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Determination of L_{den} and L_{night} using measurements

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1 Scope

This method describes how to determine L_{den} and L_{night}, as defined by the European directive 2002/49/EC, by direct measurement or by extrapolation of measurement results by means of calculation. The measurement method is intended to be used outdoors as a basis for assessing environmental noise and for verifying the quality of predictions. The method can also be used for monitoring purposes.

The method is flexible and to a large extent the user determines the measurement effort and, accordingly, the measurement uncertainty, which has to be determined and reported in each case. Often the measurement results have to be combined with calculations to correct for operating or propagation conditions different from those during the actual measurement. In each case the long term equivalent sound pressure level is calculated by taking into account the frequency of occurrence of the different operating and propagation conditions. For each of these conditions the sound pressure level is measured or calculated.

In principle two different methods are described: Long-term and short-term measurements. However, in practice, a combination of these will often be used. Short-term measurements involve measurements under specified source operating and meteorological conditions and the measurement results have to be used with a calculation method in order to determine the L_{den}-values. Long-term measurements on the other hand involve measurements during a time long enough to include variations in source operating and meteorological conditions. Thus the measurement results are more accurate and can be used with much less corrections than those of short-term measurements.

This is a frame method, which can be applied on all kind of noise sources, such as road and rail traffic noise, aircraft noise and industrial noise.

2 Normative references

The following referenced documents are indispensable for the application 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 5725, *Accuracy (trueness and precision) of measurement methods and results – Part 1-6*

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*

ISO, Guide for the expression of uncertainty in measurement (GUM)

3 Terms and definitions

For the purposes of this document the following apply:

3.1 (RMS) sound pressure level

ten times the common logarithm of the square of the ratio of the (frequency-weighted) and (time-weighted) sound pressure to the reference sound pressure of 20 micropascals (μPa), where the sound pressure is the root mean square of the instantaneous sound pressures that are frequency weighted with a standard frequency characteristic (e.g., A- or C-weighting) and exponentially time-weighted in accordance with the standardized characteristics slow (S) or fast (F), both weightings as specified in IEC 60651. The time weighting shall be specified. The frequency weighting should be specified; otherwise, A-weighting will be understood.

NOTE 1 The sound pressure is expressed in pascals (Pa).

NOTE 2 The sound pressure level is expressed in decibels (dB).

3.2 maximum (frequency-weighted) sound pressure level

the maximum sound pressure level is the largest (RMS) sound pressure level during a stated time interval. The time-weighting "F" or "S" shall be specified, and the frequency weighting should be specified; otherwise, A-weighting will be assumed.

NOTE The maximum sound pressure level is expressed in decibels (dB).

3.3 percent exceedence level

the level, obtained using stated time and frequency weightings (see IEC Publication 61672-1), that is exceeded for *N* % of the time interval considered

NOTE 1 For example $L_{AF95,1h}$ is the A-frequency-weighted, fast-time-weighted (RMS) sound pressure level exceeded for 95 % of 1 h.

NOTE 2 Percent exceedence levels as determined over a certain time interval cannot generally be extrapolated to other time intervals.

3.4 (frequency-weighted) sound exposure level

ten times the common logarithm of the ratio of the sound exposure, E_A, to the reference sound exposure, E_0, where the sound exposure is the time integral over a stated time interval, *T*, of squared, frequency weighted instantaneous sound pressures, *p(t)*, in pascals. The frequency weighting should be specified; otherwise, A-weighting will be understood.

$$L_{EA} = 10\lg\left(\frac{E_A}{E_0}\right) = 10\lg\left(\frac{\int_T p^2(t)dt}{400 \cdot 10^{-12}}\right) \tag{1}$$

NOTE 1 The sound exposure is expressed in pascal-squared second (Pa^2s).

NOTE 2 The reference sound exposure is equal to the square of the reference sound pressure of 20 micropascals (μPa) multiplied by the reference time of 1 s [400 ($\mu Pa)^2s$].

NOTE 3 The sound exposure level is expressed in decibels (dB).

3.5 equivalent-continuous (frequency-weighted) sound pressure level

ten times the common logarithm of the square of the ratio of the equivalent sound pressure to the reference sound pressure, p_0, of 20 micropascals (μPa),

$$L_{eq} = 10\lg\left(\frac{\overline{p^2}}{p_0^2}\right) \tag{2}$$

where:

a) the equivalent sound pressure is the square root of the ratio of the time integral of squared (frequency-weighted) instantaneous sound pressures, *p(t)*, in pascals to the time period of integration, *T*, in seconds

$$\bar{p} = \sqrt{\frac{1}{T}\int_{t_1}^{t_2} p^2(t)dt} \qquad (3)$$

where *T* equals $t_2 - t_1$, or

b) the equivalent sound pressure is the square root of the ratio of the sound exposure, *E*, in pascal-squared seconds, in a stated time period, *T*, in seconds, to *T*

$$\bar{p} = \sqrt{\frac{E}{T}} \qquad (4)$$

For either (a) or (b), the time period of integration shall be stated. The frequency weighting should be specified; otherwise, A-weighting will be assumed.

NOTE 1 Equivalent-continuous sound pressure level is expressed in decibels (dB).

NOTE 2 Equivalent-continuous sound pressure level is also termed time average sound pressure level.

3.6 measurement time interval

time interval during which measurements are conducted.

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

NOTE 2 For measurements of maximum sound pressure level or percent exceedence level, etc., the measurement time interval is the time-period of observation.

3.7 observation time interval

time interval during which a series of measurements is conducted

3.8 prediction time interval

time interval over which levels are predicted.

NOTE 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 except, for the former, the levels are predicted, and for the latter, the levels are measured.

3.9 reference time interval

time interval of a day to which measured or predicted levels are referred.

NOTE The reference time interval may be specified in national or international standards or by local authorities to cover typical human activities and variations in the operation of sound sources

3.10 long-term time interval

specified time interval for which the results of noise measurements or predictions are representative.

NOTE 1 The long-term time interval consists of a series of reference time intervals

NOTE 2 For L_{den} and L_{night} the time interval is one year under conditions which are representative in the long-term, e.g. 10 years average meteorological conditions, typical distribution of the traffic, etc. interval is the average year.

3.11 L_{day}

equivalent continuous sound pressure level when the reference time interval is the day, normally the 12 hours between 07-19 hours.

NOTE Individual countries may define day differently, e.g. 06-18 hours.

3.12 $L_{evening}$

equivalent continuous sound pressure level when the reference time interval is the evening, normally the 4 hours between 19-23 hours.

NOTE Individual countries may define evening differently, e.g. 18-22 hours.

3.13 L_{night}

equivalent continuous sound pressure level when the reference time interval is the night, normally the 8 hours between 23-07 hours.

NOTE Individual countries may define night differently, e.g. 22-06 hours.

3.14 L_{den}

The day- evening- night-weighted yearly average defined by

$$L_{den} = 10\lg\left[\frac{1}{24}\sum_{1}^{4}\frac{1}{4}\left(8\cdot 10^{0{,}1Liday} + 4\cdot 10^{0{,}1(Lievening+5)} + 8\cdot 10^{0{,}1(Linight+10)}\right)\right] \tag{4}$$

NOTE If the number of hours defining day, evening and night respectively differ from the default values 12, 4 and 8 hours respectively the equation has to be changed accordingly.

3.15 long-term measurements

measurements sufficiently long to encompass all emission situations and meteorological conditions which are needed to obtain a representative average.

3.16 short-term measurements

measurements during measurement intervals with well-defined emission and meteorological conditions.

3.17 receiver location

location at which the noise is assessed.

3.18 calculation method

set of algorithms to calculate the sound immission level from measured or predicted sound emission levels and sound attenuation data.

3.19 prediction method

sub-set of a calculation method, intended for the calculation of future noise levels.

3.20 meteo-window

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

3.21 emission window

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

3.22 sound path radius of curvature

R, in km, radius approximating the curvature of the sound paths, due to atmospheric refraction**.**

3.23 monitor

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

3.24 automated sound monitoring system

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

3.25 total sound

totally encompassing sound in a given situation at a given time, usually composed of sound from many sources near and far.

3.26 specific sound

component of the total sound that can be specifically identified and which is associated with a specific source.

3.27 residual sound

total sound remaining at a given position in a given situation when the specific sounds under consideration are suppressed.

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 weather conditions, the distance from the source and the measurement method and instrumentation. The measurement uncertainty shall be determined in compliance with the ISO Guide to Uncertainty in Measurements (GUM).

According to GUM each significant source of error has to be identified and corrected for. If the quantity to be measured is L_m, which is a function of the quantities x_j the equation becomes

$$L_m = f(x_j) \tag{5}$$

If each quantity has the standard uncertainty u_j the combined uncertainty is given by

$$u(L_m) = \sqrt{\sum_{1}^{n} \left(c_j u_j\right)^2} \tag{6}$$

where the sensitivity coefficient c_j is given by

$$c_j = \frac{\partial f}{\partial x_j} \tag{7}$$

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

NOTE Cognizant authorities may set other levels of confidence. A coverage factor of 1,3 will, e.g., provide a level of confidence of 80 % and one of 2 a level of confidence of 95 %.

