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A RENOVATED ANECHOIC ROOM:
SOME ASPECTS OF REQUIREMENTS AND MEASUREMENTS

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ABSTRACT

The anechoic room at the department of Technical Audiologi and the work to renovate it, is described. A new inexpensive Swedish method was chosen, where the wedges were made out of standard size glasswool. The wedges are thus very big, with broad tips and with the wedge width equal to the length of the room. At first the requirements on the room were not fulfilled. The reason of this problem is discussed. After modifications the room finally fulfilled the requirements. It is concluded that if an anechoic room shall have a reasonable volume, in which measurements can be done with a maximum deviation of ±1 dB from the 1/r law, the absorption coefficient must be higher than .995.

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INTRODUCTION

The anechoic room at the Department of Technical Audiology, Karolinska Institutet located at the Royal Institute of Technology was restored during the period November 1985 - April 1987. The old room had two major drawbacks:

1) The old wedge material, mineral wool polluted the air with dust particles.

2) The floor construction was a source of reflexions which made the room performance too bad for high quality measurements and for research and development in the psychoacoustic and electroacoustic field.

I. OLD ROOM

In Mars 1948 Ove Brandt at the Building Acoustic Laboratory, Royal Institute of Technology (KTH) wrote a report to Professor Torben Laurent at the Departement of Telegraphy and Telephony concerning an estimated cost for building an anechoic chamber at KTH. Apart from a calculated cost of 75.000 SEK, the report outlined the room design and suggested a suitable place for it. It may be worthwhile to know that the cost of 2.500 workhours were estimated to 8.000 SEK. The design principles were later followed when the room was built 1950 at the suggested place in a well at Lindstedsvägen 7 in the east wing of the Electro Engineering building.

The room was built on a floating floor structure resting upon 30 cm of sand. The compliant material was 5 cm of mineral wool. The walls resting on the floating floor were made up of concrete pillars to support the 10 cm concrete ceiling. The area between the pillars were filled with air-brick layed on edge to achieve acoustic absorption. The space, approximately 15 cm between the room walls and the walls of the well was filled with 5 cm of mineral wool. The room have the inner dimensions 6.75 x 9.75 x 5.0 m^3. The short walls are not exactly parallell to each other. To improve the sound insulation a roof of porous concrete resting on girders were attached to the walls of the well.

To improve the absorption at low frequencies 1200 milk bottles were built into the ceiling and into the walls. The bottles were tuned to have their resonance frequencies at 65, 70, and 75 Hz. The air brick walls together with the tuned milk bottles resulted in a reverberation time as low as .6 seconds at 500 Hz in the empty room. The material for the acoustic absorbent wedges was Rockwool, a Swedish brand of mineral wool. The lenght of the wedges were 100 cm. Before the wedges were mounted, 20 cm of mineral wool was applied to the surfaces of the room. The total depth of the acoustic lining was therefore 120 cm. With this design the lower cut off frequency was estimated to 70 Hz. The shape of the wedges is shown in Figure 1.

To keep the wedges mechanically robust the mineral wool was enclosed in a thin chicken fence netting. The floor of steel lattice plates rested upon a girder system. For further details see Brandt (1950). In a Master of Science thesis B. Kruger and G. Markesjö (1952) reported extensive acoustic measurements in order to investigate the discrepancy from free field conditions of the anechoic room. Measurements were made at the frequencies 57.5, 115, 230, 460, 720, 920, 1840, 3680, 7370, and 14720 Hz. To summarize the results, the room fulfilled the free field conditions according to the criteria used for the new room (described later) for the frequencies 115-720 Hz if the measuring point was closer than 1.5 m from the sound source.

II. CONSTRUCTION OF THE NEW ROOM

The acoustic design of the room was done by Lennart Karlen, ACAD - International AB. The design of the floor suspension system was done by Nylander & Hernelind AB. All the mounting of the acoustic material, the wire mesh floor, and the floor suspension system were done by Nordisol AB.
The room structure was not affected by the renovation except for one large rectangular aperture and two small holes (d=40 mm) drilled through the dubbel wall to the control rooms. These holes are reserved for the signal cables. The power cables are installed in the old through holes. The signal and the power cables are thus separated. The old wall lining, the floor with its girders and grid plates, and all electrical installations were removed. Loops of heat pipes were earlier embedded in the floor and the ceiling concrete. They may have caused low frequency transmission into the room and were therefore partly removed. It was calculated that the temperature will stay normal without these heat pipes. There is also an electrical heat battery in the ventilation system that could be used when needed. The old ventilation system, one fan for the air into the room and one

for the air from the room, was kept intact except that the inlet duct was given a new lining.

Before the absorbent material was applied a frame of girders was attached to the walls 1.2 meters above the floor. This frame shall stand the force from the wire netted floor and therefore the girders were supported by struts to the floor. Before the acoustic material was applied screw bolts (M24) were also fastened in the floor and ceiling concrete to be used as rigid suspensions for measuring objects etc. The position of these are shown in Figure 2.

The absorbent material which normally is wedge shaped with the base width and the base height equal is in this room rather different. The wedges are applied on the floor and on the ceiling with wedge width equal to the length of the room and the wall wedges has a wedge width equal to the height of the room (see Figure 3). This is the result of a design principle where the manufacturer wanted to use standard size glasswool in order to reduce the cost of the wedges. The wedges are built on a layer of 100 mm glasswool that are applied directly at the concrete surfaces. The wedge is built up of layers of glasswool with different densities (see Figure 4). The outer layers have a lower density than the inner layers. The tip and the outermost layer of the wedge were added afterwards, when it was found that the reflexion coefficient was too high in the frequency region 500 - 1000 Hz. In spite of the flat tip of the wedge the absorption coefficient is sufficiently high even at 16 kHz, see Table 1. These data were the results of a absorption coefficient measurement done at the Dept. of Building Acoustics at the Lund Institute of Technology. The glasswool was covered with an acoustic transparent syntethic cloth.

When fabricating the glasswool the material become oriented and the flow resistance in different directions are quite different. The glasswool in the tip is oriented so that the direction of low flow resistance is pointed into the anechoic room, see Figure 4. The wire netting used for the the free hanging floor was made up of 4 mm steel wires with a mesh size of 60 mm. The maximum load is specified to 1.0 kN/m^2. Under the wire netted floor there is a thin mosquito net to prevent small vital parts from falling into the glasswool. The open space of the new room has the dimensions $7.3 \times 4.2 \times 2.5\ m^3 = 77\ m^3$.

III. METHODS OF MEASUREMENT

The propagation of sound waves in an anechoic room shall as far as possible be equal to propagation in free field. That is, there should be a minimum of reflexions. That implies, that for every doubling of the distance from a small omnidirectional sound source the sound pressure level should drop 6 dB (the 1/r law). Even small reflexions in the room will interfere and produce a three dimensional standing wave pattern. In normal rooms with strong reflexions at a certain distance, the energy of the reflexions dominates over direct sound field and the total sound field is nearly independent of distance. If the reflexion components are very small, as in an anechoic room, the energy of the reflexions do not dominate over the direct sound but will interact with the direct sound and produce a small variation around the 1/r law as a function of distance.

The measurement techniques established for qualification tests of anechoic rooms are based on measuring the deviation from the 1/r curve. In practice this is done by putting an omnidirectional loudspeaker in the room and having a microphone moved continously along paths from the loudspeaker. By recording the sound pressure for different discrete frequencies as a function of distance one can evaluate the deviation from the 1/r law. An example of a measured path is shown in Figure 5. To achieve omnidirectionality, different loudspeakers have to be used for different frequency regions. In the standard ISO 3745, Annex A, there is a specification of these sound sources. Up to 400 Hz a 25 cm diameter loudspeaker in a closed .020 cubic metres box shall be used. Between 400 to 2000 Hz two 10 cm loudspeakers mounted face to face and phased to radiate as a pulsating "sphere" shall be used. Finally at frequencies 2000 through 10000 Hz a small baffled system driving a narrow (< 1.5 cm diameter) tube is prescribed.

In the same annex a qualification procedure described together with the requirements on the maximum allowable deviation from the 1/r curve. The requirements are shown in Table 2. In the standard IEC 268-5, Sound system equipment, Loudspeakers, the maximum allowable deviation is stated to ±1 dB over the frequency region of interest and in IEC 118-0, Hearing aids, the requirements are ±2 dB from 200 Hz to 400 Hz and ±1 dB from 400 Hz to 8000 Hz.

After a first qualification test it became evident that the room did not fulfill the requirements in

ISO 3745. In order to investigate the possibilities for an improvement of the absorbtion in the room, impulse response measurements were done. The inverse Fourier transform of the ratio between the output and the input spectra was calculated in order to get the impulse response (Olofsson 1975). The frequency region of interest (around 1000 Hz) was filtered out and the envelope of the response was calculated using the Hilbert transform. The envelope was used because it gives a better representation of the energy distribution in the time domain than does the impulse response. This measuring technique is implemented on a PRIME mini computer and on a PC/AT controlled measuring and filtering unit (TAMP) developed at the department. These measurements were done fairly close to the walls in order to investigate which part of the wedges that have the dominating influence on the reflexion.

To get an alternative estimate of the part of sound pressure that was reflected, the impulse responses were measured at some points along the same lines as the 1/r measurements were done. The impulse response measured fairly close to the loudspeaker has the direct sound well separated from the reflected. That holds at least for the measurements in the middle of the room far away from the reflecting surfaces. The Fourier transform of the impulse responses measured at different distances were divided by the Fourier transform of the direct part of the impulse response at 0.5 m. In this way it was possible to estimate the influence of the reflexions as a function of frequency (see Figure 6). The distance to the walls limits this measurement to frequencies above 170 Hz. Below

170 Hz the direct and the reflected sound can not be totally separated.

After these measurements the wedges were modified according to Figure 4.

IV. ACOUSTIC MEASUREMENTS OF THE NEW ROOM

The background noise in the renovated anechoic room was measured. The sound level in dB(A) and 1/3 octave band sound pressure levels were measured with a half inch microphone B&K 4165, microphone preamplifier B&K 2619 and a measuring amplifier B&K 2636 together with a band pass filter B&K 1617. The results are plotted in figure 7. Additional calculations and measurements show that the measured noise levels above 100 Hz are due to electrical noise from the measuring equipment. Thus the noise levels in the room above 100 Hz must be lower than these measured levels.

A free field condition qualification test was performed in accordance with the annex A in the ISO 3745 standard. The microphone was attached to a small rope-way with its motor and wheels concealed behind the absorbent wedges. Four paths were measured, all 1.1 m above the wire net floor (see Figure 8). Three paths were parallell to the lenght axis of the room, in the middle of the room and 0.85 m and 1.3 m from the tips of the side wall wedges. One path was diagonal. The loudspeaker positions are also indicated in Figure 8. It was assured that the sound level was at least 10 dB above the background noise originating from the rope-way transmission.

When matching the measured curve and the theoretical 1/r curve there are some practical problems to overcome. Close to the sound source the microphone path can not be approximated to go through the center of the source. This together with the fact that the source have a near field where the 1/r law is not valid makes it a bit tricky to match the two curves. However the free to near field error is calculated to be smaller than .25 dB at distances greater than .1 metre for the sources and frequences proposed in the standard. Furthermore, the error, caused by the fact that the microphone path is not going through the center of the loudspeaker, is less than .5 dB at a distance of .5 metre . At distances close to the source the ratio between the direct and reflected energy is high and therefore at close distances the 1/r curve should be nearly free from interferences. With this in mind the matching of the curves was done at a distance at .5 meter from the source.

V. RESULTS AND DISCUSSION

In appendix A the measured curves are shown, together with the ideal curve and the curves ±1 dB. All curves fit almost within the tolerance ±1 dB for a distance up to 4 metres if the path 0.85 m from the wedge tips is excluded. The measured deviations are within the tolerances given in ISO 3745, IEC 268-5, and IEC 118-0. However if the registrations in appendix A are studied in detail one can observe that the variations around the 1/r curve have a different shape for 500 and 1000 Hz compared to the curves for the rest of the frequencies. The normal shape of the curve is an ondulation around the 1/r curve, gradually increasing with the distance. This seems natural if the sound field is regarded as the sum of the direct field, decreasing with distance, and the reveberant constant field. However, for our room, the variations start relatively near the source and is fairly constant with distance for the 500 and the 1000 Hz curves. This phenomenon was more prominent before the outer layer of low flow resistance glasswool was applied on the sides of the wedges. As can be seen in Figure 9 the deviation has decreased from between 1.5 and 2 dB to less than 1 dB. In order to associate the peaks in the envelope of the impulse response with the corresponding reflective surfaces, reflecting material was applied to the different surfaces, one at a time. See Figure 10. In this way it was possible to identify the most prominent reflexion surfaces. The reflexion from the broad tip of the wedge is weak and can not be seen among the other reflexions in the envelope curve. The timing of the reflexion caused thereby could not be asscociated with any peak in the curve obtained without the hard surface.

The lack of reflexions from the tips of the wedges is due to the orientation of the wool. This is in agreement with the measurements of the absorption coefficient at the Department of Building Acoustics at Lund Institute of Technology. The dominant reflexion was rather associated with the empty space between the wedges (see Figure 10a). To verify this, the space between the wedges of one wall were filled with glasswool oriented with its fibres directed towards the room. The reflexion was reduced (see Figure 10c). However the reflex from the wedges (without extra absorption between the wedges) is stronger than expected. If the reflexion coefficient for the glasswool is R = 0.1, then the amplitude of this reflexion should be about 0.09 of the direct sound. Here we measured an amplitude of 0.16. Since the anomalities is coupled only to the frequencies 500 and 1000 Hz its not likely that the absorption coefficient per se is too low. To explain the relatively high reflexion from this part of the wedges the following hypothesis is made:

In the mid frequency region, where the wave length is of the same order as the distance between the wedge tips, the hyphothesis is that each space acts as a source to a reflected wave. The reflected energy is not a single reflexion from each boundary but a sum of reflexions. When the source and the microphone is close to each other only a few add up, but at a longer distance a greater amount of reflexions add up to a significant degree. Theoretical results of estimated reflexion from the wall were calculated for a case with a source and a microphone in front of one wall, both at a distance of 1 m from the wall. The relative amplitude of this type of reflexion from the spaces between the wedges, together with the relative amplitude of the single reflexion from a smooth wall, is shown in Table 3 for different distances between source and microphone. The total pressure at the microphone consists of the direct and the reflective part according to the following formula:

$$P_{tot} = P_d(1+R*SUM[(r_d/r_r)])$$

P_{tot} = Resulting sound pressure

P_d = Sound pressure, unreflected, direct from source

r_d = Distance between source and microphone
r_r = Distance which the reflected wave has travelled
R = Reflexion coefficient, here = .1
SUM = Summation over actual number of spaces between the wedges

As the distance is increased between the source and the microphone more and more reflexions from the spaces between the edges are summed up. The calculation is of course a large simplification but shows in principle what can happen close to a wall with no other reflexions.

In the case of a single reflexion the relative level of the reflective part is gradually getting higher with increasing distance but in the case of several reflexions the trend is a more constant reflective part, which should give unwanted strong deviations close to the source. Therefore, the demands on the reflexion coefficient must be higher in the frequency range where the wave length is of the same order as the distance between the wedges. This conclusion may be verified by simulations of the three dimensional sound-field on a computer.

After comparing the absorption coefficient curves (see Figure 11) for the glasswool used in the wedges and a lighter wool (kept in mind that the absolute values are not valid due to different conditions) it was suggested to the manufacturer that he would apply an outer layer of lower density wool on the wedges. In Figure 9 the measurement of the 1/r curve at 500 Hz before and after modification is shown.

When the wavelength is longer than the dimensions of the structure of the wedges we may assume that the sound field consists of the direct sound and 6 reflexions, one for each wall of the room. The level of the total sound field at the microphone is then

$$L_{tot} = L_d + 20*\log(1+R*r_d*SUM[1/r_r])$$

The summation is done over 6 reflexions, one for each wall of the room. Here it is assumed that all the reflexions are summed in phase. This is therefore an estimation of the upper limit of the reflected part.

In Annex G i ISO 3745 "Guidelines for the design of test rooms" it is said that the absorption coefficient shall be equal or greater than 0.99 measured in a plane wave impedance tube. Since the absorption coefficient is equal to $1-R^2$, the figure 0.99 corresponds to a reflexion coefficient of 0.1. Using that figure in the formula together with the requirement that the 20 log part should be less than 1 dB, gives a useful distance r_d, between the microphone and the source, of around .8 meter for our new room.

Diestel (1962) has used a statistical room acoustic approach to estimate the deviation. He has assumed that the reverberent sound pressure have a Rayleigh distribution (which is closely related to the gaussian distribution). With data from our new room it was calculated that the deviation is within ± 1 dB for distances up to 1.2 metres. (Here 1 dB is two standard deviations for R=.1).

However, Kutruff and Bruchmuller (1974) have showed that the probability function is not gaussian. They derived a relation between the standard deviation at many points at a given distance and the reflexion coefficient. A calculation with data from our room gave a distance of less than 1.4 meter where the deviation is within two standard deviations of ±1 dB, for R=.1.

Our new room has a deviation of less than 1 dB for distances up to 3-4 metres. It is therefore likely that the reflexion coefficient for the wedges is lower than .1. In the Acoustics Laboratory of the Danish Technical University at Lyngby (Ingerslev et al., 1967/68) the maximum deviation is within ±1 dB up to 2 metres in the small room (57 m^3 open space) and up to 4 meters in the large room (1000 m^3 open space). Measurement of the reflexion coefficient of their wedges (made of "Sillan", 120 kg/m^3) showed an R around .06-.07 for low frequencies.

It seems therefore that if an anechoic room shall have a reasonable volume, in which measurements can be done with a maximum deviation of ±1 dB from the 1/r law, the reflexion coefficient must not be higher than .07. This corresponds to a minimum absorption coefficient of .995. In ISO 3745 Annex G 0.99 is allowed, which thus contradicts its requirement of less than 1 dB deviation from the 1/r-law between 800 and 5000 Hz (Table 2).

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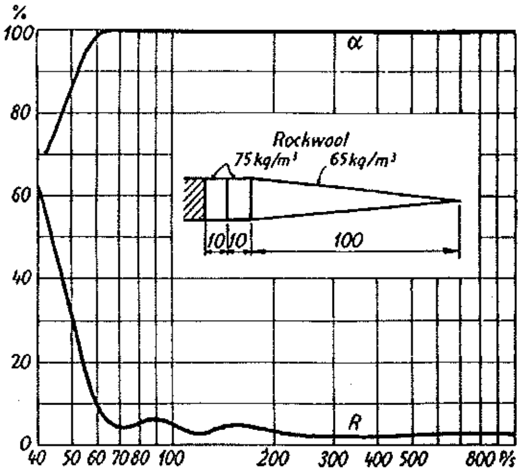
FIGURES



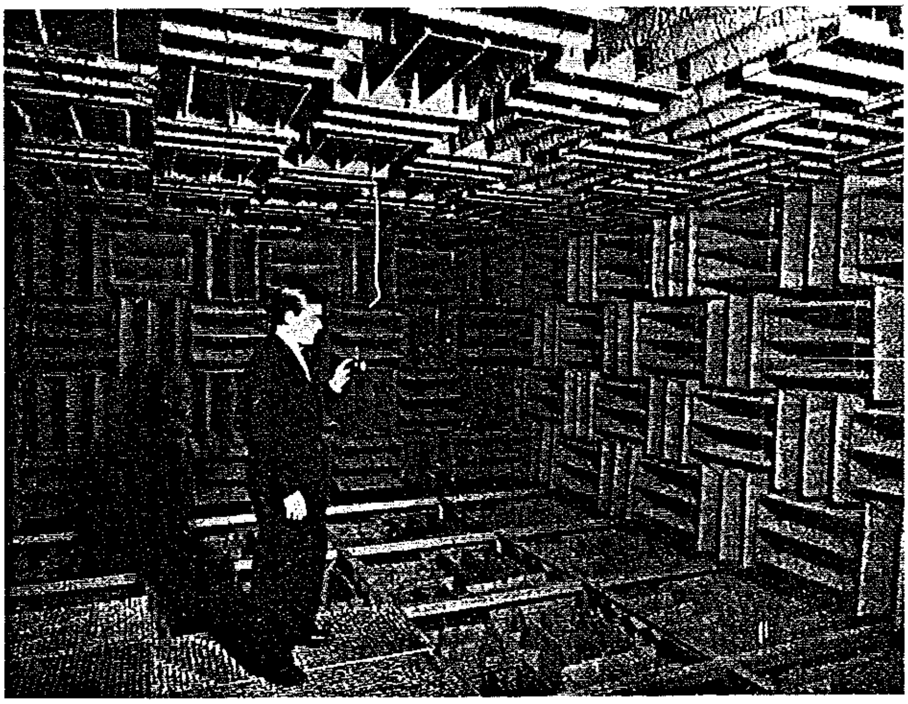


Fig. 1. Data and a photo of absorbent used in the first anechoic room at Department of Telegraphy and Telephony KTH, from Brandt 1950.

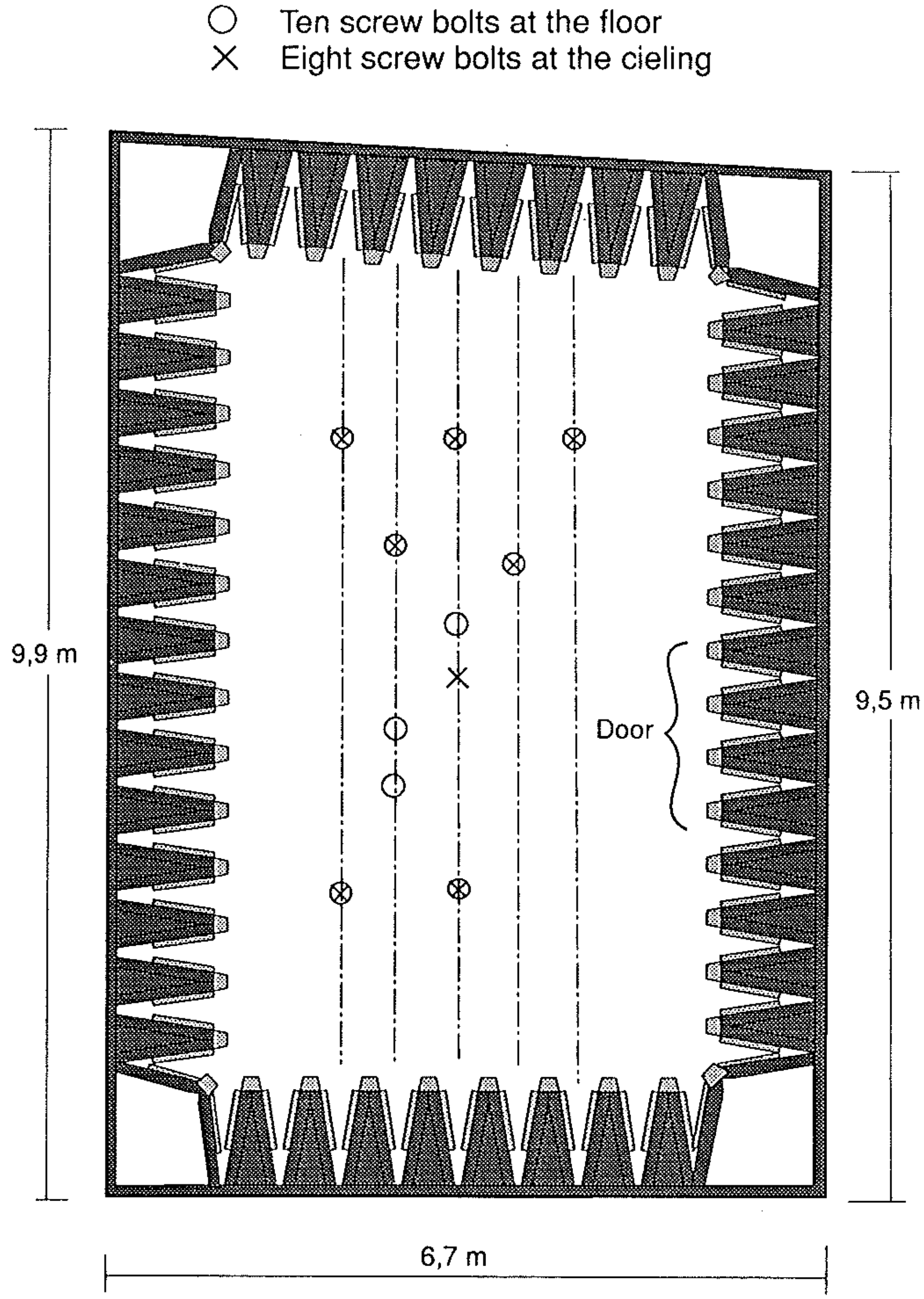


Fig. 2. Position of the screw bolts fastened in the floor and the ceiling concrete.

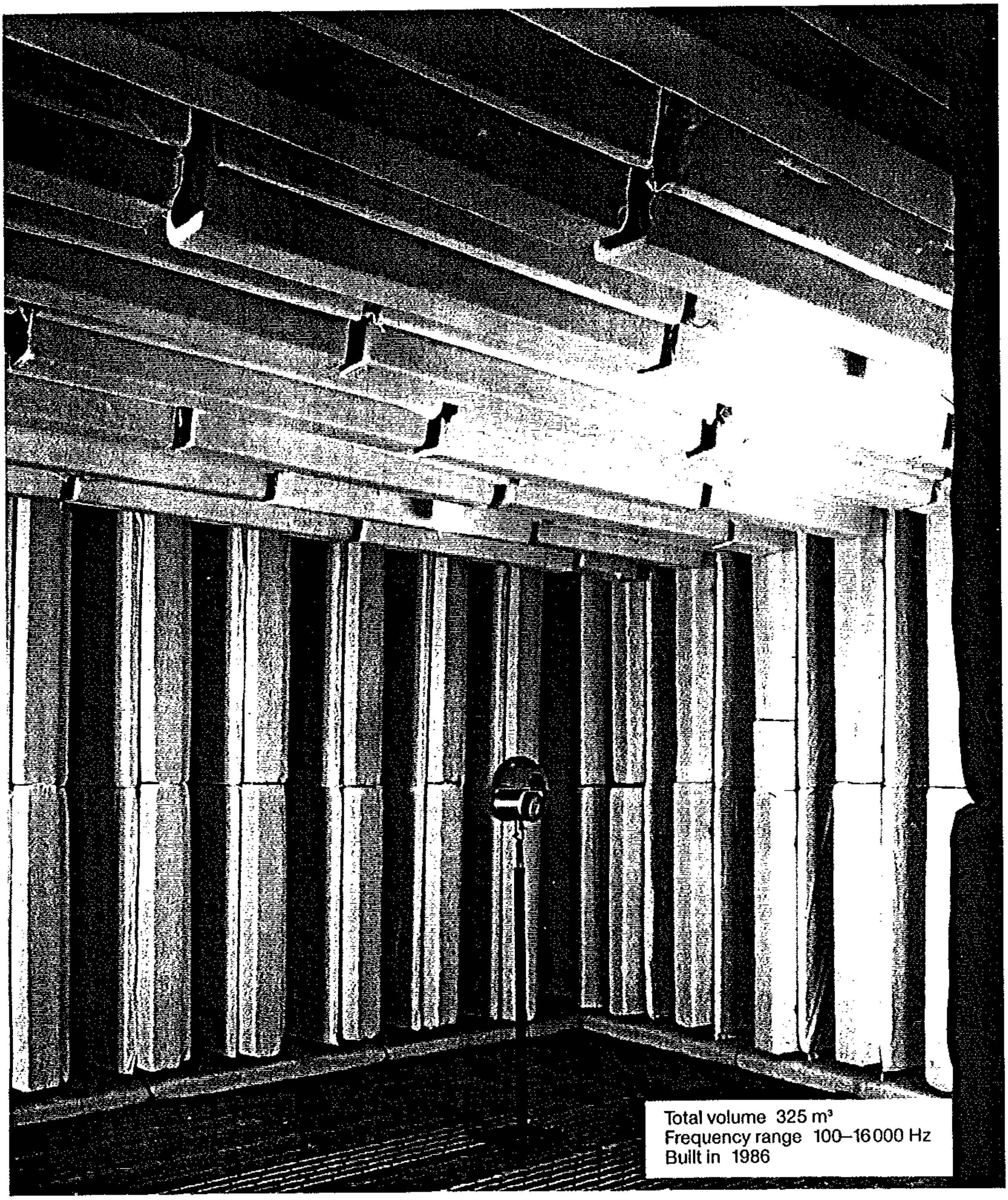


Fig. 3. Picture of the new room.

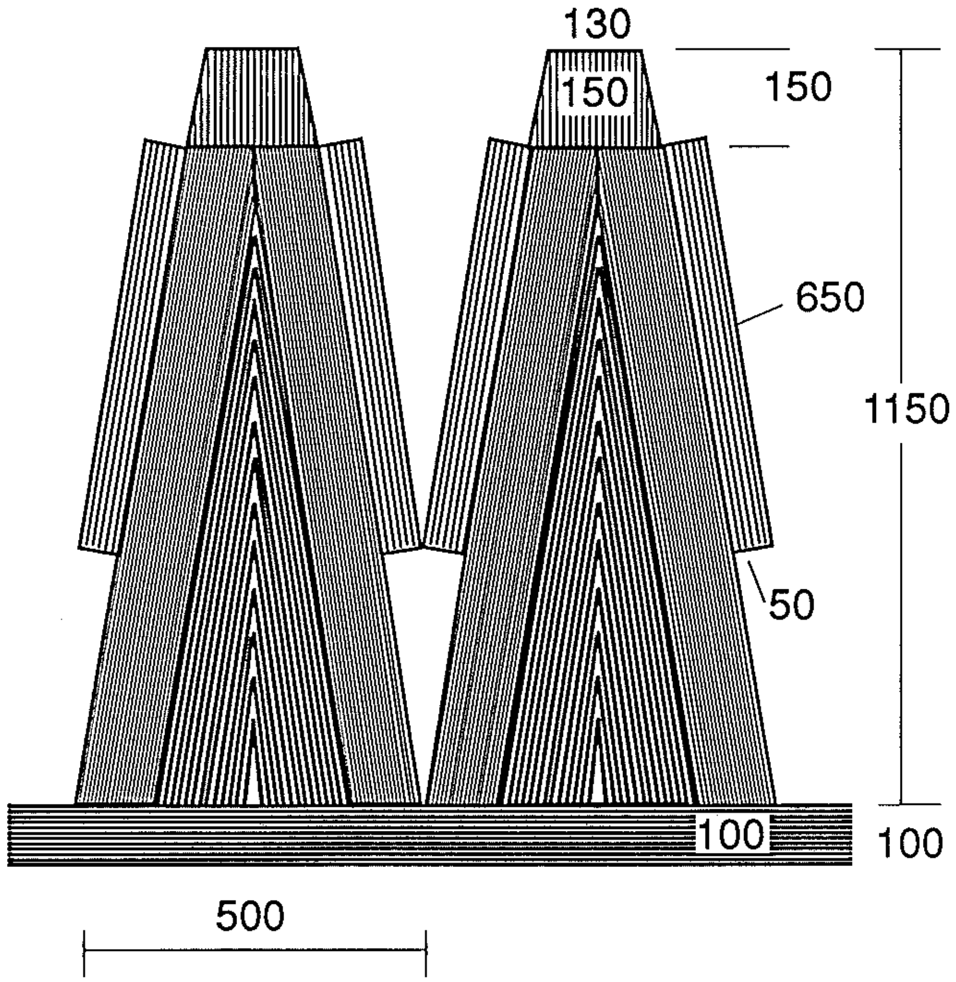


Fig. 4. The structure of the wedges. Glasswool of three different densities, 30, 50 and 70 kg/m^3, is used for different parts of the wedges. This is indicated in the figure as well as the direction of the fibres of the glasswool. The outer layer and the tip were added to fulfil the requirements. Measures in mm.

