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Part 2: Determination of sound pressure levels

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Partie 2: Détermination des niveaux de pression acoustique

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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 on 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 the following URL: www.iso.org/iso/foreword.html.

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

This third edition cancels and replaces the second edition (ISO 1996-2:2007), which has been technically revised.

A list of all the parts in the ISO 1996 series can be found on the ISO website.

Introduction

Measurements of environmental noise are complicated because there is a great number of variables to consider when planning and performing the measurements. As each measurement occasion is subject to current source and meteorological conditions which cannot be controlled by the operator, it is often not possible to control the resulting uncertainty of the measurements. Instead, the uncertainty is determined after the measurements based on an analysis of the acoustic measurements and collected data on source operating conditions and on meteorological parameters important for the sound propagation.

Because this document has the ambition both to comply with new and stricter requirements on measurement uncertainty calculations and to cover all kinds of sources and meteorological conditions, it has become more complicated than what a standard covering a single, specific source and application could have been. The best use of the standard is to use it as a basis for developing more dedicated standards serving specific sources and aims.

Acoustics — Description, measurement and assessment of environmental noise —

Part 2:
Determination of sound pressure levels

1 Scope

This document describes how sound pressure levels intended as a basis for assessing environmental noise limits or comparison of scenarios in spatial studies can be determined. Determination can be done by direct measurement and by extrapolation of measurement results by means of calculation. This document is primarily intended to be used outdoors but some guidance is given for indoor measurements as well. It is flexible and to a large extent, the user determines the measurement effort and, accordingly, the measurement uncertainty, which is determined and reported in each case. Thus, no limits for allowable maximum uncertainty are set up. Often, the measurement results are combined with calculations to correct for reference operating or propagation conditions different from those during the actual measurement. This document can be applied on all kinds of environmental noise sources, such as road and rail traffic noise, aircraft noise and industrial noise.

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 1996-1:2016, *Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures*

ISO 20906:2009/Amd 1:2013, *Acoustics — Unattended monitoring of aircraft sound in the vicinity of airports — Amendment 1*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

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

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1996-1 and the following apply.

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

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
measurement time interval
time interval during which measurements are conducted

Note 1 to entry: For measurements of sound exposure level or equivalent-continuous sound pressure level, the measurement time interval is the time period of integration.

Note 2 to entry: For measurements of maximum sound pressure level or percent exceedance level, etc., the measurement time interval is the *observation time interval* (3.2).

3.2
observation time interval
time interval during which a series of measurements is conducted

3.3
prediction time interval
time interval over which levels are predicted

Note 1 to entry: It is now perhaps more common to predict sound levels using computers than to measure them for some sources such as transportation noise sources. The prediction time interval corresponds to the *measurement time interval* (3.1) except, for the former, the levels are predicted, and for the latter, the levels are measured.

3.4
long-term measurement
measurement sufficiently long to encompass all emission situations and meteorological conditions which are needed to obtain a representative average

3.5
short-term measurement
measurement during *measurement time intervals* (3.1) with well-defined emission and meteorological conditions

3.6
receiver location
location at which the noise is assessed

3.7
calculation method
set of algorithms to calculate the sound pressure level at a specified *receiver location* (3.6) from measured or predicted sound power levels and sound attenuation data

3.8
prediction method
subset of a *calculation method* (3.7), intended for the calculation of future noise levels

3.9
meteorological window
set of weather conditions during which measurements can be performed with limited and known variation in measurement results due to weather variation

3.10
emission window
set of emission conditions during which measurements can be performed with limited variation in measurement results due to variations in operating conditions

3.11
sound path radius of curvature
R_{cur}
radius approximating the curvature of the sound paths due to atmospheric refraction

Note 1 to entry: R_{cur} is given in metres.

Note 2 to entry: Often, the parameter used is $1/R_{cur}$ to avoid infinitely large values during straight ray propagation.

3.12
monitor
instrumentation used for a single automated continuous sound monitoring terminal which monitors the A-weighted sound pressure levels, their spectra and all relevant meteorological quantities such as wind speed, wind direction, rain, humidity, atmospheric stability, etc.

Note 1 to entry: Meteorological measurements need not be taken at each monitor provided such measurements are taken within an appropriate distance from the monitors and such distance is given in the report.

