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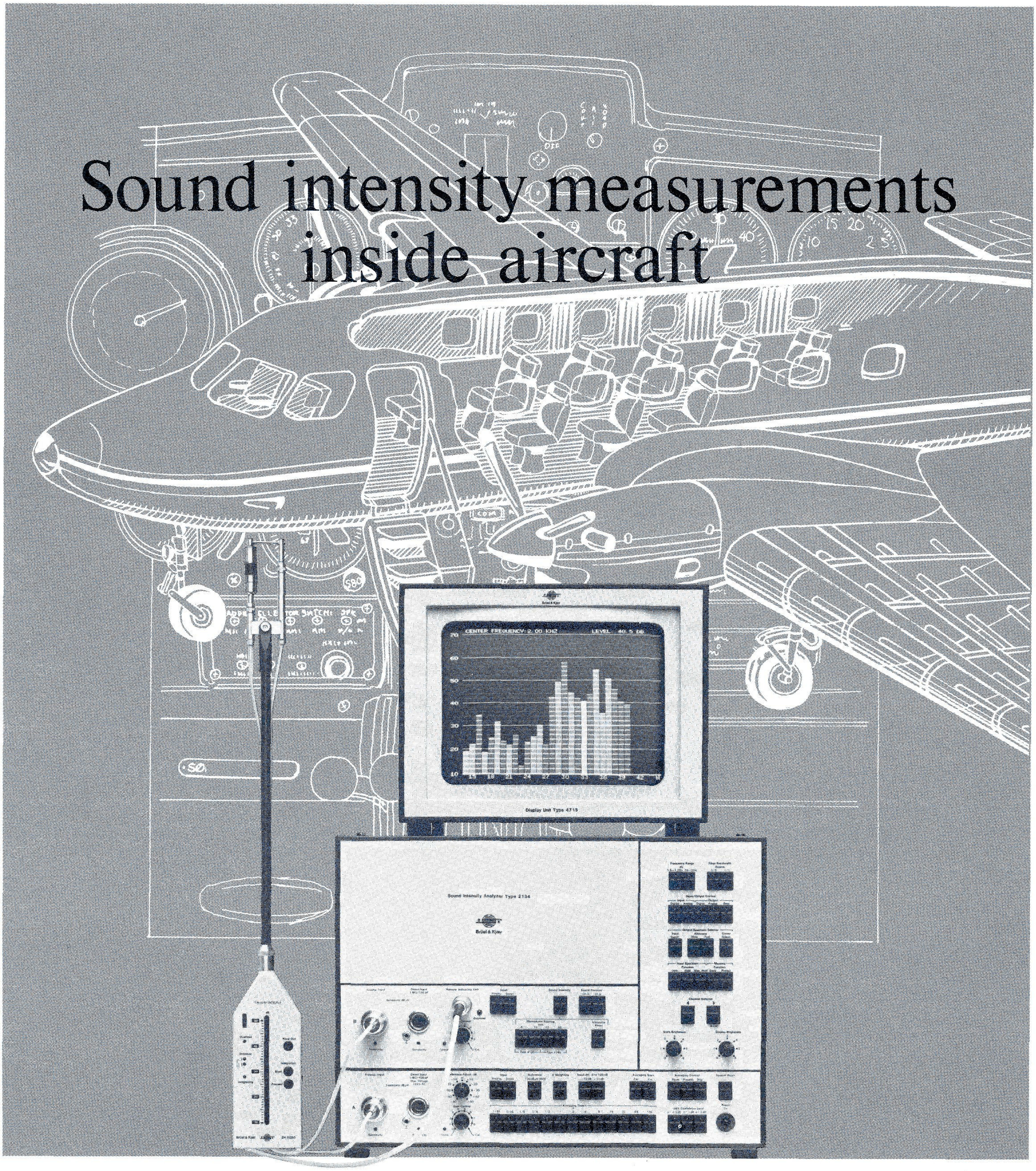
application notes

Sound intensity measurements inside aircraft



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Sound intensity measurements inside aircraft

by *J.Hee, S.Gade, K.B.Ginn & P.Cornu*

Introduction

A common problem in noise control is to determine which part of a particular surface is vibrating and producing noise. A possible solution is to use the Sound Intensity Analysing System Type 3360 in conjunction with a calculator and plotter to measure the sound intensity close to the vibrating surface, at a number of specified positions and to plot the results in the form of an intensity map. As sound intensity is the rate of flow of sound energy through a given area at right angles to the direction of flow, such an intensity map will easily show where energy flows out of the surface (i.e. a sound source) and where energy flows into the surface (i.e. a sound sink). By integration of the sound intensity over a surface the sound power radiated by the surface can be determined and the various surfaces can be ranked in order of importance.

Representation of sound intensity measurements

The representation of sound intensity data depends to a large extent on personal preference and on the programmer's imagination. The job of programming is made easier if the data are provided in a convenient form. The 3360 System is equipped with an IEC/IEEE interface so that octave and third-octave spectra can be sent directly to the calculator. When measurements are performed *in situ* (e.g. in a motor vehicle or in an aircraft, Fig.1), spectra can be stored on the Digital Cassette Recorder Type 7400 (up to 1200 third-octave or 2400 octave spectra per cassette).

B & K Sound Intensity Program Package

B & K have developed a program for the treatment of data measured with the Sound Intensity Analysing System Type 3360. The program includes:

1. Intensity maps (iso-intensity contours by interpolation)
2. Intensity maps (numerical values)
3. Three dimensional intensity maps
4. Summation of intensity spectra and calculation of sound power

What grid size should one use?

It is reasonable to ask how many measurement points are required for intensity mapping in a "real life" situation? In general one can say that the grid should be as coarse as possible to limit the number of measurements but must be fine enough to pick out detail. If necessary the grid can be further subdivided in regions of special interest.

Do measurements at discrete points yield a true picture of the sound intensity distribution?

Measurements at discrete points could lead to spatial aliasing and thus misrepresent the true situation. The problem of spatial aliasing could be mitigated by sweeping the probe back and forth over the measurement area associated with each measurement point to obtain a spatially averaged value of the sound intensity level at that point. The time and space averaging are then performed simultaneously.

Should one measure in the near- or the far-field?

The sound intensity map as measured within a few centimetres of a vibrating surface (the "near-field") can be extremely complex. If one is only interested in the total sound power radiated by a surface then one should perform the measurements at least ten centimetres from the surface (the "far-field") where the intensity pattern is usually much more uniform. In highly diffuse fields as found, for example, inside aircraft, a far-field measurement is of little value as the measured sound intensity cannot be attributed to a single surface.

Practical grid sizes

To adequately describe the noise radiation from the surface of, say, a diesel engine a measurement would be required for each 150 mm^2 of engine surface which would mean over 20 000 measurement points! Fortunately such a resolution is far finer than that required for noise control investigations and typically one measurement point per 0,05 m^2 is used i.e. a mesh size of about 200 × 200 mm. The measurements are performed at about 20 mm from the surface of the engine [1].

For tyres a grid of mesh size 75 ×75 mm has been used over the lower part of the tyre with the measurement plane about 100 mm from the plane of the tyre [2].

On large machines, such as wood chippers, a grid with mesh size of 150 × 150 mm has been used with the measurement plane being 150 mm from the surface of interest [3].

The size of a suitable mesh on large machines is frequently determined by the smallest area over which there are no significant changes in sound pressure. A more accurate but more complicated method to determine a suitable mesh size is to use a pair of accelerometers to determine a typical correlation length from vibration measurements.

Sound intensity measurements in aircraft

B & K engineers have performed sound intensity measurements on various types of aircraft to obtain experience in using the instrumentation *in situ*. The aircraft include:

