International Standard

ISO 16254

Second edition
2024-12

Acoustics — Measurement of sound emitted by road vehicles of category M and N at standstill and low speed operation — Engineering method

Acoustique — Mesurage du bruit émis par les véhicules routiers de catégories M et N à l'arrêt et en fonctionnement à basse vitesse — Méthode d'expertise

Reference number
ISO 16254:2024(en)

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Foreword

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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 document 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).

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This document was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise,* in collaboration with ISO/TC 22, *Road vehicles*.

This second edition cancels and replaces the first edition (ISO 16254:2016), which has been technically revised.

The main changes are as follows:

— addition of multiple microphones at each measurement location;

— revised signal processing to improve correlation to human perception;

— further development of tonal loudness as an alternate method to identify frequencies and to assure frequencies so identified are audible to pedestrians.

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

Introduction

The advent of road transport vehicles that rely, in whole or in part, on alternative drive trains (e.g. electromotive propulsion) is serving to reduce both air and noise pollution and their adverse impacts on citizens throughout the world. However, the environmental benefits achieved to date by these “hybrid or pure electric” road vehicles have resulted in the unintended consequence of removing a source of audible signal that is used by various groups of pedestrians (e.g. in particular, blind and low vision persons) to detect the approach, presence and/or departure of road vehicles.

Therefore, this document has been developed to provide a method to measure the sound emission of road vehicles at standstill and low speed operation, as well as to quantify the characteristics of any external sound-generation system installed for the purpose of conveying acoustic information about the approach, presence and/or departure of the vehicle to nearby pedestrians.

This document incorporates additional sensor locations and provisions to reduce the measurement variation of reported results and to introduce a metric for determining the frequency of tonal components that does not rely on prior knowledge of the sound signal. Tonal loudness calculates the audibility of the given signals considering how the sounds are perceived by people, providing an optional metric to assess detection and to identify frequency content.

This document was developed in cooperation with the Society of Automotive Engineers (SAE) Vehicle Sound for Pedestrians Subcommittee and the SAE Advanced Driver Assistance Committee.

Acoustics — Measurement of sound emitted by road vehicles of category M and N at standstill and low speed operation — Engineering method

1 Scope

This document is derived from ISO 362-1[2] and specifies an engineering method for measuring the sound emitted by M and N category road vehicles at standstill and low speed operating conditions. The specifications reproduce the level of sound which is generated by the principal vehicle sound sources consistent with stationary and low speed vehicle operating conditions relevant for pedestrian safety. The method is designed to meet the requirements of simplicity as far as they are consistent with reproducibility of results under the operating conditions of the vehicle.

The test method requires an acoustic environment which is only obtained in an extensive open space. Such conditions usually exist during the following:

— measurements of vehicles for regulatory certification;

— measurements at the manufacturing stage;

— measurements at official testing stations.

The results obtained by this method give an objective measure of the sound emitted under the specified conditions of test. It is necessary to consider the fact that the subjective appraisal of the annoyance, perceptibility, and/or detectability of different motor vehicles or classes of motor vehicles due to their sound emission are not simply related to the indications of a sound measurement system. As annoyance, perceptibility and/or detectability are strongly related to personal human perception, physiological human condition, culture, and environmental conditions, there are large variations and therefore these terms are not useful as parameters to describe a specific vehicle condition.

Spot checks of vehicles chosen at random rarely occur in an ideal acoustic environment. If measurements are carried out on the road in an acoustic environment which does not fulfil the requirements stated in this document, the results obtained might deviate appreciably from the results obtained using the specified conditions.

In addition, this document provides an engineering method to measure the performance of external sound generation systems intended for the purpose of providing acoustic information to pedestrians on a vehicle's operating condition. This information is reported as objective criteria related to the external sound generation system's sound pressure level, frequency content, and changes in sound pressure level and frequency content as a function of vehicle speed.

This document adds a metric related to the human perception of tonal loudness, the psychoacoustic tonality. The psychoacoustic tonality can be used to estimate audible frequency shifts of the sounds by identifying the most audible component in each auditory frequency band (critical band), as well as to determine if the band(s) so identified meet audibility criteria.

Annex A and Annex C contains background information relevant in the development of this document.

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 3745:2012, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for anechoic rooms and hemi-anechoic rooms*

ISO 10844, *Acoustics — Specification of test tracks for measuring sound emitted by road vehicles and their tyres*

ISO 26101-1, *Acoustics — Test methods for the qualification of the acoustic environment — Part 1: Qualification of free-field environments*

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61260-1, *Electroacoustics — Octave-band and fractional-octave-band filters — Part 1: Specifications*

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

IEC 61672-3, *Electroacoustics — Sound level meters — Part 3: Periodic tests*

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

ECMA-418-2, *Psychoacoustic metrics for ITT equipment: models based on human perception*

3 Terms and definitions

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

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

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

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

3.1
front reference plane
vertical plane tangent to the leading edge of the vehicle

3.2
rear reference plane
vertical plane tangent to the trailing edge of the vehicle

3.3
external sound generation system
system that provides an acoustic signal to the external environment of the vehicle for the purpose to provide information to pedestrians

3.4
component
external sound generation system (3.3) intended to emit sound information which can be tested separately from the vehicle

3.5
kerb mass
complete shipping mass of a vehicle fitted with all equipment necessary for normal operation plus the mass of the following elements for M1, N1 and M2 having a maximum authorized mass not exceeding 3 500 kg:

— lubricants, coolant (if needed), washer fluid;

— fuel (tank filled to at least 90 % of the capacity specified by the manufacturer);

— other equipment if included as basic parts for the vehicle, such as spare wheel(s), wheel chocks, fire extinguisher(s), spare parts and tool kit

Note 1 to entry: The definition of kerb mass can vary from country to country, but in this document, it refers to the definition contained in ISO 1176[4].

Note 2 to entry: M and N vehicle categories are defined in SAE J2889-1[8] and ISO 362-1[2].

3.6
mass in running order
nominal mass of an N2, N3 or M2 vehicle having a maximum authorized mass greater than 3 500 kg, or an M3 vehicle as determined by the following conditions:

a) the mass in running order is taken as the sum of the unladen vehicle mass and the driver's mass;

b) in the case of category M2 and M3 vehicles that include seating positions for additional crewmembers, their mass is incorporated in the same way and equal to that of the driver

Note 1 to entry: The driver's mass is calculated in accordance with ISO 2416[5].

Note 2 to entry: Unladen vehicle mass is defined in ISO 362-1[2].

3.7
full vehicle operation
operation of a vehicle with all systems and *components* (3.4) operating according to the manufacturer's specification for normal road use

3.8
simulated vehicle operation
operation of a vehicle with some systems or *components* (3.4) disabled to reduce noise interference during testing which may include external signals applied to the vehicle to simulate actual in-use signals

3.9
lowest frequency of interest
frequency below which there is no signal content relevant to the measurement of sound emission for the vehicle under test

3.10
critical band
filter within the human cochlea describing the frequency resolution of the auditory system with characteristics that are usually estimated from the results of masking experiments

3.11
tonality
characteristic of sound containing a single-frequency component or narrow-band components that emerge audibly from the total sound

3.12
specific tonality
tonality (3.11) in a single *critical band* (3.10)

4 Symbols and abbreviated terms

Table 1 — Symbols and abbreviated terms and the paragraph in which they are first used

Symbol	Unit	Subclause	Explanation
AA′	—	6.1.2	Line perpendicular to vehicle travel which indicates the beginning of the zone to record sound pressure level during test.
BB′	—	6.1.2	Line perpendicular to vehicle travel which indicates end of the zone to record sound pressure level during test.
CC′	—	6.1.2	Centreline of vehicle travel.
δ_1 - δ_7	dB	D.2	Input quantities to allow for any uncertainty in A-weighted sound pressure level.
δ_8 - δ_{14}	dB	D.3	Input quantities to allow for any uncertainty in one-third octave band A-weighted sound pressure level.

Table 1 *(continued)*

Symbol	Unit	Subclause	Explanation
δ_{15} - δ_{21}	Hz	D.4	Input quantities to allow for any uncertainty in frequency measurement used for the determination of frequency shift.
$f_{i,\text{speed}}$	Hz	7.2.5.3.1	Single frequency component of external sound generation system at a given vehicle speed.
$f_{i,\text{ref}}$	Hz	7.2.5.3.1	Single frequency component of external sound generation system at reference vehicle speed.
$\Delta f_{percent}$	%	7.2.5.3.1	Frequency shift expressed in percent of a reference frequency.
Δf	Hz	7.2.3	Frequency resolution of narrowband analysis used to measure frequency spectra for the purpose of determining frequency shift information.
F_s	Hz	5.1.1	Sampling frequency used by digital signal processing system
i	—	6.3.2	Index for left or right microphone locations
j	—	7.1.6.1	Index for single test run within stopped or slow speed cruise test conditions
$L_{\text{st,fwd}}$	dB	7.1.7.2	Vehicle A-weighted sound pressure level in stationary forward condition.
$L_{\text{st,rev}}$	dB	7.1.8	Vehicle A-weighted sound pressure level in stationary reverse condition.
$L_{\text{crs,10}}$	dB	7.1.9	Cruise vehicle A-weighted sound pressure level at a vehicle speed of 10 km/h.
$L_{\text{test},j}$	dB	7.1.6.1	A-weighted sound pressure level result of j^{th} test run.
L_{bgn}	dB	6.3.1	Background noise A-weighted sound pressure level.
$L_{\text{bgn,L},i}$	dB	6.3.1	Background noise A-weighted sound pressure level, left side of vehicle, i^{th} microphone location.
$L_{\text{bgn,R},i}$	dB	6.3.1	Background noise A-weighted sound pressure level, right side of vehicle, i^{th} microphone location.
$L_{\text{bgn\_BAND}}$	dB	6.3.2	Background noise one-third octave A-weighted sound pressure level. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{bgn\_BAND,L},i}$	dB	6.3.2	Background noise one-third octave A-weighted sound pressure level, left side of vehicle, i^{th} microphone location. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{bgn\_BAND,R},i}$	dB	6.3.2	Background noise one-third octave A-weighted sound pressure level, right side of vehicle, i^{th} microphone location. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
L_x	dB	D.2	A-weighted sound pressure level for any stationary or cruise condition for use in assessment of measurement uncertainty.
$L_{x,\text{band}}$	dB	D.3	A-weighted sound pressure level per one-third octave band for any stationary or cruise condition for use in assessment of measurement uncertainty.
$L_{x,\text{meas}}$	dB	D.2	A-weighted sound pressure level for any stationary or cruise condition for use in assessment of measurement uncertainty.
$\text{MicLeft}_{\_i}$	—	7.1.1	ith Microphone situated at left side of vehicle
$\text{MicRight}_{\_i}$	—	7.1.1	ith Microphone situated at right side of vehicle
MicLeft_1	—	7.1.1	Microphone situated at left side of vehicle, with height of 0,8 m above ground
MicLeft_2	—	7.1.1	Microphone situated at left side of vehicle, with height of 1,0 m above ground
MicLeft_3	—	7.1.1	Microphone situated at left side of vehicle, with height of 1,2 m above ground

Table 1 *(continued)*

Symbol	Unit	Subclause	Explanation
MicLeft_4	—	7.1.1	Microphone situated at left side of vehicle, with height of 1,4 m above ground
MicLeft_5	—	7.1.1	Microphone situated at left side of vehicle, with height of 1,6 m above ground
MicRight_1	—	7.1.1	Microphone situated at right side of vehicle, with height of 0,8 m above ground
MicRight_2	—	7.1.1	Microphone situated at right side of vehicle, with height of 1,0 m above ground
MicRight_3	—	7.1.1	Microphone situated at right side of vehicle, with height of 1,2 m above ground
MicRight_4	—	7.1.1	Microphone situated at right side of vehicle, with height of 1,4 m above ground
MicRight_5	—	7.1.1	Microphone situated at right side of vehicle, with height of 1,6 m above ground
$L_{\text{MicLeft\_}i\text{\_BAND},j}$	dB	7.1.6.2	Maximum one-third octave results for each band over the entire measurement interval for each MicLeft_$_i$ location for the jth measurement run. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{MicRight\_}i\text{\_BAND},j}$	dB	7.1.6.2	Maximum one-third octave results for each band over the entire measurement interval for each MicRight_$_i$ location for the jth measurement run
$L_{\text{MicLeft\_BAND},j}$	dB	7.1.6.4.2	Maximum one-third octave results for each band over the entire measurement interval for all MicLeft_$_i$ locations for the jth measurement run. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{MicRight\_BAND},j}$	dB	7.1.6.4.2	Maximum one-third octave results for each band over the entire measurement interval for all MicRight_$_i$ locations for the jth measurement run. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{MicLeft\_i\_BAND}}$	dB	7.1.6.2	Maximum one-third octave results for each band over the entire measurement interval for each MicLeft_$_\text{i}$ location.
$L_{\text{MicRight\_i\_BAND}}$	dB	7.1.6.2	Maximum one-third octave results for each band over the entire measurement interval for each MicRight_$_\text{i}$ location. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{MicLeft\_}i\text{\_OA},j}$	dB	7.1.6.3.2	Maximum overall sound pressure level result over the entire measurement interval for each MicLeft_$_i$ location for the jth measurement run
$L_{\text{MicRight\_}i\text{\_OA},j}$	dB	7.1.6.3.2	Maximum overall sound pressure level result over the entire measurement interval for each MicRight_$_i$ location for the jth measurement run
$L_{\text{MicLeft\_OA},j}$	dB	7.1.6.2	Maximum overall sound pressure level result over the entire measurement interval for all MicLeft_$_i$ locations for the jth measurement run
$L_{\text{MicRight\_OA},j}$	dB	7.1.6.2	Maximum overall sound pressure level result over the entire measurement interval for all MicRight_$_i$ locations for the jth measurement run
$L_{\text{MicLeft\_i\_OA}}$	dB	7.1.5.3.1	Maximum overall sound pressure level result over the entire measurement interval for each MicLeft_$_i$ locations averaged over all j runs
$L_{\text{MicRight\_i\_OA}}$	dB	7.1.5.3.1	Maximum overall sound pressure level result over the entire measurement interval for each MicRight_$_i$ locations averaged over all j runs

