

PUBLICLY  
AVAILABLE  
SPECIFICATION

ISO/PAS  
20065

First edition

---

---

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

*Acoustique — Méthode objective pour évaluer l'audibilité des tons  
dans le bruit — Méthode d'expertise*

iTeh STANDARD PREVIEW  
(standards.iteh.ai)  
Full standard:  
<https://standards.iteh.ai/catalog/standards/sist/49f18d9-d261-4078-8705-1f6e8e4ebd5/iso-pas-20065-2016>

# PROOF / ÉPREUVE

---

---



Reference number  
ISO/PAS 20065:2016(E)

© ISO 2016

**iTeh STANDARD PREVIEW**  
**(standards.itih.ai)**  
Full standard:  
<https://standards.itih.ai/catalog/standards/sist/4916fd99-d261-4078-8705-1f6e8e4ebd5/iso-pas-20065-2016>



**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2016, Published in Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office  
Ch. de Blandonnet 8 • CP 401  
CH-1214 Vernier, Geneva, Switzerland  
Tel. +41 22 749 01 11  
Fax +41 22 749 09 47  
copyright@iso.org  
www.iso.org

# Contents

	Page
Foreword .....	iv
<b>1 Scope</b> .....	<b>1</b>
<b>2 Normative references</b> .....	<b>1</b>
<b>3 Terms and definitions</b> .....	<b>1</b>
<b>4 Measurement procedure</b> .....	<b>5</b>
4.1 General .....	5
4.2 Measurement instruments .....	5
4.3 Merging the basic spectra .....	5
<b>5 Evaluation</b> .....	<b>6</b>
5.1 General information .....	6
5.2 Width $\Delta f_c$ of the critical band .....	6
5.3 Determination of prominent tones .....	7
5.3.1 General information .....	7
5.3.2 Determination of the mean narrow-band level $L_S$ of the masking noise .....	7
5.3.3 Determination of the tone level $L_T$ of a tone in a critical band .....	8
5.3.4 Distinctness of a tone .....	9
5.3.5 Determination of the critical band level, $L_G$ , of the masking noise .....	10
5.3.6 Masking index .....	10
5.3.7 Determination of the audibility, $\Delta L$ .....	<b>10</b>
5.3.8 Determination of the decisive audibility, $\Delta L_j$ , of a narrow-band spectrum .....	10
5.3.9 Determination of the mean audibility $\Delta L$ of a number of spectra .....	12
<b>6 Calculation of the uncertainty of the audibility <math>\Delta L</math></b> .....	<b>13</b>
<b>7 Recommendations on the presentation of results</b> .....	<b>15</b>
7.1 Measurement .....	15
7.2 Acoustic environment .....	15
7.3 Instruments for measurement, recording and evaluation .....	16
7.4 Acoustic data .....	16
<b>Annex A (informative) Window effect and Picket fence effect</b> .....	<b>17</b>
<b>Annex B (informative) Resolving power of the human ear at frequencies below 1 000 Hz and geometric position of the critical bands — corner frequencies</b> .....	<b>21</b>
<b>Annex C (informative) Masking, masking threshold, masking index</b> .....	<b>23</b>
<b>Annex D (informative) Iterative method for the determination of the audibility, <math>\Delta L</math></b> .....	<b>24</b>
<b>Annex E (informative) Example for the determination of the tonal audibility</b> .....	<b>28</b>
<b>Annex F (informative) Sample program to determine the audibility</b> .....	<b>34</b>
<b>Bibliography</b> .....	<b>53</b>

## 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](http://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](http://www.iso.org/patents)).

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

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

The committee responsible for this document is ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

iTeh STANDARD PREVIEW  
(standardsite.it)  
Full standard available on  
<https://standards.itih.ai/catalog/standards/iso-pas-20065-2016>  
d261-4078-8705-1f6e8e4ebd500-pas-2016

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

## 1 Scope

This Publicly Available Specification describes a method for the objective determination of the audibility of tones in environmental noise.

This Publicly Available Specification 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 to be captured, then this method cannot replace subjective evaluation.

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

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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.