1. Airbus (jet; seating capacity circa 250).
2. Fokker (turbo-prop; seating capacity circa 50).

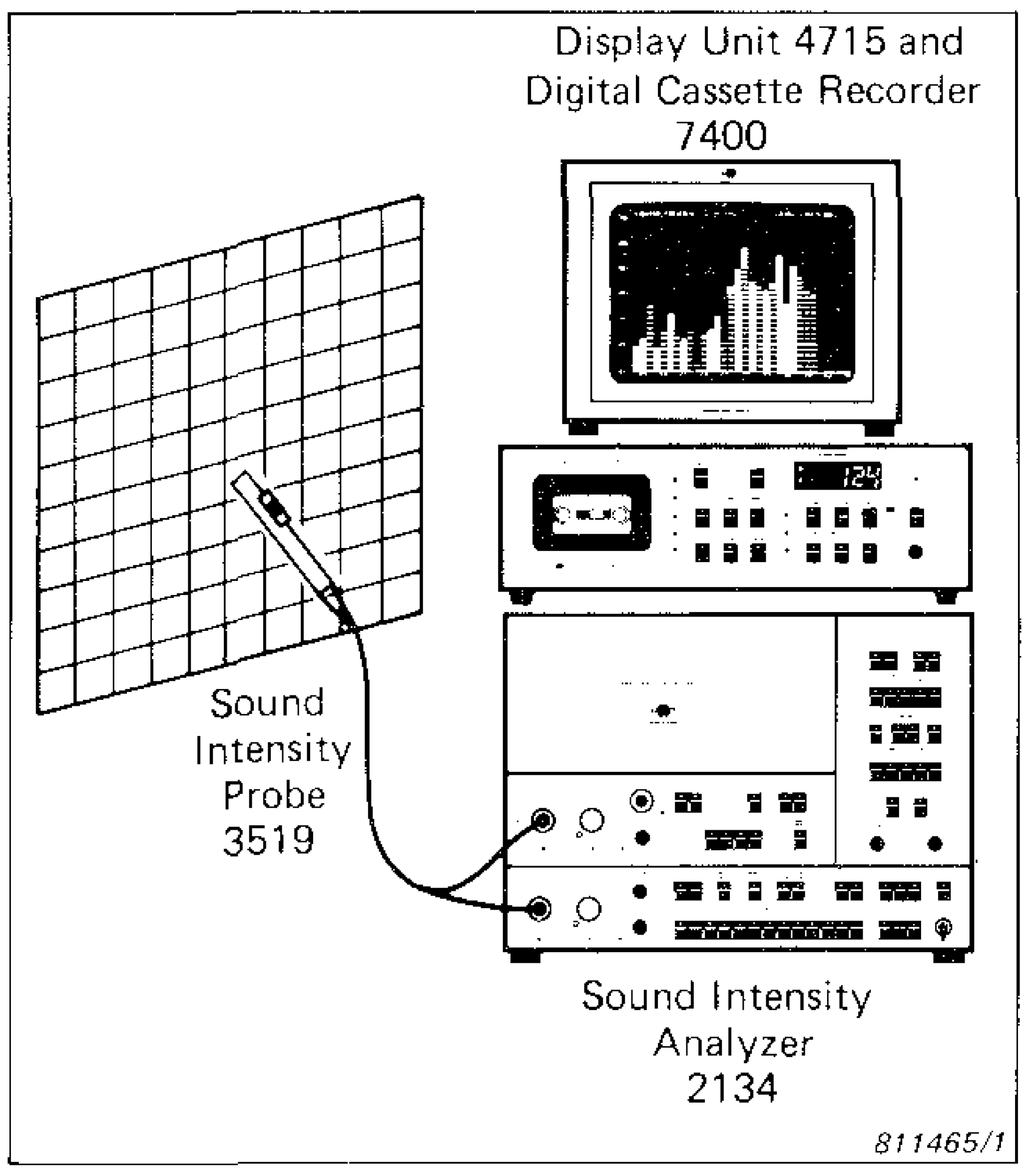

Fig. 1. Instrumentation used for intensity mapping measurements

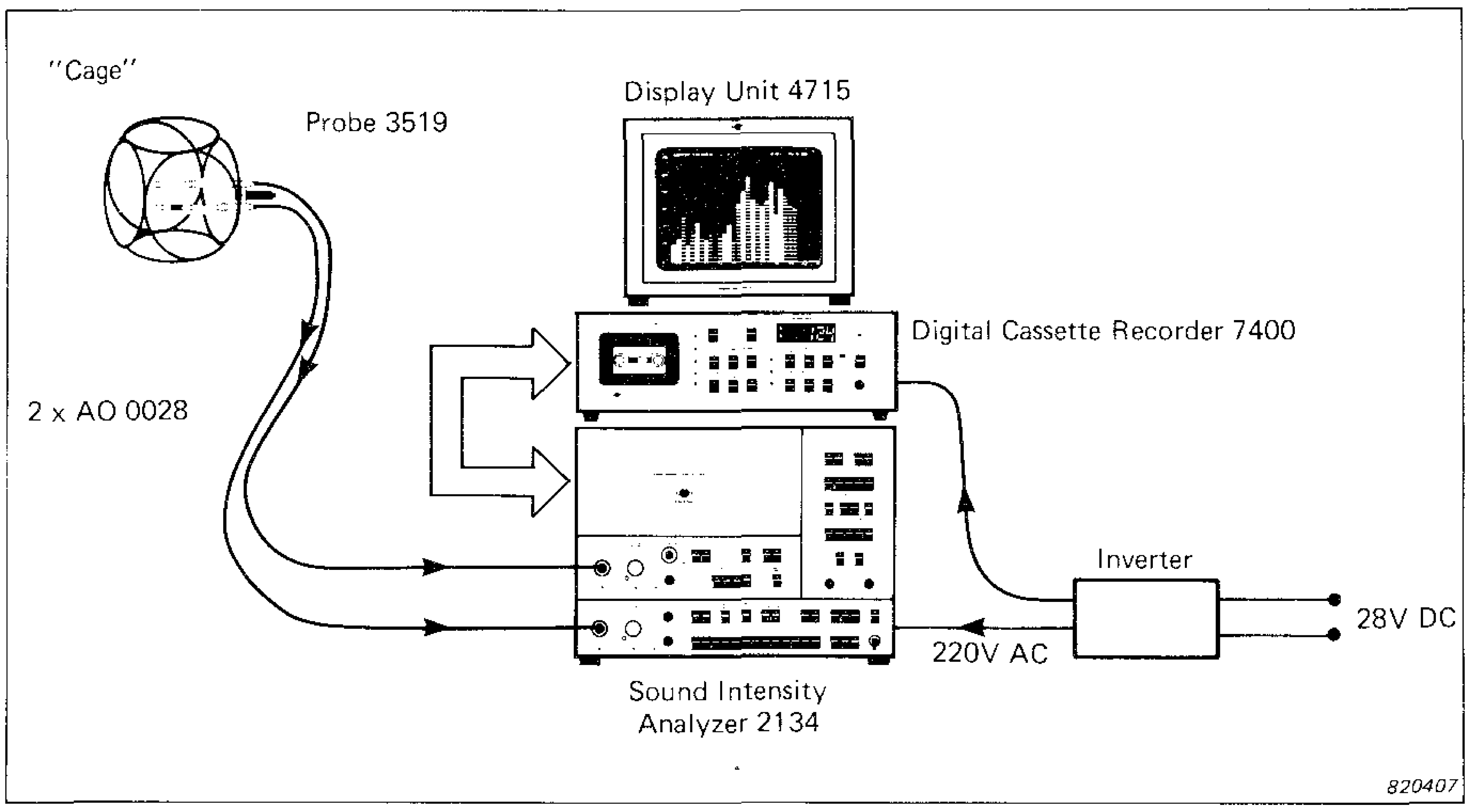

Fig. 2. Instrumentation used for in-flight measurements

3. Bandeirante (turbo-prop; seating capacity 16).

Measurements in Airbus

Measurements were performed on a cross-section of the Airbus at 20 measurement points using the instrumentation shown in Fig.2. The 300 VA, 220 V, 50 Hz required by the instrumentation was obtained from the 28 V DC from the aircraft via an inverter. The Airbus was in flight during the measurements. The airconditioning unit, which performs the important job of preventing the aircraft's computer from overheating, was switched off for the maximum permissible time of 14 minutes so that turbulent airstreams would not interfere with the measurements. For comparison purposes some measurements were also performed with the airconditioning in operation. At each measurement point the sound intensity component was measured in three orthogonal directions using the simple "cage" device shown in Fig.3. From the measured spectra the intensity vector was calculated at each measurement point and the vector was projected onto a cross-sectional drawing of the aircraft (Fig.4) where the intensity level is indicated by the length of the arrow.

