Standard ECMA-418-1

3rd Edition / December 2024

# Psychoacoustic metrics for ITT equipment – Part 1 (prominent discrete tones)

Rue du Rhône 114 CH-1204 Geneva T: +41 22 849 6000 F: +41 22 849 6001

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## Introduction

ECMA-418-1 specifies in detail methods for determining and reporting the presence of prominent discrete tone in airborne noise emissions of information technology and telecommunications equipment.

The technical contents of the 1st edition of ECMA-418-1 are based on, and mostly identical to ECMA-74, 17th edition (December 2019) Annex D. ECMA-418-1 has the following annexes:

- Annex A (normative) Tone-to-noise ratio calculation based on mean-square sound pressure data
- Annex B (normative) Prominence ratio calculation based on mean-square sound pressure data

ECMA-418 series consists of the following parts, under the general title “Psychoacoustic metrics for ITT equipment”:

– Part 1 (prominent discrete tones)

– Part 2 (methods for describing human perception based on the Sottek Hearing Model)

For the 2nd edition, there were revisions that introduced a maximum tone bandwidth for modulated tones and made corrections and clarifications to figures, tables and equations.

- For the tone-to-noise ratio method the maximum tone bandwidth was defined as 15% of the critical band containing the tone. This definition is relevant to amplitude or frequency modulated tones whose bandwidth cannot be ascertained.
- Figure 3 was replaced to show two tones in a critical band instead of the one tone incorrectly shown in the 1st edition. The vertical axes in Figures 2 and 4 were restored from the broken or missing axes in the 1st edition. Labels on the right vertical axis of Figure A.1 were removed for consistency with other figures, and annotation text boxes on the figures were refined for clarity.
- Table 1 was reformatted for full visibility of its contents, which are cut-off in the 1st edition.
- The missing $a_4$ term in Formula 1 was added. The lower critical band limit in Formula 7 and the inequality defining the frequency range of prominence ratio determination by Formula 23 were corrected. The tone-to-noise ratio criterion for a prominent tone below 1 000 Hz in Formula 11 and A.3 was reformatted for clarity. Formulae 12, 25, A.4, and B.10 were edited to make 1 000 Hz to be inclusive (>=1 000 Hz), and Formulae 11, 24, A.3 and B.9 were revised correspondingly. Formula 15 was edited to remove an unnecessary term.

For the 3rd edition, there were several updated as follows:

- In Clause 4, the terms and definitions were fully revised;
  - Instead of referencing to ECMA-74, most terms were newly defined, based on other standards and documents publicly available.
  - Clause 4 was divided into the following categories:
    - 4.1 General definitions,
    - 4.2 Psychoacoustical definitions,
    - 4.3 Other definitions, and
    - 4.4 Abbreviations.
- In Clause 11 and its counterpart Annex A;
  - The TNR procedure was updated to improve repeatability across the different FFT frequency resolutions that may be used when implementing the procedure. The end points of the tone band were revised to be the minimal points bracketing the peak frequency within or just beyond 15% of the critical bandwidth centred on the tone peak frequency. The tone level (or power) was revised to be the level (or power) above the line connecting the end points. The masking noise level (or power) was revised to be the

level (or power) in the critical band minus the tone level (or power). About the cases exceeding 15 % of the critical bandwidth, CAUTION in 11.2 and its counterpart A.2 were amended.

  - To explain the revised TNR procedure;
    - Formula (9) and its counterpart Formula (A.1) were newly added.
    - Formulae (10) and its counterpart Formula (A.2) were modified.
    - Figure 2 and its counterpart Figure A.1 were newly added to illustrate how tone band, tone power, and masking noise power are determined, and Figures 3 and 4, and their counterpart Figures A.2, and A.3 were updated. `
    - In 11.6 and A.6, NOTEs were added to advise of the critical bandwidth discontinuity near 500 Hz and the proximity spacing discontinuity near 1 000 Hz associated with formulae for critical bandwidth and proximity spacing, respectively.
- In Annex B, Formulae (B.7) and (B.8) were corrected to draw back to those of ECMA-74, Annex D, 17th edition.
- Other errors in typography, format, and references to other standards were corrected.
- No change of Scope.

This Ecma Standard was developed by Technical Committee 26 and was adopted by the General Assembly of December 2024.

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# Psychoacoustic metrics for ITT equipment – Part 1 (prominent discrete tones)

## 1 Scope

This Standard, ECMA-418-1 specifies two procedures for determining whether noise emissions of *ITT equipment* (see 4.1.1) under test contain prominent discrete tones: the tone-to-noise ratio method and the prominence ratio method.

Discrete tones occurring at any frequency within the *frequency range of interest* (see 4.1.2) can be evaluated by the procedures in this Standard.

All of the requirements of the test environment of ECMA-74:2022, 8.3 apply. However, for the purposes of this Standard, corrections neither for background noise, $K_1$, nor for test environment, $K_2$ apply (see ECMA-74:2022, 8.7.1).

NOTE 1 Since some ITT equipment emit *discrete tones* (see 4.2.2) in the 16 kHz octave band, the tone-to-noise ratio or the prominence ratio can be computed for these tones in accordance with the procedures in this Standard in an attempt to quantify their relative levels. However, the prominence criteria in either 11.5 or 12.6 cannot be applied, since there is no supporting psychoacoustical data on such high-frequency discrete tones.

Declaration of product noise emissions in accordance with ECMA-109[1] offers the option of stating whether there are prominent discrete tones in the noise emissions of a product, as determined by ECMA-418-1. Other standards, or other *noise test codes* (see 4.1.3) relating to products besides ITT equipment, can also refer to ECMA-418-1 for the declaration of prominent discrete tones. For the purposes of such declarations, either the tone-to-noise ratio method or the prominence ratio method may be used, unless otherwise specified in the standard or noise test code (see 4.1.4, *referencing document*).

NOTE 2 The tone-to-noise ratio method can prove to be more accurate for multiple tones in adjacent critical bands, for example when strong harmonics exist. The prominence ratio method can be more effective for multiple tones within the same critical band and is more readily automated to handle such cases.

## 2 Conformity requirements

Measurements are in conformity with this Standard if they meet the following requirements:

a) the procedures specified in Clauses 5 through 10 and 13 shall be taken fully into account, and
b) for the determination of tone-to-noise ratio, the method specified in either Clause 11 or Annex A (one and only one) shall be used, and/or,

for the determination of prominence ratio, the method specified in either Clause 12 or Annex B (one and only one) shall be used.

## 3 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 Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ECMA-74:2022, *Measurement of* airborne noise *emitted by* information technology *and* telecommunications equipment

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

# 4 Terms and definitions

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

And, at the end of this clause, 4.4 shows list of abbreviations.

## 4.1 General definitions

**4.1.1**
**frequency range of interest**
range of one-third-octave bands with centre frequencies from 100 Hz to 10 000 Hz inclusive

NOTE 1 This range was selected to be identical to that of ECMA-74:2022, 3.1.3.

NOTE 2 From viewpoint of test implementation by using FFT analyser, the frequency range of discrete tones are between 89,1 Hz and 11 220 Hz inclusive, referred to *the discrete tone frequency range of interest*.

**4.1.2**
**ITT equipment**
**information technology and telecommunications equipment**
equipment for information processing, and components thereof, used in homes, offices, server installations, telecommunications installations, or similar environments

NOTE 1 This range was selected to be identical to that of ECMA-74:2022, 3.1.3.

NOTE 2 Annex C of ECMA-74:2022, which specifies particular requirements for use with that ECMA Standard, may be useful in identifying many of the categories of ITT equipment.

**4.1.3**
**noise test code**
**C-type standard**
standard that is applicable to a particular class, family or type of machinery or equipment which specifies all the necessary information to carry out efficiently the declaration and verification of the noise emission characteristics under standardized conditions

[Adapted from ISO 12001:1996[5], 3.2]

**4.1.4**
**referencing document**
standard or test code that refers to ECMA-418-1 for the purpose of specifying the method(s) of determining whether noise emissions contain prominent discrete tones

[Adapted from ISO 26101-1:2021[25], 3.8]

**4.1.5**
**operator**
individual whose work station is in the vicinity of a machine and who is performing a work task associated with that machine

[Adapted from ISO 11201:2010[26], 3.12]

**4.1.6**
**operator position**
**work station**
position in the vicinity of the equipment under test which is intended for the *operator* (see 4.1.5)

NOTE This term does not refer to a computer “workstation”, which denotes a high-performance, single-user computer.

[Adapted from ISO 11201:2010[25], 3.11]

**4.1.7**
**bystander position**
positions occupied by individuals not responsible for the operation of the source under test, but who may be in its immediate vicinity, either occasionally or continuously

[Adapted from ISO 11201:2010, 1.4, e)]

## 4.2 Psychoacoustical definitions

**4.2.1**
**tone**
**tonal component**
sound characterized by a single-frequency component or narrow-band components

[Adapted from ISO/TS 20065:2022[8], 3.1]

**4.2.2**
**discrete tone**
a periodic sound pressure variation that gives rise to the sensation of pitch.

NOTE 1 A discrete tone can be either a purely sinusoidal variation (sometimes called a pure tone), in which case the frequency spectrum would show a single "spike" at the sinusoidal frequency, or, more typically, a non sinusoidal variation, in which case the spectrum would show a spike at the fundamental frequency and other spikes at harmonics (integer multiples) of the fundamental.

NOTE 2 Examples of discrete tones are the hum of a transformer, a beep from a digital instrument, a smoke alarm going off, and a note played on a musical instrument.

[Adapted from ANSI S13:1995[10], 6.2.3]

**4.2.3**
**critical band**
band of frequencies on either side of a specified frequency within which the presence of sound at a second frequency will interfere with the detection of sound at the specified frequency

[SOURCE: ISO 18405:2017[8], 3.7.2.5]

**4.2.4**
**masking**
**masking effect**
the (human ear) process by which the *threshold of audibility* (see 4.2.8) of one sound is raised by the presence of another sound

NOTE Another sound is occasionally referred to masker or masking noise.

[Adapted from Sound and Vibration POCKET HANDBOOK[29], ACOUSTICS, *Glossary of Acoustic Terms*]

**4.2.5**
**threshold of hearing**
**hearing threshold**
level of a sound at which, under specified conditions, a person gives 50 % of correct detection responses on repeated trials

NOTE The results of threshold determination depend to a certain degree on the test procedure used. The data presented in the ISO 389 series (including ISO 389-7) are all based on the use of the threshold test procedures defined in ISO 8253-1[27]. When a test procedure with other characteristics is used, differences of up to several decibels on average may be expected.

[Adapted from ISO 389-7:2019[3], 3.1]

**4.2.6**
**reference threshold of hearing**
at a specified frequency, sound pressure level of a pure tone or a one-third-octave band of noise corresponding to the median value of the binaural thresholds of hearing of *otologically normal persons* (see 4.2.7) within the age limits from 18 years to 25 years inclusive

[SOURCE: ISO 389-7:2019[3], 3.3]

**4.2.7**
**otologically normal persons**
person in a normal state of health who is free from all signs or symptoms of ear disease and from obstructing wax in the ear canals, and who has no history of undue exposure to noise, exposure to potentially ototoxic drugs, or familial hearing loss

[SOURCE: ISO 389-7:2019[3], 3.2]

**4.2.8**
**audibility threshold**
**threshold of audibility**
at a specified frequency, the sound pressure level above which persons with normal hearing begin to perceive sound

[Adapted from Sound and Vibration Pocket Handbook[29], ACOUSTICS, *Glossary of Acoustic Terms*]

## 4.3 Other definitions

**4.3.1**
**FFT**
**Fast Fourier Transform**
algorithm for computing the *discrete Fourier transform* (see 4.3.2) with optimized computational efficiency

NOTE This algorithm is typically either the Cooley-Tukey (see Reference [28]) or Sande-Tukey algorithm.

[Adapted from ISO 18431-2:2004[7], 3.2]

**4.3.2**
**DFT**
**Discrete Fourier Transform**
discrete transform in time and frequency, based on the Fourier integral transform, used to obtain a spectral estimation of $N$ uniformly time-spaced samples of a signal observed over a finite duration

$$X(m) = \frac{1}{f_\mathrm{s}} \sum_{n=0}^{N-1} x(n) e^{-i2\pi nm/N}$$

where

| | |
|---|---|
| $f_\mathrm{s}$ | is sampling frequency |
| $i$ | is index for flat-top window constants |
| $m$ | is frequency sample |
| $n$ | is time sample |
| $N$ | is block size of sampled data; the number of sampled points that are transformed |
| $x(n)$ | is sampled physical quantity in the time domain |
| $X(m)$ | is digital Fourier transform of $x(n\Delta t)$ |

[SOURCE: ISO 18431-2:2004[7], 3.1]

## 4.4 Abbreviations

| | |
|---|---|
| DFT | Discrete Fourier Transform |
| FFT | Fast Fourier Transform |
| LTH | Lower Threshold of Hearing |
| NTC | Noise Test Code |
| PSD | Power Spectral Density |
| RMS | Foot-Mean Square |
| RTH | Reference Threshold of Hearing |

## 5 Psychoacoustical background

A discrete tone which occurs together with broad-band noise is partially masked by that part of the noise contained in a relatively narrow frequency band, called the *critical band* (see 4.2.3) that is centred at the frequency of the discrete tone. Noise at frequencies outside the critical band does not contribute significantly to the *masking effect* (see 4.2.4). The width of a critical band is analytically expressed as a function of frequency (see Clause 10). In general, a *discrete tone* (see 4.2.2) is just audible in the presence of noise when the sound pressure level of the *tone* (see 4.2.1) is about 4 dB {2 dB to 6 dB, depending on frequency (see Reference [11])} below the sound pressure level of the masking noise contained in the critical band centred around the tone. This is sometimes referred to as the threshold of detectability. For the purposes of this Standard, a discrete tone is classified as *prominent* when using the tone-to-noise ratio method if the sound pressure level of the tone exceeds the sound pressure level of the masking noise in the critical band by 8 dB for tone frequencies of 1 000 Hz and higher, and by a greater amount for tones at lower frequencies. This corresponds, in general, to a discrete tone being prominent when it is more than 10 dB to 14 dB above the threshold of detectability. When using the prominence ratio method, a discrete tone is classified as *prominent* if the difference between the level of the critical band centred on the tone and the average level of the adjacent critical bands is equal to or greater than 9 dB for tone frequencies of 1 000 Hz and higher, and by a greater amount for tones at lower frequencies. Reference [12] provides the basis for these criterion values.

