QUANTIFICATION OF TONAL PENALTIES IN ENVIRONMENTAL NOISE ASSESSMENTS

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1 INTRODUCTION

Most people listening to an unwanted noise of a certain level find the noise more annoying if it contains audible tones. In noise assessment work it has been usual to add some dB in penalty to the measured level if it contains tonal sounds. Earlier it was common to judge the tonality based on listening to the noise. Recently it has been the aim to develop means to obtain an objective measurement of the prominence of tones. A German draft for an objective calculation was published in 1992 [3]. The experience since then has led to the proposal of some modifications. Furthermore, an International standard is also in preparation. The paper describes the difference between the standards and how the tonal evaluation may be implemented in a sound level meter.

2 PENALTY FOR TONAL COMPONENTS

In noise assessments, noise levels are usually measured and calculated as A-weighted sound levels or as levels for frequency bands of one- or one-third-octave bandwidth. It is common to add some decibels in penalty to the result if the sound is tonal or impulsive. Although a sound level meter with standardised octave-filter is sufficient for the level measurement, it will in general not be sufficient for judging the tonality.

In the proposal for a revised version of the International standard ISO 1996-2: *Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels,* an objective method for assessing the audibility of tones in noise is described in a normative Annex C of the proposal. 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.

The result of the assessment of each tonal component is a level correction in the range 0 to 6 dB, which shall be added to measured frequency-weighted level.

Norsonic has manufactured sound level meters for automatic assessing the audibility of tones based on the German draft standard from 1992: *Entwurf DIN 45681: Bestimmung der Tonhaltigkeit von Geräuschen und Ermittlung eines Tonzuschlages für die Beurteilung von Geräuchimmissionen.* We are waiting for the International standard to be finalised and hope that in the future, the same procedure can be applied in different countries.

3 SUMMARY OF THE METHOD

The sound signal is analysed with a narrow-band frequency analyser, normally of the FFT type. Peaks in the spectrum are regarded as potential pure tones. The level of this tone is compared with the level of the rest of the signal with frequencies around the pure tone. The width of the frequency band for the comparison is called *critical band*. The width of the critical band is a function of the

