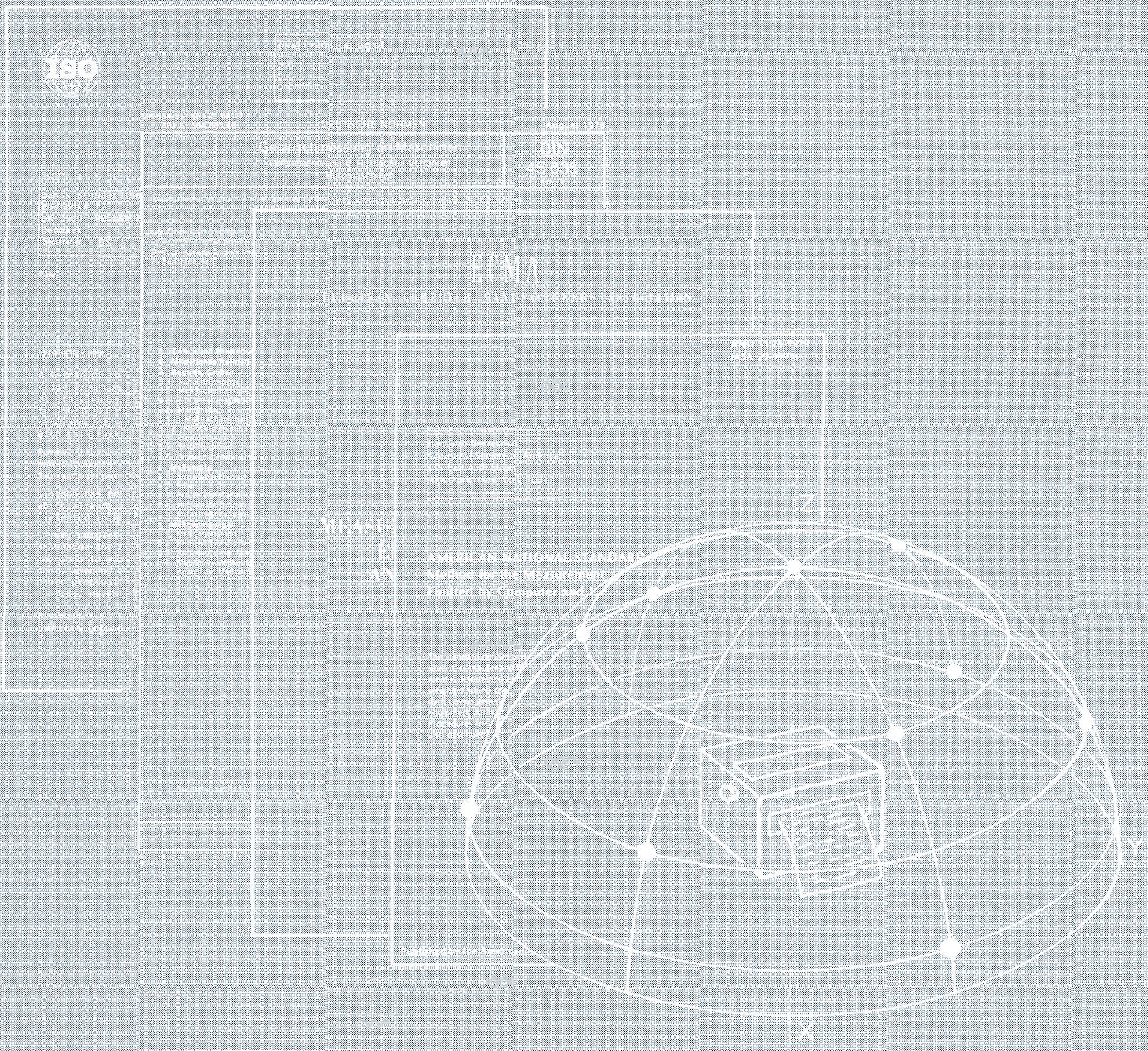
Brüel & Kjær application notes

Introduction to Noise Measurements on Business Machines



Brüel & Kjær

BO 0125–11

Introduction to Noise Measurements on Business Machines

by *Roger Upton,* B.Sc.

Introduction

In recent years, manufacturers of business machines, that is computing and office machines, have come under increasing pressure to provide noise data on their products. For instance, it is becoming increasingly common to see noise levels advertised, particularly for printers. A number of standards have been written governing how such noise measurements should be made, namely:

DIN 45 635 pt.19
ANSI S1.29, (soon to be superceded by ANSI S12.10)
ECMA 74
ISO/DIS 7779

With four separate standards in existence, one might expect some considerable divergence in their requirements. However, there has been close contact between the various standardization committees in the pursuit of harmonization, meaning that the standards agree with each other in the bulk of their requirements. This application note first discusses some acoustic measurement parameters, and then the measurements required by the various standards. Finally, it describes some Brüel & Kjær measurement systems capable of making the required measurements.

Introduction to Noise Measurement Parameters

The standards referred to in the previous section call for measurements of sound power and sound pressure. These measurements can then be used in a variety of ways, such as noise labelling, prediction of installation noise levels, comparison of noise emissions of products, and production control.

Sound power and sound pressure are fundamentally different quantities. Sound power is a measure of the ability of a device to make noise. It is independent of the acoustic environment. Sound pressure, on the other hand, is a measure of human response to noise. It is dependent on the acoustic environment. For instance, sound pressure measurements in a room will depend on the sound powers of the various noise sources in the room, the measurement position, the absorption of the floor, walls, and ceiling, etc.

A frequently used analogy to explain the difference between sound power and sound pressure concerns installing a heater in a room (Fig.1). The heater will have a certain thermal output, which can be measured in Watts, Kilocalories/ hour, B.th.U-/hour, etc. The temperature in the room, however, will depend on items such as the thermal insulation, position in the room, etc. In this analogy, the thermal output of the heater is

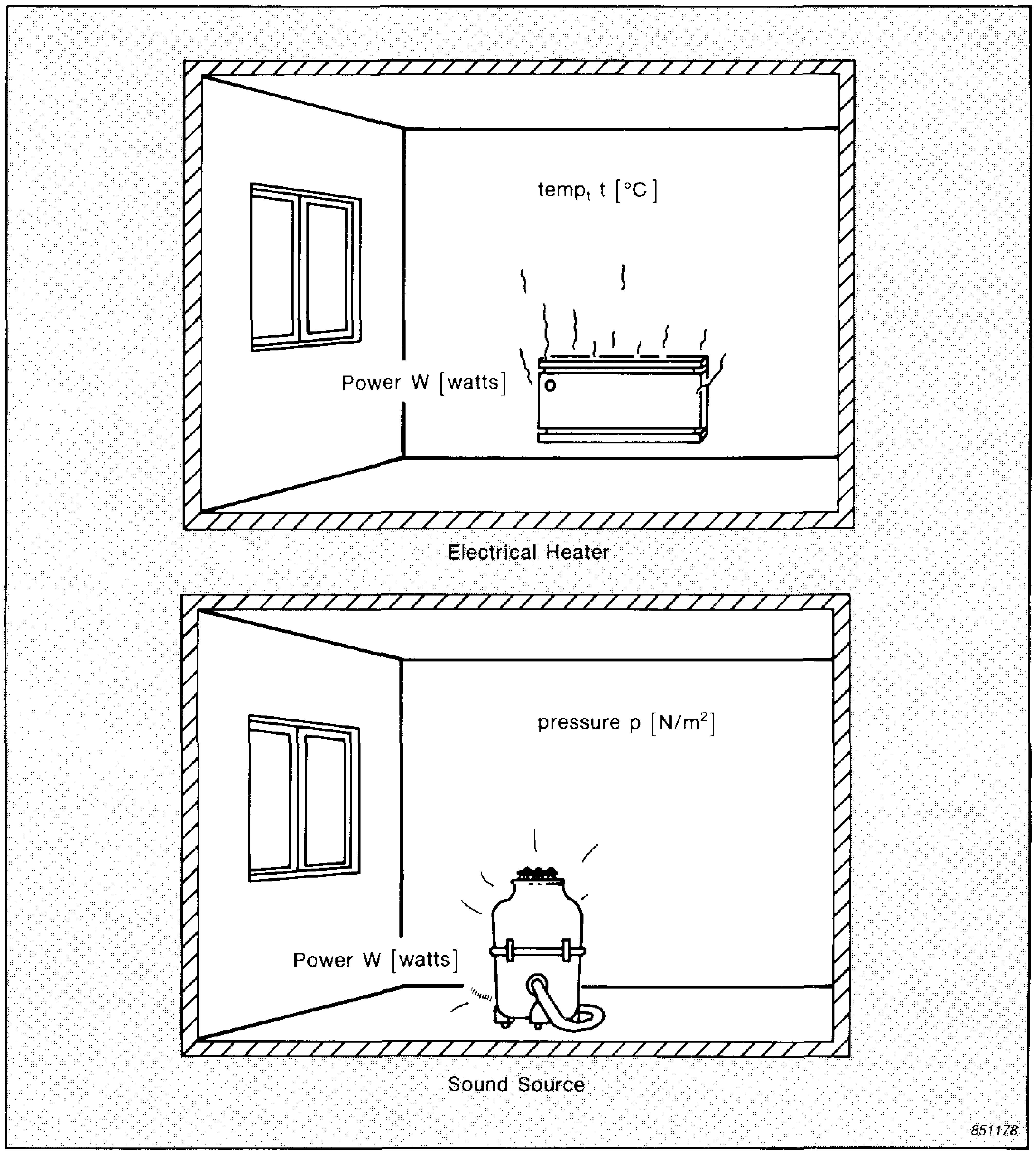


Fig. 1. Comparison of sound power and sound pressure with thermal output and temperature

equivalent to the sound power, and the temperature in the room to the sound pressure.

Sound pressure is the easiest of all acoustic parameters to measure, since it is only necessary to place a microphone in the sound field. Sound pressure is measured in Pascals, (1 Pa = 1 N/m^2), or in dB referred to 20 μPa. Sound power, on the other hand, requires special measurement techniques, and is measured in Watts, or dB referred to 1 pW. A third acoustic parameter is sound intensity, which is the flow of sound energy or sound power flux. Special techniques are required to measure sound intensity, and it is measured in W/m^2 or dB referred to 1 pW/m^2.

When a noise source is placed in a room, the sound field will vary as a function of distance from the source, (Fig.2). Close to the source, there will be a large variation in the sound pressures measured. This is referred to as the near field. As we move away from the source, there will be a region where the sound pressure drops by 6 dB per doubling of distance from the source. This is referred to as the free field. Finally, we will come to a region where reflections from the walls begin to influence the sound pressure, which begins to drop more slowly. This is referred to as the reverberant field.

All noise measurements on business machines are A-weighted. The A-weighting curve is an internationally standardized frequency weighting designed to approximate to the frequency response of the healthy human ear. It is shown in Fig.3.