3.13
automated sound monitoring system
entire automated continuous sound monitoring system including all *monitors* (3.12), the base or central data collection position (host station) and all software and hardware involved in its operation

3.14
reference condition
condition to which the measurement results are to be referred (corrected)

Note 1 to entry: Examples of reference conditions are atmospheric sound absorption at yearly average temperature and humidity and yearly average traffic flows for day, evening and night, respectively.

3.15
independent measurement
consecutive measurements carried out with a time space long enough to make both source operating conditions and sound propagation conditions statistically independent of the same conditions of other measurements in the series

Note 1 to entry: In order to achieve independent conditions for meteorological conditions, a time space of several days is normally required.

3.16
low-frequency sound
sound containing frequency components of interest within the range covering the one-third octave bands 16 Hz to 200 Hz

Note 1 to entry: This definition is specific for this document. Other definitions can apply in different national regulations.

4 Measurement uncertainty

The uncertainty of sound pressure levels determined as described in this document depends on the sound source and the measurement time interval, the meteorological conditions, the distance from the source and the measurement method and instrumentation. The measurement uncertainty shall be determined in compliance with ISO/IEC Guide 98-3 (GUM). Choose one of the following approaches that are all GUM-compatible:

a) The modelling approach that consists in identifying and quantifying all major sources of uncertainty (the so-called uncertainty budget). This is the preferred method.

b) The inter-laboratory approach that consists in carrying out a round-robin test in order to determine the standard deviation of reproducibility of the measurement method.

NOTE 1 If more than one measurement method exists for a certain measurand, any systematic deviations are taken into account, for example, by implementing ISO 21748[1].

c) The hybrid approach that consists in using jointly the modelling approach and the inter-laboratory approach. In this case, the inter-laboratory approach is used for components of the uncertainty budget for which the contributions cannot be quantified using the mathematical model of the modelling approach because of lack of technical knowledge.

NOTE 2 Note 1 equally applies.

According to the modelling approach, each significant source of uncertainty shall be identified. Systematic effects shall be eliminated or reduced by the application of corrections wherever possible. If the quantity to be measured is L, which is a function of the quantities x_j, the formula becomes:

$$L = f\left(x_1, x_2, x_3, ..., x_j\right) \tag{1}$$

If each quantity has the standard uncertainty u_j, the combined standard uncertainty is given by Formula (2):

$$u(L) = \sqrt{\sum_1^n \left(c_j u_j\right)^2} \tag{2}$$

assuming that the input quantities x_j are independent. Under the same assumptions, the sensitivity coefficient c_j is given by Formula (3):

$$c_j = \frac{\partial f}{\partial x_j} \tag{3}$$

The measurement uncertainty to be reported is the uncertainty associated with a chosen coverage probability, the so-called expanded uncertainty. By convention, a coverage probability of 95 % is usually chosen, with an associated coverage factor of 2. This means that the result becomes $L \pm 2\ u$.

NOTE 3 Cognizant authorities can set other coverage probabilities. A coverage factor of 1,3 will, for example, provide a coverage probability of 80 %.

For environmental noise measurements $f(x_j)$, it is extremely complicated and it is hardly feasible to put up exact formulae for the function f. Following the principles given in ISO 3745,[2] some important sources of uncertainty can be identified. For an individual measurement, Formula (4) applies:

$$L = L' + 10\lg\left(1 - 10^{-0,1(L' - L_{res})}\right)\ \mathrm{dB} + \delta_{sou} + \delta_{met} + \delta_{loc} \tag{4}$$

where

L is the estimated value during the specified conditions for which a measured value is wanted, expressed in decibels (dB);

L' is the measured value including residual sound, L_{res}, expressed in decibels (dB);

L_{res} is the residual sound, expressed in decibels (dB);

δ_{sou} is an input quantity to allow for any uncertainty due to deviations from the expected operating conditions of the source, expressed in decibels (dB);

δ_{met} is an input quantity to allow for any uncertainty due to meteorological conditions deviating from the assumed meteorological conditions, expressed in decibels (dB);

δ_{loc} is an input quantity to allow for any uncertainty due to the selection of receiver location, expressed in decibels (dB).

Often, $\delta_{sou} + \delta_{met}$ is determined directly from measurements; see 10.5.

