How to Match a Measurement Microphone to a Sound Field

By Santiago Rayes

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GRAS Sound & vibration

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Introduction

Selecting the right measurement microphone for the environment is essential for obtaining accurate, actionable measurement data. Therefore, measurement microphones are designed for use in particular sound fields. Understanding the differences between the microphones can help in selecting the right microphone and avoiding potential measurement errors.

Typically, sound fields are complex and therefore it is important to understand the relationship between a microphone and its acoustic surroundings. A sound field with many reflections and standing waves can be a challenge. Whether it is free field, diffuse field or something in between, a reasonable choice of the measurement microphone makes post-processing and data analysis much easier.

This application note will detail the practical differences between three microphone types:

1. Free-field microphone.
2. Pressure microphone.
3. Random-incidence microphone.

This application note also contains an explanation of how measurement microphones can disturb a sound field, the consequences of the disturbance and how to correct the measured results based on the disturbance.

Types of sound fields

Determining what type of sound field is present is important for choosing the right microphone for the measurement and getting reliable results. The three different sound fields are described below.

Free field

A free field is defined as a sound field without any objects that can introduce reflections. So, the only sound arriving to a listener in this sound field, is the direct sound without the influence of any reflections. Assuming a single monopole sound source, the sound field can be approximated to simple plane waves radiated in a well-defined direction. A loudspeaker in an anechoic chamber can be considered a free-field situation in a limited frequency range determined by the size of the chamber.

Pressure field

A pressure field is defined as the sound field on a surface or a small closed chamber, where the phase and magnitude are the same throughout. This could be the inside of a wind tunnel, small cavities, boundary layers or acoustic couplers.

Diffuse field

A diffuse field, or random-incidence field, has sound arriving with equal probability, at any level and random phase, from all directions. It can be a room with many objects causing reflections in many directions (see standard IEC 61183 Random Incidence and diffuse field calibration of sound level meters). In practice, reverberant chambers for acoustic testing try to replicate a diffuse field within a limited frequency range.

Influence of the microphone in the sound field

Any object that is placed in a sound field will cause a disturbance due to its size and shape, and microphones are no different. A standardized IEC-61094-4 WS2P ½″ pressure measurement microphone has a diaphragm diameter of approximately 12.6 mm. Imagine a situation where this microphone is in a free-field environment such as an anechoic chamber pointing at 0° incidence to an ideal sound source with a flat frequency response (Figure 1).

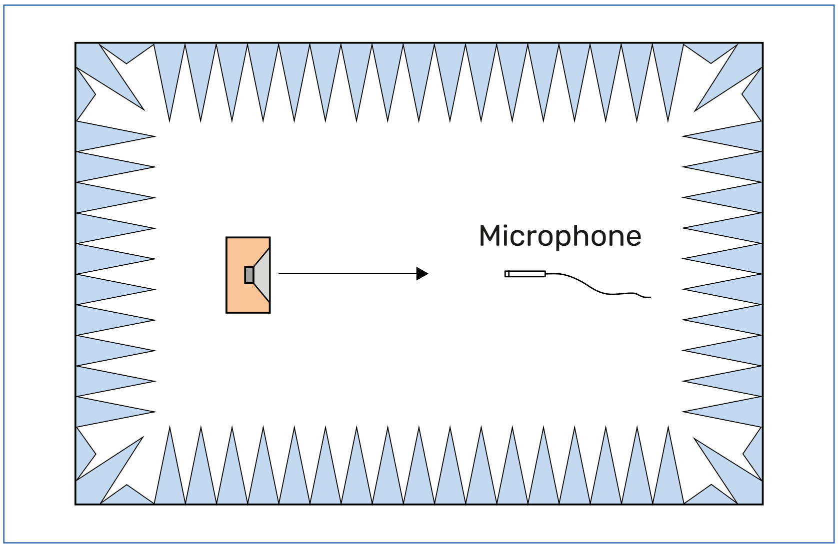


Figure 1
Pressure measurement microphone pointed at 0° incidence from a sound source inside an anechoic chamber (free-field environment).

In regard to a 100 Hz sine wave, which has a wavelength of 3.4 m, a ½″ microphone will be practically invisible to this sound wave due to the small size of the microphone (Figure 2) compared to the wavelength.

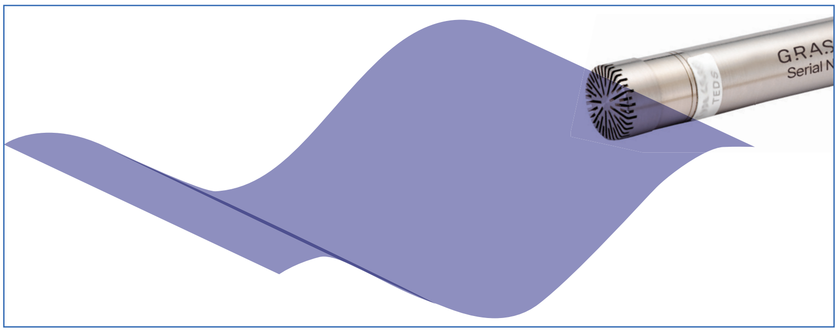


Figure 2
½″ pressure microphone set exposed to a low-frequency sound wave with a long wavelength.

Increasing the frequency of the reference signal shortens the wavelength of the signal until it starts being comparable with the size of the microphone. For example, a 10 kHz signal has a wavelength of approximately 34 mm (given the speed of sound in air of 344 m/s). Under these conditions, a diffraction effect will occur in front of the microphone diaphragm (Figure 3).

