# The Multi-Field Microphone

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**A 1/4-inch precision measurement microphone has been developed that greatly minimizes errors caused by the influence of unknown sound fields or varying angles of incidence.**

Only a small percentage of acoustical measurements are performed in the well-defined, well-controlled environment of a calibration laboratory. Well controlled and defined can be defined as: 23° C, 50% relative humidity and an ambient static pressure of 101.3 kPa. On the contrary, most acoustical measurements are done under uncontrolled conditions that are rarely known beforehand.

This is the reason that acoustical standards such as the IEC 61672 series (a standard for sound level meters) specify the performance of the measuring microphone over a wide range of environmental conditions. When using high-quality instrumentation and transducers, varying environmental conditions do not normally cause any problems.

However, one major source of error remains, and that is what effect the sound field will have on measurement uncertainty. It is common practice to assume that the sound field in any measurement situation will be either a free, diffuse or pressure field.

## Sound Fields

- *Free field* – there are no reflecting objects, only the microphone disturbs the sound field.
- *Diffuse field* – there are many reflecting surfaces and sound waves arrive with equal probability from all directions.
- *Pressure field* – this is found in small confined spaces like calibration couplers.

Depending on the nature of the sound field, an appropriate microphone is selected, one that is optimized for the sound field in question. Unfortunately, there are many practical situations where the sound field is not well defined. This may be the case inside buildings, in-vehicle noise measurements, or measurements on multi- or non-stationary sources. Often a free-field microphone is chosen more based on tradition than on real knowledge about the nature of the actual sound field. Figure 1 shows a picture of the multifield microphone that is suited for use in a free as well as in a diffuse field.

It is surprising how large the potential for errors can be if the conditions are non-ideal. Figure 2 shows the response of a free-field microphone in a true free field; the frequency response is the ideal flat response. But the angle of incidence may not be zero, as assumed in the figure). Or the sound field may not be a true free field, but diffuse, and the response will be as shown in Figure 3.

Both Figures 2 and 3 are valid for a typical 1/2-inch microphone with protection grid and (in figure 2) for zero degree of incidence (microphone diaphragm facing head on toward the sound source). By taking not only the nature of the sound field but also the angle of incidence into consideration, the potential error may be even larger.

Figure 4 shows the maximum error as a function of frequency when a free-field microphone and a diffuse-field microphone are being used in a sound field or angle of incidence for which the microphone was not optimized. As shown in Figure 4, the error is noticeable at 2 kHz, and at around 6 kHz, the potential maximal error due to "unknown conditions" largely exceeds the influence of all other environmental factors and even exceeds the IEC 61672 tolerance of 3.5 dB and the IEC 1094 ±2 dB specification.

*Figure 1. Multifield field microphone Type 4961.*

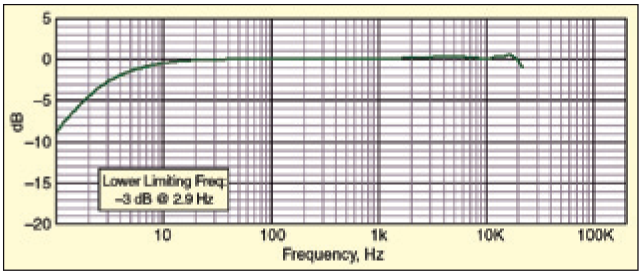

*Figure 2. Free-field response of a 1/2-inch free-field microphone.*

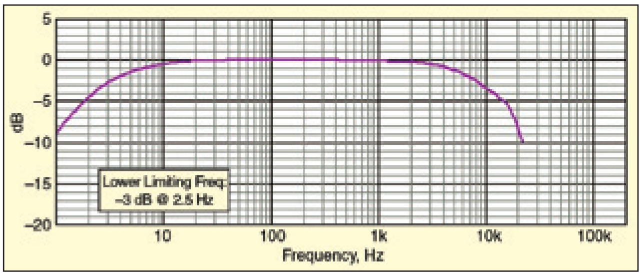

*Figure 3. Diffuse-field response of a 1/2-inch free-field microphone.*

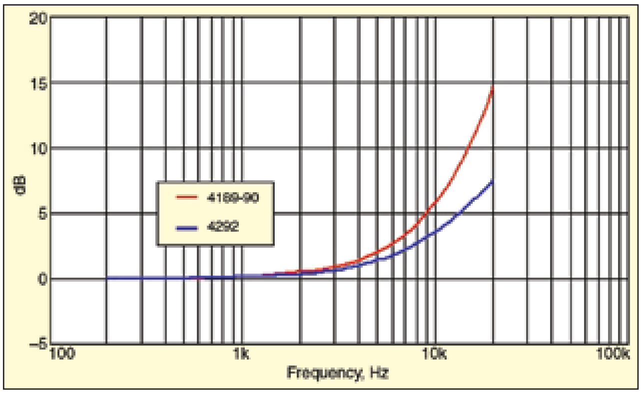

*Figure 4. Maximal error for free-field microphone Type 4189/90 (upper curve) and diffuse-field microphone Type 4942 (lower curve).*

