Brüel & Kjær application notes

# Determination of Sound Power based on Sound Pressure Measurements using the Real-time Frequency Analyzers Types 2123 and 2133

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Brüel & Kjær

## 1. Introduction

The Brüel & Kjær Real-time Frequency Analyzers Types 2123 and 2133 are ideally suited to the determination of sound power based on pressure measurements in that not only are they capable of carrying out all of the measurements and processing of data required to make the determinations, but they are also able to control the peripheral equipment such as multiplexers and rotating microphone booms frequently used during the measuements. Therefore the 2123 and 2133 can form the core of a complete stand-alone measurement system for sound power determination.

This application note describes use of the Brüel & Kjær Real-time Frequency Analyzers 2123 and 2133 in precision and engineering grade determinations of sound power in diffuse and free-field conditions according to ISO 3741 to ISO 3745, (ANSI equivalents ANSI S1.31 to ANSI S1.35). It does not describe the survey methods of ISO 3746 to ISO 3748. However, since these are largely simplifications of ISO 3744 and ISO 3745, the methods given here still apply.

## 2. Sound Power Determination using Pressure Measurements

The principle of sound power determination based on pressure measurements is that the sound source under investigation is placed in a known acoustic environment and then measurements of the spatially averaged sound pressure level are made with the source operating. The background noise is also measured, and where necessary the source noise is corrected for the background noise. The sound power of the source, that is its total acoustic energy output per second, is then calculated from the sound pressure measurements and a knowledge of the acoustic environment. Two types of acoustic environment are used for such determinations, namely a diffuse sound field as produced by a reverberation room, and a free sound field or free sound field over a reflecting plane as produced by an anechoic or semi-anechoic chamber respectively.

## 3. Sound Power Determination using the 2123 and 2133

Irrespective of the method followed, pressure-based determinations of sound power using the 2123 or 2133 proceed in a similar fashion. This procedure is summarised below:

1. The 2123/33 is set up according to the type of spatial averaging to be employed. In a diffuse field, this is normally carried out using a rotating microphone boom, such as a Brüel & Kjær 3923, (although a microphone array can also be used). In a free field, an array of microphone positions is used. This may be a single microphone which is physically moved from microphone position to microphone position, or a multiplexed microphone array where one or more multiplexers, such as the Brüel & Kjær 2811, are used to scan around the microphone positions.

A typical 2123/33 measurement set-up for a sound power determination using a rotating microphone boom is shown in Fig. 1. Here, the sound pressure level measured along the path of the boom is averaged into the 2123/33 input memory. A typical 2123/33 measurement set-up for a determination using a microphone array is shown in Fig. 2. Here, the results from each measurement position are stored in a buffer multispectrum, the number of positions in the multispectrum corresponding to the number of positions in the microphone array.

Where a Brüel & Kjær Rotating Microphone Boom Type 3923 or one or more Multiplexers Types 2811 are used with the 2123/33,

```
1W Ch.A Auto Spectrum

Bandwidth : 1/3 oct.     100Hz → 10kHz
Averaging : Lin.    T: 32s

Input     : Single                                Man. re-start
Buffer    : Empty

Ch.A      : Preamp 100mV   +  ⁄‾22.4Hz  Lin.       50.0mV/Pa
```
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*Fig. 1. Typical Measurement Set-up for Sound Power Determination using a Rotating Microphone Boom*

```
1W Ch.A Auto Spectrum

Bandwidth : 1/3 oct.      100Hz → 10kHz
Averaging : Lin.     T: 30.0s

Input     : Single                              Man. re-start
Buffer    : Multi 10

Ch.A      : Preamp 100mV   +   /‾22.4Hz  Lin.      50.0mV/Pa
```
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*Fig. 2. Typical Measurement Set-up for Sound Power Determination using a Microphone Array*

they can be automatically controlled from the 2123/33. See Section 4 for details.

2. In addition to the source and background noise measurements for the noise source under investigation, the 2123/33 will need the values of at least one or more further parameters in order to complete the determinations. Where the parameters are constant as a function of frequency, for example, room volume or area of a measurement surface, their values are entered into the 2123/33 table of constants. Where they are variable as a function of frequency, for example, reverberation time or room correction factor, their values as a function of frequency are stored in a file on disc. Where parameters such as reverberation time or room correction factor are unknown, they can be measured using the 2123/33, and then stored on disc.

