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ACOUSTICAL FREQUENCY RESPONSES AND ACCURACIES, INCLUDING TESTING

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1. INTRODUCTION

Frequency weightings and level linearity are some of the very important characteristics of a sound level meter. The following will discuss the development or improvements over the time where sound level meter standards have been available.

Even though immediately easy to understand, frequency weightings and level linearity characteristics are often difficult to specify and test. In principle all characteristics of a sound level meter are given for the entire instrument i.e. from acoustical input to level indicator. To carry out all testing with acoustical input is, however, nearly impossible or would even though possible lead to poorer results than obtainable if the tests are divided into acoustical and electrical tests.

The following will therefore also deal with the problem of how to measure and how to combine the test results to obtain the best possible accuracy.

2. FREQUENCY WEIGHTING

The idea with frequency weighting is to weight the different frequency components of the measured sound in such a way that the impression of loudness or annoyance is equal for the different parts of the spectrum. This is not possible. The hearing mechanism is far too complex as equal loudness, noisiness and annoyance depend upon a large amount of factors, some of them difficult to handle, some very difficult to handle. Some compromises are therefore necessary to keep the instrumentation relative simple, and the result of this is described in the sound level meter standards, the first of which are from the late forties.

We will now look at the basis for the standardized frequency weightings.

The basis for the frequency weightings are equal loudness contours. Some of the first contours were given by Fletcher and Munson in 1942.

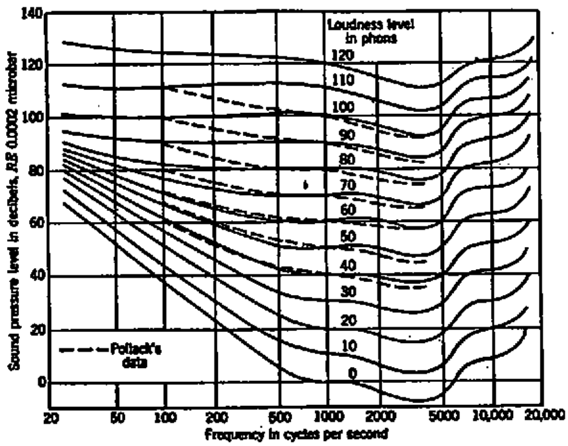

Fig.1 - Fletcher-Munsons equal loudness contours

Later they were modified, or the method for obtaining then modified, and they are now given in an ISO standard.

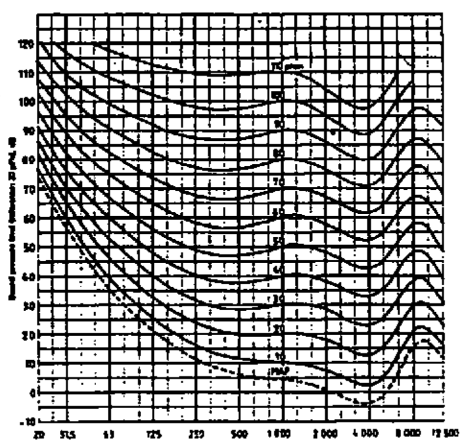

Fig.2 - ISO equal loudness contours

As seen, the impression of loudness depends upon frequency as well as level, and as a first compromise three different weightings were given to compensate for the frequency and level sensitivity. The weightings were intended to be used for measurements of weak, medium or strong sounds.

