Standard ECMA-418-1

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

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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, 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 (models based on human perception)

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

1 Scope

This document describes two procedures for determining whether or not noise emissions contain prominent discrete tones: the tone-to-noise ratio method and the prominence ratio method.

Discrete tones occurring at any frequency within the one-third-octave bands having centre frequencies from 100 Hz to 10 000 Hz can be evaluated by the procedures in this document (i.e., discrete tones between 89,1 Hz and 11 220 Hz) inclusive, referred to *the discrete tone frequency range of interest*, hereafter).

All of the requirements of the test environment of ECMA-74, 8.3 apply. However, for the purposes of this document, corrections neither for background noise, K_1, nor for test environment, K_2 apply.

NOTE 1 Since some ITT equipment emit discrete tones 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 document in an attempt to quantify their relative levels. However, the prominence criteria in either 11.6 or 12.7 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 this document. Other standards, or other noise test codes relating to products besides ITT equipment, can also refer to this document 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.

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 of this Standard 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) is shall be used, and/or.
c) for the determination of prominence ratio, the method specified in either Clause 12 or Annex B (one and only one) is 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 document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ECMA-74, *Measurement of Airborne Noise emitted by Information Technology and Telecommunications Equipment*, 17th edition (December 2019)

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

NOTE At the time of publication of this standard, ECMA-74 18th edition was nearly complete. Updating the ECMA-74 reference to the 18th edition of ECMA-74 is planned for the next revision of this standard.

4 Terms and definitions

For the purposes of this document, the terms and definitions given in ECMA-74, and the following apply.

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 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. The width of a critical band is analytically expressed as a function of frequency (see Clause 10). In general, a discrete tone is just audible in the presence of noise when the sound pressure level of the tone is about 4 dB {2 dB to 6 dB, depending on frequency (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 document, 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, the measurements shall be performed at the operator position defined in ECMA-74, 8.6.2. If there is more than one operator position, the measurements described 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 defined in ECMA-74, 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 document are to be applied to sub-assemblies, the conditions in the next two paragraphs shall be used.

For sub-assemblies intended for use in equipment with a defined operator position, the measurement shall be performed at the operator position (see ECMA-74, 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, 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, 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, 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, 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 described in this document, 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 fast Fourier transform (FFT) analyser capable of measuring the power spectral density of the microphone signal shall be used for the measurements of this document.

The analyser shall have 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 [12]).

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 document 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, 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. Discrete tones or tonal components 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 document 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 document 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 document 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 11.9 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, 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_t (see11.2, 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 document 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_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 document 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".

For the purposes of this document, 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 from Formula (1).

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

where

$P_1(f)$ is the sound pressure level that corresponds to LTH;

a_1 to a_5 are the polynomial coefficients given in Table 1.

$f' = \frac{f - f_{\text{mean}}}{f_{\text{std}}}$ is the non-dimensional parameter calculated from the values in Table 1

f_{mean} is a frequency parameter given in Table 1 for the frequency range in which f is located;

f_{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_{mean} Hz	f_{std} Hz	a_1 dB	a_2 dB	a_3 dB	a_4 dB	a_5 dB
20 ≤ f < 305	167,5	87,3212	1,415532	-2,451068	1,498869	-6,983224	8,621226
305 ≤ f < 2230	1157,5	488,582	0,397994	-0,891839	-0,815138	-1,221319	-7,600754
2 230 ≤ f < 14 000	7250,0	3033,25	1,584978	-2,766599	-6,906192	10,138553	-3,149339
14 000 ≤ 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 would be expected to hear. Formula (1) represents a 4th-order polynomial fit to data collected and tabulated in Reference [4] to estimate the LTH at a given frequency for the purposes of this document. 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]).

