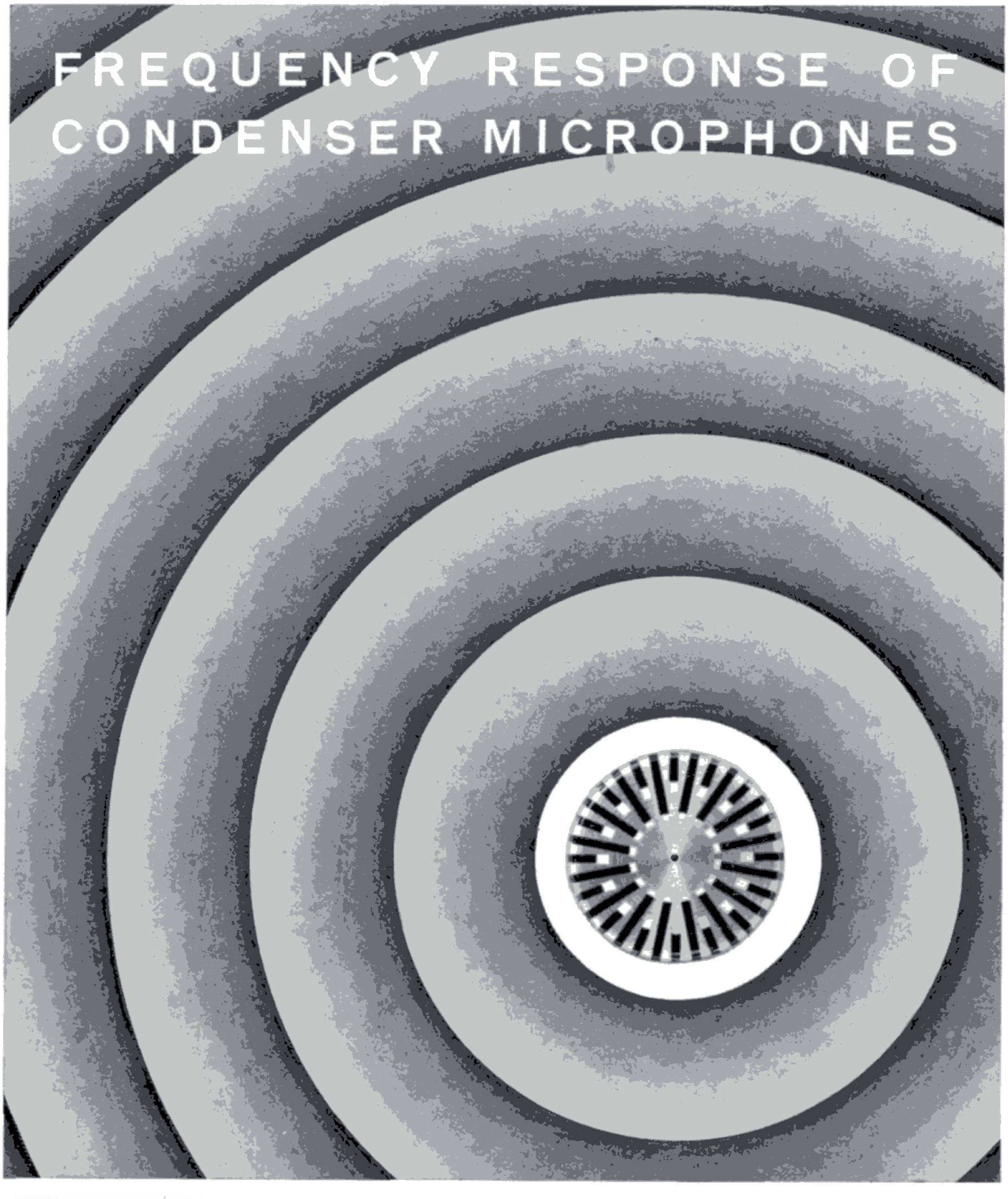
Brüel & Kjær

Technical Review

To Advance Techniques in Acoustical, Electrical, and Mechanical Measurement

FREQUENCY RESPONSE OF CONDENSER MICROPHONES



No. 2 April 1959

PREVIOUSLY ISSUED NUMBERS OF BRÜEL & KJÆR TECHNICAL REVIEW

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Continued from TR 1-1959

Free Field Response of Condenser Microphones (Part II)

by

Per V. Brüel and *Gunnar Rasmussen*

SUMMARY

The difference between free field response and pressure response characteristics of condenser microphones is determined by two different methods:

A. By measuring the pressure distribution around a model of the microphone placed in a free sound field, as well as the sensitivity distribution over the microphone diapragm. From these measurements, and by means of a specially designed concentric electrostatic actuator the effective sound pressure increase on the diaphragm is calculated.

B. By measuring the microphone sensitivity as a function of frequency according to the free field reciprocity method, and comparing the results with the pressure response of the same microphones measured by means of the electrostatic actuator method.

The pressure increase curves obtained according to the two different methods A) and B) showed excellent agreement for the Condenser Microphones Type 4131 and 4132 used for the experiments.

ZUSAMMENFASSUNG

Es werden zwei Verfahren für die Bestimmung der Druckanstiegskurve von Kondensatormikrophonen angegeben:

A. Man untersucht die Druckverteilung an einem Modell des Mikrophons im freien Feld sowie die Empfindlichkeitsverteilung über der Membran. Auf der Grundlage dieser Untersuchungen erhält man die Druckanstiegskurve mit Hilfe eines speziell entwickelten Eichgitters.

B. Die Frequenzkurve wird punktweise nach der Freifeld-Reziprozitätsmethode gemessen und mit der nach der elektrostatischen Methode gemessenen Druckkammerkurve verglichen.

Die nach den beiden Verfahren A) und B) berechneten Druckanstiegskurven der Kondensatormikrophone Typ 4131 und 4132 stimmen volkommen überein.

RÉSUMÉ

La différence entre les caractéristiques de résponse en champ libre et à la pression des microphones à condensateur est déterminée par 2 méthodes différentes:

A. En mesurant la distribution de la pression autour d'un modèle du microphone placé en champ libre, ainsi que la répartition de la sensibilité sur le diapragme du microphone. Du résultat de ces mesures ainsi que de l'emploi d'un excitateur électro-acoustique concentrique specialement étudie, on calcule l'argumentation effective de la pression sonore sur le diaphragme.

B. En measurant la sensibilité du microphone en fonction de la fréquence selon la méthode de réciprocité en champ libre et en comparant les rsultats avec la réponse à la pression des mêmes microphones, measurée par la méthode de l'excitateur électroacoustique.

Les courbes d'augmentation de la pression obtenues selon les deux méthodes différentes A et B sont en excellent accord pour les microphones à condensateur 4131 et 4132 utilisés pour les expériences.

Continuing the description of the pressure distribution measurements on the surface of a cylinder given in TR No. 1 1959 Fig. 7 shows a set of frequency-amplitude-position curves in a three dimensional view. However, not only the pressure increase in the case of perpendicularly impinging sound waves is of interest, but also the pressure increase in the case where the sound waves strike the microphone diaphragm tangentially is of considerable practical importance. These measurements can be made in a similar way and the results are shown in Fig. 9. Besides the theoretically simple cylinder shape the main interest has been devoted to the shape of the new Microphone Type 4131,—to determine the pressure increase of this microphone at high