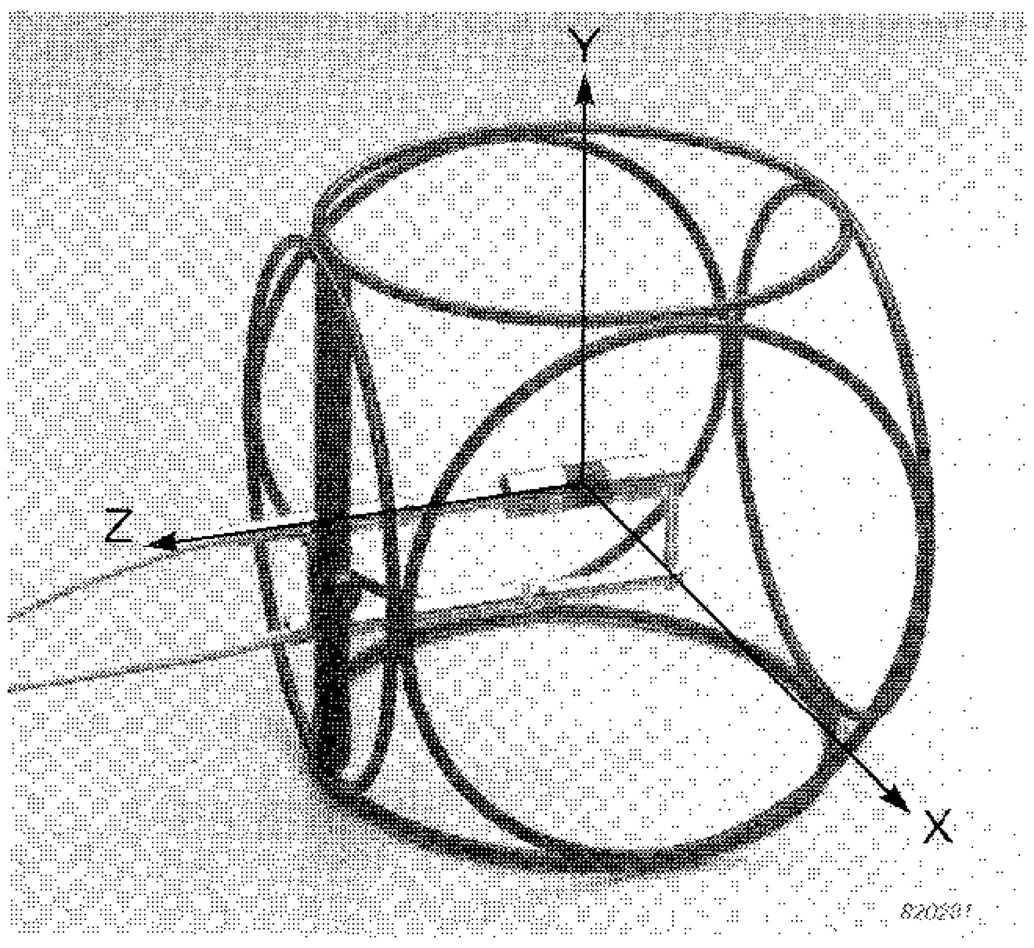

Fig. 3. Steel wire "cage" for positioning the probe for the three orthogonal measurements necessary for the calculation of the intensity vector

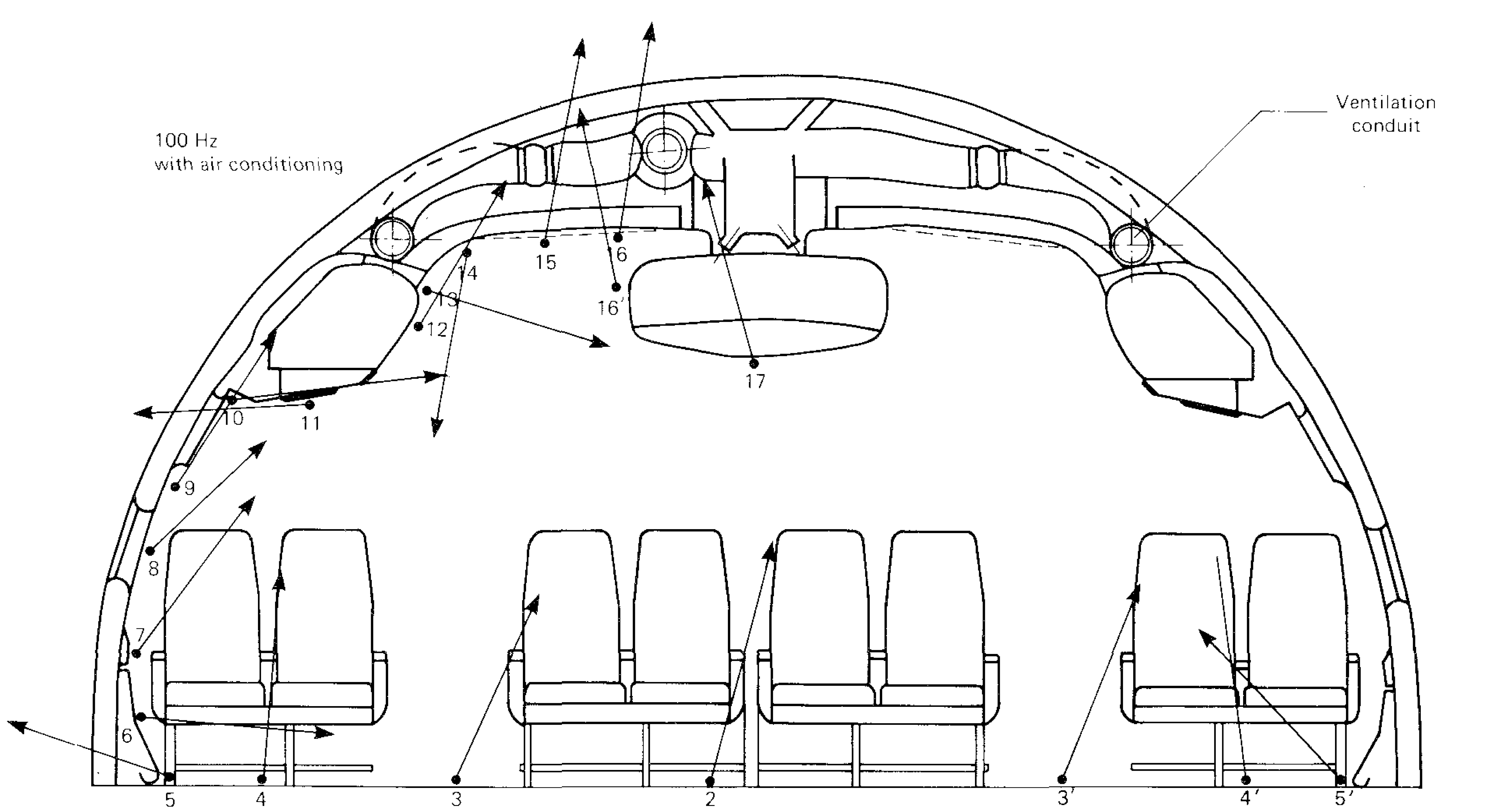

Fig. 4. Projection of the sound intensity vectors in the 100 Hz third-octave band onto a cross-section of the aircraft with air-conditioning system operating. The length of the arrow is proportional to the sound intensity level and the direction is given by the direction of the arrow.

Such diagrams contain such a mass of information that they can sometimes be difficult to assimulate at first glance especially when the vector projections criss-cross one-another. In many cases an intensity map may be preferred.

Measurements in Fokker

Measurements were performed in one of the early variants of the Fokker F27 aircraft, on that part of the passenger compartment wall directly opposite the port propeller. The aircraft was stationary on the ground during the measurements.

The engine was running at 13800 r.p.m. with a reduction ratio of 0,0929. The corresponding blade passing frequency for the 4-bladed propeller was (13800×4×0,0929)/60 $\simeq$ 85 Hz.

Sound intensity measurements were performed on a grid of dimensions 80 cm × 100 cm. The measurement points were marked by clear adhesive tape put directly on the wall (this is easy to apply and less messy than chalk) and the probe was held at a distance of 1 cm from it. Each measurement point represented an area of 10 cm × 10 cm i.e. 80 measurement points in all. A linear averaging time of 8 s was used at each point yielding a total measuring time of about 11 minutes.

The average intensity spectrum was computed for each of the following three areas: window, wall-panel and wall-panel / roof-panel joint.

From these spectra, the most interesting third-octave frequency band was seen to be the one centred on 250 Hz i.e. the third harmonic of the blade passing frequency. The