L' and L_{res} are both dependent on δ_{slm} which is an input quantity to allow for any uncertainty of the measurement chain (sound level meter in the simplest case). In addition, L_{res} depends on δ_{res} which is an input quantity to allow for any uncertainty due to residual sound. Table 1 explains further the relationship between the quantities in Formula (4) and their estimate and uncertainty.

Formula (4) is very simplified and each source of uncertainty is a function of several other sources of uncertainty. In principle, Formula (4) could be applied on any measurement lasting from seconds to years. In 9.1, the measurements are divided into long- and short-term measurements, respectively. A short-term measurement may typically range between 10 min and a few hours whereas a typical long-term measurement may range between a month and a year.

In Table 1, guidance is given on how to determine c_j and u_j for insertion into Formula (2).

Table 1 — Example of an uncertainty budget for a measured value

Quantity	Estimate dB	Standard uncertainty, u_j dB	Magnitude of sensitivity coefficient, c_j	Clause for guidance
$L' + \delta_{slm}$	L'	$u(L')$ 0,5[a]	$\frac{1}{1-10^{-0,1(L'-L_{res})}}$	Annex F
δ_{sou}	0	u_{sou}	1	7.2 to 7.5, Annex D
δ_{met}	0	u_{met}	1	Clause 8, Annex A
δ_{loc}	0,0 – 6,0	u_{loc}	1	Annex B
$L_{res} + \delta_{res}$	L_{res}	u_{res}	$\frac{10^{-0,1(L'-L_{res})}}{1-10^{-0,1(L'-L_{res})}}$	Annex F

[a] 0,5 dB refers to a class 1 sound level meter. A class 2 sound level meter would have the standard uncertainty 1,5 dB.

The numbers given in Table 1 refer to A-weighted equivalent-continuous sound pressure levels only. Higher uncertainties are to be expected on maximum levels, frequency band levels and levels of tonal components in noise. In many cases, the measured values shall be corrected to other source operating conditions not representing the measured cases but the yearly average. Similarly, other measurements may be corrected to other meteorological conditions in order to make L_{den} calculations possible. Uncertainty calculations for such cases are given in Annex F.

NOTE 4 Some examples, including a spreadsheet, of complete uncertainty calculations are given in Annex G.

5 Instrumentation for acoustical measurements

5.1 General

The instruments for measuring sound pressure levels, including microphone(s), as well as cable(s), windscreen(s), recording devices and other accessories, if used, shall meet the requirements for a class 1 instrument according to IEC 61672-1 for free-field or random incidence application, as appropriate. Filters shall meet the requirements for a class 1 instrument according to IEC 61260. A windscreen shall always be used during outdoor measurements.

NOTE 1 Class 1 tolerance limits of IEC 61672–1 apply over a temperature range of −10 °C to +50 °C. If the instrument is to be used in temperatures outside the range −10 °C to +50 °C, then there can be an increase in measurement uncertainty.

NOTE 2 Even with windscreens, measured sound pressure levels can be affected by wind noise. As an example, the A-weighted sound pressure level L_{pA} for a 13 mm microphone with a 90 mm diameter windscreen exposed to a wind speed of v m/s is approximately −18+70 lg (v/1 m/s) dB with the wind blowing perpendicular to the microphone membrane and −32+83 lg (v/1 m/s) dB with the wind blowing parallel to the membrane[3].

5.2 Calibration

At the beginning and at the end of every measurement the entire sound pressure level measuring system shall be checked at one or more frequencies by means of a sound calibrator meeting the requirements for a class 1 instrument according to IEC 60942. Without any further adjustment, the difference between the readings of two consecutive checks shall be less than or equal to 0,5 dB. If this value is exceeded, the results of measurements obtained after the previous satisfactory check shall be discarded. For long-term monitoring of several days or more, the requirements of ISO 20906:2009/Amd 1:2013 apply.

5.3 Verification

Compliance of the sound pressure level measuring instrument, the filters and the sound calibrator shall be verified by the existence of a valid certificate of compliance with the measurement parameters specified in the relevant test methods in IEC 61672-3[4], IEC 61260 and IEC 60942.

