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Comprehensive measurements of head influence on a supercardioid microphone

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ABSTRACT

The directional pickup pattern of microphones is designed as to assist the audio engineer in avoiding acoustic feedbacks or interference from other sound sources. If the pattern deviates from the specified one, it is important for the audio engineer to know. This work presents comprehensive measurements of a supercardioid microphone directivity under the influence of a dummy head. The dummy models the diffraction of a human talker or singer in front of the microphone. The discussed measurements collect information on a 15x15 degree grid in azimuth and elevation for different distances between microphone and dummy head. Based on these data, we are able to discuss the influence of a singer's body on the free field directivity of the supercardioid microphone, its directivity index and its front-to-back random ratio in detail.

1. INTRODUCTION

A general limiting factor in electroacoustical sound reinforcement is the maximum achievable gain before feedback. This quantity depends on frequency-dependent directivity patterns of the involved microphones and loudspeakers, their position and orientation, and room acoustics, cf. [1]. Sound engineers make use of the typically rotationally symmetric pickup patterns of gradient microphones when setting up well designed audio systems on big stages.

Detailed information can be found in data sheets or measurement charts of microphones, such as Fig. 1(b). It shows the polar plot of the AKG D7 supercardioid microphone in octave bands. The directivity pattern exhibits a strong attenuation of signals from 125°, the *null angle* of the microphone.

Direct field (stage monitoring). In typical stage situations, this *null angle* is exploited to equip

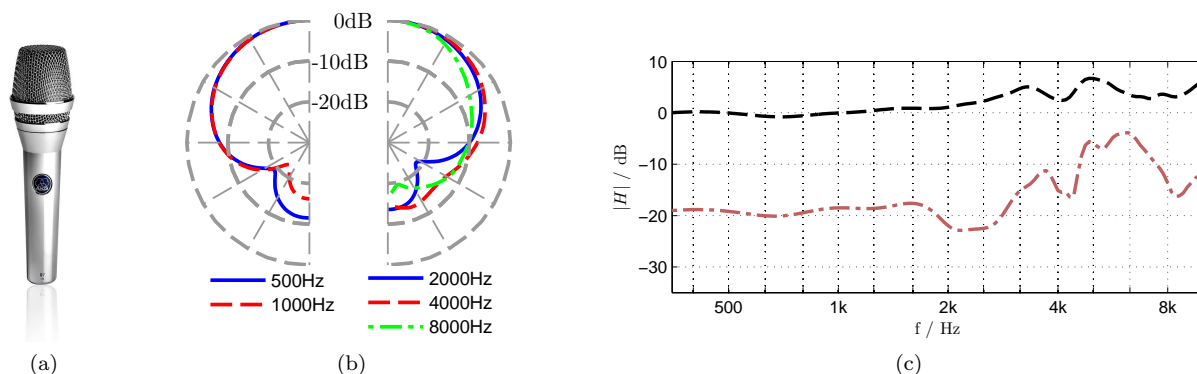


Fig. 1: (a) supercardioid microphone AKG D7, (b) its polar plot and (c) free field frequency responses; black dashed line: on axis, red dot-and-dash line: null angle.

singers with a stage monitoring loudspeaker whose signal supports the performers but must not be picked up by the gradient microphone to avoid crosstalk and feedback, cf. Fig. 2. In a free sound field an attenuation of about 20dB is achieved between the frontal direction of the supercardioid at 0° and its null angle of 125° , regarding most frequencies, cf. Fig. 1(c).

Diffuse field (sound-reinforcement): In the above-mentioned situation, the clearly located direct sound from the stage monitor is the predominant interference. By contrast, when loudspeaker and microphone are farther separated, more and more directions get involved in crosstalk and feedback by acoustic reflections, mostly in a diffuse mix.