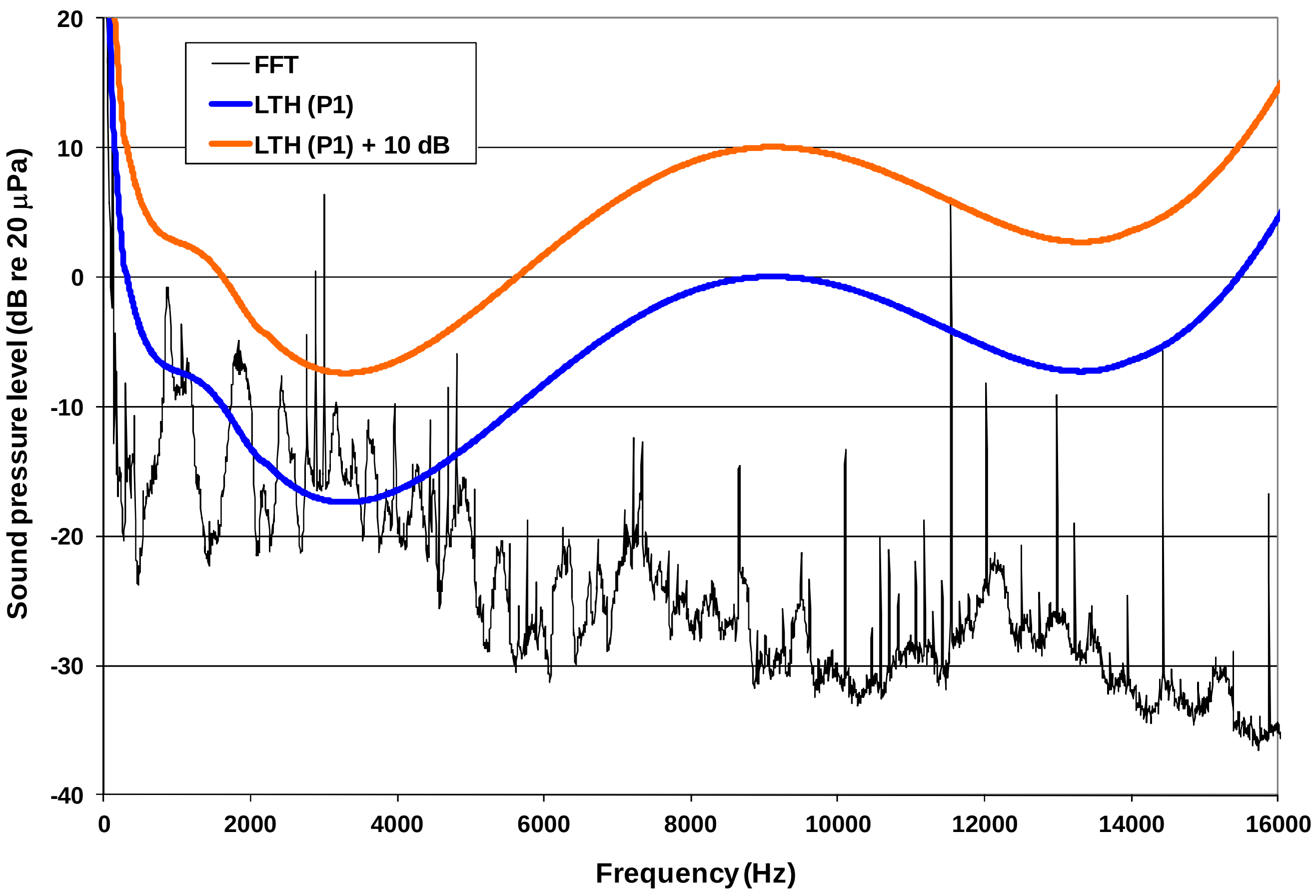

Figure 1 — Lower threshold of hearing, $P_1(f)$ curve and $P_1(f)$ + 10 dB curve illustrated for the analysis of low-level discrete tones

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 Δf_c, centred at any frequency f_0, in hertz, can be calculated from Formula (2):

$$\Delta f_c = 25,0 + 75,0 \times [1,0 + 1,4 \times (f_0/1000)^2]^{0,69} \quad (2)$$

EXAMPLE Δf_c = 162,2 Hz for f_0 = 1 000 Hz and Δf_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, where

$$f_2 - f_1 = \Delta f_c \quad (3)$$

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):

$$f_1 = f_0 - \Delta f_c/2 \quad (4)$$

and

$$f_2 = f_0 + \Delta f_c/2. \quad (5)$$

For 500 Hz < f_0 ≤ 11 200 Hz, the critical band approximates a constant-percentage bandwidth filter, where

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

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

$$f_1 = \frac{\Delta f_c}{2} + \frac{\sqrt{(\Delta f_c)^2 + 4f_0^2}}{2} \quad (7)$$

and

$$f_2 = f_1 + \Delta f_c. \quad (8)$$

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.

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

11 Tone-to-noise ratio method

11.1 Measurement using FFT analyser

This clause specifies the detail procedures of determining tone-to-noise ratio, based on measurement, using FFT analyser.

The operating procedures for the FFT analyser shall be followed to acquire the 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, 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, 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, ΔL_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, L_t is determined from the FFT spectrum measured as in 11.1 by computing the sound pressure level in the narrow band that "defines" the tone. The width of this frequency band, Δf_t, in hertz, is equal to the number of discrete data points ("the number of spectral lines") included in the band, times the resolution bandwidth ("line spacing"). If the width of the frequency band selected for the purpose of computing L_t is greater than 15 % of the width of the critical band centred at the frequency of the discrete tone, the FFT analysis should be repeated with a smaller resolution bandwidth. A discrete tone bandwidth that remains greater than 15 % of the critical band through repeated FFT analyses with smaller resolution bandwidths can indicate that the tone is not steady in frequency, or some other phenomenon. In this case, the following procedure may proceed with the discrete tone bandwidth greater than 15 % of the critical band.

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

CAUTION — Too narrow a bandwidth selected for Δf_t to delineate the discrete tone, especially when automated procedures are being used, can result in underestimation of the sound pressure level of the discrete tone and overestimation of the sound pressure level of the noise. See 11.3. If the band is too wide, masking noise or secondary tones can be erroneously included with the discrete tone computations and omitted from the noise computation.

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 width of the critical band is determined from Formula (2) 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 Formula (4) and Formula (5) or Formula (7) and Formula (8).

From the FFT spectrum, the total sound pressure level of the critical band, L_{tot}, is computed. 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. In any event, the width of the frequency band used to compute this value, Δf_{tot}, in hertz, is equal to the number of discrete FFT data points included in the band times the resolution bandwidth.

The second step is to calculate the sound pressure level of the masking noise, L_n from Formula (9):

$$\boldsymbol{L_n = 10\lg(10^{0,1L_{tot}} - 10^{0,1L_t}) + 10\lg\left(\frac{\Delta f_c}{\Delta f_{tot} - \Delta f_t}\right)} \qquad (9)$$

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

NOTE Formula (9)] accounts for both the fact that the FFT analyser bandwidth, Δf_{tot}, used to compute L_{tot}, may not be exactly equal to the critical bandwidth, Δf_c, and the fact that the calculated sound pressure level, $10\lg(10^{0,1L_{tot}} - 10^{0,1L_t})$ dB does not include the noise contained in the narrow band Δf_t.

11.4 Determination of the tone-to-noise ratio

The tone-to-noise ratio, ΔL_T, in decibels, is calculated from Formula (10):

$$\boldsymbol{\Delta L_T = L_t - L_n} \text{ dB} \qquad (10)$$

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:

$$\boldsymbol{\Delta L_T \geq 8,0 + 8,33 \times \lg(1\,000/f_t)\left(\frac{1000}{f_t}\right) \text{ dB for} 89,1 \text{ Hz} \leq f_t < 1\,000 \text{ Hz}} \qquad (11)$$

$$\boldsymbol{\Delta L_T \geq 8,0 \text{ dB for } 11\,200 \text{ Hz} > f_t > 1\,000 \text{ Hz}} \qquad (12)$$

and the discrete tone meets the audibility requirement of 11.8. The criteria in Formula (11) and Formula (12) are illustrated graphically in Figure 5.

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_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_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 $\Delta f_{\mathrm{s,p}} = |\Delta f_{\mathrm{s}} - \Delta f_{\mathrm{p}}|$ is less than the proximity spacing, Δf_{prox} , in hertz, defined Formula (13):

$$\Delta f_{\mathrm{prox}} = 21 \times 10^{1,2 \times [|\lg(f_{\mathrm{p}}/212)|]^{1,8}} \text{ for } 89,1 \text{ Hz} \leq f_{\mathrm{p}} < 1\ 000 \text{ Hz} \quad (13)$$

EXAMPLE Δf_{prox} = 23 Hz for f_{p} = 150 Hz; Δf_{prox} = 63,8 Hz for f_{p} = 850 Hz).

