Prominent tones in noise - Proficiency testing among 30 laboratories of the ISO 1996-2 Annex C method and its predecessors

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Since 1979 the Danish Environmental Protection Agency's Reference Laboratory for noise measurements, DELTA, have arranged proficiency testing for the around 30 approved Danish laboratories that measure environmental noise. Many of these "comparison measurements" have included objective analyses of the prominence of audible tones according to the Joint Nordic Method which are the predecessor and very similar to the method described in ISO 1996 part 2 Annex C. This paper gives examples of (computerized) analyses of the samples from these proficiency tests and states the uncertainties that can be expected when a number of laboratories with different experience and different types of equipment analyze the same samples. The samples are available for future reference and can be downloaded from DELTA's homepage.

1 Introduction

It is a general experience that the presence of audible tones in noise increase the annoyance relative to the same noise (level) without the audible tones. In the legislation of many countries a "penalty" of 3-6 dB is added to the measured noise levels (L_{Aeq}) to compensate for the extra annoyance due to the clearly audible tones in the noise.

An objective method for determining the audibility of tones based on psycho-acoustic principles is described in ISO 1996-2 [2]. The method finds the tonal audibility, ΔL_{ta} (the level above the masking threshold) and transforms it into an adjustment K_T of 0-6 dB to be added to the measured L_{Aeq}..

Although the ISO 1996-2 is intended for environmental noise the method is generally applicable for the declaration of the prominence of tones in noise.

The predecessor to the ISO 1996-method, which was rather similar, had been used in Denmark since 1979 and the method was accepted as a Joint Nordic Method (JNM) in 1984 [1].

In the period from 1979 a number of Nordic laboratories (mainly Danish) have participated in proficiency testing of environmental noise samples (mainly recordings of the noise). DELTA has, as the Reference laboratory for the Danish Environmental Agency, arranged these comparative measurements. The main results concerning the audible tone analysis will be given in this paper.

2 The ISO 1996-2 Annex C method

The method in ISO 1996-2 [2] has also been referred to as the Joint Nordic method version 2 (JNM2)

The aim of the method is to assess the prominence of tones in the same way as listeners do in average. The method is based on the tone to noise ratio within critical bands. Some simplifications, which normally do not have significance for practical noise types, are made in order to make the method easier to use. Results from listening tests with judgments of the audibility of tones and results of analyses done according to this method have shown good correlation. 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 (at least one minute). The audibility of tones with large variations in frequency is handled by looking at a number of frequency spectra, each representing a shorter part of the total measurement time.

The method has always three steps:

1 The narrow-band A-weighted spectrum is found by a frequency analysis (preferably a FFT-analysis with linear averaging for at least one minute).

   It is recommended that the measuring set-up including the frequency analyser is calibrated in dB re 20 µPa, and that Hanning weighting is used as window function. 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 defined as follows: 100 Hz for centre frequencies below 500 Hz, 20% of the centre frequency for frequencies above 500 Hz.

2 The sound pressure level of the tone(s) and of the masking noise within the critical band around the tone(s) are found from the analysis.

   The sound pressure levels of the tones L_{pt} are determined from the spectrum. All local maxima with a 3-dB bandwidth less than 10% of the bandwidth of the actual critical band are regarded as tones. The total tone level for a critical band with more than one tone is found by adding the tone levels from all tones within the band on energy basis.

   The critical band is positioned with its centre frequency at the tone frequency. If a number of tones are present in the range of a critical band, the critical band shall be positioned around the most significant tones.

   The sound pressure level of the masking noise within a critical band is found either by visually assigning an average noise level to all spectral lines or by a computerized assigning the resulting levels of a linear regression of the noise lines of the spectrum. The "noise" lines are found by disregarding all maxima in the spectrum resulting from tones in the band.

   The total sound pressure level of the masking noise, L_{pn} is found by adding the contributions from the assigned levels from all lines in the band, taking into account the overlap due to the weighting function.

3 The tonal audibility, ΔL_{ta} (ie. the tone level relative to the masking threshold, see figure 1) and the penalty K_T is calculated.

