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Microphone calibration service for airborne ultrasound

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ABSTRACT

The application of ultrasound techniques is wide-spread in many fields of industry. The accompanying airborne noise – produced on purpose or as a by-product – gives reason to a growing number of noise measurements at the ultrasound frequencies beyond the audible range of hearing. These are, for example, the assessment of noise immission at workplaces and the noise emission of products for safety guidelines. A general problem of such measurements is the lack of traceability of the measuring instruments at high frequencies beyond 20 kHz. In particular, the acoustical calibration of the microphones used has not been possible up to now. More recently, the primary calibration of special microphones at ultrasound frequencies has become available. Now, a secondary calibration service has been implemented at PTB to connect the measurement systems of end users to the new primary standard. By using a classical substitution procedure, a combination of a ¼-inch measurement microphone and an adapter to ½-inch preamplifiers can be traced back to a primary transfer standard up to 100 kHz. The secondary calibration procedure presented is the last link in the metrological traceability chain to create working standards for airborne ultrasound measurements. The new service is now available at PTB.

Keywords: Airborne ultrasound, microphone calibration
I-INCE Classification of Subjects Number(s): 71.9

1. INTRODUCTION

To date, the pascal, the unit for the acoustical quantity sound pressure level, is not traceable at ultrasonic frequencies in air. Experiments to measure airborne ultrasound quantitatively usually fail when trying to stretch a calibration at audible frequencies to the (ultra-) high frequencies beyond 20 kHz. The reason for this is that sound in air changes its properties, such as absorption in air, towards high and ultrasound frequencies. Classical set-ups designed for audible frequencies are not prepared for this and often reach their design limits.

The growing usage of ultrasonic techniques has increased the need for the traceability of the sound pressure level even at ultrasound frequencies greater than 20 kHz. Following this need, primary calibration was realized recently for specific types of microphones by use of the reciprocity technique (2). Beeing a precise basic method with low measurement uncertainties, this calibration method is by principle restricted to specific types of microphones which are hardly used in practice. Moreover, as a high precision method, it has not the capacity for the mass calibration of end-user devices. In fact, it currently lacks the metrological infrastructure for airborne ultrasound calibration of end-user's microphones, sound level meters and similar devices. For such an infrastructure, a procedure has to be developed that transfers the pascal from the new primary standard to any end-user devices.

A good example to follow is the calibration infrastructure for the audible frequency range: high precision primary calibration of a primary transfer standard (a 'golden' microphone cartridge), secondary calibration of secondary transfer standards (reference microphones) and the further calibration of end-user devices.

After the first step of creating a primary transfer standard has been done, the traceability of the 'golden' cartridge has to be forwarded to further cartridges by comparison. The easiest way to do this in free field is the classical substitution method where a measurement is performed two times under exactly the same conditions: once using the known reference and once using the unknown test candidate. Once adopted to the specific properties of airborne ultrasound, this method with slight variations can serve as the core method for both calibrating further references and calibrating end-user devices. This paper presents the realization of the substitution method for airborne ultrasound at PTB, in the first step as a method for creating secondary transfer standards.

2. THE PRIMARY REFERENCE

The classical way to create a reference microphone is by using the reciprocity calibration method. This is the dominant method for the primary calibration of measurement microphones at all frequency ranges and all types of sound fields. It is standardized in IEC 61094-3 for the free field (1). In practice, the method is restricted to about 20 kHz to 31.5 kHz when calibrating ½-inch microphones. For higher frequencies, smaller measurement microphones have to be used.

At the Danish metrology institute, DFM, the reciprocity calibration has been implemented for ¼-inch measurement microphones recently (2). Primary calibration is now possible for frequencies of up to 150 kHz with a measurement uncertainty of less than about 0.25 dB. Unlike the usual reciprocity set-ups, the microphone to be calibrated here is not the microphone cartridge only, but a combination of the ¼-inch cartridge plus an adaptor to half an inch (to be screwed on to a ½-inch preamplifier). This combination can serve as a transfer standard for airborne ultrasound calibration and is used as the reference microphone in the following secondary procedure.

3. SECONDARY CALIBRATION

A calibrated transfer standard for airborne ultrasound is the basic prerequisite for the secondary calibration procedure described in the following. The primary reference microphone is used to calibrate further microphones in the free field by comparison at frequencies up to 100 kHz.

