



## THE MEASUREMENT OF MICROPHONE SENSITIVITY AT LOW FREQUENCIES

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The author discusses the causes of measurement error in the measurement of microphone sensitivity at low frequencies. He proposes that the polar pattern and the frequency response of the transmission factor should be reported for a particular standardized free-field measurement distance, which has yet to be determined. By means of an example, he illustrates the implementation of the proposed measurement method.

### 1. Introduction

Throughout the world, microphones are tested in anechoic chambers. A loudspeaker broadcasts – usually simultaneously – to the microphone which is to be tested (“test microphone”) and to a reference microphone with known technical data. The frequency of the test signal is varied continuously, so as to cover the entire frequency range. The reference microphone has a flat frequency response, and its output voltage is used as input to a control circuit in order to maintain the pressure of the sound being broadcast from the loudspeaker at a constant level. The voltage curve generated by the test microphone thus corresponds directly to its frequency response, and can be recorded by means of a recording device (see Fig. 1).

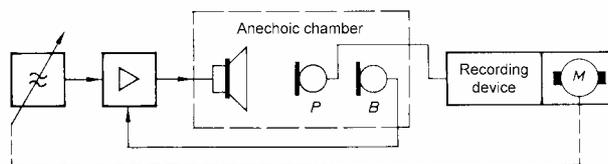


Figure 1. Schematic diagram of setup for recording the frequency response  
(B = reference microphone, P = test microphone)

In general, in the mid- and high-frequency range, this measurement method rapidly yields quite accurate results. However, for lower frequencies, precise measurements are difficult to obtain, and the results often vary from one measuring chamber to another. The reasons for this are discussed below.

### 2. The sound field in an anechoic chamber

It is particularly important for measuring chambers not to generate any reflections over the entire frequency range. With the sound-absorbing facilities available today, this requirement can generally be met – often for frequencies as low as 40 Hz, although this may require substantial effort. However, less attention is sometimes paid to the fact that at low frequencies, even in relatively large measuring chambers, the sound propagation differs from that in a free sound field. Sound waves which are propagated near a wall or ceiling lined with sound-absorbing material curve more or less sharply toward these surfaces. This applies primarily to sound waves in the low-frequency range, the wavelengths of which are relatively large in comparison to the distance from the sound-absorbing surface concerned.<sup>1</sup>

<sup>1</sup> For a sound wave with a frequency of 40 Hz, the wavelength in air is 8.50 m.



In a measuring chamber, the sound therefore diminishes more rapidly with increasing distance, and sound wave fronts exhibit greater curvature than would be the case in a free sound field. This phenomenon is referred to as the “channel effect” (see Fig. 2).

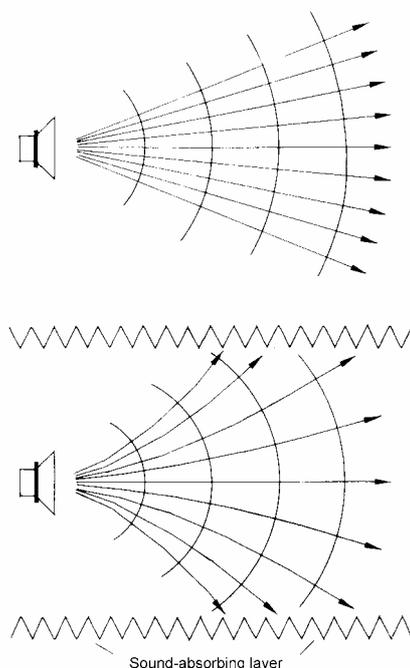


Figure 2. Illustration of the channel effect and the curvature of the sound wave front. Top: free sound field; bottom: sound propagation (at low frequencies) in a chamber lined with sound-absorbing material

### 3. Pressure microphones

How does the channel effect influence microphone testing? There is little difficulty in the case of pressure microphones, which sample the sound field essentially at a single point. Pressure microphones can be measured accurately at least when the test microphone and the reference microphone are at the same distance from the loudspeaker and also approximately at the same distance from the sound-absorbing material, or when they are measured consecutively at the same location.

