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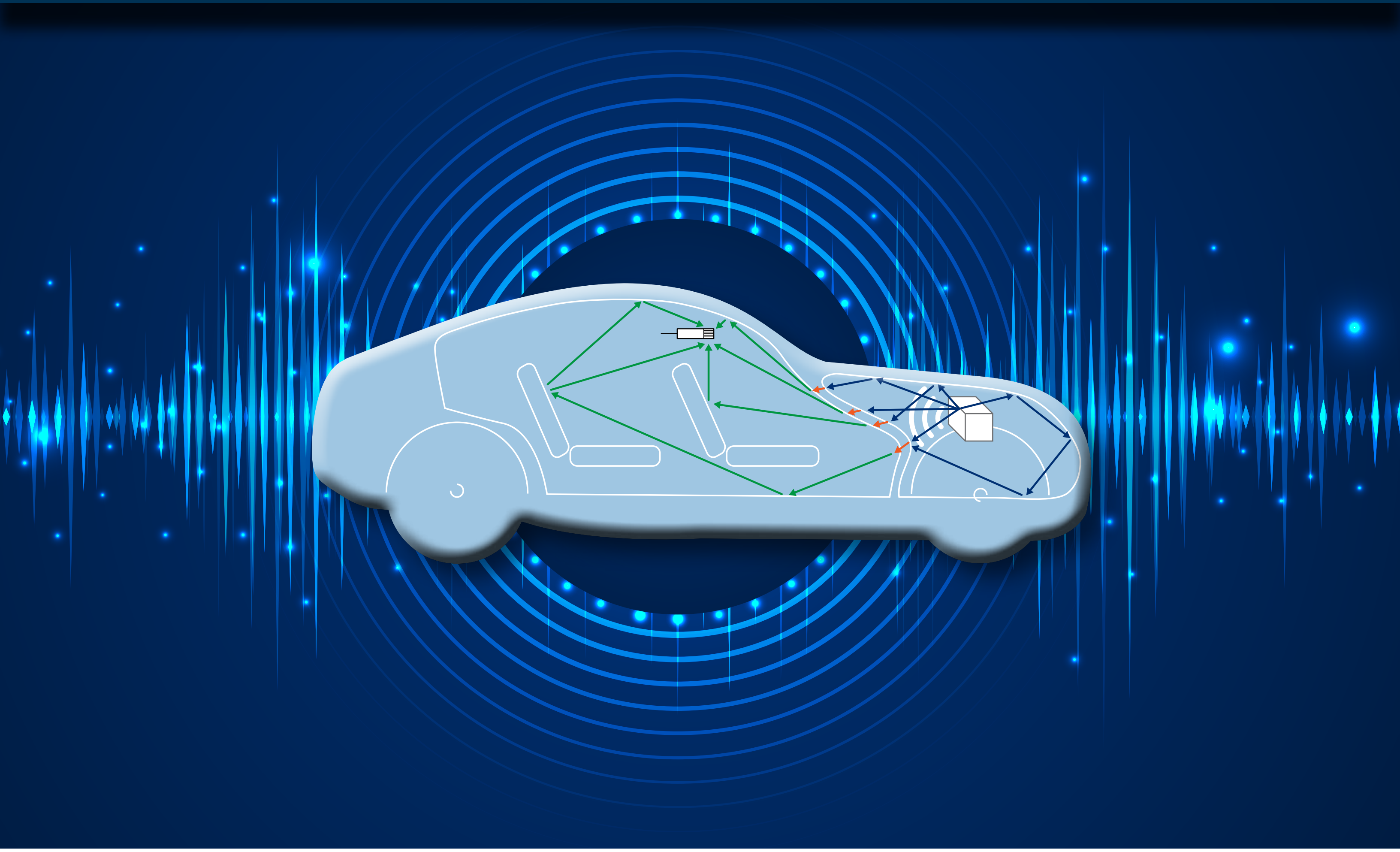

¼″ microphones for EV measurements

Low-noise, high-frequency microphones for complex sound fields in automotive applications

GRAS Sound & Vibration
Whitepaper // By Per Rasmussen

WHITEPAPER

Introduction

Measurement microphones are transducers that convert dynamic pressure fluctuations into an electrical output signal. The international series of standards, IEC 61094 [1], specifies a limited set of working standard microphones as well as methods for calibration of both level accuracy and frequency response. This ensures measurements that are traceable to the fundamental physical quantities defined in the SI system.