If the proximity criterion $\Delta f_{\mathrm{s,p}} < \Delta f_{\mathrm{prox}}$ is met, then the sound pressure level of the secondary tone, $L_{\mathrm{t,s}}$, is combined on an energy basis with the sound pressure level of the primary tone, $L_{\mathrm{t,p}}$, and subtracted on an energy basis from the total sound pressure level of the noise, L_{tot}. For discrete tone frequencies equal to or higher than 1 000 Hz, the proximity spacing, Δf_{prox} exceeds half the width of the critical band, so the criterion is always met. See Reference [18]. This is represented by Formulae (14) and (15):

$$L_{\mathrm{t}} = 10\lg\left(10^{0,1L_{\mathrm{t,p}}} + 10^{0,1L_{\mathrm{t,s}}}\right) \text{ dB} \quad (14)$$

and

$$L_{\mathrm{t}} = 10\lg\left(10^{0,1L_{\mathrm{t,p}}} - \left(10^{0,1L_{\mathrm{t,p}}} + 10^{0,1L_{\mathrm{t,s}}}\right) + \right) + 10lg \frac{\Delta fc}{\Delta ftot - (-L_{\mathrm{t,s}})}$$

$$L_{\mathrm{n}} = 10\lg\left[10^{0,1L_{\mathrm{tot}}} - \left(10^{0,1L_{\mathrm{t,p}}} + 10^{0,1L_{\mathrm{t,s}}}\right)\right] + 10\lg \frac{\Delta f_{\mathrm{c}}}{\Delta f_{\mathrm{tot}} - \left(\Delta f_{\mathrm{t,p}} + \Delta f_{\mathrm{t,s}}\right)} \text{ dB} \quad (15)$$

With the above values for L_{n} and L_{t}, Formula (10) is used to compute the tone-to-noise ratio.

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 (15) is again used for L_{n}, but Formula (14) simply becomes $L_{\mathrm{t}} = 10\lg(10^{0,1L_{\mathrm{t,p}}})$ dB. These values of L_{n} and L_{t} are then used in Formula (10) 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 [4] 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 2 shows how a single discrete tone in a critical band is analysed using the tone-to-noise ratio method. Figure 3 shows how the tone-to-noise ratio method is used when multiple tones exist in a critical band.

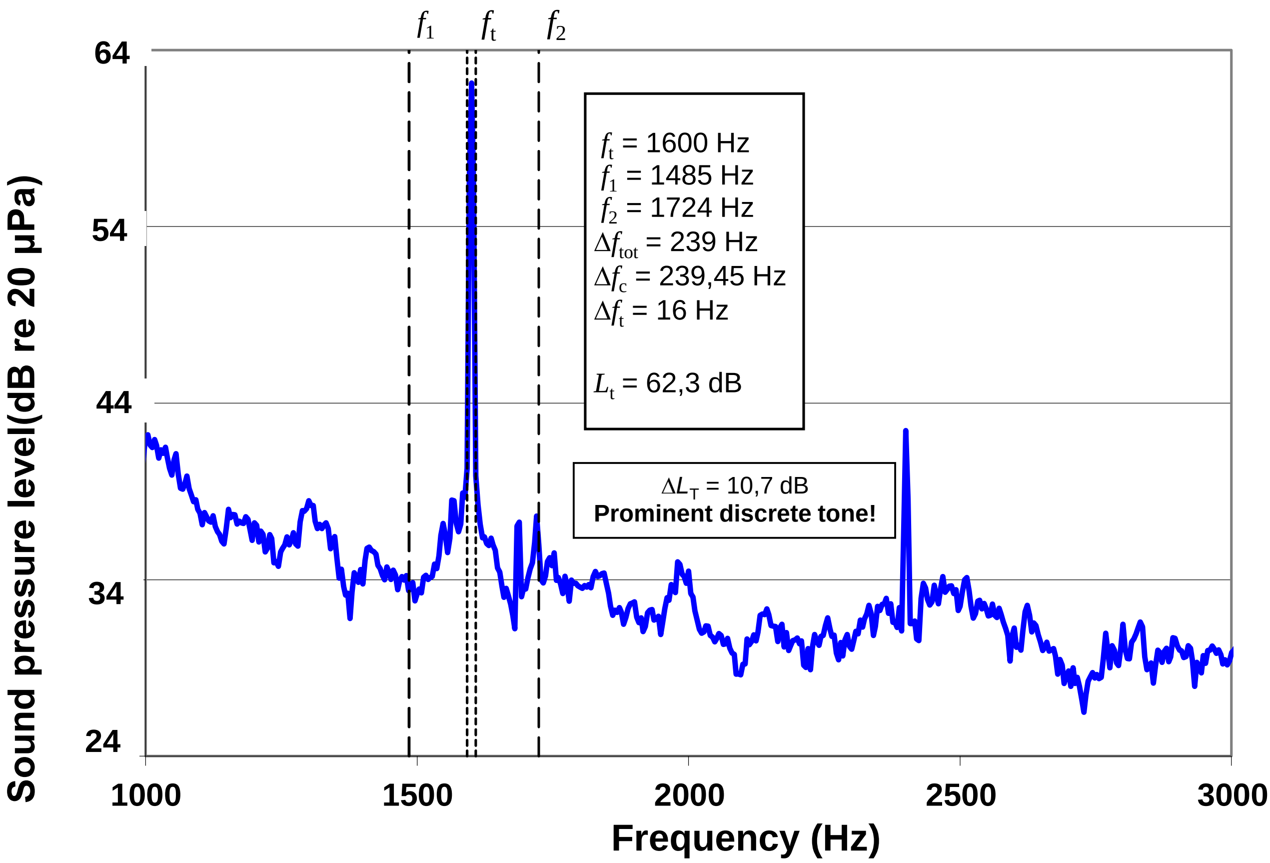

Figure 2 — Tone-to-noise ratio method applied to a single tone in a critical band

