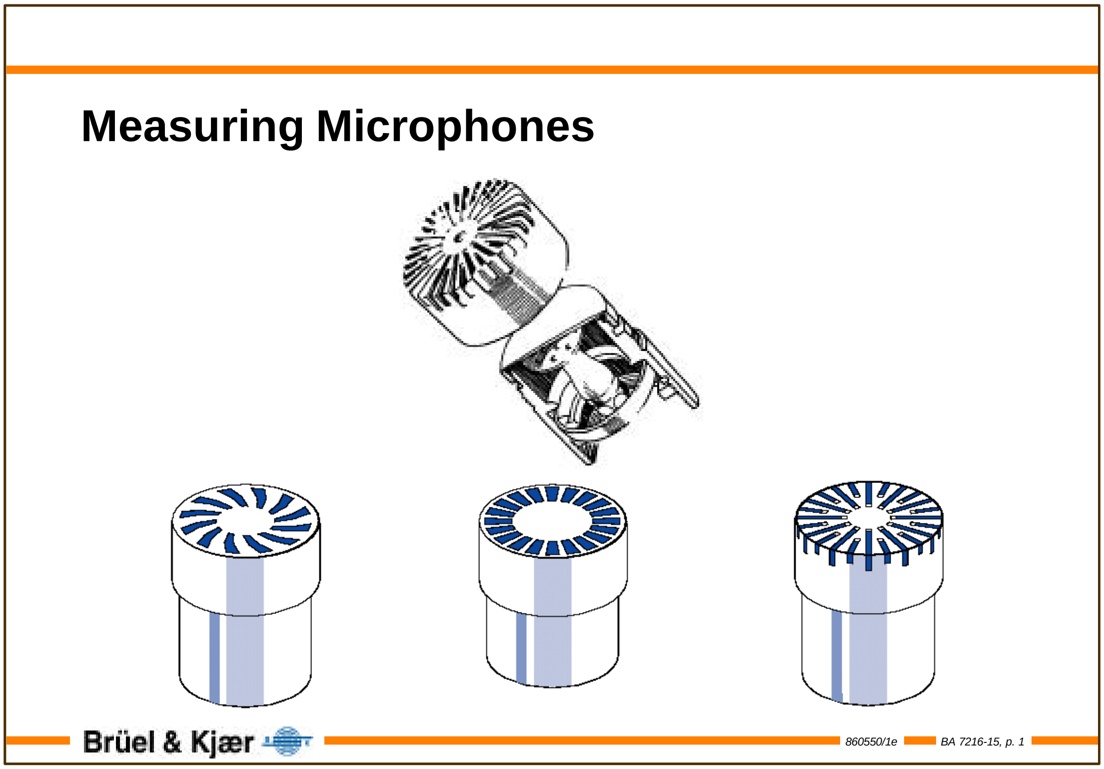
Lecture Note

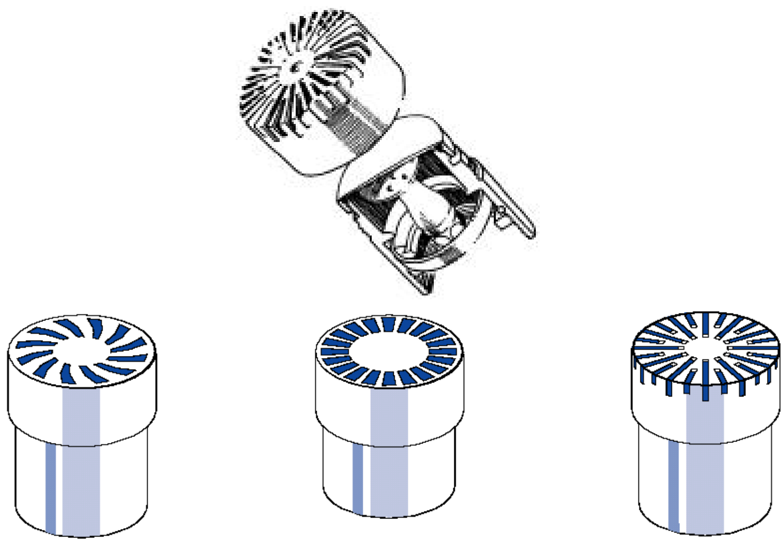


Abstract

This lecture describes the condenser microphone and its use as a measuring microphone.

It includes the principle of operation of the condenser microphone, general characteristics, types of microphones, selection of microphones and accessories, calibration – acoustic and electrical – handling and care of the microphone.

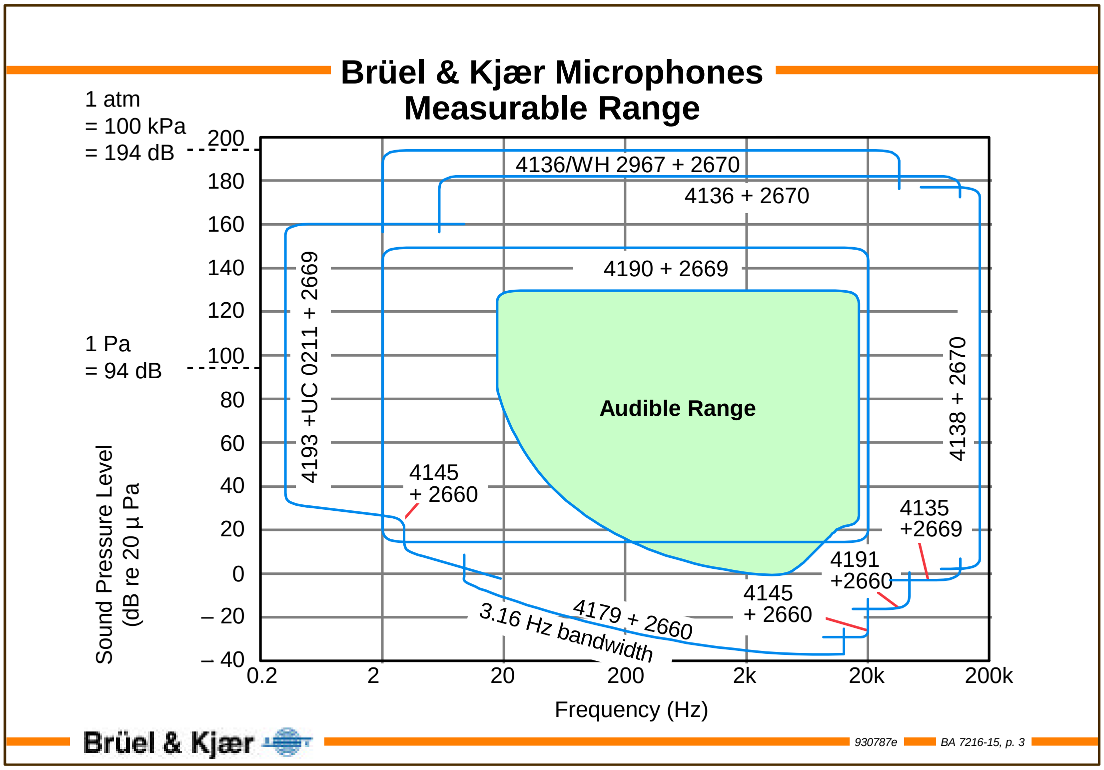
Measuring Microphones



Brüel & Kjær 860550/1e BA 7216-15, p. 2

Introduction

The condenser microphone is to-day accepted as the standard acoustical transducer for all sound and noise measurement because of its very high degree of accuracy; an accuracy which is higher than what is possible with any other acoustical transducer. Not only is the condenser microphone an accurate laboratory tool used by standards laboratories, it is also used for a broad range of field measurements under many different and often severe environmental conditions.



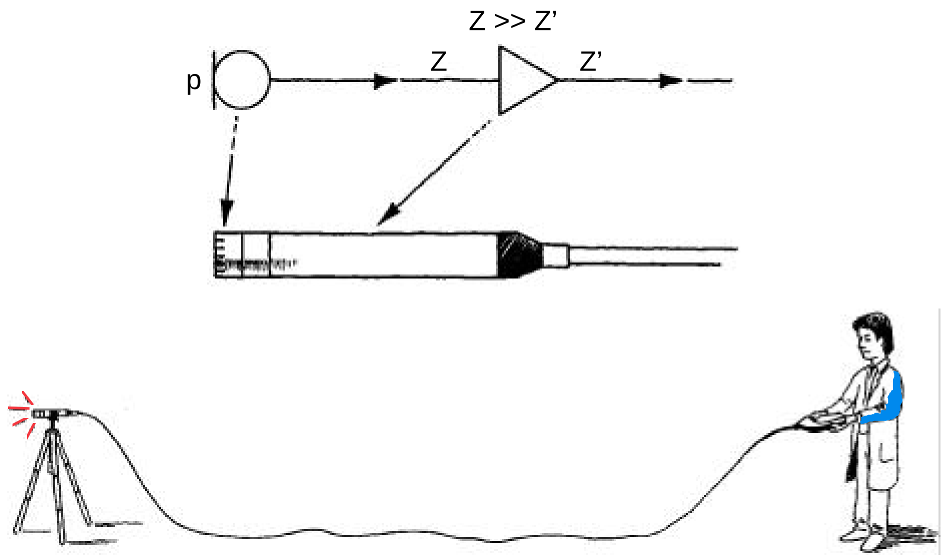
Microphone Measurement Range

The reason for the high degree of acceptance is that the condenser microphone has the following properties which are essential for a standard transducer:

1. High stability under various environmental conditions.
2. Flat frequency response over a wide frequency range.
3. Low distortion.
4. Very low internal noise.
5. Wide dynamic range.
6. High sensitivity.

In order to attain the microphone's high standard, considerable care is required in both design and production. This includes advanced clean-room techniques, very tight mechanical tolerances, a special diaphragm construction and artificial ageing techniques.

Microphones and Preamplifiers

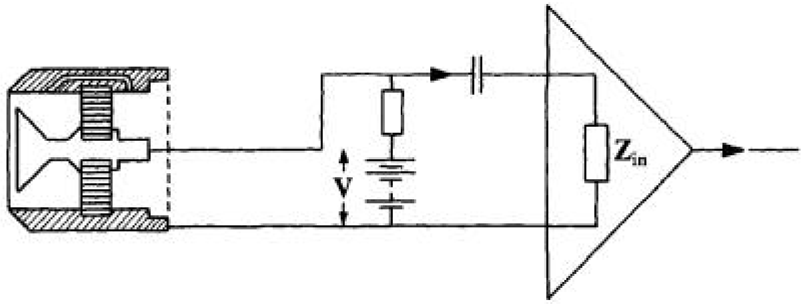


Brüel & Kjær 860551/2e BA 7216-15, p. 4

Microphones and Preamplifiers

The condenser microphone converts the acoustical pressure variations into an electrical signal which thereafter is amplified in a preamplifier. The preamplifier must always be connected very close to the microphone since its main purpose is to convert the very high impedance of the microphone into a low output impedance permitting use of long cables and connection to instruments with a relatively low input impedance. The low impedance ensures very little pick up of external electrical noise and this is especially important when using long cables.

Principle of Operation for the Polarised Condenser Microphone



$$\left.\begin{aligned} Q &= CV \\ C &= \epsilon \frac{A}{d} \end{aligned}\right\} \Rightarrow V = \frac{Q}{C} = \frac{Q}{\epsilon A} d \Rightarrow \Delta V = \frac{Q}{\epsilon A} \Delta d$$

Principle of Operation for the Polarised Condenser Microphone

The microphone consists of a thin metallic diaphragm in close proximity to a rigid backplate. This forms an air dielectric capacitor whose capacitance is variable since the diaphragm moves when excited by external forces such as a sound wave. The variable capacitance is changed into an electric signal in the following way:

Combining the formulae $Q=CV$ and $C=\varepsilon A/d$

gives $V=Q/C = (Q/\varepsilon A)d$

where Q = Charge on backplate, C = Microphone Capacitance, V = Polarisation Voltage, A = Area of Microphone, d = Distance between diaphragm and backplate.

A change in distance between diaphragm and backplate, d, is converted into a change in voltage: $\Delta V=Q/C = (Q/\varepsilon A)\Delta d$

The microphone will work according to the theory provided that Q is held constant. This required constant charge can be provided by connecting a DC voltage through a very high impedance charging resistor. This in combination with the capacitance of the microphone gives a long time constant compared to the period of the sound waves. Hence, practically no current will flow through the charging resistor – the criterion for conservation of charge. By connection of the condenser microphone to an amplifier via a coupling capacitor the DC voltage is removed, leaving the AC voltage which is an electrical replica of the sound pressure variations.

