BS EN 1793-5:2016



BSI Standards Publication

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

Part 5: Intrinsic characteristics — In situ values of sound reflection under direct sound field conditions



BS EN 1793-5:2016 BRITISH STANDARD

National foreword

This British Standard is the UK implementation of EN 1793-5:2016. It supersedes BS CEN/TS 1793-5:2003 which is withdrawn.

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

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Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 5: Intrinsic characteristics - In situ values of sound reflection under direct sound field conditions

Dispositifs de réduction du bruit du trafic routier -Méthode d'essai pour la détermination de la performance acoustique - Partie 5: Caractéristiques intrinsèques - Valeurs in situ de réflexion acoustique dans des conditions de champ acoustique direct Lärmschutzvorrichtungen an Straßen - Prüfverfahren zur Bestimmung der akustischen Eigenschaften - Teil 5: Produktspezifische Merkmale - In-situ-Werte der Schallreflexion in gerichteten Schallfeldern

This European Standard was approved by CEN on 23 January 2016.

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European foreword

This document (EN 1793-5:2016) has been prepared under the direction of Technical Committee CEN/TC 226 "Road equipment", by Working Group 6 "Anti-noise devices", the secretariat of which is held by AFNOR.

This document supersedes CEN/TS 1793-5:2003.

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of an identical text or by endorsement, at the latest by September 2016, and conflicting national standards shall be withdrawn at the latest by September 2016.

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.

With respect to the superseded document, the following changes have been done:

- the rotating loudspeaker/microphone assembly has been replaced by a loudspeaker and a 9-microphone square array (the measurement grid);
- the definition of RI has been changed;
- the geometrical divergence correction factor has been changed;
- a new correction factor for sound source directivity has been introduced;
- a new correction factor for gain mismatch has been introduced;
- the impulse response alignment for signal subtraction has been described in more detail;
- the lowest reliable one-third frequency band has been better defined;
- the way to evaluate the uncertainty of the measurement method from reproducibility data has been introduced (Annex A);
- a detailed example is given (Annex B);
- information on the near-field to far-field relationship has been added (Annex C).

It 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 1793-2, Road traffic noise reducing devices - Test method for determining the acoustic performance – Part 2: Intrinsic characteristics of airborne sound insulation 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

EN 1793-4, Road traffic noise reducing devices - Test method for determining the acoustic performance – Part 4: Intrinsic characteristics – In situ values of sound diffraction

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

This document describes a test method for determining the intrinsic characteristics of sound reflection of noise reducing devices designed for roads in non-reverberant conditions (a measure of intrinsic performance). It can be applied *in situ*, i.e. where the noise reducing devices are installed. The method can be applied without damaging the surface.

The method can be used to qualify products to be installed along roads as well as to verify the compliance of installed noise reducing devices to design specifications. Regular application of the method can be used to verify the long term performance of noise reducing devices.

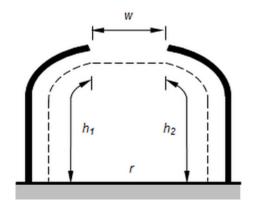
The method requires the average of results of measurements taken in different points in front of the device under test and/or for specific angles of incidences. The method is able to investigate flat and non-flat products.

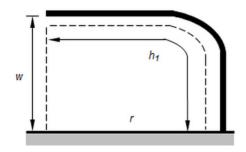
The measurements results of this method for sound reflection are not directly comparable with the results of the laboratory method (e.g. EN 1793-1), mainly because the present method uses a directional sound field, while the laboratory method assumes a diffuse sound field. The test method described in the present document should not be used to determine the intrinsic characteristics of sound reflection of noise reducing devices to be installed in reverberant conditions, e.g. claddings inside tunnels or deep trenches.

For the purpose of this document reverberant conditions are defined based on the envelope, e, across the road formed by the device under test, trench sides or buildings (the envelope does not include the road surface) as shown by the dashed lines in Figure 1. Conditions are defined as being reverberant when the percentage of open space in the envelope is less than or equal to 25 %, i.e. Reverberant conditions occur when $w/e \le 0.25$, where $e = (w+h_1+h_2)$

This method introduces a specific quantity, called reflection index, to define the sound reflection in front of a noise reducing device, while the laboratory method gives a sound absorption coefficient. Laboratory values of the sound absorption coefficient can be converted to conventional values of a reflection coefficient taking the complement to one. In this case, research studies suggest that some correlation exists between laboratory data, measured according to EN 1793-1 and field data, measured according to the method described in the present document [7], [10], [20], [21].

This method may be used to qualify noise reducing devices for other applications, e.g. to be installed nearby industrial sites. In this case the single-number ratings should be calculated using an appropriate spectrum.

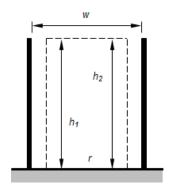




- (a) Partial cover on both sides of the road; envelope, $e = w+h_1+h_2$.
 - h₁ h₂

(c) Deep trench; envelope, $e = w+h_1+h_2$.

(b) Partial cover on one side of the road; envelope, $e = w + h_1$.



(d) Tall barriers or buildings; envelope, $e = w+h_1+h_2$.

Key

r road surface;

w width of open space

NOTE Figure 1 is not to scale.

Figure 1 —Sketch of the reverberant condition check in four cases

1 Scope

This European Standard describes a test method for measuring a quantity representative of the intrinsic characteristics of sound reflection from road noise reducing devices: the reflection index.

The test method is intended for the following applications:

- determination of the intrinsic characteristics of sound reflection of noise reducing devices to be installed along roads, to be measured either on typical installations alongside roads or on a relevant sample section;
- determination of the *in situ* intrinsic characteristics of sound reflection of noise reducing 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 noise reducing devices (with a repeated application of the method).

The test method is not intended for the following applications:

 determination of the intrinsic characteristics of sound reflection of noise reducing devices to be installed in reverberant conditions, e.g. inside tunnels or deep trenches.

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 should be given in a restricted frequency range and the reasons of the restriction(s) should be clearly reported.

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 61672-1, Electroacoustics - Sound level meters - Part 1: Specifications (IEC 61672-1)

ISO/IEC Guide 98-3, Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

3 Terms and definitions

For the purposes of this document the following terms and definitions apply:

3.1

noise reducing device (NRD)

device that is designed to reduce the propagation of traffic noise away from the road environment. This may be a noise barrier, cladding, a road cover or an added device. These devices may include both acoustic and structural elements

3.2

noise barrier

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

3.3

acoustic element

element whose primary function is to provide the acoustic performance of the device

3.4

structural element

element whose primary function is to support or hold in place acoustic elements

3.5

cladding

noise-reducing device, which is attached to a wall or other structure and reduces the amount of sound reflected

3.6

cover

noise-reducing device, which either spans or overhangs the highway

3.7

added device

added component that influences the acoustic performance of the original noise-reducing device (acting primarily on the diffracted energy)

3.8

roadside exposure

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

3.9

sound reflection index

quantity, resulting from a sound reflection test, described by Formula (1)

3.10

measurement grid for sound reflection index measurements

vertical measurement grid constituted of nine equally spaced microphones in a 3x3 squared configuration

Note 1 to entry The orthogonal spacing between two subsequent microphones, either vertically or horizontally, is s = 0.40 m.

Note 2 to entry See Figure 3 and 5.6.

Note 3 to entry Microphones are numbered like in Figure 3.b.

3.11

reference height

height h_S equal to half the height, h_B , of the noise barrier under test: $h_S = h_B/2$

Note 1 to entry When the height of the device under test is greater than 4 m and, for practical reasons, it is not advisable to have a height of the source $h_S = h_B/2$, it is possible to have $h_S = 2$ m, accepting the corresponding low frequency limitation (see 5.5.7).

Note 2 to entry: See Figures 2 and 3.

3.12

(source and microphone) reference plane for sound reflection index measurements

plane facing the sound source side of the noise reducing device and touching the most protruding parts of the device under test within the tested area

Note 1 to entry See Figures 2 and 4.

3.13

source reference position

position facing the side to be exposed to noise when the device is in place, located at the reference height h_S and placed so that the horizontal distance of the source front panel to the reference plane is $d_S = 1,50$ m

Note 1 to entry See Figures 2 and 4.

3.14

measurement grid reference position

position of the measurement grid compliant with all the following conditions: i) the measurement grid is vertical; ii) the measurement grid is on the noise reducing device side to be exposed to noise when the device is in place; iii) the central microphone (microphone n. 5) is located at the reference height h_S ; iv) the horizontal distance of the central microphone to the reference plane is $d_M = 0.25$ m; v) the line passing through the centre plate of the loudspeaker and the central microphone is horizontal

Note 1 to entry See Figures 2, 3 and 4.

3.15

reference loudspeaker-measurement grid distance

distance between the front panel of the loudspeaker and the central microphone (microphone n. 5) of the measurement grid (kept in vertical position)

Note 1 to entry The reference loudspeaker-measurement grid distance is equal to $d_{SM} = 1,25$ m (see Figures 2 and 4).

3.16

free-field measurement for sound reflection index measurements

measurement taken with the loudspeaker and the measurement grid in an acoustic free field in order to avoid reflections from any nearby object, including the ground, keeping the same geometry as when measuring in front of the noise reducing device under test

Note 1 to entry See Figure 5.

3.17

maximum sampled area

surface area, projected on a front view of the noise reducing device under test for reflection index measurements, which must remain free of reflecting objects causing parasitic reflections

3.18

Adrienne temporal window

composite temporal window described in 5.5.5

3.19

background noise

noise coming from sources other than the sound source emitting the test signal

3.20

signal-to-noise ratio, S/N

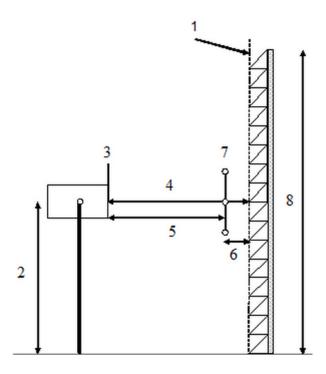
difference in decibels between the level of the test signal and the level of the background noise at the moment of detection of the useful event (within the Adrienne temporal window)

3.21

impulse response

time signal at the output of a system when a Dirac function is applied to the input. 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

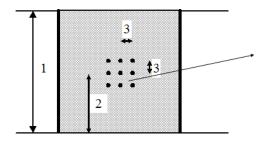
Note 1 to entry: It is impossible in practice to create and radiate true Dirac delta functions. Short transient sounds can offer close enough approximations but are not very repeatable. An alternative measurement technique, generally more accurate, is to use a period of deterministic, flat-spectrum signal, like maximum-length sequence (MLS) or exponential sine sweep (ESS), and transform the measured response back to an impulse response.

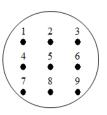


- 1 Source and microphone reference plane
- 3 Loudspeaker front panel
- 5 Distance between the loudspeaker front panel and the measurement grid d_{SM} [m]
- 7 Measurement grid

- 2 Reference height h_S [m]
- Distance between the loudspeaker front panel and the reference plane d_S [m]
- 6 Distance between the measurement grid and the reference plane d_M [m]
- 8 Noise reducing device height h_B [m]

Figure 2 — (not to scale) Sketch of the sound source and the measurement grid in front of the noise reducing device under test for sound reflection index measurements



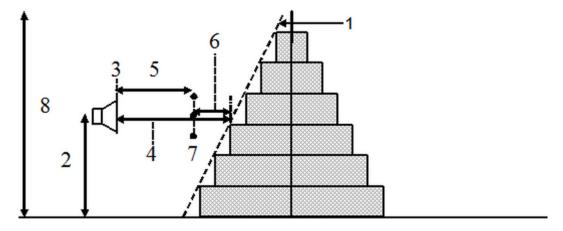


Key

- 1 Noise reducing device height h_B [m]
- 2 Reference height h_S [m]
- 3 Orthogonal spacing between two subsequent microphones *s* [m]

Figure 3 (a) — (not to scale) Measurement grid for sound reflection index measurements (source side).