## 6 Test environment and microphone position(s)

If the equipment has an *operator position* (see 4.1.6), the measurements shall be performed at the operator position defined in ECMA-74:2022, 8.6.2. If there is more than one operator position, the measurements specified in the following shall be performed at the operator position with the highest A-weighted sound pressure level.

If the equipment has no *operator position*, the measurements to determine the tone-to-noise ratios or prominence ratios shall be performed at the *bystander position* (see 4.1.7) defined in ECMA-74:2022, 8.6.3 with the highest A-weighted sound pressure level and at all other bystander positions having A-weighted sound pressure levels within 0,5 dB of the highest one.

When the methods of this Standard are to be applied to sub-assemblies, the conditions in the next two paragraphs shall be used.

For sub-assemblies (see ECMA-74:2022, 3.1.12) intended for use in equipment with a defined operator position, the measurement shall be performed at the operator position (see ECMA-74:2022, 8.6.2).

For sub-assemblies intended for use in equipment which does not require operator attention while in the operating mode, the measurements shall be performed at the bystander position (see ECMA-74:2022, 8.6.3) with the highest A-weighted sound pressure level and at all other bystander positions having A-weighted sound pressure levels within 0,5 dB of the highest one. For small, low-noise sub-assemblies needing a hemispherical measurement surface with a radius equal to or less than 1 m (see ECMA-74:2022, 5.1.7 and B.1), it is possible that the signal-to-noise ratio is not sufficient at the bystander positions. In such cases, the measurements may be performed at selected microphone positions from ECMA-74:2022, Table B.1 on the hemispherical measurement surface itself (even if the sound power determination is done without fixed positions). In such cases, the radius of the hemisphere, the coordinates of the microphone positions from ECMA-74:2022, Table B.1 and enough information to uniquely identify the equipment orientation relative to the microphone positions shall be reported.

If multiple microphone positions are used to perform the measurements specified in this Standard, the highest values computed for tone-to-noise ratio (see 11.5) and prominence ratio (see12.5), and the corresponding microphone position for each, shall be reported.

# 7 Instrumentation

A digital F*ast Fourier Transform* (FFT, see 4.3.1) analyser capable of measuring the power spectral density (PSD) of the microphone signal shall be used for the measurements of this Standard.

The analyser shall have root-mean square (RMS) averaging (linear averaging, rather than exponential averaging) capabilities, a Hanning time window function, an upper frequency limit high enough to allow computing the quantities required herein for the particular discrete tone under investigation, and an FFT resolution less than 1 % of the frequency of the tone.

For the tone-to-noise ratio procedure (see Clause 11), experience has shown that an FFT resolution of 1 % of the frequency of the discrete tone under investigation is occasionally insufficient to properly resolve the tone. Therefore, for application to the tone-to-noise ratio procedure, an FFT resolution of 0,25 % or better is recommended (see Reference [13]).

The microphone output signal fed to an FFT analyser shall meet the requirements for sound level meters specified in IEC 61672-1, class 1. Because the procedures of this Standard include the option of working directly in terms of sound pressure levels, the FFT analyser (or, alternatively, the software used for post-processing of the FFT data) should allow calibration directly in terms of sound pressure levels in decibels (reference: 20 µPa).

No frequency weighting function (e.g. A-weighting) shall be applied to the analyser input signal.

The FFT analysis shall use a sufficient number of averages to provide an analysis time satisfying the requirements of ECMA-74:2022, 8.7.2.

# 8 Initial screening tests

## 8.1 General

Before proceeding with either the tone-to-noise ratio method (see Clause 11) or the prominence ratio method (see Clause 12), one of the tests specified in 8.2 and 8.3 shall be conducted, as applicable.

## 8.2 Screening test for audibility of discrete tone(s) in noise generally well above the threshold of hearing

Discrete tones should only be classified as *prominent* if they are, in fact, *audible* in the noise emissions of the equipment under test. For the purposes of the screening test, it is assumed that the level of the noise being measured is well above the *threshold of hearing* (see 4.2.5). *Discrete tones* or tonal *components* (see 4.2.2 and 4.2.1, respectively) that can be present in the noise emissions are occasionally not audible due to masking by the noise itself or for some other reason (e.g. the tones can be harmonics of a lower fundamental tone and not individually audible). Therefore, an initial aural examination of the noise emitted from the equipment under test shall be made at the specified microphone position, with the following cases applied.

a) If one or more discrete tones are audible, then the measurement procedures of this Standard for either the tone-to-noise ratio or prominence ratio, or both, shall be carried out for each audible tone.

b) If no discrete tones are audible in the noise emissions, and there is a high degree of confidence in this conclusion, the procedures of this Standard may not be carried out and a statement such as “no audible discrete tones” or “no prominent discrete tones” may be included in the test report.

c) If there is doubt as to whether a discrete tone is audible in the noise emissions (e.g. if the test engineer has a hearing loss or is not a trained or experienced listener), then other, more objective evidence should be sought. For this purpose, a preliminary FFT analysis shall be taken of the noise emissions at the specified microphone position(s). If the spectrum indicates the presence of potentially audible discrete tones or tonal components (i.e., if the spectrum shows one or more sharp spikes), then the measurement procedures of this Standard for either the tone-to-noise ratio or prominence ratio, or both, shall be carried out for each potentially audible tone.

NOTE The aural examination in cases a) and b) can be bypassed, and the preliminary FFT analysis of case c) used directly as this screening test for the audibility of discrete tones.

Any discrete tone that is determined to be prominent in accordance with the either the tone-to-noise ratio method or the prominence ratio method shall also meet the audibility requirements of 11.8 or 12.8, respectively.

### 8.3 Screening test for audibility of discrete tone(s) in noise near the threshold of hearing

If the noise emissions to be analysed for the presence of prominent discrete tones are extremely low in level such that either the noise itself, or any discrete tone occurring in the noise is near or below the *threshold of hearing* (see 4.2.5), the following screening test shall be applied. An FFT spectrum of the noise emissions at the specified microphone position(s) shall be acquired in accordance with either 11.1 or 12.1, as applicable. The FFT spectrum shall be calibrated in terms of sound pressure level in decibels (reference: 20 μPa) following the machine manufacturer's instructions for the particular FFT analyser in use. The following cases apply.

a) If the sound pressure level, $L_\mathrm{t}$ (see 11.2, and if applicable,11.6), of a discrete tone or tonal component to be evaluated for prominence falls below the lower threshold of hearing (LTH), $P_1(f)$, as defined in 9.1 and calculated at the frequency of the tone by Formula (1), it is assumed to be *inaudible*, and the procedures of this Standard may not be carried out. A statement such as "no audible discrete tones" or "no prominent discrete tones" may be included in the test report.

b) If the sound pressure level, $L_\mathrm{t}$ (see 11.2, and if applicable, 11.6), of a discrete tone or tonal component to be evaluated for prominence is less than or equal to $P_1(f)$ + 10 dB, as calculated at the frequency of the tone by Formula (1), it is assumed to be "*not prominent*", and the procedures of this Standard may not be carried out. A statement such as "no audible discrete tones" or "no prominent discrete tones" may be included in the test report.

Figure 1 shows both the $P_1(f)$ and $P_1(f)$ + 10 dB curves.

NOTE For most ITT equipment that contain cooling fans, even for small, relatively quiet products, the noise levels are well above the threshold of hearing. However, for certain components evaluated separately from their end-use product, such as small disk drives, the levels can, in fact, be below the threshold of hearing and the above screening procedure is applicable.

## 9 Discrete tones and noise emissions near the threshold of hearing

### 9.1 Lower threshold of hearing

Studies of normal hearing thresholds have shown that the measured thresholds vary about a mean level in approximately a normal distribution. The 50-percentile distribution values have been standardized in ISO 389-7[3], as a function of frequency and termed the "*reference threshold of hearing*" (see 4.2.6).

For the purposes of this Standard, the threshold of hearing that corresponds to the 1-percentile distribution (essentially, the "lower limit" of the hearing threshold) is more suitable. This may be termed the lower threshold of hearing (LTH). The sound pressure level at frequency $f$ corresponding to this LTH is calculated, in decibels, from Formula (1):

$$P_1(f) = a_1 f'^4 + a_2 f'^3 + a_3 f'^2 + a_4 f' + a_5 \tag{1}$$

where

| | |
|---|---|
| $P_1(f)$ | is the sound pressure level that corresponds to the LTH at the tone frequency $f$; |
| $a_1$ to $a_5$ | are the polynomial coefficients given in Table 1; |
| $f' = \frac{f - f_\mathrm{mean}}{f_\mathrm{std}}$ | is the non-dimensional parameter calculated from the values in Table 1; |
| $f_\mathrm{mean}$ | is a frequency parameter given in Table 1 for the frequency range in which $f$ is located; |

$f_{\text{std}}$ is another frequency parameter given in Table 1 for the frequency range in which $f$ is located.

**Table 1 — Parameters for calculation of $P_1(f)$**

| $f$ Hz | $f_{\text{mean}}$ Hz | $f_{\text{std}}$ Hz | $a_1$ dB | $a_2$ dB | $a_3$ dB | $a_4$ dB | $a_5$ dB |
|---|---|---|---|---|---|---|---|
| $20 \leq f < 305$ | 167,5 | 87,3212 | 1,415532 | -2,451068 | 1,498869 | -6,983224 | 8,621226 |
| $20 \leq f < 305$<br>$305 \leq f < 2\,230$ | 1157,5 | 488,582 | 0,397994 | -0,891839 | -0,815138 | -1,221319 | -7,600754 |
| $305 \leq f < 2230$<br>$2\,230 \leq f < 14\,000$ | 7250,0 | 3033,25 | 1,584978 | -2,766599 | -6,906192 | 10,138553 | -3,149339 |
| $2\,230 \leq f < 14\,000$<br>$14\,000 \leq f < 20\,050$<br>$14\,000 \leq f < 22\,050$ | 16990,0 | 4049,0 | -5,775593 | -9,200034 | 26,59115 | 52,16712 | 15,61552048 |

NOTE The sound pressure level $P_1(f)$ defined in Formula (1) represents the threshold of hearing that only 1 % of individuals, having normal hearing (*ontologically normal person*, see 4.2.7) would be expected to hear. Formula (1) represents a 4th-order polynomial fit to data collected and tabulated in ISO 28961[4] to estimate the LTH at a given frequency for the purposes of this Standard. To improve the fit over a wide frequency range, four different polynomials are used to cover the range of frequencies between 20 Hz to 22 kHz (Reference [16]).

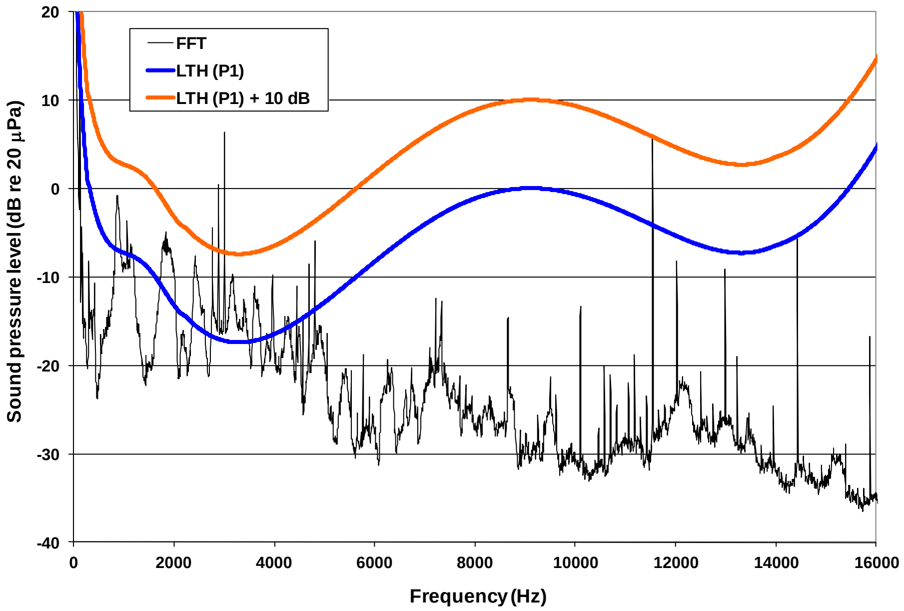

**Figure 1 — Lower threshold of hearing, $P_1(f)$ curve and $P_1(f)$ + 10 dB curve illustrated for the analysis of low-level discrete tones**

## 9.2 Normalization of noise near threshold of hearing

For low level sound, the sound pressure level of one or more data points in the FFT spectrum may fall below the LTH, as defined by Formula (1). If calculations are performed using the as-measured sound pressure levels, very high values of tone-to-noise ratio or prominence ratio can be obtained, which sometimes does not correspond to subjective impressions of the sound. If, however, the sound pressure level at each data point is adjusted to be equal to the value of the LTH, the total sound pressure level in each critical band can be overstated, leading to unrealistically low values of tone-to-noise ratio or prominence ratio. For such low level sounds, a normalization of the FFT spectrum is required so that the masking noise level (for tone-to-noise ratio) or the total levels in the lower, middle, and upper critical bands (for prominence ratio) reflects the correct psychoacoustic value. The threshold of hearing based on one-third octave bands of white or pink noise can be more appropriate for this normalization, rather than the LTH defined above, which is based on pure tones.

