Measurement Microphones

Brüel & Kjær

This booklet gives an introduction to the design features and operating principles of measuring microphones. Some knowledge about the measurement of sound would be an advantage and so you might wish to consult our companion booklets 'Measuring Sound' and 'Sound Intensity'.

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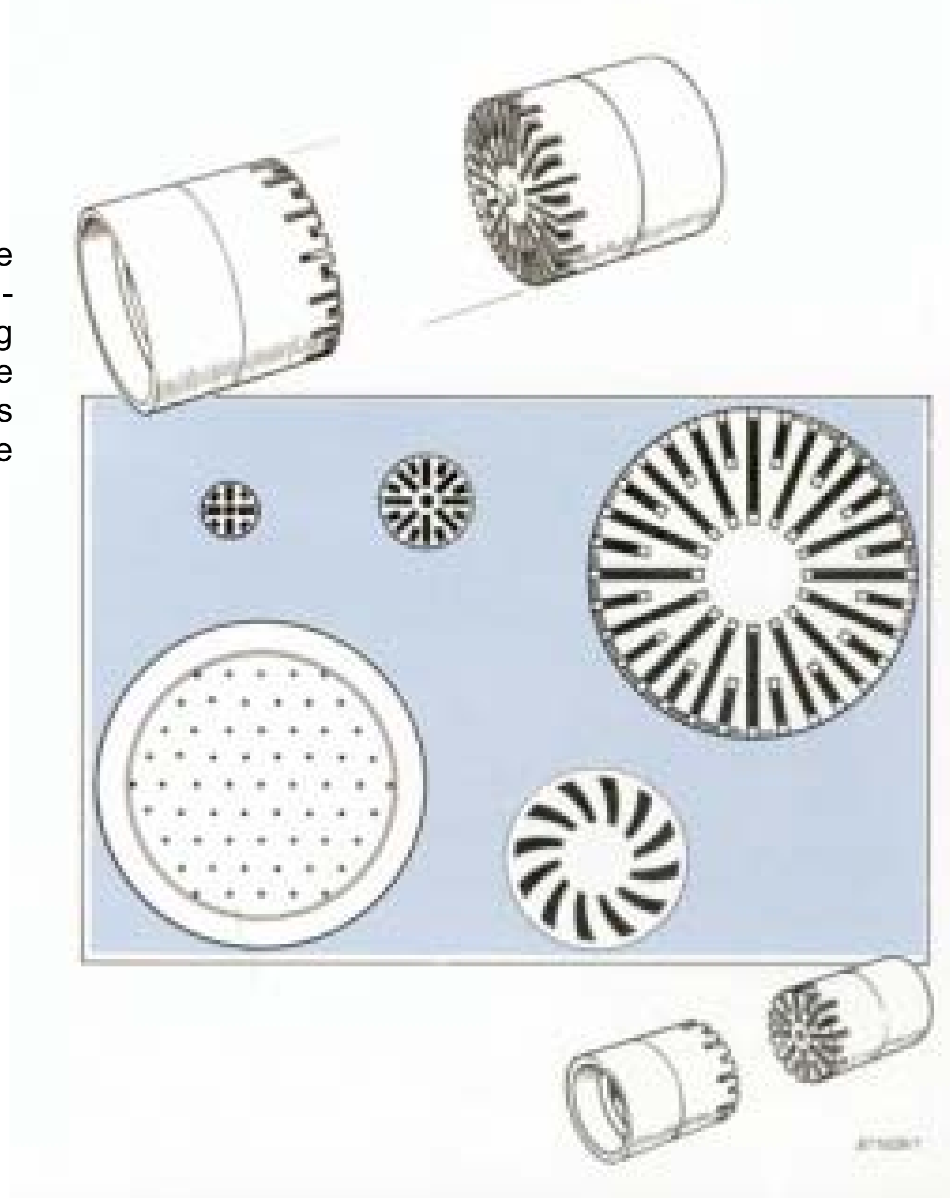
Introduction

Brüel&Kjær measuring microphones are the most famous and respected in the world; the most imitated too. But why?

Probably because Brüel&Kjær microphones have earned an unrivalled reputation for being trustworthy.

It takes a wealth of experience to build microphones that are accurate, reliable and long-lasting. The Brüel&Kjær design engineers and craftsmen have gained this experience by working at the frontiers of microphone technology for thirty years. The vast catalogue of ideas developed over this period of time has made the Brüel&Kjær range of measuring microphones the most comprehensive ever available.

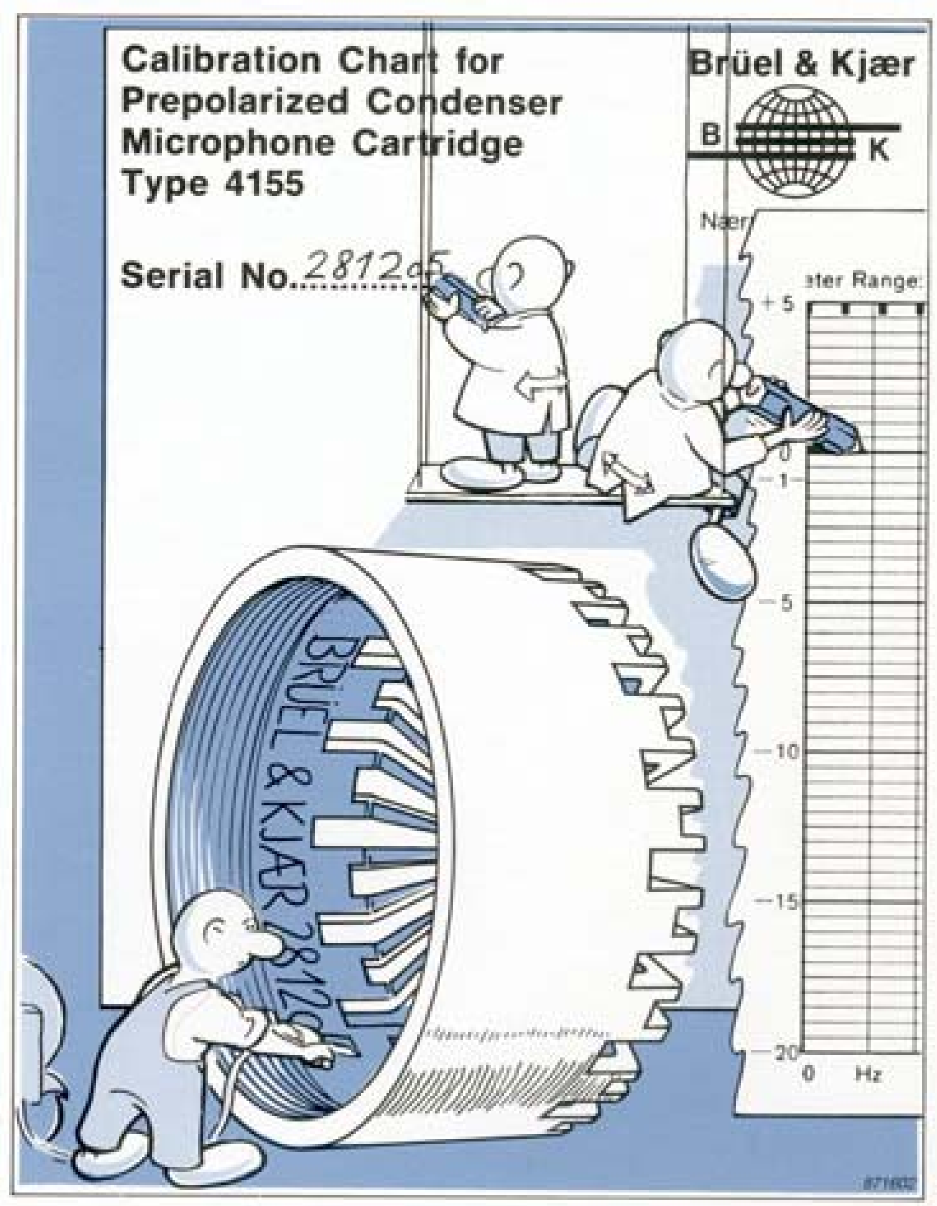


What is a measuring microphone?

A 'measuring' microphone is a calibrated microphone designed for use with systems that quantify sound, for example sound level meters. Measuring microphones are the most accurate and reliable class of microphone available.

Of course, the high performance of these microphones requires extremely high standards of engineering. The specifications of measuring microphones are certainly in a different league from other classes of microphone — but no microphone can ever be perfect. This is why measuring microphones are calibrated, because then their characteristics are well-defined and their behaviour is predictable.

Throughout the microphone's working life its accompanying **calibration chart** is a most important reference document. To ensure that the calibration chart remains valid over a long period of time, a measuring microphone must have exceptionally stable characteristics. Amongst manufacturers, Brüel&Kjær stands alone in producing measuring microphones of the necessary quality — time has proven it.



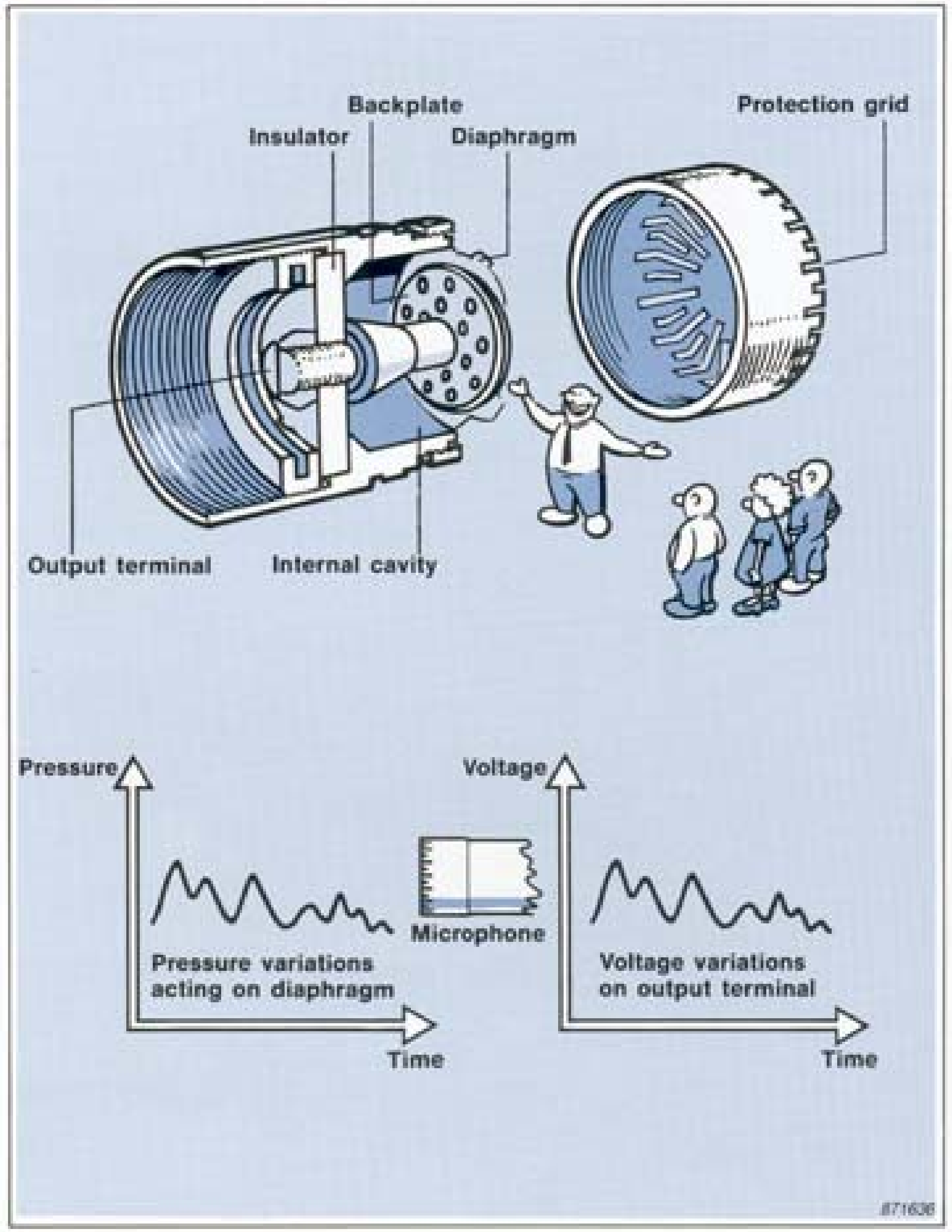
Construction and principle of operation

Construction
All Brüel&Kjær measuring microphones are **condenser** (or capacitor) designs which feature a tensioned-metal **diaphragm** supported close to a rigid metal **backplate.**

The microphone's output-voltage signal appears on a gold-plated terminal mounted on the backplate which is isolated from the microphone casing (or **cartridge)** by an **insulator.** The cartridge **internal cavity** is exposed to atmospheric pressure by a small **vent** and the construction of the microphone is completed with the addition of the distinctive Brüel&Kjær **diaphragm protection grid.**

Principle of Operation
The diaphragm and backplate form the parallel plates of a simple **air-capacitor** which is polarized by a charge on the backplate. When the diaphragm vibrates in a sound field, the **capacitance** of the capacitor varies and an output voltage is generated.

The voltage signal replicates the sound-field pressure variations as long as the charge on the microphone backplate is kept fixed.

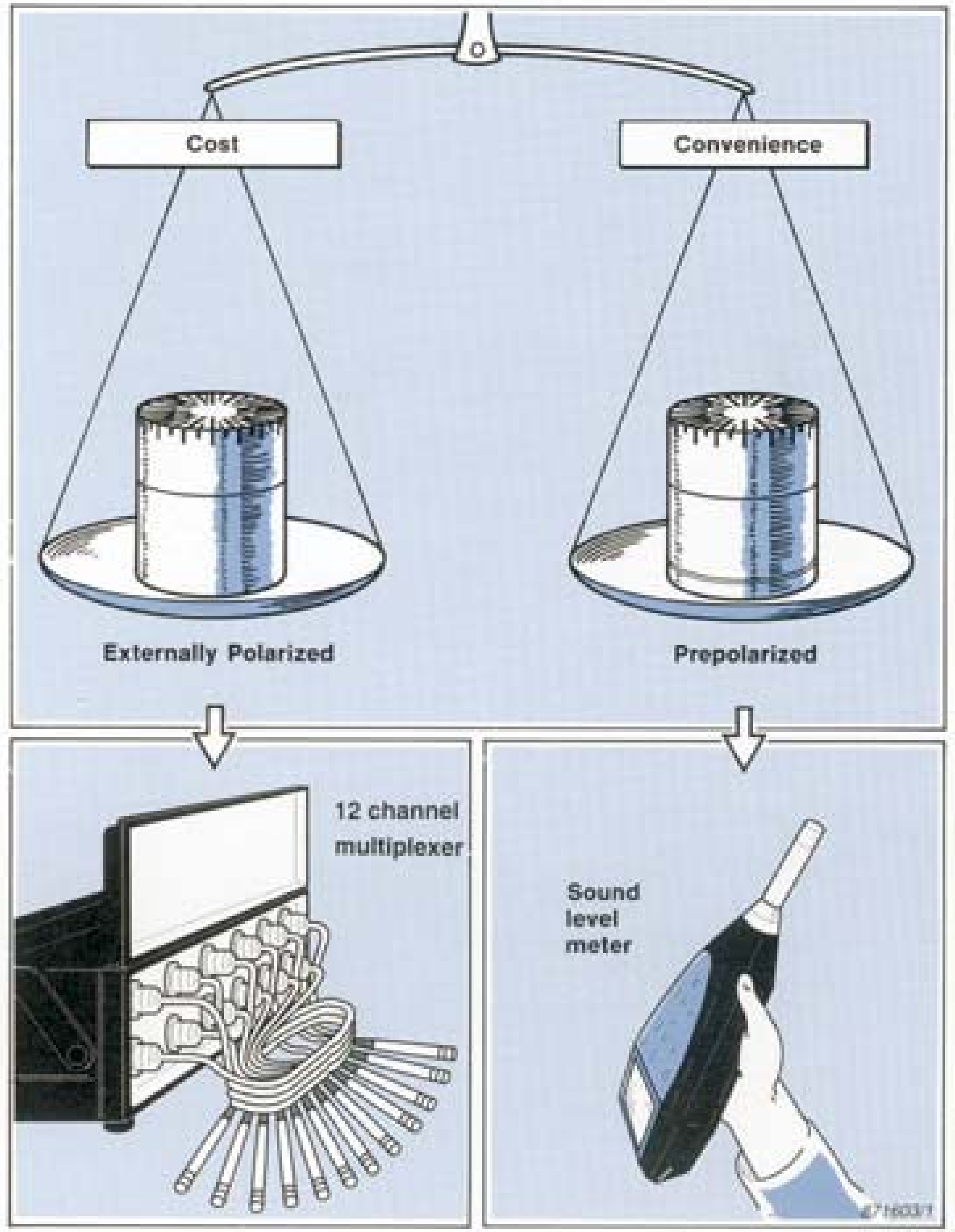


'Externally polarized' or 'prepolarized'?