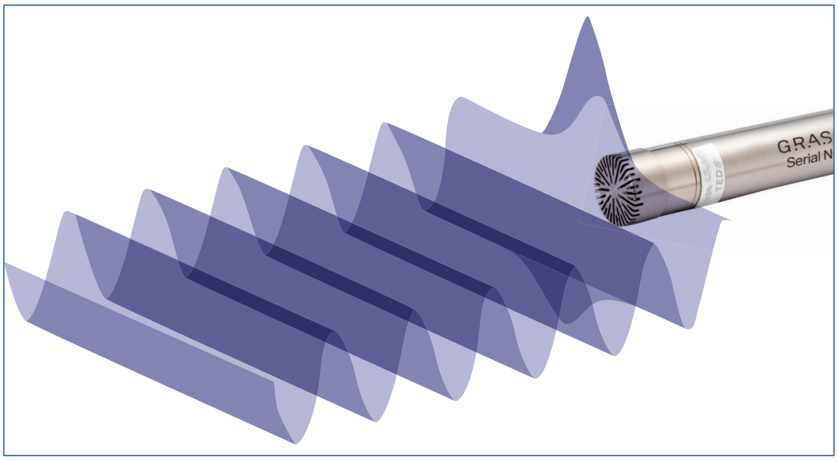
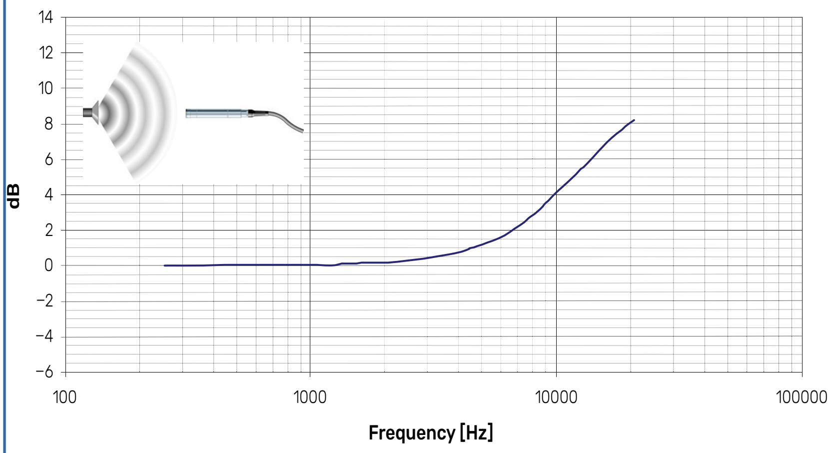


Figure 3
½″ pressure microphone set exposed to a high-frequency sound wave with short wavelength. Diffraction effect appears.

This diffraction effect continues to increase with frequency as the wavelength of the reference signal gets more comparable to the microphone size. The diffraction effect will cause a pressure increase in front of the diaphragm that will be measured by the microphone (Figure 4).



½″ Microphone Diameter: approx. 1.2 cm	
Frequency	**Wavelength**
100 Hz	3.4 m
1000 Hz	34 cm
10000 Hz	3.4 cm
20000 Hz	1.7 cm

Figure 4 – Pressure build-up for a ½″ pressure microphone pointing at 0° incidence from a sound source in a free-field environment.

The higher the frequency, the shorter the wavelength, and the shorter the wavelength, the more comparable the wavelength will be to the size of the microphone and, therefore, the more diffraction effect. The more diffraction effect, the more pressure build-up we will measure. It is important to understand that this measured pressure increase is only a consequence of the microphone being placed in this sound field, and not the frequency response of the sound source (which in this ideal situation has a flat frequency response) or due to reflections (in an ideal free field there are no reflections affecting the acoustic signal coming from a sound source and measured by the microphone).

The orientation (angle of incidence between the microphone and the sound source) and geometry of the microphone itself will have an impact on the amount of disturbance produced in the sound field. One simple way of decreasing the diffraction effect in front of the microphone´s diaphragm, and therefore the pressure build-up measured, is by tilting the microphone. Tilting the microphone (compared to the sound wave´s angle of incidence) will reduce the sound diffraction happening on the microphone capsule. The greater the microphone tilt, the less the pressure build-up due to diffraction effect. In Figure 5, it is possible to see that when the microphone is facing the sound source at 0° incidence, the local pressure build-up at the diaphragm is maximal compared to other angles. On the other hand, at 90° incidence from the sound wave, there is less diffraction effect influence.

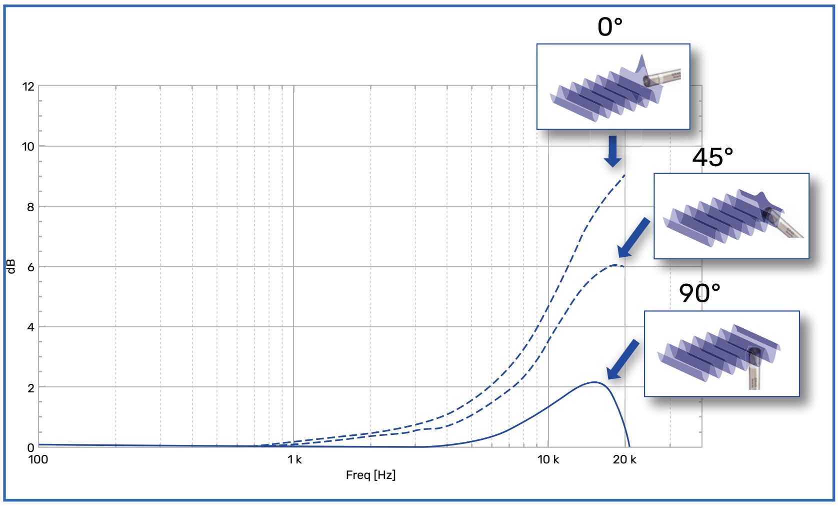


Figure 5
Pressure build-up reduction due to changes in angle of incidence of the microphone.

As mentioned above, the diffraction effect depends on the size and shape of the microphone. The larger the object is, the greater its influence in the sound field. Following the same concept, the smaller the object is, the smaller its influence in the sound field. So, it follows that for a smaller microphone, like a ¼″ measurement microphone, the diffraction effect and pressure build-up will be moved higher up in frequency (Figure 6).

