Multi-field Microphone – when the Sound Field is unknown

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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 one important – and unfortunately in many cases major – source of error is often neglected: 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 a condenser microphone which drastically reduces the error caused by influence of an unknown sound field or varying angle of incidence. Finally, test results from production samples of the new microphone are shown.

INTRODUCTION

Only a small percentage of all acoustical measurements are performed in the well defined and well controlled (for example defined as: Temperature 23^{o}C deg., Relative Humidity 50 % and Ambient Static Pressure 101.3 kPa) environment of a calibration laboratory – on the contrary most acoustical measurements are done under non controlled conditions which are not often even known in beforehand.

This is the reason that 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. When using high quality in-

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strumentation and transducers the varying environmental conditions is normally not causing any problems at all.

However, one major source of error remains and that is the impact which the nature of the sound field will have on the measurement uncertainty. It is common practice to assume that the sound field in any measurement case will be either free, diffuse or pressure field.

SOUND FIELDS

Free field: There are no reflecting objects, only the microphone disturbs the sound field.

Diffuse field: There are so many reflecting surfaces, that the sound waves arrive with equal probability from all directions.

Pressure field: This is found in small confined spaces like calibration couplers.

Depending on the nature of the sound field an appropriate microphone is selected: A microphone which is "optimised" for the sound field in question. Unfortunately there are many practical situations where the sound field is not really of a well defined type. This may be the case inside buildings, during in-cabin noise measurements or measurements on multi or non- stationary sources. Often a free-field microphone is chosen more based on tradition than on real knowledge about the nature of the actual sound field. Fig. 1 shows a picture of the Multi-field microphone, which is suited for use in a free as well as in a diffuse field.

Fig. 1 Multi-field field microphone Type 4961

It is amazing how large the potential errors are if the conditions are non ideal.

Fig. 2 shows the response of a free-field microphone in a true free field; the frequency response is the ideal flat response. But the angle of incidence may not be zero (as assumed in Fig. 2) or the sound field may not be a true free field, say it actually was diffuse instead of free and the response will be as shown in Fig. 3.

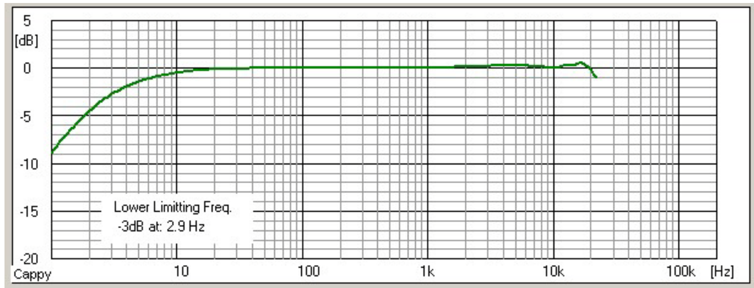

Fig. 2 Free-field response of a ½” free-field microphone

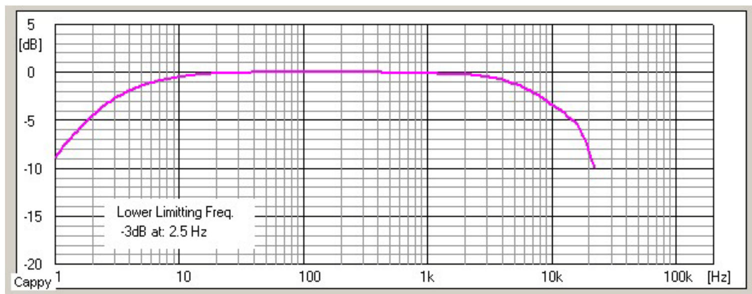

Fig. 3 Diffuse-field response of a ½” free-field microphone

Both Fig. 2 and 3 are valid for a typical ½” microphone with protection grid and (in Fig. 2) for zero degree of incidence (e.g. the microphone diaphragm is facing head on towards the sound source).

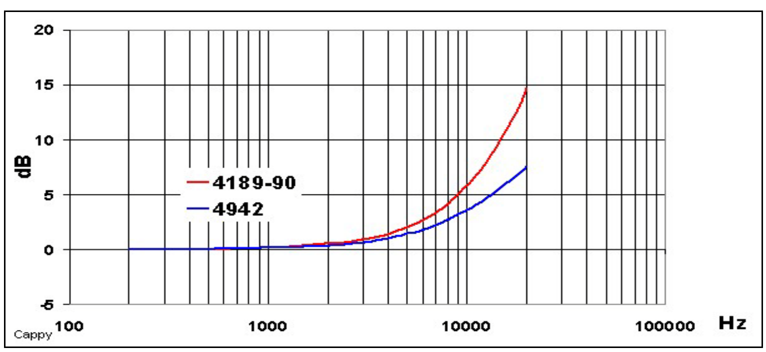

Fig. 4 Maximal error for free-field microphone type 4189/90 (upper curve) and diffuse-field microphone type 4942 (lower curve)

Actually taking not only the nature of the sound field but also the angle of incidence into consideration the potential error may be even larger.

