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Implementation of ISO 1996-2 (2007) pure tone assessment in a sound level meter

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Noise can be said to be tonal if it contains a distinguishable, discrete, continuous note. This may include a whine, hiss, screech, hum, etc., and any such subjective finding is open to discussion when reported. This is important when it is considered that the likelihood of a noise-provoking complaint depends on its relative level to background, and whether or not it has certain audible characteristics. Fortunately, ISO 1996-2 (2007) provides objective FFT (reference) and 1/3-octave band (simplified) assessment procedures to be used to verify the presence of audible tones if their presence is in dispute. Brüel & Kjær has implemented the methodology of ISO 1996-2 in relation to assessing the audibility of prominent discrete tones in environmental noise into its innovative 2250 and 2270 hand-held analysers. This paper describes the implementation in hand-held instrumentation.

1 Introduction - The rating level

When environmental noise from, for example, industrial plants is assessed, it is generally acknowledged that noise containing tonal components is more annoying than noise with no tones. In ISO 1996, the descriptor to compare to the noise limit is the rating level, L_r [1, 2]. The rating level is defined as the A-weighted time equivalent noise levels, L_{Aeq} corrected for the influence of operation time of the noise source, reflections, reverberation time and residual noise. If the noise contains annoying impulses or tones an adjustment is added to the rating level.

2 Determination of the adjustment for annoying tones

The determination of the rating level is described in "ISO 1996 (2007) Part 2: Determination of environmental noise levels" [2]. In the ISO standard, the determination of the adjustment for annoying tones is determined using two different methods. Each method is given its own *informative* annex:

1. Annex C: Objective method for assessing the audibility of tones in noise – Reference method. The method is based on the psychoacoustic concept of critical bands. The definition of a critical band is that noise outside the band does not contribute significantly to the audibility of the tones inside the critical band. The FFT analyzed spectrum is searched for local maxima. When the tone candidate(s) are identified their levels are compared to the noise in the critical band placed symmetrically around the suspected tone. When the difference reaches a certain level, a tone is found. The bandwidths of the critical bands are 100Hz at frequencies below 500Hz and 20% of the centre frequency at higher frequencies.

2. Annex D: Objective method for assessing the audibility of tones in noise – Simplified method. This method is based on 1/3 octave analysis. The 1/3-octave spectrum is searched for peaks and the search criterion is the level difference between a peak and its adjacent bands. When this difference reaches a certain frequency dependent level a tone is found.

ISO 1996 Clause 8.4.7 says that if the noise characteristics at the receiver location include audible tones an objective measurement shall be carried out according to either the reference or the simplified method. The microphone positions with the most audible tone(s) shall be selected.

3 Subjective or objective analysis?

In accordance to the practice in most measurement situations, ISO 1996 recognizes that the first evaluation of "tone" or "no tone" is carried out by the human ear. However, deciding that there is no tone and that no further analysis should be carried out is also a complicated decision, especially for measurement technicians that don't carry out noise measurements on a regular basis.

Taking into account that the "tone/no tone decision" may lead to considerable costs both on an economic basis for a noise-polluting company and on a personal basis for the neighbours to the company, some kind of proof or objective measurement is very often wanted. Preferably, the results of objective measurement supporting the subjective decision should be given on the spot.

However, the result of the tone/no tone measurement should give reliable results and, in many situations, this implies the use of FFT analysis. But FFT is considered complicated to carry out by many environmental technicians. Fortunately the ISO FFT method describes in details how the FFT-measurement should be carried out, and how the FFT-analyzed spectrum should be assessed without giving a lot of choices and possibilities for the user to consider.

4 Tone Assessment on Type 2250

Software (Tone Assessment Option BZ-7231) has been developed for the Type 2270 and 2250 Hand-held Analyzers from Brüel & Kjær (referred to as Type 2250 from now on). The design philosophy is based on extensive research, which concluded that the instrument should be easy and safe to use, while at the same time incorporating clever features. Type 2250 has been awarded several prizes for its combination of excellent ergonomics and attractive design. Innovative functions include a colour, touch screen interface, in-built sound recording and automatic detection of, and correction for, a windscreen. Type 2250 can host a

number of software modules. The combination of software modules and innovative hardware makes the instrument into a dedicated solution for performing high-precision measurement tasks, in environmental, occupational and industrial application areas.

