In order to quantify the noise emitted by an equipment, a measurement of sound power is usually performed. This quantity is a unique descriptor that allows an operator to compare noise sources.

Furthermore, recent European directives dealing with noise protection of workers specify that the noise power of industrial machinery must be estimated and clearly labelled if the noise nuisance may cause hearing damage (Leq > 85 dB (A)).

Some international standards for measuring sound power are based on sound pressure measurements. However, such measurements are clearly not exploitable if the piece of machinery under test cannot be installed in a protected environment (anechoic or reverberant room) because of its size or if other noise sources that cannot be switched off are present in the test room - a common problem on a factory floor. The mathematical relationship between sound power and sound intensity has drawn acousticians to develop sound intensity techniques and intensity meters for the determination of sound power on-site.

Specific measurement procedures for sound power determination using sound intensity have been defined in the international standards ISO9614, part 1 and part 2. The equipment required (a sound intensity meter and a sound intensity probe) must comply with the specifications of the IEC1043 standard.

This application note explains how to use the Type 1 intensity meter developed by 01dB in the context of sound power determination using sound intensity according to ISO9614. Some practical examples are given to illustrate the measurement procedures. Theoretical, practical and standardisation aspects are also dealt with.
SOUND POWER DETERMINATION ACROSS ISO9614 STANDARD

SYMPHONIE measurement system - dBFA32 software package

Application Notice

infogb@01dB-stell.com
www.01dB-stell.com

The specifications are subject to change without notice (E&OE)

SYMPHONIE® is a registered trademark of 01dB
MICROSOFT® is a registered trademark of Microsoft Corporation
Windows 95™, Windows 98™ are trademarks of Microsoft Corporation

gb_dBFA32_Intensity_ISO9614.doc - Updated 15/06/01
# TABLE OF CONTENTS

1. THEORETICAL ASPECTS .......................................................................................................................... 7
   1.1. ACOUSTIC INTENSITY ................................................................................................................... 7
   1.2. STANDING WAVE MEASUREMENTS ............................................................................................... 8
   1.3. DETERMINATION OF SOUND POWER .......................................................................................... 10

2. PRACTICAL ASPECTS ............................................................................................................................. 15
   2.1. HISTORICAL ASPECT .................................................................................................................... 15
   2.2. THE TWO MICROPHONE METHOD PRINCIPLE ........................................................................... 16
   2.3. LIMITATIONS TO MICROPHONE BASED INTENSITY METER .................................................. 18
       2.3.1. Systematic errors : finite difference approximation principle ................................................ 18
       2.3.2. Systematic errors : microphone transducers ........................................................................... 19
       2.3.3. Systematic errors : distortions of measuring instruments ....................................................... 19
       2.3.4. Statistical errors ....................................................................................................................... 22
   2.4. CALCULATION OF SOUND POWER IN A NOISY ENVIRONMENT ............................................. 23

3. STANDARDISATION .............................................................................................................................. 25
   3.1. REMARKS FOR SOUND POWER DETERMINATION USING SOUND INTENSITY .................... 25
   3.2. ISO9614 PART 1 STANDARD (MEASUREMENT AT DISCRETE POINTS) .................................... 26
       3.2.1. Overview ................................................................................................................................ 26
       3.2.2. How to perform sound power measurements according to standard ..................................... 27
   3.3. ISO9614 PART 2 STANDARD (MEASUREMENT BY SCANNING) ................................................. 31
       3.3.1. Overview ................................................................................................................................ 31
       3.3.2. How to perform sound power measurements according to standard ..................................... 31

4. 01DB EQUIPMENT REQUIRED ........................................................................................................... 35
   4.1. TRANSDUCER ............................................................................................................................... 35
   4.2. ACCESSORIES (OPTIONS) .......................................................................................................... 35
   4.3. MEASUREMENT SYSTEM .............................................................................................................. 36

5. MEASUREMENT PROCEDURES .......................................................................................................... 37
   5.1. SYSTEM SET-UP ............................................................................................................................ 37
   5.2. CALIBRATION ............................................................................................................................... 37
       5.2.1. Pressure calibration of the sound intensity probe microphones ............................................... 37
       5.2.2. Phase calibration of the sound intensity probe (to do at least one time) ................................. 37
       5.2.3. Residual pressure intensity index measurement ..................................................................... 37
   5.3. HARDWARE CONFIGURATION (FOR SOUND POWER MEASUREMENTS) ........................... 37
   5.4. SOUND POWER MEASUREMENTS : DBFA32 ......................................................................... 38
       5.4.1. Definition of the measurement surface (mesh) ...................................................................... 38
       5.4.2. Acquisition .............................................................................................................................. 38
       5.4.3. Pre-processing of the results ................................................................................................ 38
   5.5. TAKE ACTIONS TO ACHIEVE THE DESIRED GRADE OF ACCURACY (ISO9614 CONFORMITY) .......................................................... 38
   5.6. RESULTS’ EXPLOITATION ............................................................................................................ 38

6. CALIBRATION : DBSOND32 ................................................................................................................... 39
   6.1. HARDWARE CONFIGURATION ..................................................................................................... 39
   6.2. DEFINITION OF THE SOUND INTENSITY PROBE .................................................................... 40
       6.2.1. Important notice ...................................................................................................................... 41
   6.3. PRESSURE CALIBRATION OF THE MICROPHONES ................................................................. 41
   6.4. PHASE CALIBRATION OF THE SOUND INTENSITY PROBE ..................................................... 42
   6.5. PRESSURE RESIDUAL INTENSITY INDEX MEASUREMENT ..................................................... 45
       6.5.1. Manual entry .......................................................................................................................... 45
       6.5.2. Measurement ......................................................................................................................... 46

7. HARDWARE CONFIGURATION OF INTENSITY METER : DBFA32 .................................................. 49

8. SOUND POWER MEASUREMENTS : DBFA32 .................................................................................... 53
8.1. SELECTION OF THE MEASUREMENT METHOD AND THE MEASUREMENT SURFACE ..................................................53
  8.1.1. Definition of a parallelepiped mesh ..................................................................................................................54
  8.1.2. Definition of a mesh from a list of points and surfaces ..................................................................................54

8.2. ACQUISITION – PRELIMINARY MEASUREMENTS ..................................................................................................55
  8.2.1. Measurement information window and save options ..........................................................................................55
  8.2.2. Pressure calibration of the microphones ...........................................................................................................56
  8.2.3. Stationarity check of the sound field (ISO9614 – part 1 only) ...........................................................................56
  8.2.4. Calibration check by inverting the probe .............................................................................................................59

8.3. ACQUISITION – SOUND POWER MEASUREMENTS ..................................................................................................61
  8.3.1. Parameters .........................................................................................................................................................61
  8.3.2. Sound power measurements without remote control .........................................................................................63
  8.3.3. Sound power measurements with a remote control ...........................................................................................63
  8.3.4. General remarks ...................................................................................................................................................64

9. PROCESSING OF THE RESULTS ........................................................................................................................................65
  9.1. MESH DISPLAY .........................................................................................................................................................65
  9.2. POINTS’ LIST .............................................................................................................................................................65
  9.3. LISTING OF THE RESULTS PER POINT ................................................................................................................66
  9.4. GRAPHICAL PLOT OF THE RESULTS PER POINT ..................................................................................................68
  9.5. LISTING OF OVERALL RESULTS ..........................................................................................................................71
  9.6. GRAPHICAL PLOT OF OVERALL RESULTS ...........................................................................................................73
  9.7. NOISE MAP (ISO CONTOURS) OF THE OVERALL RESULTS .....................................................................................76

10. OBTAINING THE DESIRED GRADE OF ACCURACY : ISO9614 .........................................................................................79
  10.1. STATIONARITY CHECK (DISCRETE POINT METHOD – PART 1) ..............................................................................79
  10.2. SOUND POWER MEASUREMENTS .........................................................................................................................81
    10.2.1. Procedures to improve criterion 1 of the standard (Ld > F2) ..............................................................................81
    10.2.2. Procedures to improve criterion 2 of the standard (ISO9614 part 1 only) ....................................................81
  10.3. EXAMPLE OF MEASUREMENT USING THE ACTIONS TO IMPROVE THE GRADE OF ACCURACY .........................83
    10.3.1. Problematic .........................................................................................................................................................83
    10.3.2. Improving Stationarity criterion (F1 indicator) .....................................................................................................84
    10.3.3. Improving criterion 2 .........................................................................................................................................84

11. RESULT EXPLOITATION ..................................................................................................................................................89
  11.1. EXPORTING DATA TO A SPREADSHEET OR WORD PROCESSOR ...........................................................................89
  11.2. PRINCIPLE AND CONFIGURATION OF THE COPY COMMAND ...........................................................................90
  11.3. PRINTING RESULTS ..................................................................................................................................................90

12. BIBLIOGRAPHY ...............................................................................................................................................................91
  12.1. PRE-ACOUSTIC INTENSITY MEASUREMENT ...........................................................................................................91
  12.2. RECENT DEVELOPMENT OF THE TWO MICROPHONE METHOD ............................................................................91
    12.2.1. Principle and general themes ...............................................................................................................................91
    12.2.2. Particular aspects ....................................................................................................................................................92
    12.2.3. Applications ............................................................................................................................................................92
    12.2.4. Standards ...............................................................................................................................................................92
1. THEORETICAL ASPECTS

We deal in this chapter with the theoretical aspects of sound intensity measurements and sound power determination using sound intensity.

1.1. Acoustic intensity

**Acoustic intensity** is a magnitude that corresponds to an energy flux density per unit time. It is expressed in W/m² and is determined from the product of acoustic pressure and particle velocity.

\[ \vec{\Pi}(t) = p(t) \times \vec{V}(t) \tag{1} \]

The pressure may be represented by \( P \cos(\omega t) \) and the velocity as \( \vec{V} \cos(\omega t + \theta) \) at a point in space, for a sound wave of rotational frequency \( \omega \). \( \theta \) being the phase angle between pressure and velocity.

Hence an equation is obtained that defines the **instantaneous acoustic intensity**:

\[ \vec{\Pi}(t) = PV \cos^2(\omega t) \cos(\theta) - \frac{PV}{2} \sin(2\omega t) \sin(\theta) \tag{2} \]

The first term describes an **energy transfer** conveyed by the sound wave. The term \( \cos(\theta) \) indicates that this part is in phase with pressure and velocity. The second term corresponds to an oscillation of energy around a fixed point for which the mean value in time is zero. Analogous with electrical phenomena, it is described as **reactive intensity**.

It is the **time-averaged value** of the instantaneous intensity defined by equation (1) that is the magnitude currently used

\[ \bar{I} = \langle p \cdot \vec{V} \rangle = \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} p(t) \vec{V}(t) dt \tag{3} \]

It is only dependent on the first term of equation (2) as the reactive part is eliminated by integration (term \( \sin(2\omega t) \)).

The **average intensity** \( \bar{I} \) only represents the **energy transfer**. According to equation (2), when pressure and speed are separated by a 90°-phase shift, the average intensity is zero, the phenomena is purely reactive and no energy transfer produced by the sound wave is observed.

As it is particularly difficult to measure particle velocity directly, **approximations** have developed that are based on a measurement of RMS pressure using the equation.

\[ |\bar{I}| \approx \frac{<p^2>}{\rho c} \tag{4} \]

\( \rho c \) is the characteristic impedance the propagation medium where \( \rho \) is the density of air and the speed of sound.
This formula assumes free field radiation where pressure and velocity are in phase, thus $\cos(\theta) = 1$ for equation (2) such is the case for a progressive plane for which:

$$V(t) = \frac{p(t)}{\rho c}$$

In practice, conditions vary from this ideal and the relationship is not sufficient, particularly where sound sources are in close proximity or where reactive components or interference are present.

In addition, the scalar nature of the approximation $< p^2 > / \rho c$ means that all vector information is lost from the acoustic intensity concept.

Two examples are discussed in order to clarify these problems:

- Standing wave measurements.
- Calculation of acoustic pressure in a noisy fluid.

### 1.2. Standing Wave measurements

A pressure wave $P\cos(\omega x - kx)$, $P\cos(\omega x - kx)$ incident at 90° to a perfectly reflective surface produces an identical reflected wave but propagated in the inverse sense: $P\cos(\omega x + kx)$ ($k = \omega / c$ is the wave number).

Superposition of these two phenomena produces a standing wave.

$$p(t) = P[\cos(\omega x - kx) + \cos(\omega x + kx)]$$

$$p(t) = 2P \cos(kx) \cos(\omega x)$$

And $< p^2 > / \rho c = \frac{2P^2}{\rho c} \cos^2(kx) = \frac{P^2}{\rho c} (1 + \cos(2kx))$

The approximation $< p^2 > / \rho c$ describes the succession of nodes and pressure anti-nodes characteristic of a standing wave. One can equally notice that the speed is out of phase by 90° with the pressure at all points, indicating that the intensity is zero everywhere. There is no energy transfer in an ideal standing wave.

If the surface is not perfectly reflective (a Reflection coefficient $R < 1$), some energy transfer will occur. The approximation $< p^2 > / \rho c$ always appears as level fluctuations.

$$< p^2 > / \rho c = \frac{2P^2}{\rho c} \left(1 + R^2 + 2R \cos(2kx)\right)$$

While the acoustic intensity corresponding to the equation (3) contains a constant value:

$$\left| I \right| = \frac{P^2}{2\rho c} (1 - R^2)$$

The factor $1 - R^2$ represents the absorption coefficient (of the surface).
In the conditions of standing waves and more generally in diffuse fields, the approximation of the acoustic intensity by the quadratic pressure is no longer useful to describe acoustical energy transfer.

Examples of interference are commonly found in industrial environments where they are caused by reflections from walls or by different sound sources having a common mechanical excitation (coherent source).

In some instances, the results given by the quadratic pressure measurements totally obscure the energy transfer phenomena produced by the acoustic influence of a particular piece of equipment. The following chapter examines the limitations of the quadratic pressure estimation with regard to industrial applications.
1.3. Determination of sound power

Sound power $W$ radiated from a sound source is defined as the total sum of the sound energy flux that crosses a surface that completely envelopes this source.

Mathematically this may be defined by:

$$ W = \int_\Sigma (\text{flux density}) dS $$

The flux density that crosses the area ($\Sigma$) corresponds to the acoustical intensity vector component $\vec{I}$ of the vector normal to a surface element $dS$:

$$ (\text{Flux density}) = \vec{I} \cdot \hat{n} = I_n $$

Where it is impossible to directly measure the acoustic intensity in the normal direction of the measurement envelope, it is possible to substitute the quadratic pressure measurement:

$$ I_n \cong \frac{< p^2 >}{\rho c} $$

It is this measurement that is adopted for existing standards regarding sound power calculations.

The approximation is effective providing certain conditions are met simultaneously:

- **H1**: Pressure and velocity are in phase.
- **H2**: The measurement envelope corresponds to the wave front produced by the source rays.
- **H3**: The source is under free field conditions.
- **H4**: The noise source does not contain perturbations.
**H3** and **H4** are fulfilled when measurements are carried out in an anechoic environment. For pressure and speed to be in phase (**H1**) it is necessary to distance the field from the source. (**H2**) is more difficult to satisfy but acceptable results can be obtained by choosing a **spherical** measurement envelope (or **hemisphere** for a source on a reflective plane) where the radiated beams are sufficiently greater than the dimensions of the source which should be considered as a point source.