3. The background noise is measured and stored on disc. Note that the background noise should be measured in precisely the same manner as the source noise, except that the noise source under investigation is switched off. The background noise measurement is stored on disc in a file named NOISE.

4. The source noise is measured. Where a rotating microphone boom is used, only one measurement is necessary, and this is stored in the 2123/33 input memory. Where a microphone array is used, the measurement for each position in the array is stored in a multispectrum in the buffer memory.

5. The 2123 or 2133 is set to display the contents of the input memory, (rotating microphone boom), or the buffer memory, (microphone array), and the relevant pre-defined processing function is called into the display set-up. Where the 2123/33 requires further information to be recalled from disc, it will request this information. Otherwise, the sound power of the noise source under investigation, calculated from the measured data, is displayed.

## 3.1. Precision Methods of Sound Power Determination in a Reverberation Room

Precision methods of sound power determination in a reverberation room are governed by the standards ISO 3741 and ISO 3742. The measurement methods of the two standards are identical, the difference between them being that ISO 3741 is for broadband noise sources, while ISO 3742 is for narrowband noise sources and places more stringent requirements on the characteristics of the room. ISO 3741 and ISO 3742 describe two methods, the direct method and the comparison method.

### 3.1.1. Direct Method, (Function No. 31)

In the direct method, the sound power of the noise source under investigation is calculated from the spatially averaged source and background noise measurements and the physical parameters of the room. The relevant 2123/33 pre-defined processing function is **no. 31, Lw. dir. 1.** This requires that the values of the following additional parameters be entered into the 2123/33 via the table of constants:

*V_r* = volume of the test room in $m^3$
*S_r* = surface area of the test room in $m^2$
*B* = barometric pressure in **bars**
*pi* = value of $\pi$
*c*0 = speed of sound in air in m/s

The 2123/33 requires further the reverberation time of the room as a function of frequency. Where this is known, it can be entered into the 2123/33 via the keyboard. Where it is not known, it can be measured by the 2123/33. Either way, the reverberation time should be stored on disc in a file named *T*. For an octave determination of sound power, the reverberation time is required in octaves, while for a 1/3 octave determination it is required in 1/3 octaves.

