TECHNICAL SPECIFICATION

ISO/TS 20065

First edition

Acoustics — Objective method for assessing the audibility of tones in noise — Engineering method

Acoustique — Méthode objective d'évaluation de l'audibilité des tonalités dans le bruit — Méthode d'expertise

PROOF/ÉPREUVE

Reference number
ISO/TS 20065:2022(E)

Contents

Page

Foreword

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

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

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

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

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

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

This first edition of ISO/TS 20065 cancels and replaces ISO/PAS 20065:2016, which has been technically revised.

The main changes are as follows:

— guidance on residual sound (5.3.1);

— a file containing a number of other example audio files and a guidance document can be downloaded from https://standards.iso.org/iso/20065 (from “Prominent tones in wind turbine noise Round robin test IEC 61400-11, ISO/PAS 20065”);

— editorial changes for clarity and to meet the latest ISO standards, including definitions, measures, formulae, aligned and streamlined terminology, and additional background information.

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.

Acoustics — Objective method for assessing the audibility of tones in noise — Engineering method

1 Scope

This document describes a method for the objective determination of the audibility of tones in environmental noise.

This document is intended to augment the usual method for evaluation on the basis of aural impression, in particular, in cases in which there is no agreement on the degree of the audibility of tones. The method described can be used if the frequency of the tone being evaluated is equal to, or greater than, 50 Hz. In other cases, if the tone frequency is below 50 Hz, or if other types of noise (such as screeching) are captured, then this method cannot replace subjective evaluation.

NOTE The procedure has not been validated below 50 Hz.

The method presented herein can be used in continuous measurement stations that work automatically.

2 Normative references

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

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

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

3 Terms and definitions

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

ISO and IEC maintain 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/

NOTE Unless otherwise stated, the reference level for decibels (dB) values in these definitions is 20 μPa.

3.1
tone
sound characterized by a single-frequency component or narrow-band components

3.2
tone frequency
f_T
frequency of the *spectral line* (3.23) (or mid-band frequency of the narrow-band filter), to the level of which the *tone* (3.1) contributes most strongly

Note 1 to entry: Tone frequency is expressed in hertz (Hz).

3.3
tone level
L_T
energy summation of the *narrow-band level* (3.22) with the *tone frequency* (3.2), f_T, and the lateral lines about f_T, assignable to this tone

Note 1 to entry: Tone level is expressed in decibels (dB).

Note 2 to entry: If the *critical band* (3.5) for the frequency, f_T, under consideration contains a number of tones, then the tone level, L_T, is the energy sum of these tones. This level, L_T, is then assigned to the frequency of the participating tone that has the maximal value of *audibility* (3.4), ΔL.

Note 3 to entry: The method for the determination of the tone level, L_T, of a tone in a critical band is described in 5.3.3.

3.4
audibility
ΔL
Audibility of tones is the arithmetic difference between the *tone level* (3.3), L_T, and the *masking threshold* (3.15), L'_T

Note 1 to entry: Audibility is expressed in decibels (dB).

Note 2 to entry: The method for the determination of the *decisive audibility* (3.24), ΔL_j, of a *narrow-band spectrum* (3.12) is described in 5.3.8.

3.5
critical band
frequency band with a *bandwidth* (3.17), Δf_c within which the auditory system integrates the sound intensity in the formation of loudness and within which it integrates the sound intensity in the formation of the *masking threshold* (3.15)

Note 1 to entry: Critical band is expressed in hertz (Hz).

Note 2 to entry: This characteristic of a critical band (see also References [4] and [5]) holds only for a restricted sound level range. This dependence is neglected here.

3.6
mean narrow-band level of the critical band
L_S
energy mean value of all *narrow-band levels* (3.22) in a *critical band* (3.5), except for the spectral line for the frequency, f_T, under consideration and all lines that exceed this mean value by more than 6 dB

Note 1 to entry: Mean narrow-band level of the critical band is expressed in decibels (dB).

Note 2 to entry: The method for the determination of the mean narrow-band level, L_S, of the masking noise is described in 5.3.2 and Annex D.

3.7
critical band level
L_G
level of noise that is assigned to the *critical band* (3.5) that describes the masking characteristic of the noise for one or more tones of the noise in this critical band

Note 1 to entry: Critical band level is expressed in decibels (dB).

Note 2 to entry: See *narrow-band level* (3.22) and Annex C for masking.

Note 3 to entry: For the definition formula for L_G, see Formula (12).