The specifications in IEC 61094-4 for a typical working standard microphone cover only a limited part of the frequency and dynamic range required for many applications. Figure 1 shows what is normally expected to be covered for measurement microphones in the blue area; the green area indicates the limited IEC 61094 ranges for a typical ½″ microphone. The full blue area cannot be covered with a single microphone type; in fact, several different types will be needed: optimized for very low or very high level measurements and, similarly, microphones optimized for low- or high-frequency measurements.

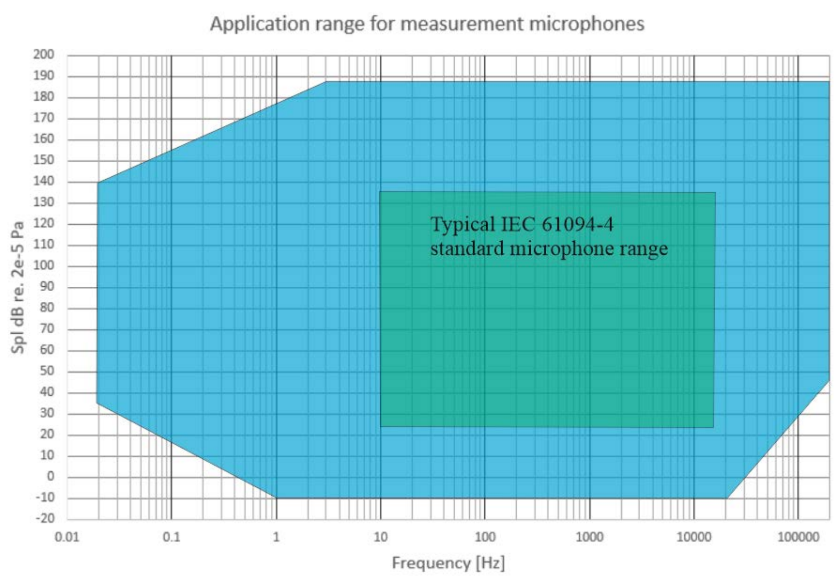

FIGURE 1.
Expected measurement range (blue) versus typical IEC standard microphone range (green).

Low level measurements

While typical measurement microphones cover only a limited dynamic range (around 20 – 145 dB for a ½" microphone and around 40 – 170 dB for a ¼" microphone), there may often be a need to measure lower levels. It should be noted that 0 dB is not "zero noise", but rather the limit of what the human ear can hear. A good, unspoiled ear can hear around 20 dB below what the typical ½" microphone can measure, and for an increasing range of applications, it is important to measure at levels below the range of the typical microphones. Low level measurements are here defined as measurements covered by the red area in Figure 2 (around -10 – 40 dB).

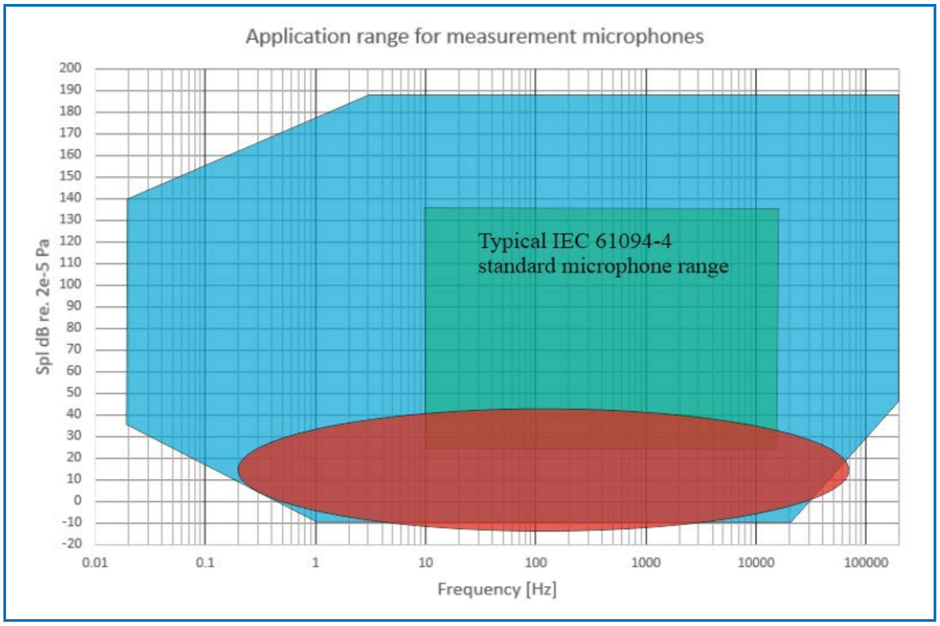

FIGURE 2.
Low level measurement range.

