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Microphone Choice: Large or Small, Single or Double?

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ABSTRACT

How do large and small diaphragm condenser microphones differ? A common misapprehension is that large capsules necessarily become less directional at low frequencies. It is shown that this is not a question of large or small, but rather of single or double diaphragm design. The different behaviours have a direct impact on the sound engineers' choice and placement of microphone. Likewise, the much debated question of proximity effect with multi-pattern microphones and omnidirectional directivity is discussed.

1. INTRODUCTION

The purpose of microphones is to convert sound waves into electrical signals. Microphones can be classified e.g. according to active or passive, electrical energy source, transducer principle, diaphragm excursion or velocity sensor, pressure / pressure-gradient transducer, directional pattern, size, and so on [3,10]. While many transducer principles can be used, condenser microphones today offer the widest range of realizations, for the most diverse and including the highest-quality applications. The main focus here shall lie on

- condenser microphones,

- pressure-gradient i.e. directional transducers,

the simple and straightforward parameter of transducer size, and realizing multiple polar patterns with single or double diaphragm construction.

A common, but not standardized distinction is to differentiate between

- large diaphragm capsules (LDC), exceeding 25 mm in diameter,
- small diaphragm capsules (SDC), typically 17 - 22 mm in diameter,
- miniature capsules, less than 10 mm in diameter.

Furthermore, directional patterns can be realized with a single diaphragm construction, open on both sides to the impinging sound waves. Or, as a combination of two capsules, i.e. with two diaphragms and the option to electrically combine them into the full variety of first order directivity patterns [3].

The general workings of condenser microphone capsules and their directivity can be found in almost all audio and electro-acoustics textbooks. Two back-to-back cardioid capsules, combined electrically with different gains and polarity, can be used to produce all first-order directivities between omnidirectional, unidirectional and bi-directional. This concept is well known and need not be discussed here. The available detailed literature on proximity is less numerous, the published work on double diaphragm designs is minimal. The interested reader can find more detailed information e.g. in [3,6,11,12].

2. HISTORICAL BACKGROUD

It all started with a measurement microphone. Wentz published his patent of an omnidirectional capacitive transducer [13] which later evolved into the Western Electric measurement microphones. Likewise, Neumann started out with omnidirectional transducers of the LDC type in 1928 [7]. The “pure” first order pressure-gradient transducer came next, with a bi-directional (“figure-8”) pattern. A major milestone was then the invention of a unidirectional capsule by Braunmühl and Weber [4]. They combined the ideas of omnidirectional and bi-directional transducers into one design, closing off the rear entry with a second, symmetrically placed diaphragm. It is not clear if the inventors were immediately aware of all the capabilities of this design. But this exact double large diaphragm capsule (DLDC) with its closed, symmetrical construction can be seen as two symmetrical, unidirectional transducers back-to-back to each other, and was later used in the 1940s for the first switchable multi-pattern condenser microphones. Bauer, on the other side, showed with his patent in 1938 [1] that unidirectional patterns could also be achieved with a single diaphragm, with modelling the rear sound entrance path to the diaphragm. In contrast to closed, double diaphragm designs, such single diaphragm capsules can maintain their directivity pattern down to lowest frequencies, as will be shown more in detail.

While most if not all of these constructions were of rather large size, the advent of television in the 1950s

led to the miniaturization of condenser microphones, and to the current “small” microphones of roughly 20 mm housing diameter. This size can be seen as a compromise between the requirements of smallness, visual and acoustical unobtrusiveness, medium sensitivity, and reduced self-noise level.

Interestingly, it was only in the 1990s that single large diaphragm capsules (SLDC) evolved, providing us with some of today’s very low-noise microphones. Like their smaller-sized counterparts, these designs can provide consistent directivity also at lowest frequencies.