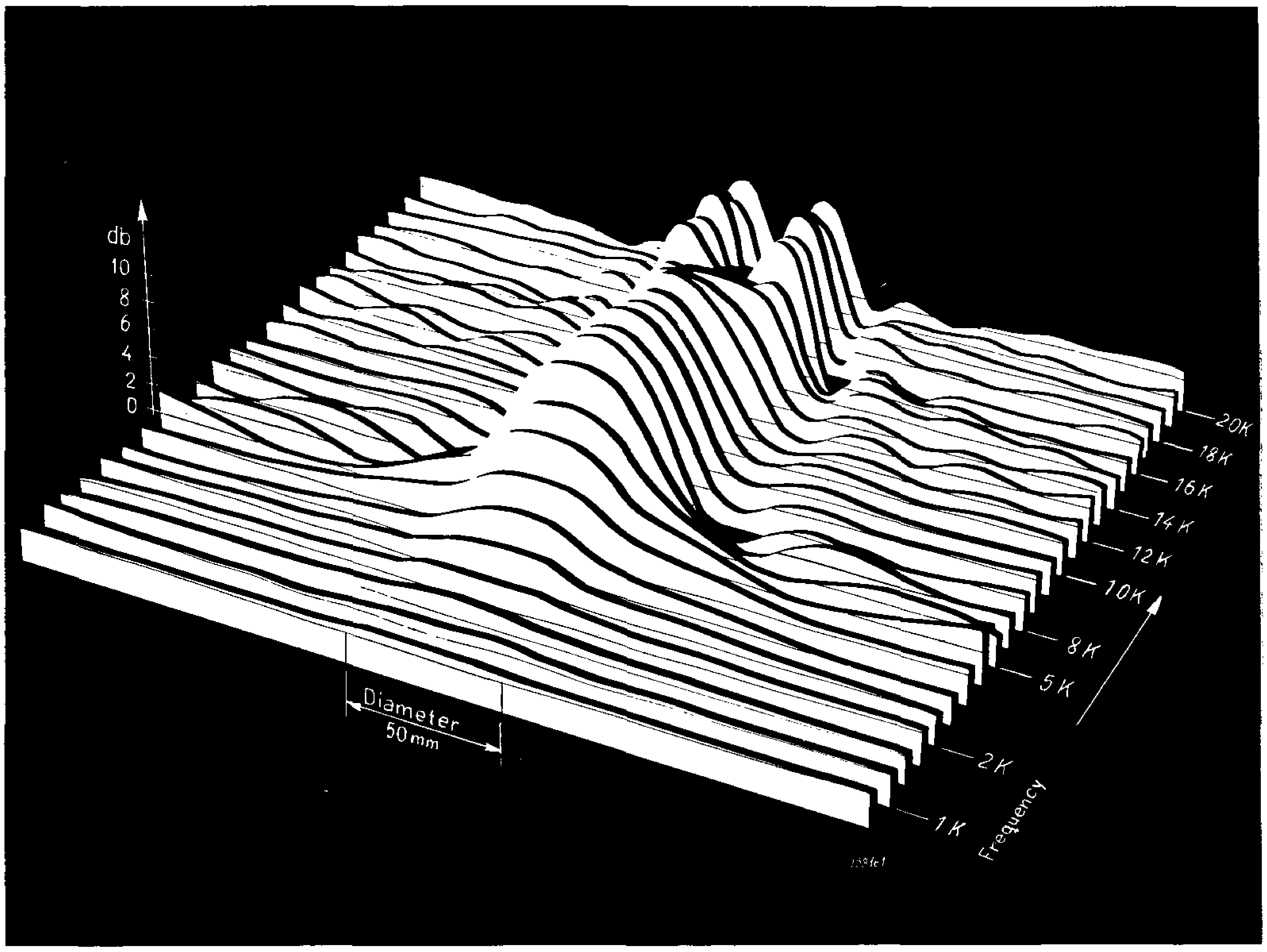

Fig. 7. Pressure distribution across the circular surface of a cylinder as a function of position and frequency. Sound waves parallel to cylinder axis.

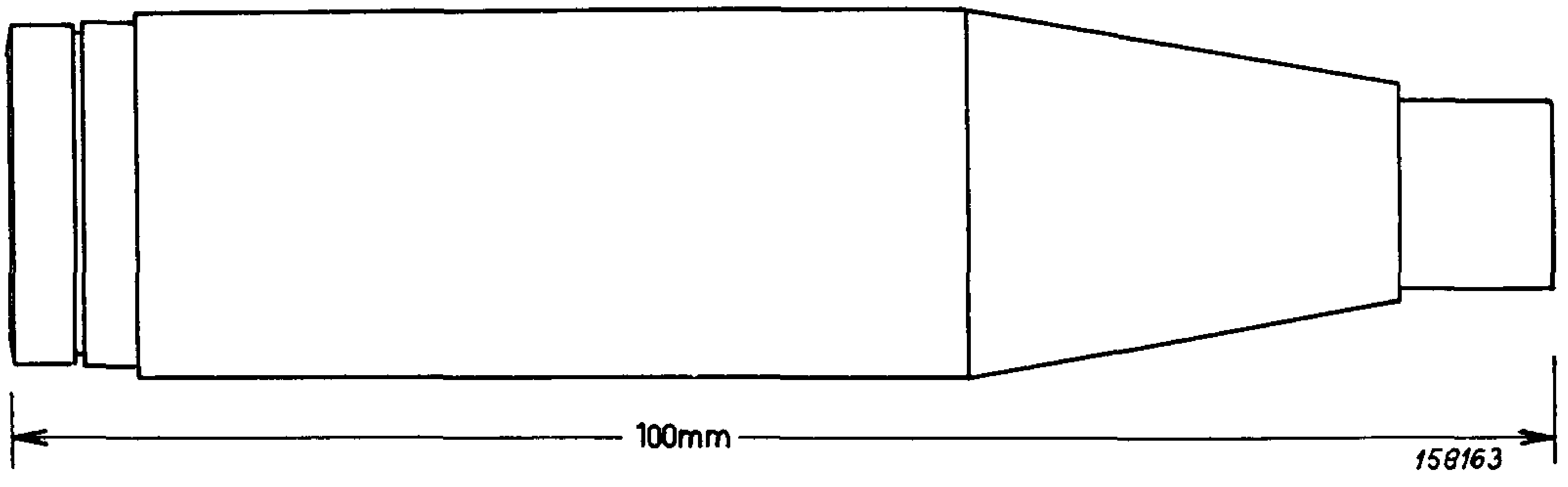

Fig. 8. Model of Microphone Type 4131 without protection grid.

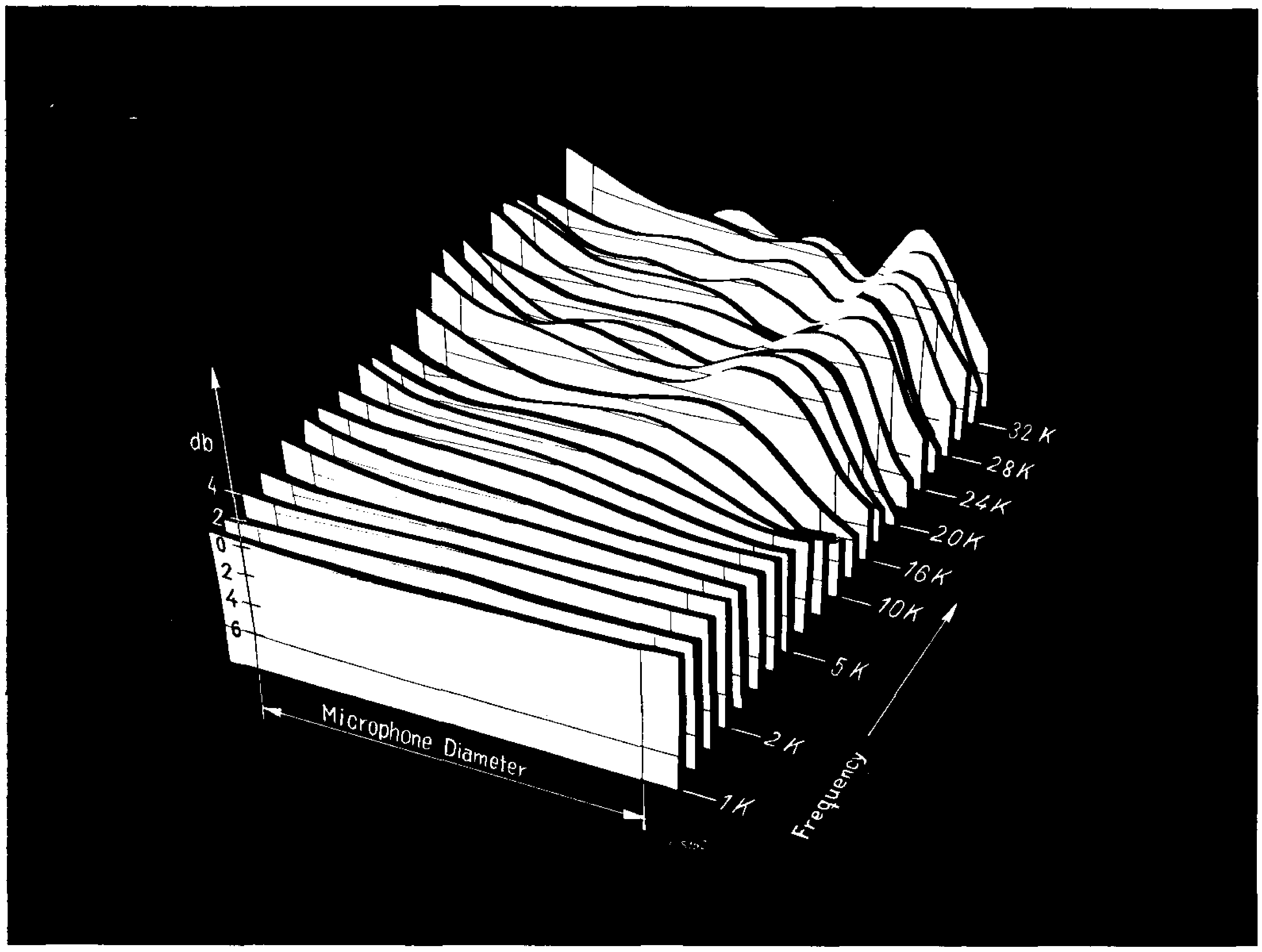

Fig. 9. Pressure distribution for sound waves parallel to diaphragm as function of frequency. Measured diameter parallel to sound direction.