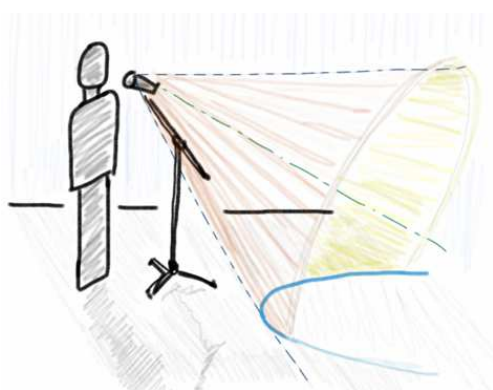
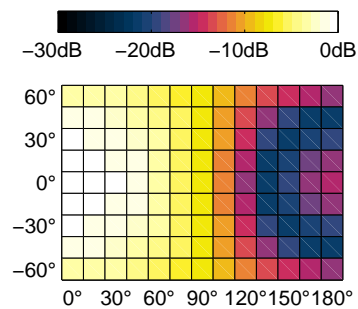


Fig. 2: Null angle of supercardioid microphone covers a cone of directions.

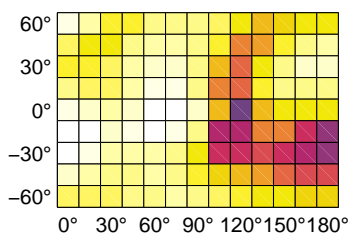
To achieve a larger gain margin before feedback in such a situation, the sound engineer can choose a microphone that is less sensitive to mixed diffuse sound from all directions than to the direct sound from the microphone axis. First-order gradient microphones achieve a maximum *directivity index* (DI) of 6dB for the hypercardioid pattern, meaning they are 6dB less sensitive to diffuse sounds.

If the diffuse interference mainly impinges from the rear hemisphere, the supercardioid pattern with a slightly lower DI of 5.7dB is preferable: It maximally rejects the diffuse sound energy from the rear in contrast to the frontal hemisphere as quantified by the *front-to-back random ratio* (FBRR), cf. [2]. The supercardioid pattern is therefore *unilateral* and achieves an FBRR of 11.4dB.

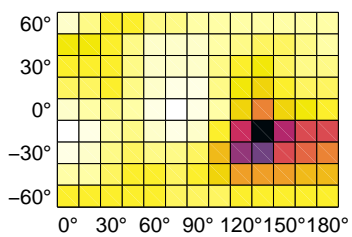
How reliable are directivity pattern, DI and FBRR in practice? The directivity pattern of a microphone is conventionally measured in free field conditions. In practice, a singer or talker steps in front of the microphone and hereby changes its directivity due to reflections and scattering on her body. This effect is rarely treated in literature. Recently, Schneider [3] presented a set of direction dependent frequency responses considering the presence of a talker's head without torso, measured in four horizontal directions. The present contribution attempts to study the head influence in greater detail, mainly by using more measurements, other analysis methods, and by considering the presence of a human body with torso at different distances.



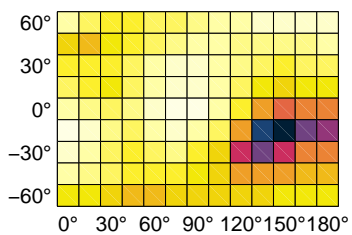
(a) without dummy head



(b) a=10cm

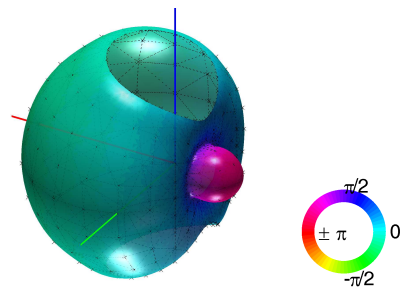


(c) a=5cm

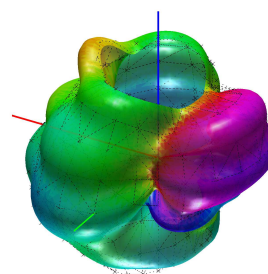


(d) a=2cm

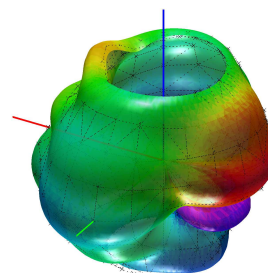
Fig. 4: Measured magnitudes at 1kHz, for (a) free field and (b) to (d) three different distances of the dummy head.