### 3.1

#### tonality

presence of a tone in a noise, the level of which is below that of the remaining noise components in the *critical band* (3.5) about the *tone frequency* (3.2) by less than the value of the *masking index* (3.16),  $a_v$

### 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 contributes most strongly

### 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: 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),  $\Delta L$ .

Note 2 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

$\Delta L$

difference between the *tone level* (3.3),  $L_T$ , and the *masking threshold* (3.15),  $L'_T$

Note 1 to entry: The method for the determination of the *decisive audibility* (3.24),  $\Delta L_j$ , of a *narrow-band spectrum* (3.12) is described in 5.3.8.

### 3.5 critical band

frequency band with a *bandwidth* (3.17),  $\Delta f_c$ , 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: This characteristic of a critical band (see also References [3] and [4]) 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) that (as a rule) does not exceed this mean value by more than 6 dB

Note 1 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 (iterative method).

### 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: See *narrow-band level* (3.22) and Annex C for masking.

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

Note 2 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)]. The algorithm of a Fast Fourier Transform analysis (the variant of a discrete Fourier Transform used typically and optimized for calculation) only permits *block lengths* (3.11),  $N$ , that correspond to a power of two. FFT analyzers 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 allow 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 FFT analyzers 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. Due to the nature of the Fast Fourier Transform, the value of  $N$  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*,  $\Delta f$ ) (3.13)

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

Note 2 to entry: Frequency 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).

### 3.13 line spacing

frequency resolution

distance between neighbouring *spectral lines* (3.23), where the line spacing in the FFT 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: In this Publicly Available Specification, the line spacing is  $1,9 \text{ Hz} \leq \Delta f \leq 4,0 \text{ Hz}$ .

### 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 FFT 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 [5] 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: See [Annex C](#) for more information on the audibility threshold and the masking noise.

### 3.16

#### **masking index**

$a_v$

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: 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 neighbouring *spectral lines* (3.23)

Note 1 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 conspicuousness of a tone based on a bandpass noise to the conspicuousness of a sinusoidal tone of the same *tone frequency* (3.2),  $f_T$ , and same *tone level* (3.3),  $L_T$

### 3.19

#### **edge steepness**

ratio 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

### 3.20

#### **useable frequency**

$f_N$

upper limit frequency of the signal components used for evaluation

### 3.21

#### **investigation range**

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

### 3.22

#### **narrow-band level**

averaged level within a *spectral line* (3.23)



**3.23****spectral line**

frequency band of *bandwidth* (3.17),  $\Delta f$  (*line spacing*) (3.13), in a *line spectrum* (3.12)

**3.24****decisive audibility**

$\Delta L_j$

maximum *audibility* (3.4),  $\Delta L$ , in the individual spectrum,  $j$

**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, is to be established for the respective spectral lines. If the spectrum is unweighted (linear), 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 analyzer. The constant line spacing,  $\Delta f$  shall lie in the range 1,9 Hz to 4 Hz (inclusive). The use of the Hanning window is mandatory in this Publicly Available Specification. 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 analyzer 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):

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

where

$L_{j,i}$  is the level of the spectrum,  $j$ , and the spectral line,  $i$ ;

$N$  is the number of merged spectra.

## 5 Evaluation

### 5.1 General information

The aim of evaluation is to establish the audibility,  $\Delta L$ . 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,  $\Delta L$  (too high, but also too low). Signals that have a very high level dynamic and/or frequency dynamic that no longer correspond with a 3-second averaging can, therefore, not be evaluated using this Publicly Available Specification. The following conditions shall be satisfied for the measurements.

- The extended uncertainty,  $U$ , of the audibility,  $\Delta L$ , with a coverage probability of 90 % in a bilateral confidence interval (see [Clause 6](#)) shall not exceed  $\pm 1,5$  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](#)).

Tonal components in different critical bands are evaluated separately. To arrive at a decision on whether a tonal audibility has to be made, only the most pronounced tone is considered. If a number of tones are present within a critical band, then an energy summation of their tone levels,  $L_{T,i}$ , is carried out to yield a tone level,  $L_T$  (see [5.3.8](#)).

A tonal audibility is performed for a tone only if its distinctness (see [3.18](#)) is at least 70 %. This means a maximal bandwidth,  $\Delta f_R$ , dependent on the tone frequency [see Formula (9)] and necessitates edge steepness (see [3.19](#)) of at least 24 dB/octave.