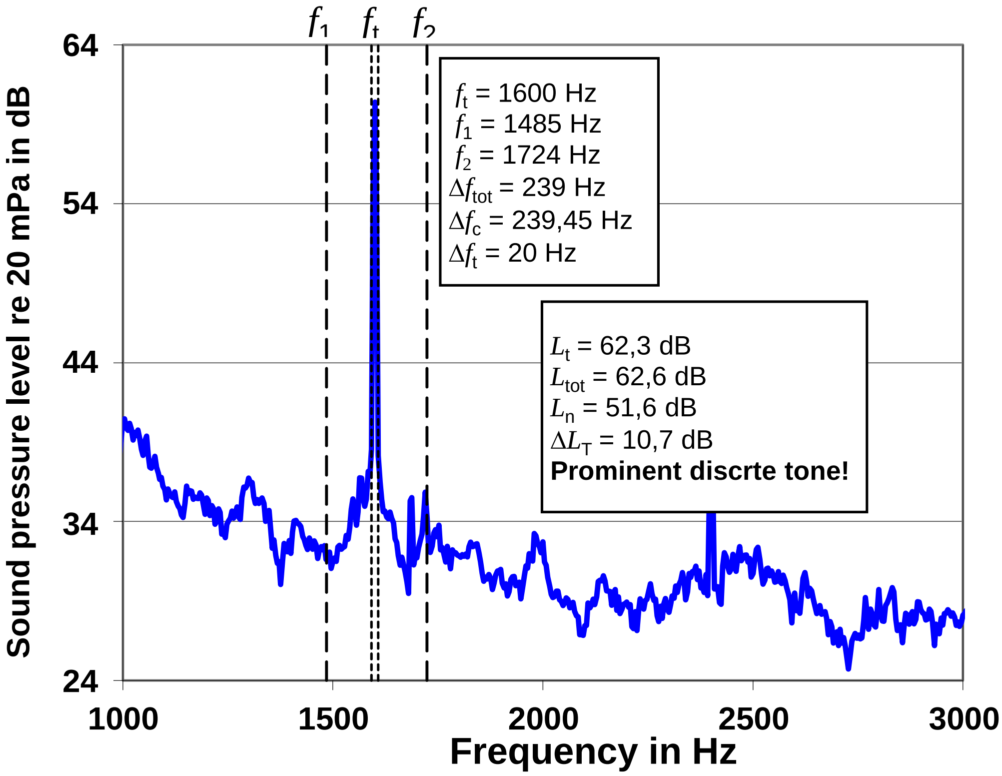

Figure 3 — Tone-to-noise ratio method applied to multiple tones in a critical band

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 power spectral density (or sound pressure level) of the 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, 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, 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, ΔL_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.

12.2 Determination of the level of the middle critical band

The sound pressure level of the middle critical band, L_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, Δf_M, as well as the lower and upper band-edge frequencies, $f_{1,M}$ and $f_{2,M}$ 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 $f \leq 500$ Hz:

$$\boldsymbol{f}_{1,\mathbf{M}} = \boldsymbol{f}_{\mathbf{t}} - \frac{\Delta \boldsymbol{f}_{\mathbf{M}}}{\mathbf{2}} \tag{16}$$

and

$$\boldsymbol{f}_{2,\mathbf{M}} = \boldsymbol{f}_{\mathbf{t}} + \frac{\Delta \boldsymbol{f}_{\mathbf{M}}}{\mathbf{2}} \tag{17}$$

For $f > 500$ Hz :

$$\boldsymbol{f}_{1,\mathbf{M}} = -\frac{\Delta \boldsymbol{f}_{\mathbf{M}}}{\mathbf{2}} + \frac{\sqrt{(\Delta \boldsymbol{f}_{\mathbf{M}})^{2} + 4\boldsymbol{f}_{\mathbf{t}}^{2}}}{\mathbf{2}} \tag{18}$$

and

$$\boldsymbol{f}_{2,\mathbf{M}} = \boldsymbol{f}_{\mathbf{t}} + \Delta \boldsymbol{f}_{\mathbf{M}} \tag{19}$$

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

The value of L_M is determined from the FFT spectrum by bracketing the data points lying between $f_{1,M}$ and $f_{2,M}$ 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_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 $f_{0,L}$, bandwidth Δf_L, and lower and upper band-edge frequencies $f_{1,L}$ and $f_{2,L}$, respectively. Since this lower critical band shall be contiguous with the middle critical band, it follows that $f_{2,L}$ = $f_{1,M}$. However, because $f_{0,L}$ 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 (20) (which has been derived from an iterative solution through the use of curve fitting).

$$\boldsymbol{f}_{1,\mathrm{L}} = \boldsymbol{C}_{\mathrm{L},0} + \boldsymbol{C}_{\mathrm{L},1}\boldsymbol{f}_{\mathbf{t}} + \boldsymbol{C}_{\mathrm{L},2}\boldsymbol{f}_{\mathbf{t}}^{2} \tag{20}$$

where

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

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

Frequency range Hz	$C_{L,0}$ Hz	$C_{L,1}$	$C_{L,2}$ Hz^{-1}
$89{,}1 \leq f_t < 171{,}4$	20,0	0,0	0,0
$171{,}4 \leq f_t \leq 1\,600$	-149,5	1,001	$-6{,}90 \times 10^{-5}$
$11\,200 \geq f_t > 1\,600$	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 X_L extends from 20 Hz up to $f_{2,L}$). The width of this lower band, Δf_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_L is determined from the FFT spectrum by bracketing the data points lying between $f_{1,L}$ 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 Clause 1), the procedure of this document permits using FFT data, $f_{1,L}$ < 89,1 Hz and $f_{2,U}$ > 11 200 Hz.

12.4 Determination of the level of the upper critical band

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

$$f_{2,U} = C_{U,0} + C_{U,1} f_t + C_{U,2} f_t^2 \quad (21)$$

where

f_t is the frequency of discrete tone under investigation;

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

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

Frequency range Hz	$C_{U,0}$ Hz	$C_{U,1}$	$C_{U,2}$ Hz-1
$89{,}1 \leq f_t \leq 1\,600$	149,5	1,035	$7{,}70\times10^{-5}$
$11\,200 \geq f_t > 1\,600$	3,3	1,215	$2{,}16\times10^{-5}$

The value of L_U is determined from the FFT spectrum by bracketing the data points lying between $f_{1,U}$ and $f_{2,U}$ 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 Clause 1), the procedure of this document permits using FFT data, $f_{2,U}$ > 11 200 Hz.

12.5 Determination of prominence ratio

The prominence ratio, ΔL_P in decibels, is calculated as follows (for discrete tone frequencies greater than 171,4 Hz):

$$\Delta L_P = 10\lg(10^{0,1L_M}) - 10\lg[(10^{0,1L_L} + 10^{0,1L_U}) \times 0,5]\,\text{dB for } f_t > 171,4\text{ Hz} \quad (22)$$

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.

$$\Delta L_P = 10\lg(10^{0,1L_M}) - 10\lg\left[\left(\frac{100}{\Delta f_L} \times 10^{0,1L_L} + 10^{0,1L_U}\right) \times 0,5\right]\text{dB for } f_t > 171,4\text{ Hz} \quad (23)$$

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:

$$\Delta L_P \geq 9,0 + 10\lg\left(\frac{1000}{f_t}\right)\text{dB for } 89,1\text{ Hz } \leq f_t \leq 1\,000\text{ Hz} \quad (24)$$

$$\Delta L_P \geq 9,0\text{ dB for } 11\,200\text{ Hz } \geq f_t > 1\,000\text{ Hz} \quad (25)$$

and the discrete tone meets the audibility requirement of 12.8. The criteria in Formulae (24) and (25) are illustrated graphically in Figure 5.