For environmental noise measurements $f(x_j)$ is extremely complicated and it is hardly feasible to put up exact equations for the function *f*. Following the principles given in ISO 3745, [5], we can identify some important sources of error and write

$$L_{true} = L_m + \delta_{slm} + \delta_{sou} + \delta_{met} + \delta_{loc} + \delta_{res} \tag{8}$$

where L_{true} is the true value during the specified conditions for which we want a measured value, L_m is the measured value, δ_{slm}= the error of the measurement chain (sound level meter in the simplest case), δ_{sou}= the error due to deviations from the ideal operating conditions of the source, δ_{met}= the error due to meteorological conditions deviating from the ideal conditions, δ_{loc}= the error due to the selection of receiver position and δ_{res}= the error due to residual noise. Often δ_{sou} + δ_{met} is determined directly from measurements, see clause 6.3.

Equation (8) is very simplified and each source of error is a function of several other sources of error. In principle eq. (8) could be applied on any measurement lasting from seconds to years. In 6.1 and 6.2 the measurements are divided into long and short term measurements respectively. A short term measurement may typically range between 10 minutes and a few hours whereas a typical long term measurement may range between a month and a year.

In table 1 guidance is given how to determine c_j and u_j for insertion into equation (6).

Table 1 Overview of uncertainties to be determined

Quantity	Estimate	Standard uncertainty, u_j	Sensitivity coefficient, c_j	Clause for guidance
	L_m	$u(L_m)$		
δ_{slm}	0	0,5 (class 1) 1,5 (class 2)	1	
δ_{sou}	0	u_{sou}	1	7.2 – 7.5
δ_{met}	0	u_{met}	1	Annex A 8
δ_{loc}	0, 3 or 6	u_{loc}	1	Annex B
δ_{res}	L_{res}	u_{res}	$\sqrt{2} \cdot 10^{0,1(L_m - L_{res})}$	Annex F
	0			

Table 1 refers 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. If short-term measurements are carried out under different meteorological conditions the uncertainty has to be determined for each condition. The combined uncertainty obtained by adding different conditions, measured or calculated, can be determined following the guidance in annex F.

NOTE Some examples of uncertainty calculations are given in Annex G.

5 Instrumentation

5.1 Instrumentation system

5.1.1 General

The instrumentation system, including the microphone, cable and recorders if any, shall conform to the requirements for a class 1 instrument laid down in IEC 61672-1. A windshield shall always be used during outdoor measurements. For measurements in octave or one-third-octave bands the instrumentation system shall meet the requirements of IEC 61260.

Instrumentation for measurements of meteorological parameters shall have a measurement uncertainty at least meeting the following requirements: wind speed better than ±0,5 m/s, temperature better than ±1ºC and relative humidity better than ±2,5%. Stability classes shall be given according to chapter 8.

5.1.2 Long-term monitoring

5.1.2.1 Air temperature

The components of a system that are located outdoors shall conform to the class 1 tolerance limits of IEC 61672-1 for the range of variations in air temperature over the range – 25° C to + 55° C.

NOTE 1 A separate specification for the influence of variations in air temperature is given as the range of air temperatures to which the outdoor part of a sound monitor may be exposed is greater than that specified for sound level meters in IEC 61672-1 and reflects the permanent nature of the installation.

NOTE 2 This requirement may be met by including artificial heating or cooling within the housing of the monitor, but if such a means of temperature regulations is used, it should be noted that in the event of failure of such a means of temperature regulation, such as that caused by failure of the power supply, measurement uncertainties may significantly increase.

5.1.2.2 Other outside influences

The mechanical design and installation of outdoor system equipment shall be such as to minimise damage by living creatures. Specific features which are advisable include running all cables in metal conduit, use microphone windscreens, sturdy locks at all access points, and in general making the equipment inaccessible to the more prevalent local creatures. The system operator shall be aware of the particular flora and fauna at the site of any installation and take steps to protect against it.

5.1.2.3 Power supply

The monitor shall remain in specification at least during a voltage deviation of the power supply of 10 % from the nominal voltage at the site. To ensure continuous operation, each sound monitor shall continue to operate to the requirements of this document in the event of a failure of the public supply or the public supply exceeding the 10 % permitted deviation. Any continuous method of supplying power is acceptable, such as solar power, energy cell etc.

NOTE It is strongly recommended that any power back-up system, such as battery operation should be capable of allowing full operation for the worst expected annual supply failure at that site. Such a power supply failure should be considered to last at least as long as the time of the longest public holiday at the location, when re-instating the supply during such a holiday may not be possible.

The system manufacturer or the system provider, if not the manufacturer, shall provide data showing that the specified period of back up is valid for up to one year after the annual verification.

5.2 Manual calibration during attended measurements

Immediately before and after each series of measurements, apply a class 1 sound calibrator according to IEC 60942 to the microphone for checking the calibration of the entire measuring system at one or more frequencies. The results are only valid between two calibrations yielding the same calibration level within 0,5 dB.

Verify the compliance of the calibrator with the requirements of IEC 60942 once a year and the compliance of the instrumentation system with the requirements of IEC 61672-1 at least every two years in a laboratory with traceability to a primary or national standard laboratory.

Record the date of the last check and confirmation of the compliance with the relevant IEC standard.

5.3 Automatic calibration during unattended measurements

5.3.1 Automatic signal sensitivity verification

Provision shall be made to check the operation of each monitoring station, and the system to which it is connected, by application of a known electrical signal in series with the microphone or to an actuator positioned on the microphone. The signal at the output of the microphone shall be a tone with a frequency between 990 Hz and 1010 Hz and an equivalent sound pressure level above 80 dB. It shall be possible to actuate this calibration manually at both the microphone site and from the central site. The results are only valid between two calibrations yielding the same calibration level within 0,5 dB.

NOTE 1 While automatic acoustic calibration is not excluded, electrostatic actuation of the microphone is the preferred method.

NOTE 2 Substituting a known electrical voltage in place of the signal from the microphone is not a reliable method of calibration or verification and can lead to serious errors. In case such a method is used it has to be checked regularly with other more reliable methods.

NOTE 3 It is permitted to perform a sensitivity check and simply store the deviation of the sensitivity without changing the calibration of the signal chain. Such a method is often known as a calibration check.

5.3.2 Frequency of signal sensitivity verification

Checking the system sensitivity of any automated system shall occur automatically at least once per day. Whenever automatic sensitivity checking is taking place, the resulting sound pressure level data shall be excluded automatically through positive means from all residual sound. Any automated checking system shall not be initiated while an important sound event is being detected, but shall be delayed until the event has finished.

5.3.3 Storage of signal sensitivity verification data

The initial calibration sensitivity level and the differences between this level and the sensitivity levels subsequently measured on each day shall be stored and reported. In addition, the standard deviation or variance of the differences in the calibration sensitivity levels shall be recorded and stored over the period between checking the acoustical sensitivity of a sound-measuring channel by means of an acoustic calibrator. At least the last twelve months of such sensitivity data shall be stored by the system.

This recording of any change of the sensitivity should not be used to ‘correct’ measured data when a significant change in sensitivity is shown, as the exact time at which the sensitivity changed cannot be known.

Such data should be regarded as very suspect. However, once a change has occurred and a second stable sensitivity is achieved, it is reasonable to ‘correct’ the data, but a note should always be made of any such correction. In general a change of sensitivity of more than one decibel should be regarded as significant and the symptom of a fault and the reason for the change should be determined as soon as reasonably practical and any fault corrected.

The standard deviation or the variance can be stored either by storing a calibration offset or a new overall figure or any method, which allows the change of sensitivity to be readily seen.

6 Principles

6.1 General

Depending on the measurement effort measurements of environmental noise can be made in infinitely many ways. Each result and each type of measurement will have a certain uncertainty, which has to be determined. It is up to the user of the results to determine which accuracy to aim for.

The long term L_{eq}, L_{long}, is given by

$$L_{long} = 10\lg\left(\sum_{i=1}^{n} p_i 10^{\overline{L_i}}\right) \qquad (9)$$

where p_i = the frequency of occurrence of the emission and meteorological conditions of window i yielding the L_{eq}-level L_i. Normally $\overline{L_i}$ is determined by several measurements

$$\overline{L_i} = 10\lg\left(\sum_{i=1}^{n_i} 10^{L_i}\right) \qquad (10)$$

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

NOTE. A window is a combination of emission, e.g. day, evening, night and meteorological conditions, e.g. four different classes, as shown in the matrix below. It is possible to measure one box at a time or to combine several boxes in one measurement

Emission	Meteo 1	Meteo 2	Meteo 3	Meteo 4
Day				
Evening				
Night				

The uncertainty has to be determined for p_i and $\overline{L_i}$. Ideally the uncertainty of $\overline{L_i}$ is determined directly from a large number of independent measurements, see clause 10.1.2. If only one or few measurements are carried out the uncertainty has to be determined using other available information. If values of $\overline{L_i}$ are missing they have to be estimated using a prediction method. This estimate shall also include an estimate of the uncertainty.

The minimum requirement is that $\overline{L_i}$ is measured 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 the requirements of table 2 have to be met.