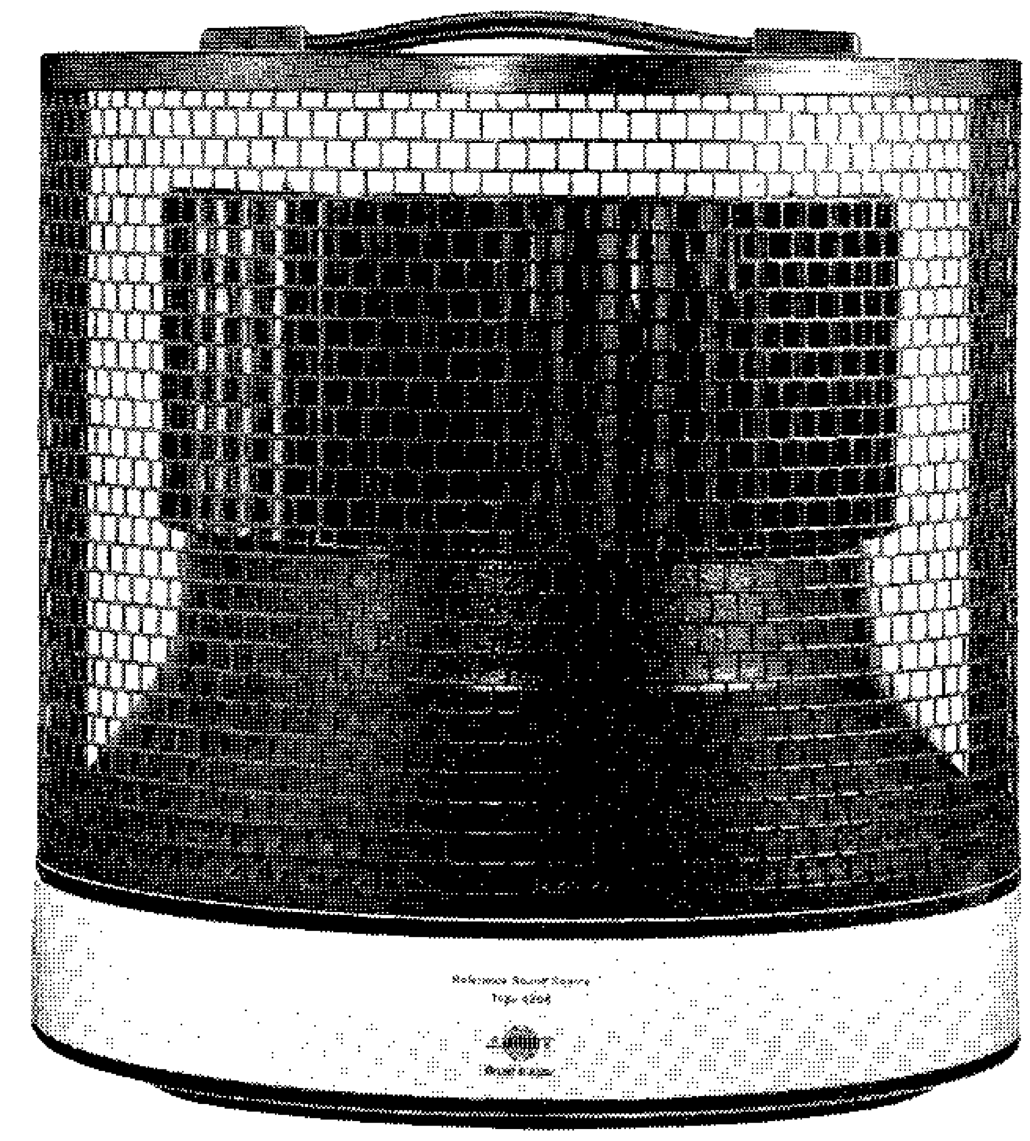

*Fig. 3. Brüel & Kjær Reference Sound Source Type 4204*

### 3.1.2. Comparison Method (Function No. 32)

In the comparison method, the influence of the environment on the determination is measured using a reference sound source such as the Brüel & Kjær 4204, (Fig. 3). The relevant 2123/33 pre-defined processing function to use is **no. 32, Lw.com.1.** In addition to the spatially averaged source and background noise measurements, this function requires that the following files have been recorded on disc:

LWREF – the sound power of the reference sound source as read from its calibration chart. This is entered, in octaves for an octave determination of sound power and 1/3 octaves for a 1/3 octave determination, via the 2123/33 keyboard and transferred to a file named LWREF on the disc.

LPREF – the spatially averaged sound pressure in the reverberation room with the reference sound source operating, measured in the same way as the source noise and in octaves for an octave determination of sound power and 1/3 octaves for a 1/3 octave determination. This is measured using the 2123/33 and transferred to a file named LPREF on the disc.

## 3.2. Engineering Methods of Sound Power Determination in a Reverberation Room

The engineering methods of sound power determination in a reverberation room are governed by ISO 3743. In this standard, the requirements for the reverbeation room are relaxed with respect to ISO 3741 and ISO 3742.

Further, the reverberation time of the room is now characterised as a single number, (the so-called nominal reverberation time of the room, see ISO 3743 for details), rather than being something which is variable with frequency. Note, however, that ISO 3743 gives reduced accuracy with respect to ISO 3741 and 3742.

Like ISO 3741 and ISO 3742, ISO 3743 describes a direct method and a comparison method for determination of sound power.

### 3.2.1. Direct Method (Function No. 33)

The direct method of ISO 3743 is simplified with respect to the direct method of ISO 3741/42. The relevant 2123/33 pre-defined processing function is **no.33, Lw.rev.3.** In addition to the spatially averaged source and background noise measurements, this requires that following additional parameters be entered into the 2123/33 via the table of constants.

*TN* = the nominal reverberation time of the test room in seconds (see ISO 3743)

*V_r* = volume of the test room in $m^3$.

### 3.2.2. Comparison Method (Function No. 32)

The comparison method described in ISO 3743 is identical to the comparison method of ISO 3741/42, see Section 3.1.2 for details.