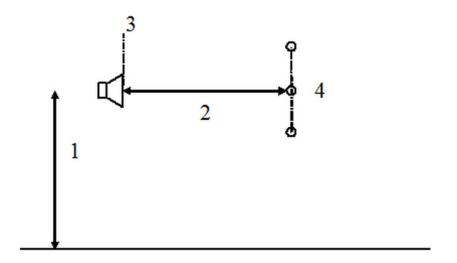
Figure 3 (b) — (not to scale) Numbering of the measurement points as seen from the sound source.



- 1 Source and microphone reference plane
- 3 Loudspeaker front panel
- Distance between the loudspeaker front panel and the measurement grid d_{SM} [m]
- 7 Measurement grid

- 2 Reference height h_S [m]
- Distance between the loudspeaker front panel and the reference plane d_S [m]
- 6 Distance between the measurement grid and the reference plane d_M [m]
- 8 Noise reducing device height h_B [m]

Figure 4 — (not to scale) Placement of the sound source and measurement grid for sound reflection index measurement for an inclined noise reducing device (side view)



Key

- 1 Reference height h_S [m]
- Distance between the loudspeaker front panel and the measurement grid d_{SM} [m]
- 3 Loudspeaker front panel
- 4 Measurement grid

Figure 5 — (not to scale) Sketch of the set-up for the reference "free-field" sound measurement for the determination of the sound reflection index

4 Symbols and abbreviations

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

Table 1 - Symbols and abbreviations

Symbol or abbreviation	Designation	Unit
а	major axis of the ellipsoid of revolution used to define the maximum sampled area at oblique incidence	
a_0, a_1, a_2, a_3	Coefficient for the expression of the four-term full Blackman-Harris window	
b_s	Depth of the surface structure of the sample under test	
b_m	Width of a portion of material of the sample under test	
С	Speed of sound in air	m/s
$C_{geo,k}$	Correction factor for the geometrical divergence	
$C_{dir,k}$	Correction factor for the sound source directivity	
$C_{gain,k}$	Correction factor for changes in the sound source gain	
d_M	Horizontal distance from the source and microphone reference plane to the measurement grid; it is equal to $d_M = 0.25$ m	
d_S	Horizontal distance from the front panel of the loudspeaker to the source and microphone reference plane; it is equal to: $d_S = 1,50 \text{ m}$	
d_{SM}	Horizontal distance from the front panel of the loudspeaker to the measurement grid; it is equal to: $d_{SM} = 1,25 \text{ m}$	m
DL_{RI}	Single number rating of sound reflection	dB
δ_i	Any input quantity to allow for uncertainty estimates	-

Δf_g	Frequency range encompassing the one-third octave frequency bands between	Hz
<i>-</i> 5 <i>y</i>	500 Hz and 2 kHz	
Δf_j	Width of the <i>j</i> -the one-third octave frequency band	
Δt	temporal step between the discrete points of the acquired data (linked to the given sample rate by $\Delta t = 1/f_s$)	
Δτ	moving step of the free field impulse response in the adjustment procedure included in the generalized signal subtraction technique (see 5.5.4)	
Δt_{k5}	Time delay gap between the arrival of direct sound at microphone k ($k \neq 5$) and microphone 5	
Δt_k	Time delay gap between the arrival of direct and reflected sound at microphone \boldsymbol{k}	
Δd_{k5}	Path length difference between the arrival of direct sound at microphone k ($k \neq 5$) and microphone 5	
Δd_k	Path length difference between the arrival of direct and reflected sound at microphone \boldsymbol{k}	
\mathcal{E}_k	Tolerance on the path length difference at microphone k	m
F	Symbol of the Fourier transform	-
f	Frequency	Hz
f_{min}	Low frequency limit of sound reflection index measurements	Hz
fs	Sample rate	
f_{co}	cut-off frequency of the anti-aliasing filter	
h_B	Noise reducing device height	m
h_S	Reference height	
$h_{ik}(t)$	Incident reference component of the free-field impulse response at the k -th measurement point	
$h_{rk}(t)$	Reflected component of the impulse response at the <i>k</i> -th measurement point	
j	Index of the <i>j</i> -th one-third octave frequency band (between 100 Hz and 5 kHz)	
k_p	Coverage factor	
k_f	Constant used for the anti-aliasing filter	-
L_p	Sample period length of a non-homogeneous noise reducing device	
n_j	Number of measurement points on which to average	
r	Radius of the maximum sampled area at normal incidence	m
R_{sub}	Reduction factor	
RI_j	Sound reflection index in the <i>j</i> -th one-third octave frequency band	
S	Orthogonal spacing between two subsequent microphones	
Sr	Standard deviation of repeatability	
SR	Standard deviation of reproducibility	
t	Time	
$T_{W,BH}$	Length of the Blackman-Harris trailing edge of the Adrienne temporal window	

$T_{W,ADR}$	Total length of the Adrienne temporal window	S
и	Standard uncertainty	-
U	Expanded uncertainty	-
$w_{ik}(t)$	Reference free-field component time window (Adrienne temporal window) at the k -th measurement point	-
$w_{rk}(t)$	Time window (Adrienne temporal window) for the reflected component at the k -th measurement point	-

5 Sound reflection index measurements

5.1 General principle

The sound source emits a transient sound wave that travels past the measurement grid (microphone) position to the device under test and is then reflected on it (Figures 2 and 4). Each microphone, being placed between the sound source and the device under test, receives both the direct sound pressure wave travelling from the sound source to the device under test and the sound pressure wave reflected (including scattering) by the device under test. The direct sound pressure wave can be better acquired with a separate free field measurement (see Figure 5). The power spectra of the direct and the reflected components, gives the basis for calculating the sound reflection index.

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.

5.2 Measured quantity

The expression used to compute the reflection index *RI* as a function of frequency, in one-third octave bands, is:

$$RI_{j} = \frac{1}{n_{j}} \sum_{k=1}^{n_{j}} \left[\frac{\int_{\Delta f_{j}} \left| F\left[h_{r,k}\left(t\right) \cdot w_{r,k}\left(t\right)\right]\right|^{2} df}{\int_{\Delta f_{j}} \left| F\left[h_{i,k}\left(t\right) \cdot w_{i,k}\left(t\right)\right]\right|^{2} df} \cdot C_{geo,k} \cdot C_{dir,k}\left(\Delta f_{j}\right) \cdot C_{gain,k}\left(\Delta f_{g}\right) \right]$$

$$(1)$$

where

- $h_{i,k}(t)$ is the incident reference component of the free-field impulse response at the k-th measurement point;
- $h_{r,k}(t)$ is the reflected component of the impulse response taken in front of the sample under test at the k-th measurement point;
- $w_{i,k}(t)$ is the time window (Adrienne temporal window) for the incident reference component of the free-field impulse response at the k-th measurement point;
- $w_{r,k}(t)$ is the time window (Adrienne temporal window) for the reflected component at the k-th measurement point;
- *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_i is the width of the j-th one-third octave frequency band;

k is the microphone number according to Figure 3.b (k = 1, ..., 9);

 n_i is the number of microphone positions on which to average $(n_i \ge 6; \text{ see } 5.6.2);$

 $C_{geo,k}$ is the correction factor for geometrical divergence at the k-th measurement point;

 $C_{dir,k}(\Delta f_i)$ is the correction factor for sound source directivity at the k-th measurement point.

 $C_{gain,k}(\Delta f_g)$ is the correction factor to account for a change in the amplification settings of the loudspeaker and in the sensitivity settings of the individual microphones when changing the measurement configuration from free field to in front of the sample under test or vice versa, if any (see 5.5.1 and Formula (4));

 Δf_g is the frequency range encompassing the one-third octave frequency bands between 500 Hz and 2 kHz.

The correction factor for geometrical divergence, $C_{geo,k}$, are given by:

$$C_{geo,k} = \left(\frac{d_{r,k}}{d_{i,k}}\right)^2 \tag{2}$$

where

 $d_{i,k}$ is the distance from the front panel of the loudspeaker to the k-th measurement point;

 $d_{r,k}$ is the distance from the front panel of the loudspeaker to the source and microphone reference plane and back to the k-th measurement point following specular reflection;

k is the microphone number according to Figure 3.b (k = 1, ..., 9).

NOTE 1 For the microphone n. 5, $d_{i,5} = d_{SM} = 1,25$ m

The distances $d_{i,k}$, $d_{r,k}$ and the correction factors $C_{geo,k}$ are given in Table 2.

Table 2 – Distances $d_{i,k}$, $d_{r,k}$ and correction factors $C_{geo,k}$

k	$d_{i,k}$, m	$d_{r,k}$, m	$C_{geo,k}$
1	1,37	1,84	1,80
2	1,31	1,80	1,87
3	1,37	1,84	1,80
4	1,31	1,80	1,87
5	1,25	1,75	1,96
6	1,31	1,80	1,87
7	1,37	1,84	1,80
8	1,31	1,80	1,87
9	1,37	1,84	1,80

NOTE 2 The reflections from different portions of the surface of the device under test arrive at the microphone position at different times, depending on the travel path from the loudspeaker to the position of each test surface portion and back. The longer the travel path from the loudspeaker to a specific test surface portion and back, the greater the time delay. Thus, the amplitude of the reflected sound waves from different test surface portions, as detected at the microphone positions, is attenuated in a manner inversely proportional to the travel time. For non flat complex devices it is difficult to predict the exact travel path of each wave, considering also non specular scattering; therefore the geometrical divergence correction factors are calculated on the basis of specular reflection on an ideal flat reflecting surface.

The correction factors for sound source directivity are given by:

$$C_{dir,k}\left(\Delta f_{j}\right) = \frac{\int_{\Delta f_{j}} \left|F\left[h_{i,k}\left(t,\alpha_{k}\right)\cdot w_{i,k}\left(t\right)\right]\right|^{2} df}{\int_{\Delta f_{j}} \left|F\left[h_{i,k}\left(t,\beta_{k}\right)\cdot w_{i,k}\left(t\right)\right]\right|^{2} df}$$

$$(3)$$

where

 α_k is the angle between the line connecting the centre of the front panel of the loudspeaker to microphone 5 and the line connecting the centre of the front panel of the loudspeaker to microphone k (see Figure 6.a);

 β_k is the angle between the line connecting the centre of the front panel of the loudspeaker to microphone 5 and the line connecting the centre of the front panel of the loudspeaker to the specular reflection path to microphone k (see Figure 6.a);

 $h_{i,k}(t,\alpha_k)$ is the incident reference component of the free-field impulse response at the k-th measurement point;

 $h_{i,k}(t,\beta_k)$ is the incident reference component of the free-field impulse response at a point on the specular reflection path for microphone k and at distance $d_{i,k}$ from the centre of the front panel of the loudspeaker;

 $w_{i,k}(t)$ is the time window (Adrienne temporal window) for the incident reference component of the free-field impulse response at the k-th measurement point;

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);

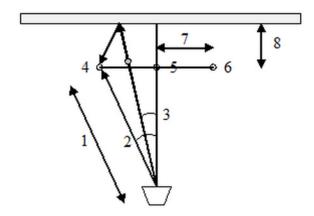
 Δf_i is the width of the *j*-th one-third octave frequency band;

is the microphone number according to Figure 3.b (k = 1, ..., 9).

