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Measuring Microphones : Challenges and New Solutions

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Abstract

Only a small percentage of all acoustical measurements are performed in the well-defined and well-controlled environment of a calibration laboratory – on the contrary most acoustical measurements are done under non-controlled conditions which in many cases are not even known in beforehand. This is the reason that some acoustical standards such as the IEC 61672 series (the "Sound Level Meter standard") specify the performance of the measuring microphone over a wide range of environmental conditions.

Modern quality measuring condenser microphones often meet or exceed the requirements even under very varying conditions. However the sound - field is always assumed to be known and well defined e.g. either a free or a diffuse field.

Consequently one important - and unfortunately in many case major – source of error is thereby neglected namely the response of the actual microphone type in the actual sound field.

The influence of different sound fields on the measurement error is discussed in some detail with practical examples and it is shown how a worst-case error exceeding 10 dB @ 20 kHz is a real risk.

After a brief discussion of some condenser microphone design rules, it is shown how the use of new technology has made it possible to develop a new condenser microphone which drastically reduces the error caused by influence of an unknown sound field and varying angle of incidence.

1 Introduction

Every measurement result is to be associated with some uncertainty; a fact which is often forgotten in the days of computers and multi digit displays! It can be claimed that without knowledge of the measurement uncertainty any measurement result is of no real value.

In acoustics we are often in the fortunate situation that our test procedures are governed by international standards and the performance parameters of systems – including transducers – is often well specified.

Instruments or systems for measurement of sound pressure is defined in the IEC 61672 series of standards and the measuring microphones[1] also have a whole series of standards of their own namely the IEC 61094 series.

In many practical cases the transducer is the single system element which contributes to the majority of the measuring uncertainty. Therefore it is interesting to investigate which impact the requirements as specified in these standards will have on the choice of microphone.

1 Although the focus area of this paper is on the properties of measuring microphone cartridges, we use the word microphone in this paper without distinction between the microphone cartridge alone and the combination of cartridge and pre-amplifier.

2 Environmental influence

The performance of Sound Level Meters – and systems – is defined and specified in the already mentioned international standard IEC 61672 – 1:2003.

In paragraph 6.2.1. in this standard it is specified that:

« *Over the range of static pressure from 85 kPa to 108 kPa, the deviation of the displayed sound level from the sound level displayed at the reference static pressure, extended by the expanded uncertainty of measurement, shall not exceed ± 0.7 dB for class 1 sound level meters"*

This can be interpreted to mean that the pressure pressure coefficient of a microphone intended for use in a class 1 sound level meter must have a value less than:

$$0.7 \text{ dB} /(101 - 85) \text{ kPa} = 0.04 \text{ dB kPa}. \qquad (1)$$

Similarly it can be seen from paragraph 6.3.1 and 6.3.3 that the maximum deviation at – 10 and + 50 degree C compared with the reading at 23 degree C shall be less than 0.8 dB for a class 1 sound level meter.

Therefore the temperature coefficient (TC) of the microphone shall be less than:

$$TC < 0.8 \text{ dB}/(23 - (-10)) \text{ degr. C} = 0.02 \text{ dB/K} \qquad (2)$$

Since the maximum deviations specified in IEC 61672 also includes measurement uncertainty the actual TC and Pressure coefficient of the transducers shall be smaller than calculated above in order to leave headroom for measuring uncertainties and influence from the electronic system elements.
Table 1 below has been compiled from data published by 3 different vendors, all the microphones except type 4961 are 1/2" free – field microphones intended for use in sound level meters.

Type	dB/degr C	dB/kPa
4188	+ 0.005	- 0.02
4189	- 0.006	- 0.01
4950	+ 0.005	- 0.02
4961	+ 0.01	- 0.013
Vendor A	+ 0.009	- 0.013
Vendor B	- 0.007	- 0.01

Table 1 data comparison

From table 1 it can be concluded that the performance of modern condenser measuring microphones more than fulfil the requirements as stated in IEC 61672.

3 Microphone Types

Measuring condenser microphones also called working standard (WS) microphones are specified in the international standard IEC 61094-4:1995.

This standard is in many respects very detailed and precise, in paragraph 5.5. the concept of "type designation" is used to classify the electro-acoustic properties of a microphone. The type designation can be either P, F or D meaning "*microphone having a pressure, free-field or diffuse – field sensitivity, which is approximately independent of frequency in the widest possible frequency range*".

