
**Acoustics — Measurement of sound
absorption properties of road surfaces
in situ —**

**Part 1:
Extended surface method**

*Acoustique — Mesurage in situ des propriétés d'absorption
acoustique des revêtements de chaussées —*

Partie 1: Méthode de la surface étendue



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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

This second edition cancels and replaces the first edition (ISO 13472-1:2002), which has been technically revised.

The main changes are as follows:

- Reference to IEC 60651 has been replaced with reference to IEC 61672-1;
- Reference to ISO 18233 has been added, in order to have a standardized description of MLS and ESS signals. Two references on ESS have been added to the Bibliography;
- Requirements of a precision $\pm 0,005$ m on the source-microphone distance has been released to $\pm 0,01$ m due to the correcting capability offered by the accurate alignment procedure in the new [Annex F](#);
- A procedure, taken from ISO 11819-2, to check the road surface dryness has been specified in [8.1](#);
- Specifications of the time window have been improved;
- Former [Annex D](#) on MLS signals has been deleted (replaced by a reference to ISO 18233);
- Former Annex G on correction of small time shifts has been replaced with the new [Annex F](#), specifying an accurate alignment procedure; [Annex F](#) is now normative.

A list of all parts in the ISO 13472 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document describes a test method for measuring, in situ, the sound absorption coefficient of road surfaces as a function of frequency under normal incidence.

This method provides a means of evaluating the sound absorption characteristics of a road surface without damaging the surface. It is intended to be used during road construction, road maintenance and other traffic noise studies. It may also be used to qualify the absorption characteristics of road surfaces used for vehicle and tyre testing. However, the standard uncertainty is limited to 0,05.

This method is based on free-field propagation of the test signal from the source to the road surface and back to the receiver, and covers an area of approximately 3 m² and a frequency range, in one-third-octave bands, from 250 Hz to 4 kHz (see IEC 61260).

To complement this method, a spot method (see ISO 13472-2) is available. This method is based on the transmission of the test signal from the source to the road surface and back to the receiver inside a tube and covers an area of approximately 0,1 m² and a frequency range, in one-third-octave bands, from 315 Hz to 2 kHz.

Both methods should give the same results in the frequency range from 315 Hz to 2 kHz.

They are both applicable also to acoustic materials other than road surfaces.

The measurement results of this method are comparable with the results of impedance tube methods, performed on bore cores taken from the surface (e.g. ISO 10534-1 and ISO 10534-2).

The measurement results of this method are in general not comparable with the results of the reverberation room method (see ISO 354), because the method described in this document uses a directional sound field, while the reverberation room method assumes a diffuse sound field.

See [Annex E](#) for information about sound absorption coefficient under non-normal incidence.

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Acoustics — Measurement of sound absorption properties of road surfaces in situ —

Part 1: Extended surface method

1 Scope

This document describes a test method for measuring in situ the sound absorption coefficient of road surfaces as a function of frequency in the range from 250 Hz to 4 kHz.

Normal incidence is assumed. However, the test method can be applied at oblique incidence although with some limitations (see [Annex F](#)). The test method is intended for the following applications:

- determination of the sound absorption properties of road surfaces in actual use;
- comparison of sound absorption design specifications of road surfaces with actual performance data of the surface after completion of the construction work.

The complex reflection factor can also be determined by this method.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10534-1, *Acoustics — Determination of sound absorption coefficient and impedance in impedance tubes — Part 1: Method using standing wave ratio*

ISO 10534-2, *Acoustics — Determination of sound absorption coefficient and impedance in impedance tubes — Part 2: Transfer-function method*

IEC 61672-1, *Electroacoustics – Sound level meters – Part 1: Specifications*

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.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

angle of incidence

angle between the normal to the surface under test and the direction of the sound wave impinging on the test surface

3.2 sound power reflection factor

Q_W

fraction of the impinging sound power which is reflected from the surface material of the road (see 3.4)

Note 1 to entry: A spherical sound wave incident on the sample surface is assumed.

3.3 sound absorption coefficient

α

ratio of the sound power entering the surface of the test object (without return) to the incident sound power:

$$\alpha = 1 - Q_W$$

3.4 sound pressure reflection factor

Q_p

complex ratio of the pressure amplitude of the reflected wave to the pressure amplitude of the incident wave at the surface of the road

Note 1 to entry: A spherical sound wave incident on the sample surface is assumed.

Note 2 to entry: This quantity is necessary in order to understand the correction procedure described in Annex B and Formula (C.4). The sound power reflection factor is equal to the squared modulus of the sound pressure reflection factor: $Q_W(f) = |Q_p(f)|^2$.

3.5 geometrical spreading factor

attenuation of the magnitude of a sound pressure wave travelling from one point to another due to the spherical spreading

3.6 plane of reference for the road surface

hypothetical plane tangential to the majority of the elements of the surface under test

3.7 maximum sampled area

surface area, contained within the plane of reflection, which shall remain free of reflecting objects causing parasitic reflections

Note 1 to entry: See Annex A.

3.8 background noise

noise coming from sources other than the test signal

3.9 signal-to-noise ratio

S/N

difference between the level of the nominal useful signal and the level of the background noise at the moment of detection of the useful event

Note 1 to entry: The signal-to-noise ratio is given in decibels.

3.10 impulse response

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

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

3.11

transfer function

Fourier transform of the *impulse response* (3.10)

4 Summary of the method

4.1 General principle

A sound source driven by a signal generator is positioned above the surface to be tested and a microphone is located between the source and the surface. The measurement method is based on the assessment of the transfer function between the output of the signal generator and the output of the microphone. This transfer function is composed of two factors, one coming from the direct path (from the signal generator through the amplifier and loudspeaker to the microphone) and a second coming from the reflected path (from the signal generator through the amplifier, loudspeaker and surface under test to the microphone) (see [Figure 1](#)).

The overall impulse response containing the direct and reflected sound is measured in the time domain. This overall impulse response consists of the impulse response of the direct path and, after some delay due to the longer travelling distance, the impulse response of the reflected path.

With suitable time domain processing (e.g. signal subtraction and temporal separation, see [4.2](#)), these responses can be separated. After a Fourier transform, the transfer functions of the direct path $H_i(f)$ and of the reflected path $H_r(f)$ are obtained. The ratio of the squared modulus of these transfer functions gives the sound power reflection factor $Q_W(f)$; in order to account for the path length difference between the direct and reflected component, the above ratio is also multiplied by a factor K_r intended to compensate for the greater geometrical spreading of the reflected path, see [Formula \(2\)](#). Then, the sound absorption coefficient can be calculated from the sound power reflection factor $Q_W(f)$ (see [3.3](#)).