In order for the diaphragm to move, a pressure difference must exist between the front and back of the diaphragm. If the air behind the diaphragm were in direct communication with the outside, the instantaneous pressure on both sides of the diaphragm would be the same and no diaphragm motion would occur. The pressure inside the microphone must therefore be kept constant which is achieved by sealing the cavity except for a small vent. This vent is usually a pressure equalisation tube which has a very high acoustical impedance compared to the impedance of the internal volume. Only at very low frequencies will air leakage occur, thus permitting the static air pressure inside the microphone to equal the outside pressure so that a bulging of the diaphragm cannot occur.

How much does the diaphragm move ?

$$\frac{\Delta V}{V} = \frac{\Delta d}{d}$$

For typical measurement microphone:

- diameter 12.5 mm
- thickness of diaphragm 5 µm
- distance between diaphragm and backplate 20 µm
- polarisation voltage 200 V
- sensitivity 50 mV/Pa

For 94 dB = 1 Pa the diaphragm moves

$$\Delta d = \frac{\Delta V \times d}{V} = \frac{50\ \text{mV} \times 20\ \mu\text{m}}{200\ \text{mV}} = 5\ \text{nm}$$

Diameter of diaphragm	Pressure (level re 20µPa	Diaphragm's movement
12.5mm	1Pa (94dB)	5nm (5×10^{-9} m)
12.5mm	0.02Pa (60dB)	1 Å (10^{-10} m)
12500km (thickness of diaphragm 5km)	0.02Pa (60dB) 0.0002Pa (20dB)	0.1m (10^{-1} m) 0.001m (10^{-3} m)

Brüel & Kjær 930856e BA 7216-15, p. 6

How much does the diaphragm move?

Take an example based on microphone 4190 and use the relationship ΔV/V = Δd/d you will be surprised at the results.

Requirements for microphone diaphragms are that:

1. The ratio of the elasticity of the diaphragm to the density should be a maximum. Ideally it should be massless! The greater its mass the more the device operates as an accelerometer and less as a microphone.

2.. Corrosion resistant.

3. Temperature coefficient should be the same as the housing.

4.The mechanical characteristics should be stable within time.

There are many possible candidates each with advantages and disadvantages. Examples of materials which have been used are steel, steel alloys, nickel, palladium, titanium, monel, and beryllium.

Brüel & Kjær traditional microphones use mostly nickel, or nickel coated with a thin layer of quartz or with a layer of hyperlon. Brüel & Kjær Falcon™ range use a stainless steel alloy. By looking at a microphone diaphragm, one can see whether it be:

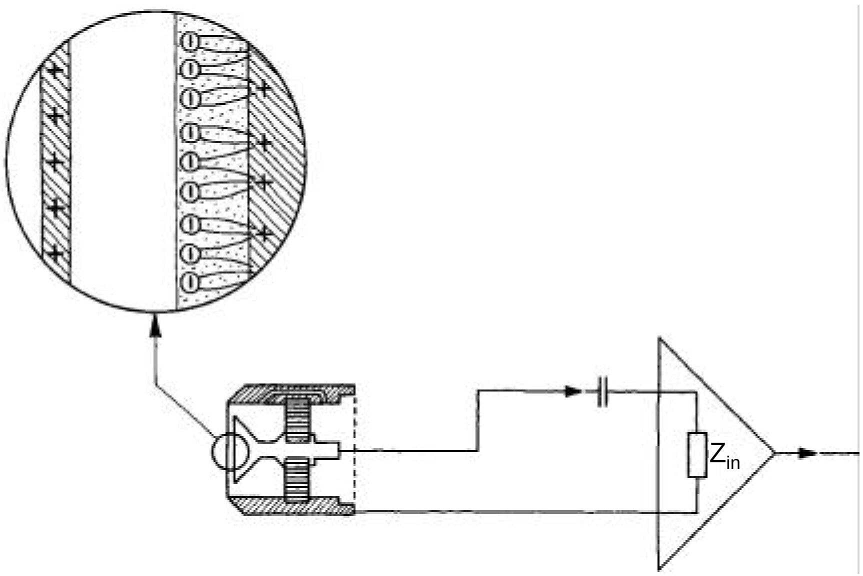
1. Pure nickel (in which case it will give a clear specular [mirror-like] reflection).

2. Nickel with a coating of quartz (diffraction causes rainbow colours to be seen on the diaphragm).

3. Nickel with a coating of hyperlon (the diaphragm appears yellowish and looks greasy).

4. Stainless steel alloy (the diaphragm appears greyish relative to a nickel diaphragm).

Prepolarised Condenser Microphone

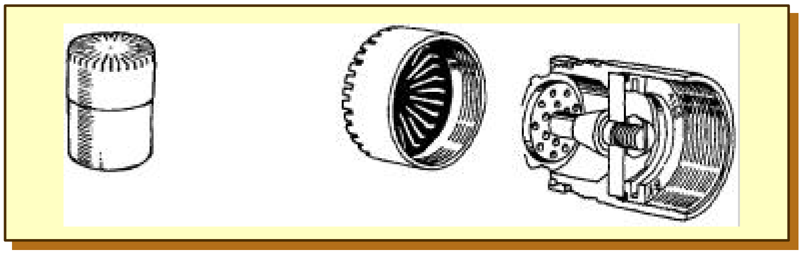


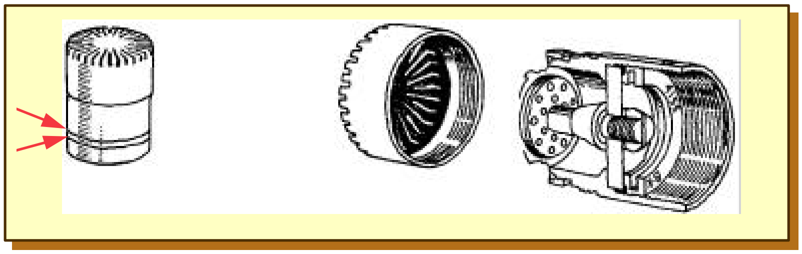
Prepolarised Condenser Microphone

Instead of providing a constant charge on the backplate of the condenser microphone with the aid of a polarisation voltage, a constant charge can be provided by placing a charge carrying element on the backplate. The charge carrying element is formed by introducing electrical space charges into a special material having a very low conductivity. A very high degree of stability of these charges has been obtained through an artificial ageing process, with the result that the charge carrying element maintains its charge under severe conditions of humidity and can withstand high temperatures. The prepolarised condenser microphone is therefore more expensive to produce than the traditional condenser microphone. Its main advantage is that no polarisation voltage is required. This is especially important when it is used with portable equipment.

When the prepolarised condenser microphone is used with preamplifiers supplying a polarisation voltage it is important that this is set to zero. Connection of polarisation voltage will not permanently damage the microphone, but the sensitivity will be reduced and the frequency response changed temporarily.

Mechanical Design





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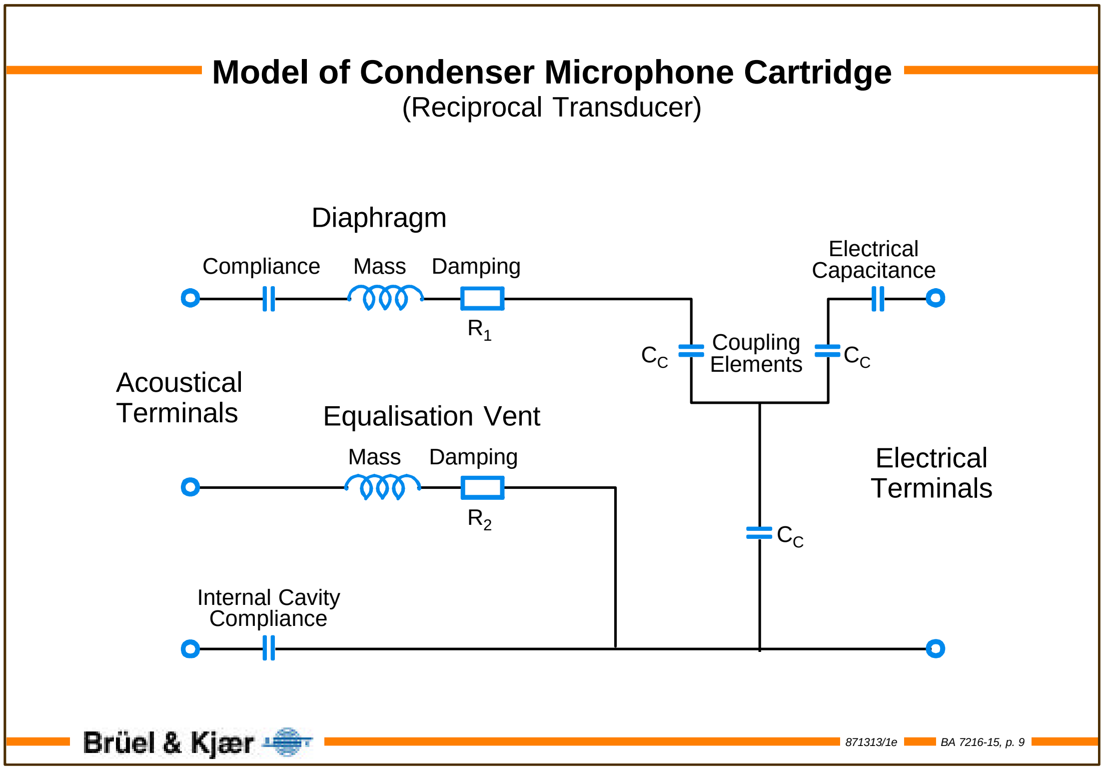
Mechanical Design

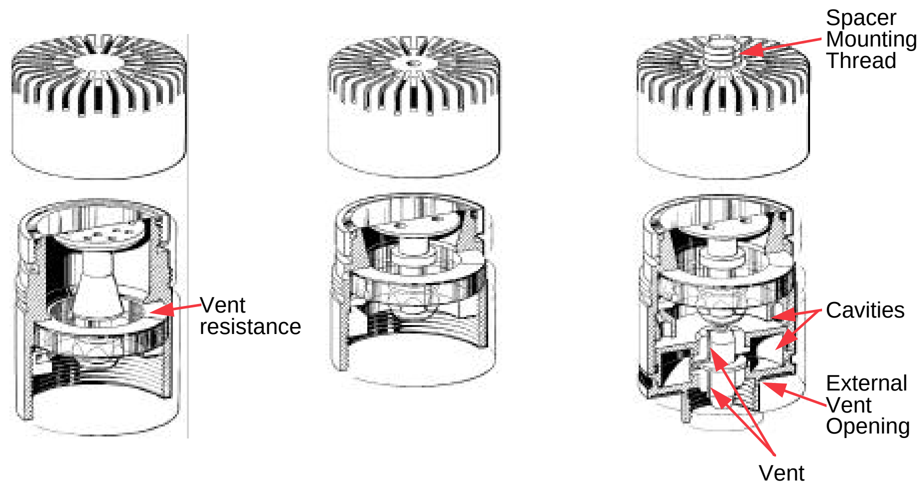
Brüel & Kjær polarised and prepolarised condenser microphones are designed in exactly the same way, the only difference being the charge-carrying layer in the prepolarised condenser microphone. The illustration shows a cut-away drawing of the two types and the two groves on the outside of the prepolarised microphone by which it can be distinguished from the polarised condenser microphone. A careful choice of materials and extreme care in design and manufacture has created microphones with a very high long-term stability which is in the order of 1 dB per several hundred years at normal room temperature.



Model of Condenser Microphone Cartridge

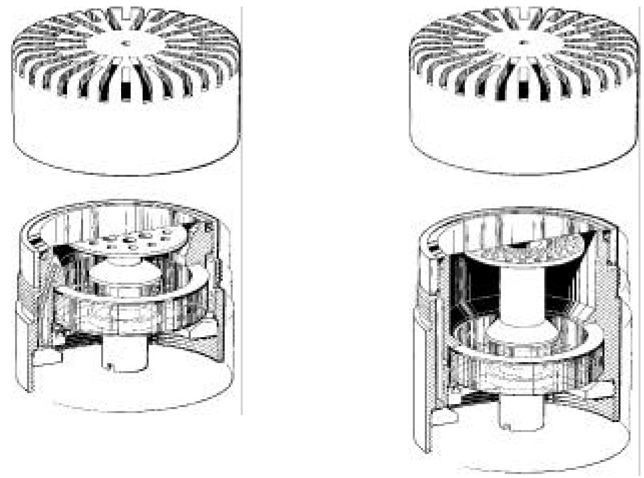
During the design of a microphone it is extremely useful to be able to model the acoustical behaviour of the cartridge by means of an analogous electrical circuit. A simple lumped parameter model is shown here. The acoustical components corresponding to these electrical components can be identified in the following cross-sectional drawings of the microphones. For example, the damping of the diaphragm is related to the number, size and position of the holes in the back plate; the internal cavity compliance is related to the volume of air behind the back plate (the more air there is, the softer the spring, the greater the compliance).