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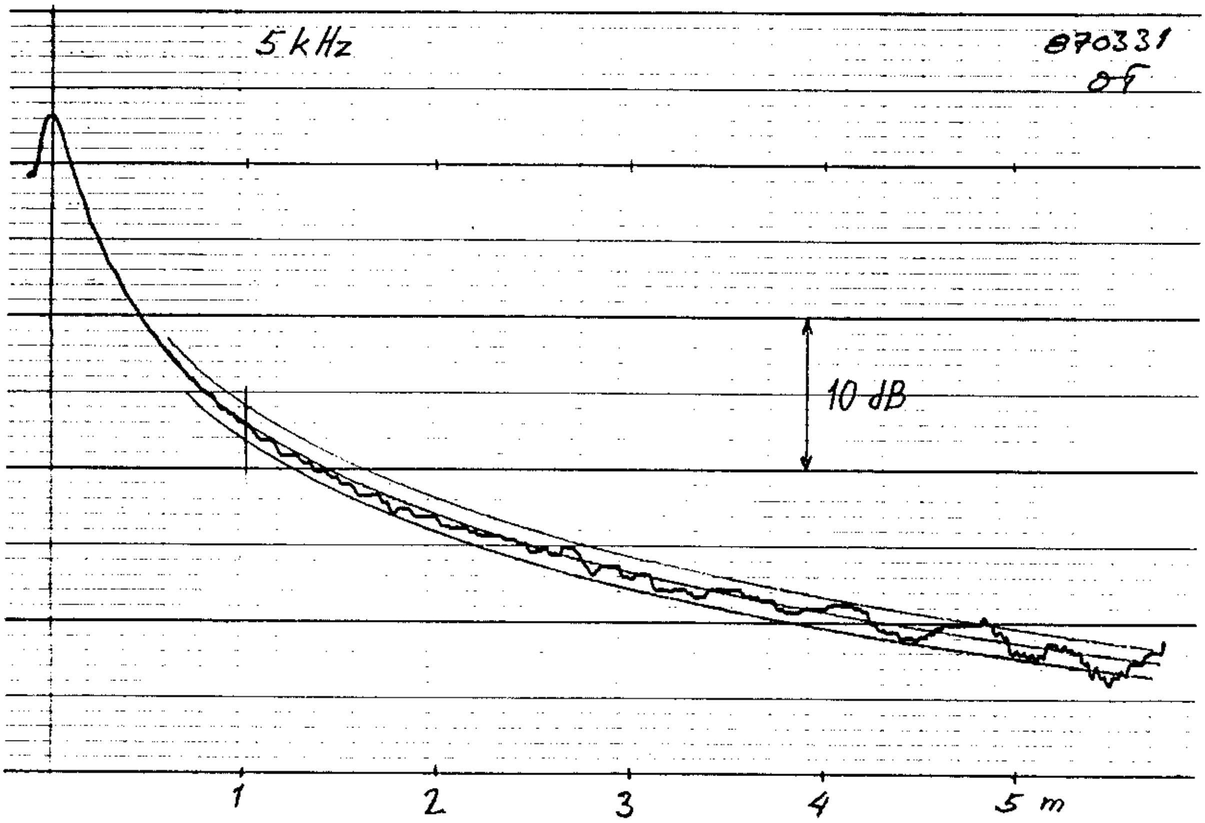
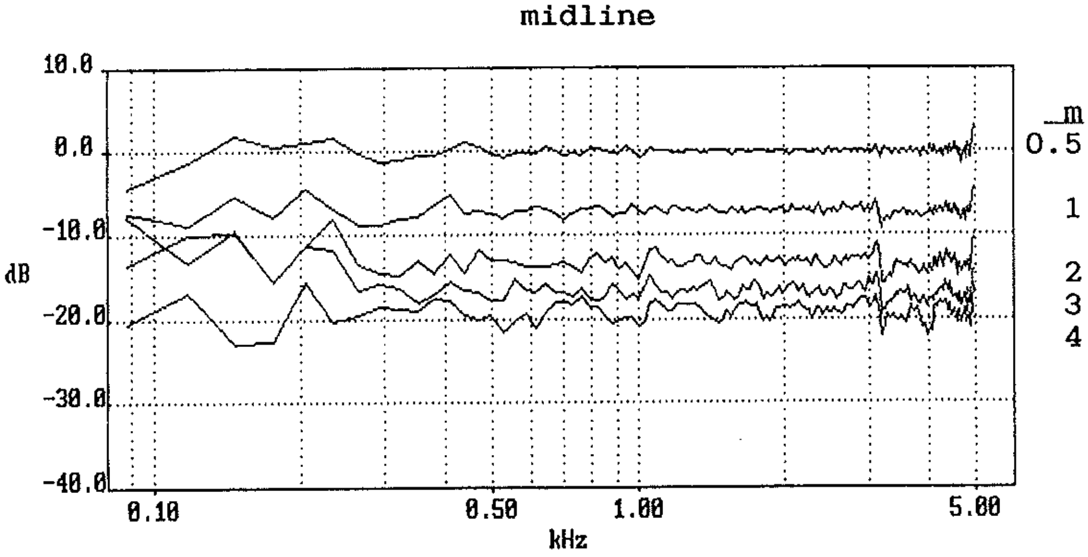


Fig. 5. Example of measured sound pressure level at 5 kHz as a function of distance from loudspeaker.



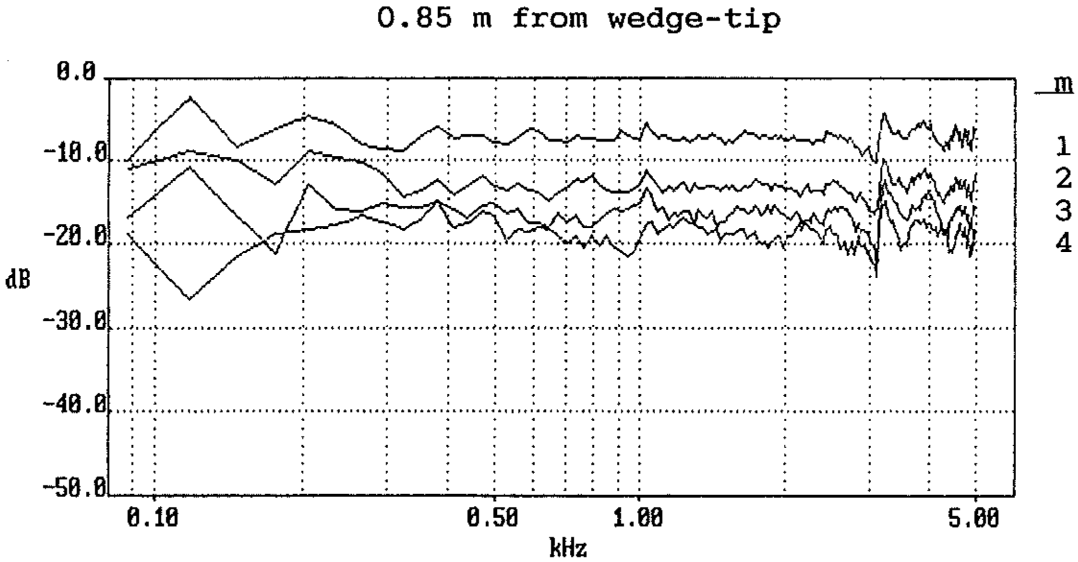


Fig. 6. Reflected spectrum at the microphone divided by the direct spectrum at 0.5 m distance from the loudspeaker. Different distances between the microphone and the loudspeaker, both placed on a line in the middle of the room or on a line 0.85 m from the wedge tips. These measurements were performed before the modification of the wedges. The curve at 0 dB refer to the relation between the **total** sound and the direct sound at a distance of 0.5 m.

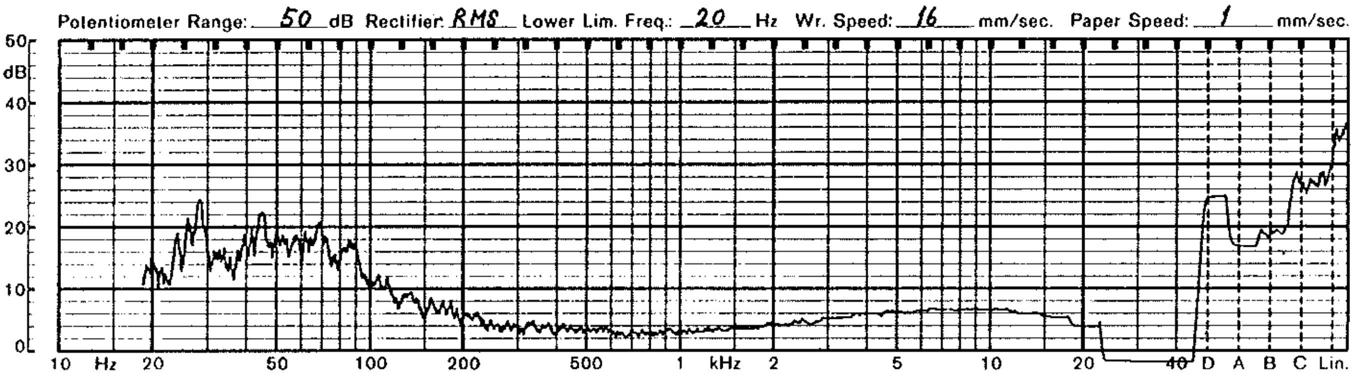


Fig. 7. Background noise levels in the anechoic room, measured with 1/3-octave filters. Ventilation turned off. Above 100 Hz the noise levels are due to electrical noise from the measuring equipment.

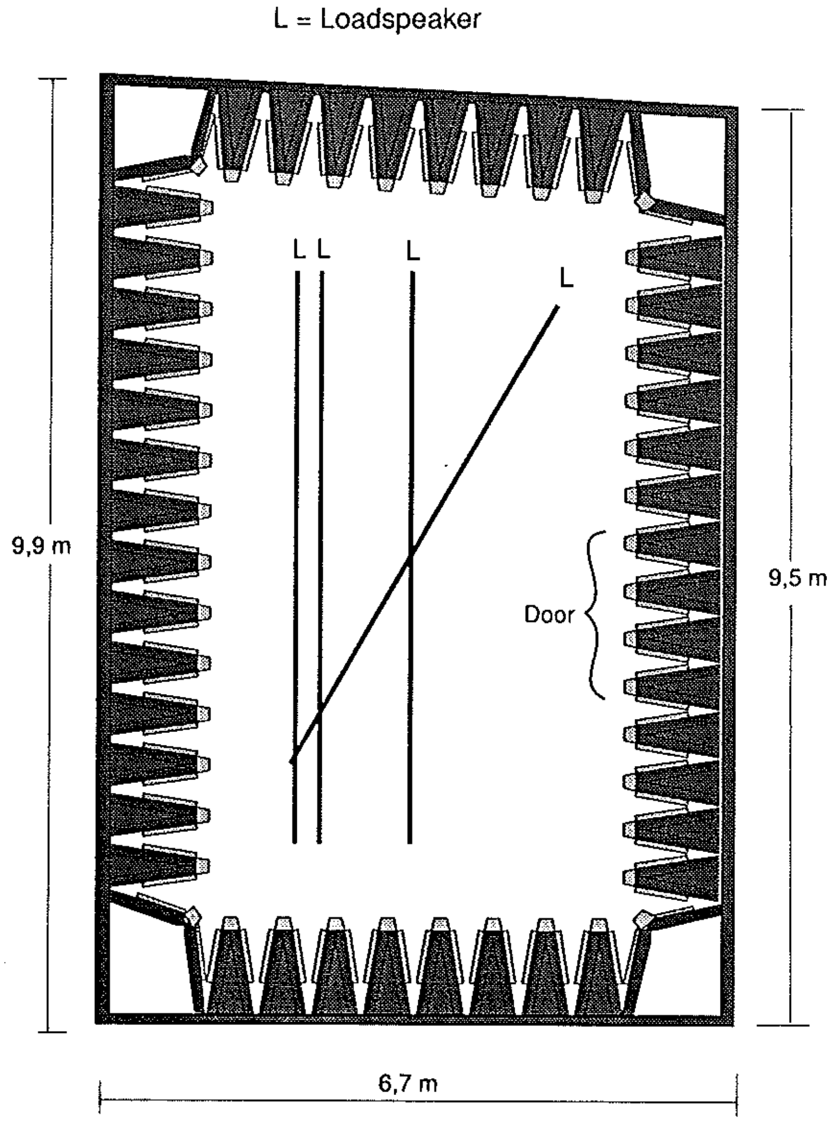
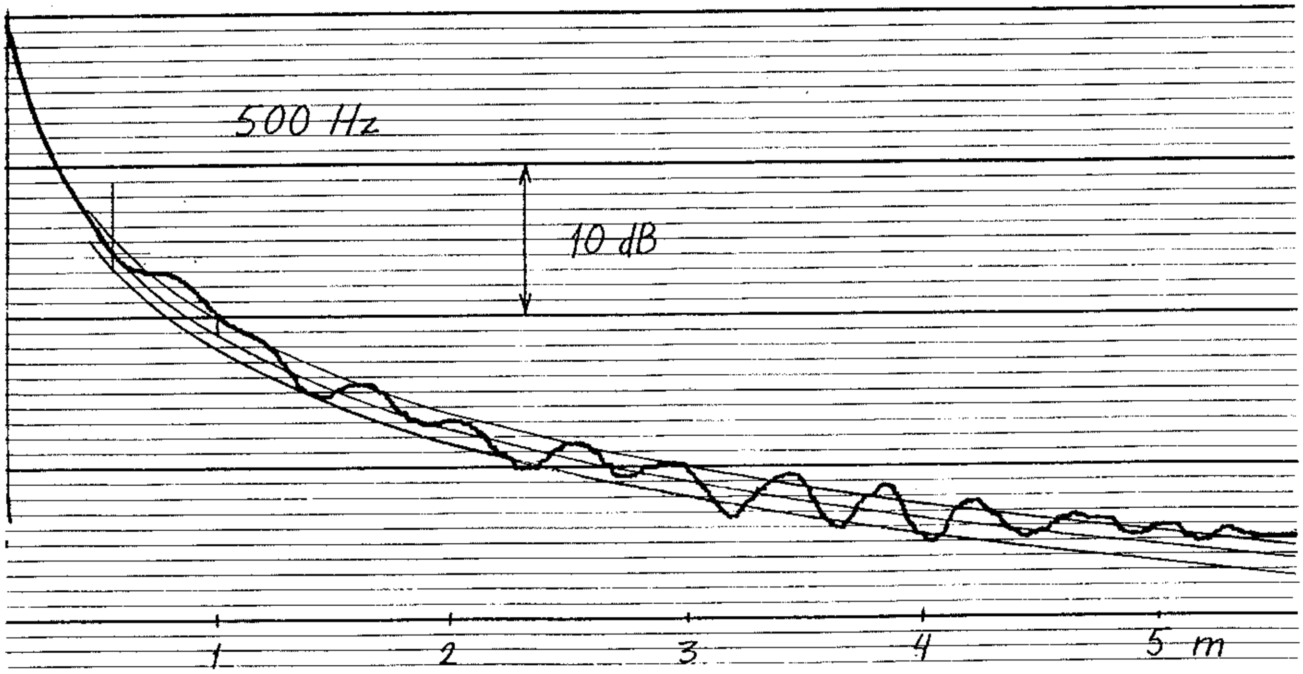


Fig. 8. Measuring paths and loudspeaker positions during qualification test. The loudspeaker positions and the other ends of the paths are all situated at a distance of .85 m to the nearest wedge tip. The parallell lines are in the middle of the room, and .85 and 1.1 m from the wedge tips respectively.

before



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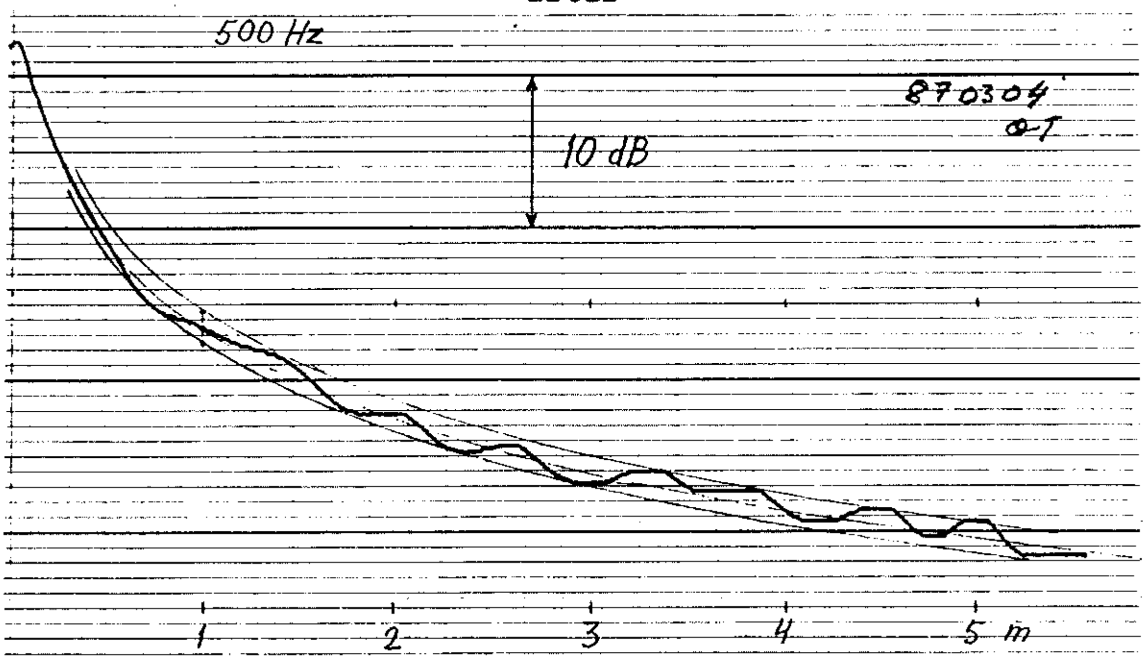
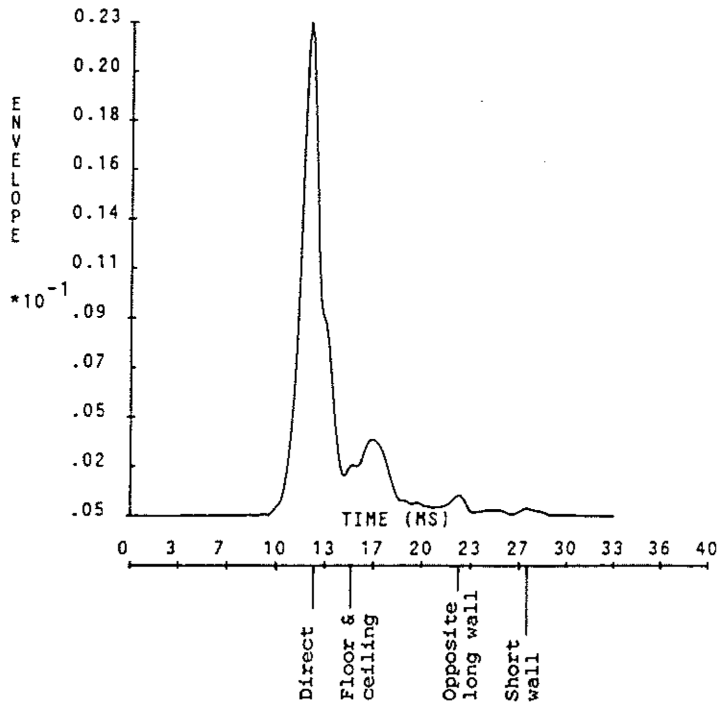


Fig. 9. 1/r-response curve for 500 Hz at the midline of the room before and after the application of a lower density glasswool layer on the sides of the wedges. In both cases the tips have got the lower density glasswool.



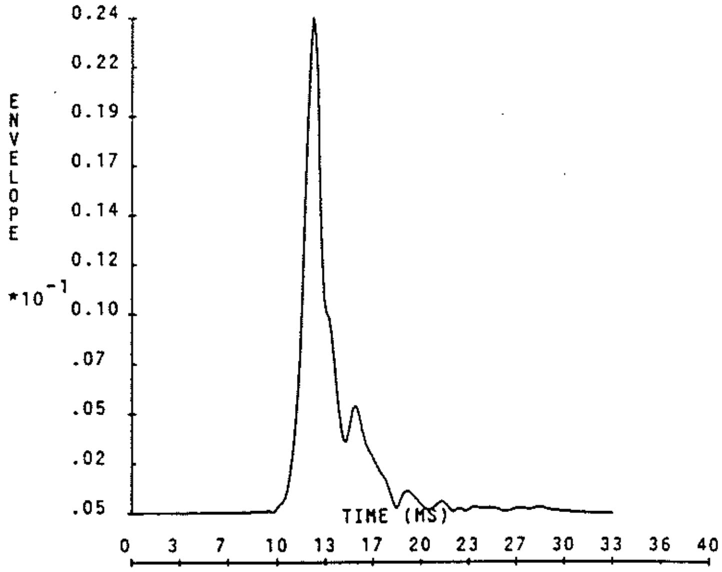
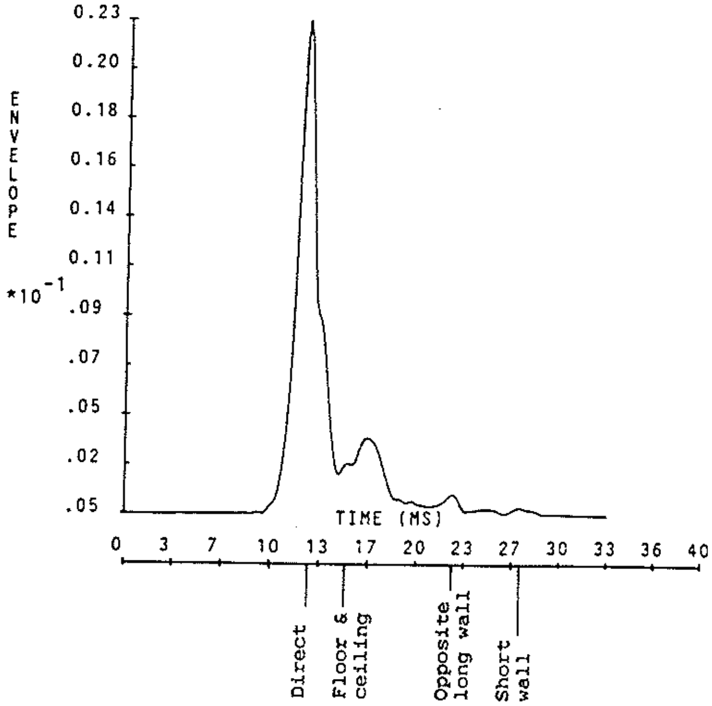


Fig. 10 (continues next page). Envelope of the impulse response. The microphone and the loudspeaker were at a distance of 5.3 m from each other, 2 m and 1.2 m from the side wall respectively.

a) "Identified reflexions"

b) With reflecting material on wedge tips at the nearest side wall.



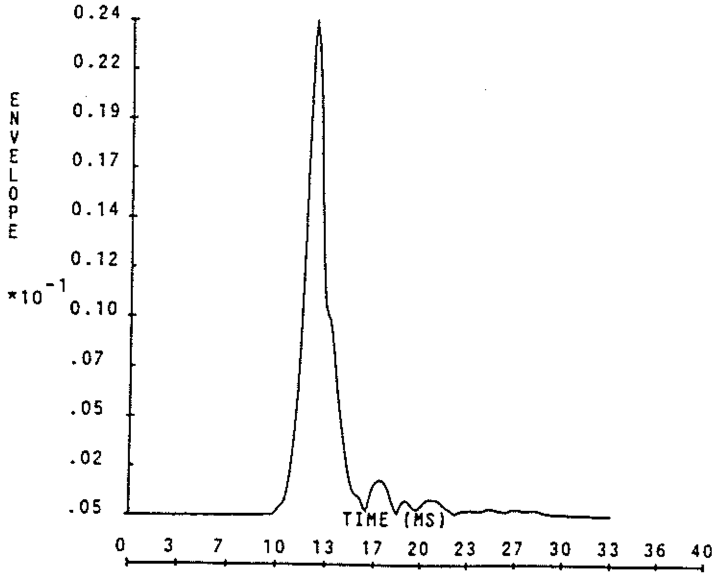


Fig. 10 (continued). Envelope of the impulse response. The microphone and the loudspeaker were at a distance of 5.3 m from each other, 2 m and 1.2 m from the side wall respectively.

a) "Identified reflexions"

c) Absorbent material between wedges at the nearest side wall.

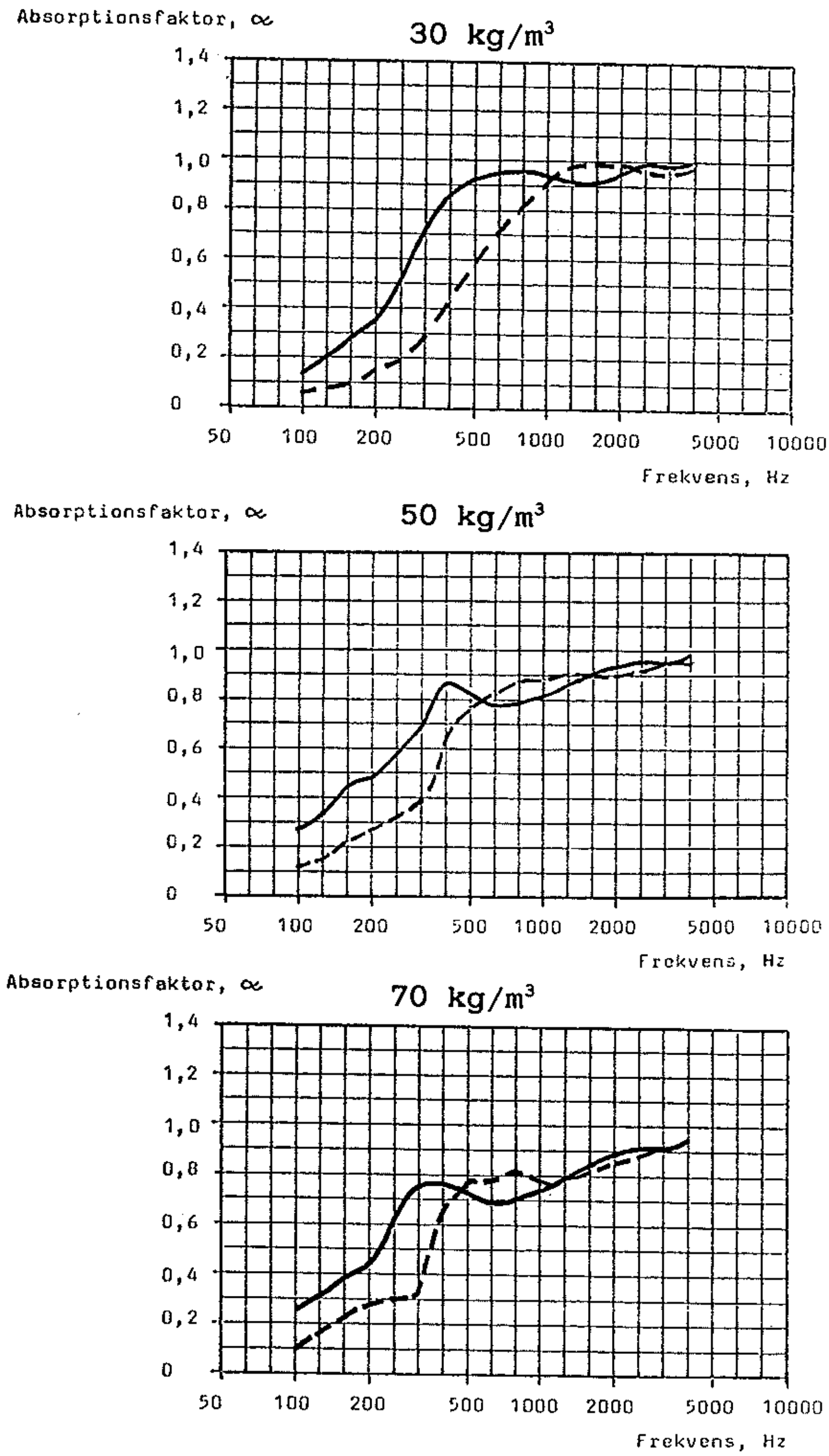


Fig 11. Absorption coefficient curves for glasswool of different density. The dashed lines show results obtained without air slit. (From Gullfiber product data cataloge.)

TABLES

	8 kHz		16 kHz	
	0°	45°	0°	45°
Absorbent only	.997	.999	.996	1.000
Absorb with cover	.997	.999	1.000	.998

Table 1. Results of absorption measurements at two incidence angles of a sample of glasswool used for the tip of the wedges.

1/3-oct centre frequency, Hz	<800	800-5000	>5000
Allowable difference, dB	±1.5	±1.0	±1.5

Table 2. Requirements on deviation from the 1/r law for an anechoic room as stated in ISO 3745 Annex A.

Meters between source & mic	refl part hom. wall	Nos of signif. reflexions	refl part wedged wall
1	.045	5	.19
2	.071	7	.22
3	.085	9	.23

Table 3. Calculated reflected part of source in front of a homogenous wall with a single reflexion and in front of a wedged wall with multiple reflexions. Different distances between source and microphone. R=0.1.

APPENDIX

This page is a translation from Swedish of the first page of a report by ACAD-International AB ubv made 1987-04-05.

