniques, such as the MLS cross-correlation, provide high *S*/*N* ratios.

4.8.4 Measurement points

The sound source shall be positioned subsequently in the two source point locations as defined in 4.3. For each source location, a microphone shall be placed at the five measurement points on the other side of the test construction. For each source-microphone couple the resulting impulse response shall be measured. Each impulse response consists of the direct component, the transmitted component through the test construction, the diffracted components and other parasitic components.

For each source location a further free-field impulse response shall be measured as described in 4.5.

4.8.5 Adrienne temporal window

For the purpose of this European Standard, windowing operations in the time domain shall be performed using a temporal window, called Adrienne temporal window, with the following specifications (see Figure 10):

- a leading edge having a left-half Blackman-Harris shape and a total length of 0,5 ms (“pre-window”);
- a flat portion having a total length of 7 ms (“main body”);
- a trailing edge having a right-half Blackman-Harris shape and a total length of 3 ms.

The total length of the Adrienne temporal window is $T_{W,ADR}$ = 10,5 ms.

NOTE A four-term full Blackman-Harris window of length $T_{W,BH}$ is:

$$w(t) = a_0 - a_1 \cos\left(\frac{2\pi t}{T_{W,BH}}\right) + a_2 \cos\left(\frac{4\pi t}{T_{W,BH}}\right) - a_3 \cos\left(\frac{6\pi t}{T_{W,BH}}\right) \quad (3)$$

where

a_0 = 0,35875;

a_1 = 0,48829;

a_2 = 0,14128;

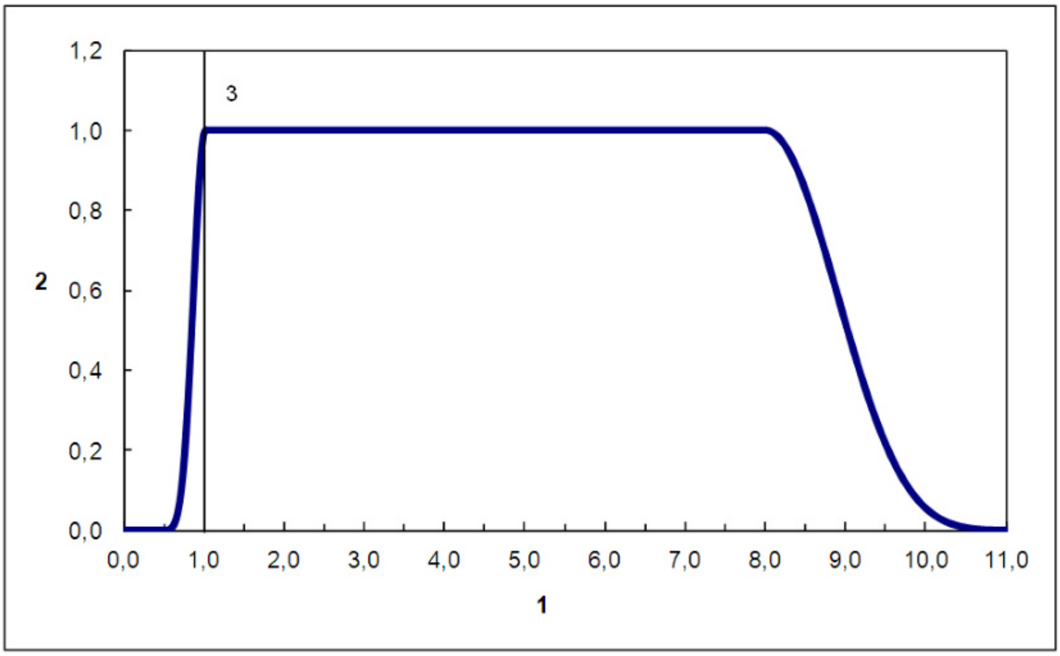
a_3 = 0,01168.

$$0 \le t \le T_{W,BH}$$

If the window length $T_{W,ADR}$ has to be varied, the lengths of the flat portion and the right-half Blackman-Harris portion shall have a ratio of 7/3. As an example, when testing reduced-height samples *in situ*, it could be necessary to reduce the window length in order to avoid parasitic components.