The lower limit of what a measurement microphone can detect is limited by the noise floor of the microphone and the electrical noise generated by the input preamplifier. The specifications for a microphone capsule, in this case the GRAS type 40AE (Fig. 3a), may state that the low end of the dynamic range is 15 dB(A). This is for the overall A-weighted noise level in the microphone itself. This can be related to the thermal movement of air particles in the gap between the microphone diaphragm and the microphone backplate inside the microphone. This specification is however of limited use in practical situations, as the microphone capsule must be connected to some sort of preamplifier.

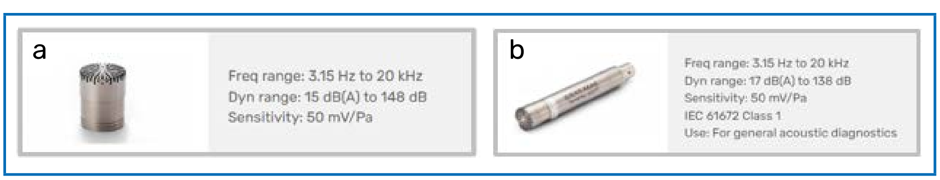

FIGURE 3.
Microphone specification, microphone (a) in combination with preamplifier (b).

Figure 3b shows the corresponding specification for the combination of the same microphone with a particular preamplifier, in this case the GRAS type 26CA. Now the noise from the preamplifier is added to microphone noise contribution and the combined noise floor is increased to 17 dB(A), which will be the practical lower limit of the dynamic range.

The noise contribution from the microphone itself dominates at high frequencies, but the preamplifier is responsible for the low-frequency content, as seen in Figure 4.

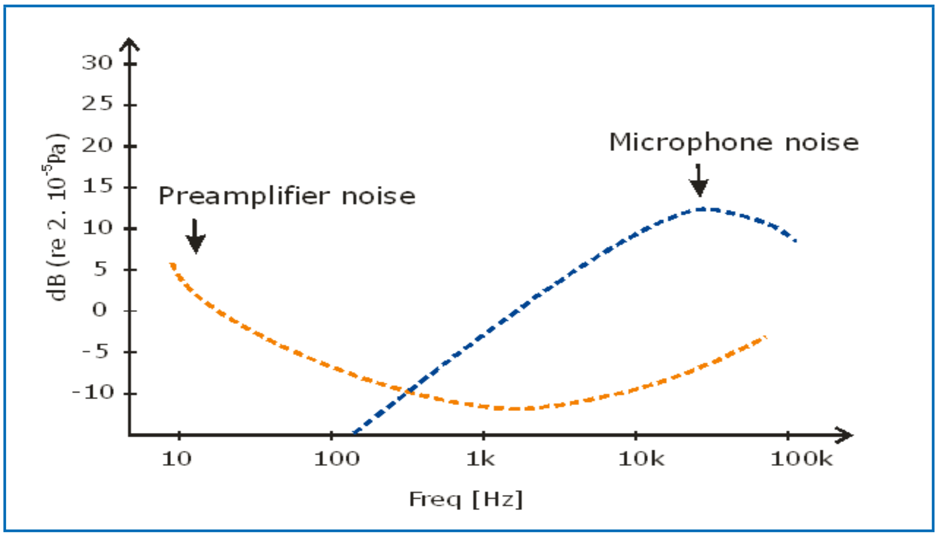

FIGURE 4.
1/3-octave spectra of noise contribution for 46AE microphone and preamplifier combination.

Low level microphones are specially designed combinations of microphones and preamplifiers for measurements of levels below what can be measured by ordinary microphones. The microphones are made with high sensitivities, and the preamplifier is designed to minimize electrical noise, exemplified by the 40HL (Fig. 5a) and 46BC (Fig. 5b).

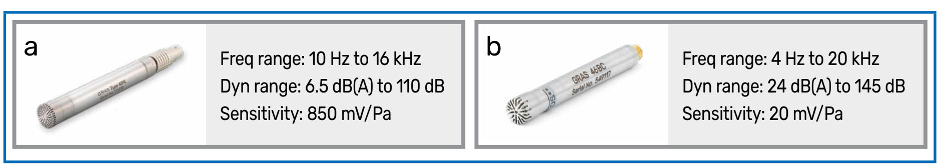

FIGURE 5.
(a) 40HL ½" low-noise microphone set and
(b) 46BC ¼" low-noise microphone set.