For **H1**, **H3** and **H4**, the scalar quantity $<p^2>/\rho c$ corresponds to the acoustic intensity modulus $I$. The choice of an spherical or hemispherical envelope in order to measure a **source of very small dimensions** can result in the acoustic intensity vector $I$ being coincident with the vector normal ($H2$ condition): the normal component $I_n$ is then equated to the modulus $|I|$.

![Figure 2: Determination of sound power over a hemispherical envelope.](image)

For machines with **significant dimensions**, it is necessary to choose a **parallelepipedal** measurement envelope that is more suitable for the geometry of the machine: the hypothesis ($H2$) is not fulfilled thus a **projection error** is introduced that increases the true value.

![Figure 3: Determination of the sound power on a parallelepiped envelope.](image)
For very large machines, where when the free space around the source is significantly reduced, the parallelepiped measurement envelope is within the near field of the source, thus invalidating the hypothesis (H1). The approximation based on the quadratic pressure gives quantities greater than the intensity module. A near field error factor can be added to the accuracy projection.

**Figure 4: Determination of the sound power in the near field.**

For industrial site applications, the measurement envelopes are frequently found in close proximity to reflective surfaces or within a reverberating medium. In many cases, the test area is particularly noisy. Hypothesis (H3) and (H4) are invalid and the power radiated by the source becomes caught up in the environment and added to disruptive sources.

**Figure 5: Acoustic power determined from quadratic pressure measurements in different industrial environments**

An increase due to reflections

An increase due to parasitical source contributions
**Standards** have defined calculation methods for a correction coefficient, which takes account of the environment. However, these methods are restrictive and often prove to be ineffective for industrial environments, particularly when perturbed noise sources are very close to the envelope or that their noise level is high.

The calculation of acoustic pressure by approximation of the quadratic pressure gives results that are totally erroneous.

These examples illustrate the limiting nature of the approximation \( < p^2 > / \rho c \) when attempting to measure acoustic intensity directly \( \Delta r < p \vec{V} > \).

Another particularly important advantage, not developed in this paper, concerns the vector aspect of the intensity \( < p \vec{V} > \). This has particular application in the location of noise sources and in spatial analysis of energy transfer fields.
2. PRACTICAL ASPECTS

In this chapter, we deal with the theoretical and practical aspects of sound intensity and sound power measuring instruments.

2.1. Historical aspect

Developments in acoustic measurement instrumentation have not accompanied the general development of acoustic theory. It was not until 1932 that the first acoustic intensity meter was patented by OLSON [1]. He developed a system that calculated the average product of signals originating from a pressure microphone and a ribbon microphone sensitive to the pressure gradient.

The idea was developed by CLAPP and FIRESTONE (1941) [2] and more recently by BURGER [5] in 1972. BAKER (1955) [3] made a device where the ribbon microphone was replaced by a hot wire anemometer. The problem common to all these methods was the inability to take pressure and speed-readings at the same point. This caused a phase mismatch, setting a limit on the frequency range and causing distortions in the direction curve.

A solution to determine the pressure and speed at the same point is the now commonly device that sample the pressure field using two microphones placed together. In 1956, SHULTZ [4] built the first instrument that consisted of a pair of condenser microphones mounted back to back. He had to wait until 1977 before the laboratories were seriously interested to proceed with a view to industrial applications.

Several studies were undertaken simultaneously by PAVIC [6], FAHY [7, 9], LAMBRICH and STAHEL [10], LAMBERT and BADIE-CASSAGNET [8] and CHUNG [11]. These authors investigated on the whole two types of intensity level meters using the two microphone principle: one that was based on analogue electronic systems and the other utilising Fast Fourier Transform (FFT) analysis, a method that has developed rapidly with digital signal processing methods.

In 1981, the first International Congress on the subject was held [12]. This enabled an appraisal of research to date and marked the start of industrial applications.
2.2. The two microphone method principle

Both the above methods use the same principle of measuring the pressure gradient by finite difference approximation. Two signals are captured from two microphones separated by a small spacer: one method derives an expression of the intensity in the time domain (analogue intensity measurement) while the other derives an equivalent spectral formula using Fast Fourier Transform analysis (FFT intensity level meter).

As the particle velocity in the acoustic field is not measured directly, the relationship defined by Euler may be employed that states equivalence between the velocity and the pressure gradient under linear and steady state conditions:

\[ v_r = -\frac{1}{\rho} \int \frac{\partial p}{\partial r} \, dt \]  

(7)

The velocity is obtained by integration of the pressure gradient estimated for the acoustic centre of the probe, by taking the difference in pressure from the two readings and dividing by the distance between them. This is referred to as the finite difference approximation of the acoustic velocity, calculated in the direction \( r \), from pressures measured by two microphones separated by a distance \( dr \):

\[ \tilde{v}_r = -\frac{1}{\rho} \int \frac{P_2 - P_1}{\Delta r} \, dt \]  

(8)

With \( \beta_c = \frac{P_2 + P_1}{2} \) as approximation of the average pressure for the acoustic centre, a point situated between the two microphones. The value approaching the component in the \( r \) direction of the acoustic intensity is (according to equation (3)):

\[ \tilde{I}_r = < \tilde{p} \tilde{v}_r > = \frac{1}{2\rho \Delta r} < (p_1 + p_2) \int (p_1 - p_2) \, dt > \]  

(9)

This formula for acoustic intensity is derived from the sound pressure signals captured from two microphones as a function of time. The schematic representation below shows the structure of a measurement instrument that uses analogue electronic circuits [7, 10].

Figure 6: Schematic of the structure of a time based acoustic intensity meter
If some filters (third octave for example) were included in the circuit, one would obtain a spectral analysis of the acoustic intensity. There is another method to bring about a spectral representation of the acoustic intensity: the use of the Fourier Transform.

For stationary signals, one notes an equivalent spectral representation according to equation (3):

\[ I_r = \langle p \cdot v \rangle = \int_{-\infty}^{\infty} I_r(\omega) \frac{d\omega}{2\Pi} \]  

(10a)

Where \( I_r(\omega) \) is the spectral density of the intensity represented by the real part of the cross spectrum between pressure and velocity (Parseval theory):

\[ I_r(\omega) = \text{Re} \{ S_{pv} \} \]

By using Eulers relationship in terms of the Fourier Transform and approximations for \( \frac{\partial p}{\partial r} \) and \( p \), it is possible to reach an expression describing the spectral intensity using the imaginary part of the cross spectra of the pressure signals obtained from the two microphones. [9, 11]:

\[ \tilde{I}_r(\omega) = \frac{1}{\rho \Delta r} \frac{\text{Im} \{ S_{21} \}}{\omega} \]  

(11)

This formula is a significant development in the two-microphone method as it offers a simple measurement system for acoustic intensity using FFT spectra for 2 channels: The principle is illustrated below:

![Diagram of an acoustic intensity meter based on F.F.T. analysis](image.png)
2.3. Limitations to microphone based intensity meter

This chapter examines the degree of accuracy inherent in the two-microphone intensity level meter discussed in the preceding chapters.

2.3.1. Systematic errors: finite difference approximation principle

The first source of error is linked directly to the finite difference approximation underlying the measurements. Spatial information is lost as soon as their order of magnitude corresponds to the distance $\Delta r$ that separates the two microphones. It is an effect known as “instrumental convolution” that amounts to a low frequency limit as it tends the intensity meter range towards the high frequencies. It is represented by the convolution factor, described by the following relationship [15]:

$$\delta = \frac{\text{approaching intensity } \tilde{I}_r}{\text{real intensity } I_r}$$

For a progressive wave, the fading is greatest when the wave propagates in the direction $r$ according to the alignment of the microphones, as illustrated by figure 8. Thus it is possible to define an operative frequency limit that tends towards the high frequencies by using the attenuation criteria of 3Db for a plane wave (convolution factor $\delta = \frac{1}{2}$).

Theoretical cut off frequency $F_T = \frac{1.9c}{2\pi \Delta r}$  \hspace{1cm} (12)

The instrumental convolution effect can also create errors when the two-microphone device is too close to a point source. Increasing the distance between point source and microphones quickly reduces the influence of these additional errors. As a precaution it is advisable to have a distance of at least ($\approx 5\Delta r$) between the point of measurement and local noise sources.

![Graph](image.png)

Figure 8: Graph to show the limitation linked to the principle of the two-microphone method, Convolution factor for a plane wave and theoretical cut off frequency $F_T$
2.3.2. **Systematic errors: microphone transducers**

The second source of error is due to the microphone transducers that cause interactive disturbances in the pressure field.

The effects of **diffraction** may be observed whose severity depends on the size and geometry of the microphones. If diffraction effects are on a small scale compared to the distance \( \Delta r \) (for example, 1/8-inch microphones for a distance \( \Delta r \) in the order of cm) the perturbations are barely perceptible.

If this condition is not satisfied (for example 1/2 inch microphones for \( \Delta r = 1 \) cm) the arrangement of the microphones is more serious. Several experimental studies have been undertaken in order to define the optimum arrangement for a progressive wave [12] though little is understood for more complex fields.

2.3.3. **Systematic errors: distortions of measuring instruments**

Thirdly, the disturbance caused by the measurement apparatus may introduce significant errors to the intensity calculation even if the apparatus meets current Standard requirements.

In particular the relative phase difference between measurement channels is the most important factor in determining the accuracy of the results.

Let us consider the case of a progressive plane wave that propagates in the direction \( r \). The signal captured by microphone 1 is identical to the signal captured by microphone 2 though delayed by a time \( \tau = \Delta r / c \) as a result of the separation distance between the two microphones (\( c \)= the speed of sound). This distance corresponds to a phase difference between the two signals that varies linearly with frequency (figure 9):

\[
\varphi_{21} = \omega \tau = k \Delta r
\]

\[
k = \frac{\omega}{c} \quad \text{wave number}
\]

![Figure 9: Phase difference between the microphone signals in a plane wave (\( \Delta r = 1 \) cm)](image-url)
The equation that describes the intensity spectrum (equation 11) may also be written under the form

\[
\bar{I}_r = \frac{1}{\rho \Delta r} \frac{\Im \{ S_{z1} \}}{\omega} = \frac{|S_{z1}|}{\rho c} \frac{\sin \varphi_{z1}}{k \Delta r} \tag{13}
\]

Illustrating the fine line that exists between acoustic intensity and the phase measurement \(\varphi_{21}\). As a result a relative phase between caused by the instrument channels will have significant consequences to the accuracy of the intensity measurement, particularly in lower frequencies where \(\varphi_{21}\) becomes very weak.

For the case of a progressive plane wave measurement having a phase distortion \(\Delta \varphi\) between the channels, the transfer characteristic is defined by the relationship:

\[
\frac{\text{Component of the intensity measurement in the direction } r}{\text{true intensity modulus}} = \frac{\bar{I}_r}{\bar{I}}
\]

is of the form [15]

\[
\frac{\bar{I}_r}{\bar{I}} = \left( \cos \alpha + \frac{\Delta \varphi}{k \Delta r} \right) \Pi \tag{14}
\]

This transfer characteristic for an ideal intensity meter corresponds to its curve of directivity: \(\cos \alpha\) (projection of the intensity vector modulus \(\bar{I}\) on the direction \(r\) as a function of the incidence angle \(\alpha\)).

From a position below the theoretical cut off frequency \(F_T\) the convolution factor \(\Pi\) is close to 1 and the equation (14) shows that the directivity curve is affected by the phase error \(\Delta \varphi\) (see figure 9).

This effect is so sensitive that the factor \(k \Delta r\) tends towards the same order of magnitude as \(\Delta \varphi\) with the result that the measurement inclines towards the lower frequencies.

It may be concluded that the intensity level meter is limited in practice to lower frequencies by phase difference effects: to achieve an order of magnitude of 200 Hz, a relative phase mismatch of one degree between the two channels would result in an error of 3 dB for a distance \(\Delta r\) of 1 cm between microphones.

For a given phase mismatch the significance of the error depends on \(\Delta r\) and more precisely on the factor \(k \Delta r\). The high frequency limitation also depends on \(k \Delta r\), since the magnitude of the relative phase error determines the upper frequency limit of the intensimeter.

Using the preceding example a phase mismatch of \(1^\circ\) allows a pass band of 3 dB of approximately 5 octaves and half.
Figure 10 Distortions of the directivity characteristic of a two-microphone intensity level meter under the influence of instrumental phase mismatch between the measurement channels and a progressive wave.

Important notice:
The preceding analysis considers measurements of a pure progressive wave for which the phase difference between the microphones in the direction of propagation would be $\Delta \phi$. For a more complex field, for example in a standing wave or in a diffuse field; the phase measurement $\phi_{21}$ is often much less than $\Delta \phi$. Phase mismatch effects may be much more noticeable than have been discussed so far.

So far the discussion has concerned phase errors introduced by microphones with rear mounted electronic circuits. The time based intensity level meter described by figure 6 can introduce another type of instrument based phase difference for circuits placed in front of the averaging multiplier.

At this level, the signals are analogous to acoustic pressure and acoustic velocity. It has been shown in equation (2) that active and reactive intensities are proportional respectively to the cosine and sine of the phase $\theta$ of velocity with respect to pressure. In this way, if these two quantities are in phase, $\cos \theta$ is equal to 1 and the intensity is purely active: a fluctuating phase mismatch $\Delta \Psi$ due to the electronics will have negligible influence on the intensity level meter readings. In the case of a measurement in a predominantly reactive field (in a near field or interference zone...), most of the signal is out of phase, thus $\cos \theta \ll 1$. A phase mismatch on $\theta$ would cause part of the reactive component of the intensity measurement to be transformed into an active part, creating distortion in the measurement.
2.3.4. Statistical errors

So far we have examined systematic errors. For industrial noise applications, errors due to statistical estimations during the calculation time T must also be considered.

For example, for the quadratic pressure \( <p^2> / \rho \), the relative standard deviation is equivalent to 
\[
\frac{1}{\sqrt{B T}} \quad (B \text{ is the width of the pass band used during the measurement}).
\]

The acoustic intensity measurement is not simply an estimation of level. Its accuracy depends on the estimation of phase difference between the pressure signals captured by the two microphones in a wave which is propagated in a free space; these signals are perfectly coherent and their phase relationship is purely deterministic: the standard deviation of the intensity corresponds to that of a simple pressure squared calculation.

If on the other hand we consider several independent sound sources active within the space, the pressure signals sampled at two points in the field are not totally coherent. [16].

It is the phenomena of diffusion in which the extreme case is that of a reverberating room. The relationship of instantaneous phase that exists between these pressures is in part uncertain and the estimation of the mean value is influenced by an additional statistical uncertainty on the phase that has as for all systematic errors; an influence particularly in the lower frequencies which contributes to the limitation on the dynamic range of the intensity level meter.

**Important remark:** All these errors are linked to the nature of the acoustic field.
2.4. Calculation of sound power in a noisy environment

In the preceding chapters we have discussed various error sources that increase the acoustic power measurement when the approximation $\frac{\langle p^2 \rangle}{\rho c} < 2$ is employed. Direct measurement of the acoustic intensity component in the normal direction to the measurement envelope enables errors in the near field to be eliminated (when $p$ and $v$ are no longer in phase) and the projection errors (when the measurement surface does not correspond to a wave front).

The measurement envelope can be chosen to be in proximity to the machine, as industrial site conditions usually impose. However, of most interest in acoustic intensity measurements is the ability to extract the acoustic power measurement from the surrounding noise.

