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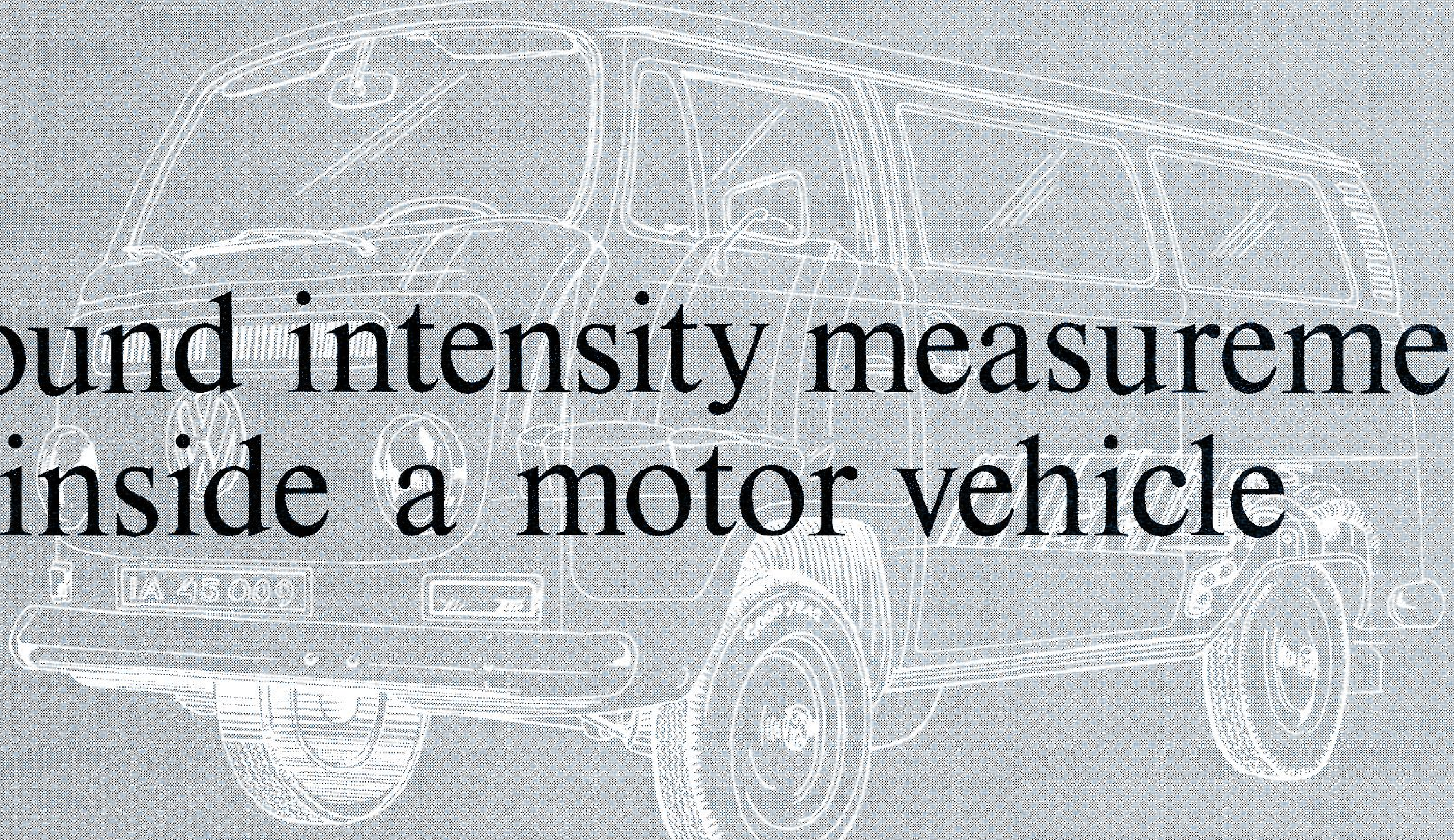
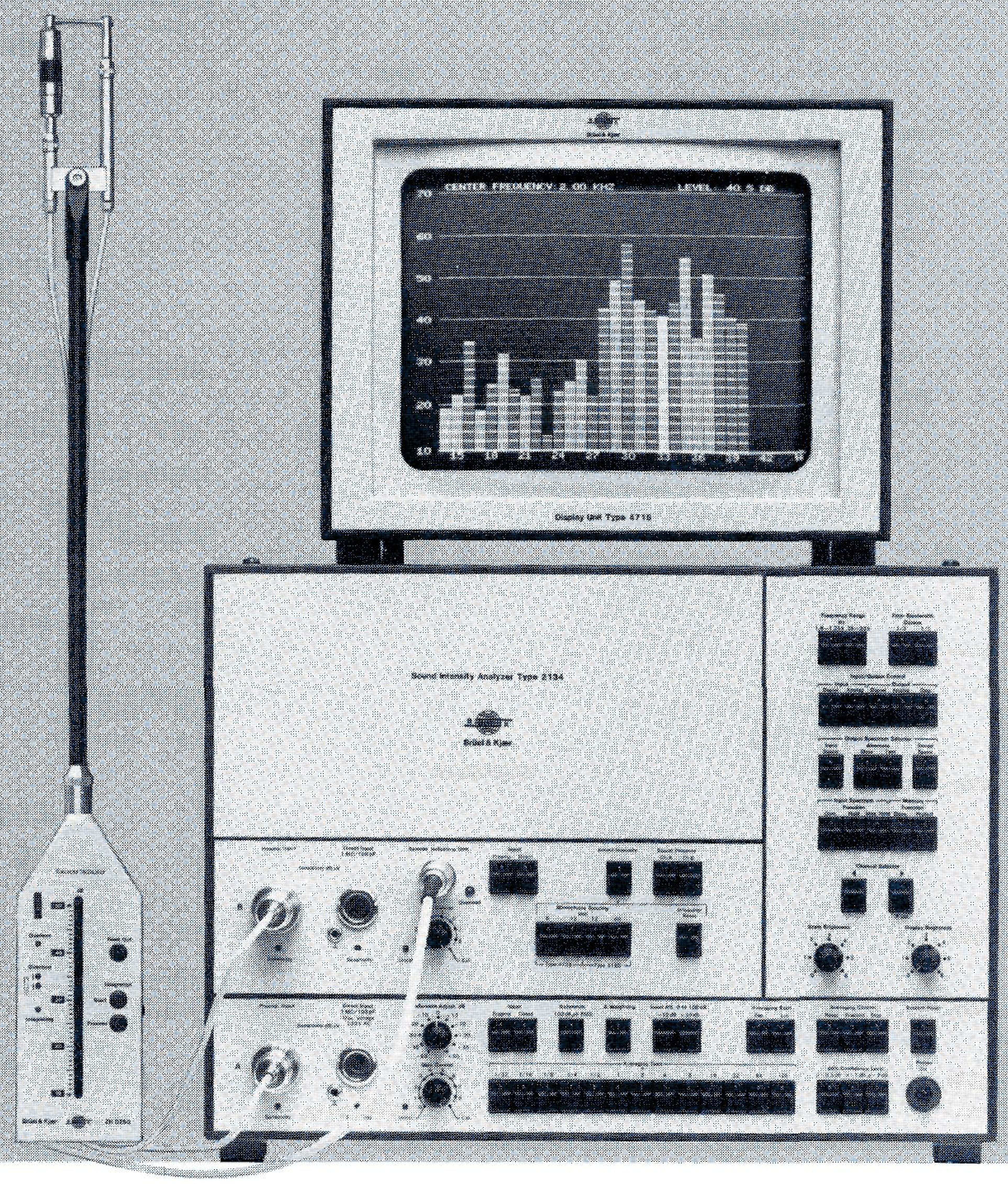
application notes

Sound intensity measurements inside a motor vehicle





BO 0019   2-043 0019-1A

Sound intensity measurements inside a motor vehicle

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Brüel & Kjær

Introduction

Measurements were performed on a VW 1600 Transporter (1972) to observe the effect of damping on the sound intensity levels close to the interior surfaces of the vehicle.