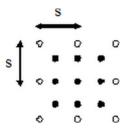
When measuring the sound source directivity correction factors, the numerator and denominator of the ratio in Formula (3) shall be measured in two different points at the constant distance $d_{i,k}$ (see Table 2) from the centre of the front panel of the loudspeaker. The first point is placed at the microphone position and the second point is placed on the specular reflection travel path of the sound emitted by the loudspeaker (see Figure 6).

NOTE 3 For non flat complex devices it is difficult to predict the exact travel path of each wave, considering also non specular scattering; therefore the correction factors for sound source directivity are calculated on the basis of specular reflection on an ideal flat reflecting surface.

The sound source directivity correction factors shall be measured only once for each sound source, assuming that the source directivity patterns don't change. For the sake of accuracy they may be measured again from time to time (e.g. once a year).



a) Sketch showing microphone positions 4, 5, and 6 (white circles), the angles α_4 and β_4 for microphone 4 and the point, at a distance $d_{i,4}$ from the loudspeaker centre plate, where measurements to get the correction factor $C_{dir,4}$ shall be done (grey circles)



b) Sketch of the front view of the nine microphone positions (white circles) and the nine positions where the specular reflection travel path of the sound emitted by the loudspeaker intersect the plane of the measurement grid (black circles)

Key

- 1 distance $d_{i,4}$ from the loudspeaker centre plate, where measurements to get the correction factor $C_{dir,4}$ shall be done [m] m
- 2~ angle α_4 between the line connecting the centre of the front panel of the loudspeaker to microphone 5 and the line connecting the centre of the front panel of the loudspeaker to microphone n.
- 3 angle β_4 between the line connecting the centre of the front panel of the loudspeaker to microphone 5 and the line connecting the centre of the front panel of the loudspeaker to the specular reflection path to microphone n. 4
- 4 Microphone n. 4

- 5 Microphone n. 5
- 7 Orthogonal spacing between two subsequent microphones *s* [m]
- 6 Microphone n. 6
- 8 Horizontal distance from the source and microphone reference plane to the measurement grid d_M [m]

Figure 6 (not to scale)

5.3 Test arrangement

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

For applications on real-size samples purposely built to be tested using the method described here the specimen shall be built as follows:

— a part, composed of acoustic elements, that extends at least 4 m and is at least 4 m high.

The test specimen shall be mounted and assembled in the same manner as the manufactured device is used in practice with the same connections and seals between components parts.

For *in situ* applications the test specimen shall be constructed as follows:

- for in situ applications using single acoustic elements to achieve full height:
 - the test specimen shall be constructed as a single element which is representative of the *in situ* application;
 - where the test specimen cannot be constructed as a single element or where the *in situ* application is lower than 4 m, the test specimen shall be centred on the loudspeaker axis (at reference height h_S above the ground) and built up to 4 m high using smaller height acoustic elements at the base and top as appropriate;
- for in situ applications using stacked elements to achieve full height:
 - the test specimen shall be constructed as used *in situ*.

For the results to be valid on the full frequency range, the minimum dimensions of the sample shall be as follows (see Figure 7):

- a part, composed of acoustic elements, 4 m wide and 4 m high;
- two posts 4 m high at both sides (if applicable for the specific noise reducing device under test);

In all cases, if the sample under test is non-flat with a periodic spatial corrugation in the vertical direction, then whenever possible the sample shall be extended in the vertical direction with one full period of the corrugation (see Figure 8).

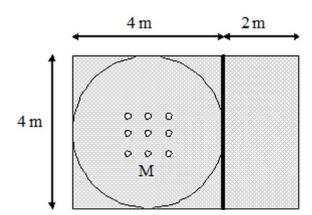
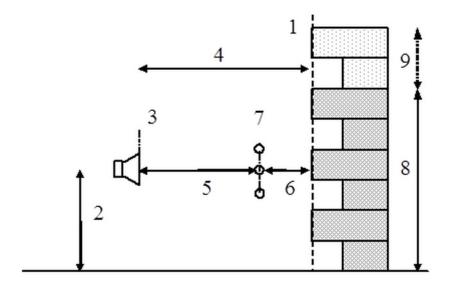
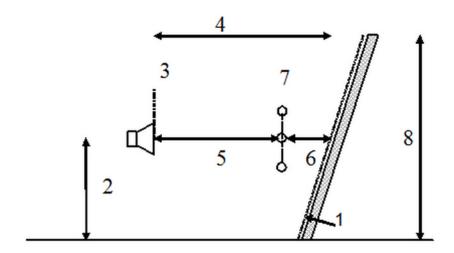


Figure 7 — Sketch of the minimum flat sample required for reflection index measurements in the 200 Hz – 5 kHz frequency range (see 5.5.7). The nine white dots represent the measurement grid. The thin circle represents the maximum sampled area for the central microphone (5.6.1)

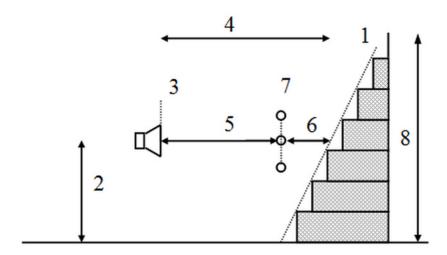


- 1 Source and microphone reference plane
- 3 Loudspeaker front panel
- Distance between the loudspeaker front panel and the measurement grid d_{SM} [m]
- 7 Measurement grid
- 9 Spatial period length of the corrugation in the vertical direction L_p [m]
- 2 Reference height h_S [m]
- 4 Distance between the loudspeaker front panel and the reference plane d_S [m]
- 6 Distance between the measurement grid and the reference plane d_M [m]
- 8 Noise reducing device height h_B [m]

Figure 8 — (not to scale) Sketch of the set-up for the reflection index measurement in front of a non-flat sample with a spatially periodic corrugation in the vertical direction (period length Lp in the vertical direction); one additional period of the structure, added on the top of the sample, is shown in lighter grey colour



(a) in front of an inclined flat noise reducing device

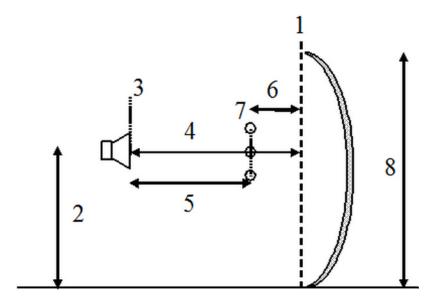


(b) in front of an inclined non-flat noise reducing device

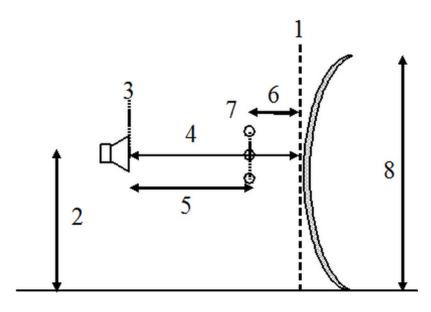
- 1 Source and microphone reference plane
- 3 Loudspeaker front panel
- Distance between the loudspeaker front panel and the measurement grid d_{SM} [m]
- 7 Measurement grid

- 2 Reference height h_S [m]
- 4 Distance between the loudspeaker front panel and the reference plane d_S [m]
- 6 Distance between the measurement grid and the reference plane d_M [m]
- 8 Noise reducing device height h_B [m]

Figure 9 — (not to scale) Sketch of the set-up for the reflection index measurement



(a) in front of a concave noise reducing device



(b) in front of a convex noise reducing device

- 1 Source and microphone reference plane
- 3 Loudspeaker front panel
- Distance between the loudspeaker front panel and the measurement grid d_{SM} [m]
- 7 Measurement grid

- 2 Reference height h_S [m]
- Distance between the loudspeaker front panel and the reference plane d_S [m]
- 6 Distance between the measurement grid and the reference plane d_M [m]
- 8 Noise reducing device height h_B [m]

Figure 10 (not to scale) — Sketch of the set-up for the reflection index measurement

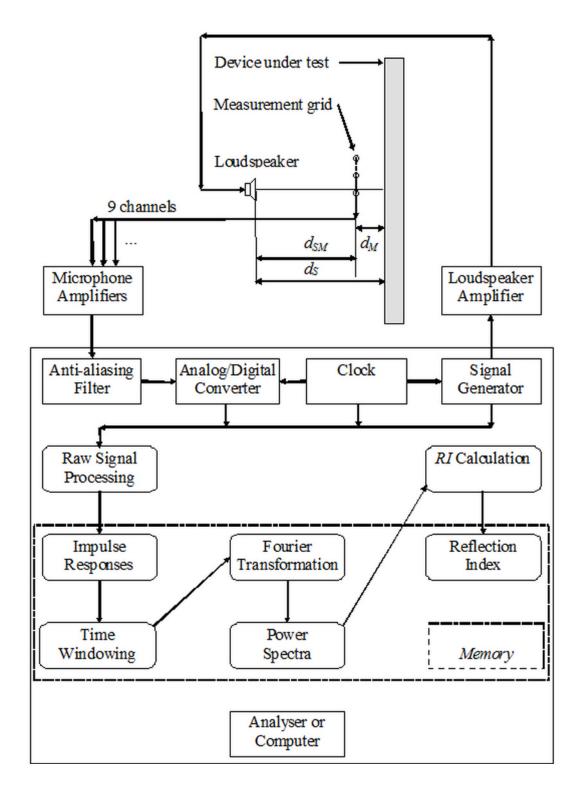


Figure 11 — Sketch representing the essential components of the measuring system

5.4 Measuring equipment

5.4.1 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, nine microphones with their microphone amplifiers, a multichannel sound card (or equivalent) capable of operating simultaneously on at least nine channels with the desired sample rate (see 5.5.2) and a signal analyser (hardware or software) capable of performing transformations between the time domain and the frequency domain.

NOTE 1 Part of these devices can be integrated into a frequency analyser or a personal computer equipped with specific add-on board(s).

The link between the essential components of the measuring system are shown in Figure 11.

The microphones shall meet at least the requirements for type 2 in accordance with EN 61672-1 and have a diameter of 1/2 inch (12,7 mm) maximum.

NOTE 2 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. Moreover, a high accuracy in measuring sound pressure levels is not of interest here. Strict requirements on the absolute accuracy of the measurement chain are, therefore, not needed.

The microphone should be sufficiently small and lightweight in order to be fixed on the measurement grid without moving. The signal subtraction technique (see 5.5.4) requires the loudspeaker and microphones relative position be kept constant. This may be very difficult in practice when *in situ* on an irregular terrain, therefore the generalized subtraction technique described in 5.5.4 allows to place the measurement grid without a rigid connection to the loudspeaker. Small, unavoidable misalignments between the impulse responses measured in front of the device under test and in the free field for the same microphone can be compensated by the adjustment procedure described in 5.5.4.

The microphones shall be mounted laying in the vertical plane of the measurement grid, in order to measure the direct and the reflected components with nominally the same directivity, and with the membrane not directed toward the ground.

5.4.2 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 magnitude of the 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 reflection index is calculated from the ratio of energetic quantities extracted from impulse responses taken using the same loudspeaker and measurement grid 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.

5.4.3 Test signal

The electro-acoustic source shall receive an input electrical signal that is deterministic and exactly repeatable.