### 3.3. Precision Method of Sound Power Determination in an Anechoic or Semi-anehoic Chamber, (Function No. 35)

The precision determination of sound power in an anechoic or semi-anechoic chamber is governed by ISO 3745. It requires measurements of the source and background noise at a number of microphone positions on a spherical measurement surface around the noise source under investigation, (anechoic chamber), or on a hemispherical measurement surface surrounding the noise source which is mounted on a reflecting plane (semi-anechoic chamber). The relevant 2123/33 pre-defined processing function is **no.35, Lw.free.5.** Note that this function is defined for a hemispherical measurement surface, and that where a spherical surface is used the surface area correction term $2\pi r^2$ should be modified to $4\pi r^2$. In addition to the source and background noise measurements, the values of the following parameters should be entered via the 2123/33 table of constants:

*pi* = value of $\pi$

*r* = radius of the hemispherical measurement surface in *m*.

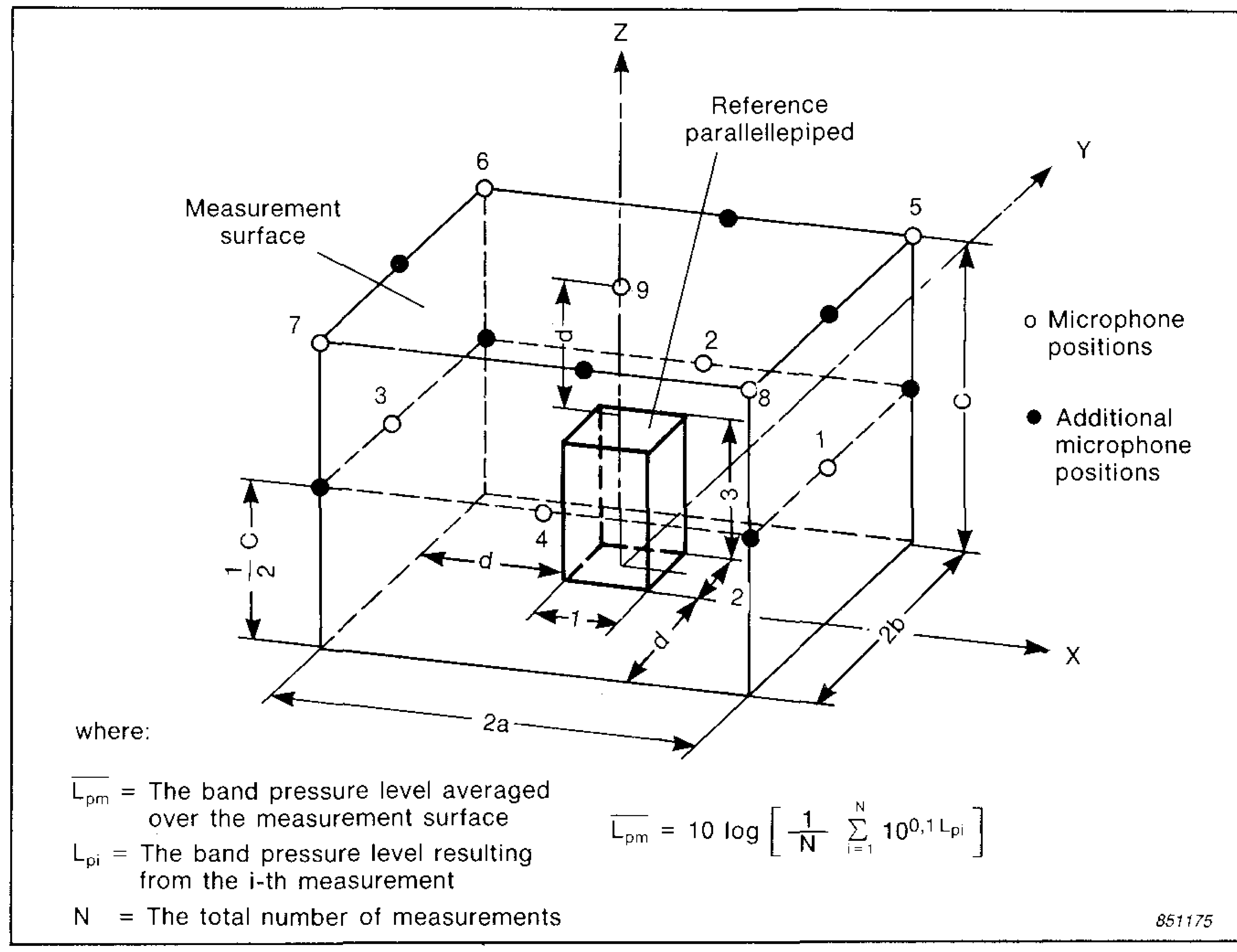

*Fig. 4. The papallelepiped or "shoebox" measuring surface allowed by ISO 3744*

### 3.4. Engineering Method of Sound Power Determination in an Almost-free-field over a Reflecting Plane, (Function No. 34)

The engineering method of sound power determination in an almost-free-field is governed by ISO 3744. This is a relaxation of ISO 3745, (but with reduced accuracy), in that it allows some deviations from true free-field conditions, and the use of measurement surfaces other than the sphere or hemisphere. One such measurement surface is the parallelapiped, or "shoebox", shown in Fig. 4. Otherwise, the method is identical to that of ISO 3745. The relevant 2123/33 pre-defined processing function is function **no. 34, Lw.free.4.** Note that when ISO 3744 is followed, the sound power determination is **always** made over a reflecting plane.

In addition to the source and background noise measurements, the determination requires that the value of the following parameters should be entered via the 2123/33 table of constants:

*S* = area of the measurement surface in $m^2$

The determination further requires entry of the environmental correction factor, which gives the amount of deviation from true free-field conditions. This is most usually measured using a reference sound source such as the Brüel & Kjær Type 4204, (see Fig. 3), and is defined as the difference in the measured sound power of the reference sound source when measured under the same conditions and in the same environment as the noise source under investigation, and the sound power read from its calibration chart. The correction factor should be in octaves for an octave determination of sound power, and in 1/3 octaves for a 1/3 octave determination, and if ISO 3744 is to be followed, must lie in the range 0 to 2 dB. The environmental correction factor should be stored on disc in a file named ROOM_COR.