There are two ways to fix the charge on the backplate and so the Brüel&Kjær range of measuring microphones is split into two main categories: **externally polarized** and **prepolarized.**

Externally polarized microphones need a DC voltage across the diaphragm-to-back-plate air-gap to fix the charge. A power supply is therefore required. Prepolarized microphones, on the other hand, require no external polarization voltage — the charge is fixed by a thin layer of charge-holding **electret** material on the backplate. This type of microphone is therefore preferred in 'hand-held' applications, such as sound level meters, where the polarization voltage supply would be inconvenient.

So why do Brüel&Kjær produce two types of microphone which essentially do the same job? The reason is that while prepolarized microphones are usually more convenient, their externally polarized counterparts are easier to make and therefore less expensive to buy. For measurements that require several microphones, externally polarized microphones provide the economic solution.

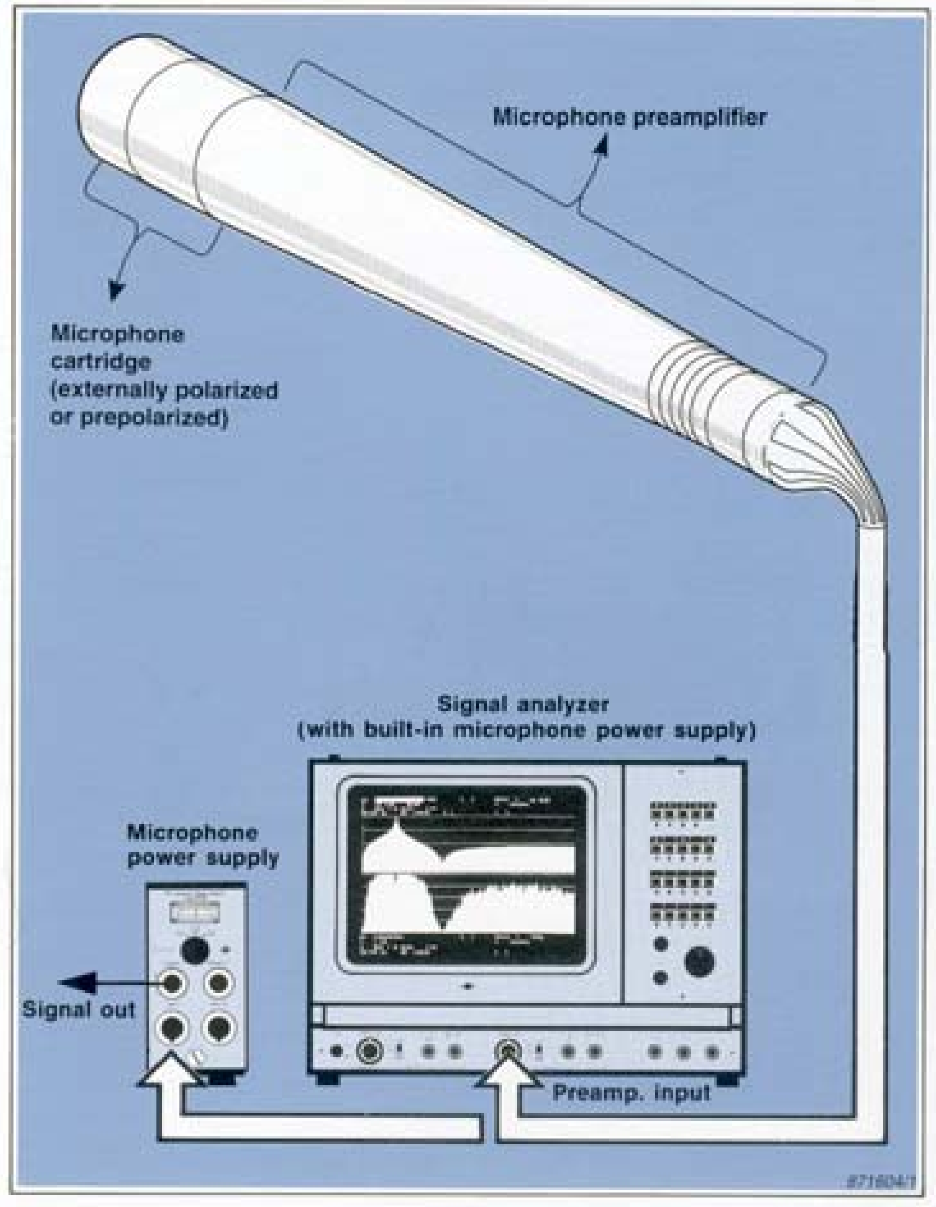


Preamplifiers and power supplies

Measuring microphones are always used in conjunction with a **microphone preamplifier.** The preamplifier converts the microphone's high output impedance to a low impedance suitable for feeding into the input of accessory equipment. This impedance conversion next to the microphone serves to minimize the pick-up of noise in the signal cable to the accessory equipment. Surprisingly, considering their name, most microphone preamplifiers actually attenuate the signal — but only by a fraction of a decibel.

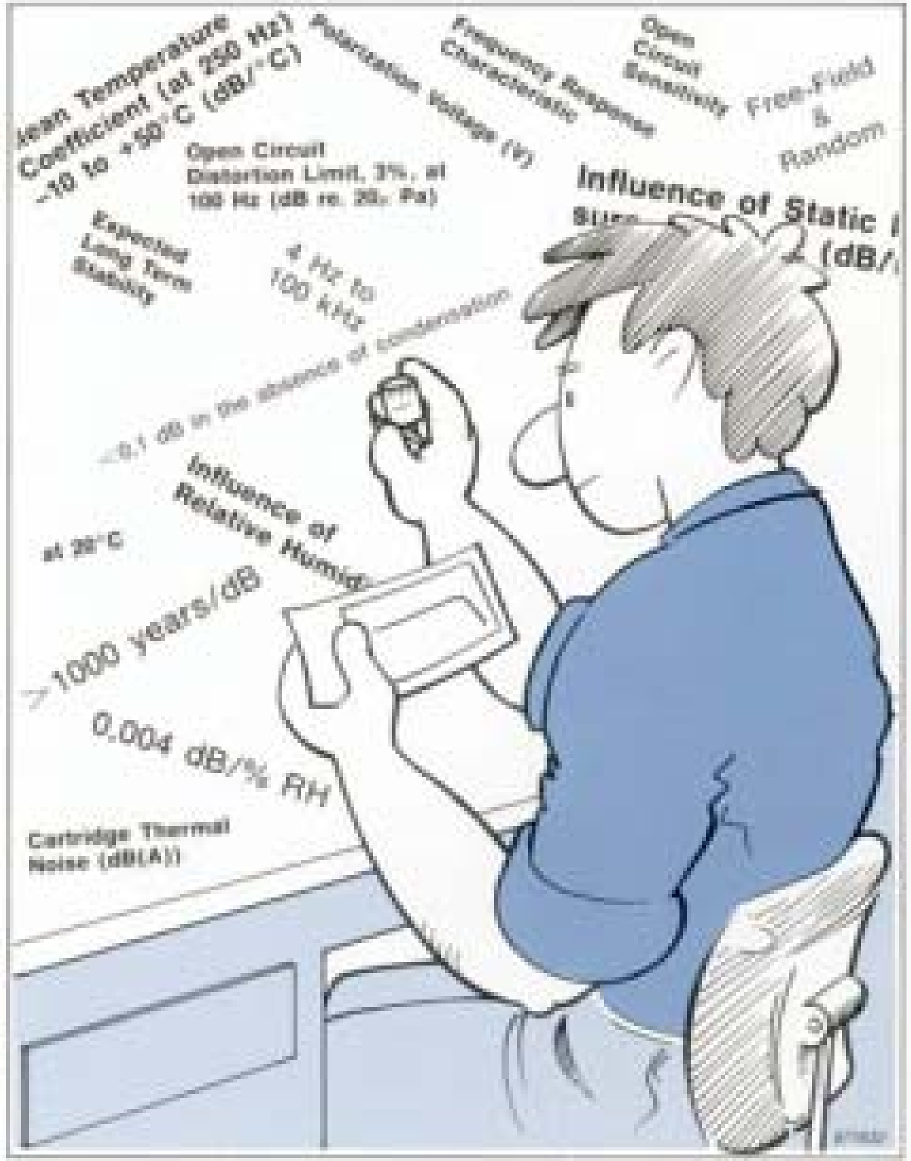
Microphone preamplifiers must be selected carefully so that their own characteristics do not impose on those of the microphone. Brüel&Kjær produce a range of low-noise microphone preamplifiers to complement the range of measuring microphones and all that we need suggest here is use *the recommended preamplifier!*

Microphone preamplifiers require a 28V (DC) or 120V (DC) or ± 14V to ±60 V supply from a **microphone power supply.** The power supply is either an independent battery- or mains-operated unit or an integral part of the 'Preamp Input' of Brüel & Kjær measuring amplifiers and frequency analyzers. The microphone power supply also serves to provide the stabilized DC polarization voltage for externally polarized microphones.



Characteristics

Now that we have have discussed some general features of measuring microphones, we can look in more detail at the characteristics of measuring microphones. Characteristics describe the performance of a microphone and are found summarized in the specification tables that appear on technical data sheets and microphone calibration charts or discs.



To the untrained eye, microphone characteristics represent a strange mix of jargon, numbers and units — there is a lot of technical information filling a very small space. But the information is absolutely invaluable if the best microphone is to be selected for a measurement task or if a microphone's potential is to be fully explored. The next few pages are therefore intended as an enlightening guide to the various microphone characteristics that are to be found in specification tables.

For your interest we have included at the end of this booklet tables of specifications relating to the Brüel&Kjær range of measuring microphones. Browse through it if you like — it is the most comprehensive range of its kind and will act as a useful standard against which to compare other measuring microphones.

Characteristics — directivity and size

All Brüel&Kjær measuring microphones are **omnidirectional.** That is, they are sensitive to sound arriving from all directions. The omnidirectional 'pickup' pattern is an important design feature of measuring microphones because every sound arriving at the microphone position is relevant — unlike for some types of microphones (e.g. directional studio microphones) where sound approaching from some angles may be 'unwanted'.

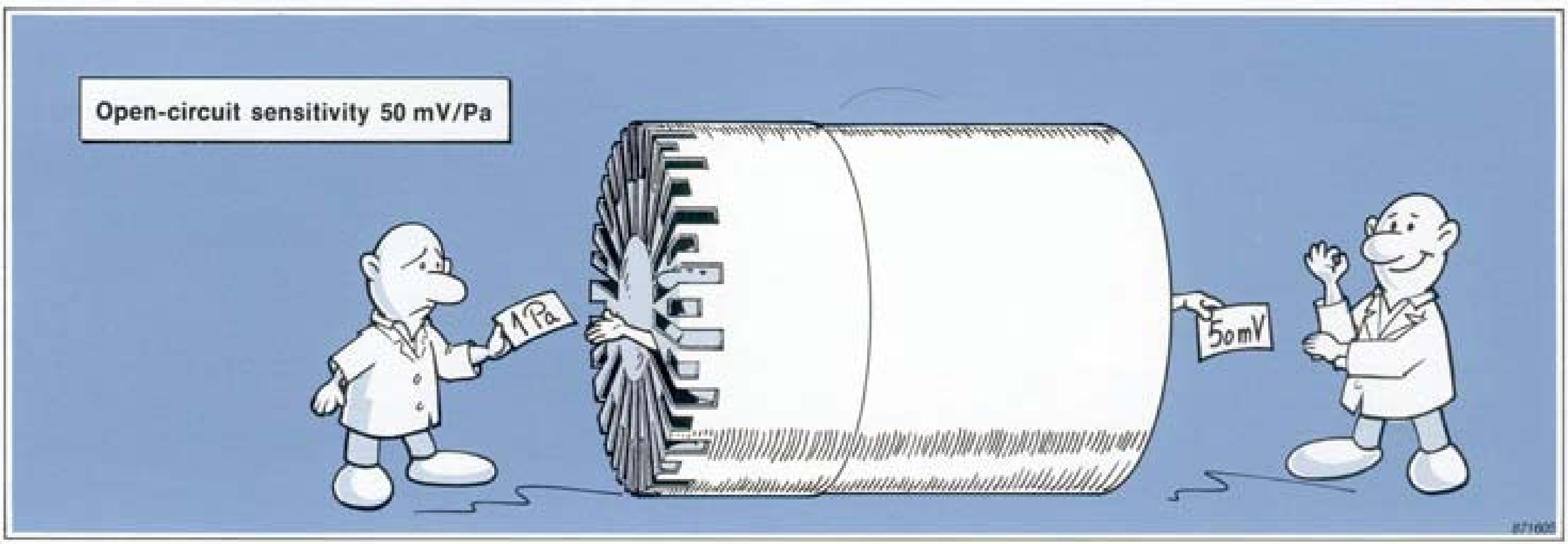
The smallest (1/8" and 1/4") measuring microphones have the best omnidirectional characteristics at audio frequencies. They respond equally to all frequencies arriving from all directions because their physical presence in the sound-field is not a big influence on incoming sound waves. The larger 1" measuring microphones, as a direct result of their size, are not so sensitive to the frequencies above about 5kHz which approach from the sides and rear of the microphone (relative to their sensitivity to frontally incident sound). They are said to be 'less omnidirectional' at these frequencies.

Unless small microphone dimensions are a particular advantage for measurements (e.g. in confined spaces or close to sound sources), it is a microphone's **characteristics** (or performance specifications) which determine its selection for an application. Since 1/2" microphones have good general-purpose characteristics, these tend to be a very popular choice. The other microphone sizes generally have characteristics suitable for more specialized measurements, e.g. at extremely high sound-pressure levels and frequencies beyond the audio range (1/8" and 1/4" microphones) or at low sound-pressure levels (1" microphones).

Characteristics — open-circuit sensitivity

An important characteristic which features prominently in the specifications for all measuring microphones is **open-circuit sensitivity.** The open-circuit sensitivity of a measuring microphone tells of the output voltage to be expected at the microphone's output terminal for every unit of sound pressure acting on the diaphragm (when the microphone is not attached to a preamplifier). Units are mV/Pascal and the frequency at which the open-circuit sensitivity is valid is always stated even if the frequency dependency is low.