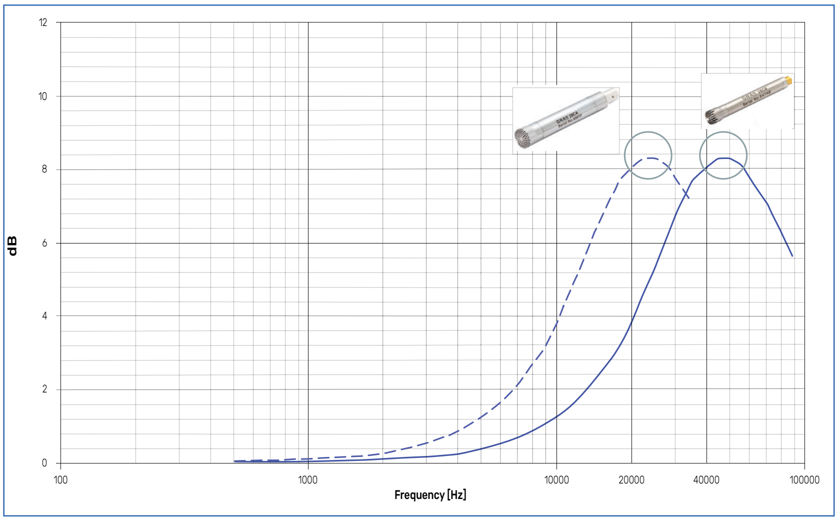


Figure 6
Pressure build-up due to diffraction effect in ½″ microphones vs ¼″ microphones.

So far only meathods of reducing the effect of pressure build-up measured by the microphone due to the diffraction effect have been discussed. But actually getting rid of the diffraction effect requires selecting a microphone that matches the sound filed where it will measure; for example, using a free-field microphone, which has been designed to measure the sound pressure as it was before the microphone was introduced in the sound field.

Types of microphones

In the previous section, the way a microphone influences the sound field was discussed. It was also possible to see how the sound-field disturbance is measured by a pressure-field microphone and how to reduce this effect. The free-field microphone was also introduced as it will help to eliminate the diffraction effect under certain circumstances. The three main measurement microphone types available in the market are discussed below.

Pressure microphones

A pressure microphone is designed to measure the actual sound pressure on the surface of the microphone diaphragm. This means that if the microphone is disturbing the sound field and causing a diffraction effect, the microphone will measure that, and the measurement results will be affected. Therefore, pressure microphones are typically mounted on a boundary (e.g., a wall; Figure 7) or as a part of a closed volume as an ear simulator. Thus, it measures the sound pressure inside a small cavity or on the boundary itself.

Free-field microphones

As explained before, placing an object in a sound field will cause some local disturbance to the sound field. The free-field microphone (Figure 8) is designed in such a way that it corrects for its presence in the sound field and measures the sound pressure as if the microphone was not present.

Free-field microphones are designed to measure the sound pressure as it was before the microphone was introduced to the sound field, therefore compensating for its disturbances caused to the sound field. Ideally, the presence of the microphone should not affect the measurement.

Free-field microphones are designed so that the sensitivity of the microphone decreases by the same amount as the acoustic pressure increases in front of the diaphragm (due to the diffraction effect). This sensitivity-pressure relation is obtained by increasing the internal acoustical damping in the microphone cartridge. The result is an output from the microphone that is proportional to the sound pressure as it existed before the microphone was introduced into the sound field.

In other words, if it is known exactly how the microphone is disturbing the sound field, the microphone can be designed with a frequency response that compensates for the disturbance it is creating.

The blue curve in Figure 9 shows the typical pressure build-up that occurs when pointing a pressure microphone directly to a sound source (due to diffraction effects). The black curve shows the pressure response of a free-field microphone. The pressure response of the free-field microphone is dampened in order to compensate for the pressure build-up at high frequencies. Therefore, using a free-field microphone in a free field (e.g., an anechoic chamber) and pointing the microphone directly to the sound source (0° incidence), the microphone will have a flat frequency response (red curve).

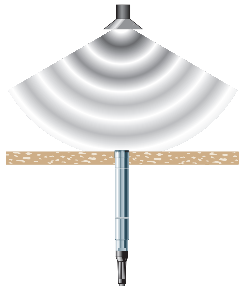


Figure 7
Pressure microphone mounted on a boundary with an angle of 0° relative to the source.

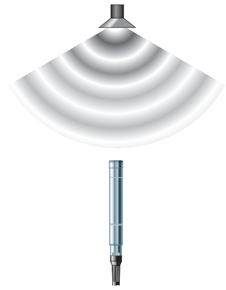


Figure 8
Free-field microphone 0° relative to source.

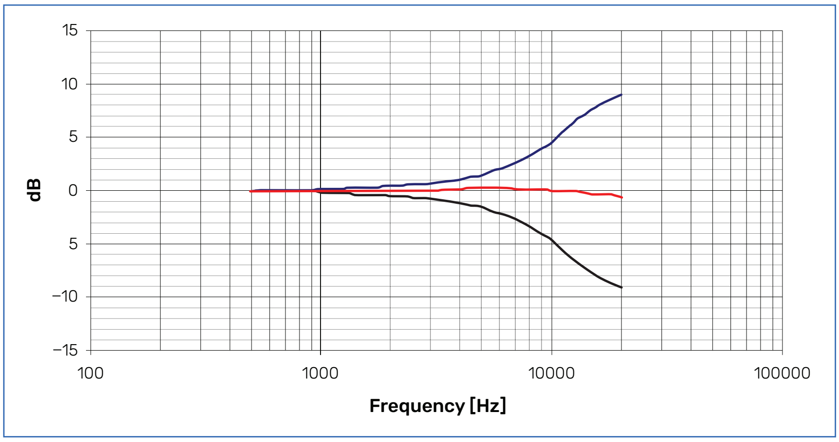


Figure 9
Typical pressure response (Black), free-field correction (Blue) and final free-field response (Red) of a ½″ free-field measurement microphone.