Measurements were performed over portions of the engine cover, the roof and a side panel with and without applied damping. On each surface an array of 10 × 10 points was marked out with 10 cm between each point yielding 100 measurement points over an area of 1 m^2.

Throughout most measurements the vehicle was stationary, with the transmission in neutral, and with the engine running at about 1900 r.p.m.

Instrumentation

The measurements were performed with the Sound Intensity Analysing System Type 3360 and the results were stored on a Digital Cassette Recorder Type 7400 (Fig.1). With this system more than 800 spectra were measured and recorded in less than an hour. The instruments were powered from a mains supply when the vehicle was stationary. For preliminary road tests the instruments were powered from an inverter which was connected across the vehicle's battery.

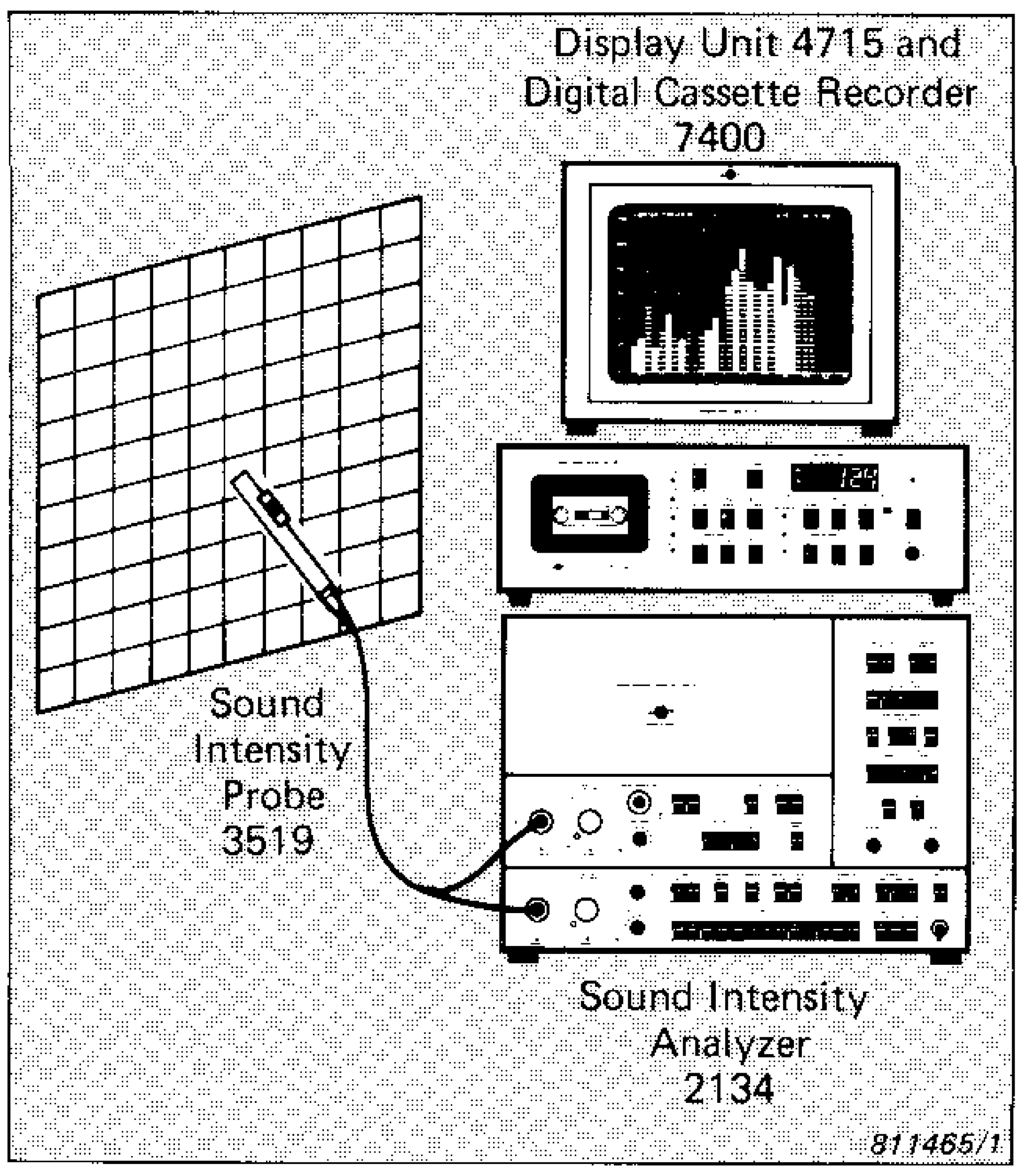

Fig. 1. Instrumentation used for sound pressure and sound intensity measurements inside a motor vehicle with a schematic representation of a measurement grid

Sound pressure measurements

Sound pressure level measurements were made to evaluate the efficacy of the damping treatment in reducing the noise inside the passenger compartment. Measurements (both linear and A-weighted) were made at the position of the ear of the driver and of a passenger seated in the mid rear seat.

The results are shown in Figs.2 & 3 and summarised in Table 1. The high

	Driver's position		Passenger's position	
	dB Lin	dB (A)	dB Lin	dB (A)
Without damping	80,7	63,6	82,5	66,2
With damping	82,0	58,1	82,2	61,2
Difference	−1,3	5,5	0,3	5,0

820020

Table 1. Summary of sound pressure level measurements showing that although the applied damping had no effect on the overall dB linear levels, the dB(A) levels (which correspond well with the impression of noisiness) were reduced noticeably

levels measured in dB linear are due to the engine noise and cavity resonances in the frequency range 16 Hz to 63 Hz. No automatic regulation of engine speed was employed so that even though the engine was allowed to warm up before the start of the measurements some variation in the noise spectrum at low frequencies was expected. The damping was effective at frequencies of 200 Hz and above and had no effect at these low frequencies. Other studies have shown that the low frequency "boom" inside passenger compartments is best combatted by structural changes of the vehicle shell [1].