If, due to delays in the diffracted components – for example due to multiple reflections – significant energy arrives outside the Adrienne temporal window, errors occur and care should be taken in interpreting the results.

The point where the flat portion of the Adrienne temporal window begins is called the marker point (MP).



Key

1 time [ms]

2 Adrienne window function w(t) [relative units]

3 marker point MP

Figure 10 — The Adrienne temporal window, with the marker point MP

4.8.6 Placement of the Adrienne temporal window

For the “free-field” direct component, the window shall be placed as follows:

- the first peak of the impulse response, corresponding to the direct component, is detected;
- a time instant preceding the direct component peak of 0,2 ms is located;
- the direct component Adrienne temporal window is placed so as its marker point corresponds to this time instant.

In other words, the direct component Adrienne temporal window is placed so as its flat portion begins 0,2 ms before the first peak of the direct component.

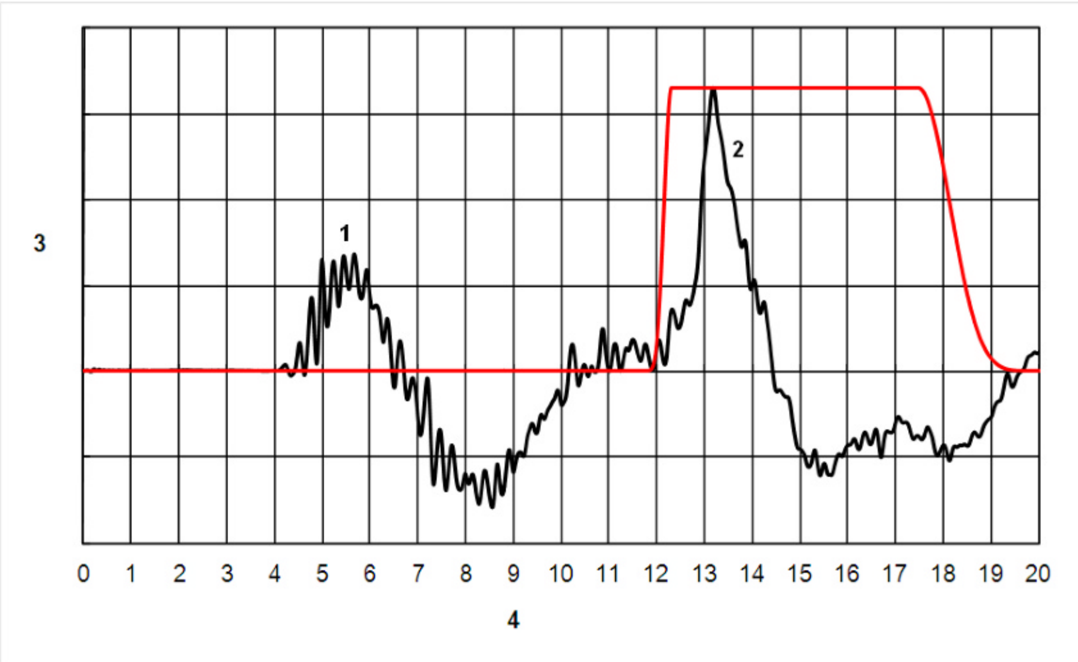
For the diffracted waves, the window shall be placed as follows:

- the time instant when the diffracted component begins is located, possibly with the help of geometrical computation (conventional beginning of diffraction);
- a time instant preceding the conventional beginning of diffraction of 0,2 ms is located;
- the diffracted component Adrienne temporal window is placed so as its marker point corresponds to this time instant;

- the time instant when the side edge diffraction begins is located, possibly with the help of geometrical computation (conventional beginning of the parasitic effects);
- the diffracted component Adrienne temporal window stops 10 ms after the marker point or at the conventional beginning of the parasitic effects, whatever of the two comes first.

In other words, the diffracted component Adrienne temporal window is placed so as its flat portion begins 0,2 ms before the first peak of the diffracted component and its tail stops before the beginning of the parasitic effects (see Figure 11).

In computations involving the sound speed *c*, its temperature dependent value shall be assumed.