It is very important to point out that this compensation will only work in a free-field environment at 0°incidence from a sound source. Free-field microphones have been stablished as the standard microphone for acoustic measurements in many applications, even when not working in an ideal free-field situation.

Random-incidence microphones

In a diffuse sound field, where the sound comes from all directions with equal level, a random-incidence microphone should be used. This can be in a reverberation chamber or spaces with many reflecting surfaces (Figure 10).

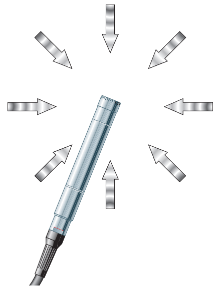


Figure 10
Random-incidence microphone with illustration of sound coming from all directions.

Following the same concept as the free-field microphones, the blue curve in Figure 11 shows the typical pressure build-up that occurs when pointing a pressure microphone directly to a sound source (due to diffraction effects). The red curve shows the pressure response of a random-incidence microphone. The pressure response of the random-incidence microphone is dampened in order to compensate for the pressure build-up at high frequencies. Therefore, if we use a random-incidence microphone in a diffuse field (e.g., reverberant chamber), the microphone will have a flat frequency response (black curve).

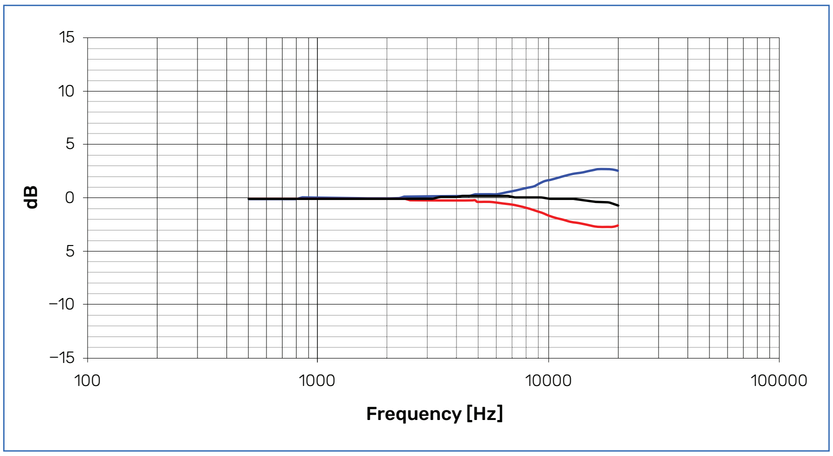


Figure 11
Typical pressure response (Red), diffuse-field correction (Blue) and final random-incidence response (Black) of a ½″ free-field measurement microphone.

Differences between microphone types

The three different microphone types have different design goals, which can most easily be seen when looking at the frequency responses of the microphones.

It is possible to measure the pressure of, not only, pressure microphones but also free-field and random-incidence microphones. To calibrate and determine these frequency responses, the electrostatic actuator method is used (Figure 12).

Figure 12
Electrostatic actuator calibration setup from GRAS.

A comparison of the pressure response of a pressure-field microphone with the pressure response of a free-field and random incidence microphone shows that the last two have less high-frequency output (Figure 13).

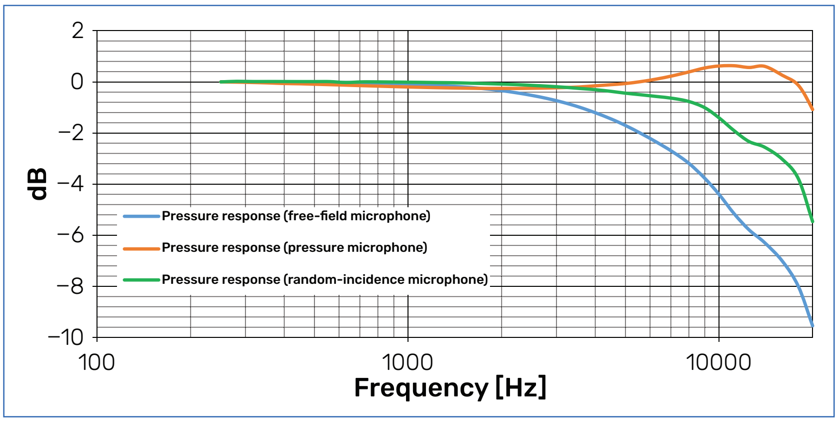


Figure 13
Example of pressure frequency response comparison of a pressure microphone against free-field and random-incidence microphones.

Finally, the free-field or random-incidence frequency response of a microphone is obtained by adding a correction to the measured pressure-field response. So, it is a calculated (not measured) frequency response.

Typical pressure responses

The pressure responses for the three microphone types are shown in this section together with their appropriate corrections. If, for instance, a pressure microphone was used in a free-field situation, the measured response would have an increase in level at high frequencies, due to the pressure build-up caused by the diffraction effect.

Free-field microphone

A typical pressure response for a free-field microphone obtained using the electrostatic actuator method is shown in Figure 14. The pressure response of a free-field microphone (blue curve) rolls off at higher frequencies in agreement with its free-field correction displayed as the green curve in Figure 14. The free-field correcton represents the pressure build-up caused by the diffraction effect. A measurement in the free field with the free-field microphone at 0° incidence from a sound source can be calculated by adding the free-field correction (green curve) to the pressure response (blue curve), which results in the orange curve.