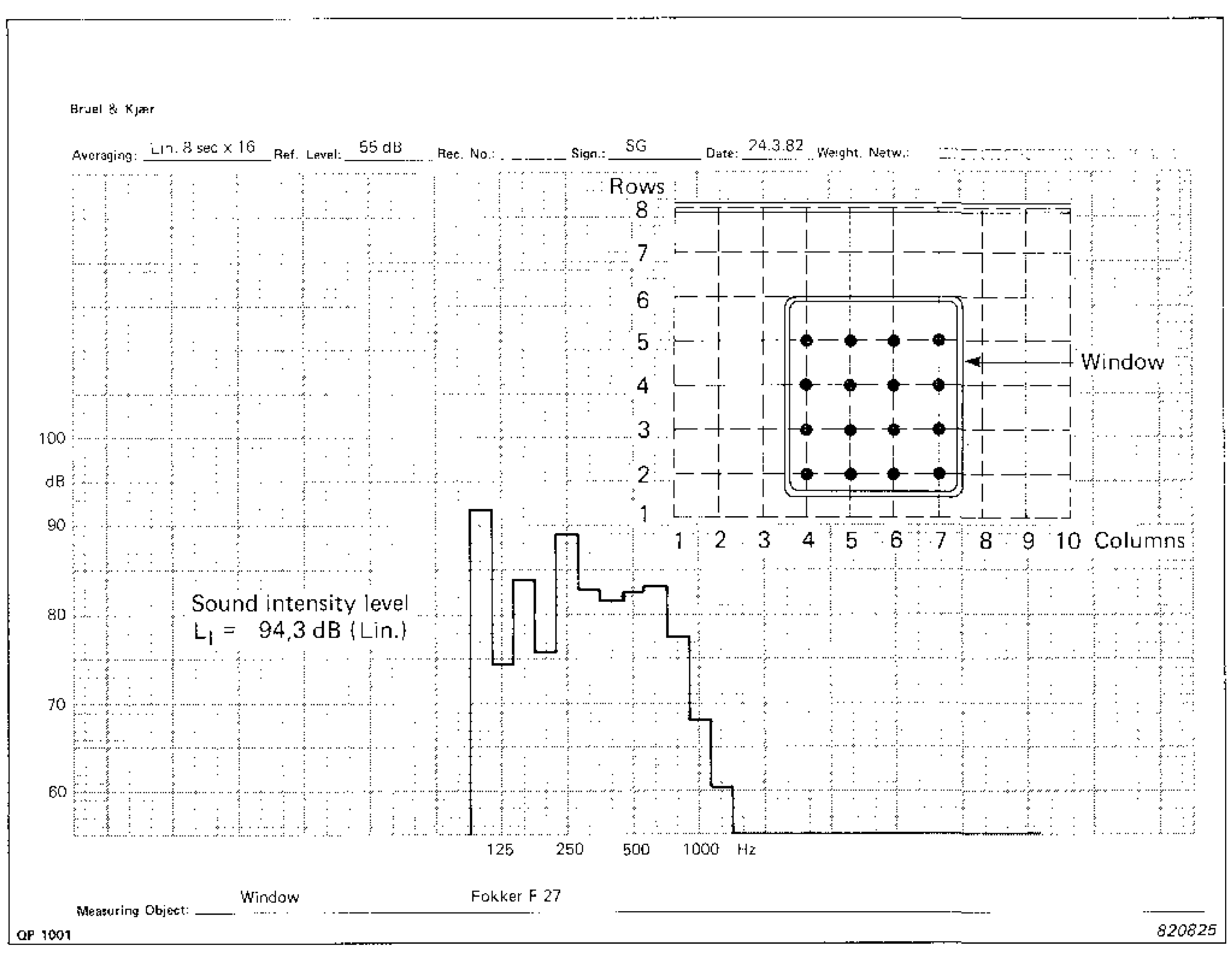

Fig. 5. **Sound intensity level over the window area, averaged over 16 measurement points**

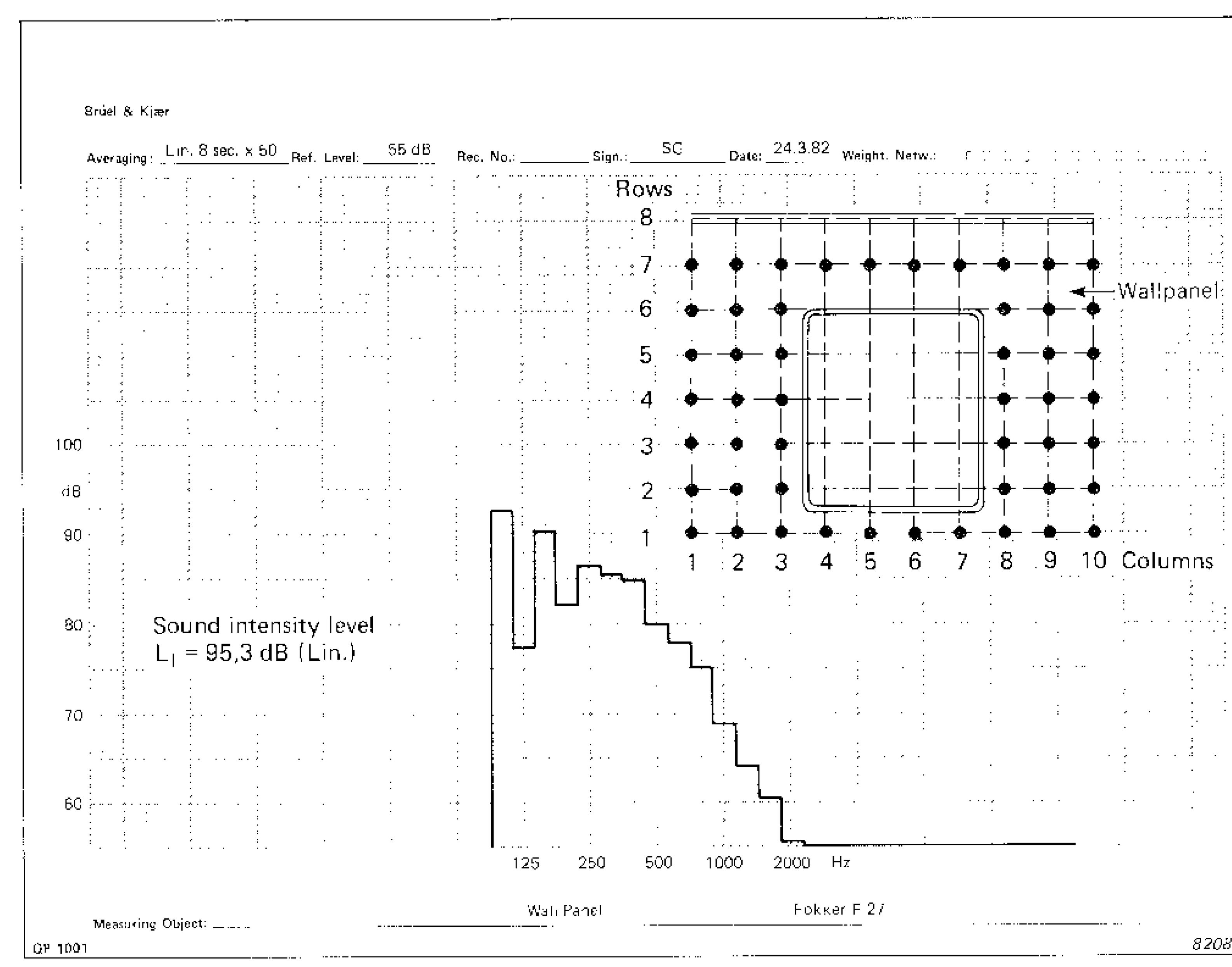

Fig. 6. **Sound intensity level over the wall-panel area, averaged over 50 measurement points**

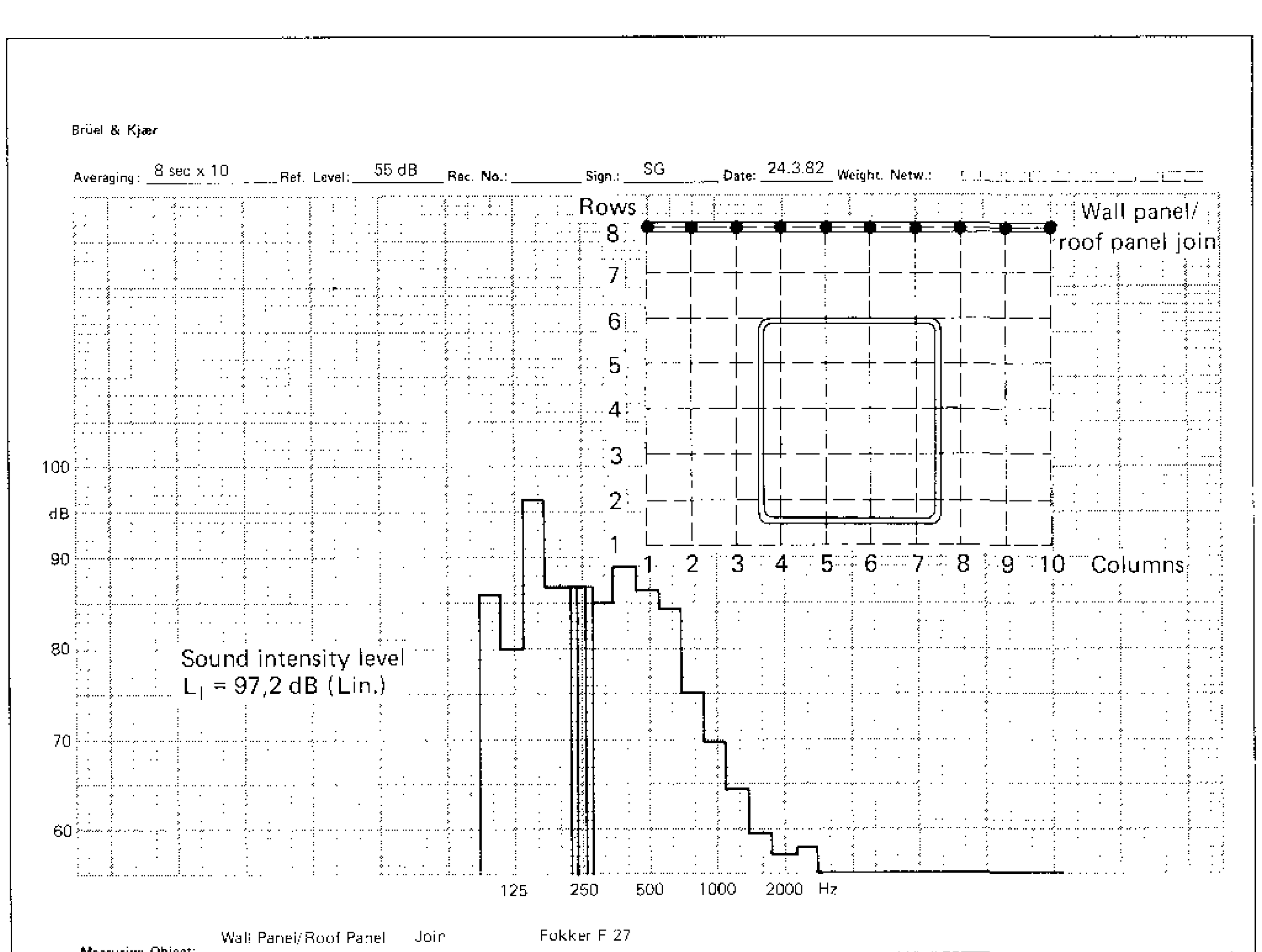

Fig. 7. **Sound intensity level over the wall-panel / roof-panel join area, averaged over 10 measurement points**