3.1 Substitution procedure

The procedure is a classical substitution procedure as given in IEC 61094-8 (3) except with an extended frequency range. The reference and the device under test (DUT) are exposed to a well-formed sound field and both transfer functions are measured successively. Comparing both transfer functions yields the difference between the microphones' sensitivities. Adding this difference to the known sensitivity of the reference microphone results in the wanted sensitivity of the DUT.

Figure 1 gives a sketch of the measurement principle. Firstly, the reference microphone is mounted on a preamplifier and is placed in an anechoic environment in front of an ultrasound loudspeaker. Secondly, the reference is substituted by the DUT. A dual-channel FFT analyzer controls the excitation chain and samples the microphone signals at both measurements. Each single part of the excitation and the acquisition chain must be suitable for usage at the ultrasound frequency range.

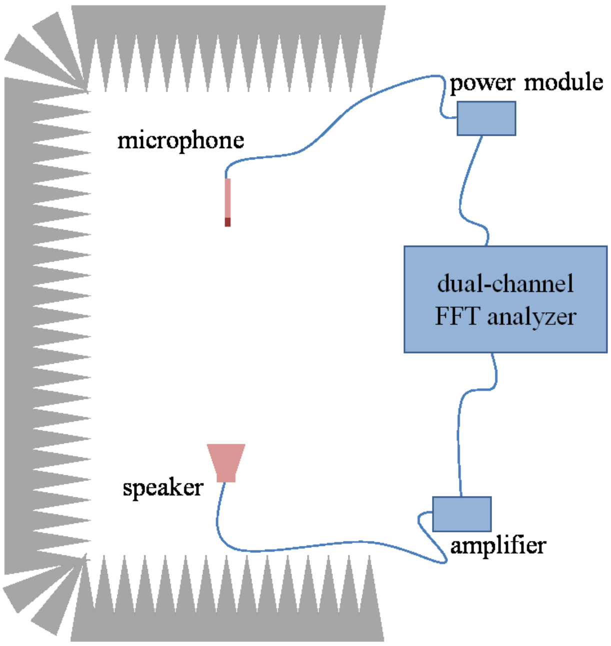

Figure 1 – Sketch of set-up in free-field environment

When substituting the reference by a DUT that is similar in construction, the described procedure is usually sufficient. An example of this is the calibration of a combination of ¼-inch cartridge mounted on ('married to') an adaptor to half an inch. In the case that the DUT is of a different type to the reference, such as a ½-inch microphone cartridge, additional transfer functions have to be measured using an insert-voltage preamplifier to consider the influence of electrical parts.

Equation (1) gives the main formula in logarithmic unit dB for calculating the sensitivity $S_{0,\mathrm{DUT}}$ of the DUT from the sensitivity of the reference $S_{0,\mathrm{Ref}}$ and the four measured transfer functions:

$$S_{0,\mathrm{DUT}} = S_{0,\mathrm{Ref}} + \left[\left(H_{\mathrm{ac,Ref}} - H_{\mathrm{el,Ref}}\right) - \left(H_{\mathrm{ac,DUT}} - H_{\mathrm{el,DUT}}\right)\right] \quad \text{(in dB)} \qquad (1)$$

The transfer functions are:

- $H_{\mathrm{ac,Ref}}$: Acoustically measured transfer function using the reference,
- $H_{\mathrm{el,Ref}}$: Electrically measured transfer function with the reference mounted on the preamplifier,
- $H_{\mathrm{ac,DUT}}$: Acoustically measured transfer function using the DUT,
- $H_{\mathrm{el,DUT}}$: Electrically measured transfer function with the DUT mounted on the preamplifier.

The secondary calibration procedure has the main advantage that it is, in principle, not restricted to special types of microphones. In practice, there is a different type of handling for different types of microphones. Whereas the calibration of a ¼-inch cartridge on an adaptor to half an inch, or the calibration of a ½-inch cartridge is mainly as described above, the set-up has to be extended when calibrating sets of microphones or ¼-inch cartridges without an adaptor. This results in extra expenditure and additional uncertainty contributions.