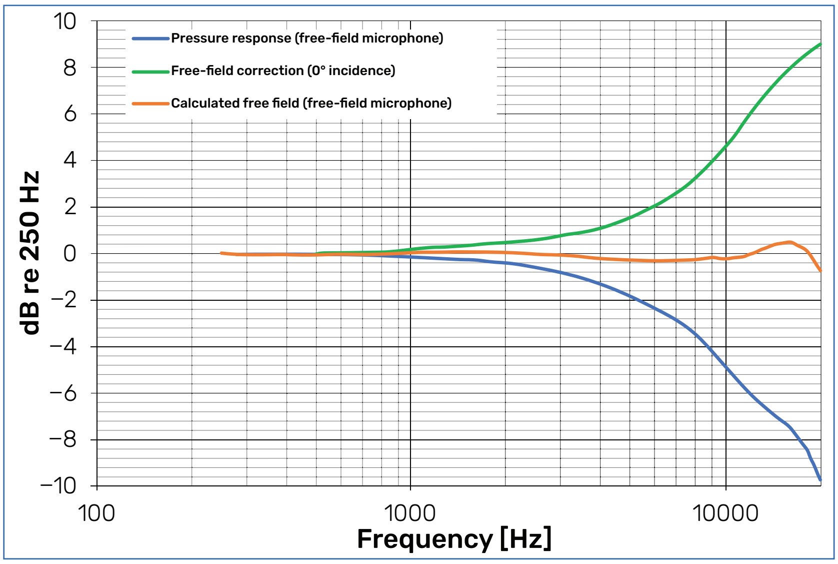


Figure 14
Pressure response of free-field microphone (blue), free-field correction (green) and calculated free-field response (orange).

Pressure microphone

Figure 15 is a graph of the typical pressure response of a given ½″ pressure microphone obtained using an electrostatic actuator. In this case no correction is applied.

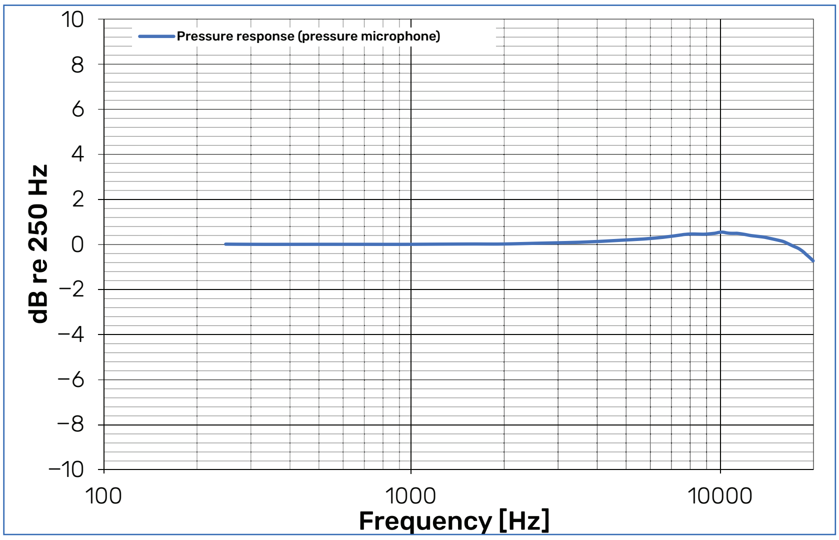


Figure 15
Pressure response of a pressure microphone

Random-incidence microphone

A typical pressure response of a given random-incidence microphone is shown in Figure 16. The dark blue curve shows the random-incidence correction, and the grey curve shows the calculated response in a random-incidence field. The random-incidence correction represents the pressure build-up caused by the diffraction effect.

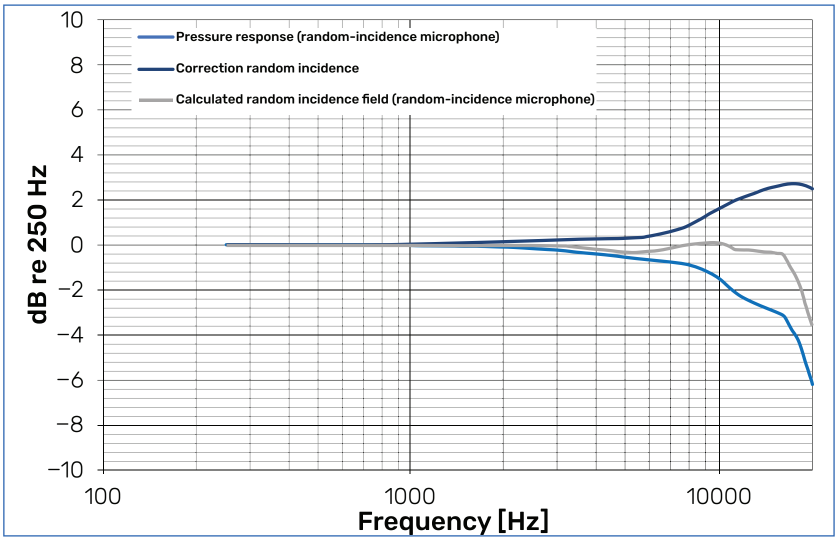


Figure 16
Pressure response of a random-incidence microphone together with the correction curve and the calculated response in a random incidence field

Free-field and random-incidence corrections

Free-field and random-incidence (also known as diffuse-field) corrections are available for most GRAS measurement microphones. These values are showing how a specific microphone disturbs the sound field due to the diffraction effect.