Key

1	transmitted component	2	diffracted component
3	impulse response [relative units]	4	time [ms]

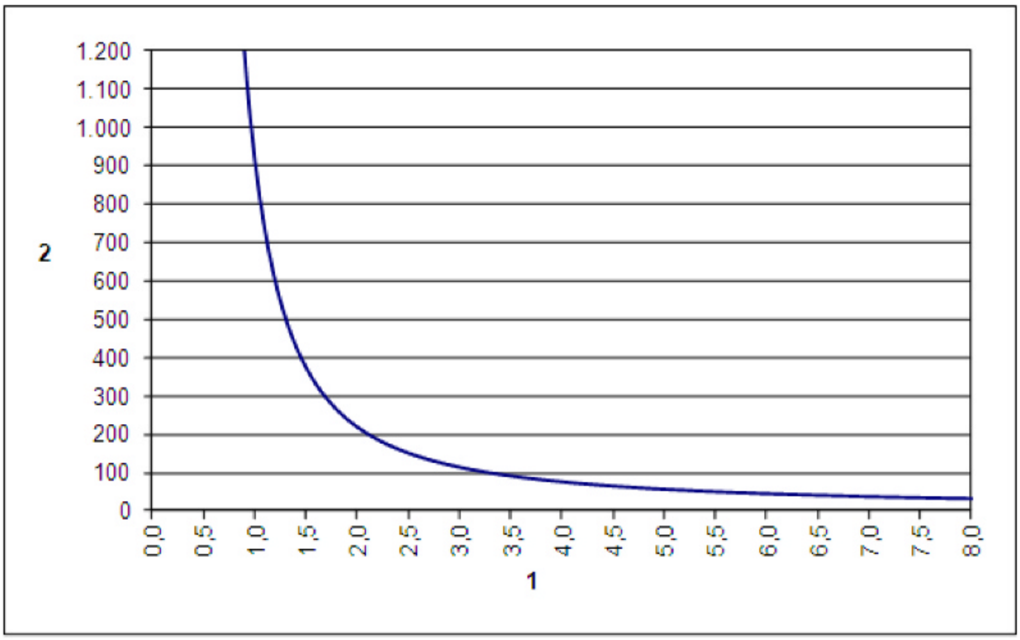
Figure 11 — Example of application of the Adrienne temporal window to the diffracted component of an impulse response

4.8.7 Low frequency limit and sample size

The method described in the present document can be used for different sample sizes.

The low frequency limit f_{min} of sound diffraction index measurements depends on the shape and width of the Adrienne temporal window. The width in turn depends on the height of the test construction and on the angle of the source-receiver line with the reference plane of the test construction. In fact, the unwanted component reflected by the ground on the receiver or source side of the test construction shall be kept out of the Adrienne temporal window for the diffracted components.

This ground-reflected component depends on the geometry of the test set-up. The low frequency limit f_{min} for sound diffraction index measurements as a function of the height of the test construction, at normal incidence of the source-receiver line with the reference plane of the test construction, is given in Figure 12.



Key

1 h_{ref} [m]

2 f_{min} [Hz]

Figure 12 — Low frequency limit of sound diffraction index measurements as a function of the height of the test construction for the obligatory source position S1 (normal incidence)

For qualification tests, the sample shall have the minimum dimensions specified in 4.2. These conditions give a low frequency limit for the sound diffraction index of about 76 Hz, i.e. using a 16,6 ms Adrienne temporal window the results are valid down to the 100 Hz one-third octave band.

4.9 Positioning of the measuring equipment

4.9.1 Selection of the measurement positions

The measuring equipment shall be placed near the noise reducing device at positions defined in 4.3 and 4.4.

In any case, distances shall be measured with an uncertainty not greater than 1 % of their nominal values.

The loudspeaker is placed at the source positions specified in 4.3.

On the opposite side of the test construction, the microphone(s) are placed at the measurement points specified in 4.4.

The measurements taken in the different microphone positions plus the corresponding free-field measurements shall be processed and averaged according to the sound diffraction index formula in 4.6.

4.9.2 Reflecting objects

Any object other than the device under test, shall be considered a reflecting object which could cause parasitic reflections (e.g. safety rails, fences, rocks, parked cars, etc.). These objects shall remain far from the microphone.