The philosophy behind the implementation of the tone assessment according to ISO 1996-2 is that the user shall have a tool that gives him the correct tone assessment result without having to bother much with the setting of the analysis parameters [3]. Of course other, more advanced users, need to be able to control the settings in detail by themselves. These different needs for different users have been dealt with by applying a default setup to the application.

5 The ISO reference method and the challenge from the requirement for frequency resolution

The next step is "just" to implement the method (FFT-analysis and assessment) into the hand held analyzer, perform the analysis and show the value of the adjustment to be added to the rating level. Brüel & Kjær has earlier implemented the FFT based Joint Nordic Method version 2 (JNM2) [4] into other sound level meters and into PC software. The JNM2 is an early version of the ISO Reference method and they only differ very little.

Looking back on earlier implementations of JNM2 in our handheld analyzers, the solutions seem to suffer from shortage of calculation power and display resolution. Based on a spectrum with 400 FFT lines, analyzing the frequency range from 20Hz to 20kHz had to be divided into 3 frequency ranges. The ISO standard (as well as JNM2) requires that the effective analysis bandwidth is less than 5% of the bandwidth of the critical band at any frequency. At frequencies below 500Hz the critical bandwidth is 100Hz. This means that we need an effective analysis bandwidth of less than 5Hz.

The FFT analyzer software for the Type 2250 has a maximum of 6400 lines, giving an effective analysis bandwidth of 4,7Hz when the frequency range from 20Hz to 20kHz is analyzed in one FFT shot [3]. This makes this platform optimized for complying with ISO in the full audible range without having to divide the FFT analysis into smaller ranges.

To carry out a tone assessment in compliance with ISO 1996-2 Annex C, Reference method (FFT based) and get the value of the tone adjustment, K_t to be added to the L_{Aeq} for calculating the rating level, the steps are as follows [5]:

- Turn on the FFT analyzer built into Type 2250
- Turn on tone assessment and accept the default settings (Figure 1). Accepting the default settings will set FFT analysis parameters to match the complete audible range from 20 to 20kHz and select A-weighting as requested by ISO 1996.
- Measure. The tone assessment calculations are automatically carried out when the measurement is stopped
- View the result. By default the settings of the result view are as can be seen from Figure 2.

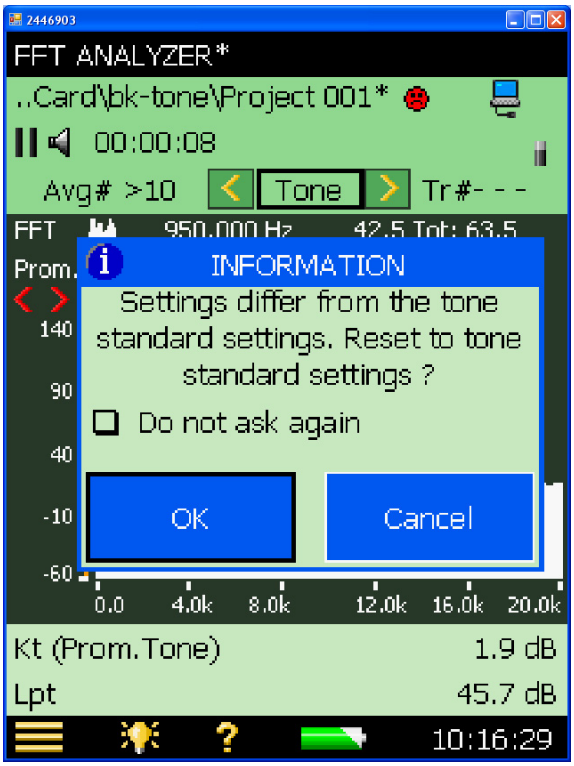

Figure 1 Accepting the default settings will select a suitable FFT-range and select settings that match the requirements in the ISO standard