Table 2 Minimum time between two measurements to be independent

Distance m	< 100		100-300		> 300	
	day	night	day	night	day	night
Road	24	24	48	48	72	72
Rail	24	24/source[1]	48	72	72	72
Industry	source	source	48	48	72	72
Aircraft[2]	source	source	source	source	source	source

time in hours

1) if freight trains are dominant

2) depend mostly on flight operation

NOTE "Source" in table 2 indicates that the minimum time is influenced by the operating conditions of the source.

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. The level of confidence and confidence interval shall be noted.

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 passbys 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 have to be monitored using all relevant parameters used as input in the prediction method.

7.2 Road traffic noise

When measuring L_{eq} the number of vehicle pass-bys shall be counted during the measurement time interval. 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 ($\geq$ 3 axles)'. To determine if the traffic conditions are representative, the average traffic speed shall be measured and the type of road surface 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 Equation (9)

$$u_{sou} \cong \frac{C}{\sqrt{n}} \text{ dB} \qquad (11)$$

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.

The maximum sound pressure levels differ between vehicle categories. Within each vehicle category a certain spread of maximum sound pressure levels is encountered due to individual differences between vehicles and due to variation in speed or driving pattern. The maximum sound pressure level should be determined based on the sound pressure level measured during at least 30 pass-bys of vehicles of the category considered. Alternatively use 10 pass-bys to determine the standard deviation and then use the statistical procedure outlined in 10.3.2 to determine the maximum level.

7.3 Rail traffic

When measuring L_{eq} the number of train pass-bys, the speeds and the train lengths 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 and freight trains.

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 Equation (12)

$$u_{sou} \cong \frac{C}{\sqrt{n}} \text{ dB} \tag{12}$$

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.

NOTE If it is not possible to obtain this many recordings it shall be stated in the report how many train pass-bys were analysed and the influence on the uncertainty shall be assessed.

7.4 Air traffic

The L_{eq} - level shall be determined from L_E-measurements of a representative operation of the airport. This includes the traffic pattern (runway use, take-off and landing procedures, air fleet mix, time-of-day distribution of the traffic) as well as the noise propagation conditions. The measured quantities are

- the continuous A-weighted sound pressure level at a rate of at least 10 Hz
- the sound exposure level L_{AE}
- the maximum sound pressure level L_{ASmax}
- time stamp for the L_{ASmax}
- duration of the event

For the L_{day}, L_n and the average L_{ASmax} the uncertainties shall be given. The difference between the cumulated exposure from the measurement and the true exposure shall be less than 3 dB.

NOTE If it is not possible to obtain this many recordings it shall be stated in the report how many aircraft pass-bys were analysed and the influence on the uncertainty shall be assessed.

7.5 Industrial plants

The source operating conditions shall be divided into classes: For each class the time variation of the sound emission from the plant shall be reasonably stationary in a stochastical sense. The variation shall be less than the variation in transmission path attenuation due to varying weather conditions, cf clause 8. If 5 minute to 10 minute L_{eq}-values measured at a distance long enough to include noise contributions from all major sources and short enough to minimize meteorological effects, see clause 8, during a certain operating condition turn out to vary considerably, a new categorisation of the operating conditions shall be made. Measure L_{eq} during each class of operating condition and calculate the resulting L_{eq} taking the frequency and duration of each class of operating condition into account.

If the purpose is to measure the maximum sound pressure level of noise from industrial plants, ensure that the measurement period contains the plant operating condition with the highest noise emission occurring at the nearest proximity to the receiver location. Maximum sound pressure levels shall be determined from at least 5 events of the most noisy relevant operation condition.

NOTE The operating condition is defined by the activity as well as its location.

In order to be able to carry out uncertainty calculations according to clause 4 it is necessary to estimate the standard uncertainty of the operating conditions. One way of doing this is to repeat the measurements at a distance sufficiently close to the source to make the sound pressure level variations independent of the meteorological conditions. The equation for this is

$$u_{sou} = \sqrt{\sum_{i=1}^{n} \frac{\left(L_{mi} - \overline{L_m}\right)^2}{n-1}} \tag{13}$$

where

L_{mi} is the measured value representing a typical cycle of operation, $\overline{L_m}$ is the arithmetic average of all L_{mi} and *n* is the total number of all independent measurements.

8 Meteorological conditions

8.1 General

For both long and short-term measurements meteorological parameters shall be measured. As a minimum requirement wind speed, wind direction, relative humidity and temperature shall be measured. Furthermore, information about the cloud coverage shall be provided. For the purpose of defining propagation conditions in the direction of the shortest distance from the receiver to the source the classes shown in table 3 can be used to fill in the measurement matrix shown in 6.1. The radius of curvature can either be determined indirectly from table 3 or be calculated from measured meteorological parameters according to Annex A.

NOTE Table 3 is a simplified table and other alternative descriptions are permitted as long as they assure that the desired curvatures are achieved. ISO 1996-2:2006 gives an alternative description of favourable conditions.

Table 3 Meteorological classes

	Wind speed component at 10 m, m/s	R/D	Verbal description
M1	< 1 (day)	< -15	Unfavourable
	< 0 (night)		
M2	1-3	30	Neutral
M3	3-6	11	Favourable
M4	> 6[1)] (day)	6	Very favourable
	$\geq$ 0 (night)		

[1)] Normally it is not possible to measure under such extreme wind conditions

Favourable propagation

If only one or a few short term measurements are carried out they should be taken during favourable or very favourable propagation conditions (Meteo class M3-M4). In that case the default value for the standard uncertainty is

$$u_{met,fav} = 2 \tag{14}$$

Favourable conditions are also assumed to be valid if

$$\frac{h_s + h_r}{r} \geq 0{,}1 \tag{15}$$

h_s = source height, h_r = receiver height and r = distance between the source and receiver.

If the ground is hard larger distances may be acceptable.

9 Measurement procedures

9.1 Selection of measurement time interval

9.1.1 Long-term measurements

Include as many important emission and propagation windows as possible. If propagation conditions or emission conditions vary strongly between the different seasons of the year, e.g. because of winter tyres and snow cover, it might be necessary to measure during several different seasons to achieve a low measurement uncertainty.

9.1.2 Short-term measurements

Select the measurement time interval to cover all significant variations in noise emission. If the noise displays periodicity, the measurement time interval should cover an integer number of at least three periods. If continuous measurements over such a period cannot be made, measurement time intervals shall be chosen so that each represents a part of the cycle and so that, together, they represent the complete cycle. Representative measurement results can be extended in time to cover the period for which they are representative and combined to provide new results.

If the noise is from single events (e.g. aircraft fly-over in which the noise varies during the fly-over and is absent during a considerable portion of the reference time interval), measurement time intervals shall be chosen so that the sound exposure level, L_{ET}, of the single event can be determined.

For short-term measurements involving propagation over long distances requiring favourable conditions as described in 8.1 and 8.2 the minimum averaging time to average meteorological conditions is 30 minutes.

9.2 Microphone location

9.2.1 Selection of measurement site

Sites for measuring microphones shall be chosen to minimise the effect of residual sound from non-relevant sound sources.

NOTE. Some guidance in the selection of measurement site is given in annex C.

9.2.2 Selection of microphone position

Select one of the following kinds of position:

a) To assess the situation at a specific location use a microphone at that specific location.

For other purposes use one of the following positions:

b) incident sound field (reference condition)

NOTE This case is either an actual case or a theoretical case for which the hypothetical free field over ground sound pressure level outside a building is calculated from measurements close to the building; see c) and d). The incident field notation refers to the fact that all reflections, if any, from any building behind the microphone are eliminated. A position behind a house which acts as a barrier is also considered to be an incident field position but in this case positions c) and d) are not relevant and reflections from the back side of the building is included.

c) position with the microphone flush-mounted on the reflecting surface.

In this case the correction to use to get free field is up to 6 dB. It is 6 dB if the conditions in annex B are met. For other conditions other corrections have to be used.

NOTE +6 dB is the difference between a façade mounted microphone and a free field microphone in an ideal case. In practice minor deviations from this value will occur. For further guidance, see Annex B.

d) position with the microphone 0,5 - 2 m in front of the reflecting surface.

In this case the correction to use to get free field is up to 3 dB. It is 3 dB if the conditions in annex B are met. For other conditions other corrections have to be used.

NOTE The difference between a microphone 2 m in front of façade and a free field microphone is close to 3 dB in an ideal case where no other vertical reflecting obstacle influences sound propagation to the studied receiver. In more complex situations (e.g. high building density on the site, canyon street, etc.) this difference may be much higher. Even in the ideal case there may be some restrictions. For near grazing incidence this position is not recommended as the deviations then may become greater. For further guidance, see Annex B.

In principle, any of the above positions can be used provided that the position used is reported together with a statement whether or not any correction to the reference condition has been made. In some specific cases the above positions are subject to further restrictions.

For general mapping, use a microphone height of 4,0 $\pm$0,2 m in multi-storey residential areas.

9.3 Measurements

9.3.1 Long-term unattended measurements

9.3.1.1 Quantities to measure

The monitor shall measure continuously and shall display on demand the A-weighted sound pressure levels of the total sound in the form of time-series of one second or less time-averaged sound pressure levels. Other quantities are optional.