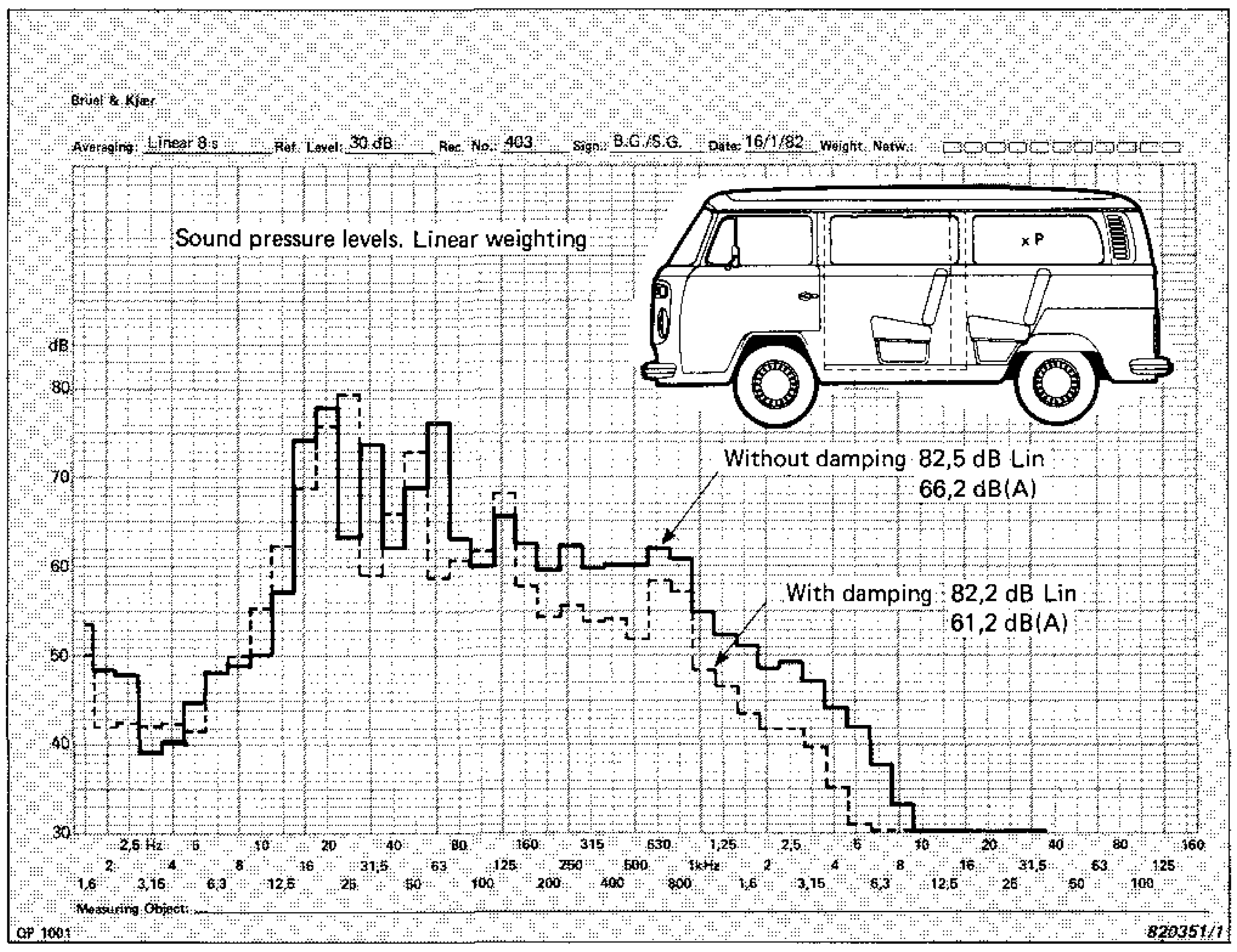

Fig. 2. Sound pressure levels on the mid-rear seat at the passenger's ear, with and without applied damping

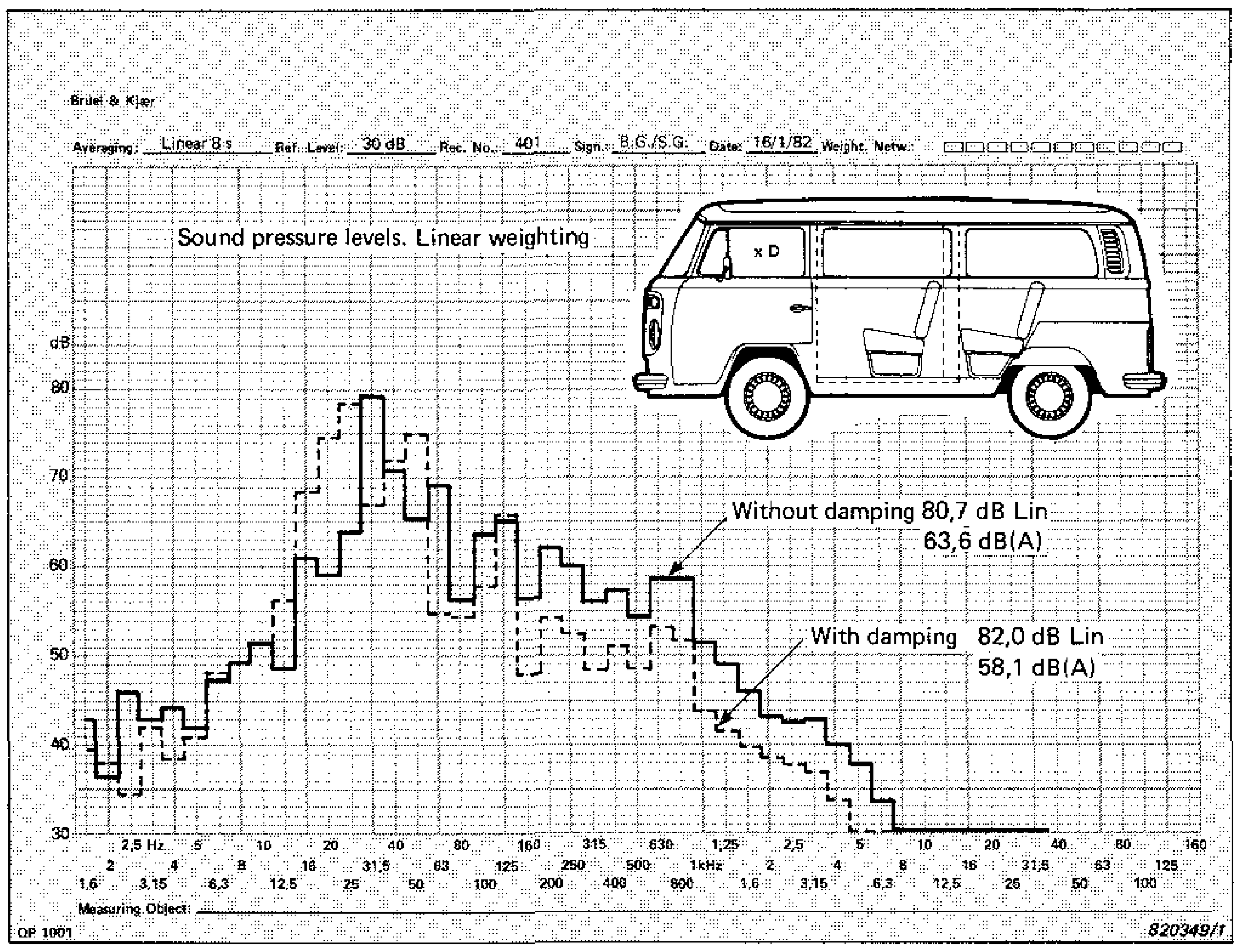

Fig. 3. Sound pressure levels at the driver's ear, with and without applied damping

The A-weighted measurements (i.e. the linear sound pressure levels weighted to allow for the sensitivity of the human ear) show a clear reduction in level with the interior surfaces damped. Expressed in terms of comfort for the driver and passengers, this meant that the vehicle became noticeably quieter.

Intensity level measurements

The sound intensity level spectrum at each point was measured using two 1/2″ microphones and a 12 mm spacer in the Sound Intensity Probe which enabled sound intensity measurements to be performed in the frequency range 125 Hz to 5 kHz with an accuracy of ± 1 dB.

In addition a 50 mm spacer was used to measure over the engine cover which gave a useful frequency range of 31,5 Hz to 1,25 kHz for an accuracy of ± 1 dB. Relative to the 12 mm spacer, the 50 mm spacer yields more information at low frequencies at the expense of the high frequencies.

The probe was hand-held about 5 mm above the measurement surface. For a further discussion of the two-microphone technique for measuring sound intensity refer to [2] & [3].

Results of sound intensity measurements

For each surface surveyed, the 100 measured spectra were summed to yield a single spectrum. The sound power level radiated from each surface was determined by subtracting -20 dB from the summed sound intensity spectrum to account for the fact that each intensity measurement represented an area of 0,01 m^2. From the sound power determinations, the surfaces could be ranked in order of importance as sound sources.

