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Selected Factors Affecting Uncertainty of All-Weather Microphones Research

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Testing of devices for acoustic measurements in a free-field are being performed at the stage of designing and type certification. Free-field tests are performed only in a few laboratories – mainly in National Metrology Institutes. These are: Danish Primary Laboratory of Acoustics (DPLA, Denmark), Physikalisch Technische Bundesanstalt in Braunschweig (PTB, Germany), National Physical Laboratory (NPL, United Kingdom) National Institute of Standards and Technology (NIST, United States of America).

The Vibroacoustic Laboratory of the Department of Mechanics and Vibroacoustics, AGH is the only place in Poland where this type of tests is performed. This is calibration laboratory, which has an accreditation of Polish Centre for Accreditation (AP 022).

Certain factors related to the determination of frequency and directivity responses of all-weather microphones, which have a significant influence on the uncertainty of the obtained results – are presented in the paper.

The response values, given below, indicate the calibration accuracy. This accuracy is necessary since the aim of the measurements is to determine corrections and designing of the proper compensating filters, which will allow to eliminate any influence of devices on the acoustic field, the parameters of which are actually under testing. This is directly related to the uncertainty assessment of environmental measurements (e.g. to the accuracy of acoustic maps).

The necessity of collaboration of laboratories performing such tests and the need of inter-laboratory comparisons is pointed out in the present paper. The unification of the method of testing and the assessment of the uncertainty of results seems to be necessary.

Keywords: all-weather microphones, free-field investigation, frequency responses, directional responses, Inter-Laboratory Comparisons.

1. Introduction

Noise became a general and troublesome phenomenon affecting larger and larger numbers of people. We are witnessing continuous worsening of environmental acoustic conditions. Due to the binding legal regulations, especially the Law of Environment Protection, the monitoring of the acoustic climate became recently obligatory.

Noise monitoring is mainly performed for transportation noises (road, rail and air transport) as well as for industrial noises.

Fast development of monitoring stations occurs and the new types of all-weather microphones are constructed – due to these requirements. All-weather microphones are the first and the most sensitive elements in the noise monitoring chain. The estimation of noise hazard requires unified ways and methods of noise assessment, including reliable and coherent estimation of the uncertainty of results. Current Standard requirements concern only the measuring microphones [1] and sound level meters [2]. There are no Standards for all-weather microphones.

A measuring microphone is subjected to the influence of external environmental factors (e.g. rain, snow, wind, abrupt temperature changes, mechanical damages). Measuring microphones are sensitive to such factors. In order to minimise those problems, either special environmental microphones are produced or special all-weather covers – "Outdoor microphone kits" – are used for typical measuring microphones. Those kits allow, relatively easily, to adjust a typical measuring microphone for its usage in various environmental conditions. They are especially convenient for users, who already have sound level meters with typical microphones.

All-weather microphones can be divided into two groups; microphones used in permanent monitoring systems, the so-called: "outdoor microphones" (e.g. airport noise monitoring stations) and microphones used periodically: "environmental microphones" (short-term installations – from a couple of days to several weeks). Their main difference is a remote calibration system built into outdoor microphones. They also differ in the materials they are made of and the way of construction ("outdoor" must be more sturdy, more corrosion- and strong winds-resistant).

Regardless of the type (typical all-weather microphone or measuring microphone with all-weather cover, which adapts it to environmental measurements), the name "all-weather microphone" will be used throughout this paper. More information on construction and application of all-weather microphones can be found in publications [3, 4].

Since there are no separate standards, metrological characteristics of all-weather microphones are determined together with sound analysers (or automatic monitoring stations) as equipment elements of the measuring system (all-weather cover is an integral part of a meter). The measurements of the whole system (all-weather microphone together with all cables regardless of their length) are performed in compliance with the Standard IEC 61672 specification [2].

Frequency responses as well as directional responses of all-weather microphones should be suitable for both directions of an acoustic wave incidence, or for the direction declared by the producer. Some all-weather microphones are of an omni-directional response, which ensures that noises from all directions are detected, regardless of the sound wave incidence – 0° or 90° (Fig. 1).

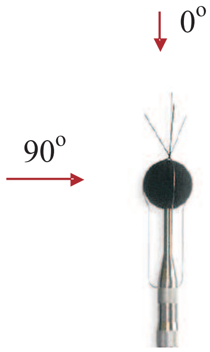


Fig. 1. Typical reference directions of acoustic wave incidence 0° and 90°.