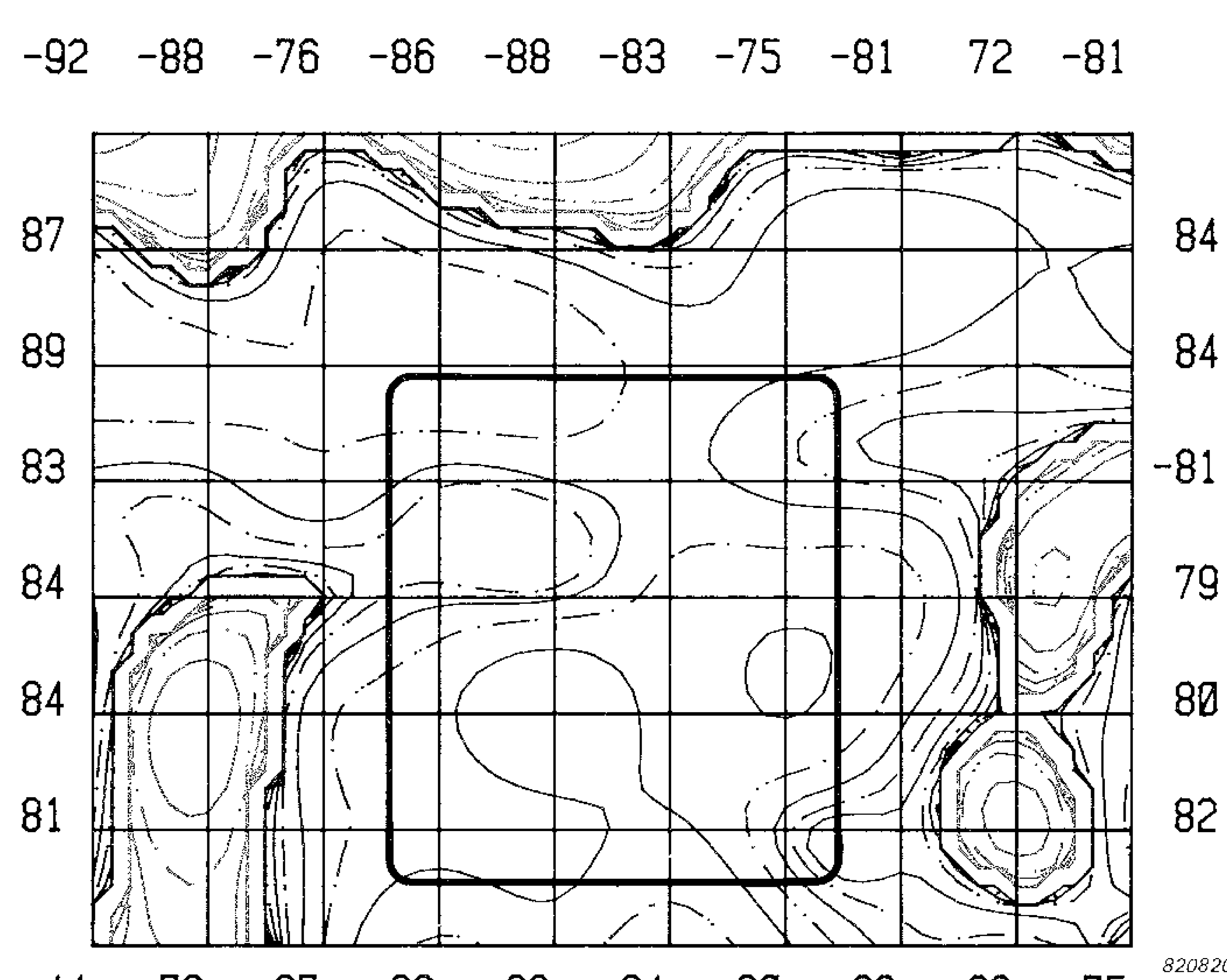

Fig. 8. **Sound intensity map over the measurement surface for the 250 Hz third-octave band. Linear interpolation with 3 dB between the contours and every second contour is drawn dashed**

Linear Weighting	L_I re 1pW/m²	L_W re 1pW
Panel	95,3 dB	92,2 dB
Window	94,3 dB	86,3 dB
Panel join	97,2 dB	87,2 dB

Fig. 9. Comparison of the averaged measured intensities over the three surfaces and the calculated sound powers

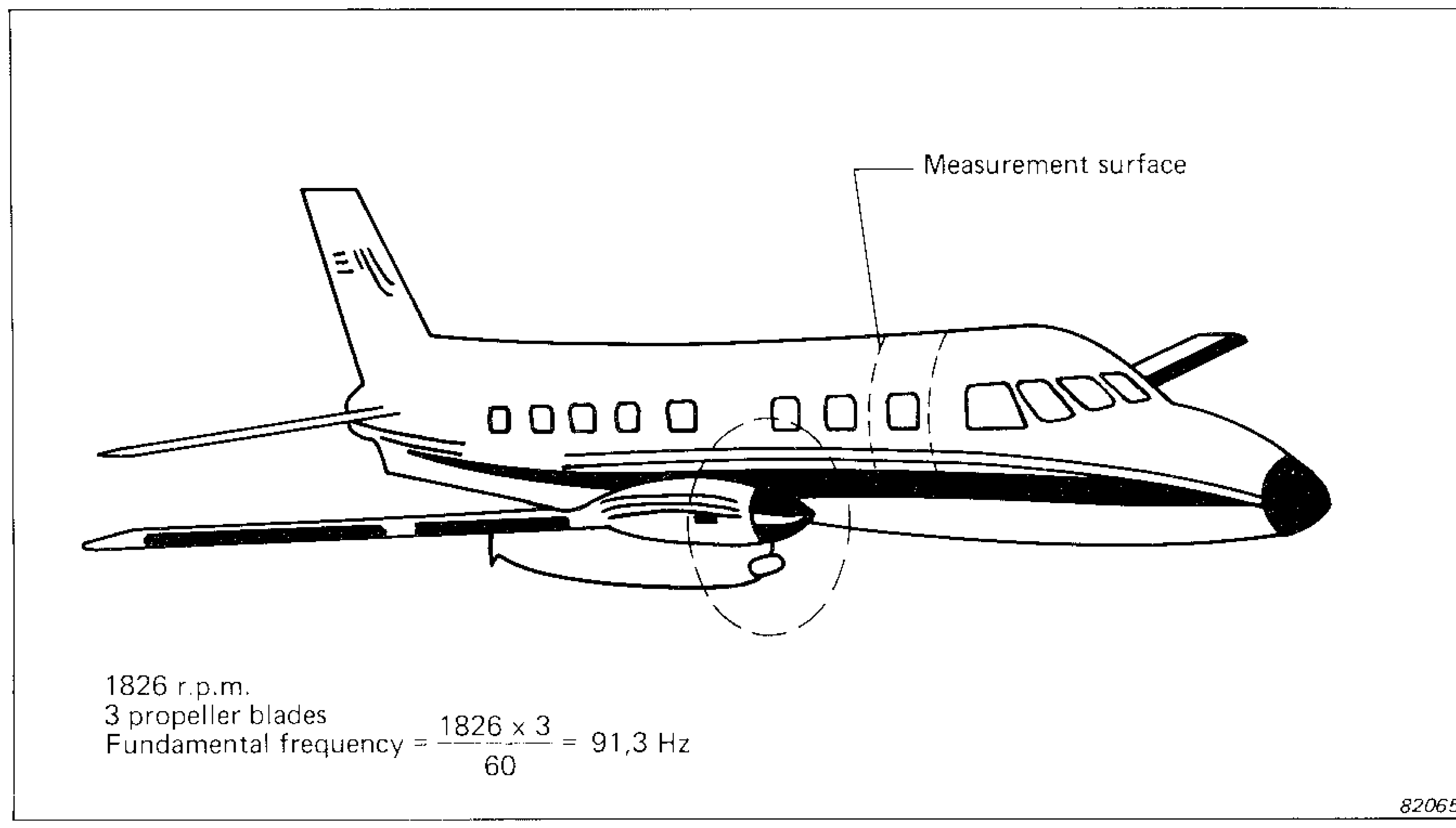

Fig. 10. Bandeirante aircraft showing the position of the measurement surface

wall-panel / roof-panel join acts as a sound sink while the window and the wall-panel act as sound sources at this frequency and under the above mentioned test condition. Note that the intensity level is 3 dB higher at the window than at the wall-panel.

