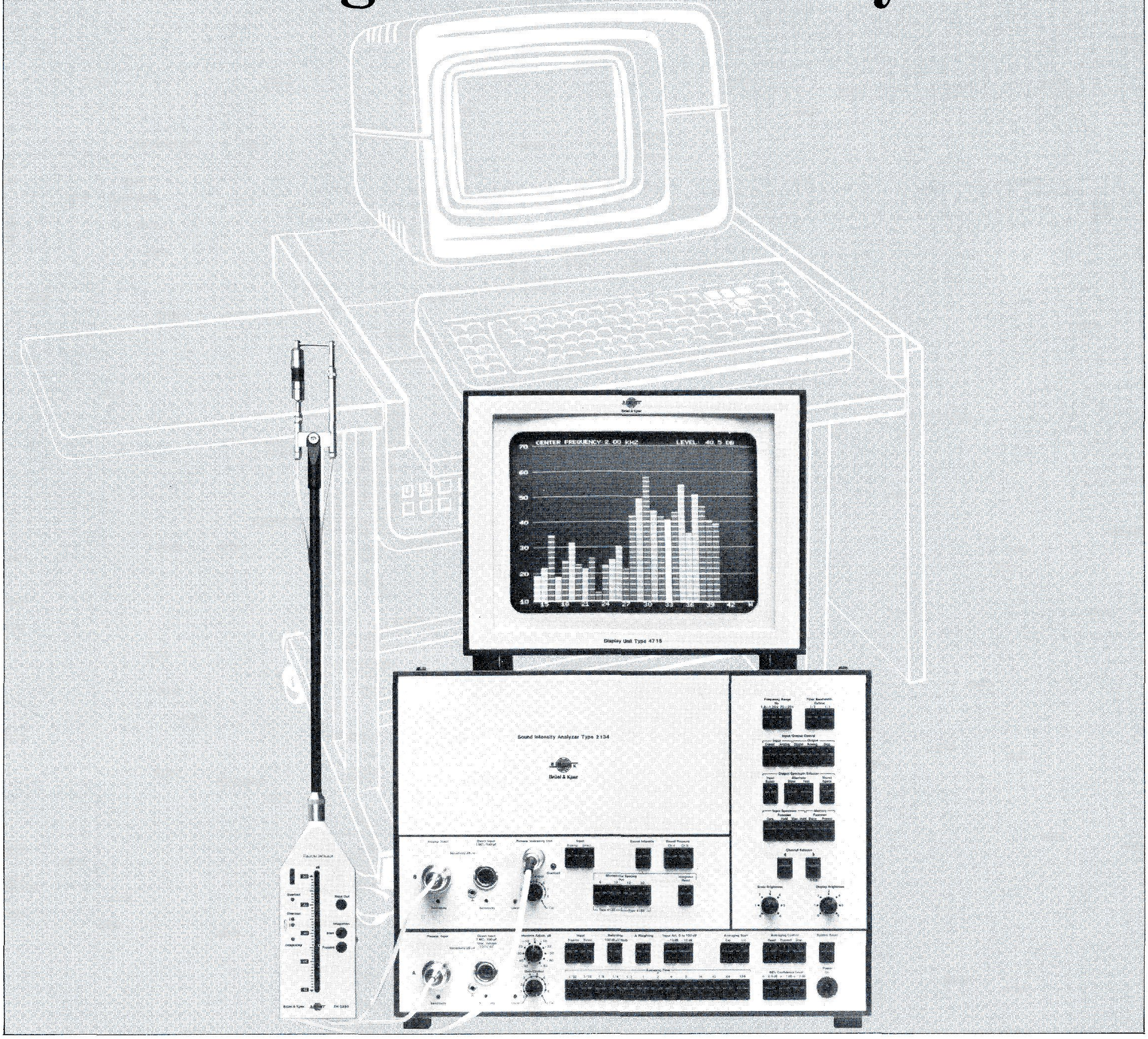
Brüel & Kjær application notes

# Business machines measurements using sound intensity



# Business Machines Measurements using Sound Intensity

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## Introduction

Manufacturers of business machines, that is office and computing machines, are becoming more and more involved in noise measurements as the end users are becoming more conscious of noise problems. Although new techniques are tending to result in quieter products, the effect of stringent work place regulations, coupled with the omnipresence of business machines and the need for faster operation, greater numbers of copies etc., means that noise from business machines is and will continue to be a vexing problem in the foreseeable future.

### Standards for noise measurements

A number of standards have been written which describe how noise measurements should be made on business machines i.e. DIN 45 635 part 19, ANSI S1.29 (soon to be superceded by ANSI S12.10), ECMA 74, ISO/DIS 7779. These standards are based on sound pressure measurements and deal with:

- Determination of sound power in known acoustical environments
- Measurement of sound pressure at the operator's or bystander's position
- Impulsive noise test
- Pure tone determination

These acoustical parameters and the measurement methods according to the above standards are described in References [1], [2] [6], [7] & [8].

### New measurement technique

This application note illustrates the use of a relatively new measurement technique, namely sound intensity and how this technique can be employed by business machines manufacturers in production testing and in the development of quieter products.

### What is sound intensity?

Sound intensity is a **vector** quantity which describes the rate and the direction of net flow of acoustic energy at a given position. Its dimensions are energy per unit time per unit area that is watts per square metre [W/m$^2$]. This is in contrast to sound pressure which is a **scalar** quantity, having magnitude only and no directional information.

### Why measure sound intensity?

Sound pressure measurements cannot and will not be superceded by sound intensity measurements. The two techniques are complementary. In broad terms, one can say that sound pressure measurements are used to investigate the **effect** of noise on people, whereas sound intensity measurements are used to examine the **cause** of the noise that is the noise source itself.

From the point of view of the business machine manufacturer two applications of the intensity technique are of particular importance:

- Sound power determination for noise labelling
- Source location for noise control purposes

Other applications include radiation efficiency, transmission loss and surface intensity measurements.

### Sound power determination

The sound power rating is the most useful specification available for predicting the noise level produced by a product operating in a given environment. Sound power is a unique measure of the "noisiness" of an acoustic source.

Any piece of machinery that vibrates emits acoustic energy and thus has a characteristic sound power, a basic measure of its acoustic output. The sound pressure levels it produces depend on factors such as the distance and orientation of the receiver relative to the machine and the environment in which the sound pressure levels are determined. Sound power, on the other hand, is a fundamental physical property of the source alone, and is therefore an important absolute parameter which is widely used for rating and comparing machinery and equipment in noise control work.

### Sound power from sound pressure measurements

Sound pressure, the measured quantity historically used in determining sound power, refers only to the pressure at a certain point in space at a given distance and direction from a sound source. In itself it tells nothing about the acoustical power that the source generates. The specific controlled environment, outlined in the various standards, provides the basis for sound power computation. Once the sound power is known for a given source, the noise level for that source can be predicted for nearly any definable environment [4].

When making precision determinations of sound power based on sound pressure measurements, conditions imposed by the Military, National and International Standards become very stringent. The acoustic environment, the number and positions of the microphones and sound source, the method of averaging, all are narrowly defined. Such measurement procedures can be lengthy and tedious.

The Standards outline methods for sound power determination with various accuracies and under different environmental conditions. The choice of the appropriate method depends on factors such as the size and noise characteristics of the machine, application of the data, type of environment available and the accuracy desired. The uncertainties in determining sound power levels by the various methods are expressed in the particular standard describing the method. The highest accuracies are obtained by following the guidelines given for measurements in an anechoic chamber (free-field) and reverberation room (diffuse-field) respectively.

Under strict measurement conditions, however, discrepancies exist between sound power measurements in an anechoic chamber and a reverberation room. They are due to: (1) the influence of reverberation room impedance on the sound power output of a source, (2) spacing between eigenmodes of the room at low frequencies and (3) determination of reverberation time from the decay curves.

In the next section it is explained how sound intensity measurements, conducted in any environment, correlate with free-field measurements.