Frequency responses of an omni-directional microphone for both reference directions (or for the one declared by the producer) should be flat in the whole range of the measured frequencies (Fig. 2).

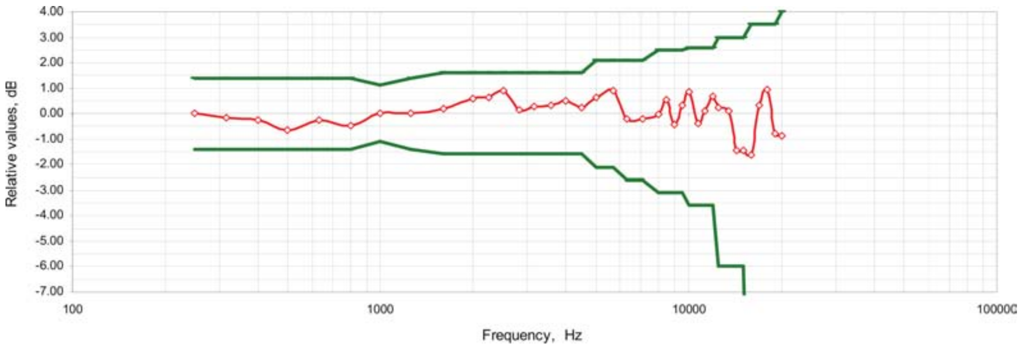


Fig. 2. An example of frequency responses of the omni-directional microphone for the reference direction 0°. Green lines mark the limit of permissible errors, acc. to [2].

Flat frequency response of microphones with all the all-weather accessories can be obtained by means of application of the proper compensation filters. Such filters are created on the basis of investigations in the free-field. Those investigations are very essential since they allow to estimate an influence of the all-weather cover and of the whole fixing system, on the frequency and directional responses. Therefore the accuracy of the results is very important. It determines the corrections and allows to design the compensating filters.

2. Measuring method applied and the equipment used

Theoretical ideas of determination of effectiveness and directivity responses of devices are relatively easy, however their practical realisation under real acoustic field conditions is very difficult, especially when we want to perform a very accurate calibration. The measuring method used in the Vibroacoustic Laboratory of AGH was developed in such a way as to meet the requirements of the Standard [2], however the realization and interpretation of its guidelines could be accomplished in various ways. Therefore the comparative inter-laboratory measurements and cooperation of these few laboratories, which are performing acoustic measurements in the free-field, is so important. The results of bilateral investigations between the Laboratory of the University of Science and Technology (AGH) and the Laboratory of the Physikalisch-Technische Bundesanstalt in Braunschweig (Germany) together with the resulting conclusions, are given in papers [5, 6].

In the Vibroacoustics Laboratory, the frequency characteristics are determined by comparing the response of the device under test with the response of the reference microphone to the same sound signal, in the same measuring set-up and under the same environmental conditions. The measurement is done in such a way that the reference microphone is placed in the given measuring point, the response being measured and then the reference microphone is substituted by the device under test (substitution method). Directional responses are estimated by recording responses of the device under test, which rotates on the turntable. Calibration is being done by a sinusoidal acoustic signal of selected frequencies and a constant amplitude (of the reference meter level).

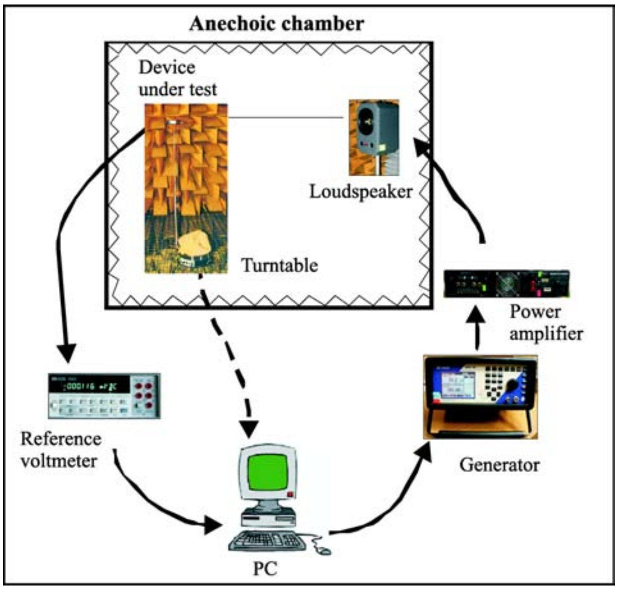


Fig. 3. Conceptual diagram of the computer-aided measuring system for the determination of frequency and directional responses.