The dynamic range for the ½" microphone combination is around 10 dB lower than for a standard ½" combination (like the 46AE), and the ¼" set is 11 dB lower than a standard ¼" combination (like the 46BE). In general, the dynamic range of a microphone relates to the size, frequency range and sensitivity of the microphone. Smaller microphones may have a wider frequency range, but this is normally accompanied with a higher noise floor. Larger microphones may have a lower noise floor with a smaller frequency range. And for all sizes, microphones with higher sensitivities generally have a lower upper limit in the dynamic range.

The choice of microphone for a particular measurement will often have to be a compromise between microphone size and sensitivity and the type of measurement. While ½" microphones will in general have lower noise floor and can therefore measure lower levels than ¼" microphones, they will result in more diffraction, therefore, poorer directionality. As described below, this may lead to considerable measurement error at high frequencies when measuring in complex sound fields. In this case it may be a better compromise to select a ¼" microphone with a much better performance in complex sound field even though the noise floor is higher. The introduction of new low noise ¼" microphones as described below, has made the choice of for many measurements In complex sound field more obvious. So while a ¼" microphone may not be suited to assessments of devices such as active noise control headphones, where the noise floor should be as low as possible, a ¼" microphone may be well suited for low-noise measurements in vehicle cabins.

The effect of the microphone noise floor can often be seen directly from the spectra of practical measurements Figure 6 shows an electric vehicle (EV) passenger car interior measurement using a standard microphone and low-noise microphone while driving at 80 km/h. It can be seen in the mid-frequency range, where the sound pressure level from the vehicle is high and the noise floor of the microphone low, that the signal-to-noise ratio is fine. However, at higher frequencies (indicated by the blue circle), the actual inverter noise produced by the vehicle is hidden by the microphone noise and can only be identified using the low-noise microphone.

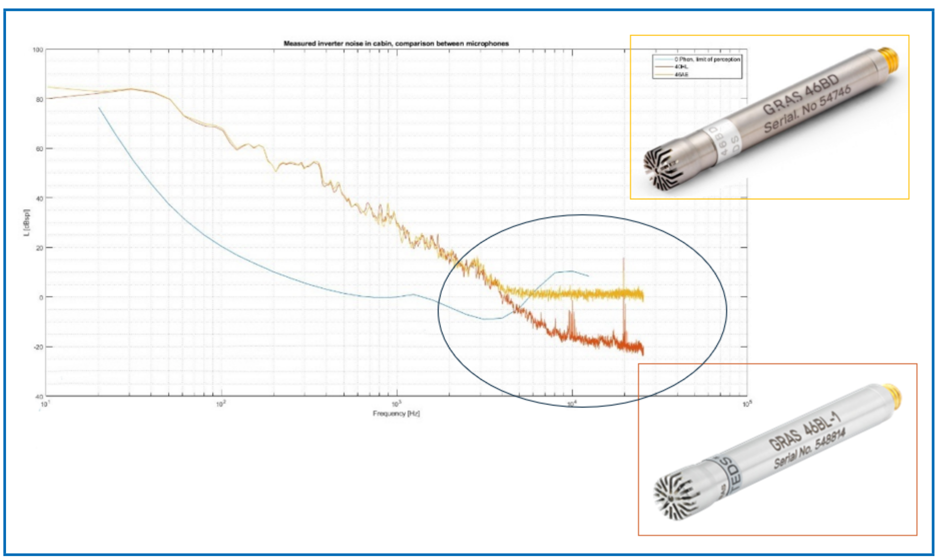

FIGURE 6.
Noise measured inside EV measured with typical microphone (yellow curve) and low-noise microphone (red curve)

New ¼″ multifield and pressure microphones

Traditionally, ½″ measurement microphones have been the preferred microphone type for most free-field sound pressure level measurements. However, this is rapidly changing with the development of new high-sensitivity ¼″ microphones. These new microphones offer a range of advantages: better directivity performance, less influence from the sound field, and less disturbance of the measured sound field.

Ideally, a free-field microphone should be infinitesimally small. However, practical microphones will depart from this ideal and have finite dimensions. As a result, the presence of the microphone in the sound field will disturb the sound field locally at the microphone position. The local diffraction around the microphone is related to the wavelength of sound waves compared to the dimensions of the microphone. At low frequencies, where the wavelength is large compared to the size of the microphone, there is little interaction, but at higher frequencies, where the wavelength becomes comparable to the size of the microphone, the local sound field around the microphone is disturbed by the presence of the microphone.