The engine cover was the principal noise source as was expected. Up to and including the 100 Hz band the power measured was "negative" and in the 125 Hz band and above the power was "positive". In other words, at high frequencies the engine cover acts as a source, with a net energy flow outward, while at low frequencies the cover is a sink, with the net energy flow inward (shown in Figs.4 & 5). One cannot really say that the engine cover "absorbs" the low frequencies. Below its coincidence frequency, the engine cover is an acoustic short circuit and a poor radiator of sound. Much of the energy radiated by the cover flows back into the cover again although some energy, of course, "escapes" into the far field and some may re-enter the vehicle elsewhere e.g. via the roof or the floor. Fig.6 shows the sound power levels on the roof.

Intensity contour maps

Figs.7 to 10 show various representations of the measured intensity distribution over the engine cover for the frequency range 200 Hz to 5000 Hz. Note that these displays are based on the same data that was used for the sound power determination. The numerical map shows the raw data (Fig.7). The three dimensional map shows the same data, smoothed by interpolation, in a more easily visualised form (Fig.8). Fig.10 shows a three dimensional plot of the positive intensity after the data displayed in Fig.9 were A-weighted. The contour map is a good balance between the other two representations. All plots were produced using Program Package WW 9038 developed by B & K engineers. This Program Package is written in HPL and is intended for use with either an HP 9826 or an HP 9836 desk-top computer.

The contour maps in Figs.11 & 12 show the engine cover data for the third-octave band centred on 63 Hz, without and with damping respectively. The red contours designate regions of "positive" intensity (energy flowing out of the surface) and the blue contours regions of "negative" intensity (energy flowing into the surface). The numbers around the maps are the sound intensity levels, to the nearest dB, at the perimeter measurement points. There are 3 dB between the contours and every second contour is drawn as a dashed line. Fig.10 shows the contour map corresponding to the conditions of Fig.8.

Since the measurements on which these intensity maps are based were made at discrete points, spatial aliasing could lead to a misrepresentation of the actual situation. The problem of spatial aliasing could be mitigated by sweeping the probe

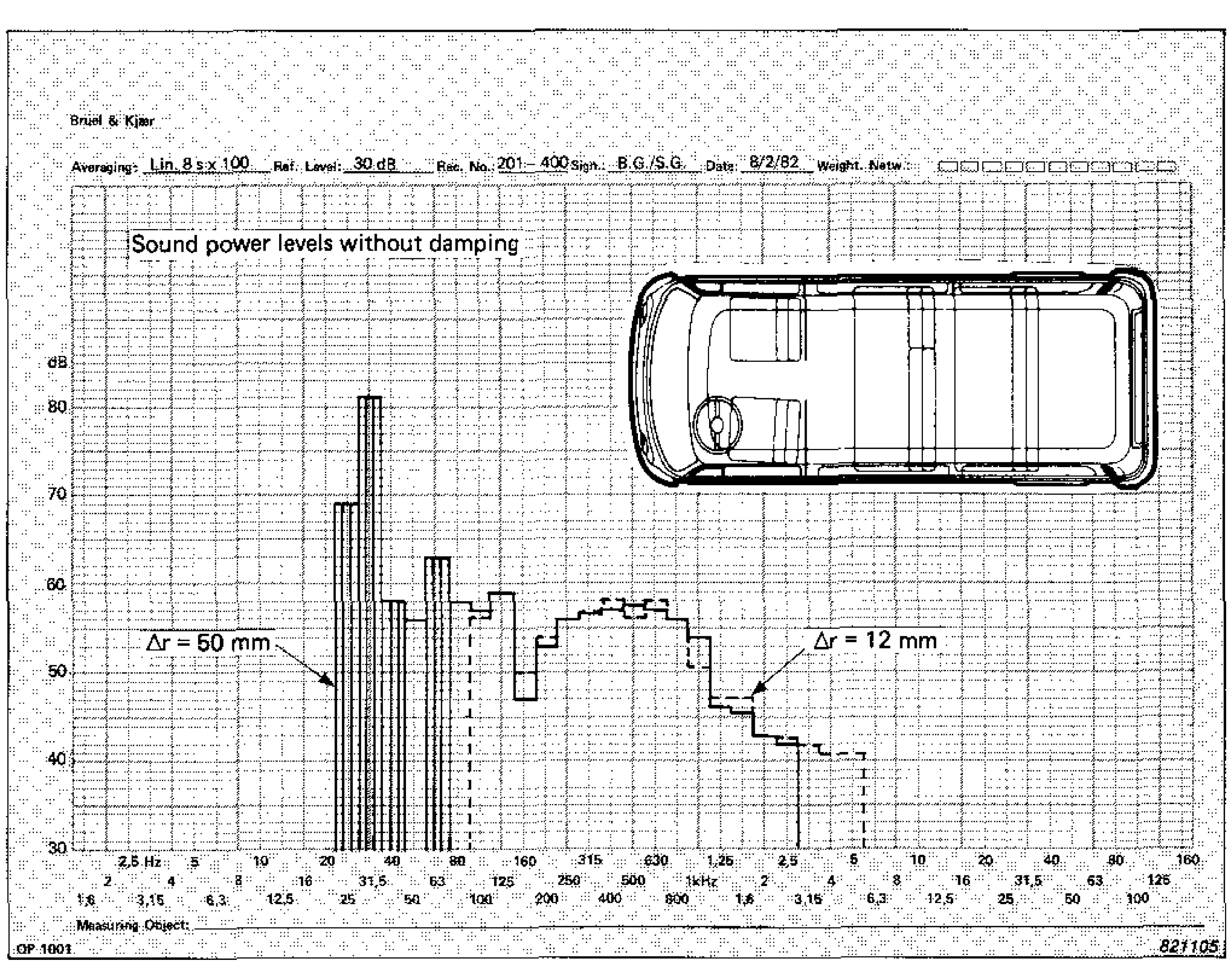

Fig. 4. Sound power levels on the engine cover measured with 12 mm and 50 mm spacer without applied damping. Hatched bands designate "negative" power

