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# Selection and Calibration of Acoustic Sensors

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***Abstract* - The basic elements of a noise measuring system are a microphone, an amplifier, a signal processor and a readout or monitoring unit. The simplest practical realization of such a system is the portable sound level meter. The microphones are the standard acoustical transducer for all sound and noise measurement. Different types of microphones are available; each has its own advantage and disadvantage. This paper attempts to compile the information on different types of microphones available, its characteristics, calibration methods and relevant standards. This paper also discusses the secondary free field calibration procedure as per IEC 61094 part 8 -2012 and highlight the contribution of various uncertainty factors affecting calibration.**

## 1. INTRODUCTION

The physical parameters of interest for noise and vibration study or measurement are related to the properties of wave motion in fluids (sound) or in solid structures (vibration). Quantifiable properties of sound waves at a point include incremental (sound) pressure, particle velocity, particle displacement, intensity, incremental density and incremental temperature. All these properties can be measured in the laboratory. However, in gases, sound pressure is by far the easiest quantity to measure, particularly under field conditions.

The basic elements of a noise measuring system are a microphone, an amplifier, a signal processor and a readout or monitoring unit. The simplest practical realization of such a system is the portable sound level meter. A wide variety of transduction devices have been developed over the years for converting sound pressure fluctuations to measurable electrical signals, but only few devices are commonly used for precision measurement of sound pressure level. The most commonly found sound pressure transducer for precision measurement is the condenser microphone. To a lesser extent piezoelectric microphones are also used.

## 2. MICROPHONES [1,2,3,4]

Among the most commonly available microphones, condenser microphone and piezoelectric microphones are widely used because of their very uniform frequency response and their long-term sensitivity stability. The condenser microphones generally give the most accurate and consistent measure but it is much more expensive to construct than the piezoelectric microphone. The condenser microphone is available in two forms, which are either externally polarized by application of a biasing voltage in the power supply or prepolarized internally by use of an electret.

### *2.1 Condenser Microphone*

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.

Figure A depicts a condenser microphone consists of a diaphragm which serves as one electrode of a condenser, and a polarized back plate, parallel to the diaphragm and separated from it by a very narrow air gap, which serves as the other electrode. The condenser is polarized by means of a bound charge on the backing plate and may be provided either by means of an externally supplied biasing voltage of the order of 200V, or by using an electret which forms either part of the diaphragm or the backing plate.

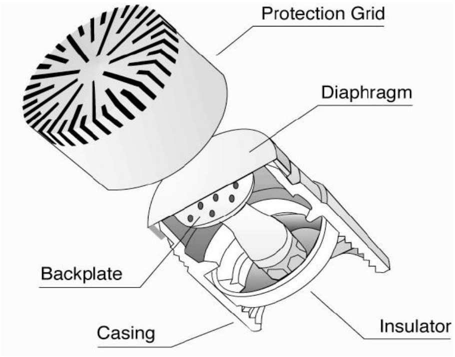

Figure A

The reason for the high degree of acceptance of condenser microphone is that, it has all the essentials of 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.
7. Low sensitivity to mechanical vibration

Disadvantages of these type of microphone are listed below

1. Small microphone capacitance
2. Susceptibility to humidity
3. Fragile diaphragm

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 technique.

*2.2 Electret microphone*

In electret microphone, instead of an air gap between the two condenser plates, a prepolarized solid dielectric electret foil is used as shown in Figure B. This eliminates the need for a DC bias voltage and provides a higher capacitance for the microphone. The electret foil has the thickness of 0.02 mm and is stretched above a perforated metal back plate. The foil has a thin metalized layer deposited on its outer surface to provide the other plate of the capacitor. The back plate is perforated to permit the electret diaphragm to move. Significant advantages of the electret microphone are the elimination of dc bias voltage, simple rugged construction and large capacitance.