Cross-section of 1/2” Microphones



General Purpose | High Frequency | Intensity

Cross-section of 1” Microphones



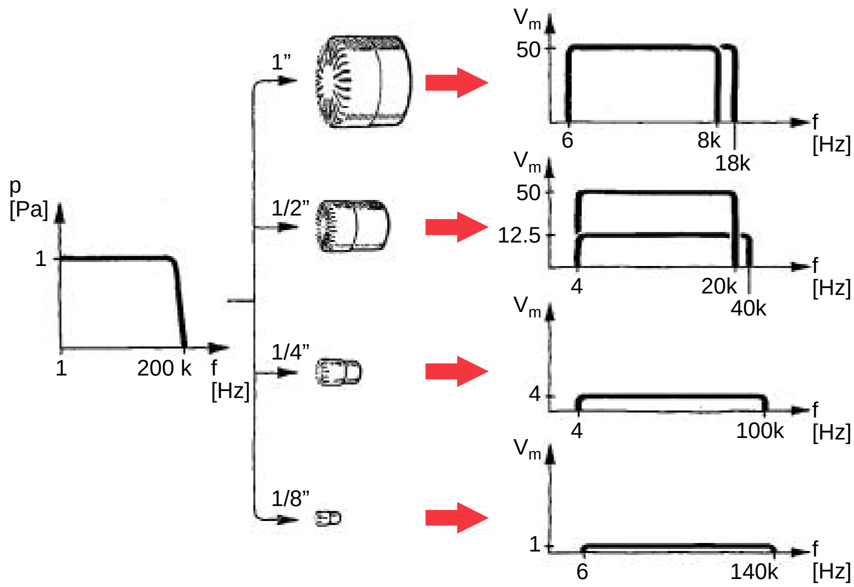
Traditional   Low Noise

Brüel & Kjær   871257/1e   BA 7216-15, p. 11

CHARACTERISTICS

Microphones are designed in different sizes and for many different purposes. Each type has its own characteristics. The most important characteristics to compare are sensitivity, frequency range, dynamic range, and directional characteristics. In order to ease comparison in the following, a generalisation will be based on the size of the microphones which are produced in the sizes 1", 1/2", 1/4", and 1/8".

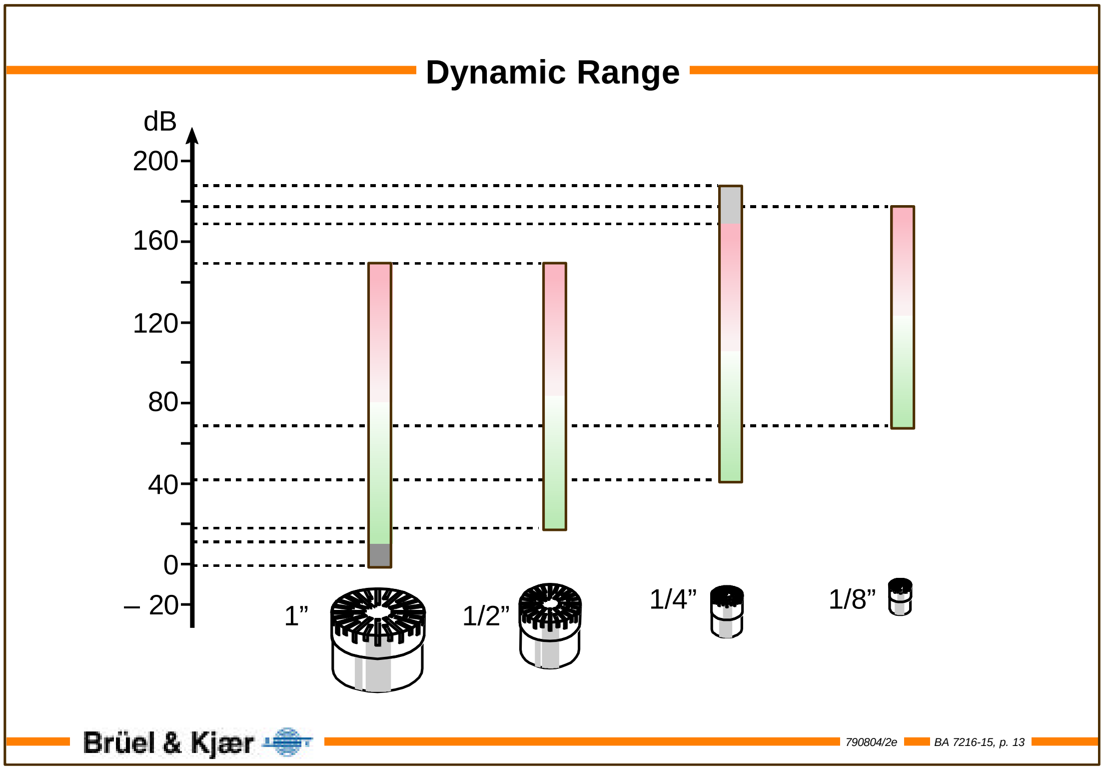
Frequency Range and Sensitivity



Brüel & Kjær 790803/3e BA 7216-15, p. 12

Frequency Range and Sensitivity

To compare the sensitivity and frequency ranges of the four sizes of microphones they are here exposed to a sound pressure of 1 Pa. This gives rise to different levels of output voltage from each. It is clearly seen that the largest microphones give the highest output voltage (they have the highest sensitivity), whereas the widest frequency range will be achieved using a 1/4", or an 1/8" microphone. Exceptions are some of the 1/2" microphones which today are produced with the same sensitivity as the standard 1" microphone (50mV/Pa) and a frequency range covering the whole audio range. The 1/2" microphone is therefore the standard size for microphones today, and it is used in most applications including all the B&K sound level meters. Other sizes are only used for special applications.



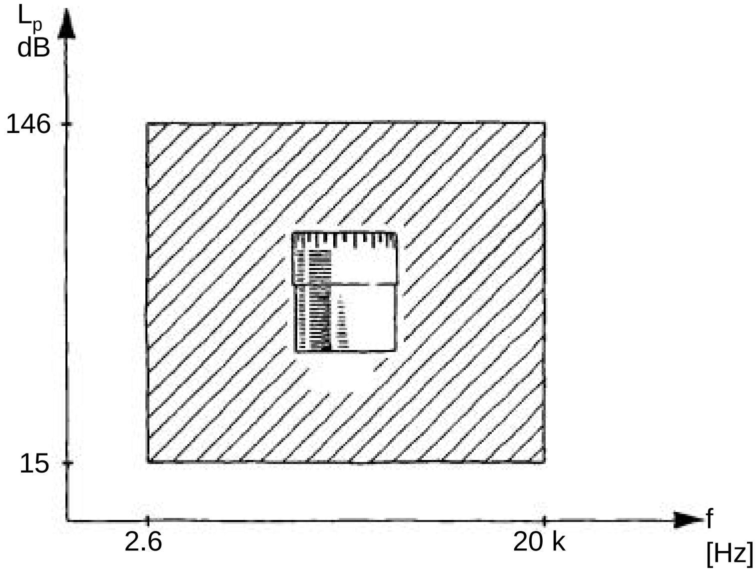
Dynamic Range

The dynamic range of the microphones is defined as the range between the A-weighted noise floor and the 3% distortion level. The noise floor is the sound pressure level which results in an output signal from the preamplifier of the same size as the thermal and electrical noise created inside the microphone and preamplifier combination. The 3% distortion level is the sound pressure level which will give an output signal with 3% distortion.

When comparing the dynamic range for the four sizes of microphones it is clearly seen that for measurement of very low sound levels, a 1/2" or a 1" microphone should be chosen, whereas for measurement of very high levels a 1/4" or an 1/8" microphone should be chosen. It should here be mentioned that with a special 1" microphone and a special preamplifier it is possible to measure sound levels as low as –2,5 dB re 20 µPa (=15 µPa) i.e. 2,5 dB below the threshold of hearing.

Specially constructed 1/4" microphones enable sound pressure levels of up to 194 dB to be measured.

Operational Region



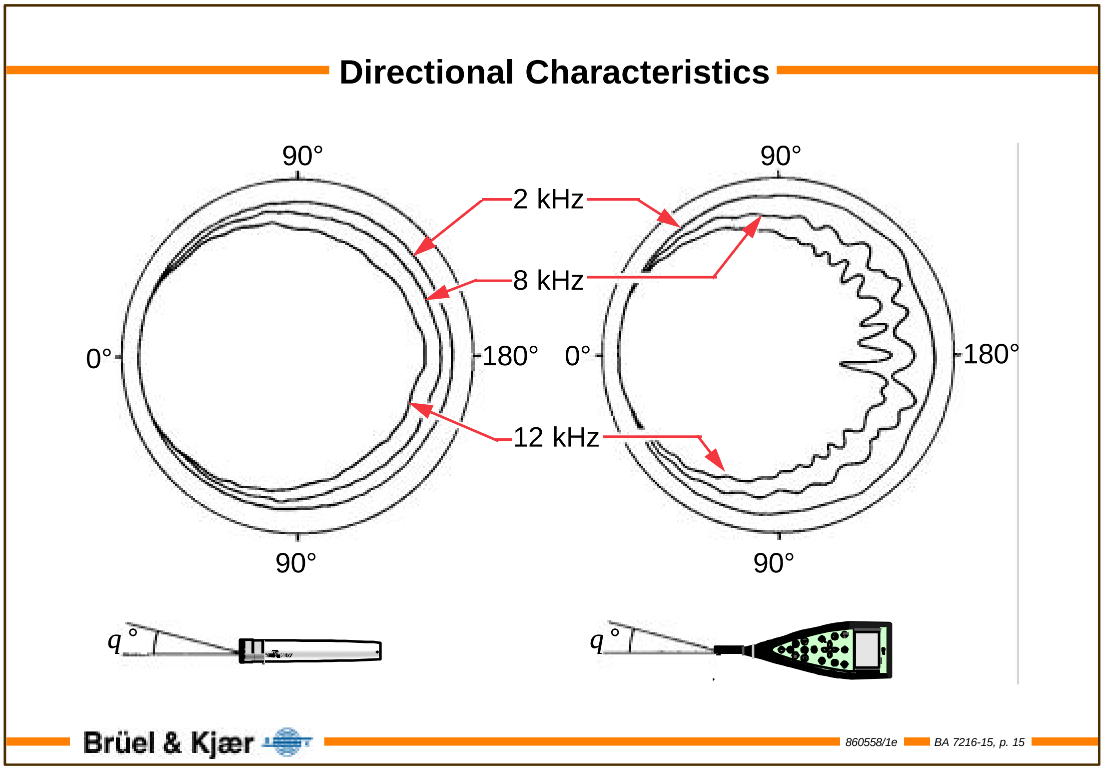
Brüel & Kjær

860557/1e *BA 7216-15, p. 14*

Operational Region

A combination of frequency range and dynamic range gives a certain operational region for a given microphone. The illustration here shows the operational range for a typical standard 1/2" microphone designed for general sound pressure level measurement. It is clearly seen that it covers more than the audio frequency range and easily handles sound pressure levels from the quietest sounds to sounds well above the threshold of pain.