**Sound power from sound intensity measurements**

Sound intensity is the net sound power crossing a unit area oriented in a specified direction at a given point in space. Integrating the sound intensity over a hypothetical "control surface" completely enclosing a noise source yields the total sound power of the source.

Sound intensity measurements are applicable for measuring sound power regardless of the nature of the machine or equipment, its size, power rating and the environment in which it is located. These sound intensity measurements provide sound power estimates whose accuracy is less dependent on the nature of the test environment than that provided by pressure methods.

The specified procedures under current standards have two major disadvantages:

1. Costly facilities are necessary to perform an accurate measurement on large machinery.

2. The procedures cannot be used in the presence of high levels of ambient noise.

In contrast, advantages of the intensity method for determining sound power can be summarized as follows:

1. No restrictions on the room where the measurements are performed are necessary.

2. Measurements may be performed in the near- as well as the far-field. Near-field measurements improve signal to noise ratio and require less "free space" about the source under test. Near-field measurements provide for sound intensity contour mapping and intensity vector field mapping of the source.

3. The intensity method places no restrictions on the shape or size of the hypothetical enclosing surface used in the measurement.

4. The sound power determinations are better than two orders of magnitude less sensitive to ambient noise.

5. The sound intensity method of determining sound power is simple and accurate. Since no special acoustical environment is needed, the determination can be performed in situ.

For the determination of the sound power of a source, it is clearly more logical to measure and use the sound intensity distribution, rather than to measure the sound pressure distribution and apply various corrections.

A disadvantage of the intensity method is that as yet (January 1986) no national or international standards exist although several committees are working at the task, e.g. ANSI, ISO, IEC. Several establishments have already produced their own internal standards.

**Intensity measurement procedure**

When determining sound power using the intensity method, the procedure is as follows:

1. Select a suitable measurement surface e.g. parallelepiped (shoebox), conformal, hemisphere.
2. Perform space averaged intensity measurements.
3. Determine the sound power

**Measurement surface**

Any surface that completely encloses the noise source under test can be used as a measurement surface. For measurements on a box-shaped printer, the most convenient surface to use would be a parallelepiped. For a small fan or motor, the best choice of surface would probably be a hemisphere. The selected surface must have a well defined area that can be measured accurately and furthermore there must not be any extraneous acoustic absorption anywhere within the measurement surface. When selecting a measurement surface it may be useful to note that the intensity perpendicular to a totally reflecting surface is zero.

**Space averaged intensity measurements**

The space averaged intensity must be measured over a number of defined portions of the measurement surface. As the vector component of intensity normal to the measurement surface and outward from the surface must be measured, the intensity probe must be held normal to the surface. The space averaging may be performed by scanning the intensity probe over the area to be averaged so as to obtain uniform coverage or by any other method that gives the true space average such as a number of measurements at defined points.

**Definition of sound power**

The weighted sound power or band sound power, W, of a source is given by:

$$W = \sum_{i=1}^{N} \bar{I}_i A_i \qquad (1)$$

where

$\bar{I}_i$ is the space-averaged sound intensity, weighted or in a specified frequency band, measured for the $i^{th}$ area.

$A_i$ is the surface area over which the $i^{th}$ intensity measurement is space-averaged.

N is the number of measurements used cover the measurement surface.

The sound power level can then be calculated from:

$$L_W = 10 \, \mathrm{Log}_{10} \left[ W/W_o \right] \qquad (2)$$

where $L_W$ is weighted sound power level or band power level of the source, in decibels, W is the weighted sound power or band sound power of the source as given above in equation (1). $W_o$ is the reference level of 1 pW.

**Declared noise emission**

To avoid confusion between sound pressure levels and sound power levels it is now common practice among business machines manufacturers to quote sound pressure levels in decibels and sound power levels in bels. An example (Table 1) from the ECMA Standard 109 "Declared noise emission values of computer and business equipment", illustrates this convention. In this example $L_{WAd}$ is the declared A-weighted sound power level value and $L_{PAm}$ is the declared A-weighted sound pressure level.

### Intensity measurements on a personal computer

To illustrate the use of intensity measurements on business machines the technique was used to measure the sound power of a personal computer work station which consisted of a visual display unit, key-board, computer unit and a printer. Furthermore, intensity mapping was made over various parts of the personal computer work station.

### Sound power

For the measurement of sound power on the personal computer, the measurement surface chosen was a rectangular box, just enclosing the computer and visual display unit and extending down to a reflecting plane, Fig.1.

The measurement was made by sweeping the sound intensity probe over each surface of the box, while carrying out a linear integration, Fig. 2. A 16 s averaging (integration) time was used for each surface, resulting in a total measurement time of two to three minutes.

Fig. 3 shows the resulting sound power spectrum. The total A-weighted sound power is 52,6 dB which expressed in bels is 5,26 B. The maximum A-weighted sound power occurs in the 400 Hz 1/3 octave; the 100 Hz component can be neglected, since it will be much attenuated by the A-weighting. The measurement was later confirmed when the rear of the computer was mapped, (these results are described later), since the sound power for the rear of the computer calculated from these results was almost identical with the value obtained during the sound power measurements themselves.

A similar sound power measurement was performed on the printer associated with the computer. The results obtained are shown in Fig. 4, the maximum sound power being in the 4 kHz 1/3 octave. The measurement took about two to three minutes. Note that here, the A-weighted sound power is higher than the linear value, since the A-weighting applies a slight amplification in the frequency bands of maximum sound power.

| **Product:** Computer, Model ABC<br>**Declared Noise Emission** | **Operating** | **Idle** |
|---|---|---|
| $L_{WAd}$ | 7,1 B | 7,0 B |
| $L_{PAm}$ (bystander position) | 57 dB | 56 dB |

*Table 1. Example of declared noise emission values from ECMA Standard 109* T00970GB0