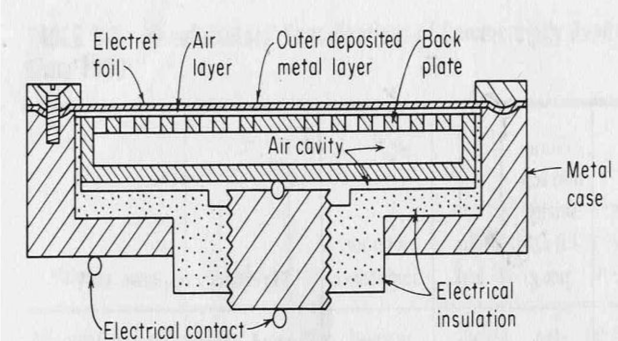

Figure B

*2.3 Piezo electric microphone*

Piezoelectric microphones use the force produced by pressure to strain a piezoelectric material which generates an electrical charge. Piezoelectric materials may be natural crystals or created by adding impurities to a natural crystalline structure. In piezoelectric microphone a diaphragm is used as a force collector as shown in Figure C. The piezoelectric material is placed behind the diaphragm so that the force exerted on the diaphragm strains the crystal. Since the diaphragm is backed by the crystal, the transducer is more rugged than a condenser microphone. Hydrophones for underwater work use piezoelectric materials, without a diaphragm.

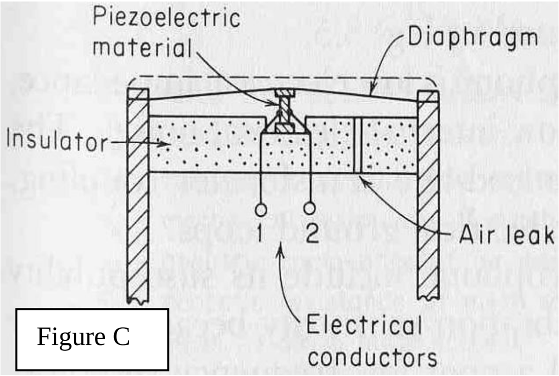

Figure C

Advantages of piezoelectric microphones are high capacitance, ruggedness, wide dynamic range and the lack of polarization voltage. Disadvantages are lower acoustic sensitivity and susceptibility to vibrations.

Piezoelectric microphones are commonly used in less expensive equipment and in general applications, as they have rather poorer specifications when compared with the condenser microphone.

*2.4 Dynamic microphone*

The dynamic microphone uses the velocity imparted to the diaphragm by the sound pressure to move a coil through a magnetic field, thereby inducing a current in the coil as depicted in Figure D.

An advantage of the dynamic microphone is low electrical impedance which permits long cables and gives low internal electrical noise. Disadvantage of the dynamic microphone is its susceptibility to external magnetic fields, vibration sensitivity and poor low frequency response.

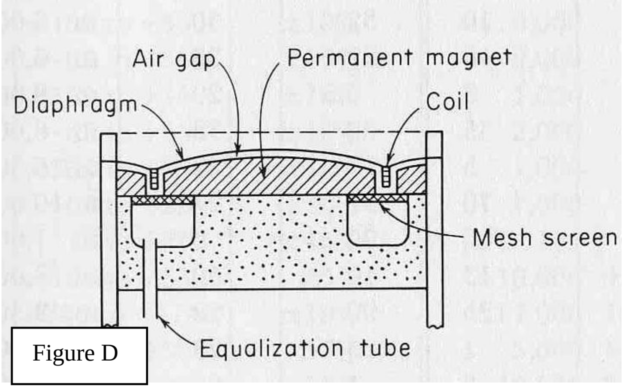

Figure D

The stability of a dynamic microphone is influenced by both the density and velocity of the gas, since these affect the acoustic elements used to extend the frequency response. The stability is also influenced by the temperature coefficients of the mechanical elements.