   From the tone-to-noise ratio in a critical band, L_{pt}-L_{pn}, both ΔL_{ta} and k_T may be determined by means of Figure 1.

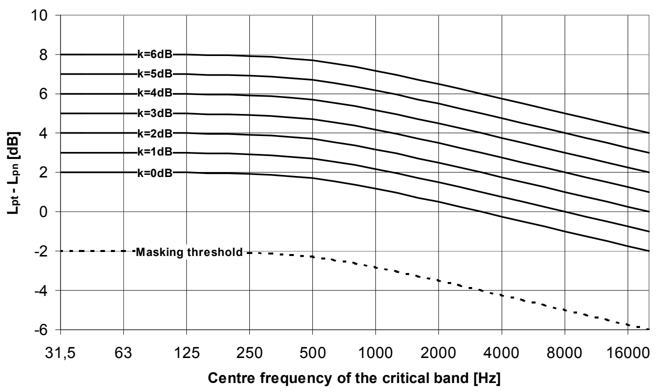

Figure 1: Masking threshold and curves for determining the penalty, k_T. L_{pt} is the total sound pressure level of the tones in the critical band, and L_{pn} is the total sound pressure level of the masking noise in the critical band. k_T is not restricted to integer values.

4 If 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_T.

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

- Averaging 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 masking 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_T).
- Tones in other critical bands that may cause a penalty should be mentioned by frequencies.

A more comprehensive description of the method can be found in reference [3]. The full description is in reference [2], which also contains formulas and procedures for computerisation of the method.

3 Proficiency testing

In order to be accepted for environmental noise measurements in Denmark, laboratories must be approved by the Environmental Protection Agency either by being an accredited laboratory or by employing persons certified to carry out environmental noise measurements. The accreditation and certification process requires a certain level of activity, skills and calibrated instrumentation. To maintain the approval, it is required that the laboratories participate in proficiency testing, now approximately every 18 months.

For the time being there are 28 approved laboratories and proficiency test no. 17 (calculation of environmental noise levels) has just been sent out to the laboratories.

Participation in the proficiency tests are open for all so in some of the tests approximately 1/4 of the laboratories were not approved.

Sometimes the Reference laboratory knows the correct result beforehand because the laboratory has “constructed” the sound samples, but normally the “true result” is found by the following process:

Firstly outliers and results with methodical errors are removed. Results less than one standard deviation from the mean value of the remaining results are regarded as the best results. The true value is defined as the mean value of the best results.

The deviation from the true value of the results from the laboratories is interpreted as a measure for their measuring ability.

4 Proficiency tests of tone prominence

In the period 1979-2006 sixteen proficiency tests has been performed. The number of participating laboratories varied between 9 and 40 with an average of 28. Thirteen of the tests contained analyses of audible tones as part of the task to be solved. In the beginning all the analyses were made by visual inspection of the spectra and a manual calculation. In the recent years many laboratories use software, but still a few laboratories make visual inspection and manual computations. A major part of the sound samples and their analyses are available in reference [4]. The results mentioned in the following are from the reports from the proficiency tests [5].

The noise samples with tones had different complexity:

- stationary tones with a smooth noise spectrum
- more than one tone in a critical band
- complex stationary tones (e.g. sidebands)
- narrow noise bands
- amplitude varying tones, frequency varying tones, varying noise and tones

The standard deviation among the results from the laboratories varied according to the complexity of the noise samples. In the first years the method was new, and not as well specified as in the ISO 1996, and only a few of the laboratories made tone analysis on a regular basis. In the first test in 1979 only 9 laboratories participated and not all made a tone analysis. The second measurement was a field measurement 400 and 800 metres from a power plant. Here the meteorological variations were the main reason for the deviations among the laboratories. This paper deal with the results from the third to the sixteenth proficiency test.

In the following, a number of examples of tone analyses are shown. They are all analyzed with the software: noiseLab Batch Processor, see reference [6]. In all graphs the tones are red, the noise is blue and the “neither nor” spectrum lines are green. The actual critical band is marked with a parallelogram and the range of regression for the noise is the lines “sticking out” from the parallelogram. All analyses are made with an effective analysis bandwidth of 4.5 Hz and Hanning weighting.