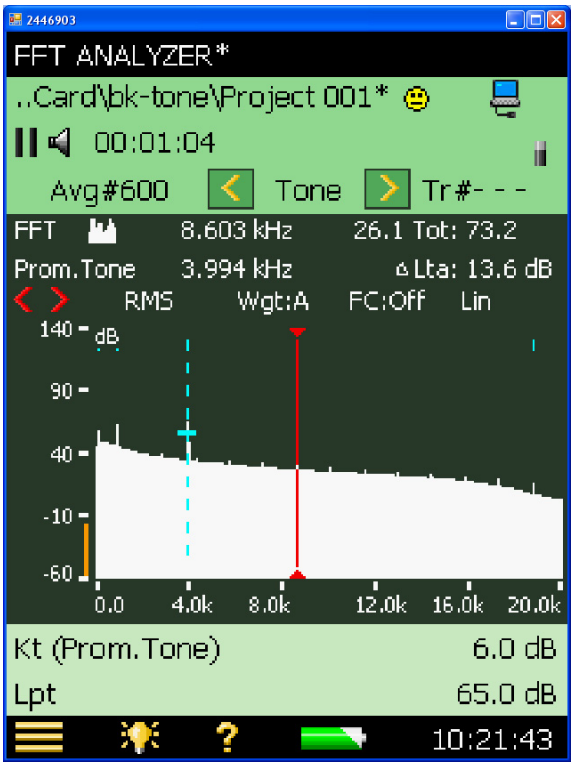

Figure 2 The results from the default tone assessment result view. The complete frequency range may be investigated in this view

The result can be zoomed on both x- and y-axis to enlarge the interesting part of the analysis result and relevant parameters may be selected and shown in the screen.

5.1 Results from tone assessment using the reference method

The tone result view holds a lot of information and functionality:

1. Graphic view of the FFT-spectrum
2. Results from the tone assessment.
    a. K_t, the adjustment, to be added to the L_{Aeq} value to obtain the rating level and the tone level (shown in the default view)
    b. L_{pt}, the tone level, the sum on energy basis of all tones in the selected band (shown in the default view, where the decisive band is selected by default)
    c. Detailed results from the tone assessment both from the overall results for the total spectrum and details for each critical band or detected tone. The accessible parameters (L_{pn} (the noise level in the selected critical band), ΔL_{ta} (the difference between the tone level and the noise level in a critical band), L_{pti} (the tone level for the selected tone) and Critical band (start and stop frequency of critical band embracing the selected tone) – all abbreviations refer to the definitions in the ISO standard.
3. General FFT results such as selection of maximum spectrum, read out of number of lines and the tone frequency corrected for the Picket Fence and much more parameters may be selected
4. L_{Aeq} and other broadband parameters from the sound level meter may be selected
5. Smiley status codes. If the analysis is not performed according to ISO 1996 or if the results of the tone assessment is not fully reliable a smiley indicates that something needs the user's attention.
6. Generate tone at cursor. Tapping on the loudspeaker icon will turn on a tone generator that puts out a pure tone on the headphone socket.

6 The implementation of the Simplified method

The simplified tone assessment based on 1/3 octave analysis is implemented on Type 2250 using the same design principles as in the FFT implementation. The default setup pop up will again guide the user to an analysis that complies with ISO 1996. The great advantage of the 1/3 octave implementation is that it is an option to be turned on with the logging and frequency analyzer templates that many users already use for environmental measurements.

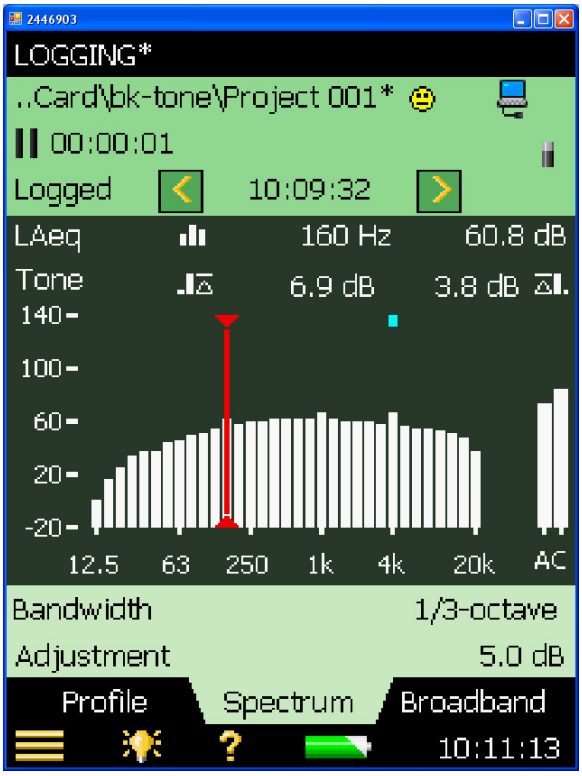

Figure 3 The result display for tone assessment using the simplified, 1/3 octave based method