*2.5 Comparison of properties*

| Parameters | Condenser Type | Piezoelectric Type |
|---|---|---|
| Dynamic Range | Good | Good |
| Sensitivity | Good | Average |
| Low frequency response | Good | Good |
| High frequency response | Good | Average |
| Need for preamplifier | Poor | Good |
| Long term stability | Good | Average |
| Influence to temp | Good | Good |
| Influence to vibration | Good | Average |
| Influence to moisture | Poor | Average |
| Influence to magnetic field | Good | Good |
| Ruggedness | | |
| Price | Poor | Average |
| | Expensive | Average |

In general, condenser microphones are good in majority of the aspects. Hence, the characteristic of condenser microphones are only described in subsequent sections.

## 3. CHARACTERISTICS

Microphones are designed in different sizes 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 above, a generalization is made based on the size of the microphones which are produced commonly in the sizes 1", 1/2", 1/4", and 1/8".

### *3.1 Frequency range and sensitivity*

Figure E. illustrates the comparison of the sensitivity and frequency ranges of the four sizes of microphones 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. Frequency response is inversely related to the microphone diameter D, while the sensitivity is directly related to the fourth power of the diameter. Exceptions are some of the 1/2" microphones which 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 and it is used in most applications. Other sizes are only used for special applications. Typical open circuit sensitivities & accepted deviations are given in the following table.

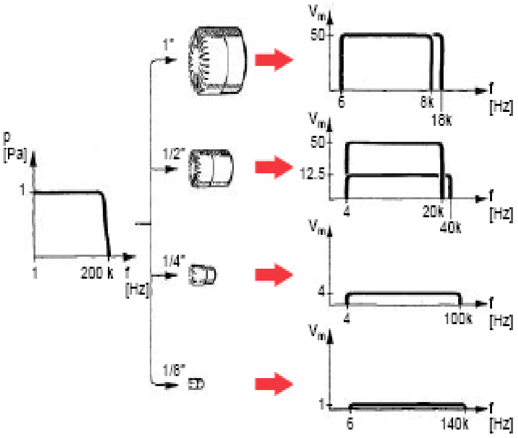

Figure E. Frequency range and sensitivity

| Size of Microphone | Open circuit sensitivity | | Deviation (dB) |
|---|---|---|---|
| | (mv / Pa) | dBre mv /pa | |
| One inch | 50 | -26 | ±1.5 |
| Half inch | 12.5 | -38 | ±2.0 |
| | 50 | -26 | ±1.0 |
| Quarter – inch | 4 | -48 | ±3.0 |
| One Eight – inch | 1 | -60 | ±3.0 |

### *3.2 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 in Figure F 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.

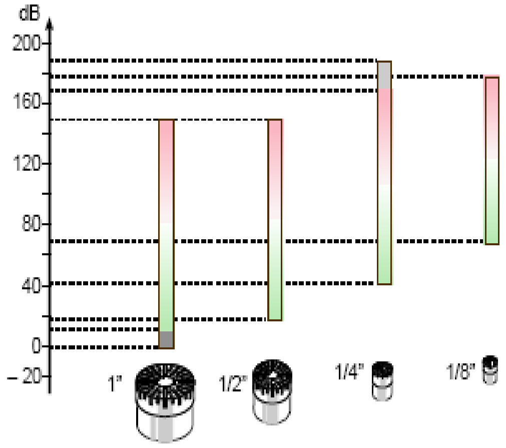

Figure F : Dynamic range of microphones

### *3.3 Operating region*

A combination of frequency range and dynamic range gives a certain operational region for a microphone. For general sound pressure level measurement ½ inch microphone 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.

## 4. TYPE OF MICROPHONES

Microphones are further divided into three 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. 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. It is required to have a closer look at the reason for the difference between the microphones and when each type should be used.

## 5. FREE FIELD CORRECTION

When a microphone is placed in a sound field, it modifies the field. 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 than the actual sound pressure. This rise in "sensitivity" is frequency dependent, with a maximum at the frequency where the wavelength ($\lambda$) is equal to the diameter (D) of the microphone, $D/\lambda$. For a 1/2" microphone, 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 prominent.

The free field correction depends not only 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.