Table 1 *(continued)*

Symbol	Unit	Subclause	Explanation
$L_{MicLeftBAND}$	dB	7.1.7.3	Maximum one-third octave sound pressure level over the entire measurement interval for all $MicLeft_i$ locations averaged over all *j* measurement runs. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{MicRightBAND}$	dB	7.1.7.3	Maximum one-third octave sound pressure level over the entire measurement interval for all $MicRight_i$ locations averaged over all *j* measurement runs. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{MicLeftOA}$	dB	7.1.7.2	Maximum overall sound pressure level result over the entire measurement interval for all $MicLeft_i$ locations
$L_{MicRightOA}$	dB	7.1.7.2	Maximum overall sound pressure level result over the entire measurement interval for all $MicRight_i$ locations
N	—	7.2.3	Block size of digital sample used for discrete Fourier transform or autopower spectrum analysis.
PP′	—	6.1.2	Line perpendicular to vehicle travel which indicates location of microphones.
v_{ref}	km/h	7.2.5.2	Reference vehicle velocity used for calculating frequency shift percentage.
v_{test}	km/h	7.2.5.3.1	Target vehicle test velocity.
$f_{band,speed}$	Hz	J.4.6	Main frequency of tonal component in a critical band belonging to a certain frequency shift and speed
$f_{band,speed,filtered}$	Hz	J.4.6	Valid frequencies from the tonality analysis over time in a critical band belonging to a certain frequency shift and speed
T'_{bgn}	tu_{HMS}	8	Specific tonality of the background noise in a critical band
$T'_{speed,shift}$	tu_{HMS}	J.4.4	Specific tonality in critical band belonging to a certain frequency shift and speed
z	$Bark_{HMS}$	J.4.6	Critical-band rate
$Z_{speed,shift}$	$Bark_{HMS}$	J.4.4	Critical-band rate corresponding to a certain frequency shift and speed

5 Instrumentation

5.1 Instruments for acoustic measurement

5.1.1 General

The apparatus used for measuring the sound pressure level shall be a sound level meter or equivalent measurement system meeting the requirements of class 1 instruments (inclusive of the recommended windscreen, if used). These requirements are described in IEC 61672–1.

The entire measurement system shall be checked by means of a sound calibrator that fulfils the requirements of class 1 sound calibrators in accordance with IEC 60942.

Measurements shall be carried out using the time weighting “F” of the acoustic measurement instrument and the “A” frequency weighting also described in IEC 61672–1. When using a system that includes a periodic monitoring of the A-weighted sound pressure level, a reading should be made at a time interval not greater than 30 ms.

When no general statement or conclusion can be made about conformance of the sound level meter model to the full specifications of IEC 61672-1, the apparatus used for measuring the sound pressure level shall be a sound level meter or equivalent measurement system meeting the conformity requirements of Class 1 instruments as described in IEC 61672-3.

NOTE The tests of IEC 61672-3 cover only a limited subset of the specifications in IEC 61672-1 for which the scope is large (temperature range, frequency requirements up to 20 kHz, etc.). It is economically not feasible to verify the whole IEC 61672-1 requirements on each item of a computerized data acquisition systems model. Apparently, until today, no computerized data acquisition system available complies with the full specifications of IEC 61672-1. It is beyond the possibilities of the users of these systems to prove conformity of the instrumentation required by the test code.

When measurements are carried out for one-third octaves, the instrumentation shall meet all requirements of IEC 61260–1, class 1.

When measurements are carried out for frequency shift, the digital sound recording system shall have at least a 16 bit quantization. The sampling rate, F_S, and the dynamic range shall be appropriate to the signal of interest.

5.1.2 Daily verification and adjustment

At the beginning of every measurement session, the entire acoustic measurement system shall be checked and adjusted, if possible, by means of a sound calibrator as described in 5.1.1. At the end of every measurement session, the entire acoustic measurement system shall be checked by means of a sound calibrator as described in 5.1.1.

Without any further adjustment, the difference between the readings at the beginning and the end shall be less than or equal to 0,5 dB. If this value is exceeded, the results of the measurements obtained after the previous satisfactory check shall be discarded.

NOTE 1 A bi-yearly IEC 61672-3 calibration permits the use of a daily sensitivity check and adjustment.

NOTE 2 The purpose of the check at the beginning of the measurement session is twofold:

a) To ensure the measurement system is in good working order, and

b) To adjust the level consistent with the environmental conditions of the day.

The purpose of the check at the end of the measurement session is also twofold:

— To ensure the measurement system remains in good working order, and

— To verify the adjusted level remains within expected tolerances for a repeatable and reproduceable measurement.

5.1.3 Conformity with requirements

Conformity of the sound calibrator with the requirements of IEC 60942 shall be verified once a year. Conformity of the instrumentation system with the requirements of IEC 61672–1 shall be verified at least every 2 years using IEC 61672-3. All conformity testing shall be conducted by a laboratory, which is authorized to perform calibrations traceable to the appropriate standards.

NOTE The tests of IEC 61672-3 cover only a limited subset of the specifications in IEC 61672-1 for which the scope is large (temperature range, frequency requirements up to 20 kHz, etc.). It is not feasible to verify the whole IEC 61672-1 requirements on each item of a computerized data acquisition system. Computerized data acquisition system available comply with the necessary specifications of IEC 61672-1 and testing specifications of IEC 61672-3 as required for this document.

5.2 Instrumentation for speed measurements

The road speed of the vehicle shall be measured with instruments meeting specification limits of at least ±0,5 km/h when using continuous measuring devices.

NOTE A continuous measuring device will determine all required speed information with one device.

5.3 Meteorological instrumentation

The meteorological instrumentation used to monitor the environmental conditions during the test shall meet the specifications of the following:

— ±1 °C or less for a temperature measuring device;

— ±1,0 m/s for a wind speed-measuring device;

— ±5 hPa for a barometric pressure measuring device;

— ±5 % for a relative humidity measuring device.

6 Acoustic environment, meteorological conditions, and background noise

6.1 Test site

6.1.1 General

The specifications for the test site provide the necessary acoustic environment to carry out the full vehicle or component tests documented in this document. Outdoor and indoor test environments that meet the specifications of this document provide equivalent acoustic environments and produce results that are equally valid.

6.1.2 Outdoor testing

The test site shall be substantially level. The test track construction and surface shall meet the requirements of ISO 10844. Figure 1 gives information on test site dimensions.

Within a radius of 50 m around the centre of the track, the space shall be free of large reflecting objects, such as fences, rocks, bridges or buildings. The test track and the surface of the site shall be dry and free from absorbing materials, such as powdery snow or loose debris.

In the vicinity of the microphones, there shall be no obstacle that can influence the acoustic field and no person shall remain between the microphone and the noise source. The meter observer shall be positioned so as not to influence the meter reading.

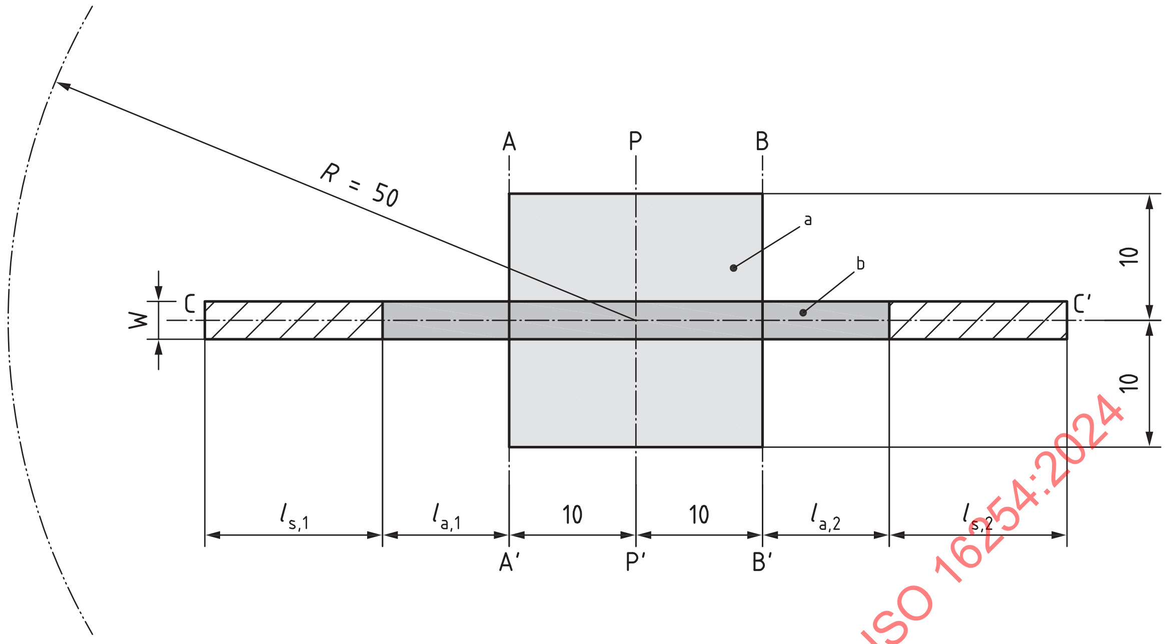
NOTE 1 Buildings outside the 50 m radius might have significant influence if their reflection focuses on the test track.

The term “substantially level” is intended to convey that the test site shall not have slopes or discontinuities that would render invalid the assumption the site provided free-field acoustic propagation. This is not to limit slopes on the test site necessary for water management, drainage, etc. Engineering judgement is expected to be applied to determine the effect on the site of any obstacle. The test track itself is subject to the requirements specified.

For the purpose of this document, test track constructions and surfaces according to ISO 10844 will also provide satisfactory results for vehicle speeds of up to 20 km/h.

NOTE 2 Government regulations can require specific surface requirements.

Dimensions in metres



Key

$l_{s,1}$	entrance construction run-up section (diagonal hatch area), in metres
$l_{s,2}$	exit construction run-up section (diagonal hatch area), in metres (length of entrance and exit construction run-up sections can differ)
$l_{a,1}$	entrance drive lane extension beyond propagation area, in metres
$l_{a,2}$	exit drive lane extension beyond propagation area, in metres (length of entrance and exit drive lane extensions can differ)
w	drive lane width, in metres
AA'	entrance to propagation area 10 m before line PP'
BB'	exit from propagation area 10 m after line PP'
CC'	drive lane centre line (longitudinal axis)
PP	microphone line (transverse axis)
a	Propagation area.
b	Drive lane.

NOTE 1 Buildings outside the 50 m radius can have significant influence if their reflection focuses on the test track.

NOTE 2 Shaded area ("test area") is the minimum area that it is required to be covered with a surface complying with ISO 10844.

Figure 1 — Test site dimensions

6.1.3 Indoor hemi anechoic or anechoic testing

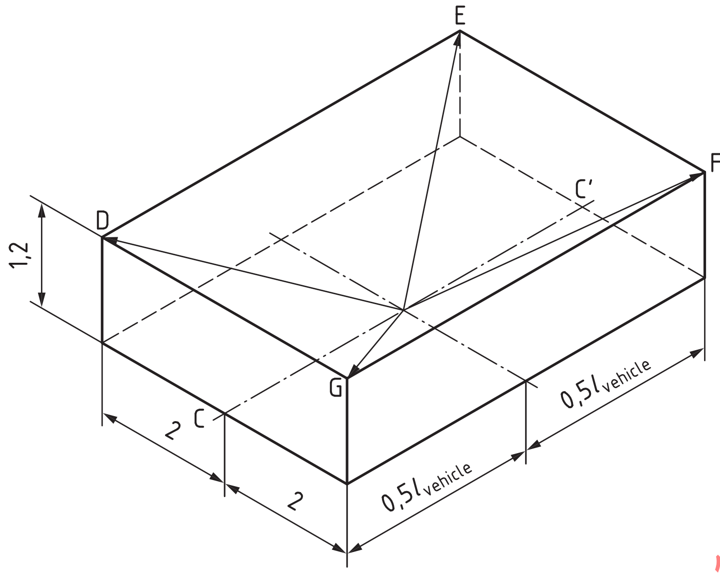
This subclause specifies conditions applicable when testing a full vehicle, either operating as it would on the road with all systems operational or operating in a mode where only the external sound generation system is operational in a hemi-anechoic space, or for testing a component in either a hemi-anechoic or anechoic space.