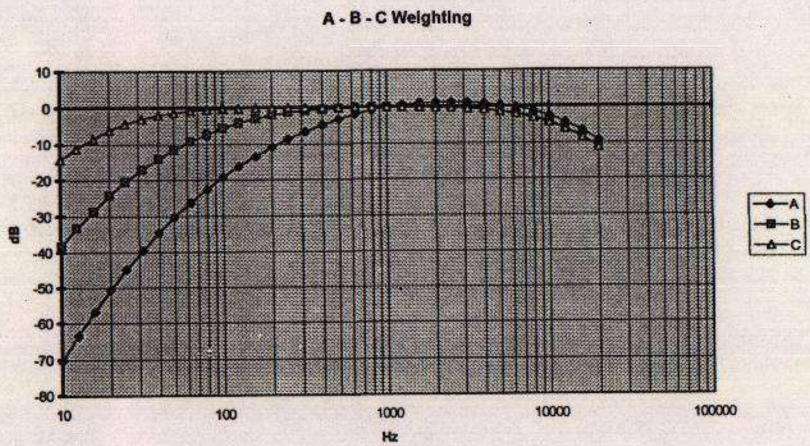

Fig.3 - Frequency weighting characteristics

The name of the weightings were "A", "B" and "C". The A-weighting was designed as a mirror image of the 40 phon contour, the B-weighting correspondingly to the 70 phon contour and the C-weighting for the loudest sounds.

This concept is difficult to handle as the choice of weighting depends on the reading of the meter, and the reading again upon the choice of weighting. The weighting curves were designed and simplified in such a way that they could be realized with simple passive electronic components.

And then the practical use! Many years of use has shown that the A-weighting is a fair compromise between simplicity and accuracy because there is a fair correlation between A-weighted measurements and the annoiance of most common types of noise. Not bad in the view of the fact that the A-weighting is simplified for the design of measuring instruments and used in another way than originally intended.

The B-weighting has only been used in a few places and even though it has been there since the first sound level meter standards were published, there are no references in any ISO standard to this weighting. Hence it is removed from the new sound level meter standard.

The C-weighting was intended to be "flat" in the audible frequency range, with smooth roll off for both high and low frequencies.

Now with respect to accuracy: It is important to notice that even though we all know that the method of frequency weighting is troublesome, it is important that measurements at least are done the same way and that accuracy is more a matter of reproducibility than a guarantee for results close to the impression for all kinds of sounds.

Let us look again at the A-weighting (see Fig.3). The definition of the A-weighting has been unchanged for more than 30 years. The A-weighting given in the first international standard for sound level meters IEC 123 is the same as now defined in IEC 1672.

The C-weighting is intended to be flat in the audible range with a smooth cut off at high- and low frequencies. The cut-off is 12 dB per octave and the 3 dB down points are placed at

$10^{1,5}$ Hz (approx. 31,5 Hz) and $10^{3,9}$ Hz (approx. 8 kHz)

respectively.

Two additional poles form the A-weighting. In IEC 1672 the formulas are given to allow the poles to be calculated to any accuracy. Approximate values are also given as

20,6 Hz, 107,7 Hz, 737,9 Hz and 12 194,2 Hz,

which corresponds to the values given in IEC 651 except for the highest pole frequency which here is given as 12 200 Hz (rounded to 4 significant digits).

Calculations of the frequency response curves may be performed by the exact pole frequencies or the rounded numbers. Calculated to the nearest 1/10 of a decibel, the results are the same as given in IEC 1672 - Table 2.

Now the accuracy. The electrical circuits may be designed with high precision but the tolerances given include the entire instrument i.e. the reading compared with the real sound pressure level. In other words: the tolerances includes the electrical circuitry and the microphone and the acoustical influence of the microphone support or the meter case for self-contained or hand held instruments.

Let us compare the tolerances given in the different standards from the first IEC 123 to the present IEC 1672.

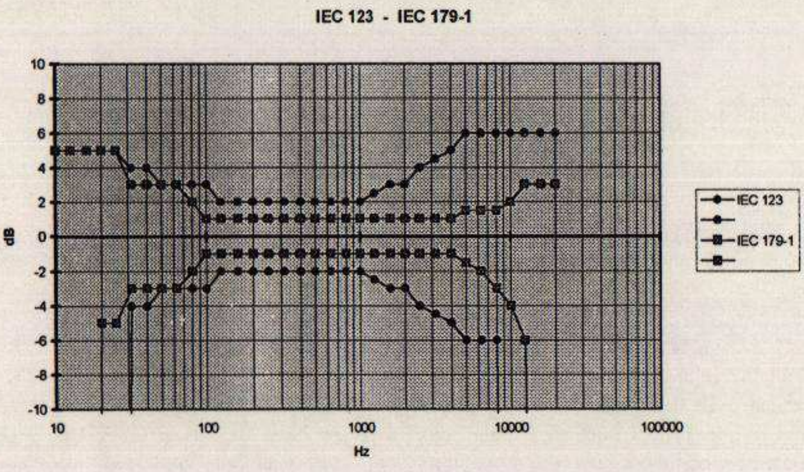

Fig.4 - IEC 123 and IEC 179 (1963) frequency weighting tolerances

It is seen that the "Precision Sound Level Meter Standard" IEC 179 (1963), which at the time of publication represented "the state of the art", improved the accuracy considerably. 10 years later (1973) a revision improved further by narrowing the low-frequency tolerances.