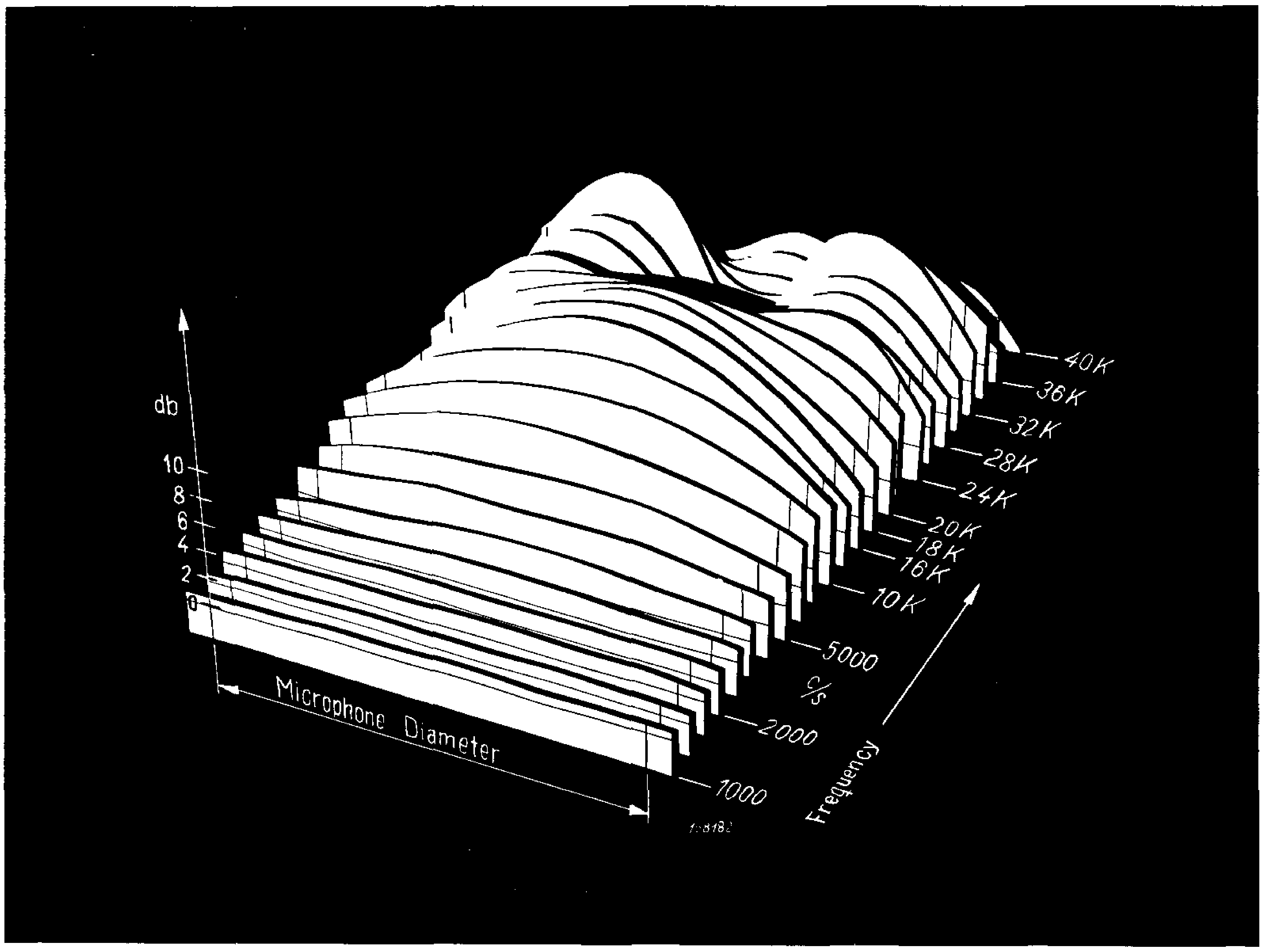

Fig. 10. Pressure distribution measured on Model Scale Microphone Type 4131. Sound waves perpendicular to diaphragm.

frequencies. A model has therefore been made of the microphone to a scale of 2 : 1 whereby the instrumentation could be used for measurements at frequencies 1 octave higher than those used with the microphone in full scale. These measurements have been carried out in exactly the same manner as the ones just described for the cylinder. In Fig. 11 the curve drawn in full indicates the pressure increase at the centre of the diaphragm (0° incidence).

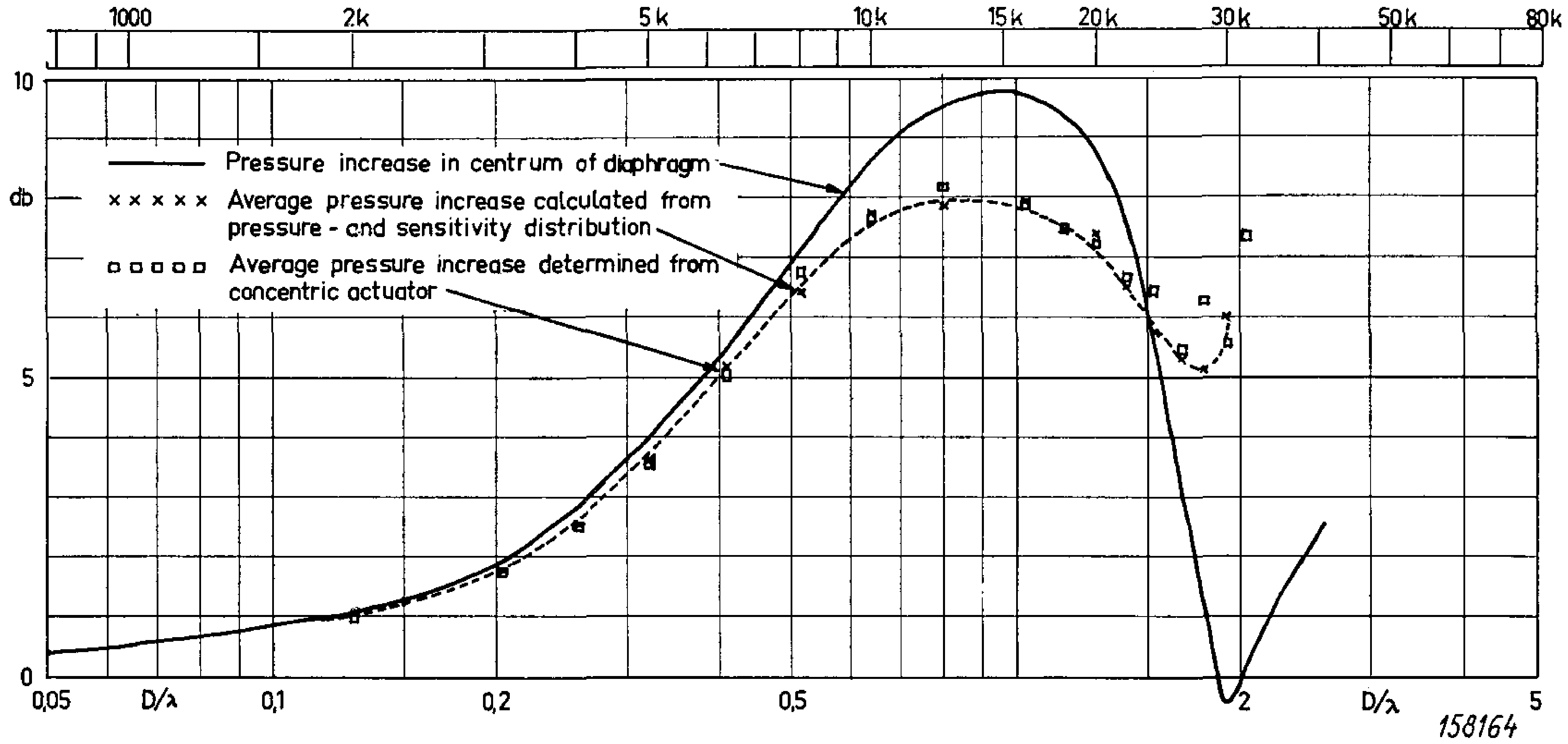

Fig. 11. Pressure increase at the centre of the model microphone (solid curve).
xxx *Average pressure increase calculated from the measured pressure and sensitivity distribution.* □□ *Obtained from measurements with concentric actuator. All measurements on the model microphone were taken without protection-grid.*