# 4. Automatic Control of a Rotating Microphone Boom or Multiplexer

Signals to control a Rotating Microphone Boom Type 3923 or up to four Multiplexers Type 2811, are available via the Remote Control socket on the rear of the 2123 or 2133. These signals are activated via a special parameter in the 2123/33 general set-up. This is special parameter number no.8, "Remote Control Output", and when it is set to "Step", (the default setting), each time a measurement is accepted into the 2123/33 buffer memory, (using

"Manual Accept" or "Auto Accept"), a pulse is transmitted from the socket. This can be used, for instance, to step the 2811 multiplexer from one channel to the next, or rotate the 3923 boom through 120°. When the special parameter is set to continuous, the Remote Control socket is continuously active. This can be used, for instance, to continuously rotate the 3923. Connection from the 2123/33 Remote Control socket to a 2811 or 3923 is via cable AQ 0034.

## 5. Automatic Measurements of Sound Power using the 2123 and 2133

Determinations of sound power according to ISO 3741 through ISO 3745 can easily be automated by using an autosequence on the 2123 or 2133. The writing of such an autosequence is greatly simplified by making use of pre-stored measurement and display set-ups, "Auto-Restart" and "Auto Accept" where buffer multispectra are required, and the delay functions "Await input full" and "Await buffer full", since these will minimise the number of keystrokes required. The attention of the user is further drawn to special parameter 28 in the 2123/33 general set-up in connection with automated measurements. When this parameter, "Overloaded Data", is set to "Not Acceptable", data corrupted by an overload will not be entered into a buffer multispectrum. Where "Auto Restart" and "Auto Accept" have been used, the 2123/33 will instead remeasure the point until a measurement without overload has been obtained, and then enter this into the multispectrum and advance to the next point.

## 6. Complete Systems for Determination of Sound Power According to ISO 3741 through ISO 3745

Figs. 5 and 6 illustrate complete systems for determination of sound power according to ISO 3741 through ISO 3743, and ISO 3744 and ISO 3745, respectively. Note that the Reference Sound Source Type 4204 is not required when the direct method of ISO 3741 through ISO 3743 is followed or when the determination is according to ISO 3745.