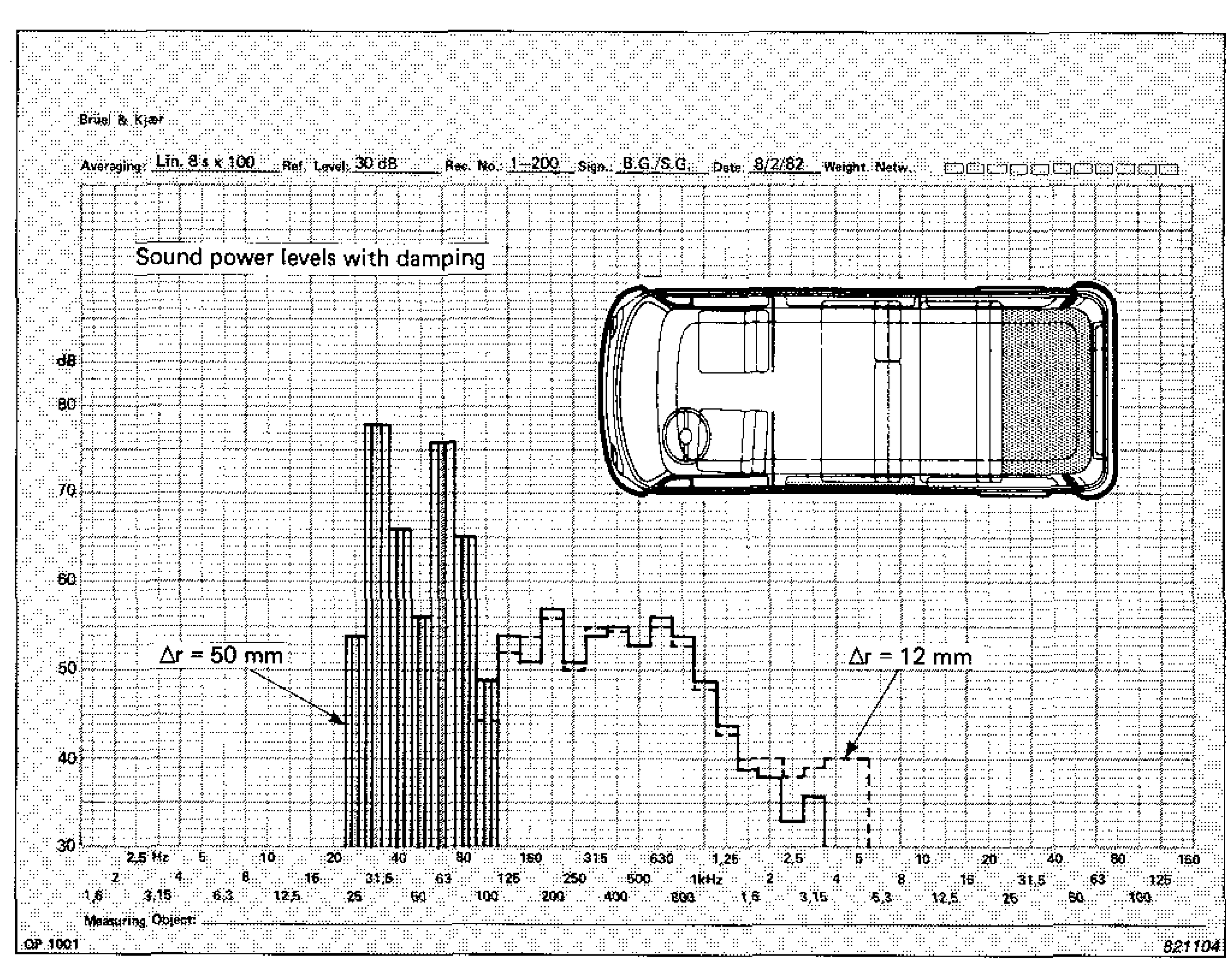

Fig. 5. Sound power levels on the engine cover measured with 12 mm and 50 mm spacer, with applied damping. Hatched bands designate "negative" power

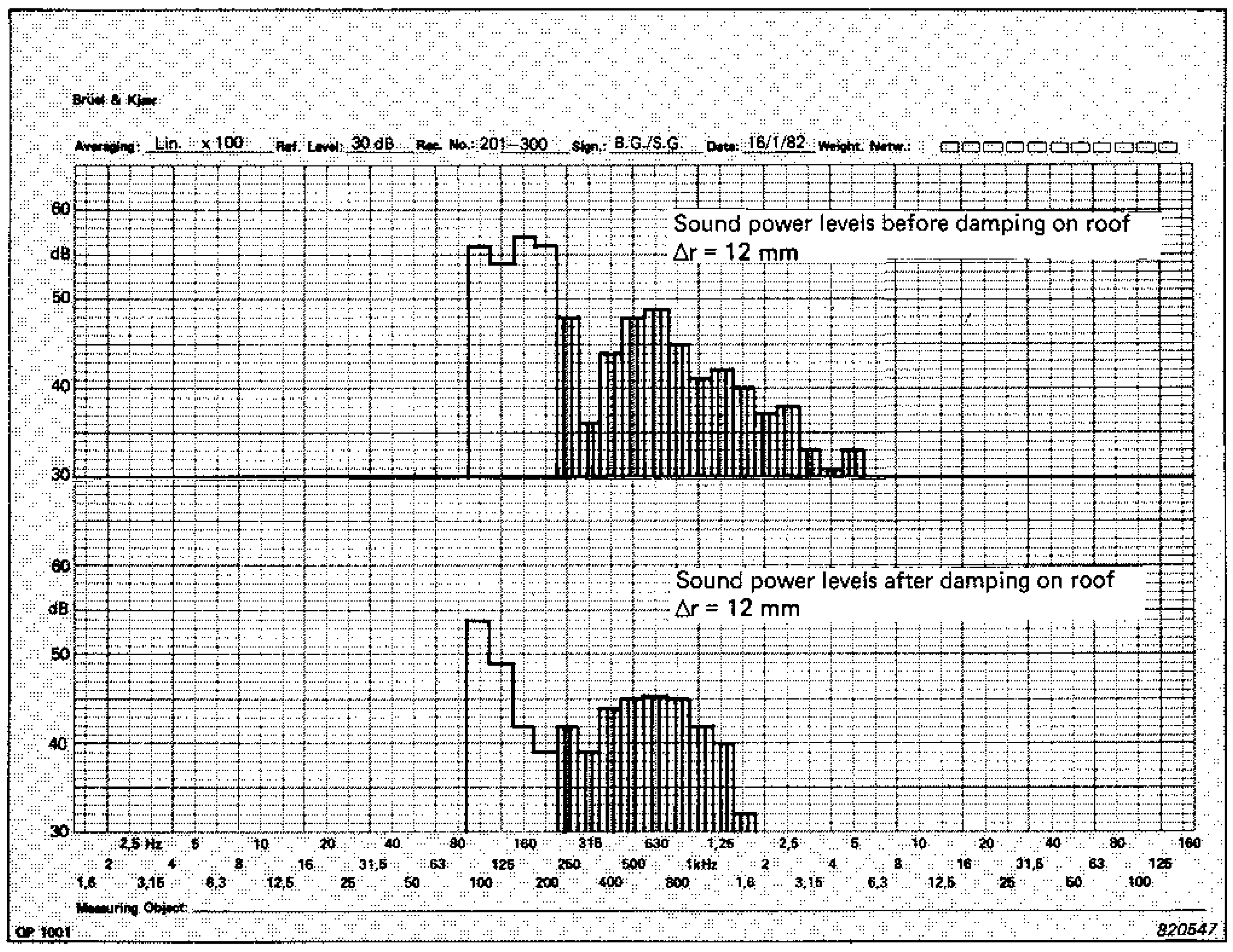

Fig. 6. Sound power levels on the roof measured with 12 mm spacer, without (upper) and with (lower) damping

62	65	68	67	64	64	64	65	64	60
63	66	67	68	67	67	66	65	63	59
61	64	65	65	66	64	62	52	55	-56
59	61	62	61	62	58	-52	-58	-54	54
56	60	61	61	60	62	50	-57	44	60
64	64	64	61	62	61	50	55	62	64
64	64	64	63	63	63	64	63	63	64
64	65	64	65	63	64	64	65	64	64
63	65	66	63	63	65	65	61	61	61
59	62	63	63	63	62	61	61	61	59

821183

Fig. 7. Numerical values of summed intensity levels rounded to the nearest dB for frequency range 200 Hz to 5000 Hz. Data measured with 12 mm spacer over the engine cover. Without damping

back and forth over the measurement area associated with each measurement point to obtain a spatially averaged value of the sound intensity level.

Several observations should be made concerning the intensity distribution maps. The low frequency maps show a sink on the engine cover directly over the cylinders. Intuitively, this is somewhat difficult to understand since the engine cylinders are undoubtedly sources of noise. It should be noted, however, that other authors have reported that sinks (where the air does work on the vibrating surface) are almost always present in the sources studied [4]. In this connection it is well to remember that the 1 m length surveyed represents less than 20% of the wavelength of sound at 63 Hz.

The high frequency maps show the general effectiveness of the damping in reducing sound transmission through the engine cover.

The intensity maps show how the distribution of sources and sinks changes appreciably with the application of damping. In general, the application of damping to a surface yielded more sinks which suggests that for noise control purposes an iterative method could be employed i.e.:

1. Locate and rank sources according to sound power emitted
2. Apply damping
3. If the desired reduction in sound pressure level is not obtained, relocate and re-rank sources
4. Apply damping etc.