9.3.1.2 Time stamp

A system for monitoring sound of discrete events shall contain an accurate clock for identification of the date and time of day for each measurement of sound events and related phenomena. Clock time shall be within 5 s of actual time of day at all times. In case of power loss, clock operation shall continue or it shall stop until reset. In either case, a clear indication of interruption of time keeping shall be given. If there are multiple clocks in the system, they shall not vary from each other by more than 2 s. The time resolution for any clock shall be at least 1 s. Time shall be in local time. Changes from summer to wintertime and vice versa have to be handled automatically by the system.

9.3.1.3 Event detection

Automatic long term monitoring is possible only when relevant events are reliably and precisely detected and identified in order to be included in or excluded from the result. Different identification techniques can be used depending on the situation. The uncertainty caused by the identification technique shall be estimated and reported.

9.3.2 Short-term attended measurements

Measure one or several of the following quantities:

9.3.2.1 L_{eqT}

For short term averaging, measure in frequency bands during at least 30 minutes to average weather induced variations in the propagation path unless Equation (2) is fulfilled. In that case 10 minutes is usually sufficient. These minimum times may have to be increased in order to get a representative sample of source operating conditions, see clause 7.

NOTE One third octave band data are required in order to allow for corrections using prediction methods.

9.3.2.2 $L_{E,T}$

Measure a minimum number of events of the source operation as specified in clause 6. Measure each event during a time period, which is long enough to include all important noise contributions. For a pass-by, measure until the sound pressure level has dropped at least 10 dB below the minimum sound pressure level recorded during the actual pass-by. Separate between different categories of vehicles as defined by the relevant prediction method.

NOTE One third octave band data are required in order to allow for corrections using prediction methods.

9.3.2.3 $L_{N,T}$

During the measurement interval, log the short term $L_{eq,t}$ (where t< 1s) at least once a second, or log the sound pressure level with a sampling time less than the time constant of the time-weighting used. The class interval into which logged results are placed must be 1,0 dB or less. The parameter basis and, where applicable, time weighting, the log period and the class interval used to determine the $L_{N,T}$ must be reported (e.g. "Based on 10 ms sampling of L_F with class interval 0,2 dB" or "Based on L_{eq}, 1s, class width 1,0 dB).

9.3.2.4 $L_{F,max}$, $L_{S,max}$

Using time weighting F or S, as specified, measure $L_{F,\ max}$ or $L_{S,\ max}$ a minimum number of events of the source operating as specified in clause 6. Record each result.

9.3.3 Residual sound

When measuring environmental noise, residual sound is often a problem. One reason is that regulations often require that the noise from different types of sources be dealt with separately. This separation, e.g of traffic noise from industrial noise, is often difficult to accomplish in practice. Another reason is that the measurements are normally carried out outdoors. Wind induced noise, directly on the microphone and indirectly on trees, buildings etc, may also affect the result. The character of these noise sources may make it difficult, or even impossible, to carry out any corrections. However, to carry out corrections, see 9.6, and to determine the measurement uncertainty, see 4, it is necessary to measure the residual sound and to determine its standard uncertainty.

NOTE. For a normal windscreen on a 13 mm microphone the A-weighted sound pressure level will typically be 30-35 dB at 5 m/s and 50-55 dB at 10 m/s.

9.3.4 Frequency range of measurements

If the frequency content of the noise is required, then, unless otherwise specified, measure the sound pressure level using octave-band filters having the following mid-frequencies in hertz:

63 125 250 500 1 000 2 000 4 000 8 000

Optionally the measurements can be made in one-third-octave bands with mid-band frequencies from 50 Hz to 10 000 Hz.

9.3.5 Measurements of meteorological parameters

The following meteorological parameters should be measured:

a) wind speed;

b) wind direction, air temperature, relative humidity;

c) occurrence of rain,

d) measurement of atmospheric stability (optional, it may also be determined indirectly).

Wind speed and wind direction shall be measured at a height of 10 m.

9.4 Transmission of data

9.4.1 General

Transmission of data from the various microphone locations to a central location may be made by any appropriate type of data link and may be either continuous or intermittent. The transmission hardware and software shall provide for a resolution of at least 0,1 dB in all sound pressure level data and for appropriate validity checking of all transmitted data. Provision shall be made for indicating calibration status and specific periods of lost data due to memory overflow, power loss, or equipment malfunction. Invalid sound pressure levels due to overflow or underflow of the measurement range shall be marked. Data transmission shall not in any way affect the accuracy of, or increase the uncertainty of the sound measurement.

While no method of data error checking is mandatory, the method employed by any system shall be clearly described by the manufacturer or supplier of the system.

It is important for each individual monitor to be separately identified in each data transmission.

Depending on the data processing capabilities of the monitor, transmitted data may consist of raw data and of processed results.

9.4.2 Data Types

If the data are transmitted intermittently in batch form, each acoustic data transmission shall include at least one of the following data sets. The data specified in each data set is a minimum requirement and any further data can be transmitted as well. Data types may be concatenated and transmitted together. The manufacturer shall supply exact details of the data transmitted. Examples of data are:

a) The time history sequence of sound pressure level.

b) The total L_{eq} and the percentile levels for the chosen measurement periods.

c) For each detected event: The A-weighted sound exposure level, $L_{AE,i}$, the maximum sound pressure level, $L_{ASmax,i}$, the duration (DT) and start time of each event and the nominal level of the event recognition thresholds $L_{threshold}$, if relevant.

The format and content of non-acoustic data is not determined by this test method.

NOTE Where the transmission of data is either partly or wholly controlled by a central station, partial data sets may be transmitted providing that full data transmission is also available.

9.4.3 Stored data

The data may be stored on hard disk or similar devices to be used later for data analysis

10 Evaluation of the measurement result

10.1 General

Correct all measured outdoor values to the reference condition, that is the free field level excluding all reflections from the façade immediately behind the microphone but includingall reflections from the groundand other vertical objects but the façade immediately behind.

10.2 Long-term measurements

10.2.1 Incomplete or corrupted data

10.2.1.1 General

A monitoring system or one of its stations may cease acquiring or processing valid sound data as a result of power failure, excessive wind sound, equipment malfunction, etc. Provision shall be made to alert the operator of such a condition, to promote ready resumption of operation, and to minimise loss of data. Where data are irretrievably lost or invalidated, sound level parameter calculations shall be modified appropriately. For example, if several hours of downtime are incurred on a certain day, the averaging process to determine the cumulative daily A-weighted sound pressure level shall be carried out over only those hours for which data are available, rather than over the entire day. Another approach could be that only these daytime or night-time hours are taken into account for which the measurement conditions were acceptable. All such data shall be flagged to indicate the circumstances.

10.2.1.2 Wind sound

Data taken in windy conditions will increase the measurement uncertainty and may adversely affect the accuracy of the data. If the local wind speed at the microphone site is known at the time of each sound event, this should be included in the report. For wind speeds creating noise close to the level to be measured the measured data shall be flagged.

NOTE In some cases, wind effects may be identified by the specific spectrum of wind sound (usually a low frequency dominated broad band sound).

10.2.2 Determination of standard uncertainty

In order to be able to determine the combined standard uncertainty it is necessary to determine the standard uncertainty of the measurements. The uncertainty to determine directly from the measurements is the combined uncertainty of the emission by the source and the meteorological conditions, u_{som}. It has to determined separately for each relevant period, such as day, evening, night and, if required, also for different seasons. The equation for this is

$$u_{som} = \sqrt{u_{sou}^2 + u_{met}^2} = 10\lg\left(10^{0,1\overline{L_i}} + S_i\right) - \overline{L_i} \qquad (16)$$

where

$\overline{L_i}$ is the energy averaged measured sound pressure level for several independent measurements within meteo and emission window i. S_i is given by

$$S_i^2 = 10\lg\left(\frac{1}{n_i - 1}\left(10^{0,1L_i} - 10^{0,1\overline{L_i}}\right)^2\right) \qquad (17)$$

where

L_i is the measured value representing one independent measurement within window i and n_i = the total number of measurements.

10.3 Short-term measurements

10.3.1 $L_{E,T}$, $L_{eq,T}$

For each microphone position and each category of source operating conditions determine the energy average of each $L_{E,T}$ or $L_{eq,T}$.

NOTE Guidance on how to correct $L_{eq,T}$ to obtain rating levels is given in ISO 1996-1.

10.3.2 L_{max}

For each microphone position and each category of source operating conditions determine the following values, whenever relevant: the maximum, the arithmetic average, the energy average, the standard deviation, the statistical distribution of the measured L_{max}.

For homogeneous groups of single events with a Gaussian distribution of sound pressure levels use Figure 1 to estimate percentiles of the distribution of maximum sound pressure levels.