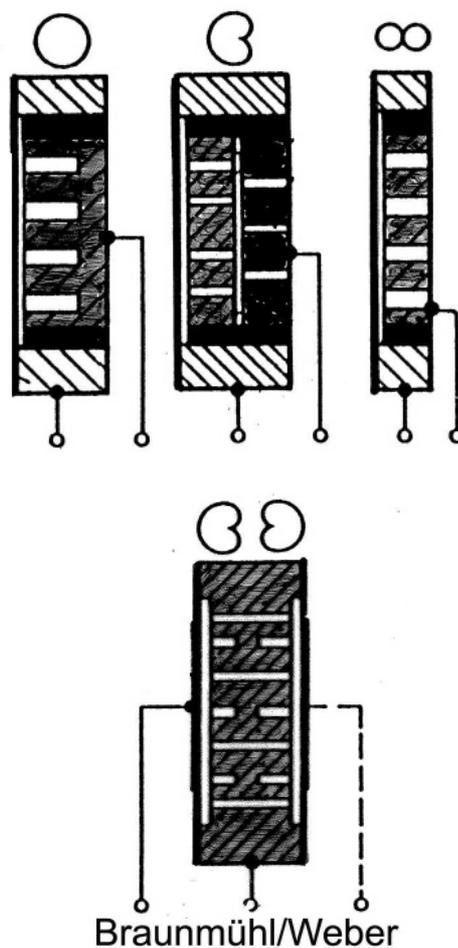


Figure 1 Schematic views of omnidirectional, unidirectional, bi-directional, and Braunmühl-Weber designs

3. MEASURING TECHNIQUE

The aim of this investigation was to verify the theoretical findings, and replicate earlier and historical measurements [2,11,12]. Three different test environments were used to measure microphone frequency responses in the near and far field:

- far field measurement in large anechoic chamber at 5 m distance to a loudspeaker,
- “mid field” measurement in typical, smaller anechoic chamber at 1.25 m distance to a loudspeaker,
- near field measurement at small distances, e.g. 0.05 m, from an artificial mouth.

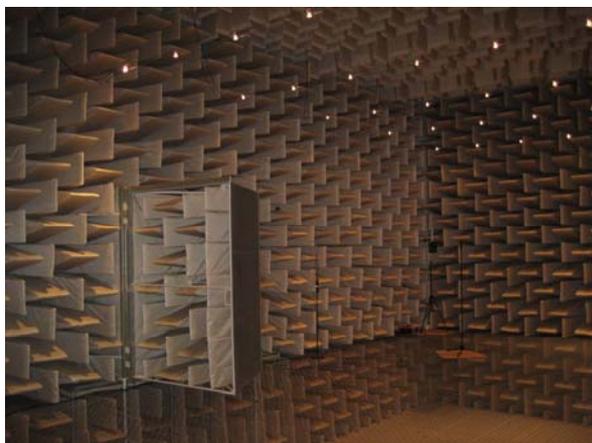


Figure 2 Anechoic room for measurements with 5 m distance between microphone and loudspeaker



Figure 3 Artificial mouth at 0.05 m distance

At 5 m distance the sound field in the very large anechoic room approaches a plane progressive wave as

required by IEC 60268-4, for frequencies above 34 Hz. With the length of the absorbers used, the room is qualified for free-field measurement requirements from approx. 65 Hz upwards.

Measurements at 1.25 m distance are presumably typical of most manufacturers' lab or series measurements, made in anechoic chambers of moderate size. In this specific chamber, a situation approaching plane wave conditions can be assumed for frequencies above 135 Hz.

At 0.05 m distance an artificial mouth as specified in ITU-T Rec. P51 was used. These measurements describe the microphone behaviour at very close distance to almost point-like sound sources, thus simulating typical vocal recordings.

At 0.05 m and 1.25 m frequency responses and polar plots were measured; with the 5 m measurements, a rotating table was not available, so measurements were only performed at discrete angles, i.e. $0^\circ / 45^\circ / 90^\circ / 135^\circ / 180^\circ$.

For the sound engineer, these three measurement distances do describe practical situations:

- the 0.05 m distance is typical of hand-held vocal microphones, a slightly larger distance is typical for studio vocal & speech recordings,
- the 1.25 m distance describes the pick-up of sound sources in the vicinity of a microphone, e.g. neighbouring instruments in an orchestra or group,
- the 5 m distance describes the behaviour of microphones when used as main microphone for orchestral or group recordings, ambient microphones, etc. and the pick-up of more distant instruments.

In the course of the measurements, nine vastly differing large diaphragm capsule designs were measured, three with a single diaphragm, six of double diaphragm design. These were compared with a selection of small diaphragm capsules, of which two were of double diaphragm design. A representative, small selection of measurements shall be discussed in the following.