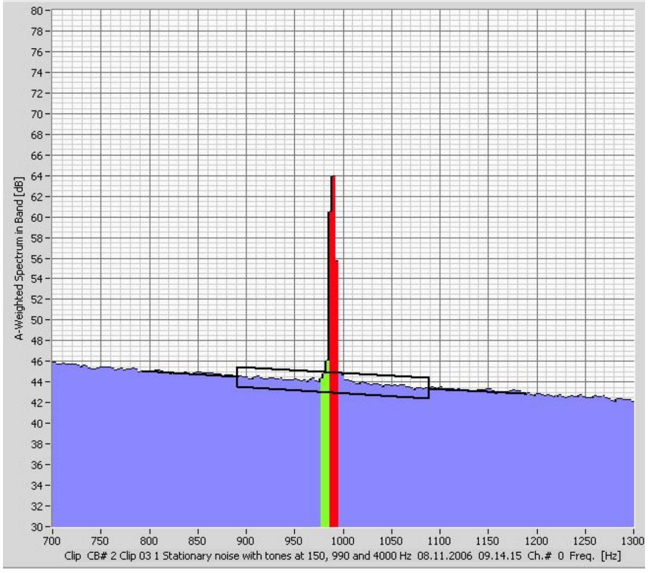

Figure 2: Example of a stationary tone with a smooth noise spectrum. Track 2 on the reference CD. The signatures in the graph are explained in the text.
Total Tone Level L_{pt}: 64.1 dB, Noise L_{pn}: 60.4 dB
L_{pt}-L_{pn}: 3.7 dB, Tonal Audibility ΔL_{ta}: 6.5 dB,
K_T: 2.5 dB

Figure 2 is an example from the third test with 13 participating laboratories. The standard deviation among their results for L_{pt}-L_{pn} were 1.1 dB

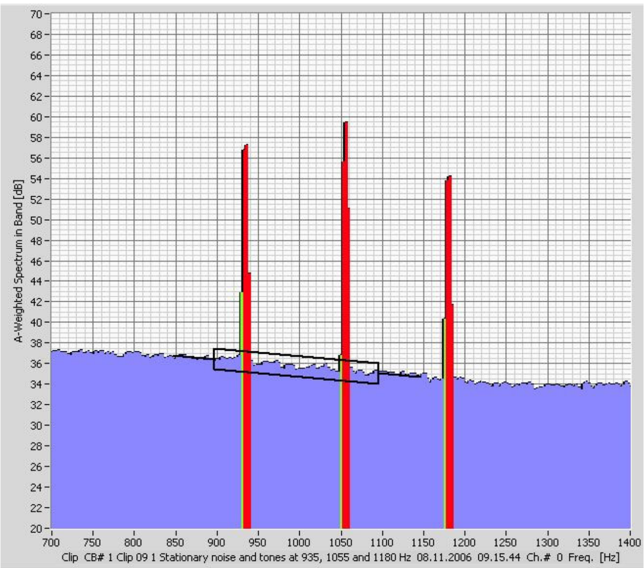

Figure 3: Example of more than one tone in a critical band. Track 9 on the reference CD. The signatures in the graph are explained in the text.
Total Tone Level L_{pt}: 62.0 dB, Noise L_{pn}: 52.2 dB
L_{pt}-L_{pn}: 9.8 dB, Tonal Audibility ΔL_{ta}: 12.6 dB,
K_T: 6.0 dB

Figure 3 is an example from the ninth test with 32 participating laboratories. The standard deviation among their results for L_{pt}-L_{pn} were 0.5 dB