The test facility shall meet requirements of ISO 26101-1 or ISO 3745:2012, Annex A:

a) within the following space as shown in Figure 2.

Points D, E, F and G are locations used for the microphones in conducting testing according to the method described in Clause 7.

Dimensions in meters



Key

CC'	centreline of vehicle travel
D, E, F, G	microphone positions

Figure 2 — Spatial dimensions for acoustic space defined to be hemi-anechoic

b) For qualifying the hemi-anechoic space, the following evaluation shall be conducted:

— sound source location shall be placed on the floor in middle of the space deemed to be hemi-anechoic;

— sound source shall provide a broadband input for measurement;

— evaluation shall be conducted in one-third octave bands;

— microphone locations for evaluation shall be on a line from the source location to each position of microphones used for measurement in the document shown by points D, E, F, and G in Figure 2. This is commonly referred at the microphone transverse;

— the maximum spacing of the measurement points for evaluation on the microphone transverse line shall depend on the size of the space deemed hemi-anechoic. A minimum of 10 points shall be used;

— the one-third octave bands used to establish hemi-anechoic qualification shall be defined to cover the spectral range of interest.

c) The test facility shall have a cut-off frequency, as defined in ISO 26101-1, lower than the lowest frequency of interest.

In the vicinity of the microphones, there shall be no obstacle that can influence the acoustic field and no person shall remain between the microphone and the noise source. The meter observer shall be positioned so as not to influence the meter reading.

NOTE 1 It is expected that users of this document will understand that valid measurements can only be made when the cut-off frequency is lower than the lowest frequency of interest. A specific numerical requirement for cut-off frequency is not given due to the range of variation of appropriate cut-off frequencies depending upon the measured vehicle.

NOTE 2 This document adds additional microphone hights up to 1,6 m. Qualification to 1,2 m height as in previous editions is expected to produce acceptable results.

In the absence of any information on the range of frequencies to be measured for hemi-anechoic qualification, it is recommended to use the frequency range from 100 Hz to 10 000 Hz.

6.1.4 Indoor external sound generation system testing

This subclause specifies conditions applicable when testing only the external sound generation system separate from the vehicle.

The test facility shall meet the requirements of ISO 26101-1 or ISO 3745:2012, Annex A following the same qualification criteria used in 6.1.3 with the following exception: The space to be deemed hemi-anechoic shall extend at least 2 m in all radial directions from the centre location used for the source.

The test facility shall have a cut-off frequency lower than the lowest frequency of interest.

In the vicinity of the microphone, there shall be no obstacle that can influence the acoustic field and no person shall remain between the microphone and the noise source. The meter observer shall be positioned so as not to influence the meter reading. Microphones shall be located as specified in 7.1.1.

6.2 Meteorological conditions

6.2.1 General

Meteorological conditions are specified to provide a range of normal operating temperatures and to prevent abnormal readings due to extreme environmental conditions.

A value representative of temperature, relative humidity, and barometric pressure shall be recorded during the measurement interval.

6.2.2 Outdoor measurements

The meteorological instrumentation shall deliver data representative for the test site and shall be positioned adjacent to the test area at a height representative of the height of the measuring microphone.

The measurements shall be made when the ambient air temperature is within the range from 5 °C to 40 °C.

The ambient temperature may of necessity be restricted to a narrower temperature range such that all key vehicle functionalities that can reduce vehicle noise emissions (e.g. start/stop, hybrid propulsion, battery propulsion, fuel-cell stack operation) are enabled according to manufacturer’s specifications.

The tests shall not be carried out if the wind speed, including gusts, at microphone height exceeds 5 m/s during the noise measurement interval.

6.2.3 Indoor measurements

The measurements shall be made when the ambient air temperature is within the range from 5 °C to 40 °C.

The ambient temperature may of necessity be restricted to a narrower temperature range such that all key vehicle functionalities that can reduce vehicle noise emissions (e.g. start/stop, hybrid propulsion, battery propulsion, fuel-cell stack operation) are enabled according to the manufacturer’s specifications.

6.3 Background noise

6.3.1 Measurement criteria for A-weighted sound pressure level

The background, or ambient noise, shall be measured for a duration of at least 10 s. A 10 s sample taken from these measurements shall be used to calculate the reported background noise, taking account to ensure the 10 s sample selected is representative of the background noise in absence of any transient disturbance. The measurements shall be made with the same microphones and microphone locations used during the test.

Background noise requirements apply to all test conditions and test locations.

The overall sound pressure level of the background shall be reported as the largest overall sound pressure level from all microphones, L_{bgn} as given by Formula (1):

$$L_{bgn} = \max(L_{bgn,L,i}, L_{bgn,R,i}) \quad (1)$$

When testing in an indoor facility, the noise emitted by the roller-bench, chassis dynamometer or other test facility equipment, without the vehicle installed or present, inclusive of the noise caused by air handling of facility and vehicle cooling, shall be reported as the background noise. The recorded maximum A-weighted sound pressure level in the selected 10 s samples and from all microphones, as given by Formula (1), shall be reported as the background noise, L_{bgn}.

The A-weighted overall sound pressure level of the background noise shall be at least 6 dB below the measurement of the vehicle or external sound generation system under test.

The use of indoor test facilities can be necessary to achieve the specifications in this document.

The background noise frequency range shall be reported from at least 160 Hz to 5 000 Hz.

Annex G gives measurement criteria for background noise A-weighted sound pressure levels in flowchart form as an aid to measurement and reporting results.

NOTE Background noise measurements account for the variations in time at all microphones. The intent of the above statements is to capture the entire range of variation experienced at the test facility to provide an assessment of the suitability of the test facility to carry out the specified measurements. It is expected that persons carrying out such measurements have evaluated the facility background noise over sufficiently long periods of time that the selected 10 second sample is representative of the facility background noise.

6.3.2 Background noise requirements when analysing in one-third octave bands

The one-third octave frequency spectrum measured according to IEC 61260–1, corresponding to the maximum hold in each individual one-third octave band of background noise shall be reported as given by Formula (2) to Formula (4). These results are reported as a frequency spectrum between 160 Hz and 5 000 Hz,

$$L_{bgn\_BAND,L,i} = \max(\text{Each frequency and each left microphone}) \quad (2)$$

$$L_{bgn\_BAND,R,i} = \max(\text{Each frequency and each right microphone}) \quad (3)$$

$$L_{bgn\_BAND} = \max(L_{bgn\_BAND,L,i}, L_{bgn\_BAND,R,i}) \quad (4)$$

The level of background noise in each one-third octave of interest, analysed according to 6.3.1, shall be at least 6 dB below the measurement of the vehicle or external sound generation system under test in each one-third octave band of interest.

Annex G gives measurement criteria for background noise one-third octave band sound pressure levels in flowchart form as an aid to measurement and reporting results.

NOTE 1 The requirements for margin between background noise and test results are given to maintain a maximum error of 1 dB or less solely due to background noise. Total measurement uncertainty will include uncertainty due to additional factors.

NOTE 2 Reporting the background noise as described is the same as treating all microphones as if they were a single microphone and reporting the maximum one-third octave result, by individual band, wherever it occurs. The purpose is to establish the highest possible disturbance signal as the baseline from which to assess the signal to noise criteria of 6.3.2.

6.3.3 Measurement background noise when testing a component

When measuring an external sound generation system separate from the vehicle as provided in this document, the background noise level shall be at least 6 dB lower than the measured level of the component under test.

The background, or ambient noise, shall be measured for a duration of at least 10 s before and after a series of component tests. A 10 s sample taken from this measurement shall be used to calculate the reported background noise, taking account to ensure the 10 s sample selected is representative of the background noise in absence of any transient disturbance. The measurements shall be made with the same microphones and microphone locations used during the test.

For measurements where narrowband results are reported, the narrowband background noise shall be reported at the same frequency resolution as the measurement results.

7 Test procedures

7.1 Full vehicle testing

7.1.1 Microphone positions

The distance from the microphone positions on the microphone line PP′ to the perpendicular reference line CC′ as specified in Figure 1 on the test track or in an indoor test facility shall be 2,0 m ± 0,05 m.

The microphones shall be located 1,6 m ± 0,02 m, 1,4 m ± 0,02 m, 1,2 m ± 0,02 m, 1,0 m ± 0,02 m, 0,8 m ± 0,02 m above the ground level. The reference direction for free field conditions as specified in IEC 61672–1 shall be horizontal and directed perpendicularly towards the path of the vehicle line CC′. Table 1 provides definitions of MicLeft_$_i$ (MicLeft$_1$ to MicLeft$_5$) and MicRight_$_i$ (MicRight$_1$ to MicRight$_5$).

A microphone may be placed in the vicinity of the external sound generation system at a distance of 0,1 m ± 0,02 m.

In case the microphone cannot be positioned 0,1 m ± 0,02 m due to the vehicle construction, the microphone shall be located at a distance as close as possible to 0,1 m. In case there is more than one equal distance from 0,1 m, the distance shall be the one closest to the external sound generation system. The microphone shall not have contact with the external sound generation system.

NOTE 1 For example, if both positions 0,05 m and 0,15 m can be used to place the microphone near the external sound generation system, the 0,05 m distance is chosen.

NOTE 2 The normative microphone positions 2 m from the vehicle at various heights are used for conformity assessment. The optional microphone in the vicinity of the external sound generation system can be used as an aid to identify frequencies.

7.1.2 Conditions of the vehicle

7.1.2.1 General conditions

The vehicle shall be supplied as specified by the vehicle manufacturer.

Before the measurements are started, the vehicle shall be brought to its normal operating conditions.

7.1.2.2 Battery state of charge

If so equipped, propulsion batteries shall have a state-of-charge sufficiently high to enable all key functionalities according to the manufacturer’s specifications. Propulsion batteries shall be within their component-temperature window to enable all key functionalities that can reduce vehicle noise emissions. Any other type of rechargeable energy storage system shall be ready to operate during the test.

7.1.2.3 Accessory loads

If the vehicle is equipped with an internal combustion engine and a second source of propulsive power, all vehicle loads that may automatically force an engine re-start or prevent engine shut down shall be switched off.

All audio, entertainment, communication, and navigation systems shall be switched off.

NOTE Example loads can include air conditioning, defroster operation, window de-icing, seat heaters or coolers, etc.

7.1.2.4 Multi-mode operation

If the vehicle is equipped with multiple driver selectable operating modes, the mode which provides the lowest sound emission during the test conditions given in 7.1.5 shall be selected. The lowest sound emission shall include both the overall sound pressure level and the minimum of all one-third octave bands of interest.

When the vehicle provides multiple operating modes that are automatically selected by the vehicle, it is the responsibility of the manufacturer to determine the correct manner of testing to achieve the minimum sound emission.

In cases where it is not possible to determine the vehicle operating mode providing the lowest sound emission, all modes shall be tested and the mode giving the lowest test result shall be used to report the vehicle sound emission in accordance with this document.

NOTE 1 Modes include, but are not limited to: engine operation state (on or off), driver selectable operating modes (sport, eco, winter, etc.), vehicle selectable operating modes (sport, eco, winter, etc.), and transmission selection mode (sport, eco, winter, etc.). Modes do not include transmission gear selection such as park, drive, reverse or neutral.

NOTE 2 Determination of "lowest sound emission" will likely require testing of all operating modes to confirm that the one-third octave spectra is the lowest for each and every band of interest at both left and right microphone locations.

7.1.2.5 Vehicle non-pedestrian safety warning signals

No sound or noise source not related to pedestrian safety shall operate during the tests.

7.1.3 Test mass of vehicle

Measurements shall be made on vehicles at kerb mass +75 kg or mass in running order, as defined by the manufacturer, with an allowable tolerance of ±25 %.

NOTE The mass tolerance is only provided for practical convenience. Mass is not expected to have any influence on the measurement result.

7.1.4 Tyre selection and condition

The tyres for test are selected by the vehicle manufacturer and shall correspond to one of the tyre sizes and types designated for the vehicle by the vehicle manufacturer.

The tyres shall be inflated to the pressure recommended by the vehicle manufacturer for the test mass of the vehicle.

NOTE Tyre noise will contribute to the sound emission of the vehicle at any speed over 0 km/h. At vehicle speeds in excess of 20 km/h, tyre noise will have a significant contribution to measured sound pressure levels.

7.1.5 Operating conditions

7.1.5.1 General conditions

The path of the centreline of the vehicle shall follow line CC′ as closely as possible throughout the entire test, from the approach to line AA′ until the rear of the vehicle passes line BB′. Any trailer, which is not readily separable from the towing vehicle, shall be ignored when considering the crossing of the line BB′.

7.1.5.2 Test speeds

The vehicle shall reach the test speed, v_{test}, when the front reference plane according to the definition given in 3.1 is at line PP′. During the constant speed test, the acceleration control unit shall be positioned to maintain a constant speed between AA′ and BB′. The vehicle shall be operated as defined by the manufacturer for normal operation.

Normal operation may include shutoff of one or more propulsion sources.

7.1.5.3 Standstill conditions

7.1.5.3.1 General

The test speed, v_{test}, shall be 0 km/h with the front reference plane or rear reference plane, as appropriate, on the PP′ line.