4. SINGLE AND DOUBLE DIAPHRAGM MICROPHONES

A typical “mid field” measurement of a single large diaphragm cardioid microphone is shown in figure 4. This measurement is presumably typical of many manufacturers’ lab measurements, and might often be used when compiling technical data sheets.

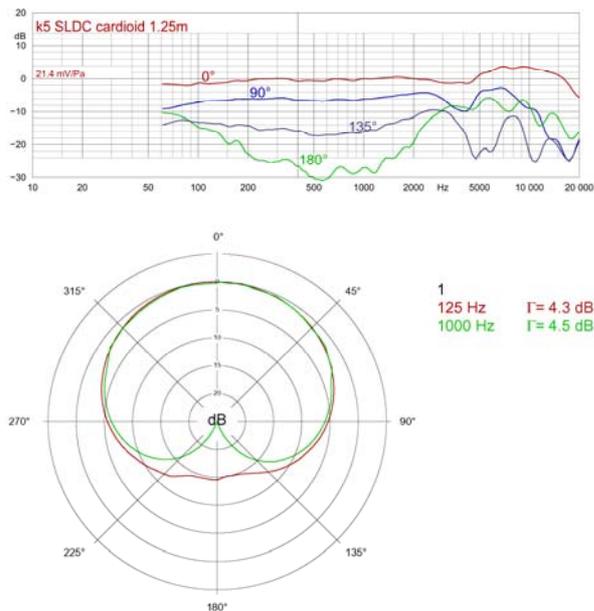


Figure 4 Single large diaphragm capsule k5, cardioid pattern, measured at 1.25 m

It shows some typical effects of non-ideal measurement set-ups, i.e. fulfilling neither plane wave nor spherical wave requirements:

- the 0° curve shows a slight bass boost below 135 Hz, due to proximity effect,
- the 90° curve shows a realistic bass roll-off, as proximity effect is not present at 90°,
- the 180° curve shows a strong bass boost, due to proximity effect.

Likewise, the polar pattern at 125 Hz has a wide cardioid shape, with the directivity index dropping from 4.7 dB to 4.3 dB.

Due to the limited anechoic room size, data is shown only down to 60 Hz.

Let’s now have a look at the double diaphragm capsule measurement in Fig 5.

- the 0° curve shows some bass boost below 135 Hz, due to proximity effect,
- the 90° curve shows a slight rise,
- the 180° curve is not as low as in Fig 3, and shows a smooth rise towards low frequencies.

The polar pattern at 125 Hz has the shape of a rather wide cardioid.

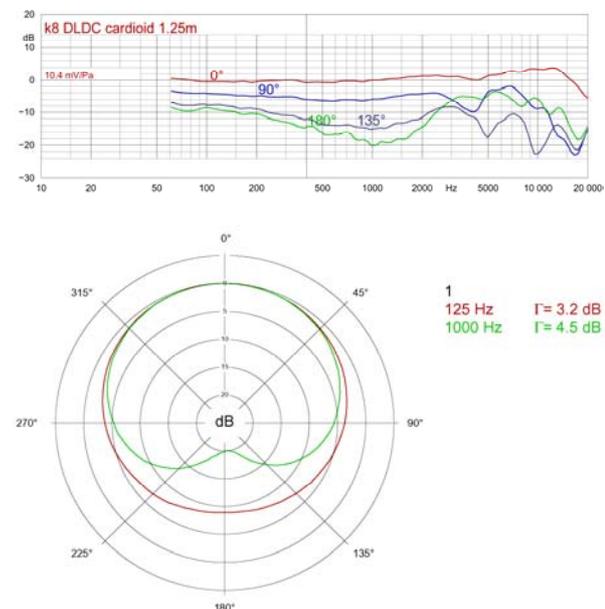


Figure 5 Double large diaphragm capsule k8, cardioid pattern, measured at 1.25 m

At first sight, the two measurements may not seem to differ so much. But the essential differences between single and double diaphragm designs become much clearer when investigated also at very small and very large distances.

4.1. Far Field

In Fig 6 we now see a measurement as it should be used if free-field data is published according to IEC 60268-4. We see a smooth roll-offs at 0° slightly “wavy” due to set-up imperfections. The 0° roll-off is slightly steeper than the one shown in figure 4, as at that distance there is no proximity effect. The 90° curve remains unchanged. The curve at 180° differs drastically from

figure 4: the single diaphragm design shows that it remains a consistent cardioid down to lowest frequencies.