Care shall be taken the microphone stand does not influence the measurement.

4.9.3 Safety considerations

This test method may involve hazardous operations when measurements are made on or aside trafficked roads. This document does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this document to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

4.10 Sound diffraction index difference

For qualification tests, the above procedure for sound diffraction index measurements shall be applied twice on the reflective reference wall, without and with the added device under test in place, and twice on the absorptive reference wall; the diffraction indices $DI_{0,refl}$ (without added device, reflective wall), $DI_{ad,refl}$ (with added device, reflective wall), $DI_{0,abs}$ (without added device, absorptive wall) and $DI_{ad,abs}$ (with added device, absorptive wall) shall be calculated as previously stated.

For *in situ* tests, the above procedure for sound diffraction index measurements shall be applied twice on the *in situ* test construction without and with the added device under test in place and the diffraction indices $DI_{0,situ}$ (without added device) and $DI_{ad,situ}$ (with added device) shall be calculated as previously stated.

For each of the two situations with and without added device, all the measurements shall be performed in “repeatability” conditions (same place, same meteorological conditions, same equipment, same operators).

Then the **sound diffraction index difference** shall be calculated as:

$$\Delta DI_{refl} = DI_{ad,refl} - DI_{0,refl} \tag{4a}$$

$$\Delta DI_{abs} = DI_{ad,abs} - DI_{0,abs} \tag{4b}$$

$$\Delta DI_{situ} = DI_{ad,situ} - DI_{0,situ} \tag{4c}$$

Only the sound diffraction index difference ΔDI shall be regarded as characteristic of the added device under test. The frequency and position dependent values $DI_0(\Delta f_j, M_k)$ and $DI_{ad}(\Delta f_j, M_k)$ should be reported in a separate table.

4.11 Single-number rating of sound diffraction index difference $DL_{\Delta DI}$

A single-number rating shall be derived to indicate the performance of the product. The individual sound diffraction index values shall be weighted according to the normalized traffic noise spectrum defined in EN 1793-3.

The single-number rating of sound diffraction index difference $DL_{\Delta DI}$, in decibels, is given by:

$$DL_{\Delta DI,refl} = -10 \cdot \lg \left[\frac{\sum_{i=1}^{18} 10^{0,1L_i} 10^{-0,1\Delta DI_{refl,i}}}{\sum_{i=1}^{18} 10^{0,1L_i}} \right] \tag{5a}$$

$$DL_{\Delta DI,abs} = -10 \cdot \lg \left[\frac{\sum_{i=1}^{18} 10^{0,1L_i} 10^{-0,1\Delta DI_{abs,i}}}{\sum_{i=1}^{18} 10^{0,1L_i}} \right] \tag{5b}$$

$$DL_{\Delta DI,situ} = -10 \cdot \lg \left[\frac{\sum_{i=1}^{18} 10^{0,1L_i} 10^{-0,1\Delta DI_{situ,i}}}{\sum_{i=1}^{18} 10^{0,1L_i}} \right] \quad (5c)$$

where

L_i Relative A-weighted sound pressure levels (dB) of the normalized traffic noise spectrum, as defined in EN 1793–3, in the *i*-th one-third octave band.

The single-number rating of sound diffraction index difference shall be calculated for samples of minimum dimensions conforming to 4.2.

The above defined single-number ratings shall be calculated keeping one decimal digit and reported after having been rounded to the nearest integer.

4.12 Sample surface and meteorological conditions

4.12.1 Condition of the sample surface

Unless the measurement specifically aims at determining the influence of weather or other environmental conditions on sound propagation, measurements shall be carried out only when the sample surfaces is dry. If the sample surface can be expected to have a significant void content, then measurement shall not be made until it has been verified that the pores are dry.

The sample surface temperature shall be within 0 °C -70 °C during the measurement.

4.12.2 Wind

Wind speed at microphone positions shall not exceed 4 m/s.

If the wind speed exceeds 2 m/s for most of the measurement time, then for each set of measurements the average speed and direction of the wind relative to the reference plane shall be measured at a height of 1 m above the highest point of the test construction in relation to the surrounding ground surface and reported.