As abscissa the ratio $\frac{D}{\lambda}$ has been used. However, also the corresponding frequency is marked in the figure above. The curve is valid for the Microphone Type 4131 without protecting grid. Fig. 12 shows the pressure increase distribution on the model microphone (0° incidence). By means of these curves the average sound pressure increase on the diaphragm might be calculated. One condition is, however, that the diaphragm has the same sensitivity at all points. This requirement seems a little unrealistic because the sensitivity at the edge of the diaphragm must necessarily be smaller than that in the immediate neighbourhood of its centre. To determine the microphone sensitivity at different points of the diaphragm the measuring arrangement shown in Fig. 13 was used. A small electrostatic actuator around 2 mm in diameter is by means of a wire coupled to the paper spindle of the Level Recorder and supported in such a way that it can be moved across the diaphragm, synchroneous with the movement of the recording paper. The microphone output voltage is then recorded whereby the sensitivity distribution curves shown in Fig. 14 are obtained. It can be seen from the curves that for frequencies up to 8 kc/s the sensitivity distribution is rather smooth and corresponds to that which would be directly assumed, i.e. the max. sensitivity decreasing towards the edges. At higher frequencies a considerably more

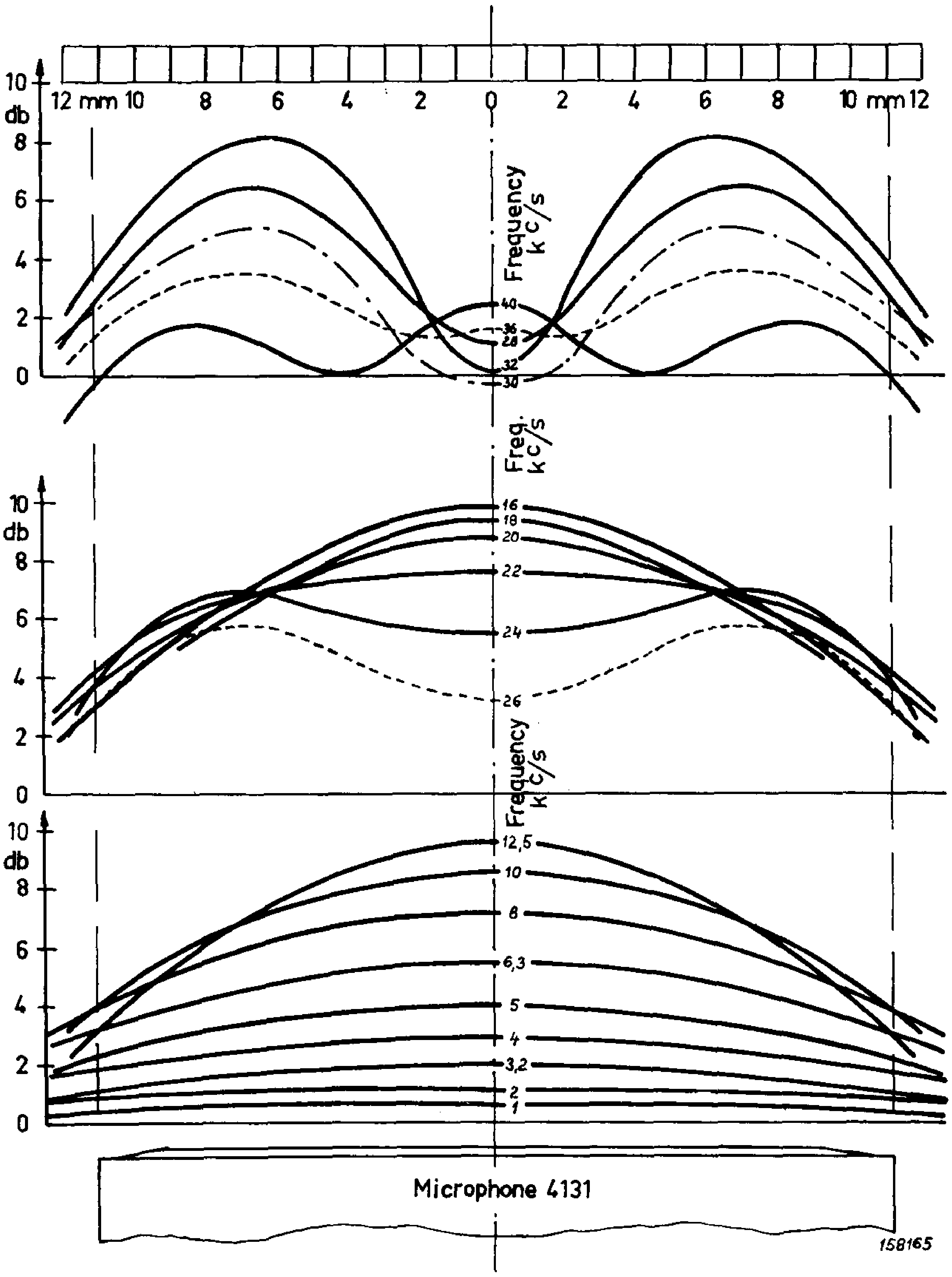

Fig. 12. Automatically recorded pressure distribution curves for model microphone. Sound waves impinging perpendicularly on the diaphragm.

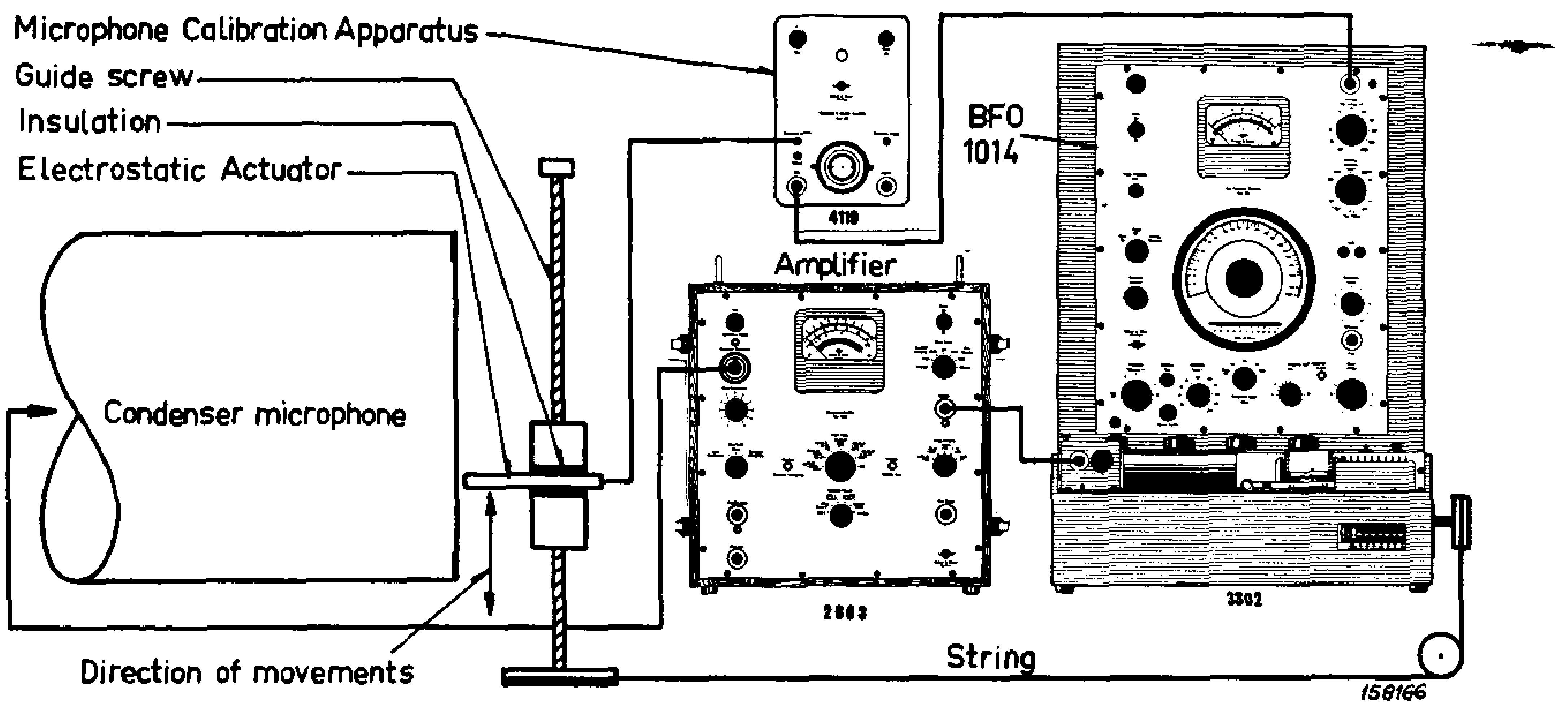

Fig. 13. Set-up used to record automatically the sensitivity distribution ovei the condenser microphone diaphragm.

irregular shape of the curve is found. For example is the sensitivity at the centre reduced and the most sensitive area is the diaphragm area just above the edge of the back-plate. The diaphragm is in this frequency range rather heavily damped and vibrates above its fundamental resonance.