In contrast, a double diaphragm design does keep its sensitivity rise towards low frequencies. The directivity of the double diaphragm thus truly tends towards a wide cardioid pattern.

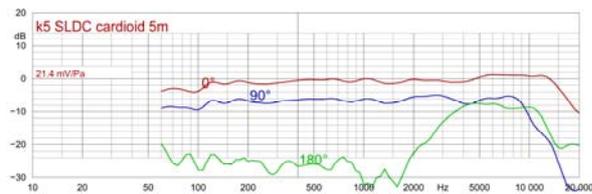


Figure 6 Single large diaphragm capsule k5, cardioid pattern, measured at 5 m

For the sound engineer this means that a double diaphragm used in the far field or in diffuse sound field conditions will pick up more bass from all directions than a single diaphragm design.

In most concert halls, reverberation time typically increases towards low frequencies. Use of double diaphragm microphones for example as ambient microphones will now overemphasize the low frequent parts of the reverberation. It is for the sound engineer now to decide if this is subjectively pleasing for the specific recording, or if he would rather choose single diaphragm designs which will provide a “drier” sound.

4.2. Near Field

What happens now in the near field? Figs 7 & 8 show that proximity effect becomes much more prominent, at 0° and 180°, as was to be expected, with an increase of more than 14 dB. The 90° curves remain almost unchanged, as proximity effect does not exist there. The polar pattern turns into a full figure-8 for the single diaphragm design, at 125Hz. The double diaphragm capsule lies somewhere between hypercardioid and figure-8 pattern.

Note: it can be a bit difficult to rotate the microphone to exactly 90°, at only 0.05 m distance to an artificial mouth, where the slightest mispositioning will have an influence on the measurement.

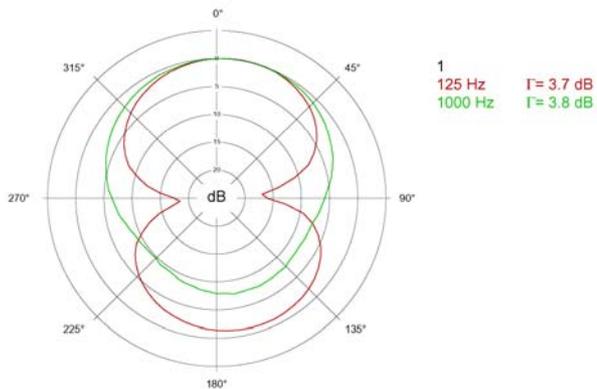
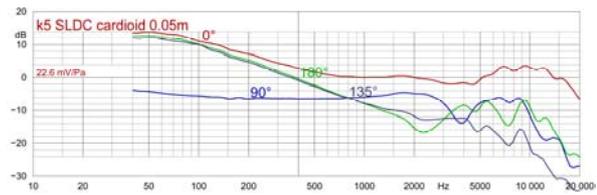


Figure 7 Single large diaphragm capsule k5, cardioid pattern, measured at 0.05 m

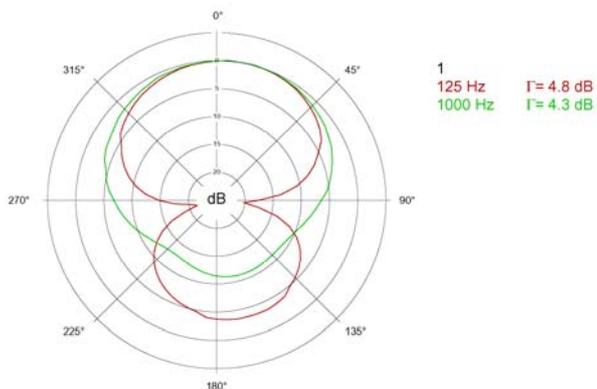
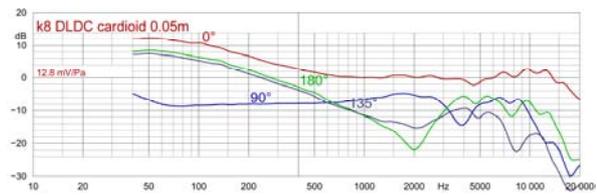


Figure 8 Double large diaphragm capsule k8, cardioid pattern, measured at 0.05 m

The steep rise at 180° in the low frequencies can usually be neglected, as one will seldom find a sound source in very close proximity to the rear of a microphone. But it can be confounding at first sight, when quickly testing a microphone by speaking into it from a small distance. The sound pick-up from the rear will sound extremely

bass-heavy and boomy, but this is only due to proximity effect. For more distant sound sources the microphone may well display a perfect directional, rear-attenuating characteristic.