### *5.1 Response of Free Field and Pressure Microphones*

The free field corrections are the same for the Free Field and Pressure microphones, if their mechanical designs are identical. 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:

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.

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.

A microphone which has a nearly flat random incidence response as a function of frequency is called a random incidence microphone.

### *5.2 Use of Microphones*

*Free Field Microphones* : 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.

*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.

*Random Incidence Microphones :* It is used for measurement in reverberation chambers, and in all situations where the sound field is a diffused, 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.

## 6. MEASUREMENT IN ACCORDANCE WITH STANDARDS IEC or ANSI [1,2]

The two most important standards governing the design of sound level meters are the IEC Publication 60651 and the American National Standard ANSI S 1.4. For all 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. 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.

## 7. CALIBRATION

The most important parameter for any measurement device is sensitivity [5]. The sensitivity can be defined as the ratio of the output parameter to the input parameter. To determine the sensitivity is to calibrate the measurement device. All the information that follows in this chapter is based on this definition. The sensitivity of a microphone is generally given in terms of volts per pascal. Pascal is defined as one Newton per square meter ($N/m^2$), i.e. a unit of pressure. The accuracy of the calibration must also be known i.e the device and method used to calibrate a microphone must perform the calibration with a known uncertainty. If these conditions are fulfilled, the calibration is called traceable because the calibration can be reliably traced back through the measurement chain, ultimately to the fundamental units of measurement. Therefore a calibration is not useful, unless the related uncertainty is known.

Calibration is performed:
— To be sure of making correct measurements.
— To prove that measurement methods and equipment are accurate
— To verify the stability of the measurement equipment
— To ensure product quality.
— To build confidence in measurement results.
The calibration can either be performed in the field or in a calibration laboratory. These calibration situations are explained in subsequent sections. .

### *7.1 Field Calibration*

Field calibration is performed at the measurement location using a calibrated reference sound source, such as a Sound Level Calibrator. This ensures the traceability of absolute sound level measurements. The fact that the measurement is traceable is important if the measurement must be recognized by legal authorities or if compliance with international standards is claimed. This gives confidence in the measurement result by verifying the stability of the entire measurement system. Calibration before and after a measurement is also something which is prescribed by various sound measurement standards to ensure the validity of the measurement.

Most Sound Level Calibrators are portable, easy-to-use and characterized by the production of a well defined sound pressure at a single frequency, usually in the range of 250Hz and 1 kHz. Some calibrators are so called Multi tone level Calibrators which provide a number of pure tones at single frequencies or multi levels at different frequencies. When using calibrators that produce a single frequency, the calibration is strictly only valid at this reference frequency. However, microphones are generally manufactured to provide a flat frequency response which means that they will give the same electrical output at all frequencies in the flat frequency range for sound pressures of equal magnitude. Therefore calibration at a single frequency is sufficient in most situations.

### *7.2 Laboratory Calibration*

Laboratory calibration is a common expression for the type of calibration that cannot be performed in the field. Laboratory calibration is an indoor method, preferably performed in a dedicated and well-controlled environment. The laboratory calibration methods are normally more accurate than the field calibration methods. This is partly due to the type of equipment used for calibration and partly due to the stable laboratory environments. Calibrations in the field are especially affected by temperature variations, wind and humidity.

### *7.3 Calibration Interval*

While field calibration is usually applied to an entire measurement system, laboratory calibration also covers the calibration of separate devices such as microphones and calibration devices. Microphone calibrations are usually performed at calibration laboratories on a regular basis. As with field calibration, this provides evidence of stability and ensures traceability.

Standards relating to calibration usually define laboratory recalibration intervals of 1 year, which apply to both the calibrator and the measurement system, for example, sound level meters. In other cases the recalibration interval is determined by the users estimate. It is advisable to start with a 1 year interval, which can then be extended when sufficient evidence of stability is obtained. The mode of use of the device should always be taken into account when determining recalibration intervals; the harsher the mode of use, the more frequent the recalibration should be because of the increased probability of changes in the performance of the device.