If the vehicle is equipped with an internal combustion engine and a second source of propulsive power, the stopped condition test measurement shall be made after a time delay from the vehicle stopped condition to allow engine shutdown, and before vehicle loads can force an engine re-start.

7.1.5.3.2 Forward testing

For forward testing, the front reference plane of the vehicle shall be on the PP′ line.

7.1.5.3.3 Backing testing

For backing testing, the rear reference plane of the vehicle shall be on the PP′ line.

7.1.5.3.4 Manual transmission vehicle

The vehicle shall be tested in the appropriate standstill mode as defined in 7.1.2.4. The gear selector shall be in a gear and the vehicle shall remain at 0 km/h for the duration of the test. The manufacturer shall determine the appropriate condition for testing.

NOTE The common situation for stopped vehicle testing is for a manual transmission vehicle to have the gear selector in neutral. However, for the purpose of this test, the intention is to place the vehicle in a state where it is ready to move.

7.1.5.3.5 Automatic transmission vehicle

The vehicle shall be tested in the appropriate standstill mode as defined in 7.1.2.4. The gear selector shall be in the normal driving position for testing when the front reference plane of the vehicle is on the PP′ line. The gear selector shall be in the reverse driving position for testing when the rear reference plane of the vehicle is on the PP′ line. The vehicle shall remain at 0 km/h for the duration of the test. The manufacturer shall determine the appropriate condition for testing.

7.1.5.4 Slow speed cruise

7.1.5.4.1 General

The test speed, v_{test}, shall have a tolerance of ±1 km/h.

If a vehicle is tested in an indoor facility, the vehicle shall be located with the front or rear reference plane on the PP′ line, as appropriate. The vehicle shall be measured for a duration of at least 5 s.

If the vehicle is tested outdoors with the vehicle moving forward, the vehicle shall be measured from when the front reference plane is at AA’ until the front reference plane reaches PP’. No measurement shall be made beyond the PP’ line.

For the purpose of measuring the performance of an external sound generation system, the sound pressure level of the vehicle may be measured with the vehicle at 0 km/h and external sound generation system controlled as to simulate operation at 10 km/h.

NOTE The appropriate measurement criteria of time or distance depends on if the vehicle is tested in a moving or simulated moving (stationary) condition, either indoors or outdoors. As a practical matter, all testing indoors will use the time criteria.

7.1.5.4.2 Automatic transmission vehicle

The gear selector shall be placed as specified by the manufacturer for normal driving.

7.1.5.4.3 Manual transmission vehicle

The gear selector shall be placed in the highest gear which can achieve the target vehicle speed with constant engine speed.

7.1.6 Measurement readings and reported values

7.1.6.1 General

It is recommended that persons technically trained and experienced in current noise measurement techniques select the test instrumentation and conduct the tests.

If a sound peak obviously out of character with the general sound pressure level is observed, that measurement shall be discarded.

At least four measurements for all test conditions shall be made on each side of the vehicle and for each mode tested.

The first four j^{th} valid consecutive measurement results for any test condition, within 2,0 dB, allowing for the deletion of non-valid results, shall be used for the calculation of the appropriate intermediate or final result. All measurements shall meet the criteria of 6.3 to be considered a valid result.

For measurement of a vehicle in motion outdoors, the maximum A-weighted sound pressure level indicated during each passage of the vehicle between AA′ and PP′ ($L_{test,j}$) shall be noted for each microphone position, to the first significant digit after the decimal place (for example, XX,X).

For measurement of a vehicle in motion indoor and in standstill, the maximum A-weighted sound pressure level indicated during each period of at least 5 s defined in 7.1.5.4.1 for each microphone position, $L_{test,j}$, shall be noted, to the first significant digit after the decimal place (for example, XX,X).

For one-third octave measurements, the frequency range shall be reported from at least 160 Hz to 5 000 Hz.

NOTE 1 Satisfying the criteria listed above requires evaluation of measured sound pressure data versus time to select the appropriate time segments for proper analysis and reporting of measured values according to this document.

NOTE 2 An intermediate result can be for one vehicle mode or operating condition.

7.1.6.2 Measurement of a vehicle in standstill conditions

This subclause specifies the requirements to measure the vehicle sound emission in standstill conditions.

For each individual test run *j* and microphone position *i*, the vehicle A-weighted sound pressure level for each microphone MicLeft_$_i$ and MicRight_$_i$ shall be measured for a duration of at least 5 s and the maximum value reported as $L_{\text{MicLeft\_}i\text{\_OA},j}$ and $L_{\text{MicRight\_}i\text{\_OA},j}$.

For each individual test run *j* and microphone position *i*, the one-third octave frequency spectrum for each microphone MicLeft_$_i$ and MicRight_$_i$ shall be measured for a duration of at least 5 s and the maximum hold in each individual one-third octave band A-weighted sound pressure level shall be reported as $L_{\text{MicLeft\_}i\text{\_BAND},j}$ and $L_{\text{MicRight\_}i\text{\_BAND},j}$.

NOTE The intent for the one-third octave band result is to provide a single spectrum which represents the highest value of each one-third octave frequency over the entire measurement interval. For example, if the frequencies of interest range from the 160 Hz to the 5 000 Hz one-third octave bands, there will be a reported frequency spectrum over this range which represents maximum envelope of the individual band results. The choice of the maximum in each band is to provide results consistent with human subjective response and are relevant for the safety purpose of this document.

7.1.6.3 Measurement of a vehicle in motion

7.1.6.3.1 General

This subclause specifies the requirements to measure the vehicle sound emission in motion.

If a sound peak obviously out of character with the general sound pressure level is observed, that measurement shall be discarded. The selected sound sample shall be representative of the vehicle minimum sound emission in the condition of test in absence of any transient disturbance.

7.1.6.3.2 Outdoor testing

For each individual test run j and microphone position i, the vehicle A-weighted sound pressure level for each microphone MicLeft_$_i$ and MicRight_$_i$ shall be measured between the AA' and PP' line and the maximum value reported as $L_{\text{MicLeft\_}i\text{\_OA},j}$ and $L_{\text{MicRight\_}i\text{\_OA},j}$.

For each individual test run j and microphone position i, the one-third octave frequency spectrum for each microphone MicLeft_$_i$ and MicRight_$_i$ shall be measured between the AA' and PP' line. The maximum hold in each individual one-third octave band A-weighted sound pressure level shall be reported as $L_{\text{MicLeft\_}i\text{\_BAND,\_}j}$ and $L_{\text{MicRight\_}i\text{\_BAND},j}$.

NOTE The intent for the one-third octave band result is to provide a single spectrum which represents the highest value of each one-third octave frequency over the entire measurement interval. For example, if the frequencies of interest range from the 160 Hz to the 5 000 Hz one-third octave bands, there will be a reported frequency spectrum over this range which represents maximum envelope of the individual band results. The choice of the maximum in each band is to provide results consistent with human subjective response and are relevant for the safety purpose of this document.

7.1.6.3.3 Indoor testing

For each individual test run j and microphone position i, the vehicle A-weighted sound pressure level for each microphone MicLeft_$_i$ and MicRight_$_i$ shall be measured for a duration of at least 5 s and the maximum value reported as $L_{\text{MicLeft\_}i\text{\_OA},j}$ and $L_{\text{MicRight\_}i\text{\_OA},j}$.

For each individual test run j and microphone position i, the one-third octave frequency spectrum for each microphone MicLeft_$_i$ and MicRight_$_i$ shall be measured and the maximum hold in each individual one-third octave band A-weighted sound pressure level shall be reported as $L_{\text{MicLeft\_}i\text{\_BAND},j}$ and $L_{\text{MicRight\_}i\text{\_BAND},j}$.

NOTE The intent for the one-third octave band result is to provide a single spectrum which represents the highest value of each one-third octave frequency over the entire measurement interval. For example, if the frequencies of interest range from the 160 Hz to the 5 000 Hz one-third octave bands, there will be a reported frequency spectrum over this range which represents maximum envelope of the individual band results. The choice of the maximum in each band is to provide results consistent with human subjective response and are relevant for the safety purpose of this document.

7.1.6.4 Intermediate processing to determine a virtual single microphone result

For each vehicle operating condition, stationary or moving, the five left and right microphone results shall be processed to provide a single left and right result for each measurement run j.

The intermediate processing for each measurement run j and for the five microphone positions i will produce a single result for the overall sound pressure level for the left and right side of the vehicle and a single one-third octave spectra for the left and right side of the vehicle. All further processing is done using these results.

Annex H gives measurement criteria for overall sound pressure level and one-third octave band sound pressure levels in flowchart form as an aid to measurement and reporting results.

7.1.6.4.1 Overall sound pressure level

The value $L_{\text{MicLeft\_OA},j}$ and $L_{\text{MicRight\_OA},j}$ for each test run j shall be the arithmetic average of each of the five microphone positions i as given by Formulae (5) and (6):

$$L_{\text{MicLeft\_OA,j}} = \left(\sum_{i=1}^{5} L_{\text{MicLeft\_}i\text{\_OA},j}\right) \Big/ 5 \tag{5}$$

$$L_{\text{MicRight\_OA,j}} = \left(\sum_{i=1}^{5} L_{\text{MicRight\_}i\text{\_OA},j}\right) \Big/ 5 \tag{6}$$

7.1.6.4.2 One-third octave band sound pressure level

The value $L_{\text{MicLeft\_BAND},j}$ and $L_{\text{MicRight\_BAND},j}$ for each test run j shall be the maximum hold of each of the five microphone positions i in all individual one-third octave bands for each measurement run j as given by Formulae (7) and (8):

$$L_{\text{MicLeft\_BAND},j} = \max(L_{\text{MicLeft\_}i\text{\_BAND},j}) \tag{7}$$

$$L_{\text{MicRight\_BAND},j} = \max(L_{\text{MicRight\_}i\text{\_BAND},j}) \tag{8}$$

NOTE 1 The reporting of a single processed value of the individual 5 microphones on each side produces the effect of creating a virtual microphone on each side of the vehicle.

NOTE 2 The reporting of maximum one-third octave results in each one-third octave band, $L_{\text{MicLeft\_BAND},j}$ and $L_{\text{MicRight\_BAND},j}$, is done to correspond to human psychoacoustic perception. In addition, the reporting of the maximum one-third octave band results per band provide a result with reduced uncertainty and improved repeatability and reproducibility.

NOTE 3 The use of $L_{\text{MicLeft\_BAND},j}$ and $L_{\text{MicRight\_BAND},j}$ one-third octave band results is done to address near field spatial variation issues that do not correspond to human psychoacoustic perception. Measurements made with a single microphone are subject to near field spatial variation. The measurement uncertainties given in Table 3 are not valid for a single microphone.

7.1.7 Data compilation

7.1.7.1 General

Further data processing uses the single left and right overall sound pressure level and left and right one-third octave frequency spectrums calculated in 7.1.6.4 for each test run j.

7.1.7.2 Maximum A-weighted sound pressure level data compilation

For a given test condition and mode (see 7.1.2.4), the four j test runs are averaged to determine the intermediate result on each side. For a given test condition and mode (see 7.1.2.4), the runs shall be averaged separately for each side.

Calculate $L_{MicLeftOA}$ according to Formula (9). Calculate $L_{MicRightOA}$ according to Formula (10).

$$L_{MicLeft\_OA} = \left(\sum_{i=1}^{4} L_{MicLeftOA,j}\right) \Big/ 4 \quad (9)$$

$$L_{MicRightOA} = \left(\sum_{i=1}^{4} L_{MicRightOA,j}\right) \Big/ 4 \quad (10)$$

Calculate the final reported overall sound pressure level for each condition and mode as the lowest of the left and right side. If the vehicle had one mode, and was calculating the forward or backing stationary result, $L_{st,fwd}$ is be calculated according to Formula (11).

$$L_{st,fwd} = \mathrm{Min}(L_{MicLeftOA}, L_{MicRightOA}) \quad (11)$$

The reported A-weighted sound pressure level for a given test condition is the lowest value of overall sound pressure level for all modes tested, rounded to the nearest integer.

For example, if the vehicle had three stationary modes, the final reported sound pressure level for the vehicle is the minimum of each individual $L_{st,fwd}$ over all three modes.

Annex H gives measurement criteria for overall sound pressure level in flowchart form as an aid to measurement and reporting results.

NOTE The reporting of arithmetic average value of the individual 5 microphones on each side produces the effect of creating a virtual microphone on each side of the vehicle and reports the result in accordance with evaluating the required minimum safety signal level.

7.1.7.3 One-third octave band sound pressure level data compilation

For a given test condition and mode (see 7.1.2.4), the four *j* test runs are averaged to determine the result on each side. Calculate $L_{MicLeftBAND}$ according to Formula (12). Calculate $L_{MicRightBAND}$ according to Formula (13).

$$L_{MicLeftBAND} = \left(\sum_{i=1}^{4} L_{MicLeftBAND,j}\right) \Big/ 4 \quad (12)$$

$$L_{MicRightBAND} = \left(\sum_{i=1}^{4} L_{MicRightOA,j}\right) \Big/ 4 \quad (13)$$

Any further processing of the one-third octave band values shall use these results.