All compliance testing shall be conducted by a laboratory meeting the requirements of ISO/IEC 17025 to perform the relevant tests and calibrations and ensuring metrological traceability to the appropriate measurement standards. The recommended time interval for testing of system performance is once a year. The maximum allowable interval is 2 years.

5.4 Long-term monitoring

The maximum permissible error for instruments used for meteorological measurements shall be

— ±0,5 K for temperature measuring devices,

— ±5,0 % for relative humidity measuring devices,

— ±0,5 hPa for barometric pressure measuring devices,

— ±0,5 m/s for wind speed measuring devices, and

— ±5° for wind direction measuring devices.

Meteorological classes shall be given according to Clause 8.

NOTE Some modern sonic anemometers are suitable for direct measurement of parameters to be used to determine meteorological classes.

6 Principles

6.1 General

There are two main strategies for environmental noise measurements:

a) make a single measurement under very well-defined meteorological conditions while monitoring the source operating conditions carefully;

b) make a long-term measurement, or many sampled measurements, spread out over time while monitoring the meteorological conditions.

Both types of measurements require post processing of measured data.

Each result and each type of measurement will have a certain uncertainty, which shall be determined. It is up to the user of the results to determine which accuracy to aim for. No upper limits of the measurement uncertainty are given.

The long-term L_{eq}, L_{long}, is given by Formula (5):

$$L_{\text{long}} = 10\lg\left(\sum_{k=1}^{N_\text{w}} p_k\, 10^{0,1 L_k}\right) \text{dB} \tag{5}$$

where

p_k is the frequency of occurrence of the emission and meteorological conditions of window k yielding the L_{eq}-level L_k, expressed in decibels (dB);

N_w is the number of windows used.

Normally, L_k is determined by several measurements; see Formula (6):

$$L_k = 10\lg\left(\frac{1}{N_\text{m}}\sum_{i=1}^{N_\text{m}} 10^{0,1 L_i}\right) \text{dB} \tag{6}$$

where

L_i is an independent measurement within window k, expressed in decibels (dB);

N_m is the number of measurements within this window.

In order to be able to calculate L_{den}, day, evening and night periods shall be separated.

A window is a combination of emission (e.g. day, evening, night) and meteorological conditions (e.g. four different classes, as shown in Table 2). Preferably, a window should include constant emission and propagation conditions. In many cases, the emission conditions are independent of the meteorological conditions and in other cases, such as for aircraft noise, there is a strong interrelationship.

Table 2 — Stratification of emission conditions and meteorological conditions during measurements

Meteorological window / **Emission window**	1	2	3	4
1				
2				
N				

The uncertainty shall be determined for p_k and L_k. Ideally, the uncertainty of L_k is determined directly from a large number of independent measurements; see 10.5. If only one or few measurements are carried out, the uncertainty shall be determined using other available information. If values of L_k are missing, they shall be estimated using a prediction method. These estimates shall also include estimates of the uncertainty.

For meaningful single measurements, the minimum requirement is that L_k is determined during favourable propagation conditions as defined in Annex A and that the source operating conditions are monitored during these measurements.

6.2 Independent measurements

For two measurements to be independent, disregarding seasonal, diurnal, weekly or other systematic variations, the requirements of Table 3 can be used as a guidance (see Reference [5]).

Table 3 — Minimum time (in hours) between two measurements to be independent

Distance	<100 m		100 m to 300 m		>300 m	
	day	night	day	night	day	night
Road	24 h	24 h	48 h	48 h	72 h	72 h
Rail	24 h	24 h/ source[a]	48 h	72 h	72 h	72 h
Industry	source	source	48 h	48 h	72 h	72 h
Aircraft[b]	source	source	source	source	source	source

[a] If freight trains are dominant.

[b] Depend mostly on flight operation.

NOTE 1 "Source" in Table 3 indicates that the minimum time is influenced by the operating conditions of the source.

NOTE 2 "Day" in Table 3 refers to the time between sunrise and sunset whereas night refers to the time between sunset and sunrise.

7 Operation of the source

7.1 General

The source operating conditions shall be representative of the noise environment under consideration. To obtain a reliable estimate of the equivalent-continuous sound pressure level, as well as the maximum sound pressure level, the measurement time interval shall encompass a minimum number of noise events. For the most common types of noise sources, guidance is given in 7.2 to 7.5. The number of vehicle pass-bys (road vehicles, trains, aircraft) needed to average the variation in individual vehicle noise emission depends on the required accuracy. Less common noise sources, such as shipping traffic, helicopters and trams are not dealt with specifically.