Figure 3 presents the conceptual diagram of the automatic system using the PomAk program for measurements in a free-field. The measuring stand in anechoic chamber is presented in Fig. 4.

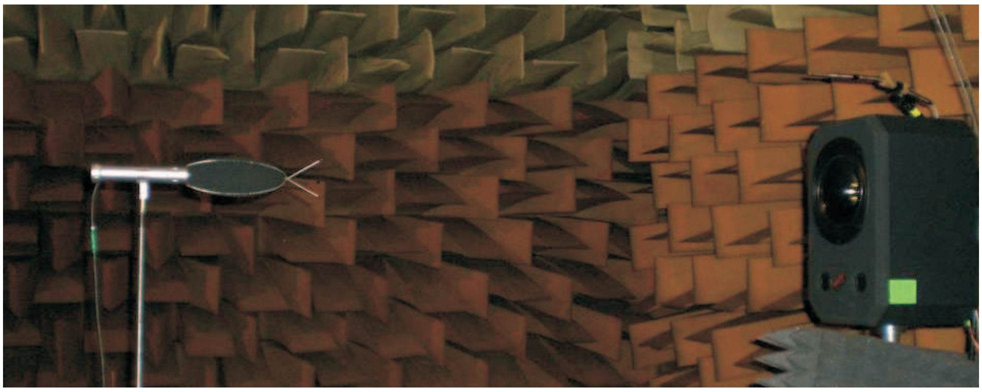


Fig. 4. Measuring stand in anechoic chamber during the calibration of all-weather microphone for the reference direction 0°.

More information on the measurement methodology, calibration problems under the free-field conditions, automatic measuring system and the obtained results, are given in publications [7, 8].

3. Selected problems of all-weather microphones calibrations and their influence on uncertainty of results

Since – until now – there are no legal regulations concerning all-weather microphones, a lot of doubt is related to their use and calibration. Questions, which concern the possibility of comparing the results obtained at testing all-weather microphones in various laboratories and the reliable estimation of the uncertainty of results, are arising from the very beginning. These problems influence also estimation of the results obtained by users of different types of microphones and various monitoring stations as well as the assessment of the uncertainty of results (e.g. for preparing of acoustic maps).

Producers declare, for which direction of angle of wave incidence the given microphone is suitable. They also give characteristics, however determined in various – often not properly defined – ways. But is it justified in reality? The question arises: what is the best way of presenting directional characteristics? For example: the microphone is declared – by the producer – as the microphone suitable for measuring of waves of 0° angle of incidence, it means suitable for monitoring airport noises. However, airport noises seldom come directly from the above, since a sound wave propagates from many directions. The same problem concerns microphones declared by producers as suitable for monitoring the community noise. In this case, the wave should only propagate from the 90° direction and this again is not fully true. The Norsonic Company gives directional responses for one other angle of incidence assuming that 25° [9].

Figure 5 illustrates various ways of determining directional responses. All directions are reasonable; however, the requirements for unification of the measuring method and presenting of the obtained results should be precisely defined. Producers – taking advantage from not adequate knowledge of their clients – present only those results, which meet the requirements.

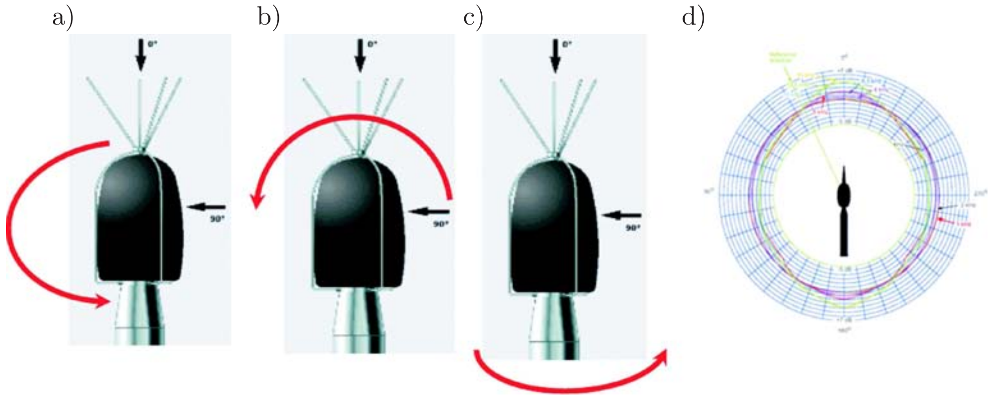


Fig. 5. Various ways of determining directional responses of all-weather microphone: a) for the reference direction 0°, b) for the reference direction 90°, c) for the reference direction 90°, at turning the microphone round its main axle, d) for the reference direction 25° [9].