This is based on Gauss theorem for acoustic energy transfer fields: the sum of the total energy flux that crosses a closed surface is zero. This problem of calculating acoustic power in a noisy environment is shown schematically in Figure 12.

The summation of Figure 12 under represents an infinite number of measurement points that does not take account of sampling estimation errors.

In this way, the effectiveness of the intensity measurement method to diminish the influence of the environment is limited by the reduction of the number of points in the measurement. As a result, due to some ambiguity in the flux level crossing the system boundary, there is a residual power, which brings some uncertainty into the calculation. The significance of this uncertainty depends on the level of back ground noise in relation to the noise emanating from the measurement source.

Observations have recorded a reduction in the influence of noise perturbations of 10 to 15 dB with respect to the pressure readings. In these circumstances it is possible to calculate acoustic pressure using methods that are not normally effective.

Figure 12: Determination of acoustic pressure in a noisy environment.
3. **STANDARDISATION**

The measurement of sound power using sound intensity would not be possible without a strict definition of the measuring equipment itself. These requirements are regrouped in the international standard **IEC1043** – The North American equivalent being named **ANSI S1-12**.

This standard classifies the measurement instruments in two categories: Type 1 and Type 2. Amongst other requirements, it specifies a minimum pressure-residual intensity index $\delta P_{I_0}$ of the intensity measurement system in each frequency and of measurement, and for every probe configuration used.

The measurement standards are classified according to the methodology used: measurements at discrete points and measurement by scanning.

The **discrete points’ technique** is now very precisely described in the international standard **ISO 9614 part 1** and their national equivalents. The North Americans have adopted the standard **ANSI S12-21**, which is greatly different from the ISO9614-1 standard, especially for the number of field indicators to validate the measurement results.

The **scanning technique** is more recent. It is described in the international standard **ISO 9614 part 2** and their national equivalents. This technique aims to lighten the measurement process in order to obtain results faster, but at the expense of a high grade of accuracy.

### 3.1. Remarks for sound power determination using sound intensity

In fact, the sound power radiated by a source is defined by the surface integral of the normal component of the intensity vector $\mathbf{I}$. The surface $S$ is a closed surface that englobes the sound source under investigation (see **chapter 1.3**). In practise, the surface is constituted of $N$ smaller ‘discrete’ surfaces.

![Figure 13: Measurement surface](image)

Below are a few remarks for the determination of sound power using the sound intensity technique:

1. The measurement surface must strictly enclose the source under investigation.
2. All forms of surfaces are acceptable.
3. The method allows the operator to perform measurements with extraneous noise sources.
4. Noise generated by the source under investigation and extraneous noise sources must be stationary during the measurement period.
5. No absorbent material should be located in the inner volume of the closed measurement surface in order to avoid an imbalance of the overall sound energy between the sources under investigation and the extraneous noise sources.
6. Measurements can be carried out in any environment that does not impose any restriction on the type of sound field.
7. Measurements can be performed either in the near field or the far field.
3.2. ISO9614 Part 1 standard (measurement at discrete points)

3.2.1. Overview

This standard is different from classical based on sound pressure measurements. First of all, sound calculations are based upon discrete point sampling of the intensity field normal to the measurement surface, which modify greatly the practical measurement process. Secondly, the uncertainty of the determination of sound power level is estimated from measurement results as well as calculations of field indicators.

In the standard, three grades of accuracy are defined:

- Precision (grade 1),
- Engineering (grade 2),
- Survey (grade 3),

The uncertainties associated to the grades of accuracy are given in table 1.

<table>
<thead>
<tr>
<th>Octave band centre frequencies Hz</th>
<th>One-third octave band centre frequencies Hz</th>
<th>Standards deviations $s^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Survey (grade 3) dB</td>
</tr>
<tr>
<td>63 - 125</td>
<td>50 - 160</td>
<td>-</td>
</tr>
<tr>
<td>250 - 500</td>
<td>200 - 630</td>
<td>-</td>
</tr>
<tr>
<td>1 000 - 4 000</td>
<td>800 - 5 000</td>
<td>-</td>
</tr>
<tr>
<td>8 000</td>
<td>6 300 - 10 000</td>
<td>4</td>
</tr>
<tr>
<td>A weighted $^2$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. The true value of the sound power level is to be expected with a certainty of 95% in the range of $s^1/2$ about the measured value.
2. 63 Hz to 4 kHz or 50 Hz à 6.3 kHz
3. Because of great variety of instruments available for application of this standard, this value is only given as test value.

Table 1 – uncertainty of determination of sound power level

Four field indicators have to be calculated to validate the measurement result:

- $F_1$: Sound field temporal variability indicator.
- $F_2$: Surface pressure – intensity indicator.
- $F_3$: Negative partial power indicator.
- $F_4$: Field non-uniformity indicator.

Finally, the grade of accuracy to obtain depends upon two criteria:

- Criterion 1: Adequacy of the measurement equipment
- Criterion 2: Adequacy of the test environment
3.2.2. How to perform sound power measurements according to standard

In order to determine a sound power level using sound intensity, three different types of measurements are required:

- Measurement of the pressure-residual intensity index corresponding to the intensity meter used.
- Measurement of sound intensity level in each characteristic point of the surface.
- Measurements of sound intensity levels and sound pressure levels for each point defining the measurement surface enclosing the noise source under investigation.

Optionally, to check the quality of the measurement equipment, a *calibration check by inverting the probe* on one point of the measurement mesh can be performed. The two values of intensity normal to the surface must have opposite signs and the difference between the two sound intensity levels shall be less than 1.5dB in octave or third octave frequency bands.

The first step will allow the operator to determine the dynamic capability index of the intensimeter by the formula:

\[
L_d = \delta p I_0 - K \text{ (dB)}
\]  
(15)

Where \(\delta p I_0\) is the pressure-residual intensity index (in dB) measured when the intensity probe is placed and oriented in a sound field such that the sound intensity is zero and \(K\) is a bias error factor selected according to the grade of accuracy required (see table 2).

<table>
<thead>
<tr>
<th>Grade of accuracy</th>
<th>(K) in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 9614 - 1</td>
<td></td>
</tr>
<tr>
<td>Survey</td>
<td>7</td>
</tr>
<tr>
<td>Engineering</td>
<td>10</td>
</tr>
<tr>
<td>Precision</td>
<td>10</td>
</tr>
</tbody>
</table>

The second step will allow the operator to estimate the temporal variability of the sound field by the formula:

\[
F_1 = \frac{1}{I_n} \left[ \frac{1}{M-1} \sum_{k=1}^{M} (I_{n,k} - \bar{I}_n)^2 \right]^{1/2}
\]  
(16)

Where:

- \(I_n\) is the mean energy value in W/m\(^2\) of \(M\) measurements of sound intensity normal to the surface for a given discrete point selected by the operator.
- \(I_{n,k}\) is the \(K\)th measurement performed. A recommended short averaging time is between 8 and 12 seconds, or any integer of cycles for periodic signals.
- \(M\) will normally take a value of 10.

The \(F_1\) indicator is in fact a standard deviation.

Finally, the third step will give all the required elements to calculate the sound power levels, but also the field indicators \(F_2\), \(F_3\) et \(F_4\).
The surface pressure – intensity indicator $F_2$ shall be calculated from the equation:

$$F_2 = \overline{L_p} - \overline{L_I} \quad \text{(dB)} \quad (17)$$

Where: $\overline{L_p}$ is the surface sound level in dB calculated from the formula:

$$L_p = 10 \log_{10} \left[ \frac{1}{N} \sum_{i=1}^{N} L_{pi} \right] \quad (18)$$

$N$ is the total number of measurement points on the surface enclosing the source:

$\overline{L_{|I|}}$ is the surface normal unsigned sound intensity level calculated from the equation:

$$\overline{L_{|I|}} = 10 \log_{10} \left[ \frac{1}{N} \sum_{i=1}^{N} I_{ni} \right] \quad (19)$$

The negative partial power indicator $F_3$ shall be calculated from the equation:

$$F_3 = \overline{L_p} - \overline{L_{In}} \quad (20)$$

Where: $\overline{L_{In}}$ is the surface normal sound intensity level.

Finally, the field non-uniformity indicator $F_4$ is given by:

$$F_4 = \frac{1}{I_n} \left[ \frac{1}{N-1} \sum_{i=1}^{N} (I_{ni} - \overline{I_n})^2 \right] \quad (21)$$

Where: $I_n$ is the surface normal sound intensity.

$I_{ni}$ is the sound intensity for each point of the measurement surface.

$F_4$ is equivalent to a standard deviation.

The field indicators defined above allows the operator to check the following criteria:

- **Check for the adequacy of the measurement equipment:**
  
  **Criterion 1 - $L_d > F_2$** \quad (22)
  
  The dynamic capability index of the intensity meter must be greater than the value of the surface pressure intensity indicator in each frequency band of measurement.

- **Check for the adequacy of the chosen array of measurement points:**
  
  **Criterion 2 - $N > CF_4^2$** \quad (23)
  
  The number $N$ of probe positions uniformly distributed over a chosen measurement surface is regarded as sufficient if the criterion 2 is fulfilled. The factor $C$ is given in Table 3.

<table>
<thead>
<tr>
<th>Octave band centre frequencies Hz</th>
<th>One-third octave band centre frequencies Hz</th>
<th>Factor C</th>
</tr>
</thead>
<tbody>
<tr>
<td>63 à 125</td>
<td>50 à 160</td>
<td>Precision (class 1)</td>
</tr>
<tr>
<td>250 à 500</td>
<td>200 à 630</td>
<td>Engineering (class 2)</td>
</tr>
<tr>
<td>1 000 à 4 000</td>
<td>800 à 5 000</td>
<td>Survey (class 3)</td>
</tr>
<tr>
<td>A weighted¹</td>
<td>6300</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14</td>
</tr>
</tbody>
</table>

(1) 63 Hz to 4 kHz or 50 Hz to 6,3 kHz

- **Check the presence of strongly directional extraneous sources:**

$$F_3 - F_2 \leq 3 \text{ dB} \quad (24)$$
Table 4 specifies the actions to be taken to increase the grade accuracy of determination of the sound power level.

Finally, the sound power level is given by

\[ L_{PW} = 10 \log \left( \sum_{i=1}^{N} \frac{P_i}{P_0} \right) \]

Where \( P_i = \ln S_i \)

Figure 14 summarises the procedure for achieving the desired grade of accuracy according to the specifications of ISO 9614 – 1 standard.

<table>
<thead>
<tr>
<th>CRITERION</th>
<th>ACTION CODE</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_1 &gt; 0.6 )</td>
<td>e</td>
<td>Take action to reduce the temporal variability of extraneous intensity or measure during periods of less variability or increase the measurement period at each position (if appropriate)</td>
</tr>
<tr>
<td>( F_2 &gt; L_d ) or ( (F_3 - F_2) &gt; 3 \text{ dB} )</td>
<td>a</td>
<td>Reduce average distance of measurement surface from source to a minimum average value of 0.25m. If no significant extraneous source or reverberation are present, increase the average distance up to 1 m. or b</td>
</tr>
<tr>
<td>Criterion 2 not satisfied and ( 1 \text{ dB} \leq (F_3 - F_2) \leq 3 \text{ dB} )</td>
<td>c</td>
<td>Increase the density of measurement positions uniformly in order to satisfy criterion 2</td>
</tr>
<tr>
<td>Criterion 2 not satisfied and ( (F_3 - F_2) \leq 1 \text{ dB} ), and the procedure of 8.3.2 (see standard) either fails or is not selected</td>
<td>d</td>
<td>Increase average distance of measurement surface from the source using the same number of measurement positions or increase number of measurement positions on the same surface.</td>
</tr>
</tbody>
</table>

Table 4 – Actions to be taken to increase grade of accuracy of determination
Define initial measurement surface and Measurement positions

Short $Jn$ - Indicator $F_1$

$F_1 \leq 0.6$ ?

Yes

No

Measurements of $L_p$, $L_{in}$ on initial measurement surface

Field indicators $F_2$, $F_3$

$F_2 < L_d$ ?

Yes

No

$(F_3 - F_2) \leq 3dB$ ?

Yes

No

Indicator $F_4$

$N > CF_4^2$ ?

Yes

No

* The path enclosed in broken lines represents an optional procedure designed to minimise the number of additional measurement positions required on the initial measurement surface

Additional measurement positions

Measurements of $L_p$, $L_{in}$ at additional positions

Final result

Figure 14 : Scheme for the procedure for achieving desired grade of accuracy

Oui

Non

* Oui

Non

Yes

No

$(F_3 - F_2) \leq 1dB$ ?

Yes

No

OPTION *

Action C

Action D

Action D

Action D

Figure 14 : Scheme for the procedure for achieving desired grade of accuracy
3.3. ISO9614 Part 2 standard (measurement by scanning)

3.3.1. Overview

This norm is different from ISO 9614 - 1 because it uses a scanning method over the surface enclosing the source. Indeed, sampling of the measurement surface is achieved by continuous swept measurements over a surface, as if the surface is being painted. This gives a single-value spatial average intensity. Multiplying by the area gives the sound power from this surface. Then the sound power for all the surfaces is added. Similarly to the first part of the standard, the same general remarks apply. However, only two grade of accuracy can be achieved: Engineering (grade 2) and Survey (grade 3). The uncertainty of determination of sound power level is given in Table 5.

<table>
<thead>
<tr>
<th>Octave band centre frequencies (Hz)</th>
<th>One-third octave band centre frequencies (Hz)</th>
<th>Standard deviation ( (S^2)^{1/2} ) in dB</th>
<th>Survey (grade 3) dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>63 – 125</td>
<td>50 – 160</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>250 – 500</td>
<td>200 – 630</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1 000 – 4 000</td>
<td>800 – 5 000</td>
<td>1,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 300</td>
<td>2,5</td>
<td></td>
</tr>
<tr>
<td>A weighted</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>(63 Hz - 4 kHz or 50 Hz - 6,3 kHz)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5

2 fields indicators validates the measurements:

- \( F_{pi} \) : negative partial power indicator
- \( F_{PPI} \) : sound field pressure-intensity indicator

3 criteria allow the user to achieve the desired grade of accuracy:

- Criterion 1: Adequacy of the measurement equipment,
- Criterion 2: Suitability of the measurement conditions (limit on negative partial power)
- Criterion 3: Partial power repeatability check.

3.3.2. How to perform sound power measurements according to standard

As for the discrete point method (part 1), sound power determination requires three types of measurements. However, a few differences exist.

If measurement of the pressure-residual intensity index for the intensimeter is still required calculation of the temporal variability of the sound field (\( F_{i} \) indicator) is replaced by a double measurement of sound intensity on each measurement surface.

It allows the user to estimate the repeatability of partial sound power measurements, hence of the overall sound power for the source under test.

Measurement of the pressure-residual intensity allows the user to determine the dynamic capability index of the intensimeter by the formula:

\[
L_d = \delta p_i - K \text{ (dB)} \quad (26)
\]

Where \( \delta p_i \) is the pressure-residual intensity index (in dB) measured when the intensity probe is placed and oriented in a sound field such that the sound intensity is zero and K is a bias error factor selected according to the grade of accuracy required (see table 6).

