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OBJECTIVE METHOD FOR ASSESSING THE AUDIBILITY OF TONES IN NOISE

T.H. Pedersen, M. Soendergaard

DELTA, Build. 356, Akademivej, DK 2800, Lyngby, Denmark

Tel.: +45 45 93 12 11 / Fax: +45 45 93 19 90 / Email: thp@delta.dk

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ABSTRACT
This paper contains a proposal for a revision of the present Joint Nordic Method for assessing the audibility of tones in noise. The method is also a proposal for the revision of ISO 1996 (TC43/SC1/WG45). The procedure described here is based on a visual inspection of a narrow-band frequency spectrum. A more comprehensive description with documentation from listening tests, hints for the practical implementation with examples and more accurate definitions and procedures can be found on www.delta.dk (search for "audibility").

1 - INTRODUCTION

The present Joint Nordic Method for assessing the audibility of tones in noise was accepted as a Nordic method in 1984 [1]. In Denmark the method is used on a regular basis by approx. 30 laboratories. This paper is a proposal for a revision of the method which includes procedures for varying tones, narrow-band noise, low-frequency tones, and a graduated 0-6 dB penalty.
The aim of the objective method is to assess the prominence of tones in the same way as listeners do in average. The method is based on the psychoacoustic concept of critical bands, which are bands defined so that tones outside a critical band do not contribute significantly to the audibility of tones inside that critical band [2].
Listening tests have shown good correlation ($R^2 = 0.91$) between judgements of the audibility of tones and measurements according to this revised method. In accordance with the results from the listening tests the audibility of tones (both with stationary and fluctuating level and of narrow bands of noise) is calculated from a frequency spectrum averaged over "long" time (minutes) [3]. The audibility of tones with large variation in frequency is handled by looking at a number of frequency spectra, each representing part of the total measurement time.

2 - OBJECTIVE METHOD

The method has three steps:

- Narrow-band frequency analysis (preferably FFT-analysis),
- Determination of the average sound pressure level of the tone(s) and of the masking noise within the critical band around the tone(s),
- Calculation of the tonal audibility, ΔL_{ta}, and the penalty, k.

2.1 - Frequency analysis

A narrow-band A-weighted spectrum is measured by linear averaging for at least one minute ("long-term average").
The effective analysis bandwidth shall be less than 5% of the bandwidth of the critical bands with tonal components. The widths of the critical bands are shown in Table 1.
It is recommended that the measuring set-up including the frequency analyzer is calibrated in dB re 20 μPa, and that Hanning weighting is used as window function.

Notes:

- With the recommended Hanning time window the effective analysis bandwidth (or the effective noise bandwidth) is 1.5 times the frequency resolution. The frequency resolution is the distance between the lines in the spectrum.
- With an effective analysis bandwidth of 5% of a critical band just audible tones will normally appear as local maxima of at least 8 dB above the surrounding masking noise in the averaged spectra.
- In rare cases of a tone complex with many closely spaced tone components a finer resolution may be needed to determine the level of the masking noise correctly.
- If the frequency of audible tones in the spectrum varies by more than 10% of the frequency range of the critical band within the averaging time, it may be necessary to subdivide the long-term average into a number of shorter-term averages.

2.2 - Determination of sound pressure levels

2.2.1 Sound Pressure Level of Tones, L_{pt}

The tones may be identified from the narrow-band frequency spectrum by visual inspection. The sound pressure levels of the tones are determined from the spectrum.

All local maxima with a 3-dB bandwidth smaller than 10% of the bandwidth of the actual critical band are regarded as a tone.

Note: if a "tone" is a narrow band of noise or if the frequency of a tone varies, the tone will appear as several lines in the averaged spectrum. In such cases the tone level, L_{pt}, is the energy sum of all lines, with levels within 6 dB of the local maximum level and corrected for the influence of the applied window function (for Hanning weighting this is the energy sum of the lines minus 1.8 dB).

The levels, L_{pti}, of all tones No. i in the same critical band shall be added on energy basis to give the total tone level for that band, L_{pt}:

$$L_{pt} = 10\log \sum 10^{\frac{L_{pti}}{10}} \tag{1}$$

Note: in cases where tones appear at low frequencies, it is advisable to investigate if the total tone level is above the hearing threshold (ISO 226, 1987). If the total tone level in a critical band is below the hearing threshold, this critical band shall be disregarded in the assessment of tonal audibility.

2.2.2 Bandwidth and Center Frequency of Critical Bands

The widths of the critical bands are shown in Table 1:

Center Frequency, f_c	50-500 Hz	Above 500 Hz
Bandwidth	100 Hz	20% of f_c

Table 1: Widths of critical bands.

The critical band shall be positioned with its center frequency, f_c at the tone frequency. When a number of tones are present in the range of a critical band, the critical band shall be positioned around the most significant tones in such a way that the difference between the total tone level, L_{pt}, and the level of the masking noise, L_{pn}, (Section 2.3) is maximized.

Notes:

- For the definition of the center frequency of a critical band, only tones with levels 10 dB or less below the level of the tone with the maximum level are regarded as significant.
- The center frequency of the critical bands, f_c, may vary continuously over the frequency range of interest. The lowest critical band is 0 Hz -100 Hz.