The use of a loudspeaker typically introduces nonlinear distortion in the system, which strictly speaking violates the requirement for linearity in this method. Distortion due to the loudspeaker increases with the excitation level, then the user shall be aware of the problem and experiment with the excitation level to obtain the optimum S/N ratio. Sometimes the S/N ratio may be increased by reducing the excitation level. With certain types of signal the S/N ratio may be improved by repeating the same test signal and synchronously averaging the microphone response.

Generally speaking, any kind of excitation signal may be used to determine the impulse response and respective frequency response function of any linear and time-invariant system, provided that it contains enough energy at every frequency of interest. The impulse response can be obtained from the response to the excitation by deconvolution, or the frequency response function can be obtained by dividing the output

spectrum of the system under test by the spectrum of the input. The latter implies Fourier transformation of the input and output signal in order to perform the division in the spectral domain.

This document recommends the use of a period of deterministic, flat-spectrum signal, like maximum-length sequence (MLS) or exponential sine sweep (ESS), and transform the measured response back to an impulse response.

It shall be verified that:

- the generation of the test signal is deterministic and repeatable;
- impulse responses are accurately sampled (without strong 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 minutes 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.

5.5 Data processing

5.5.1 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.

Due to mechanical, electronic, or software manipulations, it is sometimes difficult to completely avoid slight changes in the amplification settings of the loudspeaker and in the sensitivity settings of the individual microphones when changing the measurement configuration from free field to in front of the sample under test or vice versa. For these reasons, in Formula (1) a further correction factor $C_{gain,k}$, which may slightly differ from unity, is taken into account. It shall be calculated at least once for each measurement grid position as the ratio between the spectrum obtained from windowing the incident component from the impulse response in front of the sample under test and the spectrum of the incident component obtained from windowing the free field impulse response:

$$C_{gain,k}\left(\Delta f_{g}\right) = \frac{\int_{\Delta f_{g}} \left|F\left[h_{i,k,D}(t)\cdot w_{i,k}(t)\right]\right|^{2} df}{\int_{\Delta f_{g}} \left|F\left[h_{i,k,FF}(t)\cdot w_{i,k}(t)\right]\right|^{2} df}$$

$$(4)$$

where

$h_{i,k,D}(t)$	is the incident reference component of the impulse response at the k -th measurement
, ,	point in front of the device under test;

hi,k,FF(t) is the incident reference component of the free-field impulse response at the k-th measurement point;

 $w_{i,k}(t)$ is the time window (Adrienne temporal window) for the incident reference component of the impulse response at the k-th measurement point;

F is the symbol of the Fourier transform;

 Δf_g is the frequency range encompassing the one-third octave frequency bands between 500 Hz and 2 kHz:

k is the microphone number according to Figure 3.b (k = 1, ..., 9).

- If $C_{gain,k}$ differs less than 5 % from 1, it can be set equal to 1.
- If $C_{gain,k}$ differs more than 20% from unity, then this can be considered as a warning that some measurement system settings have substantially changed, and it is recommendable to recheck the data.
- If $C_{gain,k}$ differs less than 20 % and more than 5 % from 1, then values of this factor shall be as determined using Formula (4).

The value of $C_{gain,k}$ as described above should be considered frequency independent. Indeed, deviations from unity can be typically ascribed to deviations in the global loudspeaker amplification or microphone sensitivity settings. On the other hand, due to uncertainties in the measurements, e.g. related to windowing effects affecting mainly low frequencies, or to effects of microphone shadowing affecting mainly high frequencies, some deviations from a flat behaviour can be expected at those low and high frequencies, while negligible in the one-third octave bands between 500 Hz and 2 kHz. Therefore, the value of $C_{gain,k}$ shall be derived in the frequency range encompassed by the one-third octave bands between 500 Hz and 2 kHz.

The Adrienne window length used in the calibration procedure described here – Formula (4) – should be shorter than the standard length of $T_{W,ADR}$ = 7,9 ms (see 5.5.5) due to the fact that the incident reference component of the impulse response at the k-th measurement point in front of the device under test, $h_{i,k,D}(t)$, is followed by the reflected component. Taking into account the more unfavourable cases (microphones 1, 3, 7 and 9), the delay between the incident component of the impulse response and the reflected component is about 1,3 ms and the Adrienne window should be composed as follows (see 5.5.5): left-half Blackman-Harris shape with a length of 0,5 ms; flat portion with a length of 0,56 ms; right-half Blackman-Harris with a length of 0,24 ms; total length of 1,3 ms.

NOTE The correction factor $C_{\text{gain},k}$ is obtained from only a part of the spectrum (500 Hz to 2 kHz one-third octave bands), while the signal subtraction is optimized fitting the direct components of the free field impulse response to that of the impulse response in front of the device under test in all its details, thus broadband. Therefore the correction factor $C_{\text{gain},k}$ is taken into account separately from the signal subtraction procedure described in 5.5.4.

5.5.2 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 equal or greater than 44 kHz.

NOTE Although the signal is already unambiguously defined when the Nyquist criterion is met, higher sample rates facilitate a clear reproduction of the signal. This document prescribes the use of the signal subtraction technique (see 5.5.4), which implies knowledge of the exact wave form. Therefore, with the prescribed sample rates errors can be detected and corrected more easily, such as time shifts in the impulse responses between the measurement in front of 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:

$$f_{co} \le k_f f_s \tag{5}$$

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

The filter order shall be not smaller than 6.

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

5.5.3 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.

5.5.4 Signal subtraction technique

After positioning the loudspeaker and the measurement grid as described in 3.9 – 3.13, the overall impulse responses have to be measured.

They consist of a direct component, a component reflected from the surface under test and other parasitic reflections (Figure 12.a). The direct component and the reflected component from the device under test shall be separated for each microphone position.

This document requires this separation be done using the signal subtraction technique: the reflected component is extracted from the overall impulse response after having removed the direct component by subtraction of an identical signal (Figures 12.c and 12.d). This means that the direct sound component shall be exactly known in shape, amplitude and time delay. This can be obtained by performing a free-field measurement for each microphone using the same geometrical configuration of the loudspeaker and the measurement grid. In particular, their relative position shall be kept as constant as possible. The direct component is extracted from the free-field measurement (Figure 12.b).

This technique allows broadening of the time window, leading to a lower frequency limit of the working frequency range, without having very long distances between loudspeaker, microphone and device under test.

The principle of the signal subtraction technique is schematically illustrated in Figure 12.

In principle, the signal subtraction technique requires the loudspeaker and microphones relative position be kept constant in order to get a perfect alignment between the impulse responses measured in front of the device under test and in the free field for the same microphone.

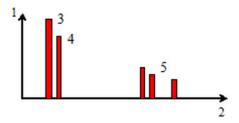
This may be very difficult in practice when *in situ*, due to placement of the equipment on an irregular terrain, small movements of the loudspeaker cone or the microphones when displacing the equipment, variations in the response of the measurement equipment due to temperature or electrical deviations occurring between the free field and the reflected measurements, etc.

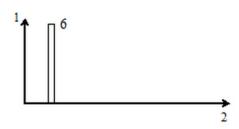
Therefore it is necessary that, before performing the signal subtraction, the free field signal is corrected for a small shift relative to the impulse response in front of the device under test at each microphone.

Since in general the actual time shift is not equal to a multiple of the temporal sample size Δt , stepwise shifting of one or more data points is inadequate.

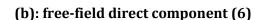
An accurate alignment can be done as follows; it allows the placement of the measurement grid without a rigid connection to the loudspeaker; the unavoidable misalignments between the impulse responses measured in front of the device under test and in the free field for the same microphone may then be compensated until then they are smaller or equal to 50 mm.

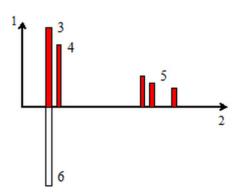
The accurate alignment procedure is composed of the following steps:

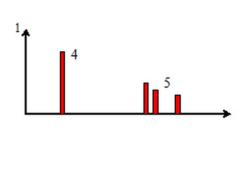




(a): Overall impulse response including: direct incident component (3), reflected component (4), unwanted parasitic components (5)







(c): direct component cancellation from the overall impulse response using the free-field direct component (4)

(d): Result

- 1 Impulse response amplitude [arbitrary units]
- 2 Time *t* [ms]
- 3 Direct incident component
- 4 Reflected component
- 5 Unwanted parasitic component
- Free-field direct component

Figure 12 — Principle of the signal subtraction technique

- 1. For each microphone position, an impulse response measured in front of the device under test and one measured in the free field with nominally the same geometry are compared.
- 2. The free field impulse response is repeatedly shifted with a small "moving step" $\Delta \tau$ (which is a fraction of the temporal step Δt between the discrete points of the acquired data, see below).
- 3. The sum of the squared differences between the free field impulse response and the impulse response measured in front of the device under test is calculated in a limited interval around the first and main peak of the impulse response measured in front of the device under test.
- 4. The operations in 2 and 3 are repeated until the minimum of the sum in 3 is found (least squares); the number n of moving steps $\Delta \tau$ needed to get this least square minimum is recorded.
- 5. The free field impulse response is finally shifted with the temporal step $n\Delta\tau$ found in 4 and its amplitude is adjusted so that the amplitude of its first (and main) peak is exactly the same of the first (and main) peak of the impulse response measured in front of the device under test.

6. The shifted and amplitude adjusted free field impulse response is subtracted from the impulse response measured in front of the device under test.

NOTE 1 The shifted and amplitude adjusted free field impulse response used in step 5 above is discarded after the subtraction; the free field impulse response used to calculate the reflection index according to Formula (1) is the original, unchanged one.

The "moving step" $\Delta \tau$ in 2 shall be about 1/50 of the temporal step Δt between the discrete points of the acquired data (linked to the given sample f_s rate by $\Delta t \approx 1/f_s$).

The least squares calculation in 3 is limited to about 50 discrete data points around the first and main peak of the impulse response measured in front of the device under test.

The iteration in 4 is limited to \pm 2 discrete data points of the acquired data, i.e. \pm 100 moving steps $\Delta\tau$; this range is centred on the first and main peak of the impulse response measured in front of the device under test, i.e. the main peak of incident component of the impulse response measured in front of the device under test.

In order to shift the free field impulse response in n moving steps, $n\Delta\tau$, with $\Delta\tau$ considerably smaller than the temporal step Δt between the discrete points of the acquired data, the following procedure shall be applied.

- a. The free field impulse response is Fourier transformed in the frequency domain and its phase is changed by multiplying it with a frequency dependent factor $exp(i2\pi fn\Delta\tau)$.
- b. The resulting phase corrected Fourier transform is inverse transformed to generate the shifted free field impulse response in the time domain, which then can be used for signal subtraction.

NOTE 2 In the accurate alignment procedure described above, no additional points are added to the original impulse response. The sentence in step 2 above saying that "The free field impulse response is repeatedly shifted with a small "moving step" $\Delta \tau$ " actually means that the free field impulse response is Fourier transformed in the frequency domain and its phase is changed as explained in steps a and b above.

As the goal of the operation is to remove the incident component of the impulse response (the "direct sound"), leaving only the reflected one, the signal subtraction effectiveness can be measured by the decibel level reduction in the direct sound from the measurement to the result. Specifically, the sum of the energy within $0.5 \, \text{ms}$ of either side of the first and main peak of direct sound can be compared before and after subtraction to find the effective reduction. Formula (6) defines the reduction factor R_{sub} .

$$R_{sub} = 10 \lg \begin{bmatrix} \int_{t_{p,k}-0.5ms}^{t_{p,k}+0.5ms} |h_{i,k,FF}(t)|^{2} dt \\ \frac{t_{p,k}-0.5ms}{t_{p,k}+0.5ms} |h_{i,k,RES}(t)|^{2} dt \end{bmatrix} dB$$
(6)

where

hi,k,FF(t) is the incident reference component of the free-field impulse response at the k-th measurement point (before the signal subtraction);

hi,k,RES(t) is the residual incident reference component of the impulse response taken in front of the sample under test at the *k*-th measurement point (after the signal subtraction);

 $t_{p,k}$ is the time instant where the first and peak of the incident component of the impulse response at the k-th measurement point is located (before the signal subtraction);

F is the symbol of the Fourier transform;

is the microphone number according to Figure 3.b (k = 1, ..., 9).