In 1979 a new standard IEC 651 was introduced giving 4 classes of precision designated as Type 0, 1, 2 and 3. Type 1 was, with respect to the frequency weighting tolerances identical with IEC 179 (1973) and Type 3 correspondingly identical with IEC 123.

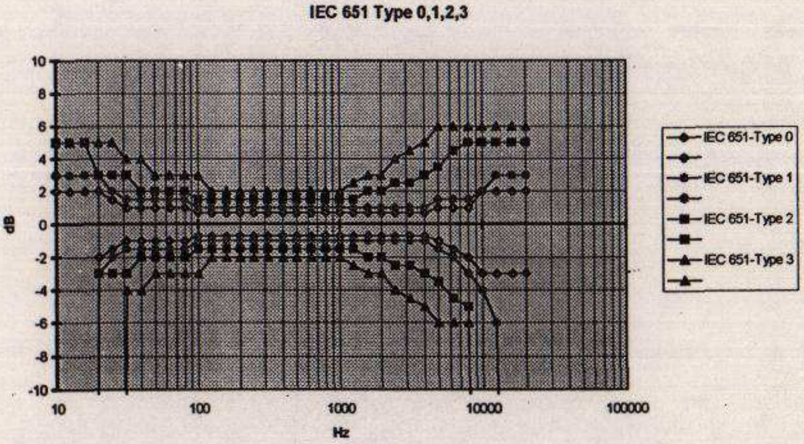

Fig.5 - IEC 651 frequency weighting tolerances

In IEC 651 two new precision classes (Types) were introduced. Type 0 with the highest precision obtainable in practice and Type 2 with a precision between IEC 179 and IEC 123. Type 2 was intended to be the future general purpose sound level meter as IEC 123 was considered to be outdated. While Type 2 became popular and forms the basis for IEC 1672 Class 2, Type 0 was almost neglected by both users and manufacturers. Type 1, slightly improved with respect to frequency weighting tolerances, is the basis for IEC 1672 Class 1.

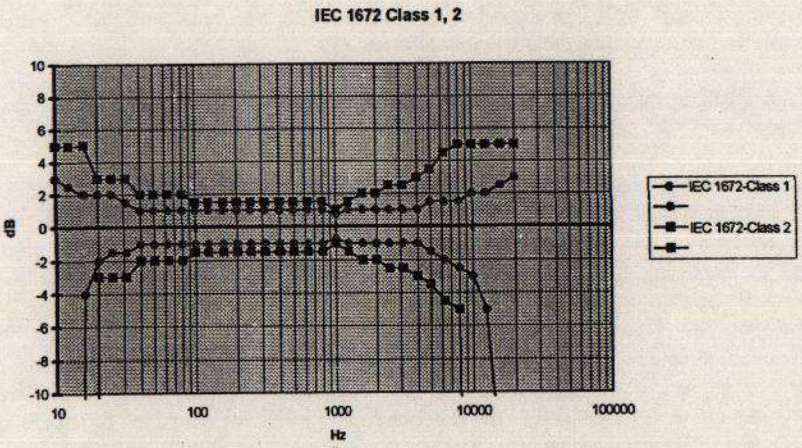

Fig.6 - IEC 1672 frequency weighting tolerances

It can be seen that it is mainly at the highest and lowest frequencies the improvements have taken place. For the most simple sound phenomena a sound level meter designed to meet IEC 179 has approximately the same accuracy as one that meets the new IEC 1672, but the new standard is better defined for more extreme sound phenomena i.e. sounds with frequency components close to the frequency limits and with strong level fluctuations.