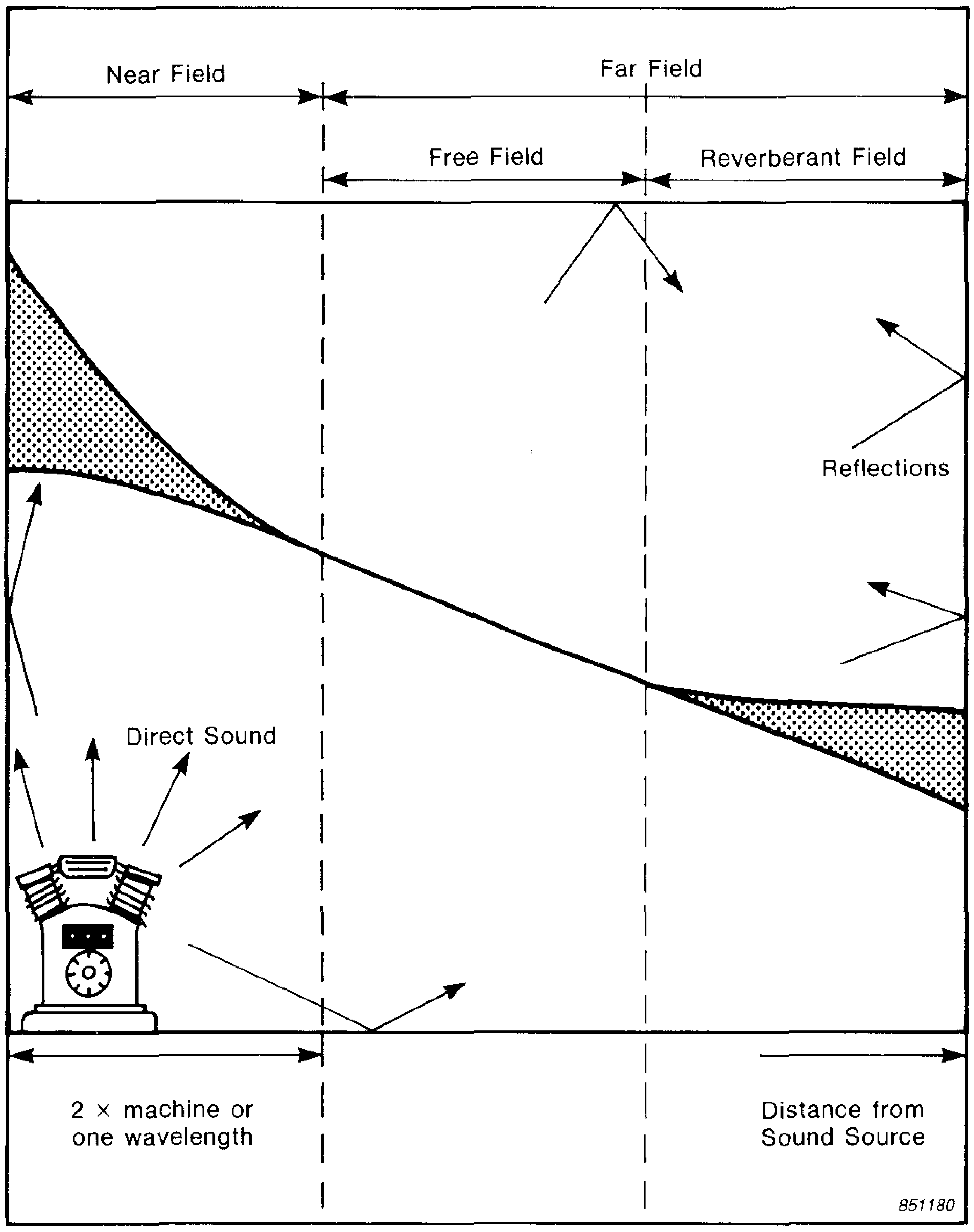


Fig. 2. Near field, free field, and reverberant field

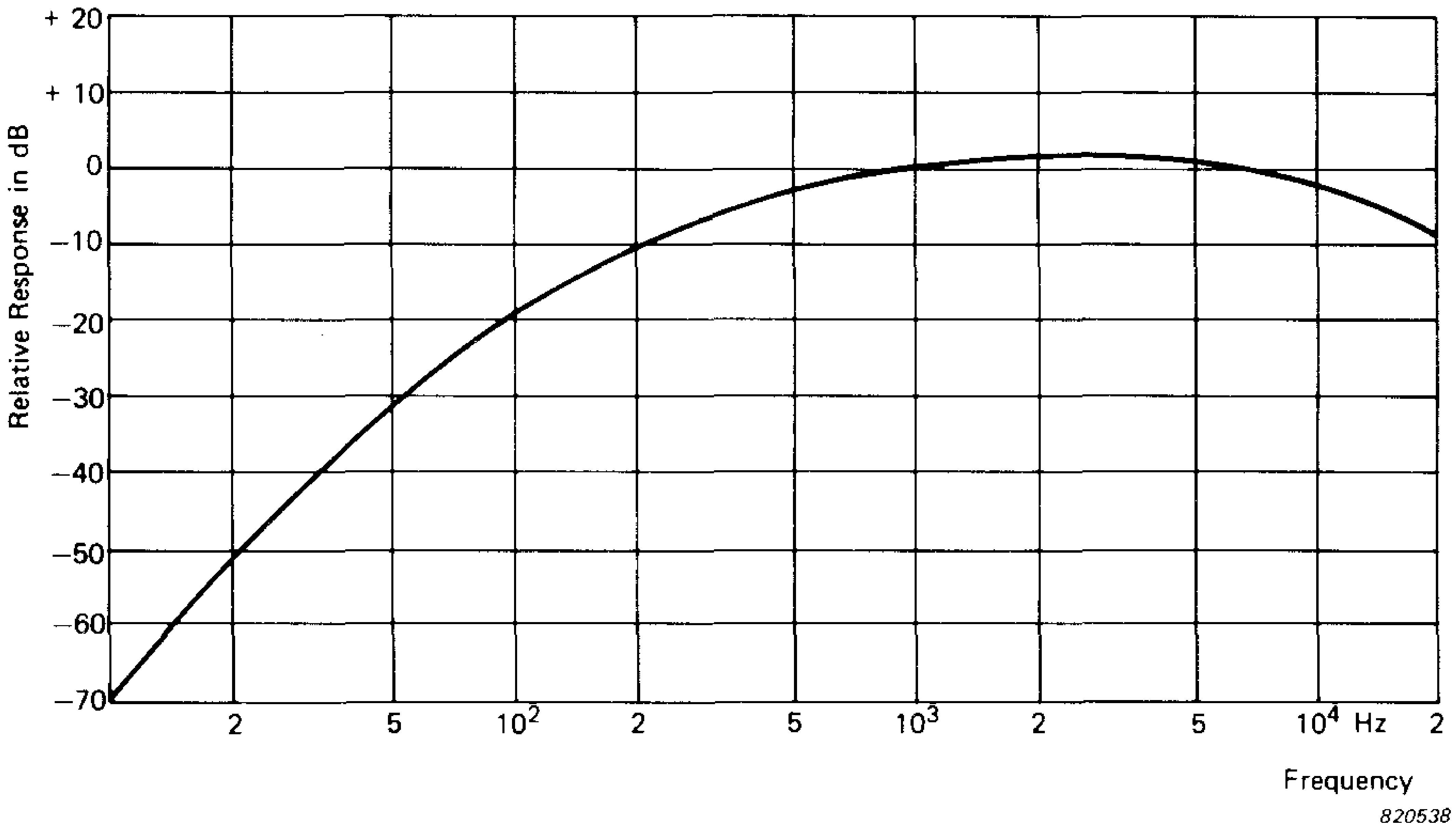


Fig. 3. A-weighting curve

Measurements of Noise from Business Machines according to the various standards

Measurement of Sound Power

The traditional method of measurement of sound power is to place the device under test in a known acoustical environment and measure the sound pressure, from which the sound power can be calculated. A more modern method is to measure the sound power directly using sound intensity. At present, the standards governing noise measurements on business machines only allow the traditional method, although it must be expected that as standards appear for sound power measurements based on intensity, this will be allowed as well.

The standards for noise measurements on business machines allow measurements of sound power according to ISO 3741, ISO 3742 and ISO 3744, (ANSI equivalents ANSI S1.31, S1.32 and S1.34 respectively). ISO 3741 and 3742 require use of a qualified reverberation room, that is, a specially designed acoustic test environment having very hard walls such that as much as possible of the sound incident on them is reflected. ISO 3744 governs measurements of sound power in an almost free field, whereby the test environment can be outdoors or in a large room.

Measurements of Sound Power in a Reverberation Room

ISO 3741 and 3742 describe two methods of measurement of sound power in a reverberation room, namely the "direct" method and the "substitution" method. Of these two methods, the substitution method is generally preferred by the standards for noise measurements on business machines.

In the direct method, the device under test is placed in the reverberation room, and the average sound pressure measured in the room with the device operating. This can be achieved by averaging over a number of microphone positions, or by using a single microphone mounted on a rotating microphone boom. The measurement requires an octave or $\frac{1}{3}$ octave frequency analysis of the average sound pressure, whereby the sound power of the device can be calculated using the equation in Fig.4. Note that the method also requires knowledge of the reverberation time of the room, (that is the time taken for the sound field to decay by 60 dB), in each octave or $\frac{1}{3}$ octave, the room volume, and the room surface area.

In the substitution method, the device under test is placed in the reverberation room with a reference sound source, this being a calibrated sound source having a known sound power, and meeting the requirements of ISO 6926. The average sound pressure in the room is then measured, as before, in each octave or $\frac{1}{3}$ octave first with the device under test operating and second with the reference sound source operating. The sound power of the device under test is then calculated using the equation given in Fig.5.