A reduction factor R_{sub} equal to the peak to noise ratio of the measurement can be considered a complete subtraction, since this would leave nothing in the area of the direct sound except the background noise.

Practical experience indicates that a value of R_{sub} < 10 dB should be considered a warning that the signal subtraction is not perfect.

The measurements shall take place in a sound field free from reflections coming from objects other than the device under test. However, the use of a time window cancels out reflections arriving after a certain time delay, and thus originating from locations further away than a certain distance (see 5.6.3).

5.5.5 Adrienne temporal window

For the purpose of this document, windowing operations in the time domain shall be performed using a temporal window, called Adrienne temporal window, with the following specifications (see Figure 13).

- a leading edge having a left-half Blackman-Harris shape and a fixed length of 0,5 ms ("pre-window");
- a flat portion ("main body");
- a trailing edge having a right-half Blackman-Harris shape;
- the lengths of the flat portion and the right-half Blackman-Harris portion shall have a ratio of 7/3.

For an Adrienne temporal window having a total length $T_{W,ADR}$ = 7,9 ms (standard length):

- a leading edge having a left-half Blackman-Harris shape and a fixed length of 0,5 ms ("pre-window");
- a flat portion having a total length of 5,18 ms ("main body");
- a trailing edge having a right-half Blackman-Harris shape and a length of 2,22 ms.

For an Adrienne temporal window having a total length $T_{W,ADR}$ = 6,0 ms:

- a leading edge having a left-half Blackman-Harris shape and a fixed length of 0,5 ms ("pre-window");
- a flat portion having a length of 3,85 ms ("main body");
- a trailing edge having a right-half Blackman-Harris shape and a length of 1,65 ms.

In all cases when the window length $T_{W,ADR}$ has to be changed from its standard value of 7,9 ms, the lengths of the flat portion and the right-half Blackman-Harris portion shall have a ratio of 7/3.

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



Key

1 Time *t* [ms]

2 Adrienne window shape [arbitrary units]

Figure 13 — The Adrienne temporal window

NOTE 1 A four-term full Blackman-Harris window of length $T_{W,BH}$ is:

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

$$\tag{7}$$

where

 $a_0 = 0,35875;$

 $a_1 = 0,48829;$

 $a_2 = 0,14128;$

 $a_3 = 0.01168$;

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

In order to fully reject the ground reflection from the reflected component analysis window, the standard Adrienne window length $T_{W,ADR}$ = 7,9 ms has to be changed (see 5.5.7). Also, when testing very large samples the Adrienne window length may be enlarged in order to achieve a better low frequency limit. In all cases when the Adrienne window length $T_{W,ADR}$ has to be changed from its standard value of 7,9 ms, the lengths of the flat portion and the right-half Blackman-Harris portion shall have a ratio of 7/3.

The Adrienne temporal window is used as follows.

When the device under test has the minimum dimensions for the results be valid on the full frequency range (height ≥ 4 m), the Adrienne temporal window shall have:

- a total length of $T_{W,ADR}$ = 7,9 ms to process the impulse responses coming from microphones 1 to 6; the RI values obtained over the six microphones shall be averaged to get the final RI values in the one-third frequency bands centred on 100 Hz, 125 Hz and 160 Hz;
- a total length of $T_{W,ADR}$ = 6,0 ms to process the impulse responses coming from microphones 1 to 9; the RI values obtained over the nine microphones shall be averaged to get the final RI values in the one-third frequency bands having centre frequency from 200 Hz to 5 kHz.

In other words, in the one-third octave bands centred on 100 Hz, 125 Hz and 160 Hz the average is taken considering only microphones 1 to 6 (see Figure 3), using an Adrienne temporal window having a total length of $T_{W,ADR} = 7.9$ ms. From the 200 Hz one-third octave band, all nine microphones are taken into account, using an Adrienne temporal window having a total length of $T_{W,ADR} = 6.0$ ms.

When the device under test doesn't have the minimum dimensions for the results be valid on the full frequency range (height < 4 m, see 5.5.7), the Adrienne temporal window shall have a reduced length so as to exclude ground reflections from the reflected component of the impulse responses; different window lengths for microphones 1 to 3, microphones 4 to 6 and microphones 1 to 9 may be used.

5.5.6 Placement of the Adrienne temporal window

Direct component

For the "free-field" direct component, the Adrienne temporal 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 direct component peak.

The above shall be repeated for each microphone positions. Changing the microphone position, the marker point is placed at slightly different time instants.

Reflected component

NOTE After the signal subtraction, the resulting signal has its first peak where the reflected component begins.

For the reflected component, the Adrienne temporal window shall be placed as follows, acting on the impulse response resulting from the signal subtraction:

- the first peak of the impulse response, corresponding to the reflected component, is detected, when possible with the use of geometrical calculations assuming specular reflection (for non-flat devices, the conventional reflection plane is the reference plane 3.12);
- a time instant preceding the reflected component peak of 0,2 ms is located;
- the reflected component Adrienne temporal window is placed so as its marker point corresponds to this time instant.

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

The above shall be repeated for each microphone positions. Changing the microphone position, the marker point is placed at slightly different time instants.

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

5.5.7 Low frequency limit and sample size

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

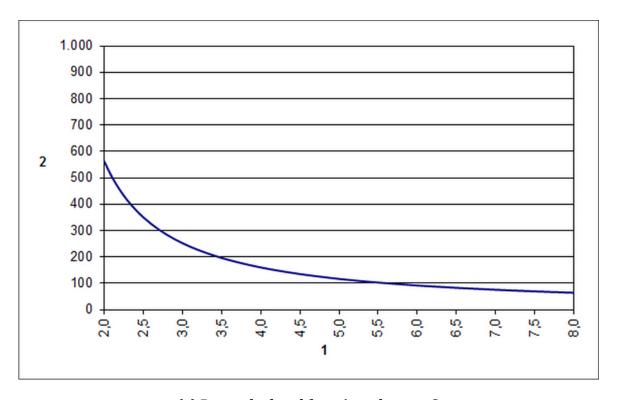
The low frequency limit f_{min} of reflection index measurements depends on the shape and width of the Adrienne temporal window. The width in turn depends on the smallest dimension (height or length) of the noise reducing device under test. In fact, the following unwanted components shall be kept out of the Adrienne temporal window for the reflected components:

- the sound components diffracted by the edges of the noise reducing device under test;
- the sound components reflected by the ground on the sound source side of the noise reducing device under test.

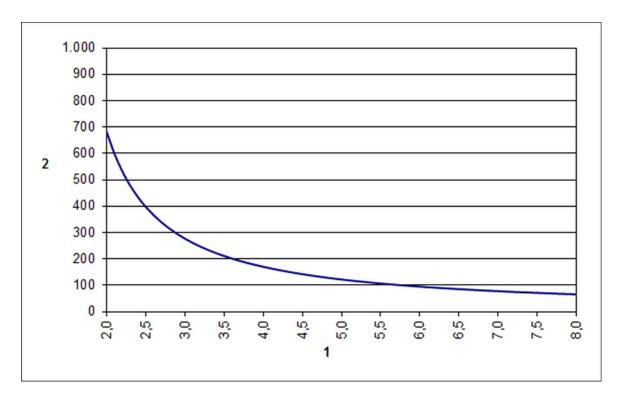
For noise reducing devices having a height smaller than the length, the most critical component is that reflected by the ground and therefore the critical dimension is the height.

For noise reducing devices having a height smaller than the length, the low frequency limit f_{min} for normal incidence measurements as a function of the height of the noise reducing device under test is given in Figure 14.

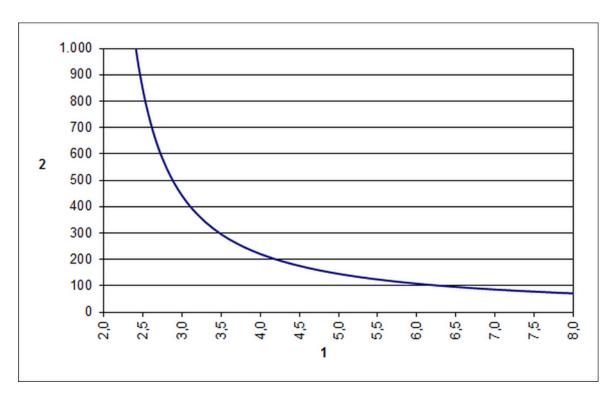
For qualification tests, the sample shall have minimum dimensions of 4 m in height by 4 m in length (see also Figure 7). These conditions give a low frequency limit for the reflection index, mainly due to the disturbance from ground reflection, of about 160 Hz at microphone 2, 170 Hz at microphone 5 and 220 Hz at microphone 8 (see Figure 14; microphone labelled according to Figure 3.b), i.e. using the two window lengths specified in 5.5.5 measurements are valid down to the 200 Hz one-third octave band. Measured values in the three one-third octave bands 100 Hz, 125 Hz and 160 Hz could be kept for information.



(a) Data calculated for microphone n. 2



(b) Data calculated for microphone n. 5



(c) Data calculated for microphone n. 8

Key

1 Noise reducing device height h_B [m] 2 Low frequency limit f_{min} [Hz]

Figure 14 — Low frequency limit of reflection index measurements as a function of the height of the noise reducing device under test

5.6 Positioning of the measuring equipment

5.6.1 Maximum sampled area

The size of the maximum sampled area is defined by the shortest distances of the loudspeaker front panel and the microphones to the reference plane for reflection index measurements of the device under test together with the width of the Adrienne temporal window.

For normal incidence measurements, the maximum sampled area for each microphone is bounded by a circle with its centre at the point of incidence. Referring to the same Adrienne temporal window length used to calculate the low frequency limit (see 5.5.6, 5.5.7 and Figures 7, 8, 9, 10), the radius r in metres of the above mentioned circle is:

$$r = \frac{1}{d_{s} + d_{M} + cT_{w,ADR}} \sqrt{\left(d_{s} + d_{M} + \frac{cT_{w,ADR}}{2}\right) \left(d_{s} + \frac{cT_{w,ADR}}{2}\right) \left(2d_{M} + cT_{w,ADR}\right) cT_{w,ADR}}$$
(8)

where

 d_S distance from the loudspeaker front panel to the reference plane (m);

 d_M distance from the microphone to the reference plane (m);

c speed of sound in air (m/s);

 $T_{w,ADR}$ width of the Adrienne temporal window for the reflected component (s).

NOTE 1 As an example, with the values of d_S , d_M , $T_{w,ADR}$ specified in this document, sample dimensions of 4 x 4 m (height x length) and c = 340 m/s the maximum sampled area radius is 1,96 m.

NOTE 2 The radius of the surface area that contributes to the measured values of the sound reflection index is a decreasing function of frequency, but is not necessarily equal to the radius of the maximum sampled area previously defined.