For a typical ½″ microphone, the diffraction in front of the microphone will result in a pressure increase of around 4 dB at 10 kHz, as shown in Figure 7a. At 20 kHz, where the wavelength is around 17 mm, the diffraction results in a pressure increase of around 8.5 dB (Fig. 7b). This is for a free field, with plane waves at 0° incidence. The pressure increase in front of the microphone as a function of frequency, (referred to as the free-field correction curves) is shown in Figure 8. A free-field microphone is designed internally to compensate for this pressure increase in front of the diaphragm, such that the microphone output is proportional to the pressure in the sound field, as it was before the microphone was introduced into the sound field.

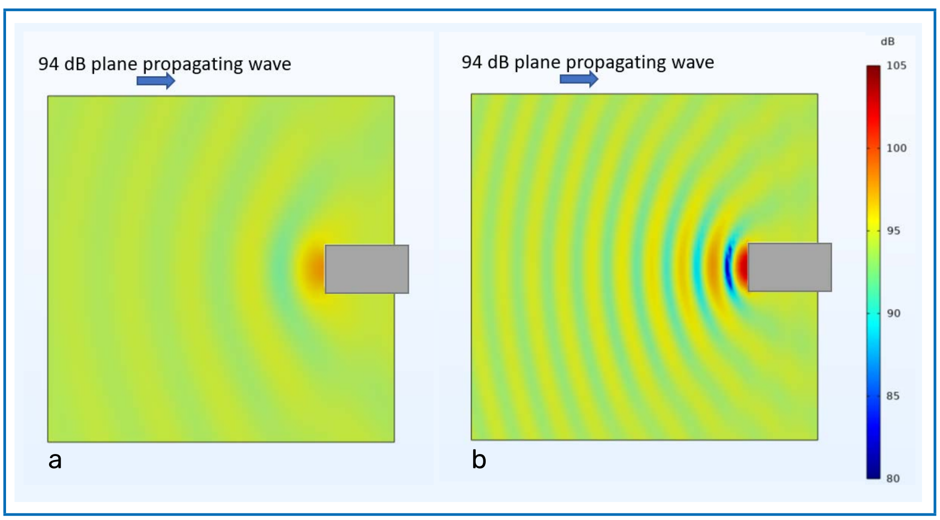

FIGURE 7.
The pressure increase of (a) approximately 4 dB at 10 kHz and (b) approximately 8.5 dB at 20 kHz.

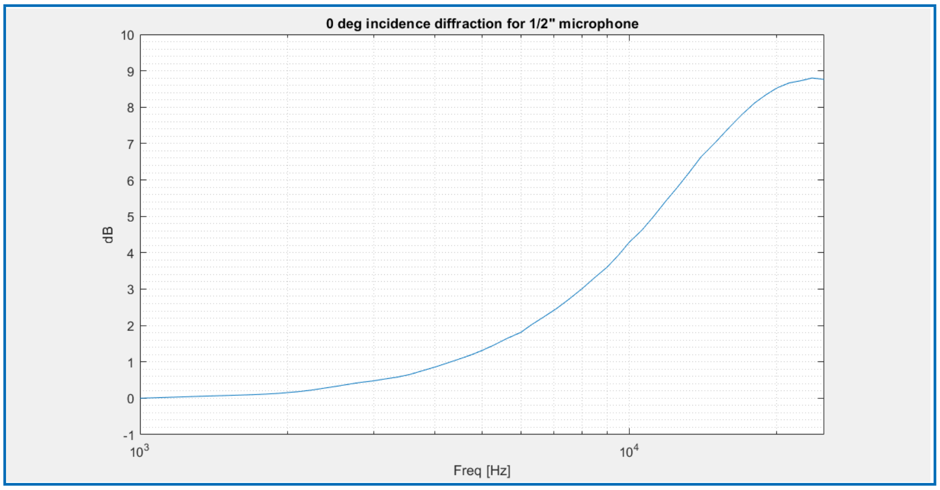

FIGURE 8.
Free-field correction curve for a ½″ microphone.

However, if the microphone is not pointing in the direction of the incoming sound wave or if the sound field is not a plane propagating wave, the diffraction in front of the microphone will be different, and the microphone will not measure the correct free-field pressure, in reference to the field before the introduction of the microphone.

As the free-field microphone must compensate for the diffraction effects caused by the presence of the microphone in the sound field, the shape of the microphone and associated preamplifier should be simple and well-defined. Therefore, most free-field measurement microphones are designed as simple cylindrical shapes with well-defined diffraction patterns.