To determine the effective pressure increase at the different frequencies one might multiply the sensitivity distribution with the pressure distribution for the microphone type in question. This method of approaching the problems is

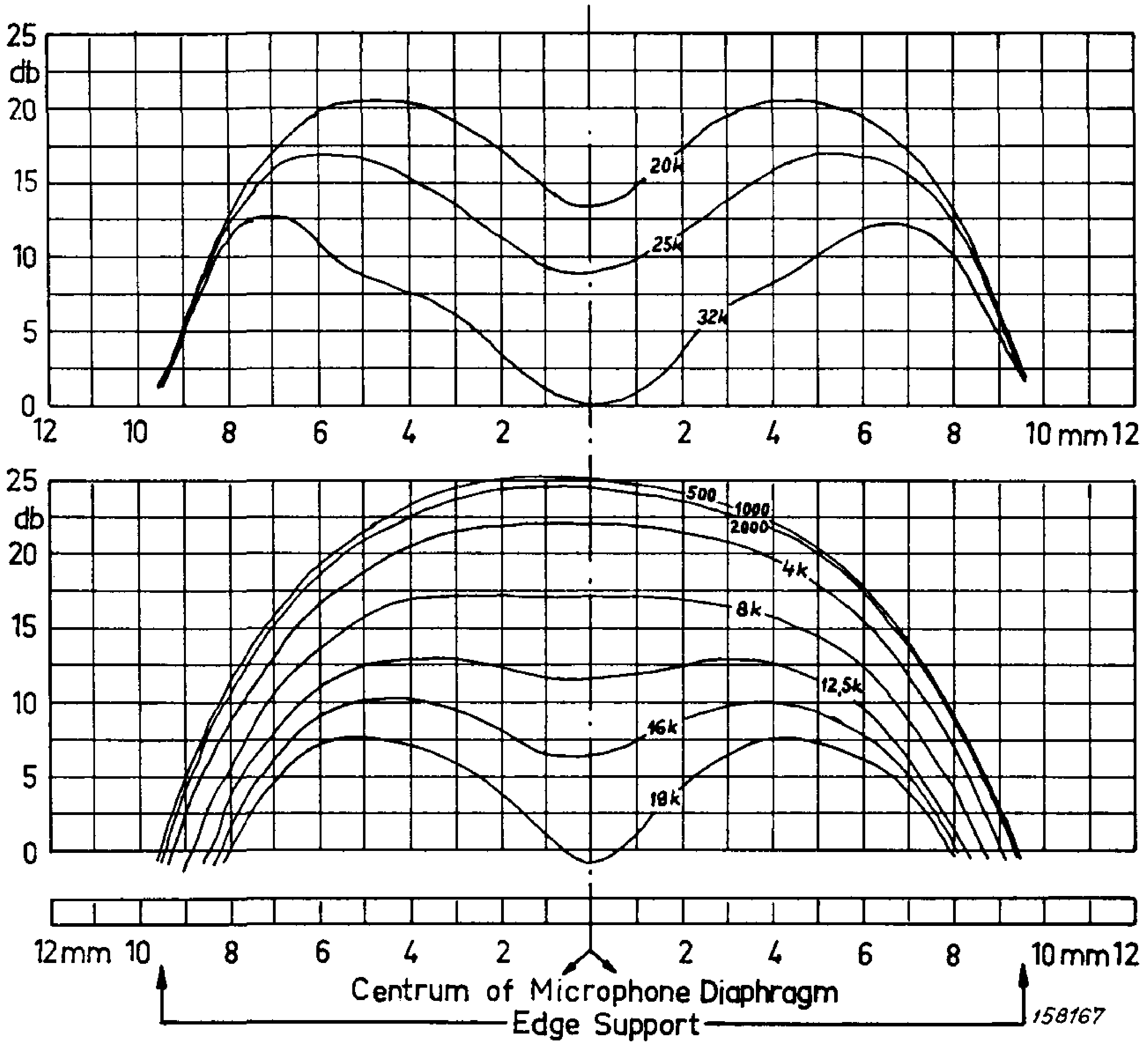

Fig. 14. Recorded sensitivity distribution curves over the diaphragm diameter

indicated in Fig. 14 (below) where the sensitivity distribution curve is drawn in full and the pressure distribution curve drawn by means of a dotted line for one single frequency (in this case 12.5 kc/s). The curves are then plotted to a linear scale multiplied by radius whereafter the pressure and sensitivity are multiplied and the average value of the pressure increase found to be 7.81 db (Fig. 15 above).

This method of approach is rather cumbersome, and has furthermore the disadvantage that possible phase differences have not been taken into account. Especially with regard to the sensitivity distribution a relatively great phase difference might be expected to exist between the movement of the diaphragm at the centre and at the edge at f. inst. 20 kc/s. Thus the method of calculation described above should result in pressure increase values which are too great. In Fig. 11 the results of the calculations at a number of different frequencies are marked with an x. At lower frequencies the measuring points will approach the curve showing the pressure increase at the centre, whereby at higher frequencies the effective increase will be considerably lower than the pressure increase at the centre. The sharp notch in the pressure increase curve around $\frac{D}{\lambda} = 2$ which is very pronounced for the curve plotted from

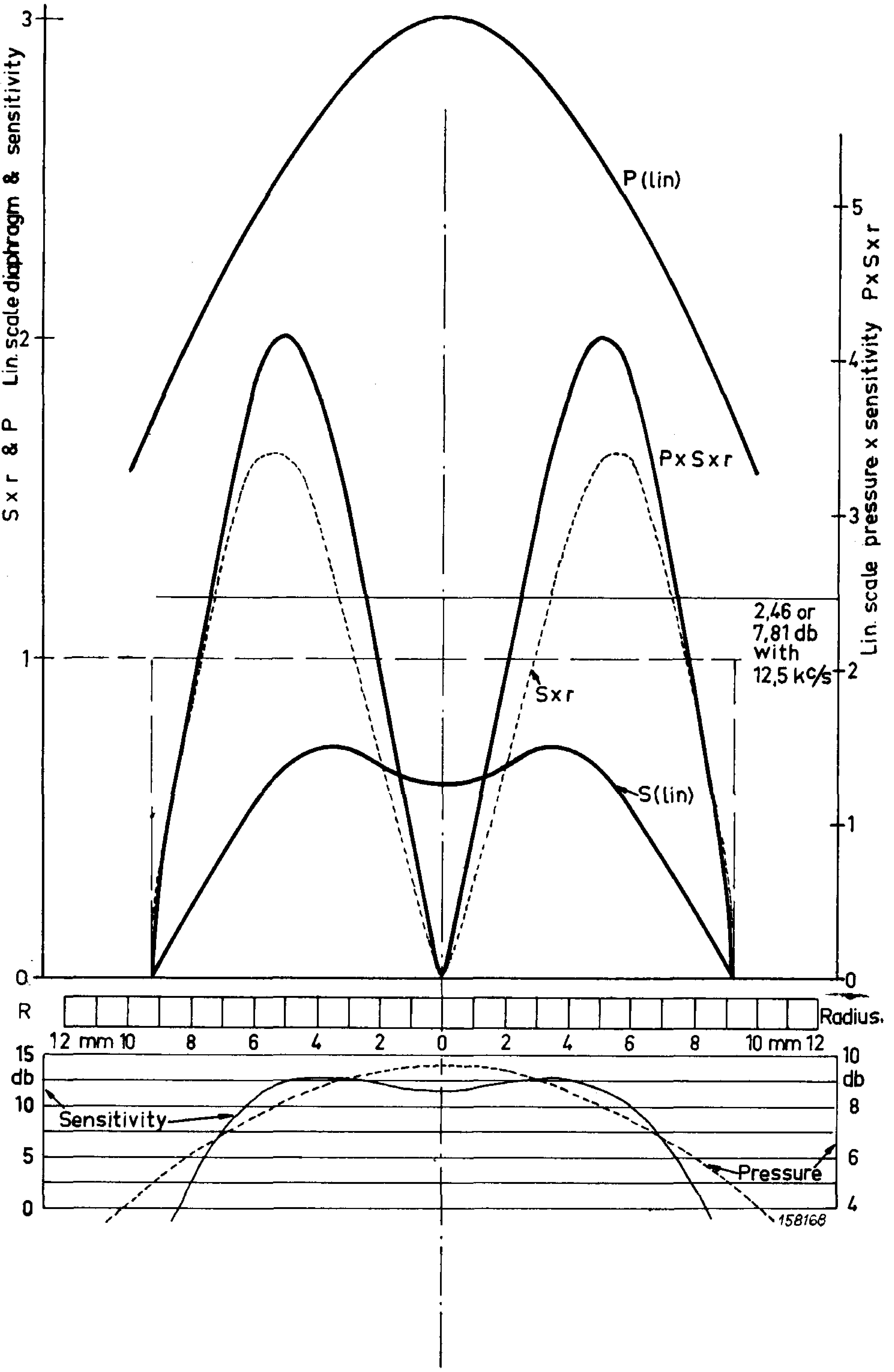

Fig. 15. Determination of the average pressure increase, taking both pressure and sensitivity distribution into account.