DEPT OF TECHNICAL AUDIOLOGY, ANECHOIC CHAMBER

Results of acoustic measurements

The performance of the measurements has been done as close as possible to the standard ISO 3745 for anechoic test rooms. Pure tones and a continuous path for the microphone have been used. There were four measuring lines, all at the height 1.1 m :

- In the middle of the room parallel to a long wall

- Along a long wall, 0.85 m from the top of the absorbent

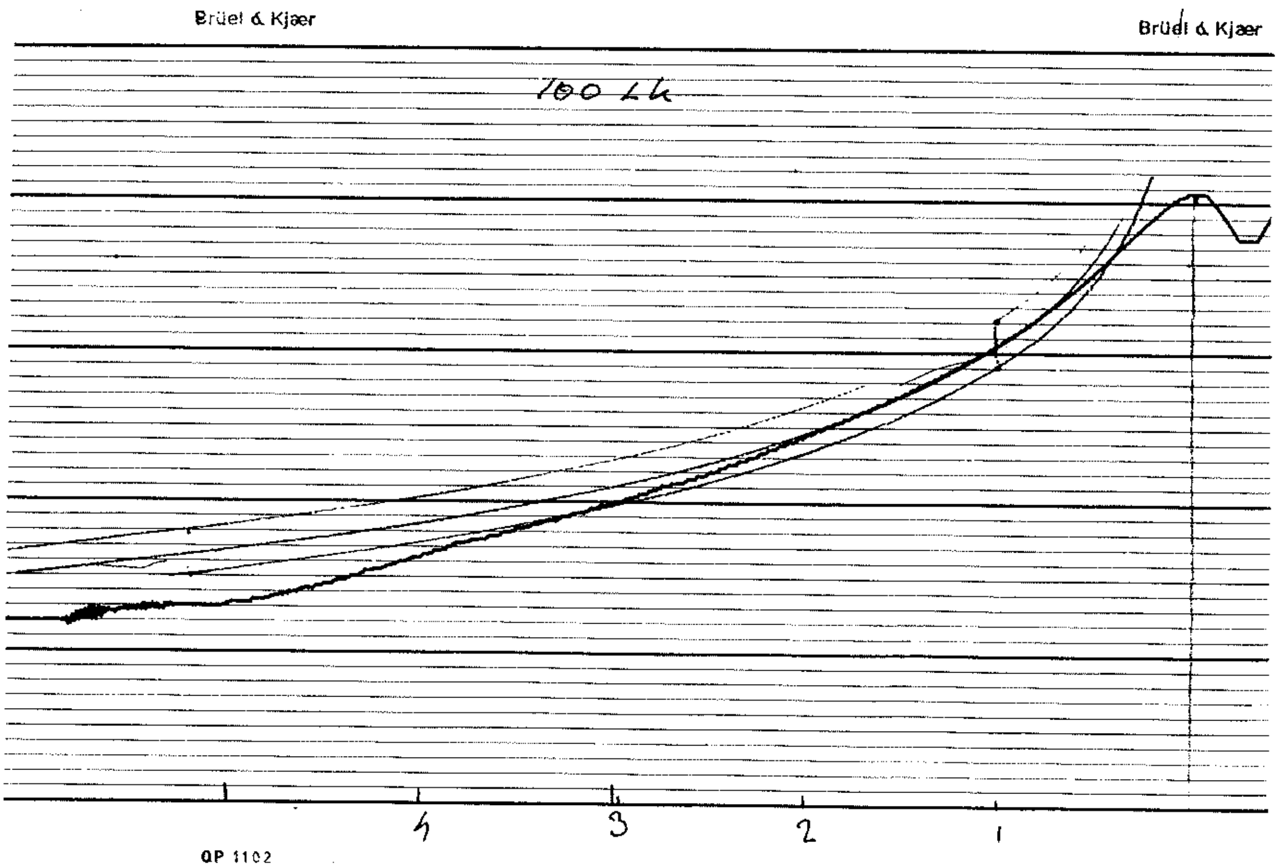
- Diagonally

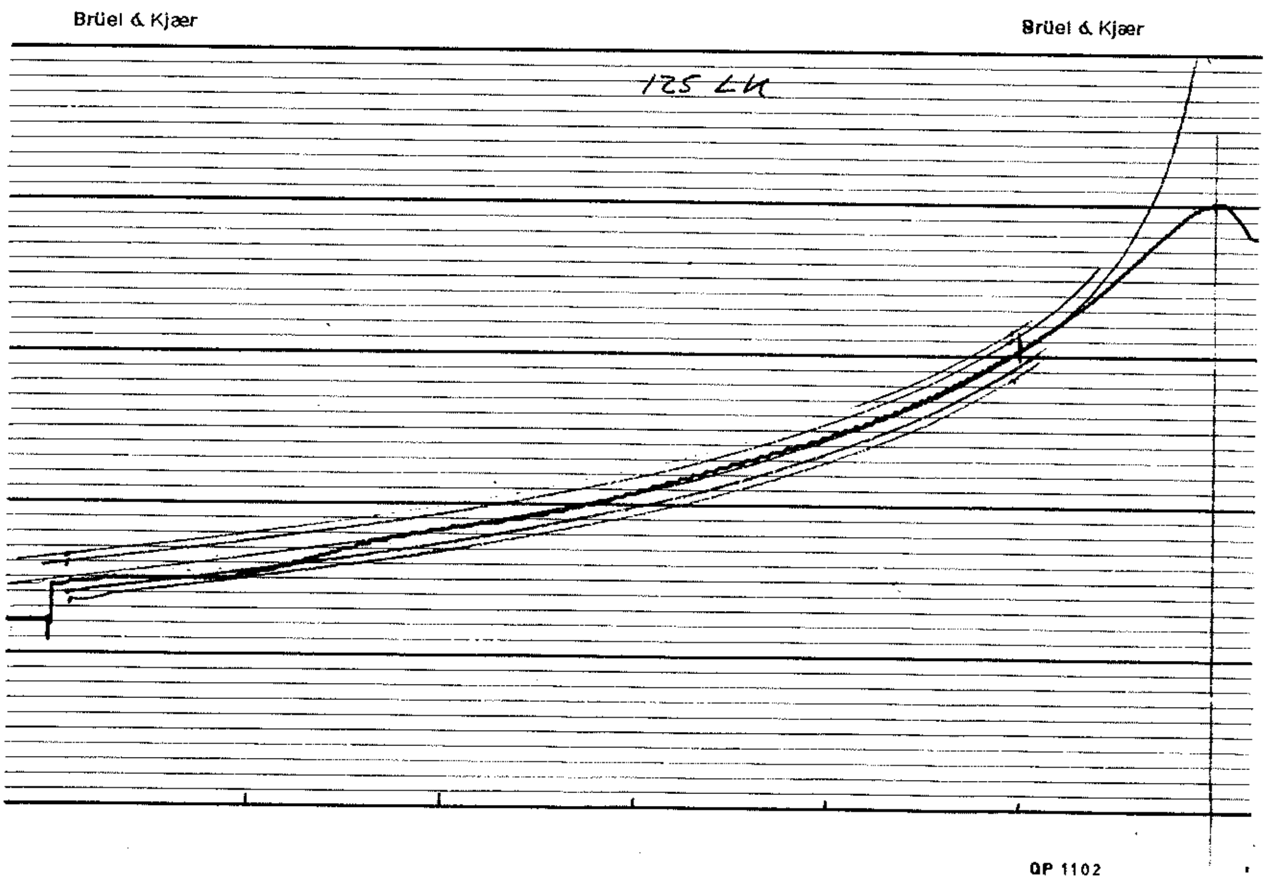
- Along a long wall, 1.3 m from the top of the absorbent

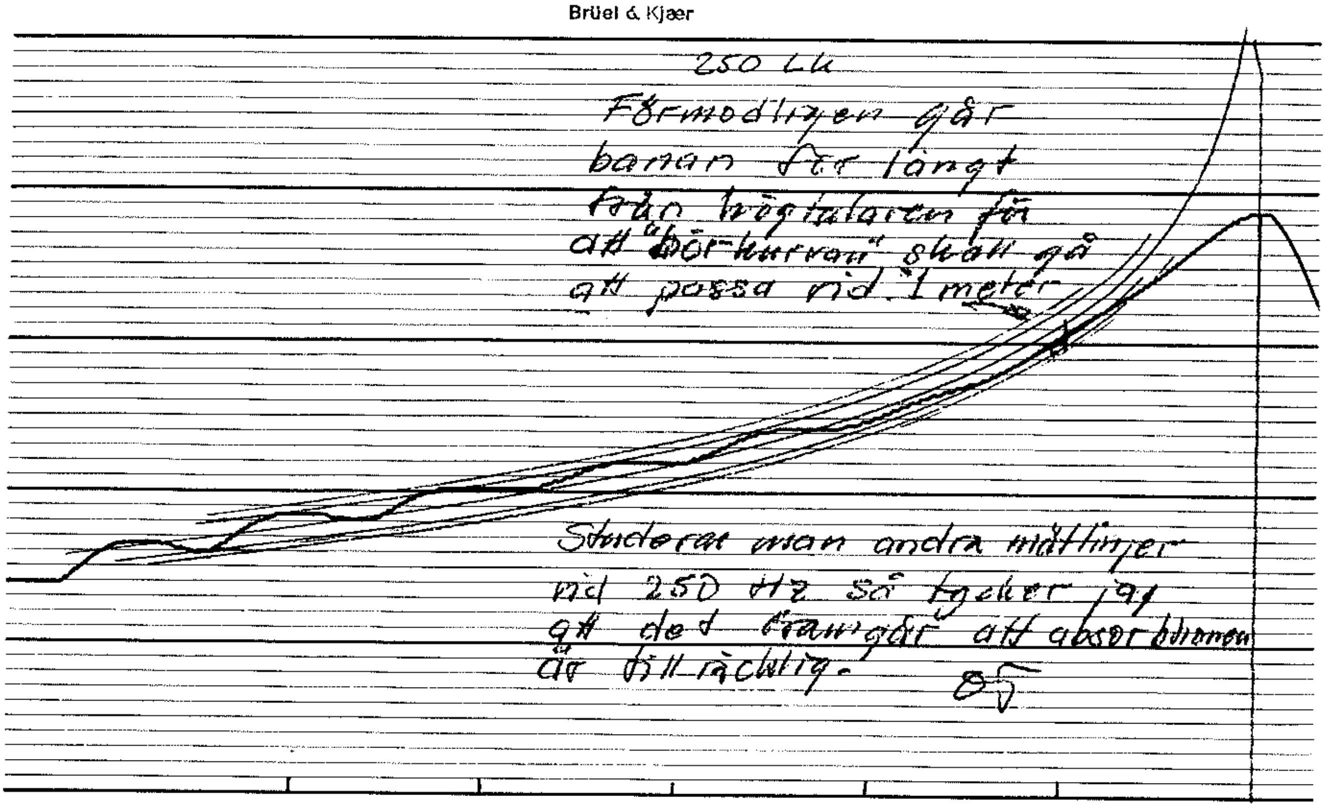
The loudspeakers were hanging 0.85 m from the nearest absorbent top if not specified otherwise in the protocol. Enclosed diagrams show the results. A 50 dB dynamic range is used throughout. The microphone has been run from the loudspeaker to a point 0.85 m from the opposite absorbent top and back again, passing the loudspeaker.

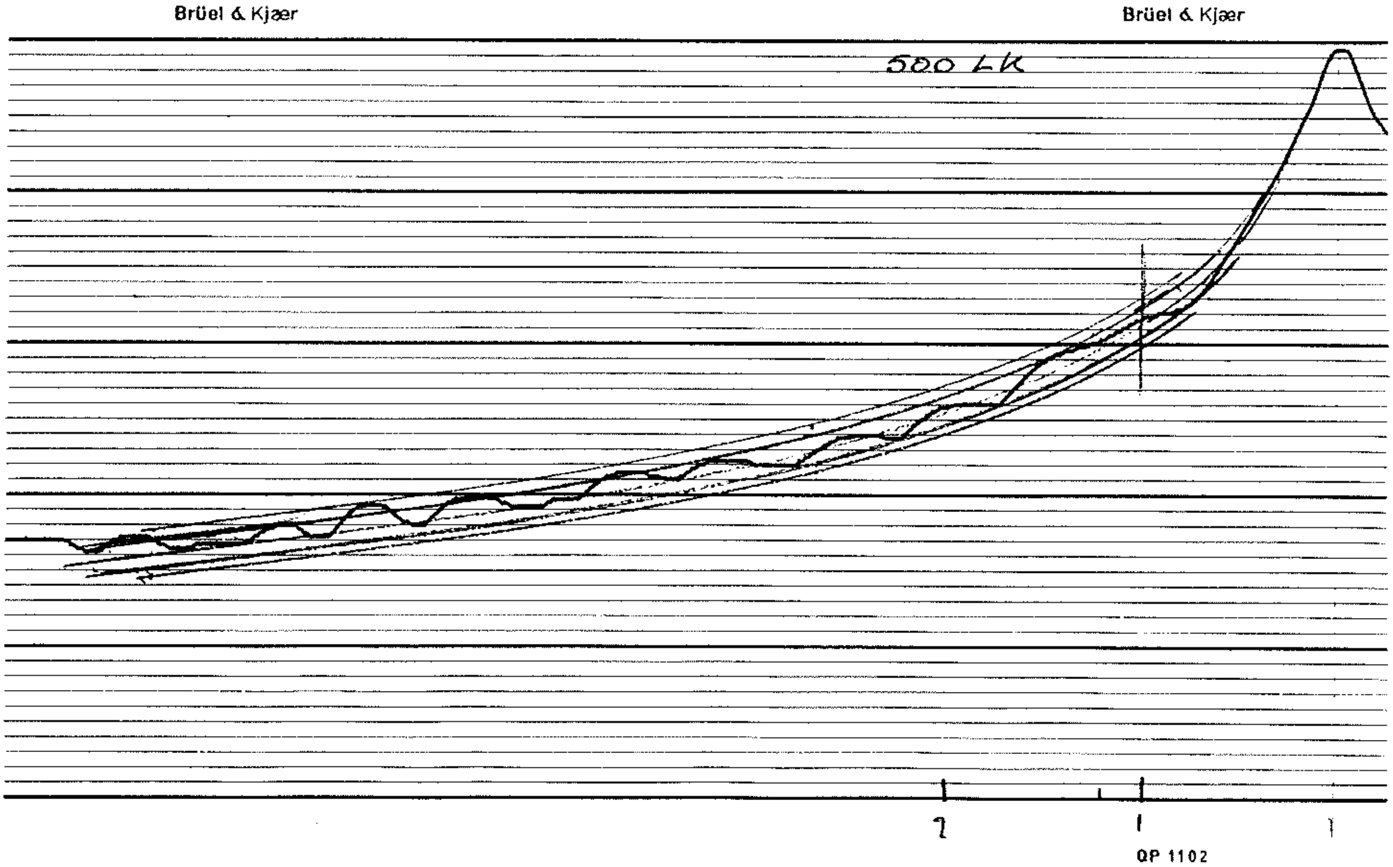
In the enclosed diagrams the tolerances according to the ISO-standard have been marked. The measurements and the interpretations of the results have been done in consultation with the Department of Technical Audiology.

In the middle, 100 and 125 Hz

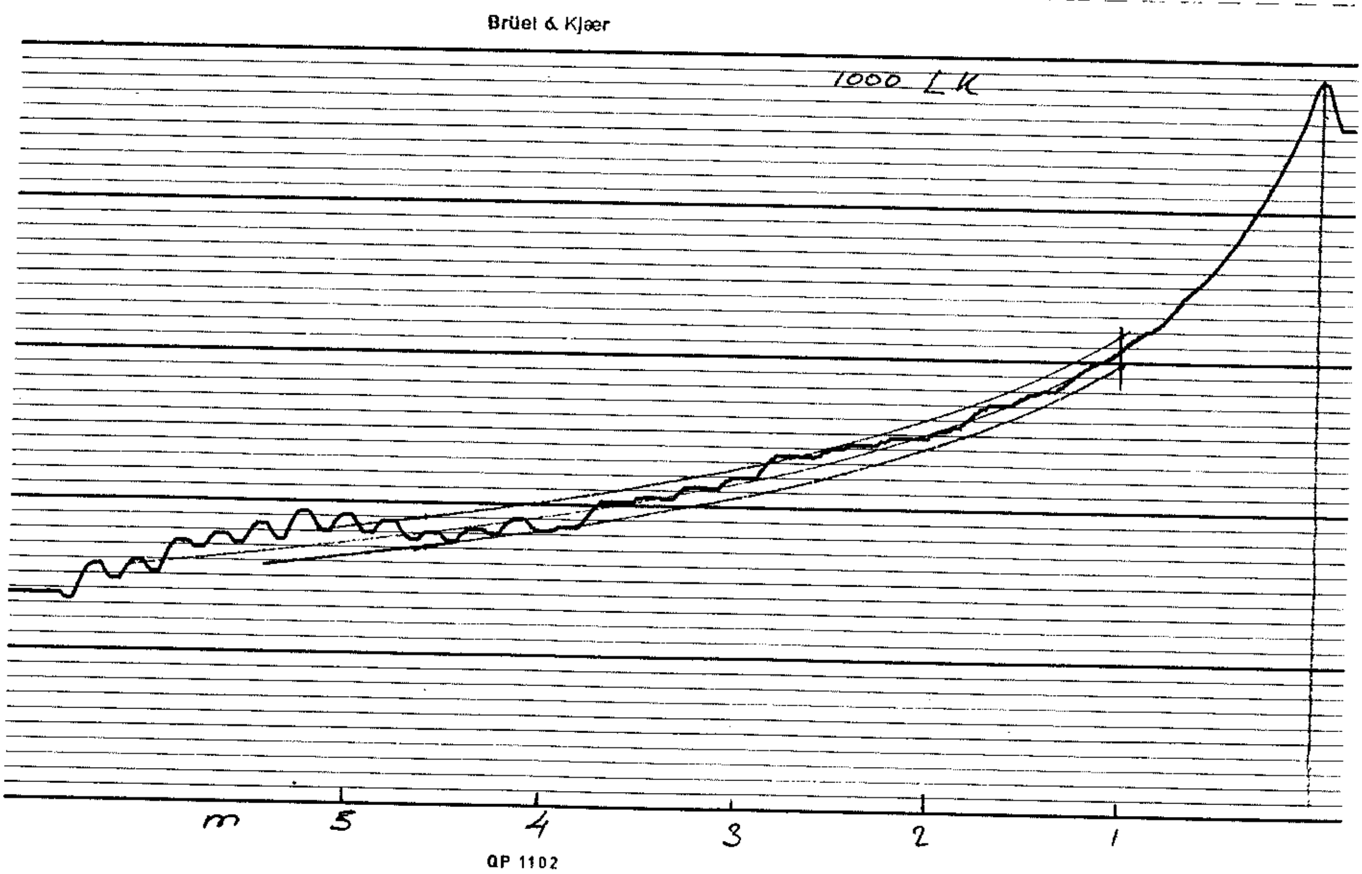


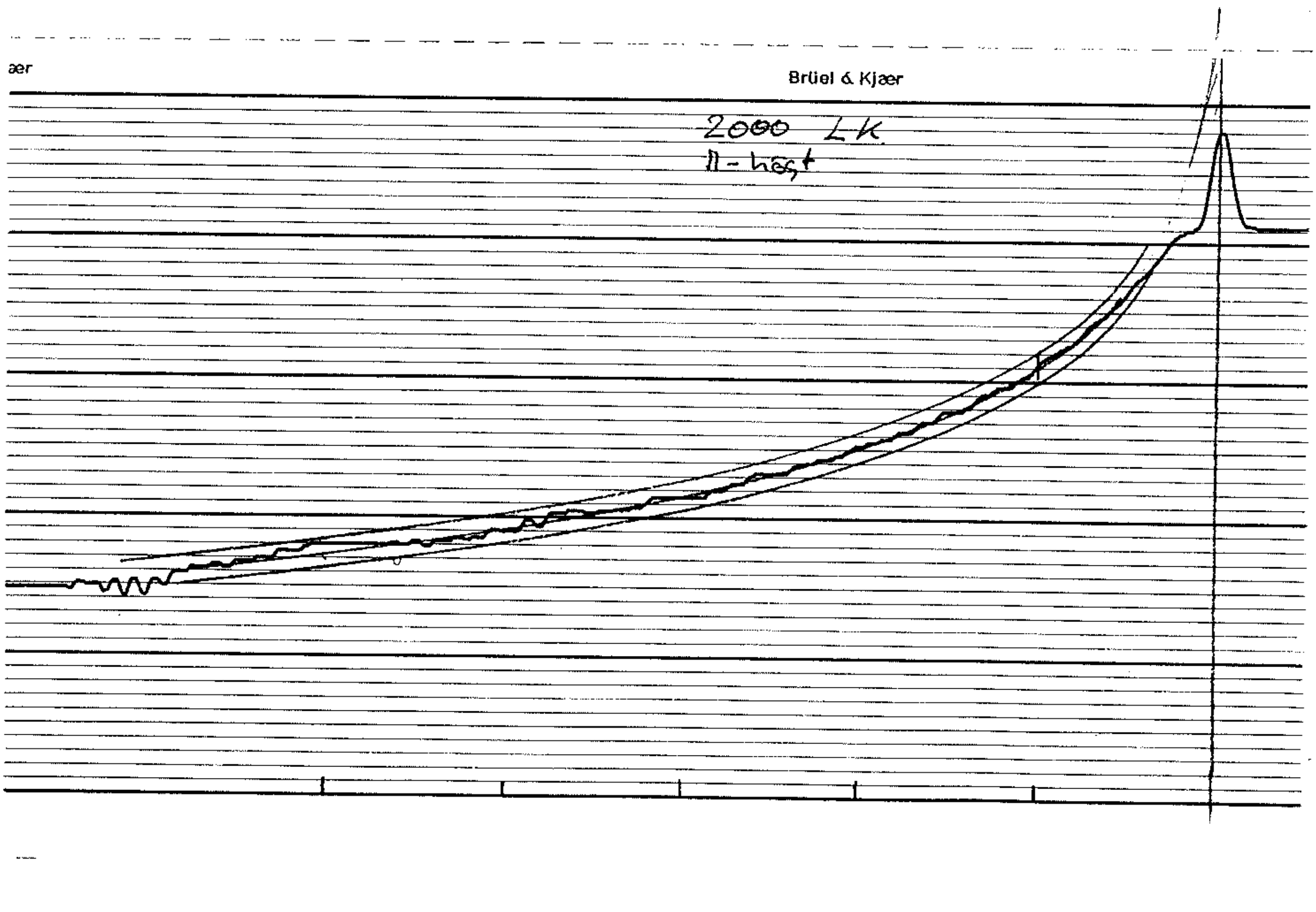



Brüel & Kjær
250 Hz
Förmodlinjen går banan för långt från högtalaren för att "börkurvan" skall gå att passa vid 1 meter
Studerar man andra mätlinjer vid 250 Hz så tycker jag att det framgår att absorbtionen är tillräcklig.