3.8
sampling frequency
f_S
number of samples taken per second

Note 1 to entry: Sampling frequency is expressed in hertz (Hz).

Note 2 to entry: The analogue data provided continuously are converted into samples through sampling at discrete time intervals for digital processing.

Note 3 to entry: To ensure the reproducibility of a digitized signal, the Shannon theorem requires that the sampling frequency, f_S, is at least 2 times the highest frequency of the signal components used for evaluation in the time signal [$f_S \geq 2\ f_N$, see also *aliasing* (3.9), *antialiasing filter* (3.10) and *useable frequency* (3.20)]. Discrete Fourier Transform (DFT) analysers thus need a sampling frequency that is at least 2,56 times the maximum frequency to be analysed.

3.9
aliasing
reflection in the *line spectrum* (3.12) of frequency components from the range above the *sampling frequency* (3.8) divided by two ($f_S/2$) in the range below $f_S/2$

Note 1 to entry: *Antialiasing filters* (3.10) are used to avoid errors through such reflections.

Note 2 to entry: Half the sampling frequency ($f_S/2$) is also known as the Nyquist frequency.

3.10
antialiasing filter
low-pass filter
ideal filter that allows frequencies below half the *sampling frequency* (3.8) to pass through completely (without influencing the signal), but completely block all higher frequencies

Note 1 to entry: To prevent *aliasing* (3.9), the noise under investigation shall be filtered using an antialiasing filter before analogue-to-digital conversion.

Note 2 to entry: Real aliasing filters have a final damping (generally 120 dB/octave) within the blocking range, i.e. signal components in this transition range are reflected (damped). For example, in the transformation of 2 048 (2 k) data points, 1 024 frequency lines are calculated and 800 lines shown. A component in the line number 1 248 is folded back into the line number 800. With a low-pass filter of 120 dB/octave the damping of these components is approximately 75 dB.

Note 3 to entry: The usual commercial DFT analysers have an antialiasing filter, the limit frequency of which can be switched automatically with the selectable sampling frequency. The reflection of simulated *narrow-band levels* (3.22) is suppressed.

3.11
block length
N
block of sampling values that in discrete form represents a time-limited range of the time signal to be analysed

Note 1 to entry: In contrast to frequency analysis with analogue and digital filters, the noise with the Fast Fourier Transform is processed in data blocks. In general, these blocks embrace only a part of the noise recording. The block length, N, expresses the number of data points processed at the same time. Regarding the Fast Fourier Transform, the value of N generally has the integer of power of 2. It has a value, for example, of $N = 2^{10} = 1\ 024$ data points.

3.12
line spectrum
narrow-band spectrum
frequency spectrum
plot of the sound pressure level (*narrow-band level*) (3.22) as a function of the frequency in frequency bands of constant *bandwidth* (3.17) (*line spacing*, Δf) (3.13)

Note 1 to entry: A-weighting of the level is assumed in this document.

Note 2 to entry: DFT analysis delivers a line spectrum, in which each line represents the output of a filter, the mid-frequency of which corresponds to the frequency of the *spectral line* (3.23).

Note 3 to entry: Line spectrum is sometimes referred to as frequency spectrum.

3.13
line spacing
frequency resolution
distance, between adjacent *spectral lines* (3.23), where the line spacing in the DFT is given by

$$\Delta f = f_S / N$$

where

f_S is the *sampling frequency* (3.8);

N is the *block length* (3.11).

Note 1 to entry: Line spacing is expressed in hertz (Hz).

Note 2 to entry: In this document, the line spacing is 1,9 Hz ≤ Δf ≤ 4,0 Hz.

3.14
time window
time data set of the signal segment (*block length*) (3.11) that is multiplied by a weighting function (window function)

Note 1 to entry: In accordance with the definition of the Fourier integral, a prerequisite of the DFT analysis is that the time data set is periodic. If this is not the case (as with stochastic signals), cut-off effects at the edges of the time window will lead to distortion of the spectrum. These distortions are avoided through weighting functions such as the Hanning function.

Note 2 to entry: For more information on window and weighting functions, see, for example, Reference [6] and Annex A.

3.15
masking threshold
L'_T
audibility (3.4) threshold for a specific sound in the presence of a masking sound (masker)

Note 1 to entry: Masking threshold is expressed in decibels (dB).

Note 2 to entry: See Annex C for more information on the audibility threshold and the masking noise.

3.16
masking index
a_v
arithmetic difference between the *masking threshold* (3.15), L'_T, and the *critical band level* (3.7), L_G, of the masking noise

Note 1 to entry: Masking index is expressed in decibels (dB).