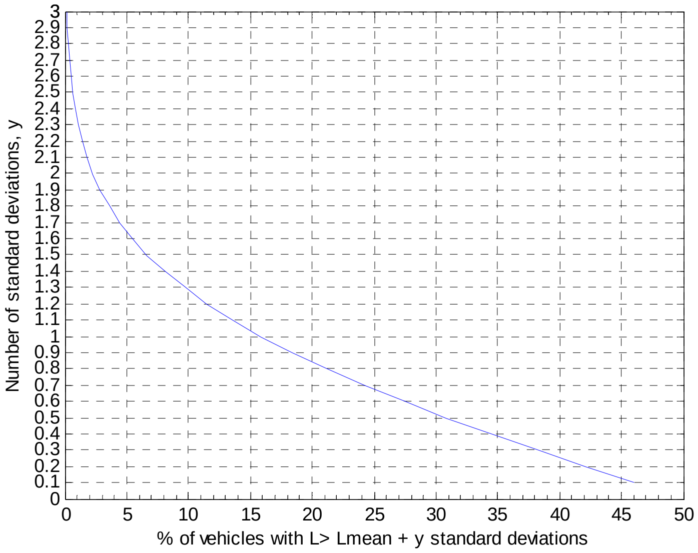


Figure 1 — Percentage of single events with a maximum sound pressure level exceeding, by a certain number y of standard deviations, the (arithmetic) mean of a normal distribution of maximum sound pressure levels

EXAMPLE If the fifth highest maximum sound pressure level is wanted out of 500 vehicles passing, then the percentile is (5/500) * 100 = 1 % and as shown in the bottom part of Figure 1 y = 2,33 ≅ 2,3, that is L_{max}(5^{th} highest) = L_{max}(arithmetic average) + 2,3 s, where *s* is the standard deviation of the maximum levels.

10.3.3 $L_{N,T}$

Analyze the sampled values statistically to obtain the statistical level,$L_{N,T}$, for N%.

10.4 Residual noise

If the residual sound pressure level is 10 dB or more below the measured sound pressure level make no corrections. The measured value is then valid for the source under test.

If the residual sound pressure level is 3 dB or less below the measured sound pressure level, no corrections are allowed. The measurement uncertainty will then be large. The results may, however, still be reported and may be useful for determining an upper boundary to the sound pressure level of the source under test. If such data are reported, it shall clearly be stated in the text of the report, as well as in graphs and tables of results, that the requirements of this test method have not been fulfilled.

For cases when the residual sound pressure level is 3 dB to 10 dB below the measured sound pressure level correct according to the following formula:

$$L = 10\lg\left(10^{L'/10} - 10^{L_{res}/10}\right) \text{ dB} \qquad (18)$$

where

L = the corrected sound pressure level

L' = the measured sound pressure level

L_{res} = the residual sound pressure level

11 Extrapolation to other conditions

11.1 Location

11.1.1 General

Extrapolation of results of measurements is often used to estimate the sound pressure level at another location. Such extrapolation is useful, for example, when residual sound prevents direct measurement at the receiver location.

11.1.2 Extrapolation by means of calculations

The noise measurements shall be carried out at a well defined location neither too close (not in the near field of some part of the source) nor too far away (accurate prediction of attenuation is desirable) from the source in relation to the extension of the source. By calculating the attenuation that has taken place during propagation from source to measuring position an estimate of the source noise emission is established. This estimate is subsequently used to calculate the sound pressure level at another receiver than the intermediate measurement position.

To perform the calculation of sound transmission attenuation, a calculation method is needed, see clause 11. The intermediate measurement position shall be chosen so that reliable measurement and calculation is facilitated. For example, there should be no screening obstacles between the source and the microphone and a high microphone position is preferred as this implies minimum influence of the weather conditions during the measurement.

11.1.3 Extrapolation by means of measured transfer functions

The noise measurements shall be carried out at the location of the desired estimation and, simultaneously, at a reference location relatively close to source (but still out of the near field of some part of the source), preferably between the first location and the source itself. The reference position shall be chosen in order to reduce the level of the residual noise. Simultaneous measurements shall be taken during a limited time period but at least for a period 2-3 times longer than the propagation delay expected between the two microphones.

EXAMPLE Assuming the reference and the assessment microphones are placed 400 m far away, the propagation delay is about 1.2 second. Therefore, setting and integration time of 5 seconds would be an adequate choice.

The two acquisition instruments shall be synchronised accurately in order to make their relative time difference fall within the measurement time interval. Carry out measurements for each selected propagation condition. The measurement time interval shall be long enough to include relevant source variations.

NOTE For almost continuous noise sources (industries, road with heavy traffic) acquisition can be made for a fixed time chosen in order to assure enough statistics but still remaining in the same propagation condition. Usually a period of 15-30 minutes should be appropriate. For variable noise sources (e.g. minor roads and railways) the number of passages should exceed the number of 10; if possible measurement should be extended to last at least 15 minutes or, if the required number of events has not been reached, even further.

The transfer function is then given by

$$L_{tf} = L_{ref} - L_{loc} \tag{19}$$

where L_{ref} is the measured level at the reference location and L_{loc} the level at the assessment location.

Low levels at the assessment location can then be determined by reversing eq. (19), that is

$$L_{loc} = L_{ref} - L_{tf} \tag{20}$$

11.2 Determination of L_{den} and L_{night} from long-term measurements

11.2.1 L_{eq} has been measured

Carry out calculations using the following steps:

1. Remove unwanted sound from the recordings. Some guidance on how to do that is given in Annex D.
2. Evaluate L_{day}, $L_{evening}$ and L_{night} for each measurement interval used.
3. Calculate L_{den} from

$$L_{den} = 10\lg\left[\frac{1}{24}\sum_{1}^{4}\frac{1}{4}\left(8\cdot 10^{0,1Liday} + 4\cdot 10^{0,1(Lievening+5)} + 8\cdot 10^{0,1(Linight+10)}\right)\right] \quad (21)$$

where Li indicates the level measured during season i.

11.2.2 L_E from individual events has been measured

1. Remove unwanted events
2. Add all events for day, evening, night representing N_{day}, N_{eve} and N_{night} days respectively
3. Calculate L_{day} from $L_{day} = 10\lg\left[\frac{1}{N_{day}}10^{0,1L_{E,alldays}}\right]$ and correspondingly for L_{eve} and L_{night}
4. Calculate L_{den} as in 11.2.1.

11.3 Determination of L_{den} and L_{night} from short term measurements

11.3.1 Short-term measurements involving variations in source emission and selected propagation conditions

In this case the measurements have either taken place

a) at a short distance, see eq. (14) minimizing the influence of weather conditions or

b) under favourable propagation conditions as described in 8.2.

c) under mixed propagation conditions

In case a) use the prediction method to normalize the measured sound pressure levels to the traffic flow conditions of the reference time intervals, that is day, evening and night. The values thus obtained are taken as L_{day}, $L_{evening}$ and L_{night} respectively. For industrial noise sources each source has to be time-weighted to take into account the actual times of operation.

In case b and c) proceed as follows

1. Normalize the measured sound pressure levels to the traffic flow conditions of the reference time intervals, that is day, evening and night.
2. Use meteo statistics to determine the ratio of time p_i for each meteo class M_i, see 8.1, distinguishing between day, evening and night.
3. Let the favourable conditions during the measurements be represented either by meteo class M3 (daytime) or M4 (night-time).

- Case b). Use the prediction method to calculate the sound pressure levels for each of the 4 meteo classes as described in table 3. Calculate the difference Δ_i between each meteo class *i* and M3 or M4 (Δ_4 = 0 dB), whichever was measured.

  Note. The prediction method is used to calculate L_{eq} using the same operating conditions for each of the 4 meteo classes M1-M4. For each of these the difference is determined to the class measured (M3 or M4). The these difference are applied to the measured value to get the simulated measured values for the othe meteo conditions.

- Case c). Use the measured noise levels in selected propagation condition in order to estimate the differences Δ_i between each meteo class *i* and M3/M4 (Δ_4 = 0 dB).

4. Calculate L_{day} using the formula

$$L_{day} = 10\lg \sum_{i=1}^{4} p_i 10^{0,1(L_i + \Delta_i)} \tag{21}$$

   where L_i is the measured value during meteo condition Mi corrected to be valid for the traffic flow of the yearly average day and averaged over the number of measurements carried out under the condition Mi.

5. Calculate $L_{evening}$ accordingly

6. Calculate L_{night} accordingly

7. Calculate L_{den} from eq. (10)

12 Information to be recorded and reported

For measurements the following information shall, if relevant, be recorded and reported:

a) Time, day and place for measurements.

b) Measured and, if relevant, corrected sound pressure levels (L_{eq}, L_E, L_{max}), A-weighted (optionally C-weighted as well) and, optionally, in frequency bands.

c) Measured N percent exceedence level (L_N) including the base on which it is calculated (sampling rate and other parameters).

NOTE. L_N is, e.g., used to estimate the residual noise using a typical value of N= 95%.

d) An estimate of the measurement uncertainty.

e) Information on background and residual noise levels during the measurements.

f) Time intervals for the measurements.

g) A thorough description of the measurement site, including ground cover and condition, and locations, including height above ground, of microphone and source.

h) A description of the operating conditions, including number of impulses or passing vehicles/trains/aircraft divided into suitable categories.

i) A description of the meteorological conditions, including wind speed, wind direction, cloud cover, temperature, barometric pressure, humidity and presence of precipitation and location of wind and temperature sensors.

j) Method(s) used to extrapolate the measured values to other conditions.

For calculations relevant information of a) to j), including calculation uncertainty, shall be given.