NOTE 3 For oblique incidence, the maximum sampled area is the geometrical figure defined by the intersection between the reference plane and the ellipsoid of revolution whose foci are the sound source position and the microphone position and whose major axis is given by:

$$a = cT_w + \sqrt{(d_S + d'_M)^2 + d_p^2}$$
(9)

with the same symbols used before and:

 d'_{M} distance from the microphone to the reference plane for the reflection index measurements, depending on the microphone position (m);

 d_p distance from the loudspeaker front panel to the microphone projected on the reference plane (m).

5.6.2 Selection of the measurement positions

5.6.2.1 General

The measuring equipment shall be placed in front of the noise reducing device to be tested in positions selected according to the following rules.

In all cases, whenever possible distances should be measured with an uncertainty not greater than 1 percent of their nominal values.

5.6.2.2 Flat homogeneous samples

The loudspeaker and the measurement grid are located so that they are in the respective *reference positions* (see 3.13 and 3.14). The measurement grid is vertical and the microphones numbered 4, 5, and 6 have the same distance $d_M = 0.25$ m from the reference plane.

The central microphone of the measurement grid (microphone 5) shall have the same distance from the edge of two subsequent posts.

The distance of the loudspeaker front panel to the microphone grid shall be kept as constant as possible and equal to $d_{SM} = 1,25$ m.

A set of nine impulse responses, one for each microphone on the measurement grid, is measured in front of the device under test.

A free-field impulse response is measured for each microphone position, displacing the loudspeaker and the measurement grid in order to avoid facing any nearby object, including the ground, and keeping nominally the same relative geometry.

The measurements taken in front of the sample plus the corresponding free-field measurements shall be processed and averaged according to the reflection index Formula (1).

For each one-third octave band, the number of measurements n_j to be taken into account in the averaging process is selected according to 5.5.5.

For each one-third octave band, the measurements to be taken into account in the averaging process are processed with the same Adrienne window length, according to 5.5.5.

5.6.2.3 Non-flat or non-homogeneous samples in one direction

For the purpose of this document, a noise reducing device is considered non-flat if the depth b_s of its surface structure is at least 85 mm, see Figure 15.a.

NOTE 1 A surface structure depth of 85 mm corresponds to one-quarter of the free-field wavelength for the nominal frequency of the predominating one-third octave band of the normalized road traffic noise spectrum according to EN 1793–3.

For the purpose of this document, a noise reducing device is considered non-homogeneous when its surface to be exposed to road or rail traffic noise when the device is in place is constituted by different materials (having different acoustic properties) and each portion of material has a minimum width b_m of least 85 mm, see Figure 15.b.

Both periodic surface structures and periodic sequence of different materials have a characteristic spatial length, called the *period length* L_p (see Figure 15).

If the device under test is non-flat and/or non-homogeneous due to a periodicity in the vertical direction due to structure corrugation or material change, the minimum height of the sample for the measurement to be valid in the full frequency range (200 Hz to 5 kHz) shall be increased from 4 m to 4 m plus a full period length L_p .

If the device under test is non-flat and/or non-homogeneous due to a periodicity in the horizontal direction due to structure corrugation or material change, the minimum length of the sample for the measurement to be valid in the full frequency range (200 Hz to 5 kHz) shall be increased from 4 m to 4 m plus a full period length L_p .

If the device under test is non flat and/or non-homogeneous due to a periodicity both in a vertical and horizontal direction due to structure corrugation or material change, the minimum height (length) of the sample for the measurement to be valid in the full frequency range (200 Hz to 5 kHz) shall be increased from 4 m to 4 m plus the projection of the full period length L_p in the vertical (horizontal) plane.

For homogeneous and non-flat samples, the loudspeaker and the measurement grid shall be located in three subsequent reference positions, labelled A, B and C, located so that (see 3.14 and Figure 15.a):

- when the microphone grid is in its *reference position* A, microphone 5 is in front of the most protruding part of the surface of the noise reducing device under test and as close as possible to the middle of the sample;
- when the microphone grid is in its *reference position* C, microphone 5 is in front of the less protruding part of the surface of the noise reducing device under test and as close as possible to the middle of the sample;
- when the microphone grid is in its *reference position* B, microphone 5 is midway to positions A and C and as close as possible to the middle of the sample;
- the subsequent reference positions A, B and C are within one period length L_p .

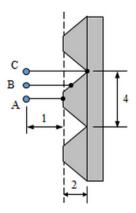
For flat and non-homogeneous samples, the loudspeaker and the measurement grid shall be located in two or more subsequent reference positions, labelled A, B, C, etc., located so that (see 3.14 and Figure 15.b):

- in each *reference position* of the microphone grid, microphone 5 is in front of a different surface material of the noise reducing device under test and as close as possible to the middle of the sample (of course gaskets, bolts and other small portion of the surface having negligible acoustic effects are excluded);
- the subsequent reference positions A, B, C, etc. are within one period length L_p .

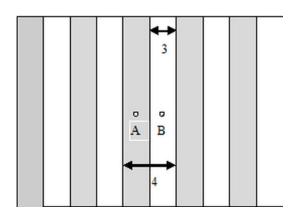
When passing from the first reference position to the others, the loudspeaker and the measurement grid shall be shifted in the same way, keeping the same relative geometry.

Impulse response measurements are taken at each microphone for each position of the measurement grid. For each microphone position a free-field measurement is taken, keeping the same relative geometry between the loudspeaker and the measurement grid.

NOTE 2 Usually the measurements at the nine microphones of a grid and the corresponding free-field measurements are performed within a short time (typically less than 20 min) using a multichannel equipment. This helps to avoid temperature differences, which may cause time shift, between the measurements in front of the sample under test and the free-field measurements.



(a) Central microphone (microphone n. 5) reference positions A (most protruding part), B (midway), and C (less protruding part) for a periodic non flat sample (side view)



(b) Microphone reference positions A and B for a periodic flat non-homogeneous sample combining two different materials (front view)

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- Distance from the loudspeaker front panel to 2 the reference plane d_M [m]
- 3 Width of each material strip b_m [m]
- A reference position for the most protruding part of the sample under test
- C reference position for the less protruding part of the sample under test
- Depth of the surface structure b_s [m]
- 4 Spatial period length L_p [m]
- B reference position midway and B of the sample under test

Figure 15 — Microphones arrangement (not to scale)

For each grid position, the measurements taken in front of the sample plus the corresponding free-field measurements shall be processed and averaged according to 5.2.

For each one-third octave band, the measurements to be taken into account in the averaging process are processed with the same Adrienne window length, according to 5.5.5.

In any case, the final reflection index as a function of frequency shall be computed as the overall average of all partial results, i.e. for each microphone of each grid position.

5.6.2.4 Non-flat or non-homogeneous samples in two directions

Changes in surface structure profile, materials used or both can give rise to periodic structures in two directions (see Figure 16).

In both directions the device under test may have a characteristic spatial length; they will be labelled L_{p1} and L_{p2} (see Figure 16).

If the device under test is non flat due to periodicity in two directions, the minimum height (length) of the sample for the measurement to be valid in the full frequency range (200 Hz to 5 kHz) shall be increased from 4 m (6 m) to 4 m (6 m) plus the projection of the two full period lengths L_{p1} and L_{p2} in the vertical (horizontal) plane.

The loudspeaker and the measurement grid shall be located in four or more subsequent reference positions, labelled A, B, C, D, etc., located so that (see 3.14 and Figure 16):

- there is a *reference position* for the microphone grid where the microphone n. 5 is in front of the most protruding part of the surface of the noise reducing device under test and as close as possible to the middle of the sample;
- there is a *reference position* for the microphone grid where the microphone n. 5 is in front of the less protruding part of the surface of the noise reducing device under test and as close as possible to the middle of the sample;
- there is a *reference position* for the microphone grid where the microphone n. 5 is midway to positions A and C and as close as possible to the middle of the sample;
- there is a *reference position* of the microphone grid where microphone n. 5 is in front of each different surface material of the noise reducing device under test and as close as possible to the middle of the sample (of course gaskets, bolts and other small portion of the surface having negligible acoustic effects are excluded);
- the subsequent reference positions A, B and C, D, etc. are within one period length L_{p1} and one period length L_{p2} .

When passing from the first reference position to the others, the loudspeaker and the measurement grid shall be shifted in the same way, keeping the same relative geometry.

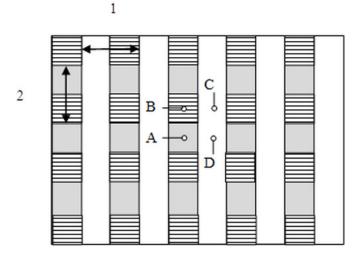
Impulse response measurements are taken at each microphone for each position of the measurement grid. For each microphone position a free-field measurement is taken, keeping the same relative geometry between the loudspeaker and the measurement grid.

NOTE Usually the nine measurements of a grid and the corresponding free-field measurements are performed within a short time (typically less than 20 min) using a multichannel equipment. This helps to avoid temperature differences, which may cause time shift, between the measurements in front of the sample under test and the free-field measurements.

For each grid position, the measurements taken in front of the sample plus the corresponding free-field measurements shall be processed and averaged according to according to 5.2.

For each one-third octave band, the measurements to be taken into account in the averaging process are processed with the same Adrienne window length, according to 5.5.5.

In any case, the final reflection index as a function of frequency shall be computed as the overall average of all partial results, i.e. for each microphone of each grid position.



Key

- Spatial period length in the horizontal direction L_{p1} [m]
- Spatial period length in the vertical direction L_{p2} [m]

Figure 16 — Example of a flat sample combining three different materials in two dimensions (front view). Reference positions A, B, C and D are shown

5.6.2.5 Check of the loudspeaker and measurement grid relative position

In order to evaluate the correctness of the relative position of the loudspeaker and measurement grid, the following procedure shall be implemented.

- 1. The loudspeaker and the measurement grid are placed in their respective positions.
- 2. A flat reflective thin plate, having the minimum dimension of $1,60 \text{ m} \times 1,60 \text{ m}$, shall be placed vertically in front of the sample under test, between the measurement grid and the sample under test, at a distance from microphone 5 of 0,25 m.
- 3. An impulse response is measured.
- 4. For each microphone, the first arrival of the direct sound is detected.
- 5. The time delay gaps Δt_{k5} between the first arrival of the direct sound at microphone k (k = 1,..., 9 and $k \ne 5$) and microphone 5 are calculated.
- 6. These time delay gaps are transformed in path length differences, taking into account the temperature dependent sound speed *c* as follows:

$$\Delta d_{k5} = c \cdot \Delta t_{k5} \quad (k = 1, \dots, 9 \text{ and } k \neq 5)$$

$$\tag{10}$$

- 7. The resulting path length differences are compared with the nominal values in Table 3.
- 8. If the resulting path length differences are close to their nominal values in Table 3 within the associated tolerance ε_k for all microphones, then the loudspeaker-grid position is correct.
- 9. Otherwise the positions of the loudspeaker and the measurement grid shall be adjusted and all the check of their relative position shall be repeated.

Table 3 – Nominal values of: the path length differences between the first arrival of the direct sound at microphone 5 and the other microphones, Δd_{k5} ; the path length differences between the arrival of the direct and reflected sound at microphone k, Δd_{k} ; and associated tolerance ε_k

k	Δd_{k5} , m	Δd_k , m	ε_k , m
1	0,122	0,467	±0,025
2	0,062	0,483	±0,025
3	0,122	0,467	±0,025
4	0,062	0,483	±0,025
5	0,000	0,500	±0,025
6	0,062	0,483	±0,025
7	0,122	0,467	±0,025
8	0,062	0,483	±0,025
9	0,122	0,467	±0,025

5.6.2.6 Check of the measurement grid position

In order to evaluate the correct position of the measurement grid in front of the sample under test, the following procedure should be implemented for each measurement grid position selected according to 5.6.2.2, 5.6.2.3, 5.6.2.4.