\* The true value of the sound power level is to be expected with a certainty of 95% in the range +/- 2S about the measured value.
Tableau 6

<table>
<thead>
<tr>
<th>Grade of accuracy</th>
<th>Bias error dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Survey (grade 2)</td>
<td>10</td>
</tr>
<tr>
<td>(grade 3)</td>
<td>7</td>
</tr>
</tbody>
</table>

Two individual measurements are performed by sweeping a surface segment. It will determine the spatial average sound pressure levels $L_{pi} (1)$ and $L_{pi} (2)$ and the partial sound power levels $L_{wii} (1)$ and $L_{wii} (2)$ calculated from sound intensity levels.

The two individual measurements must be orthogonal (Figure 15).

![Figure 15](image)

Scanning may be performed either manually or mechanically. In order to restrict the error to an acceptable limit, scanning shall be performed at a speed lying in the range 0.5 m/s to 1 m/s for mechanical scanning. The duration of any one scan over an individual surface must be not less than 20 seconds. The minimum distance between each surface segment and the source under test is 200 mm.

Calculation of the field indicators $F_{pi}$ and $F_{pi}$ is achieved by computation of the following equations:

\[
F_{pi} = 10 \log \left( \frac{\sum |P_i|}{\sum P_i} \right) \quad (27)
\]

Where: $P_i = <I_{ni}> S_i$ represent the partial sound power of a measurement surface segment with $<I_{ni}>$ the signed magnitude of the estimated spatial average normal sound intensity measured on the segment $i$, $S_i$ is the surface of the segment $i$ and $|P_i|$ = magnitude of $P_i$.

Note that $<I_{ni}> = [<I_{ni} (1)> + <I_{ni} (2)>] / 2$

Where $<I_{ni} (1)>$ and $<I_{ni} (2)>$ are the spatial average values of each individual scan on the segment $i$.

\[
F_{pi} = L_{wp} - L_{wi} \quad (28)
\]

Where $L_{wp}$ is the pseudo sound power level calculated from the average sound pressure levels for the two scans.

\[
L_{wi} = 10 \log \left( \sum_{i=1}^{N} \frac{P_i}{P_o} \right) \quad (29)
\]

$P_o$ is the reference sound power $10^{-12}$ W.
The calculated field indicators allows the operator to check:

- **Criterion 1 by the inequality** \( L_d > F_{PI} \)
The dynamic capability index of the intensity meter must be greater than the value of the surface pressure intensity indicator in each frequency band of measurement.

- **Criterion 2 by the inequality** \( F_{+/-.} \leq 3 \text{ dB} \)
The negative partial power indicator must be greater or equal to 3.

- **Criterion 3** that characterises the measurement repeatability check of partial sound power for each segment \( i \) based on the comparison between \( L_{wI_i}(1), L_{wI_i}(2) \) of equation (17).

\[
| L_{wI_i}(1) - L_{wI_i}(2) | \leq S
\]

Where \( S \) is defined in table 6.

\[ L_{wI_i} = 10 \log_{10} \left[ \frac{I_{PI}I}{P_o} \right] \text{ (dB)}. \]

Table 7 specifies the actions to be taken to increase the grade accuracy of determination of the sound power level.

Finally, determination of sound power is given by equation (29) used for the calculation of the field indicator \( F_{PI} \).

Figure 16 summarises the procedure for achieving the desired grade of accuracy according to the specifications of ISO 9614 – 2 standard.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>ACTION CODE</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_{PI} &lt; L_d ) and ( F_{+/-.} &gt; 3 \text{ dB} )</td>
<td>a</td>
<td>Reduce the average distance of the measurement surface from the source to not less than a minimum average value of 100 mm and double the scan line density</td>
</tr>
<tr>
<td>or</td>
<td>b</td>
<td>Shield the measurement surface from strong extraneous noise sources by means of a screen</td>
</tr>
<tr>
<td>( F_{PI} &lt; L_d ) and ( F_{+/-.} \leq 3 \text{ dB} )</td>
<td>a</td>
<td>Reduce the average distance of the measurement surface from the source to not less than a minimum average value of 100 mm and double the scan line density</td>
</tr>
<tr>
<td>(</td>
<td>L_{wI_i}^{(1)} - L_{wI_i}^{(2)}</td>
<td>&gt; s )</td>
</tr>
<tr>
<td>or</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>L_{wI_i}^{(1)} - L_{wI_i}^{(2)}</td>
<td>&gt; s ) and ( F_{+/-.} \leq 1 \text{ dB} )</td>
</tr>
</tbody>
</table>

Table 7
Figure 16: Scheme for the procedure for achieving desired grade of accuracy
4. 01DB EQUIPMENT REQUIRED

You will find below the list of 01dB hardware and software elements required to perform sound power measurements using an intensimeter.

4.1. Transducer

A Class 1 sound intensity probe from GRAS type 50AI for the SYMPHONIE measurement system. This probe is composed of the following elements:

- Probe handle marked 01dB with two pushing buttons, a LEMO14 connector and an extension cable.
- A pair of externally polarised ½ inch microphones, type GRAS 40AI with ¼ inch adapters
- 5 spacers of length 6 mm, 12 mm, 25 mm, 50 mm and 100 mm.
- 1 straight and 2 curved ½ inch - ¼ inch adapters.
- 2 ¼ inch preamplifiers with a 30 cm long cable and a LEMO4 connector type 26AA.
- An interface box for the SYMPHONIE hardware platform (One LEMO14 input, two LEMO7 outputs and one MiniDyn PS/2 output).

4.2. Accessories (options)

- Probe calibrator, type GRAS 51AB with cable BNC – LEMO4.

- Windshield for sound intensity probe.
- Tripod.
- Measurement case for SYMPHONIE system.
- Type 1 acoustical calibrator Cal01.

4.3. Measurement system

- Notebook, desktop or industrial PC that meets the minimum requirements specified to run 01dB applications software, and Windows 95/98 operating system.
- Acquisition unit connected to the PC type SYMPHONIE.
- DBSOND32 intensity calibration software package – require a white noise generator.
- DBFA32 software package to measure sound power according to ISO9614 standards and process the measurement results. The following software modules are required:
  - Base module.
  - Real-time intensity module.
  - ISO9614 (part 1 and 2) module.

All the above elements are available from 01dB. Contact your agent for further information and/or a quote.
5. MEASUREMENT PROCEDURES

Let summarise the procedures to determine sound power by sound intensity measurements according to the standard ISO9614, part 1 and 2, using a SYMPHONIE measurement system such as described in chapter 4.

5.1. System set-up

- Mount the sound intensity probe 50AI (see instruction manual delivered with the probe).
- Connect the probe to the SYMPHONIE acquisition box with the interface box.
- Boot the SYMPHONIE measurement system (see installation manual delivered with the system)

5.2. Calibration

Two types of calibration have to be performed: pressure calibration of the microphone and phase calibration of the sound intensity probe.

5.2.1. Pressure calibration of the sound intensity probe microphones

- Dismount the microphones from the probe handle and place them in the cavity of the Type 1 acoustical calibrator.
- Perform the hardware configuration in the dBSOND32 (or dBFA32) software package.
- Perform the pressure calibration of the microphones in dBSOND32 (or dBFA32).

5.2.2. Phase calibration of the sound intensity probe (to do at least one time)

- Connect the BNC – LEMO4 cable between the probe calibrator 51AB and the output of the SYMPHONIE acquisition box.
- Dismount the microphones from the probe handle and place them in the cavity of the probe calibrator.
- Perform the hardware configuration in the dBSOND32 software package.
- Perform phase calibration of the probe in the dBSOND32 software package.
- Create a phase correction datafile.

5.2.3. Residual pressure intensity index measurement

- Measure the pressure – residual intensity index in the dBSOND32 software package.

5.3. Hardware configuration (for sound power measurements)

- Define the transducers associated with each channel in coherence with the configuration used at the calibration stage in the dBSOND32 software package.
- Load the phase correction datafile corresponding to the intensity probe to be used.
- Configure and define a remote control (if applicable)
5.4. Sound power measurements: dBFA32

- Open a new or existing ISO9614 measurement session
- Give a title and comments for the measurements
- Select the measurement method (discrete point method as defined in ISO9614-1 or scanning method as defined in ISO9614-2)

5.4.1. Definition of the measurement surface (mesh)

- Select the shape of the measurement surface: parallelepiped or list of points

Parallelepiped surface
- Enter the dimensions of the source
- The mesh dimensions are automatically defined as a function of the sources’ dimensions and the standard specifications.
- Modify the automatic mesh
- Note the co-ordinates of the measurement positions

Surface made of a list of points
- Edit the number of points for the measurement mesh and the associated surface

5.4.2. Acquisition

Preliminary measurements
- Perform a stationary check (discrete point method only)
- Perform a calibration check by inverting the probe

Sound power measurements
- Choose the acquisition order
- Define and apply measurement marks around the source under test
- Perform the measurements according to defined acquisition order

5.4.3. Pre-processing of the results

- List and plot results point by point
- List and plot overall results with calculation of the field indicators according to the specifications of ISO9614 standard
- Plot results as noise maps (ISO contours)

5.5. Take actions to achieve the desired grade of accuracy (ISO9614 conformity)

If one (or more) criteria of the ISO9614 are not fulfilled, we illustrate with an example the procedure to achieve the desired grade of accuracy:

- In the stationary measurement
- In the sound power measurements

5.6. Results’ exploitation

- Export values and graphics to a spreadsheet or word processor
- Print the results
6. CALIBRATION : DBSOND32

The first step, compulsory before any sound power measurement, is to calibrate the probe's microphones (pressure calibration) then the probe itself (phase correction).

These operations can be performed in the DBSOND32 software package and the results are saved in a probe calibration data file (extension .AU), that also features two important parameters useful during the measurement process:

- The value of the pressure-residual intensity index for the complete intensity measurement system, used to calculate criterion 1 in the standard ISO 9614 (part 1 and part 2).
- The pattern of the intrinsic phase difference spectra of the intensity meter, in order to apply a phase correction during measurements.

6.1. Hardware configuration

Hardware configuration of the measurement chain is compulsory before proceeding with calibration operations and pressure-residual intensity index measurement.

1. To access hardware configuration, use the command File / Hardware Configuration, the hardware configuration window shown aside appears on screen.

   This window allows the user to select the hardware acquisition platform, defined in the software utility dBCONFIG32.

2. For the SYMPHONIE system, select the SYMPHONIE platform (by the key >>), then click on the Configuration key.

   Check in this dialog box that the signal conditioning option 200V is ticked. This is an important feature because the microphone pair of the 50Al probe requires an external polarisation voltage of 200V. Once this parameter has been activated, click on OK to return to the previous dialog box.

3. Select as well an acoustical calibrator, in the list of calibrators defined in the software utility dBCONFIG32.

   Consult the SYMPHONIE installation manual for further details on transducer, calibrator and hardware platform management for 01dB-measurement systems.

If, when selecting the hardware platform, the warning message shown aside appears on screen, it means that the hardware platform has not been defined in dBCONFIG32.

Open this software utility and update the list of hardware platform available for measurements with 01dB applications software packages.
6.2. Definition of the sound intensity probe

1. The user may either define a new probe by the command File / New or use an existing probe definition by the command File / Open / *.AU file. The following dialog box appears on screen when defining a new probe.

The dialog shown aside allows the user to give a title to the probe definition datafile with comments and, most of all to associate to each measurement channel the appropriate probe transducer, such as defined in dBCONFIG32.

2. Click on Micro 1 and Micro 2 to select a microphone in the list defined in dBCONFIG32, respectively for Channel 1 and Channel 2 of the acquisition unit. The following dialog box appears on screen.

It shows the list of transducers available and, for each one, additional information such as sensitivity, serial number, model, etc.

The key Options gives, for each transducer, the type of signal conditioning required.

3. On validation, a new probe definition datafile is created and its information window is displayed on screen.

The user may then visualise the titles and comments associated with the data file, the characteristics of the probe microphones, the dates of creation and modification of the datafile.

Furthermore, the information window notifies the user if the pressure residual intensity index measurement has been performed, as well as the low and high frequency phase difference measurements.

While the latter measurements are not performed, the information window indicates "matched" to state that the operator prefers using phase matched microphones rather than measuring a phase difference and applies a phase correction during sound power measurements.

If a phase correction has been carried out, the indication "done" is displayed.
In this information window, it is also possible to modify:
- the transducers used by the command Setup / Microphones
- the title or the comments on the probe data file by the command Setup / Title and comments

6.2.1. Important notice

In the information window of the probe datafile, write down the model and serial number of the microphones for each measurement channel. The user will therefore be able to check, during the hardware configuration stage in dBFA32, that the transducers defined for each measurement channel are exactly the same than that use in this calibration procedure in dBSOND32. Loading the AU phase correction file will result otherwise in increasing the phase error (or even double the phase difference if the microphones are inverted on the measurement channels).

6.3. Pressure calibration of the microphones

Pressure calibration of the probe's microphones is not compulsory to measure phase differences but it is advised to do it before any measurement sessions.

The current calibration is done using LEQ over a 125-millisecond period. It measures the LEQ value of the input signal and converts it into the unit set in the transducer’s characteristics. By adjusting the level to the expected level, it changes the sensitivity of the transducer. By validating it, the adjusted value will now become the default value for the next time the program is used.

1. Use the command Measure / Calibration or to access pressure calibration of the microphones.

   The dialog box shown aside appears on screen. Select the microphone to calibrate then press Execute.

   On validation, the calibration dialog box shown below appears on screen.

2. In this dialog box, adjust the calibration result (field Level) if the default value of the selected calibrator is not correct.

3. Then insert the microphone into the calibrator cavity then switch the calibrator on.

   The sound pressure level on the left is the one measured by the transducer.

4. Adjust the gain of the measurement channel to a maximum without saturation (when the view meter does not become red) in order to finely tune the microphone sensitivity.

5. If the measured sound pressure level is different from the calibration level, click on Adjust to automatically adjust the transducer sensitivity. If the first adjustment is not satisfying, click again on the Adjust key, and use the + and – keys, for a fine tuning until the sound pressure level measured is stable.
Caution! Before calibration:
- Verify that the calibration signal remains constant for a sufficiently long period.
- Verify that the gain view meter is correctly positioned (neither too weak, nor overloading).
- It is preferable to place the calibrator on foam to reduce the effect of vibrations.

Caution! After calibration:
- If, for the same transducer/calibrator pair, the sensitivity after calibration differs greatly from the original sensitivity, damage to the microphone may have occurred.
- If the measured values are not correct but the calibration value is OK, it could mean that the sensitivity of the microphone is correct only at 1 000 Hz. Check the microphone membrane.

A microphone is very fragile equipment. A fall of 10-cm may damage the microphone membrane.

As general rule, if the measured value in dB varies by +/- 1.5 dB from the value that would be measured with the microphone according to the original sensitivity (see calibration data sheet), consider your microphone as faulty.

Example: For a microphone that as a factory sensitivity of 50 mV / Pa and a calibrator that delivers 94 dB at 1000 Hz.

The microphone is able to perform correct measurements if:
- The measured calibration level lies between 92.5 dB and 95.5 dB.
- The current microphone’s sensitivity lies between (around) 40 mV/Pa and 60 mV/Pa (multiply or divide the original value by a factor of 1.1885)

For greater or lower microphone’s sensitivities, consider the microphone as faulty. Return it to your 01dB agent

6.4. Phase calibration of the sound intensity probe

The principle of phase calibration of the probe is to measure the intrinsic phase difference of the probe in order to obtain a phase correction spectrum that will weight the acquired spectrum before calculation of a sound intensity spectrum.