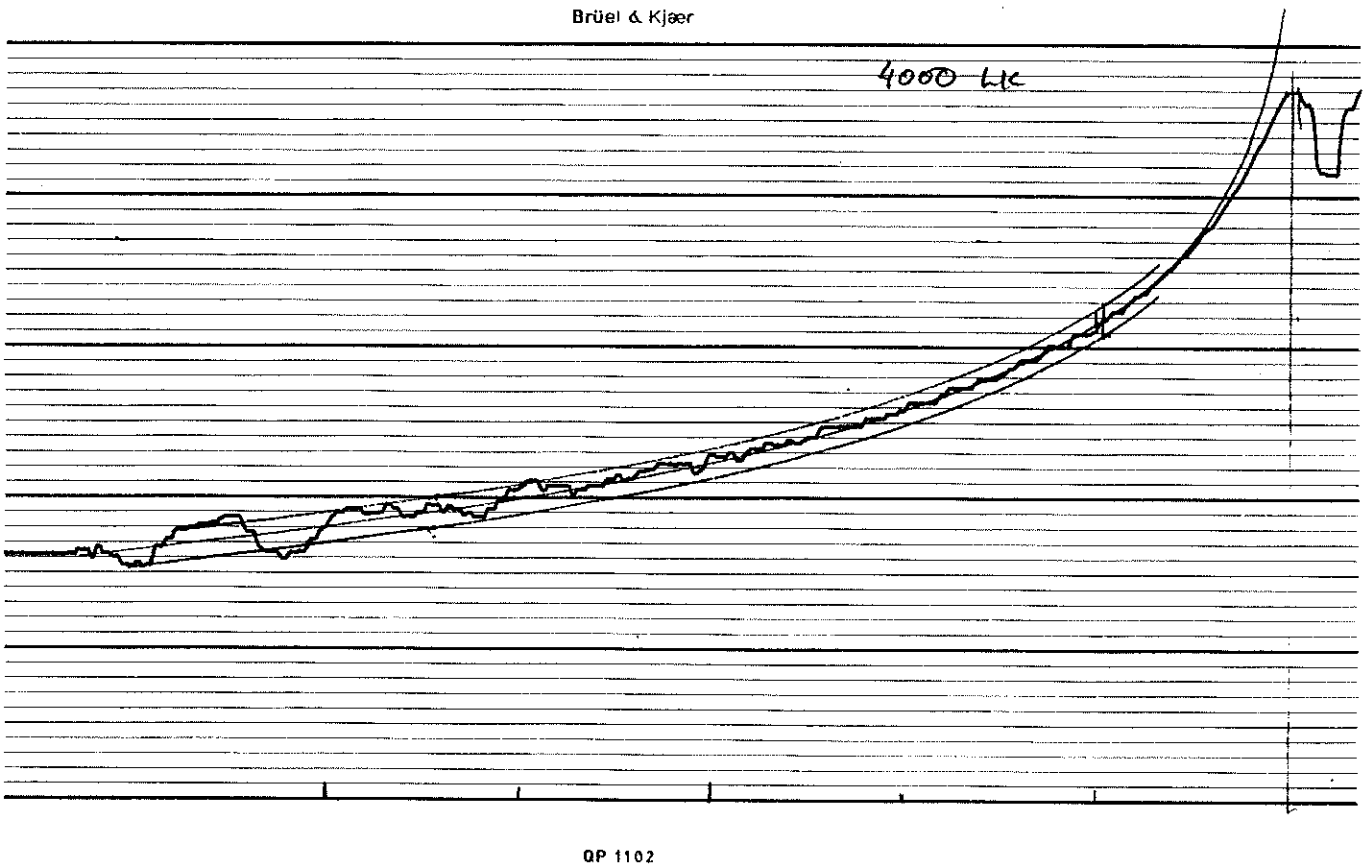

Brüel & Kjær
Brüel & Kjær
500 Hz
QP 1102

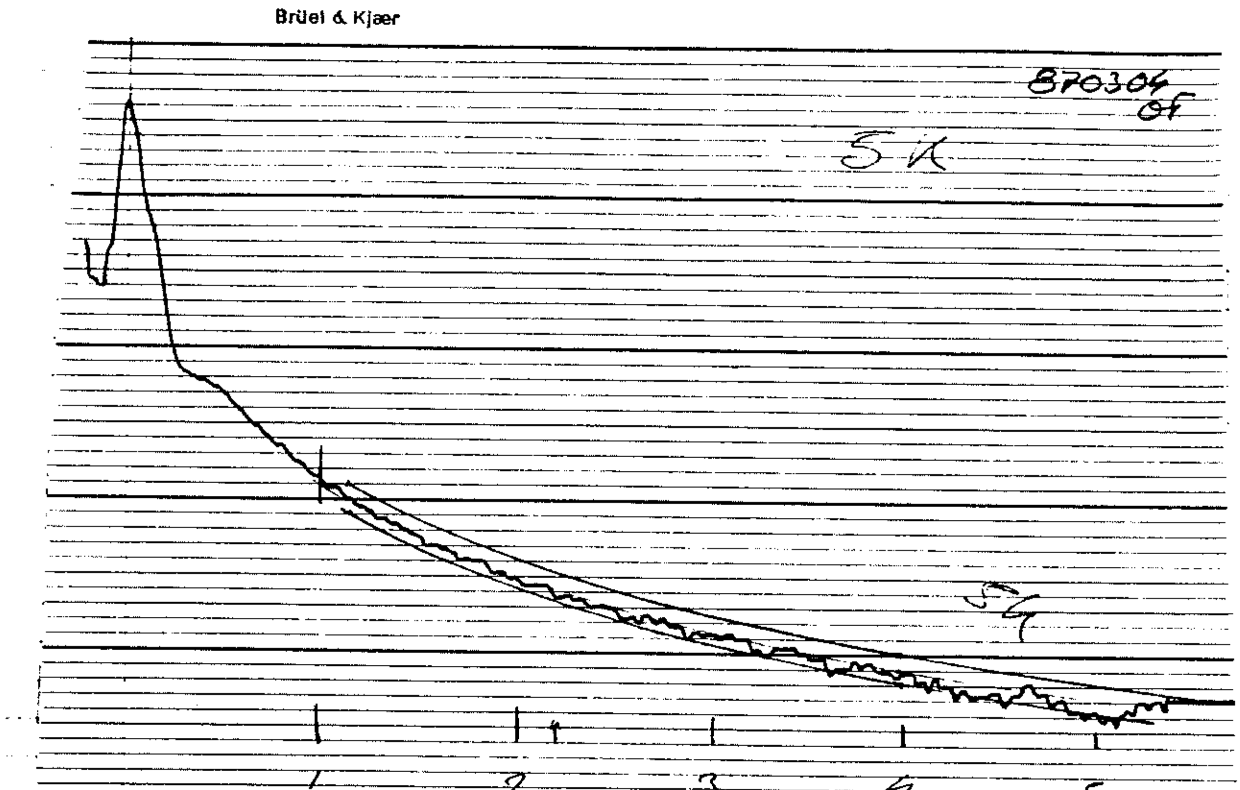
In the middle, 1000 and 2000 Hz



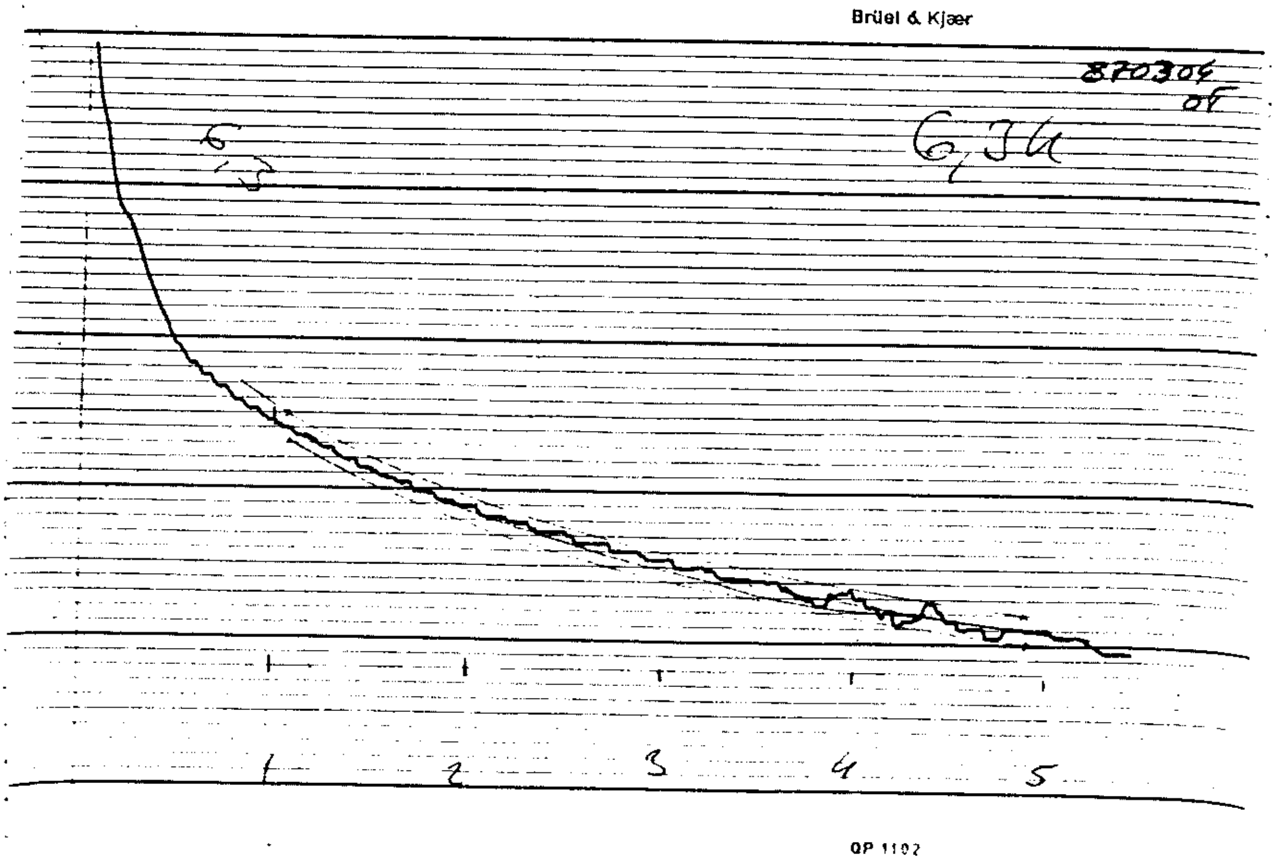


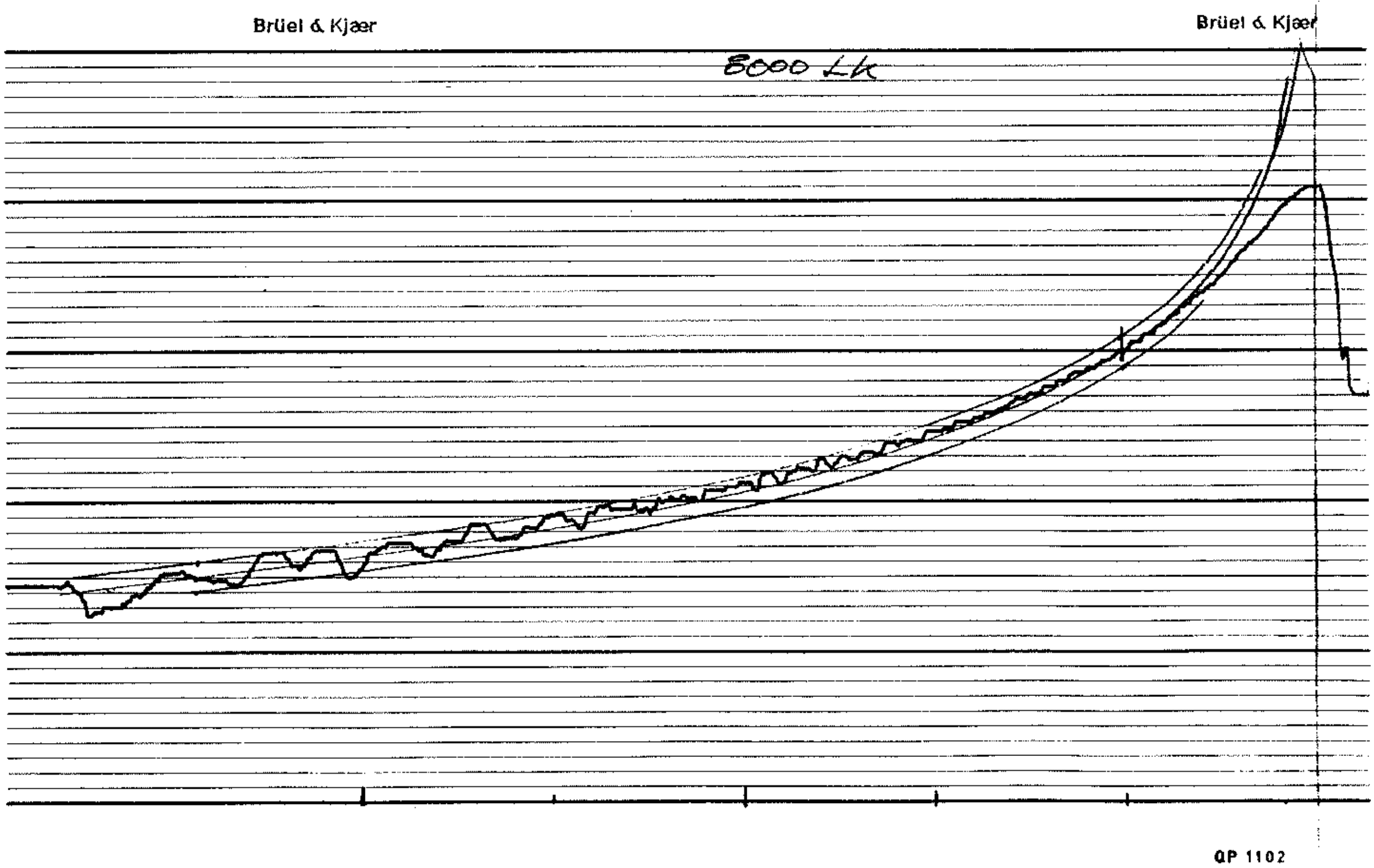
In the middle, 4000 and 5000 Hz

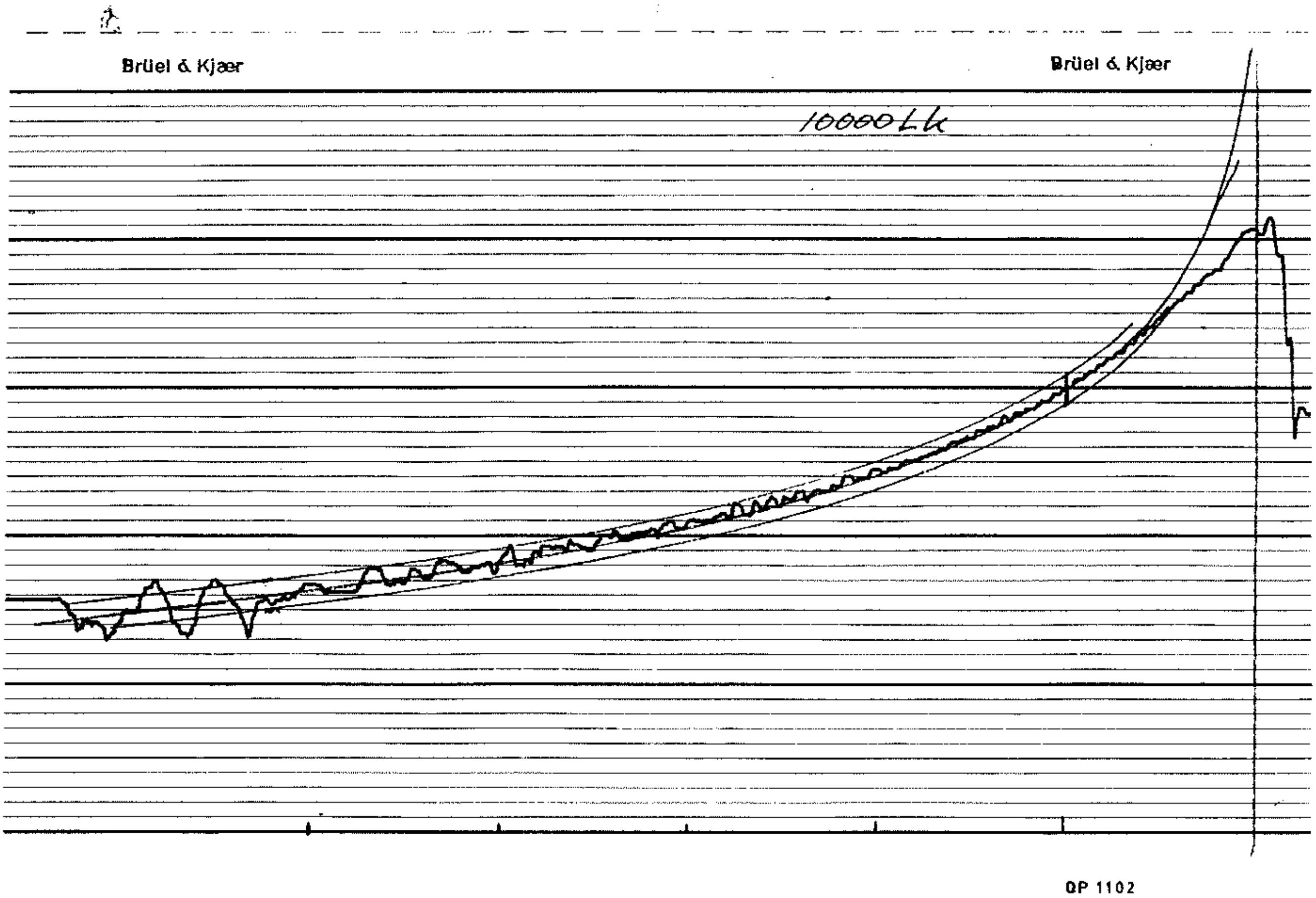


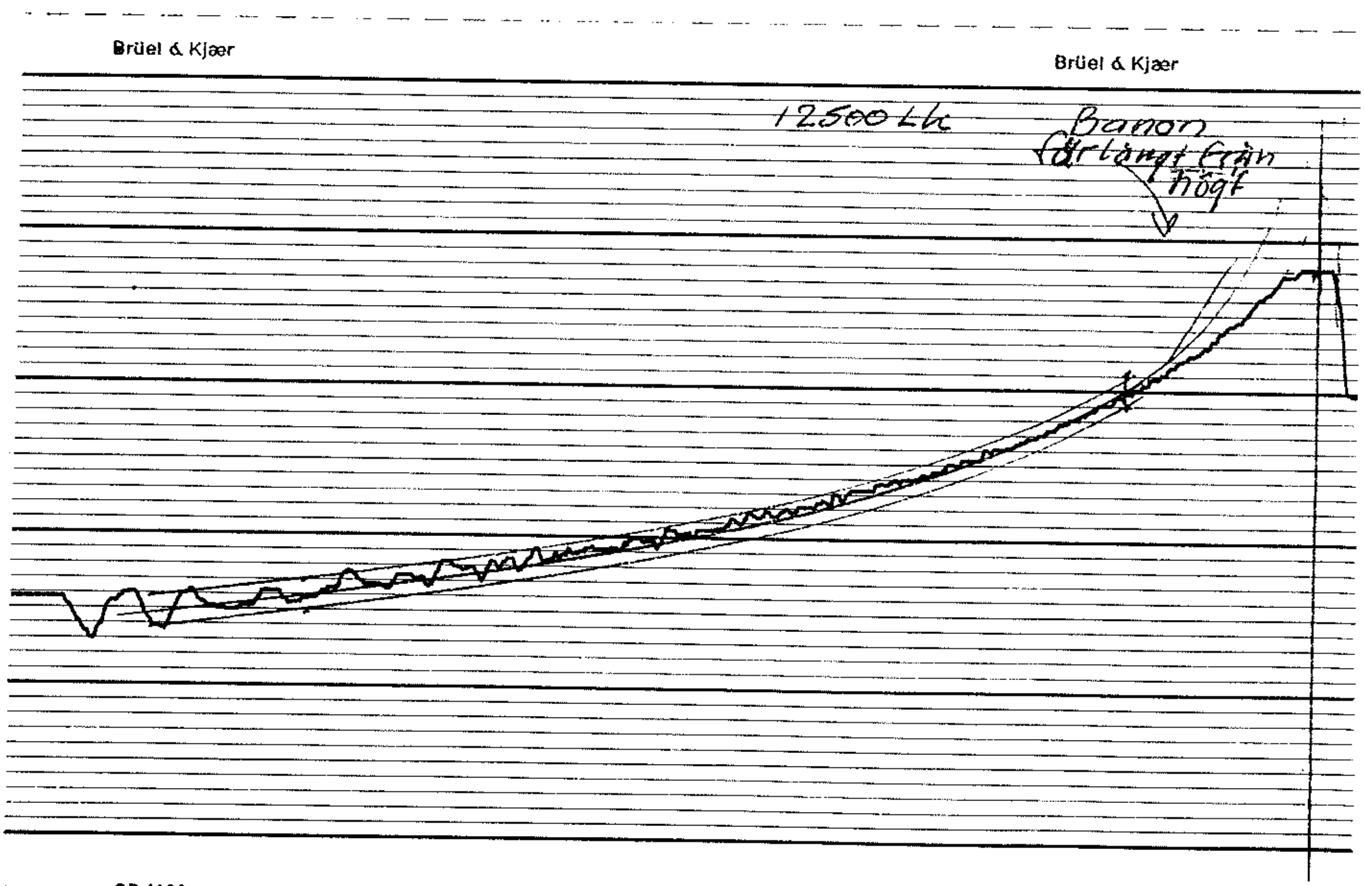


In the middle, 6300 and 8000 Hz

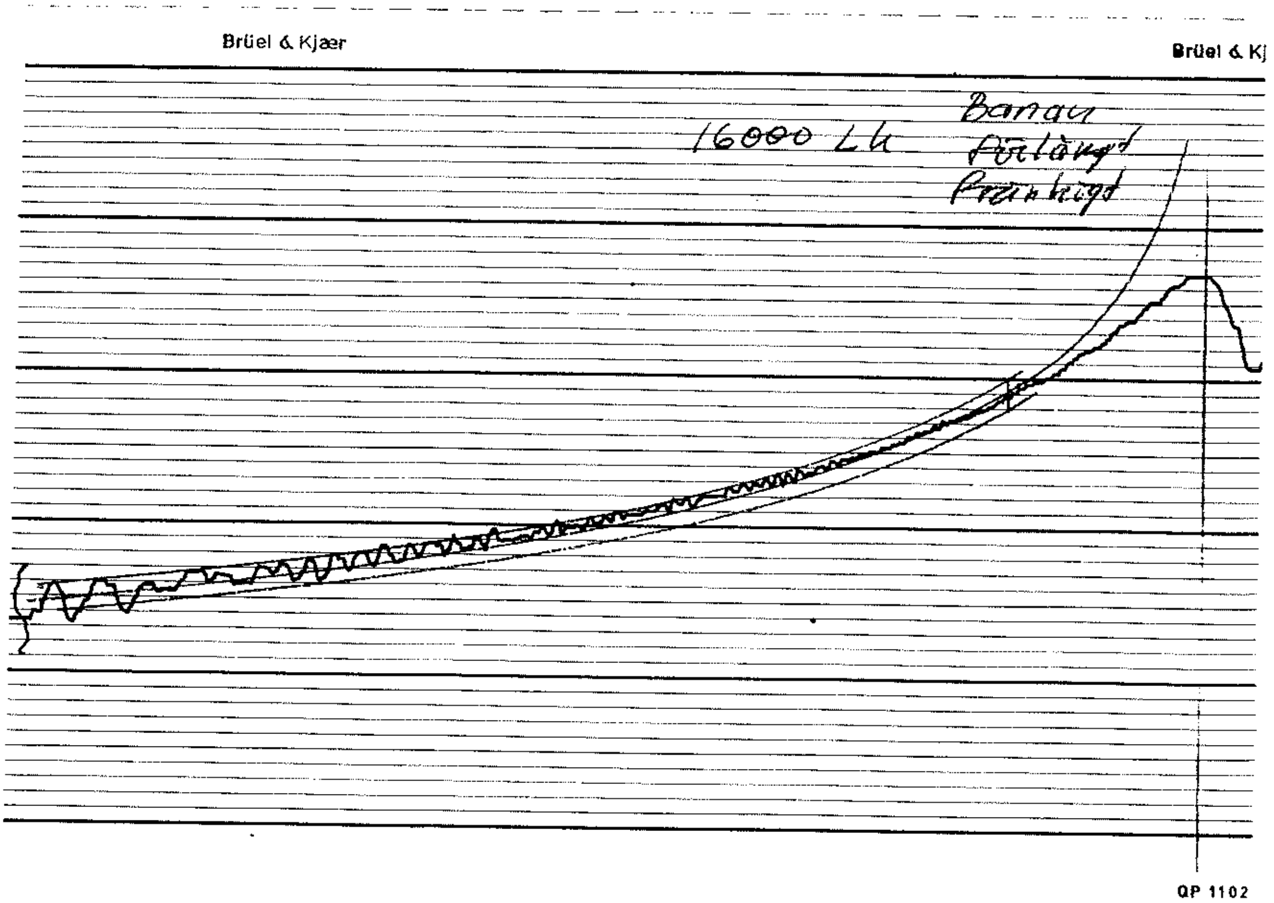


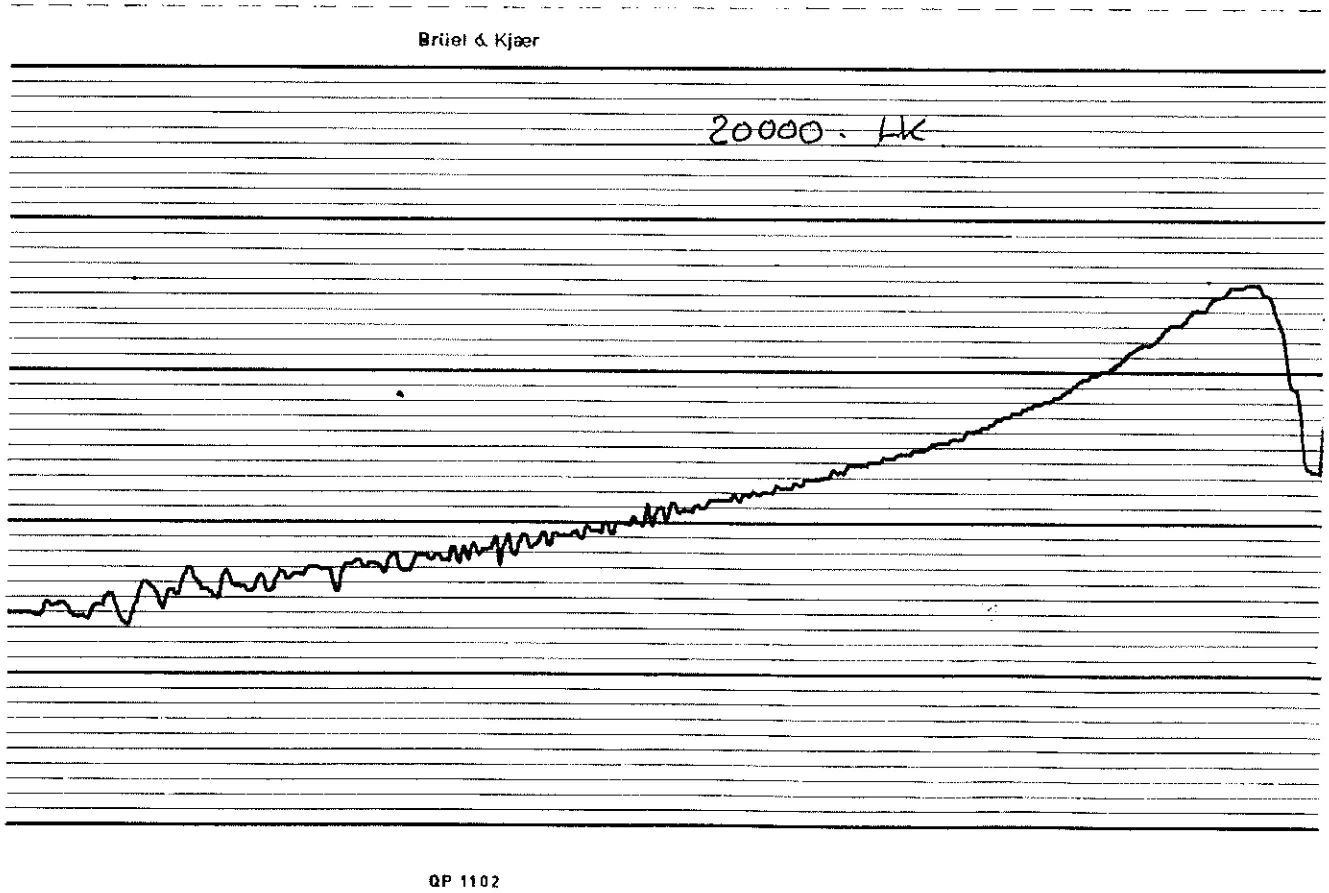


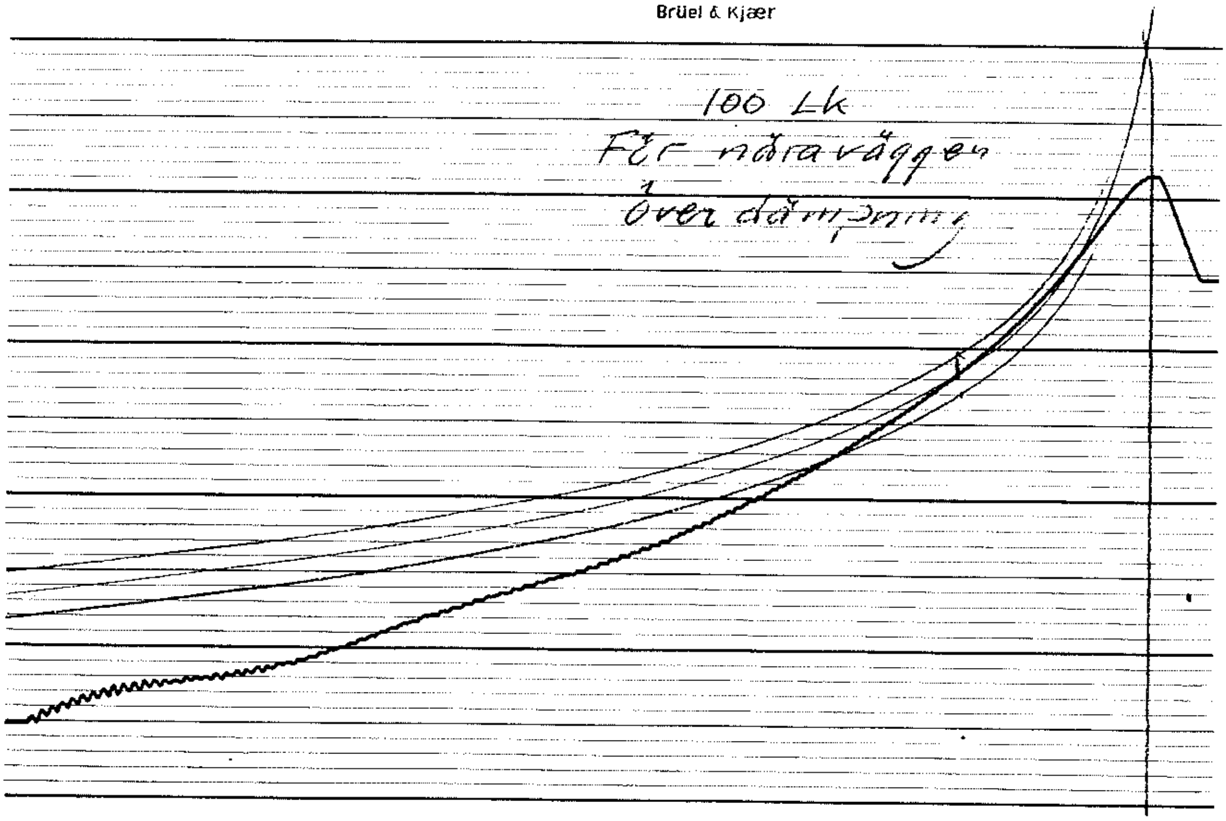

Brüel & Kjær
Brüel & Kjær
QP 1102


Brüel & Kjær
Brüel & Kjær
QP 1102

In the middle, 16000 and 20000 Hz

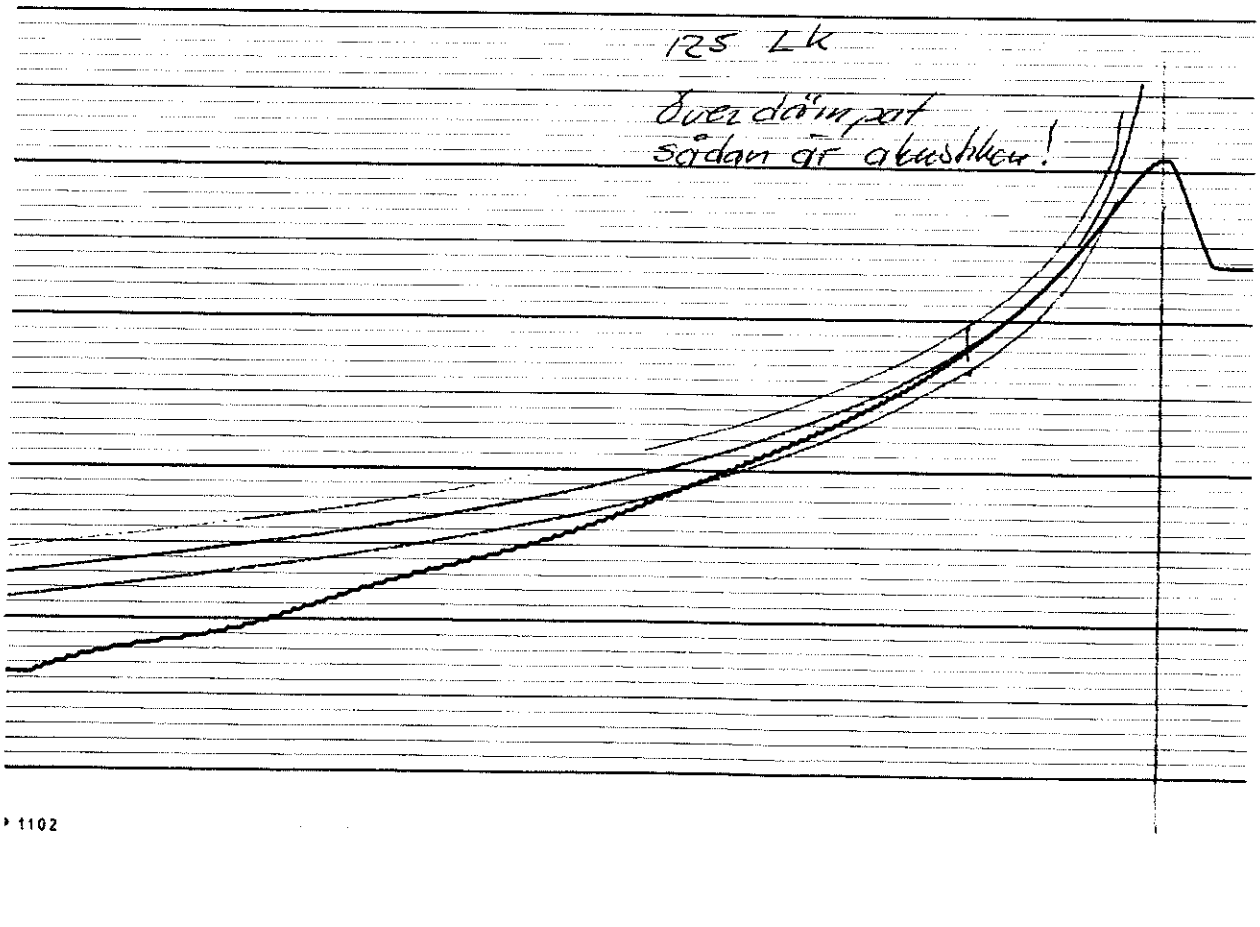






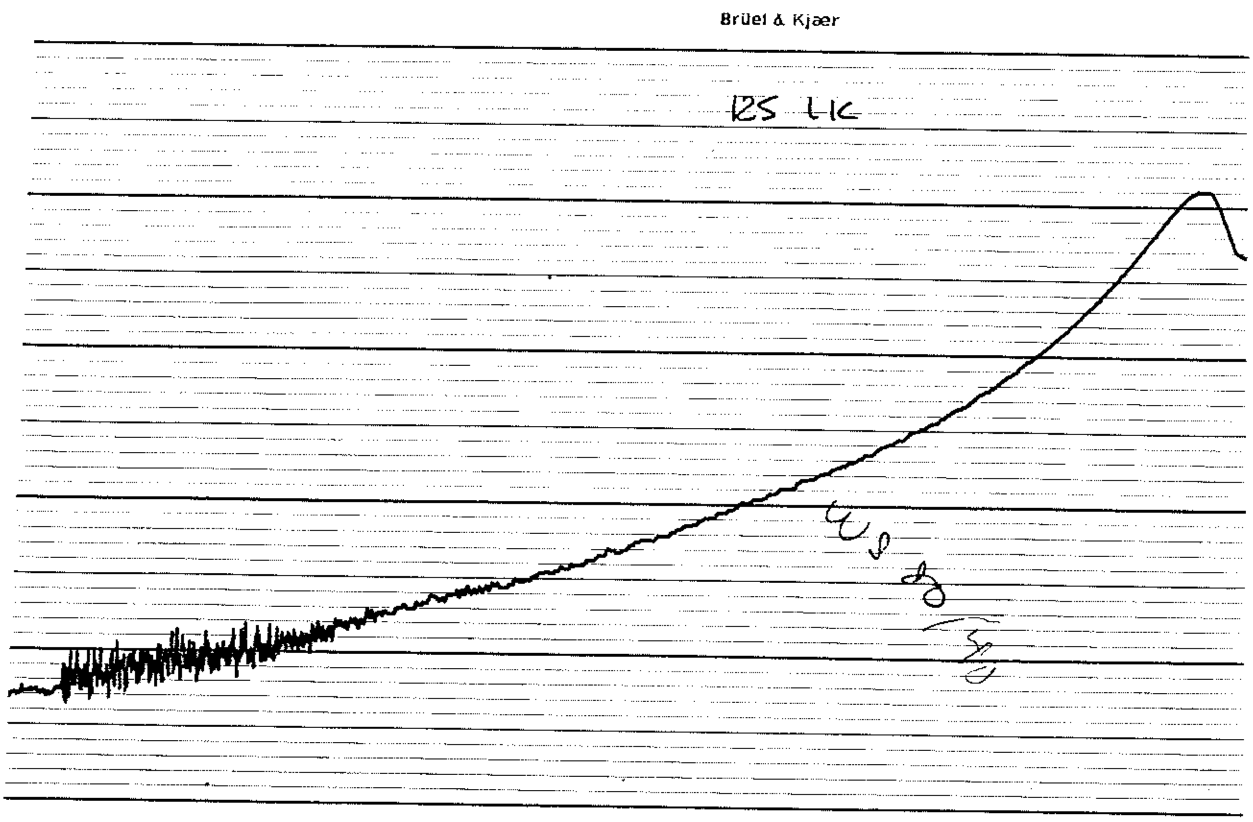
QP 1102

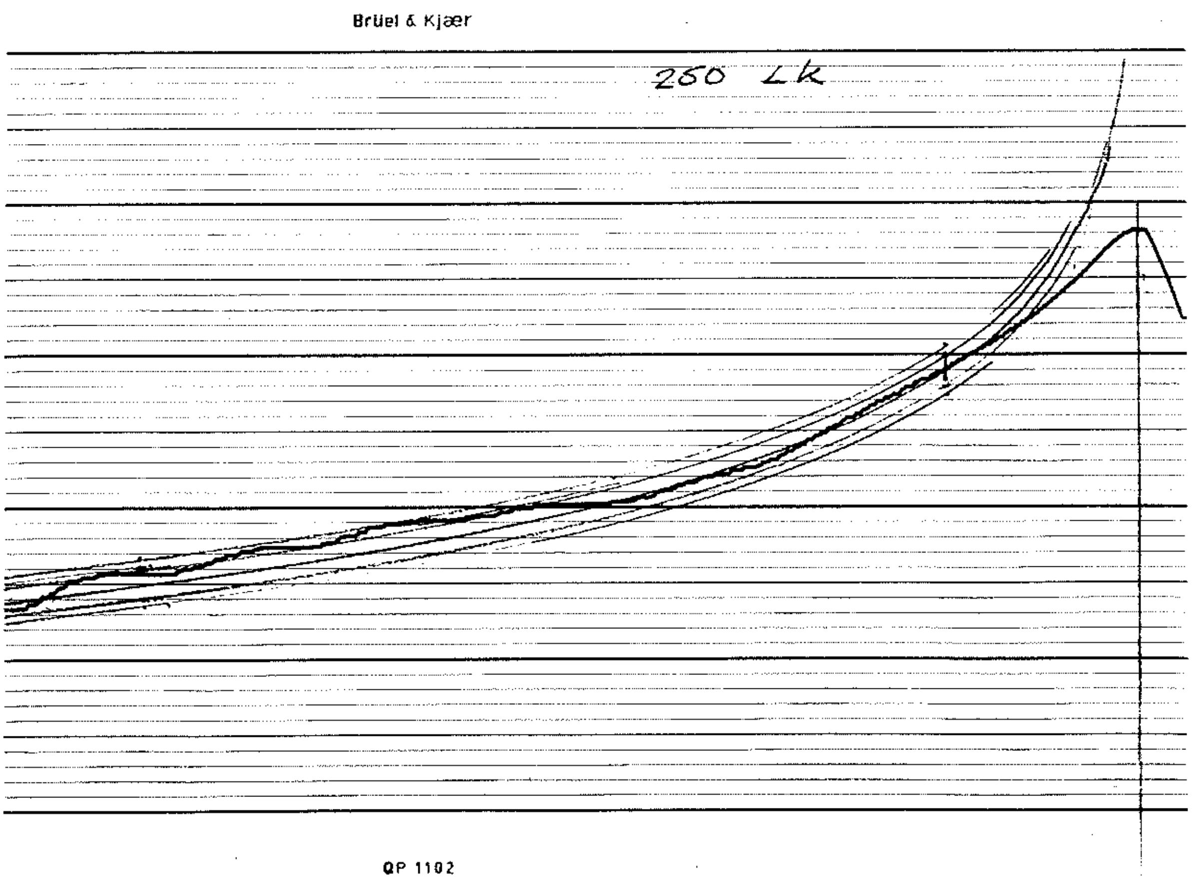
& Kjær



1102

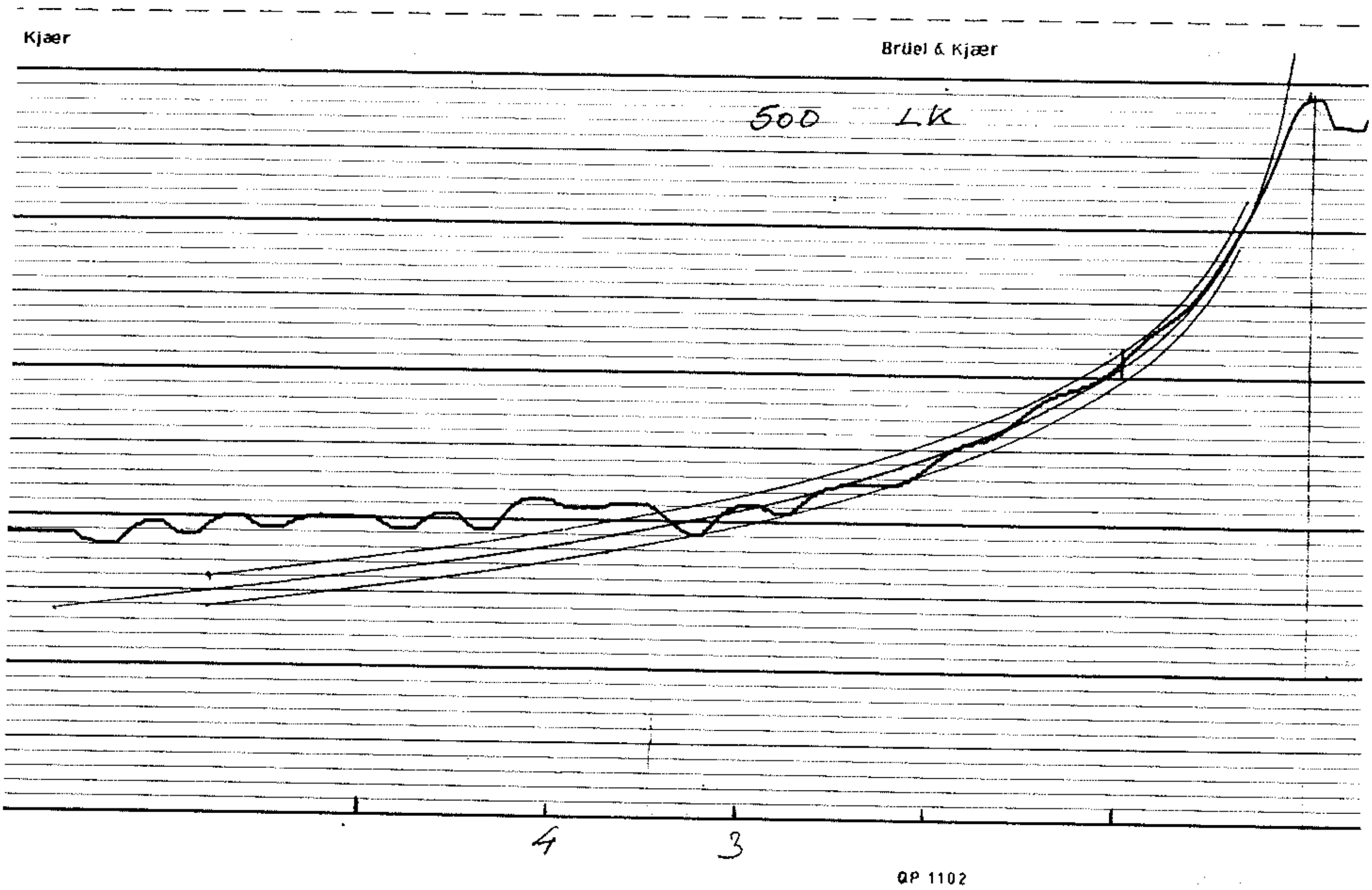
0.85 m from the long wall, 125 and 250 Hz