However, instead of being positioned side by side, the two microphones are very often arranged 20 cm to 50 cm one behind the other, in order to reduce interference from the sound reflected from the microphone housings at high frequencies, and in order to avoid errors arising from a slightly nonuniform radiation of sound from the loudspeaker in various directions. For instance, if the test microphone is 100 cm and the reference microphone is 130 cm from the loudspeaker, in a free sound field, the sound pressure at the reference microphone will be  $100/130$  of that at the test microphone, a difference of 2.3 dB. However, in a medium-sized anechoic chamber, with interior dimensions of 3.2 m x 4.2 m x 2.8 m, as a result of the channel effect, for frequencies of less than 100 Hz, differences in sound pressure for two microphones positioned at 100 cm and 130 cm from the loudspeaker were found to be as great as 4.8 dB. If this discrepancy is not taken into account, the level indicated for all microphones tested will be as much as  $4.8 \text{ dB} - 2.3 \text{ dB} = 2.5 \text{ dB}$  too high, thus generally resulting in an apparent frequency response which is “too good”. Due to the control circuit, the 2.5 dB decrease in sound pressure detected at the reference microphone causes a corresponding increase in the power supplied to the loudspeaker.

This error can of course be readily eliminated by a corresponding boost in the frequency response of the reference microphone. However, it can be presumed that this correction is not carried out at all sites.<sup>2</sup>

<sup>2</sup> The measuring chamber used here as an example was equipped with compensating distortion correction when it was first put into operation many years ago.



## 4. Pressure gradient microphones

The accurate measurement of microphones in the low-frequency range is significantly more difficult in the case of pressure gradient microphones. In order to clarify the discussion, the mode of operation of these microphones is briefly reviewed here. Generally, in pressure gradient microphones, the front and rear of the diaphragm are exposed to the sound field.<sup>3</sup> The sound field is thus sampled at two points located one behind the other. In an ideal plane sound field, both points are exposed to the same sound pressure, with the result that the operation of the microphone is based solely on the fact that the sound reaches the rear of the diaphragm later, resulting in a phase difference.

At the lowest frequencies, the forces arising from the phase difference, that cause the diaphragm to move, are very small. For microphones of normal dimensions, the decisive phase angle at 40 Hz is only 1° to 3°. The size of the angle naturally increases continuously as the frequency increases.

In a spherical sound field, and hence also in an anechoic chamber, the sound pressure decreases with increasing distance from the sound source. Thus, in addition to the phase-related force acting on the diaphragm, there is also a force resulting from the difference in sound pressure amplitude at the front and rear of the diaphragm. Although this difference is very small, it can cause pronounced boosts in the frequency response at low frequencies (the “proximity effect”), because in this range the force arising from the phase difference, which is independent of distance, is very weak.

Thus, for pressure gradient microphones in the nearfield, the polar pattern and the frequency response of the transmission factor are also generally dependent on the distance from the sound source. In order to eliminate the effects of this phenomenon, which can vary depending on the construction of the microphone, the German industrial standard DIN 45 591 prescribes measurement in a “plane sound field”, in other words at a theoretically “infinite” distance.

It is permissible for the phase angle to be larger only in the case of special microphones which operate as pressure gradient transducers at low frequencies, but as pressure transducers at mid-range or higher frequencies, where their directional characteristic is based on the interference effect, since here the proximity effect and associated problems do not arise.

## 5. Measurement in a nonreflecting closed tube

An almost ideal sound field, even for low frequencies, can be created in a sufficiently large nonreflecting tube. The standard DIN 45 591 specifies several requirements which must be met by such a tube. A sound-absorbing plug is suitable for use as a closure. For measurements with frequencies as low as 40 Hz, the plug should be at least 2.20 m long (1/4 of the wavelength). The tube diameter must also be large enough so that the dimensions of the microphone cause practically no reduction in the tube cross section. Unfortunately, such tubes are currently available only at very few sites.<sup>4</sup>

It is true that the conditions of a “plane sound field” can be considered to be approximated sufficiently closely out-of-doors, at a distance appropriate for the sound wavelength. However, the weather and environmental influences almost always prevent accurate measurements from being obtained out-of-doors.

<sup>3</sup> However, it should be noted that in some pressure gradient microphones, two spatially separate diaphragms are connected electronically.

<sup>4</sup> For 16 years, a tube has been available to the author which permits correct measurements “in a plane sound field” even for frequencies as low as 25 Hz. The tube is 14 m long, with an inside diameter of 44 cm. Its closure is a rock wool sound-absorbing plug more than 4 m long. The tube is embedded in sand, to ensure that vibration of the 4 cm thick tube walls is prevented at high sound pressure levels.



## 6. Measurement problems in an anechoic chamber

What is the situation in an anechoic chamber? Here the wave front curvature and hence the decrease in sound pressure with increasing distance at low frequencies is even more pronounced due to the sound-absorbing material lining the chamber (see Fig. 2). This causes an apparent diminution of the measuring distance, which in fact must be as large as possible. The proximity effect exhibited by pressure gradient microphones,<sup>5</sup> the effects of which are to be eliminated from the measurement in compliance with DIN 45 591, has an even more significant influence here than is the case in a free sound field, and low-frequency sounds are boosted more than they are for measurements at the same distance in a free sound field.