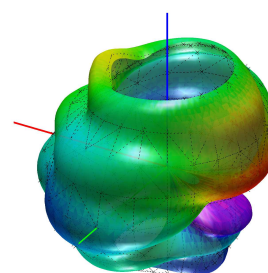
(a) without dummy head



(b) a=10cm



(c) a=5cm



(d) a=2cm

Fig. 5: Interpolated balloon plots of the measured data at 1kHz, for (a) free field and (b) to (d) three different distances of the dummy head ; radius depicts the magnitude from -30dB to 0dB, color represents phase.

in this work allows interpolation up to an order of $N=11$. Fig. 5 shows the interpolated balloon plots at 1kHz. The radius depicts the magnitude from -30dB to 0dB, the color represents phase, and the gray mesh shows the discretely measured values. The interpolation achieves good results below 3kHz for the examples including the dummy head, using the rough estimate $kr < N$ with the torso size $r \approx 50\text{cm}$ and the wave number k .

These examples give a brief impression of how the presence of a talker can influence directivity. In principle, the measured data allow to generate such balloon diagrams for all frequencies below 3kHz. The geometric configuration causes non rotationally symmetric diffraction and comb filtering. Consequently, the dependency of the directivity on frequency is complex, which is of questionable relevance for the sound engineer. General tendencies are hard to identify based on such plots.

How to characterize the head influence on the directivity then?

For the sound engineer mainly two scenarios are noteworthy: On the one hand, the pronounced attenuation at the null angle should be preserved in situations with dominant direct sounds, e.g. for stage monitoring. On the other hand, interference from a diffuse field should be kept small as indicated by a large directivity index or front-to-back random ratio.

3.2. Direct field: null angle

Applying interpolation to the measured values, all directions lying on the free field null angle can be plotted. Fig. 6 shows the achieved attenuation at the 125° angle under the influence of the dummy head. The gray lines depict all frequency responses found on the 125° cone, c.f. Fig. 2, in 1° rotational steps; the solid black line depicts their average. The dot-and-dash red line and the dashed black line represent the free field null angle response and on-axis response, respectively, cf. Fig. 1(c).

The attenuation at the 125° angle largely varies with frequency and exhibits direction-dependent comb filter effects due to the dummy head. The directional average of the attenuation at the original null angle is strongly decreased under head influence. Averaging the attenuation at 125° from 350Hz to 4kHz yields about 20dB for the free field curves. Aver-