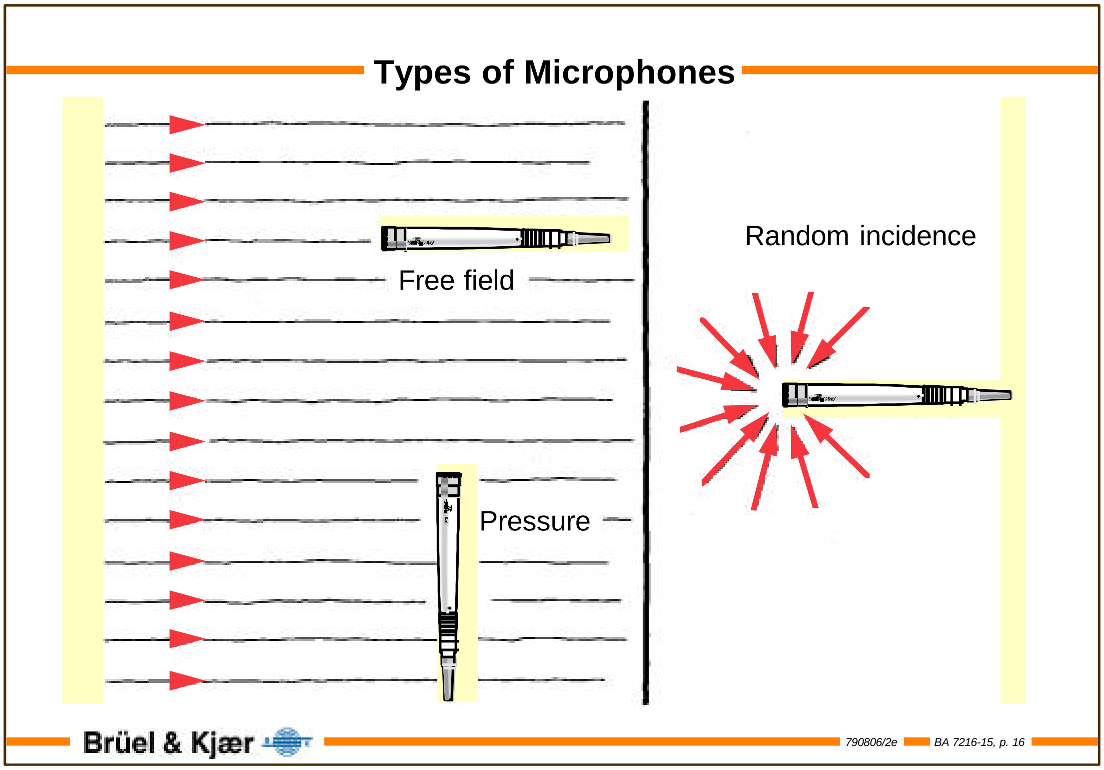
In order to select the optimum microphone for a particular application, consult the Microphone Selection Guide (BA 7539).



Directional Characteristics

The microphone will not respond equally well to sound coming from different directions with different angles of incidence. At low frequency the microphone is nearly perfectly omnidirectional, whereas for high frequencies the sensitivity to sound coming from behind the microphone is considerably reduced.

Comparing the characteristics of the microphone alone and when mounted on a sound level meter, it is clearly seen that the sound level meter case affects the directional characteristics. This also gives an indication of how the presence of the operator will affect measurement, a topic which is discussed later in the lecture “Noise Measurement and Documentation”.



Types of Microphones

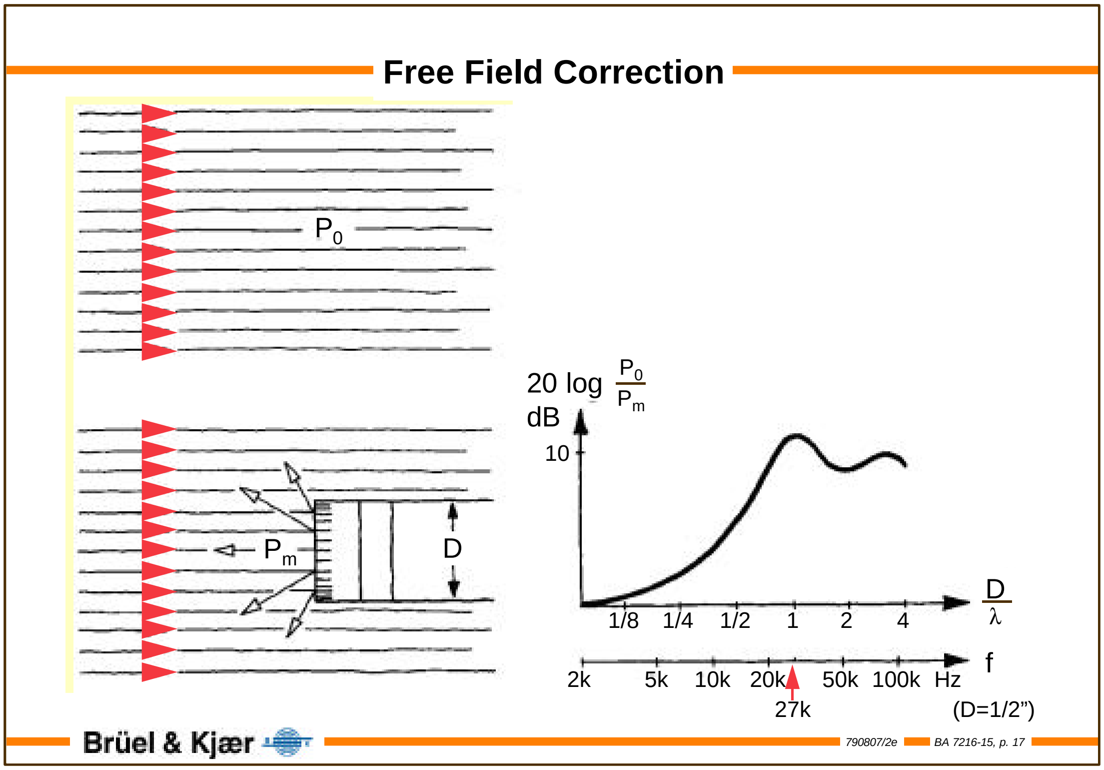
Microphones are divided into 3 types according to their response in the sound field: free field, pressure, and random incidence.

Free field microphones have uniform frequency response for the sound pressure that existed before the microphone was introduced into the sound field. It is of importance to note that any microphone will disturb the sound field, but the free field microphone is designed to compensate for its own disturbing presence as discussed later.

The pressure microphone is designed to have a uniform frequency response to the actual sound level present. When the pressure microphone is used for measurement in a free sound field, it should be oriented at a 90° angle to the direction of the sound propagation, so that the sound grazes the front of the microphone.

The random incidence microphone is designed to respond uniformly to signals arriving simultaneously from all angles. When used in a free field it should be oriented at an angle of 70° – 80° to the direction of propagation.

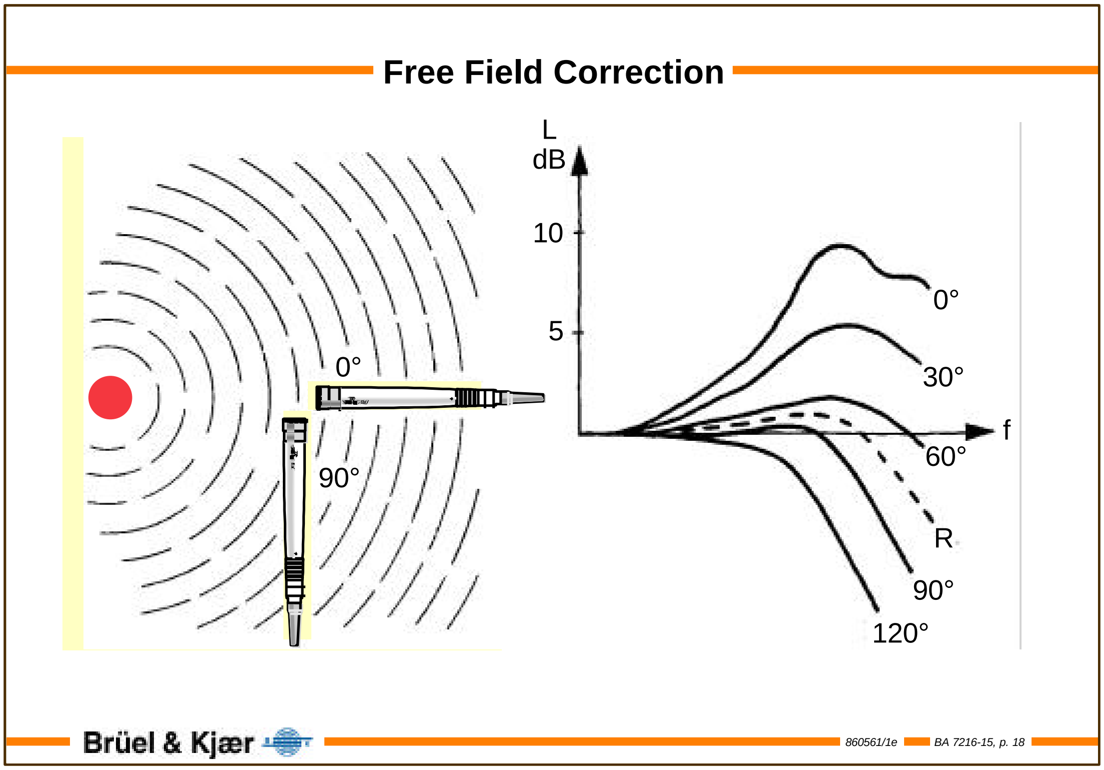
In the following we will have a closer look at the reason for the difference between the microphones and when each type should be used.



Free Field Correction

When a microphone is placed in a sound field, it modifies the field. The illustration shows a free field where sound comes from only one direction. The sound pressure in this field without the microphone is called p_0.

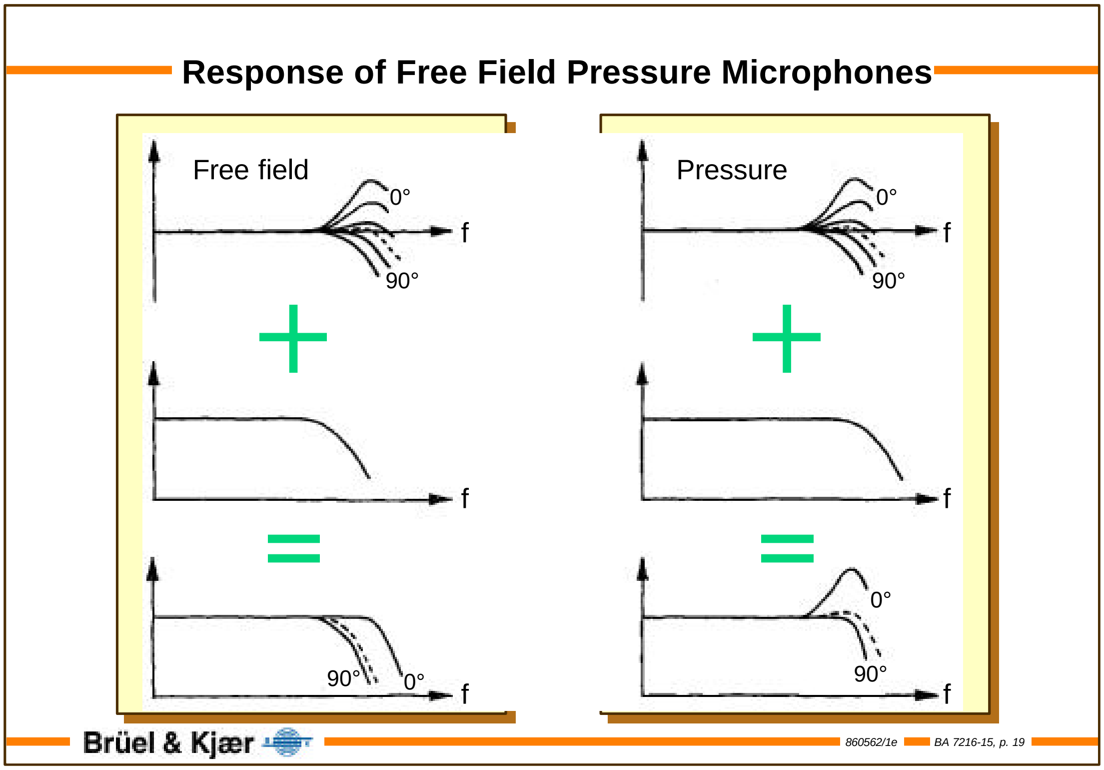
When the microphone is placed in the field a pressure rise will take place in front of the microphone caused by local reflections and the microphone will measure too high a sound pressure pm. This rise in "sensitivity" is frequency dependent, with a maximum at the frequency where the wavelength is equal to the diameter of the microphone, D/l. If the corresponding frequency axis for a 1/2" microphone is plotted along the D/l axis it is seen that the increase starts at 2 kHz with a maximum of approximately 10 dB at 27 kHz.