3.2 Interfering influences and measurement uncertainty

The calibration set-up has to take the specific properties of airborne ultrasound into account. The wavelength is in the range of some millimeters (e.g. the wavelength is 3.4 mm at the frequency of 100 kHz). This leads to the fact that even small areas and edges induce reflection and diffraction. Free fields at ultrasound frequencies are much more sensitive to environmental disturbances than at audible frequencies. Moreover, sound sources usually show a strong directivity, which gives the need for a precise positioning in the set-up. The propagation loss of sound in air cannot be neglected as is usually done with audible sound. Figure 2 gives ultrasound propagation loss at acoustical standard climatic conditions (temperature 23 °C, relative humidity 50 %, static air pressure 1013 mbar). At 100 kHz the damping of a propagating wave is about 7.5 dB per meter. This makes special requirements of the performance of the sound source. Furthermore, this propagation loss is strongly dependent on ambient parameters such as temperature and humidity. These have to be held constant in the course of the complete calibration procedure.

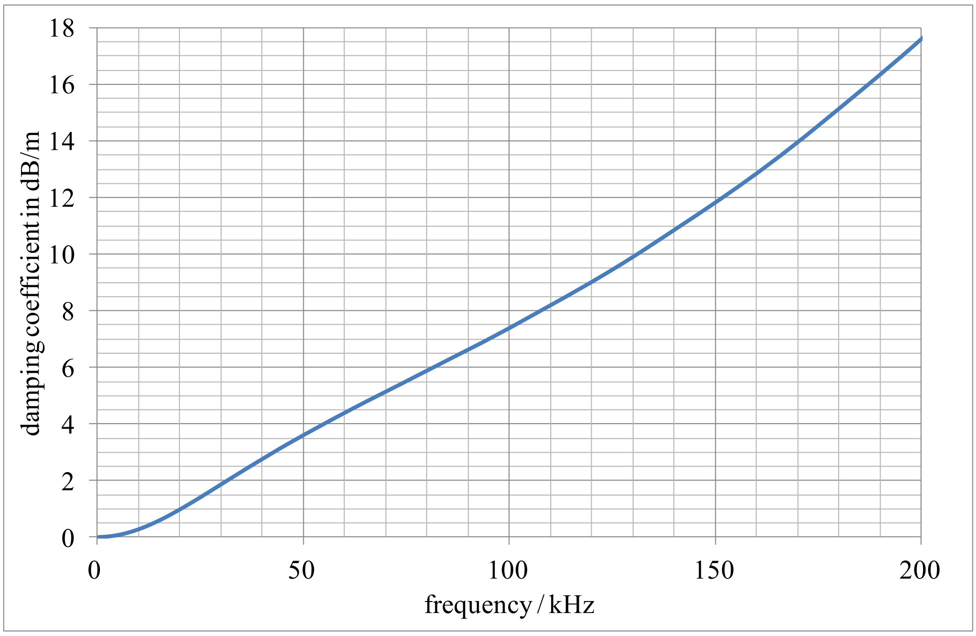

Figure 2 – Propagation loss of airborne ultrasound at standard climatic conditions according to Bass et al. (4)

These influences are the reason for the extended expenditure of the ultrasound substitution calibration compared to a standard calibration in the audible range. Furthermore, these also lead to expanded measurement uncertainties (k=2) of 0.4 dB to 0.6 dB, depending on the frequency and the type of the DUT.

4. EXAMPLES

Two examples of measured ultrasound frequency responses are given for microphones of different sizes. These examples demonstrate the influence of a protection grid.

Figure 3 shows the frequency response of two ¼-inch microphones. The first (solid blue line) is the sensitivity of a reference microphone as calibrated by the reciprocity procedure. The type is a B&K 4939 working standard microphone 'married' to an adaptor to half an inch. The frequency response is linear in a range of about ±1 dB up to about 100 kHz.