Direct method

$$L_w = \overline{L_p} - 10 \log\left(\frac{T}{T_0}\right) + 10 \log\left(\frac{V}{V_0}\right) + 10 \log\left(1 + \frac{S\lambda}{8V}\right) - 10 \log\left(\frac{B}{B_0}\right) - 14$$

where:

L_w = The sound power level of the equipment under test

$\overline{L_p}$ = The mean band pressure level

T = The reverberation time of the room in s

T_0 = 1 s

V = The volume of the room in m^3

V_0 = 1 m^3

λ = The wave length at the centre frequency of the octave or one-third octave band in m

S = The total surface area of the room in m^2

B = The barometric pressure in mbar

B_0 = 1000 mbar

851254

Fig. 4. Calculation of sound power in a reverberation room using the direct method (ISO 3741/42)

Substitution method

$$L_w = \overline{L_p} + \left(L_{wr} - \overline{L_{pr}}\right)$$

where:

L_w = The band power level of the equipment under test

$\overline{L_p}$ = The mean band pressure level of the equipment under test

L_{wr} = The calibrated band power level of reference sound source

$\overline{L_{pr}}$ = The mean band pressure of reference sound source

851255

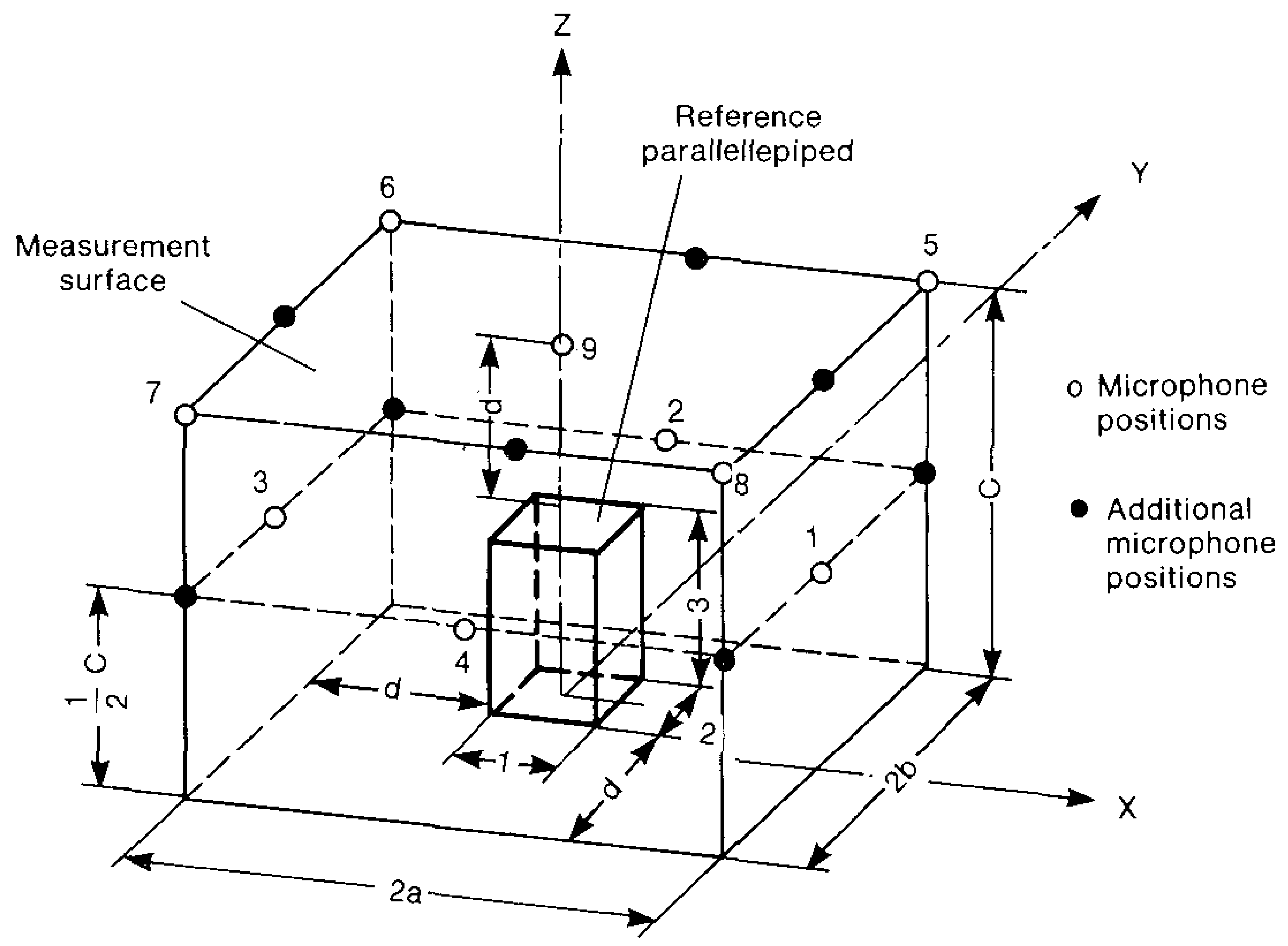
Fig. 5. Calculation of sound power in a reverberation room using the substitution method (ISO 3741/42)

Measurement of Sound Power in an Almost Free Field

An anechoic chamber is an acoustic test environment designed to produce free field conditions. In true free field conditions, the sound pressure and the sound intensity are equal, meaning that the sound power can be calculated directly from the sound pressure. ISO 3744 allows measurement of sound power in almost free field conditions, the advantage being that a large room can be used instead of an anechoic chamber, hence avoiding the extensive capital outlay required for an anechoic chamber. Typically, a large office can be used. Note, however, that the measurements must be made over a reflecting plane, meaning that the office should have a hard, reflecting floor.

In measurements according to ISO 3744, the sound pressure is averaged over a number of fixed microphone positions on a predetermined measurement surface. One such surface, the parallelepiped or shoe-box is shown in Fig.6. The sound pressures at each microphone are measured in octaves or 1/3 octaves, and then averaged in each octave or 1/3 octave band according to the equation shown.

The parallelepiped or shoe-box is the preferred measurement surface for noise measurements on business machines. For small objects, however, an alternative surface, the hemisphere is also allowed. The microphone positions for the hemisphere are shown in Fig.7. Another arrangement using the hemisphere, rapidly gaining acceptance, is to use 5 microphones on a quarter circle, as shown in Fig.8. The microphones are then rotated around the device under test, or the microphones are kept fixed and the device rotated, and the average sound pressure measured.



where:

$\overline{L_{pm}}$ = The band pressure level averaged over the measurement surface

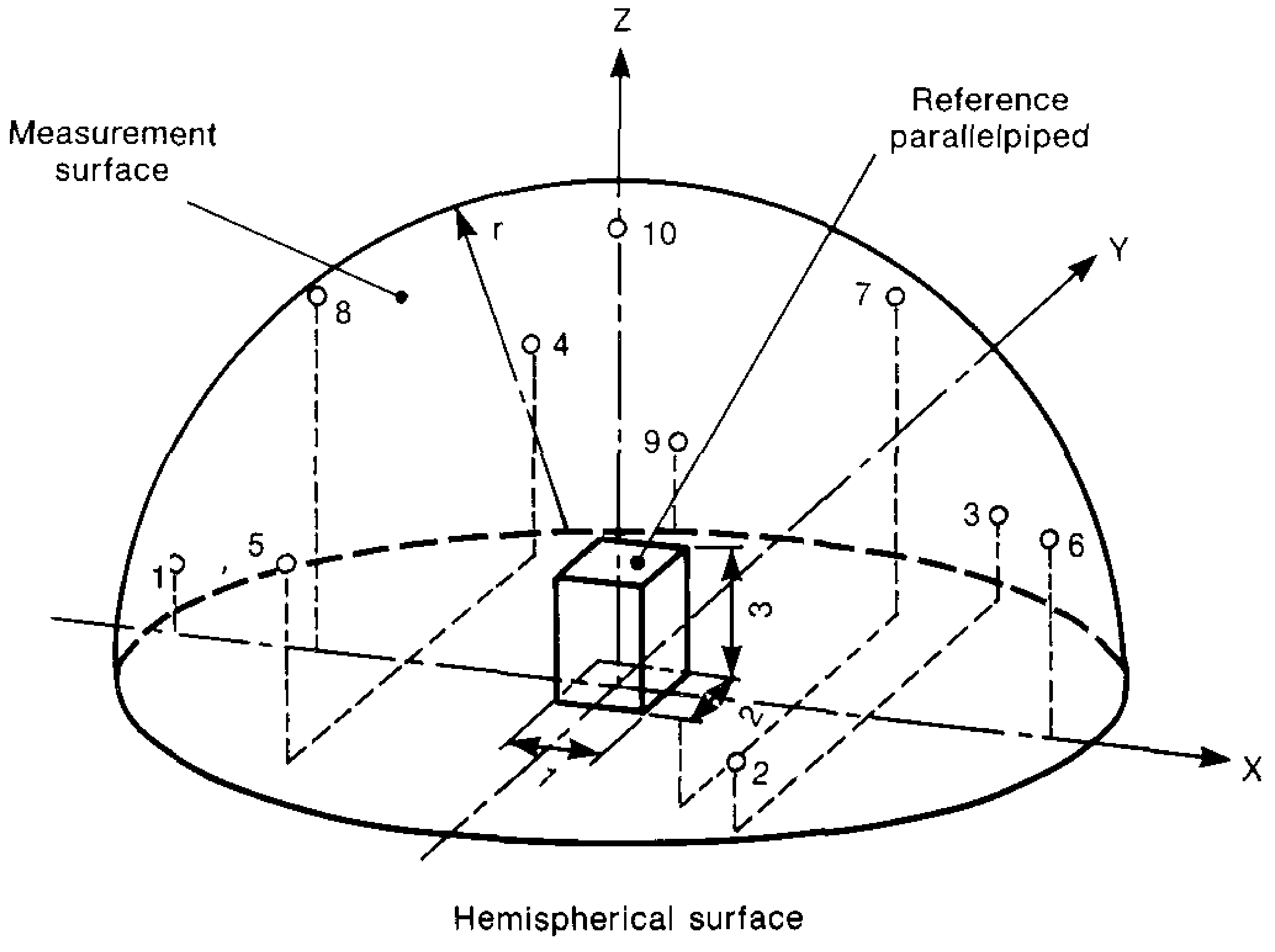
L_{pi} = The band pressure level resulting from the i-th measurement

N = The total number of measurements

$$\overline{L_{pm}} = 10 \log \left[\frac{1}{N} \sum_{i=1}^{N} 10^{0,1 L_{pi}} \right]$$

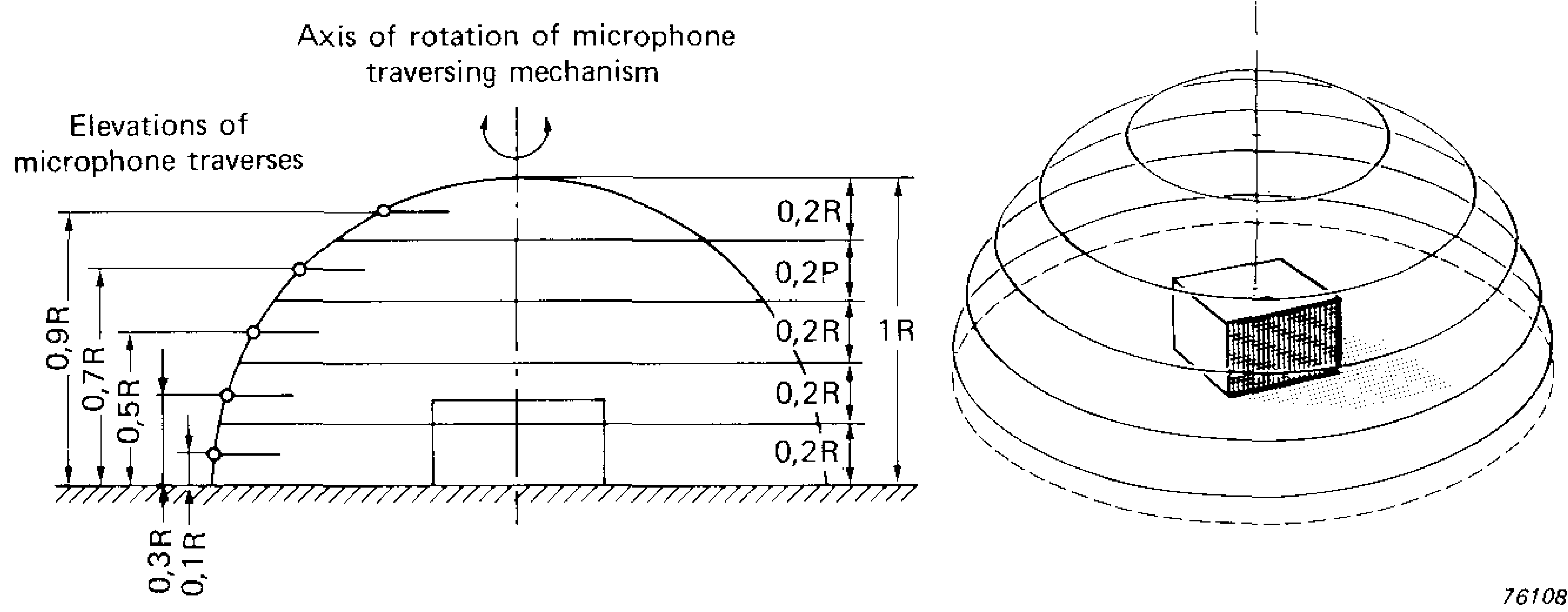
851175

Fig. 6. Parallelpiped surface area according to ISO 3744



851181

Fig. 7. An alternative measurement surface for measurements according to ISO 3744