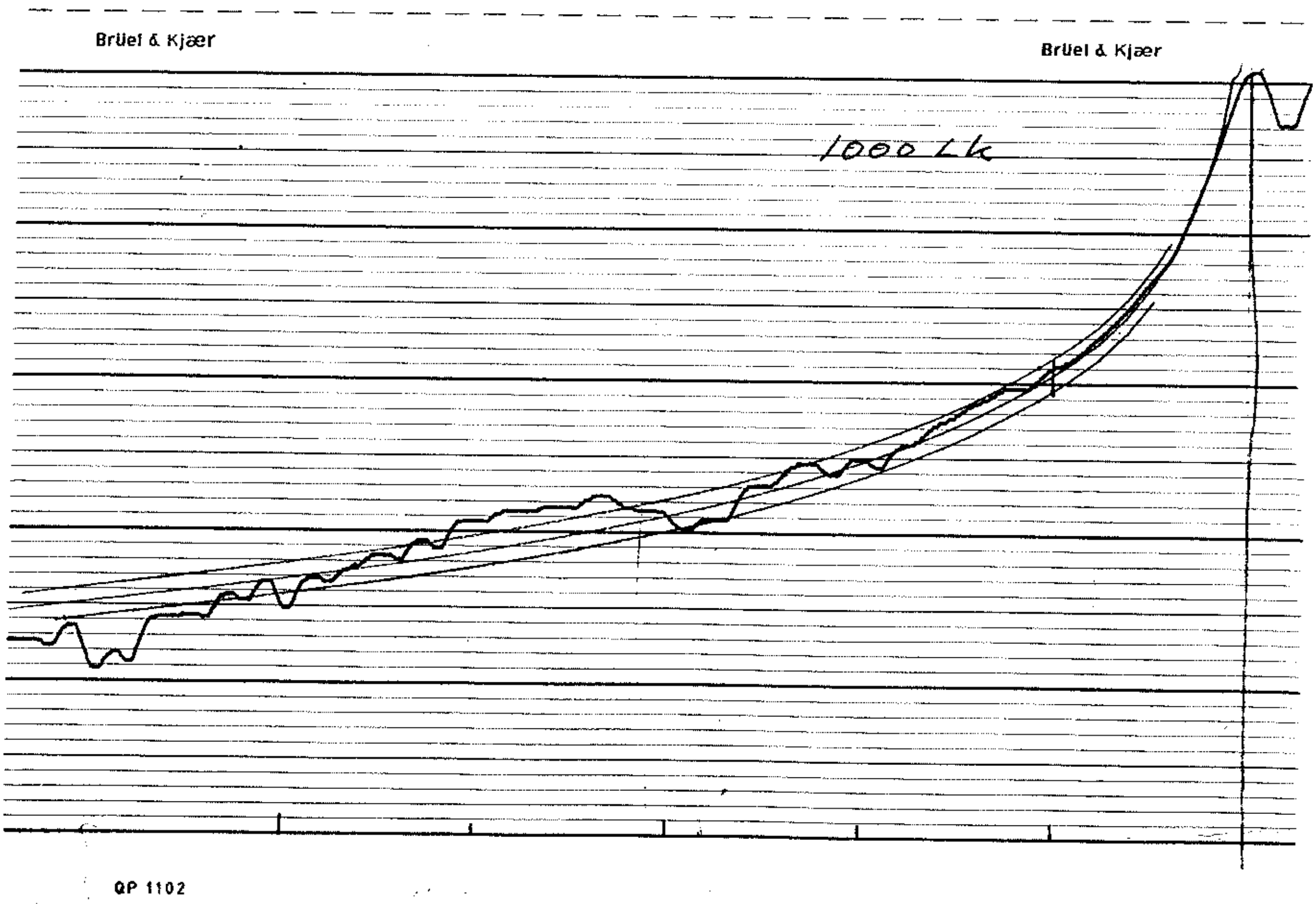


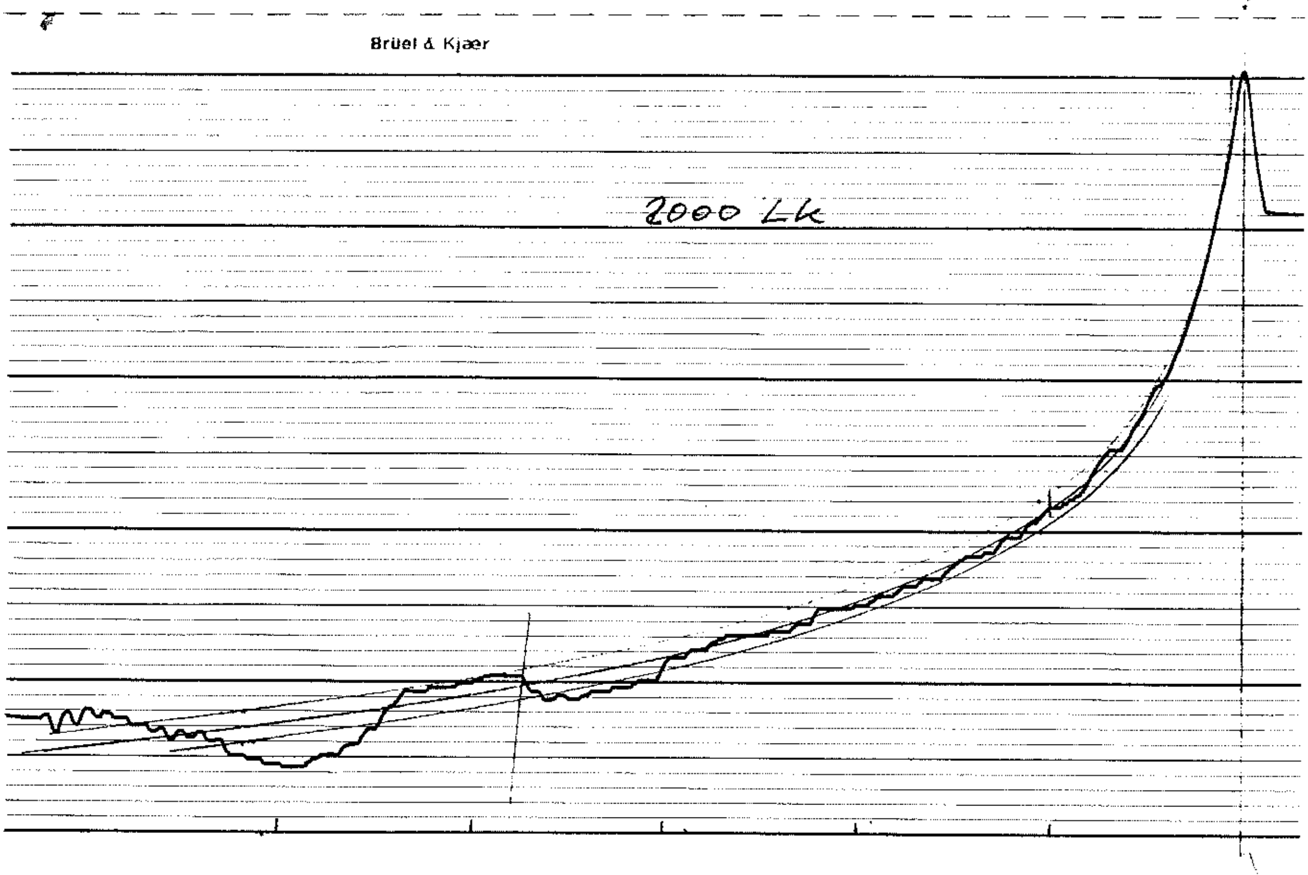


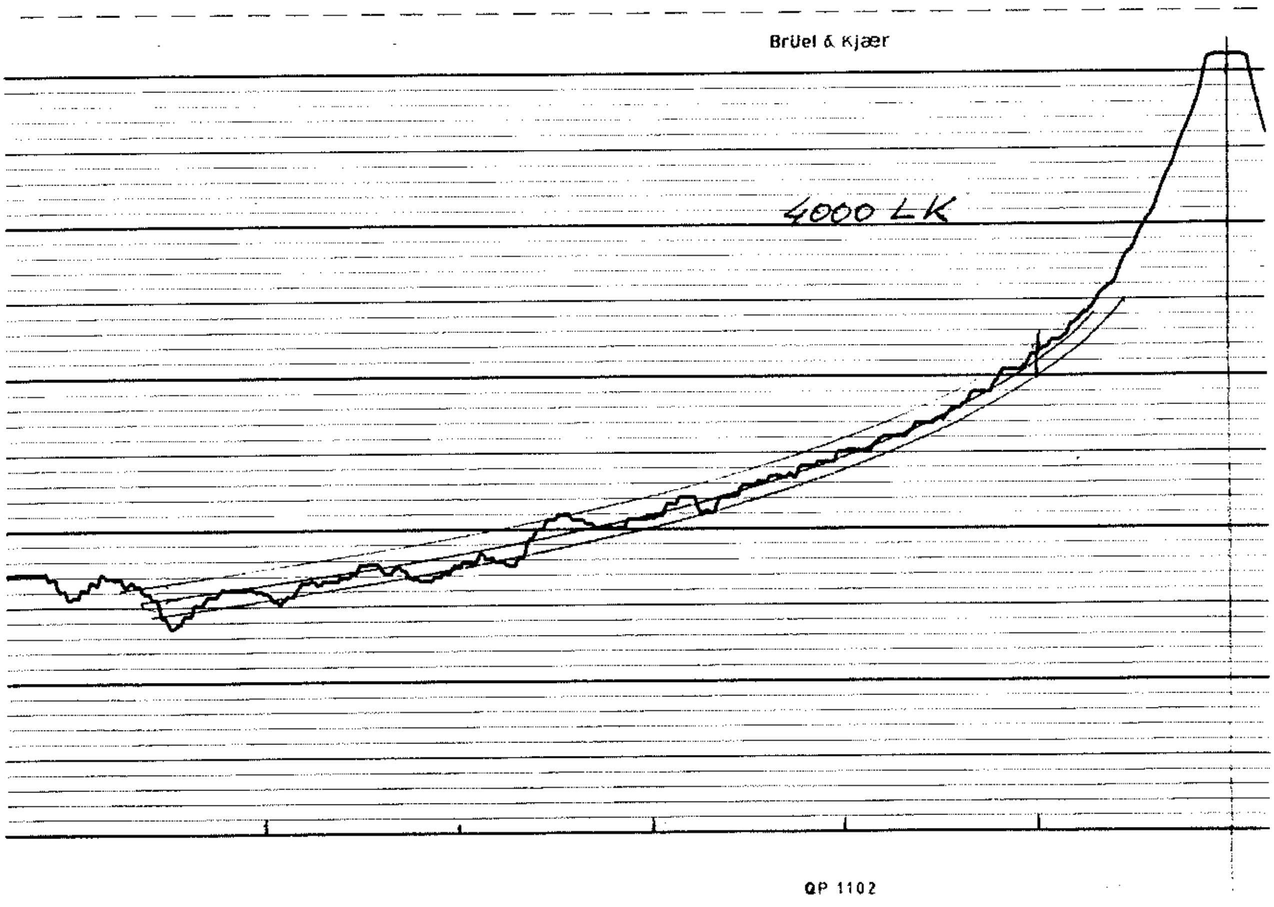
QP 1102

0.85 m from the long wall, 500 and 1000 Hz



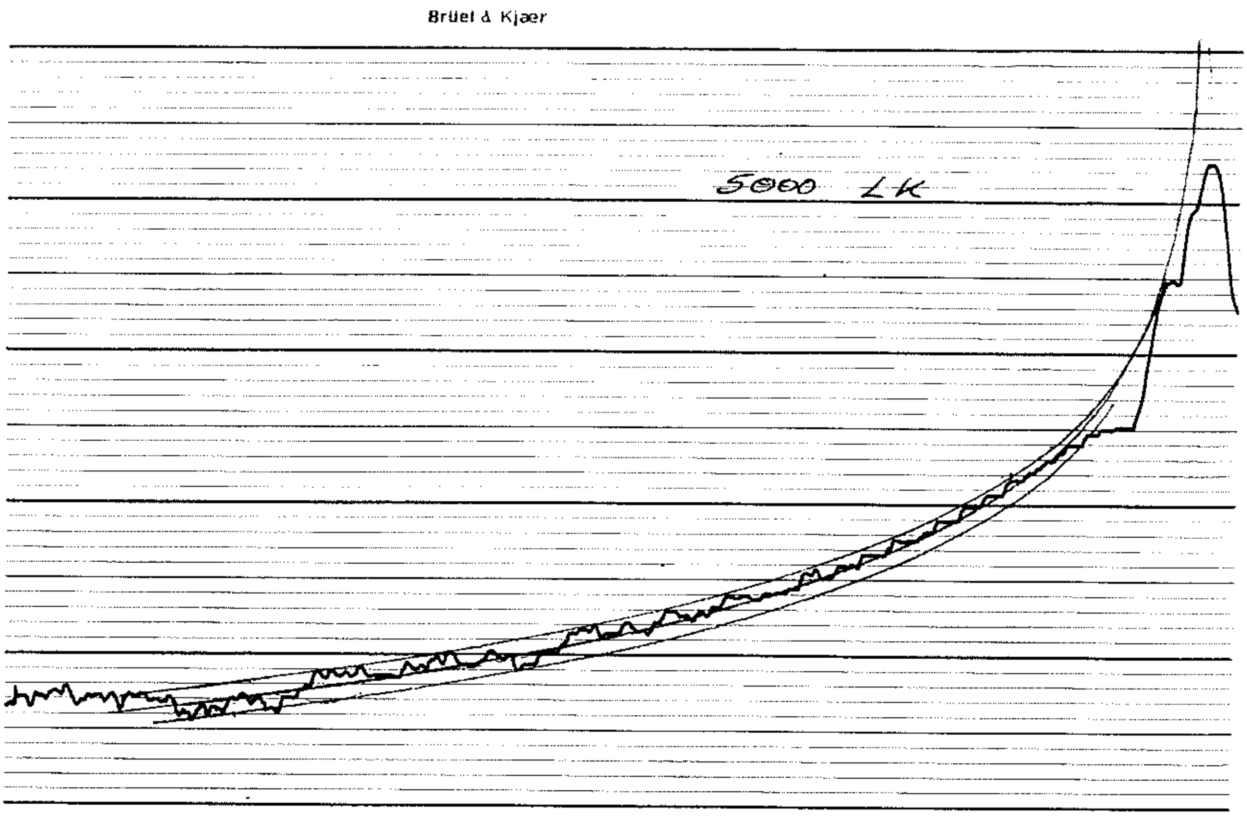


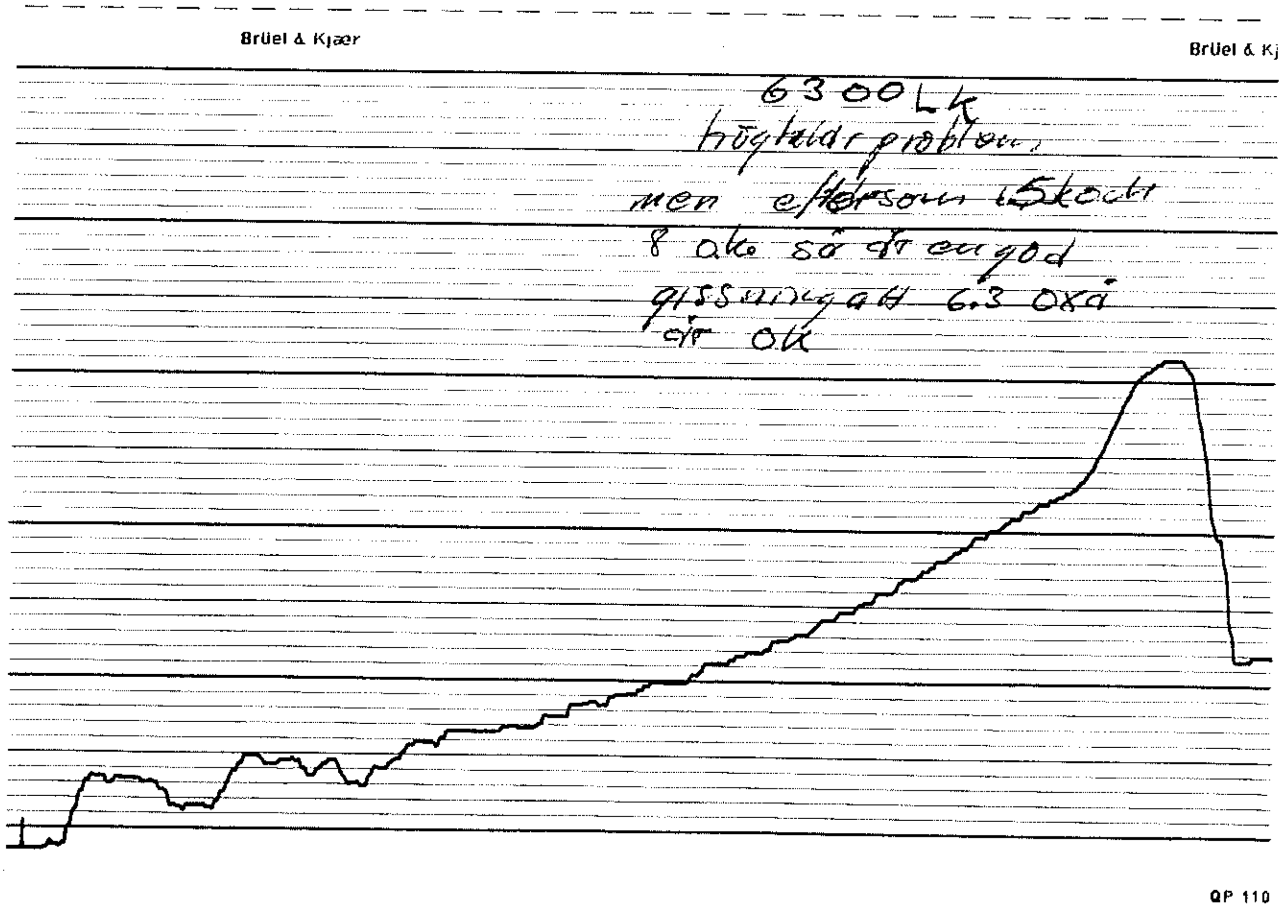




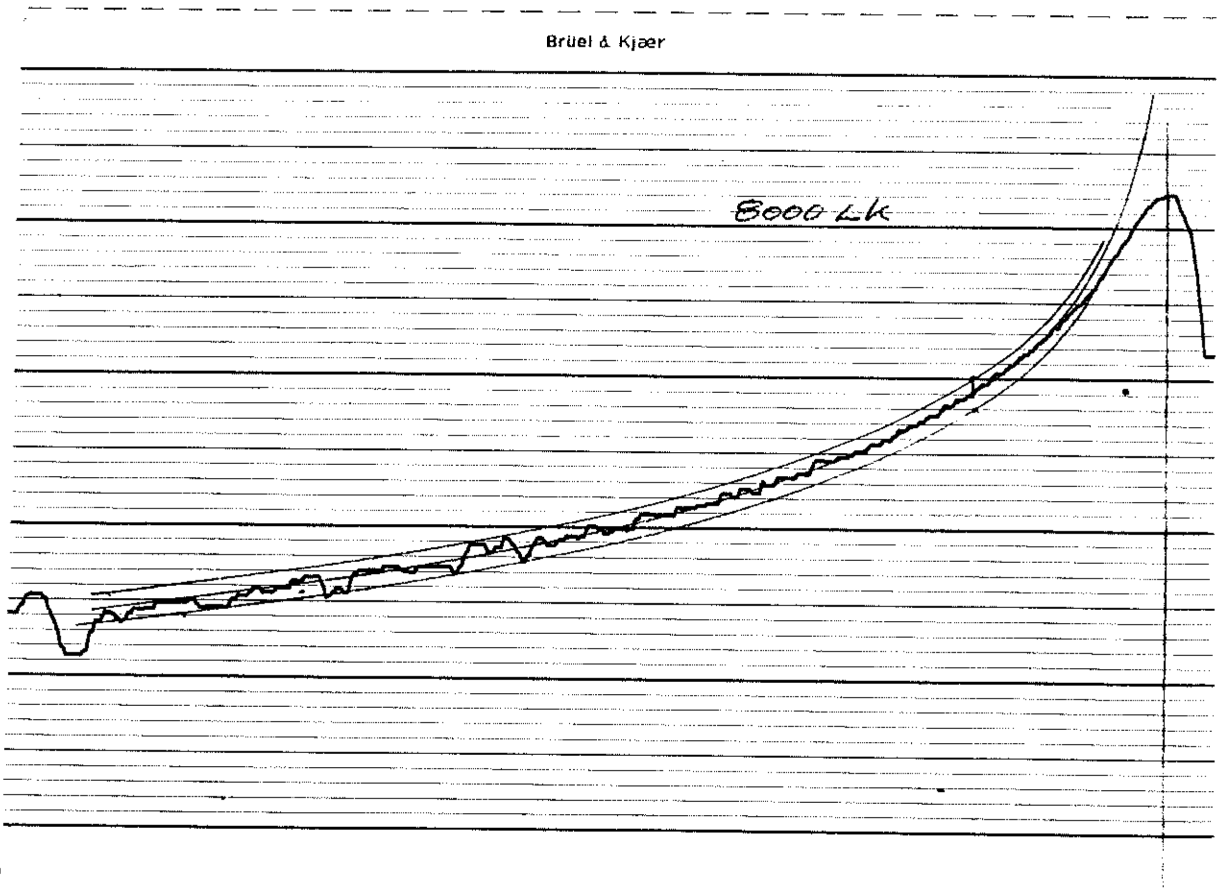
QP 1102

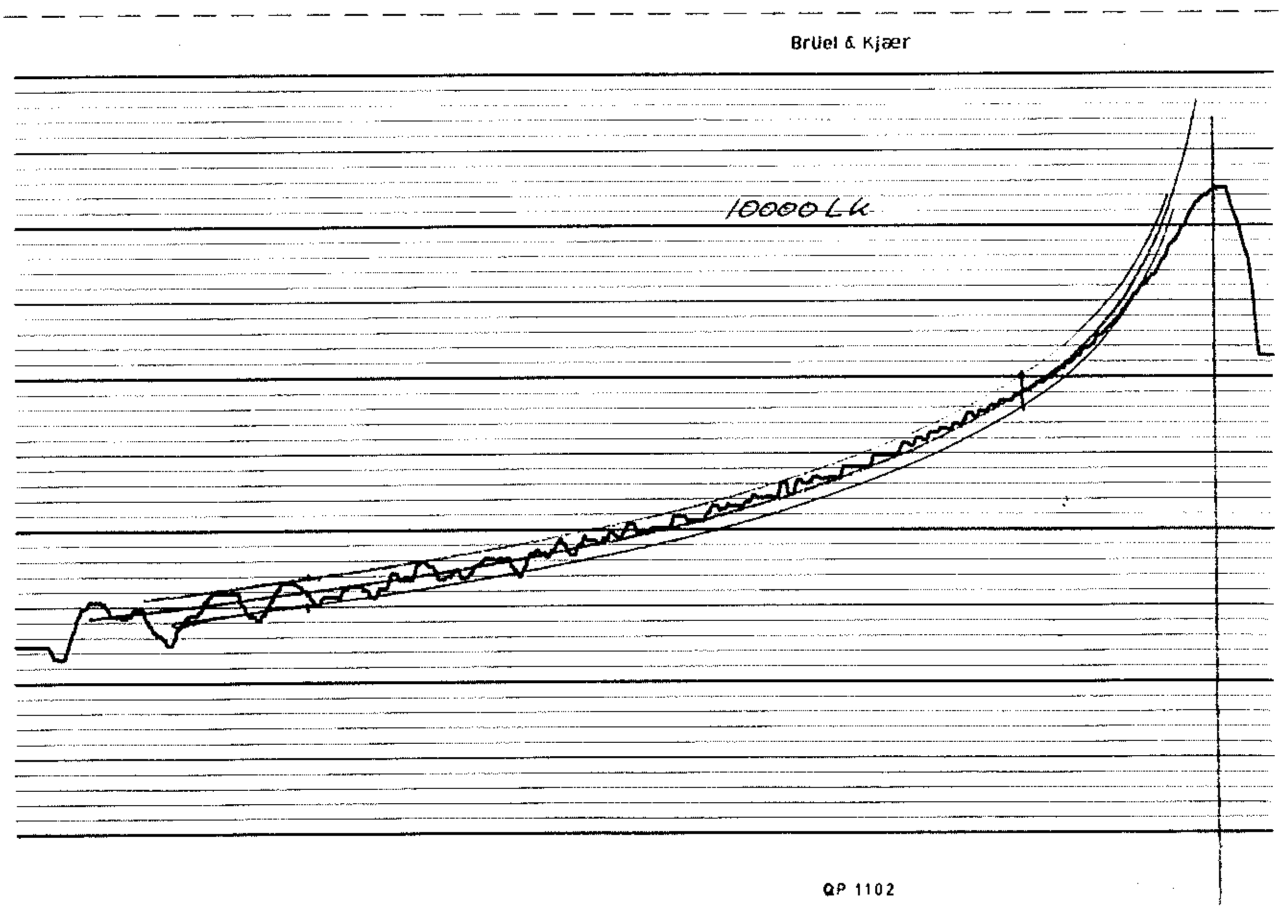
0.85 m from the long wall, 5000 and 6300 Hz