An intensity contour plot at 250 Hz reveals that the window acts as a piston with a loudspeaker effect. Furthermore the contour plot clearly shows the strong sink effect at the panel joint.

Note that although the greatest overall intensity is found at the panel joint, it is the wall-panel which is the strongest noise source since the it represents a much larger region. The radiated sound power for each of the three areas can be found by multiplying the measured intensity with the corresponding area.

Measurements in Bandeirante

Measurements were performed in a Bandeirante aircraft in-flight on that part of the passenger compartment wall directly opposite the starboard propeller. The instrumentation was powered via an inverter by two 12 V car batteries in parallel which could supply the necessary 300 VA for two hours. When cruising with the engines running at 1826 r.p.m. the blade passing frequency (three blades per propeller) was (1826 × 3) / 60 = 91,3 Hz which corresponded with the fact that by far the most important noise components were in the 100 Hz third-octave band. From the sound intensity measurements at the 210 measurement points on the measurement surface, the sound power level radiated from various parts of the measurement surface were calculated and the sources ranked in order of importance. The sound field within the aircraft was very diffuse so a relatively long averaging time of 8 seconds was employed. Allowing a couple of seconds for moving the probe between measurement points and for read-out of the data to the Digital Cassette Recorder Type 7400, the total measurement time was 38 minutes.

At four positions on the aircrafts cross-section, both the sound intensity levels, L_I, and the sound pressure levels, L_p, were measured with a linear averaging time of 16 s (Figs. 11 to 14). The difference between these levels was about 25 dB which indicates the degree of diffuseness of the sound field. In a plane wave the relationship between these levels is:

$$L_I = L_p - 0{,}16\,\mathrm{dB}$$

The sequence of curves in Fig. 11 to 14 show that the fundamental fre-

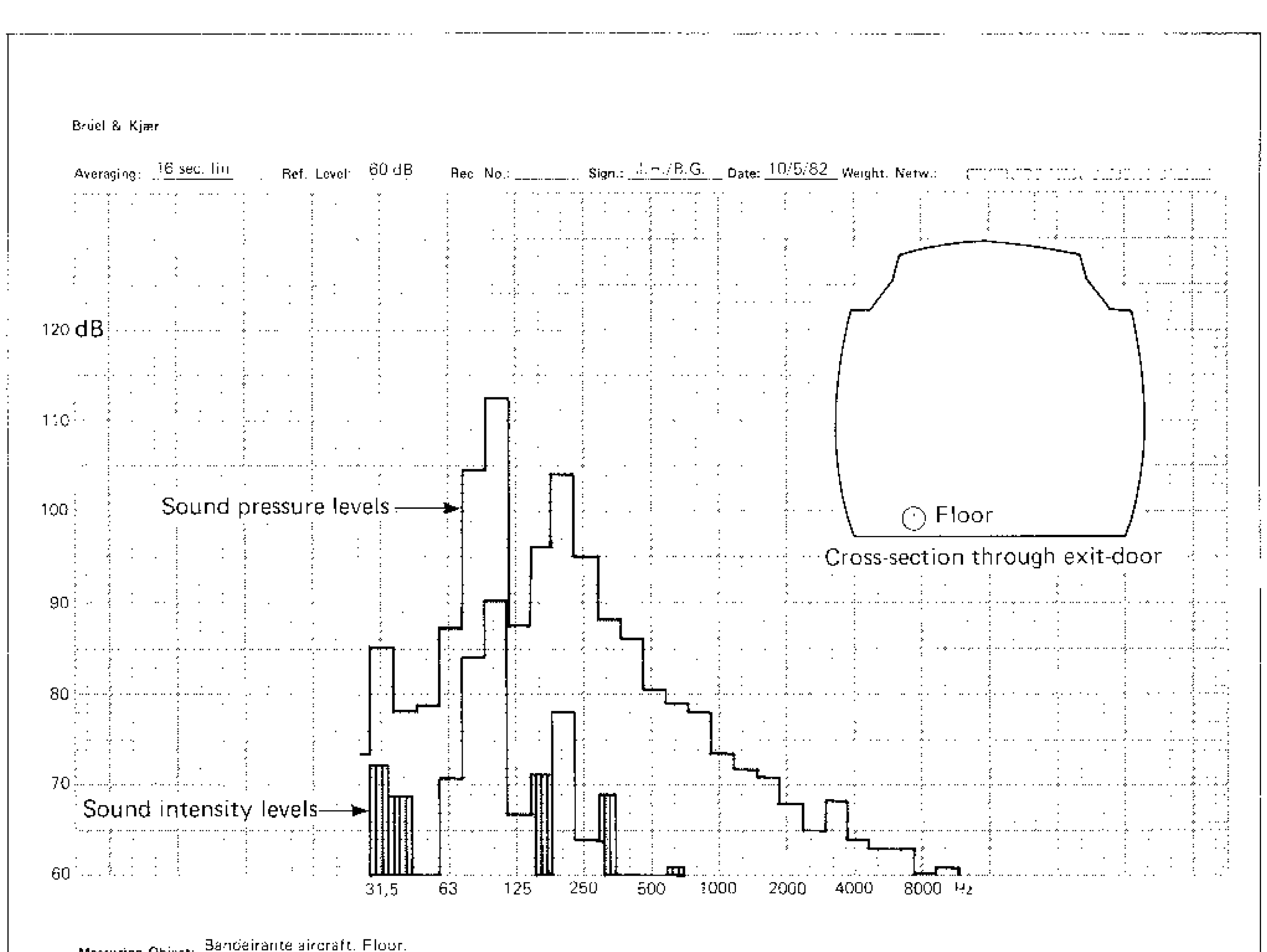

Fig. 11. Sound pressure level and sound intensity level measured on floor

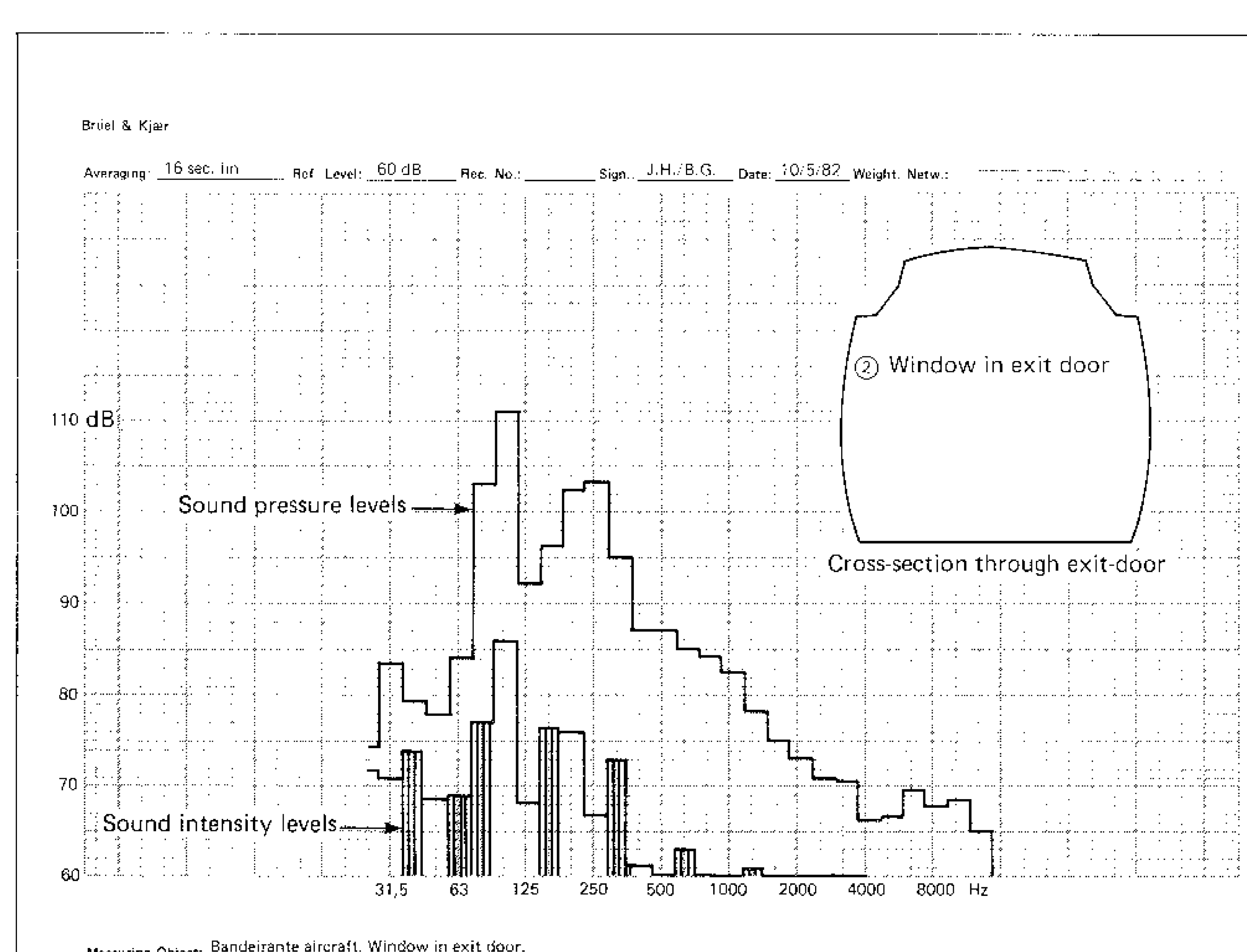

Fig. 12. Sound pressure level and sound intensity level measured over window in exit door