The bass boost at 0° is massive with single diaphragm designs. It is likewise present with double diaphragms, but not as overwhelmingly. This small difference in behaviour could explain to some part why double diaphragm designs are often preferred for vocal & speech recordings in studios, especially for artists who work the microphone at very small distances.

Still, the same or a similar result might be obtained when using single diaphragm designs at slightly larger distances than their double diaphragm counterparts. This may be well allowable without affecting the overall sound too much, as the polar pattern of single diaphragm designs remains more directional at low frequencies, thus better attenuating unwanted room reflections.

5. OMNIDIRECTIONAL MICROPHONES IN THE NEAR FIELD

Do double diaphragms designs show proximity effect, i.e. a bass boost, when set to omnidirectional? This question often arises with people working mostly with omnidirectional microphones. The answer is: yes, slightly, but only at minimal distances. Fig 9 shows the behaviour of such a double diaphragm design at 0.05 m.

In theory, if the double capsule were perfectly thin, the proximity effect at the front and the rear diaphragm would compensate each other. But with typical real capsules, the front diaphragm will be e.g. 3 - 6 mm closer to the sound source. Thus, proximity effect on the front half of the capsule will be slightly higher than on the rear side, and results in a very slight rise in the low frequencies, with a directivity index of perhaps 0.8 dB. For practical applications, this slight rise may well be neglected, and the polar pattern regarded as fully omnidirectional.

6. OMNIDIRECTIONAL MICROPHONES IN THE FAR FIELD

Finally, we'll have a look at the behaviour of omnidirectional capsules at high frequencies in the far field. For the high frequencies, the small anechoic

chamber measurement set-up at 1.25 m distance is fully sufficient.

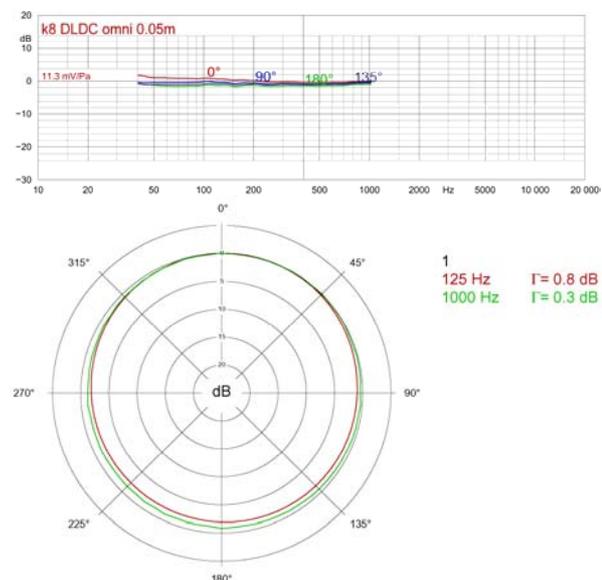


Figure 9 Double large diaphragm capsule, omnidirectional, measured at 0.05 m

As stated, all microphones become directional at high frequencies, when the wavelengths approach the microphone dimensions. Depending on the shape of capsule and housing, the polar pattern of a single diaphragm capsule will turn into a predominantly unidirectional, lobar or lobar/hypercardioid shape [8,9]. The case of small cylindrical and spherical omnidirectional microphones is shown in Fig 10 & 11. Directivity index increases from 0 dB to e.g. 8.7 and 5.9 dB.

Note: larger sized capsules will produce a more pronounced directivity increase towards the high frequencies. In this test set-up, no single large diaphragm capsules with omnidirectional characteristics were available for comparison.

The case for double diaphragm capsules is slightly different. Each side constitutes a cardioid characteristic, the shape of the capsule mostly being a disc. These also become directional at high frequencies, see Fig. 12, with a lobar pattern, and directivity index increasing e.g. from 4.4 dB to 12.5 dB.