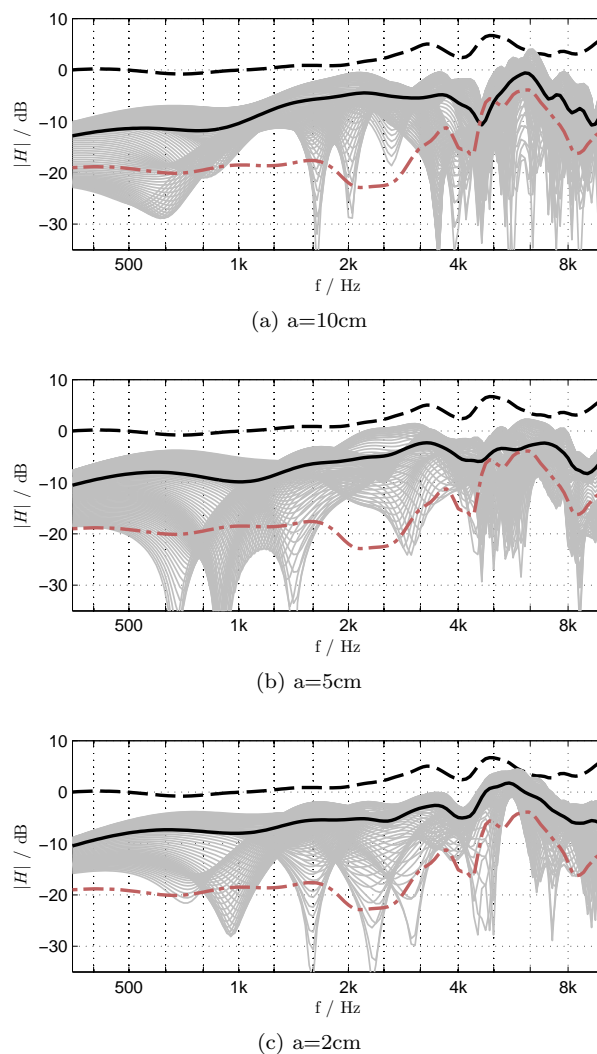


Fig. 6: Frequency responses on the 125° cone for three different distances of the dummy head; gray lines depict the responses sampling the cone in 1° rotational steps; solid black line depicts average, red dot-and-dash line depicts the free field null angle response, and black dashed line depicts the on-axis response.

aging the curves with dummy over both the 125° directions and frequency yields only 10dB.

3.3. Diffuse field: DI and FBRR

Directivity index. The directivity index is defined as $DI = 10 \lg \left(\frac{4\pi |g_0|^2}{RE} \right)$, where the reference value g_0 is the on-axis sensitivity, and the random energy $RE = \int_{S^2} |g(\phi, \theta)|^2 d\Omega$ is the surface integral of the direction dependent microphone sensitivity $g(\phi, \theta)$ over the unit sphere S^2 . For rotationally symmetric directivities integration reduces to a semicircle. For measurements of g at discrete directions this integral is approximated by weighted summation.

The measurement grid used in this work has a gap around the north and the south pole and only covers an area \tilde{S} ranging from $\theta_1 = -67.5^\circ$ to $\theta_2 = +67.5^\circ$ elevation¹. Furthermore, we assume that the on-axis response picking up the talker's signal corresponds to the free field on-axis sensitivity $g_{0,free}$ as it is not affected by scattering.

The directivity index is estimated from the measured sensitivities g_i by discrete summation over the surface elements $\Delta\Omega_i$,

$$\tilde{DI} = 10 \lg \left(\frac{|g_{0,free}|^2 \sum \Delta\Omega_i}{\sum |g_i|^2 \Delta\Omega_i} \right).$$

Fig. 7(a) shows the directivity index for the AKG D7 with and without the influence of the dummy head. For idealized hyper, super, and cardioid the DI is 6dB, 5.7dB and 4.8dB, respectively, and their estimated \tilde{DI} verifies the method, indicated by the gray dashed lines in Fig. 7(a).

Up to 1.6kHz the DI of the AKG D7 closely matches 5.7dB. Its nulling is best at 3kHz where the DI exceeds the maximum value of a first order transducer. At 6kHz the DI is minimal, and above 8kHz its diaphragm size (20mm) yields a DI that is constantly increasing with frequency.

The DI curves with head influence are the same above 4kHz. Below, the directivity index is at most deteriorated by 1dB in comparison to the free field curve.

¹It is assumed that the covered angular area is extended by $\Delta\theta/2$ above and below the last measurement point.