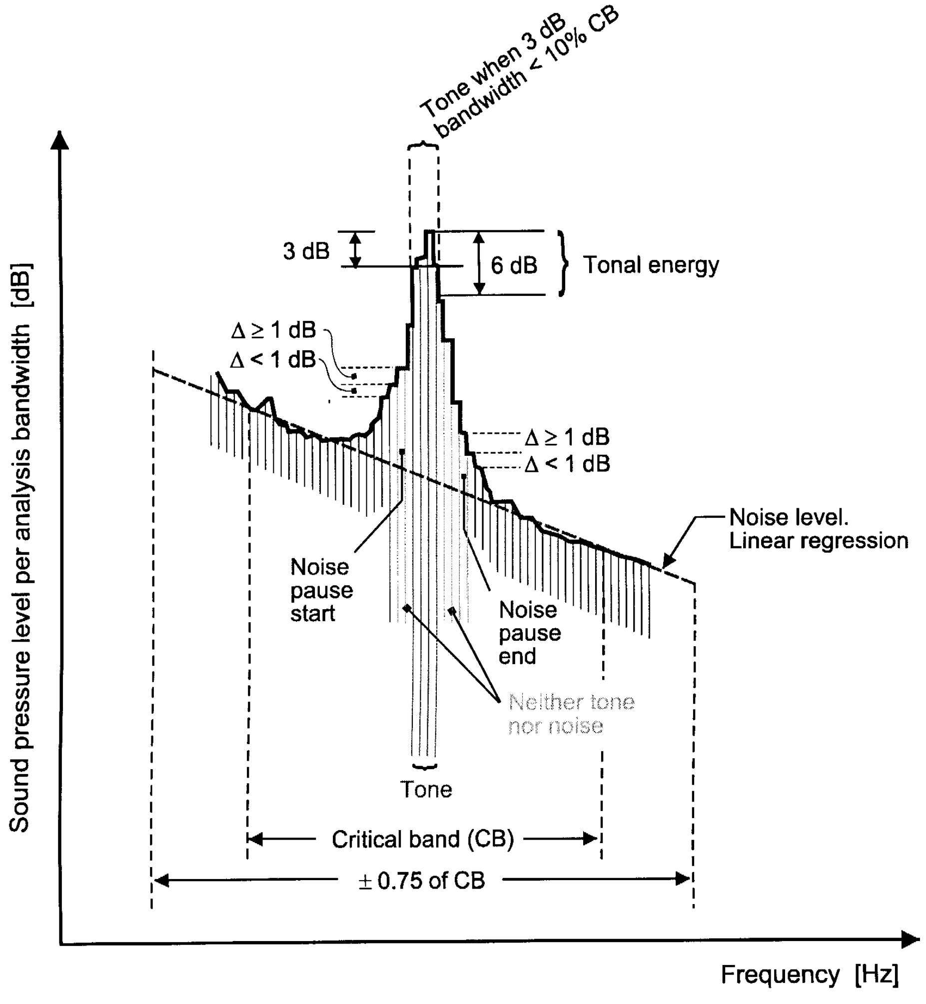


***Fig. 1** Illustration of the calculation procedure from ISO 1996-2 (Draft june 2001)*

pure tone frequency and is usually 100 Hz for lower frequencies and increases for higher pure tone frequencies. The critical bands are established through psychoacoustic research and so selected that a tone outside a critical band do not contribute significantly to the audibility of the tone inside the critical band.

If the level of the pure tone are a certain number above the level of the rest of the signal within the same critical band, the tone is regarded to be audible. Dependent on how much above the detection level the pure tone is found to be, a penalty in the form of a certain number of decibels to be added to the measured A-weighted level is calculated. The penalty is in the range 0 to 6 dB.

The penalty is calculated for each pure tone. Finally, the largest value of all calculated penalty values is used for correcting the overall level.

The analysis and calculation may be done with an ordinary FFT-analyser, but the analysis is time-consuming and requires a certain skill from the user.

Table 1 Comparison of Methods			
	ISO 1996-2 (June 2001)	**DIN 45681 (1992)**	**DIN 45681 (June 2001)**
Frequency resolution	< 5 % of critical bandwidth (5 Hz)	< 8 % of critical bandwidth (8 Hz)	< 4 % of critical bandwidth (4 Hz)
Width of critical band	100 Hz for f ≤ 500 Hz 0,2 f for f > 500 Hz	Formula, starting at 100 Hz	Formula, starting at 100 Hz
Recommended window for FFT	Hanning	Hanning	Hanning
Calculation of the level of the tone	Energy summation of highest lines	Highest line	Energy summation of highest lines based on an iterative procedure
Picket fence correction	Yes	No	Yes
Masking noise calculation	Energy summation based on values from linear regression	Energy summation	Energy summation based on an iterative procedure
Audibility level	Dependent of frequency	Dependent of frequency	Independent of frequency
Level adjustment – penalty	0 – 6 dB	0 – 6 dB	0 – 6 dB

Table 1 shows a comparison between the ISO 1996-2 proposal, the DIN 45681 draft from 1992 and the proposed second edition of same DIN-draft.

The width of the critical band is a function of the frequency of the pure tone. The lowest width for all the three standard listed are 100 Hz. As shown in table 1, the ISO-proposal uses a very simple