Note 2 to entry: For frequency-dependent masking index, a_v, masking and masking noise, see Annex C.

3.17
bandwidth
frequency bandwidth
frequency range of a number of adjacent *spectral lines* (3.23)

Note 1 to entry: Bandwidth is expressed in hertz (Hz).

Note 2 to entry: If the width of a frequency band is calculated for which its beginning or end does not correspond to the boundary between two spectral lines, then only the spectral lines that lie in their full width within the calculated frequency range are assigned to the frequency band.

3.18
distinctness
clarity ratio of the prominence of a tone based on a bandpass noise to the prominence of a sinusoidal tone of the same *tone frequency* (3.2), f_T, and same *tone level* (3.3), L_T

Note 1 to entry: Distinctness is expressed in percentage (%).

3.19
edge steepness
slope of the level difference between the maximum *narrow-band level* (3.22) of a tone, L_{Tmax}, and the narrow-band levels of the first line below/above the tone to the corresponding frequency difference

Note 1 to entry: Edge steepness is expressed in decibels per hertz (dB/Hz).

3.20
useable frequency
f_N
upper limit frequency of the signal components used for evaluation

Note 1 to entry: Useable frequency is expressed in hertz (Hz).

3.21
investigation range
frequency range within which tones are investigated in the *line spectrum* (3.12)

Note 1 to entry: Investigation range is expressed in hertz (Hz).

3.22
narrow-band level
averaged level within a *spectral line* (3.23)

Note 1 to entry: Narrow-band level is expressed in decibels (dB).

3.23
spectral line
frequency band of *bandwidth* (3.17), Δf (*line spacing*) (3.13), in a *line spectrum* (3.12)

Note 1 to entry: Spectral line is expressed in hertz (Hz).

3.24
decisive audibility
ΔL_j
maximum *audibility* (3.4), ΔL in the individual spectrum, j

Note 1 to entry: Decisive audibility is expressed in decibels (dB).

3.25
mean audibility
ΔL,
energy average of *decisive audibility* (3.24), ΔLj, calculated for each narrow-band averaged spectrum

Note 1 to entry: Mean audibility is expressed in decibels (dB).

4 Measurement procedure

4.1 General

The measurement procedure will depend on the aims. The requirements for the measurement and assessment procedure in terms of the choice of measurement point, measurement time and duration of measurement, extraneous noise, etc. shall be satisfied.

The variable for determination of audibility of prominent tones is the sound pressure, $p(t)$. For frequency analysis, the A-weighted equivalent continuous sound pressure level, L_{Aeq}, as given in ISO 1996-1, shall be established for the respective spectral lines. If the line spectrum is unweighted (LIN or Z), then it shall be corrected to A-weighting in accordance with IEC 61672-1.

4.2 Measurement instruments

Sound level meters that meet, or exceed, the requirements of Class 1 in IEC 61672-1 shall be used. These have a frequency weighting “A”/“LIN” or “A”/“Z” with a lower limit frequency equal to, or below, 20 Hz.

Additional instruments such as recording instruments (digital or magnetic tape) may also be used. The measured values derived through recording instruments shall lie within the tolerance range given in IEC 61672-1.

Analysis of frequency components in the measurement signals is performed using a frequency analyser. The constant line spacing, Δf, shall lie in the range 1,9 Hz to 4 Hz (inclusive). The use of the Hanning window is mandatory in this document. For further processing, it shall be ensured that the digitalization of the sound pressure signal across the entire dynamic range used has a resolution of at least 0,1 dB.

Before it is processed further, the analogue measurement signal shall be passed through a steep low-pass filter (antialiasing filter) to avoid errors in frequency analysis. The sampling frequency (see 3.8) shall be at least two times the maximum usable frequency present (see 3.20). The Hanning window is to be used as time window to reduce lateral bands (see 3.14).

4.3 Merging the basic spectra

The spectra for the prominent tone assessment shall have an averaging time of approximately 3 s. Due to the line spacing of 1,9 Hz to 4 Hz (see 4.2) and the typical frequency range, f, of a few kHz, the basic spectra given by the frequency analyser will have an averaging time below 1 s. To get the averaging time of approximately 3 s, a number of basic spectra shall be merged. This shall be done line by line with Formula (1):

$$L_i = 10 \lg\left(\frac{1}{N}\sum_{j=1}^{N} 10^{0,1 L_{i,j}/\text{dB}}\right)\text{dB} \quad (1)$$

where

$L_{i,j}$ is the level of the i^{th} spectral line for the j^{th} spectrum, in dB;

N is the number of merged spectra.