Although this wording leave some room for interpretation the idea is clear: We use the phrase that the microphone is "optimised" for a specific sound field to express that its frequency response is flat(test) in the widest bandwidth in the kind of sound field for which the microphone is optimised.

As mentioned the microphones compared in table 1 were all 1/2" free – field types (type designation WS2F) except the 4961, which is of the so called multi – field type[2].

So it all seems very easy:

- Free – field microphones are optimised for free – field type sound fields.
- Random – field microphones are optimised for random/diffuse type sound fields.
- Pressure -field microphones are optimised for pressure type sound fields.

Many mechanical properties of the measuring microphones are identical and therefore there is no easy way to see on the microphone for which kind of sound field it has been optimised and even worse: In many cases the nature of the sound field is not well defined or is unknown for other reasons.

2 Not governed by any standards yet

4 Influence of Different Sound Fields

The following four figures shows a comparison of typical ½ "microphones in 4 different cases:

Fig. 1	WS2F microphone in Free – field
Fig. 2	WS2F microphone in diffuse – field
Fig. 3	WS2D microphone in diffuse field
Fig. 4	WS2D microphone in free – field

Here the green curves in fig. 1 and 3 show the response when the correct microphone is used used, while the pink curves in fig. 2 and fig. 4 shows the response under erroneous conditions. To keep things simple it has been assumed that the free- field microphones are mounted correctly e.g. "pointing" at the sound source (also called zero degree of incidence).
In the figures 1 to 4 all responses[3] are with protection grid mounted on the microphone.

4.1 Practical Examples

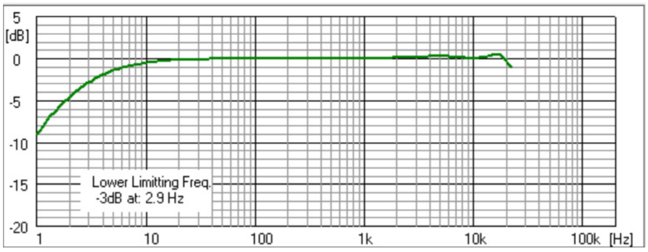

Fig. 1 Free – field microphone in free- field

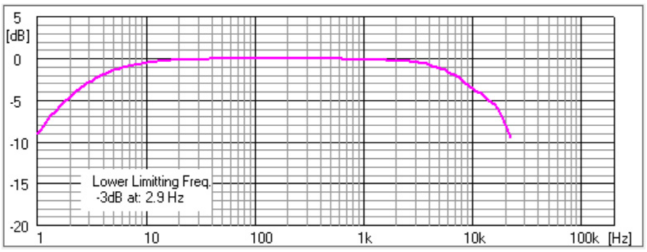

Fig. 2 Free – field microphone in diffuse – field

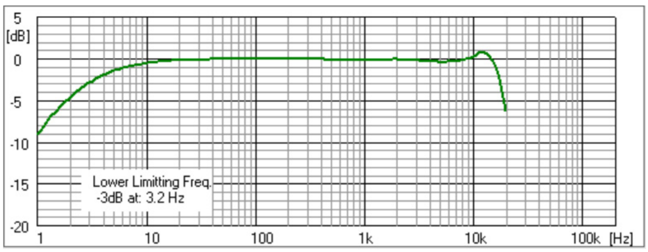

Fig. 3 Diffuse – field microphone in diffuse – field

3 The graphs were produced with the Brüel & Kjær Microphone Viewer, available free of charge from Brüel & Kjær

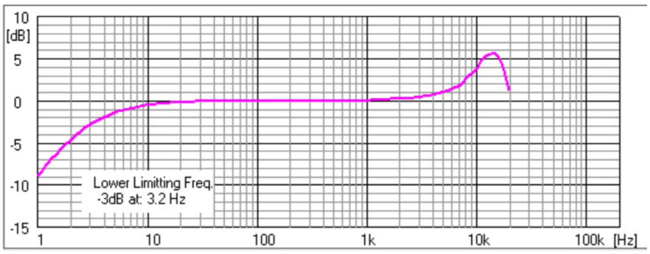

Fig. 4 Diffuse – field microphone in free – field

These graphs are valid for typical 1/2" microphones and are "optimistic" because it has been assumed that the angle of incidence is 0 degree in the free – field cases. Nevertheless the measurement error already at 10 kHz can be anywhere between + 4 dB and – 4 dB.
This can be compared with the requirement to class WS2 microphones which must sustain flatness within +/- 2 dB up to 16 kHz. Unfortunately errors like this are quite common.
For measurements outside the known and well controlled controlled laboratory environment the measurement uncertainty is at risk.