2.2.3 Sound Pressure Level of the Masking Noise within a Critical Band, L_{pn}

The average noise level in a critical band, $L_{pn,avg}$, may be found by visually averaging the levels of the "noise" lines in the narrow-band frequency spectrum in a range of approximately ± 0.5 to ± 1 critical band from the center frequency, f_c. The "noise" lines are found by disregarding all maxima in the spectrum resulting from tones and their possible side bands in that range.

The total sound pressure level of the masking noise, L_{pn} is calculated from the average noise level within the critical band, $L_{pn,avg}$, as follows:

$$L_{pn} = L_{pn,avg} + 10\log\frac{\text{Critical Bandwidth}}{\text{Effective Analy sis Bandwidth}} \tag{2}$$

2.3 - Calculation of the tonal audibility, ΔL_{ta}, and the penalty, k

The tonal audibility, ΔL_{ta}, is expressed in dB above the masking threshold, MT. The penalty, k, is the value to be added to the value of L_{Aeq} for a time interval to give the tone-corrected rating level for that interval. From the difference between tone level and noise level in a critical band, L_{pt}-L_{pn}, both ΔL_{ta} and k may be determined by means of Figure 1.

The audibility of tones in a critical band can also be calculated by means of Equation (3):

$$\Delta L_{ta} = L_{pt} - L_{pn} + 2 + \log\left(1 + \left(\frac{f_c}{502}\right)^{2.5}\right), \text{ dB re MT} \tag{3}$$

where L_{pt} is the total sound pressure level of the tones in the critical band, L_{pn} is the total sound pressure level of the masking noise in the critical band, and f_c is the center frequency in Hz of the critical band. The penalty, k, in dB is determined by Equation (4):

$$\begin{gathered}\text{for } \Delta L_{ta} < 4dB: \ k = 0dB, \ \text{for } \Delta L_{ta} > 10dB \ : \ k = 6dB \\ \text{for } 4dB \leq \Delta L_{ta} \leq 10dB \ : \ k = \Delta L_{ta} - 4,\end{gathered} \tag{4}$$

Note: k is not restricted to integer values.

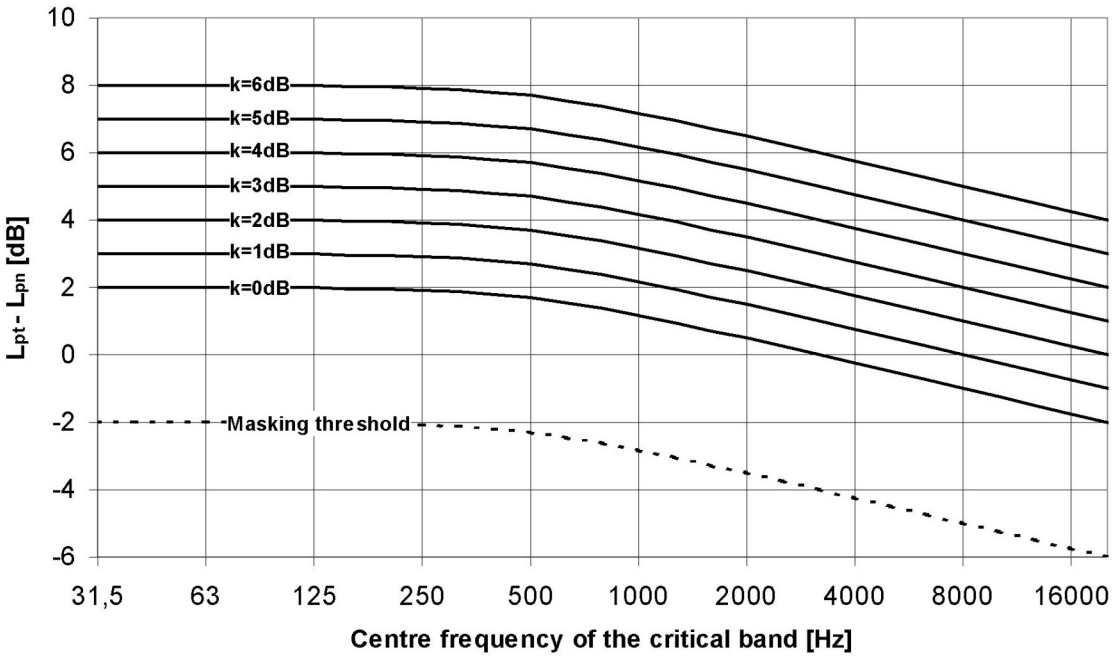

Figure 1: Masking threshold and curves for determining the penalty, k; L_{pt} is the total sound pressure level of the tones in the critical band, and L_{pn} is the total sound pressure level of the masking noise in the critical band.

When several tones (or groups of tones) occur simultaneously in different critical bands, separate assessments shall be made for each of these bands. The critical band containing the most dominant tone(s) (i.e. giving the highest value of ΔL_{ta}) is decisive for the value of ΔL_{ta} and the penalty, k.

3 - DOCUMENTATION

As documentation for the analysis the following information shall be given:

- Measuring time, time window, time- and frequency weighting, effective analysis bandwidth and (at least) one typical spectrum with an indication of the position of the critical band and the average noise level in that band.

- Frequency limits of the decisive critical band, the frequencies and levels of the tones and L_{pt} in that band, the masking noise level in the critical band (L_{pn}), the audibility of the tones (ΔL_{ta}), the size of the penalty (k).
- Tones in other critical bands that may cause a penalty should be mentioned by frequencies.

REFERENCES

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