The result of the tone assessment is – again - the adjustment to be added to the L_{Aeq} value to calculate the rating level. The adjustment is an "on/off" adjustment. The size of this adjustment is indicated by a range of values in ISO 1996-1 (2003) [1] and the size may be configured by the user. From the result display (figure 3), the differences to the left and right of the selected band may be read.

7 Manual or default setup

If the user doesn't accept the default setup, the tone assessment will be carried out with the settings as they are. This functionality makes the tone assessment more flexible and allows the user to e.g. focus on a narrower frequency range or read out detailed results for adapting the reference method algorithms to obtain results that comply to local FFT based standards.

Selecting a smaller number of FFT lines than the 6400 lines used by the default setup will lead to shorter calculation times. By selecting a suitable combination of frequency range and number of lines the analysis setup can be optimized and a reduced calculation time can be achieved.

Using the default setup with 6400 lines covering the frequency range from 20 to 20kHz may lead to a 1-3 minutes calculation time in the worst case. Usually the calculation time is less than 30 seconds for normal spectra.

Another way of reducing FFT calculation times for spectra with many tones is to increase the tone search criterion to a higher value than the 1dB that is suggested as default by the reference method in the ISO standard. This is especially useful for analyzing spectra with short averaging times.

8 Time variant tones

Tones may vary with time either in level or in frequency. By default the ISO reference method suggests an averaging time of 60 seconds or more. If the tone frequency varies the tone will smear out and if the averaging time isn't shortened the reference method may not detect the tone even though it is audible. The solution to analyzing tones that vary with frequency is to divide the averaging time into shorter intervals and manually average the result. However, the standard does not contain specific definitions of how to average the results from analysis of time varying tones. If it did, automatic averaging procedures could be implemented in different software with only small deviations between the solutions. Type 2250 does not include automatic procedures for averaging results for time variant tones.

9 Interaction with the subjective evaluation

Objective tone assessment is meant for producing an objective result (the value of the adjustment to the rating level) that refers to the subjective evaluation of the average listener. This means that it must be verified that the obtained objective result is valid with respect to subjective evaluation. To support and improve the subjective skills of the user the generation of pure tones and sound recording has been built into the Type 2250.

To help the user to verify the presence of pure tones, a tone generator has been built into the FFT based tone assessment software. Tones that match the frequencies of the detected tones in the noise spectrum may be generated from the headphone socket. This is intended for:

- Subjective verification of the detected tones
- Identifying the noise source(s)
- Interactive dialogue with e.g. a complainant

Sound recording is always available with the Type 2250. Sound recordings are very important to environmental noise measurements for documentation, and dialogue with complainants, industries and other consultants.

10 Experiences of implementing the ISO standard

Implementing the FFT based ISO Reference method was straight forward and we found the structure of the annex very useful. The annex has three layers

- Introduction – For every body with just a bit of interest in this field
- Objective method – For those who are going to make the analysis either:
  - by hand or
  - by using a piece of software
- Documentation – for programmers of the software

While implementing the method the development team found the structure of this annex very clear and the division into different layers made it easily accessible for all stakeholders, programmers as well as management and application specialists.

During the implementation we encountered one minor problem that lead to a decision that may or may not be as intended by the ISO working group. The doubt concerns the situation when the tone peak only embraces two or three FFT-lines. The most correct way to deal with this is to use a Picket Fence algorithm to calculate the tone level but since this is not mentioned in the standard it was decided only to add up the FFT-lines on an energy basis.

The principle of comparing the level in one 1/3 octave band to levels of the adjacent bands is quite uncomplicated and straight forward. The complete annex is very brief, and wordings as "possible choices" are used. To comply with the standard the development team decided to make frequency divisions, level differences leading to the tone/no tone indication and frequency weightings fully user configurable.

The method for calculating the level difference between one spectral band and its neighbours is not defined in the standard. When a band is taller than both its neighbouring bands the level difference to the neighbours may be calculated either as the mean of the difference to both the bands or as the difference to the maximum of the two neighbouring bands. The last method was chosen for the implementation.