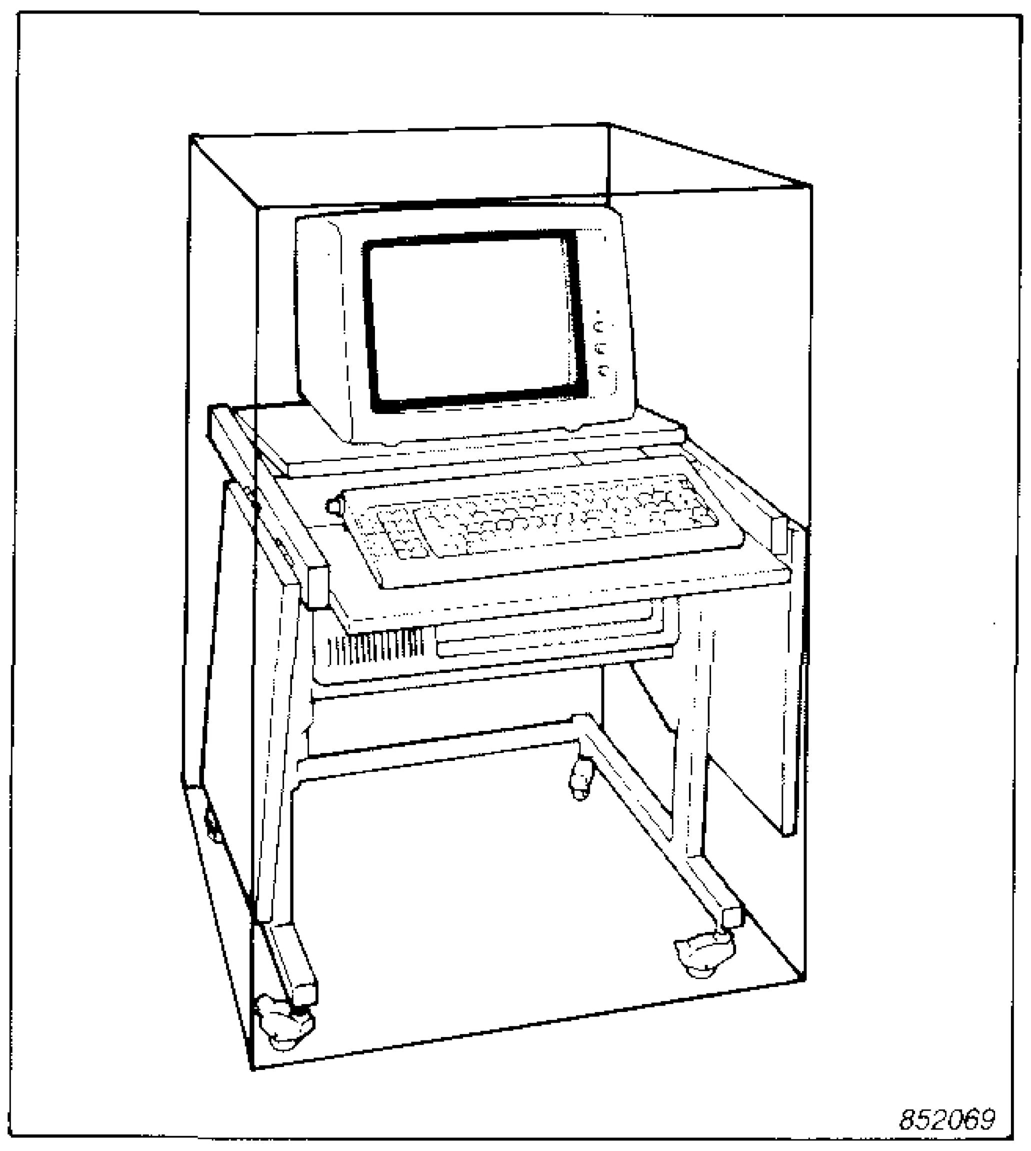


*Fig. 1. Measurement surface about a personal computer*

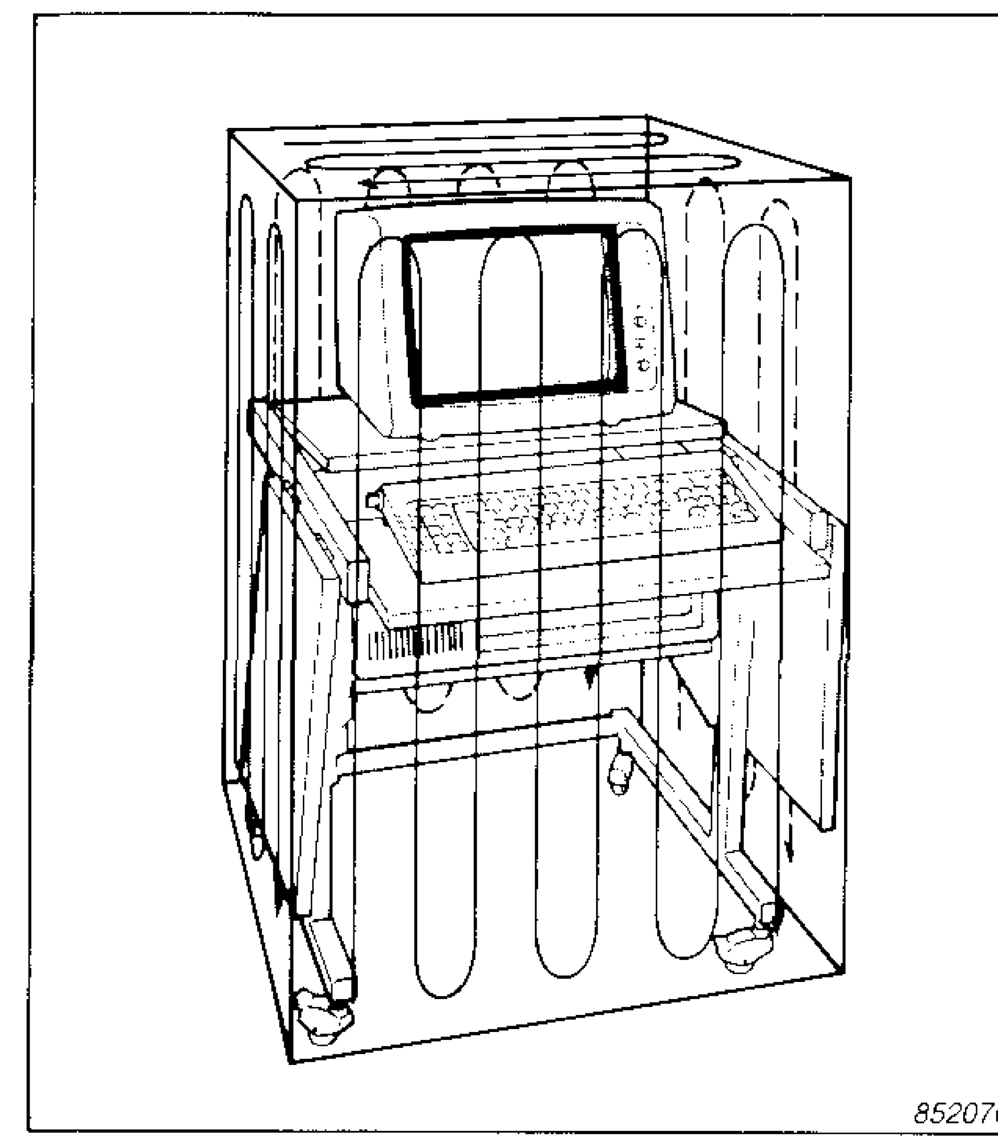


*Fig. 2. Measurement of sound power on a personal computer showing the intensity probe's path over the measurement surface*