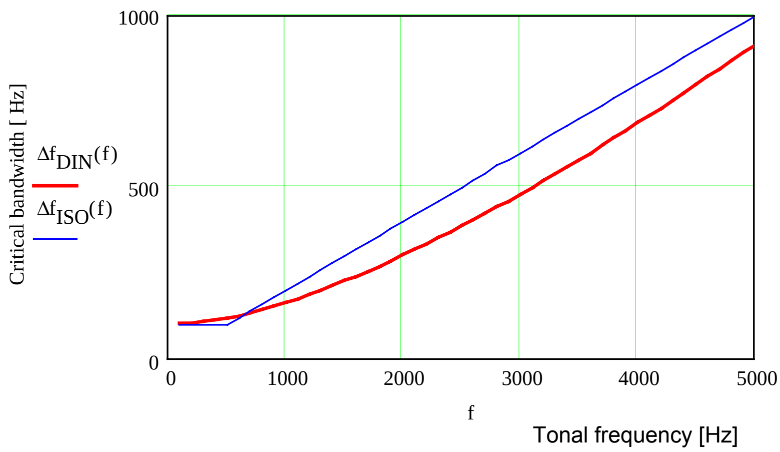


Fig 2 The critical bandwidth in the proposal for ISO 1996-2 and in DIN 45681

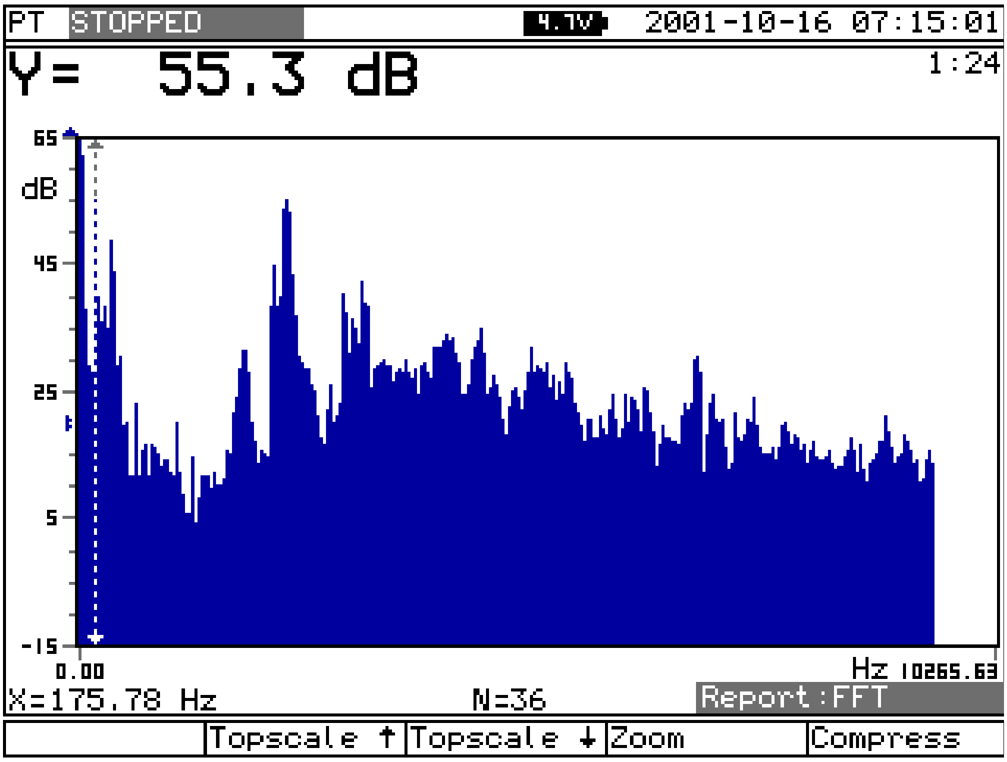


Fig. 3 *FFT analysis of the measured signal as displayed on the Nor-121*

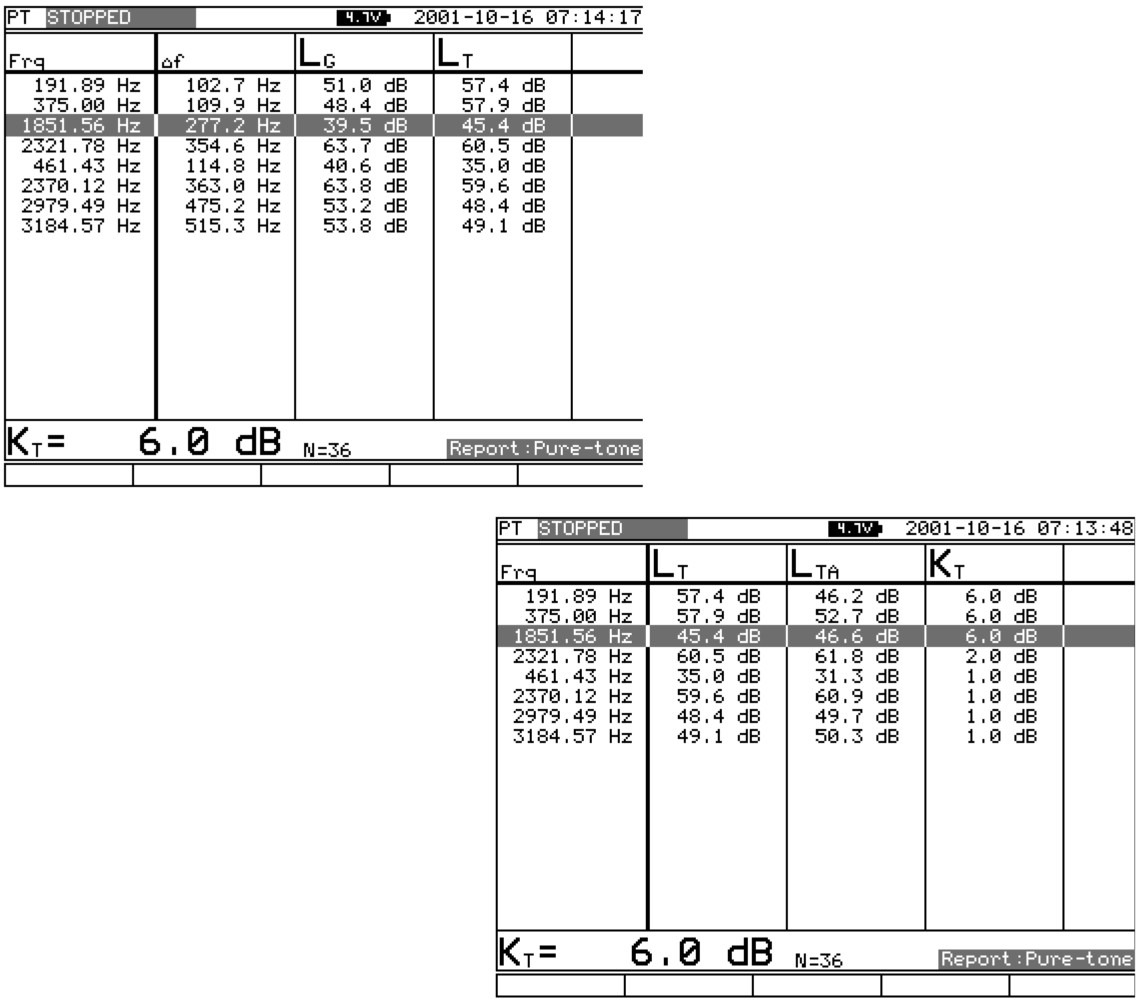
formula. The formula in the DIN-standards is more complicated. The critical widths are shown in figure 2.