Open-circuit sensitivity is a quantity to which many of the other microphone characteristics are referenced — including frequency response. In view of this, Brüel&Kjær accurately measures (or 'calibrates') the open-circuit sensitivity of every one of its microphones individually and states the result on the calibration chart. Typical values are in the range 10 to 50mV/Pa, at 250 Hz. A highly 'sensitive' measuring microphone might have open-circuit sensitivity of up to 100mV/Pa at 250 Hz, whereas the least sensitive microphones might have open-circuit sensitivity of 0.2 mV/Pa at 250 Hz.



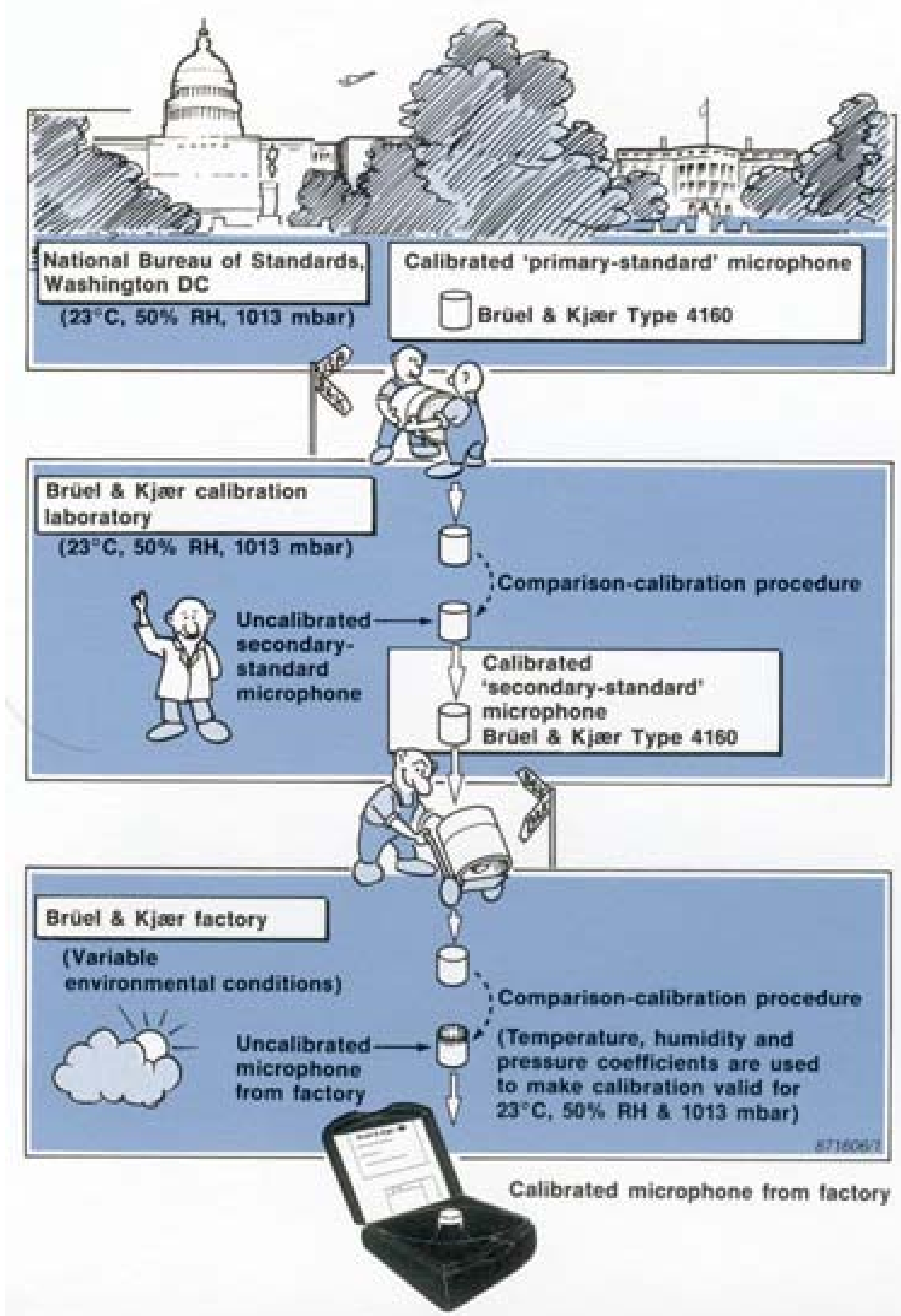
Factory-calibration

The chain of procedures used in the factory-calibration of open-circuit sensitivity together form a calibration 'hierarchy'. At the top of the Brüel&Kjær hierarchy are the **primary-standard** microphones — on whose accuracy and reliability all other links in the chain depend. The Brüel&Kjær 'primary standards' undergo absolute calibration once a year by an independent institution — the National Bureau of Standards, Washington DC.

To prevent exposure to routine calibration work, use of the Brüel&Kjær 'primary standard' microphones is restricted to an environmentally controlled calibration laboratory. Here, a primary-standard microphone and a **secondary-standard** microphone are exposed in turn to a sound source which generates a continuous high-level tone at 250 Hz. By comparing the output voltages of the microphones and with a knowledge of the primary-standard's open-circuit sensitivity, the open-circuit sensitivity of the secondary-standard microphone can be calculated. It is the secondary-standard microphone that is then used as the reference for every-day factory calibrations of measuring microphones by the same method.

The calibration chart of every Brüel&Kjær measuring microphone states that 'this calibration is traceable to the National Bureau of Standards, Washington DC'. This statement is *your* proof that the calibration hierarchy has been established to a recognised standard.

In many countries, Brüel&Kjær has established a calibration service that makes use of the above procedure to periodically recalibrate customers' microphones.



Loaded sensitivity and correction factor, K_0

Open-circuit sensitivity is a valid quantity if it can be assumed that the microphone output terminal is looking into infinite electrical impedance. In practice, of course, the output terminal is connected to a microphone preamplifier which has very high but not infinite input impedance. **Loaded sensitivity** is then a more relevant quantity because it accounts for the presence of the preamplifier. Loaded sensitivity can be calculated by adding the preamplifier's gain factor, G, to the microphone's open-circuit sensitivity. 'G' for the various Brüel&Kjær preamplifiers is printed in the Product Data Sheets and the Microphone Handbook.

Many measuring amplifiers and analyzers have an **internal reference** signal and are designed to read correctly when the loaded sensitivity of the microphone and preamplifier combination is -26 dB re 1V/Pa. Where the actual loaded sensitivity differs from this, a correction is automatically added to the reading.

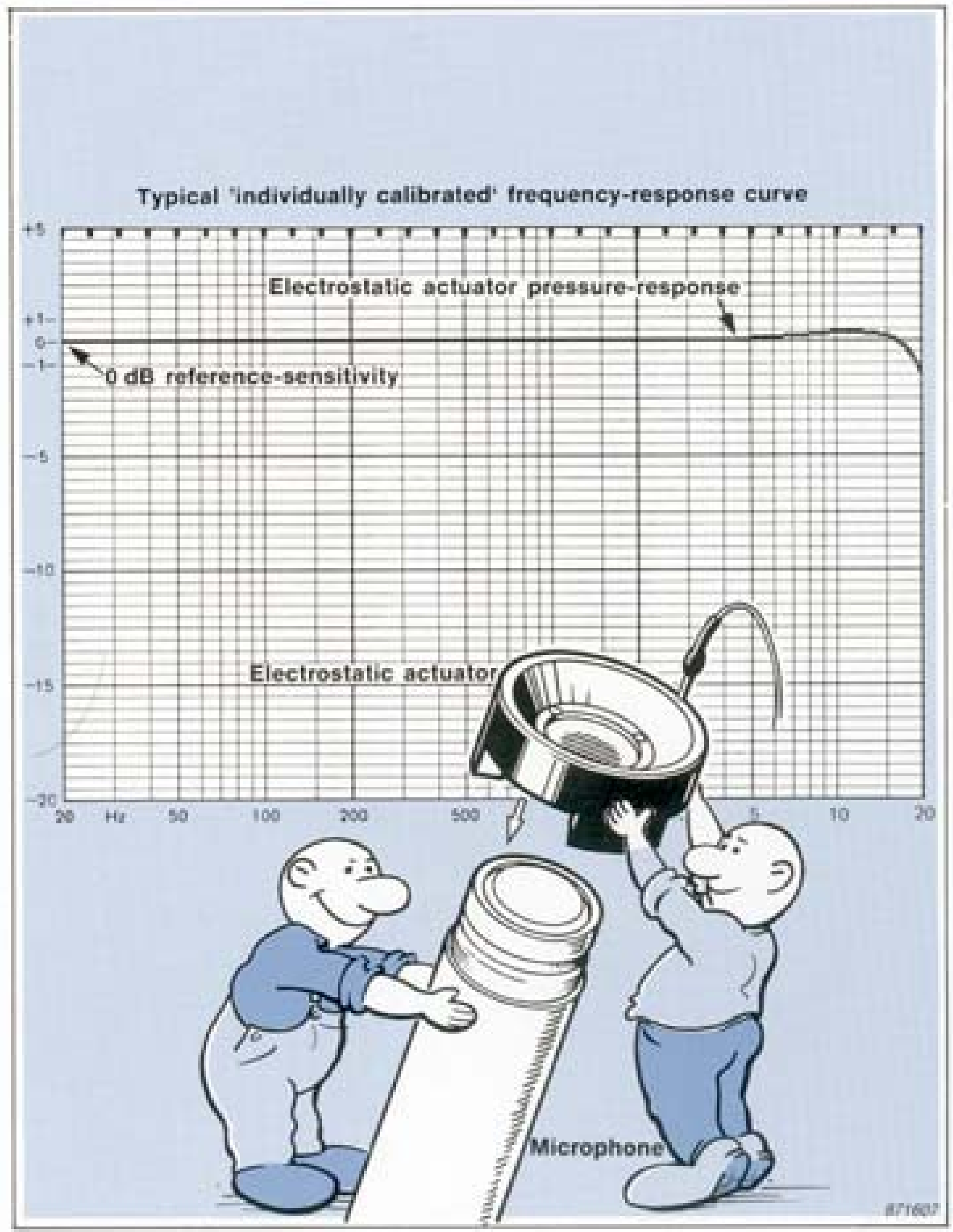
Characteristics — frequency response

Actuator-response curve
The microphone's actuator-response curve shows how open-circuit sensitivity varies with frequency and represents the pressure response of the microphone. The vertical scale features units of decibels (dB) because these are convenient to use. The simple relationship between mV/Pa and dB re 1 mV/Pa is given below:

$$\text{Sensitivity, dB re 1 V/Pa} = 20 \log_{10} \frac{(\text{Sensitivity, mV/Pa})}{(1000 \text{ mV/Pa})}$$

Most of the measuring microphone types in the Brüel&Kjær range are supplied with their own unique (or 'individually calibrated') actuator-response curve. This is measured as part of the quality-control procedure at the Brüel&Kjær laboratories and proves that the microphone is performing to specifications.

The curve is factory-calibrated by using an **electrostatic actuator.** This device fits to the front of a microphone and excites the diaphragm in a similar way to sound pressure. The actuator-response curves are plotted relative to a 0 dB reference-sensitivity line (whose absolute value at 250 Hz is the calibrated value of open-circuit sensitivity of the microphone).



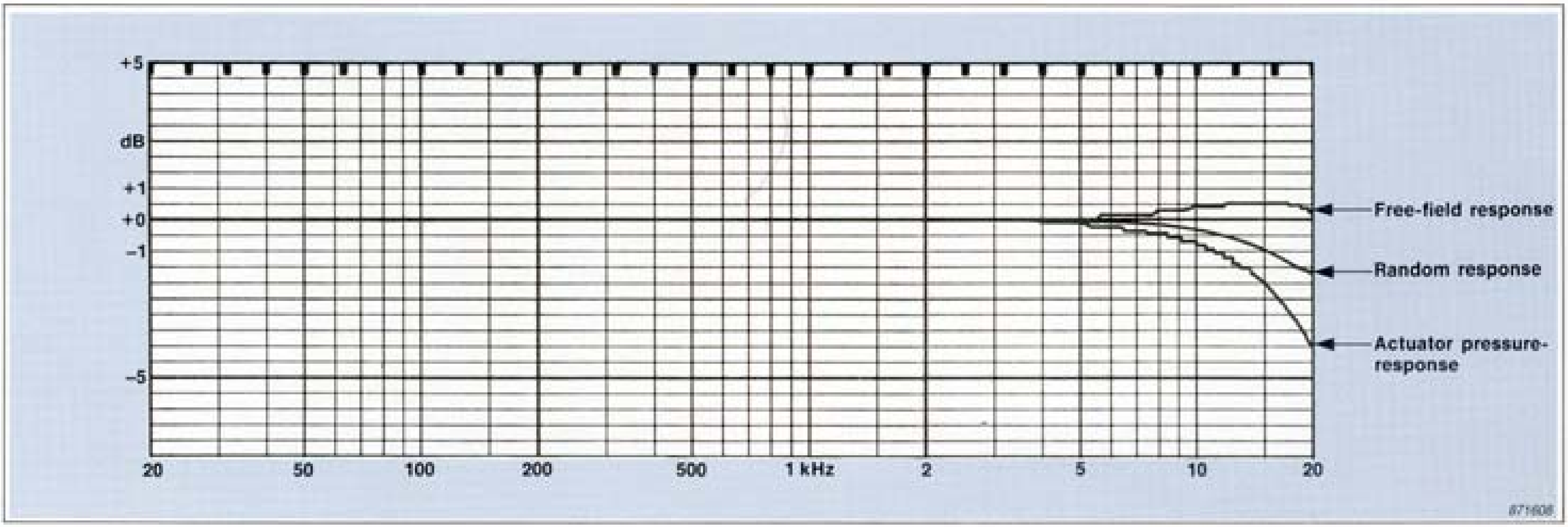
Free-field and random-response corrections
The electrostatic-actuator calibration procedure cannot simulate the diffraction and interference effects that occur at the diaphragm when a microphone is placed in a free or diffuse sound-field. Corrections are therefore added to the actuator responses of **free-field** and **random-response microphones** during factory calibration procedures to account for these effects.

When the orientation of a free-field microphone to oncoming sound changes, the 0° incidence free-field corrections become invalid. Free-field responses for different microphone-orientations are not given on the calibration chart but are published in specialist literature that supports the Brüel&Kjær range of microphones.

Frequency-response range
This is the range of frequencies to which a microphone usefully responds. It is essentially a quantitative description of the frequency-response curve of a microphone that can be printed in a table of specifications. Here is a typical example of how frequency-response range is written:

Type 4190 Frequency Range 3.15 Hz to 20 kHz (± 2dB)

This statement does not mean that the curve fluctuates by ± 2dB, but rather that the curve is smooth and flat apart from a gentle rise of up to 2dB (but typically much less than 2 dB) at the higher frequencies and a gradual roll-off to -2 dB at 3.15 Hz and 20 kHz. Since the Type 4190 is a free-field-response microphone, the frequency-response range refers to the free-field-response curve, not the actuator-response curve.

