REMOVING ADDITIVE NOISE IN MEASUREMENTS OF LOW SOUND PRESSURE LEVELS

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Noise belongs among the negative phenomena in our environment and can have a negative effect on human health. Excessive noise occurs in many areas, e.g. in transport, aeronautics and during manufacturing processes. It is often necessary to meet specified noise limits. Acoustic measurements are carried out in many cases, e.g. in order to evaluate the sound absorption properties of investigated materials and acoustic conditions in a given environment. Measurements of extremely low sound pressure levels can be used to describe the acoustic environment in an acoustic laboratory or to measure noise emissions from quiet machines and equipment. Furthermore, measurements of extremely low noise levels are limited by the thermal noise of the measurement chain. If the sound pressure levels are lower than the thermal noise of the measurement chain, then the measurement is not correct. This paper describes the measurement of extremely low sound pressure levels using an improved correlation function method.

KEYWORDS

Acoustics, sound pressure level, extremely low noise, microphone, thermal noise.

1 INTRODUCTION

An integral part of existing investment, construction and/or R&D (research and development) projects is their environmental impact, generally understood as the interaction of human activities and the environment. For this purpose, the quality of the environment influenced by human activities is assessed by measuring parameters that quantify our quality of life, such as pollution, traffic density, ozone layer quality, etc. Noise also belongs among the negative impacts of human activities; it is a phenomenon that has a significant effect on mental health as well as the health of the human auditory apparatus [Junga 2019]. Noise is an increasingly important priority in current technical practice, and numerous scientific and engineering tasks are focused on lowering noise levels and reducing the negative impacts of noise. Noise intensity is expressed by the sound pressure level L_p (in dB), which is defined by the equation [Klimenda 2019], [Guo 2007]:

$$L_p = 10 \cdot \log\left(\frac{p}{p_0}\right)^2 = 20 \cdot \log\left(\frac{p}{p_0}\right), \qquad (1)$$

where p is the root mean square sound pressure and p_0 is the reference sound pressure in the given environment (e.g. in air p_0 = 20 μPa). It is evident from Equation (1) that the level L_p = 0 dB corresponds to an acoustic pressure of 2×10^{-5} Pa, so if the sound pressure is lower than the reference sound pressure p_0, the sound pressure level is negative. The sound pressure level is also weighted in order to take into account relative loudness as perceived by the human ear, which is less sensitive to low sound frequencies. In practice, the A-weighted sound pressure level (L_{pA}) is most commonly used for this purpose. The C-weighting filter is applied for measurements of high-intensity sounds [Sun 2016]. The B-weighting filter is intermediate between A and C, and is not often used. The D-weighting filter is designed for measuring aircraft fly-over noise [Gray 2000].

The trend towards improving the acoustic properties of consumer products reflects changes in legislative frameworks that impose increasingly strict noise limits throughout all areas of human activity. Together with the development of acoustic properties of products, there is also a significant increase in the volume of acoustic testing carried out on samples from serial production, as well as R&D focusing on sophisticated methods of sound measurement, analysis and evaluation. These developments have one thing in common: they require appropriately designed and properly constructed acoustic measurement equipment. Measurements specified by common standards require an acoustic test in a free acoustic field, i.e. in a field without acoustic reflections and echoes. Compliance with this condition is achieved in an anechoic acoustic chamber (alternatively, a semi-anechoic acoustic chamber is also permitted) [Rusz 2015].

In connection with acoustic testing and research, attention is naturally focused on acoustic rooms (anechoic or semi-anechoic). These are special rooms in which the walls, ceiling and floor (in the case of semi-anechoic chambers) are equipped with sound-absorbing materials in order to ensure the dissipation of the maximum incident energy on the surface in the form of a direct acoustic wave emitted by the sound source. An essential feature of these special rooms is the unusually low level of background noise inside the chamber itself, i.e. noise that is not caused by the sound source being tested. This feature of anechoic or semi-anechoic chambers is particularly important for so-called silent sources, i.e. low-noise sound sources, since it is not possible to measure the sound source unless it can be reliably distinguished from background noise [Kim 2012].

One of the basic acoustic parameters for the certification of anechoic chambers is background noise. The usual background noise level is from 10 to 30 dB(A) in the frequency range from 50 Hz to 20 kHz. At the highest-quality laboratories, the noise level is below 10 dB(A); in extreme cases it is below 0 dB(A). Standard background noise measurements cannot be used for such noise levels, and the measured signal needs to be evaluated correctly [ISO 2012].