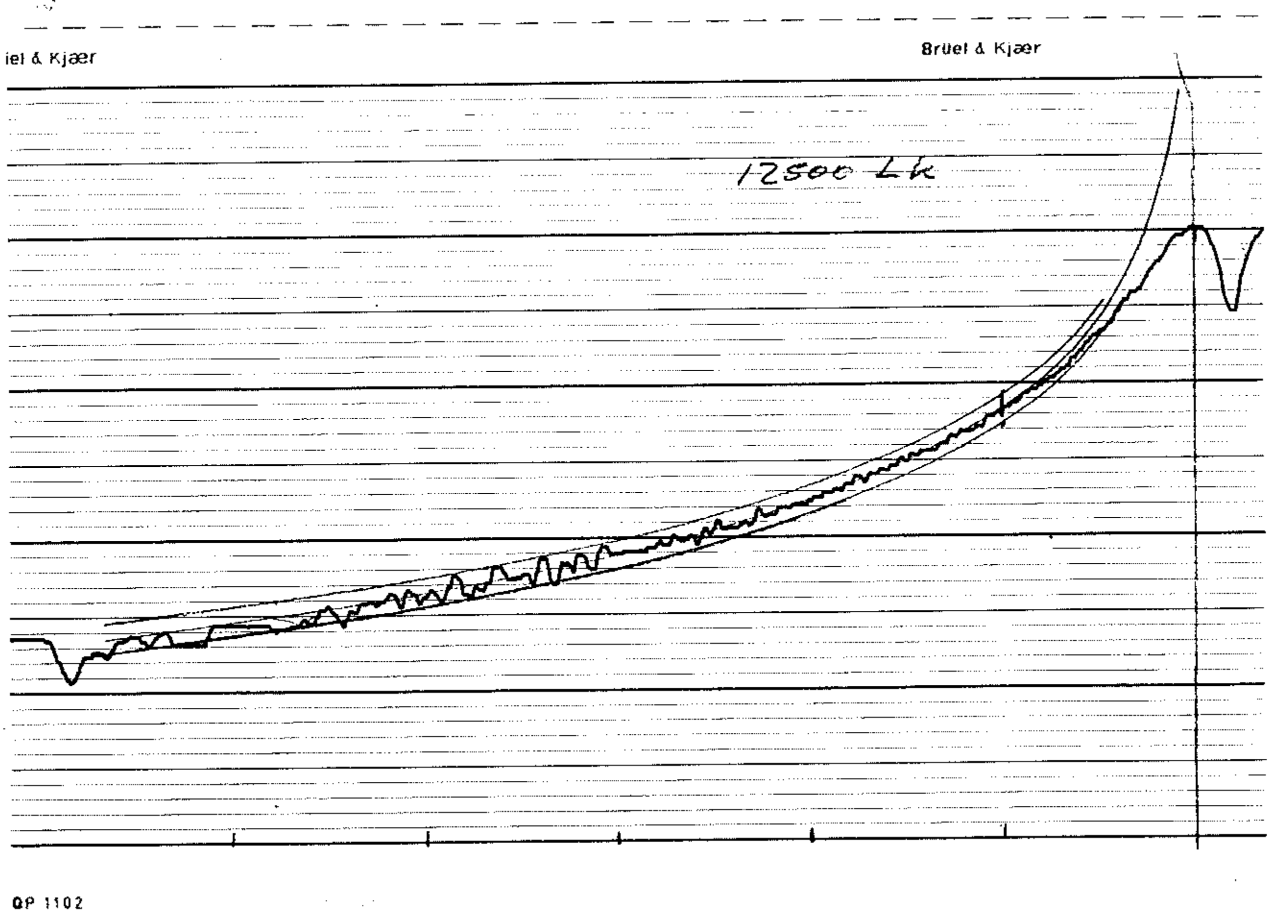


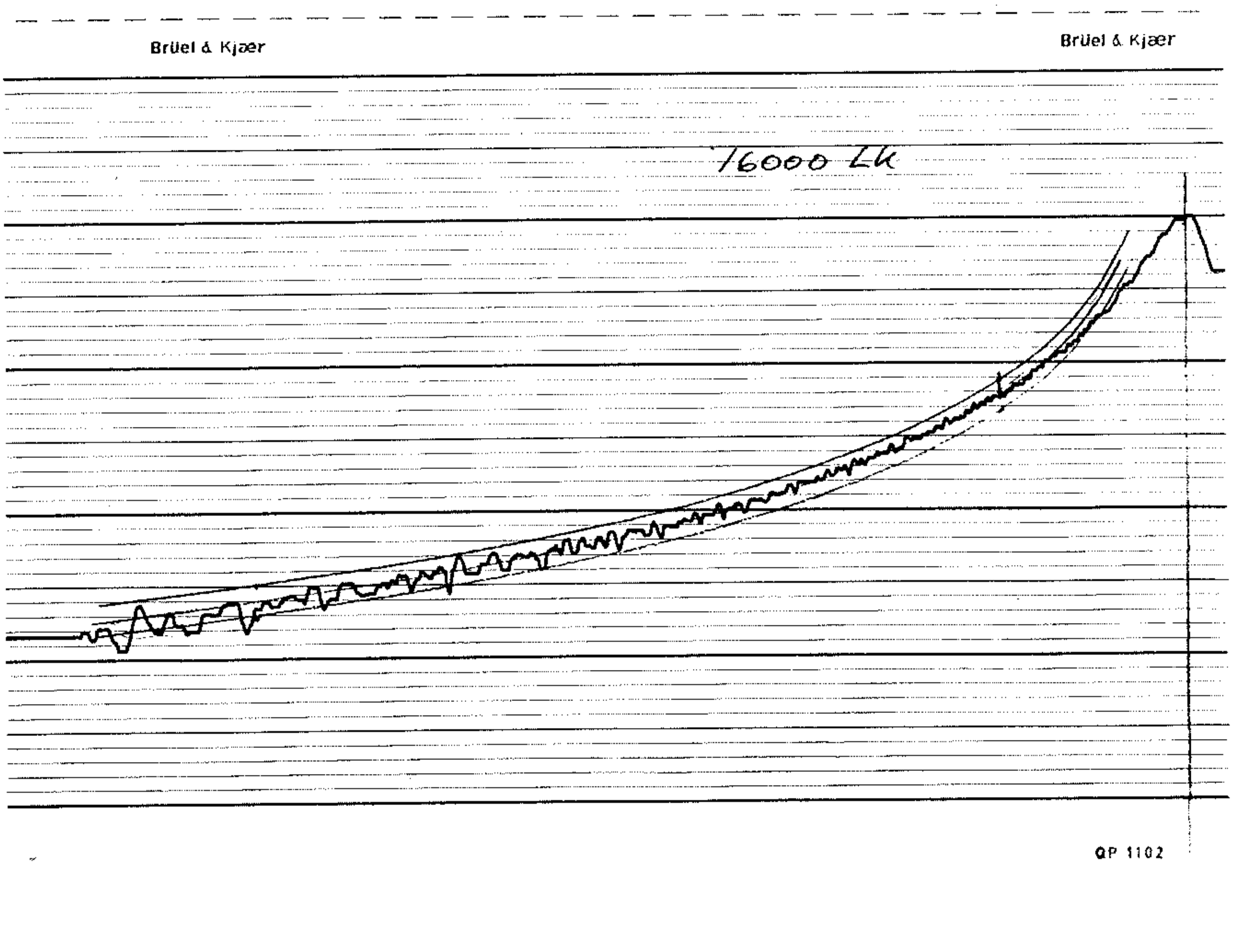


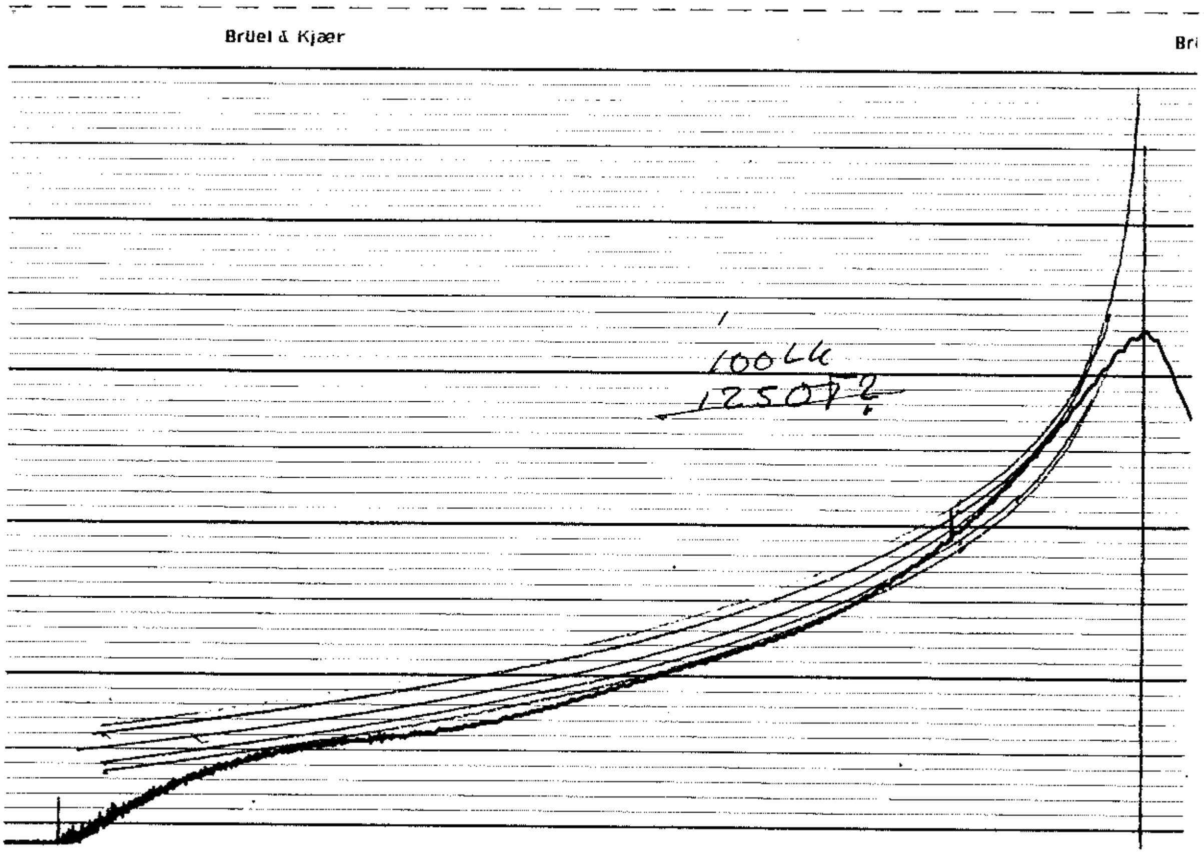
0.85 m from the long wall, 8000 and 10000 Hz