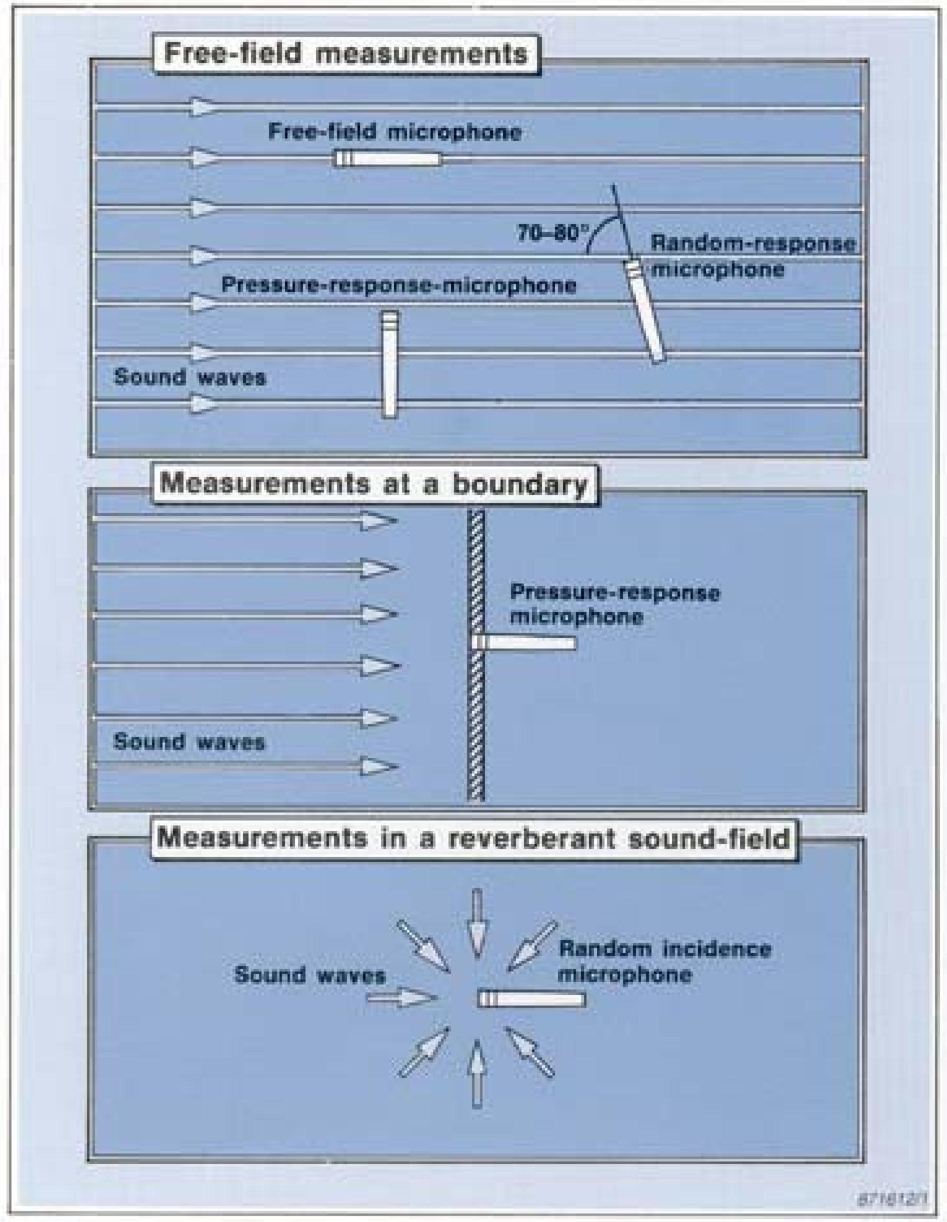


Free-field-, pressure- and random-response microphones

Free-field-response microphones are used for measuring sound coming mainly from one direction. Their frequency-response curve is designed to compensate for the pressure build-up at the diaphragm caused by interference and diffraction effects. Measured sound-pressure levels are therefore equal to those that would exist in the sound-field if the microphone were not present.

Pressure-response microphones do not compensate for the pressure build-up at the microphone diaphragm — they measure the actual sound-pressure level at the diaphragm. Uses include measuring sound-pressure levels at a surface (if the microphone is flush-mounted), or in a closed cavity (where the microphone is part of the cavity wall). Pressure-response microphones can be used as free-field microphones if they are oriented at right-angles to the direction of sound propagation — but their effective frequency range is then reduced.

Random-response microphones have a flat frequency response in diffuse sound-fields where sound arrives from all angles.

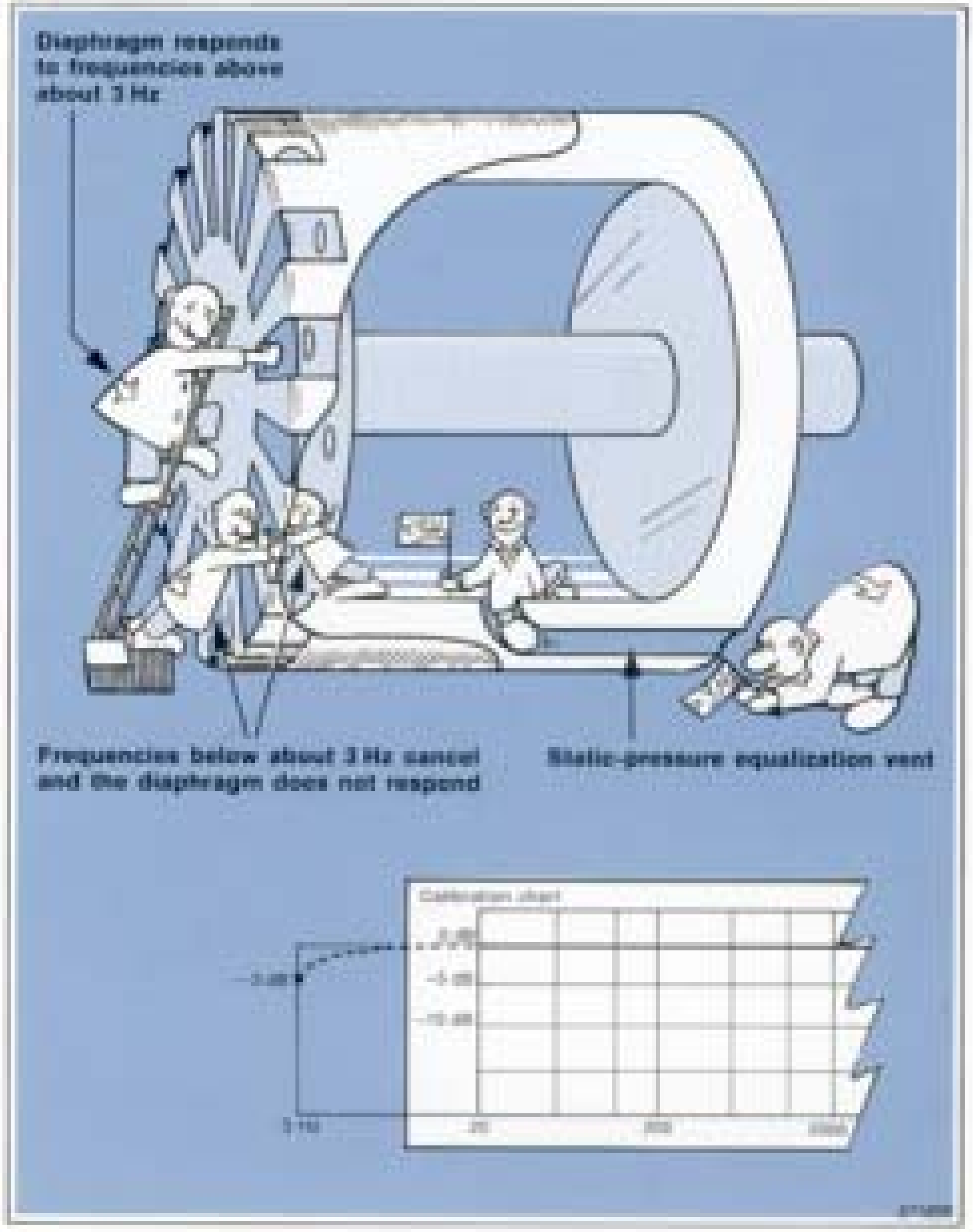


Low-frequency cut-off
The lowest frequency to which a microphone responds is largely dependent on the size of the **static-pressure equalization vent** whose purpose is to prevent the diaphragm from bulging if there is a change in atmospheric pressure.

At most frequencies in the audio range the vent is small enough for its air resistance to prevent sound waves from entering the microphone's internal cavity. However, at lower frequencies a small proportion of sound waves acting on the vent do enter the cavity. The low-frequency sound'in the cavity then starts to oppose the motion of the diaphragm and the microphone's frequency-response curve 'tails-off' and its phase response changes.

The **low-frequency cut-off,** or lower limiting frequency, is the frequency at which the frequency-response curve has fallen to 3 dB below the 0 dB-reference line. This '-3 dB point' usually occurs at between 1 and 3 Hz for Brüel&Kjær microphones and in production each microphone is individually checked and adjusted, if necessary, to ensure that the specified low-frequency cut-off is obtained.

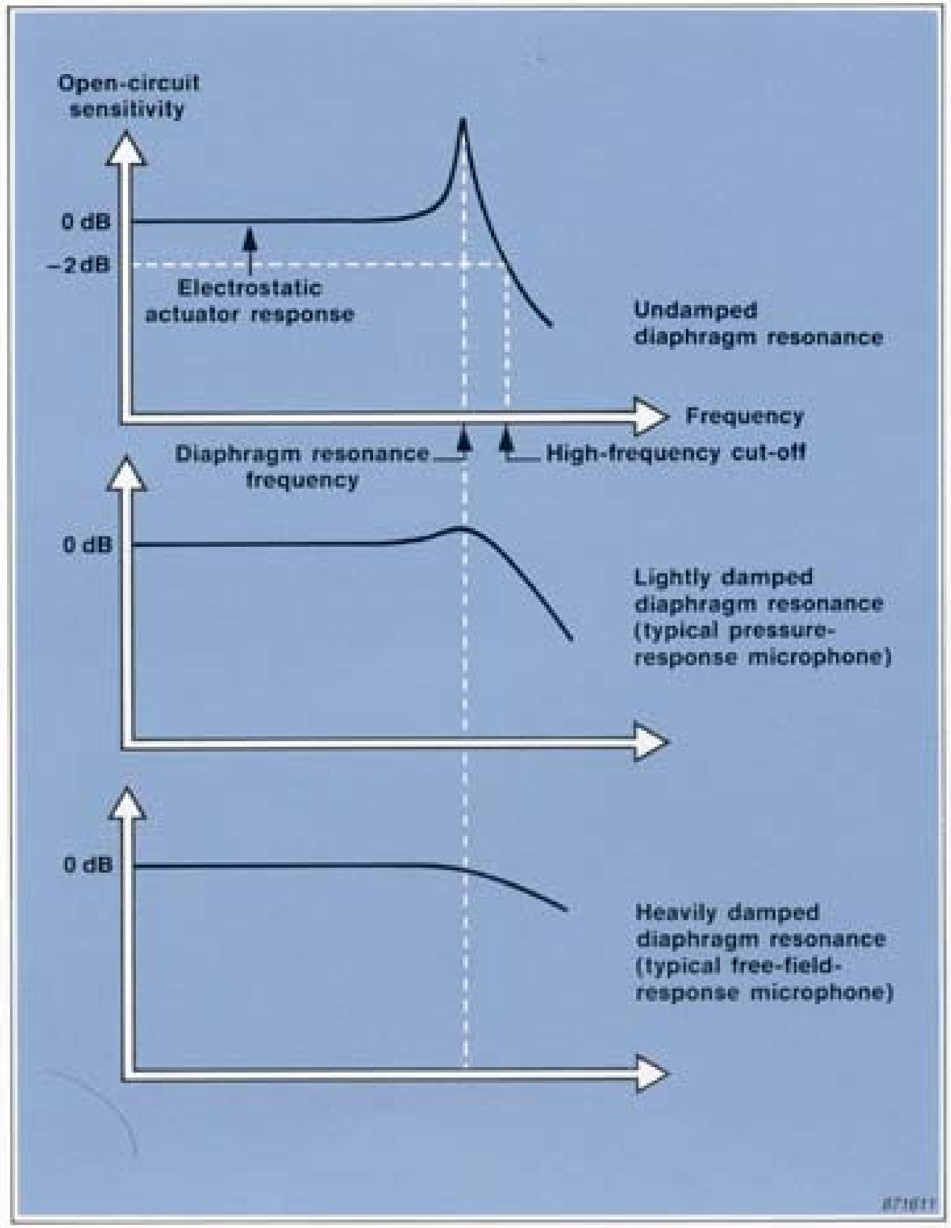
The microphone ceases to respond altogether when the instantaneous low-frequency sound pressure is the same on both sides of the diaphragm (because there must be a pressure difference across the diaphragm to make it move).



High-frequency cut-off
At higher frequencies the microphone's frequency-response curve tails off after the diaphragm resonance. The **high-frequency cut-off** is the frequency at which the frequency-response curve is 2 dB below the 0 dB-reference line.

The diaphragm resonance frequency is fixed at the design stage by controlling the diaphragm's mass, tension and stiffness. At the resonance frequency, the microphone is particularly sensitive. This is normally undesirable and so the resonance is damped. **Damping** has the effect of squashing the resonance peak on the frequency response curve so that it is flatter.

The damping of the resonance is controlled by holes in the backplate. The more holes there are, the less is the damping effect on the diaphragm. Microphones with different amounts of diaphragm damping are **free-field-response** microphones (heavily damped) and **pressure-response** microphones (lightly damped).



Characteristics — dynamic range

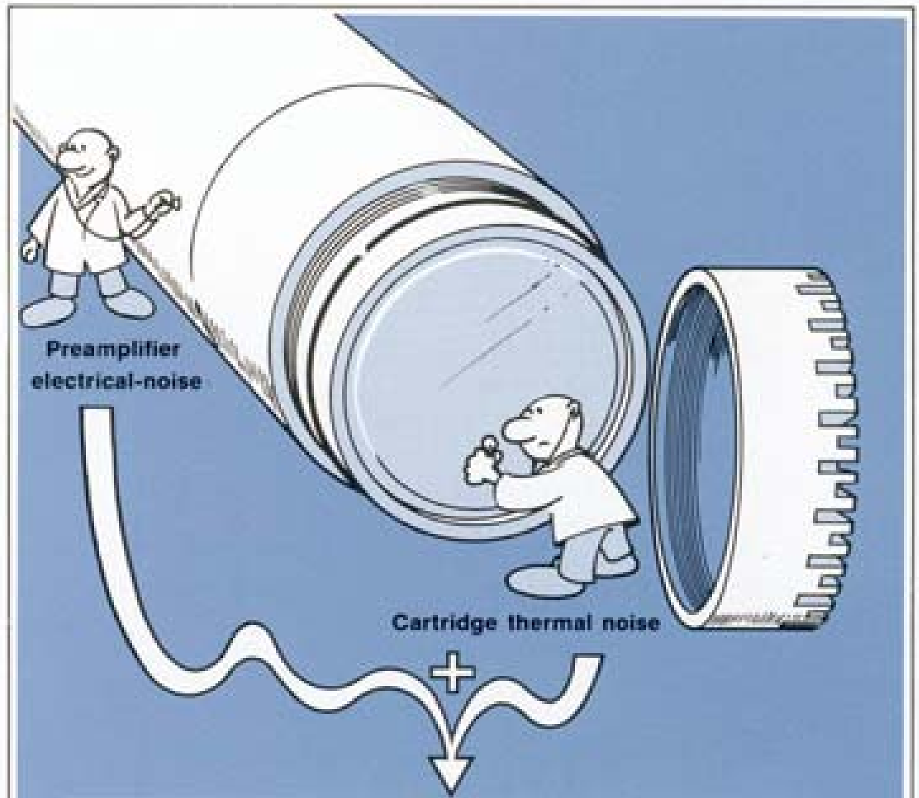
The difference between the highest and lowest measurable sound-pressure levels in a measurement system is called the **dynamic range.**

Lower limit of dynamic range
The lower limit of dynamic range for a microphone-preamplifier combination is fixed by **preamplifier electrical-noise** and **cartridge thermal-noise** levels.