## Is There a Cure?

It has been known for many years[1,3,4] that a microphone disturbs the sound field and that the issues addressed here are caused solely by the physical size of the microphone. Generally speaking a microphone can be considered non-diffractive as long as $(\pi/\lambda)2a \leq 1$, where $\lambda$ is the wavelength and $2a$ the microphone diameter. Therefore, a 1/2-inch microphone can measure without disturbance of the sound field up to around 8 kHz, while a 1/4-inch microphone can measure up to around 16 kHz. In reality, microphones can measure to higher frequencies, because the measurement error at higher frequencies is predictable, and the microphone frequency response can be optimized in the microphone itself. In this way, a flat frequency response can be achieved – but only for one kind of sound field.

That is why there are three different microphone types: free-field, diffuse-field and pressure-field microphones. As noted above, a 1/4-inch microphone would be readily usable in all fields up to 20 kHz, but unfortunately all commercial 1/4-inch measuring microphones have less sensitivity and a much higher noise floor than their 1/2-inch counterparts. A typical 1/4-inch free-field microphone has a noise floor around 40 dBA opposed to 16-18 dBA for a typical premium quality 1/2-inch free-field microphone.

**Limiting Factors**. To cover the most important factors that determine the sensitivity of a condenser microphone, we will introduce a set of simple equations that describe the sensitivity of a condenser microphone (see Figure 5). The microphone mid-range pressure sensitivity $M_p$ (V/Pa) can be expressed as the product of two sensitivities $M_p = M_e M_m$ Here $M_e$ is the electrical transfer function in V/m, and $M_m$ is the mechanical transfer function in m/Pa and as one observes the dimension of $M_p$ equals [V/m] [m/Pa], which means that $M_p$ is in V/Pa as expected.

As shown in Ref. 2, the following equations apply:

$$M_e = E_0 / h_0 \left[1-\left(b^2/2a^2\right)\right]\left[1+\left(C_1+C_s\right)/C_{10}\right] \tag{1}$$

Now in most practical cases, $b \sim 0.8a$ and typically $C_i + C_s << C_{to}$. Therefore, Eq. 1 can be approximated as:

$$M_e = \left[0.68E_0\right] / h_0 \tag{2}$$

For the mechanical transfer function in m/Pa, Ref. 2 shows that:

$$M_e = a^2 / 8T \tag{3}$$

Where $T$ is the tension of the diaphragm in $N/m$, which depends on the radial stress $s_{rr}$ ($N/m^2$) and the thickness $d$ of the diaphragm accordingly to:

$$T = s_{rr} d \tag{4}$$

In practical cases, $T$ is often in the interval 2000-3000 Pa. Combining Eqs. 2 and 3, the simplified equation for the microphone mid range sensitivity is:

$$M_d = M_m M_e = \left[0.11E_0 a^2\right] / \left[T h_0\right] \tag{5}$$

Using Eq. 5 and a polarization voltage of 200 V, 20 µm distance between the back-plate and diaphragm and 2000 Pa tension (Eq. 5) yields 3.3 mV/Pa for a 1/4-inch microphone, which is in good agreement with practical values.

## Suggestions to Increase Sensitivity

By inspection of Eq. 5, it is easy to see how to increase the sensitivity of a microphone:

- Increase the polarization voltage
- Decrease the distance between backplate and diaphragm
- Reduce the diaphragm tension

Some comments and limitations to the suggestions are as follows:

**Increase Polarization Voltage**. For external polarized microphones, the polarization voltage must be 200 V to be compatible with existing front ends on the market. Besides, there are practical limitations determined by arc over and static diaphragm deflection; for these and other reasons, the polarization voltage cannot be changed.

**Reduce Backplate-to-Diaphragm Distance**. Reducing the backplate-to-diaphragm distance is also dangerous, since this increases the electrical field strength with increased risk of arc overs (excess noise in the microphone). Further, the backplate-diaphragm distance at maximum SPL should ideally be larger than 50% of the distance under quiescent conditions.

**Lower Diaphragm Tension**. The last resort is to have a much lower diaphragm tension, but there are severe limitations when using the traditional cobalt-base alloy as the diaphragm material. Instead, a beneficial solution has been found by using a titanium diaphragm. If processed properly, the tension can be reduced to such a low value that the sensitivity of the 1/4-inch microphone is very close to that of a normal 1/2-inch high-sensitivity microphone. The low tension means that the resonance frequency for this microphone is much lower than for a normal 1/4-inch microphone, or about 26 kHz instead of say 70-100 kHz. Additional sensitivity has been achieved by using more of the outer diameter (of the 6.25 mm) for the active part of the microphone (larger $b$ value than in a normal 1/4-inch microphone. To achieve excellent temperature stability, the cartridge was all made of titanium, which brings additional benefits with respect to corrosion resistance and insensitivity to magnetic fields.