761082

Fig. 8. Use of the hemisphere with 5 microphones

Since the measurements are not being made in a true free field, a room correction factor must be measured in order to correct for the influence of reflections from the walls, etc.. This uses a calibrated reference sound source of the type described earlier. The device under test is replaced with the reference sound source, and the sound power of the reference sound source is measured, assuming true free field conditions, and using the same measurement surface as for the device under test. The room correction factor, K, in each octave or ⅓ octave, is the difference between the measured sound power and the sound power read from the calibration chart of the reference sound source, (see Fig.9). The maximum range of values allowed for the room correction factor, K, is 0 to + 2 dB. The sound power of the device under test can then be calculated according to the equation given in Fig.10, where $\overline{L_{pf}} = \overline{L_{pm}} - K$.

The room correction factor K can also be calculated. However, this is not usually recommended, since it requires the measurement of reverberation times, which in an almost free field will be very short, and hence prone to error.

Corrections for Background Noise

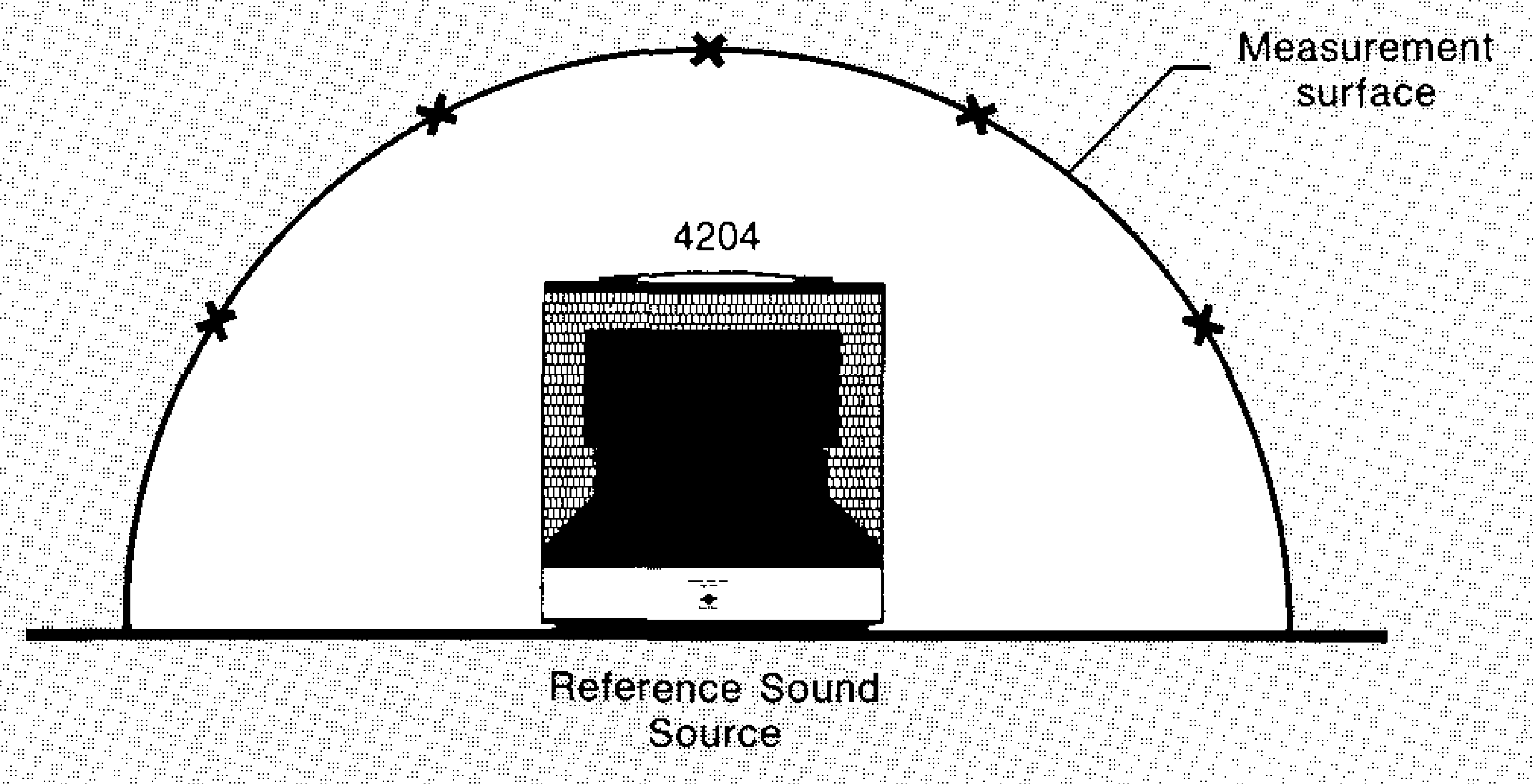
Where background noise levels become significant, a background noise correction is made. Should the background noise be less than 6 dB below the noise from the device under test in any octave or ⅓ octave, then the measurement is invalid in that octave or ⅓ octave. For differences of 6 dB or greater, a background noise correction is allowed, according to either the table or the equation given in Fig.11. Where measurements are made over multiple microphone positions, the background noise is measured and, where necessary, the background noise correction made at each microphone position.

Accuracy of Results

Fig.12 gives the maximum standard deviations which can be expected when ISO 3744 is followed. When ISO 3741 or 3742 is followed, the maximum standard deviations are 0,5 dB less in the 500 hz octave, but 0,5 dB more in the 8 kHz octave.

Units of Results

Where the sound pressures are measured in dB referred to 20 μPa, then the procedures described will give



$K = L_w - L_{wr}$

where:

L_w = is the calculated sound power level assuming perfect free field condition

L_{wr} = is the sound power level from the calibration chart of the reference sound source

851174

Fig. 9. Measurement of the room correction factor K

Test environment:
Outdoors or in a large room

$$L_w = \overline{L_{pf}} + 10 \log \frac{S}{S_0}$$

where:
L_w = The band power level of the equipment
$\overline{L_{pf}}$ = The mean surface band pressure level
S = The area of the measurement surface in m^2
S_0 = 1 m^2

851256

Fig. 10. Calculation of sound power according to ISO 3744

Difference between sound pressure level measured with equipment operating and background noise alone	Correction to be subtracted from sound pressure level measured with equipment operating to obtain sound pressure level due to equipment alone
dB	db
< 6	measurement invalid
6	1,3
7	1,0
8	0,8
9	0,6
10	0,4
> 10	0,0

or $B = L_c - 10 \log_{10} (10^{0,1 L_c} - 10^{0,1 L_b})$

where B = background noise correction
L_c = band pressure level with equipment operating
L_b = background noise level alone

T00834GB0

Fig. 11. Background noise correction factors

sound powers in dB referred to 1 pW. However, there is an increasing trend to quote sound powers in Bels, where 10 dB = 1 Bel, in order to avoid confusion between sound power and sound pressure measurements.

Octave band centre frequencies	One-third octave band centre frequencies	Standard deviation of the mean value
Hz	Hz	dB
125	100 to 160	3,0
250 to 500	200 to 630	2,0
1000 to 4000	800 to 5000	1,5
8000	6300 to 10000	2,5

T00835GB0

Fig. 12. Standard deviations for a measurement according to ISO 3744

Reverberation room or free field measurements, which are better?

The advantage of sound power measurements in a reverberation room is that they are fast, and therefore can be more economical for labelling purposes. However, they require a specialised test facility, and the sound pressure measurements required, described later, cannot be made in a reverberation room.

Free field measurements of sound power take longer than those in a reverberation room. However, the methods of ISO 3744 do not require a specialised test facility, hence saving the considerable capital outlay involved, (although later, a semi-anechoic chamber might be required, especially if background noise becomes a problem). Further, the same room can be used for the sound pressure measurements required by the standards.

Sound Power Measurements based on Sound Intensity

Sound power measurements based on sound intensity offer the advantage that they can be made in-situ, without the need for a specialised test facility. Further, the background noise can be considerably higher than the noise from the device under test, (up to 10 to 15 dB higher), and accurate measurements can still be made. Also, sound intensity measurements can be a highly significant tool in noise source location during development work.

No standards exist yet for sound power measurements based on sound intensity. However, they can still be used for engineering measurements of sound power during development work, and also for production testing. Further, when standardized measurements of sound power are required, the sound intensity analyzer can be switched to its pressure mode, whereby the methods of ISO 3741/42 or ISO 3744 can be followed. Applications of intensity measurements on business machines are more fully described in Reference [5].

Frequency Range of Measurements

The frequency range for sound power measurements on business machines is at present 100 hz to 10 kHz. There is much discussion, though, on increasing this frequency range to 20 khz, since devices such as visual display units and dot-matrix printers can have considerable noise emissions above 10 khz.

Measurement of Sound Pressure

Where a piece of equipment is normally operator attended, the standards for noise measurements on business machines require measurement of the mean A-weighted sound pressure level, $\overline{L_pA}$ at the operator position. The operator position for a standing and seated operator is shown in Fig.13. The microphone should be orientated such that it has a flat frequency response at an angle 30° below the horizontal pointing towards the equipment under test.