Measurement of the phase difference spectrum can be performed either for low frequencies (from 0 to 1250 Hz), for high frequencies (from 0 to 10000Hz) or for low and high frequencies simultaneously. This is due to the fact that 01dB acquisition software packages are using two FFT passes (one low and one high) and also that some probe calibrators can only be used on one or the other frequency ranges.

- To calibrate the probe only at low frequencies, use the command Measure / Low frequency phase difference
- To calibrate the probe only at high frequencies, use the command Measure / High frequency phase difference
- To calibrate the probe on both FFT passes, use the command Measure / Low and high frequency phase differences
On selection of one of these commands, two windows are displayed: an intensity measurement window, containing one or two FFT passes and an overload window. The measurement process is then identical for the three types of measurements.

We will illustrate phase calibration by a measurement of low and high frequency phase differences.

1. Place both microphones in the 51AB calibrator cavity, as shown aside and connect the BNC – LEMO4 cable between the BNC connector of the calibrator and the LEMO4 output of the SYMPHONIE acquisition unit.

The phase difference is zero in the cavity of the calibrator.

2. To measure the phase difference of the probe, it is require to generate a white noise in the calibrator. You may use and external noise source or the built-in generator of the SYMPHONIE system.

To do so, use the command **Config / generator** and activate it by ticking the box **On/Off** in the dialog box shown aside. Select a **signal** type **White** to produce white noise.

The signal is generated as soon as OK validates this dialog.

3. It is also possible set the output level of the signal generator by clicking with the right button of the mouse onto the Symphonie icon in Windows 95 task bar and to select the menu position **Configuration**.

Adjust the **output level** and click on OK to validate.
For phase calibration of the probe, it is important to select an adequate averaging time, so that the stationary criterion of standard ISO9614 is fulfilled.

In the averaging dialog box (Command Config./ Average), the default number of linear averages is 256, corresponding to about 82 seconds of measurements.

Click on Modify to edit the measurement duration. We will see later on in this notice how to select an appropriate averaging duration.

During calibration measurements, the acquisition will be stopped and would have to be started again if an overload occurs. However, underloads will not stop acquisition. For these reasons, it is important to set correctly the gains of each measurement channel before starting an acquisition.

Use the command Config / gain and threshold to access the dialog box shown opposite.

Applying a gain introduces a phase difference. However, the phase difference would be the same on both channels if the gain setting is the same. There would be therefore no phase difference if the gains were linked and identical on both channels.

This is the reason why gains are identical by default on both channels (options Linked and Identical always activated).

Set the gains with the view meter to a maximum without overload (when overloads are detected, the view meter is shown in red – set the levels in the top quarter of the view meter) in order to avoid underload and to increase the measurement accuracy.

Perform this operation will the generator is activated and the microphones are placed in the calibrator cavity.

Before starting measuring, use the command Config / Parameters, to enter the exact characteristics of the medium (speed of sound and medium density – those of air by default)

The user may also select an automatic autorange to automatically adjust the gains of the acquisition channels before each single measurement.
Once all settings have been performed, start the phase calibration measurement by Action / Start or the keyboard shortcut F3.

When all averages have been measured, and if no overload occurred, it is possible to:

- Either repeat the measurement (command Action / Repeat or F6 or ).
- Either validate the measured result (command Action / Valid or F7 or ). In this case, the measurement window disappears, and it is specified in the information window that the phase calibration has been performed in the selected frequency ranges.

If the user starts again the same phase correction measurement and validate the result, the last result will be saved in the probe data file.

To see the measured phase differences, use the command Results / Graphics or The following plot appears on screen.

### 6.5. Pressure residual intensity index measurement

The last step for calibrating the probe is to measure its pressure residual intensity index. This quantity is used in criterion 1 of the standard ISO9614 (parts 1 and 2) to check the adequacy of the measurement equipment for sound power measurements.

This index represents in fact the dynamic capability of the probe. If the difference between sound pressure and sound intensity levels is greater than the dynamic capability of the probe, the measurement is not valid.

#### 6.5.1. Manual entry

The pressure residual intensity index of a probe is always given by its manufacturer, although the dBSOND32 software package allows its measurement, with phase correction spectra, which gives rather advantageous results. If the user does not want to perform this measurement, it is possible to manually enter the values of the pressure residual intensity index according to manufacturer's abacus.
6.5.2. Measurement

1. Use the command **Measure / Residual P/I index: Edition** to manually enter the values of the pressure residual intensity index.

2. Enter the values for each one-third-octave centre frequencies (between 50Hz and 8 kHz) from the manufacturer's abacus.

   By convention, the values of the index are given for 25mm microphone spacer.

   If during measurements longer or shorter spacers are used, the dBFA32 software package will automatically convert these values.

---

**Notes:**

- **Configuration**
  - This dialog box allows the user to select the frequency range for the acquisition. This range can include all one-third-octave frequency bands from 50 Hz to 6.3kHz.
  - The options **Complete** and **Replace** allows the user respectively to complete a previous pressure residual intensity index spectrum with results in frequency bands that were not measured at the time or to replace entirely the values of the pressure residual intensity index spectrum by the measured values.

- **Acquisition**
  - Once the acquisition has been configured, use the command **Measure Residual P/I index: Acquisition** to start the measurement process. An acquisition window, with the associated measurement window, appears on screen.

  - The dark (red) spectrum represents the averaged sound pressure spectrum and the light (green) spectrum represent the sound intensity spectrum (positive or negative).

  - Before starting the measurement, apply the same gain settings and averaging time than for the phase correction measurements.

  - Select a Pink noise for the generator this time.

- See paragraph 6.4 for these settings.
Once all settings have been performed, start the residual P/I index measurement by or the command **Action / Start** or the keyboard shortcut **F3**.

When all averages have been measured, and if no overload occurred, it is possible to:

- Either repeat the measurement (command **Action / Repeat** or **F6** or ![Action / Repeat](image)),
- Either validate the measured result (command **Action / Valid** or **F7** or ![Action / Valid](image)). In this case, the measurement window disappears, and it is specified in the information window that the residual P/I index measurement has been performed in the selected frequency ranges.

If the user starts again the same residual P/I index measurement and validate the result, the last result will be saved in the probe data file.

To see the measured phase differences and the residual P/I index, use the command **Results / Graphics**. The following plot appears on screen.

The probe calibrator is not efficient at high frequencies (at about 5000 Hz for the GRAS 51AB calibrator). The phase correction plot is therefore not acceptable at these frequencies.

To display the plot after this value, the high frequency phase difference can be extrapolated above this cut-off frequency (**Fmax Extrapolation**) by calculating the slope of the straight line by the least mean square method between **Fmin Extrapolation** and **Fmax Extrapolation**.

These two frequencies and the extrapolation flag (**Extrapolation**) may be modified in the configuration file **dBSOND32.INI** at the section *[Meas Config]*. Default values: **Extrapolation=1** (activated), **FMin Extrapolation = 3000**, **Fmax Extrapolation = 5000**.

The measured residual P/I index is always very important, thanks to the phase correction plot. In order to be realistic, the software limits itself by a pattern accounting for the errors of the measurement chain (in particular the tolerances of the calibrator between 45 and 1000 Hz, given in the standard IEC 1043). This limitation, under normal atmospheric pressure and at ambient temperature, is 26,8 dB for a microphone ‘spacer of 25 mm.

This is the default limit that is defined in the section *[Meas Config]* of the file **dBSOND32.INI** under the name **Residual Limit**. The values of the limit are given per third-octave band, starting at 50Hz. A comma separates each value.
It is possible to plot, for comparison purposes, the pressure residual intensity index spectra with and without phase correction (and limited by the residual limit pattern in the data selection dialog box. Use the command **Set-up / Data** or to display this dialog box.

The calibration process is now finished. The user may close the dBSOND32 application and save the probe data file *.AU by the command **File / Save** or the icon .

This file will be used during sound power measurement in the dBFA32 application. It will have to be selected during the hardware configuration procedure.

The dBSOND32.INI file is located in the same directory than the program DBSOND32.EXE on the computer hard disk.

Your 01dB sound intensity meter is now fully calibrated.
7. HARDWARE CONFIGURATION OF INTENSITY METER : DBFA32

Hardware specification and settings are required before any measurement. Use the command Acquisition / Hardware configuration in the DBFA32 application to access the following dialog box.

From here, define:

- The type of acquisition platform
- The active channels for measurement
- For each active measurement channel, a calibrator/transducer pair of the same type.
- Where applicable, the remote control to start an acquisition from the handle buttons of the probe.
- The phase correction datafile that contains calibration data for the probe (phase differences and pressure residual intensity index measured in dBSOND32).

The set-up parameters are saved by default in a HCF file.

The acquisition platforms, transducers and calibrators are selected from the group previously defined under the hardware configuration programme dBCONFIG32.

We describe in this chapter an example of hardware configuration for an intensity meter made of the SYMPHONIE measurement system and the sound intensity probe 50AI, such as described in chapter 4.

1. Hardware peripheral tab : Select first of all, the hardware platform. Click on >> and select SYMPHONIE in the dialog box. Then click on the Configure key and check that the option 200V is activated on both measurement channels.

2. This is an important feature because the microphone pair of the 50AI probe requires an external polarisation voltage of 200V that should be provided by the acquisition box.
Then, define for each measurement channel a transducer and a calibrator from those available.

Select with the mouse the measurement channel, then click on the Transducer key to display the list of transducers available and defined in the software utility dBCONFIG32. Select the appropriate transducer in the list.

Similarly, select a pressure calibrator in a list by clicking on the Calibrator key and activate the measurement channel by pressing the Enable key.

To enable the direct power supply of a transducer from a SYMPHONIE unit, it is necessary to define the same option(s) when defining the transducer(s) in dBCONFIG32 and when selecting the hardware platform (Configuration command).

Beware when selecting transducers: the two microphones selected must be the same than those used during calibration, and they must be associated to the same measurement channels.

Loading the AU phase correction file will result otherwise in increasing the phase error (or even double the phase difference if the microphones are inverted on the measurement channels).

Loading a phase correction file does not automatically configure the measurement channels.
Remote Control tab: If the user wishes to use a remote control to perform measurements, it needs to be selected in the list of available remote control by pressing the >> key.

Using a remote control for sound power measurements allows the user to start, stop and validate successive acquisitions by simple key pushes on the handle of the 50AI probe. The settings of the remote controls are defined in the file dBCD32.INI.

Select the GRAS probe in the list of available remote controls for the sound intensity probe 50AI.

Then press the Configure key and select the Symphonie in the communication field.

This is important because the interface box between the probe and the acquisition unit uses the digital inputs / outputs (Mini PS/2 connector) to pass remote control signals.

The duration parameters apply to the LEDs on the probe handle.
4 Phase tab: For sound power measurement according to ISO9614 standard, a phase correction data file needs to be activated. Tick the Active field and select an AU file by the >> key.

Phase correction data files (Au extension) are created or can be modified in the dBSOND32 software application (see chapter 6).

If the operator uses phase matched microphones, or if phase calibration has not been done, an AU file is still required as it contains the pressure residual intensity index for the probe. Even if it has not been measured in dBSOND32, manually enter the manufacturer values in an AU file.

5 Once these parameters have been defined, save the hardware configuration of the sound intensity meter in a configuration file of type HCF.

To do so, click on the key Save As and give a name to the configuration file.

Previous configurations can also be loaded by clicking on the Open key. A new configuration can be performed by pressing on the New key.

For further details on hardware configuration, consult the installation manual of your system as well as the on-line help file of the application software.

Your 01dB sound intensity meter is now ready for sound power measurements according to ISO9614 standard.
8. SOUND POWER MEASUREMENTS : DBFA32

In this chapter, we illustrate sound power determination using sound intensity according to the ISO9614 standard and with the SYMPHONIE measurement system and a GRAS 50AI probe.

8.1. Selection of the measurement method and the measurement surface

1. After hardware configuration, create a new measurement session for ISO9614 sound power measurements.

Use the command File / New or and select ISO 9614 session in the dialog box (see opposite). Valid by OK.

2. The mesh definition window for a new sound power measurement according to ISO 9614 is then displayed on screen (see opposite).

This dialog box allows the user to give a name (Title field) and enter comments (Comments field) to the measurement session.

But its primary function is to define the ISO9614 method of measurement (Type field). Choose either the discrete point method as described in Part 1 of the standard (Point by point) or the scanning method (scanning) as described in Part 2 of the standard.

Select as well the shape of the measurement surface that encloses the source under test: the software proposes a parallelepiped mesh or a list of surfaces.

A mesh made of a list of surfaces allows the user to define any type of measurement surface (hemispherical, cylindrical, etc.) but no graphical support would be available in dBFA32.

A parallelepiped mesh enables graphical assistance during the measurements as well as graphical display of the results (noise maps, 2D-mesh display).

When using a parallelepiped mesh, the user may also define the dimensions of the source. The software will therefore propose automatically an indicative mesh in accordance with the specifications of ISO9614 standard.

They Units key allows the user to define the degree of accuracy of the source dimensions.

The shape of the measurement mesh and the measurement method cannot be modified after validation of this dialog box. Be very careful when defining these parameters.

On validation of this dialog box, the operator is going to define more precisely the measurement surface.
8.1.1. Definition of a parallelepiped mesh

On validation of the previous dialog box for a parallelepiped mesh, the following window appears on screen. It features the indicative mesh and its structure. The example shown below shows an indicative mesh in the case of source dimensions not defined.

For point by point measurements, the mesh always features inappropriate measurement locations (because they are not in front of the source). The mesh may of course be modified.

The measurement surface is represented in two dimensions, as if the parallelepiped was flatten out.

In this window, the **surface dimensions** that enclose the source may be modified as well as the number of measurement positions, dividing each surface according to the three axis X, Y and Z.

Once the mesh has been correctly defined, click on OK.

To further divide a mesh already defined, use the command **Results / Mesh modification** or 🔄. See paragraph 10.2.2.2 for further details.

8.1.2. Definition of a mesh from a list of points and surfaces

On validation of the previous dialog box for a list mesh, this dialog box appears on screen. It allows the user to add, modify and remove lists of surfaces for the measurement mesh.

Such mesh is defined by a sequence of surfaces.

Prior to this definition, the operator must calculate the surface of each segment of the mesh enclosing the source and to subdivide each segment into smaller surfaces, with an associated number of measurement locations. The shape of the measurement mesh will depend upon the size and shape of the source.

To add a surface, click on **Add**. Another dialog box (shown opposite) appears on screen.

Give a name, a surface area and the density of measurement locations for each segment composing the measurement surface.

When using this type of mesh, the software will not take into account the co-ordinates of each measurement location or of the surface segments. The operator must therefore know exactly where each measurement position is physically located on site.
8.2. Acquisition – Preliminary measurements

For the rest of this notice, we illustrate the measurement process for sound power determination according to the discrete point method, described in Part 1 of the ISO9614 standard, and for a parallelepiped measurement surface.

8.2.1. Measurement information window and save options

When the mesh has been defined (list of surfaces or parallelepiped), an information window for the measurement is displayed on screen (see aside). It features all the parameters already defined.

This information window means that the sound intensity measurement session has been created.

1. Save this file (File / Save) to disk and start the measurement process, analyse the results, etc.

2. It is possible to save at the same time the analysis parameters and the results as well as the size and position of all the windows open in the software.

Like so, when opening an existing ISO9614 file (File / Open /*.CMG), the windows that will be displayed will be the ones left open previously.