The preamplifier electrical noise depends to a large extent on the capacitance of the microphone — the higher the capacitance the lower the noise that is generated in the preamplifier. This means that the larger 1" microphones have the lowest associated preamplifier noise because they are the biggest capacitors.

When a preamplifier has very low electrical-noise, the thermal noise of the cartridge (generated by thermal agitations of the diaphragm) becomes significant. In the microphone specifications, cartridge thermal noise is quoted as an 'equivalent' sound-pressure level in units of dB(A).

The combined effect of the thermal- and electrical-noise levels for a particular microphone-preamplifier combination are stated as a 'lower limit of dynamic range' on the preamplifier data sheet. You can see from the data-sheet extract shown opposite that if a sound signal is filtered (e.g. in 1/3-octaves) then the lower limit is considerably improved — a negative dB value indicating that the lower limit of dynamic range is below the 0 dB (SPL) threshold of hearing.



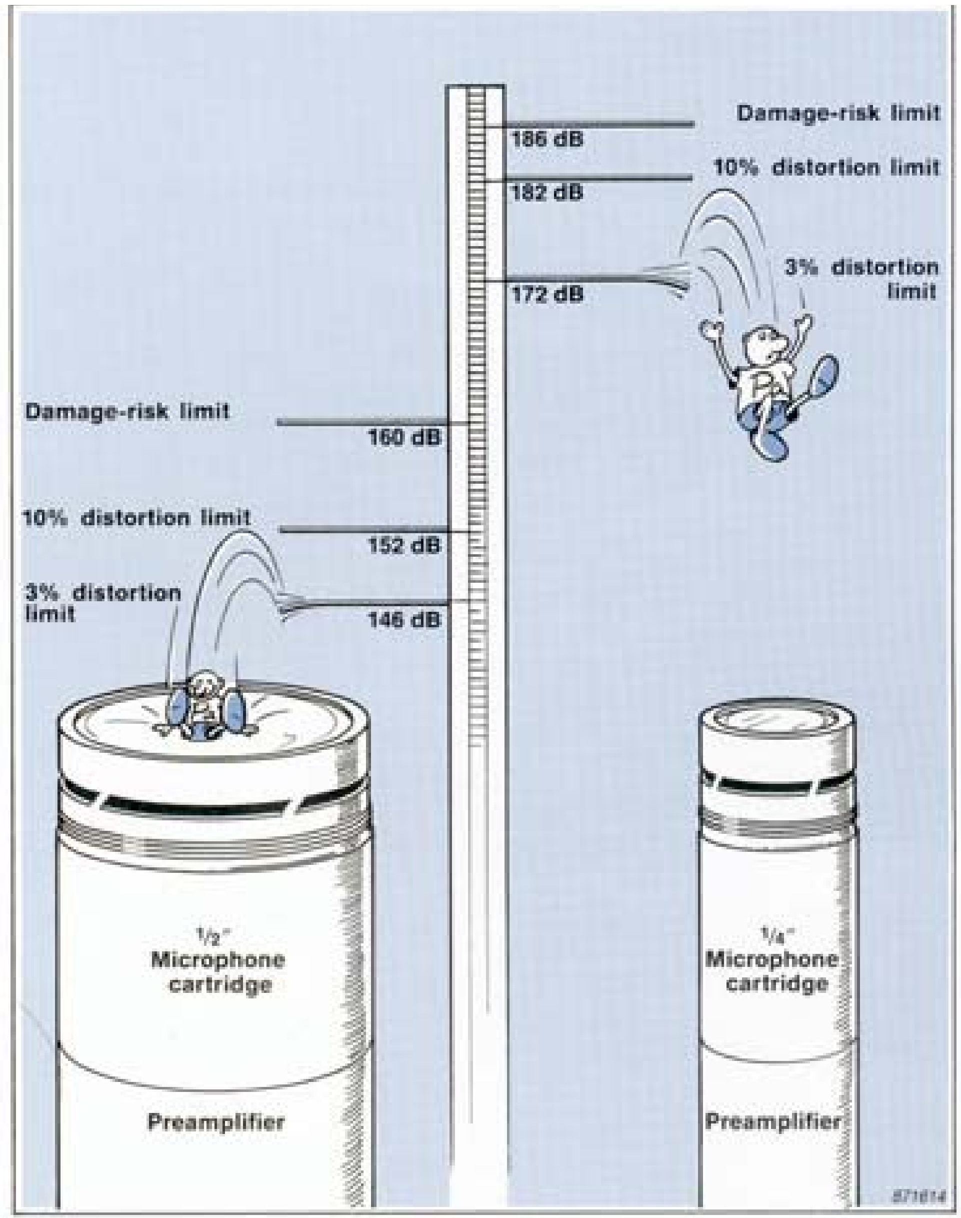
Assembly		Lower limit of dynamic range		
Preamplifier Type	Microphone Type	1/3 octave at 1 kHz (dB)	A-weighted Level (dB)	Linear 20 Hz to 20 kHz (dB)
2669	1" 4144	−5	10	11
	1/8" 4138	45	55	66

Upper limit of dynamic range

The upper limit of the dynamic range is set by the **distortion limit** of the measuring system. In the microphone-preamplifier combination, distortion results from non-linear behaviour of the diaphragm and/or amplifier 'clipping'. These effects only occur when the microphone is exposed to very high sound-pressure levels.

Distortion that arises in the microphone cartridge is specified as the 3% **open-circuit distortion limit** at 100 Hz (units are dB re *20* μPa). The limit is defined as the sound-pressure level at which harmonic distortions amount to 3% of the amplitude of the main signal. The value of the limit is generally related to the size of the microphone — the smaller the microphone the higher the open-circuit distortion limit.

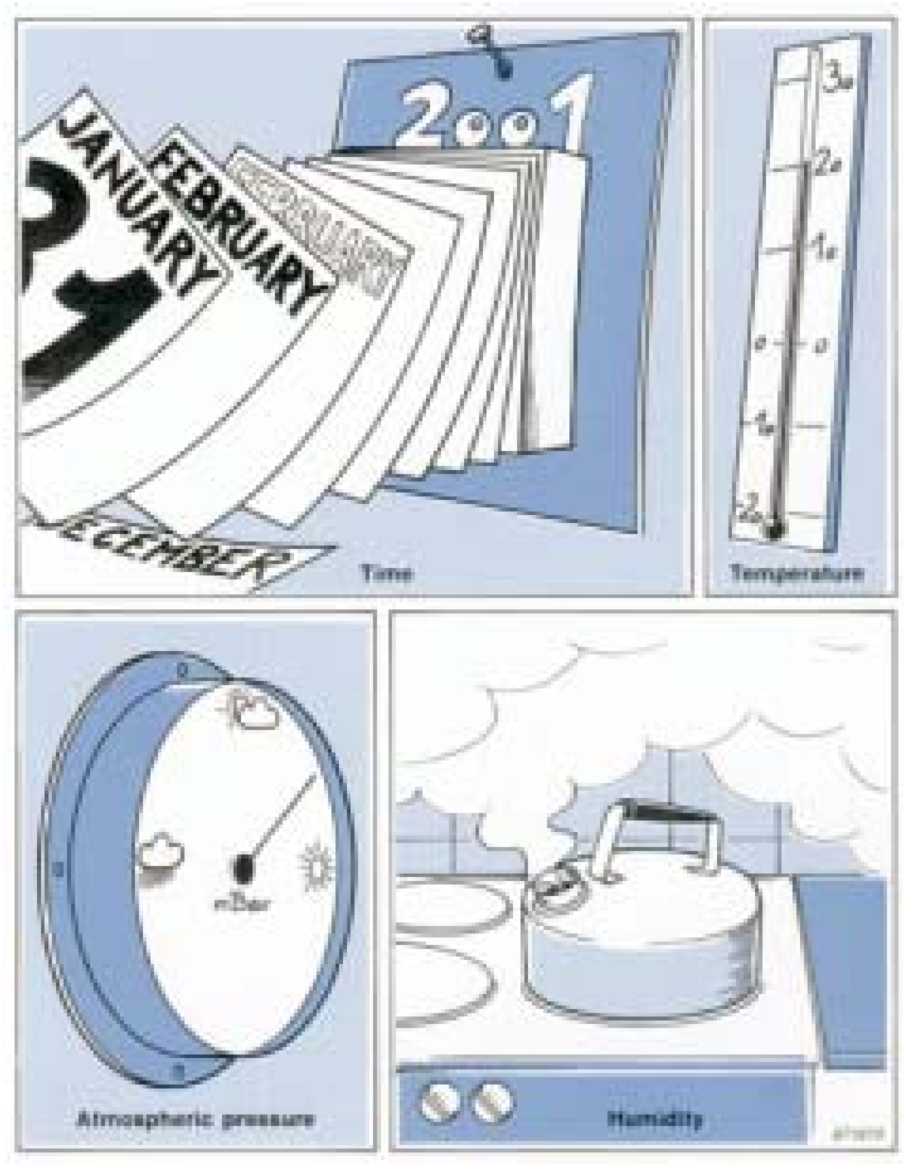
The 3% distortion limit is not an absolute limit to the sound-pressure levels that can be measured. In fact, preamplifier specifications state the 10% distortion limit for the various combinations of Brüel&Kjær microphones and preamplifiers. However, above the 10% distortion limit there is greater risk that the microphone diaphragm will be forced against the backplate, possibly causing permanent damage.



Influences on characteristics

Once the characteristics are embodied in a microphone, it remains for the manufacturer to state how measurement results will be affected by passing time or changing environmental conditions. This is done by publishing time, temperature, pressure and humidity **coefficients** to describe the influence of the environment on microphone sensitivity. External influences on the sensitivity of Brüel&Kjær microphones are minimized by careful design. The specific intention of the Brüel&Kjær microphone designer is to have the smallest possible coefficients so that measurement results need not be continually corrected for environmental changes.

The various coefficients described in the following pages are stated in the microphone specifications. They are not measured individually for each microphone since the production quality of the Brüel&Kjær measuring microphones is very consistent. This consistency permits Brüel&Kjær to publish information that is useful to users whether their microphone was manufactured yesterday — or several years ago.



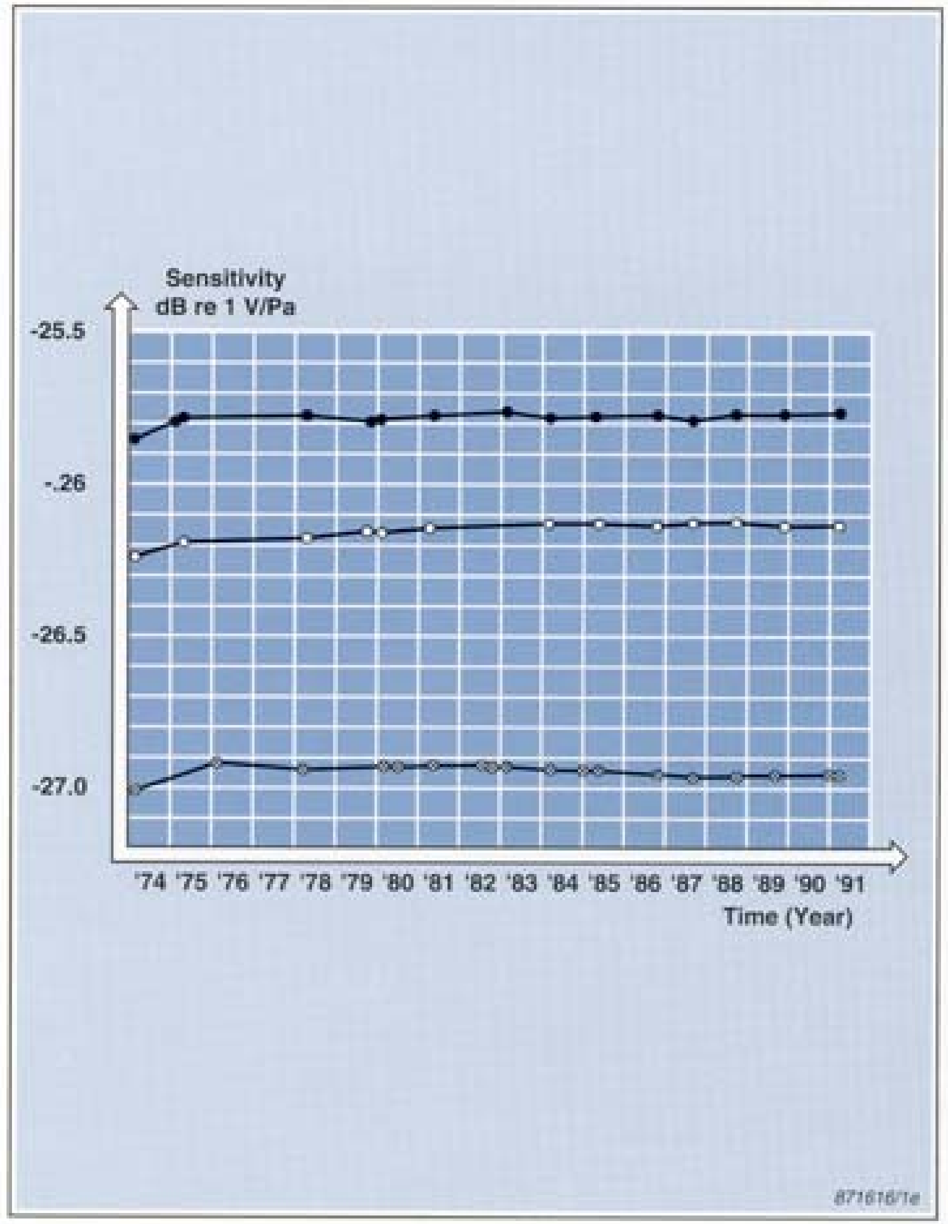
Influences on characteristics — the progress of time

Perhaps one of the most important requirements of a measuring microphone is that it should have good **long-term stability.** The calibration chart can then be trusted over a long period of time.

The long-term stability of Brüel&Kjær microphones is the estimated time (usually many hundreds of years) it will take for the microphone's open-circuit sensitivity to change by 1 dB. Obviously, this quantity is hard to verify, but periodic checks on the sensitivities of microphones kept in storage since 1967 confirm that the long-term stability of Brüel&Kjær microphones is excellent.

The most likely contributor to the instability of a microphone is a 'creeping' (or 'floating') diaphragm where changes in diaphragm tension affect the sensitivity of the microphone. The creep rate of a diaphragm is fast when the diaphragm has been newly tensioned, but decreases over a period of time. Brüel&Kjær stabilise the sensitivity of the microphone by **artificially ageing** the diaphragm so that, by the time the microphone is calibrated, creep is insignificant.

Brüel&Kjær has pioneered the art of artificially ageing microphones. The microphones produced at the Brüel&Kjær factory are without doubt the most stable available.