Conclusions

Sound intensity measurements provide a powerful and exciting diagnostic tool for the acoustical or

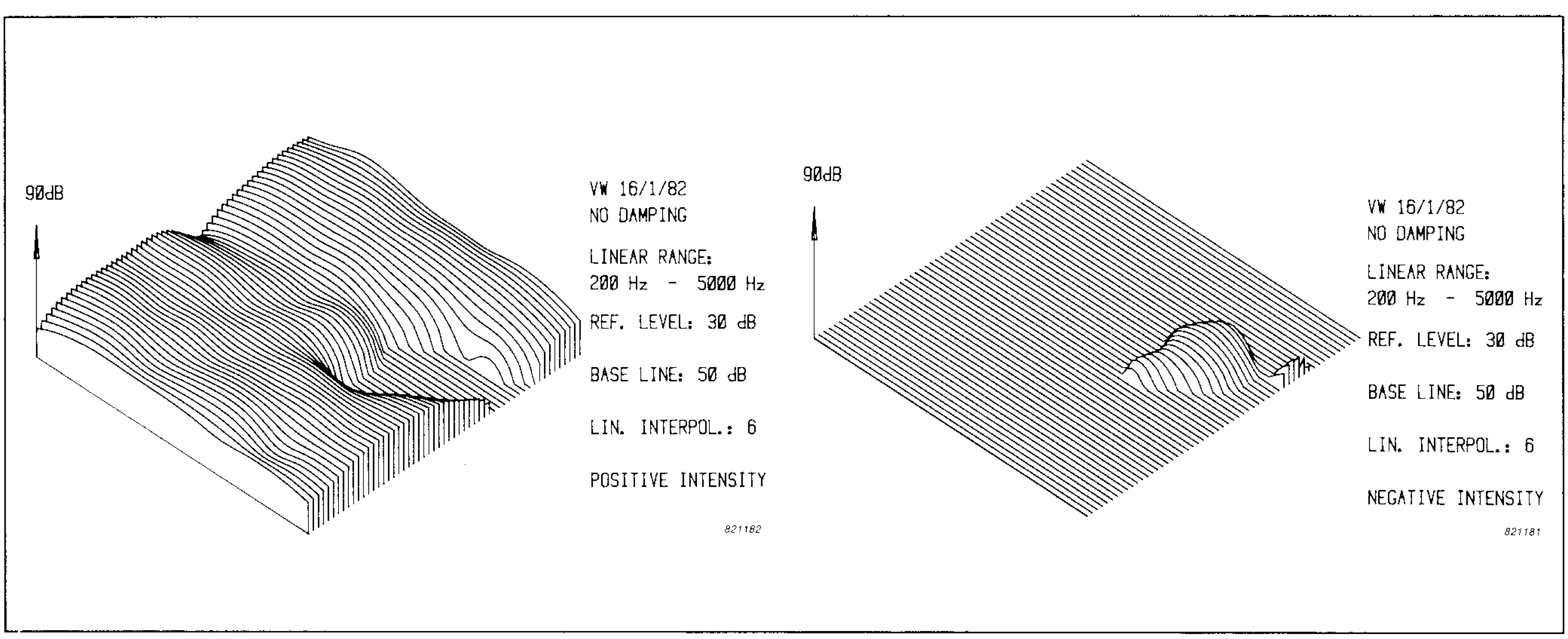

Fig. 8. Three dimensional plots of summed intensity levels for the frequency range 200 Hz to 5000 Hz. Data measured with 12 mm spacer over the engine cover. Without damping. Positive intensity on the left, negative intensity on the right

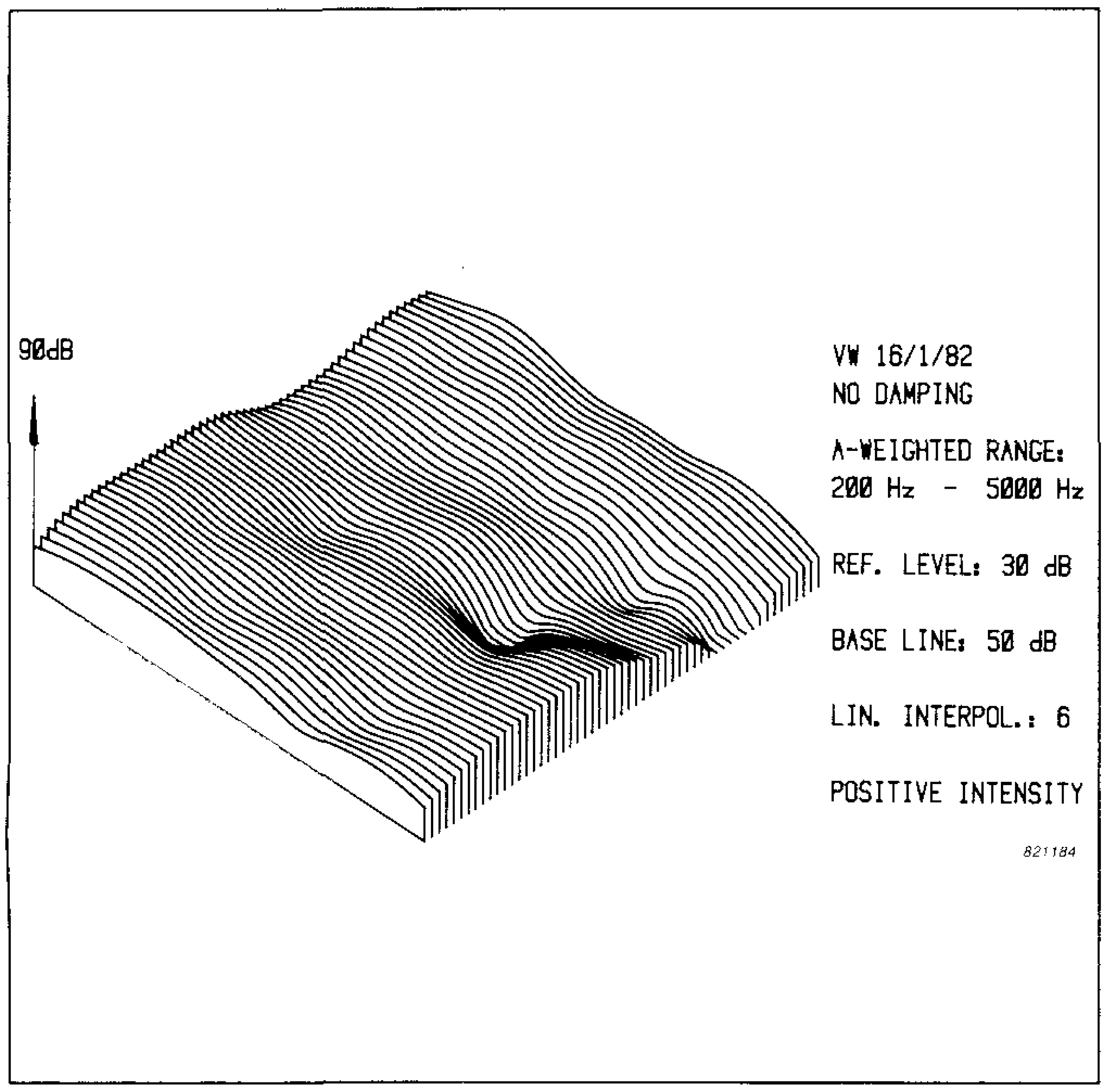

Fig. 9. Three dimensional plot of the summed intensity levels for A-weighted data in the frequency range 200 Hz to 5000 Hz. Data measured with 12 mm spacer over the engine cover. Without damping. The resulting intensity was practically all positive therefore only the positive values are shown