A pure tone and a noise signal behaves differently when they are frequency-analysed. The level of the pure tone will be independent of the frequency resolution in the analysis, whether the noise signal level will decrease when the resolution is increased. The noise has therefor to be described by its spectral *density*. Therefore when the tonal component and the noise are compared, the effective bandwidth (resolution) of the analyser or FFT-processor has to be taken into consideration. For an FFT, which applies a Hanning window function, the noise bandwidth is equal to 1,5 times the distance between the frequency lines.

4 IMPLEMENTATION IN A SOUND LEVEL METER

Norsonic has implemented the tone detection method specified in the German draft standard DIN 45681 in two models of sound level meters: *Nor-110 and Nor-121*. Although they are quite similar, this description will be based on the Nor-121 instrument.

The sound level meter Nor-121 is basically a real-time analyser where the noise may be analysed in octave- or one-third-octave bands to obtain the traditional sound pressure levels over a certain measurement period or just the A-weighted sound level. During the measurement, the instrument has the ability to store the microphone signal as digital samples of the waveform. The tonal analysis may be performed on the recorded waveform or a new measurement may be initiated for this purpose.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Frq	Δf	L_G	L_T
191.89 Hz	102.7 Hz	51.0 dB	57.4 dB
375.00 Hz	109.9 Hz	48.4 dB	57.9 dB
1851.56 Hz	277.2 Hz	39.5 dB	45.4 dB
2321.78 Hz	354.6 Hz	63.7 dB	60.5 dB
461.43 Hz	114.8 Hz	40.6 dB	35.0 dB
2370.12 Hz	363.0 Hz	63.8 dB	59.6 dB
2979.49 Hz	475.2 Hz	53.2 dB	48.4 dB
3184.57 Hz	515.3 Hz	53.8 dB	49.1 dB

K_T= 6.0 dB N=36 Report:Pure-tone

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Frq	L_T	L_{TA}	K_T
191.89 Hz	57.4 dB	46.2 dB	6.0 dB
375.00 Hz	57.9 dB	52.7 dB	6.0 dB
1851.56 Hz	45.4 dB	46.6 dB	6.0 dB
2321.78 Hz	60.5 dB	61.8 dB	2.0 dB
461.43 Hz	35.0 dB	31.3 dB	1.0 dB
2370.12 Hz	59.6 dB	60.9 dB	1.0 dB
2979.49 Hz	48.4 dB	49.7 dB	1.0 dB
3184.57 Hz	49.1 dB	50.3 dB	1.0 dB

K_T= 6.0 dB N=36 Report:Pure-tone

***Fig. 4** Two displays from Nor-121 shows the detected pure tones, together with the associated critical bandwidth Δf, masking noise level L_G ,the level of the tone L_T, the A-weighted level of the tone L_{TA} and the penalty K_T. The K_T at the bottom shows the number of decibels to be added as penalty to the overall level.*