4.12.3 Air temperature

The ambient air temperature shall be within 0 °C -40 °C during the measurements. In calculations involving the sound speed value, its temperature dependent value shall be taken, using the actual temperature value around the test area.

5 Measurement uncertainty

The uncertainty of results obtained from measurements according to this European Standard shall be evaluated, preferably in compliance with ISO/IEC Guide 98. If reported, the expanded uncertainty together with the corresponding coverage factor for a stated coverage probability of 95 % as defined in ISO/IEC Guide 98 shall be given. More information on measurement uncertainty is given in Annex B.

6 Measuring procedure

6.1 General

The measurement shall be carried out as follows, both with and without the added device in place:

a) the sample surface and meteorological conditions are checked to ensure they comply with the specifications in 4.12. If not, the measurement cannot be carried out.

b) The measuring equipment is placed on site as specified in 4.9. The safety considerations in 4.9.3 apply.

c) The test signal is selected. If the measurements are performed indoor, special care shall be taken in order to avoid parasitic reflections and detrimental effects of reverberation (see Annex A).

d) The test signal is generated.

e) The total signal as received by the microphone is sampled with a sample rate selected according to 4.8.2.

f) The total signal as received by the microphone(s) is processed in order to obtain the overall impulse response in the selected measurement positions;

g) If it is suspected that the measurement may be contaminated by the background noise, the overall impulse response data are averaged, until a given degree of accuracy is obtained in each one-third frequency band of interest. In any case, at least 16 averages shall be kept (see 4.7.3).

h) In parallel with each set of measurements, the average wind speed (plus wind direction if the wind speed exceeds 2 m/s) relative to the reference plane is measured (see 4.12.2).

i) For each source position a free-field impulse response with the measurement set-up in the free field is acquired.

j) The direct components from the sound source and the components diffracted by the top edge of the test construction are isolated using Adrienne temporal windows (see 4.8.5 and 4.8.6).

k) The power spectra of the windowed signals are computed.

l) The sound diffraction index is computed.

m) The appropriate sound diffraction index differences are calculated according to the formulae in 4.10.

n) The appropriate single-number ratings are calculated according to 4.11.

o) The measurement report is written.

6.2 Test report

The test report shall include the information listed below:

a) reference to this document;

b) name and address of testing organization;

c) date and place of the test;

d) description of the test site: drawing or pictures showing the device under test, measurement set-up, reflecting or diffracting objects nearby the maximum sampled area (if any);

e) description of the added device under test: brand, type, dimensions, age, actual conditions, composition;

f) surface conditions of the noise reducing device and the added device with regard to dryness and temperature;

g) meteorological conditions prevailing during the test (wind speed and direction, air temperature);

h) test arrangement, indicating, on a scale drawing or a sketch with dimensions marked on it, the reference positions of the source and the microphone;

i) equipment used for measurement and analysis, including name, type, serial number, software version (if applicable) and manufacturer;

j) type and characteristics of the anti-aliasing filter and sample rate of the sampling/analysis device;

k) shape and length of the Adrienne temporal windows used for the analysis;

l) low frequency limit of the measurement and its relationship with the reference height of the noise reducing device with and without added device (see 4.8.7);

m) result of measurements, i.e. sound diffraction index difference, ΔDI, in one-third octave bands;

n) single-number rating of the sound diffraction index difference;

o) signature of the person responsible for the measurements.

The test results shall be given in the form of a graph and a table, showing the values of the sound diffraction index difference in one-third octave frequency bands between 100 Hz and 5 kHz for reflective, absorptive or for *in situ* test construction. If it is not possible to get valid measurements results over the whole frequency range indicated, the results shall be given in a restricted frequency range and the reasons of the restriction(s) shall be clearly reported.

The values of the sound diffraction index difference shall be rounded off to one decimal place.

The single-number rating of the sound diffraction index difference should be calculated according to 4.11 and reported after having being rounded to the nearest integer.