Where a piece of equipment is not normally operator attended, then the $\overline{L_pA}$ measurement is made at the bystander position(s). A number of bystander positions can be defined, at the front, back and sides of the equip-

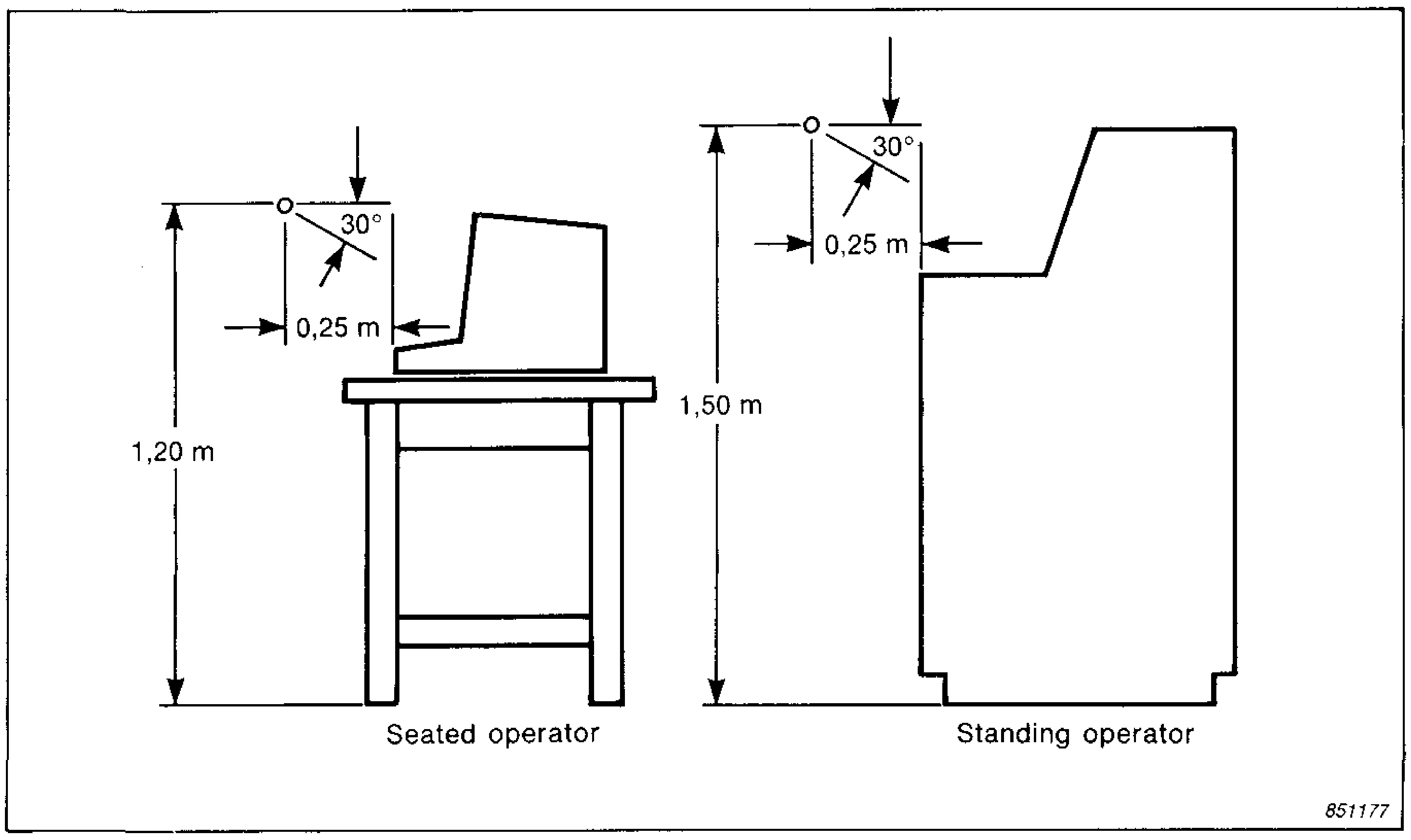


Fig. 13. Examples of microphone positions for a standing and seated operator

ment. It is left to the manufacturer to decide how many positions are relevant. The bystander position(s) are defined similarly to the operator position, except that they are now 1 m from the edge of the equipment.

Where equipment is normally table mounted, a standard test table, (Fig. 14), has been defined. This is to ensure that all tests are carried out on a table having the same surface area, and such that effects such as table top resonances are minimised.

The sound pressure measurements required by the standards should be carried out in a free field over a reflecting plane, and no correction is allowed for the presence of unwanted reflections. Where impulsive noise and/or pure tones are audible, than in addition to the $\overline{L_pA}$ measurement, an impulsive noise test and/or a pure tone determination must be carried out.

Impulsive Noise Test

The impulsive noise test requires the measurement of L_pAI, the A-weighted sound pressure level measured with an "impulse" time weighting. (Impulse is an internationally standardized time weighting for sound pressure measurements, designed to approximate to the impulse response of the human ear). Where averaging of the L_pAI measurement is necessary, this must be on an equal energy basis, implying the use of an integrating sound level meter, that is one which can measure the equivalent continuous noise level, L_{eq}. If the sound level meter can be set to measure L_{eq} with an impulse weighting instead of the usual "fast" weighting, the result will be equal to L_pAI.

The impulsive noise test is made at the operator and/or bystander positions. If the noise has significant impulsive content, L_pAI will be higher than $\overline{L_pA}$. If the difference between the two is equal to or greater than 3 dB, the noise from the equipment under test must be labelled as being impulsive.

As mentioned previously, the impulsive noise test implies use of an integrating sound level meter. $\overline{L_pA}$ can then be measured by setting the sound level meter to measure L_{eq}, since this is equal to L_pA averaged on an equal energy basis.

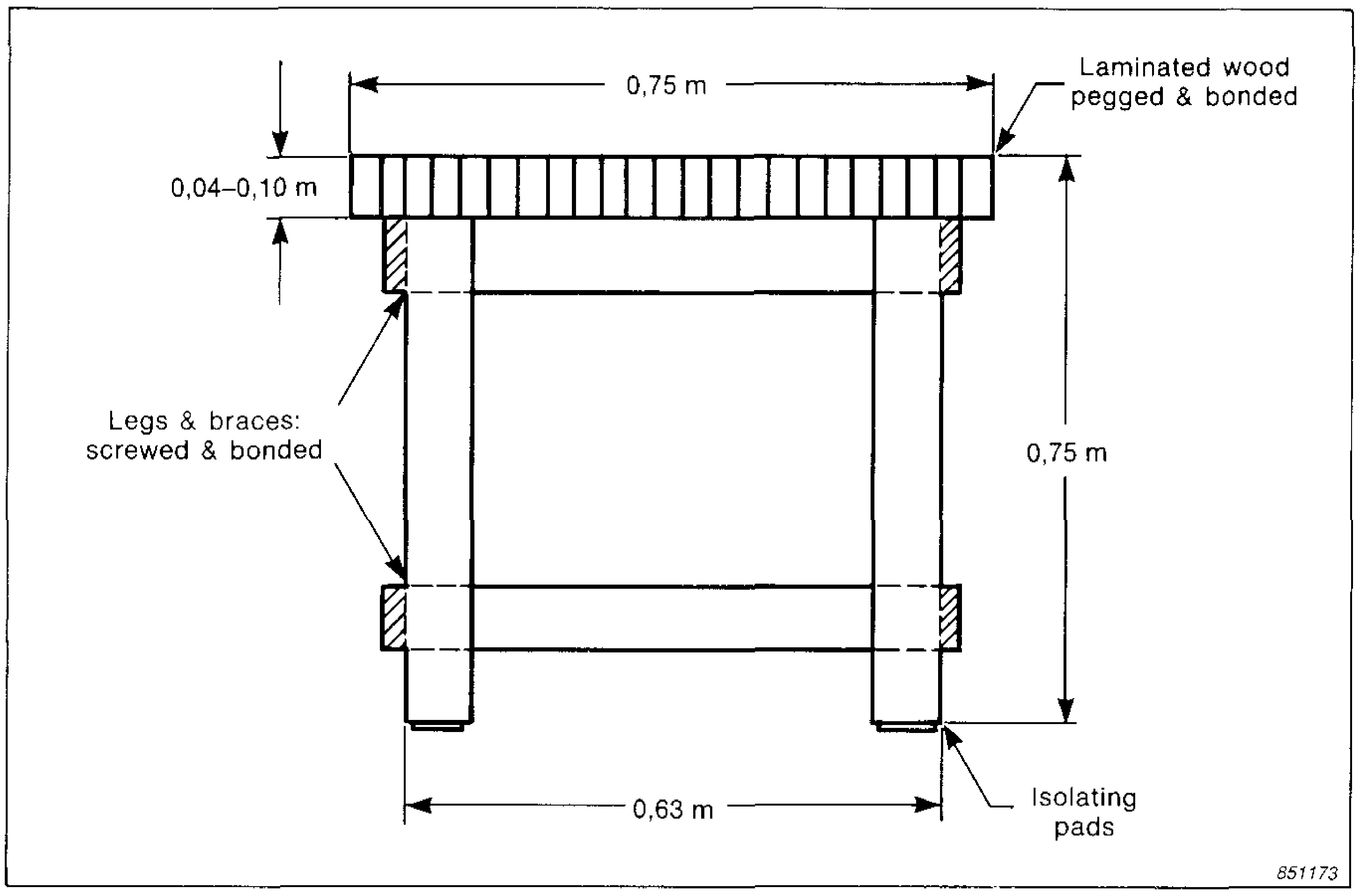


Fig. 14. Standard test table

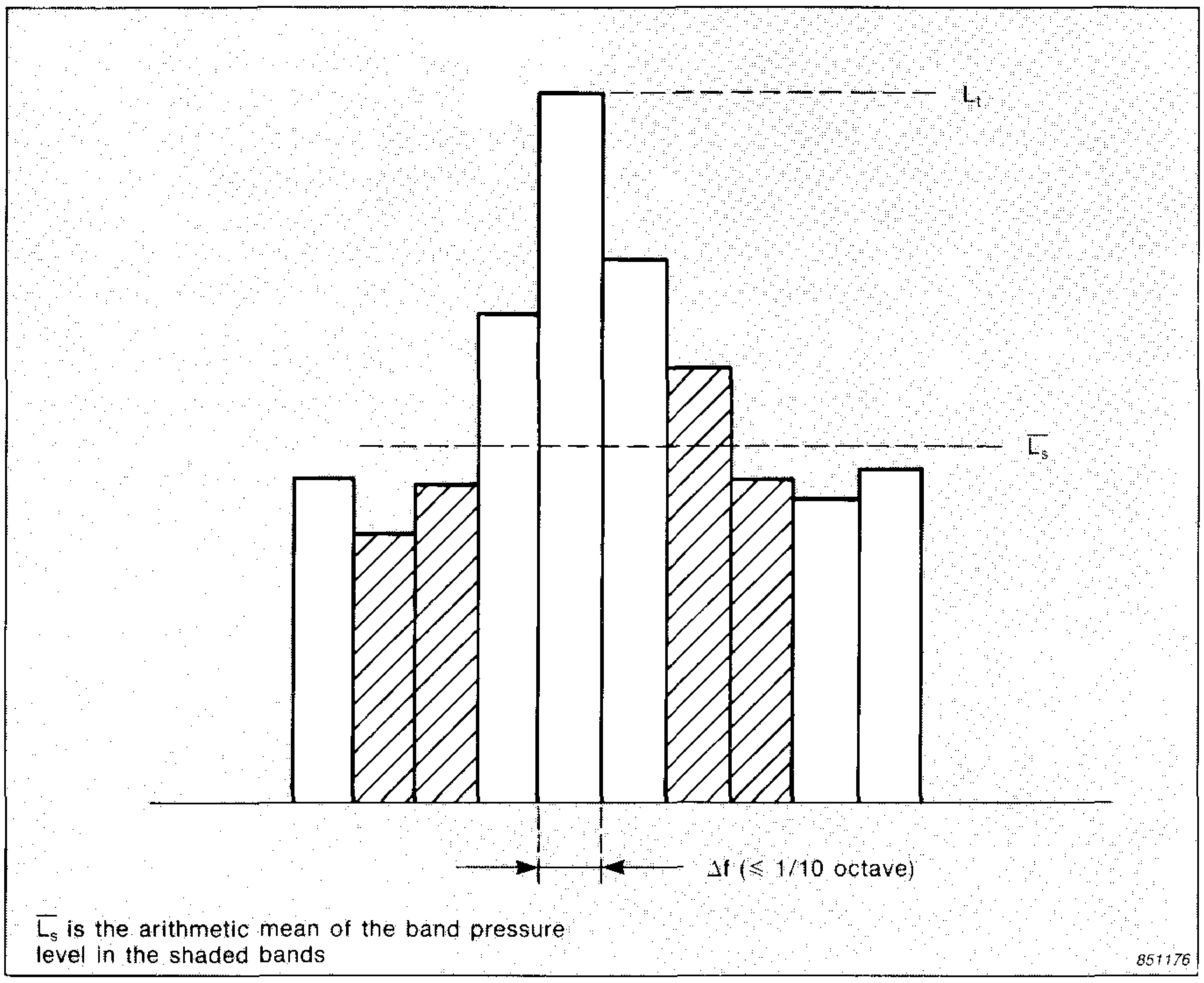


Fig. 15. Determination of L_t and $\overline{L_s}$ for the pure tone determination