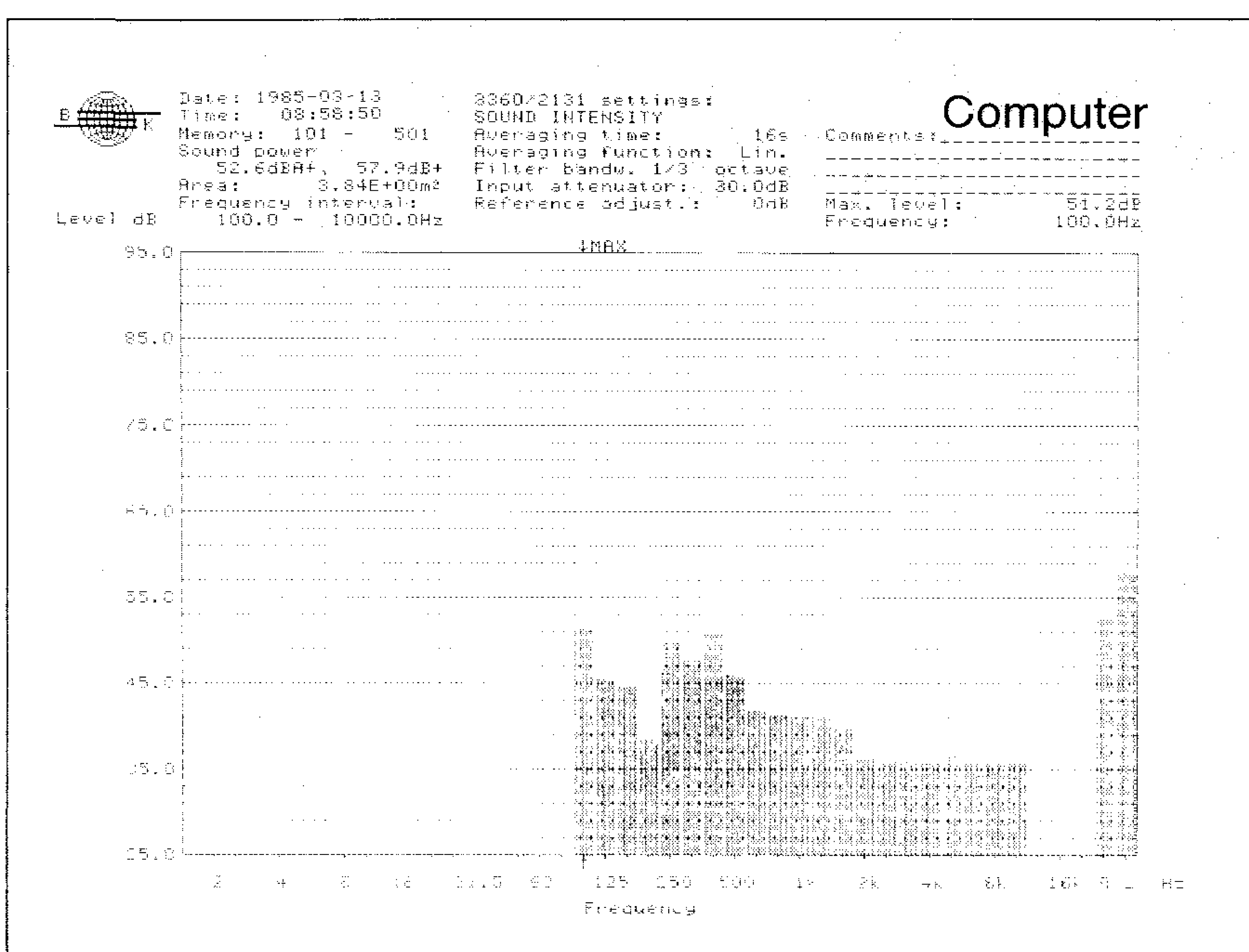


*Fig. 3. Sound power of a personal computer*

### Source location

Another application of sound intensity is noise source location. If the sources on the machine under test are few and well-defined then it might be possible to locate them by using a "real-time" method. In this method use is made of the figure-of-eight directional characteristic of the sound intensity probe. The direction of maximum response of the probe is used to define the approximate position of the noise source and then the null response plane is used to locate the source more precisely.

On machines where there are several sources it is usually more informative to use an “off-line” method of source location. Here, a series of intensity measurements is made over a measurement grid and then intensity plots are generated to reveal the location of the sources. The ways of using sound intensity to map sources are summarised in Table 2.

Having found the sources, the individual contributions to the overall sound power of the machine under test can be compared and ranked in order of importance; a process known as source ranking, Fig. 5.

## Measurement example

These principles can be applied to the measurements on the personal computer. Returning to the original measurement of sound power, the various measurement surface elements on the computer i.e. the front, sides, back and top can be ranked in terms of their contribution to the overall sound power. This shows that the major contribution comes from the rear of the computer, Fig. 5.

In this case, the noise source on the rear of the computer is fairly obvious, since there is a ventilation fan, and this could be quickly verified using a real-time source location. However, the procedure will be illustrated by means of an intensity map. A measurement grid is set up across the rear of the computer, and the sound intensity is measured at each point on the grid, all measurements being made with the probe perpendicular to the plane of the grid, Fig. 6.