Taking into account also the factor K_r due to geometrical spreading, the sound absorption coefficient is computed as given by [Formula \(1\)](#):

$$\alpha(f) = 1 - Q_W(f) = 1 - \frac{1}{K_r^2} \frac{|H_r(f)|^2}{|H_i(f)|^2} \quad (1)$$

$$K_r = \frac{d_s - d_m}{d_s + d_m} \quad (2)$$

where

d_s is the distance between the sound source and the reference plane for the surface under test;

d_m is the distance between the microphone and the reference plane for the surface under test.

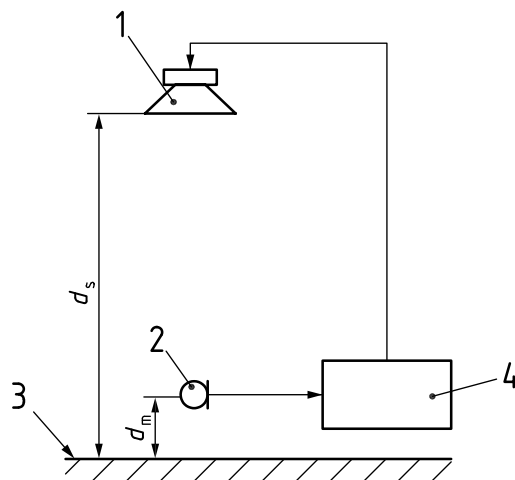
NOTE The complex reflection factor, necessary for propagation calculations or comparison of measurement results with theoretical calculations can be found as follows in [Formula \(3\)](#):

$$Q_p(f) = \frac{1}{K_f} \cdot \frac{H_r(f)}{H_i(f)} \cdot \exp(i2\pi\Delta\tau) \quad (3)$$

where $\Delta\tau$ is the time difference between arrival of the direct and the reflected impulses (see [Annex C](#)).

No special requirement is placed upon the signal source as long as it enables determination of the impulse response over the designated frequency interval (see also [5.2](#)).

The method considers the part of the energy that is reflected in a non-specular way and not captured by the microphone as being absorbed. Thus, the sound absorption coefficient may be slightly overestimated.



Key

- 1 sound source
- 2 microphone
- 3 surface under test
- 4 signal processing unit

d_m is the distance between the microphone and the reference plane for the surface under test

d_s is the distance between the sound source and the reference plane for the surface under test

Figure 1 — Sketch of the essential components of the measurement set-up

4.2 Signal separation technique

This document specifies how the sound source and the microphone shall be positioned over the surface under test and how the overall impulse response shall be measured.

The overall impulse responses consist of a direct component, a component reflected from the surface under test and other parasitic reflections, see [Figure 2 a](#)). The direct component and the reflected component from the surface under test shall be separated.

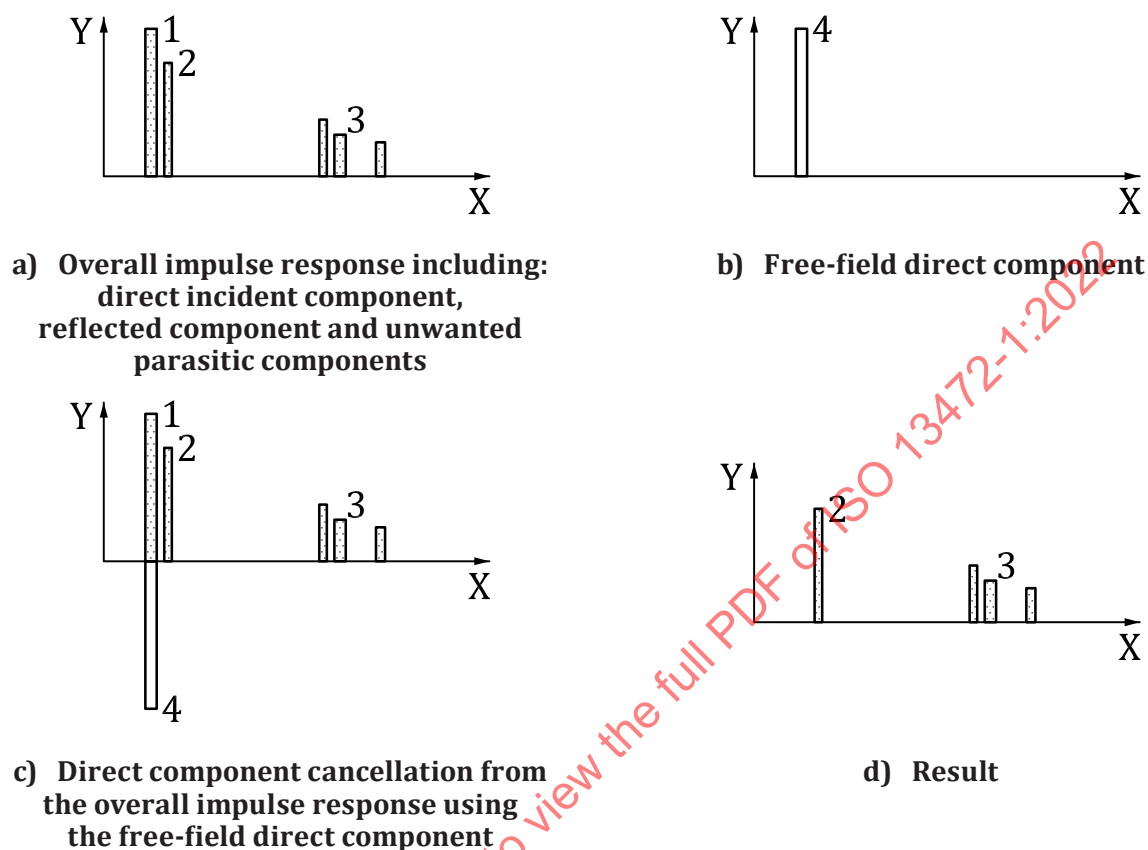
This separation shall be done using the signal subtraction technique (see [Figure 2](#)): the reflected component is extracted from the overall impulse response after having removed the direct component by subtraction of an identical signal [see [Figures 2 c](#)) and [2 d](#))]. This can be obtained by performing a free-field measurement using the same geometrical configuration of the loudspeaker and the microphone. In particular, their relative position shall be kept as constant as possible. The direct component is extracted from the free-field measurement [see [Figure 2 b](#))].

NOTE 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 surface under test. Furthermore, the microphone can be placed closer to the road surface so as to improve the S/N ratio and decrease the effect of geometrical spreading.

For source and microphone distances from the plane of reference for the road surface, this document requires the following values: $d_s = 1,25$ m and $d_m = 0,25$ m (see [Figure 1](#)). These distances shall be kept constant during the averaging process ($\pm 0,01$ m).