The G.R.A.S. Company gives directional responses for 41CN microphone turned around its axle at the wave angle of incidence 90° – and this is also reasonable due to an asymmetric microphone insert. An electrostatic actuator enabling remote determination of frequency characteristics is applied in this microphone.

Relevant factors, which should be taken care of at measurements in a free-field and which constitute main sources of uncertainty, are:

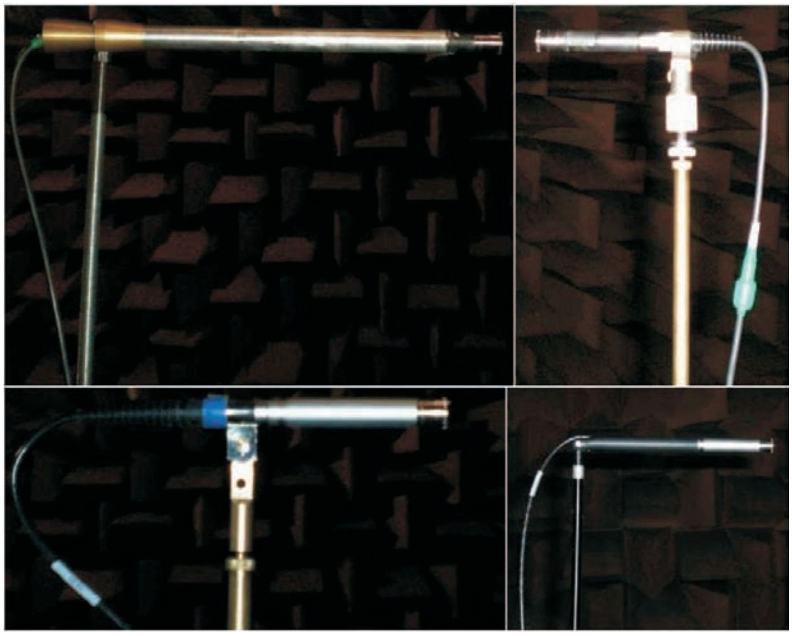
- factors related to equipment and measuring system,
- factors related to a measuring stand and anechoic chamber; reflections, diffractions, interference phenomena, proper placement of devices on stable structures not causing any reflections,
- factors related to standard microphone (only at performance tests) and positioning devices under testing versus the standard microphone and the sound source,
- factors related to influence of environment conditions.

Out of many problems, which occurred at the initial stage of investigation, quite a few have been solved after years of experimental efforts. Those are, among others, problems related to the stability of measuring paths, accuracy of voltage and sound source measurements (among others with its stability).

On the basis of the assessment of uncertainty investigations [7] as well as on the basis of the analysis of results obtained when testing the reproducibility, repeatability and performing the calibration the factors affecting – the most significantly – the uncertainty results, have been singled out. Thus, highly influencing the uncertainty in the directional responses and the performance determination, are: positioning of devices and the method of their fixing.

The example of the influence of the way of fixing the measuring microphone in the determination of its characteristics is given in Fig. 6.

a)



b)