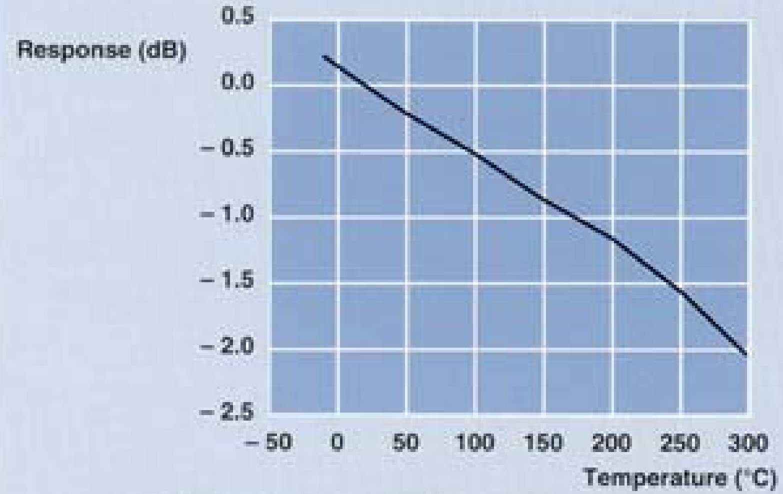
Influences on characteristics — temperature

It is essential that temperature variations do not cause permanent changes to the sensitivity of measuring microphones, otherwise the long-term stability suffers. Materials used in the construction of the Brüel&Kjær measuring microphones are therefore chosen very carefully, with the result that temperature changes have virtually negligible effect on the mechanics and hence the sensitivity of Brüel&Kjær microphones.

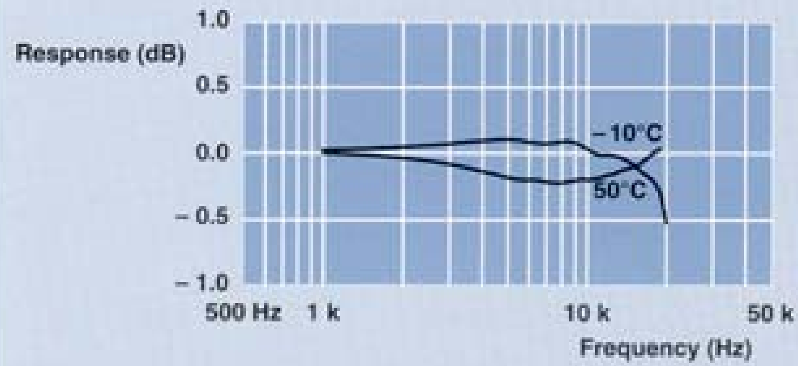
This is easily demonstrated by looking at the **mean temperature-coefficients** of the Brüel&Kjær 1/2" microphones, which are very small at between -0.002 and -0.007 dB/°C (averaged over the temperature range -10 to +50°C). The minus sign of the coefficient denotes that sensitivity *decreases* for every degree rise in temperature.

The mean temperature-coefficient is frequency-dependent and so its value is quoted in the microphone specifications at a frequency of 250 Hz. For most general measurements, however, the temperature coefficient is small enough to be disregarded. It is only at extreme temperatures that curves such as that shown opposite need to be referenced.

Microphones which are operated outside the recommended temperature range are at risk of permanent damage. Normally, this will not be a concern until temperatures reach about 150°C where the electret layer can be partly discharged and 'metal creep' can introduce irreversible changes in the diaphragm. Externally polarised microphones of the Falcon™ Range can be used up to 300°C.



Typical variation in sensitivity (at 250 °C) as a function of temperature, relative to the sensitivity at 20 °C



Typical variation in 0°-incidence free-field response (normalized at 250 °C) as a function of temperature, relative to the response at 20 °C

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Influences on characteristics — atmospheric pressure

As ambient pressure varies, so does the stiffness of the air in the cavity behind the diaphragm. The resulting effect on microphone sensitivity is described by the **ambient-pressure coefficient.**

Brüel&Kjær 1/2" microphones have ambient-pressure coefficients of between -0.00025 and -0.002 dB/mbar (at 250 Hz). The minus sign indicates that the sensitivity will *decrease* with increases in ambient pressures. For most general measurements, then, small changes in ambient atmospheric pressure have negligible effect on the sensitivity of Brüel&Kjær microphones.

The coefficient is stated at a fixed frequency of 250 Hz since it is frequency-dependent. Curves showing the corrections to add to a microphone's frequency response at different ambient 'static' pressures are available. Uses of such a curve might include correcting measurements made in an aircraft.

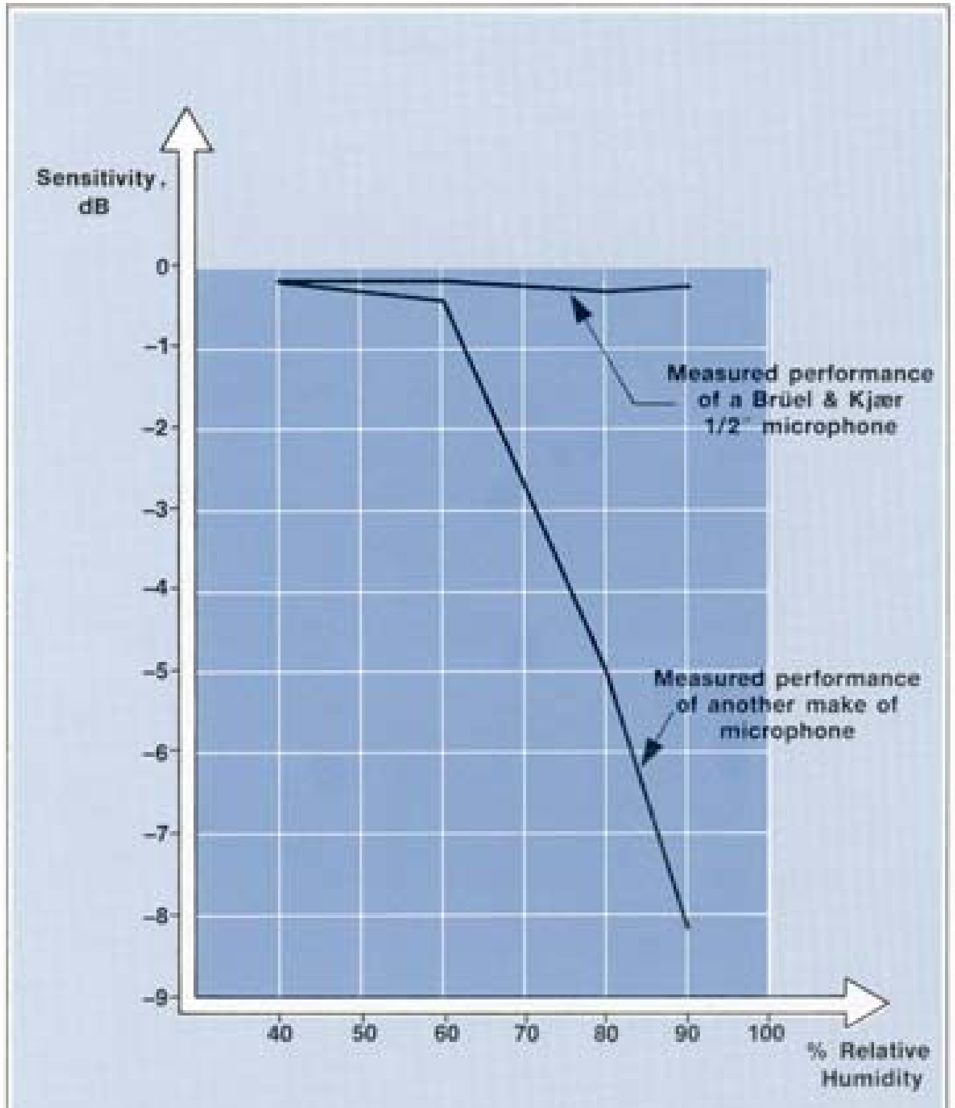
Influences on characteristics — humidity

Brüel&Kjær research has lead to the production of microphones whose calibration charts state simply that 'the influence of humidity does not exceed 0.1 dB in the absence of condensation'. This is an impressive statement when you consider that measurements made one day at a Relative Humidity (RH) of 5% can be repeated the next at 95% RH without undue influence on measurement accuracy.

For some Brüel&Kjær microphone types, the effect of humidity on microphone sensitivity is specified more closely by the **humidity coefficient.** For example, 0.000008 dB/%RH for the 1/2" reference-standard microphone Type 4180.

Shown opposite are the changes in open-circuit sensitivity of a typical Brüel&Kjær 1/2" microphone (Type 4133, mounted on preamplifier Type 2639) when exposed to different humidities at the elevated, but not uncommon, temperature of 40°C. On the same diagram is the performance of an apparently similar microphone from a manufacturer who has not specified the microphone's humidity coefficient.

Condensation
In measurement situations where condensation is likely to form inside the internal cavity, a backvented microphone may be used with a **dehumidifier.** The dehumidifier is a unit which contains a drying agent and it fits between the preamplifier and microphone cartridge. Some Brüel&Kjær backvented microphones also have their diaphragms coated with a very thin film of quartz to protect the diaphragm in very moist environments.



Sensitivity (at 250 Hz) as a function of relative humidity, 40°C.

Influences on characteristics — vibration

When a microphone is vibrated, it produces a small output voltage whose magnitude is related to the mass per unit area of the diaphragm. The sensitivity of a microphone to vibration is quantified in terms of an 'equivalent' sound-pressure level, i.e. the sound-pressure level that would produce the same output voltage as the vibrations.

In specifications, the influence of vibration is quoted as the equivalent sound-pressure level produced by an RMS acceleration amplitude of 1 m/s^2 (acting at right angles to the diaphragm in the frequency range 10 Hz to 2kHz). An acceleration amplitude of 1 m/s^2 might be experienced by a microphone if it were clamped to the casing of an electric motor — hopefully an unlikely situation. So how helpful is this specification? The answer is that since it is stated for all Brüel&Kjær measuring microphones (and microphone preamplifiers) it is useful for making comparisons between microphones when low vibration sensitivity is a selection requirement.

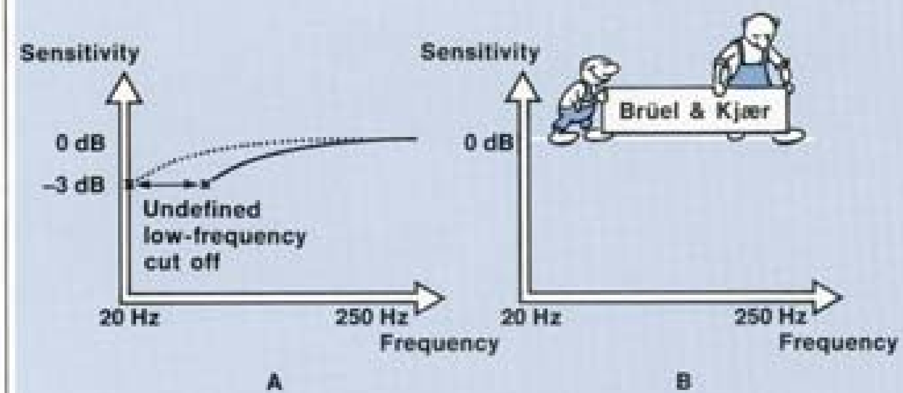
Influences on characteristics — leakage

Leakage is the name given to the ion currents which can flow across the diaphragm-to-backplate air-gap and across the surface of the backplate insulator. Uncontrolled leakage affects the open-circuit sensitivity of externally polarized microphones and reduces the effectiveness of the backplate insulator.

Brüel&Kjær stops leakage by thoroughly cleaning and polishing the microphone backplate to inhibit the formation of **leakage paths** and prevent arcing. Additional measures against leakage, such as specially coated backplate insulators, mean that leakage paths remain inhibited even in very humid conditions. The result of this attention-to-detail is a very high **insulation** (or **leakage) resistance.**

Brüel&Kjær factory-tests the insulation resistance of every microphone constructed, to ensure that leakage has been controlled.

Leakage is controlled by thorough polishing and cleaning of the microphone's backplate



The effect of uncontrolled (A) and controlled (B) leakage on microphone open-circuit sensitivity

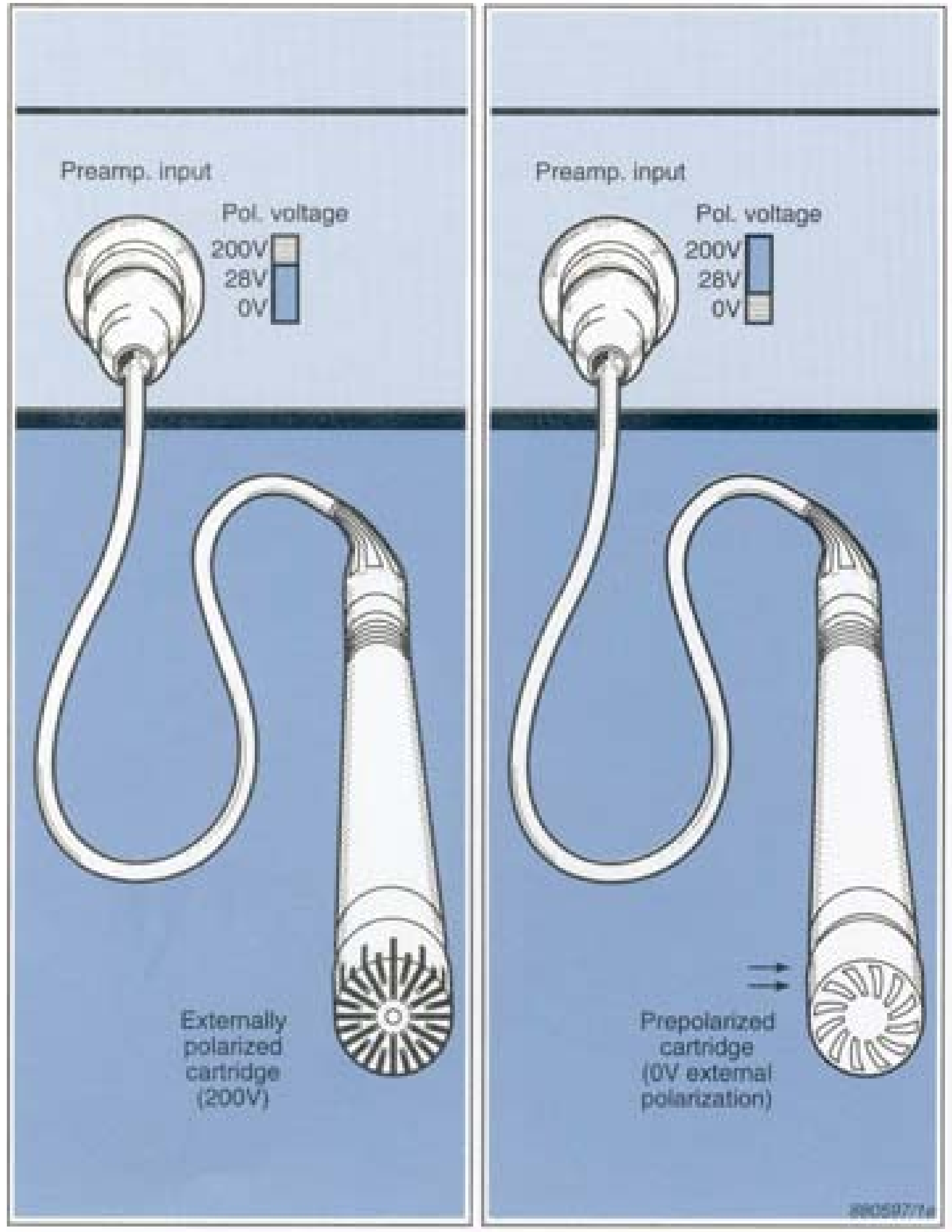
871610

Other influences on characteristics

Magnetic fields
The microphone specification relating to the influence of magnetic fields is expressed as the equivalent sound-pressure level that is produced when the microphone is exposed to a magnetic field of strength of 80A/m (at 50 Hz) acting at right-angles to its diaphragm. The magnetic field strength 25 cm away from typical shop-floor machinery is generally less than 30A/m.