Annex A (informative) - **Determination of radius of curvature**

For flat terrain the radius *R* approximating the curvature of the sound paths caused by atmospheric refraction can be determined by Equation (A.1).

$$\frac{1}{R_{cur}} = \frac{1}{R_A} + \frac{1}{R_B} \tag{A.1}$$

$$R_A = \frac{A}{|A|}\sqrt{\left(\frac{c_0}{|A|}\right)^2 + \left(\frac{D}{2}\right)^2} \tag{A.2}$$

$$R_B = \frac{B}{|B|}\frac{1}{8}\sqrt{\frac{2\pi c_0}{|B|}}D \tag{A.3}$$

where:

- A is the linear sound speed coefficient in 1/s, given by equation (A.4) and (A.5)
- B is the logarithmic sound speed coefficient in m/s, given by equation (A.6)?
- D is the horizontal distance between the source and the receiver in m
- c_0 is the reference sound speed = 331.4 m/s,

during day (stability classes S_1, S_2 and S_3 (see below):

$$A = \frac{u_*}{C_{vk}L} + \left(\frac{1}{2}\frac{c_0}{T_{ref}}\right)\left(0.74\frac{T_*}{C_{vk}L}\frac{g}{c_p}\right)\text{*cos(wd)} \tag{A.4}$$

during night (stability classes S_4 and S_5 (see below):

$$A = 4.7\frac{u_*}{C_{vk}L} + \left(\frac{1}{2}\frac{c_0}{T_{ref}}\right)\left(4.7\frac{T_*}{C_{vk}L} - \frac{g}{c_p}\right)\text{*cos(wd)} \tag{A.5}$$

$$B = \frac{u_*}{C_{vk}} + \left(\frac{1}{2}\frac{c_0}{T_{ref}}\right)\left(0.74\frac{T_*}{C_{vk}}\right)\text{*cos(wd)} \tag{A.6}$$

where:

- u_* is the friction velocity in m/s
- T_* is the temperature scale in K
- L is the Monin-Obukhov length in m,
- C_{vk} is the Von Karman constant = 0.4
- g is Newton's gravity acceleration = 9.81 m/s²
- c_p is the specific heat capacity of air at constant pressure, 1005 J/kg K
- T_{ref} is the reference temperature = 273 K.
- Wd is the wind direction from source to receiver

The meteorological parameters *u**, *T** and the inverse of the Monin-Obukhov length, 1/*L* can be measured directly or taken from the Tables of Appendix A

NOTE Positive values of *R* correspond to downward sound ray curvature (for example downwind or temperature inversion); 1/*R* = 0 corresponds to straight-line sound propagation ('no-wind', homogeneous atmosphere); negative values of *R* correspond to upward sound propagation (for example upwind or on a calm summer day). Temperature inversions occur e.g. at night time when the cloud cover is less than 70%.

The radius of curvature, *R*, depends on the gradient of wind speed and temperature and is the most important factor determining the sound propagation conditions. Positive values of *R* correspond to downward sound ray curvature (e.g. during downwind). Such sound propagation conditions are often referred to as "favourable", that is the sound pressure levels are high. 1/*R* = 0 corresponds to straight-line sound propagation (homogeneous atmosphere, 'no-wind'); negative values of *R* correspond to upward sound propagation (e.g. during upwind or on a calm summer day). The ray curvature can be determined directly from measuring the parameter *T**, *u** and *L* . In case no direct measurements are possible the parameters given in the following tables can be used:

Table A.1: Friction velocity, by wind speed

	u* m/s
W1	0
W2	0.13
W3	0.3
W4	0.53
W5	0.87

Table A.2: Temperature scale, inverse Monin-Obukhov length 1/*L*, by wind speed and stability classes

T*/ 1/L	S1 D 0/8-2/8	S2 D 3/8-5/8	S3 D 6/8-8/8	S4 N 5/(-8/8	S5 N 0/8-4/8
W1: 0-1 m/s	-0.4 / -0.08	-0.2 / -0.05	0/ 0	0.2 / 0.04	0.4/ 0.06
W2: 1-3 m/s	-0.2 / -0.05	-0.1 / -0.02	0 / 0	0.1 / 0.02	0.2 / 0.04
W3: 3-6 m/s	-0.1 / -0.02	-0.05 / -0.01	0 / 0	0.05 / 0.01	0.1 / 0.02
W4: 6-10 m/s	-0.05 / -0.01	0 / 0	0 / 0	0 / 0	0.05 / 0.01
W5:> 10 m/s	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0

S: stability class
W: wind class
T* Temperature Scale
L : Monin-Obukhov length
u*: friction velocity

Annex B(informative) - **Microphone positions relative to reflecting surfaces**

B.1 Standard uncertainty of different locations

For the most common cases default values for the standard uncertainties using different microphone positions are given in table 1 for traffic noise. For industrial noise and other positions the uncertainties have to be determined for each individual case.

Table B.1 Standard uncertainty of different microphone positions relative to vertical reflecting surfaces. The table is valid for traffic noise only (moving sources)

Microphone location	Standard uncertainty, *V* dB
Traffic noise incident from all angles	
Reference position in a free field	0
Position meeting the requirements of B.2	0,5
Position using the correction 5,7 dB and meeting the requirements of B.3	0,4
Position using the correction 3 dB and meeting the requirements of B.4	0,4
Traffic noise with predominantly grazing incidence	
Reference position in a free field	0
Position meeting the requirements of B.2	
Position using the correction 6 dB and meeting the requirements of B.3	2,0
Position using the correction 3 dB and meeting the requirements of B.4	1,0

B.2 Free field position

This is a position where there are no reflecting surfaces other than the ground close enough to influence the sound pressure level. The distance from the microphone to any sound reflecting surface apart from the ground shall be at least twice the distance from the microphone to the dominating part of the sound source.

NOTE Exceptions can be made for small sound reflecting surfaces and when it can be shown that the reflection has insignificant effect. This can be based on calculations taking the major dimensions of the reflecting surface and the wavelength into account.

B.3 Microphone directly on the surface - Conditions for nominally +6 dB

The default correction for this position is 5,7 dB.

This position is flush-mounted on a reflecting surface and the direct and reflected sound will be in phase below a certain frequency, *f*. For broad band traffic noise with sound incident from many angles *f* is about 4 kHz for a 13 mm microphone mounted on the reflecting surface. This position should be avoided if the sound arrives predominantly at grazing incidence.

The facade must be plane within ± 0,05 m within a distance of 1 m from the microphone, and the distance from the microphone to the surface edges of the façade wall shall be larger than 1 m. The microphone can be mounted as shown in Figure B.1 or with the microphone membrane flush with the surface of the mounting plate. The plate should not be thicker than 25 mm and its dimensions not less than 0,5 m × 0,7 m. The distance from the microphone to the edges and symmetry axes of the mounting plate shall be greater than 0,1 m to reduce the influence of diffraction at the plate edges.

The plate shall be of an acoustically hard and stiff material in order to avoid sound absorption and resonance in the frequency range of interest[1)].

NOTE Care has to be taken that no disturbing aerodynamic noise is created between the plate and a rough façade.

The microphone can be used without a plate when the wall is made of concrete, stone, glass, wood, or similar hard material. In this case the wall surface must be flat within ± 0,01 metres within a radius of 1 metre from the microphone[2)].

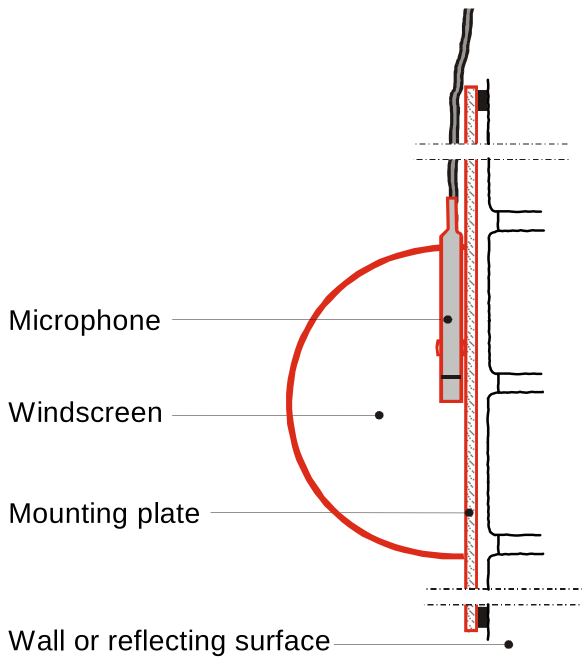


Figure B.1 — Microphone mounting on reflecting surface

B.4 Microphone near reflecting surface – Conditions for nominally +3 dB

When the microphone is at a distance from a reflecting surface, provided that certain conditions are met, the direct and reflected sound is equally strong and when the frequency band considered is wide enough the

1) E.g. painted chipboard thicker than approx. 19 mm or 5 mm aluminium plate with minimum 3 mm damping material on the side facing the wall.

2) For octave band measurements a 13 mm microphone or smaller must be used. If the frequency range is expanded above 4 kHz a 6 mm microphone must be used.

reflection causes a doubling of the energy of the direct sound field and a 3 dB increase in sound pressure level.

The facade shall be plane within ± 0,3 m, and the microphone shall not be placed at positions where the sound field is influenced by multiple reflection of sound between protruding building surfaces.

Windows shall be considered as any other part of the façade. They shall be closed during measurement, but a small opening for the microphone cable is allowed.