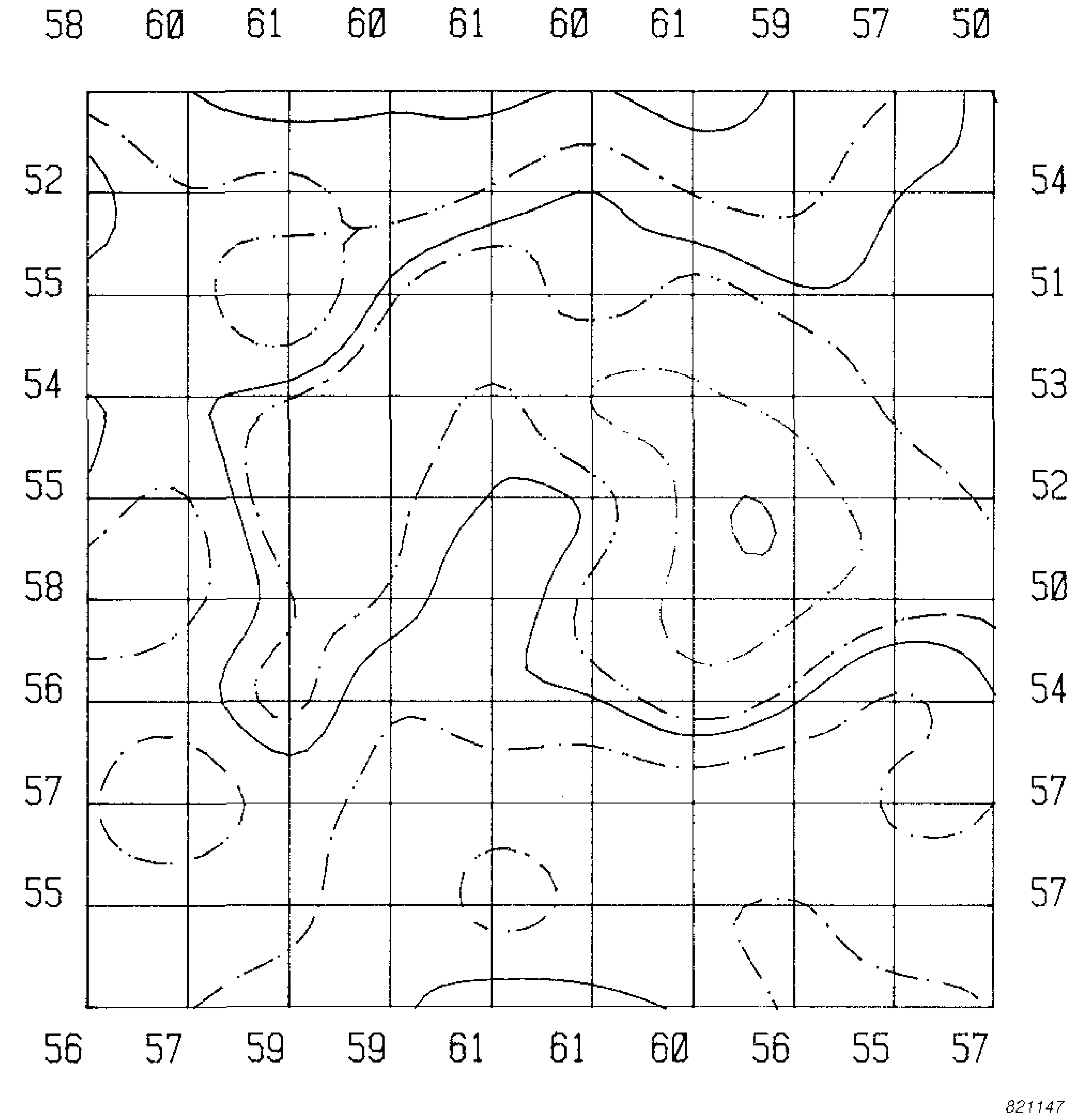

Fig. 10. Sound intensity contour map for summed intensity levels for frequency range 200 Hz to 5000 Hz. Data measured with 12 mm spacer over the engine cover. With damping

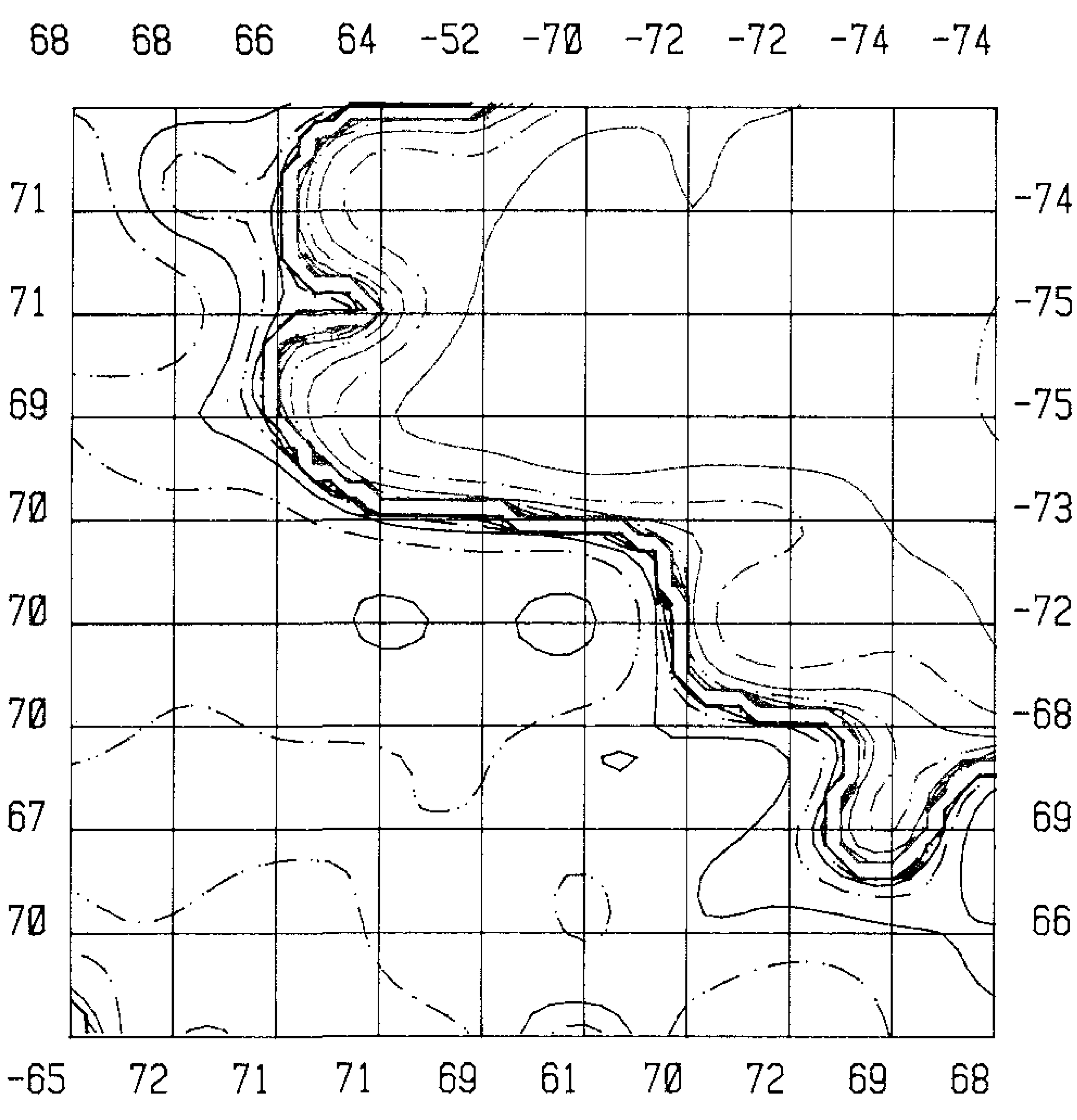

Fig. 11. Sound intensity contour map measured with 50 mm spacer over the engine cover at 63 Hz. Without damping