Dirty diaphragm
Small specks of dust often settle on microphone diaphragms but these have no effect on microphone performance. Heavier dust particles or liquids that contaminate the diaphragm may be cleaned away carefully with a piece of cotton wool.

Incorrect polarization voltage
A Brüel&Kjær prepolarized microphone will not be damaged if supplied with the wrong polarization voltage — but its open-circuit sensitivity will be different from that stated on the calibration chart.



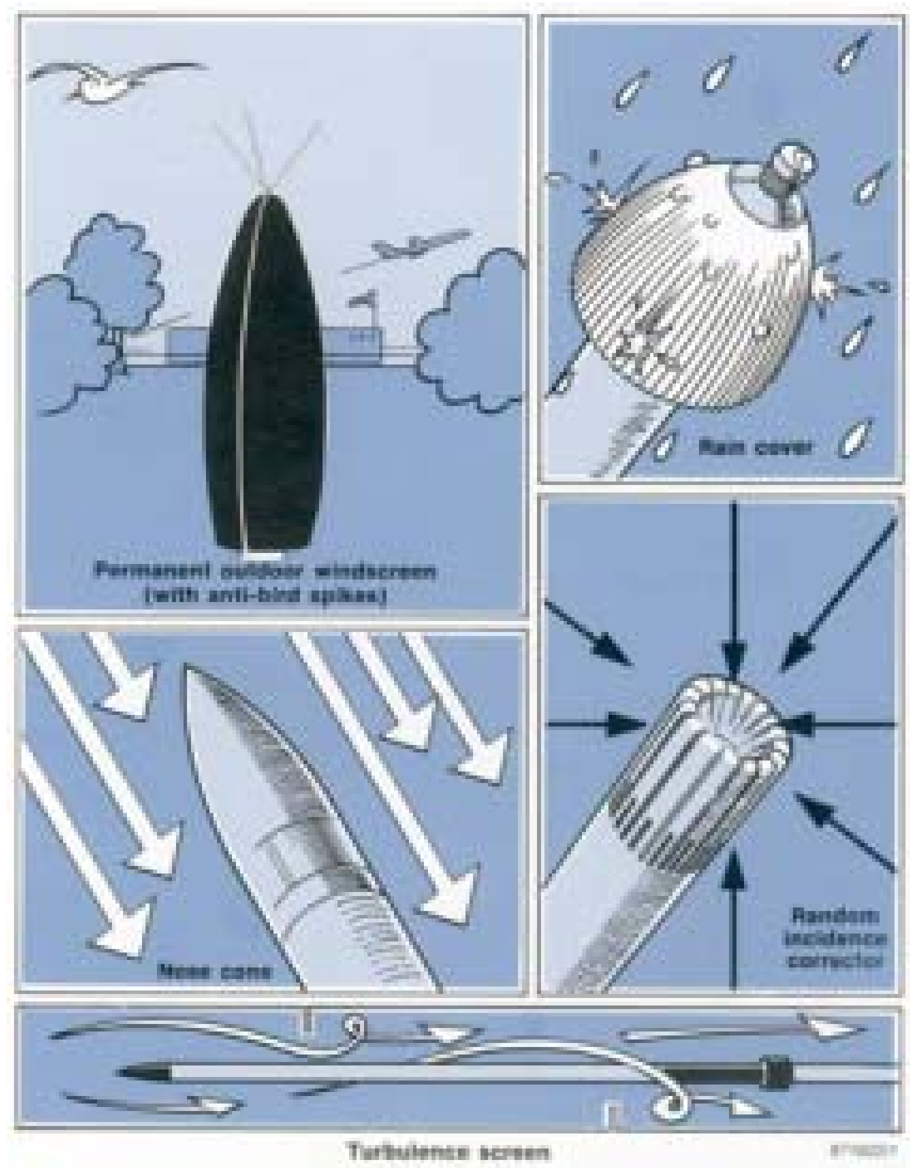
Accessory devices

In some situations, measurements cannot be made without the use of accessory devices because of local environmental conditions. Such devices subtly change the frequency-response of microphones and so Brüel&Kjær publish frequency-response curves showing the effects of these devices.

The Brüel&Kjær **rain cover** fits onto 1/2" microphones and, when combined with a **permanent outdoor windscreen** and suitable microphone, long-term outdoor measurements are possible. A special microphone for outdoor measurement Type 4184 is available.

While windscreens are effective at attenuating general wind-induced noise, a **nose cone** is more effective at reducing noise caused by high winds blowing past the microphone in a known direction. A **turbulence screen,** on the other hand, is an improvement on the nose cone when measurements are required in, for example, air-conditioning ducts which have flow noise caused by turbulence.

Another type of accessory is the **random-incidence corrector** which improves the omnidirectivity of 1" microphones at higher frequencies and modifies the response of certain 1/2" free-field microphones so that they may be used as random-response microphones.

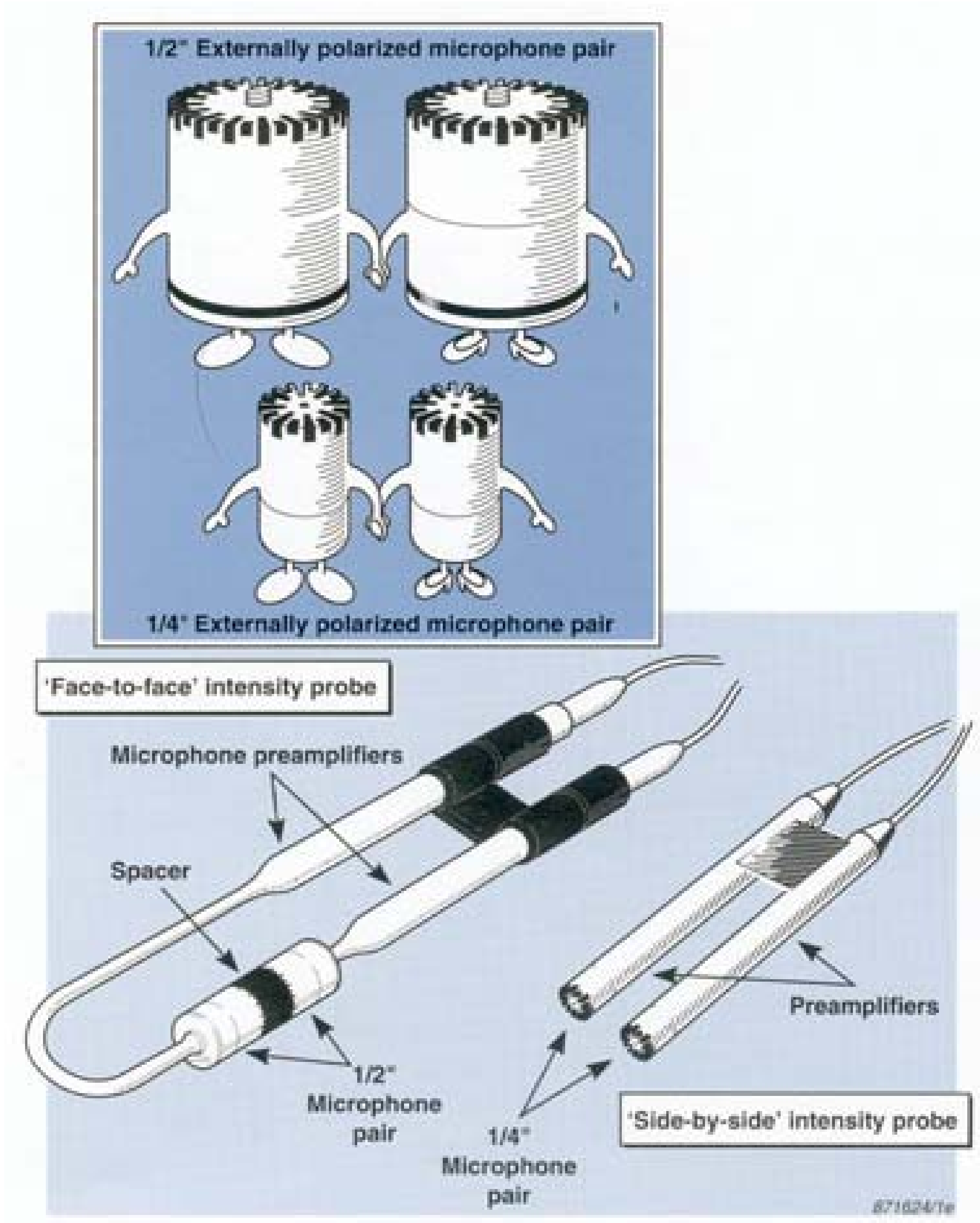


Microphone pairs for sound intensity

Brüel&Kjær produce special pairs of microphones for use in **sound intensity probes.** These microphones are similar in most respects to other Brüel&Kjær measuring microphones — except that these **matched pairs** are selected to have similar open-circuit sensitivity, frequency- and phase-response characteristics.

Brüel&Kjær matched pairs are easily identified by the small 'screw studs' on their diaphragm protection grid. These are used to secure the microphone **spacer** which is part of the sound intensity probe assembly. The two microphones in the matched pair are additionally labelled *Part 1* and *Part 2* respectively. The two parts are uniquely matched — so don't separate or lose them!

Brüel&Kjær produce both 1/2" and 1/4" matched microphones. 1/2" matched pairs are the most popular choice for general sound intensity measurements. 1/4" matched pairs are selected
for high-frequency sound intensity measurements and for use in **side-by-side** probe assemblies. The side-by-side arrangement enables the microphones to be used much nearer to a source than the more common and more acoustically ideal **face-to-face** probe assembly.



Microphone pairs for sound intensity — matching specifications

Ideally, the 'matched pair' microphones used for measuring sound intensity should have identical characteristics. In practice, there are slight differences documented by the following **microphone matching specifications:**

Amplitude-response difference, normalized at 250 Hz
This describes the maximum difference between two frequency-response curves when they are aligned (or normalized) at 250 Hz. For a typical Brüel&Kjær 1/2" microphone pair, the amplitude-response difference is <0.4dB (20 Hz to 5 kHz).

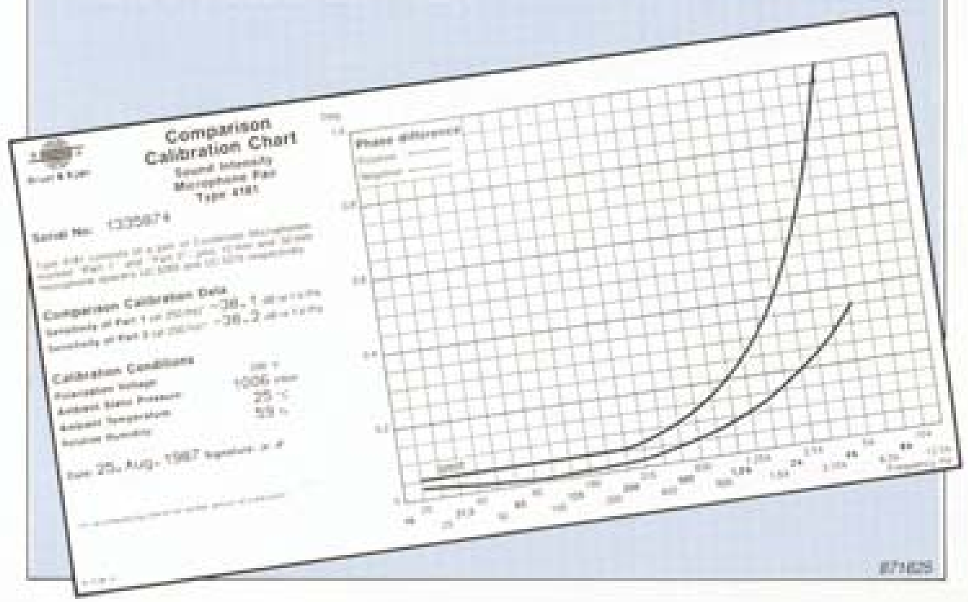
Phase-response difference (or 'phase matching')
The closeness of the phase-response matching is perhaps the biggest influence on the accuracy of sound intensity measurements — and is therefore the most telling specification. The Brüel&Kjær 1/2" matched-microphone pairs have the best phase-response difference of any microphone pairs — phase-response differences are <0.05° between 20 Hz and 250 Hz (the frequency range where the influence of phase differences are most critical). The success of these Brüel&Kjær microphone pairs is largely due to their very low **vent sensitivity** which makes the phase responses of each microphone in the pair extremely stable.

Matching specifications for a Brüel & Kjær 1/2" microphone pair

Type No.	4181
Phase Response Difference	20 Hz – 250 Hz: < 0.05° ★ 250 Hz – 5 kHz: < $\frac{f}{5000}$ °
Amplitude Response Difference (normalized at 250 Hz)	20 Hz – 1 kHz: < 0.2 dB 20 Hz – 5 kHz: < 0.4 dB
Sensitivity Difference (250 Hz)	< 1 dB

★ Individually Calibrated

Phase-difference calibration chart



Microphone pairs for sound intensity — vent sensitivity

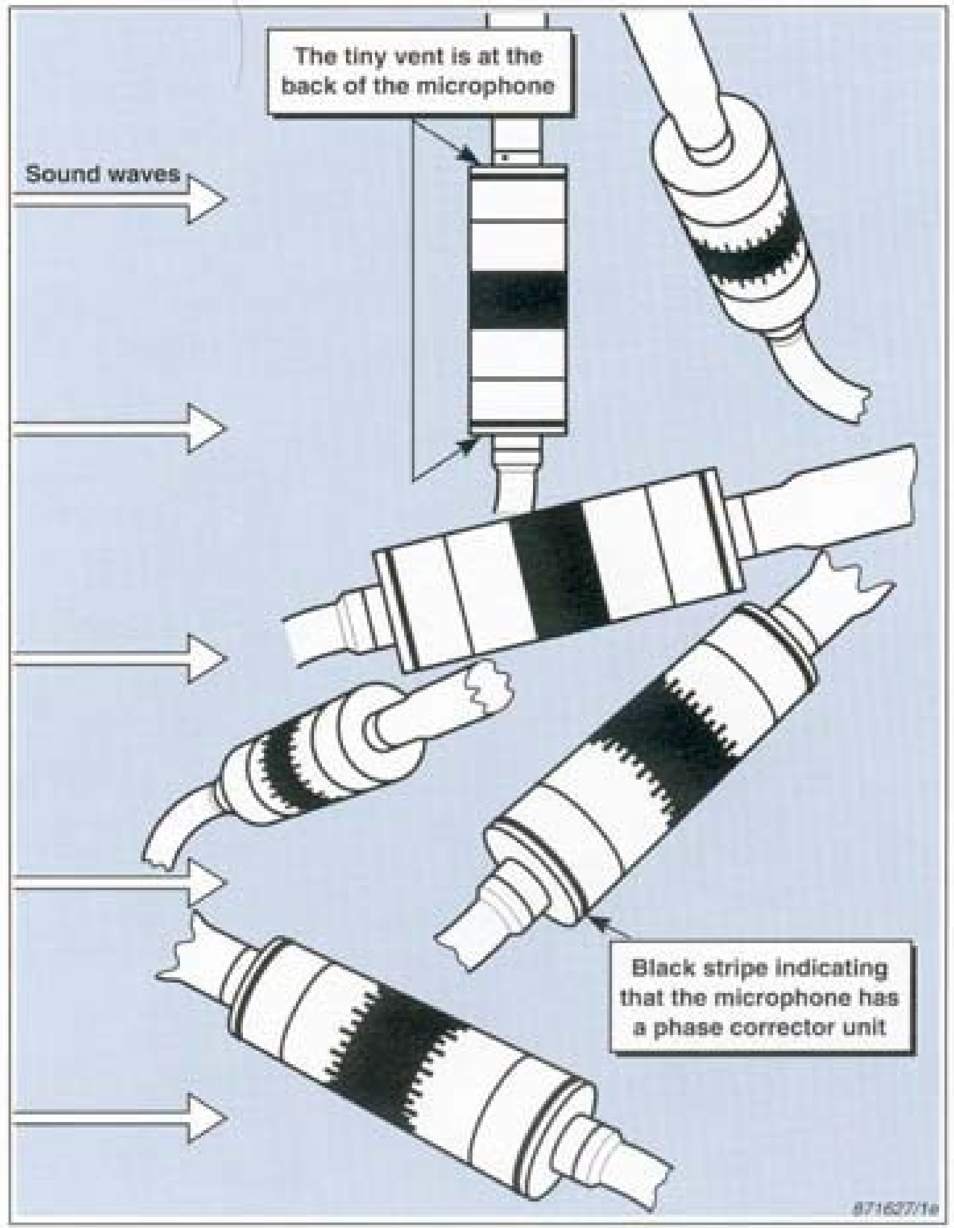
The vent-sensitivity specification states how much sound enters the static-pressure equalization vent relative to the sound level at the microphone diaphragm.