The biggest increase in “sensitivity” is obtained when the sound wave comes from a direction perpendicular to the diaphragm (defined as 0° incidence). At all other angles the increase will be less pronounced as shown here. The curve labelled R, which stands for random incidence, is a calculated average response to sound arriving with equal probability from all directions.

The free field correction curves shown are typical, as they not only depend on the diameter of the microphone but also to some extent on the design of the microphone’s protection grid, and to a very small degree the acoustical impedance of the diaphragm.

In a sound field where the sound comes mainly from one direction, the free field correction must be applied to all microphones independent of their type. This is shown in the following.



Response of Free Field and Pressure Microphones

The illustration shows the free field correction (upper curves), the pressure response (middle curves), and the free field response (lower curves) for the two types of microphones labelled Free Field and Pressure microphones respectively.

The free field corrections are the same for the two types of microphones if their mechanical designs are identical as discussed above.

The pressure response of a microphone is measured by exposing the microphone to a known sound pressure in a specified cavity over a very wide frequency range.

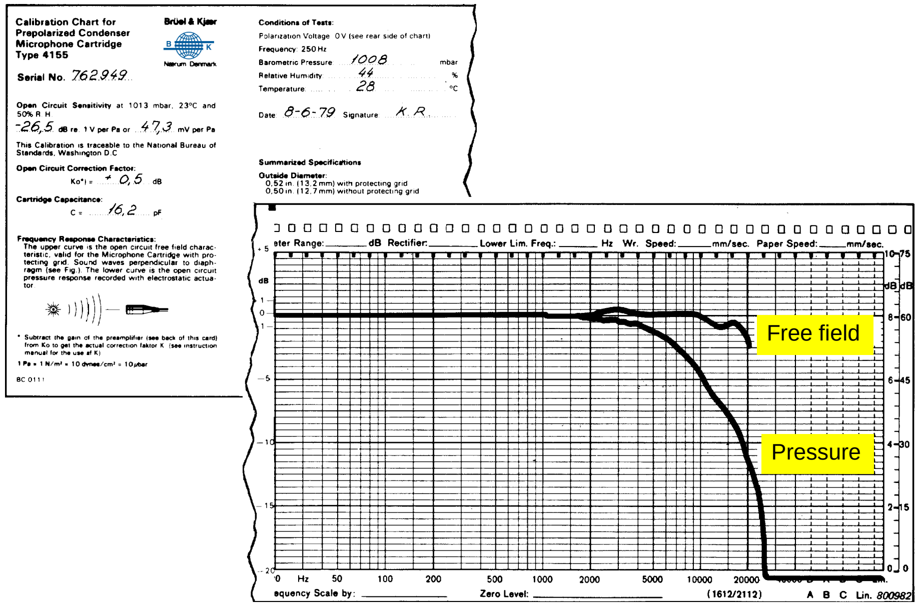
The free field response for the two types of microphones is the sum of their pressure response and the free field correction giving the following responses:

a. The free field microphone is constructed so that the pressure characteristic of the microphone drops off at the frequency where the presence of the microphone in the sound field starts to create an increase, and a very flat characteristic is obtained up to very high frequencies (at 0° incidence). In other words, the microphone compensates for its own presence in the sound field, if it is directed towards the source.

b. The pressure microphone is constructed so that its pressure response is flat up to very high frequencies. This type of microphone is mainly used for measurement where the local pressure is of interest regardless of whether the microphone itself disturbs the sound field. However, if it is used in a free field and pointed towards the noise source an error will arise at high frequencies as shown in the lower right hand curve.

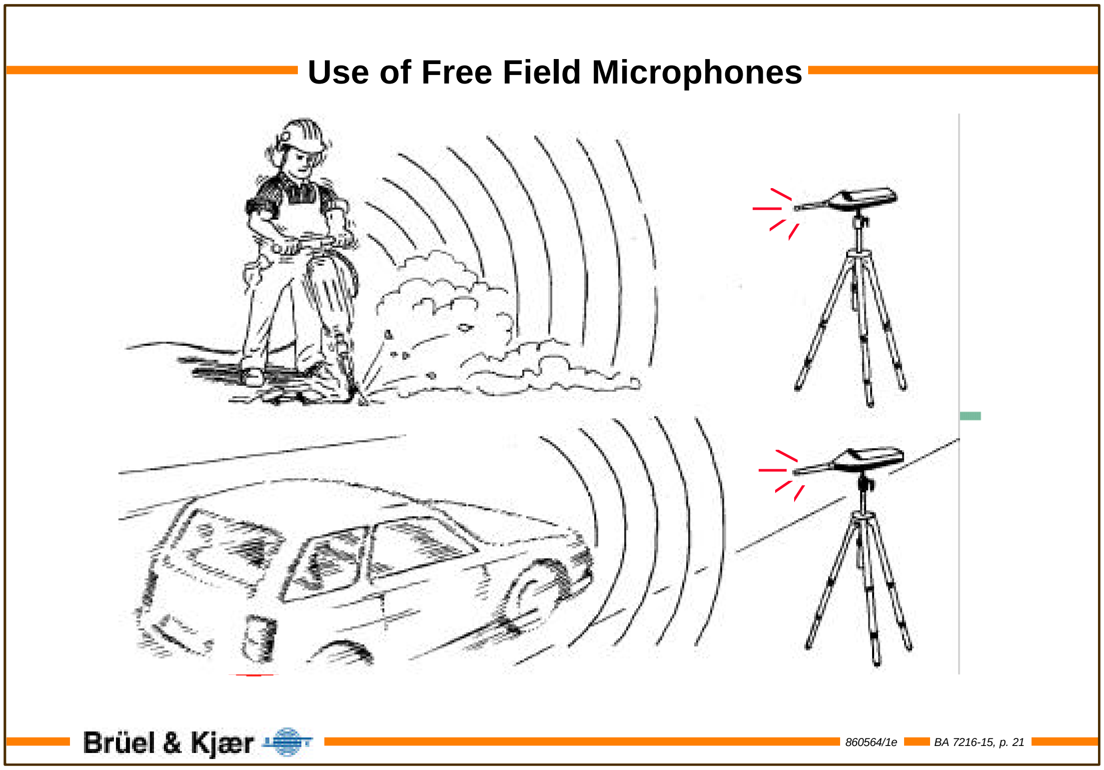
The illustration also includes the random incidence response (dashed curve) for each type. A microphone which has a nearly flat random incidence response as a function of frequency is called a random incidence microphone.

Calibration Chart



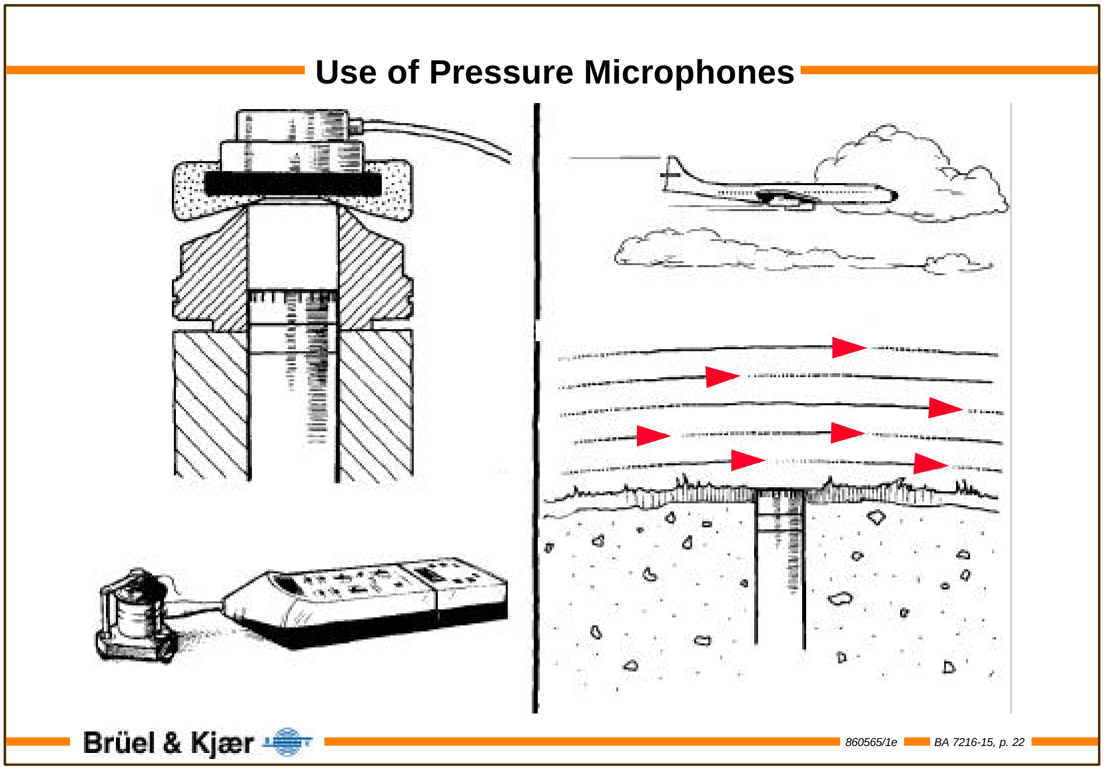
Calibration Chart

Each microphone has its own serial number and is provided with its own calibration chart which gives the exact sensitivity of the microphone, the cartridge capacitance, and a summary of its general specifications. It also includes the relevant individually measured frequency response curves. The example here is for a free field microphone showing the pressure response and the free field response (0° incidence).



Use of Free Field Microphones

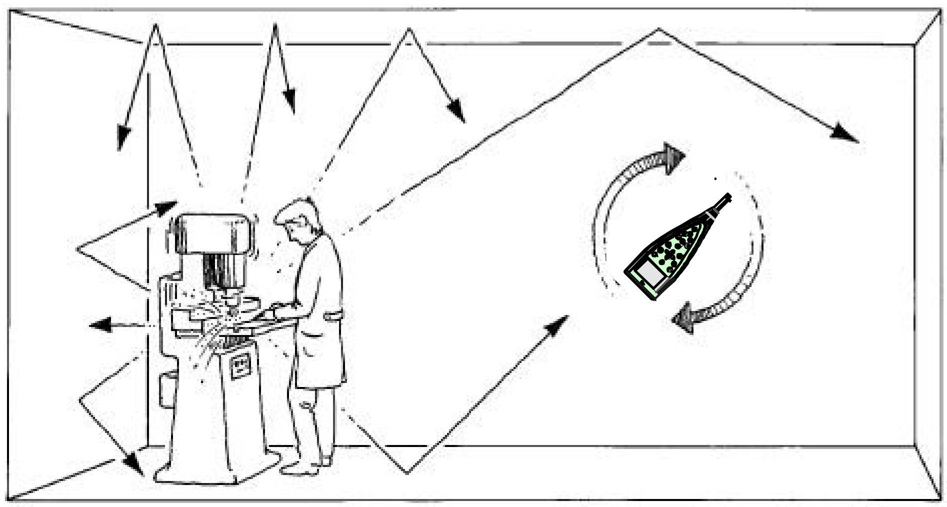
The free field microphone is used in all applications where the sound mainly comes from one direction. Therefore the microphone must be pointed directly at the sound source during a measurement. Typical applications of the free field microphone are in outdoor measurements and for measurements indoors where there are very few or no reflections, so that the sound is mainly from one direction only. An example of the latter is measurements in an anechoic chamber where a free field microphone should always be used.



Use of Pressure Microphones

The main application of the pressure microphone is for measurement in closed cavities e.g. coupler measurement and audiometer calibration, and for measurements at walls or surfaces, where the microphone can be mounted with its diaphragm flush with the surrounding surface.