The Pure Tone Determination

The pure tone determination requires a frequency analysis in bandwidths of less than a 1/10 octave of the noise at the operator and/or bystander positions. Where a pure tone is present, (that is, there is a peak in the spectrum), the two values L_t and $\overline{L_s}$ are determined as shown in Fig.15.

If

$$L_t - \overline{L_s} \geq 10 - 10 \log \left(\frac{\Delta f}{f_c}\right) \text{ dB}$$

a pure tone is defined as being present, where Δf is the bandwidth of the analyzing filter, and f_c is the Fletcher critical bandwidth, tables of which appear in the standards. The noise from the device under test then has to be labelled as containing pure tones.

Information to be Reported

The information to be reported includes the follows:

1. Name and model number of the device under test
2. The A-weighted sound power level
3. The A-weighted sound pressure level at the operator and/or bystander position(s)
4. The results of the tests for impulsive noise and prominent discrete tones
5. A description of the operating conditions of the device under test.

Brüel & Kjær Systems for Noise Measurements on Business Machines

Brüel & Kjær can supply a number of systems of differing sophistication and complexity for noise measurements on business machines, ranging from sound level meters for measurements of L_pA and L_pAI, to fully automated test systems capable of making all of the measurements required by the standards for noise measurements on business machines. Some of these systems are described in the following.

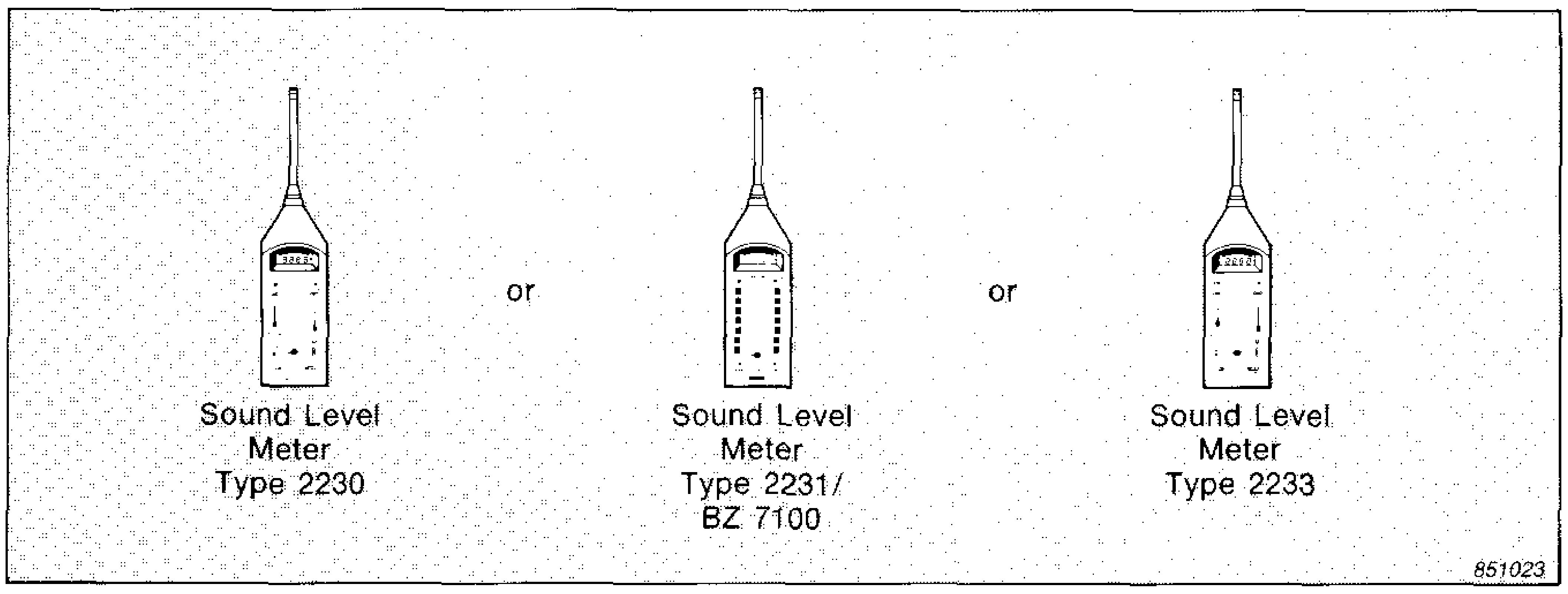


Fig. 16. Sound Level Meters Types 2230, 2231, 2233

Sound Level Meters for Measurements of L_pA and L_pAI

All of the sound level meters shown in Fig.16, are capable of making the L_pA and L_pAI measurements required by the standards. Note, however, that when the 2230 is set to measure L_pAI, it will display an error message. This is because L_{eq} is not normally measured using an impulse time weighting. The L_pAI measurement is performed correctly, though, and the error message can be removed by making a modification to the 2230. Contact your local Brüel & Kjær agents for details.

Sound Level Meter Based systems for Measurements of Sound Power (ISO 3744)

Addition of an octave or ⅓ octave filter set to the sound level meters described in the previous sections allows extension of the system to measure sound power according to ISO 3744. Addition of a portable level recorder to the system, (see Fig.17) is advised as a means of recording the octave or ⅓ octave spectra at the various microphone positions. A reference sound source is also required for the measurement of the room constant, K. (Note that the Type 4205 Sound Power Source cannot be used for this purpose, since it does not meet the requirements of ISO 6926. It is the Type 4204 Reference Sound Source which should be used.)

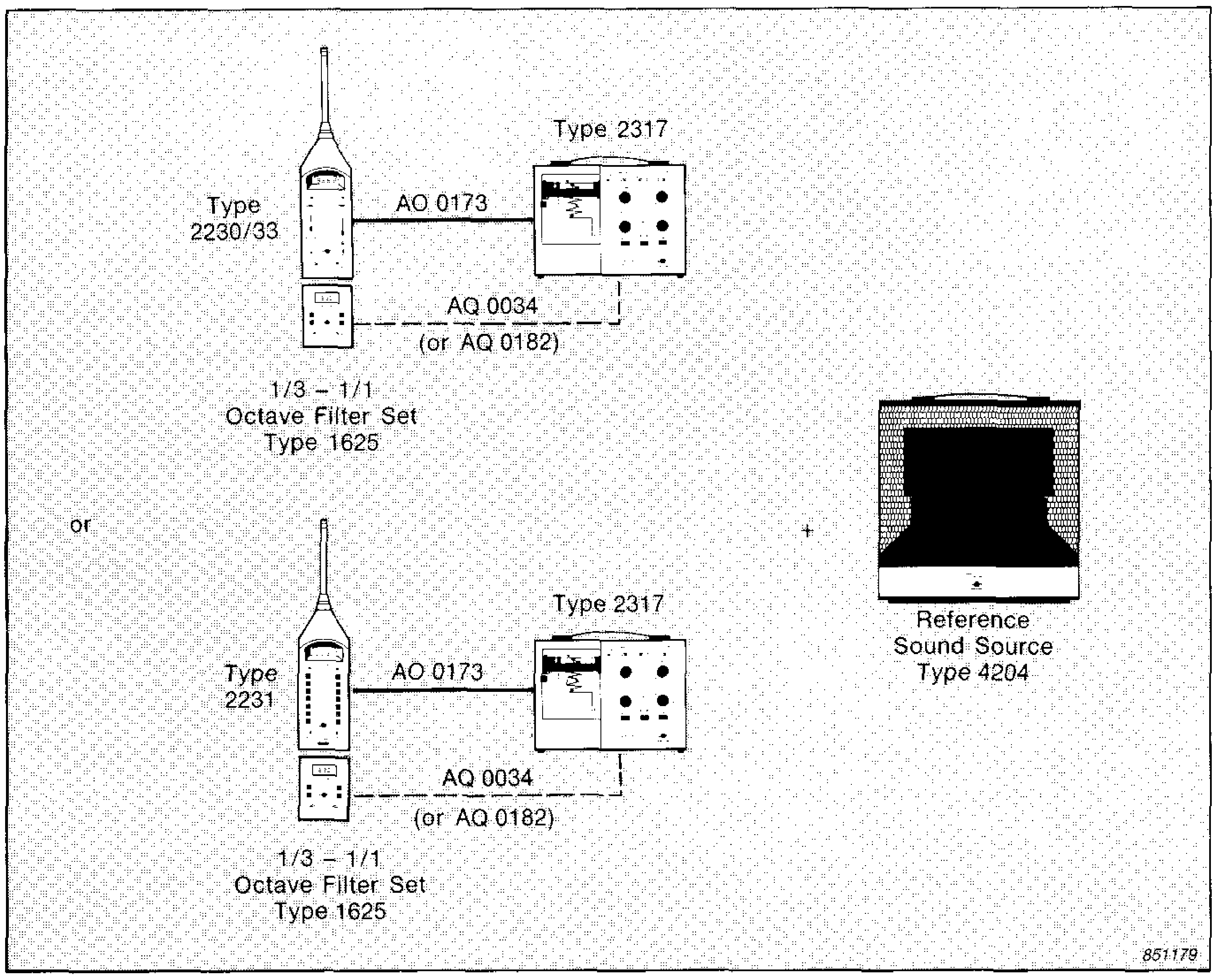


Fig. 17. Sound level meter based systems for measurements of sound power according to ISO 3744

Sound level meter based systems are usually only recommended for sound power measurements when such measurements are going to be infrequent. Measurements of sound power using such a system are tedious and time consuming, and the sound power must be calculated manually from the measured results. For frequent measurements of sound power, a real-time analyzer based system is usually preferred.