Annex A
(informative)

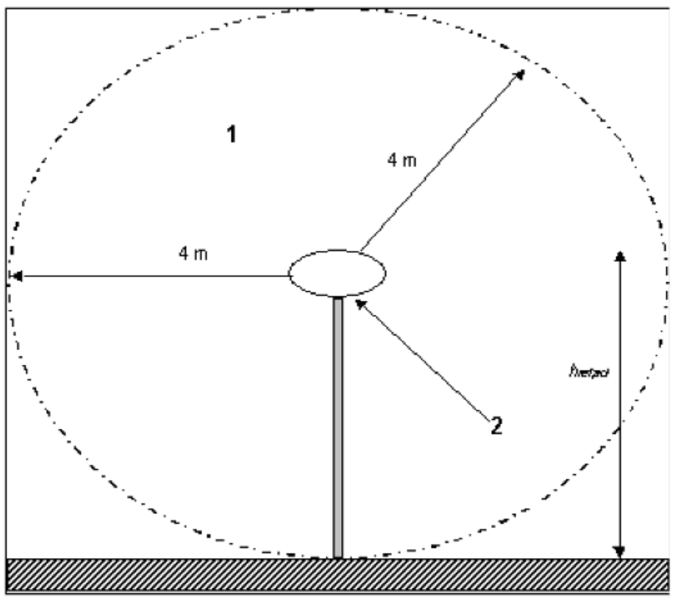
Indoor measurements for product qualification

A.1 General

Sound diffraction index measurements are possible indoor as well as outdoor, but in the indoor case special care shall be taken in order to avoid parasitic reflections and detrimental effects of reverberation.

A.2 Parasitic reflections

Parasitic reflections shall be kept outside the Adrienne temporal window. This will be accomplished by assuring that the nearest object (including ground, ceiling, vertical walls, columns, etc.) are at least 4 m away from the external surface of the added device.



Key

1 Clearance zone

2 Added device

Figure A.1 — Clearance zone in a vertical cross section of the reference wall with added device

A.3 Reverberation time of the room

If a MLS test signal is used and the MLS repetition period is comparable with the reverberation time of the test room, the starting and ending sections of the measured impulse response will overlap: this is the so-called time aliasing. Time aliasing can usually be recognized by the appearance of noticeable noise in the time-of-flight gap of the measured impulse response (before the arrival of the direct component) which cannot be reduced by averaging.

To avoid this problem, the MLS period shall be chosen at least equal to the reverberation time of the test room, at the frequency in the measurement range where the reverberation time is the highest.

Annex B
(informative)

Measurement uncertainty

B.1 General

The accepted format for expression of uncertainties generally associated with methods of measurement is that given in the ISO Guide to the Expression of Uncertainties in Measurement (ISO/IEC Guide 98). This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified, from which the combined total uncertainty can be obtained.

The intention of this Annex is to provide a basis for the development of suitable information by which the ISO/IEC Guide 98 could be applied. However, the information in this annex has not been validated through round robin testing, and further research could reveal additional considerations. It remains the final responsibility of a laboratory performing a measurement to determine its uncertainty (which might be higher or lower than the data given) and this Annex should only be regarded as a guide.

B.2 Expression for the calculation of sound diffraction index

At the present stage, no information exists to develop an analytical model of the sound diffraction index as a function of (many) input variables. Preliminary estimations show that the sound diffraction index of a noise reducing device, DI_j, determined according to this European Standard, is a function of a number of parameters, indicated by the following equation:

$$DI_j = \overline{DI}_j + \delta_{1j} + \delta_{2j} + \delta_{3j} + \delta_{4j} + \delta_{5j} + \delta_{6j} + \delta_{7j} \tag{B.1}$$

where

$\overline{DI}_j$ is the time and space averaged sound diffraction index in the *j*-th one-third-octave frequency band;

δ_{1j} is an input quantity to allow for any uncertainty in the incident reference component of the free-field impulse response acquisition;

δ_{2j} is an input quantity to allow for any uncertainty in the diffracted components of the impulse response acquisition;

δ_{3j} is an input quantity to allow for any uncertainty in the measuring equipment;

δ_{4j} is an input quantity to allow for any uncertainty due to the finite number of microphone and source positions;

δ_{5j} is an input quantity due to fluctuations in air temperature;

δ_{6j} is an input quantity due to fluctuations in air humidity;

δ_{7j} is an input quantity due to fluctuations in wind speed.