Both the $L_{MicLeftBAND}$ and the $L_{MicRightBAND}$ shall be reported. These results are reported as a frequency spectrum between 160 Hz and 5 000 Hz.

Annex I gives measurement criteria for one third octave sound pressure level in flowchart form as an aid to measurement and reporting results.

NOTE All frequency spectrums are required to report as it is not possible to determine “lowest” one-third octave spectrum where some bands are higher or lower than other spectra. While some results will be clearly lower in all spectral bands and are therefore able to be categorized as “lower”, this cannot always be assumed.

7.1.8 Reported standstill results

The overall sound pressure level $L_{st,fwd}$ and $L_{st,rev}$ value according to 7.1.2.4 shall be the result from 7.1.7.2 using the definitions given in 7.1.6.

If one-third octave bands are analysed, they shall use the result given in 7.1.7.3. and reported for each side and mode. These results are reported as a frequency spectrum between 160 Hz and 5 000 Hz,

7.1.9 Reported slow speed cruise result at 10 km/h

The overall sound pressure level $L_{crs,10}$ value according to 7.1.2.4 shall be the result from 7.1.7.2 using the definitions given in 7.1.6.

If one-third octave bands are analysed, they shall use the results given in 7.1.7.3. and reported for each side and mode. These results are reported as a frequency spectrum between 160 Hz and 5 000 Hz,

7.2 Measurement of sound to determine frequency shift

7.2.1 General

The specifications contained in these sections are intended to measure the emitted acoustic information from an external sound generation system installed for purposes of providing acoustic information to pedestrians in the near vicinity of a vehicle. The information so measured characterizes the frequencies emitted by the system, as well as the change in frequency as a function of vehicle operating parameters.

No background noise correction shall be applied to any measured result.

See Annex B for further information on frequency shift.

See Annex F for further information on frequency shift.

Annex J is provided as information on a psychoacoustic tonality method to calculate frequency shift.

NOTE Annex J is informative until such time as it is determined to be technically mature to include as a normative method.

7.2.2 Instrumentation

The digital sound recording system shall have at least a 16 bit quantization. The sampling rate, F_s, and the dynamic range shall be appropriate to the signal of interest.

NOTE No specific requirements have been given for sampling rate due to the wide range of signal frequency content that can be analysed. It is expected that knowledgeable and trained personnel will select appropriate sampling rates.

7.2.3 Signal processing requirements

The frequency resolution, Δf, of the measurement shall be sufficiently precise to differentiate between the frequencies at the various test conditions. The sound analysis system shall be capable of performing discrete Fourier transform and auto power spectrum analysis at a frequency resolution and over the frequency range containing all frequencies of interest. The block size, N, used for subsequent signal processing shall enable the required Δf, where $\Delta f \leq F_s/N$.

Analyser settings shall be determined by the user to provide data according to these requirements.

7.2.4 Test facilities

7.2.4.1 Vehicle test facilities

The test facility shall meet the requirements given in 6.1.2 or 6.1.3.

7.2.4.2 Component test facilities

The test facility shall meet the requirements given in 6.1.4.

The sound emitting component of the external sound generation system is recommended to be mounted 0,5 m above a reflecting plane (floor) of the test space. The primary propagation axis of the sound emitting component shall be oriented horizontal to the reflecting plane.

The microphone is recommended to be located 1,0 m from the centre of the component at a height of 0,5 m.

NOTE Specific recommendations have been given for placement of the external sound generation system and the microphone within the test facility to provide guidance for successful testing. There are other arrangements of the external sound generation system and microphone that can be effective to measure frequency content.

7.2.5 Frequency shift measurement test procedure

7.2.5.1 General

Frequency shift may be determined by using any or all of the MicLeft$_{-i}$ or MicRight$_{-i}$ locations.

A microphone may be placed in the vicinity of the external sound generation system at a distance of 0,1 m ± 0,02 m.

The frequency shift shall be measured by a vehicle, a simulated vehicle operation, or a component-based test procedure.

7.2.5.2 Full vehicle operation

The vehicle shall be installed in an indoor test facility where the vehicle can operate in the same manner as outdoors. All microphone locations shall be as for the full vehicle test conditions as specified in Figure 1. The front plane of the vehicle shall be on the PP′ line.

Outdoor variant: The vehicle shall be operated in the same outdoor test facility and according to the same general operating condition as for the full vehicle testing (see 7.1). A frequency, f_i, shall be identified that is intended to change as a function of vehicle speed, which can be measured and can be tracked for operating conditions specified in this document.

Special care shall be taken to carry out the frequency shifting measurements in outdoor facilities with the vehicle in motion or in indoor facilities with the tires in motion. The signal intended to be measured should not be masked by other vehicle or background noise.

NOTE 1 Typical signal analysis tools provide frequency versus speed of the tonal component(s) that correspond with vehicle speed.

NOTE 2 It is understood when using an indoor test facility that the vehicle will remain in position relative to the microphones. This is for the purpose to provide an acoustically stationary signal for subsequent analysis and reporting of results.

Microphones mounted in close proximity to the sound emitting device do not have relative motion from the external sound generation system and deliver a more reliable signal for identifying correct frequencies when determining frequency shift. For a microphone installed in the direct vicinity of the emitting surface of the external sound generation system, it is recommended:

— to position the microphones on the axis (if it exists) of the acoustic emission of the system;

— at a distance of approximately 10 cm from the emitting surface: not too far to be influenced by other sound sources, and not too close to have any distorted signal;

— to use a decoupling attachment device between microphone and vehicle body.

Special care shall be taken to perform the frequency shifting measurements in indoor facilities with the tyres rotating. This is due to the contaminating signal from the tyre/roll interface.

NOTE The distance of a close proximity microphone is only given as a guideline. The purpose is to capture the source sound with an improved signal to noise ratio compared to the normative microphone locations 2 m from the vehicle centerline. The resulting signal can then be analyzed to ensure the frequencies so identified in the normative 2 m microphones come from the intended safety source signal.

7.2.5.2.1 Simulated vehicle operation (for indoor or outdoor)

The vehicle shall be operated in a test facility where the vehicle can accept an external vehicle speed signal simulating vehicle operation. All microphone locations shall be as for the full vehicle test conditions as specified in Figure 1. The front reference plane of the vehicle shall be on the PP′ line.

A frequency, f_i, shall be identified that is intended to change as a function of vehicle speed, which can be measured and can be tracked for operating conditions specified in this document as described in 7.2.5.3.

If additional close proximity microphone(s) are used, they shall fulfil the requirements of 7.2.5.2.2.

NOTE 1 Typical signal analysis tools provide frequency versus speed of the tonal component(s) that correspond with vehicle speed.

NOTE 2 It is understood when using an indoor test facility that the vehicle will remain in position relative to the microphones. This is for the purpose to provide an acoustically stationary signal for subsequent analysis and reporting of results. The use of the simulated operation further removes potentially interfering noise due to the tyre/road interaction.

7.2.5.2.2 Component test procedure

A frequency, f_i, shall be identified that is expected to change as a function of vehicle speed, which can be measured and can be tracked for operating conditions specified in this document as described in 7.2.5.3.

For component test, only the nearfield microphone is used.

NOTE 1 Typical signal analysis tools provide frequency versus speed of the tonal component(s) that correspond with vehicle speed.

NOTE 2 A nearfield microphone is the only possible microphone for a component test, as a vehicle is not involved, so the 2 m microphone locations are irrelevant.

7.2.5.3 Measurement procedure

In the following two methods for the identification of the frequency shift are presented. The first method based on the fast Fourier transform, is only considering the physical properties of the signal, while the second one, based on the psychoacoustic tonality, also takes the human perception into account. See Annex J for a description of psychoacoustic tonality.

In the tonality approach the shift is estimated in $\text{Bark}_{\text{HMS.}}$ This is done since a given change in the Bark scale is equivalent to the same change in the pitch perception.

7.2.5.3.1 Identification using fast Fourier transform

Frequency shift may be determined by using any or all of the MicLeft_$_i$ or MicRight_$_i$ locations. When more than a single MicLeft_$_i$ or MicRight_$_i$ location is used per side, the multiple microphone FFT results shall be energetically averaged to produce a single FFT spectrum.

The frequency characteristics of the sound shall be measured together with an input signal to the external sound generation system corresponding to the reference vehicle speed.

The sound output of the system shall be measured as follows.

— Record at least 5 s of the sound at a constant vehicle speed.

— Using a Hanning window, calculate the autopower of the signal with a frequency resolution of at least 1 Hz using at least 66,6 % overlap averages from the 5 s time signal.

The frequencies, $f_{i,\text{speed}}$, of the external sound generation system signal shall be measured and recorded.

The corresponding vehicle speeds, $f_{i,\text{speed}}$ and $f_{i,\text{ref}}$, shall be measured and recorded.

Calculate $\Delta f_{percent}$, the frequency shift of the external sound generation system signal according to Formula (14):

$$\Delta f_{percent} = \{[(f_{i,speed} - fi_{,ref})/(v_{test} - v_{ref})]/f_{i,ref}\} \cdot 100 \quad (14)$$

where

$f_{i,speed}$ is the frequency at a given speed value;

$f_{i,ref}$ is the frequency at the reference speed value;

v_{test} is the vehicle velocity, actual or simulated, corresponding to the frequency $f_{i,speed}$;

v_{ref} is the vehicle velocity, actual or simulated, corresponding to the frequency $f_{i,ref}$.

Formula (14) is only valid when the actual vehicle speed, v_{test}, is higher than the reference vehicle speed, v_{ref}.

Results shall be reported using Table 2.

Table 2 — Vehicle speed for measurement to determine frequency shift $\Delta f_{percent}$

		Test results at target speeds			
		5 km/h (Reference)	10 km/h	15 km/h	20 km/h
Reported speed	km/h				
Frequency, $f_{i,speed}$, left side	Hz				
Frequency, $f_{i,speed}$, right side	Hz				
Frequency shift, $\Delta f_{percent}$, left side	%/(km/h)	n.a.			
Frequency shift, $\Delta f_{percent}$, right side	%/(km/h)	n.a.			

The reference speed should be 5 km/h unless other speeds are desired.

7.3 Measurement uncertainty

The measurement procedure described in 7.1 and 7.2 is affected by several parameters (e.g. environmental conditions, measurement system uncertainty, test speed variation, actual centring of a driven vehicle in the test lane, etc.) that lead to variation in the resulting level observed for the same subject. The source and nature of these perturbations are not completely known and sometimes affect the end result in a non-predictable way. The uncertainty of results obtained from measurements according to this document can be evaluated by the procedure given in ISO/IEC Guide 98-3, or by inter-laboratory comparisons in accordance with ISO 5725 (all parts)[6]. Since extensive inter- and intra-laboratory data were not available, the procedure given in ISO/IEC Guide 98-3 was followed to estimate the uncertainty associated with this document. The uncertainties given below are based on existing statistical data, analysis of tolerances stated in this document, and engineering judgement. The uncertainties so determined are grouped as follows:

a) variations expected within the same test laboratory and slight variations in ambient conditions found within a single test series (run-to-run);

b) variations expected within the same test laboratory but with variation in ambient conditions and equipment properties that can normally be expected during the year (day-to-day);

c) variations between test laboratories where, apart from ambient conditions, equipment, staff and road surface conditions are also different (site-to-site).

If reported, the expanded uncertainty together with the corresponding coverage factor for the stated coverage probability of 95 % as defined in ISO/IEC Guide 98-3 shall be given. Information on the determination of the expanded uncertainty is given in Annex D.

NOTE 1 Annex D gives a framework for analysis in accordance with ISO/IEC Guide 98-3, which can be used to conduct future research on measurement uncertainty for this document.

These data are given in Table 3 for three different measurement types. The variability is given for a coverage probability of 95 %. The data express the variability of results for a certain measurement object and do not cover product variation. See Annex E for additional information on the use of this document to achieve these stated uncertainties.

Table 3 — Variability of measurement results for a coverage probability of 95 %

Measurement type	Run-to-run	Day-to-day	Site-to-site
A-weighted sound pressure level, in dB (outdoor)	1,8	1,8	1,9
A-weighted one-third octave sound pressure level, in dB (outdoor)	4,9	5,0	5,2
Frequency shift $\Delta f_{\text{percent}}$ in %/(km/h)	1,0	1,0	10,0

NOTE 2 The measurement uncertainties listed here, with exception of the tonality and frequency shift slope, are the results after averaging the four individual measurement runs of this document. The individual measurement runs will have variation in excess of these values.

NOTE 3 The uncertainties for indoor measurement are taken from ISO 362-3[3].

NOTE 4 The uncertainties for site-to-site measurements are strongly dependent on the vehicle speeds actually used. The uncertainties for outdoor measurements in Table 3 are based on ISO 362-1[2].

NOTE 5 The uncertainties for the tonality value were obtained by averaging multiple measurements in two different test sites for 4 different cars.

NOTE 6 The uncertainties for the frequency shift slope are based on all known systematic errors of the calculation and measurement process and it is not based on measured data.

Until more specific knowledge is available, the data for site-to-site variability can be used in test reports to state the expanded measurement uncertainty for a coverage probability of 95 %.