Criteria (B.1) – (B.3) ensure that the overall equivalent or maximum sound pressure level measured deviates less than 1 dB from the level of the incoming sound plus 3 dB. Two cases are distinguished between, cf. Figure B.2: a) extended source, i.e. the source angle of view α is 60 degrees or more, and a) point source, i.e. α is less than 60 degrees.

NOTE For narrow band sources or frequency band measurement free-field or +6 dB positions are recommended.

The distance from the microphone, M, perpendicular on the reflecting surface to the point O is *d*, see Figure B.2. Point O is considered representative of the microphone position when determining the angle of view, α. The distances *a’* and *m’* are measured along the dividing line of the angle α..

The distances from point O to the nearest edges of the reflecting surface are *b* (measured horizontally) and *c* (measured vertically). To avoid edge effects in the frequency range including the octave bands 125 Hz to 4 kHz, Criterion (B.1) shall be fulfilled:

$$b \geq 4d \quad and \quad c \geq 2d \tag{B.1}$$

Criterion (B.2) ensures that the incident and reflected sounds are equally strong.

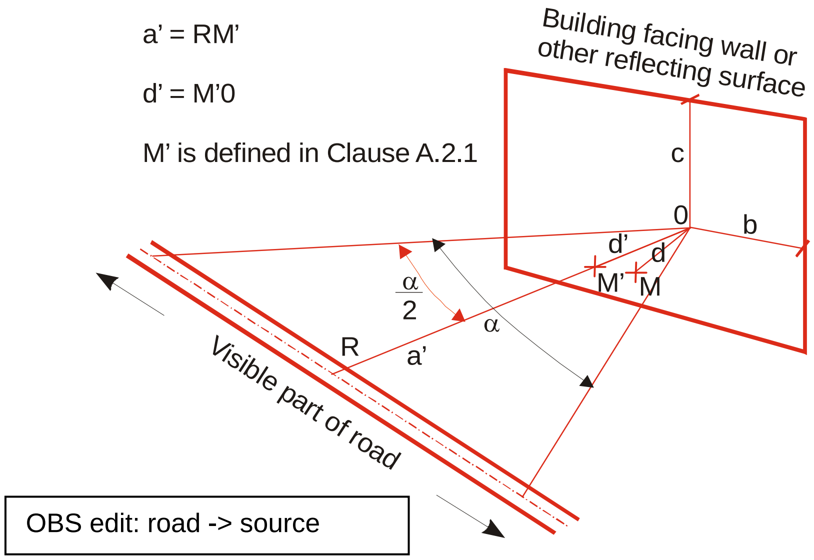
Extended source:	$m' \leq 0.1a'$
Point source:	$m' \leq 0.05a'$

(B.2)

Criterion (B.3) ensures that the microphone is sufficiently far away from the +6 dB region near the facade.

Extended source:	Overall A-weighted sound pressure levels	$m' \geq 0.5$ m
	Octave band sound pressure levels	$m' \geq 1,6$ m
Point source::	Overall A-weighted sound pressure levels	$m' \geq 1.0$ m
	Octave band sound pressure levels	$m' \geq 5.4$ m

(B.3)



To be revised in the figure:
1) road => extended source
2) M' is defined in Clause A.2.1 => M' is defined in the text

Figure B. 2 — MO is the perpendicular distance from the microphone position to the reflecting surface. RO is the dividing line of the angle, a

Annex C (Informative) - Selection of measurement/monitoring site

C.1 General

The location of sound monitoring stations is critical in obtaining accurate and useful sound data. Because the requirements for sound data at particular locations may vary considerably, the engineering guidelines for placing sound monitor stations may also differ considerably. The selection of monitoring sites should be carefully considered early in the development of a monitoring plan, once the objectives for the monitoring system have been clearly identified. In order to analyse to what extent a proposed site influences the uncertainty of the results at that site, it is necessary to examine carefully the relation between the residual sound and the sound pressure levels to be measured. For accurate measurements, the level difference should exceed 15 dB.

C.2 Process of site selection

The selection of sound monitoring sites is usually a two-stage process. The first stage involves the general location of the monitors. This is based upon monitoring objectives, which might include the following:

- to obtain accurate sound information in specific sound-sensitive community areas;

- to obtain accurate information on the sound pressure levels produced by different types of noise sources at the particular location and operations for sound regulatory (sound limit) purposes, sound budget analyses, etc;

- to obtain sound information to monitor noise events;

- to meet monitoring system technical considerations, particularly the need to obtain sound information from more than one station under important noise events;

- to monitor compliance with periodical sound exposure level requirements.

The second stage of the site selection process is the selection of specific monitor sites within the general area. This is based upon practical and other considerations such as:

- interference from other sound sources (other traffic or industry, wildlife, leisure activities etc.);

- ease of access to utilities (telephone and electrical power);

- terrain and building obstructions;

- ease and costs of obtaining site access and approvals (location on private property may require payments of rent or easements; location on publicly owned land such as parkways may be less costly for public agencies, but obtaining formal approvals may be difficult and/or time consuming.);

- monitor station security considerations (vandalism and theft);

- the likely uncertainty of the measurements.

C.3 Method to determine acoustical suitable sound monitoring sites

For an acoustically reliable measurement, the event to be measured must be clearly distinguishable from environmental (residual) sound, i.e. the gap between the average residual sound and the onset of a measurement should be at least 5 dB. This leads to the requirement, that monitors should only be installed at sites, where the events of interest will be at least 15 dB louder than the average residual sound.

Annex D (normative) - **Source specific calculation models**

D.1 Road traffic

Harmonoise

D.2 Rail traffic

Harmonoise

D.3 Air traffic

Imagine

D.4 Industrial noise

Imagine

To be completed later with reference to Harmonoise and Imagine reports.

Annex E (informative) Elimination of unwanted sound

E1 Discrete sound event data (Typically aircraft and rail traffic noise).

A discrete event is established when:

- the A-weighted sound pressure level exceeds a threshold for a continuous period, and

- discrimination tests or by human operator indicate a discrete event source which can be characterised by several parameters, specified by the manufacturer or supplier.

As a minimum, an automatic system shall provide processing to produce the maximum time and frequency weighted sound pressure level of i-th event $L_{max,i}$, the local time at which this maximum sound pressure level takes place, the sound exposure level of i-th event L_E, i and the duration of i-th event, DTi. In addition, the system may determine the time interval between initial threshold crossing and attainment of the maximum sound pressure level, the final threshold crossing, the complete time history and other potentially useful data.

Not all events reported from monitors are related to aircraft operation. Before any further data processing takes place, the events have to be verified and non-aircraft events have to be dismissed. Verification of aircraft event can be made by correlation with an aircraft movement, using the knowledge from airport operation, that an aircraft movement took place at the time of the reported sound event. If the verification is successful, the aircraft event is identified and the additional information on the aircraft and its operation may be added to the sound event data to form the "flight event data".

When automatic event detection is used, the algorithms and associated criterion values used for this process at any given time shall be well described and recorded.

Annex F (Informative)- Measurement uncertainty

F1 Determination of standard deviation for a mixture of conditions

L_{eq} for condition *i*, which lasts for p_i of the total time is denoted L_i. The total L_{eq} for the whole time interval is denoted *L*. We then get

$$L = 10\lg\left(p_1 10^{L1/10} + p_2 10^{L2/10} + ... + p_n 10^{Ln/10}\right) \tag{F.1}$$

The sensitivity coefficient c_{Li} is then given by

$$C_{Li} = \frac{\partial L}{\partial L_i} = 10\lg(e)\frac{p_i \cdot 10^{Li/10}\ln(10)\cdot 0{,}1}{p_1 10^{L1/10} + p_2 10^{L2/10} + ... + p_n 10^{Ln/10}} = \frac{p_i 10^{Li/10}}{\sum p_i 10^{Li/10}} \tag{F.2}$$

For c_{pi} we get

$$c_{pi} = \frac{\partial L}{\partial pi} = \frac{10^{Li/10}}{\sum p_i 10^{Li/10}} \tag{F.3}$$

L_i is determined with the standard uncertainty σ_{Li} and p_i with the standard unctainty σ_{pi}. The standard uncertainty of *L* is then given by

$$\sigma = \sqrt{\sum_{i=1}^{n} \frac{\partial L^2}{\partial L_i^2}\sigma_{Li}^2 + \sum_{i=1}^{n} \frac{\partial L^2}{\partial p_i^2}\sigma_{pi}^2} \tag{F.4}$$

F2 Determination of sensitivity coefficient for residual noise

For residual noise the sensitivity coefficient is no longer 1. The basic equation is

$$L_{without} = 10\lg\left(\left(10^{0,1L_{without}} + 10^{0,1L_{res,m}}\right) - 10^{0,1L_{res,cor}}\right) \tag{F.5}$$

where $L_{without}$ is the level to be measured without influence from background noise and the indices res,m and res,cor denote the residual noise during the measurement and the residual noise used for correction respectively. Thus we get

$$c_{res,m} = \frac{10^{0,1L_{res,m}}}{\left(10^{0,1L_{without}} + 10^{0,1L_{res,m}}\right) - 10^{0,1L_{res,cor}}} \approx 10^{-0,1(L_{res,m} - L_{without})} \tag{F.6}$$

$$c_{res,cor} = \frac{10^{0,1L_{res,cor}}}{\left(10^{0,1L_{without}} + 10^{0,1L_{res,m}}\right) - 10^{0,1L_{res,cor}}} \approx 10^{-0,1(L_{res,cor} - L_{without})} \tag{F.7}$$

The total uncertainty is given by

$$u_{without} = \sqrt{c_{res,m}^2 u_{res,m}^2 + c_{res,cor}^2 u_{res,cor}^2} \approx \sqrt{2} c_{res} u_{res} \approx \sqrt{2} \cdot 10^{0,1(L_{without} - L_{res})} \tag{F.8}$$

where we have assumed that there is little difference between the residual noise during the measurement and the residual noise used for correction. If the residual noise level is much smaller than the noise level from the source to be measured we get

$$c_{res} \approx \sqrt{2} \cdot 10^{0,1(L_m - L_{res})} \tag{F.9}$$

Annex G (Informative)- Examples of uncertainty calculations

G.1 One long term measurement

In table G.1 an example of a simple uncertainty calculation for a long term measurement is given. In practice it should be a little more elaborate as we should consider the effect of cancelled measurement periods, e.g. due to rain, strong winds or excessive background noise.