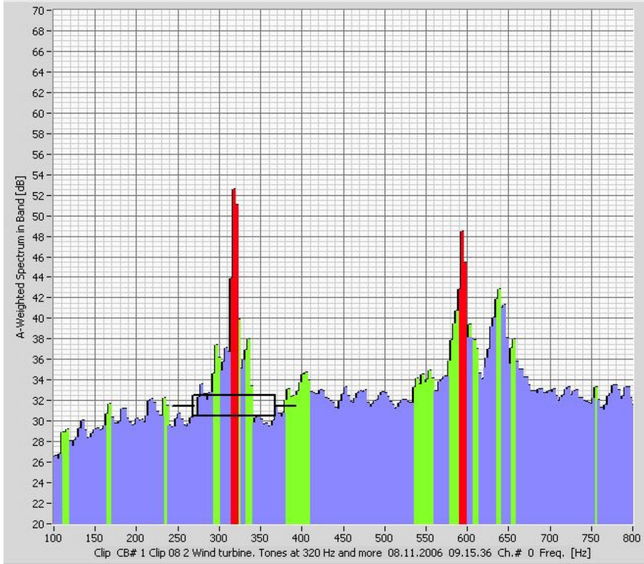

Figure 4: Example of complex stationary tones (sidebands). Track 8 on the reference CD. The signatures in the graph are explained in the text.
Total Tone Level L_{pt}: 53.4 dB, Noise L_{pn}: 44.9 dB
L_{pt-Lpn}: 8.5 dB, Tonal Audibility ΔL_{ta}: 10.6 dB,
K_T: 6.0 dB

Figure 4 is an example from the eight test with 36 participating laboratories. The standard deviation among their results for L_{pt}-L_{pn} were 1.3 dB

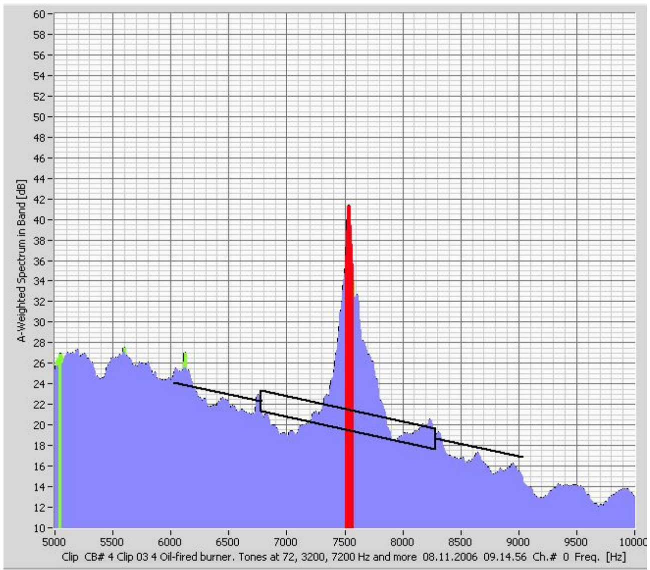

Figure 5: Example of a narrow noise band (1,7% of a critical band). Track 5 on the reference CD. The signatures in the graph are explained in the text.
Total Tone Level L_{pt}: 49.5 dB, Noise L_{pn}: 45.9 dB
L_{pt}-L_{pn}: 3.6 dB, Tonal Audibility ΔL_{ta}: 8.6 dB,
K_T: 4.6 dB

Figure 4 is an example from the third test with 13 participating laboratories. The standard deviation among their results for L_{pt}-L_{pn} were 1.4 dB

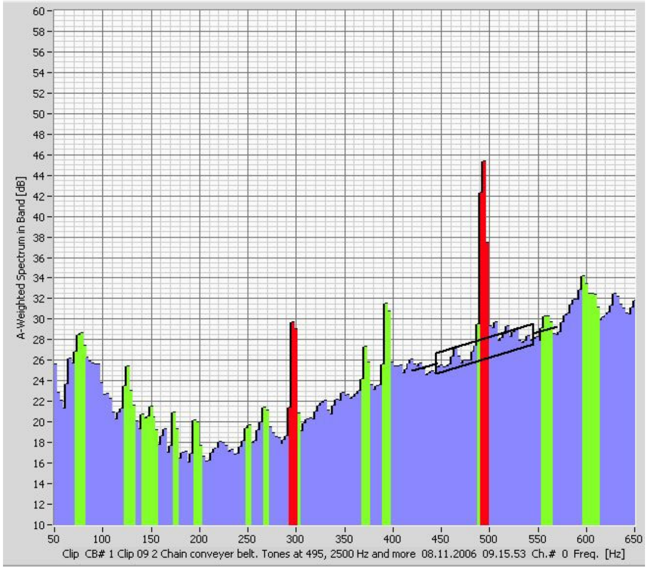

Figure 6: Example of varying tones and noise. Track 10 on the reference CD. The signatures in the graph are explained in the text.
Total Tone Level L_{pt}: 45.7 dB, Noise L_{pn}: 40.6 dB
L_{pt}-L_{pn}: 5.2 dB, Tonal Audibility ΔL_{ta}: 7.5 dB,
K_T: 3.5 dB