The direct impulse response has to be exactly known in shape, amplitude and time delay. This is obtained by performing a free-field measurement using the same geometrical configuration of the loudspeaker and the microphone. In particular, the distance between them shall be kept strictly

constant. This requirement can be met by using a fixed and stable connection between the source and the microphone. If the direct impulse response has been subjected to a small time shift between the free field measurement and the reflection measurement, this shall be corrected (see [Annex F](#)).



Key

- X time, expressed in milliseconds
- Y impulse response amplitude
- 1 direct incident component
- 2 reflected component
- 3 unwanted parasitic component
- 4 free-field direct component

Figure 2 — Principle of the signal subtraction technique

In order to avoid temperature differences between the free field measurement and the measurement on the surface under test, it is recommended to perform the two measurements within a short time (<10 min).

4.3 Test method

The measurement shall take place in an essentially free field, i.e. a field free from reflections coming from objects other than the surface under test. However, the use of a time window cancels out reflections arriving after a certain time period, and thus originating from locations further away than a certain distance (see [Clause 7](#)).

In order to minimize the effects of the background noise and meteorological variations, a number of impulse responses shall be acquired and averaged to get the minimum S/N ratio as specified in [7.4](#).

NOTE Experience shows that usually the average of 16 to 32 impulse responses is sufficient.

Often, very small sound absorption values are measured in the low-frequency range. Accurate values in this range are very difficult to obtain. Small variations in the assessment of the sound pressure levels of both the direct signal and the reflected signal can induce high inaccuracies in the sound absorption values. In order to avoid this problem, and in order to improve the accuracy of the method, a reference measurement on a totally reflective surface shall be performed (see [Annex B](#)).

5 Test system

5.1 Components of the test system

The test equipment shall comprise an electronic signal generator, a power amplifier and a loudspeaker, a microphone with amplifier and a signal analyser capable of performing cross-correlation and transformations between the time and the frequency domains.

A sketch of the essential components of the measuring system is shown in [Figure 1](#).

The complete measuring system shall meet the requirements of at least a type 2 instrument in accordance with IEC 61672-1. For the purposes of this document, the measurement frequency range is displayed in one-third-octave bands, from 250 Hz to 4 kHz.

5.2 Sound source

The loudspeaker shall

- 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, and
- 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 sound power reflection factor is calculated from the ratio of energetic quantities extracted from impulse responses taken using the same loudspeaker and microphone 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.

5.3 Test signal

The test signal shall consist of a repeatable short signal with a low peak-to-RMS ratio, typically below 2, and an almost flat spectrum that covers the one-third-octave bands from 250 Hz up to 4 kHz with an acceptable S/N ratio. Several signals may be used, such as maximum-length sequences (MLS) or exponential sine sweep (ESS), see ISO 18233.

6 Data processing

6.1 Calibration

The measurement procedure described in this document is based on the power ratio of two transfer functions extracted from the same electro-acoustical chain. An absolute calibration of the measurement chain with regard to the sound pressure level is, therefore, unnecessary. However, a reference measurement as described in [Annex B](#) is required.

6.2 Sampling frequency

The subtraction principle implies knowledge of the exact wave form, especially for checking change of time delays in the measurement chain. The sampling frequency, f_s , shall therefore have a value greater than 40 kHz.

NOTE 1 A time delay is often introduced in the measurement chain when using an audio card connected to a portable computer. This time delay is compensated before performing the signal subtraction technique described in 6.3.

NOTE 2 Although the signal is already unambiguously defined when the Nyquist criterion for the sampling frequency is met (see Reference [18]), higher sampling frequencies facilitate a clear reproduction of the signal. Errors can be detected and corrected more easily, such as corrections needed to account for time shifts due to temperature changes.

6.3 Temporal separation of the signals

Before measurements, a preliminary check shall ensure that no parasitic signals appear in the temporal windows (see 7.3).

The separation of the direct and the reflected signals is obtained by applying the signal subtraction technique (see 4.2).

The low-frequency limit of the analysis is proportional to the reciprocal of the length of the narrowest temporal window used and dependent on the window shape. For measurements in the 250 Hz one-third octave band to be valid, the low-frequency limit is 220 Hz, which implies a minimum time window length of approximately 5,9 ms. For more details see Annex F.

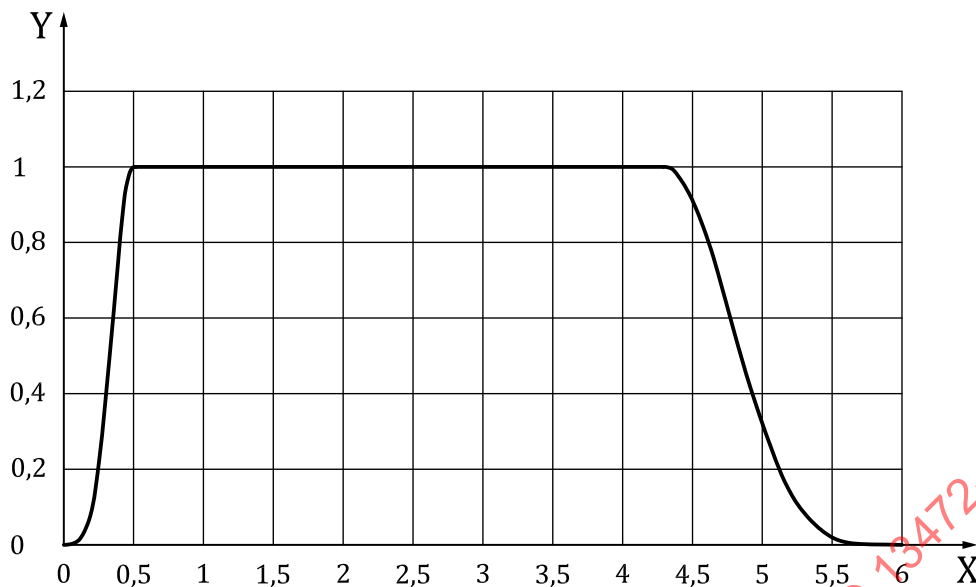
In every case the shape and the lengths of the selected temporal window shall be reported in the test report.

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 3):

- 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.

The Adrienne window having a total length $T_{W,ADR} = 5,9$ ms (standard length), is made of:

- 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 3,78 ms (“main body”);
- a trailing edge having a right-half Blackman-Harris shape and a length of 1,62 ms.