2 EXPERIMENTAL MEASUREMENT

2.1 *Equipment for measurement of low sound pressure levels*

The basic measuring equipment consists of a measuring microphone, an analyzer, and a PC with software. The experimental measurement used a Brüel & Kjær measuring kit, which consists of a B&K analyzer (type 3560C), a PC with B&K Pulse software, cabling and a low-noise B&K microphone (type 4955) inside an anechoic chamber (Fig. 1) [B&K 2019].

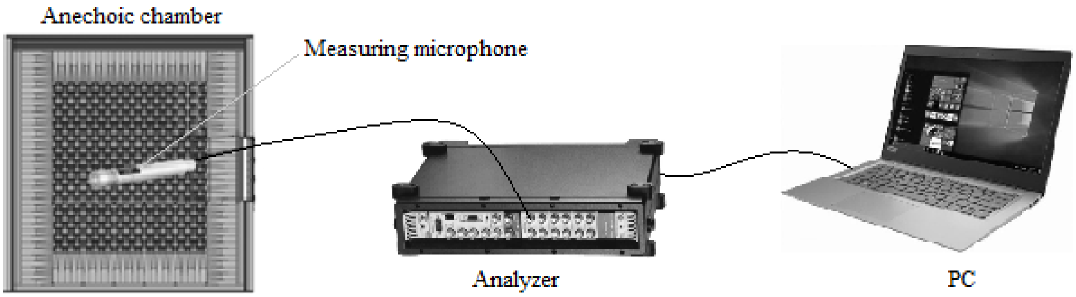

Figure 1. Measuring system.

The greatest influence on the measurement of low sound pressure levels is the choice of the measuring microphone and the preamplifier. A special microphone (B&K type 4955) with a low-noise preamplifier (20 dB gain) is usually used. This assembly has a supplier-specified dynamic measurement range 6.5 dB – 110 dB. This means that the microphone cannot be reliably used to measure below 10 dB (with the recommended 4 dB distance from the dynamic range limits) [Sujatha 2009]. If the noise is very low in the frequency range of the given measurement, only the microphone's own noise (thermal noise, noise floor), which has a typical spectrum (Fig. 2), will be measured. Nor does this special microphone allow for the measurement of sound pressure levels below 5 dB. For measuring these extremely low sound pressure levels ($L_{pA} < 5$ dB), no suitable microphone is available. In such cases it is necessary to apply special measurement techniques.

2.2 The origin of the signal's own noise and the possibility of its removal

The signal's own noise, usually known as thermal noise, Johnson noise or Nyquist noise, is an irregular fluctuation of the transmitted electrical signal and is caused by thermal excitation of electric charge carriers along the path of the electrical conductor. The existence of thermal noise does not depend on voltage type or level, and it occurs in any electrical circuit. However, the noise level is usually low. This phenomenon is becoming increasingly important in all sensitive equipment, such as measurement transducers, microphones etc., as it can distort a weak signal, causing the noise to become a limiting factor on the sensitivity of an electrical measuring instrument [Gualtierotti 2015]. This noise can be denoted as "white noise" as it is a random signal. It is equal to an intensity at a wide frequency range, resulting in a constant power spectral density [Gualtierotti 2015], [Moser 2009].

This is the specific characteristic of white noise that allows it to be removed. There are several ways to remove this white noise from the signal. The improved correlation method will be described in the following section.

2.3 Removing additive noise using the correlation function

The correlation function expresses the degree of similarity between two signals. This method uses the mathematical properties of the correlation function: the autocorrelation function for the stochastic signal (white noise) is zero for T ≠ 0, where T is the time shift between functions; the correlation function of two signals, of which one is stochastic, is zero. The measured signal is a composition of a useful signal and the additive noise. When measuring two signals in the same time section (*t*) and at the same location, both signals are composed of the same useful signal and random (dissimilar) thermal noise [Meyer 2013]. The mathematical notation of the first signal $f_{(t)}$ is expressed by the formula:

$$f_{(t)} = x_{(t)} + u_{(t)}, \tag{2}$$

where $x_{(t)}$ is the useful signal and $u_{(t)}$ is the random (thermal) noise signal.