NOTE At the time of publication of this Standard, such a normalization procedure is not standardized yet.

# 10 Critical bandwidths

The width of the critical band $\Delta f_\mathrm{c}$, centred at any frequency $f_0$, in hertz, can be calculated from Formula (2):

$$\Delta f_\mathrm{c} = 25{,}0 + 75{,}0 \times [1{,}0 + 1{,}4 \times (f_0/1000)^2]^{0{,}69}. \qquad (2)$$

EXAMPLE $\Delta f_\mathrm{c}$ = 162,2 Hz for $f_0$ = 1 000 Hz and $\Delta f_\mathrm{c}$ = 117,3 Hz for $f_0$ = 500 Hz. See Reference [17].

For the purposes of this document, the critical band is modelled as an ideal rectangular filter with centre frequency $f_0$, lower band-edge frequency $f_1$ and upper band-edge frequency $f_2$, in decibels, where

$$f_2 - f_1 = \Delta f_\mathrm{c}. \qquad (3)$$

For 89,1 Hz ≤ $f_0$ < 500 Hz, the critical band approximates a constant-bandwidth filter, and the band-edge frequencies are computed as per Formulae (4) and (5):

$$f_1 = f_0 - \Delta f_\mathrm{c}/2 \qquad (4)$$

and

$$f_2 = f_0 + \Delta f_\mathrm{c}/2. \qquad (5)$$

For $500\ \mathrm{Hz} < f_0 \leq 11\ 200\ \mathrm{Hz}$, the critical band approximates a constant-percentage bandwidth filter, where

$$f_0 = \sqrt{f_1 f_2} \qquad (6)$$

and the band-edge frequencies, in hertz, are computed from Formulae (3) and (6) as follows:

$$f_1 = -\frac{\Delta f_\mathrm{c}}{2} + \frac{\sqrt{(\Delta f_\mathrm{c})^2 + 4{f_0}^2}}{2} \qquad (7)$$

and

$$f_2 = f_1 + \Delta f_\mathrm{c}. \qquad (8)$$

NOTE Although Formula (2) for the width of the critical band is well-known and widely used, formulae for the corresponding band-edge frequencies have not been formally derived. Given the behaviour of the critical band below and above 500 Hz, however, the assignment of the band-edge frequencies in accordance with the above Formulae (7) and (8) seems to be logical. That is, for constant-bandwidth filters, the lower and upper band-edge frequencies are arithmetically related to the centre frequency, whereas for constant-percentage bandwidth filters, they are geometrically related. The formulae have small band-edge frequency discontinuities near 500 Hz, which have negligible effect on TNR.

For the purposes of determining the tone-to-noise ratio of the *discrete tone frequency range of interest* (see NOTE 1 of 4.1.2), the procedure of this document permits using FFT data $f_1 < 89{,}1\ \mathrm{Hz}$ and $f_2 > 11\ 200\ \mathrm{Hz}$.

# 11 Tone-to-noise ratio method

## 11.1 Measurement using FFT analyser

This clause describes the procedures of determining tone-to-noise ratio using FFT analysis.

The operating procedures for the FFT analyser shall be followed to acquire the PSD (power spectral density) of the sound pressure signal at the measurement position (see Clause 6), for the same mode(s) of operation and measurement conditions as used for the measurements in ECMA-74:2022, 8.7, employing the Hanning time window and RMS averaging (linear averaging). No frequency weighting, such as A-weighting, shall be applied to the signal before forming its FFT spectrum. The FFT analysis shall use a sufficient number of averages to provide an analysis time satisfying the requirements of ECMA-74:2022, 8.7.2. Zoom analysis should be used, with the centre frequency of the zoom band corresponding, approximately, to the frequency of the discrete tone, and the width of the zoom band at least equal to, and preferably slightly greater than, the width of the critical band.

The power spectral density of a signal is usually calculated and displayed as a mean-square value per cycle of some quantity (e.g. a mean-square voltage per cycle, in volts squared per hertz, or a mean-square sound pressure per cycle, $X$, in pascals squared per hertz, versus frequency). To indicate that any quantity can be used, the symbol that has been chosen is “$X$”.

For the purposes of determining the tone-to-noise ratio, $\Delta L_{\mathrm{T}}$, the units of the measured power spectral density are not important, and absolute calibration of the analyser to some reference value (such as 1 V or 20 μPa) is unnecessary. However, calibration of the instrument in pascals squared enables sound pressure level quantities to be readily obtained.

The procedures in this clause assume this calibration and the text is written in terms of the sound pressure level, $L$.

For the application of “mean-square sound pressure” Annex A states alternative procedures to this clause.

From view point of conformity (see Clause 2), both procedures of Clause 10 and Annex A have equal footing.

## 11.2 Determination of discrete tone level

The sound pressure level of the discrete tone is determined from the FFT spectrum measured as in 11.1 by first identifying the tone band that “defines” the tone and then computing the associated discrete tone level $L_{\mathrm{t}}$. The width $\Delta f_t$ of the tone band in hertz equals the number of discrete data points (“the number of spectral lines”) in the band times the frequency resolution (“line spacing”) of the FFT. If the tone band is wider than 15 % of the critical bandwidth$\Delta f_{\mathrm{c}}$ of the critical bandwidth centred on the tone peak frequency $f_0$, FFT analysis should be repeated with finer frequency resolution. A tone band remaining wider than 15 % of the critical bandwidth through iterative FFT analysis may indicate a tone of time-varying frequency or another phenomenon. The lower and upper limits of the tone band shall be defined as the minimal points on both sides of the tone peak frequency that are within 15% of the critical band, as shown in Figure 2, with corresponding sound pressure levels $l_1$ and $l_2$ [24]. If either of the minimal points is on the edge of the 15% critical band, the nearest local minimal point beyond the 15% critical band edge shall be searched and used as the corresponding edge point of $\Delta f_t$ .

The discrete tone sound pressure level, $L_t$ is determined from the FFT spectrum by calculating the sound pressure level above the line connecting between the two limits of the tone band, $\Delta f_t$, using Formula (9):

$$L_t = 10lg\left[10^{0,1L_t'} - \left(10^{0,1l_1} + 10^{0,1l_2}\right)\frac{N}{2}\right] \tag{9}$$

where, $N$ and $L_{\mathrm{t}}'$ are the number of frequency points and total sound pressure level within the tone band width $\Delta f_{\mathrm{t}}$ .

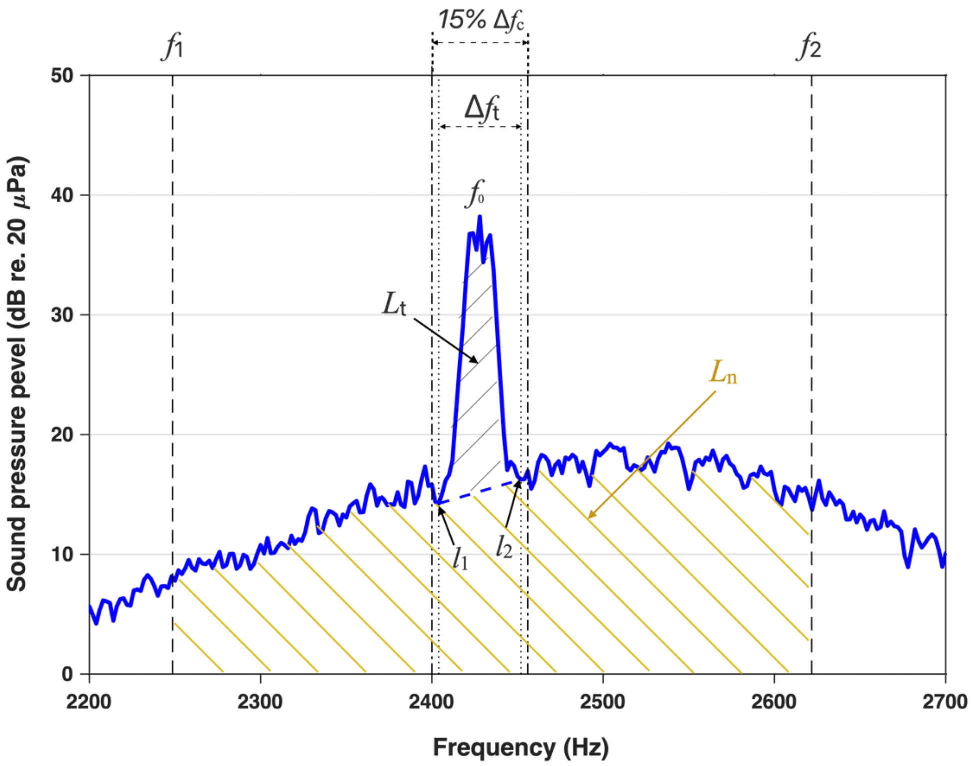

**Figure 2 — Discrete tone level $L_t$ determination from the FFT spectrum**

For the determination of the sound pressure level of the discrete tone for multiple tones in a single critical band, see 11.6.

**CAUTION** — If the tone band is wider than 15% of the critical bandwidth, the tone-to-noise ratio method may not accurately describe perception of the tone in question due to inclusion of secondary tones or masking noise in the tone band. For this reason, the prominence ratio method in Clause 12 should be used along with the TNR method.

## 11.3 Determination of masking noise level

For the purposes of this document, the sound pressure level of the masking noise, $L_n$ is taken as the value determined using the following two-step procedure.

The first step is to compute the total sound pressure level in the critical band. The critical bandwidth $\Delta f_c$ is determined from Formula **Error! Reference source not found.Error! Reference source not found.** with $f_0$ set equal to the frequency of the discrete tone under investigation, $f_t$, and with lower band-edge frequency $f_1$ and upper band-edge frequency $f_2$ as given in either Formulae (4) and (5) or Formulae (7) and (8).

The second step is to compute the total critical band sound pressure level $L_{\text{tot}}$ from the FFT spectrum band contributing to the critical band between $f_1$ and $f_2$. This is accomplished using band cursors, appropriate software, or other means. The spectrum bandwidth $\Delta f_{\text{tot}}$ used to compute $L_{\text{tot}}$. is equal to the number of discrete FFT data points within the critical band times the FFT frequency resolution. The masking noise $L_n$ in decibels is given by Formula (10):

$$L_n = 10\lg(10^{0,1L_{\text{tot}}} - 10^{0,1L_t}) + 10\lg\left(\frac{\Delta f_c}{\Delta f_{\text{tot}}}\right) \qquad (10)$$

For the determination of the sound pressure level of the masking noise for multiple tones in a critical band, see 11.6.

NOTE Formula (10) accounts for the fact that the FFT spectrum bandwidth, $\Delta f_{\text{tot}}$, used to compute $L_{\text{tot}}$, generally differs from the critical bandwidth, $\Delta f_{\text{c}}$.

### 11.4 Determination of the tone-to-noise ratio

The tone-to-noise ratio, $\Delta L_{\text{T}}$, in decibels, is calculated from Formula (11):

$$\Delta L_{\text{T}} = L_t - L_n \tag{11}$$

For the determination of the tone-to-noise ratio for multiple tones in a critical band, see 11.6.

### 11.5 Prominent discrete tones criteria for tone-to-noise ratio method

A discrete tone is classified as *prominent* in accordance with the tone-to-noise ratio method if one of the following conditions is met:

$$\Delta L_{\text{T}} \geq 8{,}0 + 8{,}33 \times \lg\left(\frac{1000}{f_{\text{t}}}\right) \text{ for } 89{,}1 \text{ Hz} \leq f_{\text{t}} < 1\,000 \text{ Hz} \tag{12}$$

or

$$\Delta L_{\text{T}} \geq 8{,}0 \text{ for } 11\,200 \text{ Hz} > f_{\text{t}} \geq 1\,000 \text{ Hz} \tag{13}$$

and the discrete tone meets the audibility requirement of 11.8. The criteria in Formulae (12) and (13) are illustrated graphically in Figure 6 (see Clause 13).