The current trend in measurement microphones is to replace the traditional ½″ free-field microphones with similar ¼″ microphones that have almost the same specifications. Traditionally, ¼″ microphones have been optimized for a broad frequency range (typically up to 70 kHz), sacrificing sensitivity and thereby increasing the noise floor. This has meant that ¼″ microphones could not measure at as low levels as ½″ microphones. However, by restricting the frequency range of ¼″ microphones to the same frequency range as ½″ microphones, it is possible to increase the sensitivity of ¼″ microphones to almost the same sensitivity as for ½″ microphones and thereby obtain a comparable dynamic range. At the same time, the smaller size of the ¼″ microphone reduces the diffraction and influence from the microphone on the sound field. Figure 9 shows the influence of the microphone presence in the sound field for a ¼″ microphone at (a) 10 kHz and (b) 20 kHz. It can be seen that the diffraction is much smaller than for the ½″ microphone in Figure 2, and the free-field correction curve for the ¼″ microphone shown in Figure 10 shows much lower corrections than the corrections for the ½″ microphone shown in Figure 8.

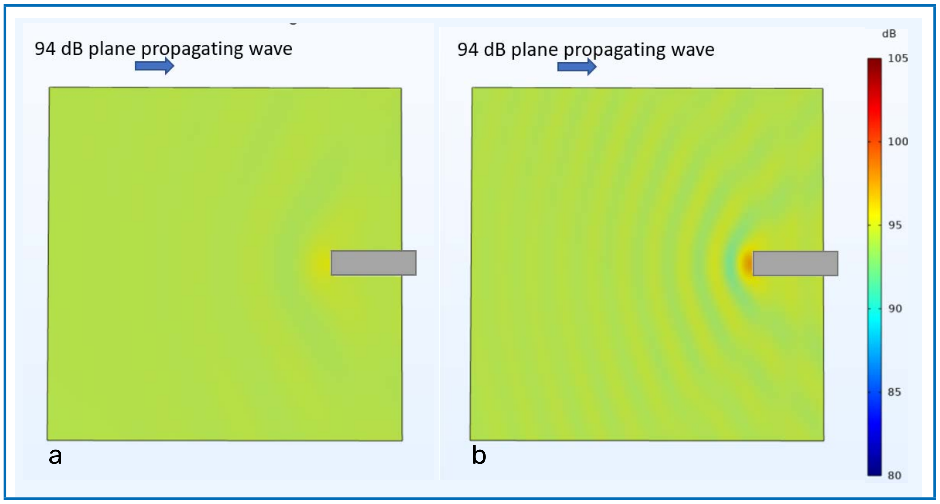

FIGURE 9.
The pressure increase for a ¼" microphone at (a) 10 kHz and (b) 20 kHz.

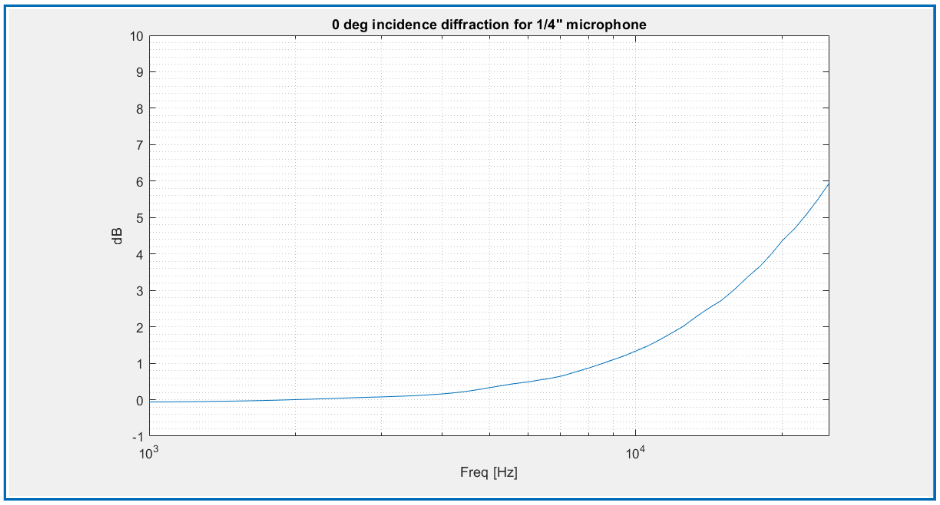

FIGURE 10.
Free-field correction curve for a ¼" microphone.

Requirements for testing accuracy are often derived from the specifications for sound level meters (class 1) in the international standard IEC 61672-1: "Electro acoustics – Sound level meters – Part 1: Specifications". For a traditional ½" microphones, these requirements are easily fulfilled in a typical free-field condition, where the noise is coming from a specific well-defined direction. However, in more complicated sound fields (such as inside a car cabin) where sound sources are not located in any specific position and where the free-field conditions are not fulfilled due to reflections and standing waves, ½" microphones will not meet the requirements. The requirements may be met for sound waves arriving at 0° incidence, but for other angles of incidence, the diffraction around the microphone will be less pronounced and the output of the microphone will fall outside the specified tolerances (Fig. 11).