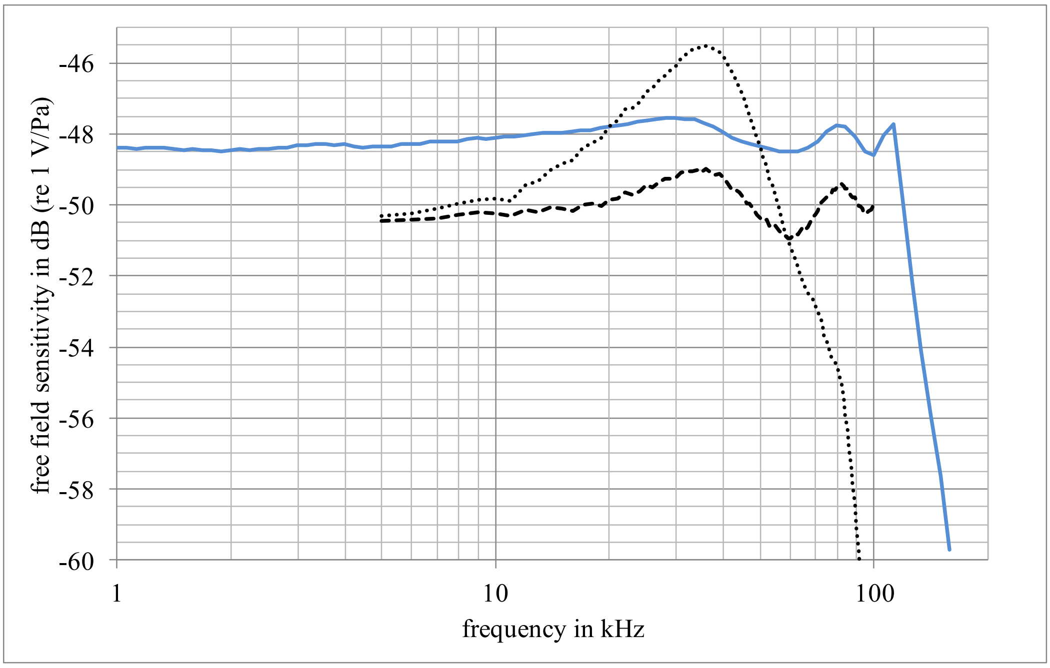

Figure 3 – Free-field frequency response as measured by three microphones. Solid (blue): ¼-inch cartridge combined with adaptor to half an inch (primary calibration by DFM). Dashed (black): ¼-inch cartridge integrated in a microphone set with preamplifier and power module (secondary calibration by PTB). Dotted (black): Same as dashed but with mounted protection grid.

The second (dashed black line) is the measured sensitivity of a ¼-inch working standard microphone of the type GRAS 40BF which is integrated into a set with a preamplifier and a power module. Both ¼-inch cartridges are quite similar concerning the shape of the frequency response. The difference in sensitivity of about 2 dB is mainly due to the electrical chain of the microphone set. Both solid lines show the frequency response as measured without the protection grid mounted on the cartridge.

The third (dotted black line) is the sensitivity of the above-described microphone set with the protection grid mounted on it. This gives a strong increase in sensitivity of about 4 dB around 35 kHz compared to the unprotected cartridge, followed by an immense decrease in sensitivity: the cartridge looses more than 10 dB at 100 kHz. The influence of the protection grid is less than 1 dB below frequencies of about 10 kHz. When calibrating the microphone set with a standard calibrator at 1 kHz, this difference will not be noticed at all.

5. CONCLUSIONS

The ultrasound calibration of measurement microphones is now available as a calibration service at PTB. Based on primary calibrated reference microphones, the method allows free-field calibration at frequencies up to 100 kHz. Typical measurement uncertainties lie between 0.4 dB to 0.6 dB. The actual uncertainty depends on the frequency and on the type of microphone to be calibrated.

The specific properties of sound in air at ultrasound frequencies pose a challenge at the calibration set-up. Compared to the free-field calibration at the audible range of hearing, more time and effort is needed, making high demands on the quality of the free field, the performance of the source, the precision of the positioning and the control of ambient conditions.

Up to now, it has been possible to calibrate ¼-inch cartridges on adaptor to half an inch and ½-inch cartridges. Moreover, complete microphone sets (cartridge including preamplifier and power module) have also been calibrated successfully. The next step is to further develop the procedure for the calibration of end-user devices such as sound level meters. By this, the ultrasound substitution calibration method presented will be the core for the future traceability infrastructure of the pascal in the ultrasound frequency range. At the moment, the method allows airborne ultrasound to be measured quantitatively even in practice.

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