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 Reference ECMA TR/108 [4] 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 4. The prominence ratio was calculated in accordance with 12.5 and was found to be ΔL_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*.

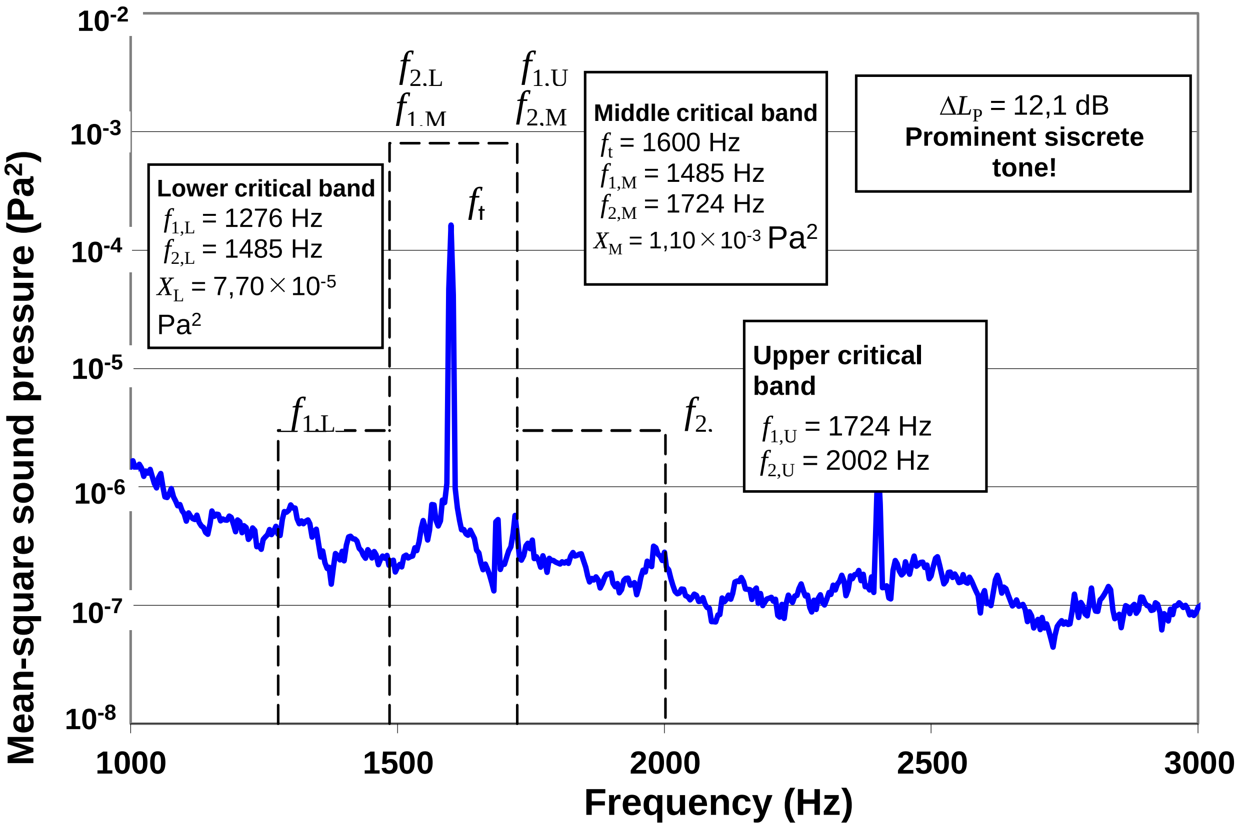

Figure 4 — Illustration of the prominence ratio method for prominent discrete tone identification

13 Information to be recorded for prominent discrete tones

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

a) the frequency, f_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-74;

c) if the tone-to-noise ratio method was used, the tone-to-noise ratio, ΔL_T, in decibels or if the prominence ratio procedure was used, the prominence ratio ΔL_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 ΔL_T *or* ΔL_P for each tone.

NOTE 1 A discrete tone is classified as *prominent*, if both (i) ΔL_T or ΔL_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.