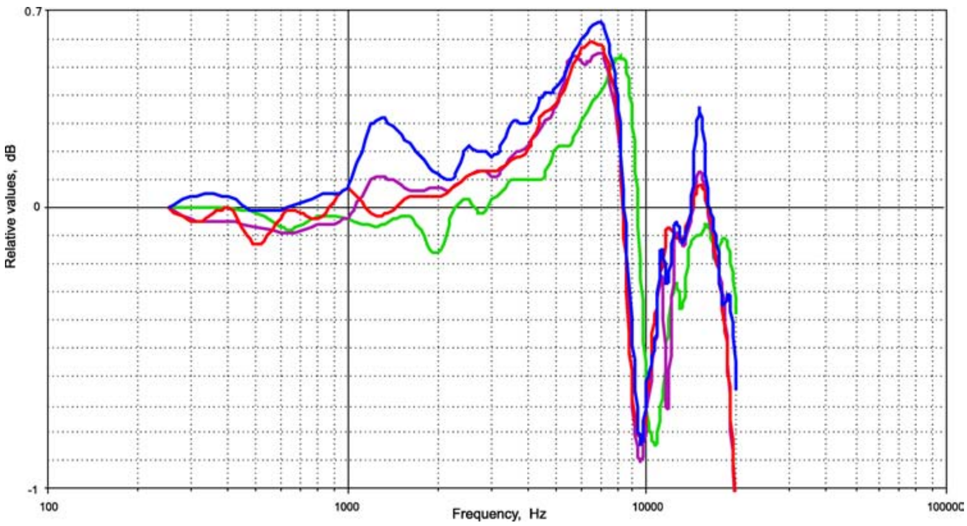


Fig. 6. Example of the influence of fixing the measuring microphone on its responses: a) different types of fixing, b) scatter of the obtained frequency responses.

Additionally, in the case of determining the frequency responses, performing measurements at several distances between a source and a microphone is very important.

Figure 7 illustrates differences of responses obtained at two different measuring distances. The repeatability of results in each distance is very good. The experimental standard deviation of the mean value of results is not higher than 0.03 dB (Table 1).

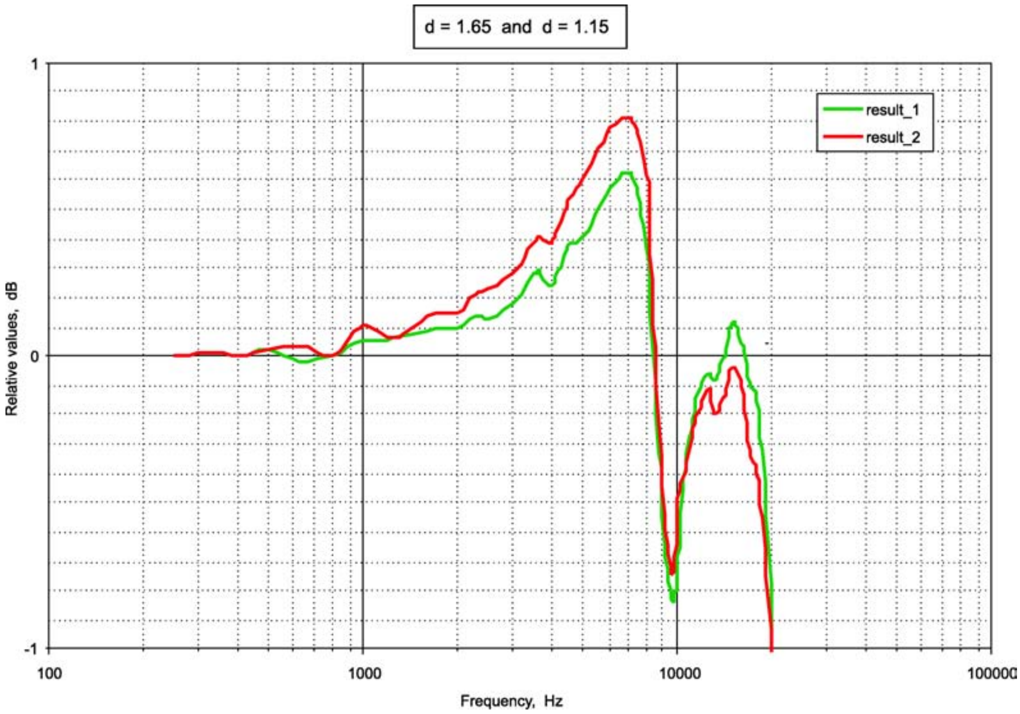


Fig. 7. Frequency responses of the microphone obtained at two different measuring distances.

Changing the measuring distance causes significant scatter of responses related to the phenomena occurring in the actual acoustic field in the chamber, sound source and positioning. Thus, this is an essential measuring element, which significantly influences the uncertainty of the obtained results. The Standard [2] takes into account this problem, however not all laboratories adhere to these guidelines (as it was presented in papers [5, 6]).

All-weather microphones – during their typical operations – are usually placed on sturdy stands of large dimensions, while – for their testing in the chamber – we place them on definitely lighter stands. Thus, we try to minimize the participation of the stand in the influence of the results. Since different microphones (even produced by the same Company) have various structures and dimensions, different methods of positioning of the instruments, versus the standard micro-

Table 1. Repeatability of results obtained in one measuring point. Average of 11 measurements, experimental standard deviation, experimental standard deviation of the mean value.