8 Test report

The test report includes the following information:

a) a reference to this document, i.e. ISO 16254:2024;

b) the details of the test site, site orientation, and weather conditions including wind speed, air temperature, wind direction, barometric pressure, and humidity; or if an indoor facility is used, description of the facility, including dimensions and cut-off frequency of facility;

c) the type of measuring equipment, including the windscreen;

d) the A-weighted sound pressure level typical of the background noise;

e) the one-third octave band spectrum typical of the background noise;

f) the identification of the vehicle, its engine, its transmission system, including available transmission ratios, size and type of tyres, tyre pressure, tyre production type, power, test mass, vehicle length and location of the front reference plane and rear reference plane;

g) the auxiliary equipment of the vehicle, where appropriate, and its operating conditions;

h) the technology content of the vehicle's propulsion system (e.g. internal combustion engine, stop/start, battery electric, hybrid, plug-in hybrid, extended-range electric, fuel cell);

i) any special test or vehicle conditions, including operating modes of the vehicle or settings reflective of the technology content listed in h);

j) if a vehicle is being tested to measure the sound emission performance of an external sound generation system, this system shall be noted in the report;

k) all valid A-weighted sound pressure level values measured for each test, listed according to the side of the vehicle and the direction of the vehicle movement on the test site;

l) the final overall sound pressure level results, $L_{\text{crs,10}}$, $L_{\text{st,rev}}$ and $L_{\text{st,fwd}}$;

m) the final one-third octave result for each side, $L_{\text{MicLeftBAND}}$ and $L_{\text{MicRightBAND}}$, at each test condition $L_{\text{crs,10}}$, $L_{\text{st,rev}}$ and $L_{\text{st,fwd}}$. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,

n) all valid individual narrowband frequencies measured and all one-third octave frequency spectra measurements for each test;

o) the expanded measurement uncertainty for a coverage probability of 95 % for each of the measured quantities.

p) if calculated, all valid frequency shifts $\Delta z/\Delta v$ found and their respective specific tonality values $T'_{\text{speed,shift}}$ with the corresponding noise at the bands T'_{bgn}.

Table 4 is an example template of a test report in table format. Additional lines shall be included if the vehicle has more than one mode.

Table 4 — Example template of reported results

ISO 16254 Report																	
Operating conditions		One-third octave band frequency (Hz)															
	Overall SPL (dB)	160	200	250	315	400	500	630	800	1 000	1 250	1 600	2 000	2 500	3 150	4 000	5 000
Background noise																	
Forward Stationary dB																	
Left one-third octave dB																	
Right one-third octave dB																	
Reverse dB																	
Left one-third octave dB																	
Right one-third octave dB																	
10 km/h dB																	
Left one-third octave dB																	
Right one-third octave dB																	

Table 4 *(continued)*

other speed km/h dB																	
Left one-third octave dB																	
Right one-third octave dB																	

Annex A
(informative)

Information on development of ISO 16254

The development of this document was motivated by the need to measure the minimum noise emission of a motor vehicle in an objective, reproducible, repeatable, and technically correct manner for the purposes of understanding potential safety concerns with low noise emission vehicles. Additional analyses or specification are necessary to provide correlation between the objective measures of vehicle noise emission specified in this document and the subjective evaluation of human subjects to detectability, annoyance, perception, or any other psychoacoustic analysis of sound. Such psychoacoustic parameters are by their very nature subjective parameters that can only be accurately presented as percentages of a given population that will report a response to a certain sound in the presence of a specified background noise.

This test procedure was based on the existing vehicle noise emission test procedures of ISO 362-1[2] and SAE J2805[7]. These existing noise test procedures for maximum noise emission, which form the technical basis for global vehicle exterior maximum noise regulation, have been developed over the past 50 years to provide objective, reproducible, repeatable, and a technically correct manner for conducting exterior vehicle noise emission measurements. Issues relating to the acoustic characteristics of the measurement site, the road surface used for measurement, the instrumentation used for measurement, the environmental conditions necessary for accurate measurement, and an understanding of the sources of, and bounds on, measurement uncertainty; these have all been considered, developed, and refined in ISO 362-1[2] and SAE J2805[7].

The second edition of this document addresses the observed measurement uncertainty by specifying additional measurement locations. The additional measurement locations have the purpose to reduce the frequency transfer function solely coming from the measurement apparatus, which is not in the acoustic signal as perceived by humans. The result is to reduce the measurement uncertainty of the one-third octave results by over 50 %.

To ensure the fitness for purpose of this document, the following adaptations have been made to the ISO 362-1[2] and SAE J2805[7] specifications.

a) The microphone location has been moved from 7,5 m to 2,0 m. This change is to improve the signal to noise ratio of the measurement.

b) The specifications on the background (ambient) sound have been extended to provide conditions suitable for the typical sound pressure levels at the vehicle operating conditions specified in this document. Consistent with the use of this document, it is the maximum background sound level that is reported and used for determining the suitability of the test site or in any correction of measured vehicle noise emission levels.

c) The vehicle operating conditions have been modified to conditions representative of both minimum vehicle sound pressure level and conditions where vehicle noise emission is highly likely to cause a safety concern. The conditions so specified cover a wide range of real-world conditions of concern and are judged to provide a practical set of conditions suitable for carrying out testing with a reasonable workload.

d) The alternative of using an indoor semi-anechoic space for measurement of the specified zero vehicle speed (stopped) condition has been provided. This was later extended to also include the moving vehicle condition as information was presented to show that the error due to measurement of tyre/road noise on a roll was acceptable. This is in recognition that the necessary ambient noise conditions for accurate vehicle measurement are difficult to obtain in an outdoor space for vehicles with low noise emission in the standstill and moving conditions.

e) The selection of the minimum, as opposed to the maximum, average of the left and right average result for overall sound pressure levels for reporting a vehicle test condition result is consistent with the purposes of this document which is to provide pedestrian safety relevant metrics.

f) The selection of the lesser of (minimum) of the vehicle conditions specified as the reported minimum sound emission level of the vehicle is consistent with the purposes of this document. This applies when testing multiple operating modes according to the details given in 7.1.2.4.

g) When using this document for the purposes of determining the noise emission of a specific external sound pressure generation system, the measurement requirement is specified to use the maximum recorded sound pressure level to provide accurate measurement of both continuous and intermittent sources.

h) The vehicle level test procedure was extended to provide support to determine the change in frequency of a vehicle's emitted sound as a function of vehicle speed or other operating parameters. This is termed the frequency shifting of the sound.

i) This document was extended to be able to measure an external sound generation system (ESG) system at a component level. Measurements of an ESG system at a component level allow for additional accuracy of measurement and control of the background noise level that are typically not available when conducting an outdoor or full vehicle measurement. Component testing measures the frequency content of an ESG system at a sufficient precision to allow for the frequency shift information to be determined when using the FFT method.

j) For the purposes of use in a regulation, it can be necessary to determine that additional units of a production process or replacement units are sufficiently similar to an original unit. This evaluation may be accomplished by using the frequency shift measurement procedures and applying the necessary tolerances to the frequency (Hz) information and the level (dB) information. This evaluation may also be accomplished by verifying the respective sound source has identical software.

k) In the second edition of this document, additional procedures considering human perception of sound are provided for frequency shift estimation based on the psychoacoustic tonality method. The psychoacoustic tonality can be used to reliably estimate audible frequency shifts of the sounds by identifying the most audible component in each auditory frequency band (critical band). The use of the psychoacoustic tonality based on ECMA-74 17th edition was mentioned in the second edition of this document in an informative Annex and is now further extended to reference ECMA-418-2 second edition (2022). This update improves the calculation results for low frequencies according to the equal loudness contours of ISO 226[1]. The psychoacoustic tonality analysis allows for a fully automated frequency shift estimation.

l) In the second edition of this document, the addition of extra microphone locations provides for an improved measurement of the one-third octave signal perceptible to humans. The additional microphone locations reduce the error in measuring signal that may be subject to nearfield spatial cancellation of a point measurement, which phenomenon is not how a human with spatially separated hearing perceives the signal.

Annex B
(informative)

Development of frequency shift information

In motor vehicles where combustion engines provide the propulsive power, the sound emission of the vehicle naturally provides information to a pedestrian and the vehicle occupants on the operating state of the vehicle. One primary source of information is the correlation between the frequencies emitted by road vehicles and the velocity of the road vehicle. In broad terms, the acoustic characteristics of the propulsive motor generate higher frequencies at higher vehicle speeds, and humans have come to associate these characteristics to provide information on how fast a vehicle is travelling, or if a vehicle is accelerating.

As the measurement of the frequencies and/or the change of frequencies relative to vehicle speed or other vehicle operating conditions may be useful to characterize necessary pedestrian information, measurement procedures have been provided to accomplish this purpose.

The following assumptions have been taken when developing this test procedure.

a) The persons conducting the test are familiar with the latest acoustic measurement procedures, equipment and standards.

b) The persons conducting the test are trained on the test equipment to be used during the test.

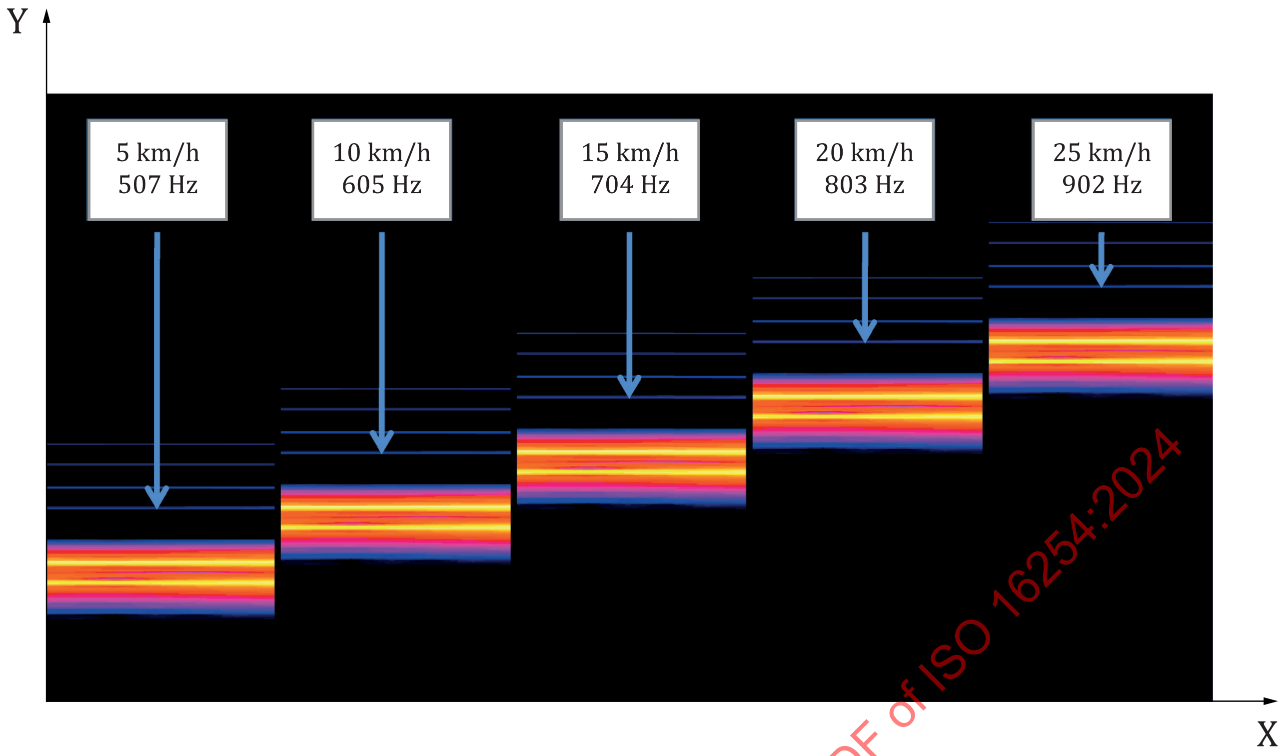
c) There is at least one frequency component that may be tracked as a function of vehicle speed or other vehicle operating condition.

d) The necessary hardware and software is available to simulate vehicle operating conditions where an external sound generation system can be accurately tested as a component.

e) The persons conducting the test know what frequencies should be produced by the external sound generation system or vehicle under measurement.

f) The sound is a stationary signal within all time periods used for measurement.

The procedure is specified as a manual process but may be automated if the measuring equipment provides such capability. The process operates using the same frequency tracking principles as used for rotating machinery order tracking measurements. Figure B.1 provides an example of such a measurement process where multiple frequencies are present, and a single frequency has been chosen to provide the tracking information.



Key

X vehicle speed (km/h)

Y frequency (Hz)

Figure B.1 — Example of measurement of frequency versus vehicle speed information

Annex C
(informative)

Relevance of objective acoustic data to pedestrian safety

This document provides measurement procedures for the following:

a) A-weighted sound pressure level (SPL) at the full vehicle;

b) one-third octave frequency information at the full vehicle level;

c) narrowband (1 Hz resolution) frequency information at the full vehicle level;

d) narrowband (1 Hz resolution) frequency information at the component level;

e) the frequency shift of either a full vehicle or a component versus vehicle speed or other vehicle operating parameter.

f) specific psychoacoustic tonality information at the full vehicle level

In regulatory discussions, the concepts of presence (detection), direction, location, and operation are terms used to attempt to specify the needed information transmitted from the vehicle to the pedestrian, in the case of this document, transmitted by acoustic means. It is recognized that all road vehicles make some acoustic signal; the only relevant question for regulatory authorities is whether the signal is of sufficient magnitude and of a character to allow pedestrians to have necessary acoustic information to enable the pedestrian to travel safely in the presence of road vehicles. In no case has any assumption been made that pedestrians need acoustic information in all cases, and in all places, to allow them to distinguish individual road vehicles.