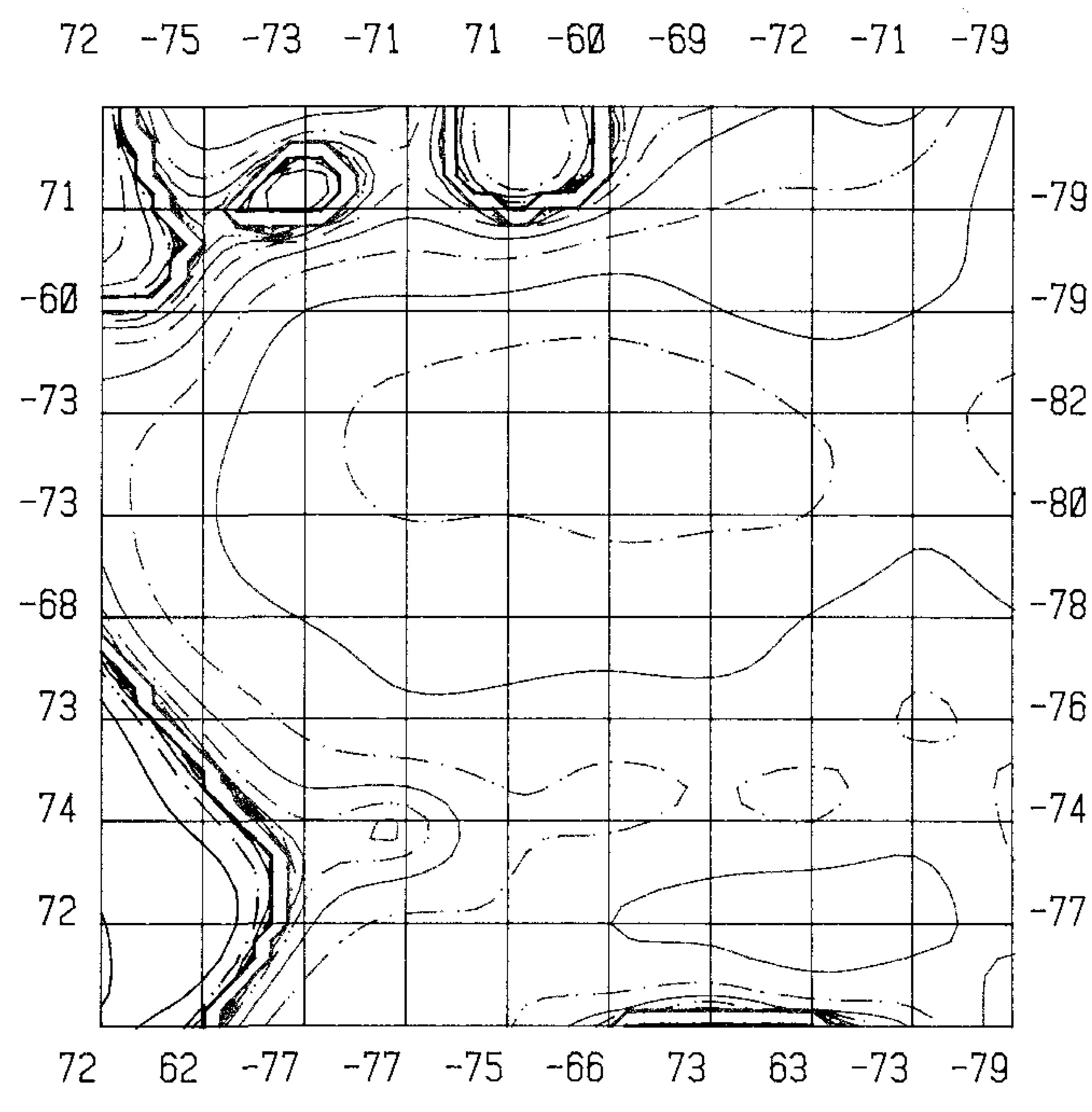

Fig. 12. Sound intensity contour map measured with 50 mm spacer over the engine cover at 63 Hz. With damping

mechanical engineer. In particular, 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 stationary and moving vehicles. The wealth of data stored on a cassette tape can be treated using the B & K Sound Intensity Program Package WW 9038 to calculate the sound power from various surfaces or to plot pressure or intensity maps. The rapidity of both measurement and treatment of the data means that less time need be spent "data crunching" and more time is available for solving the problem in hand.

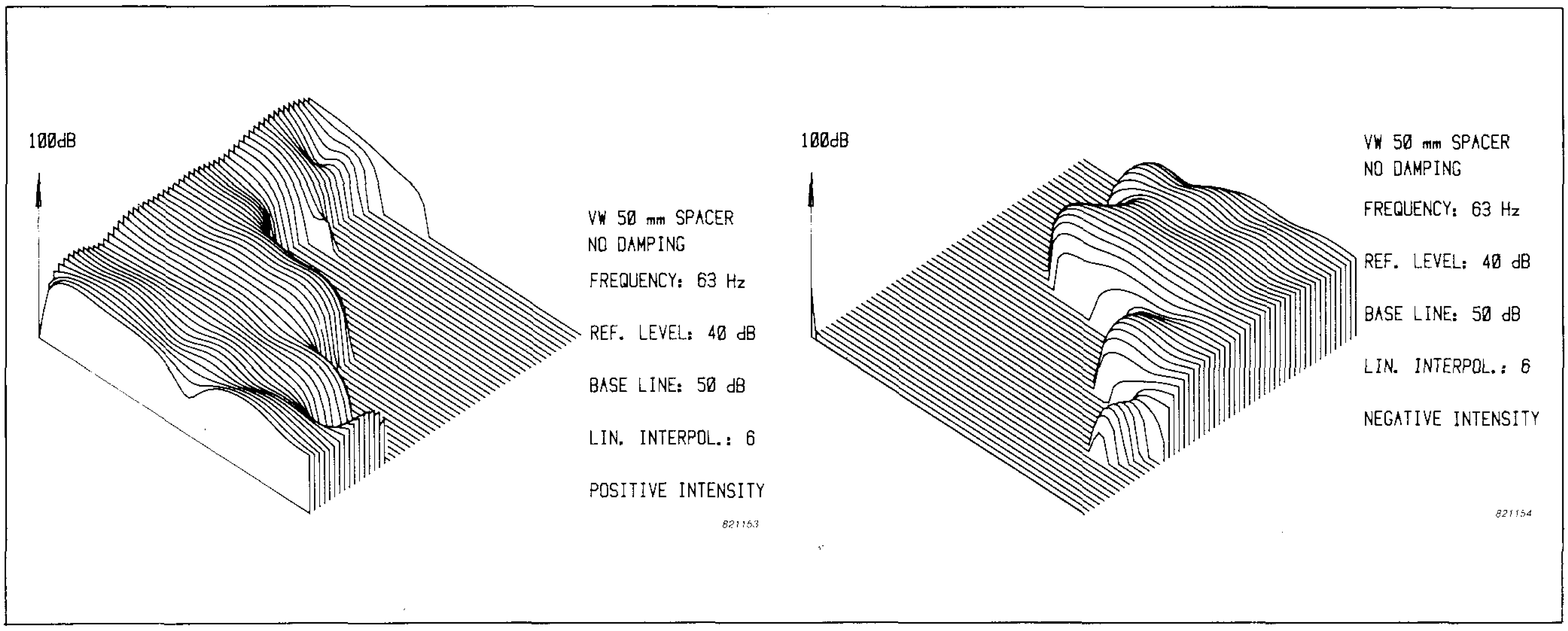

Fig. 13. Three dimensional plots of sound intensity levels at 63 Hz. Data measured with 50 mm spacer over the engine cover. Without damping. Positive intensity on the left, negative intensity on the right

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PRINTED IN DENMARK: K. LARSEN & SØN A/S . DK-2860 SØBORG