Real-time Analyzer Based System for Sound Power Measurements in a Reverberation Room (ISO 3741/42)

When a real-time 1/3 octave analyzer is used instead of a sound level meter with a 1/3 octave filter set, the 1/3 octave spectra can be measured in parallel instead of in series, hence considerably reducing the measurement time. The system shown in Fig.18 can be used to measure sound power in a reverberation room. The spatial averaging of the sound field in the room is achieved using the rotating microphone boom, and the reference sound source is required when the comparison method is followed.

When the system shown in Fig.18 is used, the final sound power must still be calculated manually. However, when the comparison method is followed, this is relatively simple, especially if there are no background noise problems.

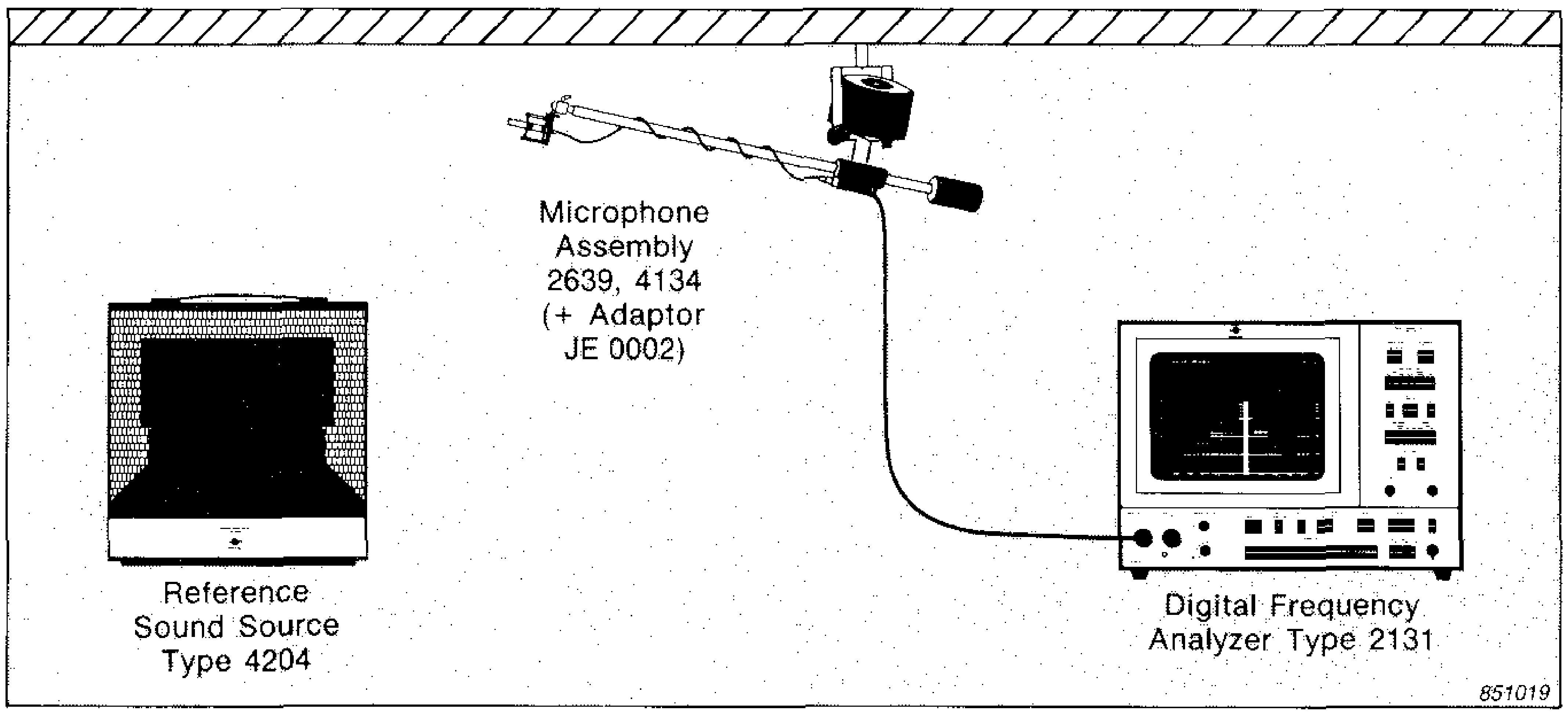


Fig. 18. Real-time analyzer based system for measurements of sound power according to ISO 3741/42

Real-time Analyzer Based Systems for Measurements in an Almost Free Field (ISO 3744)

The system shown in Fig.19 can be used for measurements of sound power according to ISO 3744. Use of the system is relatively easy, provided that there are no background noise problems, since the average sound pressure level in each octave or 1/3 octave can be accumulated in the real-time 1/3 octave analyzer. The final octave or 1/3 octave spectrum obtained must be corrected for the number of microphone positions, the measurement surface area, and the room correction factor K, this involving the addition or subtraction of a certain number of dB in each octave or 1/3 octave of the spectrum.

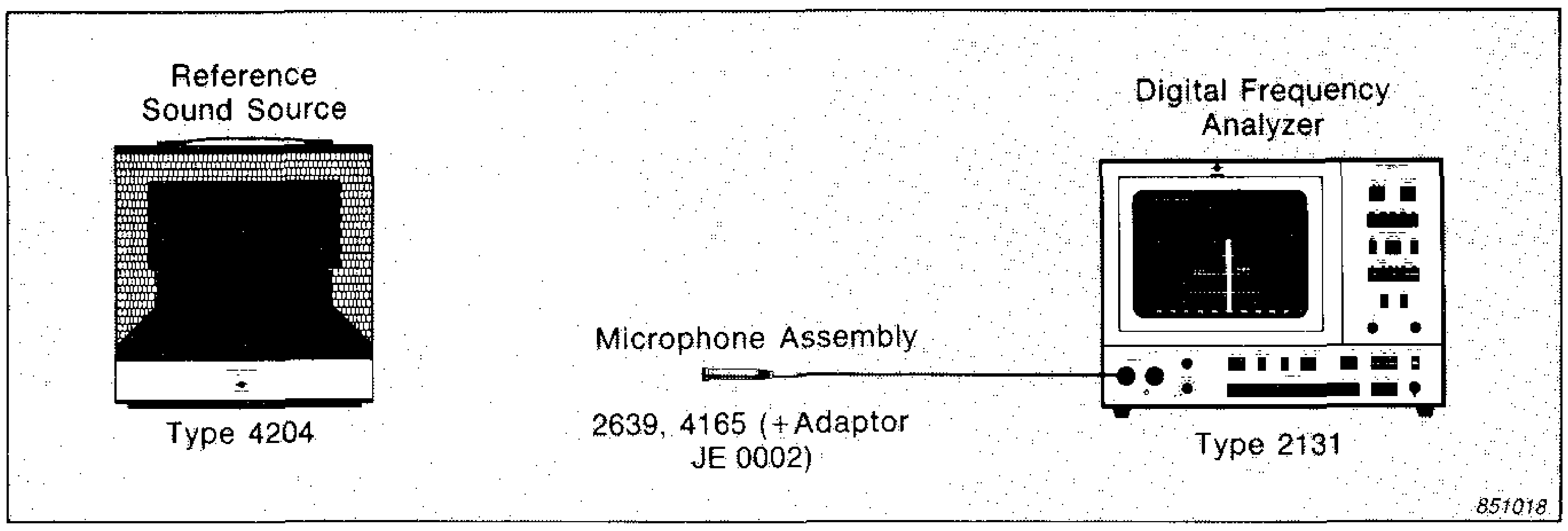


Fig. 19. Real-time analyzer based system for measurements of sound power according to ISO 3744

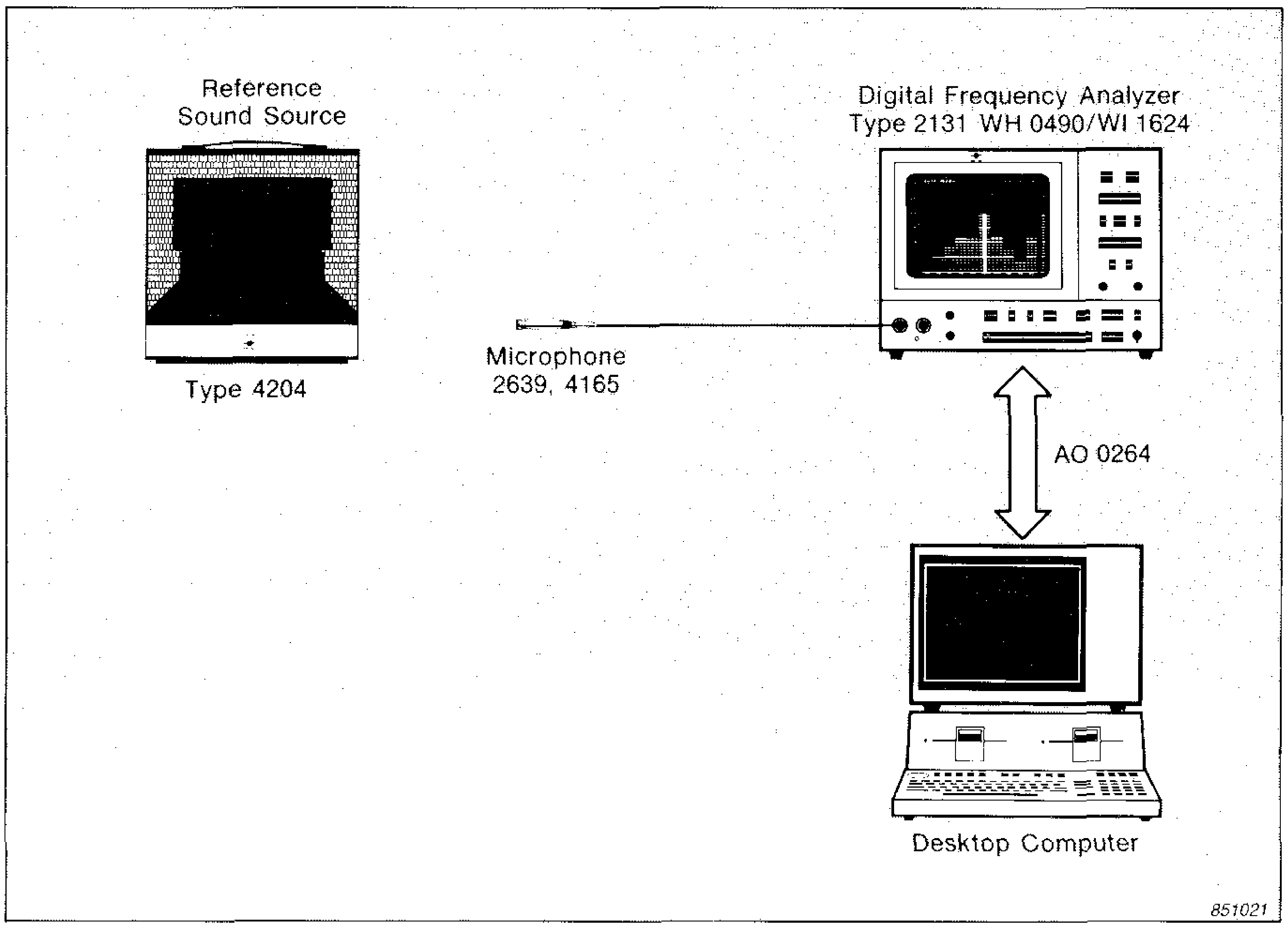


Fig. 20. A semi-automatic system for making all of the measurements required by ECMA 74

Semi-automatic System for Making all of the Measurements Required by ECMA 74

The systems described so far can only make some of the measurements required by the standards for noise measurements on business machines. The system shown in Fig.20 can make all of them, and follows ECMA 74. The sound power determination is made according to ISO 3744, and is controlled by the software package WW 9041 in the desk-top computer. The software also controls the real-time 1/3 octave analyzer in a 1/12 octave mode for the pure tone determination, the analyzer being modified with WH 0490 and WI 1624 for the measurement of L_pA and L_pAI, and the impulsive noise test. All measurements are fully documented, the analyzed results can be transferred to a disc for storage and later recall. The only manual operation involved is the positioning of the microphone at the various positions required for the measurements.