To do so, tick the box Save windows in the following dialog, accessed by the menu position Preferences / ISO9614 module then save the measurement session by the command File / Save.

3. It is also possible to automatically save the measurement results by the command Measure / Configuration.

In the example shown aside, the results will be automatically saved after each stationarity measurement (or probe inversion) and after each measurement point for sound power determination.
8.2.2. Pressure calibration of the microphones

If pressure calibration of the microphones is not required for the probe phase calibration, it is highly recommended to do it before any sound intensity measurement session. To perform calibration, use the command Measure / Calibration and proceed as described in paragraph 6.3.

8.2.3. Stationarity check of the sound field (ISO9614 – part 1 only)

Determination of sound power by sound intensity measurements in different points of a surface enclosing the source is based on the hypothesis that the sound field is stationary. In other words, the noise level must not vary significantly with time.

This preliminary measurement is therefore very important: It means to find a measurement duration for which the source noise level is stationary, and then to keep this duration for all sound power measurements in order to guarantee accurate results. The stationarity check corresponds to the F1 field indicator of the standard ISO9614. To conform to its specifications, F1 must be less than 0.6 (F1 < 0.6).

1 A stationarity check is made over N successive measurements that are compared with one another to see if the noise is the same. The number N can be set in the measurement configuration window, accessible by the command Measure / Configuration.

In the Stationarity field, set the number of successive acquisitions.

The Chained acquisitions option allows the user to perform successively the N stationarity measurements automatically.

2 To perform the measurement itself, use the command Measure / Stationarity or A sound intensity acquisition window is displayed on screen.

The interspectra of sound pressure and sound intensity levels between channel 1 and channel 2 are displayed by default.

The vertical toolbar features acquisition parameters and analyser commands, while the vertical toolbar is used to set graphical parameters.

Before acquisition, the user must set parameters such as the input gains, the measurement duration, etc.
Analysis parameters. Use the command Config / Parameters or.

This dialog box allows the user to determine the data storage mode.
By default, in the customised mode, the analyser only save the results that are used in sound power determination.

Then, set the physical characteristics associated with the measurement: the microphone 'spacing used, the celerity of sound and the medium density (air by default).

It is also possible to perform an automatic autorange before each acquisition and to use an overlap for the FFT analysis of the signal.

The convolution correction option allows the user to adjust the high frequency limit due to the finite difference approximation errors (see below) to a maximum of 3 dB.

Select as well the frequency limits of analysis. They depend upon the microphone spacing, the minimum frequency band required and if the convolution correction is activated or not.

The table below summarises these interactions for various microphone spacing. The values between brackets give the high frequency limit when the convolution correction is activated.

<table>
<thead>
<tr>
<th>Fmin (Hz)</th>
<th>20</th>
<th>25 to 40</th>
<th>50 to 80</th>
<th>100 and more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacing (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>12,5 - 1K (1,6K)</td>
<td>25 - 1K (1,6K)</td>
<td>50 - 1K (1,6K)</td>
<td>100 - 1K (1,6K)</td>
</tr>
<tr>
<td>25</td>
<td>25 - 2K (2K)</td>
<td>25 - 2K (3,15K)</td>
<td>50 - 2K (3,15K)</td>
<td>100 - 2K (3,15K)</td>
</tr>
<tr>
<td>12</td>
<td>50 - 2K (2K)</td>
<td>50 - 4K (4K)</td>
<td>50 - 4K (6,3K)</td>
<td>100 - 4K (6,3K)</td>
</tr>
<tr>
<td>6</td>
<td>100 - 2K (2K)</td>
<td>100 - 4K (4K)</td>
<td>100 - 8K (8K)</td>
<td>100 - 8K (12,5K)</td>
</tr>
</tbody>
</table>

The option Adjust to physical frequency limits when activated automatically reduces the frequency limits to a frequency range in which sound intensity can be calculated.

The physical limitation of the frequency range is due, for high frequencies to the approximation of the pressure gradient and, for low frequencies to the microphone spacing (the lager the spacer, the lower the frequency band accessible).

With a 12 mm spacer (and the convolution correction activated), the software the frequency range required by the international standard (50 Hz - 6,3 kHz) but the user can advantageously perform its sound intensity measurements in two stages:

- A first series of measurements with a 12mm spacer for high frequency bands,
- Then a second series with a 25-mm spacer to cover low frequency bands.

For more details on the intensity meter physical limitations at low and high frequencies, refer to paragraph 2.3.
If the measurements are performed in two steps, with different spacers, check the option **complete spectra** in the measurement configuration window (command **Measure / Configuration**).

This option allows the user to complete the spectra resulting from the first series of measurements with the frequency bands of the spectra resulting from the second series of measurements.

**Example:** A measurement is made in one point of the mesh over the frequency range 25Hz–4kHz with a 12 mm spacer, then over the range 80Hz – 8kHz with a 25 mm spacer. The result will cover the range 25Hz – 8kHz, the frequency bands with centre frequencies ranging from 25 Hz to 63 Hz are taken from the first measurement, the other bands from the current measurement.

This option will be applied to any measurement made.

4. Use the command **Config / Gain and threshold** to access the set-up dialog box aside.

Adjust the gains (that are linked and identical for both channels) with the probe placed on the surface enclosing the source. The source must be switched on. Set the gains with the view meter to a maximum without overload (when overloads are detected, the view meter is shown in red – set the levels in the top quarter of the view meter).

5. Use the command **Config / Average** or **Average** to set the measurement duration.

First perform a stationarity measurement for a relatively short duration (example: 32 averages).

If the result is not satisfying, use longer measurement duration in order to obtain a stationarity criterion that complies with the standard specifications.

**Example:** If the user performs sound power measurements for a printer or a copier, the sound field will not be considered as stationarity if the measurements are not performed over the complete printing cycle (warm up, sheet capture, inking, noise of the rollers, form feed).

When a satisfying averaging time is found, use it for all successive sound power measurements.
6. Once all settings have been performed, start the stationarity measurements by the command Action / Start or the keyboard shortcut F3.

7. When all averages have been measured, and if no overload occurred, it is possible to:
   - Either repeat the measurement (command Action / Repeat or F6 or ),
   - Either validate the measured result (command Action / Valid or F7 or ) and pass to the next measurement.

8. The spectrum resulting from the stationarity measurements is displayed once the N measurements have been made and accepted by the user.

   ![Stationarity spectrum](image)

   The dark (red) spectrum is the conformity pattern (0.6 dB in all frequency bands) and the light (green) spectrum is the measurement result.

   This result, if satisfying, can be validated by Yes, and replace an existing result from a previous stationarity measurement.

   Otherwise, click on No and perform the measurement again with longer measurement duration. This iterative process allows the user to find the appropriate measurement duration.

   If the resulting spectrum features only a few frequency bands that does not comply with the specifications of the ISO9614 standard (value in dB per frequency band greater than 0.6dB), these bands can be excluded from the following calculations but it must be stated and explained in the test report.

   To exclude frequency bands, their combined influence on the overall dB(A) sound power level must be considered as negligible. Refer to the standard to know exactly what the term "edge" means.

   Refer to chapter 9 to know how frequency bands can be excluded from sound power calculations.

8.2.4. Calibration check by inverting the probe

This measurement allows the user to check the probe calibration. A first measurement is made at a given location on the mesh, then a second one is performed at the same location with the probe inverted, keeping the probe on the same axis (see sketch aside).

If the probe has been correctly calibrated, the sum of the two intensity spectra must be less than 2dB for all the frequency range.

This measurement is only valid of course if the sound field is stationary. This is the reason why calibration check if performed after the stationarity check.

If the microphones of the 50AI probe are mounted in a symmetrical manner, with right-angle preamplifiers, the calibration will be optimal.
To perform a calibration check, use the command **Measure / Calibration check** or \( \text{\textbox{\textdagger}} \). A sound intensity acquisition window is displayed on screen. Before acquisition, the user must set parameters such as the input gains, the measurement duration, etc.

Please note that these parameters are kept the same from one acquisition window to another: if the settings have already been performed for the stationarity check, it is not required to go through the configuration steps again.

For a description of the dialog boxes relative to the analysis parameters and the gains and threshold, refer to paragraph 8.2.3 of the stationarity check measurement process.

Use the command **Config / Average** or \( \text{\textbox{\textdagger}} \) to set the measurement duration. Use the same measurement duration that for the stationarity check.

Once all settings have been performed, start the calibration check measurements by \( \text{\textbox{\textdagger}} \) or the keyboard shortcut **Action / Start** or **F3**.

When all averages have been measured, and if no overload occurred, it is possible to:

- Either repeat the measurement (command **Action / Repeat** or **F6**, or \( \text{\textbox{\textdagger}} \).
- Either validate the measured result (command **Action / Valid** or **F7**, or \( \text{\textbox{\textdagger}} \)) and pass to the next measurement with the probe inverted.

The resulting spectrum is displayed on screen once the two measurements have been performed.

The dark (red) spectrum is the conformity pattern (1.5 dB in all frequency bands) and the light (green) spectrum is the measurement result.

This result, if satisfying, can be validated by **Yes**, and replace an existing result from a previous stationarity measurement. Otherwise, click on **No** and perform the measurement again.

Calibration check by inverting the probe tests only the probe itself. It is therefore recommended to perform this preliminary measurement on a stationary noise source rather than the source under investigation.

If the user considered some frequency bands as negligible during the stationarity measurements, it is normal that these bands do not comply with the conformity pattern of the calibration check.
8.3. Acquisition – Sound power measurements

8.3.1. Parameters

1 To start sound power measurements, use the command Measure / Power or . Two windows are displayed on screen: an acquisition window (left below) and an acquisition order window (right below) showing the measurement progresses with a mesh display.

The light greyed (Yellow) parts of the mesh in the acquisition order window represent the points already measured while the dark (Green) greyed parts represent the points not yet measured. The blinking point (Bottom left hand corner on the example above) represents the active measurement position and the arrows represent the order of the successive acquisitions. When starting a new measurement, the acquisition order is not yet defined and it must be done before starting any measurement.

2 Definition of the acquisition order

Use the command Set-up / Measurement order or . The acquisition order definition window is then displayed on screen.

To define the acquisition order, click with the mouse on the different parts of the mesh in the order that suits best the measurement conditions.

There are also two automatic orders that can be defined: face by face or horizontal.

It is also possible to recall the previous acquisition order defined or to clear all the selected points.

If measurements have already been made, and if you close down dBFA32 during a measurement session, the last acquisition order will be recalled exactly where it was left.

The user may change the last acquisition order for the points not yet measured. If it has to be changed for all the points of the mesh, click on the option Measured points.
However, if the user wishes to re-do existing measurements (because the measurement conditions have changed or when using a different microphone spacer), the option **Measured points** must be validated to be able to select automatically an acquisition order taking into account the measured points.

For a mesh made of a list of points and surfaces, the option **Measured points** must be validated to be able to select automatically an acquisition order taking into account the measured points.

For a mesh made of a list of points and surfaces, the user must add one by one the points in the acquisition order by **adding** points (it will be the last one measured) or by **inserting** points (it will be positioned at the current position). It is possible to select automatically all the points, in the order they were defined, and the option **Measured points** has the same meaning.

Mesh set-up around the source

Now that the acquisition order has been defined, the user must prepare physically the measurement environment around the source. That is to use precise markers to place the probe exactly at the defined measurement locations.

The most practical is to use markers on the floor, a tripod to fix the probe and a ruler.

Use the command **Results / points’ list** to visualise the co-ordinates of each measurement locations of the mesh. A mesh listing is displayed on screen.

- The co-ordinates of the current point are recalled in the header of the acquisition window.

- The icon **allows the user to select which faces of the mesh have to be listed (Command Set-up / zone). By default, all points of each and every face are listed.

These co-ordinates are given for a direct orthonormal marking: the software only knows the measurement surfaces.

The origin and the orientation of the source in the mesh are left to the user, as long as the mesh completely enclose the source (a good practice is to place the source at the centre of the mesh).

For a mesh made of a list of points and surfaces, the software does not manage the co-ordinates of the measurement points. The physical markers should be placed manually.

Now that the mesh is physically defined, the sound power measurements can be performed.
8.3.2. Sound power measurements without remote control

1. Configure the analysis parameters, the averaging time and the gains as previously explained (see paragraph 8.2.3 for the stationarity measurement). By default, these settings are the same than for the previous acquisition window.

2. Place the probe at the exact location of the first measurement position, according to the defined acquisition order.

3. Start calibration check by or the command Action / Start or the keyboard shortcut F3.

4. When all averages have been measured, and if no overload occurred, it is possible to:
   - Either repeat the measurement (command Action / Repeat or F6 or ),
   - Either validate the measured result (command Action / Valid or F7 or ).

5. If the measurement has been validated, re-do operations 3 and 4 for all the following points, according to the defined acquisition order. If the measurement has not been accepted, re-do the same measurement.

6. In order to re-do some measurements with a different probe configuration (i.e. for a different frequency range), make sure that the option Complete spectra has been activated in the dialog accessed by the command Measure / Configuration. This option allows the user to complete the spectra resulting from the first series of measurements with the frequency bands of the spectra resulting from the second series of measurements.

As long as an acquisition order is not defined, sound power measurements are not accessible.

During acquisition, check the input gains: if an overload occurs, re-do the measurement for the active point.

Before each measurement, manually or automatically (autorange) adjust the input gains. Some measurement locations may be noisier than others (real-life sound sources are very rarely omni-directional).

The option "Automatic autorange" in the analysis parameter dialog box, command Config / Parameters can be useful to automatically adjust the input gains before each measurement.

Consult chapter 3 for more details on the sound power measurement process according to ISO9614, part 1 and part 2.

8.3.3. Sound power measurements with a remote control

If you are using a sound intensity probe type GRAS 50AI with a remote control, the measurement process is simplified because the operator does not need to use the keyboard or the mouse to start, stop, valid a measurement. The remote control is very useful if the source under test is located at a certain height or in a location difficult to access.

The handle of the sound intensity probe features two remote control buttons that can be used to pilot the acquisition process and two LEDs to inform the user on the measurement progress.

- The Blue button is a ‘positive’ button: it is used to start and validate a measurement.
- The Grey button is a ‘negative’ button: it is used to prematurely stop an acquisition or to repeat the current measurement.
1. Place the sound intensity probe at the first measurement location, according to the defined acquisition order. When the Green LED blinks, it means that the system waits to start an acquisition.

2. Press the Blue button. The acquisition starts. At the end of the acquisition, the two LEDs blink. It means that the system waits for a decision:
   - validation of the measurement by the blue button
   - repetition of the measurement by the grey button

3. Whatever the choice, the system waits for another measurement start action: for the same measurement points if the last acquisition has been eliminated, for the next measurement point if it has been validated.

The Red LED indicates a possible overload during acquisition.

4. Perform the measurement again for each point, according to the defined acquisition order.

8.3.4. General remarks

In the measurement configuration (command Measure / Configuration), there is an option called Keep interrupted measurement. If activated, this option allows the user to consider an acquisition that was stopped before the end of the averaging duration (by the use of the grey button or the command Actions / Stop or F4 or as valid. The software therefore proposes to accept or eliminates this measurement.

If this option is not activated, interrupting a measurement before the end of the averaging duration will result in repeating the same acquisition.

When using the scanning method, this option should always be validated and the measurement duration should be as long as possible. Like so, a measurement surface can be swept and manually interrupted at the end of scanning. The remote control is particularly recommended for sound power measurement using the scanning technique.