In any case, in measuring chambers of the usual dimensions, at low frequencies it is not possible under any circumstances even to approximate the conditions of a plane sound field. Therefore, it is worth considering whether, instead of using a plane sound field, it would not be better to record all values for a particular, uniformly defined distance from the sound source – a distance which could be replicated in most anechoic chambers. It is true that the currently prescribed measurement in a “plane sound field” is physically the “cleanest” measurement method, and is the least impaired by limiting conditions. However, if one checks the published data recorded at low frequencies for the available pressure gradient microphones, one finds that there is virtually no type of microphone with data which are even approximately valid for a “plane sound field”, as prescribed in DIN 45 591.

Nevertheless, many of these microphones are considered to be of high quality and are favored by users. Perhaps this is because the measurement procedures upon which their data sheets are based, while not corresponding to the standards, are nevertheless application-oriented. Also, in a practical setting, microphones are less and less often placed at a great distance from the sound source to be recorded.

Using a small pressure gradient condenser microphone as an example, Fig. 3 illustrates how much the measured values for low frequencies can vary from one measuring chamber to another, and the extent to which they can deviate from the values for a plane sound field (represented by tube measurements). Figure 3 shows measured values recorded a) in a relatively small and b) in a somewhat larger anechoic chamber, at a distance of 1 m from the loudspeaker, as well as values recorded c) in a tube, using the same microphone for purposes of comparison.

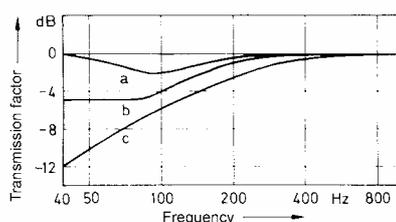


Figure 3. Frequency response of a small pressure gradient microphone, measured a) in a small anechoic chamber, b) in a larger anechoic chamber, and c) in a nonreflecting closed tube

Figure 4 shows how the sound field can affect the polar pattern of the same microphone at very low frequencies.

<sup>5</sup> Reuber, C.: Taschenbuch der Unterhaltungselektronik (Handbook of entertainment electronics) 1973/74, pp. 42-44. Berlin: Schiele und Schön.

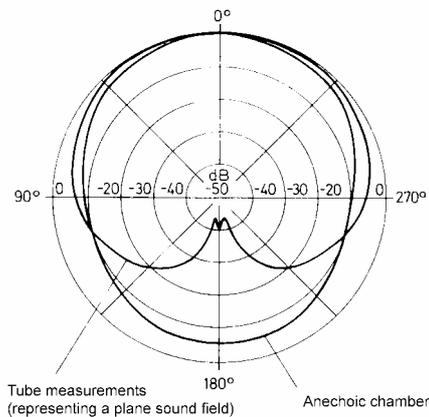


Figure 4. Polar pattern of a small condenser microphone at 40 Hz, measured in an anechoic chamber and in a tube

Unfortunately, there is no universally applicable method for converting values measured in the nearfield into data which are valid for a plane sound field, because some pressure gradient microphones operate as such down to the low frequencies, while others shift to an omnidirectional pattern at low frequencies.

## 7. Proposal for a practical measurement method

In order to obtain comparable data even for the low-frequency range that can be correctly measured everywhere, and that are not, as hitherto, dependent on the particular measuring chamber used, the following is proposed: reporting of the polar pattern and the frequency response of the transmission factor for a particular, uniformly defined free-field measuring distance. For every anechoic chamber, it must be initially ascertained at what distance from the loudspeaker the sound field conditions correspond to the conditions of this free-field measuring distance. A simple method of doing this is given in DIN 45 573 part 1, par. 2.5, and is described at the end of this article, in Section 8.

Distances from the loudspeaker will always be greater in a measuring chamber, because the more pronounced curvature of the sound field (channel effect) simulates a closer proximity to the sound source, even at increased distances. In selecting a numerical value for the proposed **free-field measuring distance**, it might at first seem reasonable to specify a value of 1 meter. However, it has become apparent that the channel effect can have such a strong influence not only in small, but also in medium-sized measuring chambers, that even with distant microphone positions it is not possible to find a point at which the sound field conditions correspond to those of a free-field measuring distance of 1 meter. Therefore it is necessary to specify a lower value, so that uniform measurements can be obtained even at sites with only a small or narrow anechoic chamber. A free-field distance of 60 cm could be considered.