Fig. 4 shows the maximal error as a function of frequency when a free-field (4189/90), respectively diffuse-field (4942) microphone is being used in a field or in an angle of incidence for which the actual microphone was not optimised.

As clearly shown in Fig. 4 the error is noticeable from 2 kHz and already at around 6 kHz the potential maximal error due to “unknown conditions” largely exceeds the influence of all other environmental influence factors and even exceeds the IEC 61672 tolerance of 3.5 dB not to mention the IEC 1094 + - 2 dB requirement.

IS THERE A CURE?

It has been known for many years (refs. [1, 3, 4]) that a microphone disturbs the sound field and that the issues addressed here are caused solely by the physical size of the microphone.

Generally speaking a microphone can be considered non-diffractive as long as $(\pi/\lambda) * 2a \leq 1$, where λ is the wavelength and 2a the microphone diameter. Therefore a ½” microphone can measure without disturbance of the sound field up to around 8 kHz, whereas a ¼” microphone can measure up to around 16 kHz. In reality, microphones can measure up to higher frequencies, because the measurement error at higher frequencies is predictable and the microphone frequency response can be compensated for (optimised) in the microphone itself. In this way, a flat frequency response can be achieved – but only in one given kind of sound field.

That is why there exist three different microphone types: Free-field, diffuse-field and pressure-field microphones. As mentioned above a ¼” microphone would be readily useable in all fields up to 20 kHz, but today unfortunately all commercial ¼” measuring microphones have less sensitivity and much higher noise floor than their ½ ” counterparts. A typical ¼” free - field microphone has a noise floor around 40 dB(A) opposed to 16 - 18 dB(A) for a typical premium quality ½” free-field microphone.

The limiting factors

In order to discuss the most important factors which determine the sensitivity of a condenser microphone we will introduce a set of simple equations which describe the sensitivity of a condenser microphone.

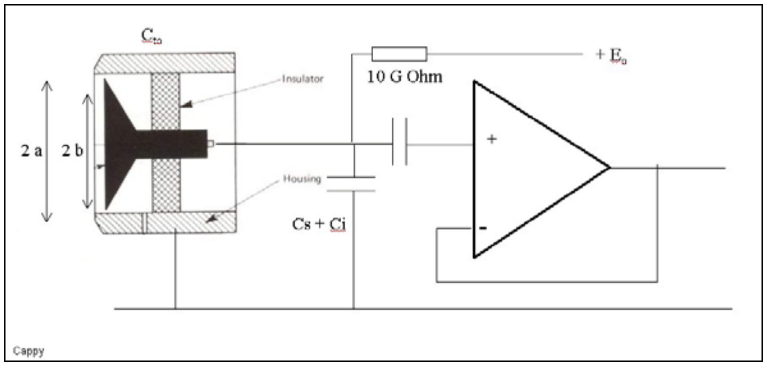

Fig. 5 Principal schematic of a condenser microphone with pre-amplifier

2a is the diaphragm diameter
2b is the diameter of the back-plate
h_0 is the distance back-plate to diaphragm
E_0 is the polarization voltage
C_i is the pre-amplifier input capacitance
C_s is the stray capacitance

Now the microphone mid range pressure sensitivity M_p (V/Pa) can be expressed as the product of two sensitivities $M_p = M_e * M_m$

Here M_e is the electrical transfer function in V/m and M_m is the mechanical transfer function in m/Pa and as one observes the dimension of M_p equals [V/m] * [m/Pa] which means that M_p is in V/Pa as expected.

As shown in the literatures see. f. inst. (ref. [2]) the following equations apply:

$$M_e = E_0/h_0 * [1 - b^2/2a^2)]*[1 + (C_i + C_s)/C_{to}] \qquad (1)$$

Now in most practical cases b equals approximately 0.8 * a and typically $C_i + C_s << C_{to}$ hence (1) is with good approximation

$$Me = [0.68 * E_0] / h_0 \qquad (2)$$

For the mechanical transfer function in m/Pa (ref. [2]) shows that

$$Me = a^2/8T \qquad (3)$$

Where T is the tension of the diaphragm in N/m, which depends on the radial stress s_{rr} (N/m^2) and the thickness d of the diaphragm accordingly to

$$T = s_{rr} * d \qquad (4)$$

In practical cases T is often in the interval 2000 – 3000 Pa.
Combining (2) and (3) the simplified equation for the microphone mid range sensitivity is:

$$M_p = M_m * M_e = [0.11 * E_0 * a^2] / [T * h_0] \qquad (5)$$

Using (5) and a polarization voltage of 200 V, 20 µm distance between the backplate and diaphragm and 2000 Pa tension (5) yields 3.3 mV/Pa for a ¼" microphone, which is in good agreement with practical values.

SUGGESTIONS ON HOW TO INCREASE THE SENSITIVITY OF A ¼" MICROPHONE

By inspection of (5) it is very easy to see how to increase the sensitivity of a microphone:

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

Short comments and limitations to the suggestions:

Increased Polarisation voltage

For external polarized microphones the polarisation voltage must be 200 V in order to be compatible with existing front – ends on the market.