In order to obtain the free-field corrections* of a microphone, the microphone under test must be placed in a free-field environment and exposed to a well-known reference signal (such as a logarithmic sine sweep). The

*Free-field and Random incidence corrections for most GRAS microphones can be found at grasacoustics.com.

microphone is first pointed at 0° incidence from a reference sound source with well-known frequency response (Figure 1). The frequency range for the test will depend on the frequency range of the microphone and its size. For example, a GRAS 46BE ¼″ Free-field Microphone set has a frequency range from 4 Hz to 80 kHz, but this set will cause a sound pressure increase (due to diffraction effect) of less than 0.09 dB below 2kHz and no disturbance at all below 500 Hz. Once the results for 0° incidence are obtained, the microphone or sound source can be rotated to obtain results for different angles. Because, in the real world, there is no sound source that has a completely flat frequency response, it needs to be corrected. In this case, the area of interest is the disturbance in the field caused by the microphone and not the frequency response of our sound source. In order to differentiate which deviations are caused by the influence of the microphone in the sound field and which are caused by the non-flat sound-source response, the same measurement procedure must be repeated, but with a smaller microphone. A smaller microphone will move the diffraction effect to higher frequencies (see Figure 6) and therefore allow a precise assessment of the frequency response of the sound source so the non-flatness can be corrected.

The procedure described above can be replicated in a diffuse-field environment (like a reverberant chamber) to obtain the random-incidence corrections of a measurement microphone.

The free-field and random-incidence corrections are typically used for two specific purposes:

Option 1

Due to its convenience and ease of implementation, the electrostatic actuator method is one of the most common methods used to obtain the pressure frequency response of a measurement microphone. When calibrating a free-field or random-incidence microphone, the pressure response will be measured first and then its free-field/diffuse-field response will be calculated by adding the free-field/random-incidence corrections to the pressure response (Figures 17 – 19):

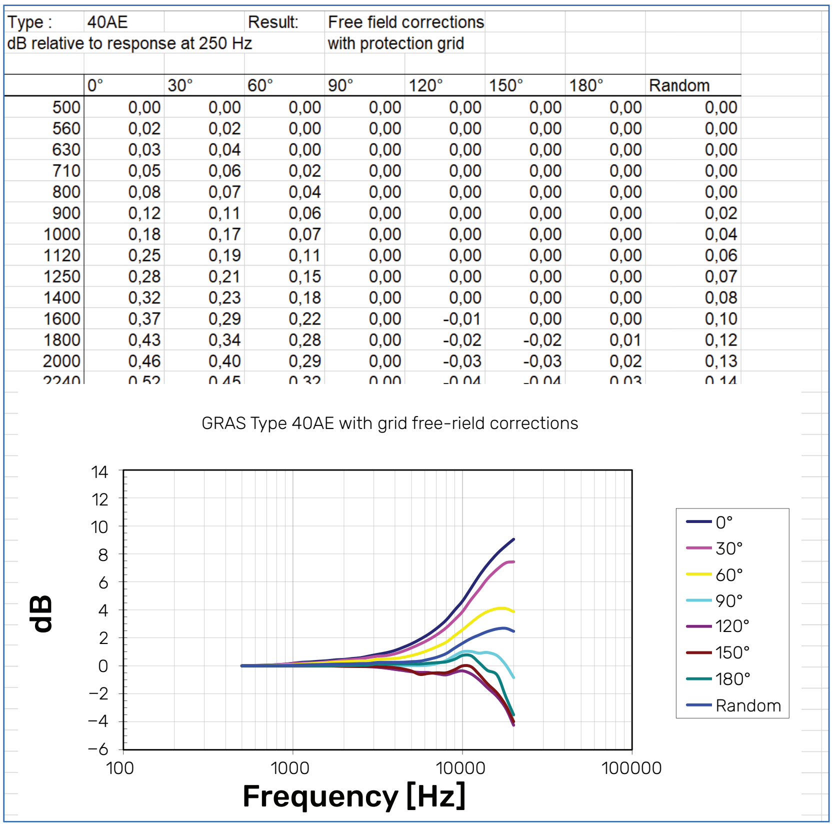
Calculated free-field response =
measured pressure response + free-field correction

Calculated random incidence response =
measured pressure response + random-incidence correction

Example:

Given: When calibrating a GRAS 40AE ½″ Free-field Microphone capsule, the pressure response is –0.40 dB @ 2 kHz (referred to 250Hz). If the free-field correction @ 2 kHz and 0°incidence for that microphone is 0.46 dB, then the free-field response can be calculated as follows:

Calculated free-field response (@2 kHz, 0-deg) =
–0,40 dB + 0.46 dB = 0.06 dB (referred to 250 Hz)



Type :	40AE		Result:	Free field corrections				
dB relative to response at 250 Hz				with protection grid				
	0°	30°	60°	90°	120°	150°	180°	Random
500	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
560	0,02	0,02	0,00	0,00	0,00	0,00	0,00	0,00
630	0,03	0,04	0,00	0,00	0,00	0,00	0,00	0,00
710	0,05	0,06	0,02	0,00	0,00	0,00	0,00	0,00
800	0,08	0,07	0,04	0,00	0,00	0,00	0,00	0,00
900	0,12	0,11	0,06	0,00	0,00	0,00	0,00	0,02
1000	0,18	0,17	0,07	0,00	0,00	0,00	0,00	0,04
1120	0,25	0,19	0,11	0,00	0,00	0,00	0,00	0,06
1250	0,28	0,21	0,15	0,00	0,00	0,00	0,00	0,07
1400	0,32	0,23	0,18	0,00	0,00	0,00	0,00	0,08
1600	0,37	0,29	0,22	0,00	-0,01	0,00	0,00	0,10
1800	0,43	0,34	0,28	0,00	-0,02	-0,02	0,01	0,12
2000	0,46	0,40	0,29	0,00	-0,03	-0,03	0,02	0,13
2240	0,52	0,45	0,32	0,00	-0,04	-0,04	0,03	0,14

Figure 17
Typical free-field corrections chart for a GRAS measurement microphone at different angles of incidence. Random-incidence correction is also shown.