5 Evaluation

5.1 General information

The aim of evaluation is to establish the audibility, ΔL. The procedure is the same for stationary and non-stationary noises. For tones that can only just be perceived, a quaver (eighth note) is to be adopted as a base time that is adequate for hearing. However, comprehensive studies have shown that the lower limit for use of the procedure is reached at averaging times of approximately 3 s. Lower averaging times lead to unjustified values of audibility, ΔL (too high, but also too low). Signals that have very high level and/or frequency dynamics that no longer correspond with a 3-second averaging can, therefore, not be evaluated using this document. The following conditions shall be satisfied for the measurements.

— The extended uncertainty, U, of the audibility, ΔL, with a coverage probability of 90 % in a bilateral confidence interval (see Clause 6) shall not exceed ±1,5 dB. This is generally the case with evaluation of at least 12 time-staggered narrow-band averaged spectra. If there are less than 12 averaged spectra then the uncertainty shall be taken into consideration as given in Clause 6.

— Where there are alternating operating states, all of the operating states shall be covered by the averaging spectra used (see Annex E).

Tones in different critical bands are evaluated separately. To arrive at a decision on whether an assessment has to be made, only the critical band with the most pronounced tone is considered (see 5.3.8).

If a number of tones are present within a critical band, then an energy summation of their tone levels, L_{Ti}, is carried out to yield a tone level, L_T (see 5.3.8).

An assessment is performed for a tone only if its distinctness (see 3.18) is at least 70 %. This means a maximal bandwidth, Δf_R, dependent on the tone frequency [see Formula (9)] and necessitates edge steepness (see 3.19) of at least 24 dB/octave.

The mean audibility, ΔL, which is the conclusive result of this method for the noise to be assessed, is determined by averaging in energy terms the decisive audibility ΔL_j calculated for each narrow-band averaged spectrum. In this averaging, the ΔL_j, the maximum audibility in each line spectrum, is used regardless of the frequency of the tone. Because the aim of this method is to estimate the annoyance of a noise containing tones relative to a noise without tones, not the annoyance of a tone at a particular frequency.

NOTE 1 For the distinctness of a tone, see 5.3.4.

NOTE 2 Harmonic multiples of a tone are evaluated, independently of that tone, similarly to all other components of the line spectrum.

A sample program to determine audibility can be downloaded from https://standards.iso.org/iso/20065. This is based on ISO/PAS 20065. It is useful for validating proprietary analysis codes.

5.2 Width, Δf_c, of the critical band

The width, Δf_c, of the critical band about the tone frequency, f_T, is given by Formula (2):

$$\Delta f_c = 25{,}0\,\text{Hz} + 75{,}0\left[1{,}0 + 1{,}4\left(\frac{f_T/\text{Hz}}{1\,000}\right)^2\right]^{0{,}69}\,\text{Hz} \tag{2}$$

Assuming a geometric position of the corner frequencies of the critical band (see Annex B), these corner frequencies, f_1 and f_2, are derived as follows:

$$f_T = \sqrt{f_1 \times f_2} \tag{3}$$

$$f_1 = \frac{-\Delta f_c}{2} + \frac{\sqrt{(\Delta f_c)^2 + 4 f_T^{\,2}}}{2} \tag{4}$$

$$f_2 = f_1 + \Delta f_c \tag{5}$$

5.3 Determination of prominent tones

5.3.1 General information

The audibility of a tone is determined using the tone level, L_T, and the critical band level, L_G, of the masking noise in the critical band about the tone frequency, f_T. The frequency of all maxima of the line spectrum is considered as the tone frequency.

The use of the Hanning window is recommended in Annex A. With window functions (except for rectangular windows), the effective analysis bandwidth, Δf_e, is greater than the bandwidth, Δf, of an ideal filter (see 3.13), i.e. the individual bands are thus superimposed. In the summation process, the energy components are counted a number of times (see Annex A for more information).

In a frequency analyser, this influence of summation (number of lines >1) is taken into consideration through a correction value; if the level addition is simulated by the analyser program, then this correction value has to be considered in the computing program, both in the formation of the tone level [see Formula (8)] and in the calculation of the masking noise [see Formula (12)].