How to verify the frequency response

This is really a difficult task as it includes the entire instrument from microphone to the level indicator. To make an acoustical test it is necessary to define the type of sound field for which the specifications are valid. In the IEC world (i.e. where ANSI standards are not in use) the instrument is specified for a plane progressive sound wave from the reference direction given. A plane progressive sound wave can only be approximated and here we are faced with the first difficulty. How to measure in practice. In an "anechoic room" a free field can be approximated, but it is important to realize that anechoic rooms are not anechoic! They are low level echoic! Sounds will be reflected from the walls as in other rooms but of course with a much lower level. For most purposes this is not important but for sound level meter testing, where we are dealing with small fractions of a dB it is important to take this fact into account and use appropriate methods to eliminate or reduce the unwanted effects.

The following will, in short, describe the method used to obtain the frequency characteristics of a sound level meter.

It is necessary with a reference microphone. The characteristics of this microphone shall be known, both with respect to absolute sensitivity at some frequency and with respect to frequency response. Of course it is also necessary with an adjustable sound source, i.e. a transducer (loudspeaker) connected with a sine generator where both frequency and output level are adjustable in a way that any combination can be reproduced.

1 - Place the sound source and the reference microphone in the middle of the anechoic room with a distance of approx. 2 m. Place both slightly asymmetrical with respect to the walls. A measuring amplifier connected to the reference microphone shall be adjusted so that the reading at the reference frequency (1000 Hz) and reference level (94 dB) is correct. For all test frequencies in question, find the generator adjustment to give the reference level measured by the reference microphone system. Take into account the frequency characteristics of the reference microphone (its calibration data). Now the sound source is calibrated for all frequencies in question.

2 - Now substitute the reference microphone with the sound level meter under test. It is important to place the microphone in the same position as earlier occupied by the reference microphone. For each frequency, reproduce the setting of the sound source. The correct reading for the sound level meter for each frequency is the reference sound pressure level minus the nominal attenuation of the frequency weighting used. It is advisable here to use a "flat" frequency response if available or C-weighting. Using A-weighting for this test may cause difficulties at the lower frequencies due to the heavy attenuation of the weighting filter.

3 - If the previous test is performed using "flat" frequency response, the result of the test is immediately the free-field response of the microphone plus the influence of the sound level meter case. The results of the test are then, for each frequency, added to the results from an electrical test. If another frequency response than "flat" is used the same results can be obtained if the measurements are corrected by the results from an electrical test (see 4) using the actual frequency weighting (for instance "C"). The whole idea is to extract the free-field response of the microphone and the acoustical influence of the sound level meter case.

4 - An electrical test is performed by substituting the microphone with an electrical input. Unless the input circuit has an impedance so high that it do not influence the response of the microphone, it is important that the signal is fed through an impedance substituting that of the

microphone. The reference is the reference frequency (1000 Hz) and a signal level to obtain a reading corresponding to the reference level (94 dB). The frequency response is tested for all frequency weightings available.
For all frequencies, the results from "3" are added to obtain the total acoustical response of the sound level meter. These results should then be compared with the nominal response given in Table 2 of the standard and the results shall be within the stated tolerances.

It is important to notice that while the electrical tests normally may be carried out using 1/3 octave frequency steps, the acoustical test to verify the influence of the sound level meter case has to be carried out with much smaller steps. However, verification of the influence of the sound level meter case has only to be performed once for a sound level meter model or configuration and is therefore connected to conformance testing more than to the periodic tests.

3. STEADY LEVEL LINEARITY

The characteristic "steady level linearity" is very important because it specifies how accurate we can measure sound levels other than the reference level. Of course we expect that if the sound level changes by N dB then the reading also changes by N dB. However, over a large level range, this is not a matter of course. In IEC 1672 the minimum range is 60 dB which, in this case, means that over a level span of 1:1000 the sound pressure level shall be measurable to within the same accuracy tolerances. In many other instruments the accuracy is specified as a percentage of full-scale or full-range reading resulting in poorer accuracy at low levels than at high. For sound level meters the accuracy requirements are the same all over the level range and over a large frequency range too.