Fig. 7 shows a number plot for the measurement in the frequency band

**Real-time source mapping**

- Maximum search
- Null search

**Off-line source mapping**

- Number plot
- 3-D plots
- Contours plots

T00836GB0

*Table 2. Source location: intensity mapping a summary of the methods*

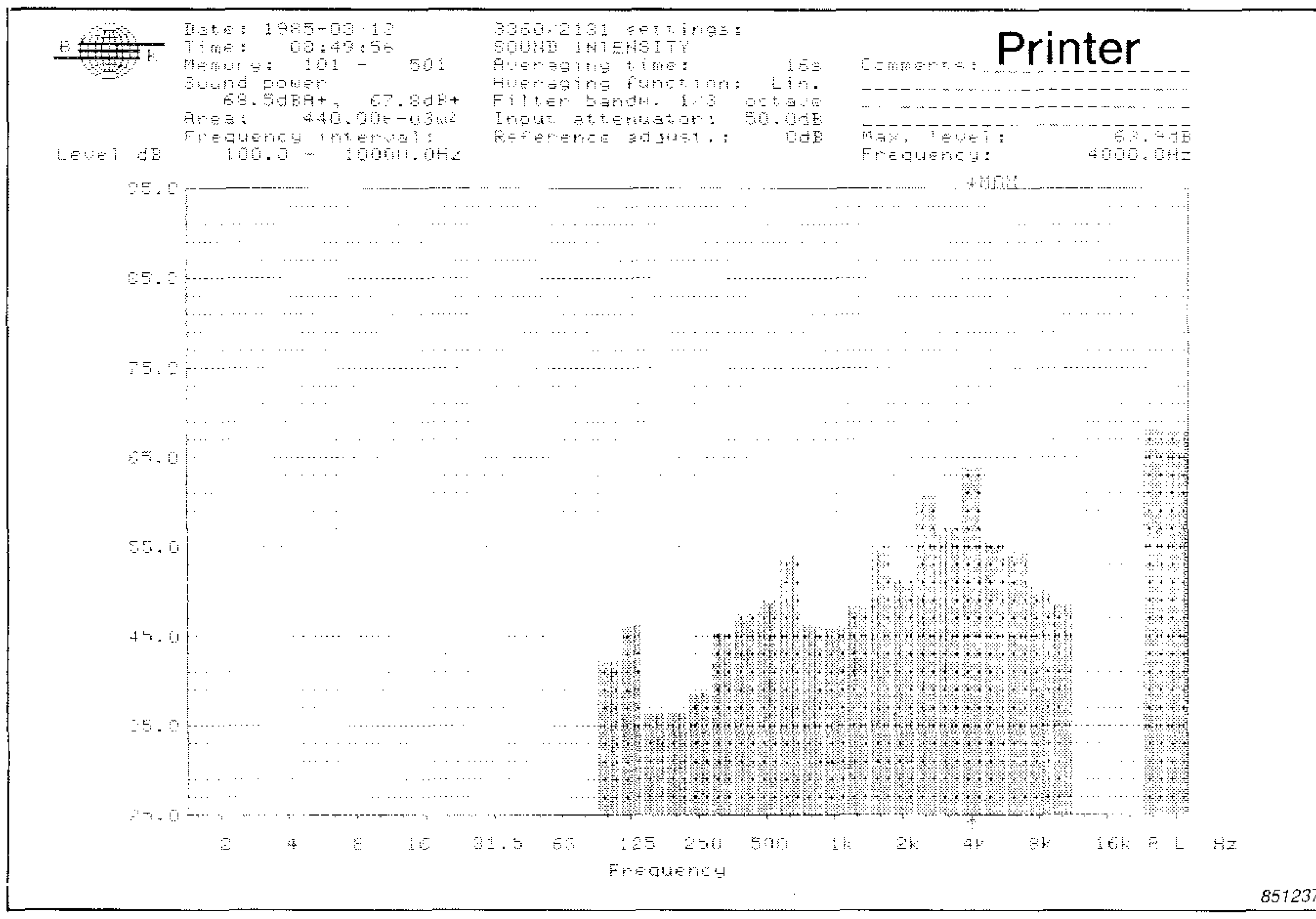


*Fig. 4. Sound power of a printer*

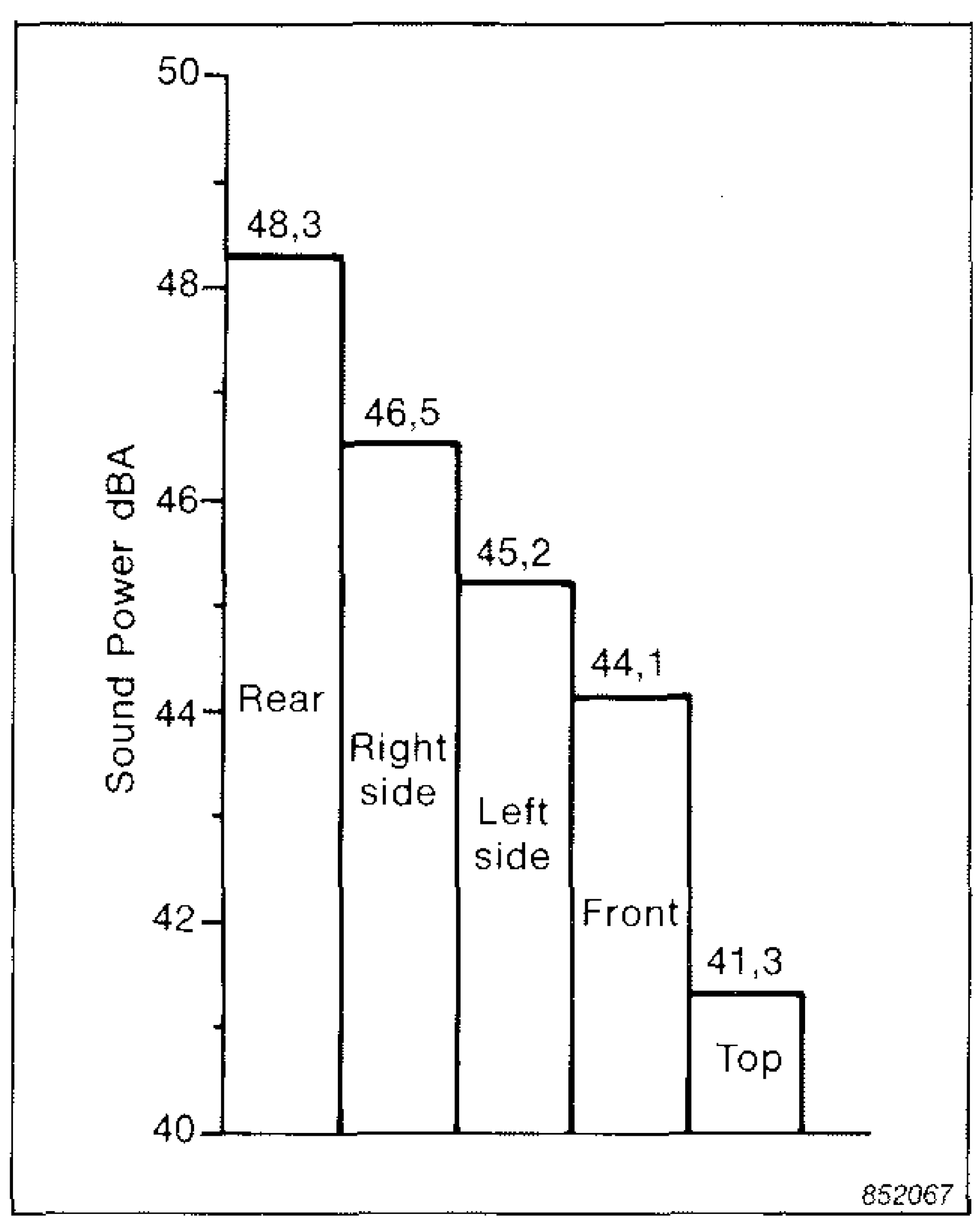


*Fig. 5. Ranking of the sound power passing through the various measurement surface elements on a personal computer*