Similarly, the second signal $g_{(t)}$ is given by the sum of the useful signal $y_{(t)}$ and the thermal noise signal $v_{(t)}$ as follows:

$$g_{(t)} = y_{(t)} + v_{(t)}. \tag{3}$$

The above-mentioned equations are valid for the time domain or for the discrete region where the symbol (*t*) is replaced by the discreet index (*k*). Then, the correlation function of these discrete signals is described by the equation:

$$(f * g)_k = \sum_{i=-\infty}^{\infty} f_i \cdot g_{(k+i)}. \tag{4}$$

After substituting the decomposed signals $f_{(t)}$ and $g_{(t)}$ from the equations (2) and (3) into the equation (4), it is possible to determine the correlation function $C_{fg(k)}$ of these signals by the formula (5):

$$\begin{aligned} C_{fg(k)} &= \sum_{t=t_0}^{t_c} \left[\left(x_{(t)} + u_{(t)} \right) \cdot \left(y_{(t+k)} + v_{(t+k)} \right) \right] \\ &= \sum_{t=t_0}^{t_c} C_{xy(k)} + C_{xv(k)} + C_{uy(k)} + C_{uv(k)} \\ &= C_{xy(k)}. \end{aligned} \tag{5}$$

In the equation (5), $C_{xv(k)}$, $C_{vy(k)}$ and $C_{vv(k)}$ are zero correlation functions, because it is a correlation with random noise. The total correlation function is then directly equal to the correlation function of the useful signals $C_{xy(k)}$, from which the useful signal spectrum can be determined and the additive noise has been removed. This is true if the random signal component is completely independent; in practice, this component is usually weakly linearly dependent, so the additive noise is not completely eliminated [Rahali 2016].

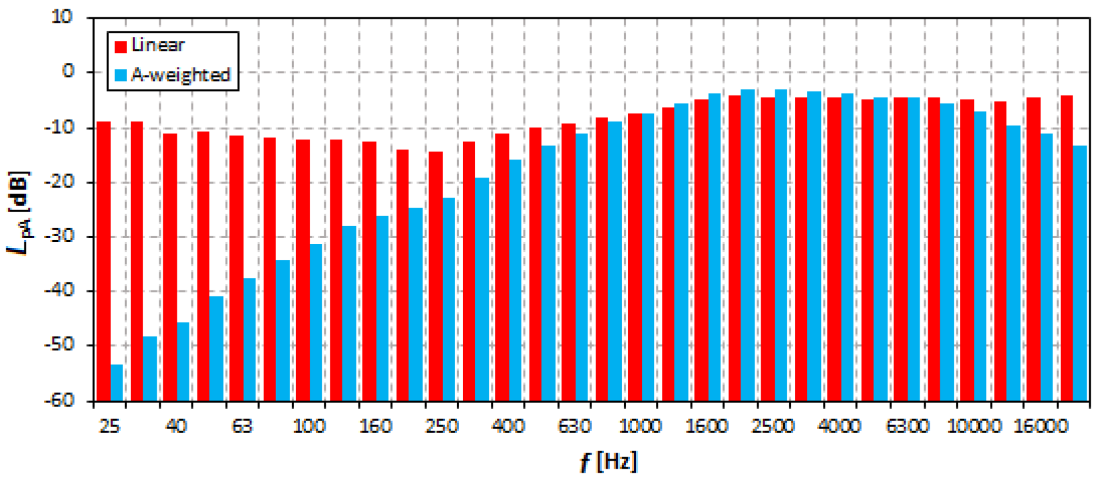

Figure 2. B&K type 4955 typical noise floor spectrum shown in 1/3-octave bands [B&K 2019].

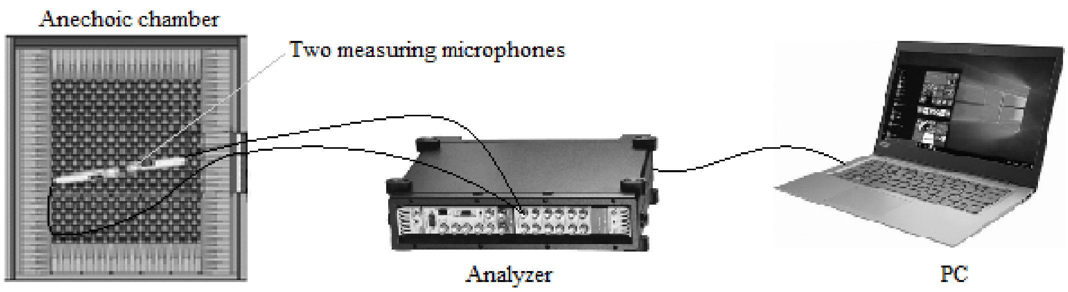

Figure 3. Measuring system for removal of additive noise.

2.4 Removal of additive noise in practice

A schematic diagram of the measuring system for removing additive noise is shown in Fig. 3. A view of the measurement of background sound pressure levels using the correlation function method is shown in Fig. 4. In order to apply this method, it is necessary to evaluate two signals. Two-channel measurements were carried out with the same type of microphones, in the same time interval and in close proximity (see Fig. 4). The measurement was subsequently evaluated on the PC. In this case, the correlation between these signals and the frequency spectrum was evaluated.