measurements taken at the centre of the diaphragm is not so pronounced when the average value is calculated. By comparing the sensitivity distribution curves and the pressure distribution curves it can be seen that the pressure distribution curve is rather smooth up to approx. 20 kc/s and a great phase difference between the pressure at the centre and the pressure at the edge up to this frequency is not to be expected. On the other hand the sensitivity phase differences are expected to be quite considerable. To determine the influence of the sensitivity phase differences a measuring arrangement as shown in Fig. 16 was used, where a specially designed ring actuator was employed to actuate the microphone diaphragm. This actuator consisted of a number of isolated concentric rings on which different voltages could be impressed. The voltages being impressed upon the different rings were proportional and corresponding to the pressure distribution for the frequency at which measurements were taken. In this way the diaphragm was subjected to an electrostatic pressure distributed over the diaphragm in the same way as the sound pressure when the microphone was placed in a free sound field. Possible sensitivity phase differences were in this way compensated for by comparing the microphone output voltage measured according to this method with the output voltage obtained with the microphone placed in a free field, and the effective pressure increase for the microphone can then be found directly in db for each frequency.

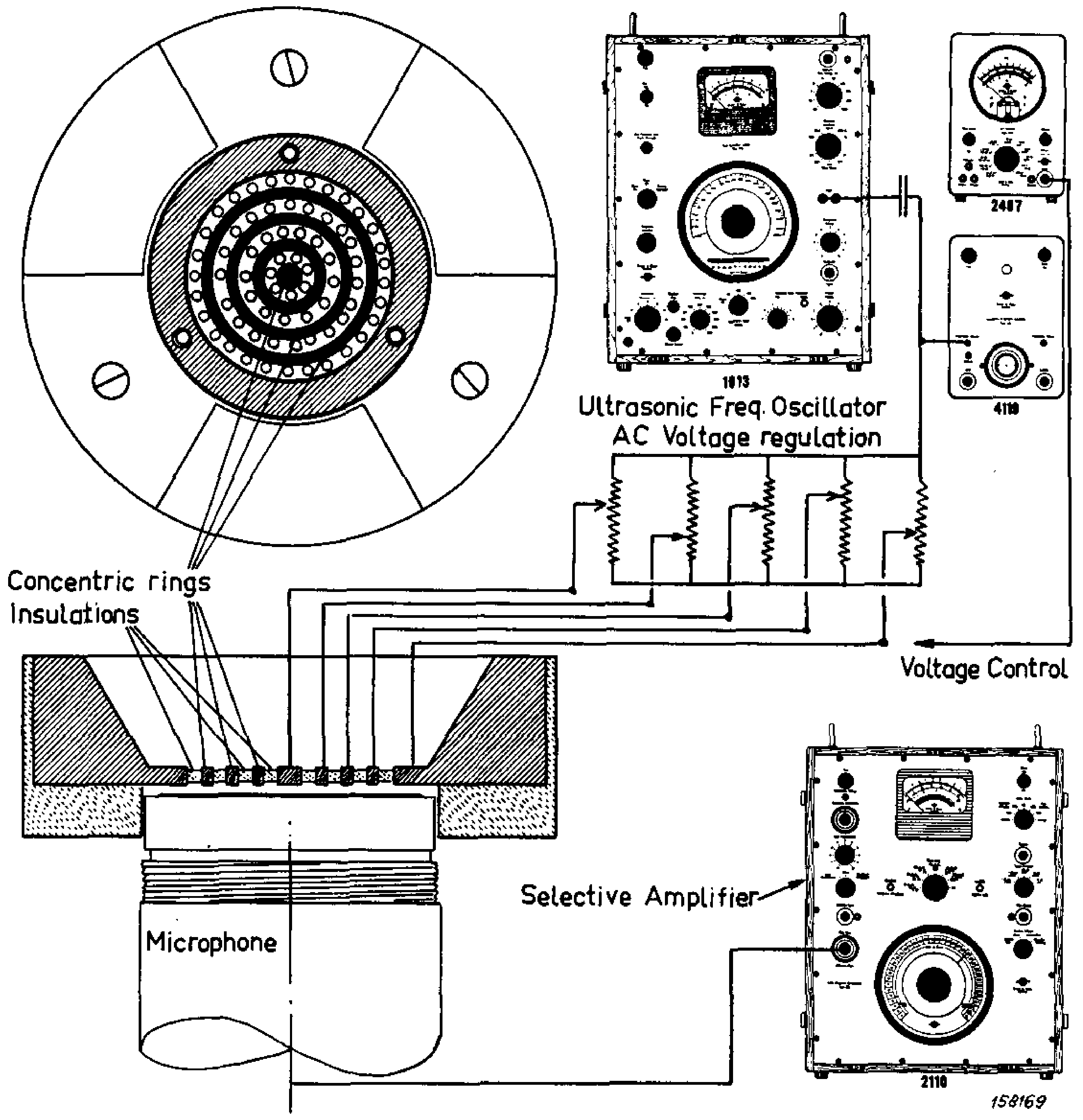

Fig. 16. Electrostatic Actuator made of concentric rings where AC voltages can be supplied corresponding to pressure distribution over the diaphragm.

To investigate whether the actuator itself distorted the measuring results at higher frequencies or not the measurements were carried out with different distances between actuator and diaphragm. No difference could be detected in the curves obtained from these measurements, proving that no resonance phenomenon had been present in the actuator system. The result from the actuator measurements are shown as small squares in Fig. 10. It can be seen that the expected phase difference in reality has no great influence on the measured results for frequencies below 20 kc/s and an astonishingly good agreement exists between the actuator measurements and the effective pressure increase calculated on the basis of the measured sensitivity distribution curves. The actuator method has also been used to investigate a great number of microphones of the Type 4131 and 4132 stating the uniformity of the sensitivity distribution for frequencies up to 32 kc/s. The greatest deviation from the average value of the pressure increase was ± o.2 db.