**Key**

X time, expressed in milliseconds

Y Adrienne window shape

Figure 3 — Adrienne temporal window

NOTE 1 A four-term full Blackman-Harris window of length $T_{W,BH}$ is given by [Formula \(4\)](#):

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

where: $a_0 = 0,358\,75$; $a_1 = 0,488\,29$; $a_2 = 0,141\,28$; $a_3 = 0,011\,68$; $0 \leq t \leq T_{W,BH}$.

7 Positioning of the equipment

7.1 Maximum sampled area

The size of the maximum sampled area is defined by the distances from the sound source and the microphone to the surface under test, together with the length of the time window. For normal incidence, the maximum sampled area is bounded by a circle with its centre at the point of incidence and radius r given by the relationship in [Annex A](#).

The mandatory reference surface shall at least comprise the maximum sampled area (see [Annex B](#)).

7.2 Positioning of the measuring equipment

The measuring equipment shall be placed above the surface under test or above the reference surface according to the arrangement as shown in [Figure 1](#) and the positions given in [4.2](#).

The sound source shall be located at a height, d_s , of 1,25 m above the plane of reference for the road surface. The receiver microphone shall be located at a height, d_m , of 0,25 m above the plane of reference for the road surface. The distances shall be kept constant to within $\pm 0,01$ m.

The acoustic centre of the sound source and the acoustic centre of the microphone shall lie on a line normal to the plane of reference, and the axis of the microphone shall be parallel to the plane of reference.

This location of the source and the microphone shall be such that the maximum sampled area (see 7.1 and Annex A) is totally included in the road surface under test.

7.3 Reflecting objects

Any object other than the road pavement shall be considered a reflecting object which could cause parasitic reflections (e.g. fences, rocks, anti-noise barriers, parked cars). These objects shall remain out of the maximum sampled area at a distance to the microphone greater than d_s .

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

7.4 Background noise

The effective signal-to-noise ratio S/N shall be larger than 10 dB within each one-third-octave band between 250 Hz and 4 kHz.

In order to evaluate this signal-to-noise ratio S/N for each impulse response, a time interval including only the background noise and a time interval including the reflected signal must be identified. The time interval for the evaluation of the background noise is selected with a “noise window” $w_n(t)$. The time interval for the evaluation of the reflected component of the signal is selected with a window $w_r(t)$.

The time interval for the evaluation of the background noise can be chosen in two ways:

- From the beginning of the impulse response ($t = 0$) to the beginning of the direct signal; in this case the low-frequency limit of the signal-to-noise ratio calculation is 400 Hz.
- From the end of the impulse response toward its beginning, using an Adrienne window of the same length as that used for the reflected signal; in this case the low-frequency limit of the signal-to-noise ratio calculation is the same as for the sound absorption coefficient calculation.

The signal-to-noise ratio in each frequency band is:

$$S/N_j = 10 \lg \left\{ \frac{\int_{\Delta f_j} |F[h_r(t)w_r(t)]|^2 df}{\int_{\Delta f_j} |F[h_n(t)w_n(t)]|^2 df} \right\} \quad (5)$$

where

$h_r(t)$ is the reflected component of the impulse response taken in front of the surface under test;

$h_n(t)$ is the background noise component of the impulse response;

$w_r(t)$ is the time window (Adrienne temporal window) for the reflected component;

$w_n(t)$ is the time window (Adrienne temporal window) for the background noise component;

F is the symbol of the Fourier transform;

j is the index of the one-third octave frequency bands (between 250 Hz and 4 kHz);

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

The overall signal to noise ratio is:

$$S/N = 10 \lg \left\{ \frac{\sum_{j=1}^{13} \int_{\Delta f_j} |F[h_r(t)w_r(t)]|^2 df}{\sum_{j=1}^{13} \int_{\Delta f_j} |F[h_n(t)w_n(t)]|^2 df} \right\} \quad (6)$$

7.5 Safety considerations

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

8 Road surface and meteorological conditions

8.1 Condition of the road surface

The road surface under test shall be visually homogeneous and free of changes in the material properties.

Measurements shall not be carried out unless the road surface is dry. If the road surface can be expected to have a significant void content, then it should be verified that the pores are dry.

Measurements which for study or research purposes specifically aim at determining the influence of weather or other environmental conditions on sound absorption may be carried out when the road surface is not dry, but the results cannot be used for classification or qualification of the road surface under test.

The following procedure for checking the road surface dryness shall be applied.

NOTE The procedure is the same described in ISO 11819-2:2019, Annex F.

The surfaces can be assumed to be sufficiently dry for measurements, if the minimum time periods for drying up after rainfall given in [Table 1](#) are observed. However, note that the times depend very much on wind and sunshine conditions, so the values given may be adjusted accordingly.

Table 1 — Recommended time periods between rainfall and measurement

Surface type	Recommended time before measurements	Comments
Dense, non-permeable surfaces, e.g. hot rolled asphalt (HRA), DAC, cement concrete (CC)	No special time	Make visual judgement
Negatively textured surfaces, potentially containing deep troughs, e.g. SMA and thin asphalt layers	3 h	Make visual judgement
Porous (permeable) surfaces	24 h to 48 h	The lower value is acceptable only if there is sunshine during the day, and significant air movement over the surface either by wind or by traffic. Furthermore, the daytime should not be short

Unless more than 2 days have passed since the latest precipitation, a check of whether a surface assumed to have a significant porosity still contains residual moisture is recommended.

Compressed air is blown into the road surface, e.g. using a standard pistol-grip air jet or a spray can with compressed air, directed vertically towards the surface. Any remaining moisture is revealed in a clearly visible spray cloud. The surface can be regarded as dry if five tests at representative points along the length of the road surface fail to show a spray cloud (blotting paper can also be used to indicate presence of water).

NOTE This test can be carried out using a portable compressor. A short pulse of compressed air at 0,5 kPa to 0,8 kPa is sufficient for the test.

8.2 Wind

The wind speed at microphone height shall not exceed 5 m/s during the measurements.

8.3 Temperature

The ambient air temperature shall be between 0 °C and 40 °C during the measurements. The road surface temperature shall be between 0 °C and 55 °C during the measurements.