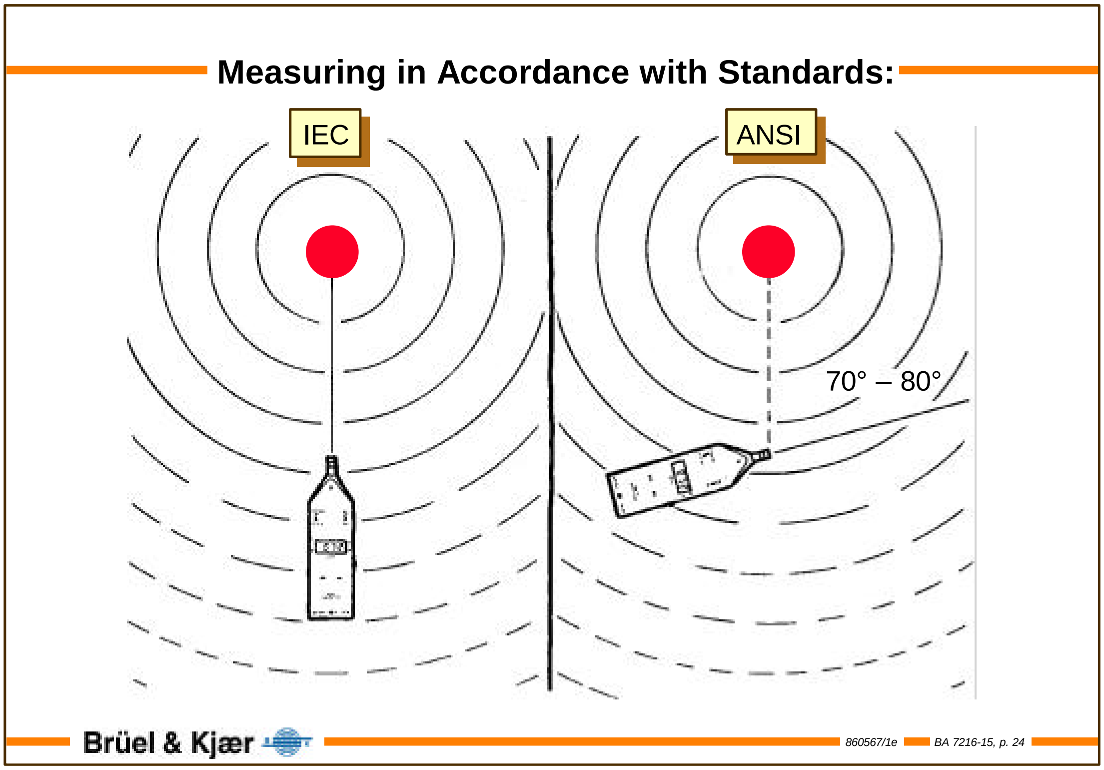
Use of Random Incidence Microphones



Brüel & Kjær 860566/1e BA 7216-15, p. 23

Use of Random Incidence Microphones

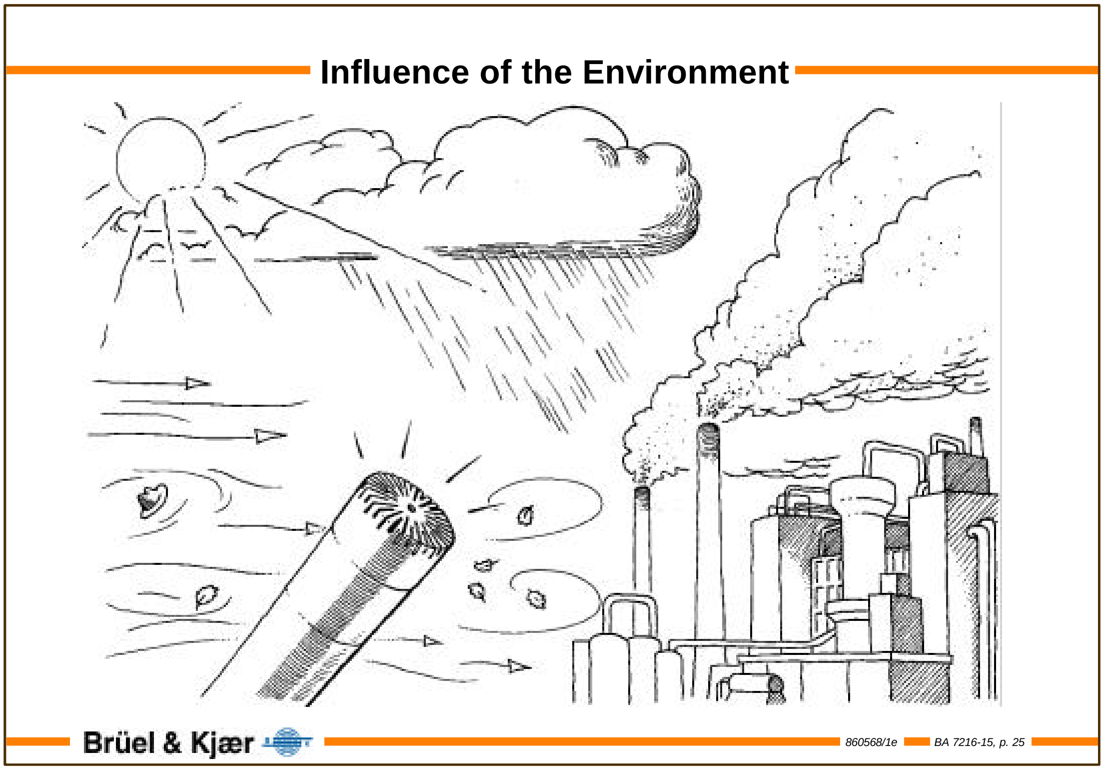
The random incidence microphone is designed to respond uniformly to signals arriving simultaneously from all angles. It should therefore not only be used for measurement in reverberation chambers, but in all situations where the sound field is a diffuse sound field e.g. in many indoor situations where the sound is being reflected by walls, ceilings, and objects in the room. Also in situations where several sources are contributing to the sound pressure at the measurement position a random incidence microphone should be used.



Measuring in Accordance with Standards: IEC or ANSI

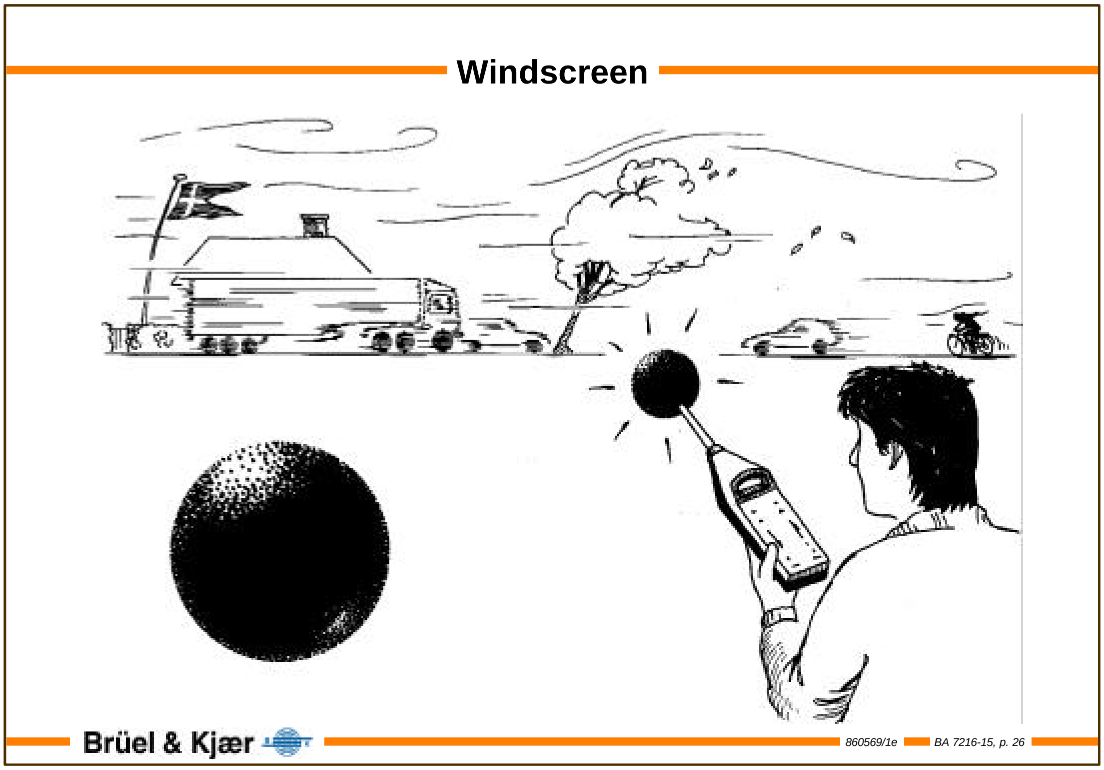
The two most important standards governing the design of sound level meters are the IEC Publication 651 and the American National Standard ANSI S 1.4. For practical purposes the two standards are completely alike – except for the direction of incidence of the sound field. The IEC specifies use of free field microphones and ANSI use of random incidence microphones. This means that when sound level measurements are made in accordance with IEC a free field microphone should be used, and the sound level meter pointed towards the source (0° incidence). When measurements are made in accordance with ANSI a random incidence microphone should be used, and the sound level meter held at an angle of 70° – 80° with the direction of incidence.

It would be desirable if forthcoming standards specify both the free field and the random incidence microphone as standard and indicate when each should be used. For many sound level meters used today the response of the microphone can be changed either by the use of small corrector fitted on the microphone or by the flip of a switch on the sound level meter which then performs the correction electronically.



INFLUENCE OF THE ENVIRONMENT

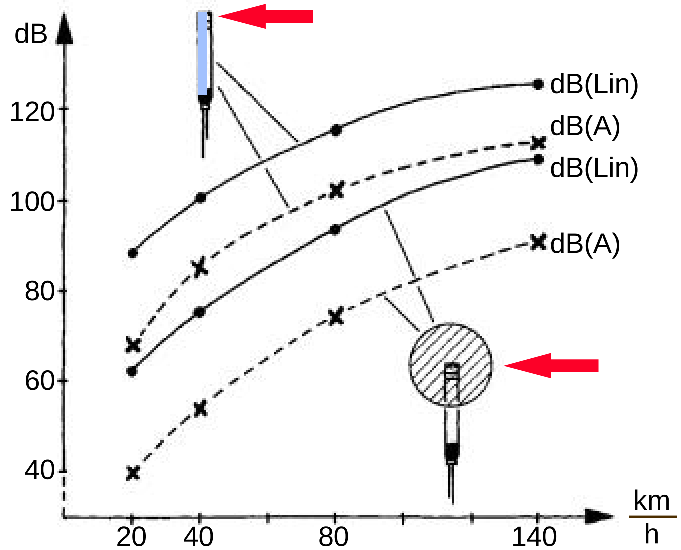
The microphone is used in many different environments, where humidity, temperature, and wind could affect measurements if not taken into account. To reduce or eliminate the effect of these, a number of accessories are available.



Windscreen

In a moving air stream any microphone produces turbulence, which causes the diaphragm to deflect. This generates a spurious signal which is superimposed on the acoustic signal giving rise to serious errors. To reduce the effect of wind-induced noise on sound measurements, the microphone should be fitted with a windscreen. This is made of a specially designed polyurethane foam. It also protects the microphone from dust and light precipitation.

Windscreen



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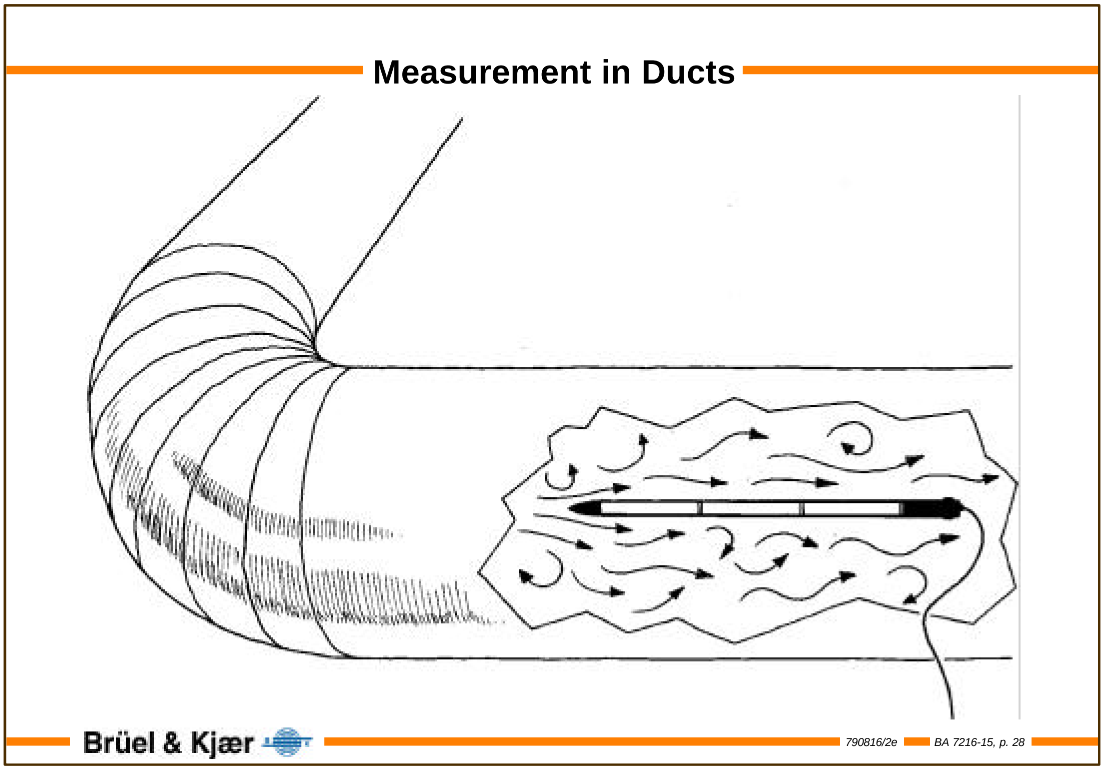
Windscreen