Table G.1. Uncertainty calculation for a single long term measurement

Quantity	Estimate	Standard uncertainty, u_i dB	Sensitivity coefficient, c_i	Uncertainty contribution $c_i u_i$
$L_{eq,year}$	L_m =58 dB			
δ_{slm}		0,5	1	0,5
δ_{som}	Evaluated from 24h values	0,5	1	0,5
δ_{loc}	+3 dB	0,5	1	0,25
δ_{res}	L_{res} = 50	2	$\sqrt{2} \cdot 10^{-0,1(L_m - L_{res})} = 0,23$	0,45
$u(L_m) = \sqrt{\sum_1^n \left(c_j u_j\right)^2}$				0,87
Expanded uncertainty				1,74

G.2 Single measurement under favourable conditions

In table G.2 a possible uncertainty calculation of a single measurement along a road during one hour under favourable propagation conditions is given.

Table G.2. Uncertainty calculation for a single measurement under favourable propagation conditions

Quantity	Estimate	Standard uncertainty, u_i dB	Sensitivity coefficient, c_i	Uncertainty contribution $c_i u_i$
$L_{eq,1h}$	L_m =58 dB			
δ_{sm}		0,5	1	0,5
δ_{sou}	1000 vehicles	$\frac{10}{\sqrt{1000}} = 0{,}3$	1	0,3
δ_{met}	Favourable	1,5	1	1,5
δ_{loc}	+5,7 dB	0,25	1	0,25
δ_{res}	L_{res} = 50	2	$\sqrt{2} \cdot 10^{-0,1(L_m - L_{res})} = 0{,}23$	0,46
$u(L_m) = \sqrt{\sum_1^n (c_j u_j)^2}$				1,69
Expanded uncertainty				3,38

G.3 Long term values calculated from short term measurements

NOTE. This example neglects the uncertainty of frequency of occurrence, see Annex F.1, and uses other meteorological classes than those of clause 8.

For each short term measurement we can determine the uncertainty as outlined in table G.2. The measurement value has to be corrected to be representative for the time period for which we want to estimate the long term level. The first correction to make is to adjust the level to be representative for the actual traffic flow, which may be different from that of the measurement period. The most straightforward thing is to assume that this correction, which will result in a level shift, will not affect the standard uncertainty but only the sensitivity coefficient.

The next correction to take into account is the one for the meteorological conditions. It is necessary to have results for a sufficient number of meteorological conditions to make it possible to combine the results to correspond to the actual mixture of conditions. To do that, we need either to repeat the measurement under additional meteorological conditions or to adjust the measured levels using a recognized prediction method. It is not unlikely to assume that it is at least as accurate to use a prediction method than to use single measurements as single measurements under all conditions but favourable are very inaccurate.

Assume that we want to calculate the yearly average. We have access to complete meteorological statistics and divide the propagation conditions into 4 (example) different classes: Unfavourable (M1), neutral (M2), favourable (M3) and very favourable (M4). These classes are illustrated in figure G.1, which shows the calculated sound pressure level 200 m from a road using Nord 2000. We can see that the sound pressure level varies about 20 db due to the different meteorological conditions.

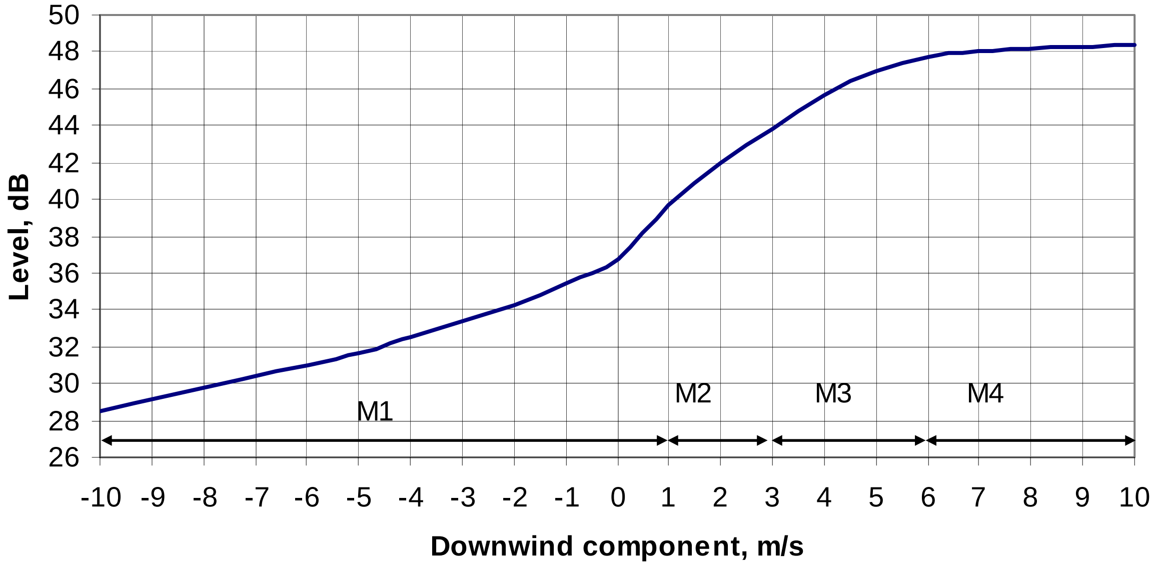


Figure G.1 Calculated sound pressure levels using Nord 2000 200 m from a road

Assume that each meteorological condition exists during the ratio p_i of the time or in the example below 30, 20, 40 and 10% of the time respectively. We have one measurement during favourable conditions, L_{fav}. The other conditions are calculated as a difference ΔL_i to L_{fav}. The yearly average is then given by

$$L_{year} = L_{fav} + 10\lg\left[\sum_{i=1}^{4} p_i 10^{0,1\Delta L_i}\right] \tag{G.1}$$

ΔL_i has to be calculated by a prediction method capable of having meteorological conditions as input variables. Examples of such methods are Harmonoise and Nord 2000. In this casing using the data above and in column 2 of table G.3 we get

$$L_{year} = L_{fav} - 1{,}3 \tag{G.2}$$

In table G.3 en example of a possible uncertainty calculation is given. The sensitivity coefficients are given by eq. (F.3) by replacing Li with ΔLi. The denominator of eq. (F.3) becomes 0,75. The standard uncertainties of the calculated corrections ΔL_i are just examples which have been taken from figure G.1. In figure G.1 the values during upwind conditions are probably not very accurate and experience indicates that the spread in data is greater. Nevertheless the data of the figure will be used here as an example and as we will see it is not very critical what data we use for upwind conditions as the sensitivity coefficients become very small. For the frequency of occurrence we have assumed that the uncertainty in the statistics is 25% which corresponds to 1 dB. We can see that for the values chosen the influence of the calculated terms on the uncertainty is moderate.

Table G.3 Uncertainty of long term values calculated from short term measurements

Quantity	Estimate	Standard uncertainty, u_i, dB	Sensitivity coefficient, c_i	Uncertainty contribution, $c_i u_i$
L_{fav} (measured)	L_{fav} (see 5.3)	1,63	1	1,63
ΔL_{fav} (M3, measured)	0	0	$\frac{0,2}{0,75} = 0,27$	0
ΔL_{vfa} (M4, calculated)	+2	2	$\frac{0,3 \cdot 10^{0,2}}{0,75} = 0,64$	1,27
ΔL_{neu} (M2, calculated)	– 6	3	$\frac{0,2 \cdot 10^{-0,6}}{0,75} = 0,07$	0,20
ΔL_{ufa} (M1, calculated)	– 12	5	$\frac{0,3 \cdot 10^{-1,2}}{0,75} = 0,03$	0,13
p_1	0,3	1	0,03	0,03
p_2	0,2	1	0,07	0.07
p_3	0,2	1	0,27	0,27
p_4	0,3	1	0,64	0,64
$u(L_{year}) = \sqrt{\sum_1^n (c_j u_j)^2}$				2,2
				4,40