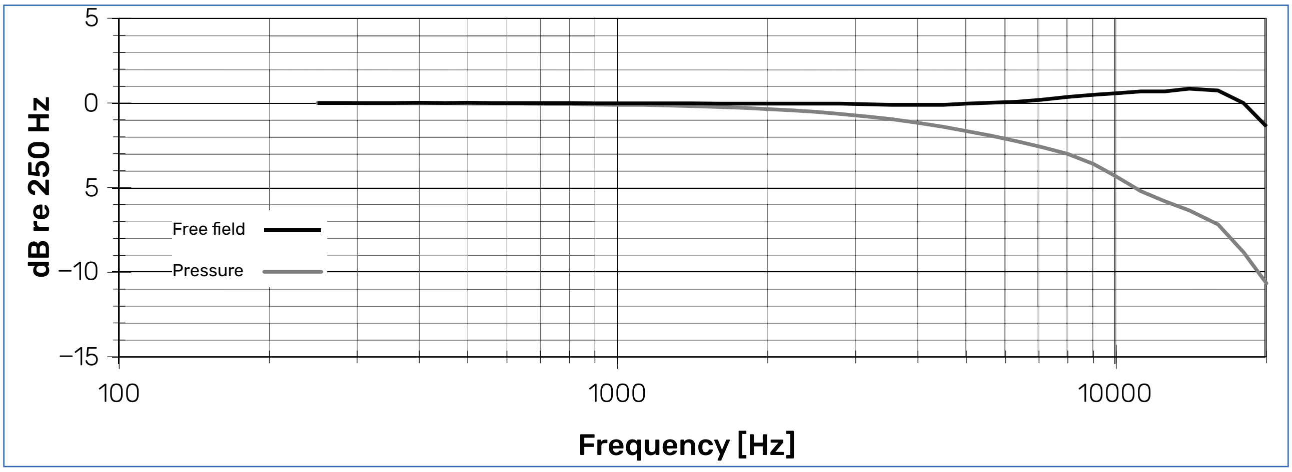


Figure 18 – Measured pressure response and calculated free-field response of a free-field measurement microphone.

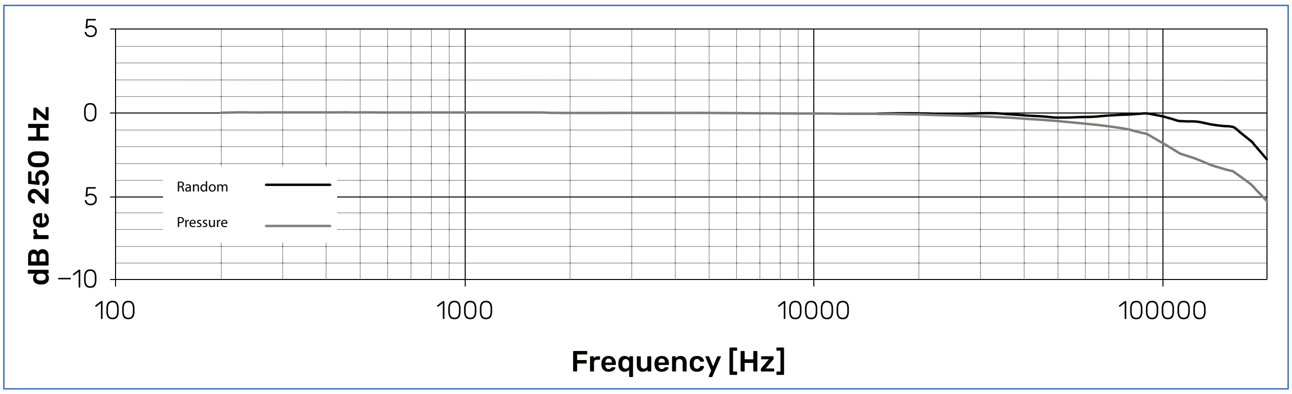


Figure 19 – Typical frequency response of a random-incidence microphone. Upper curve shows the calculated frequency response in a diffuse sound field (random incidence). The lower curve shows pressure response.

Option 2

When a pressure microphone is used in a free-field/diffuse-field environment, the diffraction effect will cause a pressure build-up that will be measured by the microphone. Using free-field/random-incidence corrections for that pressure microphone, it is possible to process the measured data to get rid of the pressured build-up caused by the diffraction effect. This way, the post-processed data will be the same as if the measurement was made with a free-field/random-incidence microphone:

Corrected response =
measured data with pressure microphone in a free-field environment –
free-field corrections

Corrected response =
measured data with pressure microphone in a diffuse-field environment –
random-incidence corrections

Example:

Given: A GRAS 46AO ½″ Pressure Microphone set in a free-field environment pointing at 60° incidence from the sound source and measuring 75 dB @ 10 kHz, and using free-field corrections for 46AO provided by GRAS showing that @ 10 kHz and 60° incidence the correction is 2.09 dB. The corrected response is calculated as follows:Corrected response (@ 10 kHz, 60-degree incidence) = 75 dB – 2.09 dB = 72.91 dB

Then the corrected response in the entire frequency range can also be calculated.

Measurement errors

The difference between the microphone types is not always that obvious. It is important to be aware of the difference, for example, between a ½″ free-field microphone and a ½″ pressure microphone.

For example, as shown in Figure 14, the difference between the pressure responses of a typical ½″ free-field microphone and a typical ½″ pressure microphone up to a frequency of 10 kHz can be up to approximately 4 dB. This means that a measurement error can be introduced if a pressure microphone is erroneously used instead of a free-field microphone. and vice versa. However, if the measurement error can be accepted, or the microphone is used at frequencies where diffraction effect is minor, then the difference between the different microphone types can be negligible.

But what happens if the wrong microphone is picked for the task? In Figures 20 – 22, the three microphone types are shown together in the three sound fields. In each sound field a one microphone will measure correctly and the other two will have some amount of error. This comparison should make it easier to get a feel for the size of the possible error.