The measurement is to be made where possible at such times that tones from sources of residual sound are not present as these can impact the assessment of the source of specific sound under investigation. Justification of the selection of the measurement time period is to be reported. Where not possible, the influence of the sources of residual sound on the measurement is to be reported. When unattended measurements are used, ancillary data such as audio recording or other methods of source identification are recommended. It is recommended that tones that are suspected of being caused by sources of residual sound are excluded from analysis. In addition, it is recommended to consider limiting the frequency range over which tones are searched for.

5.3.2 Determination of the mean narrow-band level of the critical band, L_S, of the masking noise

The mean narrow-band level of the critical band, L_S, [see Formula (6)] is derived in an iterative procedure from the lines of the critical band about the line under investigation. The procedure commences with the energy averaging of all lines of the critical band with the exception of the line under investigation itself. In the subsequent steps, the levels of the lines of the critical band under consideration are no longer taken into consideration in the averaging procedure if their level exceeds the energy mean value determined beforehand by more than 6 dB. The iterative procedure is discontinued, if in an iteration step, the new energy mean value is equal within a tolerance of ±0,005 dB to that of the previous iteration step or if the number of lines contributing to the mean narrow-band level to the right or left of the line under investigation falls below a value of 5. In this case, the energy mean value from the last iteration step, at which the number of energy averaged levels on both sides of the line under investigation in each case was still at least 5 is used to form the mean narrow-band level.

For determination of the mean narrow-band level, the entire critical band about the line under investigation is used. Consequently, the range under investigation (see 3.21) is limited relative to the useable frequency, f_N, such that the upper limit of the uppermost critical band being considered does not exceed the useable frequency, f_N. A corresponding condition also applies in principle for the lower limit of the lowest critical band considered. Since the use of this document is restricted to tone frequencies greater than or equal to 50 Hz and the usual analysers generate line spectra starting at 0 Hz, it is not generally necessary to take any special precautions.

The mean narrow-band level, L_S, is given by Formula (6):

$$L_S = \left[10 \lg \left(\frac{1}{M} \sum_{i=1}^{M} 10^{0,1 L_i / \mathrm{dB}} \right) + 10 \lg \left(\frac{\Delta f}{\Delta f_e} \right) \right] \mathrm{dB} \tag{6}$$

 PROOF/ÉPREUVE

where

- L_i is the narrow-band level of the i^{th} spectral line of the critical band under consideration, in decibels (dB);
- M is the number of spectral lines to be averaged in the critical band;
- Δf is the line spacing, in hertz (Hz) (see 3.13);
- Δf_e is the effective bandwidth in Hz; if a Hanning window is used then the effective bandwidth, Δf_e, is 1,5 times the frequency resolution (line spacing), Δf (see Annex A).

If the line spectrum is unweighted (LIN or Z), then it shall be A-weighted in accordance within IEC 61672-1.

NOTE 1 If the iteration is discontinued, because the remaining number of spectral lines to be averaged on one or both sides falls below 5, then the audibility can be somewhat greater than the audibility calculated with this mean narrow-band level.

NOTE 2 The iteration procedure is described in Annex D.

NOTE 3 Using a digital calculation program, the equal condition in the iteration procedure is typically given by the resolution of the number format (high resolution should be used).

5.3.3 Determination of the tone level L_T of a tone in a critical band

The tone level, L_T, is determined from the individual levels of the spectral lines in the critical band about f_T that contain energy to be assigned to the tone. In principle, a tone may only be present if the level of the spectral line considered is at least 6 dB greater than the corresponding mean narrow-band level, L_S.

In general, a number of spectral lines have to be taken into consideration, since, for instance, because of the Picket fence effect (see Annex A), or actual small frequency fluctuations during data capture, the tone energy is represented through the levels of a number of spectral lines.

Adjacent spectral lines should be used for summation purposes if

- they differ from the narrow-band level at a frequency, f_T, by less than 10 dB, and
- they differ from the mean narrow-band level, L_S, of the masking noise within the critical band about the tone by more than 6 dB.

In case $K = 1$:

$$L_T = L_T \tag{7}$$

In case $K > 1$:

$$L_T = \left[10 \lg \left(\sum_{i=1}^{K} 10^{0,1 L_i / \mathrm{dB}} \right) + 10 \lg \left(\frac{\Delta f}{\Delta f_e} \right) \right] \mathrm{dB} \tag{8}$$

where

- L_i is the narrow-band level of the i^{th} spectral line of this critical band with tone energy, in decibels (dB);
- K is the number of spectral lines with tone energy;
- Δf is the line spacing, in hertz (Hz) (see 3.13);
- Δf_e is the effective bandwidth, in hertz (Hz) (see 5.3.2).