## 8. CALIBRATION METHODS

Various calibration methods available are, Reciprocity Calibration, Comparison Method, Substitution Method, piston phone / sound level calibrator and Actuator frequency response. Estimates of the expected uncertainty that can be obtained using the various methods and calibration situation are indicated below.

| Method | Uncertainty | Calibration situation |
|---|---|---|
| Reciprocity Calibration | 0.03 to 0.05dB | Laboratory |
| Comparison Method | 0.06 to 0.14dB | Laboratory |
| Substitution Method | 0.06 to 0.14dB | Laboratory |
| Piston phone<br>Sound level calibrator | 0.07 to 0.3 dB | Laboratory or Field |
| Actuator Frequency Response | 0.1 to 0.5dB | Laboratory |

### *8.1 Reciprocity Calibration Method*

This is the most accurate calibration method for determination of the open circuit sensitivity of the microphone cartridges. The sensitivity can be obtained either as a pressure sensitivity or as a free-field sensitivity, by using a coupler (cylinder) or an anechoic chamber respectively. Certain physical requirements of the microphone must be fulfilled to perform the calibration in a coupler, for example, the mechanical configuration are described in IEC 61094-1. The reciprocity method is an absolute method, which means that it requires the measurement of a number of fundamental physical units such as electrical voltage and impedance, length, temperature, humidity and also ambient pressure. But no reference sound pressure is required.

The method determines the unknown sensitivities of three microphones simultaneously. At least two of the microphones must be reciprocal. This means that they can be used both as receivers (microphones) and as transmitters (sound sources). The coupler properties must be known to a high degree of accuracy.

To performing a complete calibration, three measurements of receiver voltage and transmitter current ratios must be performed in three different setups (interchanged microphones). The three ratios are then used to solve three equations with three unknowns: the sensitivities of the microphones. To obtain reliable results, clean and stable environments are required. Practice at performing the calibration is also important. The method is described in detail in IEC 61094-2, Pressure Calibration and IEC 61094-3, Free-field Calibration.

### *8.2 Substitution method*

The substitution method involves of a device replaced (substituted) by a reference device, preferably of the same type and the measurement is repeated. Thus the ratio of the sensitivities of the devices are obtained directly. This method is well suited for both microphones and sound pressure calibrators. If the measurement and reference objects are of the same type, the measurement uncertainty is reduced due to identical measurement conditions. The measurement capability requirements are also reduced, as only a small part of the dynamic range is used i.e. there is no need to know the absolute level.

Any sound source used for the calibration of microphones must obviously be very stable during the measurement and must not be affected by differences in microphone configurations. In this case, the method is well suited for calibration of free field microphones, provided that a suitable reference microphone is available.

### *8.3 Comparison Method*

In the comparison method, both the measurement- and the reference objects are present at the same time and are exposed to the same sound pressure. As a result, a simultaneous measurement can be performed. In principle something unknown is compared with something known. The method is often confused with the substitution. The method reduces the number of error sources, and also reduces the stability requirements in situations where external sound sources are used. It also covers the compressor loop principle used in a number of sound level calibrators, where a reference microphone inside the calibrator constantly monitors the sound pressure. In this situation the reference microphone must be very stable as it is the “known” object. This method is also used for calibration and checking of sound intensity measurement equipment, which ideally requires two identical measurement channels.

### *8.4 Sound Pressure Calibrator Method*

The purpose of using a sound pressure calibrator is to get a well defined sound pressure with a certain microphone. This makes the calibrators equally suited for calibration of single microphones as well as entire measurement channels. In most cases, the calibrator has only a single tone frequency in the range 200 to 1000Hz, at which the calibration is performed, (IEC 60942 ‘Sound Calibrators’) but multi tone calibrators are also available, usually with frequencies in steps of one octave. When using the calibrator for microphone calibration, the output from the microphone is measured with the well defined sound pressure from the calibrator applied to its front. The sensitivity is determined by dividing the output voltage by the sound pressure. When the calibrator is used to calibrate the entire measurement channel, the well defined sound pressure is applied to the front of the microphone and a proper. It should be noticed that sound calibrators always establish a pressure field. As a result, a free field calibration can be performed by applying a suitable correction.