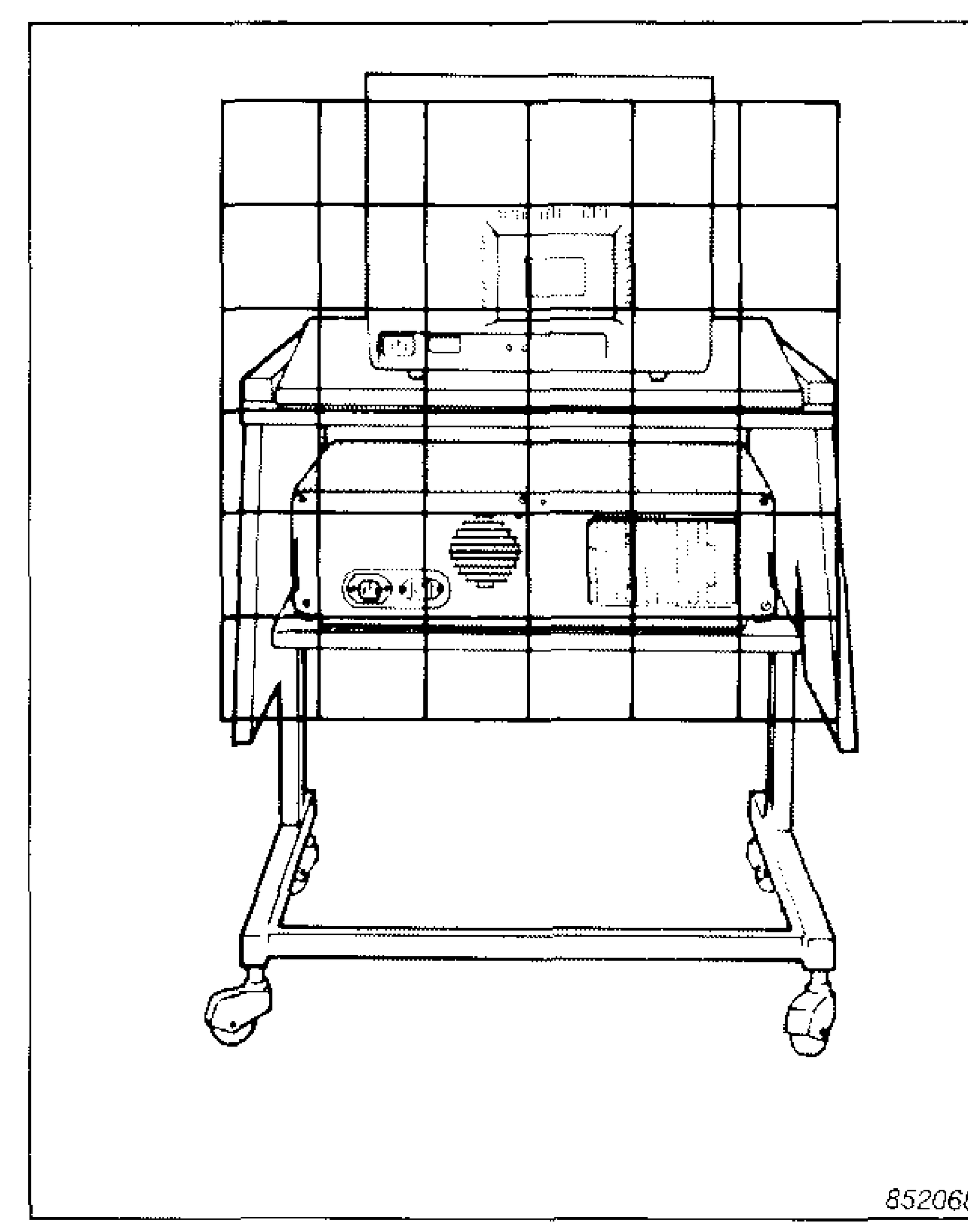


*Fig. 6. Setting up the measurement grid over the rear of the personal computer*

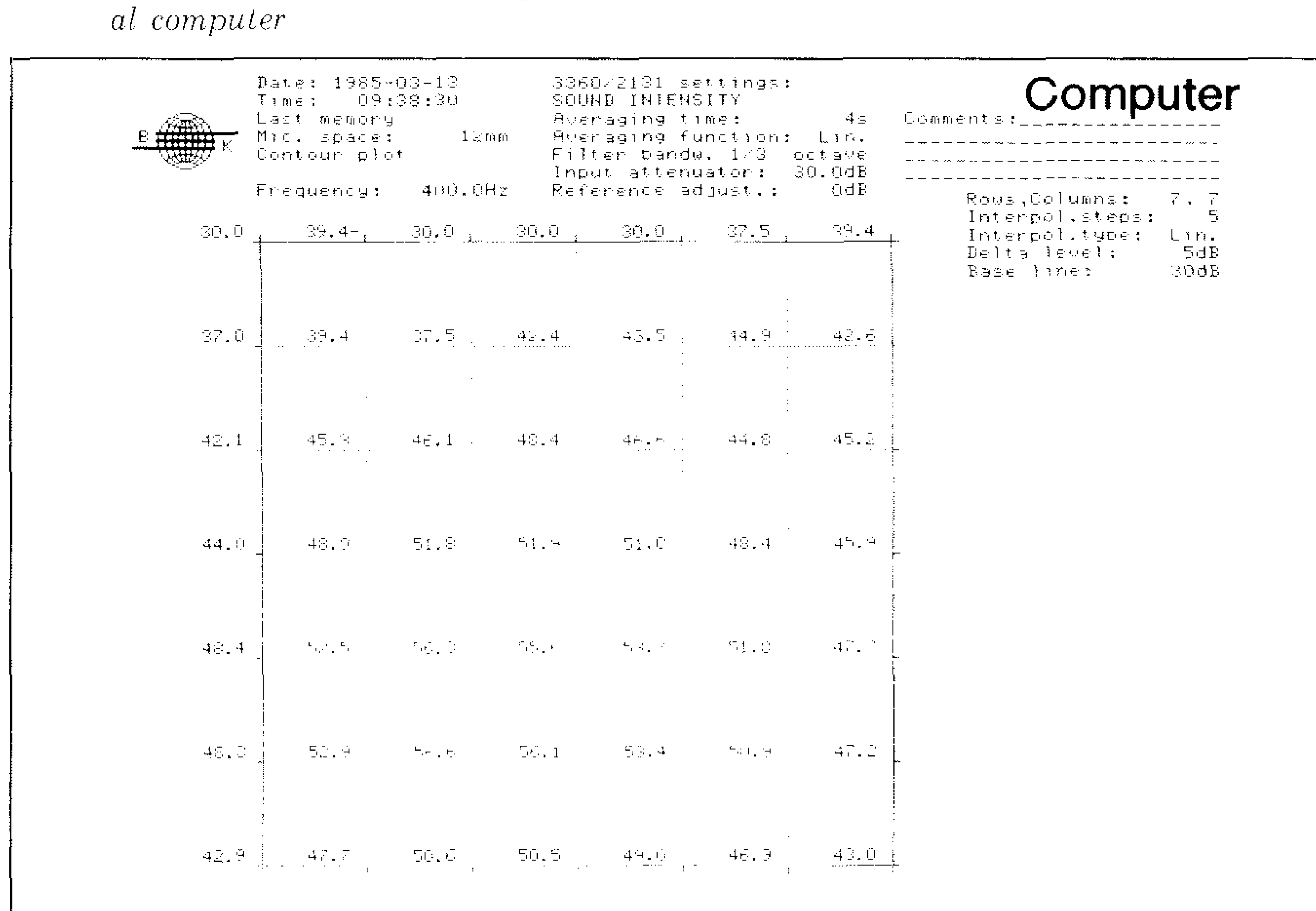


*Fig. 7. Number plot over rear of personal computer in the 400 Hz one-third octave band*

where the maximum sound power was found, 400 Hz, that is the sound intensities measured at each point on the grid in that 1/3 octave. Note that some of the numbers are negative, this indicating that at that point on the grid and in that 1/3 octave, the direction of flow of sound energy is into the grid rather than out from it.

Another means of representing the intensity data is in a contour plot, Fig. 8. The contour plot gives more detail than a number plot since it is possible to interpolate between the measured points. This contour plot, in the 400 Hz 1/3 octave, clearly shows the noise source to be the ventilation fan, as expected.

A third means of representing the intensity data is a 3–D plot, which can be viewed from different observation corners, and with different angles of view, Fig. 9.

An intensity map was also made of the printer, Fig. 10 shows the measurement grid.

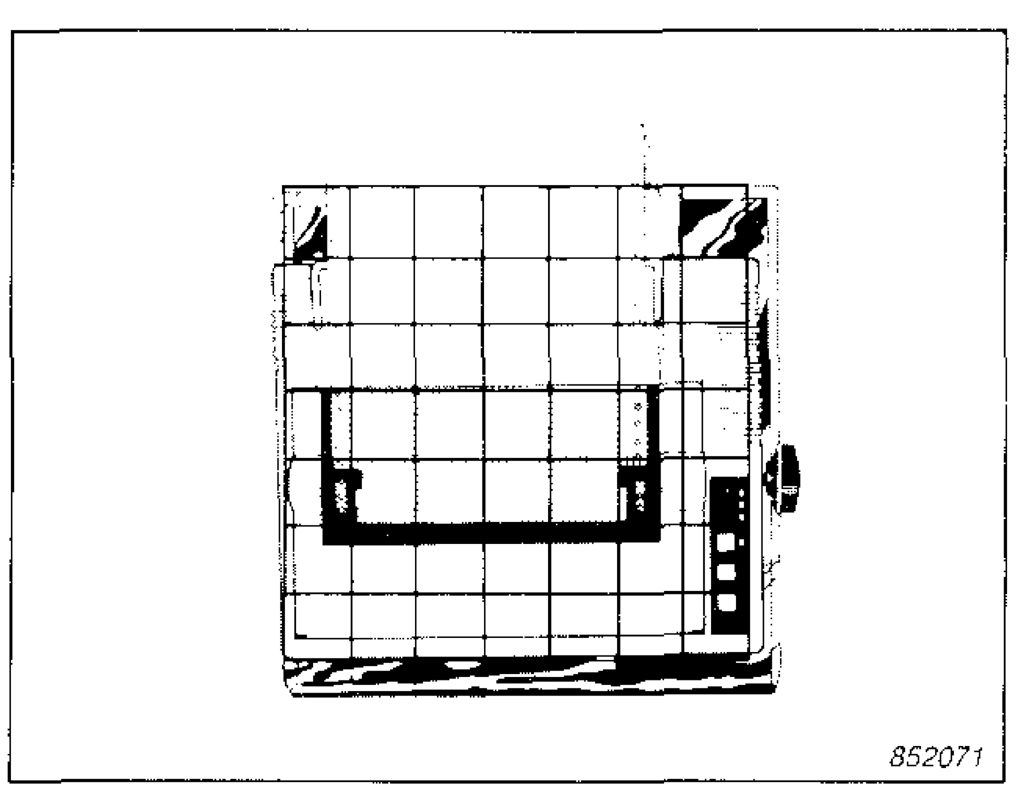


*Fig. 10. Setting up the measurement grid over the printer*

Fig. 11 shows a contour plot of the intensity data in the 4 kHz 1/3 octave, the 1/3 octave of maximum sound power. It shows the area of maximum noise radiation to be where the paper exits from the printer, this is probably due to acoustic leakage of the noise from the printing operating itself.

# Instrumentation

All the foregoing measurements were performed with the real-time Sound Intensity Analyzing System Type 3360 together with the Graphics Recorder Type 2313 equipped with a dedicated Application Package BZ 7004 (Fig.12). All measurement data were stored on the Digital Cassette Recorder Type 7400 for later reference.