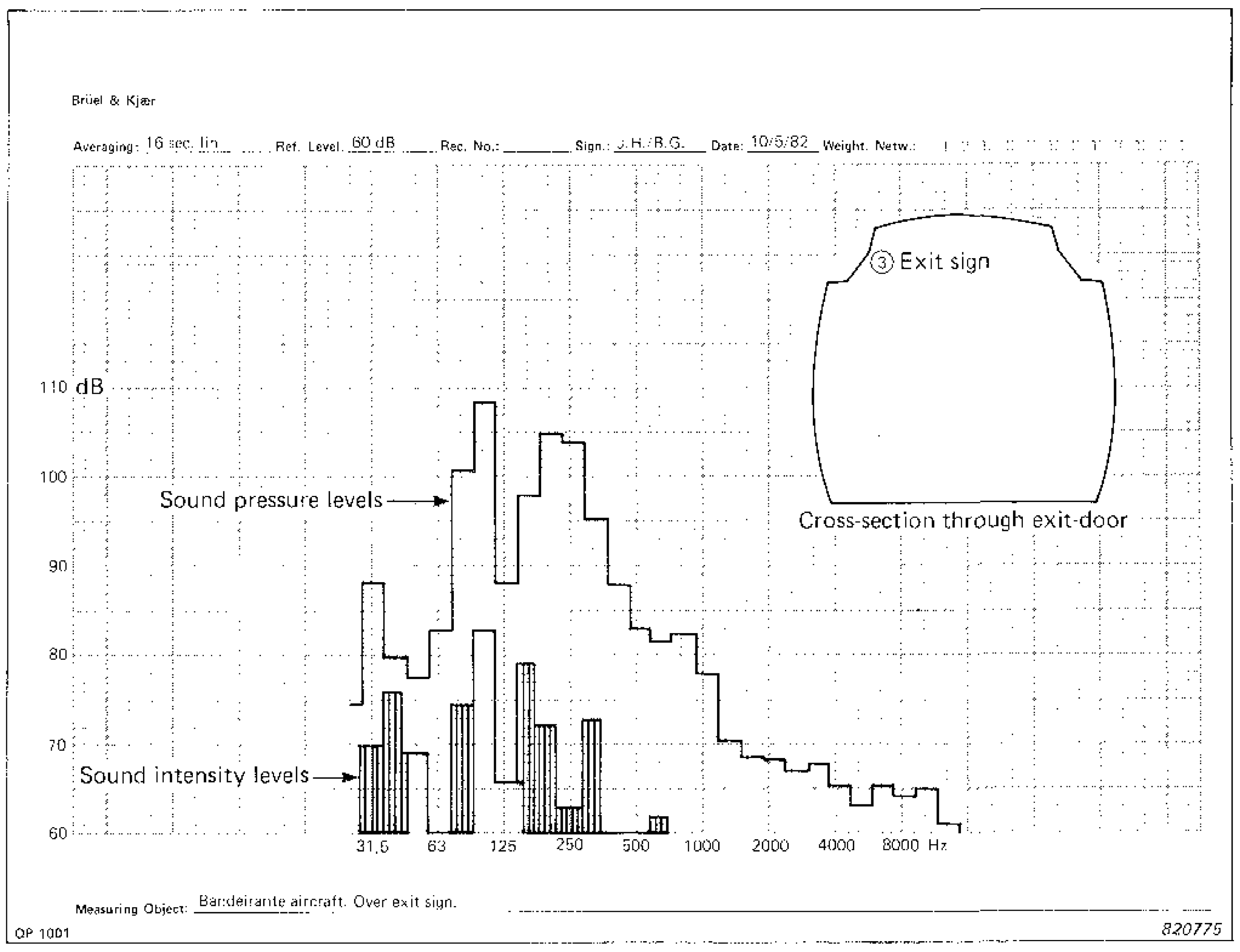

Fig. 13. Sound pressure level and sound intensity level measured over exit sign

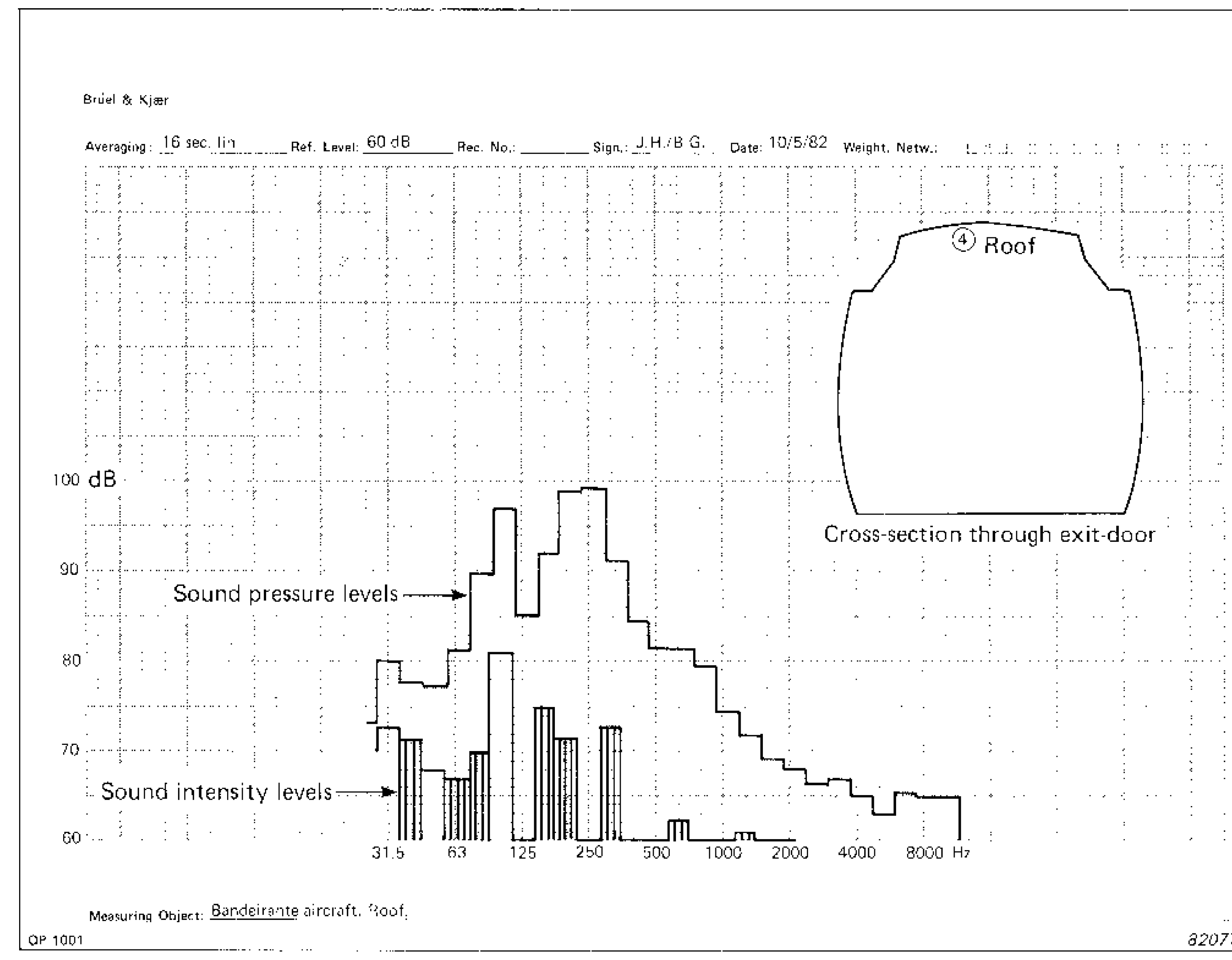

Fig. 14. Sound pressure level and sound intensity level measured on roof

quency and its second harmonic are most strongly radiated from the floor and that the amount of radiated energy decreases towards the roof. This effect is clearly shown in the intensity map for the fundamental frequency in Fig.17.