In IEC 1672 the level linearity is specified using an electrical input i.e. without the microphone. This is a compromise! Testing this acoustically is nearly impossible and it is supposed that microphones by their nature are linear with respect to level. Not necessarily true but the requirements and test methods are expected to be the best possible. As a new requirement the level linearity tolerances also include the frequency weighting (electrical test). This means that from the reference point (1000 Hz and 94 dB) the level shall be indicated within the stated tolerances within both frequency and level range. The specifications also include level range shifts.

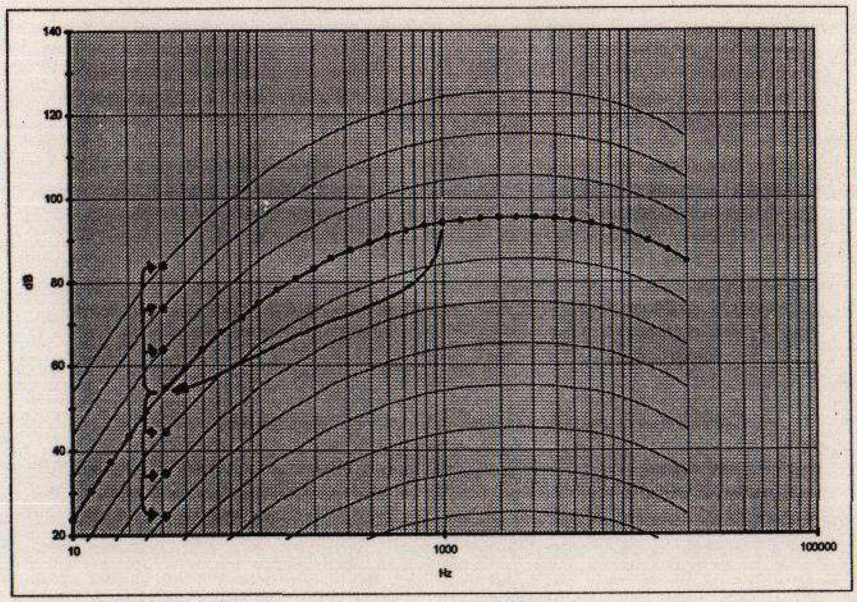

Fig. 7 - From the reference level at the reference frequency to any level and frequency within the specified range the reading shall be correct within the stated level linearity tolerances i.e. ±0,7 dB for class 1 and ±1 dB for class 2.

3. OVERLOAD- AND UNDERRANGE INDICATION

When measuring sinusoidal signals, an overload indication is not very important. The top of the range is easy to identify. However, sound signals are complex and the ratio between absolute peak values and RMS values may be large. Because of the squaring in the detector, peaks give a high contribution to the calculated RMS (exponentially or linear averaged) and clipping due to overload of the amplifiers may therefore strongly affect the result. An overload indication is therefore important to ensure that the readings from the sound level meter's level indicator are correct.

Overload indication is tested in connection with testing of both steady level linearity and tone-burst response. The general principle is that for increasing signals, the level linearity shall be within the stated tolerances as long as no overload is indicated. For exponential averaging (Fast or Slow), overload shall be indicated as present i.e. the overload indication disappears when the overload disappears; for linear averaging (Leq) the overload indication shall be latched. This is necessary as Leq is measured over a long time and it is impossible to know the magnitude of an error caused by overload (a sound pressure level of 165 dB in 1 ms has the same energy as a 90 dB sound pressure level in 8 hours).

For analog indicators, no special **underrange indication** is needed. When the indication reaches the bottom no reading is possible. For digital indicators it is different. Comparing the reading with some knowledge of the level range used is possible but in practical cases it may be overlooked. A clear indication of underrange is therefore necessary to avoid false readings. Underrange indications do not need to be latched. A signal level occasionally in the underrange region will have little effect on the final result. For Leq, underrange shall be indicated if the result is below the level corresponding to the lower boundary of the level range in question.

Underrange is tested in connection with the steady level linearity test. In brief, by lowering the signal level the reading of the instrument shall be correct within the stated tolerances as long as no underrange is indicated.