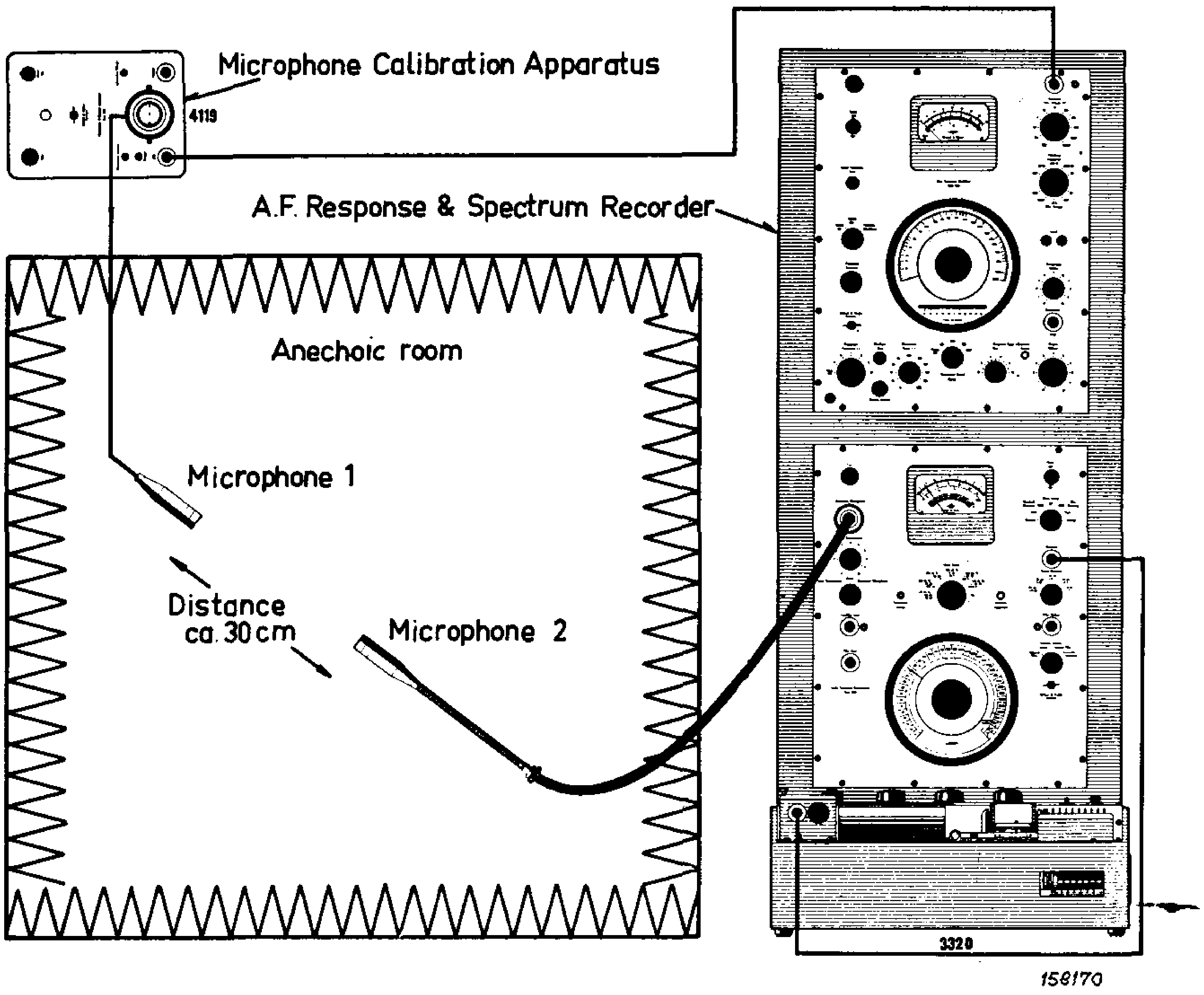

Fig. 17. Set-up for free field reciprocity calibration of two condenser microphones recording automatically the product of the frequency responses.

Finally a direct determination of the free-field response of the microphone Type 4131 was tried by means of the free-field reciprocity method (11, 12). Two microphones 1 and 2 were mounted just opposite to each other in an anechoic chamber as shown in Fig. 17. The distance between the microphones was great enough to avoid any interaction between the microphones from taking place. The output voltage from microphone 2 was measured and recorded, keeping the voltage across microphone 1 constant. The output voltage is, according to the reciprocity theorem, $e = k_1 f^2 F_1 F_2$ where F_1 and F_2

are the free field sensitivity of microphone 1 and 2 respectively. Immediately afterwards, employing the same measuring arrangement, the actuator curves for both microphones were recorded. The curves are shown in Fig. 18, above, and are equivalent to the microphone pressure response T_1 and T_2 as a function of frequency. The actuator curves are then multiplied with each other and the product multiplied with the square of the frequency resulting in the curve shown in Fig. 18, below. The difference between the recorded free-field response and the product of the two pressure response curves times the square of the frequency gives the desired effective pressure increase as a function of frequency. See curve drawn in full Fig. 18 marked 0°. These measurements are carried out with the protection grid on the microphones removed. It can be seen that measurements were successfully carried out up to 70 kc/s. However, above 35 kc/s the effective pressure increase curve is rather irregular but should at still higher frequencies approach an average value of 6 db. The pressure increase curve obtained by means of the free-field reciprocity method is in excellent agreement with the result obtained from measurements with the ring shaped electrostatic actuator. It is thus plausible to assume that the pressure increase curve shown for the microphones Type 4131 and 4132 is very accurate because it has been determined by means of two completely different methods.

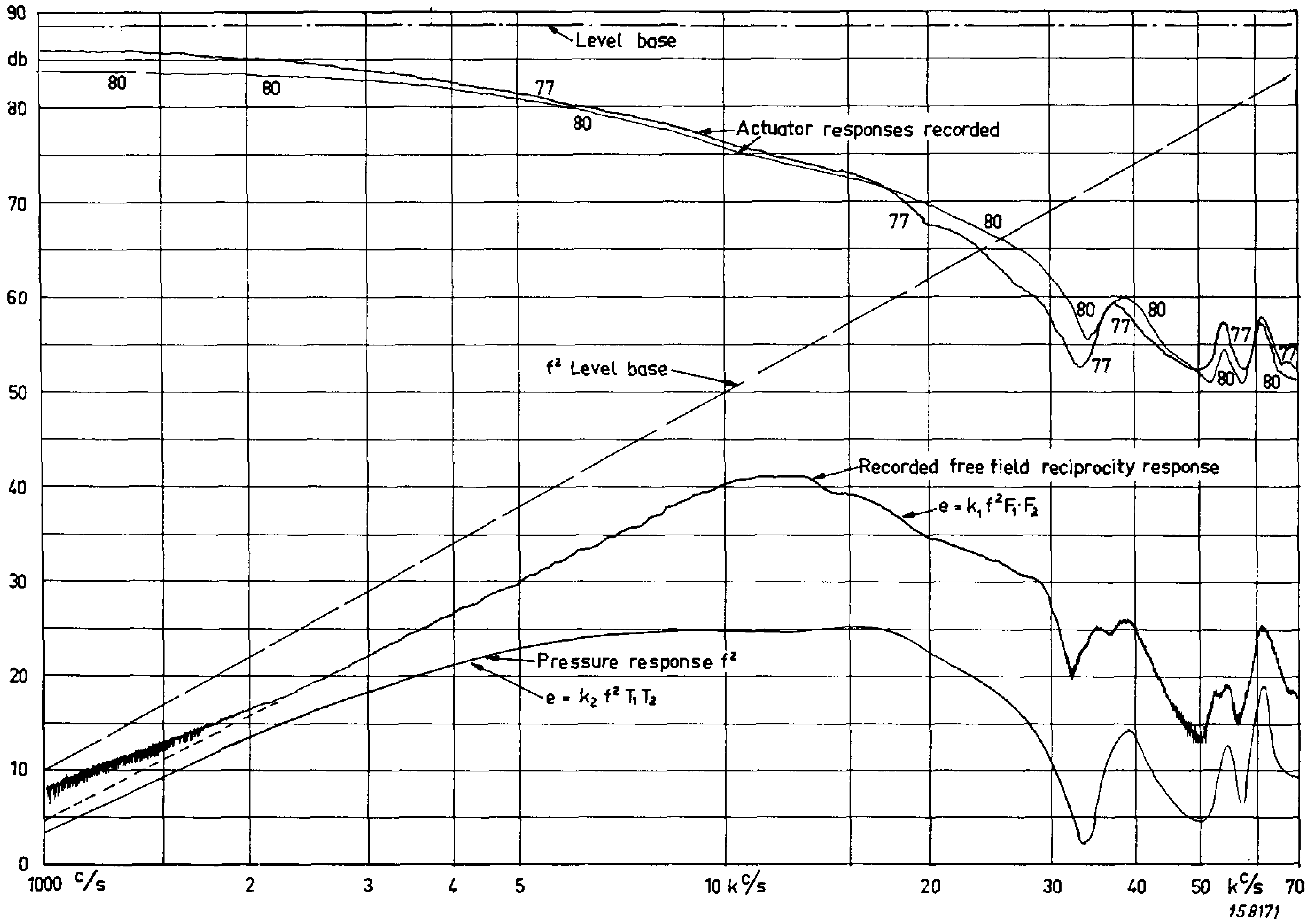

Fig. 18. Recorded actuator curves of two microphones and free-field reciprocity response compared to the product of the pressure responses and f^2.

The microphone sensitivity for other angles of incidence can now be readily measured and recorded by means of the Level Recorder Type 2304 supplied with a 10 db potentiometer.

The influence of the protecting grid can be determined by means of the free-field reciprocity method recording the measurements with and without grid on the same piece of recording paper. The difference between the two curves immediately gives the influence of the two protecting grids (transmitter and receiver cartridge). The results of the measurements are shown in Fig. 19 and Fig. 20 and it can be seen from the curve that the protecting grid gives an "extra" increase in the pressure increase up to around 18 kc/s. Above this frequency the protecting grid acts as an acoustic screen and reduces the microphone sensitivity considerably.