A Fully-automated System for Measurements According to ECMA 74

This system extends that described in the previous section by the addition of multiplexed microphones such that the measurements can be made completely automatically. 10 microphone

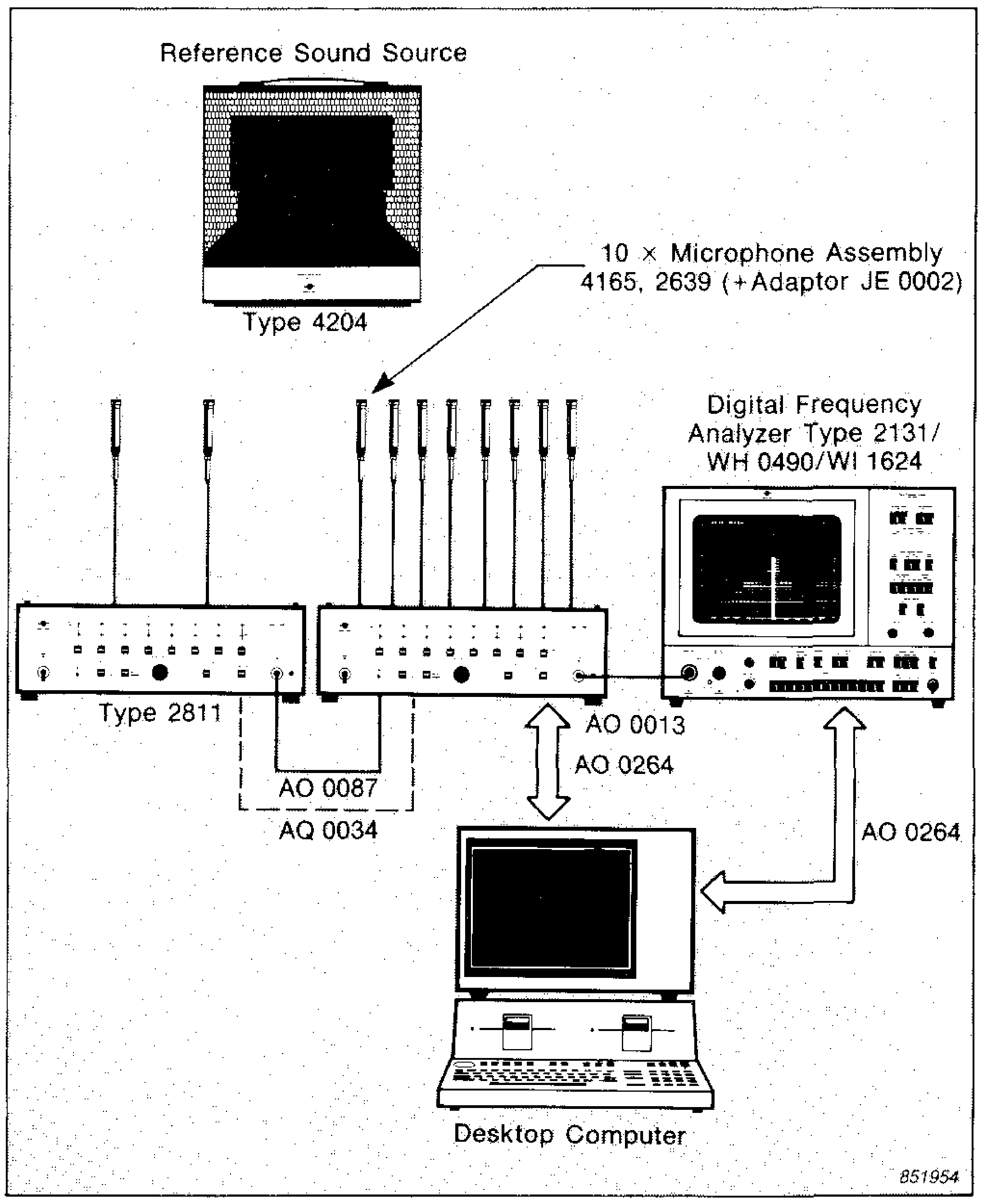


Fig. 21. A fully-automated system for measurements according to ECMA 74

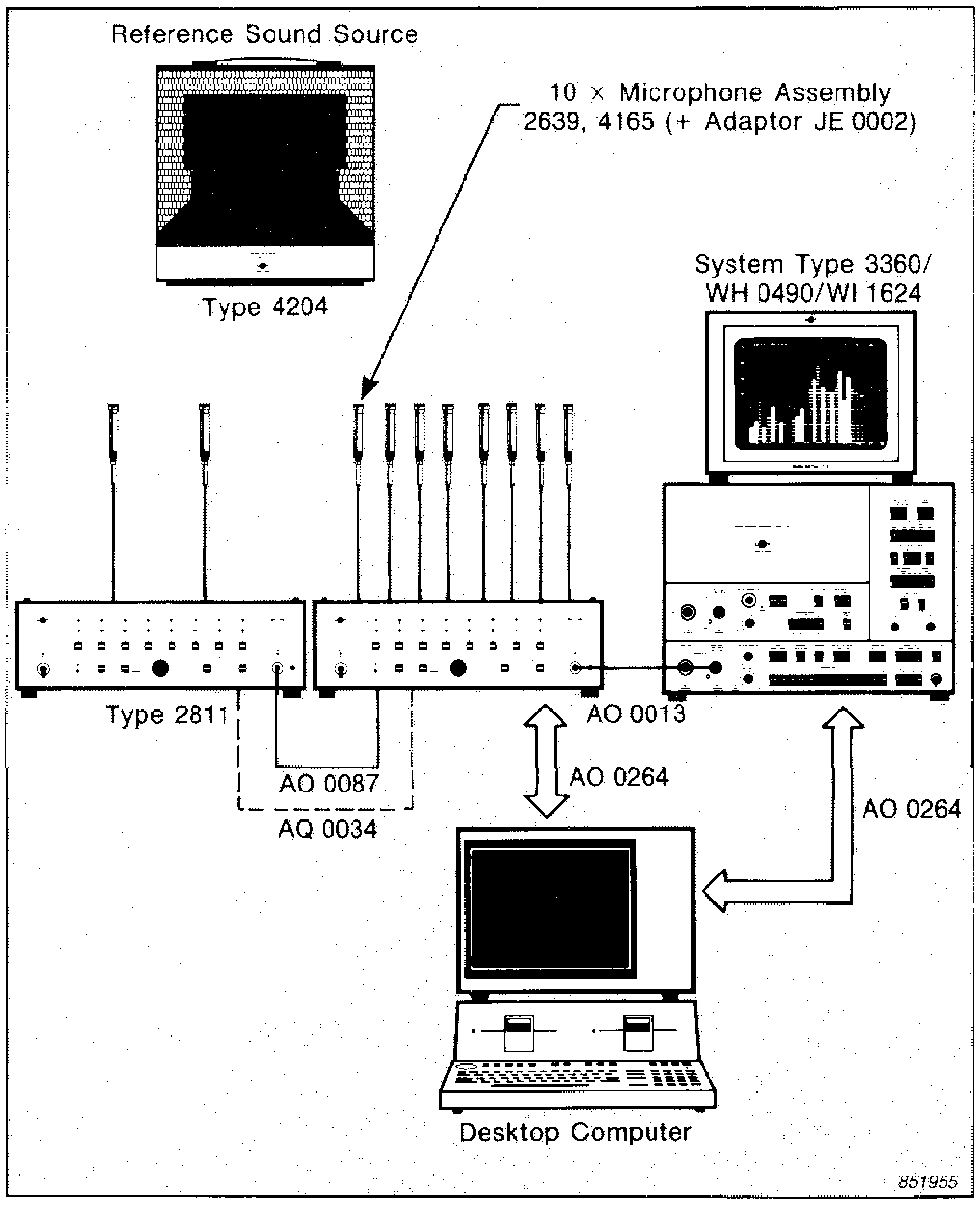


Fig. 22. A fully-automated system for measurements according to ECMA 74 based on a sound intensity analyzer

channels are shown, which is the minimum number of positions for the hemisphere, (the parallelepiped uses 9). However, extra microphone channels will usually be required for the sound pressure measurements at the operator and/or bystander positions, since these positions will only rarely coincide with those on the measurement surface. The system can control up to 4 multiplexers and 32 microphone channels.

The system can be extended further by replacing the real-time 1/3 octave analyzer with a sound intensity analyzing system. The sound intensity analyzer is modified in the same way as the real-time 1/3 octave analyzer, such that when operated in pressure mode, all of the measurements required by ECMA 74 can be made. The system offers the additional possibility of sound intensity measurements for in-situ measurement of sound power, and for noise source location.

Conclusions

An increasing awareness of noise problems in places of work, stricter legislation and codes of practice have meant that business machine manufacturers are increasingly interested in measuring noise, not only during the development of new products, but also in production control.

References

[1] DIN 45 635 Teil 19, "Geräuschmessung an Maschinen, Luftschallmessung, Hüllflächen-Verfahren, Büromaschinen" Beuth Verlag, Berlin 30, B.R.D.

[2] ANSI S1.29, "Method for Measurement and Designation of Noise Emitted by Computer and Business Equipmnet", Standards Secretariat, Acoustical Society of America, 335 East 45th Street, New York, New York 10017, U.S.A.

[3] ECMA 74, "Measurement of Airborne Noise Emitted by Computers and Business Equipment", European Computer Manufacturers Association, 114 Rue du Rhône, 1204 Geneva, Switzerland.

[4] ISO/DIS 7779, "Acoustics – Measurement of Airborne Noise Emitted by Computer and Business Equipment" ISO Central Secretariat, Case Postale 56, 1211 Geneva, Switzerland.

[5] R. UPTON & K.B. GINN, "Business Machines Measurements using Sound Intensity" Brüel & Kjær Application Note.

Brüel & Kjær

DK-2850 Nærum · Denmark · Telephone: +45 2 80 05 00 · Telex: 37316 bruka dk

Printed in Denmark by Nærum Offset