It is desirable for matched microphones to have very low vent sensitivity because they can then be pointed in any direction in a sound-field without the vent influencing their phase response. A matched-microphone pair then has a constant phase-response difference when assembled into an intensity probe (e.g. in the face-to-face configuration).

Since it is only lower frequencies which can enter the vent, vent sensitivity is usually only a consideration below about 250 Hz. Brüel&Kjær always quote the vent sensitivity of microphone pairs at 20 Hz (the lowest frequency in the audio range) where the vent is at its most sensitive.

Brüel&Kjær phase correctors
Typical vent sensitivities are <-60 dB (at 20 Hz) for Brüel&Kjær matched microphones. This is a very low value and has been achieved by including **phase correctors** in the microphone design. A phase corrector attenuates the low frequencies that enter the microphone vent. Microphones that have phase correctors are capable of measuring sound intensity at least one octave below the lowest value measurable by other microphones, and with greater accuracy too.

Brüel&Kjær microphones fitted with these unique phase correctors are marked with a thick black line on the microphone cartridge.



Standards relevant to measuring microphones

When selecting a measuring microphone, you would normally consider whether or not you require it to fulfil standardised specifications such as ANSI S1.12-1967 (Specifications for Laboratory Standard Microphones) or I EC-651 and/or ANSI S1.4-1983 (Specifications for Sound Level Meters). By choosing a microphone which does fulfil a standard, you are assured that it has certain minimum acceptable specifications and a recognised grade of precision and environmental robustness.

ANSI S1.12-1967
This standard specifies microphones that are suitable for calibration by absolute methods and for *laboratory-type* measurements. The table opposite lists the Brüel&Kjær microphones which fulfil the standard. The four classes of microphone defined in the standard are summarized below:

Type L: Precisely calibrated reference-standard with a closely specified outer diameter (to enable use in couplers).
Type XL: As above, but with no specified outside diameter.
Type M: For measuring sound-pressure magnitudes of the order 0.1 N/m^2, or higher. Better high-frequency and high sound-pressure performance than for Types L and XL. Copes with relatively large ambient-pressure changes.
Type H: For applications in which diffraction errors in the measurements must be small or in which the sound-pressure magnitude is of the order of 0.5 N/m^2, or higher. Copes with relatively large ambient-pressure changes.

Brüel & Kjær microphones fulfilling ANSI S 1.12 – 1967

Type	XL	L	M	H
4144	•	•		
4145/4179	•	•		
4160	•	•		
4133/4191	•		•	
4134/4192	•		•	
4147/4193	•		•	
4149	•		•	
4155/4189/4165/4190	•			
4166	•			
4180	•		•	
4135			•	•
4136			•	•
4138				•

Outside diameter of microphones classified as follows:

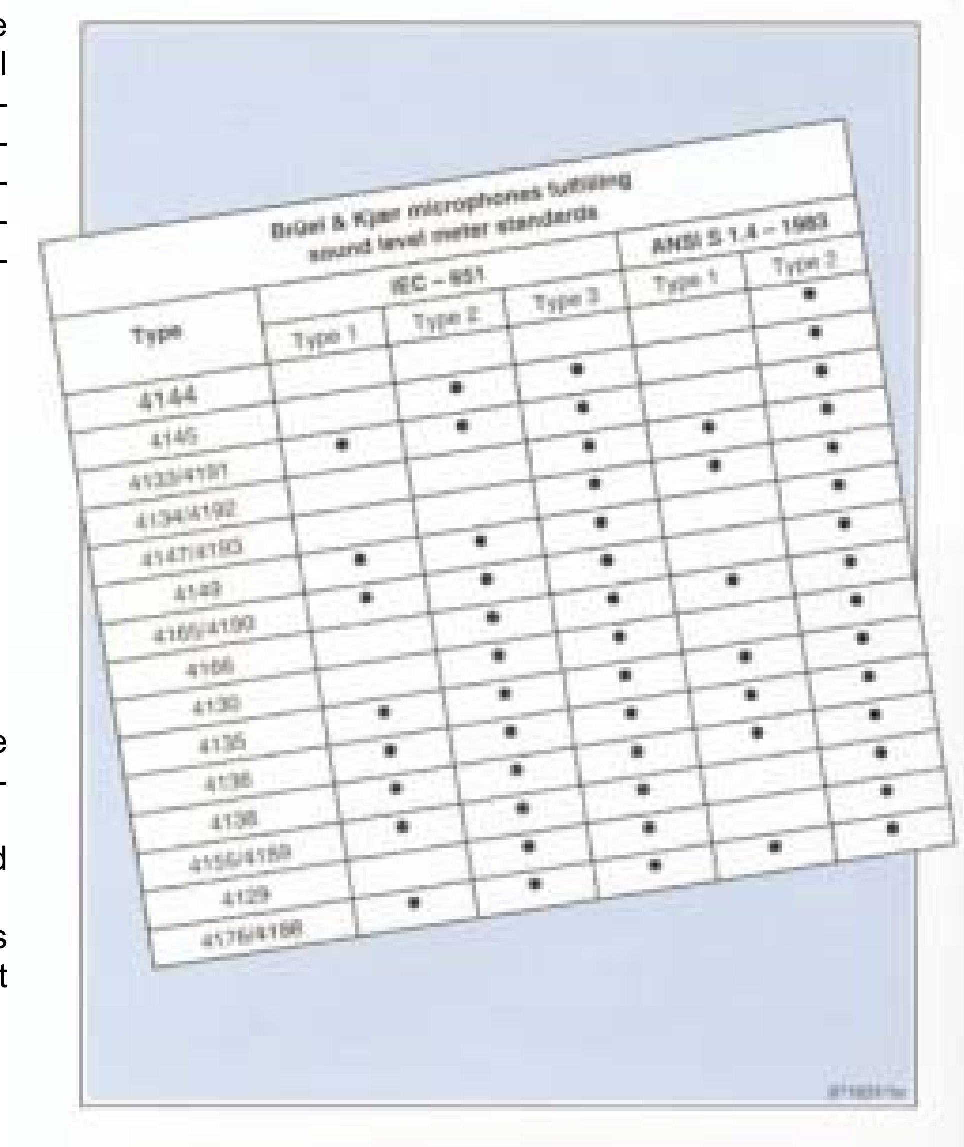
Type XL 1.5000" maximum
Type L 0.936" ± 0.002
Type M 0.627" maximum
Type H 0.285" maximum

871630/1e

Other standards relevant to general-purpose microphones are those for sound level meters. This is because the sound level meter ratings (e.g. Type 0, Type 1 etc.) usefully reflect the accuracy and environmental robustness of the accompanying microphone. The table opposite lists the Brüel&Kjær microphones which fulfil the requirements of the sound level meter standards. The various sound level meter Types' are summarized below.

IEC-651
Type 0: Laboratory reference standard.
Type 1: Intended especially for laboratory use, and for field use where the acoustical environment can be closely specified and/or controlled.
Type 2: For general field applications.
Type 3: Primarily for field noise surveys to determine whether an established noise limit has been significantly violated.

ANSI S1.4-1983
Type 0 (Laboratory Standard): Intended as a reference standard and therefore not required to satisfy the environmental requirements of other types.
Type 1 (Precision): For accurate measurements in the field and in the laboratory.
Type 2 (General Purpose): For general field measurements of typical environmental sounds when high frequencies do not dominate.



Brüel & Kjær microphones fulfilling sound level meter standards

Type	IEC – 651			ANSI S 1.4 – 1983	
	Type 1	Type 2	Type 3	Type 1	Type 2
4144					•
4145		•	•		•
4133/4191	•	•	•		•
4134/4192			•	•	•
4147/4193			•	•	•
4149	•	•	•		•
4165/4190	•	•	•		•
4166		•	•	•	•
4130		•	•		•
4135	•	•	•	•	•
4136	•	•	•	•	•
4138	•	•	•	•	•
4155/4189	•	•	•		•
4129		•	•		•
4176/4188	•	•	•	•	•

Microphone selection guide

Inside the backcover is a table of measuring microphone specifications. To help you find your way quickly and easily, we have included references to the pages which explain particular features of the table.

For those of you who are perhaps seeing such a specification table for the first time, it might be useful to know that 1/2" microphones are generally selected for the majority of measurement tasks. The most popular Brüel&Kjær microphone is the 1/2" Type 4190 which has excellent all-round performance. (Please note that omissions from the table include the Type 4182 probe microphone and the sound intensity microphone pairs.)

Useful selection hints are as follows:

Requirement	Type
Permanent outdoor measurements	1/2" 4188, 4184, et al.
Extremely low-level measurements	1" 4179
Extremely high-level measurements	1/4" 4136
Very low-frequency measurements	1/2" 4193
High altitude measurements	1/4" 4136
Laboratory reference-calibrations	1" 4160, 1/2" 4180
Very low noise	1" microphones
Excellent pulse response	1/4" 4135&4136, 1/8" 4138
Low vibration-sensitivity	1/4" 4135, 1/8" 4138
No polarization-voltage	prepolarized types

We hope this booklet has answered many of your questions and will continue to serve as a handy reference guide. If you have other questions about Brüel&Kjær measuring microphones, please contact one of our local representatives or write directly to:

Brüel&Kjær
2850 Nærum
Denmark

Type no	(Page)	4144	4145	4160	4179	4133	4134	4165	4166	4180	4135	4136	4138	4155[P]	4176[P]	4188	4189	4190	4191	4192	4193
Nominal Diameter	8	1"				1/2"					1/4"		1/8"	1/2"							
Frequency Response Characteristic	14	Pressure	Free-field 0° Incidence	Pressure	Free-field 0° Incidence	Free-field 0° Incidence	Random Incidence & Pressure	Free-field 0° Incidence	Random Incidence & Pressure	Pressure	Free-field & Random	Pressure	Random Incidence & Pressure	Free-field 0° Incidence	Free-field & Random	Free-field & Random	Free-field 0° Incidence			Random Incidence & Pressure	
Open Circuit Frequency Respons *a (± 2 dB)	13	2.6Hz to 8kHz	2.6Hz to 18kHz	Up to 8 kHz ±1 dB	10 Hz to 10kHz**	4Hz to 40kHz	4Hz to 20kHz	2.6Hz to 20kHz	2.6Hz to 10kHz	up to 20kHz ±1.5dB	4Hz to 100kHz	4Hz to 70kHz	6.5Hz to 140kHz	4Hz to 16kHz	7Hz to 12.5kHz	8Hz 12.5Hz	6.3Hz 20Hz	3.15Hz 20kHz	3.15Hz 40kHz	3.15Hz 20kHz	70 mHz 20kHz
Open Circuit Sensitivity — **mV/PA**	9	50		47	100	12.5		50		12.5	4	1.6	1.0	50		31.6	50	50	12.5	12.5	12.5
Open Circuit Sensitivity — **dB re 1V/Pa**		-26		-26.5	-20	-38		-26		-38	-48	-56	-60	-26		-30	-26	-26	-38	-38	-38
Lower Limiting Frequency, - 3 dB	15	1 to 2Hz		1 to 2Hz+	5 to 7Hz	1 to 3 Hz		1 to 2Hz		1 to 3Hz+	0.3 to 3Hz		0.5 Hz to 5 Hz	1 to 3Hz	0.5 Hz to 5Hz	1 to 5Hz	2 to 4Hz	1 to 2Hz	1 to 2Hz	1 to 2Hz	0.01 to 0.05 Hz
Cartridge Thermal Noise (dB(A))	17	9.5	10	9.5	-2.5***	20	18	14.5	15	18	29.5	30.5	-	14.5	13.5	14.2	14.6	14.6	20	19	19
Open Circuit Distortion Limit, 3%, at 100 Hz (dB re. 20 µPA)	18	>146			140	>160		>146		>160	>164	>172	>168	146	142	>146	>146	>148	>162	>162	>162
Polarization Voltage (V)	5	200												—		0		200			
Polarized Cartridge Capacitance at 200 Hz*		55 pF	66 pF	55pF	40pF	18pF	18.5pF	19pF	21 pF	17.5pF	6.4pF		3.5pF	15pF	12.5pF	12pF	14pF	16pF	18pF		
Mean Temperature Coefficient (at 250 Hz) -10 to +50 °C (dB/°C)	21	-0.003	-0.002	-0.003	-0.004	-0.002		-0.007		-0.002	-0.01			-0.006	-0.004	+0.005	-0.001	-0.007	-0.002		
Equivalent Air Volume at 250 Hz, 1 atm. (mm^3)		148	130	148	400	10		40		9.3	0.6	0.25	0.1	40	50	65	46	46	11.6	8.8	8.8
Expected Long-term Stability — **at 20 °C**	21	>1000 years/dB			250 y/dB	>1000 years/dB		>600 years/dB		>400 y/dB	—			>400 y/dB	> 250 y/dB	>1000 y/dB	>1000y/dB	>1000 years/dB			
Expected Long-term Stability — **at 150 °C[11]**		>2 hours/dB				>2 hours/dB		>1 hours/dB								>10h/dB	>2h/dB	>100 years/dB			
Influence of Static Pressure at 250 Hz (kPa)	22	-0.016	-0.015	-0.016		-0.007		-0.01		-0.007	-0.007	-0.0025	-0.01	-0.01	-0.02	-0.021	-0.010	-0.010	-0.007	-0.005	-0.005
Influence of 1 m/s^2 Axial Vibration (dB re. 20 µPa)	24	67			60	6	7	6	0	65	59	69	58	60		63.5	62.5	62.5	65.5	65.5	65.5
Typ. influence of 50 Hz, 80 A/m magnetic field (dB re. 20 µPa)	26	18			12	2	0	3	0	20	30	38	40	30		7	6	4	16	16	16
Influence of Relative Humidity	23	0.0025 dB/100% RH			<0.1 dB in the absence of condensation			0.004 dB/100% RH		0.0008dB/ 100%RH	<0.1 dB in the absence of condensation			<0.1 dB in the absence of condensation		<0.1dB at 100%RH					

a) Not for random incidence
b) 125°C for 4188

c) Typical value
d) With preamplifier Type 2639

* Individually calibrated
** With frequency response compensation network built in to Preamplifier Type 2660
*** A-weighted noise floor of combined assembly (4179 + 2660)

\+ Vent exposed to sound field
p Prepolarized

Brüel & Kjær

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