The instrument operates normally with a sampling frequency of 48 kHz. For the tonal analysis this is reduced to 24 kHz after a suitable bandwidth reduction to about 10 kHz. A Fast Fourier Transform (FFT) is performed on these samples. The transform has order 14 (16384 samples) and will therefore have a frequency resolution of 1,46 Hz. This satisfies the requirements in the present German draft standard for 8Hz, the proposed modification German standard for 4 Hz and the committee draft for the ISO standard [1] which require 5 Hz resolution. Some standards for wind mills require a resolution of 2 Hz.

The FFT applies the Hanning window to each block of samples and has the possibility to make a linear average of more blocks. The average value of at least 30 auto-spectrum is required as requested by the standard. Figure 3 shows the result of the FFT as presented on the instrument display. The display may be zoomed for more graphical resolution.

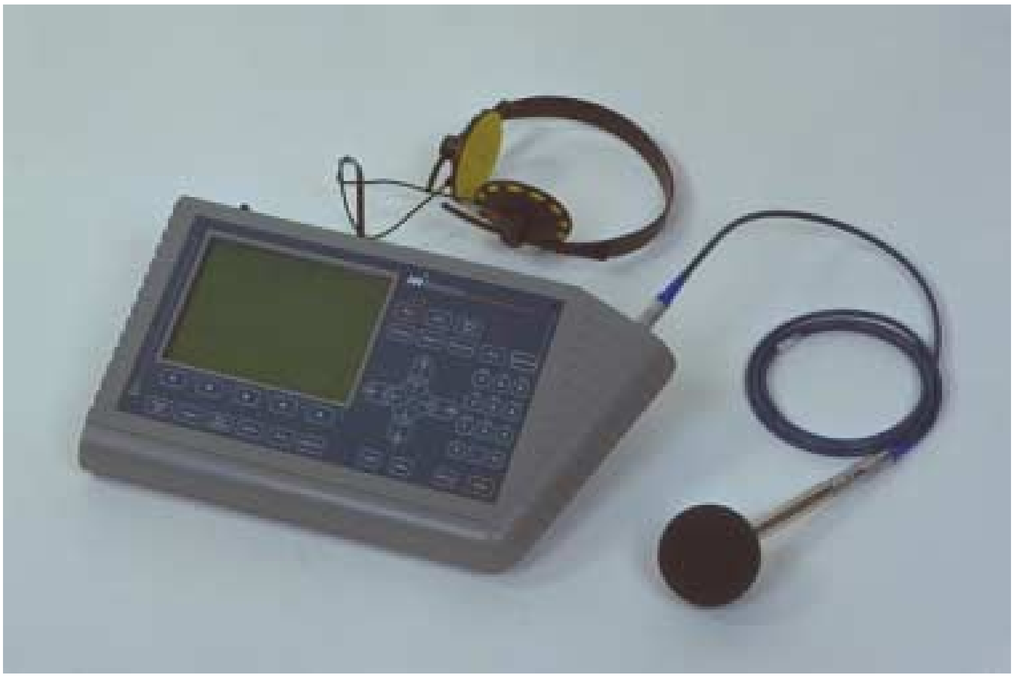

Fig. 5 *The sound level meter Nor-121 for quantification of tonal penalties.*

The instrument uses the procedure specified in the German standard for finding audible tones. The result is presented as shown in figure 4. Each detected tone are listed with its frequency, the level of the tone, the A-weighted level of the tone, the bandwidth of critical band, the level of the masking noise, and the penalty value K_T. Furthermore, the overall penalty is also indicated.

5 CONCLUSION

The calculation of the penalty for tonal components in noise assessments can be automatically done in a digital sound level meter. It would be a benefit for the user as well as the instrument manufacturers if an International standard for the procedure can be defined and accepted.

6 REFERENCES

1. ISO/CD 1996-2: Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels (2001-05-21)

2. IEC 61400-11, Ed2: Wind turbine generator systems – Part 11: Acoustic noise measurement techniques (2000-09) Draft for discussion.

3. DIN 45681 Bestimmung der Tonhaltigkeit von Geräuschen und Ermittlung eines Tonzuschlages für die Beurteilung von Geräuchimmissionen (Draft 1992).

4. Dirk Sagemühl, Lothar Schmidt: Revision of E DIN 45681 (Tonality), Internoise 2001, Paper 624