The primary and reasonable assumption behind the development of this document is to measure the sound emission of vehicles in a range of sound emission that will correspond to road vehicle sound emissions that can be reasonably expected to be heard in a residential situation. In no case is there any expectation that vehicles can be, or should be, heard when loud or unusual noise is present; for example, construction sites, in the presence of vehicles exceeding maximum noise regulatory limits, or in situation where the natural sound level would exceed the level where a person with normal hearing would reasonably expect to hear a road vehicle.

The term "presence" is closely related to the acoustic term "detection" but is not identical. Detection has a specific meaning and definition in signal processing (acoustic or electromagnetic) of sufficient signal energy in excess of natural or background signal energy. Detection is also (usually) applied to signals of assumed stationary character. Therefore, detection is specifically related to the signal energy present in relation to the background, in this case, the background noise. As this is a vehicle and component measurement standard, detection in a specific situation cannot be assessed. Presence, however, is understood in this context as the ability of a pedestrian to determine a vehicle is nearby. As such, there are multiple objective measurements that contribute to the determination of presence. The first is the A-weighted sound pressure level, the second is the frequency content of the sound emission of the vehicle, the third is the shifting of the frequency(ies) of the vehicle with respect to the vehicle velocity and the fourth is the psychoacoustic tonality that is based on a hearing model and addresses human perception of sound.

The A-weighted sound pressure level [SPL, with sound pressure in units of Pascal (Pa), and expressed in this document as A-weighted levels expressed in decibels (dB)], provides the necessary sound energy to provide a listener with some sort of audible sound. The frequency or frequencies of the sound emitted by the vehicle provide an additional source if information to pedestrians that can render the underlying SPL more or less effective, depending on the frequencies, and combination of frequencies, present in the signal. The frequency shifting of the sound signal as a function of the vehicle speed and/or other vehicle operating parameter provides significantly important information to a pedestrian on the vehicle speed; information on the vehicle acceleration or deceleration; and the characteristic of frequency shifting provides the means by which a wide number of undesirable sounds may be excluded from use. Finally, the psychoacoustic tonality in tu_{HMS} is a high-quality surrogate to presence since it takes in consideration how people process sounds in their environments, thus providing a very accurate approach to classify sound signals.

The term “direction” is used in this context to mean the ability of a pedestrian to locate spatially a sound relative to their position. Given the assumption that the sound has been detected, it is the frequency content of the sound signal that will contribute to the accurate spatial location of the vehicle. Of importance to the determination of direction is the large amount of information that can be determined by a pedestrian independent of the sound emitted by the vehicle. This comes from two basic sources: the movement of the vehicle relative to the pedestrian, and the movement of the pedestrian relative to the vehicle.

By the very nature of movement of the vehicle relative to the pedestrian, human hearing processes naturally detect the spatial change of the sound source relative to their current location. From this information, including both changes in amplitude (volume) and changes in relative angle, determinations can be made on the direction and movement of a vehicle. In addition, this process works similarly if the pedestrian moves relative to the vehicle, with the additional source of information that a human can change the orientation of their head relative to the sound, exploiting the binaural hearing capability to provide additional information on the direction of a vehicle.

The term “location” is similar to direction, but in this usage incorporates the additional information of range in addition to spatial orientation. The development of location information uses the same process as used for direction information, with the additional integration of the frequency shifting to provide reinforcing information to the change in sound pressure level, allowing improved determinations if a vehicle is moving closer or further away, and by how much.

The term “operation” is used in this context to mean the pedestrian understanding how the vehicle is being operated by the driver: is the driver moving at a steady speed; is the driver braking quickly or slowing down gradually; or is the driver accelerating the vehicle? This information is provided primarily by the frequency shifting of the vehicle sound, augmented by additional information from the vehicle SPL. From both of these sources of information, a pedestrian can determine the vehicle operation and can therefore make judgments on the action and intent of the driver.

All of the objective criteria specified in this document operate independently as necessary, but not sufficient criteria to provide adequate information to pedestrians. In combination, the criteria of SPL, frequency content, frequency shifting and psychoacoustic tonality provide a set of measures which provide the necessary information to pedestrians to allow them to safely interact with vehicle traffic. Finally, the objective criteria provide a limiting set of specification that may be used by regulatory authorities to enable appropriate sounds to be used and produced.

Annex D
(informative)

Measurement uncertainty – Framework for analysis according to ISO/IEC Guide 98-3 (GUM)

D.1 General

The measurement procedure is affected by several factors causing disturbance that leads to variation in the resulting level observed for the same subject. The source and nature of these perturbations are not completely known and sometimes affect the end result in a non-predictable way. The accepted format for expression of uncertainties generally associated with methods of measurement is that given in ISO/IEC Guide 98-3. This format incorporates an uncertainty budget, in which all the various sources of uncertainty are identified and quantified and from which the combined standard uncertainty can be obtained. Uncertainties are due to the following factors:

— variations in measurement devices, such as sound level meters, calibrators and speed-measuring devices;

— variations in local environmental conditions that affect sound propagation at the time of measurement of $L_{st,fwd}$, $L_{st,rev}$,and $L_{x,band}$;

— variations in vehicle speed and in vehicle position during the pass-by run;

— variations in local environmental conditions that affect the characteristics of the source;

— effect of environmental conditions (air pressure, air density, humidity, air temperature) that influence the mechanical characteristics of the source, mainly engine performance;

— effect of environmental conditions that influence the sound production of the propulsion system (air pressure, air density, humidity, air temperature) and the rolling sound (tyre and road surface temperature, humid surfaces);

— test site properties (test surface texture and absorption, surface gradient).

The uncertainty determined according to 7.3 represents the uncertainty associated with this document. It does not cover the uncertainty associated with the variation in the production processes of the manufacturer. The variations in the sound pressure level or frequency of identical units of a production process are outside the scope of this document.

The uncertainty effects may be grouped in the three areas composed of the following sources (see 7.3):

a) uncertainty due to changes in vehicle operation within consecutive runs, small changes in weather conditions, small changes in background noise levels, and measurement system uncertainty; these are referred to as run-to-run variations;

b) uncertainty due to changes in weather conditions throughout the year, changing properties of a test surface over time, changes in measurement system performance over longer periods and changes in the vehicle operation; these are referred to as day-to-day variations;

c) uncertainty due to different test site locations, measurement systems, road surface characteristics and vehicle operation; these are referred to as site-to-site variations.

The site-to-site variation comprises uncertainty sources from a), b) and c). The day-to-day variation comprises uncertainty sources from a) and b).

D.2 Expression for the calculation of A-weighted sound pressure levels of vehicle low speed operation

The general expression for the calculation of the low speed operation sound pressure level, L_x, is given by Formula (D.1):

$$L_x = L_{x,\text{meas}} + \delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5 + \delta_6 + \delta_7 \quad \text{(D.1)}$$

where

$L_{x,\text{meas}}$ is the A-weighted sound pressure level from any relevant test specified in this document;

δ_1 is an input quantity to allow for any uncertainty in the measurement system;

δ_2 is an input quantity to allow for any uncertainty in the environmental conditions that affect sound propagation from the source at the time of measurement;

δ_3 is an input quantity to allow for any uncertainty in the vehicle speed and position;

δ_4 is an input quantity to allow for any uncertainty in the local environmental conditions that affect characteristics of the source;

δ_5 is an input quantity to allow for any uncertainty in the effect of environmental conditions on the mechanical characteristics of the power unit;

δ_6 is an input quantity to allow for any uncertainty in the effect of environmental conditions on the sound production of the propulsion system and the tyre/road noise;

δ_7 is an input quantity to allow for any uncertainty in the effect of test site properties, primarily related to road surface characteristics and surface absorption characteristics.

NOTE 1 The inputs included in Formula (D.1) to allow for errors are those considered applicable according to the state of knowledge at the time when this document was being prepared, but further research can reveal that there are others.

NOTE 2 The estimated values of the delta functions can be principally positive or negative although they are considered to be zero for the given measurement (see Table D.1). Their uncertainties are not additive for the purpose of determining a measurement result.

NOTE 3 The estimated value of δ_7 is a nonlinear function of vehicle speed. It is effectively zero at zero km/h and increases nonlinearly with potential significance on the measurement result at any vehicle speed of 20 km/h or higher.

D.3 Expression for the calculation of one-third octave band sound pressure levels of vehicle low speed operation

The general expression for the calculation of the one-third octave band sound pressure level at a low speed operation condition, $L_{x,\text{band}}$, is given by Formula (D.2):

$$L_{x,\text{band}} = L_{x,\text{band,meas}} + \delta_8 + \delta_9 + \delta_{10} + \delta_{11} + \delta_{12} + \delta_{13} + \delta_{14} \quad \text{(D.2)}$$

where

$L_{x,\text{band,meas}}$ is the A-weighted one-third octave band sound pressure level from any test specified in this document at a band specified in IEC 61260–1;

δ_8 is an input quantity to allow for any uncertainty in the measurement system;

δ_9 is an input quantity to allow for any uncertainty in the environmental conditions that affect sound propagation from the source at the time of measurement;

δ_{10} is an input quantity to allow for any uncertainty in the vehicle speed and position;

δ_{11} is an input quantity to allow for any uncertainty in the local environmental conditions that affect characteristics of the source;

δ_{12} is an input quantity to allow for any uncertainty in the effect of environmental conditions on the mechanical characteristics of the power unit and any external sound generation system;

δ_{13} is an input quantity to allow for any uncertainty in the effect of environmental conditions on the sound production of the propulsion system, any external sound generation system, and the tyre/road noise;

δ_{14} is an input quantity to allow for any uncertainty in the effect of test site properties, primarily related to road surface characteristics and surface absorption characteristics.

NOTE 1 The inputs included in Formula (D.2) to allow for errors are those considered applicable according to the state of knowledge at the time when this document was being prepared, but further research can reveal that there are others.

NOTE 2 The estimated values of the delta functions can be principally positive or negative although they are considered to be zero for the given measurement (see Table D.2). Their uncertainties are not additive for the purpose of determining a measurement result.

NOTE 3 The estimated value of δ_{14} is a nonlinear function of vehicle speed. It is effectively zero at zero km/h and increases nonlinearly with potential significance on the measurement result at any vehicle speed of 20 km/h or greater.

D.4 Expression for the calculation of frequency shift of vehicle low speed operation

The general expression for the calculation of the frequency shift a low speed operation condition, *del_f*, is given by Formula (D.3):

$$del\_f = \{[(f_{i,\text{speed}} - f_{i,\text{ref}})/(v_{\text{test}} - v_{\text{ref}})]/f_{i,\text{ref}}\} \cdot 100 + \delta_{15} + \delta_{16} + \delta_{17} + \delta_{18} + \delta_{19} + \delta_{20} + \delta_{21} \quad \text{(D.3)}$$

where

$f_{i,\text{ref}}$ is the frequency identified at the reference vehicle speed which is defined as the reference frequency;

$f_{i,\text{speed}}$ is the frequency identified at any vehicle speed higher than the reference speed which is the shifted reference frequency due to the increase in vehicle speed;

v_{test} is the actual vehicle speed during the test;

v_{ref} is the reference vehicle speed from which relative speed changes are calculated;

δ_{15} is an input quantity to allow for any uncertainty in the measurement system;

δ_{16} is an input quantity to allow for any uncertainty in the signal processing functions used for identification of a frequency;

δ_{17} is an input quantity to allow for any uncertainty in the measured vehicle speed;

δ_{18} is an input quantity to allow for any uncertainty in the input of measured vehicle speed to any external sound generation system;

δ_{19} is an input quantity to allow for any uncertainty in the identification of reference or shifted frequencies by the responsible test engineer;

δ_{20} is an input quantity to allow for any uncertainty in the effect of environmental conditions on the sound production of the propulsion system, any external sound generation system, and the tyre/road noise;

δ_{21} is an input quantity to allow for any uncertainty in the effect of test site properties.

NOTE 1 The inputs included in Formula (D.3) to allow for errors are those considered applicable according to the state of knowledge at the time when this document was being prepared, but further research can reveal that there are others.

NOTE 2 The estimated values of the delta functions can be principally positive or negative although they are considered to be zero for the given measurement (see Table D.3). Their uncertainties are not additive for the purpose of determining a measurement result.