It is also possible to display windows containing results during the measurement process. They will be updated in real-time each time an acquisition has been validated. This can be useful to monitor the results as we go along (see chapter 9).

For measurement by scanning, the standard recommend to sweep the probe over each measurement surface according to orthogonal directions. See sketch below.

Consult chapter 3 for more details on the measurement process according to the standard ISO9614, part 1 and part 2.
9. PROCESSING OF THE RESULTS

In dBFA32, the user can display the measurement results in different ways:
- Graphics or tables of the measurement results for a given point of the mesh
- Graphics or tables of the overall measurement results
- Noise maps (ISO contours) of the overall measurement results for parallelepipedic meshes only.

These results can be displayed while performing the measurements. The results will then be updated after validation of every acquisition, in order to know if the given measurement point as to be performed again.

9.1. Mesh display

Use the command Results / Mesh plot or .

This command is used to plot a parallelepipedic mesh.

The dark greyed (green) points are the points already measured. The light greyed surfaces (yellow) are the points not yet measured.

9.2. Points' list

Use the command Results / Points' list.

This command is used to display the characteristics of the mesh: the co-ordinates of every measurement locations and their associated surface, their positions on the mesh (back, front, right, left, top) and if the measurement has been done yet at this location.

With the command Set-up / zone or it is possible to display the points’ characteristics for a given face only.

The example shown aside corresponds to a list of points for a parallelepipedic mesh and a mesh made of a list of surfaces.
9.3. Listing of the results per point

1. Use the command Results / List per point or .

This command is used to display the sound intensity and/or sound pressure values for given frequency bands and at one measurement location.

It is possible to open such result window for several measurement points.

2. Use the command Set-up / Point or to select which the measurement point for which the listing will be displayed.

To select a point, use the mouse or the keyboard arrows (spacebar to select). Valid by OK.

3. Use the command Set-up / Data or to select which type of data will be displayed.

It is possible to display the sound intensity and/or sound pressure spectra in octaves or third octaves.

4. It is also possible to select the frequency bands that will be considered for overall level calculations by pressing the Select key.

The frequencies displayed are the centre frequencies of the third-octave or octave bands, according to the previous choice.

When opening this dialog box, the frequencies selected by default are those of the frequency range of the last acquisition.

Add or exclude frequency bands by a simple mouse click on the appropriate frequency value. Two keys can be used to include all or clear all the frequencies for calculating overall noise levels.

To exclude negligible frequency bands from subsequent calculations (see chapter 8.2.3 page 56), perform this operation in this dialog box.
Use the command **Set-up / Displayed frequencies** or ![Icon](image) to select the frequency bands for which sound pressure and/or sound intensity spectra values will be displayed as a table of results.

Select with the mouse the frequency bands to display in the results' list.

The keys **All** and **Clear All** allows the user respectively to select automatically all the frequencies or to clear them all.

Some frequency bands are preceded by a mark *.

They correspond to the frequency bands excluded from the calculation of overall noise levels in the data selection dialog box.

These frequency bands cannot be selected for display either manually or automatically.

The command **Set-up / Optimise frame size** or ![Icon](image) allows the user, when activated, to automatically resize the listing window. It is recommended to activate this option if the results are displayed in real-time during the measurements.
9.4. **Graphical plot of the results per point**

1. Use the command **Results / Display per point** or 

![Graphical plot of the results per point](image)

This command is used to display sound pressure and/or sound intensity spectra in octaves or third octaves for a given point of the mesh. It is possible to open such plot several measurement points.

2. Activate the option **Set-up / Mesh Display** or 

![Mesh Display](image)

To display the mesh plot. The measured points are displayed in light grey (yellow) and the selected points are displayed in dark grey (green). The mesh, featuring the selected points, is displayed with the spectra in the graphic window.

3. Use the command **Setup / Zone** 

To select the mesh points for which the graphical results will be displayed.

![Setup / Zone](image)

To select a point, use the mouse or the keyboard arrows (spacebar to select). Valid by **OK**.

Automatic selection keys can also be used to select all the points, the points of a given mesh surface or clear all the selected points.

If you click again on a point already selected, it will be unselected.

The option **Non measured points** allows the user to only select the points that have not yet been measured.

Tick this option if you wish to display the results in real-time during the measurements.
4. Use the command **Set-up / Data** or to select which type of data will be displayed.

It is possible to display the sound intensity and/or sound pressure spectra in octaves or third octaves.

5. It is also possible to select the frequency bands that will be considered for overall level calculations by pressing the **Select** key.

The frequencies displayed are the centre frequencies of the third-octave or octave bands, according to the previous choice.

When opening this dialog box, the frequencies selected by default are those of the frequency range of the last acquisition.

Add or exclude frequency bands by a simple mouse click on the appropriate frequency value. Two keys can be used to include all or clear all the frequencies for calculating overall noise levels.

To exclude negligible frequency bands from subsequent calculations (see chapter 8.2.3 page 56), perform this operation in this dialog box.

These settings apply to all the graphical results in the window. If you wish, for example, to visualise spectra in octave bands for a given point and spectra in third octave bands for another point, open two Display per point windows and select independent settings.

6. Use the command **Set-up / Displayed frequencies** or to select the frequency bands for which sound pressure and/or sound intensity spectra will be displayed as a graphical plot.

In this dialog box, select the octave and third octave frequency ranges to display and activate the display of the overall A-weighted and unweighted levels.

The option **Adjust as global level range** sets the display frequency ranges in octaves and third octaves according to the lowest and the highest frequencies previously selected for calculation of overall levels.

If some frequency bands that are not taken into account in the calculation of overall levels are selected, the corresponding graphics will present a null value for these frequency bands.

These settings apply to all the graphical results in the window. If you wish, for example, to visualise spectra from different points according to different frequency ranges, open two Display per point windows and select independent settings.
Use the command **Setup / Options** or 📊 to configure general display parameters.

The **automatic** Y-axis option is used to perform an autoscale automatically for each plot, while the **Global optimisation** option set the same Y-axis dynamic range for all plots (useful to compare spectra from different points).

The **Synchronised cursors** option can be used to synchronise the cursors on the different graphics.

It is a useful option to find "hot spots" when trying to locate a source: the sound levels are more important at given locations than others (see paragraph 10.2.2.1) and for a given frequency band.

Other graphical settings for each individual plot, are available by the command **Setup / Setup**.

The command **Setup / Layout** or 📊 allows the user to define the graphical plot layout in the window.

When opening a new result window, the software keeps all compatible settings from the previous result window. As most of the settings for a listing table and a graphical plot are similar, the frequency bands selected for calculation of overall results and for display are kept the same for the two types of result windows.
9.5. Listing of overall results

1. Use the command `Results / Global list`.

This command allows the user to calculate the overall results of the sound power measurement (power, preliminary measurements, field indicators and conformity criteria) as a listing table.

The greyed areas of the table correspond to the results that do not comply with the specifications of the standard, according to the desired grade of accuracy.

In order to improve the accuracy of the results, several actions can be taken (see chapter 10).

2. Even if some criteria are not displayed in the table, they are calculated by dBFA32. For example, if F2 and F3 are displayed but not criterion 1 (Ld and F2), F2 and F3, and F2 might be greyed because of a non-conformance of criterion 1.

2. The command `Setup / Zone` or `..` to select the mesh points for which the overall results will be calculated.

To select a point, use the mouse or the keyboard arrows (spacebar to select). Valid by `OK`. Automatic selection keys can also be used to select all the points, the points of a given mesh surface or clear all the selected points.

It can be useful for example to eliminate a mesh surface that cannot be measured if the source is located against a wall.

When clicking again on a point, it will be unselected.

The option `Non measured points` allows the user to only select the points that have not yet been measured. Tick this option if you wish to display the results in real-time during the measurements.
Use the command Setup / Data or \( \text{Setup} / \text{Data} \) to select which type of data will be displayed.

It is possible to display the field indicators F1, F3 and F2, F4, the conformity criteria 1 and 2, the measured power spectrum, the calibration and stationarity check spectra – in octave bands or third octave bands.

Select as well the grade of accuracy required (Precision, Engineering or Survey). The greyed areas in the table will depend on the grade of accuracy selected. The Precision grade is the most selective.

For measurements according to the scanning technique, the criteria 1 and 2, the sound power spectrum or the calibration check by inverting the probe can be displayed. The user can select either the Engineering or Survey grade of accuracy.

It is also possible to select the frequency bands that will be considered for overall level calculations by pressing the Select key. The frequencies displayed are the centre frequencies of the third-octave or octave bands, according to the previous choice (octave bands or third octave bands).

When opening this dialog box, the frequencies selected by default are those of the frequency range of the last acquisition.

Add or exclude frequency bands by a simple mouse click on the appropriate frequency value. Two keys can be used to include all or clear all the frequencies for calculating overall noise levels.

To exclude negligible frequency bands from subsequent calculations (see chapter 8.2.3 page 56), perform this operation in this dialog box.

Use the command Set-up / Displayed frequencies or \( \text{Set-up} / \text{Displayed frequencies} \) to select the frequency bands for which overall levels will be calculated.

Select with the mouse the frequency bands to display in the results’ list.

The keys All and Clear All allows the user respectively to select automatically all the frequencies or to clear them all.

Some frequency bands are preceded by a mark *.

They correspond to the frequency bands excluded from the calculation of overall noise levels in the data selection dialog box.

These frequency bands cannot be selected for display either manually or automatically.
6. The command **Set-up / Optimise frame size** or allows the user, when activated, to automatically resize the listing window. **It is recommended to activate this option if the results are displayed in real-time during the measurements.**

Consult chapter 3 for more details on the measurement process according to the standard ISO9614, part 1 and part 2.

9.6. **Graphical plot of overall results**

1. Use the command **Results / Global display** or .

![Graphical plot of overall results](image)

This command is used to display the following overall results: display the field indicators F1, F3 and F2, F4, the conformity criteria 1 and 2, the measured power spectrum, the calibration and stationarity check spectra – in octave bands or third octave bands.

2. Activate the option **Set-up / Mesh Display** or to display the mesh plot. The measured points are displayed in light grey (yellow) and the selected points are displayed in dark grey (green). The mesh, featuring the selected points, is displayed with the results in the graphic window.

![Mesh display](image)

3. Use the command **Setup / Zone** to select the mesh points for which the graphical results will be calculated.

To select a point, use the mouse or the keyboard arrows (spacebar to select). Valid by **OK**. Automatic selection keys can also be used to select all the points, the points of a given mesh surface or clear all the selected points.

It can be useful for example to eliminate a mesh surface that cannot be measured if the source is located against a wall. When clicking again on a point, it will be unselected.
The option **Non measured points** allows the user to only select the points that have not yet been measured. Tick this option if you wish to display the results in real-time during the measurements.

4. Use the command **Setup / Data** or ![Select](image) to select which type of data will be displayed.

It is possible to display the field indicators F1, F3 and F2, F4, the conformity criteria 1 and 2, the measured power spectrum, the calibration and stationarity check spectra – in octave bands or third octave bands.

Select as well the grade of accuracy required (Precision, Engineering or Survey). The greyed areas in the table will depend of the grade of accuracy selected. The Precision grade is the most selective.

5. It is also possible to select the frequency bands that will be considered for overall level calculations by pressing the **Select** key. The frequencies displayed are the centre frequencies of the third-octave or octave bands, according to the previous choice.

When opening this dialog box, the frequencies selected by default are those of the frequency range of the last acquisition.

Add or exclude frequency bands by a simple mouse click on the appropriate frequency value. Two keys can be used to include **all** or **clear all** the frequencies for calculating overall noise levels.

To exclude negligible frequency bands from subsequent calculations (see chapter 8.2.3 page 56), perform this operation in this dialog box.

6. Use the command **Set-up / Displayed frequencies** or ![Select](image) to select the frequency bands for which overall levels will be displayed as a graphical plot.

In this dialog box, select the octave and third octave frequency ranges to display and activate the display of the overall A-weighted and unweighted levels.

The option **Adjust as global level range** sets the display frequency ranges in octaves and third octaves according to the lowest and the highest frequencies previously selected for calculation of overall levels.

If some frequency bands that are not taken into account in the calculation of overall levels are selected, the corresponding graphics will present a null value for these frequency bands.
These settings apply to all the graphical results in the window. If you wish, for example, to visualise results according to different frequency ranges, open two Global display windows and select independent settings.

Use the command Setup / Options or to configure general display parameters.

The automatic Y scale option is used to perform an autoscale automatically for each plot.

The Synchronised cursors option can be used to synchronise the cursors on the different graphics.

It is a useful option to find "hot spots" when trying to locate a source: the sound levels are more important at given locations than others (see paragraph 10.2.2.1) and for a given frequency band.

The Display non-conformity indicator option allows the user to check straight away for each criterion or field indicator graphics if the measurement is valid according to the desired grade.

The option “Only if non empty" can be activated to display the non-conformity bar only if the graphics contain a frequency band that does not fulfil the requirements of the grade of accuracy.

If the graphical plot window is too small, the non-conformity bar will not be shown, even if you wish to display this information bar.

Other graphical settings for each individual plot, are available by the command Setup / Setup.

The command Setup / Layout or allows the user to define the graphical plot layout in the window.

When opening a new result window, the software keeps all compatible settings from the previous result window. As most of the settings for a listing table and a graphical plot are similar, the frequency bands selected for calculation of overall results and for display are kept the same for the two types of result windows.
9.7. Noise map (ISO contours) of the overall results

1. Use the command **Results / Map** or ![icon] to display ISO contours.

These noise maps, or ISO contours, allow the user to quantify visually the noise levels per frequency band on the measurement surface.

2. Use the command **Setup / Zone** or ![icon] to select for which faces of the measurement surface the noise maps will be plotted.

This function can be useful to exclude some measurement faces from the noise map display.

3. Use the command **Setup / Data** or ![icon] to select the type of data to display as noise map.

The sound intensity or sound pressure values can be plotted as noise maps, in either octave bands or third octave bands.
It is also possible to select the frequency bands that will be considered for overall level calculations by pressing the Select key.

The frequencies displayed are the centre frequencies of the third-octave or octave bands, according to the previous choice.

When opening this dialog box, the frequencies selected by default are those of the frequency range of the last acquisition.

Add or exclude frequency bands by a simple mouse click on the appropriate frequency value. Two keys can be used to include all or clear all the frequencies for calculating overall noise levels.

To exclude negligible frequency bands from subsequent calculations (see chapter 8.2.3 page 56), perform this operation in this dialog box.

Use the command Set-up / Displayed frequencies or to select the frequency bands for which the noise maps will be plotted.

Select with the mouse the frequency bands to display in the results' list.

The keys All and Clear All allows the user respectively to select automatically all the frequencies or to clear them all.

Some frequency bands are preceded by a mark *.

They correspond to the frequency bands excluded from the calculation of overall noise levels in the data selection dialog box.

These frequency bands cannot be selected for display either manually or automatically.

Use the command Setup / Colours or to configure the plot as noise map.

This dialog box allows the user to:

- Display the mesh and/or the noise map and/or the ISO-contours.
- Select the colours of the different ISO - contours, and the colours to represent positive and negative intensities.
- Authorise the display of negative intensities.
- Select the step (between 1 and 10 dB) and the minimum and maximum limit values of the plot (maximal dynamic = 13 times the step).