### 11.6 Multiple tones in a critical band

The noise emitted by a machine can contain multiple tones, and several of these can fall within a single critical band. If one or more discrete tones are audible, the procedure above is followed for each tone, with the following differences. The discrete tone with the highest amplitude in the critical band is identified as the primary tone, and its frequency is denoted as $f_{\text{p}}$. For the critical band centred on this primary tone, the discrete tone with the second highest level is identified as the secondary tone and its frequency denoted as $f_{\text{s}}$.

If the secondary tone is sufficiently close in frequency to the primary tone, then the two are considered to be perceived as a single discrete tone and the prominence is determined by combining their sound pressure levels. Two discrete tones may be considered sufficiently close or “proximate” if their spacing $\Delta f_{\text{s,p}} = \left|\Delta f_{\text{s}} - \Delta f_{\text{p}}\right|$ is less than the proximity spacing, $\Delta f_{\text{prox}}$, in hertz, defined Formula (14):

$$\Delta f_{\text{prox}} = 21 \times 10^{1{,}2\times[|\lg(f_{\text{p}}/212)|]^{1{,}8}} \text{ for } 89{,}1 \text{ Hz} \leq f_{\text{p}} < 1\,000 \text{ Hz} \tag{14}$$

EXAMPLE $\Delta f_{\text{prox}} = 23 \text{ Hz}$ for $f_{\text{p}} = 150 \text{ Hz}$; $\Delta f_{\text{prox}} = 63{,}8 \text{ Hz}$ for $f_{\text{p}} = 850 \text{ Hz}$).

If the proximity criterion $\Delta f_{\text{s,p}} < \Delta f_{\text{prox}}$ is met, then the sound pressure level of the secondary tone, $L_{t,s}$, is combined on an energy basis with the sound pressure level of the primary tone, $L_{t,p}$, and subtracted on an energy basis from the total sound pressure level of the noise, $L_{\text{tot}}$. For discrete tone frequencies equal to or higher than 1 000 Hz, the proximity spacing, $\Delta f_{\text{prox}}$ exceeds half the width of the critical band, so the criterion is always met. See Reference [18]. This is represented by Formulae (15) and (16):

$$L_t = 10\lg(10^{0{,}1L_{t,p}} + 10^{0{,}1L_{t,s}}) \tag{15}$$

and

$$L_{\text{n}} = 10\lg[10^{0{,}1L_{\text{tot}}} - (10^{0{,}1L_{t,p}} + 10^{0{,}1L_{t,s}})] + 10\lg\left(\frac{\Delta f_{\text{c}}}{\Delta f_{\text{tot}}}\right) \tag{16}$$

With the above values for $L_n$ and $L_t$, Formula (11) is used to compute the tone-to-noise ratio.

NOTE The proximity spacing $\Delta f_{\text{prox}}$ has a small discontinuity near 1 000 Hz because critical band limits are linearly related to centre frequency below 1 000 Hz and geometrically related to centre frequency above 1 000 Hz. The discontinuity has been observed to have no practical effect on TNR calculation.

If the proximity criterion is not met, then the discrete tones are considered to be perceived as separate discrete tones and are treated individually. In this case, the sound pressure level of the secondary tone is still subtracted on an energy basis from the sound pressure level of the noise, but it is not added to the sound pressure level of the primary tone, before calculating the tone-to-noise ratio of the primary tone. In this case, Formula (16) is again used for $L_n$, but Formula (15) simply becomes $L_{\text{t}} = 10\lg\left(10^{0,1\Delta L_{t,p}}\right)$, in decibels of $L_n$ and $L_t$ are then used in Formula (11) to compute the tone-to-noise ratio for the primary tone.

When the proximity criterion is not met and it is desired to compute the tone-to-noise ratio for the secondary tone individually, then the above procedure may be repeated with the secondary tone considered as the primary tone. The critical band is then centred on this discrete tone, with all quantities being recomputed.

## 11.7 Complex tones containing harmonic components (tone-to-noise ratio method)

Although laboratory-generated discrete tones can be pure sinusoids, most of the discrete tones that occur in the noise emissions from real machinery and equipment are not. As such, the FFT spectrum generally shows a series of tonal components (called harmonics, or partials) at integral multiples of some fundamental frequency. Usually the fundamental is the strongest component, but this is not always the case. For the purposes of this document, each tonal component in the harmonic series shall be screened for audibility in accordance with Clause 8 and, depending on the outcome, evaluated independently in accordance with the procedures of this document. Alternatively, since presumably the presence of harmonics has already been determined from inspecting an FFT spectrum of the noise emissions, the procedures of this document may be applied to each tonal component without the initial audibility screening. In this case, any tonal component that meets the prominence criteria of 11.5 shall also meet the audibility requirements of 11.8 before it can be classified as *prominent*.

NOTE For the cases of noise emissions from small fans consisting of many harmonic components and other discrete tones, a new evaluation parameter, Total Tone-To-Noise Ratio which is based on tone-to-noise ratio, is under development. See ECMA TR/108[2] and References [19], [20] and [21].

## 11.8 Audibility requirements

A discrete tone shall not be classified as *prominent* if it is not, in fact, *audible*. Therefore, for each discrete tone identified as *prominent* in 11.5, an aural examination of the noise emitted from the equipment under test shall be made at the microphone position, or positions, used for the analysis. If the discrete tone is audible in the noise emissions, then it shall be reported as *prominent*, as determined. If the discrete tone is clearly not audible in the noise emissions, and there is a high degree of confidence in this conclusion, then it shall not be reported as *prominent*. If there is any doubt as to whether or not a discrete tone is audible in the noise emissions (e.g. if the test engineer has a hearing loss or is not a trained or experienced listener), then the following listening test shall be conducted to help make determination whether or not the tone is audible.

A sinusoidal signal corresponding to the frequency of the discrete tone in question shall be reproduced audibly and compared by the listener to the noise from the product, noting whether or not a tone at the same frequency is audible in the product noise emissions. If the discrete tone is audible in the noise emissions, then it shall be reported as *prominent*, as determined. If the discrete tone is not audible in the noise emissions even with the help of the comparison tone, then it shall not be reported as *prominent*.

## 11.9 Example (tone-to-noise ratio method)

Figure 3 shows how a single discrete tone in a critical band is analysed using the tone-to-noise ratio method. Figure 4 shows how the tone-to-noise ratio method is used when multiple tones exist in a critical band.

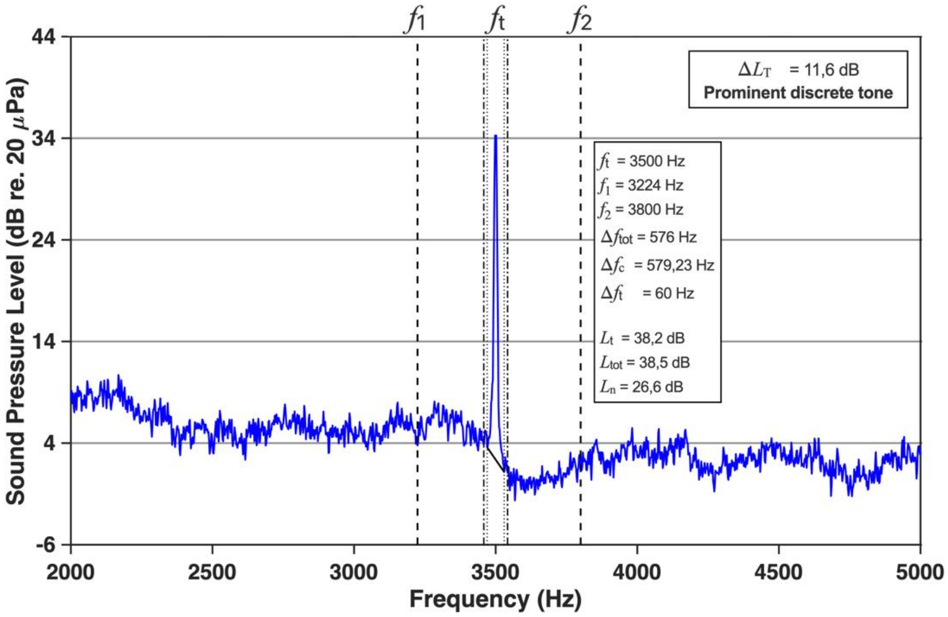

**Figure 3 — Tone-to-noise ratio method applied to a single tone in a critical band**

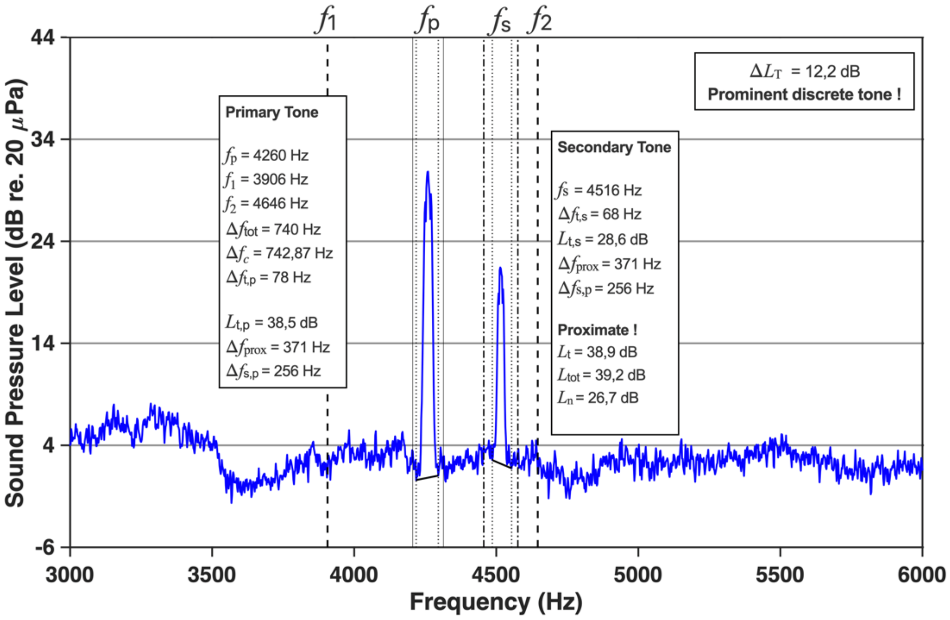

**Figure 4 — Tone-to-noise ratio method applied to multiple tones in a critical band**

## 12 Prominence ratio method

### 12.1 Measurement using FFT analyser

This clause specifies the detail procedures of determining prominence ratio, based on measurement using FFT analyser.

The operating procedures for the FFT analyser shall be followed to acquire the PSD (power spectral density) of the sound pressure signal at the measurement position (see Clause 6), for the same mode(s) of operation and measurement conditions as used for the measurements in ECMA-74:2022, 8.7, employing the Hanning time window and RMS averaging (linear averaging). No frequency weighting, such as A-weighting, shall be applied to the signal fed to the FFT analyser. The FFT analysis shall use a sufficient number of averages to provide an analysis time satisfying the requirements of ECMA-74:2022, 8.7.2. Zoom analysis should be used with the centre frequency of the zoom band corresponding, approximately, to the frequency of the discrete tone, and the width of the zoom band equal to about four times the width of the critical band.

The power spectral density of a signal is usually calculated and displayed as a mean-square value per cycle of some quantity (e.g. a mean-square voltage per cycle, in volts squared per hertz, or a mean-square sound pressure per cycle, in pascals squared per hertz, versus frequency). To indicate that any quantity can be used, the symbol that has been chosen is “$X$”.

For the purposes of determining the prominence ratio, $\Delta L_\mathrm{P}$, the units of the measured power spectral density are not important, and absolute calibration of the analyser to some reference values (such as 1 V or 20 μPa) is unnecessary. However, calibration of the instrument in pascals squared per hertz enables sound pressure level quantities to be readily obtained.

The procedures in this clause assume this calibration and the text is written in terms of the sound pressure level, $L$.

For the application of “mean-square sound pressure, $X$” Annex B states alternative procedures to this clause.

From viewpoint of conformity (see Clause 2), both procedures of Clause 12 and Annex B have equal footing.

## 12.2 Determination of the level of the middle critical band

The sound pressure level of the middle critical band, $L_\mathrm{M}$, is defined as the total sound pressure level contained in the critical band centred on the discrete tone under investigation. The width of the middle critical band, $\Delta f_\mathrm{M}$, as well as the lower and upper band-edge frequencies, $f_{1,\mathrm{M}}$ and $f_{2,\mathrm{M}}$ are determined from the relationships in Clause 10 with $f_0$ set equal to the frequency of the discrete tone under investigation, $f_t$. The band-edge frequencies then become:

For $f \leq 500\ \mathrm{Hz}$:

$$f_{1,\mathrm{M}} = f_t - \frac{\Delta f_\mathrm{M}}{2} \tag{17}$$

and

$$f_{2,\mathrm{M}} = f_t + \frac{\Delta f_\mathrm{M}}{2} \tag{18}$$

For $f > 500\ \mathrm{Hz}$:

$$f_{1,\mathrm{M}} = -\frac{\Delta f_\mathrm{M}}{2} + \frac{\sqrt{(\Delta f_\mathrm{M})^2 + 4 f_t^2}}{2} \tag{19}$$

and

$$f_{2,\mathrm{M}} = f_{1,\mathrm{M}} + \Delta f_\mathrm{M} \tag{20}$$

EXAMPLE $f_{1,\mathrm{M}} = 922{,}2\ \mathrm{Hz}$ and $f_{2,\mathrm{M}} = 1084{,}4\ \mathrm{Hz}$ when $f_t = 1\ 000\ \mathrm{Hz}$.