Frequency Hz	Average from 11	Standard deviation	St. dev. of the mean	Frequency Hz	Average from 11	Standard deviation	St. dev. of the mean
250	113.96	0.04	0.01	5600	113.01	0.01	0.00
315	114.44	0.04	0.01	6300	114.44	0.03	0.01
400	116.42	0.04	0.01	7100	113.92	0.04	0.01
500	115.69	0.06	0.02	8000	114.17	0.02	0.01
630	116.41	0.05	0.01	8500	114.36	0.02	0.01
800	117.66	0.05	0.01	9000	114.50	0.03	0.01
1000	114.63	0.04	0.01	9500	114.41	0.02	0.01
1250	115.67	0.04	0.01	10000	114.84	0.01	0.00
1600	114.28	0.05	0.01	10600	115.56	0.02	0.01
2000	113.59	0.02	0.01	11200	114.99	0.04	0.01
2240	113.58	0.06	0.02	11800	114.58	0.04	0.01
2500	112.41	0.03	0.01	12500	114.62	0.02	0.01
2800	113.79	0.04	0.01	13200	115.11	0.02	0.01
3150	113.41	0.03	0.01	14000	116.07	0.02	0.01
3550	114.01	0.02	0.01	15000	112.64	0.07	0.03
4000	114.25	0.01	0.00	16000	112.83	0.03	0.01
4500	113.89	0.01	0.00	17000	108.83	0.09	0.03
5000	113.91	0.01	0.00	18000	107.67	0.09	0.03
5600	113.01	0.01	0.00	19000	111.53	0.06	0.02
6300	114.44	0.03	0.01	20000	114.72	0.07	0.02

phone, sound source and the axis of rotation of the turn-table, must be developed separately for each individual test.

The Standard IEC 61672 Part 2 [2] gives only very general guidelines for performing tests of sound level meters in the free-field, which are also applied for testing all-weather microphones. As it was shown above, such parameters as: measuring distances, fixing holders, angles of wave incidence, have impacts on the obtained results.

The Standard [2] in its paragraph 6.22 informs that at least 5 components of uncertainty should be taken into consideration:

- The uncertainty attributed to calibration of the individual instruments and equipment used to perform the test, including the sound calibrator, where applicable.
- Any contribution resulting from environmental effects or adjustments.
- Any small errors that maybe present in the applied signals and are considered as uncertainties.

- Any random uncertainty attributed to repeated measurements and dependent on the characteristics of the sound level meter under test.
- An uncertainty contribution for reading the indication from the display device of the sound level meter under test (resolution of the meter).

Those data constitute very general guidelines realized in an arbitrary way by individual laboratories.

Methodology of the estimation of the measurement uncertainty is not an exact physical theory but rather an approximate description of the experiment imperfection. Estimation of uncertainty in measurements – in the final effect – depends entirely on the knowledge and expertise of the person performing measurements, regardless of referring to the *Guide to the Expression of Uncertainty in Measurement*, or EA-4/02 document: *Expression of the Uncertainty of Measurement in Calibration.*

There are a lot of papers describing the subject area of estimation uncertainty of microphone calibration with pressure methods (reciprocity and comparison technique). Only sparse publications are about estimation uncertainty of calibration of acoustic device for free-field measurement. Exemplary articles are contained in [10–14]. The author of this paper does not know any articles about uncertainty analysis for free-field calibration of all-weather microphones.

4. Conclusions

Instruments for acoustic measurements as well as techniques of their calibration, undergo constant development. Environment monitoring requires unification of noise measurement methods. All-weather microphones are the basic links in the environment noise measuring chain.

Laboratories performing calibration of instruments have to meet higher and higher requirements concerning the accuracy of measurements, while in certain fields there are no explicit guidelines. It should be emphasised that both the measuring technique and uncertainty estimation requires the creativity, knowledge and expertise of researchers.

The performed investigations have shown that as far as the calibrations in the free-field are concerned, there is a need for cooperation of the few laboratories involved. This would allow to unify the measuring methods (selection of: the proper sound sources, measuring distances, holders fixing instruments, etc.) as well as the way of uncertainty estimation (exact defining of error sources, which are unavoidable in the uncertainty budget). Such activities have been introduced in other metrological zones many years ago.

Acknowledgment

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