### *8.5 Actuator method*

The electrostatic actuator is well suited for calibration of a relative frequency response of microphones with a metallic or metalised diaphragm. It consists of a metallic grid positioned close to the diaphragm (approx. 0.5 mm). By applying 800 VDC and 100 VAC to the actuator, electrostatic forces equivalent to a sound pressure of approximately 100 dB re 20micropascal are established. The actuator is not suited for absolute calibration due to the extreme dependency of the equivalent sound pressure level on the distance between actuator and diaphragm.

The actuator method is a reliable method for determination of the microphones relative frequency response under laboratory conditions. The response obtained with the actuator does not however correspond to any of the acoustical sound fields. Although there is no difference between the actuator response and the pressure field response at low frequencies and only minor difference at higher frequencies for microphones with high impedance diaphragms. It should, however be noted that different types of actuators will give slightly different frequency responses, even for the same microphone.

The frequency responses of the microphone in pressure-, random and free sound fields are determined by adding actuator and microphone type-specific corrections to the individual actuator response. The disadvantages of the method are that care is required to position the actuator, that the system uses high voltages and that the grid must be removable.

## 9. FCRI FACILITIES FOR CALIBRATION

Figure G: Free field calibration system

Secondary calibration system for measuring microphones, sound level meters and acoustical calibrators, is now available at FCRI. Figure G illustrates this unique system, commercially available in India to carry out free field calibration of noise measuring instruments. CS18FF system from SPEKTRA, Germany employs an anechoic chamber, laboratory standard reference microphones and reference acoustical calibrators traceable to International standards for the calibration. This facility is recently accredited by NABL. Using this system, the following calibrations can be performed.

A) Secondary Free field calibration of Measuring Microphones as per IEC 61094-8
B) Secondary calibration of Sound Level Meters as per IEC 61672
C) Secondary calibration of Acoustical Calibrators as per IEC 60942
D) Calibration of Charge/Voltage and ICP Amplifiers

Since the subject under discussion is microphones, this section explains about secondary Free field calibration of Measuring Microphones

It is the basic principle of a **substitution test** that test item and reference standard are exposed to the same sinusoidal sound pressure one after the other as explained in section 8.2. The sound pressure is generated electromagnetically loudspeaker in an anechoic chamber. The ratio of microphone voltages in one channel, taken in quick succession, is equal to the ratio of the transfer coefficients of the microphone under test and the traceable reference standard.

*Uncertainty Budget:*

As required, evidence of the smallest measurement uncertainty is furnished theoretically by drawing up a measurement uncertainty budget.

Components:

*Free-field sensitivity of the reference microphone*

The uncertainty in the sensitivity of the reference microphone directly affects the uncertainty in the sensitivity of the microphone under calibration. The reference microphone sensitivity may be derived by applying free-field to pressure differences according to IEC/TS 61094-7 to a pressure reciprocity calibration according to IEC 61094-2.

*Stability of sound source*

The stability of a loudspeaker sound source should be monitored by some means during the course of a calibration. Options for monitoring the sound source include the use of an auxiliary monitor microphone and using the repeatability in results.

*Positioning accuracy*

Uncertainty due to the accuracy in positioning the microphones in the sound field in terms of the distance from the source and the angle of incidence.

*Alignment between source and receiver*

The free-field sensitivity of a microphone is a function of the angle of incidence, particularly at high frequencies. Some means of setting the orientation of the microphone in a repeatable manner shall be used.

*Quality of free-field environment or influence of signal processing*

The presence of indirect sound is related to the quality of the free-field environment in which measurements are carried out. This can be expressed in terms of the root-mean-square deviation from idealized free-field conditions. These deviations are dependent on the distance between loudspeaker and microphone.