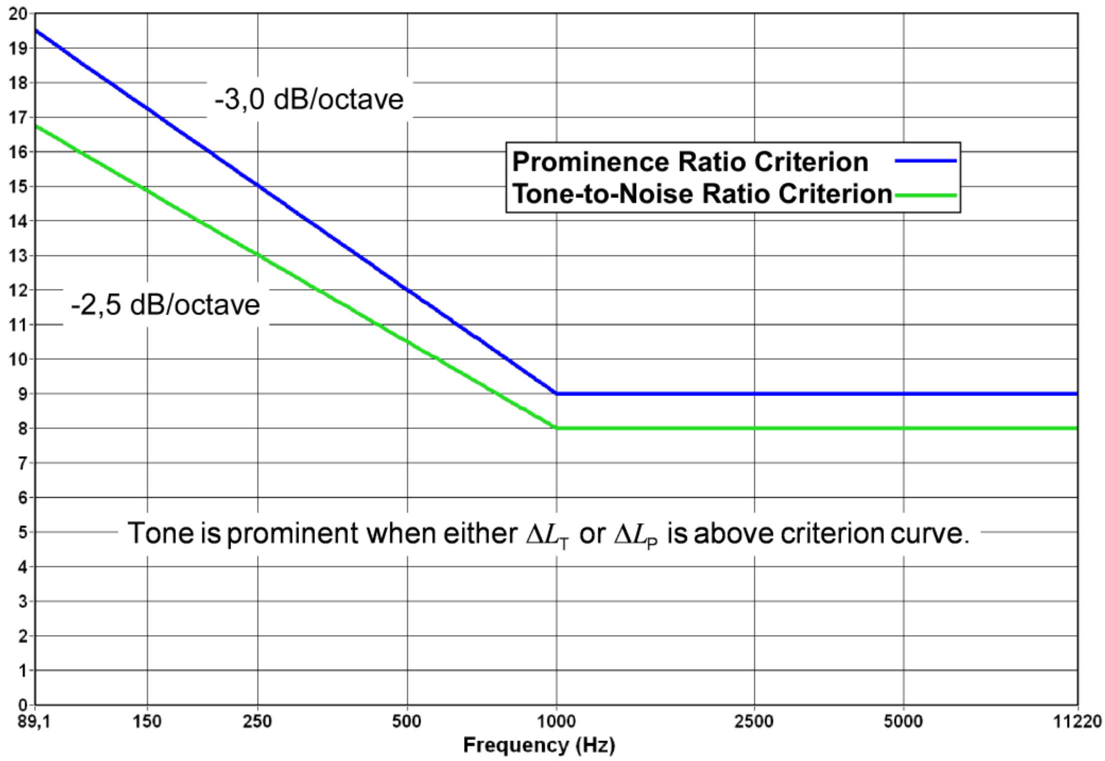

Figure 5 — Criteria for prominence for both tone-to-noise ratio (11.6) and prominence ratio (12.7) as a function of frequency

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.

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 (or sound pressure level) of the 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, 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, 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, ΔL_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 users which are familiar with the application of "mean-square sound pressure" Annex A states alternative procedures to this clause.

A.2 Determination of discrete tone level

The mean-square sound pressure of the discrete tone, X_t is determined from the FFT spectrum measured as in A.1 by computing the mean-square sound pressure in the narrow band that "defines" the tone. The width of this frequency band, Δf_t, in hertz, is equal to the number of discrete data points ("the number of spectral lines") included in the band, times the resolution bandwidth ("line spacing"). If the width of the frequency band selected for the purpose of computing X_t is greater than 15 % of the width of the critical band centred at the frequency of the discrete tone, the FFT analysis should be repeated with a smaller resolution bandwidth. A discrete tone bandwidth that remains greater than 15 % of the critical band through repeated FFT analyses with smaller resolution bandwidths can indicate that the tone is not steady in frequency, or some other phenomenon. In this case, the following procedure may proceed with the discrete tone bandwidth greater than 15 % of the critical band.

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 — Too narrow a bandwidth selected for Δf_t to delineate the discrete tone, especially when automated procedures are being used, can result in underestimation of the mean-square sound pressure of the tone and overestimation of the mean-square sound pressure of the noise. See A.3. If the band is too wide, masking noise or secondary tones can be erroneously included with the discrete tone computations and omitted from the noise computation.

A.3 Determination of masking noise level

For the purposes of this document, the mean-square sound pressure of the masking noise, X_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 width of the critical band is determined from Formula (2) 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 Formula (4) and Formula (5) or Formula (7) and Formula (8).

From the FFT spectrum, the total mean-square sound pressure of the critical band, X_{tot}, is computed. 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. In any event, the width of the frequency band used to compute this value, Δf_{tot}, in hertz, is equal to the number of discrete FFT data points included in the band times the resolution bandwidth.

The second step is to calculate the masking noise mean-square sound pressure, X_n, from Formula (A.1):

$$X_{\mathrm{n}} = (X_{\mathrm{tot}} - X_{\mathrm{t}}) \frac{\Delta f_{\mathrm{c}}}{(\Delta f_{\mathrm{tot}} - \Delta f_{\mathrm{t}})} \qquad \text{(A.1)}$$

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.1) accounts for both the fact that the FFT analyser bandwidth, Δf_{tot}, used to compute X_{tot}, may not be exactly equal to the critical bandwidth, Δf_c, and the fact that the calculated mean-square sound pressure ($X_{tot} – X_t$) does not include the noise contained in the narrow band Δf_t.

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

The tone-to-noise ratio, ΔL_T, in decibels, is calculated from Formula (A.2):

$$\Delta L_{\mathrm{T}} = 10 \lg \frac{X_{\mathrm{t}}}{X_{\mathrm{n}}} \ \mathrm{dB} \qquad \text{(A.2)}$$

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:

$$\Delta L_{\mathrm{T}} \geq 8,0 + 8,33 \times \lg(1\ 000/f_{\mathrm{t}}) \left(\frac{1000}{f_{\mathrm{t}}}\right) \ \mathrm{dB\ for\ } 89,1\ \mathrm{Hz} \leq f_{\mathrm{t}} < 1\ 000\ \mathrm{Hz} \qquad \text{(A.3)}$$

$$\Delta L_{\mathrm{T}} \geq 8,0\ \mathrm{dB\ for\ } 11\ 200\ \mathrm{Hz} > f_{\mathrm{t}} > 1\ 000\ \mathrm{Hz} \qquad \text{(A.4)}$$

and the discrete tone meets the audibility requirement ofA.8. The criteria in Formula (A.3) and Formula (A.4) are illustrated graphically in Figure 5 (see Clause 13).

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_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_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 $\Delta f_{s,p} = |\Delta f_s - \Delta f_p|$ is less than the proximity spacing, $\Delta f_{prox,}$ in hertz, defined Formula (A.2):

$$\Delta f_{prox} = 21 \times 10^{1,2 \times |\lg(f_p/212)|^{1,8}} \text{ for } 89,1 \text{ Hz} \le f_p < 1\ 000 \text{ Hz} \tag{A.5}$$

EXAMPLE Δf_{prox} = 23 Hz for f_p = 150 Hz; Δf_{prox} = 63,8 Hz for f_p = 850 Hz).

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

For discrete tone frequencies equal to or higher than 1 000 Hz, the proximity spacing, Δf_{prox} exceeds half the width of the critical band, so the criterion is always met. See Reference [44]. This is represented by Formulae (A.6) and (A.7):

$$X_t = X_{t,p} - X_{t,s} \tag{A.6}$$

and

$$X_n = [X_{tot} - (X_{t,p} - X_{t,s})] \times \left[\frac{\Delta f_c}{\Delta f_{tot} - (\Delta f_{t,p} - \Delta f_{t,s})}\right] \tag{A.7}$$

With the above values for X_n and X_t, Formula (A.2) is used to compute the tone-to-noise ratio.

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 (.7) is again used for X_n, but Formula (A.6) simply becomes $X_t = X_{t,\,p}$. These values of X_n and X_t are then used in Formula (A.2) 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 [4] 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.