Fig. 5 shows the hypothetical worst case where by mistake a diffuse field microphone is used under free – field conditions but with 120 degree angle of incidence.
In this example shown the measurement error at 20 kHz is more than 13 dB!

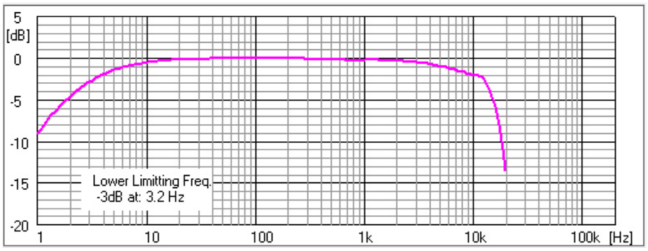

Fig. 5 Worst case conditions

5 Potential Improvements

It is obvious that correct use of the correct microphone is one way to reduce measurement uncertainty, but under un-known or even changing conditions it is not always possible at all to specify the "correct" microphone.
A solution to this dilemma would be to use a microphone which compared with the commonly used 1/2" microphones have the following features:

- Less sensitive to the nature of the sound field
- Less sensitive to angle of incidence

It has been known by acoustics engineers for many years that the presence of the microphone disturbs the sound field which it is intended to measure [1] and that the issues addressed here are caused mainly by the physical size of the microphone.
Generally speaking a microphone can be considered non-diffracting as long as:

$$(\pi/\lambda) * 2a \leq 1 \quad (3)$$

Where λ is the wavelength of the signal being measured and 2a is the microphone diameter. Therefore a ½" microphone can measure without significant disturbance[4] of the sound field up to around 8 kHz, whereas a ¼ " microphone can measure up to around 16 kHz.

Actually the use of 1/4" microphones instead of 1/2" is a way to reduce measurement uncertainty in the audible range considerably. There is only one problem: The noise floor of 1/4" microphones – typically around 40dB - is much too high for most acoustical applications, since such a high noise floor would not allow measurement of SPL's below 50 dB with sufficient accuracy.
The challenge is now to design a 1/4" microphone with high sensitivity, low inherent noise and the stability of ½" measuring microphones.

6 Microphone Sensitivity

Figure 6 shows a generic schematic of a condenser microphone and its associated pre – amplifier, where the microphone cartridge now act as a capacitor to ground.

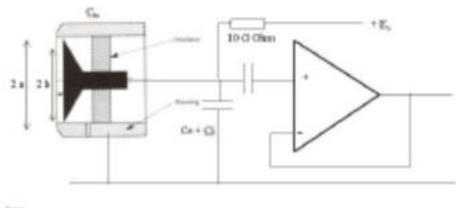

Figure 6

As shown in [2] the sensitivity of a condenser microphone can be expressed as:

$$M_p = [0.11 * E_0 * a^2] / [T * h_0] \quad (4)$$

Where:
M_p is the sensitivity of the cartridge in V/Pa
E_0 is the polarization voltage in Volts
a^2 is the radius squared e.g. $D^2/4$ with d =diameter in m
T is the tension in the diaphragm expressed in N
and
h_0 is the back-plate to diaphragm distance in m
The relation between T and the radial stress r_{ss} is

$$r_{ss} = T/d \quad (5)$$

Where d is the thickness of the foil.

For a 5 um foil with T = 2000 N the radial stress is therefore

$$r_{ss} = (2000/5 * 10^{-6}) = 400 \text{ MN/m}^2 \text{ or } 400 \text{ MPa}$$

Interesting enough using the simple formula (4) and typical values like a polarization voltage of 200 V, distance between the back-plate and diaphragm equal to 20 um and a diaphragm tension of 2000 Pa (4) yields a sensitivity of

4 Here defined as 3 dB error without grid correction

3.3 mV/Pa for a ¼” microphone, which is in good agreement with practical values.

Theoretically a 1/4” microphone is expected to have a sensitivity which is only 25% of that of a ½” microphone.