9 Measurement procedure

The measurements shall be carried out as follows:

- a) Check the road surface and meteorological conditions to ensure compliance with the specifications in [8.1](#) to [8.3](#). Otherwise, the measurements cannot be carried out.
- b) Place the measuring equipment on site as specified in [7.2](#). The safety considerations given in [7.5](#) apply.
- c) Compute the radius of the maximum sampled area as specified in [Annex A](#). Check that no reflecting objects are inside the maximum sampled area. Otherwise, the measurements cannot be performed.
- d) Select the sound source and the test signal according to [5.2](#) and [5.3](#).
- e) Generate the test signal.
- f) Sample the total signal as received by the microphone with a sampling frequency selected according to [6.2](#).
- g) The data measured at the microphone shall be repeatedly averaged until a stable impulse response function is obtained (see [4.3](#)).
- h) Record the free-field impulse response with the measurement set-up removed from any reflecting surface which could influence the measurement and keeping the same geometrical configuration (see [4.2](#)).
- i) Isolate the impulse response of the reflected path using the signal subtraction technique. Parasitic reflections are cancelled by a suitable temporal window (see [6.3](#)). The accurate alignment procedure in [Annex F](#) shall be used.
- j) Extract the direct component of the impulse response and the reflected component of the impulse response with an equal temporal window and compute the power spectra of the two extracted signals by means of Fourier transform. If it is necessary to calculate the complex reflection factor, the complex spectra should be used.
- k) Compute the sound power reflection factor (see [4.1](#) and [Annex C](#)), taking into account the geometrical spreading factor as specified in [4.1](#) ([Formula \(2\)](#)).
- l) Repeat the whole procedure from point a) to point k) on a highly reflective reference surface, and apply the procedure specified in [Annex B](#).
- m) Compute the road surface sound absorption coefficient by linear averaging narrow band absorption in one-third-octave bands (see [4.1](#) and [Annex B](#)).
- n) If necessary, repeat measurements at different points on the road surface.
- o) Write a test report (see [Clause 11](#) and also [Annex D](#)).

10 Measurement uncertainty

10.1 The measurement procedure specified in this document is affected by several influencing factors that lead to variation in the results observed for the same subject. The source and nature of these perturbations are not completely known. The measurement uncertainty is determined in accordance with ISO/IEC Guide 98-3.

In accordance with ISO/IEC Guide 98-3, each significant source of error shall be identified and corrected for. The following sources of error have been identified and shall be processed in accordance with the procedure described in ISO/IEC Guide 98-3.

10.2 When using the signal subtraction technique (see 4.2) the zeroing out of the direct response may be not perfect, leading to a small error. However, it is usually negligible if the accurate alignment procedure described in Annex F is applied, which makes it possible to obtain a reduction factor, $R_{\text{sub}} \geq 15$ dB.

10.3 The reference surface (see Annex B) cannot be perfectly reflecting, especially when a portable construction is used. Care shall be taken that it is correctly placed on the road surface under test without intermediate gaps (if it is a composite surface) and damped against vibration.

10.4 The measurement chain may be not absolutely stable, leading again to non-perfect zeroing of the direct response. Therefore, it is recommended to perform the two measurements from the surface under test and in the free field within a short time (<10 min, see 4.2).

Determination of the geometrical spreading factor, K_r , is implicitly based on the reference measurement situation with a reflective surface. In the case of thick absorptive surfaces, the plane of reflection is not unambiguously defined, which may lead to an underestimate of the reflection factor.

10.6 On highly reflective surfaces the relative error of the sound absorption coefficient becomes larger. In order to improve the accuracy in this case, it is recommended to average several measurements on the same location until a stable result is obtained.

10.7 The statistical representativity of the chosen area on the road surface is a source of error different from an error in the determination of the absorption coefficient at a certain position; it presents a source of variance in the determination of the acoustic absorption of a road section. It can be minimized by repeating the measurement until an acceptable spread in the results is obtained. However, it shall be pointed out that the maximum sample area is large enough to give a representative result for the width of a single lane.

10.8 The general expression for the calculation of the corrected absorption coefficient, $\alpha(f)$, is given by Formula (7):

$$\alpha(f) = \alpha_{\text{road}}(f) + \delta_1 + \delta_2 + \delta_3 + \delta_4 \quad (7)$$

where

$\alpha_{\text{road}}(f)$ is the measured sound absorption coefficient corrected using the reference surface as prescribed in Annex B;

δ_1 is an input quantity to allow for any uncertainty in zeroing out of the direct response when applying the signal subtraction technique (see 4.2); $\delta_1 \approx 0$ when $R_{\text{sub}} \geq 15$ dB (see Annex F);

δ_2 is an input quantity to allow for any uncertainty in the reflection from the reference surface (see Annex B);

- δ_3 is an input quantity to allow for any uncertainty due to changes in the measurement chain between the measurement on the surface under test and in the free field;
- δ_4 is an input quantity to allow for any uncertainty in the determination of the geometrical spreading factor, K_r .

This document encourages the collection of additional data on environmental conditions, to improve the understanding of the influence of these factors on the measurements. This document also encourages the acquisition of additional data in order to improve the understanding of the possible effects of different instrumentation on the measurements.

The value of these input quantities shall be evaluated by the procedure given in ISO/IEC Guide 98-3. That can be based on existing statistical data, analysis of tolerances stated in this document and engineering judgement. The information needed from which to derive the overall uncertainty is given in [Table 2](#).

Table 2 — Uncertainty budget for the determination of the sound absorption coefficient

Quantity	Estimate	Probability distribution	Standard uncertainty u_i	Sensitivity coefficient c_i	Uncertainty contribution $c_i u_i$
δ_1	0			1	
δ_2	0			1	
δ_3	0			1	
δ_4	0			1	
Combined standard uncertainty $[u(\alpha)]$					

The combined standard uncertainty is calculated using [Formula \(8\)](#):

$$u(\alpha) = \sqrt{\sum_{i=1}^4 (c_i u_i)^2} \quad (8)$$

The expanded uncertainty, U , is determined by multiplying the combined standard uncertainty, $u(\alpha)$, by the appropriate coverage factor k for the chosen confidence level (coverage probability) as described in ISO/IEC Guide 98-3. [Table 3](#) reports the coverage factors for typical confidence levels, assuming a Gaussian distribution.

Table 3 — Coverage factors for typical confidence levels (Gaussian distribution)

Coverage factor k	Confidence level %
1,3	80
1,6	90
2,0	95

However, data for completing a budget like the one in [Table 2](#) in each one-third octave band are not yet available in the literature. On the basis of experiences gained with the method a standard uncertainty of no more than 0,05 over the entire frequency range can be expected under normal conditions.

The uncertainty shall be stated in the test report. The uncertainty should be stated as both the combined standard uncertainty and the expanded uncertainty together with a confidence level.

EXAMPLE $u(\alpha) = 0,05$ and $U = k \cdot u(\alpha) = 0,1$ ($k = 2$ at 95 % of confidence).