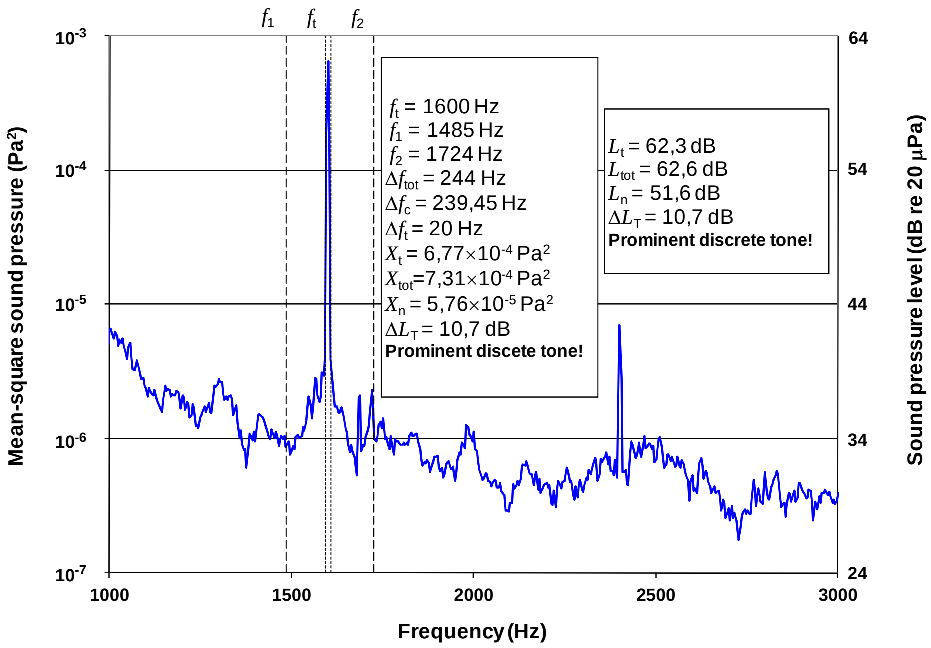

Figure A.1 — Tone-to-noise ratio method applied to a single tone in a critical band

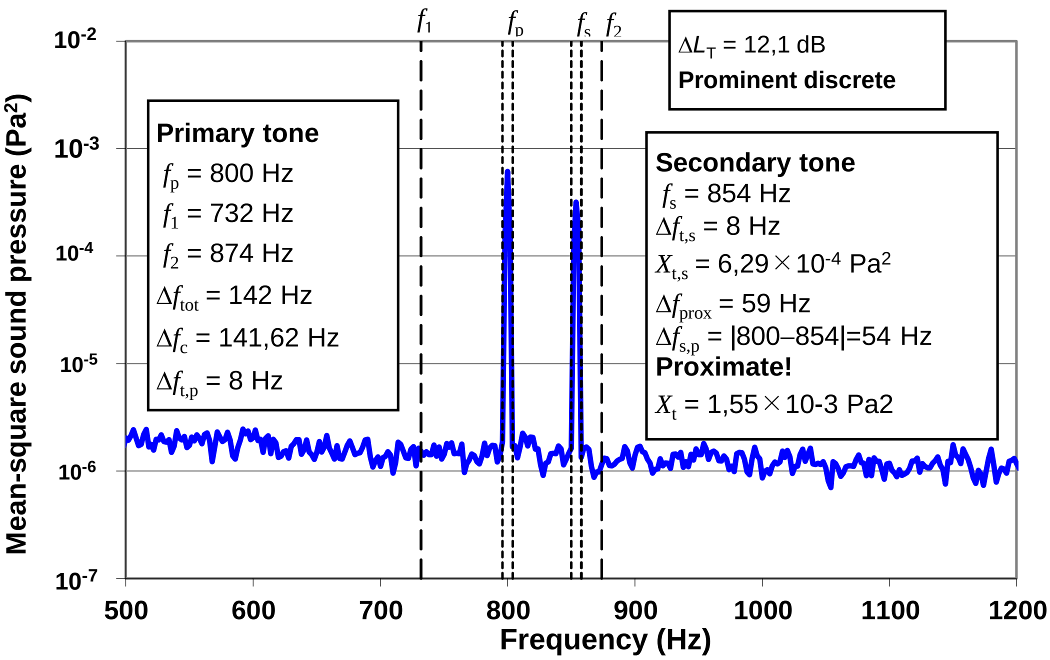

Figure A.2 — Tone-to-noise ratio method applied to multiple tones in a critical band

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.

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 power spectral density (or sound pressure level) of the 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, 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, 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, ΔL_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.

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

The mean-square sound pressure of the middle critical band, X_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, Δf_M, as well as the lower and upper band-edge frequencies, $f_{1,M}$ and $f_{2,M}$ 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 $f \leq 500$ Hz

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

and

$$f_{2,M} = f_t + \frac{\Delta f_M}{2} \tag{B.2}$$

For $f > 500$ Hz :

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

and

$$f_{2,\mathrm{M}} = f_{1,\mathrm{M}} + \Delta f_\mathrm{M} \quad \text{(B.4)}$$

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

The value of X_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 Δf_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 (B.5) (which has been derived from an iterative solution through the use of curve fitting).

$$f_{1,\mathrm{L}} = C_{\mathrm{L},0} + C_{\mathrm{L},1} f_\mathrm{t} + C_{\mathrm{L},2} f_\mathrm{t}^2 \quad \text{(B.5)}$$

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 B.1.

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

Frequency range Hz	$C_{\mathrm{L},0}$ Hz	$C_{\mathrm{L},1}$	$C_{\mathrm{L},2}$ Hz^{-1}
$89{,}1 \le f_\mathrm{t} < 171{,}4$	20,0	0,0	0,0
$171{,}4 \le f_\mathrm{t} \le 1600$	-149,5	1,001	$-6{,}90\times10^{-5}$
$11\,200 \ge f_\mathrm{t} > 1\,600$	6,8	0,806	$-8{,}20\times10^{-6}$

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, Δf_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 $f_{1,\mathrm{L}}$ and $f_{2,\mathrm{L}}$ 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 Clause 1), the procedure of this document permits using FFT data, $f_{1,L}$ < 89,1 Hz and $f_{2,U}$ > 11 200 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 $f_{0,U}$, bandwidth Δf_U, and lower and upper band-edge frequencies $f_{1,U}$ and $f_{2,U}$, respectively. Since this upper critical band shall be contiguous with the middle critical band, it follows that $f_{1,U} = f_{2,M}$. However, because $f_{0,U}$ is not known *a priori*, Formulae (2) to (8) cannot be used directly to determine the value of $f_{2,U}$, and an iterative method of solution would ordinarily have to be used. For the purposes of this document, the value of $f_{2,U}$ shall be computed from Formula (B.6) (which has been derived from an iterative solution through the use of curve fitting):

$$\boldsymbol{f}_{2,\mathrm{U}} = \boldsymbol{C}_{\mathrm{U},0} + \boldsymbol{C}_{\mathrm{U},1}\boldsymbol{f}_{\mathrm{t}} + \boldsymbol{C}_{\mathrm{U},2}\boldsymbol{f}_{\mathrm{t}}^{2} \quad \text{(B.6)}$$

where

f_t is the frequency of discrete tone under investigation;

$C_{U,0}$, $C_{U,1}$, $C_{U,2}$ are constants given in Table B.2.