This choice may lead to the result that a pure tone with a frequency very close to the limit of at 1/3-octave band limit are not detected because the energy from the tone is spread between two 1/3 octave bands. However if the approach that searches the 1/3 octave spectrum for tones by detecting the average difference to the neighbouring tones had been chosen this may have lead to false detection of a tone in a band where there is no tone but just a change in the spectrum.

In the standard there is no suggestion for the size of the adjustment. But since the result of the tone assessment is the value if the adjustment the development team decided that the default setting of the on/off adjustment should be given a value different from 0dB. The default value of the adjustment is set to 5dB in accordance with earlier versions of this and other methods.

The broadband weighting to be used with the simplified method is not defined in the standard. But for the default settings a choice was needed. In accordance with the settings of the reference method A-weighting is selected when the default settings are applied.

11 Test material for verifying the obtained analysis results

The Reference method is documented by DELTA in "Reference CD – Sound Samples with Tones in Noise Analyses according to IDO/DIS 1996-2 Annex C" [6]. The

development team found this material very well documented and easy to use for testing the measurement correctness of the complex algorithms from Annex C, Reference method.

Validating the simplified method was done using the Brüel & Kjær PC software Evaluator Type 7820 in combination with spreadsheet calculations.

12 The first experiences with the new handheld "tone meter"

At the time of writing we only have a few observations of the effect of the new more easy to use "tone meter". But the beta testing of the simplified method and the first half year with the released software for tone assessment according to the reference method has lead to the following results.

Much more tones are found! The simplified method is implemented into the 1/3 octave display that Type 2250 users very often use for assessment of environmental noise. This leads to a lot more focus on tones and probably more FFT based analysis in accordance with the reference method.

Using the reference method indoors at frequencies from 20 to 20kHz leads to detection of many tones at frequencies above 10kHz. Of course the ISO 1996-2 standard only refers to exterior noise but one cannot avoid thinking that perhaps the frequency range of the method should be restricted only to embrace the frequencies up to approximately 10kHz.

Using the reference method at very low noise levels may lead to the detection of tones that are below the threshold of hearing and therefore not audible. In some cases tones may even be detected in the inherent noise of the measurement equipment itself. Care has to be taken to identify the true cause of results at very low noise levels.

In the "old" days, tone assessment would only be made if there was a serious suspicion that it would be worth spending the consultant's time and the customer's money making an FFT based tone assessment. Now the cost of the tone assessment is much smaller and this will definitely lead to more reliable rating levels with smaller influence of the subjective evaluation made by environmental officers and measurement technicians.

Tone assessment is a process that involves both and objective evaluation and the risk of detection of tones is dealt with by adding the generation of tones and sound recording to the software implementation.

13 Summary/Conclusion

ISO 1996 uses the rating level, L_r to compare levels to the noise limit. This includes an adjustment if the noise contains annoying tones. ISO 1996 offers two methods for tone assessment in informative annexes: Reference (FFT-based) method and Simplified (1/3-octave based) method. Taking into account that the "tone/no tone decision" may lead to considerable costs, objective measurement is very often wanted.

Any objective measurement should give reliable results and, in many situations, this implies the use of FFT analysis. Software (Tone Assessment Option BZ-7231) has been developed for the Type 2250 Hand-held Analyzer giving the user a tool that gives him the correct tone assessment result without having to bother much with the setting of the analysis parameters. In addition, a manual set-up is available for more experienced users.

Issues implementing the methods are described in the paper. Implementing the FFT based ISO Reference method was straight forward and we found the structure of the annex very useful. The simplified method is described only briefly and in ambiguous terms To comply with the standard the development team had to make some of their own decisions, despite discussions with ISO working group members.

Based on initial experiences with the reference method, it has been found that much more tones are found, particularly above 10kHz. In addition, with this reduced cost of objective tone assessment, the overall quality of tone assessments will improve.

References

[1] ISO 1996-1 "Acoustics -- Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures" (2003)

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[6] Reference CD – Sound Samples with Tones in Noise Analyses according to ISO/DIS 1996-2 Annex C, *Technical Note AV 1558/04*, DELTA Danish Electronics, Light & Acoustics (2004)