When the total pressure level of the background noise was measured with thermal noise 5 dB(A) and the correlation technique was used to remove additive noise, the sound pressure level of the background noise dropped to minus 4.5 dB(A), which is a significant difference. A negative value in the decibel noise scale expresses the value below the audibility threshold for the human ear. A value of 0 dB corresponds to an acoustic pressure of 2×10^{-5} Pa, so if the sound pressure in the tested medium is lower than this reference sound pressure, the sound pressure level is negative. The quietest place in the world, where noise levels have been verified by this method, is an anechoic chamber belonging to Microsoft in Redmond, Washington (USA); at this place, a three-signal correlation method was used and the noise level of -20.35 dB(A) was determined.

The frequency spectrum of the A-weighted sound pressure level with and without the additive noise is shown in Fig. 5. It is evident that the above-mentioned correlation method is beneficial mainly for measurements of sound pressure levels at higher excitation frequencies (f > 100 Hz), as shown in Fig. 5. In this case, the measured background sound pressure levels are significantly lower compared to the background pressure levels which were measured by means of the single microphone measurement method. For this reason, the improved correlation method is suitable for measuring very low sound pressure levels in these cases.

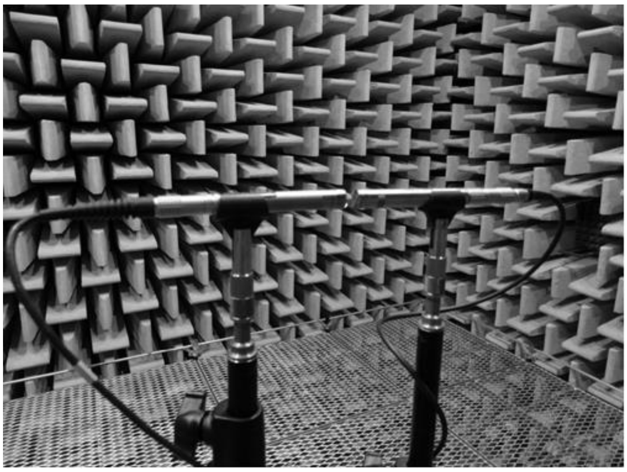

Figure 4. Position of the measuring microphones in an anechoic chamber.

3 CONCLUSIONS

This paper focused on an improved method for the measurement of very low sound pressure levels of sound sources. The method was based on the reduction of additive thermal noise using the correlation function of two signals that were measured by two measuring microphones. The application of this method led to a significant reduction of the background sound pressure level, mainly at higher acoustic wave excitation frequencies. For this reason, the correlation function method leads to more accurate measurements of very low sound pressure levels, which are not significantly influenced by the background thermal noise in anechoic chambers.

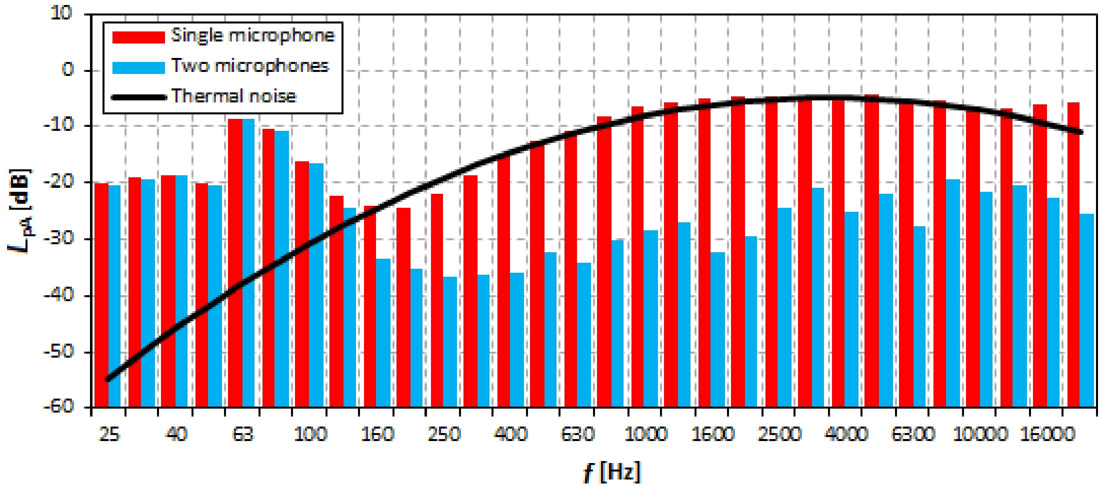

Figure 5. Frequency spectrum of the A-weighted sound pressure level with and without additive noise.

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