4. PEAK C-WEIGHTED SOUND PRESSURE LEVEL

Why peak and why "C"? It is necessary with some explanation. While our hearing sensation is (more or less) connected to the energy of the signal, short high sound pressure levels may cause lasting destruction in the inner ear. The impressions of these sounds are far from the damaging effect. Therefore it may be necessary to be able to measure the absolute peak level of the sound. This level may easily be as high as 50 dB or more above the Leq level. The choice of the C-weighting needs some (historical) explanation.

In the first EU rules concerning this matter, it was stated that peak sound pressure levels should be measured "unweighted". In principle OK because of lack of knowledge about how the frequency influenced the damaging effect. However, the wording "unweighted" cause practical problems. Taking into account that peak pressure level measurements in connection with sound level meters are supposed to be connected with damaging effects on the hearing, that "unweighted" in principle has no frequency limits, and that very high sound pressure levels at low frequencies may occur in real life (door-slams etc.) with no damaging effects, it became necessary to limit the "unweighted" frequency range. For practical reasons to the audible range. To do this without unnecessary phase distortion (important for peak but not for RMS) it is necessary with smooth frequency cut-off for both high- and low frequencies. But doing this, the signal is no longer "unweighted". A special filter (weighting) could have been designed but it would have been with a frequency response close to the C-weighting. Therefore the C-weighting was chosen. "C" is the best compromise between being "unweighted" and including some frequency limitations. And "C" was already defined. Therefore!

Testing peak sound pressure level indication causes some problems. In IEC 651 "peak" was tested by comparing the response of a 10 ms square shaped pulse (reference) with a 100 µs square shaped pulse. This is a very poor method for several reasons. Firstly, there are no connections to the sine wave RMS response and secondly the response to the 10 ms pulse may be disturbed by low-frequency cut-off filters (as in "C") causing this response to be higher than intended. As the 10 ms response was given as the reference, the 100 µs response was often interpreted to be too low even though it was correct!

In IEC 1672 peak is tested using tone-bursts. One-cycle tonebursts at 31,5 Hz, 500 Hz and 8 kHz are used for the test. The response is then referred to the RMS response for constant signals at the same frequencies. 31,5 Hz and 8 kHz are chosen because these frequencies are at the limits of the C-weighting (3 dB down), and 500 Hz because this is the middle of the band. Half cycles at 500 Hz are used for testing symmetry of the indication.

The method may cause some problems using digital signal processing. For simplicity, imagine a critical sampling of the 8 kHz toneburst. With 4 samples the sampling may be at zero crossings and at the maximum. But it may also be at 45, 135, 225 and 315 degrees. Selecting the highest numerical value causes a 3 dB difference for the two situations. For RMS calculations there are no differences. For lower frequencies (or higher sampling frequency) the difference is smaller. However, for testing it is necessary to repeat the tests as dispersion is expected and to ensure that all readings are within the stated tolerances. It is, of course, possible to overcome the problem in digital systems, but it is necessary to be aware of the possible errors.

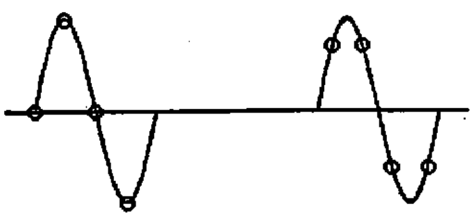

Fig.8 - Sampling errors for digital peak detection

14. REFERENCES

IEC 123 - 1961	Recommendations for sound level meters
IEC 179 - 1963	Precision sound level meters
IEC 179 - 173	Precision sound level meters
IEC 179A - 1973	Impulse sound level meters
IEC 651 - 1979	Sound level meters
IEC 804 - 1985	Integrating-averaging sound level meters
IEC 804 Amendment 1 - 1989	
IEC 651 Amendment 1 - 1992	
IEC 804 Amendment 2 - 1993	
IEC 1672 1.CDV - 1997	Sound level meters
Z24.2-1942	American Standard for noise measurement,
ISO R226	Normal Equal-loudness contours for pure tones and normal threshold of hearing under free-field listening conditions