11 Test report

The test report shall include the following information:

- a) a reference to this document, i.e. ISO 13472-1:2022;
- 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 road surface under test, measurement set-up, reflecting objects near the maximum sampled area (if any);
- e) description of the road surface under test: age, measurement condition, composition [number of layers, thickness(es), material specification, porosity, etc.];
- f) road surface condition with regard to dryness and temperature;
- g) meteorological conditions prevailing during the test (wind speed and direction, air and road surface temperatures);
- h) test arrangement, indicating on a scale drawing or a sketch with dimensions marked on it the position(s) of the source and the microphone;
- i) equipment used for measurement and analysis, including name, type, serial number and manufacturer;
- j) description of the sound source used for the test (see [5.2](#));
- k) type and characteristics of the anti-aliasing filter and sample rate of the sampling/analysis device;
- l) shape and lengths of the temporal windows used for the analysis;
- m) test results;
- n) uncertainty of the test results;
- o) name of the person responsible for the measurements.

The test results shall be given in the form of a graph and a table, showing the values of the sound absorption coefficient in one-third-octave frequency bands from 250 Hz up to 4 kHz. In addition, the test results may also be presented in narrow frequency bands.

The values of the sound absorption coefficient shall be rounded off to two decimal places.

An example of a test report is supplied in [Annex D](#).

Annex A (normative)

Radius of the maximum sampled area

The surface area, contained within the plane of reflection which shall remain free of reflecting objects causing parasitic reflections, is called the maximum sampled area. For normal incidence, the maximum sampled area is bounded by a circle with its centre at the point of incidence and radius r , in metres, given by [Formula \(A.1\)](#):

$$r = \frac{1}{d_s + d_m + cT_w} \sqrt{\left(d_s + d_m + \frac{cT_w}{2}\right) \left(d_s + \frac{cT_w}{2}\right) (2d_m + cT_w) cT_w} \quad (\text{A.1})$$

where

d_s is the distance from the sound source to the reflecting plane (m);

d_m is the distance from the microphone to the reflecting plane (m);

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

T_w is the length of the temporal window used to isolate the sound pressure wave reflected by the surface under test (s).

EXAMPLE With the values of d_s , d_m and T_w specified in this document and $c = 340$ m/s, the maximum sampled area radius is 1,34 m.

NOTE The radius of the surface area which contributes to the measured values of absorption is a decreasing function of frequency, but is not necessarily equal to the radius of the maximum sampled area previously defined. A calculation of the radii of the Fresnel zones in the plane of the sample will assist the determination of the area of influences across the range of frequencies of interest.

Annex B (normative)

Reference measurement and correction procedure

The reference measurement shall be performed on a highly reflecting surface with at least the same size as the maximum sampled area. The highly reflecting reference surface shall be a plane smooth dense surface without joints. If a portable surface is applied, it shall be clear that no movement of the surface is possible which might lead to resonant absorption of the surface.

The measured sound pressure reflection factor $Q_{p,\text{ref},\text{meas}}(f)$ is considered to be the product of the reflection factor of the reference surface, $Q_{p,\text{ref}}(f)$, and the error function, $e(f)$ and given in [Formula \(B.1\)](#):

$$Q_{p,\text{ref},\text{meas}}(f) = Q_{p,\text{ref}}(f) e(f) \quad (\text{B.1})$$

A sample of the reference surface material shall be measured in an impedance tube in accordance with ISO 10534-1 or ISO 10534-2 to confirm that the reference surface may be considered as having an absorption coefficient lower than 0,05 in the measured frequency range.

If the reference surface is assumed to be totally reflective over the whole frequency range:

$$Q_{p,\text{ref}}(f) = 1$$

then the measurement gives directly the error function using [Formula \(B.2\)](#):

$$Q_{p,\text{ref},\text{meas}}(f) = e(f) \quad (\text{B.2})$$

A second measurement, this time performed on the road surface under test, gives the reflection factor $Q_{p,\text{road},\text{meas}}(f)$ which, assuming that the error function does not vary during the time period between the two measurements, corresponds to [Formula \(B.3\)](#):

$$Q_{p,\text{road},\text{meas}}(f) = Q_{p,\text{road}}(f) e(f) = Q_{p,\text{road}}(f) \cdot Q_{p,\text{ref},\text{meas}}(f) \quad (\text{B.3})$$

and thus, $Q_{p,\text{road}}(f)$ being the reflection factor of the road surface under test, it is given by [Formula \(B.4\)](#):

$$Q_{p,\text{road}}(f) = \frac{Q_{p,\text{road},\text{meas}}(f)}{Q_{p,\text{ref},\text{meas}}(f)} \quad (\text{B.4})$$

Recalling that the sound power reflection factor, $Q_{W,\text{road}}(f)$, is equal to the squared modulus of the sound pressure reflection factor $Q_{p,\text{road}}(f)$, the final sound absorption coefficient of the road surface becomes following [Formula \(B.5\)](#):

$$\alpha_{\text{road}}(f) = 1 - |Q_{p,\text{road}}(f)|^2 = 1 - \left| \frac{Q_{p,\text{road},\text{meas}}(f)}{Q_{p,\text{ref},\text{meas}}(f)} \right|^2 = 1 - \frac{Q_{W,\text{road},\text{meas}}(f)}{Q_{W,\text{road},\text{ref}}(f)} \quad (\text{B.5})$$

Annex C (informative)

Physical principle of the measurement

The source emits a sound wave that travels past the microphone position to the surface under test where it reflects. The microphone placed between the sound source and the surface under test detects the direct sound pressure wave travelling from the sound source to the surface under test, followed by the sound pressure wave reflected by the surface under test.

The overall impulse response at the microphone, $h_m(t)$, can be described by [Formula \(C.1\)](#):

$$h_m(t) = h_i(t) + K_r h_i(t) \cdot r_p(t - \Delta\tau) + \sum_j K_{r,j} h_i(t) \cdot r_{p,j}(t - \Delta\tau_j) + h_n(t) \quad (C.1)$$

where

$h_i(t)$ is the impulse response of the direct path;

$r_p(t)$ is the reflection factor of the surface under test;

$h_n(t)$ is the background noise response;

$*$ is the convolution sign;

j denotes the “parasitic” reflections;

K_r is the geometrical spreading factor accounting for the path length difference between the direct and reflected paths (see [Figure 1](#)):

$$K_r = \frac{d_s - d_m}{d_s + d_m}$$

where

d_s is the distance between the sound source and the reflecting plane;

d_m is the distance between the microphone and the reflecting plane.

$\Delta\tau$ is the delay time, resulting from the path length difference between the direct and reflected paths, as detected by the microphone:

$$\Delta\tau = \frac{2d_m}{c}$$

where c is the speed of sound in air.