A probability distribution (normal, rectangular, Student's t, etc.) is associated with each of the input quantities. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of the dispersion of values. The uncertainty in the estimate of the input quantity is termed the standard uncertainty. It is a function of the standard deviation, probability distribution and number of degrees of freedom.

B.3 Contributions to measurement uncertainty

The combined uncertainty associated with the value of the sound diffraction index depends on each of the input quantities, their respective probability distributions and sensitivity coefficients, c_i. The sensitivity coefficients are a measure of how the values of the sound diffraction index are affected by changes in the values of the respective input quantities. Mathematically, these coefficients are equal to the partial derivatives of the function DI_j (Formula (B.1)) with respect to the relevant input quantities. The contributions of the respective input quantities to the overall uncertainty are then given by the products of the standard uncertainties and their associated sensitivity coefficients.

Table B.1 — Information to derive the overall uncertainty

Quantity	**Estimate**	**Standard uncertainty**	**Probability distribution**	**Sensitivity coefficient**
Time and space averaged sound diffraction index in the *j*-th one-third octave frequency band	$\overline{DI}_j$	$u_0 = u\left(\overline{DI}_j\right)$	normal	c_0
Effect of fluctuations of the incident reference component of the free-field impulse response at the *k*-th microphone position	δ_{1j}	$u_1 = u_1\left(\delta_{1j}\right)$		c_1
Effect of fluctuations of the diffracted components of the impulse response at the *k*-th microphone position	δ_{2j}	$u_2 = u_2\left(\delta_{2j}\right)$		c_2
Effect of fluctuations in the reading of the measuring equipment	δ_{3j}	$u_3 = u_3\left(\delta_{3j}\right)$		c_3
Effect of the finite number of microphone and source positions	δ_{4j}	$u_4 = u_4\left(\delta_{4j}\right)$		c_4
Effect of fluctuations in air temperature	δ_{5j}	$u_5 = u_5\left(\delta_{5j}\right)$		c_5
Effect of fluctuations in air humidity	δ_{6j}	$u_6 = u_6\left(\delta_{6j}\right)$		c_6
Effect of fluctuations in wind speed	δ_{7j}	$u_7 = u_7\left(\delta_{7j}\right)$		c_7
Combined standard uncertainty of the best estimate of DI_j	$u\left(DI_j\right)$		normal	-
Expanded uncertainty (*k* is a coverage factor)	$U = k \cdot u$			-

For the case of negligible correlation between the input quantities, the combined standard uncertainty of the determination of the sound diffraction index, $u(DI_j)$, is given by the following formula:

$$u\left(DI_j\right) = \sqrt{\sum_{i=0}^{7}\left(c_i u_i\right)^2} \quad \text{(B.2)}$$

The standard uncertainties from the various contributions remain to be established by research. An example of the type of information needed to derive the overall uncertainty of the method is given in Table B.1.

B.4 Expanded uncertainty of measurement

The ISO/IEC Guide 98 requires an expanded uncertainty, U, to be specified, such that the interval [$DI_j - U$, $DI_j + U$] covers e.g. 95 % of the values of DI_j that might reasonably be attributed to DI_j. To that purpose, a coverage factor, k, is used, such that $U = k \cdot u$. The coverage factor depends on the probability distribution associated with the measurand.

B.5 Measurement uncertainty based upon reproducibility data

In the absence of data for uncertainty contributions, values for the standard deviation of reproducibility, when available, may be used as an estimate of the combined standard uncertainty of determinations of sound diffraction index. A value may then be selected for the coverage factor, and the product of the two will yield an estimate of the expanded measurement uncertainty, with the chosen coverage probability. By convention, a coverage probability of 95 % is usually chosen. To avoid any misinterpretations, the chosen coverage probability should always be stated in test reports together with the expanded measurement uncertainty.

The information on measurement reproducibility can be helpful towards the derivation of measurement uncertainties, but it is incomplete. In particular, it does not give an analysis of the various components of measurement uncertainty and their magnitudes.

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