D.5 Uncertainty budget for determination of A-weighted sound pressure level and one-third octave sound pressure level

Table D.1 — Uncertainty budget for determination of A-weighted overall sound pressure level of vehicle low speed operation -outdoors

Situation	Quantity	Peak to peak estimation L_{OA}	Probability distribution	Standard uncertainty	95% Uncertainty
	Bias factors				
		dB		±dB	±dB
	Inherent spatial frequency bias	NA	Not Applicable	Not Applicable	NA
	Inherent spatial frequency variation	0,1	Skewed	0,025	**0,03**
	Uncertainty factors				
		dB		±dB	±dB
Run to Run	Wind speed	0,02	gaussian	0,005	**1,8**
	Wind gradient	0,01	gaussian	0,003	
	Temperature	0,04	gaussian	0,010	
	Temperature gradient	0,05	gaussian	0,013	
	Relative humidity	0,00	gaussian	0,000	
	Speed variation (±1 km/h)	1,20	gaussian	0,316	
	Varying background noise	1,0	gaussian	0,300	
	Deviation from centred driving	3,23	gaussian	0,808	
Day to Day	Pressure	0,00	gaussian	0,000	
	Microphone location tolerance X	0,00	gaussian	0,000	**1,8**
	Microphone location tolerance Y	0,32	gaussian	0,080	
	Microphone location tolerance Z	0.27	gaussian	0,068	

Table D.1 *(continued)*

Situation	Quantity	Peak to peak estimation L_{OA}	Probability distribution	Standard uncertainty	95% Uncertainty
Site to Site	Barometric pressure - altitude	0,00	gaussian	0,000	1,9
	Test track surface absorption (2 % to 8 %)	0,12	gaussian	0,030	
	Microphone Class 1 IEC 61672	1,0	gaussian	0,250	
	Sound calibrator IEC 60942	0,5	gaussian	0,125	
	IEC 61260-1 one-third octave filter tolerance	NA	rectangular	NA	
	Speed measuring equipment continuous at PP	0,12	rectangular	0,030	

Table D.2 — Uncertainty budget for determination of A-weighted one-third octave sound pressure level of vehicle low speed operation - outdoors

Situation	Quantity	Peak to peak estimation $L_{1/3}$	Probability distribution	Standard uncertainty	95 % Uncertainty
	Bias Factors				
		dB		±dB	±dB
	Inherent spatial frequency bias	1,5	Not Applicable	Not Applicable	NA
	Inherent spatial frequency variation	5,50	Rectangular	1,588	**1,6**
	Uncertainty factors				
		dB		±dB	±dB
Run to Run	Wind speed	0,20	gaussian	0,050	4,9
	Wind gradient	0,01	gaussian	0,003	
	Temperature	1,40	gaussian	0,350	
	Temperature gradient	0,20	gaussian	0,050	
	Relative humidity	0,10	gaussian	0,025	
	Speed variation (±1 km/h)	1,2	gaussian	0,300	
	Varying background noise	1,0	gaussian	0,250	
	Deviation from centred driving (±50 cm)	7,27	gaussian	1,818	
Day to Day	Pressure	0,00	gaussian	0,000	
	Microphone location tolerance X	0,02	gaussian	0,005	5,0
	Microphone location tolerance Y	0,90	gaussian	0,225	
	Microphone location tolerance Z	1,66	gaussian	0,415	

Table D.2 *(continued)*

Situation	Quantity	Peak to peak estimation $L_{1/3}$	Probability distribution	Standard uncertainty	95 % Uncertainty
Site to Site	Barometric pressure - altitude	0,02	gaussian	0,005	5,2
	Test track surface absorption (2 % to 8 %)	0,13	gaussian	0,033	
	Microphone Class 1 IEC 61672	1,0	gaussian	0,250	
	Sound calibrator IEC 60942	0,5	gaussian	0,125	
	IEC 61260-1 one-third octave filter tolerance	2,00	rectangular	0,577	
	Speed measuring equipment continuous at PP	0,12	rectangular	0,030	

D.6 Uncertainty budget for determination of A-weighted sound pressure level and one-third octave sound pressure level: Updated first version of ISO 16254 using a single microphone

Table D.3 — Uncertainty budget for determination of A-weighted overall sound pressure level of vehicle low speed operation

Situation	Quantity	Peak to peak estimation L_{OA}	Probability distribution	Standard uncertainty	95 % Uncertainty
	Bias factors				
		dB		±dB	±dB
	Inherent spatial frequency bias	NA	Not Applicable	Not Applicable	NA
	Inherent spatial frequency variation	0,1	Skewed	0,029	**0,1**
	Uncertainty factors				
		dB		±dB	±dB
Run to Run	Wind speed	0,00	gaussian	0,000	**2,0**
	Wind gradient	0,00	gaussian	0,000	
	Temperature	0,04	gaussian	0,010	
	Temperature gradient	0,00	gaussian	0,000	
	Relative humidity	0,00	gaussian	0,000	
	Speed variation (±1 km/h)	1,2	gaussian	0,300	
	Varying background noise	1,0	skewed	0,250	
	Deviation from centred driving	3,60	gaussian	4,525	
Day to Day	Microphone location tolerance X	0,00	gaussian	0,000	**2,0**
	Microphone location tolerance Y	0,24	gaussian	0,060	
	Microphone location tolerance Z	0,19	gaussian	0,048	
	Pressure	0,00	gaussian	0,000	

Table D.3 *(continued)*

Situation	Quantity	Peak to peak estimation L_{OA}	Probability distribution	Standard uncertainty	95 % Uncertainty
Site to Site	Barometric pressure - altitude	0,00	gaussian	0,000	**2,1**
	Test track surface absorption (2 % to 8 %)	0,11	gaussian	0,028	
	Microphone Class 1 IEC 61672	1,0	gaussian	0,250	
	Sound calibrator IEC 60942	0,5	gaussian	0,125	
	IEC 61260-1 one-third octave filter tolerance	NA	rectangular	NA	
	Speed measuring equipment continuous at PP	0,12	rectangular	0,030	

Table D.4 — Uncertainty budget for determination of A-weighted one-third octave sound pressure level of vehicle low speed operation

Situation	Quantity	Peak to peak estimation $L_{1/3}$	Probability distribution	Standard uncertainty	95 % Uncertainty
	Bias Factors				
		dB		+/-dB	+/-dB
	Inherent spatial frequency bias	4,3	Not Applicable	Not Applicable	NA
	Inherent spatial frequency variation	14,8	Rectangular	4,272	**8,5**
	Uncertainty Factors				
		dB		+/-dB	+/-dB
Run to Run	Wind Speed	0,31	gaussian	0,078	**12,5**
	Wind Gradient	0,10	gaussian	0,025	
	Temperature	1,90	gaussian	0,475	
	Temperature Gradient	1,10	gaussian	0,275	
	Relative Humidity	0,30	gaussian	0,075	
	Speed variation (+/- 1 km/h)	1,2	gaussian	0,316	
	Varying background noise	1,0	skewed	0,249	
	Deviation from Centred Driving	9,69	gaussian	2,422	
Day to Day	Microphone Location Tolerance X	0,20	gaussian	0,050	**12,6**
	Microphone Location Tolerance Y	1,00	gaussian	0,250	
	Microphone Location Tolerance Z	1,70	gaussian	0,425	
	Pressure	0,28	gaussian	0,071	

Table D.4 *(continued)*

Site to Site	Barometric Pressure - Altitude	0,20	gaussian	0,050	**12,6**
	Test Track Surface Absorption (2 %-8 %)	0,30	gaussian	0,075	
	Microphone Class 1 IEC 61672	1,0	gaussian	0,250	
	Sound calibrator IEC 60942	0,5	gaussian	0,125	
	IEC 61260-1 one-third octave filter tolerance	2,00	rectangular	0,577	
	Speed measuring equipment continuous at PP	0,12	rectangular	0,030	

D.7 Uncertainty budget for determination of frequency shift

Table D.5 — Uncertainty budget for determination of frequency shift of vehicle low speed operation

Quantity	Estimate in Hz	Standard uncertainty, u_i in Hz	Probability distribution	Sensitivity coefficient, c_i	Uncertainty contribution, $u_i c_i$ in Hz
del_f_{meas}	*del_f*	—	—	1	—
δ_{15}	0	—	—	1	—
δ_{16}	0	—	—	1	—
δ_{17}	0	—	—	1	—
δ_{18}	0	—	—	1	—
δ_{19}	0	—	—	1	—
δ_{20}	0	—	—	1	—
δ_{21}	0	—	—	1	—

From the individual uncertainty contributions, $u_i c_i$, the combined standard uncertainty, u, can be calculated according to the rules of ISO/IEC Guide 98-3, taking into account potential correlations between various input quantities.

NOTE The uncertainty evaluation described represents a framework that provides useful information to users of this document. This information represents the state of technical information at this time. Further work is necessary to provide uncertainty information on all terms in Formula (D.3) and all interactions between such terms.

D.8 Expanded uncertainty of measurement

The expanded uncertainty, U, is calculated by multiplying the combined standard uncertainty, u, by the appropriate coverage factor for the chosen coverage probability as described in ISO/IEC Guide 98-3.

Annex E
(informative)

Testing requirements for reduced uncertainty

Regulatory usage of test procedures is influenced by the administrative processes used by various national and international regulatory authorities. This document was developed with the expectation that it is utilized in regulatory assessment where the vehicle manufacturer has control over the test location, test equipment, and determines the day of test; however, the test is carried out under direct supervision of governmentally accredited technical authorities. These types of regulatory processes typically also include conformity of production assessment. The combination of these measures ensures the test results represent the actual vehicle performance while applying engineering judgement where necessary. The basic assumption is if the vehicle meets the performance requirements anywhere within the tolerances specified in the test, the vehicle will provide satisfactory performance for all relevant operating conditions.

There are regulatory processes where this is not the case. For the regulatory procedures where a third party will test a vehicle, additional stringency on the test procedure is required to ensure repeatable and reproducible results. In these cases, engineering judgement cannot be applied due to the regulatory process assuming that a vehicle shall meet the regulatory requirements for all combinations of tolerances specified in the test. If a vehicle cannot meet requirements for all possible conditions of test, the vehicle is deemed unsatisfactory and noncompliant with regulatory requirements.

Annex F
(informative)

Frequency identification of tones using the fast Fourier transformation

F.1 General

The fast Fourier transformation or FFT is a powerful and commonly used algorithm to identify the spectral content of sampled time series. The FFT algorithm is to be used with appropriate selected digital signal processing (DSP) parameters in order to guarantee optimal results. The differences in DSP parameters depend on what aspect of the signal needs identification or foreknowledge of some characteristics of the signal to be analysed.

The sampled representation of a signal should not contain frequency content above the Nyquist frequency or half of the sampling frequency. Measurement systems include anti-aliasing filters to guarantee this requirement. The practical implementations of anti-aliasing filters have their cut-off frequency set at 80 % to 90 % of the Nyquist frequency.

Applying an FFT on a block of time data inherently assumes that this block repeats itself over time. This implies that the end of the block continues to the start of the block without any transient behaviour. This is rarely the case and transients can be observed. This effect is referred to as leakage. In order to keep the frequency content as close as possible to the exact frequencies, several time windows have been developed[9]. These windows attenuate the signal on the extremes to minimize effects of transients. The Hanning-, Flattop-, and Rectangular window are commonly used.

For the identification of the frequency shift as a function of vehicle speed, the frequency of one or more tonal components in stationary signals is required.

F.2 Concept

The identification of tonal components requires an observation of the signal for a sufficient time lapse. This is commonly obtained by processing the time series to an averaged power spectrum. This averaged power spectrum is the average of the power spectra of a number of overlapping time blocks.

A power spectrum is the square norm of the FFT spectrum of a time block multiplied with a time window of the same length. The square norm is obtained by the multiplication of that FFT spectrum with its complex conjugate spectrum.

In order to give equal weight to all time samples from a signal energy point of view, the overlap percentage has to be well chosen. This overlap percentage depends on the type of time window.

F.3 Implementation

The sampling frequency of the time series to be analysed should exceed the highest frequency of concern with a factor of 2,5 corresponding to an anti-aliasing filter placed at 80 % of the Nyquist frequency. However, it is recommended to use a higher factor (e.g. 4) to have negligible impact of that filter on the levels of the tonal components of interest.

The size of each time block depends on the frequency resolution that is needed. Tonal components can be identified with sufficient resolution if this component is on a spectral line index 100 or higher. The size of the time block is determined by the lowest frequency of interest.

In order to suppress leakage, the use of the Hanning window is recommended. This window is a compromise between correct amplitude estimation and adequate frequency identification. As a consequence, an overlap factor of around 67 % is known to give equal weight to all time samples of the time series being analysed.

F.4 Example

Assume the case below:

— Minimal frequency of interest: F_{min} = 125 Hz

— Maximum frequency of interest: F_{max} = 2 400 Hz

Minimal sampling frequency:

— $F_s \geq F_{max} \times 4$ = 2 400 Hz × 4 = 9 600 Hz

Minimal duration and size of time block or maximum resolution of the spectrum:

— $T \geq 100/F_{min}$ = 100/125 Hz = 0,8 s

— $B_s = F_s \cdot T$ = 9 600 Hz × 0,8 s = 7 680 samples

— $\Delta F = F_s/B_s$ = 9 600/7 680 = 1,25

A wide number of selections apply to the requirements above. The selected sampling frequency should be equal or higher than the minimal sampling frequency and the frequency resolution equal or smaller than the maximum resolution:

— F_s = 12 800 Hz > 9 600 Hz

— B_s = 16 384 samples

— ΔF = 12 800/16 384 = 0,781 25 < 0,8

— F_{min} is at spectral line 125 Hz/0,781 25 = 160 Hz