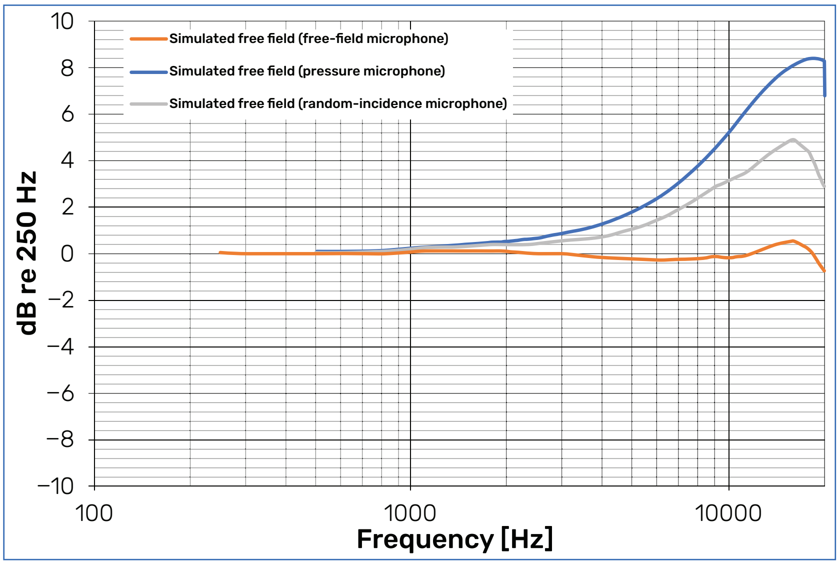


Figure 20
Simulation of a free-field environment showing the Difference between free-field responses of a free field

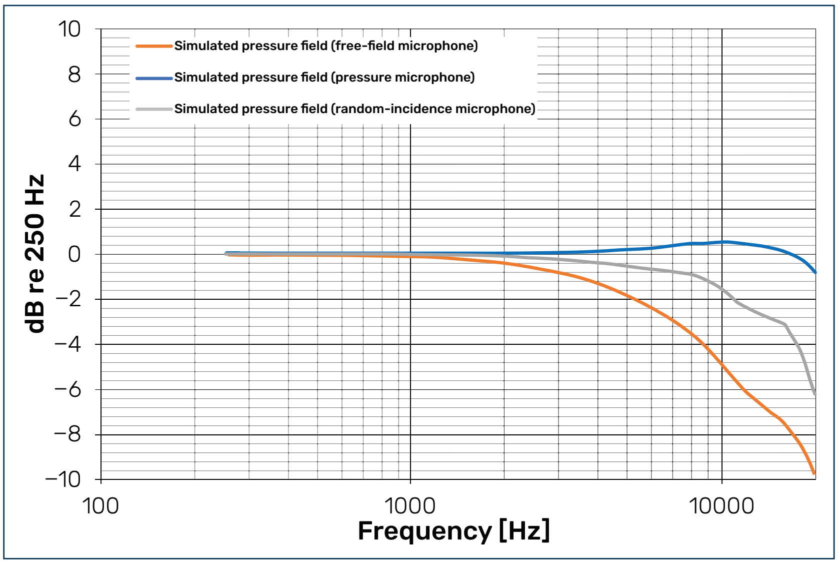


Figure 21
Simulation of a pressure field showing the difference between pressure responses of a free-field microphone, a pressure microphone and a random-incidence microphone.

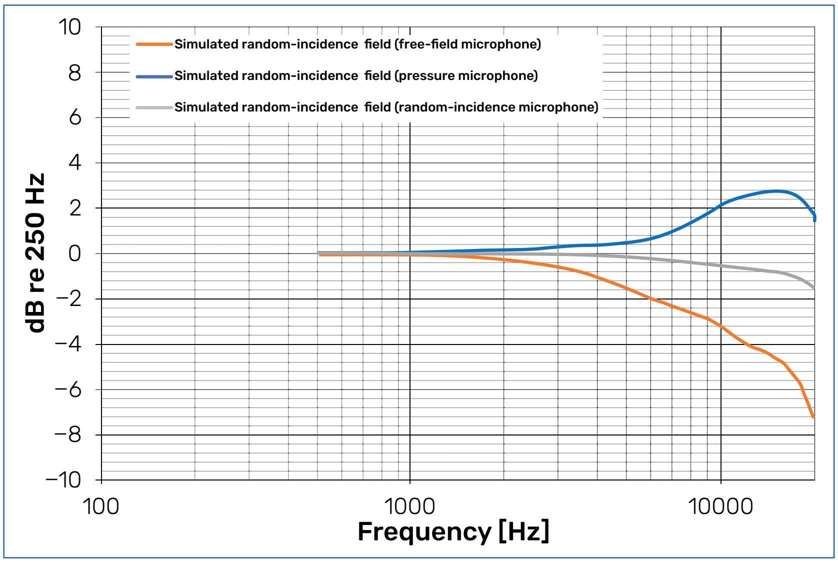


Figure 22
Simulation of random-incidence field showing the difference between random-incidence responses of a free-field microphone, a pressure microphone and a random-incidence microphone.

Table 1 shows the typical differences in pressure response (dB) between microphones:

	Low (250 Hz)	Mid (2.5 kHz)	High (10 kHz)
Free field-pressure	0 dB	-0.7 dB	-5.4 dB
Free field-random	0 dB	-0.4 dB	-3.2 dB
Pressure-random	0 dB	0.2 dB	2.0 dB

Table 1
Typical differences in level between pressure responses of a free-field microphone, a pressure microphone and a random-incidence microp-hone for low, mid and high frequency ranges

Conclusion

A pressure microphone pointing at 0° incidence of a sound source in a free-field environment can cause a pressure build-up of up to approx. 9 dB @ 20 kHz (Figure 20). This is why it is of paramount importance to know the type of microphone used for our measurements. There are usually no visual cues to help identify a free-field microphone from a pressure or random-incidence microphone, so the microphone´s data sheet must be checked. The better understood the equipment used in testing, the more reliable, and therefore useful, the measurement data.