Fig. 6 assumes that the sound power determination is to be made using a ten microphone array on a hemisphere. Note, however, that fewer or more microphones can be necessary depending on the measurement surface used and the complexity of the sound field produced by the noise source. Further, determinations can be carried out using a single microphone with the analyzer, provided the microphone is moved manually from measurement position to measurement position.

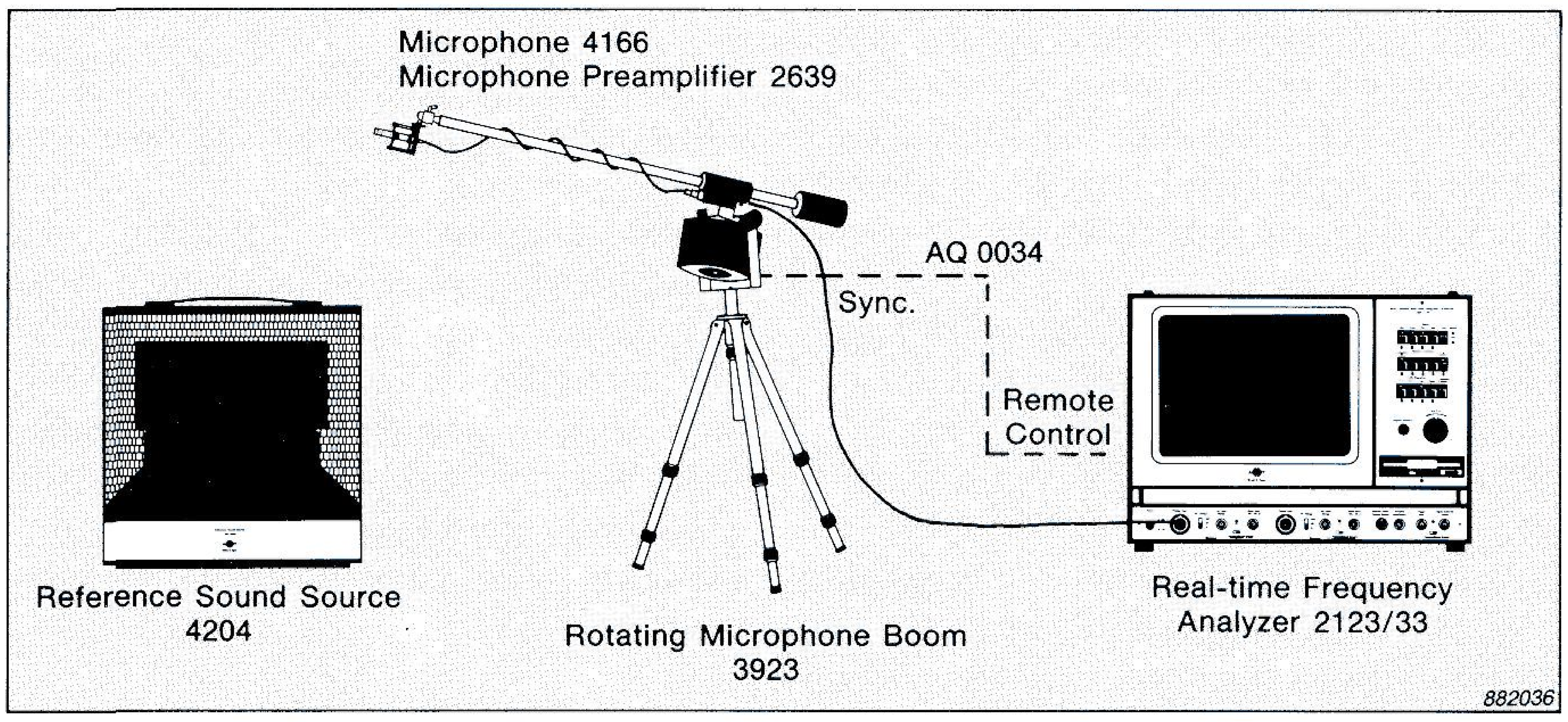


*Fig. 5. Complete system for sound power determination according to ISO 3741 through ISO 3743, (the 4204 is not required when the direct method is followed)*