The value of $L_\mathrm{M}$ is determined from the FFT spectrum by bracketing the data points lying between $f_{1,\mathrm{M}}$ and $f_{2,\mathrm{M}}$ and computing the sound pressure level of the middle critical band. Depending on the particular instrumentation used, this may be performed on the FFT analyser itself using band cursors, on an external computer using appropriate software, or by some other means.

## 12.3 Determination of the level of the lower critical band

The sound pressure level of the lower critical band, $L_\mathrm{L}$, is defined as the total sound pressure level contained in the critical band immediately below, and contiguous with, the middle critical band defined in 12.2 The relationships in Clause 10 govern this lower critical band, with centre frequency $f_{0,\mathrm{L}}$, bandwidth $\Delta f_\mathrm{L}$, and lower and upper band-edge frequencies $f_{1,\mathrm{L}}$ and $f_{2,\mathrm{L}}$, respectively. Since this lower critical band shall be contiguous with the middle critical band, it follows that $f_{2,\mathrm{L}} = f_{1,\mathrm{M}}$. However, because $f_{0,\mathrm{L}}$ is not known *a priori*, Formulae (2) to (8) cannot be used directly to determine the value of $f_{1,\mathrm{L}}$, and an iterative method of solution would ordinarily have to be used. For the purposes of this document, the value of $f_{1,\mathrm{L}}$ shall be computed from Formula (21) (which has been derived from an iterative solution through the use of curve fitting).

$$f_{1,\mathrm{L}} = C_{\mathrm{L},0} + C_{\mathrm{L},0} f_t + C_{\mathrm{L},2} f_t^2 \tag{21}$$

where

| | |
|---|---|
| $f_t$ | is the frequency of discrete tone under investigation; |
| $C_{\mathrm{L},0}, C_{\mathrm{L},1}, C_{\mathrm{L},2}$ | are constants given in Table 2. |

**Table 2 — Parameters for calculation of $f_{1,L}$**

| Frequency range Hz | $C_{\mathrm{L},0}$ Hz | $C_{\mathrm{L},1}$ | $C_{\mathrm{L},2}$ Hz$^{-1}$ |
|---|---|---|---|
| $89{,}1 \leq f_t \leq 171{,}4$ | 20,0 | 0,0 | 0,0 |
| $171{,}4 \leq f_t \leq 1\,600$ | -149,5 | 1,001 | -6,90×10$^{-5}$ |
| $11\,200 \geq f_t > 1\,600$ | 6,8 | 0,806 | -8,20×10$^{-6}$ |

For discrete tone frequencies less than or equal to 171,4 Hz, the lower band-edge frequency for the lower critical band would compute to less than 20 Hz, the accepted lower limit of human hearing. For such cases, the lower band-edge frequency shall be set equal to 20 Hz (so that the band used for the determination of $X_{\mathrm{L}}$ extends from 20 Hz up to $f_{2,\mathrm{L}}$). The width of this lower band, $\Delta f_{\mathrm{L}}$, is now less than the width of the true critical band, and the determination of the prominence ratio takes this into account (see 12.5).

The value of $L_{\mathrm{L}}$ is determined from the FFT spectrum by bracketing the data points lying between $f_{1,\mathrm{L}}$ and $f_{2,L}$ and computing the sound pressure level of the lower critical band. Depending on the particular instrumentation used, this may be performed on the FFT analyser itself using band cursors, on an external computer using appropriate software or by some other means. Care should be taken to ensure that the lower critical band and the middle critical band do not overlap computationally; i.e., that the FFT data points closest to the common band edge are assigned uniquely to one band or the other, and not to both.

For the purposes of determining prominence ratio of the *discrete tone frequency range of interest* (see NOTE 1 of 4.1.2), the procedure of this document permits using FFT data, $f_{1,\mathrm{L}} < 89{,}1\ \mathrm{Hz}$ and $f_{2,\mathrm{U}} > 11\,200\ \mathrm{Hz}$.

## 12.4 Determination of the level of the upper critical band

The sound pressure level of the upper critical band, $L_{\mathrm{U}}$, is defined as the total sound pressure level contained in the critical band immediately above, and contiguous with, the middle critical band defined in 12.2. The relationships in Clause 10 govern this upper critical band, with centre frequency $f_{0,\mathrm{U}}$, bandwidth $\Delta f_{\mathrm{U}}$, and lower and upper band-edge frequencies $f_{1,\mathrm{U}}$ and $f_{2,\mathrm{U}}$, respectively. Since this upper critical band shall be contiguous with the middle critical band, it follows that $f_{1,\mathrm{U}} = f_{2,\mathrm{M}}$. However, because $f_{0,\mathrm{U}}$ is not known *a priori*, Formulae (2) to (8) cannot be used directly to determine the value of $f_{2,\mathrm{U}}$, and an iterative method of solution would ordinarily have to be used. For the purposes of this document, the value of $f_{2,\mathrm{U}}$ shall be computed from Formula (21) (which has been derived from an iterative solution through the use of curve fitting).

$$f_{2,\mathrm{U}} = C_{\mathrm{U},0} + C_{\mathrm{U},1} f_t + C_{\mathrm{U},2} f_t^2 \tag{22}$$

where

| | |
|---|---|
| $f_t$ | is the frequency of discrete tone under investigation; |

$C_{\mathrm{U},0}$, $C_{\mathrm{U},1}$, $C_{\mathrm{U},2}$ are constants given in Table 3.

**Table 3 — Parameters for calculation of $f_{2,\mathrm{U}}$**

| Frequency range<br>Hz | $C_{\mathrm{U},0}$<br>Hz | $C_{\mathrm{U},1}$ | $C_{\mathrm{U},2}$<br>Hz$^{-1}$ |
|---|---|---|---|
| $89{,}1 \leq f_t \leq 1\,600$ | 149,5 | 1,035 | $7{,}70 \times 10^{-5}$ |
| $11\,200 \geq f_t > 1\,600$ | 3,3 | 1,215 | $2{,}16 \times 10^{-5}$ |

The value of $L_{\mathrm{U}}$ is determined from the FFT spectrum by bracketing the data points lying between $f_{1,\mathrm{U}}$ and $f_{2,\mathrm{U}}$ and computing the sound pressure level of the upper critical band. Depending on the particular instrumentation used, this may be performed on the FFT analyser itself using band cursors, on an external computer using appropriate software, or by some other means. Care should be taken to ensure that the upper critical band and the middle critical band do not overlap computationally; i.e., that the FFT data point(s) closest to the common band edge is (are) assigned uniquely to one band or the other, and not to both.

For the purposes of determining prominence ratio of the *discrete tone frequency range of interest* (see NOTE 1 of 4.1.2), the procedure of this document permits using FFT data, $f_{2,\mathrm{U}} > 11\,200\ \mathrm{Hz}$.

## 12.5 Determination of prominence ratio

The prominence ratio, $\Delta L_{\mathrm{P}}$ in decibels, is calculated as follows (for discrete tone frequencies greater than 171,4 Hz):

$$\Delta L_P = 10\lg(10^{0,1L_M}) - 10\lg[(10^{0,1L_L} + 10^{0,1L_U}) \times 0{,}5] \ \text{ for } f_t \leq 171{,}4\ \mathrm{Hz} \quad (23)$$

For discrete tone frequencies less than or equal to 171,4 Hz, the lower critical band becomes truncated (see 12.4) so that its width is less than what would be calculated from Formula (2). Therefore, for the purposes of computing the prominence ratio for discrete tone frequencies less than or equal to 171,4 Hz, the level in the lower band is to a bandwidth of 100 Hz (the width of a full critical band at these frequencies), so that the above formulae are modified as follows.

$$\Delta L_{\mathrm{P}} = 10\lg(10^{0,1L_{\mathrm{M}}}) - 10\lg\left[\left(\frac{100}{\Delta f_{\mathrm{L}}} \times 10^{0,1L_{\mathrm{L}}} + 10^{0,1L_{\mathrm{U}}}\right) \times 0{,}5\right] \ \text{ for } f_t \leq 171{,}4\ \mathrm{Hz} \quad (24)$$

## 12.6 Prominent discrete tone criterion for prominence ratio method

A discrete tone is classified as *prominent* in accordance with the prominence ratio method if:

$$\Delta L_{\mathrm{P}} \geq 9{,}0 + 10\lg\left(\frac{1\,000}{f_t}\right) \ \text{ for } 89{,}1\ \mathrm{Hz} \leq f_t < 1\,000\ \mathrm{Hz} \quad (25)$$

$$\Delta L_{\mathrm{P}} \geq 9{,}0 \text{ for } 11\,200\ \mathrm{Hz} > f_t \geq 1\,000\ \mathrm{Hz} \quad (26)$$

and the discrete tone meets the audibility requirement of 12.8. The criteria in Formulae (25) and (26) are illustrated graphically in Figure 6 (see Clause 13).

## 12.7 Complex tones containing harmonic components (prominence ratio method)

Although laboratory-generated discrete tones can be pure sinusoids, most of the discrete tones that occur in the noise emissions from real machinery and equipment are not. As such, the FFT spectrum will generally show a series of tonal components (called harmonics, or partials) at integral multiples of some fundamental frequency. Usually the fundamental is the strongest component, but this is not always the case. For the purposes of this document, each tonal component in the harmonic series shall be screened for audibility in accordance with 8.1

and, depending on the outcome, evaluated independently in accordance with the procedures of this document. Alternatively, since presumably the presence of harmonics has already been determined from inspecting an FFT spectrum of the noise emissions, the procedures of this document may be applied to each tonal component without the initial audibility screening. In this case, any tonal component that meets the prominence criteria of 12.6 shall also meet the audibility requirements of 12.8 before it can be classified as *prominent*.

NOTE For the cases of noise emissions from small fans, consisting of many harmonic components and other discrete tones, a new evaluation parameter, Total Prominence Ratio which is based on prominence ratio, is under development. See ECMA TR/108 [2] and References [19], [20] and [21].

## 12.8 Audibility requirements

A discrete tone shall not be classified as *prominent* if it is not, in fact, *audible*. Therefore, for each discrete tone identified as *prominent* in 12.6, an aural examination of the noise emitted from the equipment under test shall be made at the microphone position, or positions, used for the analysis (see Clause 6). If the discrete tone is audible in the noise emissions, then it shall be reported as *prominent*, as determined. If the discrete tone is clearly not audible in the noise emissions, and there is a high degree of confidence in this conclusion, then it shall not be reported as *prominent*. If there is any doubt as to whether or not a discrete tone is audible in the noise emissions (e.g. if the test engineer has a hearing loss or is not a trained or experienced listener), then the following listening test shall be conducted to help make determination whether or not the tone is audible.

A sinusoidal signal corresponding to the frequency of the discrete tone in question shall be reproduced audibly, and compared by the listener to the noise from the product, noting whether or not a tone at the same frequency is audible in the product noise emissions. If the discrete tone is now audible in the noise emissions, then it shall be reported as *prominent*, as determined. If the discrete tone is not audible in the noise emissions even with the help of the comparison tone, then it shall not be reported as *prominent*.

## 12.9 Example (prominence ratio method)

The prominence ratio method is illustrated graphically in Figure 5. The prominence ratio was calculated in accordance with 12.5 and was found to be $\Delta L_\mathrm{P} = 12{,}1\ \mathrm{dB}$ for the 1 600 Hz discrete tone. Because the result is more than 9,0 dB, which is the prominence ratio criterion at 1 600 Hz, the discrete tone is classified as *prominent*.

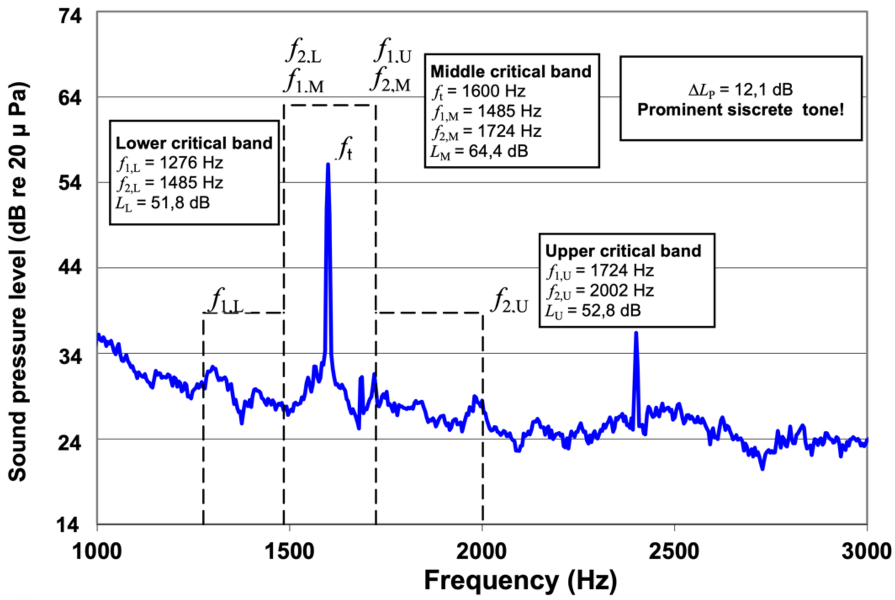

Figure 5 — Illustration of the prominence ratio method for prominent discrete tone identification

## 13 Information to be recorded for prominent discrete tones

For each discrete tone that has been identified as prominent in accordance with this Standard, the following information shall be recorded:

a) the frequency, $f_\mathrm{t}$, in hertz, of the discrete tone;

b) details of the method used to evaluate the discrete tone (Clause 11, tone-to-noise ratio or Clause 12, prominence ratio), together with a reference to this Standard, i.e., ECMA-418-1:2024;

c) if the tone-to-noise ratio method was used, the tone-to-noise ratio, $\Delta L_\mathrm{T}$, in decibels or if the prominence ratio procedure was used, the prominence ratio $\Delta L_\mathrm{P}$, in decibels;

d) if the noise emissions under investigation include more than one identified prominent discrete tone, the frequency of each tone, and either $\Delta L_\mathrm{T}$ *or* $\Delta L_\mathrm{P}$ for each tone.