For a number of years so called high sensitivity 1/2” microphones with a sensitivity of 50 mV/Pa are commercially available from many manufacturers, however that doesn't change the fact that the “theoretical” sensitivity of a 1/2” microphone cartridge is around 12.5 mV/Pa and the sensitivity of a 1/4” microphone will be in the mV range.

7 Modern Microphone Design

By inspection of (4) it is very easy to suggest ways to increase the sensitivity of a condenser measuring microphone with fixed diameter:

1. Increase the polarization voltage
2. Decrease the distance between the back - plate and the diaphragm
3. Reduce the diaphragm tension

Comments and limitations to the suggestions above:

7.1 Increased Polarisation voltage

For external polarized microphones the polarisation voltage must be 200 V in order to be compatible with existing front – ends. For pre-polarized (electret-type) microphones the polarization voltage is a design parameter, but there are practical limitations determined by the arching and too large static diaphragm deflection.

7.2 Reduction of the back-plate to diaphragm distance

This can be dangerous since this increases the electrical field strength with increased risk of sparks (excess noise in the microphone). If the distance is too small there is also the risk that the diaphragm will touch the backplate when the microphone is exposed to high dynamic pressure fluctuations.

7.3 Reduction of the diaphragm tension

This is the only parameter left, but until now long term stability concerns would have prohibited the use of low diaphragm tension due to the stainless material being used.

We consider stainless diaphragms necessary in most applications in order to achieve corrosion resistance and good long term stability (avoid pinholes)

Now a solution has been found, using a diaphragm made from thin precision grade Titanium foil; this diaphragm has the benefit that - if it is processed properly -its tension can be reduced to such a low value that it is possible to produce a ¼” microphone with the same sensitivity and inherent noise as that of a ½” high sensitivity microphone !

But nothing comes for free: The low tension means that the resonance frequency for this microphone is much lower than for a normal ¼” microphone namely around 26 kHz instead of around 80 - 100 kHz.

Additional sensitivity increase has been achieved by using more of the outer diameter (of the 6.25 mm) for the active part of the microphone which could be made around 20 % larger than in a normal ¼” microphone, resulting in further increase of the sensitivity.

In order to achieve excellent temperature stability the cartridge was made “all Titanium” which brings additional benefits with respect to corrosion resistance and in-sensitivity to magnetic fields.

8 Practical Example

Using the principles described here it has been possible to develop a new microphone which is called the multi-field microphone and has the following main specifications:

Diameter	¼”
Sensitivity	50 mV/Pa
Noise floor	< 20 dB(A)
Frequency range	10 Hz – 20 kHz

A new Titanium encapsulated ¼” Constant Current Line Drive (DeltaTron) pre-amplifier has been also developed in order to be able to offer a complete all Titanium microphone with multi-field performance.

Fig (7) shows the response in different types of sound – fields for a typical multi-field microphone.

As it can be seen the measurement error will typically always be less than the industry standard criteria +/- 3 dB.

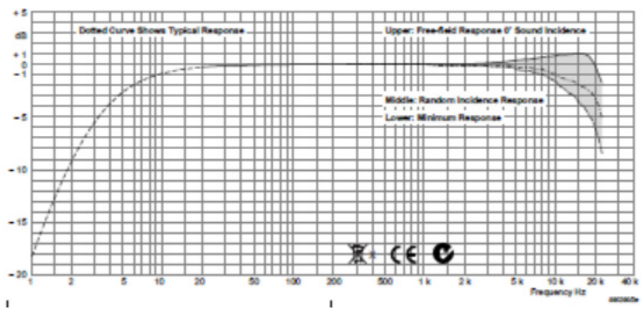

Fig. 7 Multi-field microphone calibration Chart

9 Summary

Serious measurement errors may be the consequence when a microphone is used, which is not optimised for the actual sound field. Unfortunately the nature of the sound field is not always known and the noise sources may also be non stationary.

Using new technology, we overcame the limitations which the use of traditional technologies and materials have imposed on ¼” microphones until now. The result is a microphone, which widely eliminates the influence of unknown measurement conditions and additionally it releases the user from the challenge to choose between different microphones.

References

[1] Free-field response of Condenser Microphones

Brüel & Kjær Technical Review No. 1 and 2. 1959

[2] Niels V. Bøgholm « Milestones in Measuring Microphone Development » National Society of Acoustics, Vishakhapatnam, India, (2008)