Conclusions

The combination of the Sound Intensity Analysing System Type 3360 and the Digital Cassette Recorder Type 7400 has proved to be a rapid measuring and data gathering system suitable for use in aircraft where, with present day fuel prices, one can truly say that “time is money”.

The wealth of data stored on a cassette tape can be treated using the B & K Sound Intensity Program Package to calculate the sound power from various surfaces or plot intensity maps which present the measured intensity spectrograms in a manner which is easy to assimulate.

The rapidity of both measurement and treatment of sound intensity data means that less time needs to be spent “data crunching” and more time is available for solving the problem in hand [4] [5].

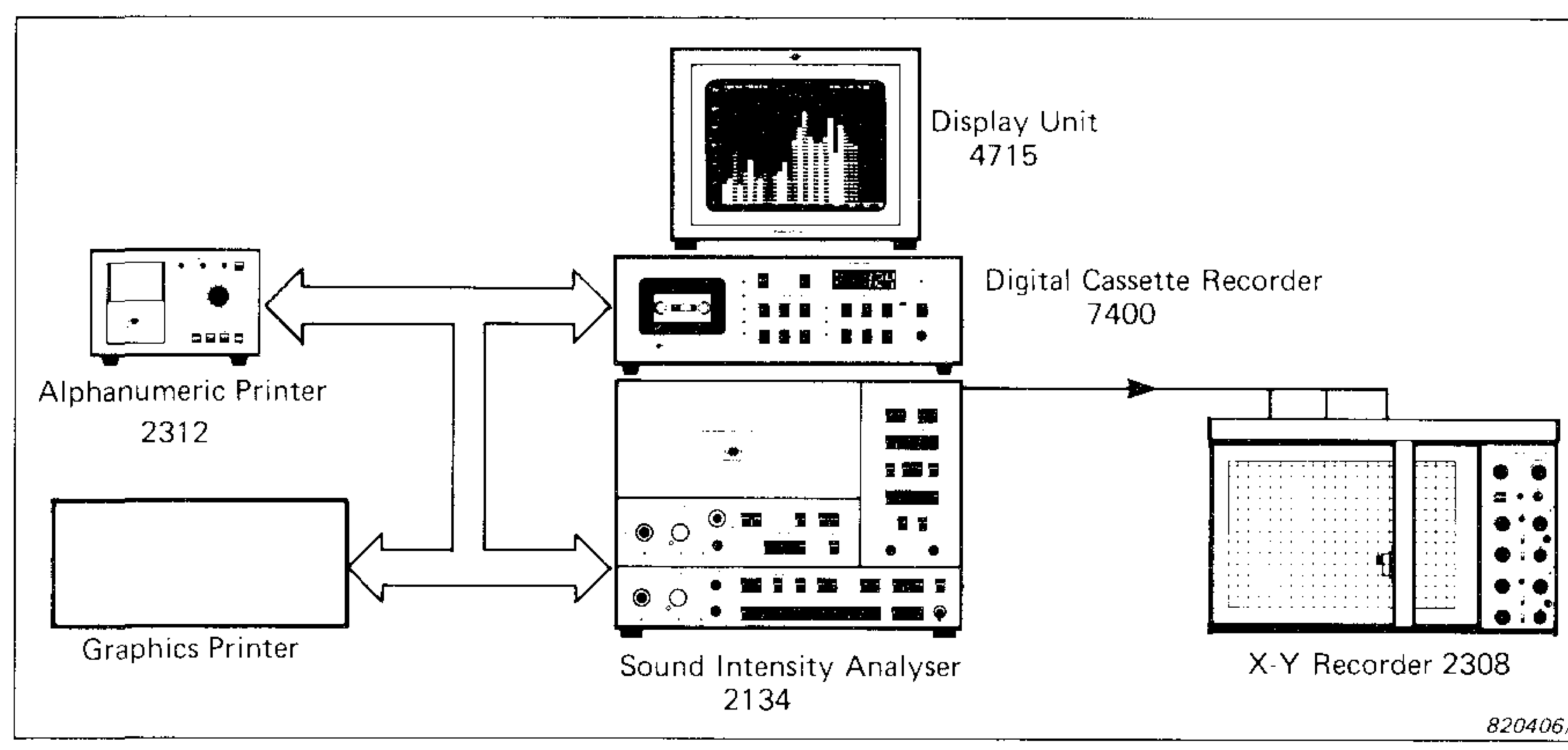

Fig. 15. Instrumentation used for the treatment of the recorded data

Area	Linear dB	A-weighted
Wall	96,1	84,0
Lower part of exit door	91,5	82,4
Window (upper part of exit door)	87,3	73,0
Roof	87,6	79,4
Whole panel	98,2	87,3

Fig. 16. Calculated sound power for various areas of the measurement surface

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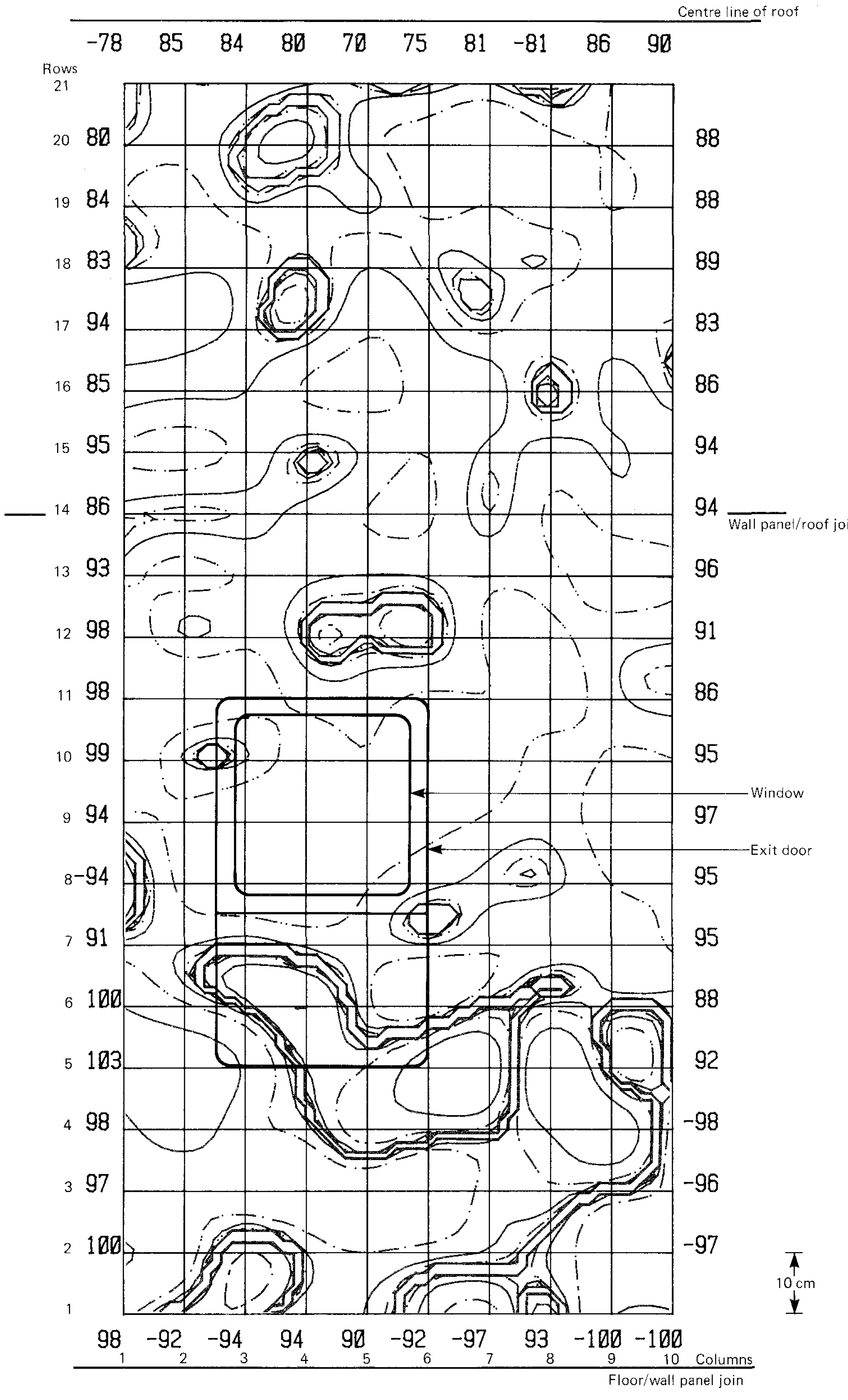

Fig. 17. Intensity map over the measurement surface for the 100 Hz 1/3 octave band with 6 dB between the intensity contours. Linear interpolation with every second contour drawn dashed

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