The overall impulse response at the microphone $h_m(t)$ contains the impulse response of the reflected path coming from the surface under test, given by [Formula \(C.2\)](#):

$$h_r(t) = K_r H_i(t) \cdot r_p(t - \Delta\tau) \quad (C.2)$$

The impulse response of the direct path $h_i(t)$ and impulse response of the reflected path coming from the surface under test $h_r(t)$ can be extracted from the overall microphone response in the time domain by using a suitable windowing function, provided that the amplitude of $h_i(t)$ decays to an insignificant value with respect to $h_r(t)$ within the delay time $\Delta\tau$.

Alternatively, the impulse response of the direct path can be measured in a free field, keeping the distance of the microphone from the sound source strictly constant; then, the road surface response can be obtained using the subtraction technique as described in [4.2](#).

Fourier transform of the preceding expression for $h_r(t)$ yields the sound power reflection factor in the frequency domain using [Formula \(C.3\)](#):

$$Q_W(f) = |Q_p(f)|^2 = \frac{1}{K_r^2} \left| \frac{H_r(f)}{H_i(f)} \right|^2 \quad (\text{C.3})$$

where

$H_r(f)$ is the transfer function of the reflected path (from the signal generator through the amplifier, loudspeaker and reflection at the surface under test to the microphone);

$H_i(f)$ is the transfer function of the direct path (from the signal generator through the amplifier and loudspeaker to the microphone).

From here, the sound absorption coefficient can be computed as given by [Formula \(C.4\)](#):

$$\alpha(f) = 1 - |Q_p(f)|^2 = 1 - \frac{1}{K_r^2} \left| \frac{H_r(f)}{H_i(f)} \right|^2 \quad (\text{C.4})$$

Annex D
(informative)

Example of a test report

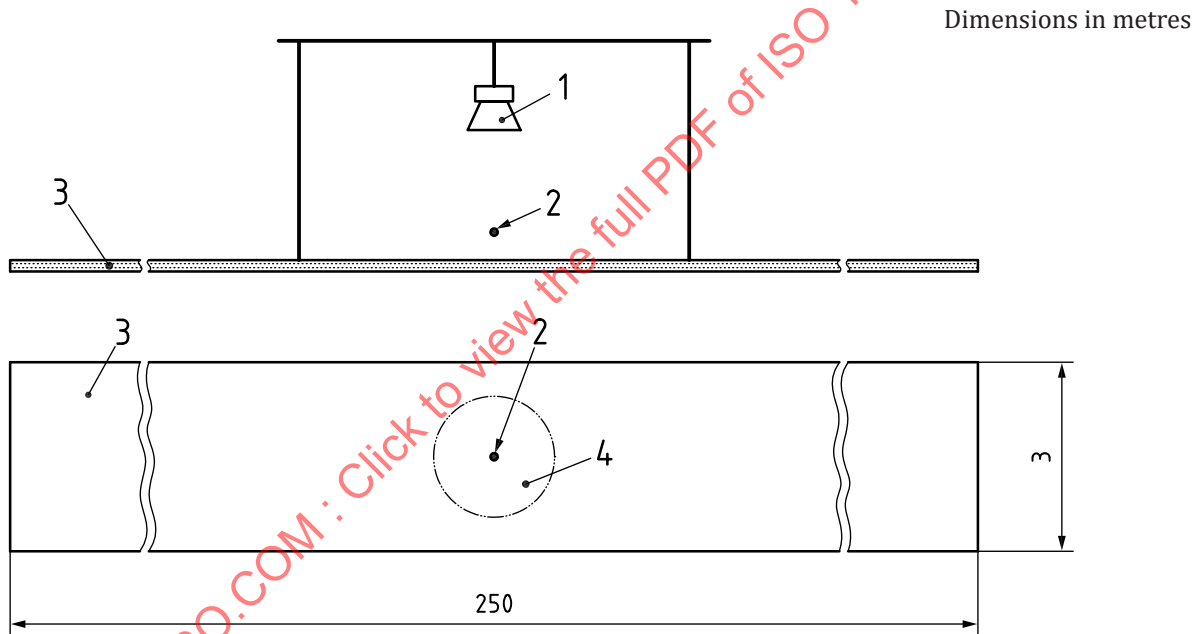
ACOUSTIC TEST AS SPECIFIED IN INTERNATIONAL STANDARD ISO 13472-1

Testing organization (name, address): XXXXX.

Date of the test: XXXXX.

Place of the test: XXXXX.

Description of the test site: (see [Figure D.1](#))



Key

- 1 sound source
- 2 microphone
- 3 porous asphalt track (surface under test)
- 4 maximum sampled area

Figure D.1 — Description of the test site

Description of the road surface under test:

Age: 8 years.

Measurement condition: surface layer in good condition.

Composition: porous asphalt: 0/10 mm;
porosity: 20 %;
thickness: 0,04 m.

Road surface dryness: apparently dry; suspected slight water infiltration from adjacent areas.

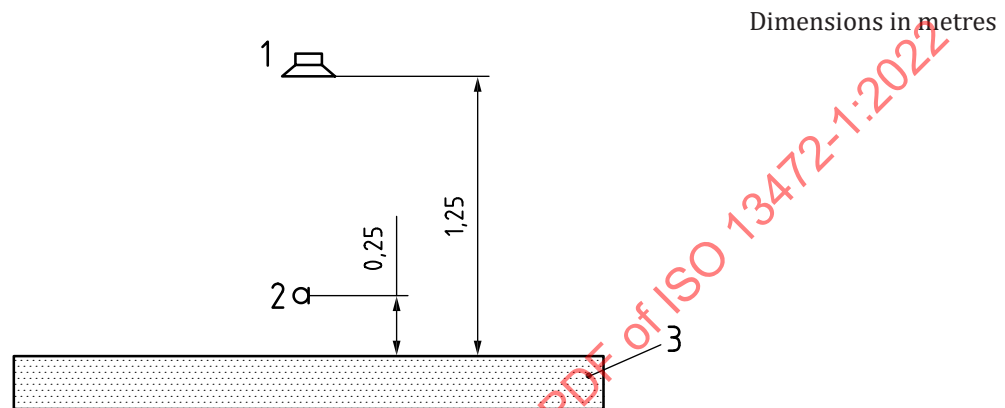
Road surface temperature: 5 °C.

Meteorological conditions prevailing during the test:

Wind speed and direction: 4 m/s from S-E.

Ambient air temperature: 4 °C.

Test arrangement (with dimensions): (see [Figure D.2](#))



Key

- 1 sound source
- 2 microphone
- 3 porous asphalt track (surface under test)

Figure D.2 — Test arrangement

Equipment used:

Loudspeaker XXXXX in a closed cabinet.

Loudspeaker amplifier XXXXX.

Microphone: XXXXX with power supply.

XXXXX board equipped with XXXXX software for impulse response acquisition.