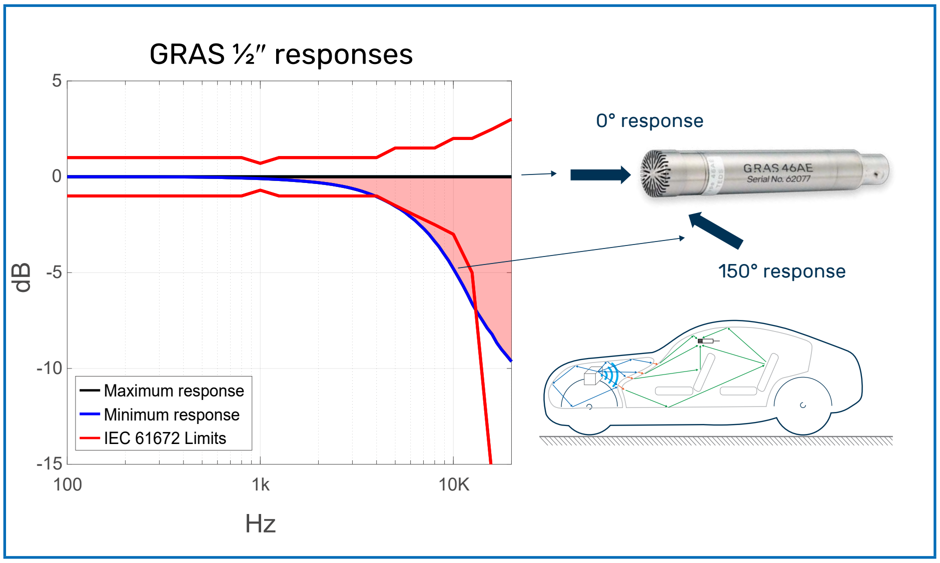

FIGURE 11.
As the angle of incidence increases, the pressure buildup in front of the diaphragm decreases, and the microphone's internal compensation begins to under-represent the actual sound level.

Due to their smaller size, the diffraction around ¼″ microphones is decreased, and the influence of the microphone presence in the sound field is significantly reduced, which produces an omni-directional characteristic in the important frequency range up to 20 kHz. A 'soft lift' to the correction curve in a ¼″ microphone can build on the size-related properties. The new 46BC ¼″ multifield microphone will takes advantage of these to easily stay within IEC 61672 specifications for any type of sound field as shown in Figure 12.

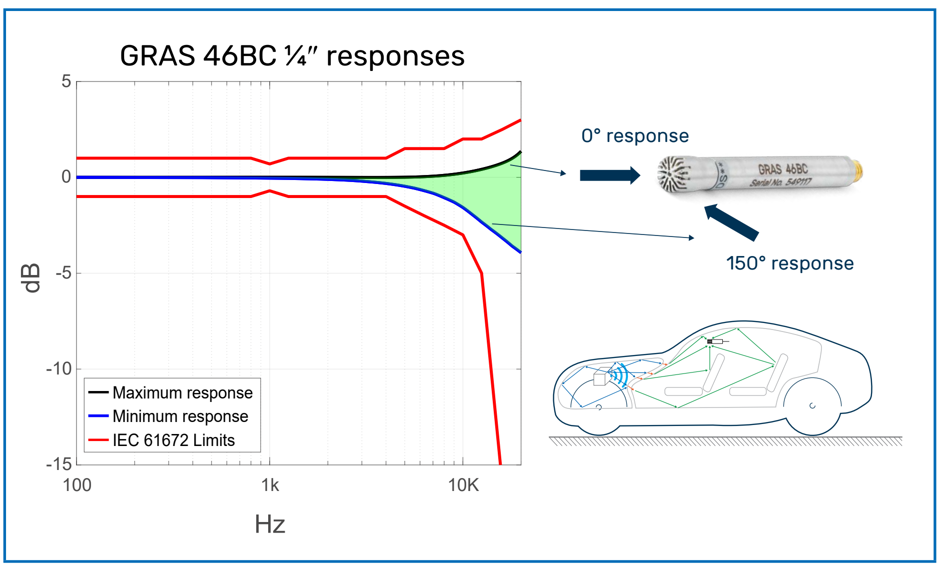

FIGURE 12.
Regardless of the angle of incidence, the pressure buildup in front of the diaphragm never causes the maximum or minimum responses to approach IEC 61672 limits.