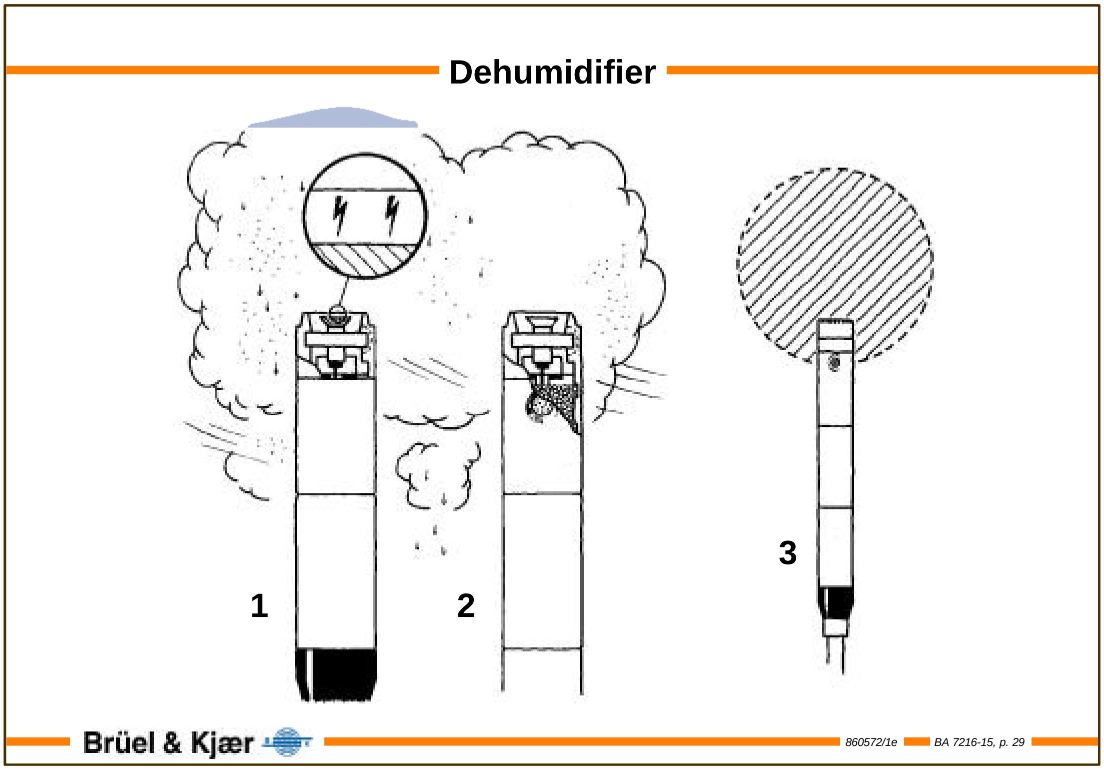
The full curves show the wind induced noise as a function of wind speed for a 1/2" microphone with and without a windscreen. It is clearly seen that the windscreen gives a considerable reduction although it cannot completely eliminate the wind induced noise. The dashed curves show how the influence of the wind induced noise is further reduced when the A-weighting is used in connection with a measurement. The reason for this is that wind induced noise is mainly low frequency noise which is heavily attenuated when A-weighting is used.



Measurement in Ducts

For special conditions where the airflow speed is high and in well-defined direction, a nose cone can be mounted on the microphone. This offers far less resistance to the flow, thus reducing turbulence and wind induced noise.

In wind tunnels or ducts, a turbulence screen should be used. This gives a good rejection of the flow noise caused by turbulence while passing the acoustic signal to the microphone.

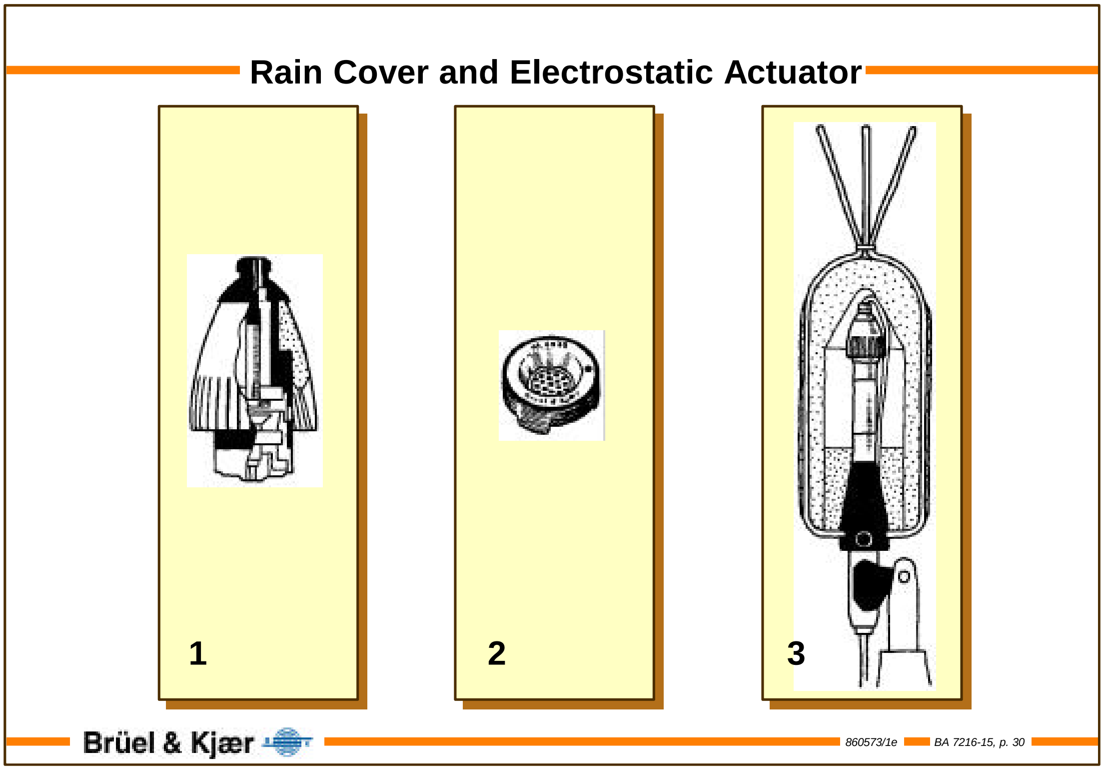


Dehumidifier

When a microphone is taken from a low temperature environment to a high temperature environment, condensation may occur inside the microphone resulting in electric discharge, or arcing, between the diaphragm and back plate, ①. This is normally not a problem if the microphone is allowed to stabilise at the new temperature for a few minutes before applying the polarisation voltage. Even in places with high humidity the problem can be completely eliminated by fitting a dehumidifier between the preamplifier and the microphone, . However, this requires that the microphone is one of the types having a pressure equalisation vent in the back of the microphone.

The dehumidifier contains a moisture absorbent (silica gel) which changes colour from blue to red when it becomes wet. A small window on the side of the dehumidifier allows the colour of the moisture absorbant to be observed from the outside. To dry out the moisture absorbant, remove the dehumidifier from the microphone and preamplifier and let it dry out at approximately 100 °C for a few hours (t_{max} = 135 °C). It is important that the dehumidifier is removed from the microphone and preamplifier, since these may be damaged if exposed to such high temperatures.

To complete the assembly a windscreen should be mounted over the microphone to protect this from dust and light precipitation, .



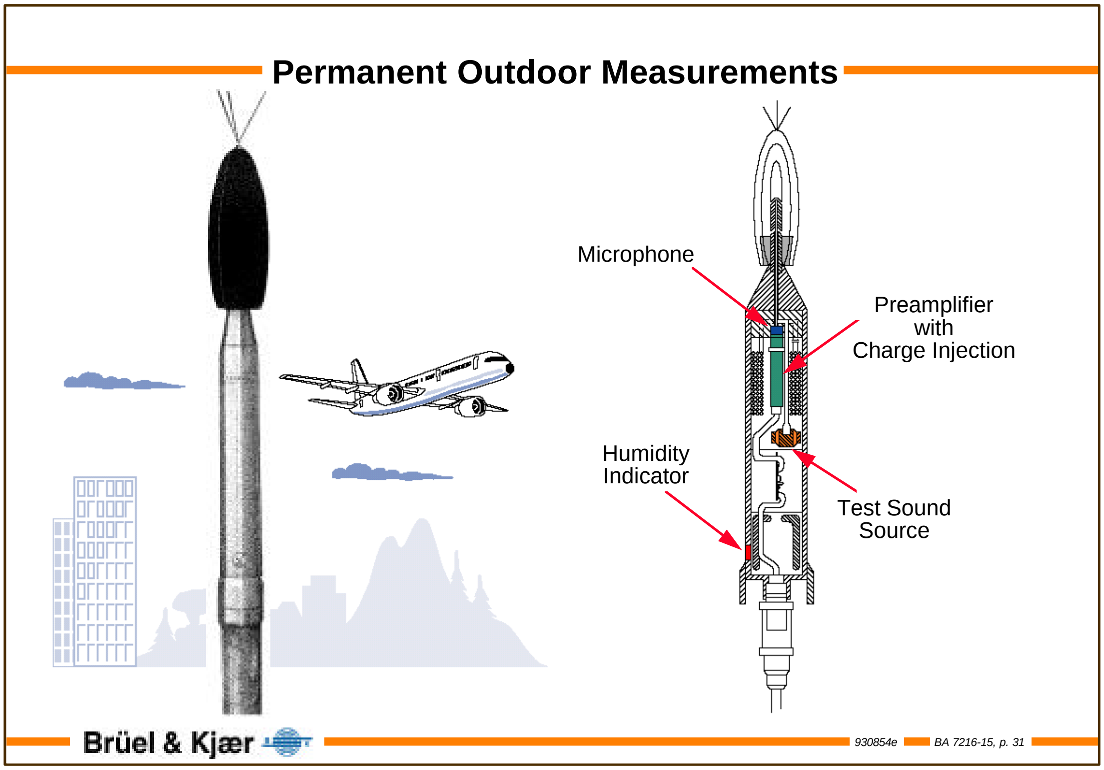
Rain Cover and Electrostatic Actuator

For short-term outdoor installations where measurements are to take place over a few days it is recommended to use a combination of accessories with the preamplifier and the microphone: dehumidifier, rain cover and a windscreen with anti-bird spikes,3.

The rain cover, 1, which is fitted on top of the microphone will prevent rain drops from reaching the microphone, but this requires that the microphone assembly is mounted vertically during the measurement.

The rain cover has a built-in electrostatic actuator which is also available as a separate accessory, 2. The electrostatic actuator will, when supplied with an alternating test voltage, electrically load the diaphragm in a way similar to the action of sound waves and it can therefore be used for calibration purposes. As a matter of fact, the pressure response curve on the calibration chart shown earlier is obtained using an electrostatic actuator. The electrostatic actuator built into the rain cover is used for remote calibration of the microphone as shown in the next illustration.