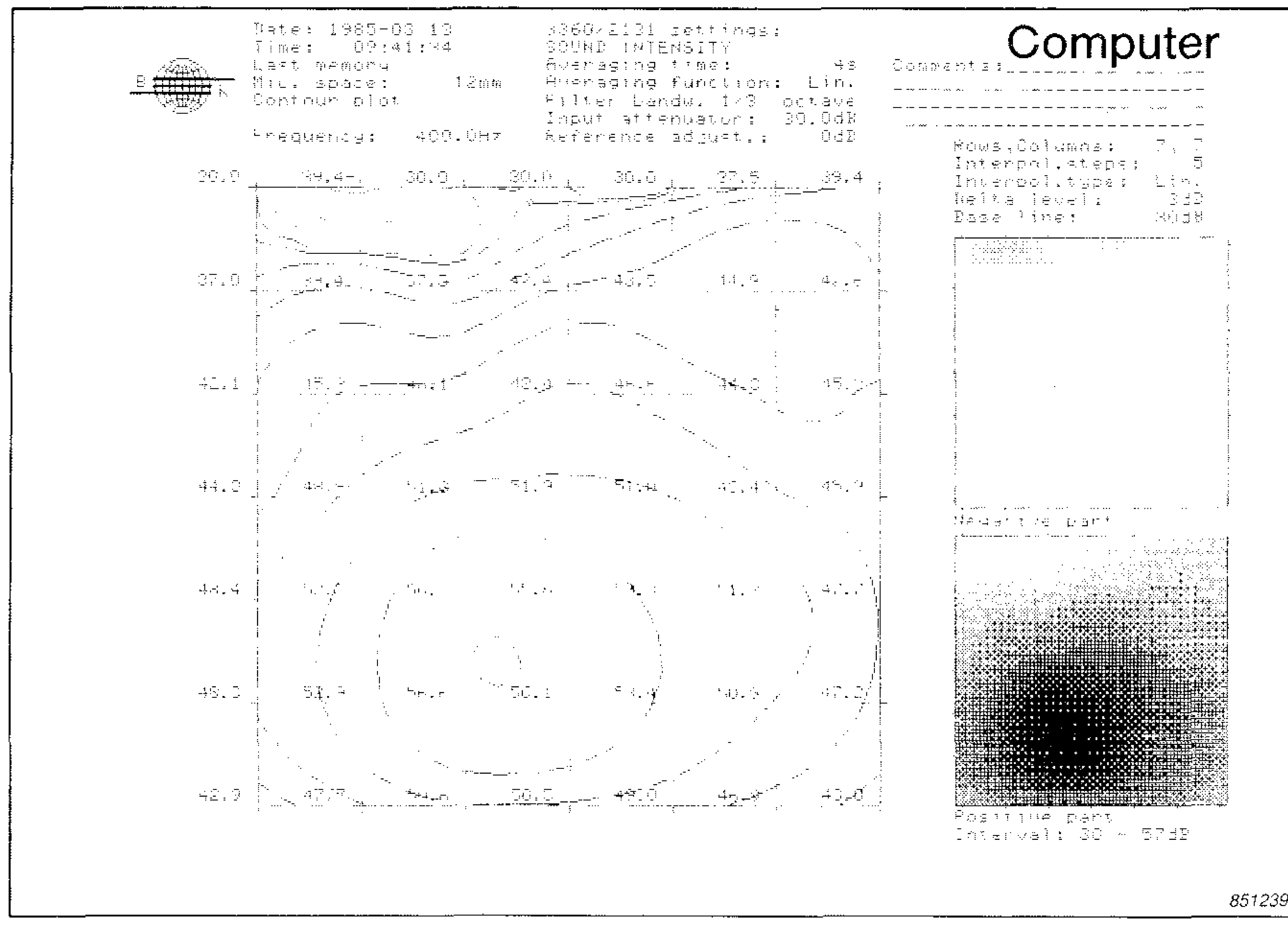


*Fig. 8. Contour plot over rear of personal computer in the 400 Hz one-third octave band*