Besides there are practical limitations determined by the arching and static diaphragm deflection and for these and other reasons the polarization voltage can not be changed.

Reduce backplate to diaphragm distance

Reduction of the back-plate to diaphragm distance is also dangerous since this increases the electrical field strength with increased risk of sparks (excess noise in the microphone). Further the backplate to diaphragm distance at max SPL should ideally be larger than 50 % of the distance under quiescent conditions.

Lowering diaphragm tension

The last resort is to have a much *lower diaphragm tension* but here there are severe limitations when using the traditional cobalt base alloy as the diaphragm material.

Instead a solution has been found using a Titanium diaphragm; this diaphragm has the benefit that if it is processed properly the tension can be reduced to such a low value that the sensitivity of the ¼" microphone is very close to that of a normal ½" high sensitivity microphone.

The low tension means that the resonance frequency for this microphone is much lower than for a normal ¼" microphone around 26 kHz instead of say 70 - 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 e.g. a larger b value than in a normal ¼" microphone.

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,

A new Titanium housed ¼" Constant Current Line Drive (DeltaTron) preamplifier with TEDS (Transducer Electronic Data Sheet) has been developed in order to be able to offer a complete all Titanium microphone with multi-field performance, see Fig. 1.

In summary, the microphone described here has the following key parameters:

Diameter	¼"
Sensitivity	60 mV/Pa
Noise floor	< 20 dB(A)
Frequency range	5 Hz – 20 kHz
Dynamic range	20 – 130 dB
Upper SPL limit	130 dB (3% distortion)
Max SPL	> 150dB (peak)
Temperature	-20 to +70°C (-4 to +158°F)

Fig. 6 shows the performance in unknown field for a multi-field microphone Frequency Response Function compared against IEC 61672 limits and compared with the already mentioned ½" microphones (worst cases) used today. Fig. 7 shows a typically Calibration Chart for a Multi-field Microphone.

SUMMARY

Using all Titanium technique it has now been possible to overcome the limitations which traditional technologies and materials have imposed on ¼" microphones so far. The result is a microphone which widely eliminates the influence of unknown measurement conditions and additionally it releases the user from the pain to be forced to choose between different microphones. Main uses are measurement in unpredictable sound field conditions, cabin noise measurements, near-field measurements and ad hoc sound measurements.

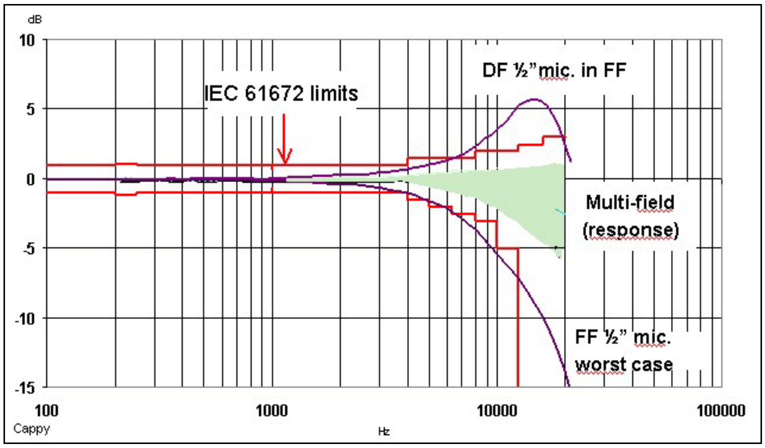

Fig. 6 Multi-field FRF compared against IEC 61672 limits and ½" microphones (worst cases), DF = Diffuse Field, FF = Free Field

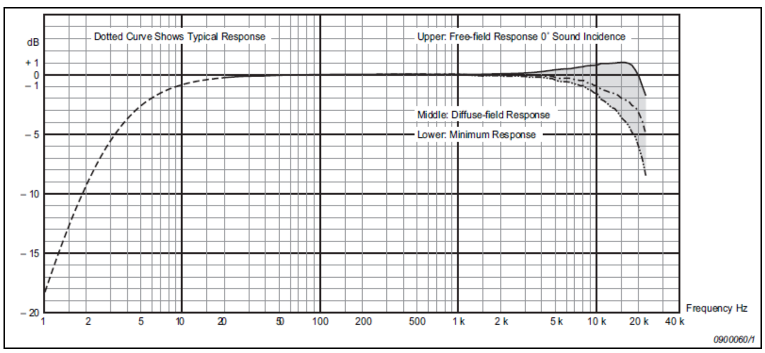

Fig. 7 Multi-field Frequency responses: Free-field response (upper), Diffuse-field response (middle) and minimum response (lower)

The multi-field measuring microphone, Type 4961, is the only ¼" measuring microphone in the world with a 20 dB noise floor and sensitivity exceeding 50 mV/Pa (nominal sensitivity is 60 mV/Pa) – enabling it to take accurate measurements in free, diffuse or diverse sound fields. Because Type 4961 is small and relatively insensitive to the angle of incidence, it simplifies the process of taking complex sound measurements, saving technicians' valuable time planning, setting up and analyzing results.

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