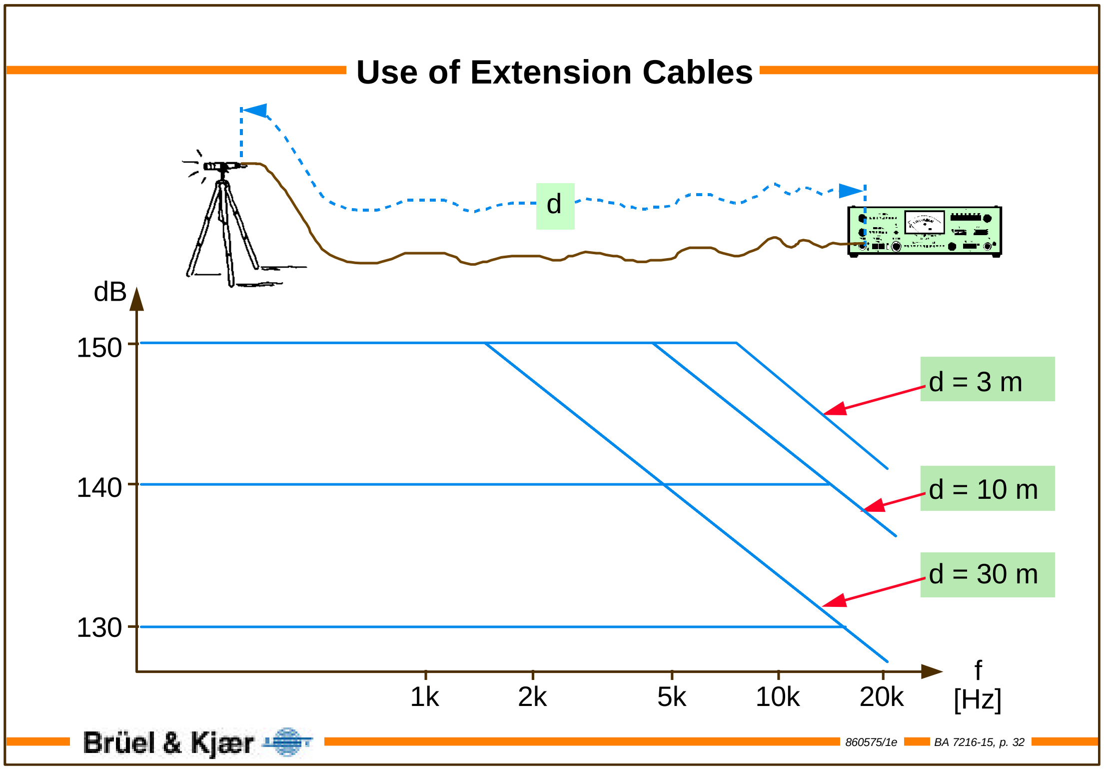
When assembling installations for outdoor use it is recommended to apply a little silicone grease (or petroleum jelly) in the threads of the assembly. This sealing ensures that the microphone only breathes dry air through the dehumidifier and no moist air can leak through the threads.



Permanent Outdoor Measurements

For permanent and semi-permanent outdoor monitoring of sound a special weatherproof microphone unit should be used.

The unit may be used in most humid and corrosive atmospheres as the casing is made completely of stainless steel and the unit has a built-in protection system against humidity. The unit has a charge injection calibration facility and also a built-in test sound source.



Use of Extension Cables

At the beginning of this lecture it was described how a preamplifier mounted close to the microphone allows use of long cables between the microphone and the sound level meter. However, in situations where high sound levels are to be measured, the capacitance of the cable itself will influence the amount of distortion at high frequencies i.e. the frequency range will be limited. The illustration shows an example of this, but in each case where long cables are used, consult the instruction manual for the instrument being used.

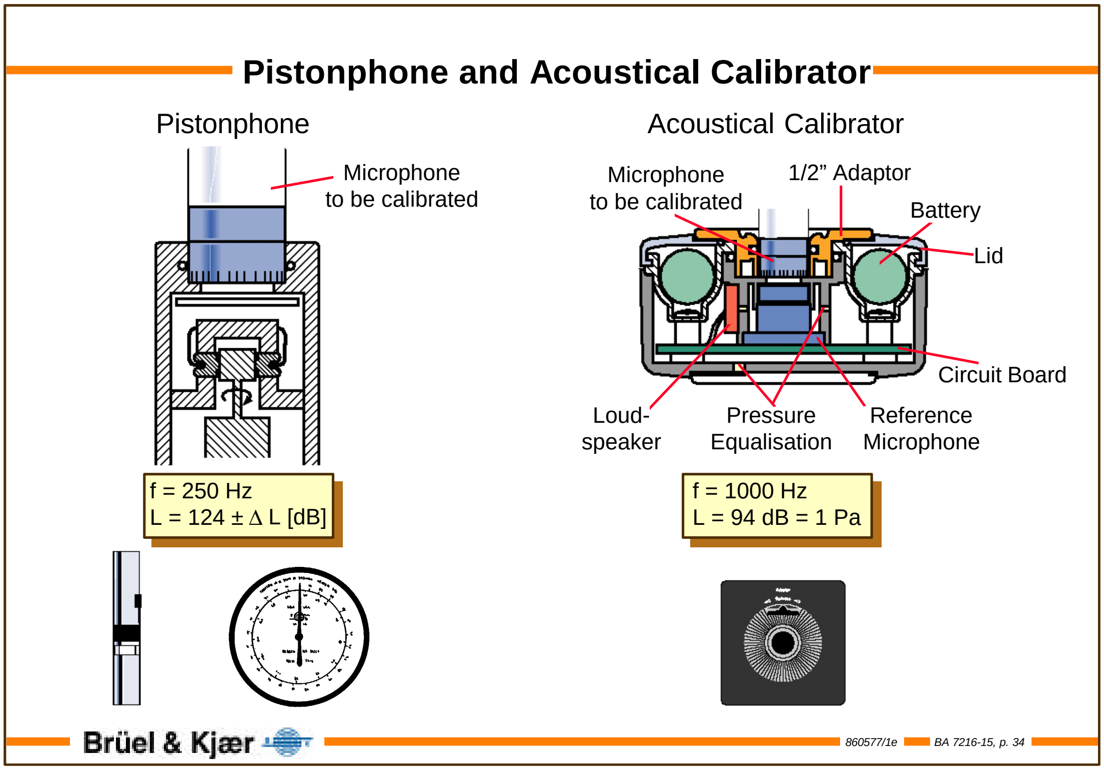
Standard cables are designed and constructed to deal with most practical situations e.g. high sound pressure levels, high frequencies. With standard cables there is rarely a need to worry about specifications. Other factors can however influence the choice of cable for example length, suppleness, temperature range, different plugs etc.

CALIBRATION

Before measurements are undertaken, it is important to calibrate the microphone and instrument together. This will check the function of the measurement system and ensure that high accuracy can be obtained allowing comparison to be made between measurements taken at different times. Calibration ought therefore to be made before each series of measurements and it is recommended that the calibration is repeated after a series of measurements as a double check.

Acoustic Calibration

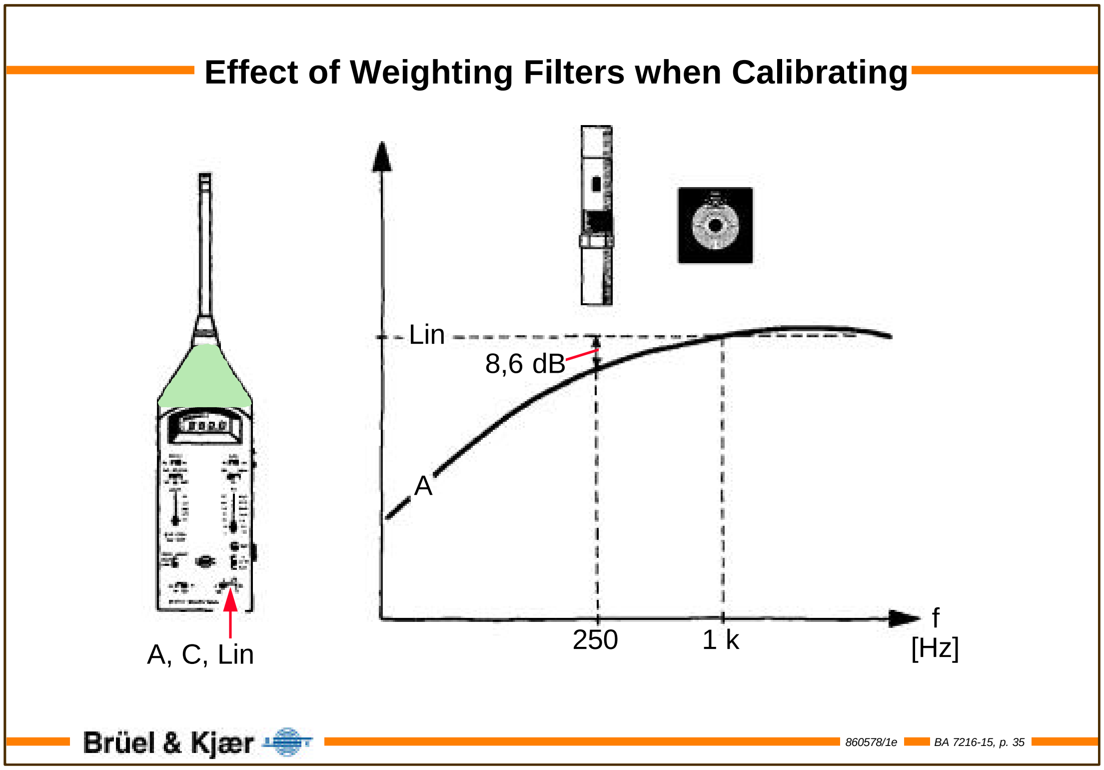
Acoustic calibration is normally to be preferred, since the whole system from microphone to indicating device will be checked. To carry out acoustic calibration, fit the calibrator on the microphone, making sure it fits snugly. Switch on the calibrator and adjust the read out on the indicating device to the sound level produced by the calibrator being used. Two different calibrators are available for acoustic calibration: a pistonphone and an acoustical calibrator.



Pistonphone and Acoustical Calibrator

The pistonphone produces a nominal sound pressure level of 124 dB at 250 Hz with the aid of two small pistons driven by a motor. To attain a high calibration accuracy with the pistonphone, a correction due to the static barometric pressure has to be subtracted or added to the value given on the individual calibration chart for the pistonphone. The correction can be read directly off a barometer supplied with the pistonphone.

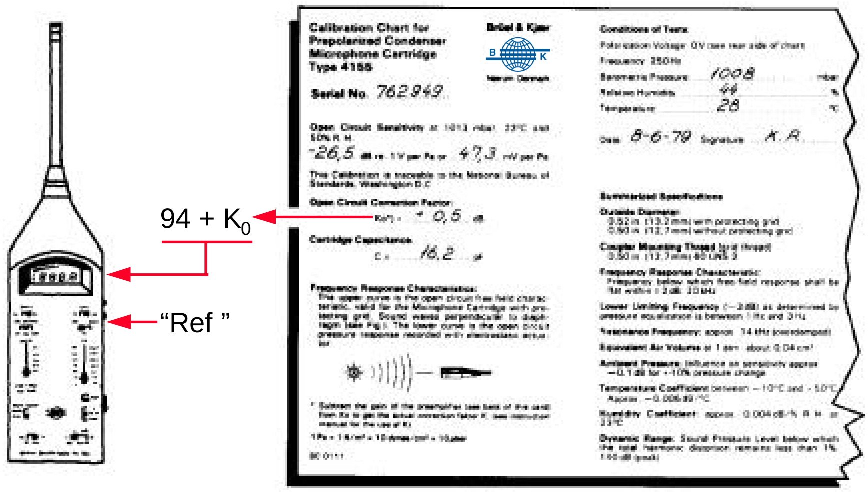
The acoustical calibrator operates with a miniature loudspeaker and produces a sound pressure level of 94 dB ≈ 1 Pa at 1 kHz by means of an active feedback loop based on a built-in precision microphone.



Effect of Weighting Filters when Calibrating

When the acoustical calibrator, which operates at 1 kHz, is used for acoustic calibration, the weighting filters in the sound level meter will not effect the displayed level since all weighting filters have zero attenuation at 1 kHz When the pistonphone is used it is recommended to select “Linear” weighting during calibration in order to obtain the highest accuracy. If calibration is carried out with the weighting filter included, a correction has to be made. If, for example, the A-weighting filter is included the sound level meter will display a level of 8,6 dB below the level of the pistonphone.

Use of Internal Reference



Use of Internal Reference

Some sound level meters and other measuring equipment for use with microphones have a built-in reference oscillator which can be used for calibration. The reference signal is supplied at a point after the microphone and preamplifier. These will therefore not be checked using this method. The method is not to be recommended as a replacement for an acoustic calibration, but often it is found useful for a quick check, especially in situations where the sound level meter output is connected to other instruments such as level recorders and tape recorders. In order to use the method, a correction factor, K_0, for the microphone has to be known. This factor, which can be read off the calibration chart for the microphone, is then added to 94 dB to give the level which the sound level meter should display.