The need for specific measurements of sound pressure levels in the frequency range from 10 to 20 kHz has become more important with the introduction of EVs. This has introduced high-frequency noise sources from inverters, electrical motors, etc., while at the same time some of the low-frequency noise sources from engines and exhaust systems have been removed. As explained above, using a standard ½″ microphone to measure these high-frequency components will give different results depending on the orientation of the microphone, and it is therefore better to use a ¼″ microphone with the more omni-directional performance.

Previously, the problem with ¼″ microphones has been that the noise floor. It was too high to register the inverter noise, for example; although, that noise is well within human hearing capabilities. A typical ¼″ free-field microphone will have a noise floor of around 35 dB(A) and may not be able to capture the low level, high-frequency signals in an EV. The new 46BC multifield microphones have been optimized for high frequency, low level measurements with a noise floor of 25 dB(A).

Along with the 46BC multifield microphone, which is optimized for general purpose use in free-field and diffuse-field conditions as well as more complex sound fields in between these two, there is another high-sensitivity microphone focusing on measurements in pressure environments. GRAS 46BL-1 is a high-sensitivity pressure-type microphone with a flat pressure response up to 20 kHz and a noise floor of 24 dB(A). This is a considerable improvement over the typical noise floor of a traditional ¼″ pressure microphone that has a noise floor of around 35 dB(A). The advantage of this microphone can be illustrated with an example from noise measurements of noise inside an EV as shown in Figure 13.

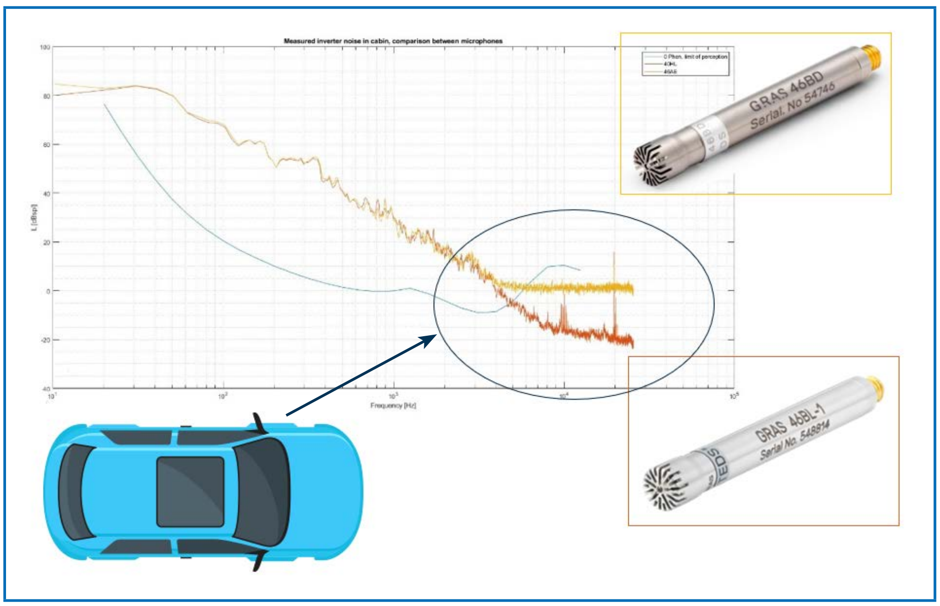

FIGURE 13.
The traditional ¼″ pressure microphone (46BD) cannot measure the high-frequency noise signal (around 10 kHz), as this is below the noise floor of the microphone. The 46BL-1 has a noise floor which is 16 dB lower and captures the high-frequency low level signal.

The 46BL-1 high sensitivity microphone is also the recommended microphone type for in-car measurements of audio systems. The Audio Engineering Society Technical Committee on Automotive Audio has published a whitepaper recommending the use of a six-microphone setup using microphones that match the specifications of 46BC and 46BL-1 type low noise microphones (Fig. 14), for evaluating the performance of high-end car audio systems.

FIGURE 14.
AES recommendation for mic array configuration

Conclusion

Low noise ¼″ type microphones are increasingly replacing the traditional ½″ measurement microphones for many demanding applications in situations where the sound field is not a simple well-defined free field. The smaller size minimizes the disturbances to the original sound field and allows omni-directional measurements with a dynamic range that matches the traditionally used microphones.

Reference

[1] IEC Standard 61094-5 Measurement microphones Part 4; Specifications for working standard microphones (1995).