- 1. The loudspeaker and the measurement grid are placed in their respective positions in front of the sample under test.
- 2. A flat reflective thin plate, having the minimum dimension of $1,60 \text{ m} \times 1,60 \text{ m}$, shall be placed in front of the sample under test in the position of the reference plane.
- 3. A short sharp sound pulse is emitted from the sound source.
- 4. For each microphone, the first arrival of the direct sound and the first arrival of the reflected sound are detected.
- 5. The time delay gaps Δt_k between the first arrival of the direct sound and the first arrival of the reflected sound at microphone k (k = 1,..., 9) are calculated.
- 6. These time delay gaps are transformed in path length differences, taking into account the temperature dependent sound speed *c* as follows:

$$\Delta d_k = c \cdot \Delta t_k \ (k = 1, ..., 9) \tag{11}$$

- 7. The resulting path length differences are compared with the nominal values in Table 3.
- 8. If the resulting path length differences are close to their nominal values in Table 3 within the associated tolerance ε_k for all microphones, then the loudspeaker-grid position is correct.
- 9. Otherwise, the positions of the loudspeaker and the measurement grid shall be adjusted and all the check of their relative position shall be repeated.

The above procedure may be time consuming when on site; therefore it can be avoided using a loudspeaker and microphone grid set up designed to guarantee the correct positioning. Pictures of the measurement set up shall be shown in the measurement report.

5.6.3 Reflecting objects

Any object other than the device under test, shall be considered as a reflecting object that could cause parasitic reflections (e.g. safety rails, fences, rocks, parked cars, etc.). These objects shall remain out of the maximum sampled area and at a distance from the microphone greater than the radius of the maximum sampled area.

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

5.6.4 Safety considerations

This test method may involve hazardous operations when measurements are made on or aside railways in use. 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 based on a risk assessment and determine the applicability of regulatory limitations prior to use.

5.7 Sample surface and meteorological conditions

5.7.1 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 0-70 °C during the measurement.

5.7.2 Wind

Wind speed at microphone positions shall not exceed 5 m/s during the measurements.

5.7.3 Air temperature

The ambient air temperature shall be within 0-40 °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.

5.8 Single-number rating of sound reflection DL_{RI}

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

The single-number rating of sound reflection DL_{RI} , in decibels, is given by:

$$DL_{RI} = -10 \cdot \lg \left[\frac{\sum_{i=m}^{18} RI_i \cdot 10^{0,1L_i}}{\sum_{i=m}^{18} 10^{0,1L_i}} \right]$$
 (12)

where

m number of the lowest reliable one-third octave frequency band;

L 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.

In some cases the ratio of the summations term in the expression of DL_{RI} can exceed 1 which precludes the correct calculation of DL_{RI} . For this reason the maximum value of this ratio shall be limited to 0,99.

For qualification purposes, the single number rating of sound reflection DL_{RI} shall be calculated for samples of minimum dimensions conforming to 5.3.

For other purposes, for example assessing a roadside barrier of 3,5 m height, single number ratings shall be informative and explicitly reported with the frequency range, in one-third octave bands, over which they are calculated. For example, for a 3,5 m high barrier the single number rating of sound reflection is DL_{RI} (400 - 5 000 Hz), because 300 Hz is the lowest frequency applicable to all microphones and this invalidates the measurements in the 315 one-third octave band and below.

5.9 Measurement uncertainty

The uncertainty of results obtained from measurements according to this European Standard shall be evaluated, preferably in compliance with ISO/IEC Guide 98-3. If reported, the expanded uncertainty together with the corresponding coverage factor for a stated coverage probability of 95 % as defined in ISO/IEC Guide 98-3 shall be given. More information on measurement uncertainty is given in Annex A.

5.10 Measuring procedure

The measurement shall be carried out as follows:

- a. the sample surface and meteorological conditions are checked to ensure they comply with the specifications in 5.7. If not, the measurement cannot be carried out;
- b. the measuring equipment is placed on site as specified in 5.6. The safety considerations in 5.6.4 apply;
- c. The loudspeaker and measurement grid positions are checked as described in 5.6.2.5 and 5.6.2.6;
- d. the radius of the maximum sampled area as specified in 5.6.1 is computed and it is checked that no reflecting objects are in this area. If not, the measurement cannot be carried out;
- e. the test signal is selected;
- f. the test signal is generated;
- g. the total signal as received by the microphones is sampled with a sample rate selected according to 5.5.2;
- h. the total signal as received by the microphone is processed in order to obtain the overall impulse response in the selected measurement positions;
- i. if it is suspected that the measurement may be contaminated by the background noise, the overall impulse response data are further averaged or new impulse response are acquired according to the best procedure recommended for the selected test signal (see 5.4.3) until a given degree of accuracy is obtained in each one-third frequency band of interest;
- j. for each microphone position in front of the device under test a free-field impulse response with the measurement set-up oriented toward the free space is acquired;
- k. the signal subtraction technique (see 5.5.4) is applied to each measurement of each set of measurements on the measurement grid. The direct component from the sound source is isolated from the free-field measurement using the Adrienne temporal window (see 5.5.5); the components reflected by the maximum sampled area are isolated, using the Adrienne temporal window, from measurements in front of the sample under test (see 5.5.5);
- l. the quality of the signal subtraction is evaluated using the reduction factor R_{sub} (see 5.5.4);
- m. the power spectra of the windowed signals are computed;

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- n. the correction factors $C_{geo,k}$, $C_{dir,k}$ and $C_{gain,k}$ are calculated;
- o. the reflection index is computed according to 5.2;
- p. the single-number rating is calculated according to 5.8, if applicable;
- q. the measurement uncertainty is evaluated (see Annex A);
- r. the measurement report is written.

5.11 Test report

The test report shall include the information listed below (see Annex B):

- 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 noise reducing device under test, measurement set-up, reflecting objects nearby the maximum sampled area (if any);
- e. description of the noise reducing device under test: brand, type, dimensions, age, actual conditions, composition (number of layers, thickness(es), material specification, etc.);
- f. surface conditions of the noise reducing 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 microphones and the number of measurements;
- equipment used for measurement and analysis, including name, type, serial number and manufacturer, pictures;
- j. correction factors for sound source directivity, as per Formula (3);
- k. correction factors for changes in the sound source gain, if any (see 5.5.1);
- l. type and characteristics of the anti-aliasing filter and sample rate of the sampling/analysis device;
- m. length of the Adrienne temporal window used for the analysis;
- n. low frequency limit of the measurement and its relationship with the smallest dimension of the noise reducing device under test (see 5.5.7);
- o. results of the measurements:
- p. measurement uncertainty;
- q. single-number rating of the result (when applicable); the lowest reliable one-third octave frequency band used in the single-number rating calculation shall be clearly indicated;
- r. 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 reflection index in one-third octave frequency 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 a restricted frequency range and the reasons of the restriction(s) shall be clearly reported.

The values of the reflection index shall be rounded off to two decimal places.

The single-number rating shall be reported after having being rounded to the nearest integer.

Annex A

(informative)

Measurement uncertainty

A.1 General

The accepted format for expression of uncertainties generally associated with methods of measurement is that given in ISO/IEC Guide 98-3. 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.

However, this method implies the statement of an analytical model of the sound reflection index as a function of many input variables and this seems, at the state of the art of the knowledge, not feasible.

A.2 Measurement uncertainty based upon reproducibility data

In the absence of an analytical model for the evaluation of an uncertainty budget, values for the standard deviation of reproducibility, when available, may be used as an estimate of the combined standard uncertainty of determinations of sound reflection index.

In each one-third octave band the standard deviation of reproducibility $s_{R,j}$ is assumed as an estimate of the of the combined standard uncertainty u_i of the sound reflection index RI_i :

$$u_{j} = u(RI_{j}) = s_{R,j} \tag{A.1}$$

Then the expanded uncertainty, U_j , is specified, such that the interval $[RI_j - U_j, RI_j + U_j]$ covers e.g. 95 % of the values of RI_j that might reasonably be attributed to RI_j . 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.

To that purpose, a coverage factor, k_p , is used, such that $U_j = k_p \cdot u_j$. The coverage factor depends on the probability distribution associated with the measurand.

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

A.3 Standard deviation of repeatability and reproducibility of the sound reflection index

In the frame of the European project QUIESST an inter-laboratory test has been carried out in order to assess the repeatability and reproducibility of the test method described in this European standard when applied to real-life samples. The values for the standard deviation of repeatability and reproducibility of sound reflection index, in one-third octave band and for the single number rating, are given in Table A.1. These values may be used as an estimate of the combined standard uncertainty of determinations of sound reflection index.

 $\begin{tabular}{ll} Table A.1 - Standard deviation of repeatability and reproducibility of the sound reflection index, \\ after the QUIESST project [23] \end{tabular}$

1/3 octave band	Std. dev. of repeatability, s _r			Std. dev. of reproducibility, s_R				
Hz	Median	Low	High	Median	Low	High		
100	0,25	0,21	0,30	0,27	0,23	0,32		
125	0,12	0,10	0,14	0,14	0,12	0,18		
160	0,06	0,05	0,07	0,09	0,08	0,12		
200	0,08	0,07	0,10	0,11	0,09	0,14		
250	0,08	0,06	0,09	0,10	0,09	0,13		
315	0,08	0,07	0,10	0,10	0,09	0,13		
400	0,07	0,06	0,09	0,10	0,08	0,12		
500	0,07	0,06	0,08	0,09	0,08	0,12		
630	0,09	0,08	0,11	0,11	0,09	0,14		
800	0,10	0,09	0,12	0,12	0,11	0,15		
1000	0,09	0,08	0,10	0,10	0,09	0,13		
1250	0,10	0,08	0,12	0,12	0,10	0,15		
1600	0,12	0,10	0,14	0,14	0,12	0,16		
2000	0,11	0,09	0,13	0,13	0,11	0,15		
2500	0,11	0,09	0,13	0,13	0,11	0,15		
3150	0,12	0,10	0,14	0,14	0,12	0,17		
4000	0,15	0,13	0,18	0,17	0,15	0,20		
5000	0,17	0,14	0,20	0,19	0,16	0,23		
DL_{RI} , dB	0,53	0,44	0,62	0,68	0,54	0,81		

Annex B

(informative)

Template of test report on sound reflection of road noise barriers

NOTE Logically, all references in this template to Annex B have to be removed when drafting a test report.

B.1 Overview

for product xxxx produced by the firm yyyyy

(a)	<u>Remark:</u>							
	The present test is based on the test method according to the European Standard EN 1793–5.							
(b)	Name and address of testing organization:							
(c)	Date of test:							
	Place of test:							
(d)	Test situation: see description and photographic presentation in B.1							
(e)	<u>Test object</u>							
	Manufacturer:							
	Type:							
	Dimensions : height, length, distance between support posts or ribs							
	Date of manufacture:							
	Date of installation:							
	Exposure classes according to EN 14389-1:							
	Physical condition during test (by visual inspection):							
	Composition: see description and photographic presentation in B.2. Drawings and photographs clearly show how the product is built; include at least front view, side view, back view.							
(f)	Surface conditions of the test object							
	Dryness:							
	Temperature:							
(g)	Meteorological conditions prevailing during the test							
	Wind speed:							
	Wind direction:							
	Air temperature:							
(h)	Test arrangement: see description and photographic presentation in B.2. Note that this representation should include the exact positions of the microphone with respect to the sample e.g. showing the microphone positions opposite a ridge on a non-flat product.							