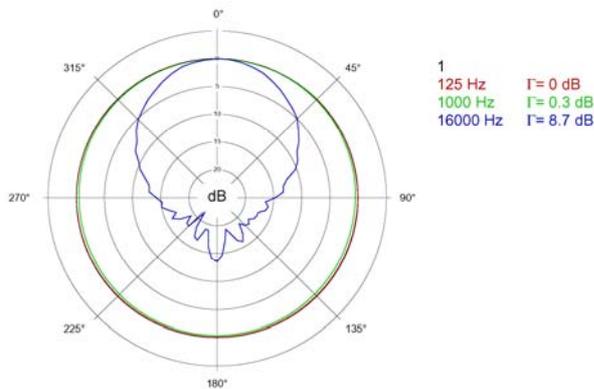


Figure 10 Single small diaphragm capsule k30, cylindrical shape, omnidirectional, measured at 1.25 m

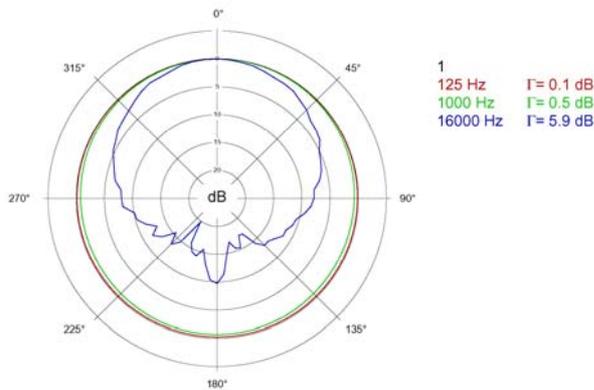


Figure 11 Single small diaphragm capsule k35, spherical shape, omnidirectional, measured at 1.25 m

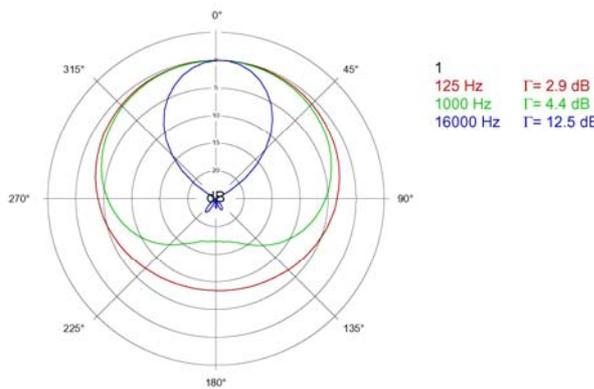


Figure 12 Double large diaphragm capsule k8, cardioid, measured at 1.25 m

Electrically combining the two capsule sides we obtain an omnidirectional construction at low frequencies. At the opposite end of the audible spectrum, the combination of the two lobar patterns looking front and rear yields a pattern similar to a higher order figure-8, but more of a “propeller” shape, with directivity index increasing from 0 dB to 10 dB.

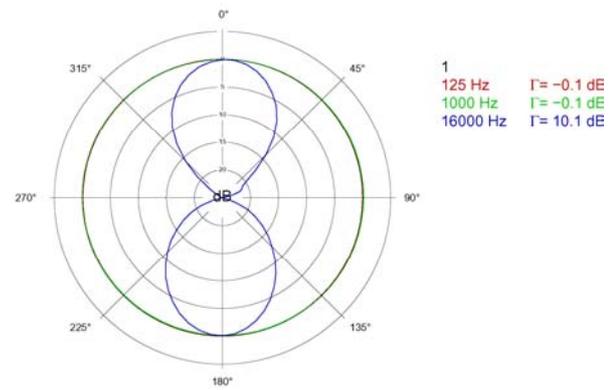


Figure 13 Double large diaphragm capsule k8, omnidirectional, measured at 1.25 m

For the sound engineer, the main differences between omnidirectional capsules in the far field are that

- large capsules become more directional at high frequencies than their smaller counterparts,
- double capsules become slightly less directional at very high frequencies than single diaphragm designs, due to their “propeller”-shaped pattern.

The differing directivity patterns should be considered mainly in those cases where loud, very high frequent sound sources impinge on the microphone.

7. CONCLUSION

Most of the aforementioned results are not mentioned for the first time, and may be well-known to microphone designers or skilled sound engineers. Still, the author hopes to have given a short insight into the behaviour of different microphone constructions, both in the near and the far field, giving a guideline for practical recording applications.

8. ACKNOWLEDGEMENTS

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