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 spectrum.

### 5.2 Width $\Delta f_c$ of the critical band

The width  $\Delta f_c$  of the critical band about the tone frequency  $f_T$  is given by Formula (2):

$$\Delta f_c = 25,0 \text{ Hz} + 75,0 \left[ 1,0 + 1,4 \left( \frac{f_T / \text{Hz}}{1000} \right)^2 \right]^{0,69} \text{ Hz} \quad (2)$$

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:

$$f_T = \sqrt{f_1 \times f_2} \quad (3)$$

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

$$f_2 = f_1 + \Delta f_c \quad (5)$$

### 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 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,  $\Delta f_e$ , is greater than the bandwidth,  $\Delta f$ , 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 analyzer, this influence of summation (number of lines  $>1$ ) is taken into consideration through a correction value; if the level addition is simulated by the analyzer 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)].

#### 5.3.2 Determination of the mean narrow-band level $L_S$ of the masking noise

The mean narrow-band level,  $L_S$ , [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  $\pm 0,005$  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 Publicly Available Specification is restricted to tone frequencies greater than or equal to 50 Hz and the usual analyzers 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):

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

where

$L_i$  is the narrow-band level of the  $i$ th spectral line, in decibels (dB);

$M$  is the number of spectral lines to be averaged in the critical band;

$\Delta f$  is the line spacing, in Hertz (Hz) (see 3.13);

$\Delta f_e$  is the effective bandwidth in Hz; if a Hanning window is used then the effective bandwidth,  $\Delta f_e$ , is 1,5 times the frequency resolution (line spacing),  $\Delta f$  (see Annex A).

If the spectrum is unweighted (linear), 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 may 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.

Neighbouring 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  $K = 1$ :

$$L_T = L_T \quad (7)$$

In case  $K > 1$ :

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

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;

$\Delta f$  is the line spacing, in Hertz (Hz) (see 3.13);

$\Delta f_e$  is the effective bandwidth, in Hertz (Hz) (see 5.3.2).

NOTE The individual levels of the spectral lines with tone energy [see Formula (8)] also contain energy components of the masking noise. These can generally be neglected.

### 5.3.4 Distinctness of a tone

The distinctness of a tone depends on the bandwidth of the tone and its edge steepness; if the corresponding criteria are not satisfied then the tone is not audible to individuals with normal hearing.

If a tone based on bandpass noise has a distinctness of 70 % relative to that of a sinusoidal tone then the maximum permitted bandwidth  $\Delta f_R$  as a function of the tone frequency  $f_T$  is approximated (see Figure 1 in Reference [8]) by

$$\Delta f_R = 26,0(1,0 \text{ Hz} + 0,001 f_T) \quad (9)$$

The bandwidth of a tone with a frequency  $f_T$  is derived from the number of spectral lines  $K$  [see Formula (8)], multiplied by the line spacing,  $\Delta f$ .

First criterion: The bandwidth of the tone shall not exceed the maximum permitted bandwidth given by Formula (9).

Second criterion: The edge steepness shall be at least 24 dB/octave.

This yields the level differences between the maximum narrow-band level of the tone,  $L_{T\max}$ , and the narrow-band levels of the first spectral line below the tone  $L_u$ /above the tone  $L_o$  as follows:

The lower level difference  $\Delta L_u$  is given by Formula (10):

$$\Delta L_u = \frac{f_T}{2} \frac{L_{T\max} - L_u}{f_T - f_u} \geq 24 \text{ dB} \quad (10)$$

where

$f_u$  is the frequency of the first spectral line below the tone, in Hertz (Hz);

$f_T$  is the frequency of the maximum narrow-band level, in Hertz (Hz).

The upper level difference  $\Delta L_o$  is given by Formula (11):

$$\Delta L_o = f_T \frac{L_{T\max} - L_o}{f_o - f_T} \geq 24 \text{ dB} \quad (11)$$

where

$f_o$  is the frequency of the first spectral line above the tone, in Hertz (Hz);

$f_T$  is the frequency of the maximum narrow-band level, in Hertz (Hz).