NOTE 1 A discrete tone is classified as *prominent*, if both (i) $\Delta L_\mathrm{T}$ or $\Delta L_\mathrm{P}$ is above the relevant criterion curve and (ii) the discrete tone is audible according to the procedures of 11.8 or 12.8, respectively.

NOTE 2 It can be useful to record the A-weighted sound pressure level of the prominent discrete tone.

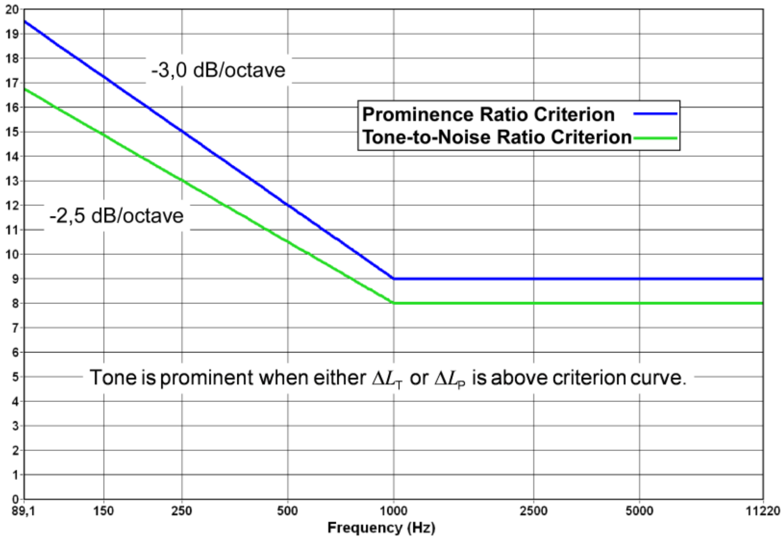

**Figure 6 — Criteria for prominence for both tone-to-noise ratio (11.6) and prominence ratio (12.7) as a function of frequency**

# Annex A
(normative)

# Tone-to-noise ratio calculation based on mean-square sound pressure data

## A.1 Measurement using FFT analyser

Clause 11 of this document specifies the detail procedures of determining tone-to-noise ratio, based on measurement using FFT analyser. In the procedures of Clause 11, the text is written in terms of the sound pressure level, $L$.

For users which are familiar with the application of “mean-square sound pressure”, Annex A states the alternative procedures, based on the measurement of mean-square sound pressure, $X$.

From view point of conformity, both procedures of Clause 11 and Annex A have equal footing.

The operating procedures for the FFT analyser shall be followed to acquire the power spectral density (PSD) of the sound pressure signal at the measurement position (see Clause 6), for the same mode(s) of operation and measurement conditions as used for the measurements in ECMA-74:2022, 8.7, employing the Hanning time window and RMS averaging (linear averaging). No frequency weighting, such as A-weighting, shall be applied to the signal fed to the FFT analyser. The FFT analysis shall use a sufficient number of averages to provide an analysis time satisfying the requirements of ECMA-74:2022, 8.7.2. Zoom analysis should be used, with the centre frequency of the zoom band corresponding, approximately, to the frequency of the discrete tone, and the width of the zoom band at least equal to, and preferably slightly greater than, the width of the critical band.

The power spectral density of a signal is usually calculated and displayed as a mean-square value per cycle of some quantity (e.g. a mean-square voltage per cycle, in volts squared per hertz, or a mean-square sound pressure per cycle, $X$, in pascals squared per hertz, versus frequency). To indicate that any quantity can be used, the symbol that has been chosen is “$X$”.

For the purposes of determining the tone-to-noise ratio, $\Delta L_{\mathrm{T}}$, the units of the measured power spectral density are not important, and absolute calibration of the analyser to some reference value (such as 1 V or 20 μPa) is unnecessary. However, calibration of the instrument in pascals squared enables sound pressure level quantities to be readily obtained.

## A.2 Determination of discrete tone level

The mean-square sound pressure of the discrete tone, $X_{\mathrm{t}}$ is determined from the FFT spectrum measured as in A.1 by first identifying the tone band that “defines” the tone and then computing the associated discrete tone mean-square sound pressure, $X_{\mathrm{t}}$. The width $\Delta f_{\mathrm{t}}$ of the tone band in hertz equals the number of discrete data points (“the number of spectral lines”) in the band times the frequency resolution (“line spacing”) of the FFT. If the tone band is wider than 15 % of the width $\Delta f_{\mathrm{c}}$ of the critical band centred on the tone peak frequency $f_0$, FFT analysis should be repeated with finer frequency resolution. A tone band remaining wider than 15 % of the critical bandwidth through iterative FFT analysis may indicate a tone of time-varying frequency or another phenomenon. The lower and upper end points of the tone band shall be defined as the minimal points on both sides of the tone peak frequency that are within 15% of the critical band, as shown in Figure A.1, with corresponding mean-square sound pressure $x_1$ and $x_2$ [24]. If either of the minimal points is on an edge of the 15% critical band, the nearest local minimal point beyond 15% critical band edge shall be searched and used as the corresponding edge point of $\Delta f_{\mathrm{t}}$.

The discrete tone mean-square sound pressure, $X_t$, is determined from the FFT spectrum by calculating the mean-square sound pressure above the line connecting between two end points $x_1$ and $x_2$ of the tone band $\Delta f_t$, using Formula (A.1):

$$X_t = X_t' - (x_1 + x_2)\frac{N}{2} \qquad \text{(A.1)}$$

where $N$ and $X_t'$ are the number of frequency points and total mean-square sound pressure within the tone band width $\Delta f_t$.

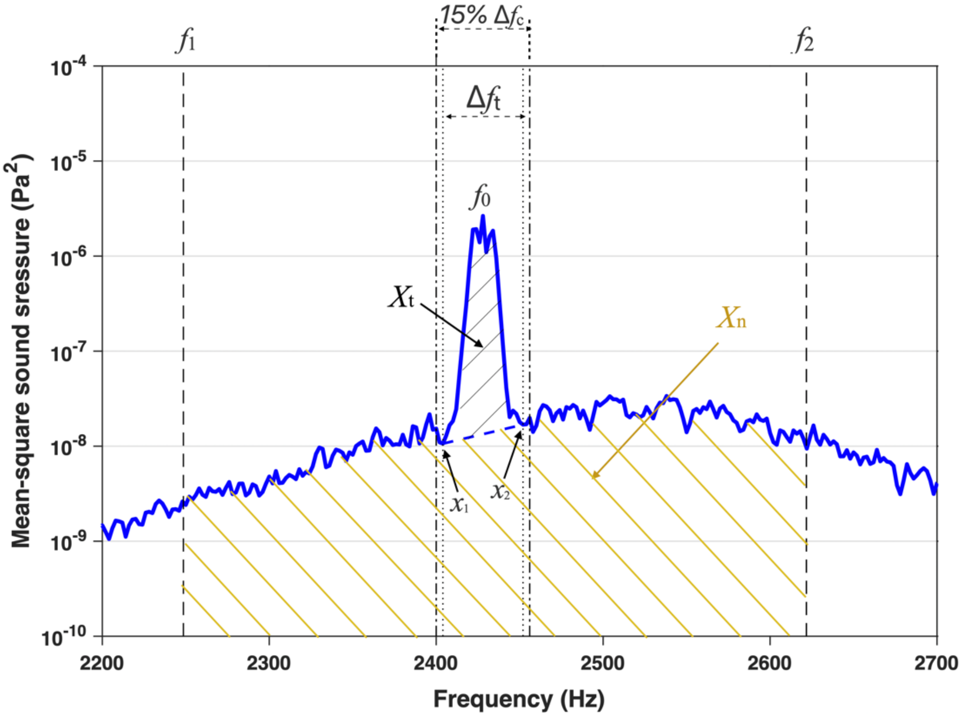

**Figure A.1 — Discrete tone mean-square sound pressure $X_t$ determination from the FFT spectrum**

For the determination of the mean-square sound pressure of the discrete tone for multiple tones in a single critical band, see A.6.

**CAUTION** — If the tone band is wider than 15% of the critical bandwidth, the tone-to-noise ratio method may not accurately describe perception of the tone in question due to inclusion of secondary tones or masking noise in the tone band. For this reason, the prominence ratio method in Annex B should be used along with the TNR method.

## A.3 Determination of masking noise level

For the purposes of this document, the mean-square sound pressure of the masking noise, $X_{\mathrm{n}}$, is taken as the value determined using the following two-step procedure.

The first step is to compute the total mean-square sound pressure in the critical band. The critical bandwidth $\Delta f_{\mathrm{c}}$ is determined from Formula (2) with $f_0$ set equal to the frequency of the discrete tone under investigation, $f_{\mathrm{t}}$, and with lower band-edge frequency $f_1$ and upper band-edge frequency $f_2$ as given in either Formulae (4) and (5) or Formulae (7) and (8).

The second step is to compute the total critical band mean-square sound pressure $X_{\mathrm{tot}}$, from the FFT spectrum band contributing to the critical band between $f_1$ and $f_2$. This is accomplished using band cursors, appropriate software, or other means. The spectrum bandwidth $\Delta f_{\mathrm{tot}}$ used to compute $X_{\mathrm{tot}}$ is equal to the number of discrete

FFT data points within the critical band times the FFT frequency resolution. The masking noise mean-square sound pressure $X_n$ is given by Formula (A.2):

$$X_n = (X_{tot} - X_t)\frac{\Delta f_c}{\Delta f_{tot}} \tag{A.2}$$

For the determination of the mean-square sound pressure of the masking noise for multiple tones in a critical band, see A.6.

NOTE Formula (A.2) accounts for both the fact that the FFT spectrum bandwidth, $\Delta f_{\mathrm{tot}}$, used to compute $X_{\mathrm{tot}}$, generally differs from the critical bandwidth, $\Delta f_{\mathrm{c}}$.

## A.4 Determination of the tone-to-noise ratio

The tone-to-noise ratio, $\Delta L_{\mathrm{T}}$, in decibels, is calculated from Formula (A.3):

$$\Delta L_T = 10\lg\left(\frac{X_t}{X_n}\right) \tag{A.3}$$

For the determination of the tone-to-noise ratio for multiple tones in a critical band, see A.6.

## A.5 Prominent discrete tones criteria for tone-to-noise ratio method

A discrete tone is classified as *prominent* in accordance with the tone-to-noise ratio method if one of the following conditions is met:

$$\Delta L_{\mathrm{T}} \geq 8{,}0 + 8{,}33 \times \lg\left(\frac{1000}{f_t}\right) \text{ for } 89{,}1\ \mathrm{Hz} \leq f_t < 1\,000\ \mathrm{Hz} \tag{A.4}$$

or

$$\Delta L_{\mathrm{T}} \geq 8{,}0 \text{ for } 11\,200\ \mathrm{Hz} > f_{\mathrm{t}} \geq 1\,000\ \mathrm{Hz} \tag{A.5}$$

and the discrete tone meets the audibility requirement of A.8. The criteria in Formula (A.4) and Formula (A.5) are illustrated graphically in Figure 6 (see Clause 13).

NOTE Formulae (A.3) and (A.4) are identical to Formulae (11) and (12), respectively.

## A.6 Multiple tones in a critical band

The noise emitted by a machine can contain multiple tones, and several of these can fall within a single critical band. If one or more discrete tones are audible, the procedure above is followed for each tone, with the following differences. The discrete tone with the highest amplitude in the critical band is identified as the primary tone, and its frequency is denoted as $f_{\mathrm{p}}$. For the critical band centred on this primary tone, the discrete tone with the second highest level is identified as the secondary tone and its frequency denoted as $f_{\mathrm{s}}$.