Gain coefficients / ratio of gain coefficients

*Influence of non-plane wave*

The sound source shall be capable og generating plane progressive waves at the measurement position. In practice the sound source may not radiate plane waves, but at a sufficiently long distance from the source, wave fronts can be considered plane across the region occupied by the reference or microphone under test.

*Influence of environmental conditions*

The free-field sensitivity of the microphone depends on static pressure, temperature and humidity. This dependence can be determined by comparison with a well characterized laboratory standard microphone over a range of conditions. The actual conditions during calibration shall be reported.

*Polarizing voltage*

If the microphone under test requires an external polarization voltage, the manufacture’s recommendations shall be followed. The actual polarizing voltage used during the calibration shall be stated, along with the reported free-field sensitivity.

*Microphone capacitance*

The capacitance difference between the microphones will cause small changes in the preamplifier gain, leading to uncertainty in the voltage ratio.

*Measurement system non-linearity*

The measurement system is required to measure a voltage ratio. The linearity of the measurement system ie. Its ability to correctly indicate voltage ratio over the expected range of voltages produced by the microphones has an associated uncertainty

*Measurement repeatability*

Uncertainties of a random nature in the measurement of the outputs of the microphones directly affects the sensitivity of the microphone under test.

Uncertainties of a systematic nature in the measurement of the outputs of the microphones may affect the uncertainty but may be reduced if the same system is used for both the test and reference microphones.

Calibration Measurement Capability of FCRI:

| Device under calibration | Range(s) of measurement | Calibration and Measurement Capability | Method used |
|---|---|---|---|
| Measuring Microphone with preamplifiers | 125Hz to 250Hz | 0.5 dB | Free field Calibration System as per IEC 61094-8:2012. Comparison with reference microphone-Substitution method in an anechoic chamber. Using laboratory standard microphone |
| | 250Hz to 8kHz | 0.3dB | |
| | >8kHz to 10kHz | 0.4dB | |
| | >10kHz to 20kHz | 0.5dB | |
| Sound level meter | 125Hz to 250Hz | 0.5dB | Substitution method in an anechoic chamber with laboratory standard microphone |
| Sound level calibrator / Piston phone | 94 dB,<br>114 dB<br>124 dB | 0.5 dB | Substitution method with laboratory standard microphone and reference sound calibrator |
| Multifunction acoustic calibrator | 94dB, 104dB & 114 dB<br>31.5Hz to 16kHz | 0.5dB | Measurement method with laboratory standard microphone and Control unit |

## 10. CALIBRATION STANDARDS

Calibration of microphones are performed as per following standards

| | |
|---|---|
| IEC 60942 Ed. 3.0 b:2003 | Electro acoustics - Sound calibrators |
| IEC 61094-1 Ed. 2.0 b:2000 | Measurement microphones - Part 1: Specifications for laboratory standard microphones |
| IEC 61094-2 Ed. 1.0 b:1992 | Measurement microphones - Part 2: Primary method for pressure calibration of laboratory standard microphones by the reciprocity technique |
| IEC 61094-3 Ed. 1.0 b:1995 | Measurement microphones - Part 3: Primary method for free-field calibration of laboratory standard microphones by the reciprocity technique |
| IEC 61094-4 Ed. 1.0 b:1995 | Measurement microphones - Part 4: Specifications for working standard microphones |
| IEC 61094-5 Ed. 1.0 b:2001 | Measurement microphones - Part 5: Methods for pressure calibration of working standard microphones by comparison |
| IEC 61094-6 Ed. 1.0 b:2004 | Measurement microphones - Part 6: Electrostatic actuators for determination of frequency response |
| IEC/TS 61094-7 Ed. 1.0 b:2006 | Measurement microphones - Part 7: Values for the difference between free-field and pressure sensitivity levels of laboratory standard microphones |
| IEC 61094-87 Ed. 1.0 b:2012 | Methods for determining the free-field sensitivity of working standard microphones by comparison |
| IEC 61672 | Sound Level Meters |
| IEC 60942 | Acoustical Calibrators |

## 12. REFERENCE

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