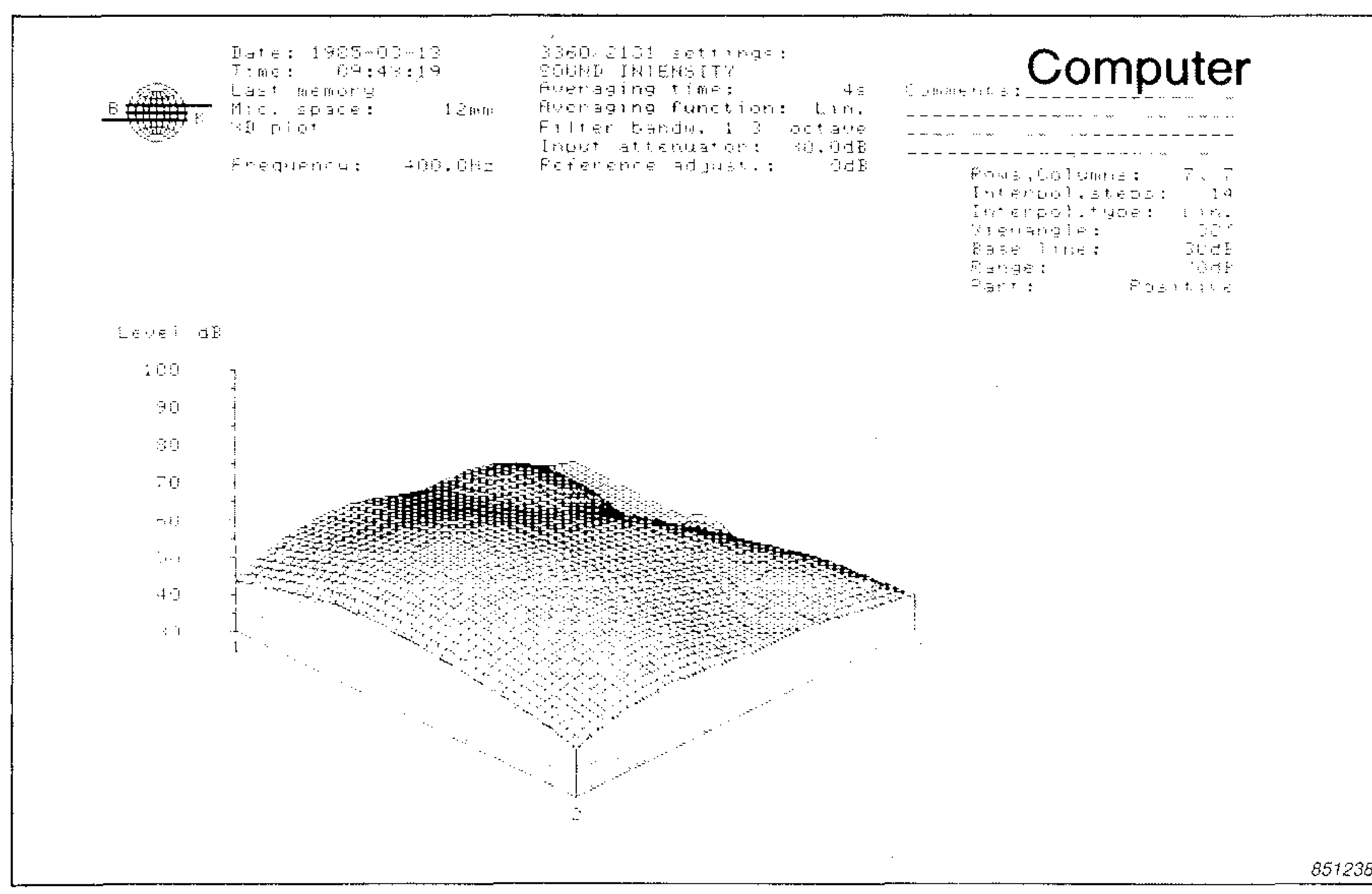


*Fig. 9. 3–D of personal computer in the 400 Hz one-third octave band*

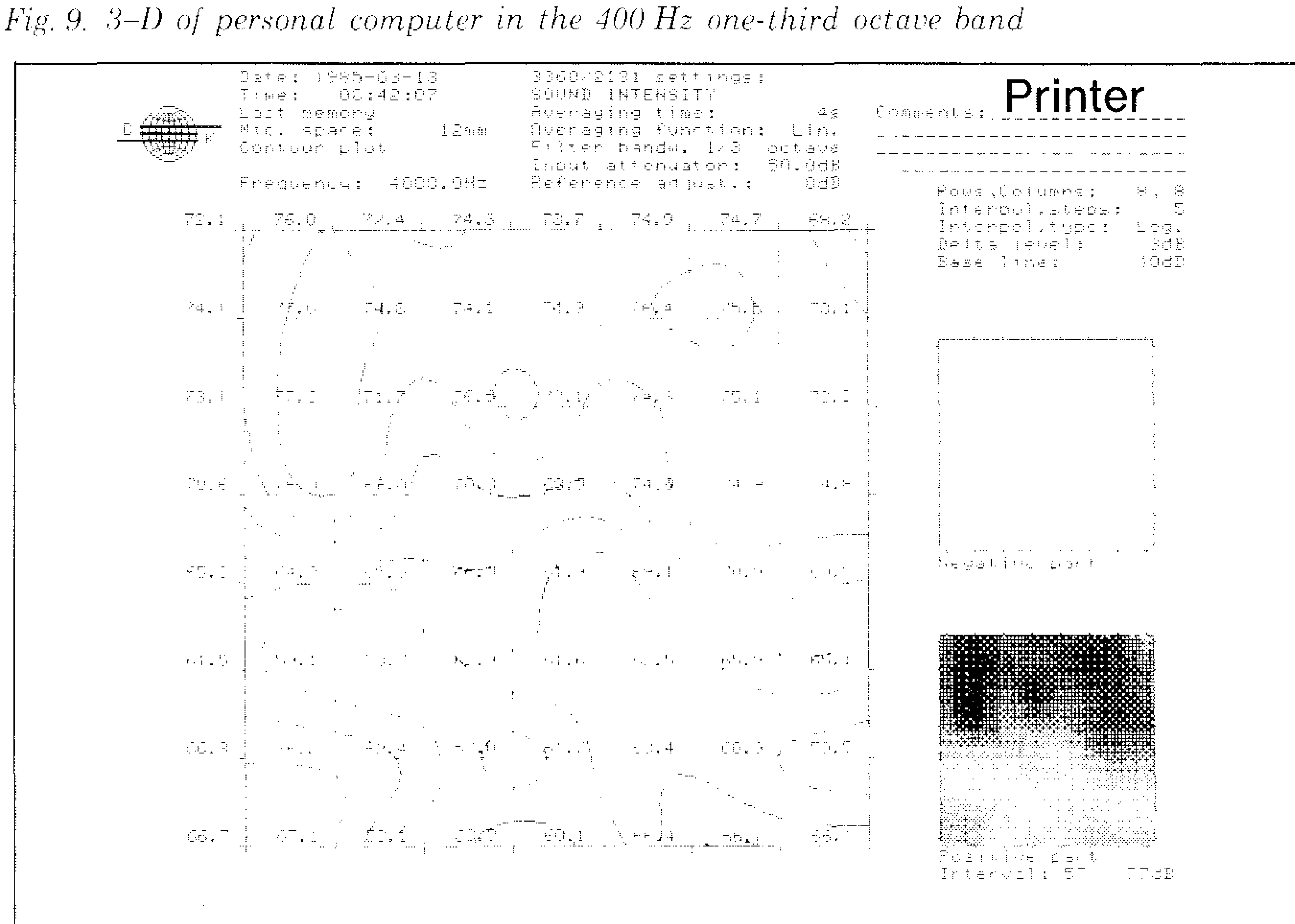


*Fig. 11. Contour plot over printer in the 4 kHz one-third octave band*

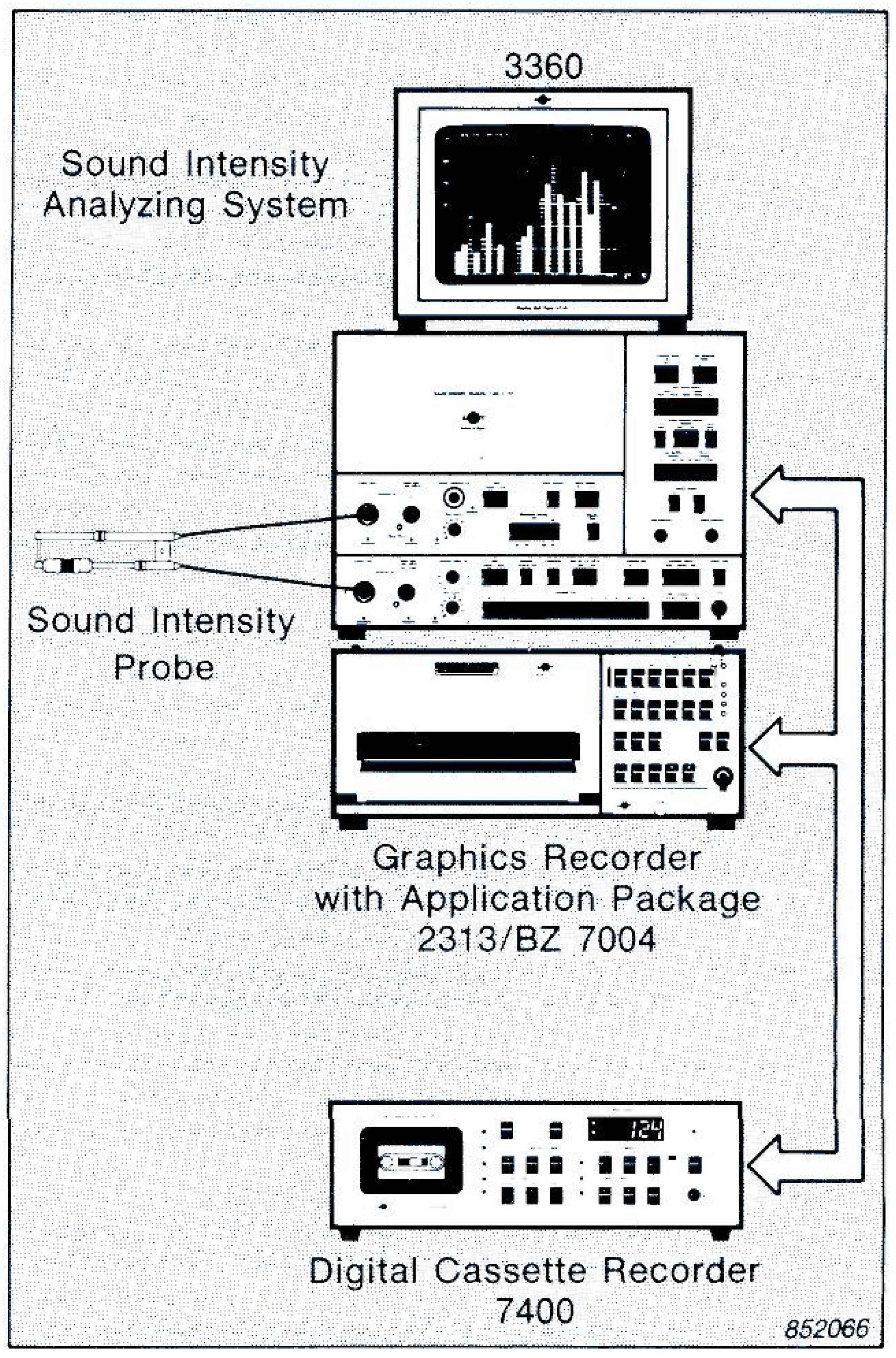


*Fig. 12. Sound Intensity Analysing System*

This instrumentation enables analysis to be performed in 1/1, 1/3 and 1/12 octave bands. The Sound Intensity Analysing System can also be used with a computer and the Software Package WW 9038 for sound power calculations and intensity mapping.

If one is interested in narrower bands for example, in locating a pure tone emitted from a product then the Dual Channel Analyzer Type 2032 together with Sound Intensity Probe 3519, a computer and Software Package WW 9078 provides a narrow band sound intensity analysing system with the facility of synthesizing 1/3 octave bands. A comparison of sound intensity measurements made using these two systems and the compromises involved is discussed in [5].

### Other measurements

Some other applications of intensity based measurements relevant for business machines are measurements of radiation efficiency transmission loss and surface intensity. These are described in other B & K literature but a brief description of radiation efficiency measurements is given below.

### Radiation efficiency

The sound power radiated by a structure depends on the radiation efficiency of the structure. The radiation efficiency $\sigma$ is defined by

$$\sigma = \frac{I}{\rho c u^2}$$

where I is the sound intensity measured over the surface of interest, $\rho c$ is the acoustical impedance of air and $u^2$ is the RMS surface velocity averaged over the surface of interest. Further, the radiation efficiency may vary for acoustical ($\sigma_a$) and vibrational ($\sigma_v$) excitation. Sound intensity measurements can be used to measure $\sigma_a$ and $\sigma_v$ for various types of panels to enable an estimate to be made of the sound power radiated by structures excited by acoustical inputs, vibrational inputs or both.

## Conclusion

Sound intensity is a useful complement to sound pressure measurements in the business machines industry where the new technique may be used for sound power determination and source location. Sound intensity can be used for the determination of sound power in situ which means that production testing may take place close to or even in the production areas instead of transporting batches of machines to a central test facility. Furthermore, sound intensity is useful in development and noise control work when there is no ready access to an acoustics laboratory for standardised measurements.

## References


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