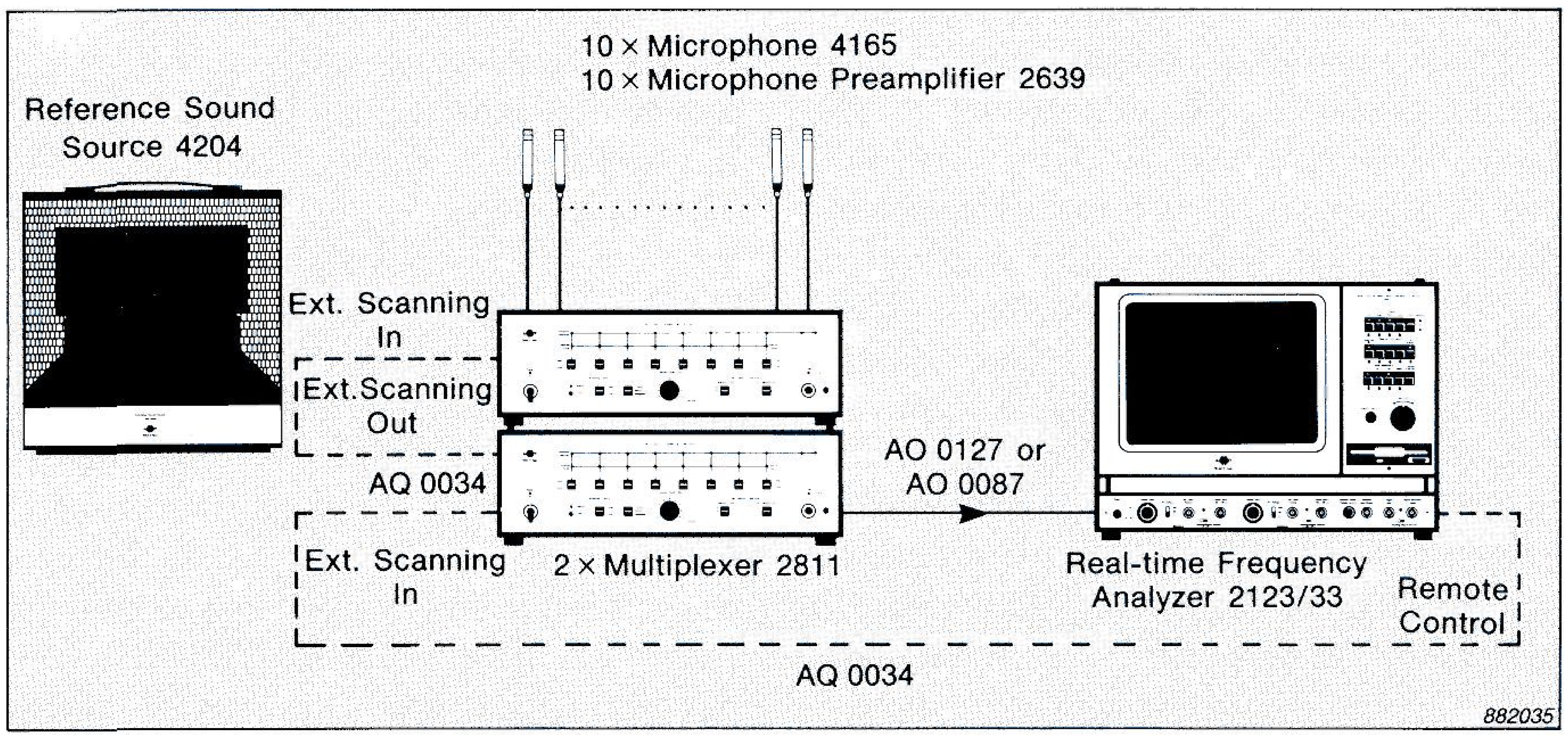


*Fig. 6. Complete system for sound power determination according to ISO 3744 and ISO 3745, (the 4204 is not required for determinations according to ISO 3745)*

## 7. Conclusion

It has been demonstrated that the Brüel & Kjær Real-time Frequency Analyzers Types 2123 and 2133 are very well suited to pressure-based determinations of sound power. Complete, stand-alone systems can be put together for sound power determinations according to ISO 3741 through ISO 3745, (and by default, ISO 3746 through ISO 3748), and these systems can be totally automated, where required.

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