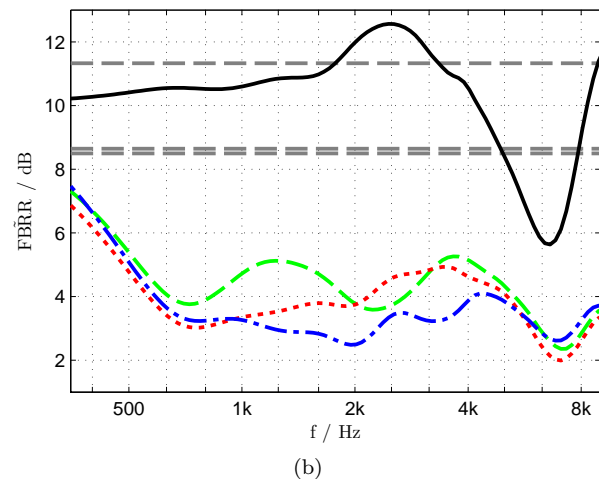
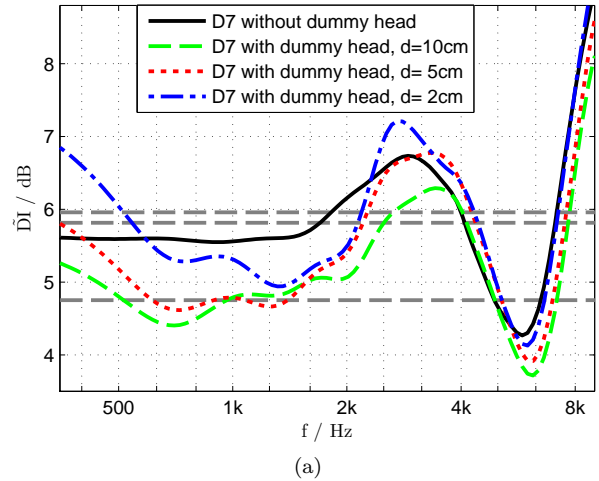


Fig. 7: (a) estimated directivity index, and (b) front-to-back random ratio with and without the influence of the dummy head; gray dashed lines depict the estimated values for idealized hyper, super and cardioid.

Front-to-back random ratio. The front-to-back random ratio is defined as $\text{FBRR} = 10 \lg \left(\frac{\text{RE}_f}{\text{RE}_b} \right)$, where RE_f and RE_b are the random energies of sounds arriving from the frontal and rear hemisphere, respectively.

Similar to the estimation of the directivity index, we assume that the frontal sensitivity is not affected by scattering. Thus the FBRR is estimated by

$$\text{FBRR} = 10 \lg \left(\frac{\sum_{i \in f} |g_{i,\text{free}}|^2 \Delta\Omega_i}{\sum_{i \in b} |g_i|^2 \Delta\Omega_i} \right),$$

where $g_{i,\text{free}}$ are the free field sensitivities and g_i the sensitivities under head influence, and $i \in f$ expresses all frontal and $i \in b$ all rear measurement positions.

Fig. 7(b) shows the front-to-back random ratio for the AKG D7 with and without the influence of the dummy head. Again the estimated FBRR for idealized hyper, super, and cardioid are depicted in Fig. 7 by gray dashed lines.

In the free field, the FBRR of the AKG D7 is close to the ideal value of 11.4dB, exhibiting a peak at about 3kHz and a minimum at about 6kHz. Under the head influence, the FBRR curves strongly decrease in contrast to the free field curve, falling far below the values of even the idealized hypercardioid or cardioid.

4. CONCLUSION

We have shown that the presence of a talker or singer in front of a microphone strongly affects its directivity pattern. For this purpose, we took and analyzed a comprehensive set of sensitivity measurements involving a dummy head at various distances.

Our measurements on the AKG D7 dynamic reference microphone (supercardioid) indicate a reduction of its 20dB attenuation at the 125° null angle to 10dB. Supercardioid microphones do not entirely lose their nulling under the human influence, but sound engineers should save enough gain-before-feedback reserve for stage monitoring during the performance; even with a good, properly set up microphone that is not moved.

A similar picture was revealed for the supercardioid's property to suppress diffuse sounds from the

rear half-space: Its FBRR of 11.4dB drops to 4dB under the influence of a human talker or singer.

Nevertheless, the insensitivity of the microphone to an entirely surrounding diffuse field, its directivity index, does not change a lot under the influence of the singer's or talker's head. This is hardly surprising as the sensitivity of the microphone is mainly deflected but not occluded.

Note that all observations have been made with a dummy head of reflecting surface; clothed performers will have a slightly different effect.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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