The equivalent-continuous sound pressure level of noise from rail and air traffic can often be determined by measuring a number of single-event sound exposure levels for vehicle/train pass-bys and calculating the equivalent-continuous sound pressure level based on these.

If the measured values are to be corrected to other operating conditions using specified prediction models, the operating conditions shall be monitored using all relevant parameters used as input in the prediction method. The resulting uncertainty will depend on how accurately the different parameters are determined.

NOTE Guidance on how to correct to other conditions are given in Annex D.

The guidance given does not consider potential additional problems with low-frequency sound sources such as helicopters, bridge vibrations, subway trains, freight trains, mine sites, stamping plants, pneumatic construction equipment, etc. ISO 1996-1:2016, Annex C contains a further discussion on low-frequency sound. Procedures to measure low-frequency sound are given in 9.2.2 and 9.3.2.7.

7.2 Road traffic

7.2.1 L_{eq} measurement

When measuring L_{eq}, the number of vehicle pass-bys during the measurement time interval shall be determined by direct counting or by other means. If the measurement result shall be converted to other traffic conditions, distinction shall be made between at least the three categories of vehicles "passenger cars" and "'medium heavy (2 axles)" and "heavy (≥3 axles)". To determine if the measurement conditions are representative, the average traffic speed shall be determined by measurements or by other means and the condition and type of road surface shall be noted.

The number of vehicle pass-bys needed to average the variation in individual vehicle noise emission depends on the required accuracy. If no better information is available, the standard uncertainty denoted u_{sou} in Table 1 can be calculated by means of Formula (7):

$$u_{sou} \cong \frac{C}{\sqrt{n}} \text{ dB} \tag{7}$$

where n is the number of pass-bys.

For mixed traffic $C = 10$, for heavy vehicles only $C = 5$ and for passenger cars only $C = 2{,}5$. In each case, a more accurate standard uncertainty can be determined from the statistics of direct L_E measurements of individual pass-bys either category by category or for a representative traffic mix.

7.2.2 L_{max} measurement

The maximum sound pressure levels differ among vehicle categories. In addition, within each vehicle category, a certain spread of maximum sound pressure levels is encountered due to individual differences among vehicles and variation in speed or driving patterns. Depending on definition the maximum sound pressure level can either be measured directly from a specified number of pass-bys or calculated from the arithmetic mean value and the standard deviation using statistical theory; see Annex H.

7.3 Rail traffic

7.3.1 L_{eq} measurement

When determining L_{eq}, either by direct measurement or by measurement of L_E of individual pass-bys, the number of train pass-bys, the speeds and the train lengths, or, alternatively, the number of cars shall be determined during the measurement time interval. If the measurement result shall be converted to other traffic conditions, distinction shall be made between at least the following categories: high-speed trains, inter-city trains, regional trains, freight trains and diesel trains. For increased accuracy for freight trains, train length and brake type (disc-brakes, tread-brakes using cast iron or sinter) should be recorded.

The number of vehicle pass-bys needed to average the variation in individual vehicle noise emission depends on the required accuracy. If no better information is available, the standard uncertainty denoted u_{sou} in Table 1 can be calculated by means of Formula (8):

$$u_{sou} \cong \frac{C}{\sqrt{n}} \text{ dB} \tag{8}$$

where n is the number of pass-bys.

If the sampling was made regardless of the operating conditions, assume $C = 10$, while if the sampling takes into account the relative occurrence of the different train classes (freight, passenger, etc.), this value can be lowered to 5. In each case, a more accurate standard uncertainty can be determined from the statistics of direct L_E measurements of individual pass-bys either category by category or for a representative traffic mix.

7.3.2 L_{max} measurement

The maximum sound pressure levels differ among train categories. In addition, within each train category, a certain spread of maximum sound pressure levels is encountered due to individual differences among vehicles and variation in speed operating conditions. Depending on definition, the maximum sound pressure level can either be measured directly from a specified number of pass-bys or calculated from the arithmetic mean value and the standard deviation using statistical theory; see Annex H.