The Extrapolation option allows the user to extrapolate the results behind the boundaries of the points of the mesh.
The noise maps below are represented without the Extrapolation option:

![Noise Maps Example](image)

The X and Y computation factors are used to interpolate the measured values on each surface in order to obtain a better definition of the noise maps. Below are two examples for which the results are extrapolated and for different computation factors:

- The command Setup / Legend or ![Legend Icon] is used to display a legend on the noise map.
- The command Setup / Layout or ![Layout Icon] is used to choose the type of layout in the display window.
10. OBTAINING THE DESIRED GRADE OF ACCURACY : ISO9614

In this chapter, we deal with the actions that can be taken to improve the accuracy on the measurement results according to the specifications of ISO9614, part 1 and part 2. This chapter should be read simultaneously to chapter 3 that deal with the standardisation aspects of sound power determination using sound intensity measurement.

10.1. Stationarity check (discrete point method – part 1)

As previously seen, the principle of the ISO 9614- Part 1 (discrete point method) is based on the hypothesis that the sound field is stationary. It is therefore required to fulfil this criterion (F1 < 0.6 dB) in order to obtain accurate results.

The first stationarity check is made for a short averaging duration. If the criterion is not fulfilled, the first action to take is to increase the measurement duration.

If this measurement cannot be improved, and if only a few frequency bands do not fulfil the condition, the standard allows the user to exclude these frequency bands from the calculation of the A weighted sound power level of the source.

In order to exclude one frequency band, the A weighted level for this band must be inferior by 10 dB to the highest A weighted band level.

To exclude several frequency bands, the sum of the A weighted sound power level for these bands must be inferior by 10 dB to the highest A weighted band level.

Here is the practical process to exclude frequency bands:

1. Realise the sound power measurements.

2. Open a global result display window (or global listing window) and display the F1 criterion (stationarity) and the sound power spectrum for all the acquired frequency bands, according to the required grade of accuracy. Take into account all the measured points for the calculations of the overall results, display the non-conformity bar and synchronise the cursors.
3. If a band level is less than at least 10 dB with respect to the highest band level obtained in dB(A), the user is allowed to remove this band from calculation.

4. If you wish to exclude several bands of level $L_{wi}$:
   - Calculate the power $W_i$:
     \[ W_i = 10^{-12} \times 10^{\left(\frac{L_{wi}}{10}\right)} \]
   - Add the power values for these bands:
     \[ W_{total} = \sum W_i \]
   - Calculate the overall level for these bands in dB:
     \[ L_{W_{total}} = 10 \log \left( \frac{W_{total}}{10^{-12}} \right) \]

   General formulae: $L_{W_{total}} = 10 \log \left( 10^{L_{w1/10}} + 10^{L_{w2/10}} + \ldots + 10^{L_{wi/10}} \right)$

5. If $L_{W_{total}}$ is inferior by 10 dB to the highest A weighted band level, you are allowed to exclude these bands from the sound power calculation.
10.2. Sound power measurements

As seen in chapter 3, the uncertainty on the sound power determination according to ISO9614 is defined by the grade of accuracy (Survey, Engineering or Precision for the discrete point method).

The main interest of the standard ISO 9614 part 1 and part 2 is therefore to accurately measure the sound power of a source.

Schemes for procedures for achieving the desired grade of accuracy and the actions to increase the grade of accuracy are available in the Annex B of ISO 9614 part 1 (respectively Figure B1 and Table B3), and in the Annex B of ISO 9614 part 2 (respectively Figure B1 and Table B1).

They also are available in chapter 3.

10.2.1. Procedures to improve criterion 1 of the standard (\(L_d > F_2\))

If the surface pressure intensity field indicator \(F_2\) is greater or equal to the dynamic capability index of the intensity meter, sound power measurements have to be performed again in different conditions:

- Reduce the average distance of measurement surface from source to a minimum average value of 0.25m in presence of significant extraneous source or reverberation.
- Increase the average distance of measurement surface from up to 1m if no significant extraneous source or reverberation is present.

10.2.2. Procedures to improve criterion 2 of the standard (ISO9614 part 1 only)

Criterion 2 of ISO9614 part 1 standard (\(N > CF_4^2\)), the discrete points’ method, can be improved by increasing the density of the measurement positions called 'hot spots', that is the mesh surfaces for which the criterion is not fulfilled at given frequency bands.

10.2.2.1. Find hot spots

1. Perform sound power measurements has described in chapter 8.3.)

2. Open a global result display window (or global listing window) and display Criterion 2 for all the measurement frequencies, according to the desired grade of accuracy. Take into account all measured points for the calculation and display the non-conformity bar. Note in which frequency bands the criterion is not fulfilled.

3. Open a graphical plot of the results per point (or a listing per point) and display the sound power spectrum for all the measurement positions. Synchronise the cursors and increase the size of the window if you do not see the cursors’ values.

4. Place the cursors on the first frequency band that does not fulfil the criterion and note which graphics present the highest sound power level in the band.

5. Identify on the mesh the points corresponding to these graphics (they are the hot spots). To do so use the co-ordinates of the point displayed on each graphic.

6. Repeat this operation for all the frequency bands that do not fulfil the criterion.
10.2.2.2. Increase the density of measurement positions for the hot spots

Now that you have identified which surfaces of the mesh require complementary measurements, you need to sub-divide the mesh for these surfaces.

1. Use the command Results / Mesh modification.

   ![Mesh modification dialog box](image)

   Select with the mouse the mesh points to sub-divide or use the automatic selection keys.

   The option "Non measured points" allows the user to take into account during the automatic selection only the measurement positions that have not yet been measured.

2. Once the points have been selected, press on the key Factor.

   ![Sub-mesh factor dialog box](image)

   Determine here the sub-division factors according to two axes for each point.

3. You may now perform the measurements for each new point after selecting an acquisition order (automatic selection is not possible anymore).
10.3. Example of measurement using the actions to improve the grade of accuracy

10.3.1. Problematic

The following example deals with sound power measurement of a printer. During a first measurement session, we tried to perform the measurements according to the scanning method (ISO9614 part 2) by sweeping the probe on the surfaces of a parallelepipedic mesh.

We did not obtain very good results because the measurement repeatability was impossible to obtain. Indeed, as the acoustic field of the printer varies greatly during a printing cycle and the position of the probe in the sound field also varies during the scan, it was pretty much impossible to exactly repeat a measurement.

The graphical plot below shows conformity results for these first measurement results:

![Graphical plot](image)

We see that criterion 3 (repeatability) is not fulfilled for all the mesh surfaces. We therefore used the discrete points' method (ISO9614 part 1) to determine the sound power level of the printer.

A first measurement made with the default parallelepipedic mesh given by the software gave poor results. Most of the measurement locations were not placed in front of the printer. We therefore carried another measurement session with a mesh more adapted to the layout of the printer. The defined measurement surface is shown below:

![Measurement surface](image)
10.3.2. Improving Stationarity criterion (F1 indicator)

Sound power determination of a printer is a good example to illustrate how to find an appropriate averaging time to obtain a stationary sound field: the printing cycle of a page consists of different stages. Each one generates a different noise: warm up, sheet capture, inking, noise of the rollers, form feed. It is therefore impossible to correctly measure the printer’s sound power level if the averaging time (or measurement duration) does not cover a complete printing cycle.

We therefore timed the printing cycle, and then used this duration as the measurement averaging time (156 averages, 50 seconds). We did not use the chained acquisition option (measurement configuration command) because it was required to print a page for each stationarity measurement.

The F1 indicator spectrum thereby obtained fulfilled the requirements of the standard:

10.3.3. Improving criterion 2

The criterion 2 spectrum shows that the third-octave bands' values of centre frequencies ranging from 50 Hz to 125 Hz and 1,6 kHz do not fulfill the standard requirements:
Let first check if we can exclude some frequency bands from the results' calculations:

<table>
<thead>
<tr>
<th>Frequencies (Hz)</th>
<th>50</th>
<th>63</th>
<th>80</th>
<th>100</th>
<th>125</th>
<th>1600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level (dBA)</td>
<td>16</td>
<td>17.6</td>
<td>8.9</td>
<td>9.8</td>
<td>17.1</td>
<td>47</td>
</tr>
</tbody>
</table>

- The highest sound power band level is the band centred on 1.25 kHz with 53.3 dB, that is **53.9 dB(A)**.

- If we sum the sound energy for all the above frequency bands, we obtain:

$$L_{w_{tot1}} = 10 \log (10^{1.6} + 10^{1.76} + 10^{0.89} + 10^{0.98} + 10^{0.171} + 10^{4.7}) = 47 \text{ dB(A)}$$

These bands can therefore be neglected because they are inferior by 10 dB to the highest A-weighted sound power band level, calculated previously.

- However, let perform the same calculation without the frequency band centred on 1600Hz, we obtain:

$$L_{w_{tot}} = 10 \log (10^{1.6} + 10^{1.76} + 10^{0.89} + 10^{0.98} + 10^{0.171}) = 20.7 \text{ dB(A)}$$

We will therefore neglect the frequency bands ranging from 50 Hz to 125 Hz without any doubt but we will try to improve the result obtained at 1600 Hz.

- Let display point by point graphics, with synchronised cursors located on the frequency band centred on 1600 Hz:

![Graphics for frequency bands](image)

- We now locate the graphics for which the 1.6 kHz band level is the greatest. There are the plots 1 and 2 of the first line, of value 47.3 dB and 51.4 dB respectively.
Let display point by point graphics for these two points in order to find their co-ordinates. Double click on the plots of interest for a full screen display. We thereby locate the co-ordinates of these hot spots. Let display point by point graphics for these two points in order to find their co-ordinates.

Let sub-divide the mesh for these two positions by a factor 2 on the X-axis then let measure sound power for these four new points, after selection of an acquisition order.

When displaying overall results, we see that this first mesh modification improved criterion 2 at 1.6kHz, but the non-conformity band shifted to 1.25 kHz. Another sub-division of the mesh is thereby required:
- We therefore proceed as before to locate the hot spots: the fourth graph of the first line, with 55.6 dB, is the highest sound power spectrum band level at 1.25kHz. When editing the graph full screen, we locate its co-ordinates on the mesh:

![Graph Image]

- We then sub-divide the mesh for this point by a factor 2 on the X-axis and define an acquisition order before proceeding with the measurements.

![Mesh Image]

- We display the new overall results. This time Criterion 2 is fulfilled, excluding the bands we can neglect. This iterative process allowed use to obtain an accurate value of a printer sound power level, according to the Precision grade of the standard ISO9614 part 1.

![Results Image]
11. RESULT EXPLOITATION

11.1. Exporting data to a spreadsheet or word processor

The user may either export results as graphics (time history plots and results listings) by the command **Edit / copy / Image** or export the results as values by the command **Edit / Copy / Values**. After the copy command of dBFA32, simply paste (Edit / Paste) the data in a word processor or a spreadsheet processor as shown below:
11.2. Principle and configuration of the Copy command

The copy command may be configured to work in different ways in dBBAI32. Use the command Preferences / Copy to define how the copy command will work. The following dialog box appears on screen.

By default, for all graphical views, the command Edit / Copy can be used to copy the image of the graphical view. The data values cannot be copied.

- **Copy of tables of results**
  
  In some cases, for a table of results mainly, it is possible to copy either an image of the table or the data values of the table at the ASCII format.

  The default option Be prompted for the type of copy each time allows the user to display a dialog box for choosing to copy either the image or the values of the table of results. The option Copy the values only can be used to copy directly the data values. The option Copy the image only can be used to directly copy the image of the table.

- **Copy of an item when a study zone has been defined**

  For items where a study zone can be defined (an audio signal for example), it is possible to copy the image of the view over the complete duration of the item (option Copy the whole) or to copy only the image of the view over the defined study zone (Copy only the study zone).

  The default option Be prompted for the type of copy each time allows the user to display a message to either copy the image of the view over the complete duration or the study zone. The following message appears on screen:

- **Copy data items at ASCII format**

  When copying directly data items from the measurement session window at ASCII format, an additional parameter is the way it will be pasted in a word or spreadsheet processor.

  The data values can be displayed vertically (default value) : data of X-axis and Y-axis are displayed in columns. Alternatively, they can be displayed horizontally : data of X-axis and Y-axis are displayed in lines.

11.3. Printing results

Using the commands of the File menu, results can be directly printed by dBFA32, if a printer is connected to the computer. Use the command File / Print to display the Print dialog box.
12. BIBLIOGRAPHY

12.1. Pre-acoustic intensity measurement

1. H.F. OLSON
   Field-Type Acoustic Wattmeter

2. C.W CLAPP et F.A. FIRESTONE
   The Acoustic Wattmeter, an Instrument for Measuring Sound Energy Flow

3. S. BAKER
   An Acoustic Intensity Meter

4. T.J. SHULTZ
   Acoustic Wattmeter

5. J.F. BURGER, C.J.J. Van der MERWE, B.G. YAN ZYL et L. JOFFE
   Measurement of sound intensity applied to the determination of radiated sound power.

12.2. Recent development of the two microphone method

12.2.1. Principle and general themes

6. G. PAVIC
   Measurement of sound intensity
   J. Sound Vib., 51 (4), 1977, pp 533-545

7. F.J. FAHY
   A Technique for Measuring Sound Intensity with a Sound Level Meter

8. J.M. LAMBERT et A. BADIE-CASSAGNET
   La mesure directe de l'intensité acoustique ; application à la détermination de la puissance
   acoustique des machines en environnement industriel.
   CETIM-Informations n°53, 1977, pp 78-91

9. F.J. FAHY
   Measurements of acoustic intensity using the cross-spectral density of the two microphones
   signals.

10. H.P. LAMBRICH et W.A. STAHEL
    A sound intensity meter and its applications in car acoustics. Inter Noise 77 Proceedin, Zurich,
    1-3 March 1977, pp 142-147.

11. J.Y. CHUNG
    Cross-Spectral method of measuring acoustic intensity without error caused by instrument
    phase mismatch.

12. Recueil des conférences du "Congrès International sur les Progrès Récents dans la Mesure de
13 G. RASMUSSEN (GRAS) et A. ROZWADOWSKI (01dB)  
ISO9614 : From high quality probe through to software  
Euronoise95, Vol. 3, pp 933-937

14 G. RASMUSSEN (GRAS)  
Internoise 94,

12.2.2. Particular aspects

15 J.C. PASCAL  
Détermination de la puissance acoustique des machines de grandes dimensions  
Thèses Docteur-Ingénieur, Université de Paris-VI, 1980

16 A.F. SEYBERT  
Statistical errors in Acoustic intensity measurements  

12.2.3. Applications

17 A. BADIE-CASSAGNET, M. BOCKHOFF, J.M. LAMBERT et J. TOURRET. La mesure directe  
de l'intensité acoustique : son intérêt pour la détermination de la puissance acoustique des  
équipements industriels sur site.  

18 J.C. PASCAL et G. SALVAN  
Discrimination du rayonnement acoustique d'une vanne sur un circuit de vapeur.  
Tenth International Congress on Acoustics, Sydney, 6-16 July 1981, C1-5.1.

12.2.4. Standards

19 ISO 9614-1 standard : Acoustics: Determination of sound power levels of noise sources using  
sound intensity – Part 1 : Measurement at discrete points

20 ISO 9614-2 standard : Acoustics: Determination of sound power levels of noise sources using  
sound intensity – Part 2 : Measurement by scanning

21 IEC 1043 standard: Instruments for the measurement of sound intensity – Instruments which  
measure intensity with pairs of pressure sensing microphones