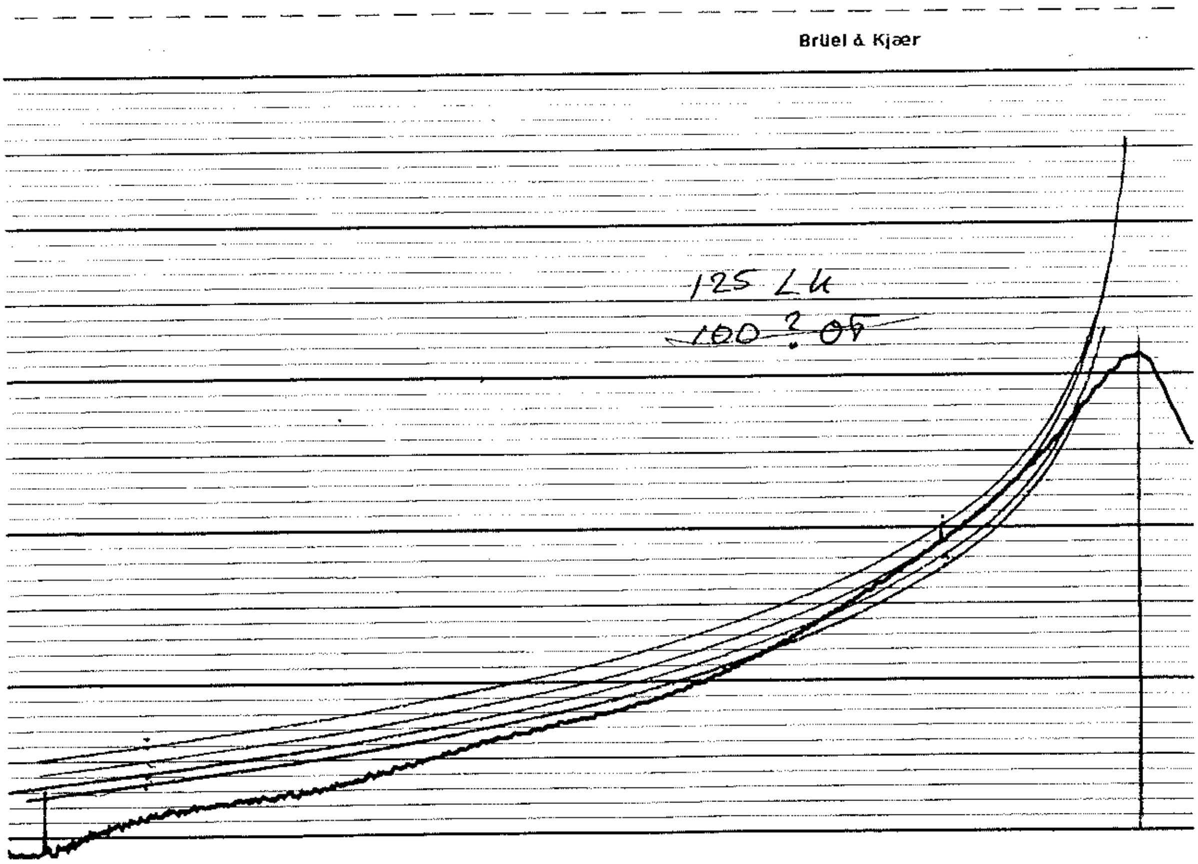


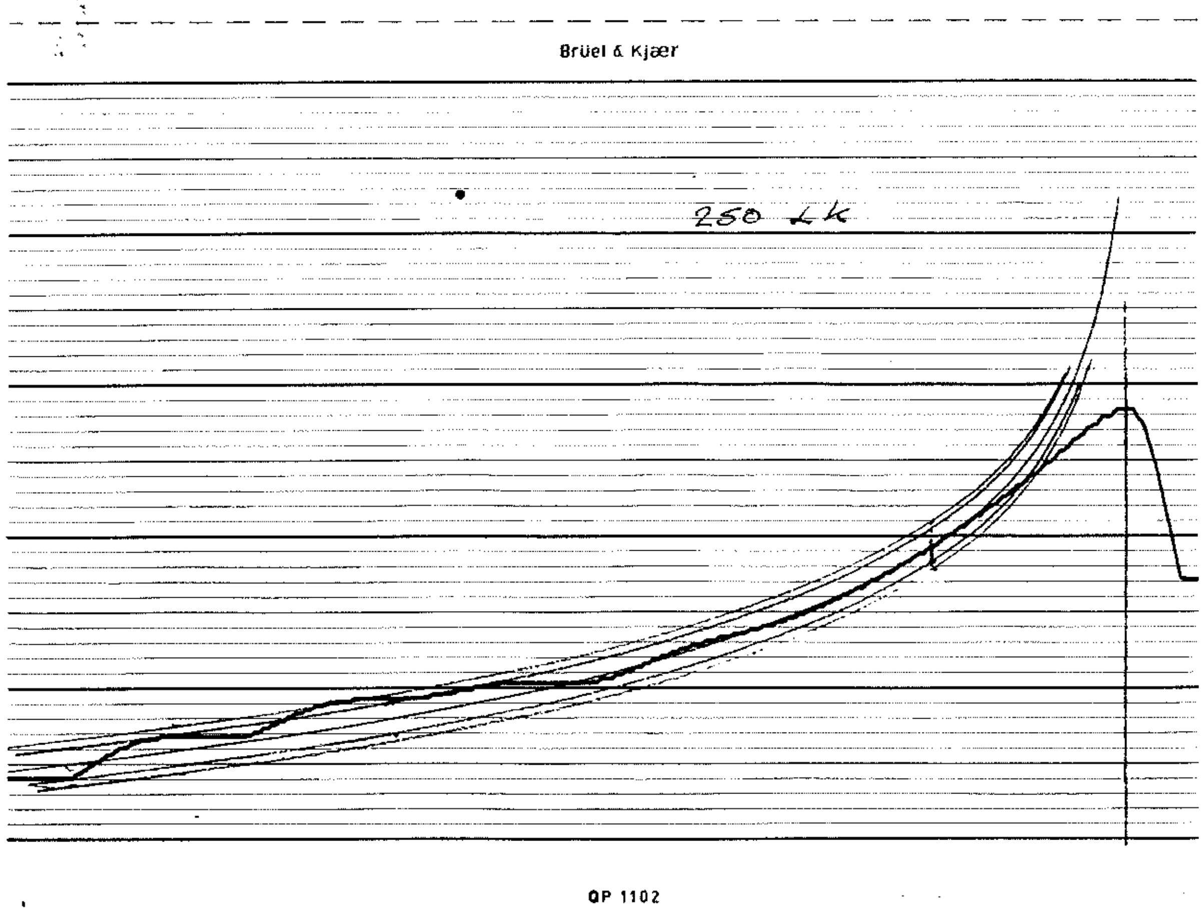


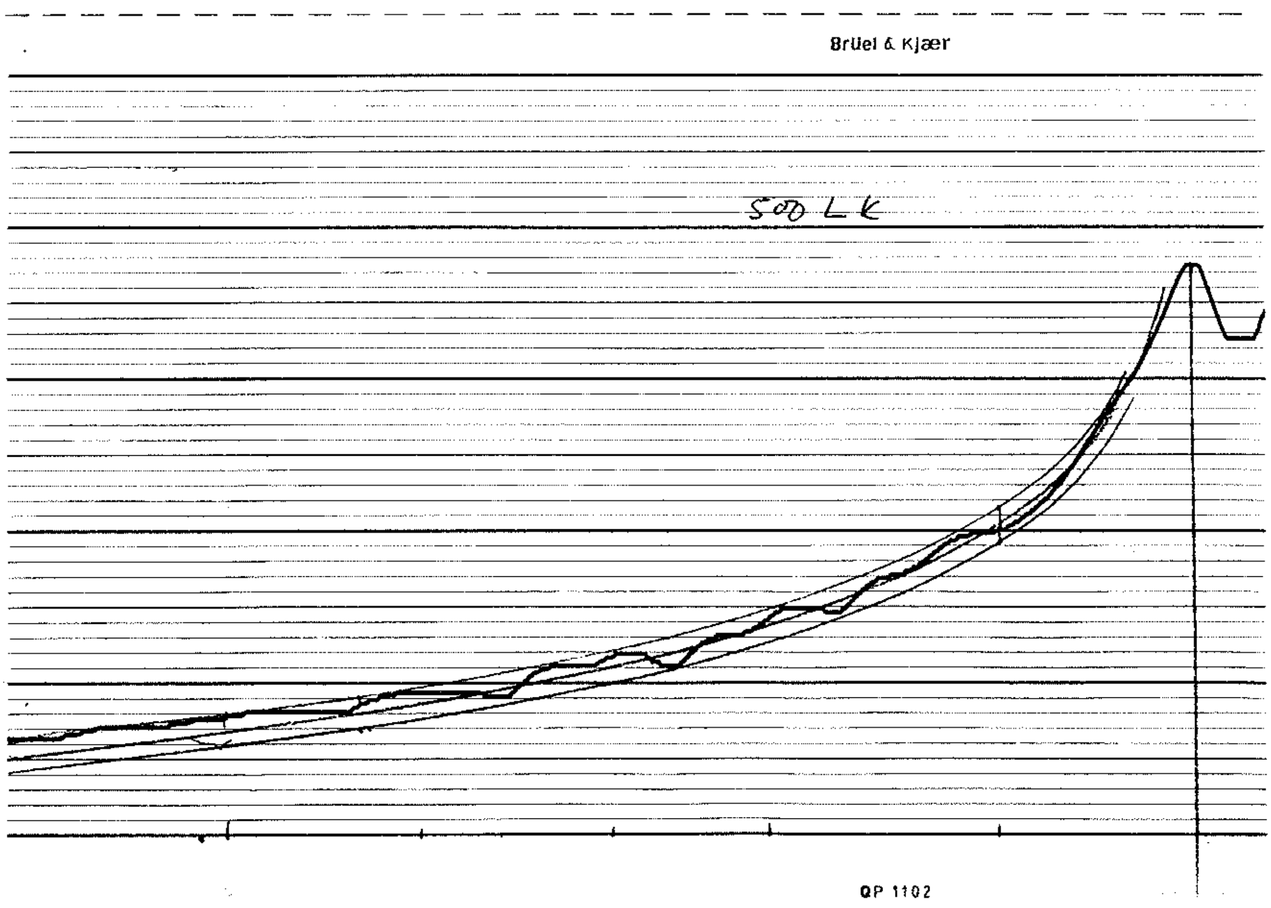

iel & Kjær
Brüel & Kjær
12500 Lk
QP 1102


Brüel & Kjær
Brüel & Kjær
16000 Lk
QP 1102

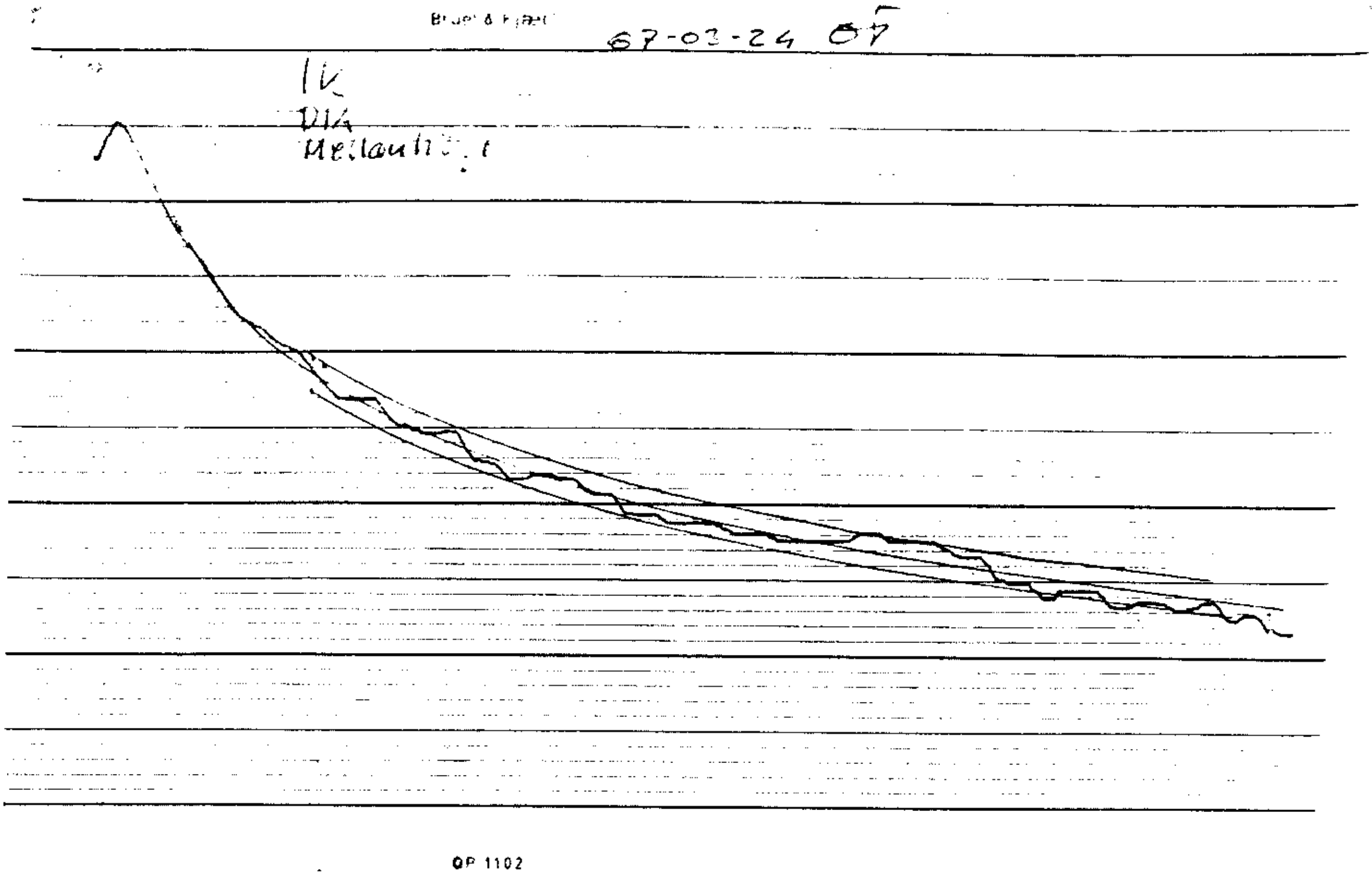

Brüel & Kjær
100 Lk

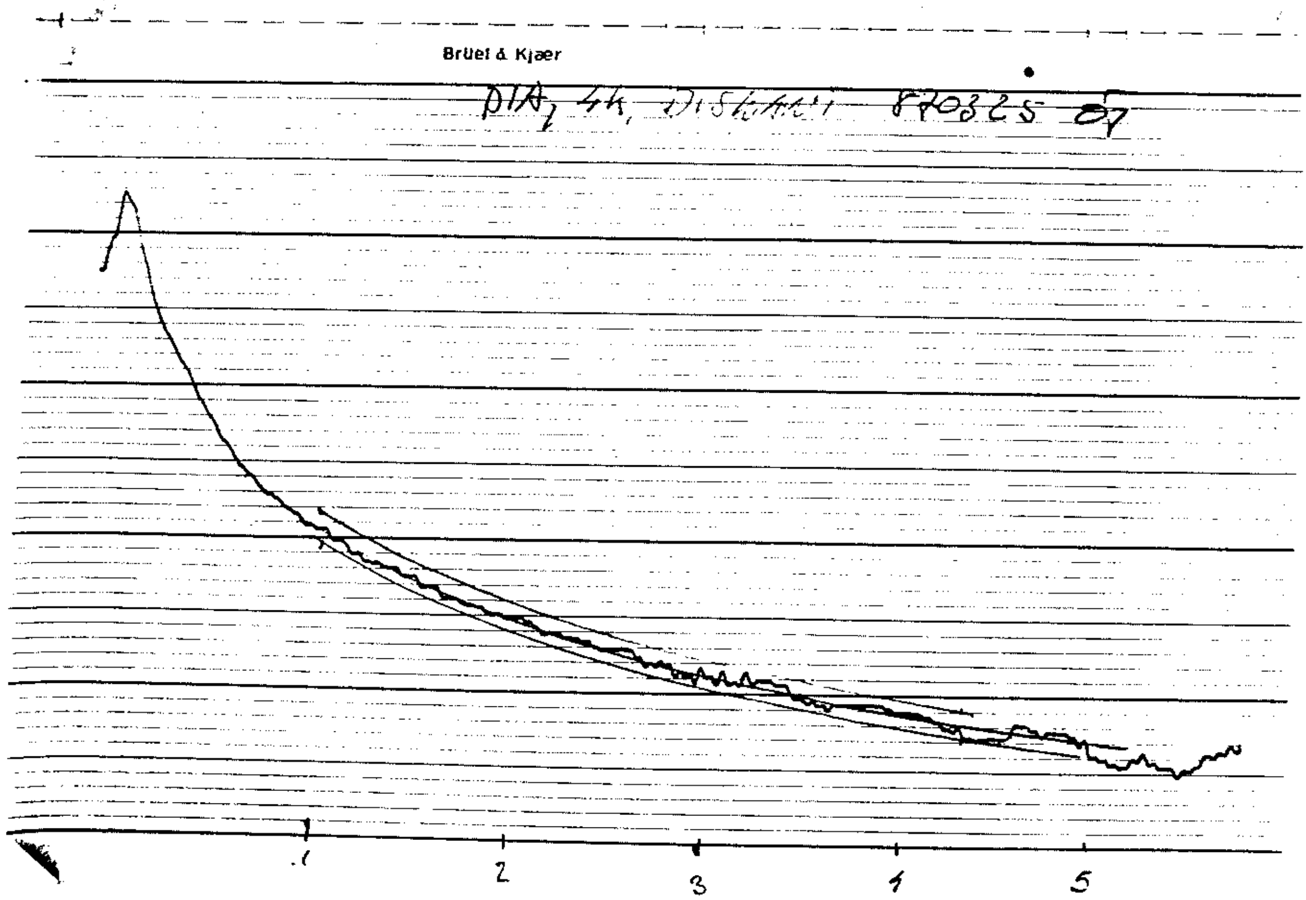

Brüel & Kjær
125 Lk

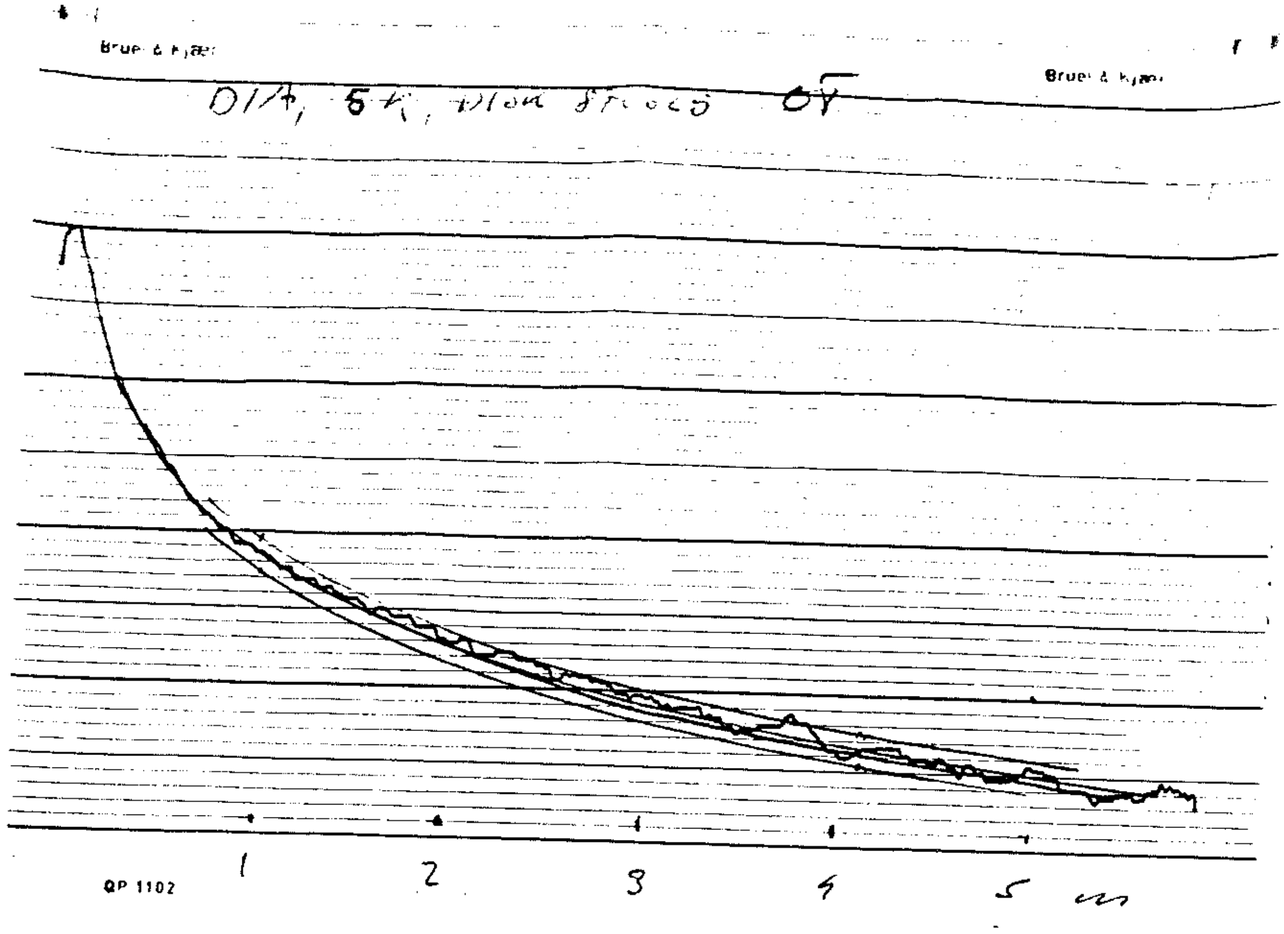

Brüel & Kjær
250 LK
QP 1102


Brüel & Kjær
500 LK
QP 1102

Diagonally, 1000 and 2000 Hz




Brüel & Kjær
1
2
3
4
5


Brüel & Kjær
1
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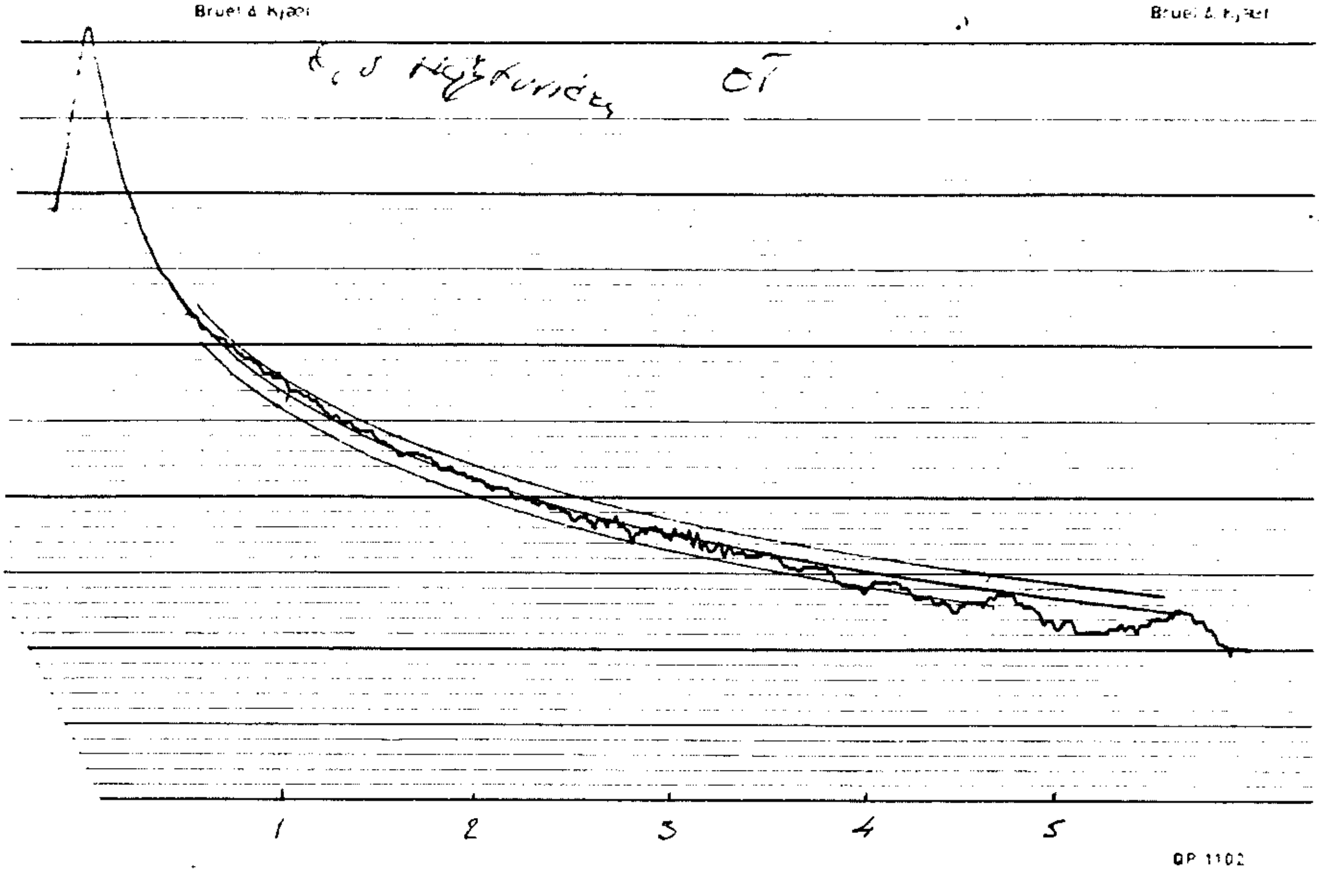
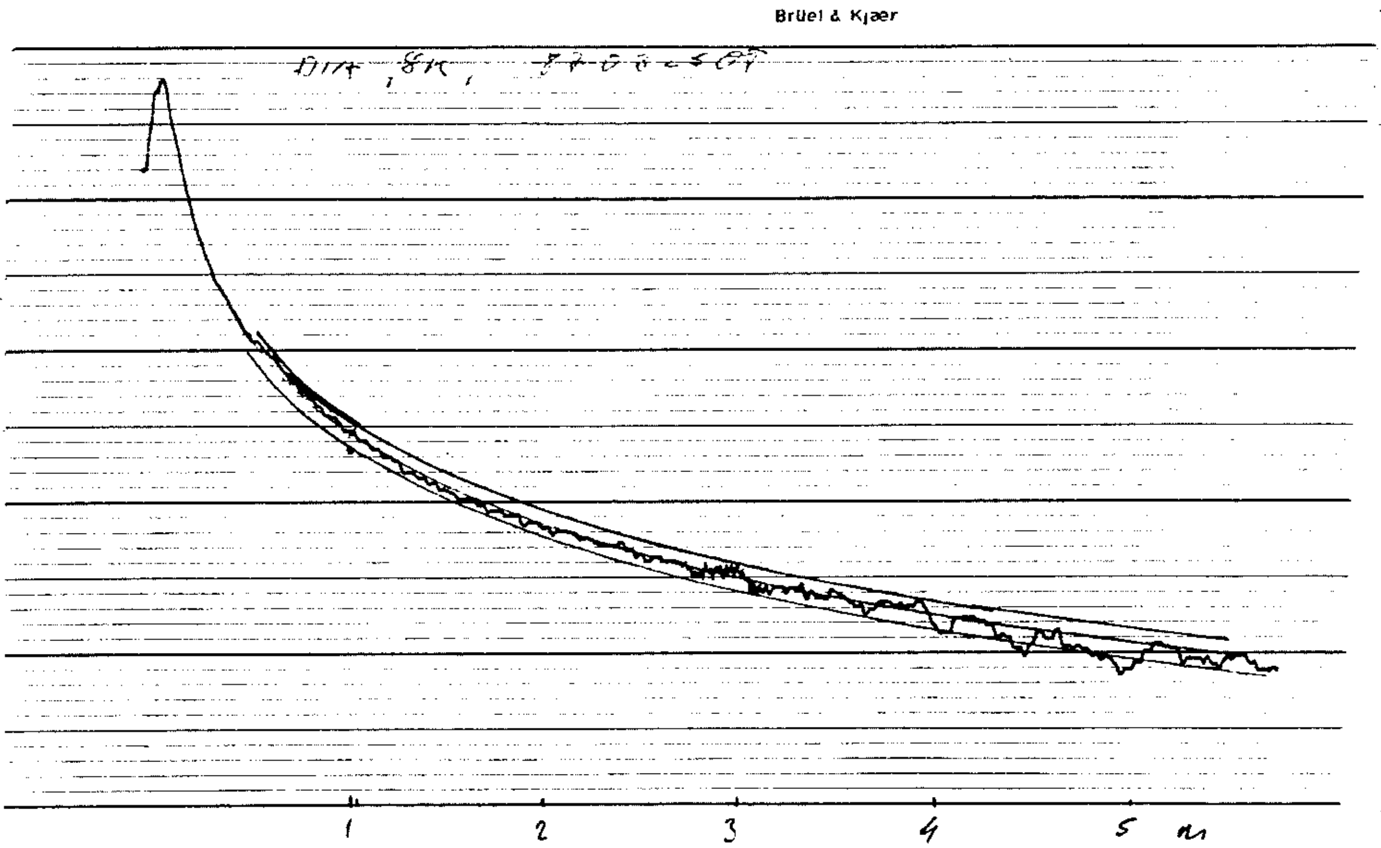
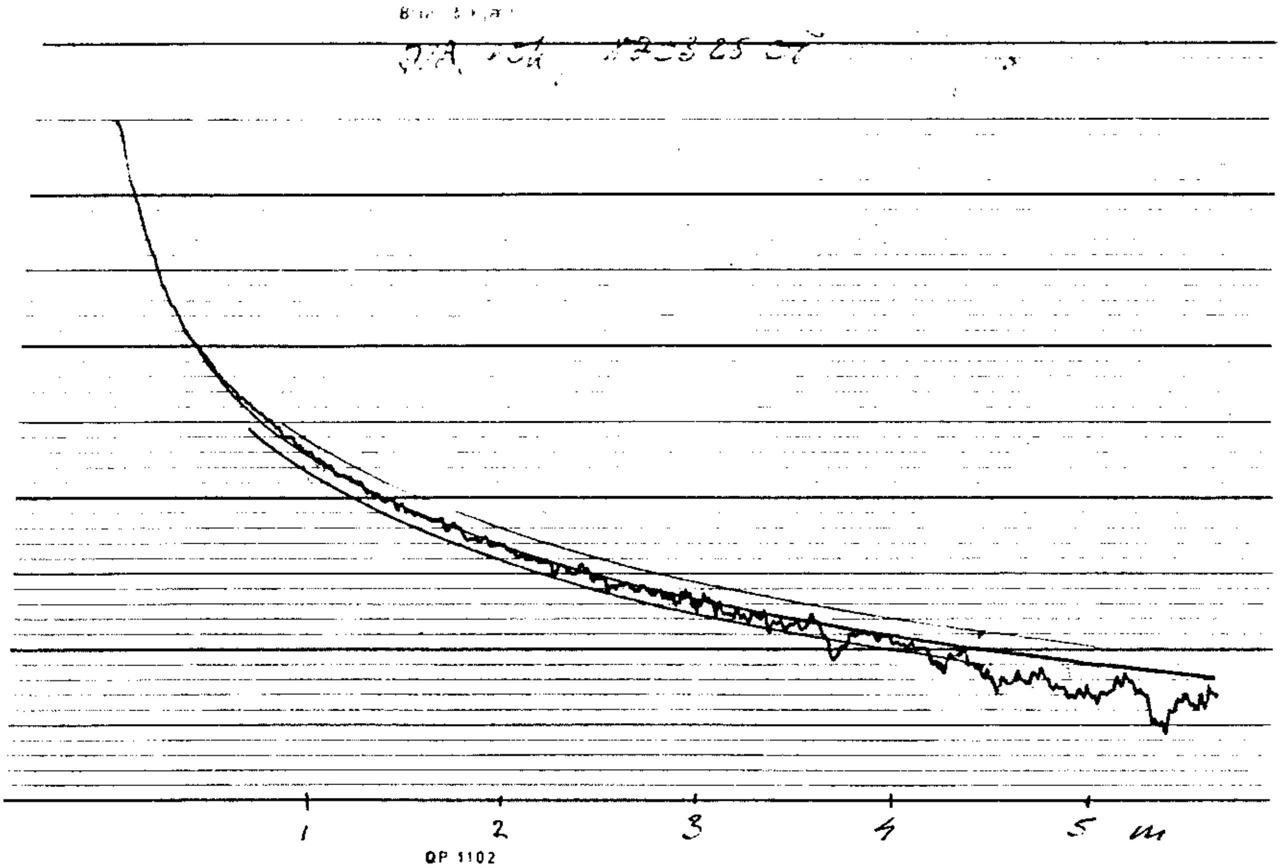
5
QP 1102


Brüel & Kjær
Brüel & Kjær
1
2
3
4
5
QP 1102


Brüel & Kjær
1
2
3
4
5 m


1
2
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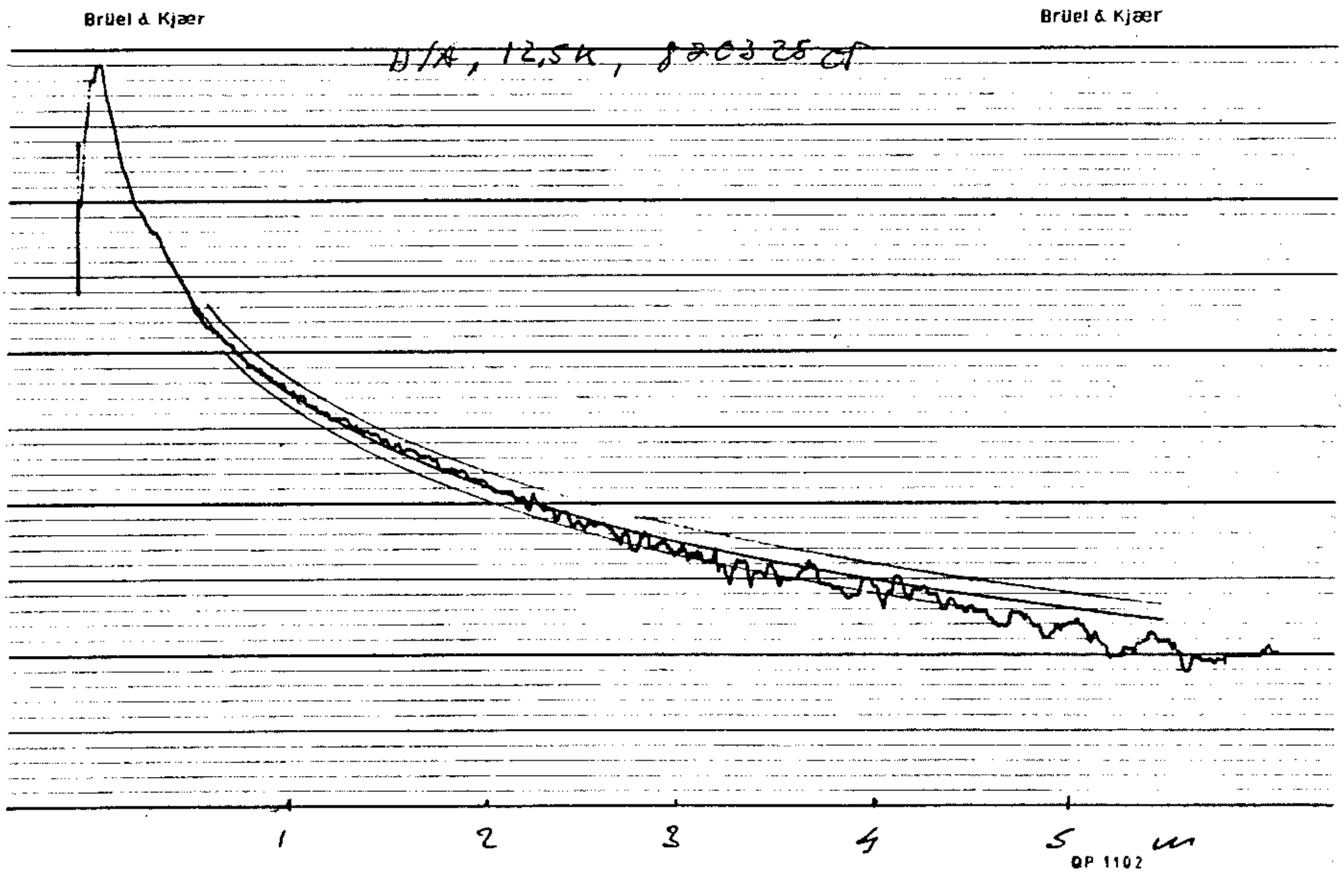
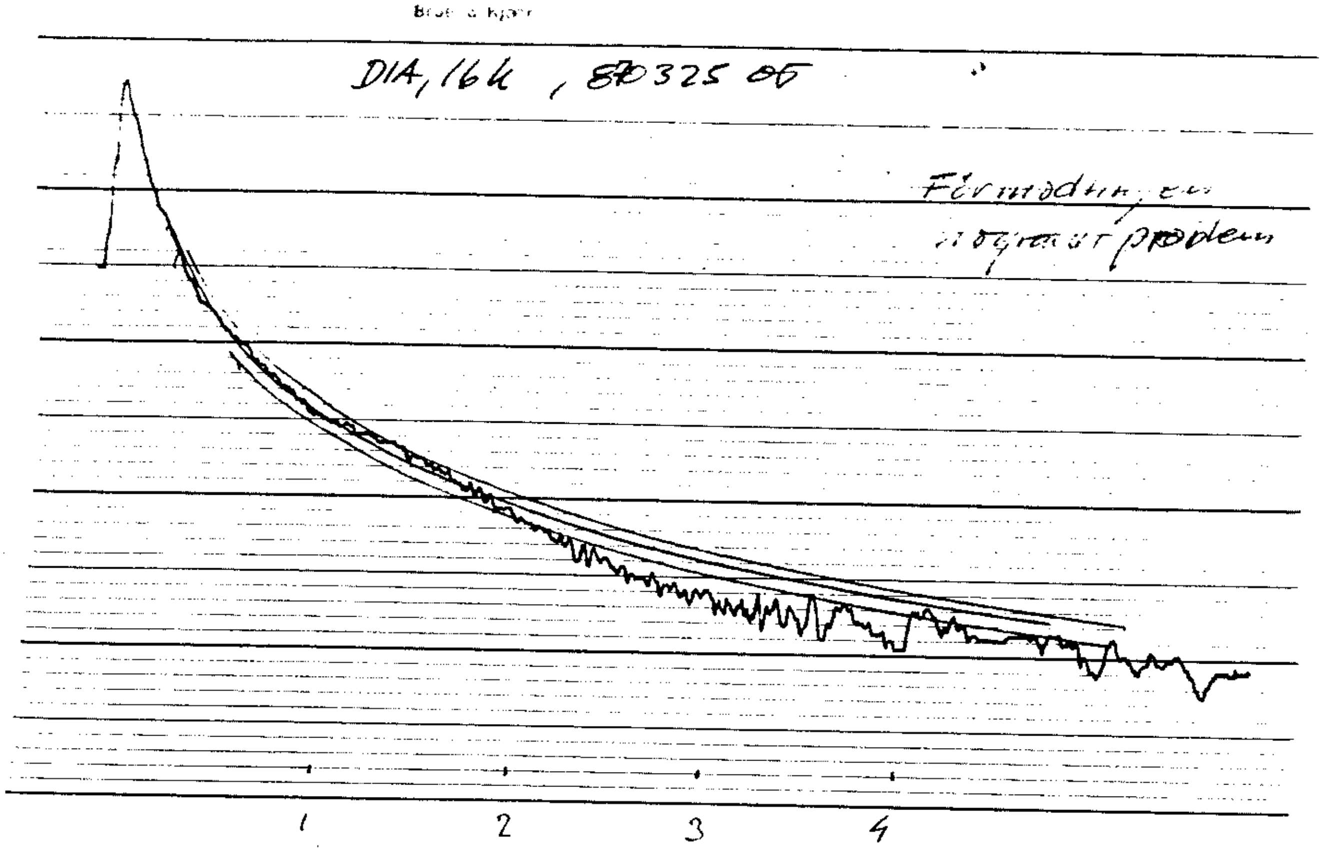
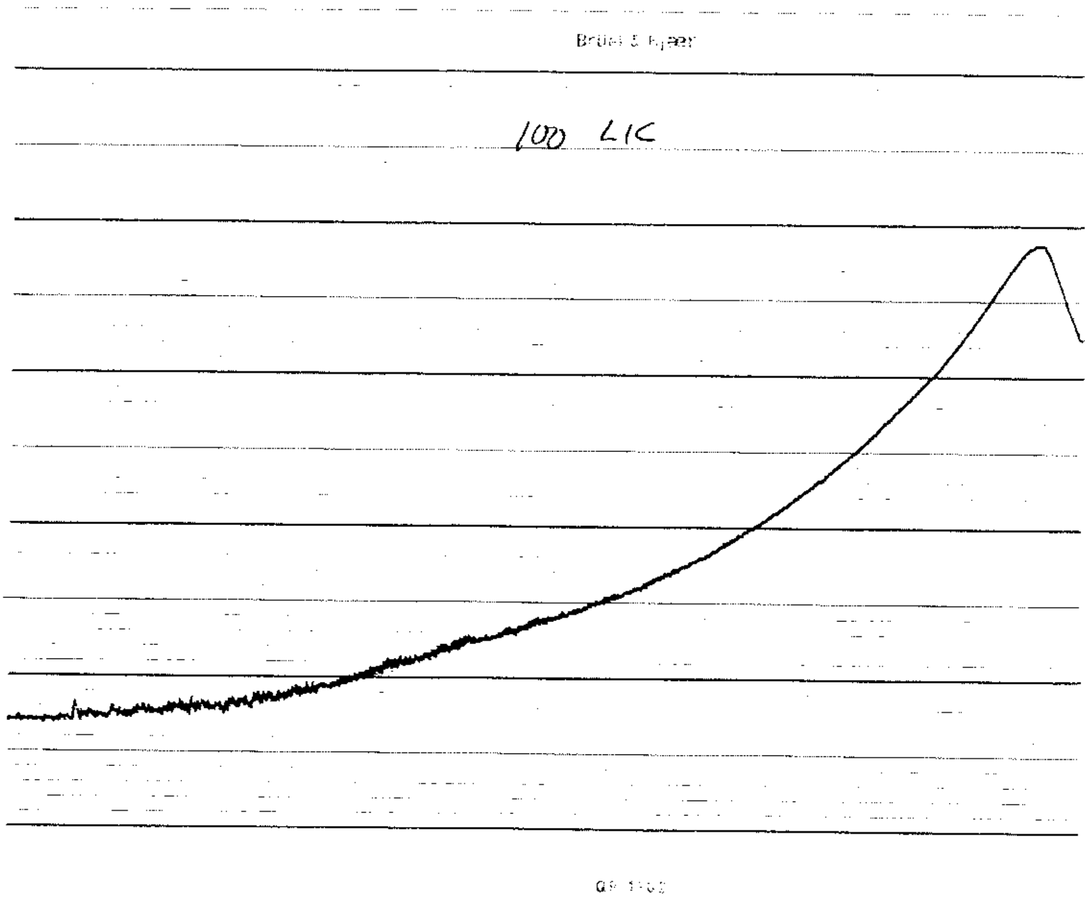
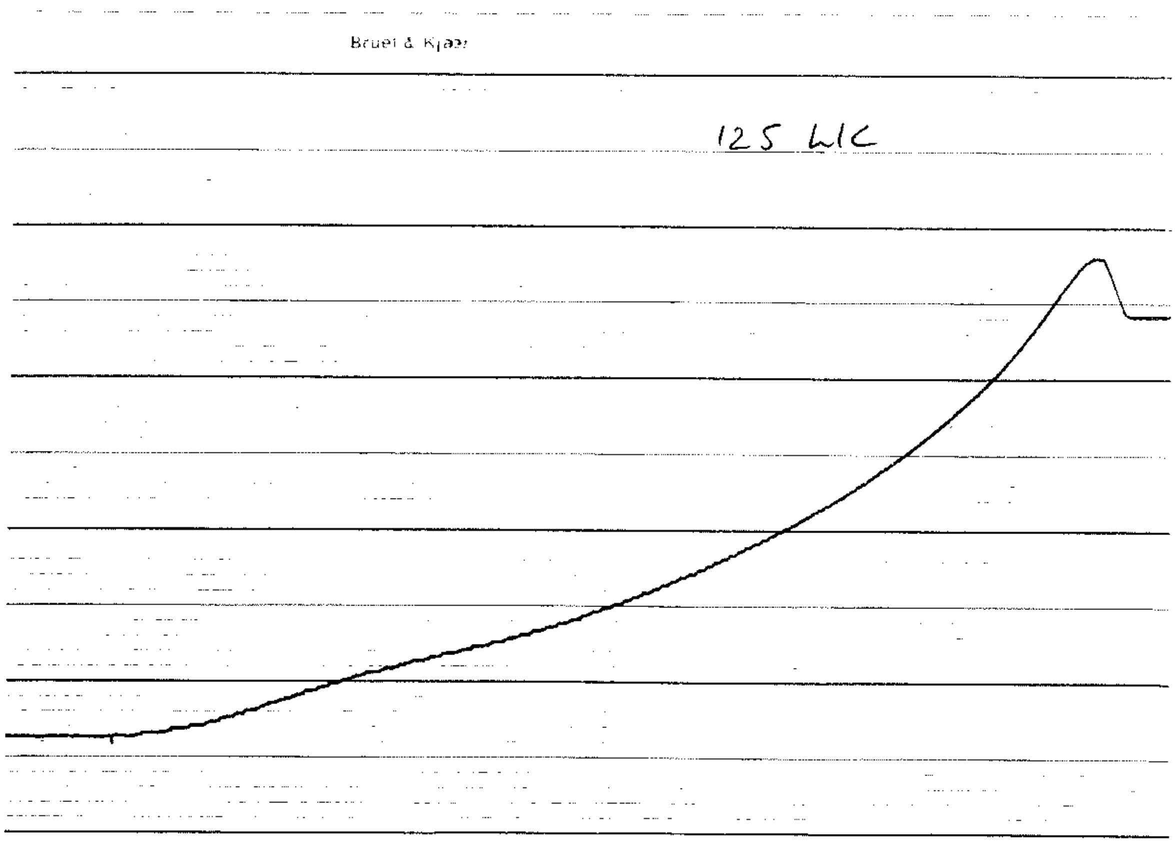
4
5 m
QP 1102