(i)	Equipment used for measurement and analysis								
	Sound source:								
	Manufacturer:								
	Type:								
	Serial number:								
	Microphone:								
	Manufacturer:								
	Type:								
	Serial number:								
	Analyser:								
	Manufacturer:								
	Туре:								
	Serial number:								
(j)	Correction factors for sound source directivity (if any; if none, state 'none')								
(k)	Correction factors for changes in sound source gain (if any; if none, state 'none')								
(l)	Filtoring and campling								
(1)	Filtering and sampling Type and sharestoristics of the anti-aliceing filter.								
	Type and characteristics of the anti-aliasing filter:								
(m)	Sample rate: Adrienne temporal window (State length for each microphone height)								
(111)	Length for microphones 1-3:								
	Length for microphones 4–6: Length for microphones 7–9:								
(n)	Test frequency range								
(11)	Low frequency limit:								
(o)	Smallest dimension of the test object: Test results: see tables and graphs in P.2								
(p)	Test results: see tables and graphs in B.3								
(P)	Measurement uncertainty For each one third active frequency hand and the single number ratings								
	For each one-third octave frequency band and the single-number rating:								
	Combined standard uncertainty: Expanded uncertainty:								
	Coverage factor:								
	Confidence level:								
(q)	Single-number rating								
(4)	The single-number rating for the sound reflection index amounts to:								
	The single-number rating for the sound reflection index amounts to: For qualification (minimum sample size 4 m x 4 m): $DL_{RI} = $ dB								
	i or quantication (minimum sample size + iii x + iii). DERI ub								

	For other purposes: DL_{RI} (Lower freq. limit – 5 000 Hz) = dB						
(r)	Signature of the person responsible for the measurements						
	Name:						
	Place, date:						
	signature						

B.2 Test setup (example)

The noise reducing device under test is a composite, absorptive barrier constructed in perforated metal sheet, 1 mm thick, and mineral wool backed by a blind metal sheet, 1 mm thick. It is composed by two sections, each section comprising 4.0 m wide x 4.0 m high panels, supported in between steel H-section posts which are at 4.0 m centres. This is representative of the construction arrangement used alongside highways. The overall dimensions of the test configuration are height = 4.0 m and width = 8.0 m. Figure B.1 shows the barrier viewed from the front (traffic side).

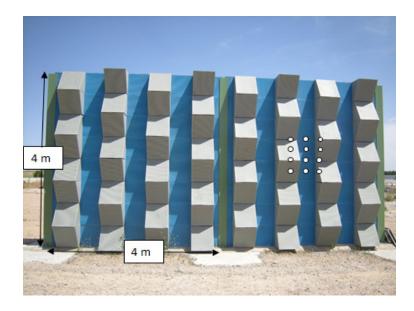


Figure B.1 – (Example) General view of test barrier (from front (road) side) – White circles mark measurement positions based on the post spacing of 4 m

The source is at a height of 2,0 m above the ground. The prescribed measurement grid is applied in 12 different positions (the circles in Figure B.1 show the approximate positions of the loudspeaker/centre microphone axis).

There are no sound reflecting nor sound diffracting parasitic objects acting in the sample area.

The test situation including the loudspeaker and microphone array is shown in Figure B.2.

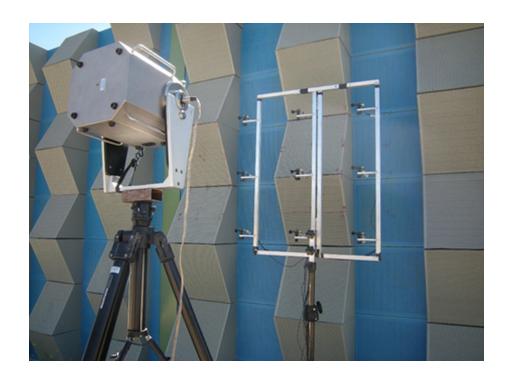


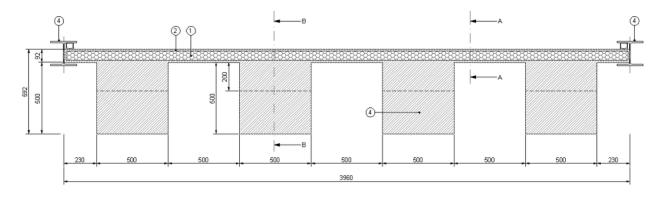
Figure B.2 — (Example) Test arrangement showing loudspeaker and microphone array when measuring

B.3 Test object and test situation (example)

Figure B.3 shows a typical plan section through the barrier, including the dimensions of the different elements.

The posts are steel columns of the type HeA 180. The panels are held in place between the posts by means of metallic wedges at the rear.

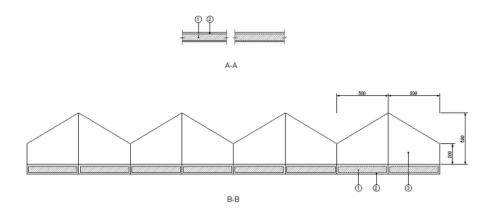
Figure B.4 shows a typical cross-section through the barrier, including the dimensions of the different elements.



Key

- 1 Sound absorbing material
- 2 Blind steel sheet, 1 mm thick
- 3 Front perforated steel sheet, 1 mm thick
- 4 Post, HeA 180 type

Figure B.3 - (Example) Plan view of the noise barrier (dimensions in millimetres)



Key

- 1 Sound absorbing material
- 3 Front perforated steel sheet, 1 mm thick
- 2 Blind steel sheet, 1 mm thick
- 4 Post, HeA 180 type

Figure B.4 – (Example) Cross-sections through noise barrier (dimensions in millimetres). Top: cross-section through A-A. Bottom: cross-section through B-B

B.4 Test Results (example)

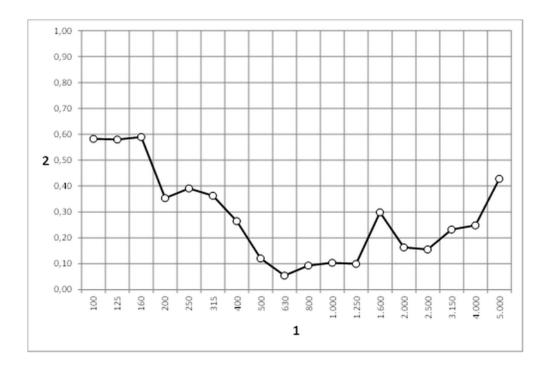
B.4.1 Part 1 - Results in tabular form

Table B.1 - Results in tabular form

Third-	Particular values of sound reflection index RI for the 12 measurement grid positions and the mean												
octave band centre frequency (Hz)	Particular values												Average
	RI ₁	RI ₂	RI ₃	RI ₄	RI ₅	RI ₆	RI ₇	RI ₈	RI ₉	RI ₁₀	RI ₁₁	RI ₁₂	RI
100	0,59	0,62	0,57	0,55	0,58	0,59	0,57	0,57	0,51	0,61	0,61	0,62	0,58
125	0,60	0,62	0,58	0,54	0,57	0,58	0,58	0,58	0,51	0,60	0,59	0,61	0,58
160	0,63	0,65	0,60	0,55	0,57	0,59	0,60	0,60	0,53	0,60	0,57	0,60	0,59
200	0,38	0,42	0,31	0,37	0,37	0,35	0,37	0,39	0,31	0,36	0,31	0,32	0,35
250	0,43	0,47	0,35	0,39	0,39	0,36	0,42	0,43	0,35	0,38	0,34	0,36	0,39
315	0,43	0,45	0,34	0,37	0,37	0,34	0,37	0,37	0,33	0,33	0,33	0,33	0,36
400	0,34	0,33	0,26	0,28	0,30	0,27	0,22	0,24	0,22	0,21	0,25	0,23	0,26
500	0,15	0,15	0,12	0,13	0,15	0,15	0,07	0,08	0,08	0,11	0,12	0,12	0,12
630	0,05	0,04	0,04	0,07	0,05	0,06	0,06	0,04	0,04	0,09	0,05	0,06	0,05
800	0,07	0,07	0,06	0,13	0,08	0,07	0,17	0,11	0,09	0,11	0,09	0,07	0,09
1 000	0,11	0,10	0,09	0,13	0,11	0,08	0,17	0,16	0,10	0,08	0,07	0,04	0,10
1 250	0,11	0,13	0,10	0,07	0,11	0,08	0,10	0,13	0,09	0,10	0,09	0,07	0,10
1 600	0,39	0,53	0,16	0,37	0,28	0,21	0,30	0,23	0,18	0,30	0,35	0,29	0,30
2 000	0,19	0,28	0,10	0,20	0,15	0,12	0,16	0,15	0,08	0,13	0,17	0,22	0,16
2 500	0,15	0,23	0,21	0,14	0,13	0,17	0,15	0,15	0,16	0,12	0,15	0,10	0,16
3 150	0,31	0,33	0,27	0,26	0,23	0,19	0,18	0,25	0,18	0,16	0,23	0,21	0,23
4 000	0,39	0,27	0,22	0,23	0,26	0,21	0,28	0,22	0,18	0,28	0,21	0,24	0,25
5 000	0,55	0,43	0,25	0,52	0,53	0,53	0,40	0,43	0,23	0,46	0,36	0,45	0,43

Single number rating of sound reflection index, $DL_{RI} = 8 \text{ dB}$.

B.4.2 Part 2 – Results in graphic form



Key

- 1 Third-octave band centre frequency [Hz]
- 2 Sound reflection index

Figure B.5 - Results in graphic form

B.5 Uncertainty (example)

The uncertainty of the declared values of sound reflection index, in one-third octave band and for the single number rating, is estimated using the values for the standard deviation of reproducibility given in Table A.1.

A coverage factor of 1,96, corresponding to a confidence level of 95 % for a Gaussian distribution, is assumed.

In order to have a conservative (worst case) estimate, the chosen value of the standard deviation of reproducibility are the maximal ones (last column of Table A.1).

The main step of the calculation are summarized in Table B.2.

It can be seen that the conservative estimate of the 95 % confidence interval of the single-number rating is [6,09, 9,27] dB.

Table B.2 – Estimation of the uncertainty of the declared values of RI

1/3 octave band, Hz	RI	s _R (High)	U (95 %)
100	0,58	0,32	0,62
125	0,58	0,18	0,34
160	0,59	0,12	0,24
200	0,35	0,14	0,27
250	0,39	0,13	0,25
315	0,36	0,13	0,25
400	0,26	0,12	0,24
500	0,12	0,12	0,23
630	0,05	0,14	0,26
800	0,09	0,15	0,28
1000	0,10	0,13	0,25
1250	0,10	0,15	0,28
1600	0,30	0,16	0,31
2000	0,16	0,15	0,29
2500	0,16	0,15	0,29
3150	0,23	0,17	0,32
4000	0,25	0,20	0,39
5000	0,43	0,23	0,45
DL_{RI} , dB (before rounding)	7,68	0,81	1,59

Annex C (informative)

Near field to far field relationship

The sound reflection index is determined by the properties of the materials of the noise reducing device under test as well as by the geometrical shape of this device, which may enhance or diminish sound reflections in certain directions.

The reflectivity effect in the far field is thus not only related to the noise reducing device and its design, but also to the receiving position in the far field. The determination of performance in the far-field has been investigated within the framework of the QUIESST project [22] and an engineering computation method has been developed that gives the values of two far field performance indicators (for high rise and low rise buildings) for a specific barrier type.

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