### 7.1. Implementation of the proposed measurement method

A numerical example is used to illustrate how the recommended measurements can be performed. The free-field measuring distance for which the data are to be recorded is assumed to be 60 cm.



First a table is prepared, where the left column lists several frequencies ranging from 40 Hz to 160 Hz, and the right column gives the corresponding (greater) distances from the loudspeaker, ascertained by means of the procedure described at the end of this article. For instance, such a table may appear as follows:

F	s
40 Hz	97 cm
50 Hz	120 cm
63 Hz	116 cm
80 Hz	70 cm
100 Hz	68 cm
120 Hz	71 cm
160 Hz	62 cm

(f = frequency. s = distance of the microphone from the loudspeaker in the anechoic chamber concerned, where the curvature of the sound waves is the same as that for a free-field distance of 60 cm. The values for s are obtained by means of the procedure given in Section 8.)

For this measuring chamber, at a frequency of 63 Hz, the position of the microphone is 116 cm from the loudspeaker. The reference microphone and the test microphone are placed in this position one after the other, and are exposed to sound with a frequency of 63 Hz. The difference in level (not the absolute value) between the two microphone voltages is recorded. Because the sensitivity of the reference microphone (a pressure transducer) is known and is independent of the distance from the sound source, the desired value for the test microphone can be readily calculated from the difference in voltage level. This value can be referred to as the “sensitivity at a free-field distance of 60 cm for a frequency of 63 Hz”.

If this relatively complex measurement has been performed initially for several frequencies for each type of microphone, routine microphone measurements can then be carried out again in the usual manner (see Fig. 1). Naturally the data sheets cannot be based on the values thus obtained. However, the difference between these values and the values obtained from the (initial) transmission factor measurements for the relevant microphone type, performed according to the procedure proposed above, can be used in order to correct the recorded measured values and curves for the microphone type concerned. Once corrected, the values will no longer be valid only for the conditions in a particular measuring chamber, but will be generally valid for a free-field distance of 60 cm, for instance.

If polar patterns for individual frequencies are recorded, for low frequencies this should in fact be done with the microphone positioned in the measuring chamber at the distances specified in the table.

In addition, every manufacturer is naturally also free to provide additional values for other distances, and if possible also for a plane sound field. However, in any case, the data for the (yet to be defined) free-field distance should be included in the microphone data sheets, because only these values can, with some degree of certainty, be measured correctly everywhere even at low frequencies, and thus be employed by users to obtain an objective comparison of different microphones.

In conclusion, it is again emphasized that the above discussion applies only to the low-frequency range. At and above approximately 160 Hz, and occasionally even above 100 Hz, the differences among transmission factor and polar pattern values measured in different ways and at different locations rapidly become negligible.



## 8. Appendix

For a position A at a distance  $s_1$  from the loudspeaker, in order to determine what free-field distance corresponds to the sound field conditions acting on a microphone at this position, the reciprocal value of the sound pressure,  $1/p$ , is plotted as a function of the distance  $s$  from the sound source, and the points on the curve corresponding to distances  $s_2$  and  $s_3$  (on each side of  $s_1$ ) are connected by a straight line. Parallel to this straight line, a line is then constructed which intersects the curve at the point corresponding to distance  $s_1$ . This line cuts the abscissa at point B. The distance A B then represents the free-field distance  $a$  which corresponds to the sound field conditions prevailing at point A, at distance  $s_1$  from the loudspeaker. In the example illustrated in Fig. 5,  $a = 66$  cm. This procedure is then repeated for other microphone distances  $s$  until a value of 60 cm (or another value, to be determined) is found for  $a$ . If necessary, interpolation is to be used.  
(In accordance with DIN 45 573 part 1, par. 2.5.)

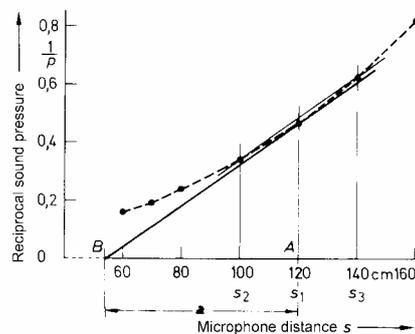


Figure 5. Graphical determination of the free-field distance  $a$  which corresponds to the sound field conditions acting on a microphone at distance  $s$  from the loudspeaker. The point  $s = 0$  and the scale of the ordinate representing  $1/p$  may be selected as desired.