If the secondary tone is sufficiently close in frequency to the primary tone, then the two are considered to be perceived as a single discrete tone and the prominence is determined by combining their mean-square sound pressures. Two discrete tones may be considered sufficiently close or “proximate” if their spacing $\Delta f_{\mathrm{s,p}} = \left|\Delta f_{\mathrm{s}} - \Delta f_{\mathrm{p}}\right|$ is less than the proximity spacing, $\Delta f_{\mathrm{prox}}$, in hertz, defined Formula (A.3):

$$\Delta f_{\mathrm{prox}} = 21 \times 10^{1{,}2\times\left|\lg(f_{\mathrm{p}}/212)\right|^{1{,}8}} \text{ for } 89{,}1\ \mathrm{Hz} \leq f_{\mathrm{p}} < 1\,000\ \mathrm{Hz} \tag{A.6}$$

EXAMPLE $\Delta f_{\mathrm{prox}} = 23\ \mathrm{Hz}$ for $f_{\mathrm{p}} = 150\ \mathrm{Hz}$; $\Delta f_{\mathrm{prox}} = 63{,}8\ \mathrm{Hz}$ for $f_{\mathrm{p}} = 850\ \mathrm{Hz}$).

If the proximity criterion $\Delta f_{\mathrm{s,p}} < \Delta f_{\mathrm{prox}}$ is met, then the mean-square sound pressure of the secondary tone, $X_{\mathrm{t,s}}$, is added to the mean-square sound pressure of the primary tone, $X_{\mathrm{t,p}}$, when calculating the mean-square sound pressure of the discrete tone, $X_{\mathrm{t}}$, and subtracted from the total mean-square sound pressure, $X_{\mathrm{tot}}$, before calculating the tone-to-noise ratio $\Delta L_{\mathrm{T}}$.

For discrete tone frequencies equal to or higher than 1 000 Hz, the proximity spacing, $\Delta f_{\mathrm{prox}}$ exceeds half the width of the critical band, so the criterion is always met. See Reference [18]. This is represented by Formulae (A.7) and (A.8):

$$X_t = X_{t,p} - X_{t,s} \tag{A.7}$$

and

$$X_n = \left[X_{\mathrm{tot}} - \left(X_{t,p} - X_{t,s}\right)\right] \times \left(\frac{\Delta f_{\mathrm{c}}}{\Delta f_{\mathrm{tot}}}\right) \tag{A.8}$$

With the above values for $X_n$ and $X_t$, Formula (A.3) is used to compute the tone-to-noise ratio.

NOTE *The* proximity spacing $\Delta f_{prox}$ has *a small discontinuity near 1 000 Hz because critical band limits are linearly related to centre frequency below 1 000 Hz and geometrically related to centre frequency above 1 000 Hz*. The discontinuity has been observed to have no practical effect on TNR calculation.

If the proximity criterion is not met, then the discrete tones are considered to be perceived as separate discrete tones and are treated individually. In this case, the mean-square sound pressure of the secondary tone is still removed from the mean-square sound pressure of the masking noise (but otherwise ignored; i.e., not added to the mean-square value of the primary tone) before calculating the tone-to-noise ratio of the primary tone. In this case, Formula (A.8) is again used for $X_{\mathrm{n}}$, but Formula (A.7) simply becomes $X_{\mathrm{t}} = X_{\mathrm{t,p}}$. These values of$X_{\mathrm{n}}$ and$X_{\mathrm{t}}$ are then used in Formula (A.3) to compute the tone-to-noise ratio for the primary tone.

When the proximity criterion is not met and it is desired to compute the tone-to-noise ratio for the secondary tone individually, then the above procedure may be repeated with the secondary tone considered as the primary tone. The critical band is then centred on this discrete tone, with all quantities being recomputed.

## A.7 Complex tones containing harmonic components (tone-to-noise ratio method)

Although laboratory-generated discrete tones can be pure sinusoids, most of the discrete tones that occur in the noise emissions from real machinery and equipment are not. As such, the FFT spectrum generally shows a series of tonal components (called harmonics, or partials) at integral multiples of some fundamental frequency. Usually the fundamental is the strongest component, but this is not always the case. For the purposes of this document, each tonal component in the harmonic series shall be screened for audibility in accordance with Clause 8 and, depending on the outcome, evaluated independently in accordance with the procedures of this document. Alternatively, since presumably the presence of harmonics has already been determined from inspecting an FFT spectrum of the noise emissions, the procedures of this document may be applied to each tonal component without the initial audibility screening. In this case, any tonal component that meets the prominence criteria of A.5 shall also meet the audibility requirements of A.8 before it can be classified as *prominent*.

NOTE For the cases of noise emissions from small fans consisting of many harmonic components and other discrete tones, a new evaluation parameter, Total Tone-To-Noise Ratio which is based on tone-to-noise ratio, is under development. See ECMA TR/108 [2] and References [19], [20] and [21].

## A.8 Audibility requirements

A discrete tone shall not be classified as *prominent* if it is not, in fact, *audible*. Therefore, for each discrete tone identified as *prominent* in A.5, an aural examination of the noise emitted from the equipment under test shall be made at the microphone position, or positions, used for the analysis. If the discrete tone is audible in the noise emissions, then it shall be reported as *prominent*, as determined. If the discrete tone is clearly not audible in the noise emissions, and there is a high degree of confidence in this conclusion, then it shall not be reported as *prominent*. If there is any doubt as to whether or not a discrete tone is audible in the noise emissions (e.g. if the test engineer has a hearing loss or is not a trained or experienced listener), then the following listening test shall be conducted to help make determination whether or not the tone is audible.

A sinusoidal signal corresponding to the frequency of the discrete tone in question shall be reproduced audibly and compared by the listener to the noise from the product, noting whether or not a tone at the same frequency is audible in the product noise emissions. If the discrete tone is audible in the noise emissions, then it shall be reported as *prominent*, as determined. If the discrete tone is not audible in the noise emissions even with the help of the comparison tone, then it shall not be reported as *prominent*.

## A.9 Example (tone-to-noise ratio method)

Figure A.1 shows how a single discrete tone in a critical band is analysed using the tone-to-noise ratio method. Figure A.2 shows how the tone-to-noise ratio method is used when multiple tones exist in a critical band.

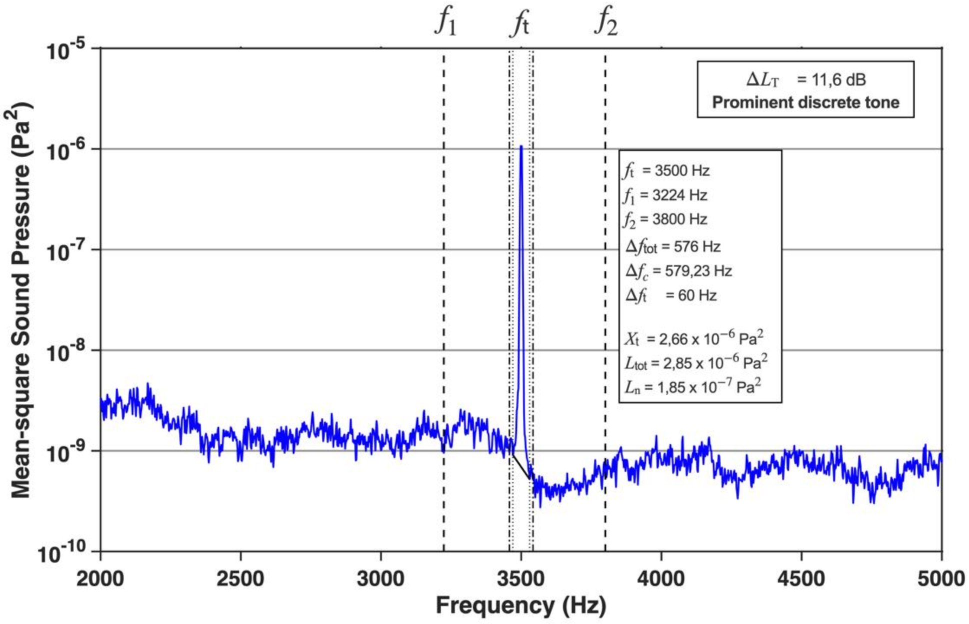

**Figure A.2 — Tone-to-noise ratio method applied to a single tone in a critical band**

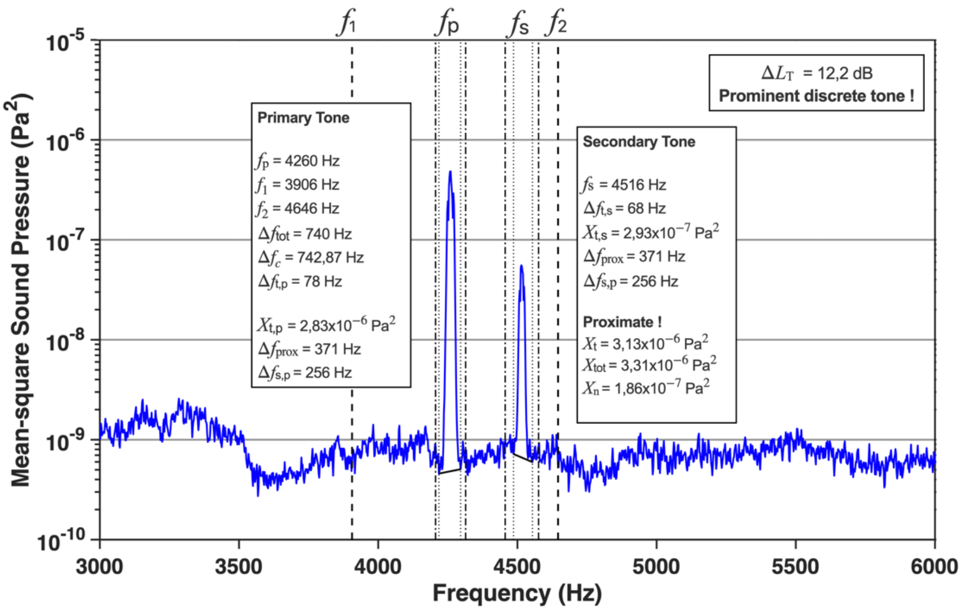

Figure A.3 — Tone-to-noise ratio method applied to multiple tones in a critical band

# Annex B
(normative)

# Prominence ratio calculation based on mean-square sound pressure data

## B.1 Measurement using FFT analyser

Clause 12 of this document specifies the detail procedures of determining prominence ratio, based on measurement using FFT analyser. In the procedures of Clause 12, the text is written in terms of the sound pressure level, $L$.

For users familiar with the application of “mean-square sound pressure”, Annex B states the alternative procedures, based on the measurement of mean-square sound pressure, $X$.

From view point of conformity, both procedures of Clause 12 and Annex B have equal footing.

The operating procedures for the FFT analyser shall be followed to acquire the PSD (power spectral density) of the sound pressure signal at the measurement position (see Clause 6), for the same mode(s) of operation and measurement conditions as used for the measurements in ECMA-74:2022, 8.7, employing the Hanning time window and RMS averaging (linear averaging). No frequency weighting, such as A-weighting, shall be applied to the signal fed to the FFT analyser. The FFT analysis shall use a sufficient number of averages to provide an analysis time satisfying the requirements of ECMA-74:2022, 8.7.2. Zoom analysis should be used with the centre frequency of the zoom band corresponding, approximately, to the frequency of the discrete tone, and the width of the zoom band equal to about four times the width of the critical band.

The power spectral density of a signal is usually calculated and displayed as a mean-square value per cycle of some quantity (e.g. a mean-square voltage per cycle, in volts squared per hertz, or a mean-square sound pressure per cycle, in pascals squared per hertz, versus frequency). To indicate that any quantity can be used, the symbol that has been chosen is “$X$”.

For the purposes of determining the prominence ratio, $\Delta L_{\mathrm{P}}$, the units of the measured power spectral density are not important, and absolute calibration of the analyser to some reference value (such as 1 V or 20 μPa) is unnecessary. However, calibration of the instrument in pascals squared per hertz enables sound pressure level quantities to be readily obtained.

## B.2 Determination of the level of the middle critical band

The mean-square sound pressure of the middle critical band, $X_{\mathrm{M}}$, is defined as the total mean-square sound pressure contained in the critical band centred on the discrete tone under investigation. The width of the middle critical band, $\Delta f_{\mathrm{M}}$, as well as the lower and upper band-edge frequencies, $f_{1,\mathrm{M}}$ and $f_{2,\mathrm{M}}$ are determined from the relationships in Clause 10 with $f_0$ set equal to the frequency of the discrete tone under investigation, $f_{\mathrm{t}}$. The band-edge frequencies then become:

For $f \leq 500\ \mathrm{Hz}$:

$$f_{1,\mathrm{M}} = f_{\mathrm{t}} - \frac{\Delta f_{\mathrm{M}}}{2} \tag{B.1}$$

and

$$f_{2,\mathrm{M}} = f_{\mathrm{t}} + \frac{\Delta f_{\mathrm{M}}}{2} \tag{B.2}$$

For $f > 500\ \mathrm{Hz}$:

$$f_{1,\mathrm{M}} = -\frac{\Delta f_{\mathrm{M}}}{2} + \frac{\sqrt{(\Delta f_{\mathrm{M}})^2 + 4{f_{\mathrm{t}}}^2}}{2} \tag{B.3}$$

and

$$f_{2,\mathrm{M}} = f_{1,\mathrm{M}} + \Delta f_{\mathrm{M}} \tag{B.4}$$

EXAMPLE $f_{1,M} = 922{,}2\ \mathrm{Hz}$ and $f_{2,M} = 1084{,}4\ \mathrm{Hz}$ when $f_t = 1000\ \mathrm{Hz}$.