Software by XXXXX for on-site processing.

Portable computer XXXXX.

Sample rate: 75,5 kHz.

Temporal windows shape and length: Sharp leading edge; 5 ms flat portion; Blackman-Harris trailing edge: (see [Figure D.3](#))

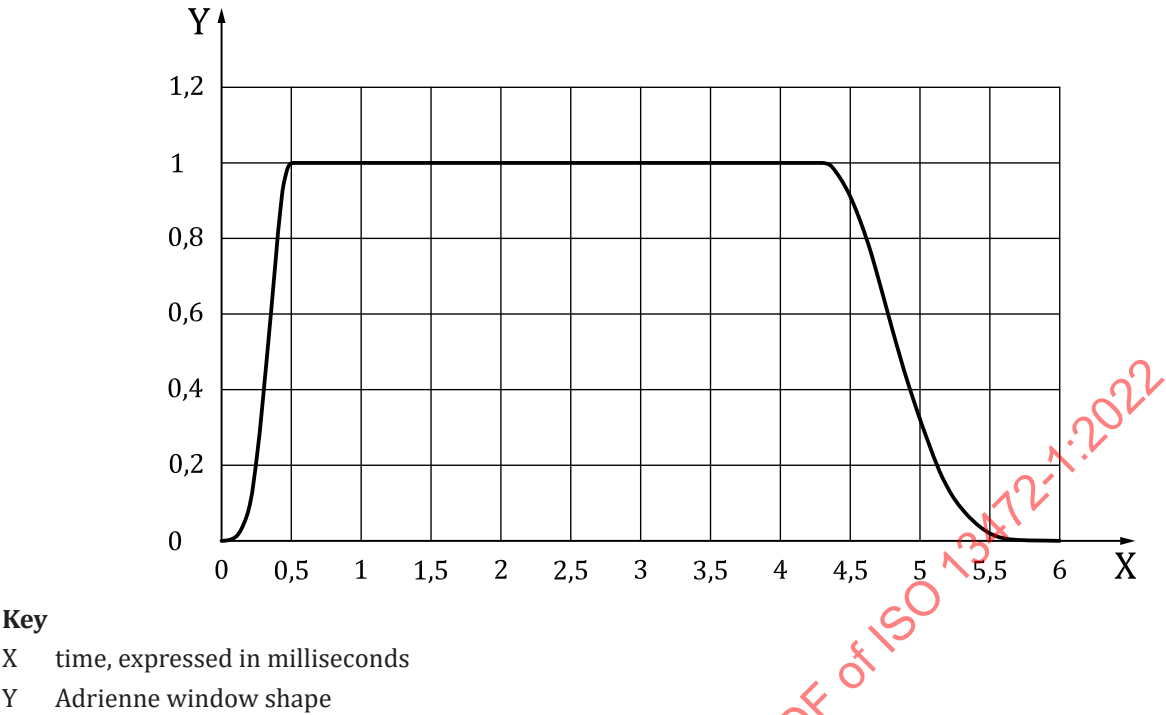


Figure D.3 — Temporal windows shape and length

Results of the measurement in one-third-octave bands: (see [Figure D.4](#))

Hz	250	315	400	500	630	800	1 000	1 250	1 600	2 000	2 500	3 150	4 000
α	0,01	0,02	0,01	0,08	0,20	0,39	0,69	0,65	0,34	0,23	0,26	0,55	0,29

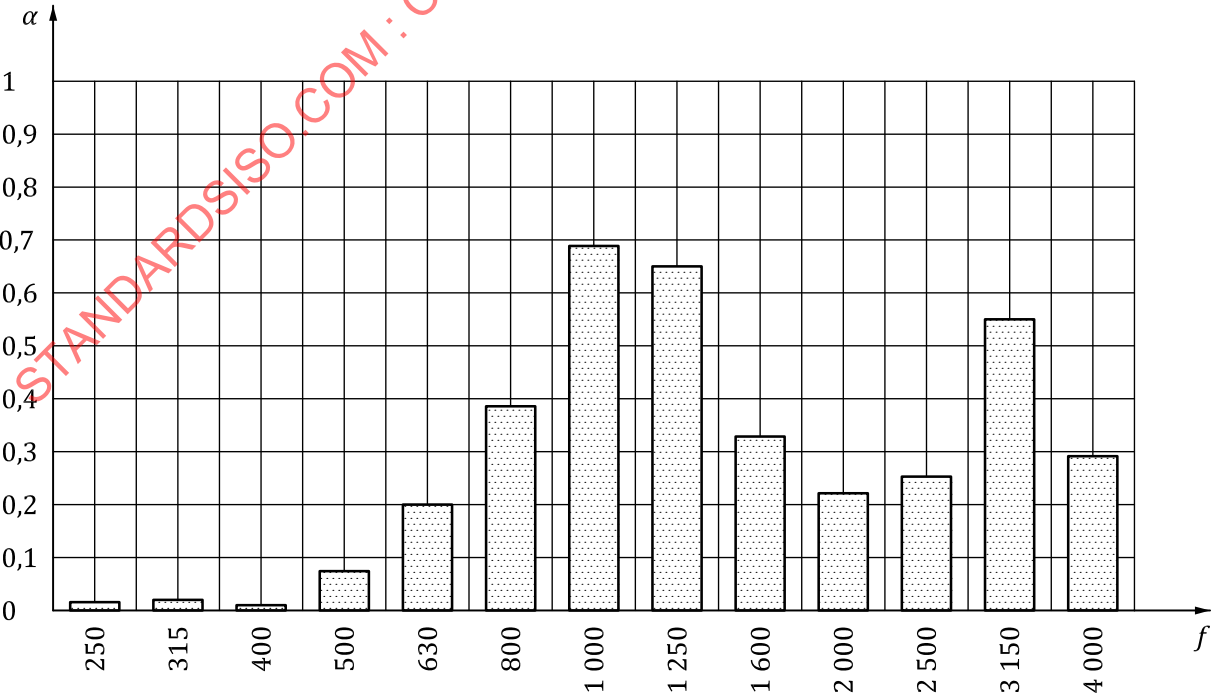


Figure D.4 — Results of the measurements in one-third-octave bands

Measurement uncertainty, at a confidence level of 95 %:

Hz	250	315	400	500	630	800	1 000	1 250	1 600	2 000	2 500	3 150	4 000
α	0,01	0,02	0,01	0,08	0,20	0,39	0,69	0,65	0,34	0,23	0,26	0,55	0,29
$u(\alpha)$	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
$U (k = 2 \text{ at } 95 \%)$	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10

Date of the report: XX XXXXXX XXXX.

Signature: XXXXX

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