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

Frequency range Hz	$C_{U,0}$ Hz	$C_{U,1}$	$C_{U,0}$ Hz-1
89,1 ≤ f_t ≤ 1 600	149,5	1,035	7,70×10−5
11 200 ≥ f_{tt} >1 600	3,3	1,215	2,16×10−5

The value of X_U is determined from the FFT spectrum by bracketing the data points lying between $f_{1,U}$ and $f_{2,U}$ 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 Clause 1), the procedure of this document permits using FFT data, $f_{2,U}$ > 11 200 Hz.

B.5 Determination of prominence ratio

The prominence ratio, ΔL_P in decibels, is calculated as follows (for discrete tone frequencies greater than 171,4 Hz):

$$\Delta \boldsymbol{L}_{\mathrm{P}} = \mathbf{10lg}(\mathbf{10}^{\mathbf{0,1}\boldsymbol{L}_{\mathrm{M}}}) - \mathbf{10lg}[(\mathbf{10}^{\mathbf{0,1}\boldsymbol{L}_{\mathrm{L}}} + \mathbf{10}^{\mathbf{0,1}\boldsymbol{L}_{\mathrm{U}}}) \times \mathbf{0,5}] \ \mathbf{dB\ for}\ \boldsymbol{f}_{\mathrm{t}} > \mathbf{171,4\ Hz} \quad \text{(B.7)}$$

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.

$$\Delta \boldsymbol{L}_{\mathrm{P}} = \mathbf{10lg}\left[\frac{\boldsymbol{X}_{\mathrm{M}}}{\{[\boldsymbol{X}_{\mathrm{L}} \times (\mathbf{100}/\Delta \boldsymbol{f}_{\mathrm{L}})] + \boldsymbol{X}_{\mathrm{U}}\} \times \mathbf{0,5}}\right] \ \mathbf{dB\ for}\ \boldsymbol{f}_{\mathrm{t}} \leq \mathbf{171,4\ Hz} \quad \text{(B.8)}$$

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:

$$\Delta L_{\mathrm{P}} \geq 9{,}0 + 10\lg\left(\frac{1000}{f_{\mathrm{t}}}\right) \mathrm{dB\ for\ } 89{,}1\ \ \mathrm{Hz} \leq f_{\mathrm{t}} \leq 1000\ \ \mathrm{Hz} \qquad \text{(B.9)}$$

$$\Delta L_{\mathrm{P}} \geq 9{,}0\ \ \mathrm{dB\ for\ } 11\ \ 200\ \ \mathrm{Hz} \geq f_{\mathrm{t}} > 1000\ \ \mathrm{Hz} \qquad \text{(B.10)}$$

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 5.

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 Reference ECMA TR/108 [4] 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 ΔL_{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*.

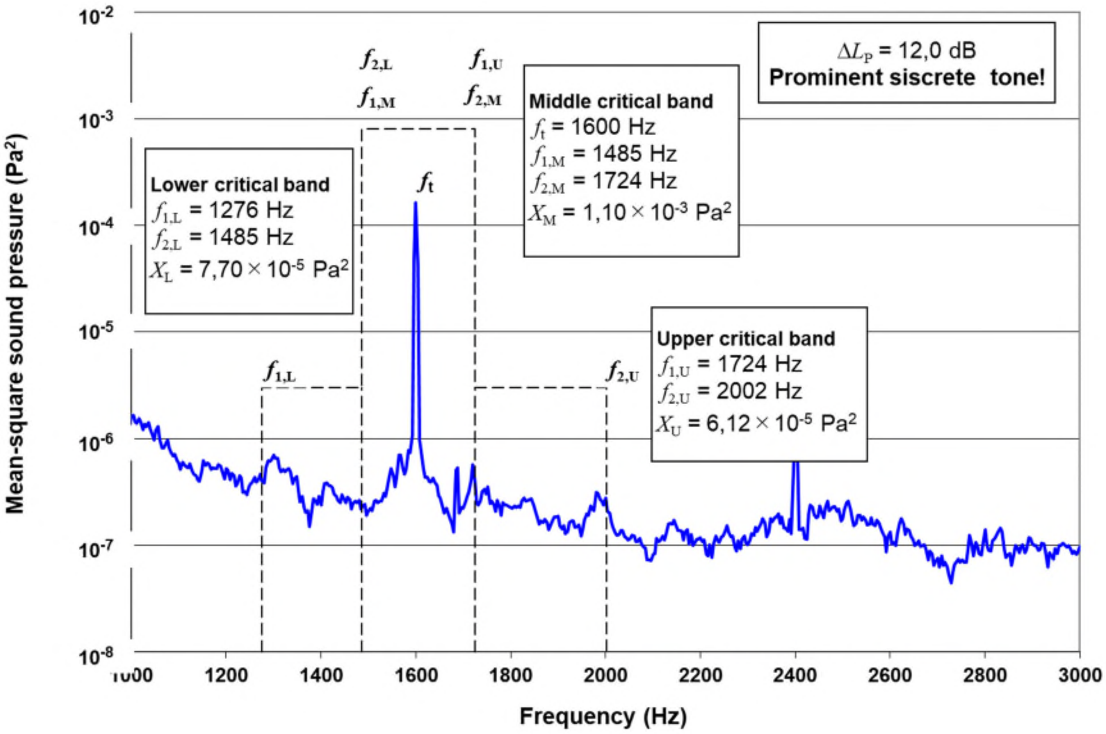

Figure B.1 — Illustration of the prominence ratio method for prominent discrete tone identification

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[4] ISO 28961, Acoustics — Statistical distribution of hearing thresholds of otologically normal persons in the age range from 18 years to 25 years under free-field listening conditions

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