Figure 6 is an example from the tenth test with 26 participating laboratories. The standard deviation among their results for L_{pt}-L_{pn} were 2.9 dB

Test	Year	No. of Lab	St. dev [dB]	Type of tone
3	1984	13	1.5	Stationary
3	1984	13	1.1	Stationary
3	1984	13	1	Stationary
3	1984	13	1.1	Stationary, three tones
3	1984	13	1	Ampl. var. long integr.
3	1984	13	2.2	LF ampl. variations
3	1984	13	1.1	Small variations
3	1984	13	1.4	Narrow band
5	1987	32	1	Stationary
6	1989	40	1	Stationary
7	1990	38	0.8	Frequency modulated
8	1992	36	1.3	Sidebands
9	1993	32	0.5	Stationary, three tones
9	1993	32	0.5	Stationary
9	1993	32	4	Large ampl. variations
10	1994	26	2.9	Amplitude var. tone
11	1998	35	3.7*	Ampl. + freq. var. tone
12	2000	35	5.7*	Ampl var + drift
13	2001	36	1.1	Two tones
16	2006	33	0.4	Stationary

Table 1. Overview over the standard deviations on L_{pt}-L_{pn} from proficiency testing of tone analyses among Nordic (mainly Danish) laboratories. The large variations marked with an asterisk are due to measurements made at different times with different integration times.

From Table 1 it is seen that the stationary tones have the smallest standard deviations. It should be noted that the proficiency tests are made with the Joint Nordic Method version 1. According to this method the level of amplitude varying tones should be measured as the maximum level with time weighting F. This is a more difficult measurement than the long time averaging method used in ISO 1996-2. For this reason one may expect the that future standard deviations among the laboratories for amplitude varying tones measured according to ISO 1996-2 will be in line with the standard deviations for the stationary tones.

From the table it is seen that there is a tendency for standard variations for tests with stationary tones to decrease with time.

5 Conclusion

A method for determining the audibility of tones is described in ISO 1996-2 [2]. The aim of the method is to assess the prominence of tones in the same way as listeners do in average. Therefore the method is based on psychoacoustic principles. The correlation with results from listening tests is described elsewhere.

The predecessor of the ISO 1996 method has been used in the Nordic countries since 1979 and a number of proficiency tests of this method have been made. The sound samples from these are available for future reference [4].
From the results of these tests it can be concluded, that when a number of laboratories with different experience and different types of equipment analyze the same samples using the ISO 1996-2 Annex C method standard deviations in the range 0.5-1 dB can be expected for the tone declaration value, ΔL_{ta} in normal cases. In complicated cases standard deviations 2-3 times this magnitude may occur.

References

[1] Danish Environmental Protection Agency, Guidelines for Measurements of Environmental Noise, 6/1984 (in Danish), Nov. 1984.

[2] ISO 1996-2 Acoustics – Description, assessment and measurement of environmental noise. Annex C: Objective method for assessing the audibility of tones in noise. February 2007

[3] Pedersen. T. Holm. Søndergaard. Morten : Objective Method for Assessing the Audibility of Tones in Noise. Internoise 2000 proceedings.

[4] Pedersen., T. Holm: Reference CD – Sound Samples with Tones in Noise. Analyses according to ISO/DIS 1996-2 Annex C. The report and the sound samples can be downloaded from www.noiselab.dk. Search for “Description of the Tone Files”

[5] Reports from the Environmental Protection Agency’s Reference laboratory (DELTA) on proficiency tests 1-16. All in Danish. The latest reports can be downloaded from www.delta.dk/reflab

[6] DELTA. noiseLAB, a software recording and analysis package see www.noiselab.dk.