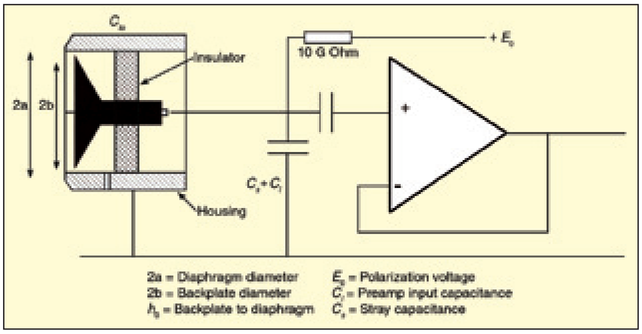

*Figure 5. Principal schematic of condenser microphone with pre-amplifier.*

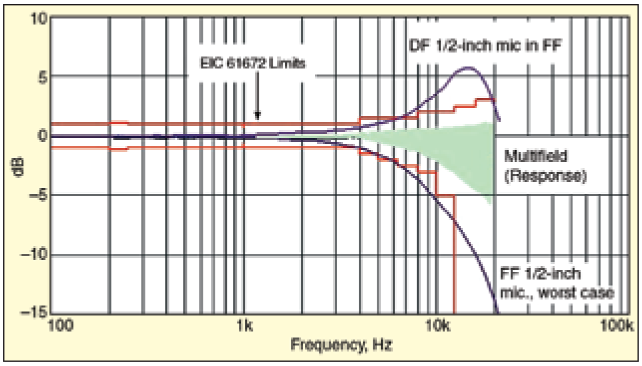

*Figure 6. Multifield FRF compared against IEC 61672 limits and 1/2-inch microphones (worst cases).*

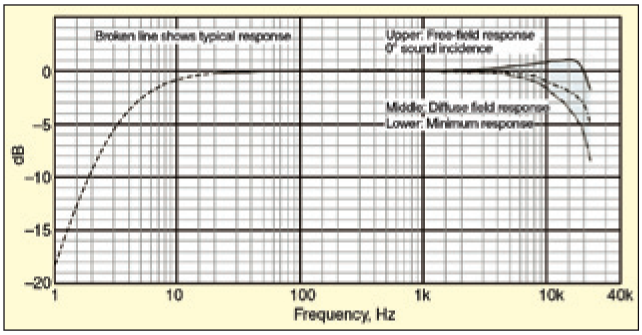

*Figure 7. Multifield frequency responses: free-field response (upper) and diffuse-field response (middle), and minimum response (lower).*

A new titanium-housed 1/4-inch constant-current, line-drive (DeltaTron) preamplifier with TEDS (transducer electronic data sheet) has been developed to to offer a complete all-titanium microphone with multifield performance (Figure 1).

In summary, the microphone described here has the following key parameters:

- Diameter – 1/4 inch
- Sensitivity – 60 mV/Pa
- Noise floor – < 20 dBA
- Frequency range – 5 Hz-20 kHz
- Dynamic range – 20-130 dB
- Upper SPL limit – 130 dB (3% distortion)
- Max SPL – >150 dB (peak)
- Temperature – –20 to +70° C (–4 to +158° F)

Figure 6 shows the performance in an unknown field for a multifield microphone. The frequency response function is compared against IEC 61672 limits and compared with the 1/2-inch microphones (worst cases) used today. Figure 7 shows a typical calibration chart for a multifield microphone.

## Summary

By using an all-titanium construction, it has now been possible to overcome the limitations that traditional technologies and materials have imposed on 1/4-inch microphones so far. The result is a microphone that widely eliminates the influence of unknown measurement conditions and additionally releases the user from being forced to choose between different microphones. Its main uses are measurements in unpredictable sound field conditions, vehicle inside noise measurements, near-field measurements and *ad hoc* sound measurements.

The multifield measuring microphone, Type 4961, is the only 1/4-inch measuring microphone in the world with a 20-dB noise floor and sensitivity exceeding 50 mV/Pa (nominal sensitivity is 60 mV/Pa) – enabling accurate measurements in free, diffuse or combination sound fields. Because Type 4961 is small and relatively insensitive to the angle of incidence, it simplifies the process of taking complex sound measurements, saving technicians' valuable time planning, setting up and analyzing results.

## References

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2. *AIP Handbook of Condenser Microphones*, George S. Wong and Tony E. W. Embleton, Eds., p. 43, American Institute of Physics, New York.
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