The value of $X_{\mathrm{M}}$ is determined from the FFT spectrum by bracketing the data points lying between $f_{1,\mathrm{M}}$ and $f_{2,\mathrm{M}}$ and computing the mean-square sound pressure of the middle critical band. Depending on the particular instrumentation used, this may be performed on the FFT analyser itself using band cursors, on an external computer using appropriate software, or by some other means.

## B.3 Determination of the level of the lower critical band

The mean-square sound pressure of the lower critical band, $X_L$, is defined as the total mean-square sound pressure contained in the critical band immediately below, and contiguous with, the middle critical band defined in B.2. The relationships in Clause 10 govern this lower critical band, with centre frequency $f_{0,\mathrm{L}}$, bandwidth $\Delta f_{\mathrm{L}}$, and lower and upper band-edge frequencies $f_{1,\mathrm{L}}$ and $f_{2,\mathrm{L}}$, respectively. Since this lower critical band shall be contiguous with the middle critical band, it follows that $f_{2,\mathrm{L}} = f_{1,\mathrm{M}}$. However, because $f_{0,\mathrm{L}}$ is not known *a priori*, Formulae (2) to (8) cannot be used directly to determine the value of $f_{1,L}$, and an iterative method of solution would ordinarily have to be used. For the purposes of this document, the value of $f_{1,L}$ shall be computed from Formula (B.5) (which has been derived from an iterative solution through the use of curve fitting).

$$f_{1,\mathrm{L}} = C_{\mathrm{L},0} + C_{\mathrm{L},1} f_t + C_{\mathrm{L},2} f_t^2 \tag{B.5}$$

where

| | |
|---|---|
| $f_{\mathrm{t}}$ | is the frequency of discrete tone under investigation; |
| $C_{\mathrm{L},0}$, $C_{\mathrm{L},1}$, $C_{\mathrm{L},2}$ | are constants given in Table B.1. |

**Table B.1 — Parameters for calculation of $f_{1,L}$**

| Frequency range<br>Hz | $C_{L,0}$<br>Hz | $C_{L,1}$ | $C_{L,2}$<br>Hz$^{-1}$ |
|---|---|---|---|
| $89{,}1 \le f_t < 171{,}4$ | 20,0 | 0,0 | 0,0 |
| $171{,}4 \le f_t \le 1\ 600$ | -149,5 | 1,001 | $-6{,}90 \times 10^{-5}$ |
| $11\ 200 \ge f_t > 1\ 600$ | 6,8 | 0,806 | $-8{,}20 \times 10^{-6}$ |

For discrete tone frequencies less than or equal to 171,4 Hz, the lower band-edge frequency for the lower critical band would compute to less than 20 Hz, the accepted lower limit of human hearing. For such cases, the lower band-edge frequency shall be set equal to 20 Hz (so that the band used for the determination of $L_L$ extends from 20 Hz up to $f_{2,\mathrm{L}}$). The width of this lower band, $\Delta f_L$, is now less than the width of the true critical band, and the determination of the prominence ratio takes this into account (see B.5).

The value of $X_L$ is determined from the FFT spectrum by bracketing the data points lying between $f_{1,L}$ and $f_{2,L}$ and computing the mean-square sound pressure of the lower critical band. Depending on the particular instrumentation used, this may be performed on the FFT analyser itself using band cursors, on an external computer using appropriate software or by some other means. Care should be taken to ensure that the lower critical band and the middle critical band do not overlap computationally; i.e., that the FFT data points closest to the common band edge are assigned uniquely to one band or the other, and not to both.

For the purposes of determining prominence ratio of the *discrete tone frequency range of interest* (see NOTE 1 of 4.1.2), the procedure of this document permits using FFT data, $f_{1,L} < 89{,}1\ \mathrm{Hz}$ and $f_{2,U} > 11\ 200\ \mathrm{Hz}$.

## B.4 Determination of the level of the upper critical band

The mean-square sound pressure of the upper critical band, $X_U$, is defined as the total mean-square sound pressure contained in the critical band immediately above, and contiguous with, the middle critical band defined in D.2. The relationships in Clause 10 govern this upper critical band, with centre frequency $f_{0,\mathrm{U}}$, bandwidth $\Delta f_{\mathrm{U}}$, and lower and upper band-edge frequencies $f_{1,\mathrm{U}}$ and $f_{2,\mathrm{U}}$ respectively. Since this upper critical band shall be contiguous with the middle critical band, it follows that $f_{1,\mathrm{U}} = f_{2,\mathrm{M}}$. However, because $f_{1,\mathrm{U}}$ is not known *a priori*, Formulae (2) to (8) cannot be used directly to determine the value of $f_{2,\mathrm{U}}$, and an iterative method of solution would ordinarily have to be used. For the purposes of this document, the value of $f_{2,\mathrm{U}}$ shall be computed from Formula (B.6) (which has been derived from an iterative solution through the use of curve fitting):

$$f_{2,\mathrm{U}} = C_{\mathrm{U},0} + C_{\mathrm{U},1} f_t + C_{\mathrm{U},2} f_t^2 \qquad \text{(B.6)}$$

where

| | |
|---|---|
| $f_t$ | is the frequency of discrete tone under investigation; |
| $C_{\mathrm{U},0}$, $C_{\mathrm{U},1}$, $C_{\mathrm{U},2}$ | are constants given in Table B.2. |

**Table B.2 — Parameters for calculation of $f_{2,\mathrm{U}}$**

| Frequency range Hz | $C_{\mathrm{U},0}$ Hz | $C_{\mathrm{U},1}$ | $C_{\mathrm{U},2}$ $\mathrm{Hz}^{-1}$ |
|---|---|---|---|
| $89{,}1 \leq f_t \leq 1{,}600$ | 149,5 | 1,035 | $7{,}70 \times 10^{-5}$ |
| $11{,}200 \geq f_t > 1{,}600$ | 3,3 | 1,215 | $2{,}16 \times 10^{-5}$ |

The value of $X_{\mathrm{U}}$ is determined from the FFT spectrum by bracketing the data points lying between $f_{1,\mathrm{U}}$ and $f_{2,\mathrm{U}}$ and computing the mean-square sound pressure of the upper critical band. Depending on the particular instrumentation used, this may be performed on the FFT analyser itself using band cursors, on an external computer using appropriate software, or by some other means. Care should be taken to ensure that the upper critical band and the middle critical band do not overlap computationally; i.e., that the FFT data point(s) closest to the common band edge is (are) assigned uniquely to one band or the other, and not to both.

For the purposes of determining prominence ratio of *the discrete tone frequency range of interest* (see NOTE 1 of 4.1.2), the procedure of this document permits using FFT data, $f_{2,\mathrm{U}} > 11\ 200\ \mathrm{Hz}$.

## B.5 Determination of prominence ratio

The prominence ratio, $\Delta L_{\mathrm{P}}$ in decibels, is calculated as follows (for discrete tone frequencies greater than 171,4 Hz):

$$\Delta L_P = 10lg(X_{\mathrm{M}}) - 10\lg[(X_{\mathrm{L}} + X_{\mathrm{U}}) \times 0{,}5]\ \text{for}\ f_t > 171{,}4\ \mathrm{Hz} \qquad \text{(B.7)}$$

For discrete tone frequencies less than or equal to 171,4 Hz, the lower critical band becomes truncated (see B.4) so that its width is less than what would be calculated from Formula (2). Therefore, for the purposes of computing the prominence ratio for discrete tone frequencies less than or equal to 171,4 Hz, the level in the lower band is to a bandwidth of 100 Hz (the width of a full critical band at these frequencies), so that the above formulae are modified as follows.

$$\Delta L_P = 10lg(X_\mathrm{M}) - 10\lg\left[\left(\frac{100}{\Delta f_\mathrm{L}}X_\mathrm{L} + X_\mathrm{U}\right)\times 0{,}5\right] \text{ for } f_t \le 171{,}4 \text{ Hz} \qquad \text{(B.8)}$$

## B.6 Prominent discrete tone criterion for prominence ratio method

A discrete tone is classified as *prominent* in accordance with the prominence ratio method if:

$$\Delta L_\mathrm{P} \ge 9{,}0 + 10\lg\left(\frac{1000}{f_t}\right) \text{ for } 89{,}1 \text{ Hz } < f_t \le 1\,000 \text{ Hz} \qquad \text{(B.9)}$$

and

$$\Delta L_\mathrm{P} \ge 9{,}0 \text{ for } 11\,200 \text{ Hz } > \; f_t \; \ge 1\,000 \text{ Hz} \qquad \text{(B.10)}$$

and the discrete tone meets the audibility requirement of B.8. The criteria in Formulae (B.9) and (B.10) are illustrated graphically in Figure 6.

## B.7 Complex tones containing harmonic components (prominence ratio method)

Although laboratory-generated discrete tones can be pure sinusoids, most of the discrete tones that occur in the noise emissions from real machinery and equipment are not. As such, the FFT spectrum will generally show a series of tonal components (called harmonics, or partials) at integral multiples of some fundamental frequency. Usually the fundamental is the strongest component, but this is not always the case. For the purposes of this document, each tonal component in the harmonic series shall be screened for audibility in accordance with 8.1 and, depending on the outcome, evaluated independently in accordance with the procedures of this document. Alternatively, since presumably the presence of harmonics has already been determined from inspecting an FFT spectrum of the noise emissions, the procedures of this document may be applied to each tonal component without the initial audibility screening. In this case, any tonal component that meets the prominence criteria of B.6 shall also meet the audibility requirements of B.8 before it can be classified as *prominent*.

NOTE For the cases of noise emissions from small fans, consisting of many harmonic components and other discrete tones, a new evaluation parameter, Total Prominence Ratio which is based on prominence ratio, is under development. See ECMA TR/108 [2] and References [19], [20] and [21].

## B.8 Audibility requirements

A discrete tone shall not be classified as *prominent* if it is not, in fact, *audible*. Therefore, for each discrete tone identified as *prominent* in B.6, an aural examination of the noise emitted from the equipment under test shall be made at the microphone position, or positions, used for the analysis (see Clause 6). If the discrete tone is audible in the noise emissions, then it shall be reported as *prominent*, as determined. If the discrete tone is clearly not audible in the noise emissions, and there is a high degree of confidence in this conclusion, then it shall not be reported as *prominent*. If there is any doubt as to whether or not a discrete tone is audible in the noise emissions (e.g. if the test engineer has a hearing loss or is not a trained or experienced listener), then the following listening test shall be conducted to help make determination whether or not the tone is audible.

A sinusoidal signal corresponding to the frequency of the discrete tone in question shall be reproduced audibly, and compared by the listener to the noise from the product, noting whether or not a tone at the same frequency is audible in the product noise emissions. If the discrete tone is now audible in the noise emissions, then it shall be reported as *prominent*, as determined. If the discrete tone is not audible in the noise emissions even with the help of the comparison tone, then it shall not be reported as *prominent*.

## B.9 Example (prominence ratio method)

The prominence ratio method is illustrated graphically in Figure B.1. The prominence ratio was calculated in accordance with B.5 and was found to be $\Delta L_{\mathrm{P}}$ = 12,1 dB for the 1 600 Hz discrete tone. Because the result is more than 9,0 dB, which is the prominence ratio criterion at 1 600 Hz, the discrete tone is classified as *prominent*.

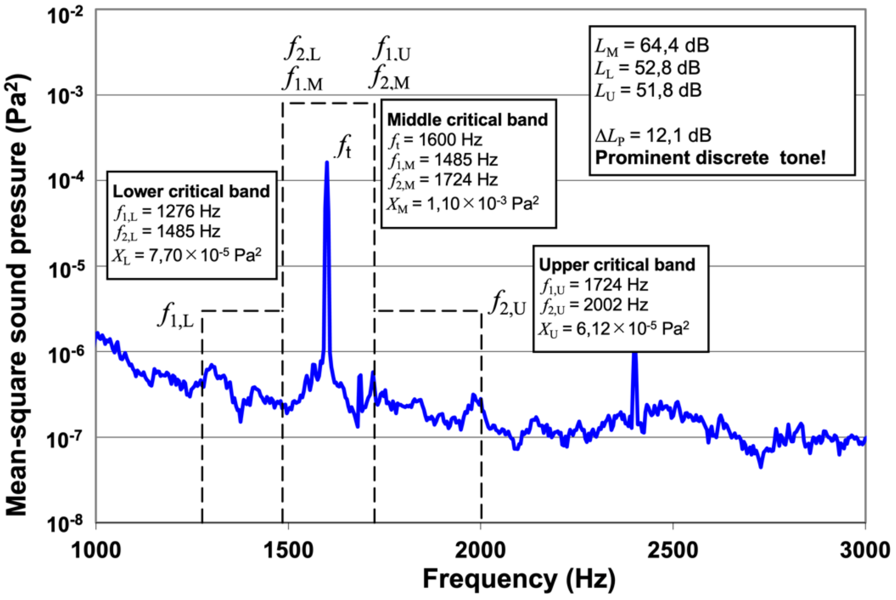

**Figure B.1 — Illustration of the prominence ratio method for prominent discrete tone identification**

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