Brüel & Kjær
Brüel & Kjær
1
2
3
4
5 m
QP 1102

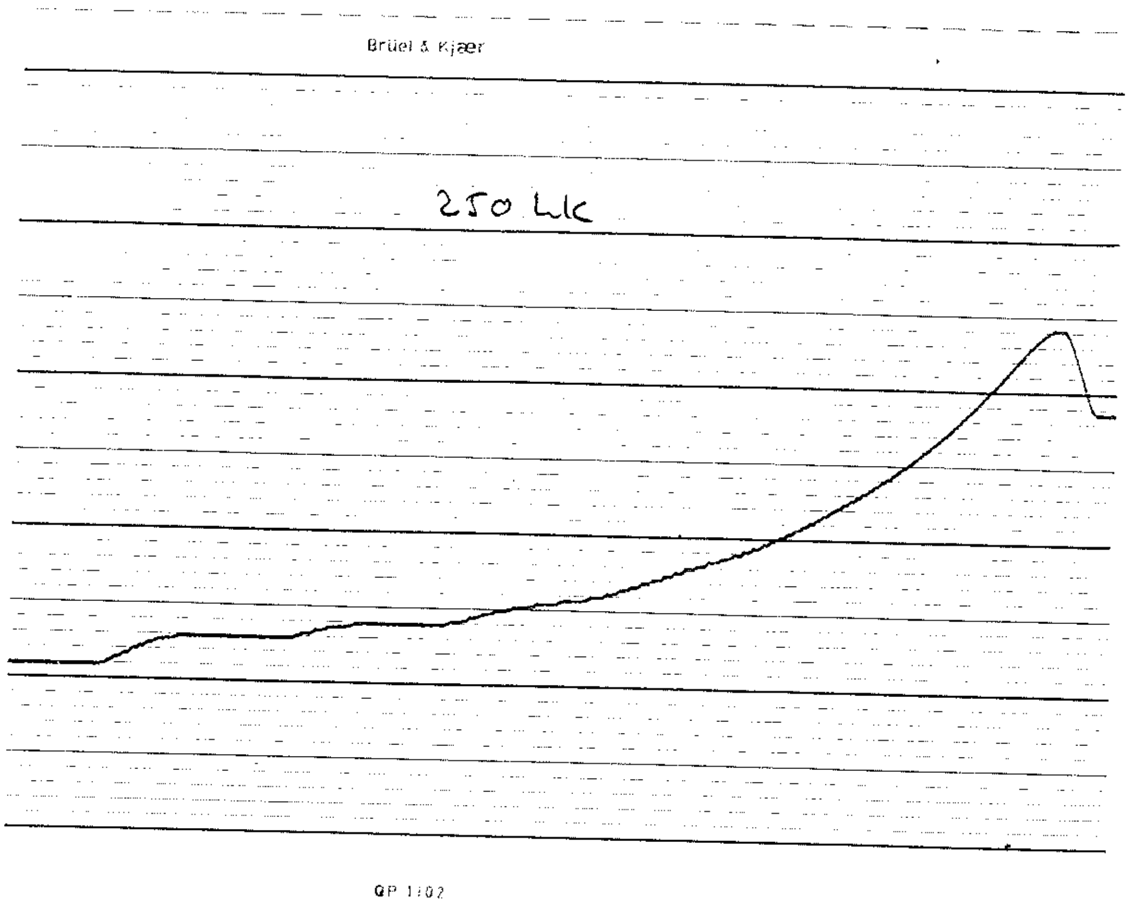

DIA, 16k, 870325 05
1
2
3
4

1.3 m from the long wall, 100 and 125 Hz

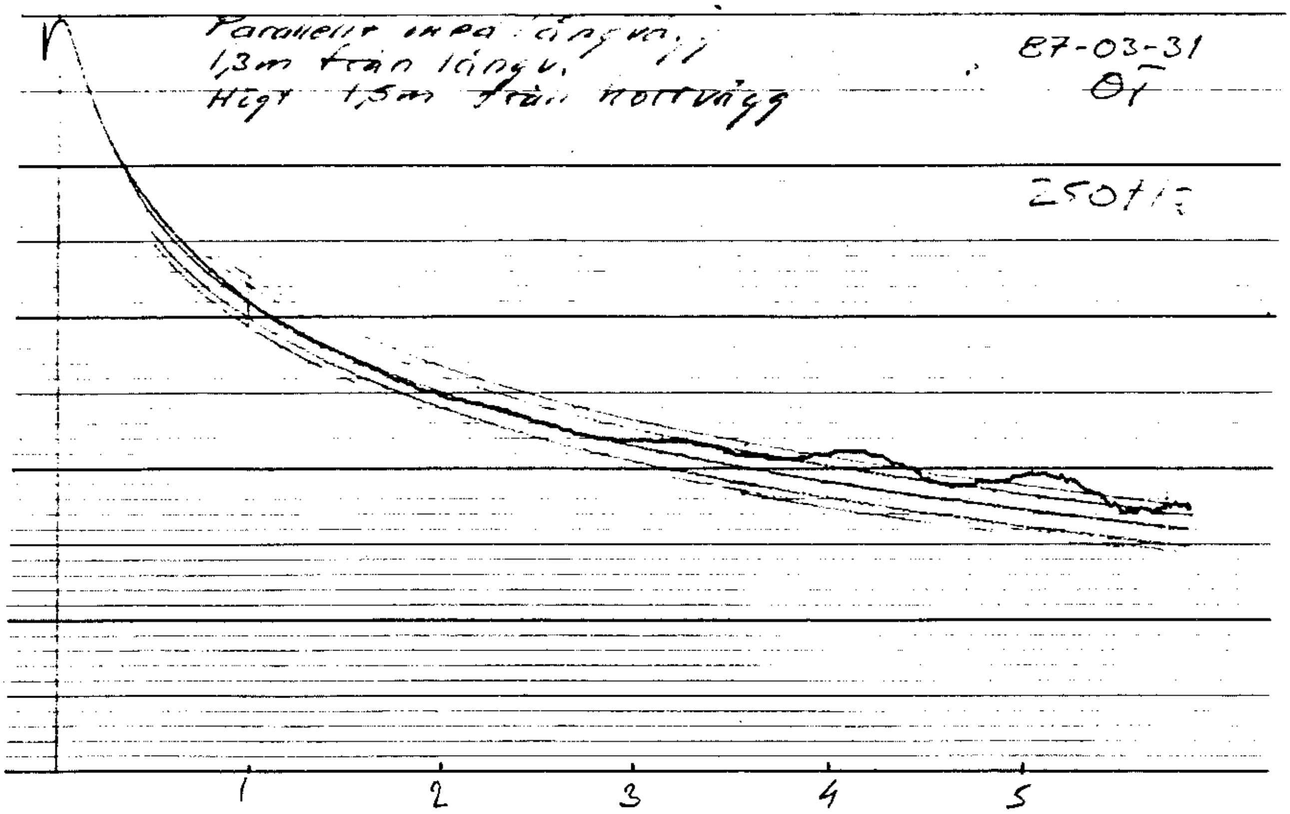


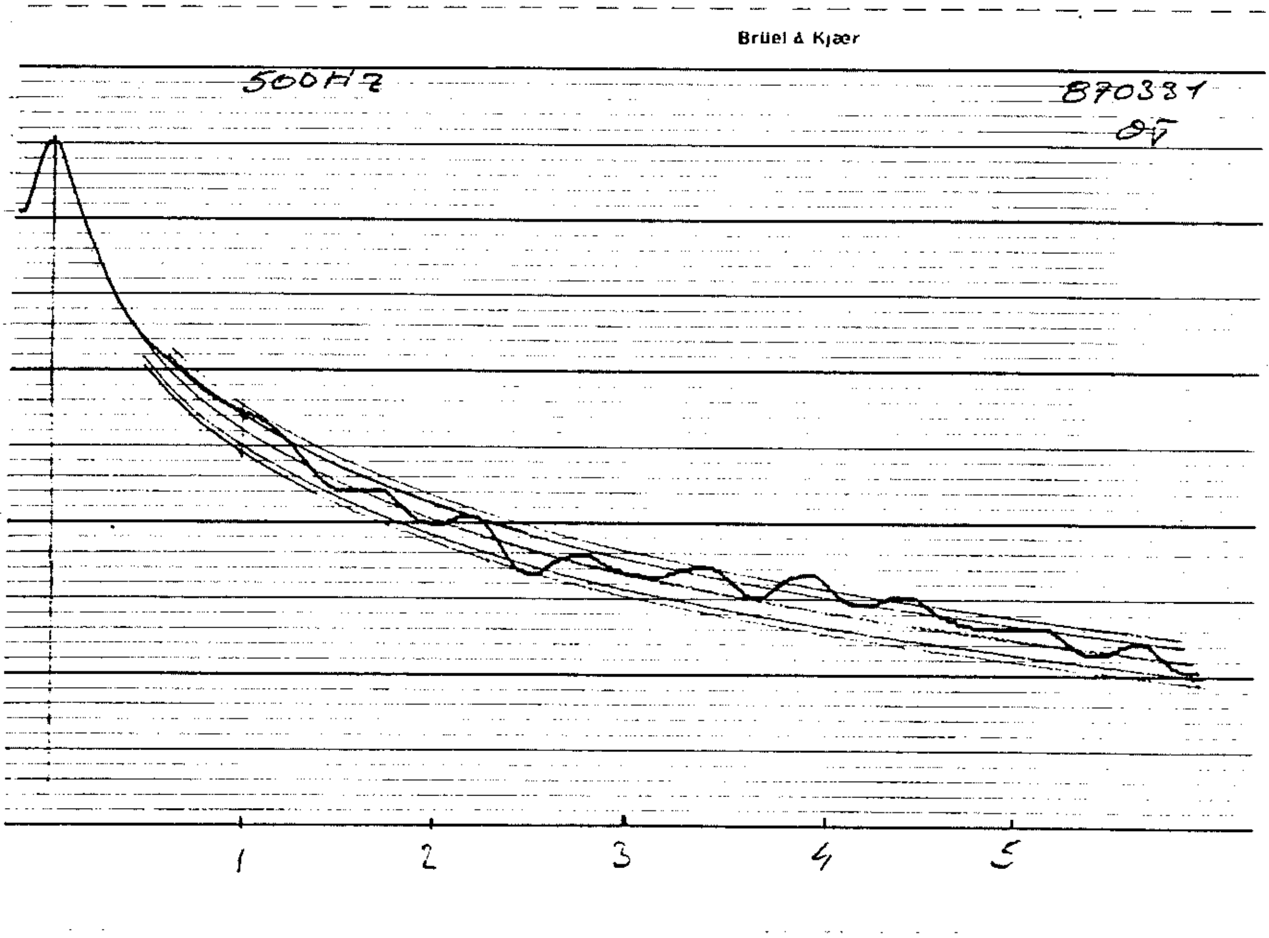


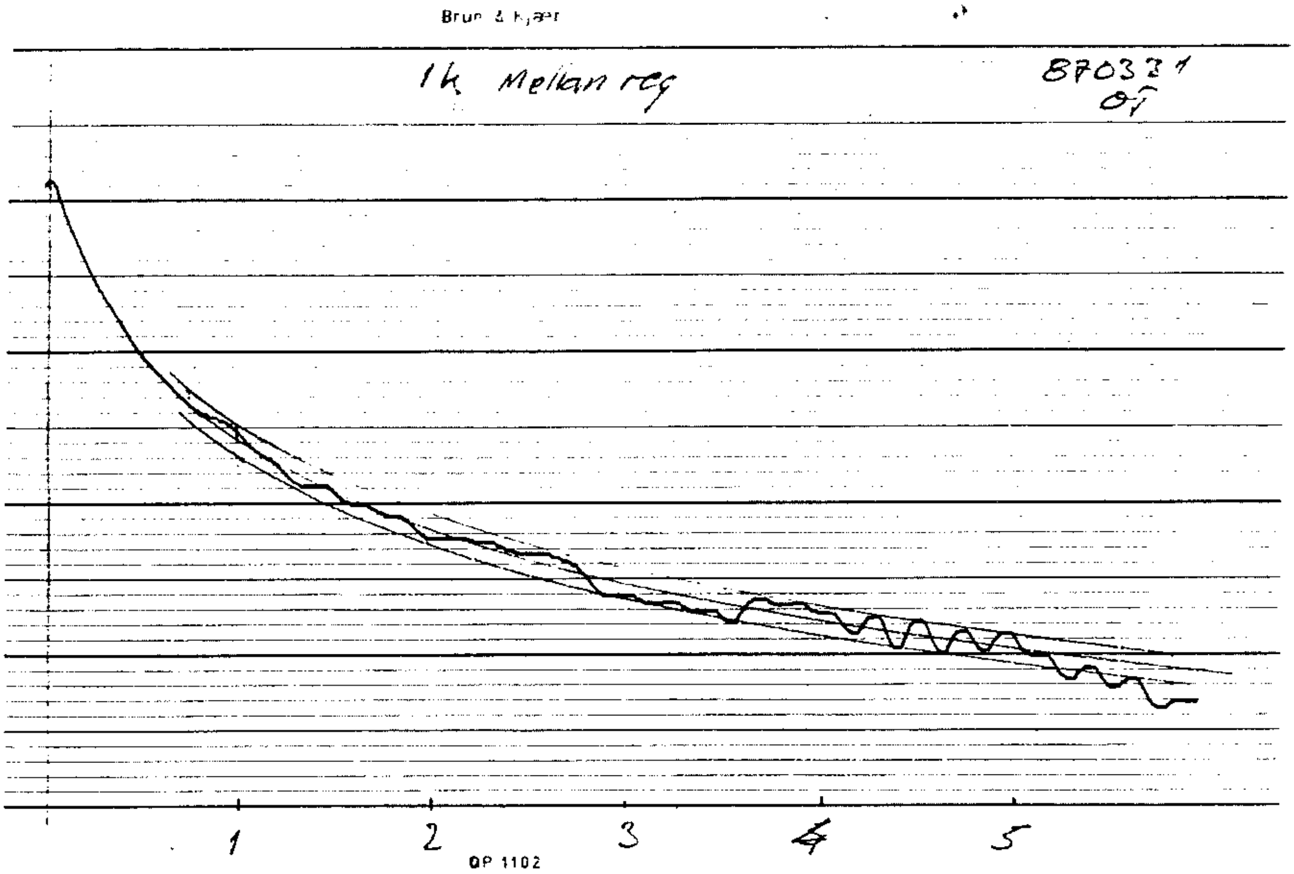
1.3 m from the long wall, 250 Hz



1.3 m from the long wall, 250 and 500 Hz






Brüel & Kjaer
1k Mellan reg
870331
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2
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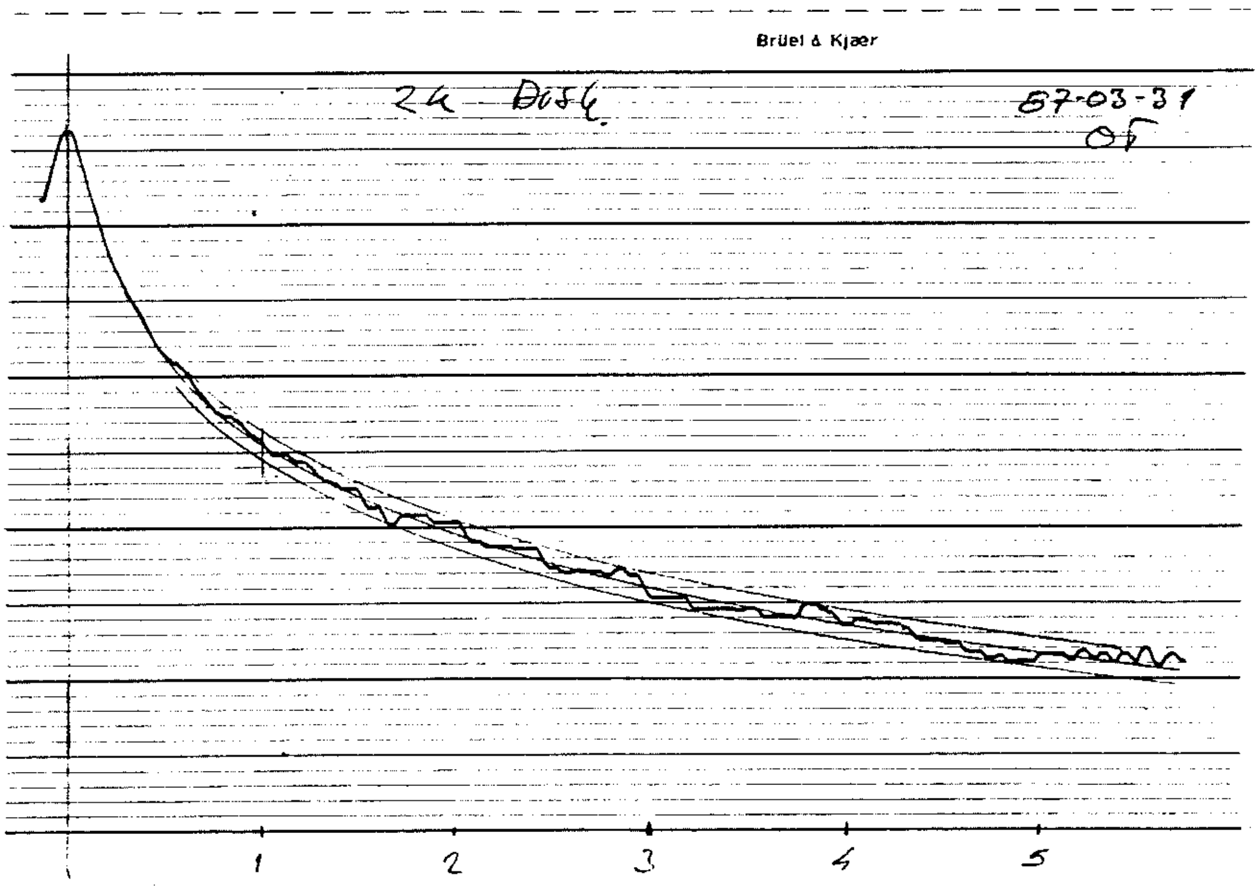
5
QP 1102


Brüel & Kjaer
87-03-31
OF
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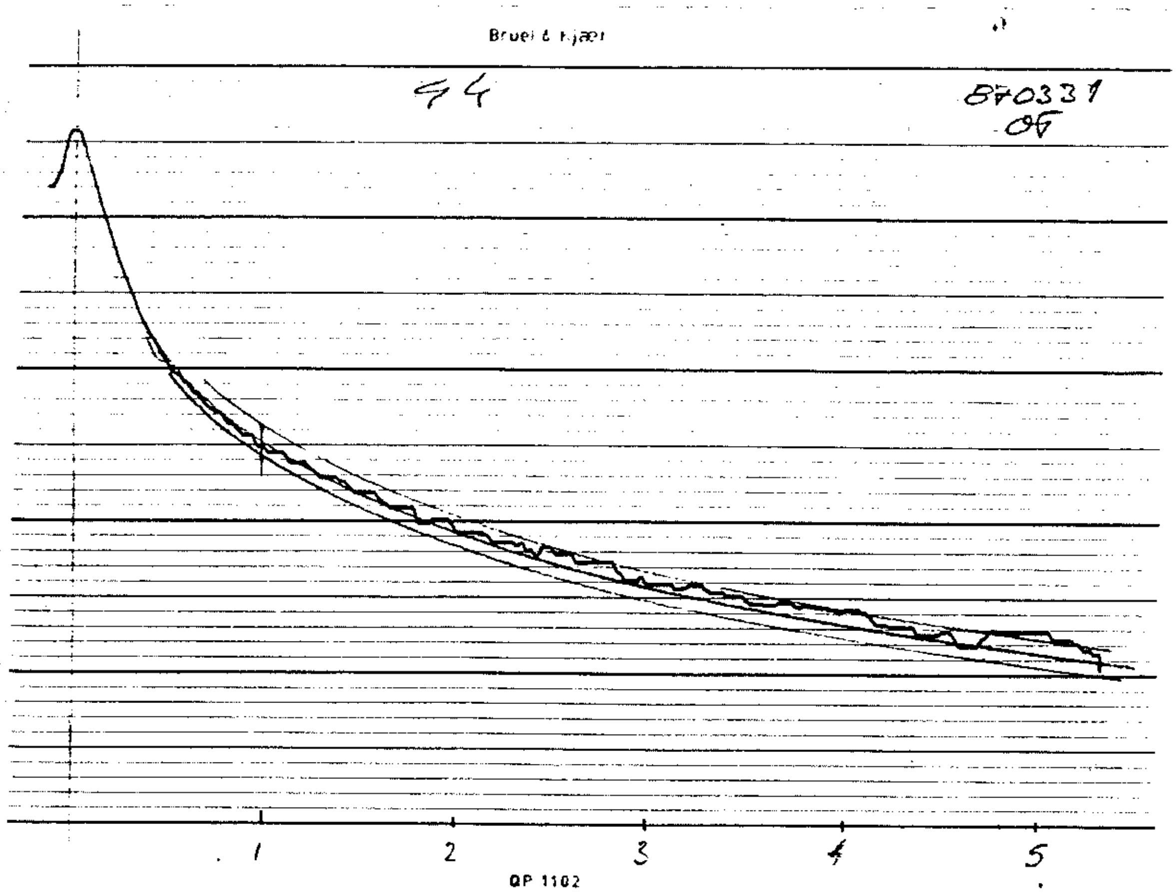
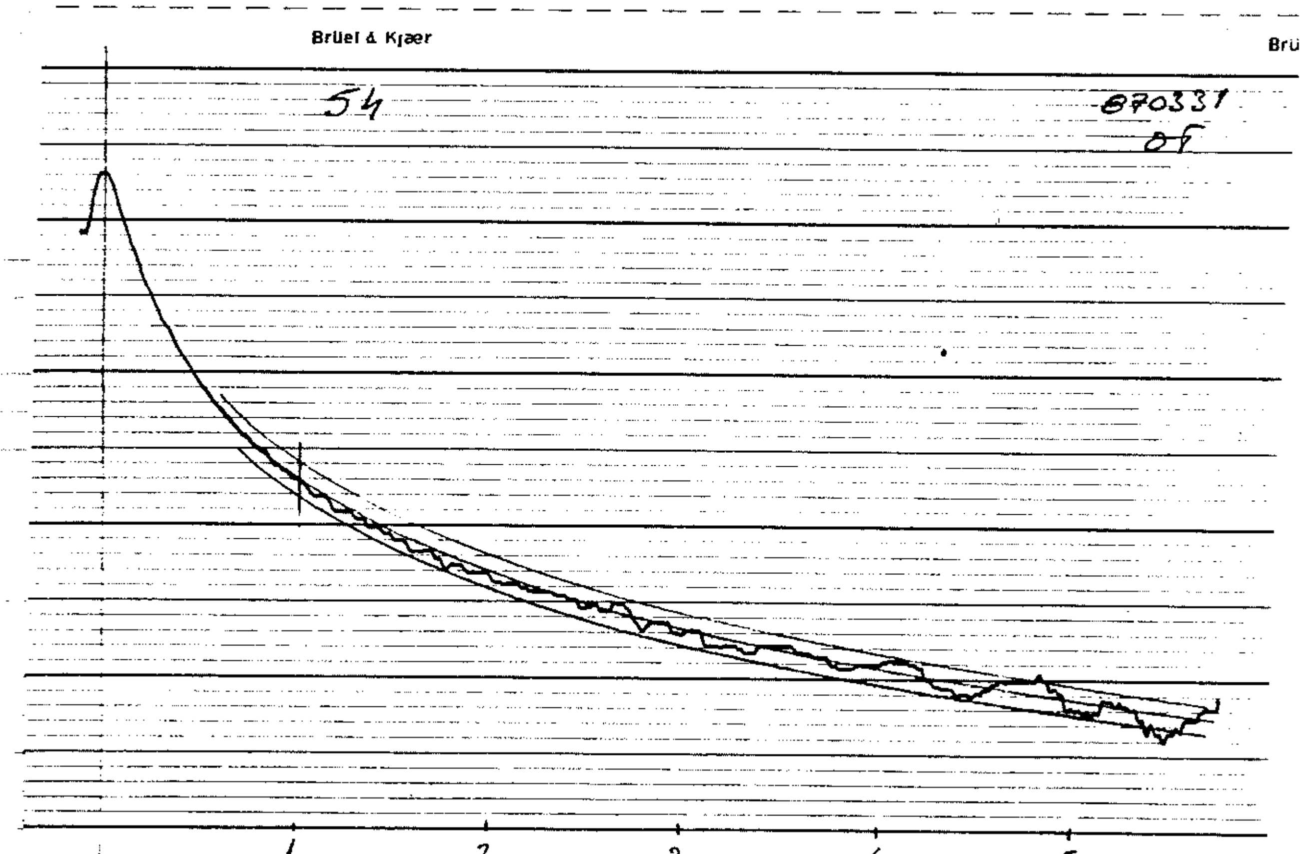
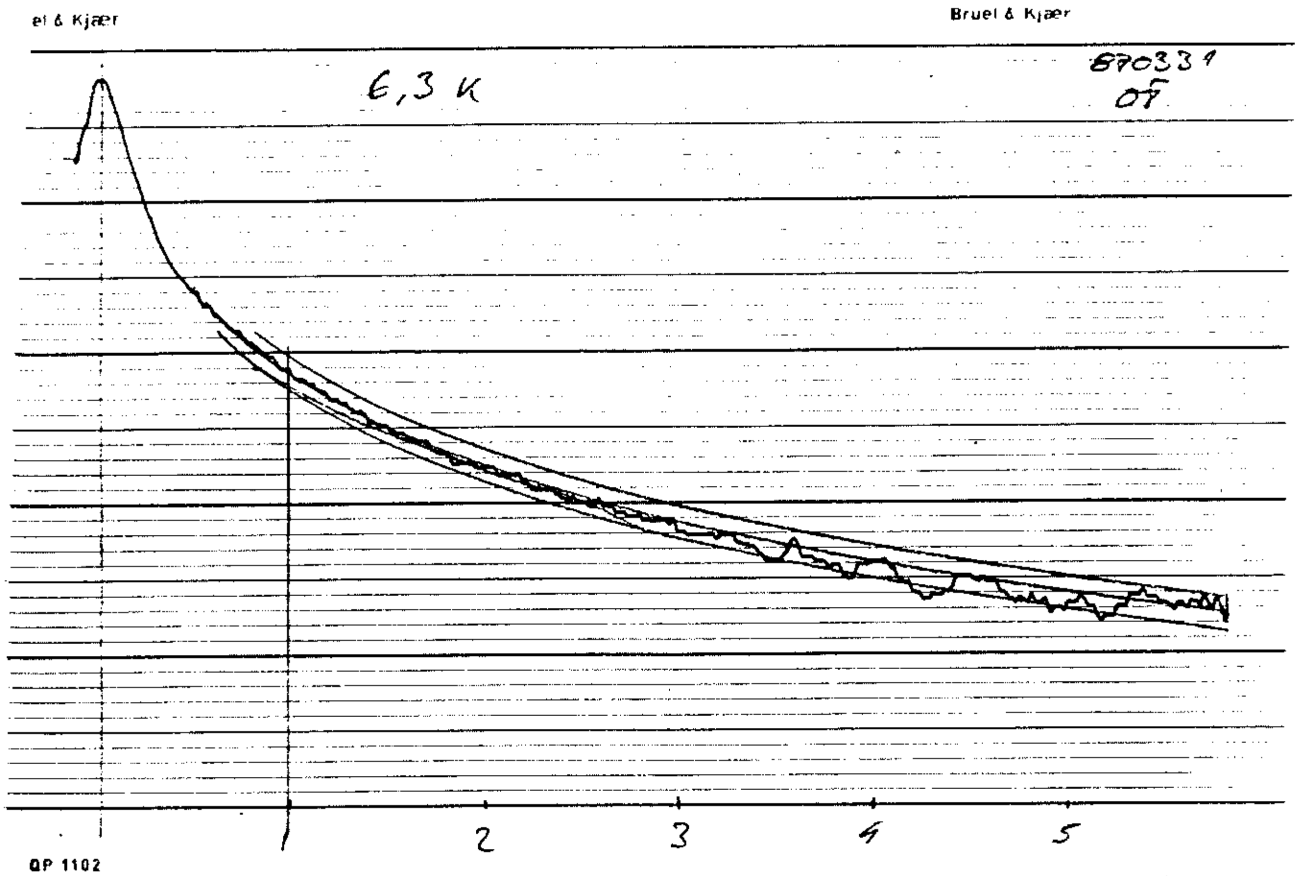
5

1.3 m from the long wall, 4000 and 5000 Hz






el & Kjær
Bruel & Kjaer
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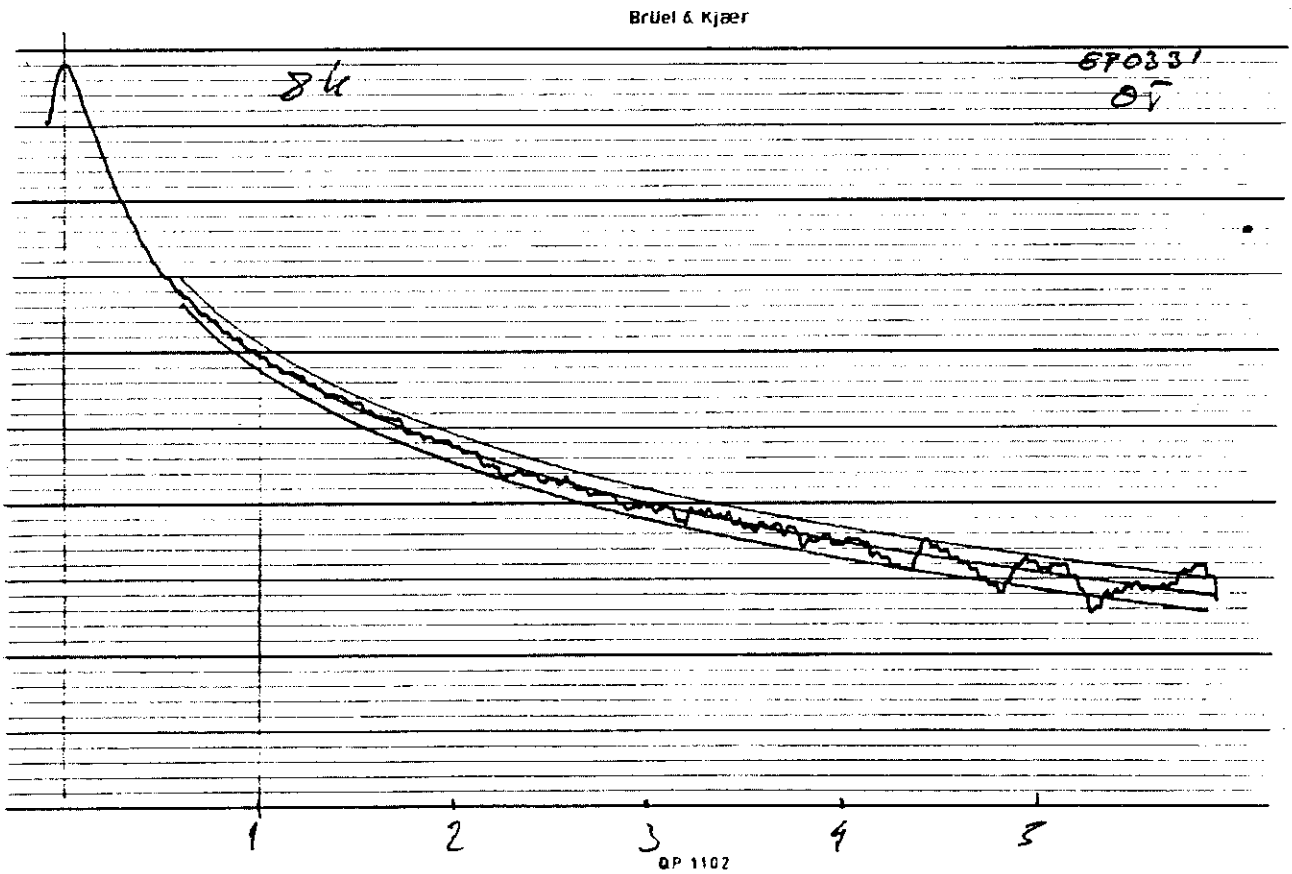
QP 1102


Brüel & Kjær
8 k
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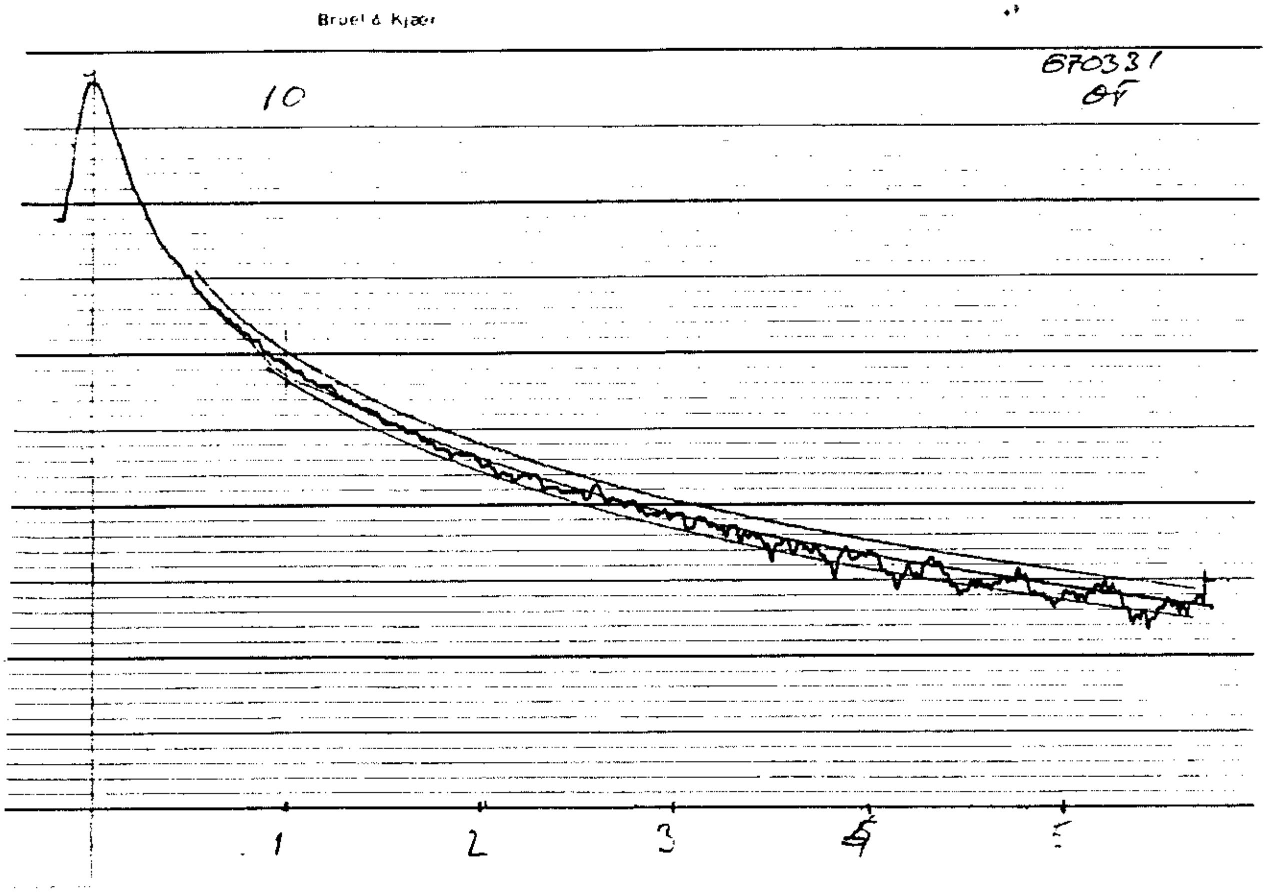
QP 1102


Brüel & Kjær
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870331
OF
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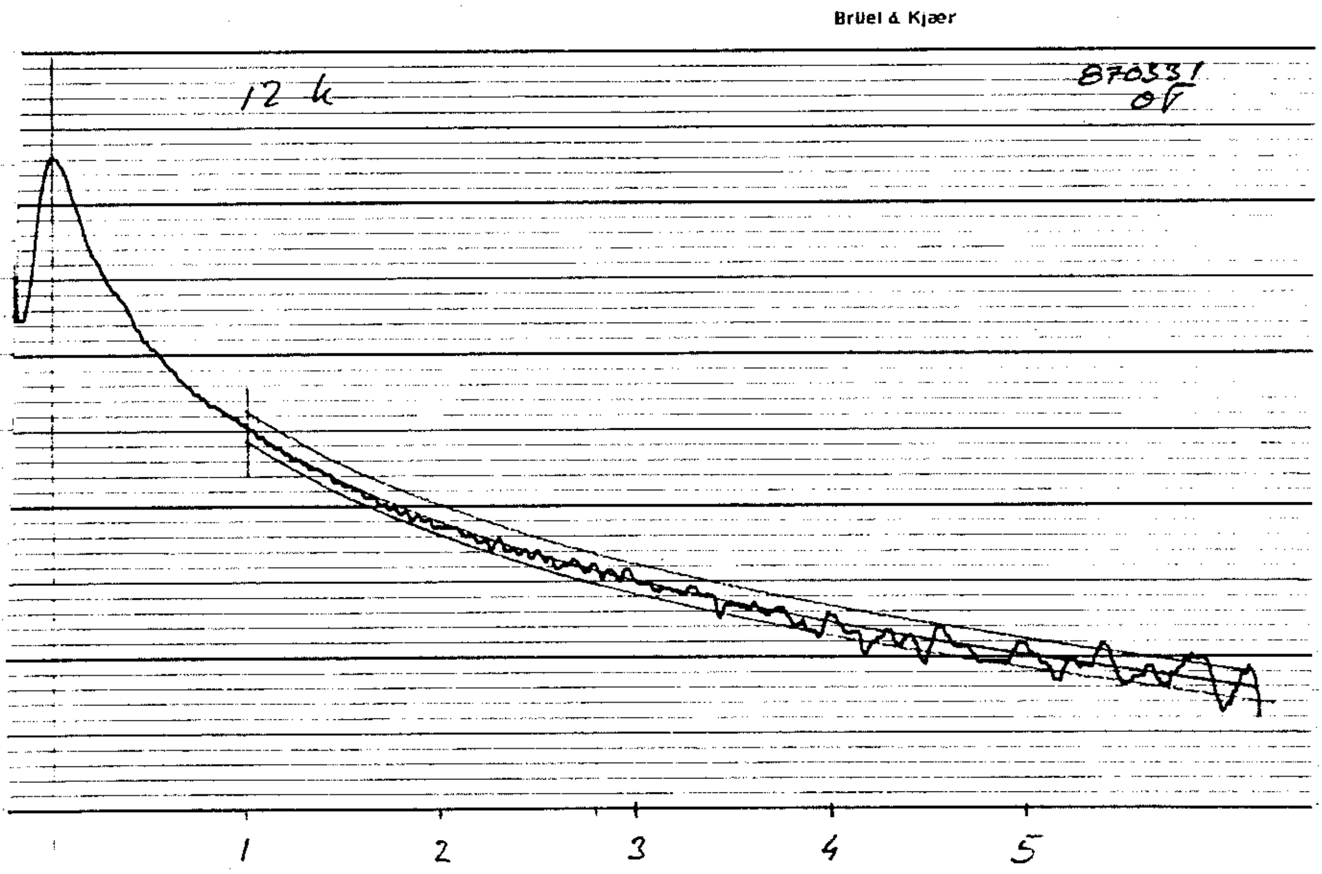
Brüel & Kjær
12 k
870331
OF
1
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1.3 m from the long wall, 16000 Hz