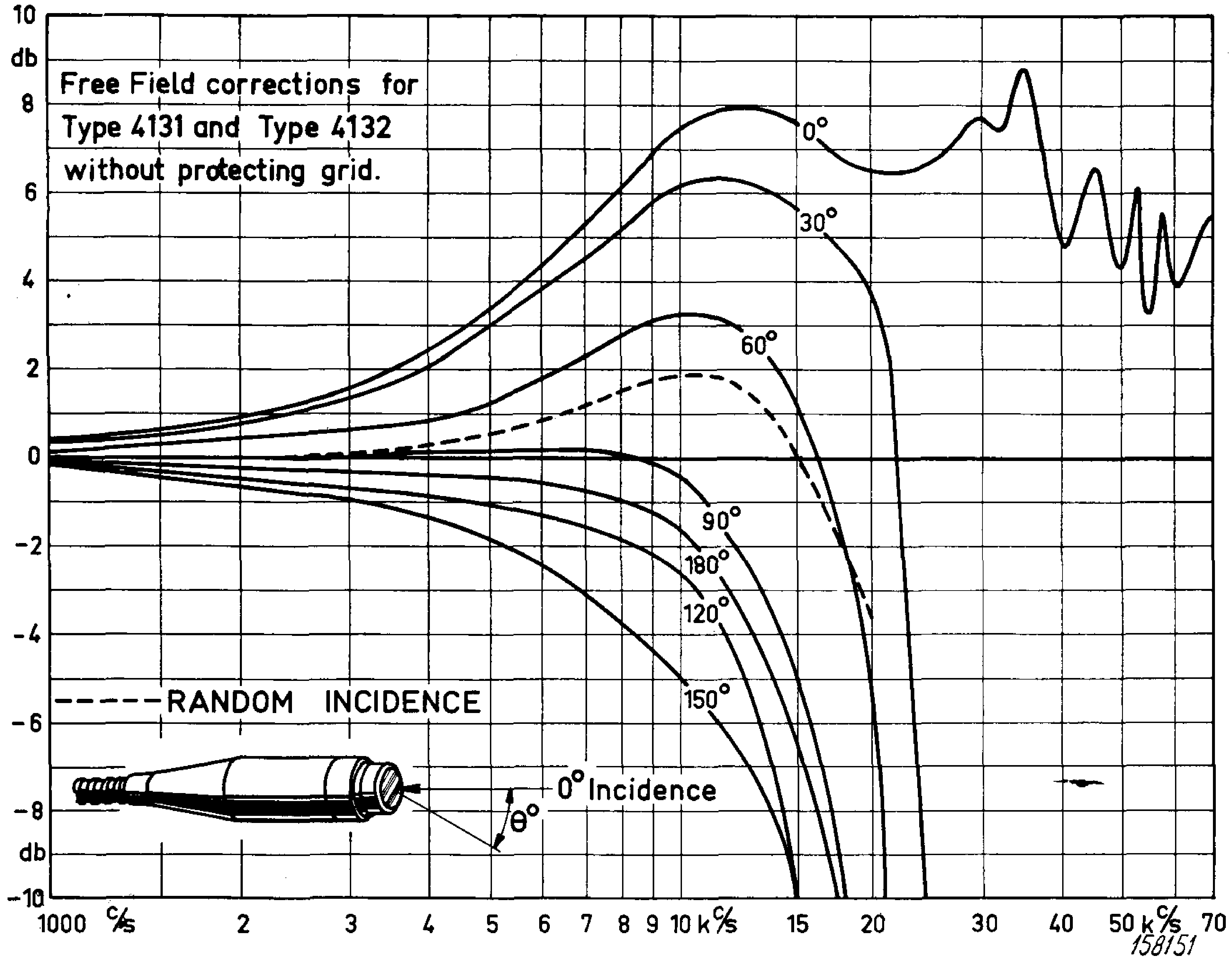

Fig. 19. Pressure increase as a function of frequency and for different angels for Condenser Microphones Type 4131 and 4132 without protecting grid.

Also the microphone sensitivity for different angles of incidence are shown in Figs. 19 and 20. Above 20 kc/s certain deviations exist between measurements on different cartridges the reason being the rather great influence of the protecting grid structure on the microphone sensitivity in the centre of the diaphragm where the sensitivity varies very greatly at higher frequencies.

The microphone Type 4132 can also be supplied with an extra ring and protection grid. By mounting this ring, DD 0014, the dimensions of the microphone Type 4132 will equal those of the Western Electric 640 AA, whereby 4132 can be fitted into instruments built for use with the well known Western

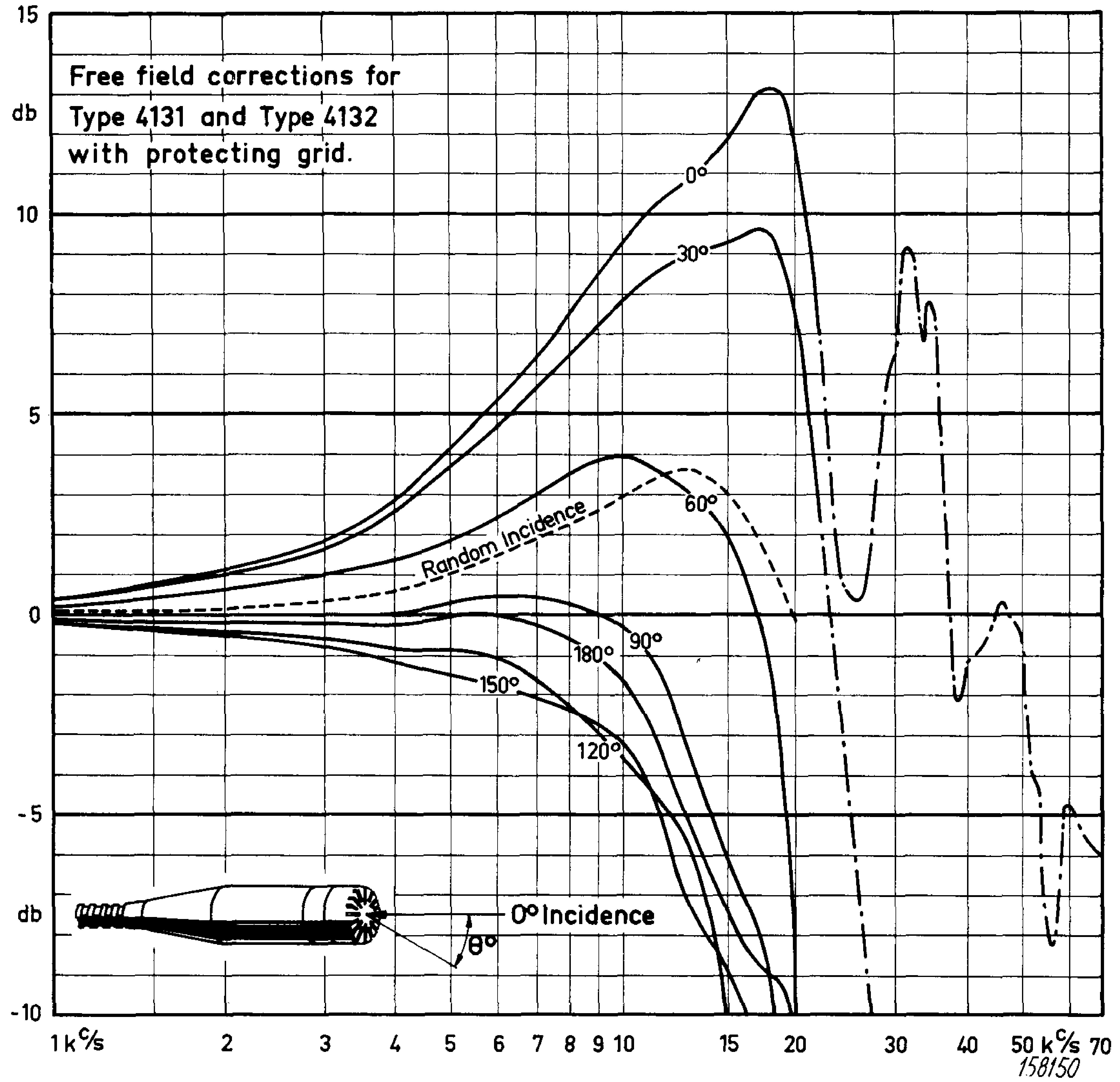

Fig. 20. Pressure increase as a function of frequency for the Condenser Microphones Type 4131 and 4132 with protecting grid.

Electric microphone. The free-field pressure increase curve for the microphone in this version will differ a little from the pressure increase curve obtained for the normal version of the microphone, the difference being caused by the cavity in front of the microphone diaphragm, see Fig. 21. Apparently the cavity has the same effect as an increase in the microphone diameter. The effective pressure increase curve for the microphone Type 4131 with ring and protection grid DD 0014 is shown in Fig. 23, above, together with measuring points corresponding to those given by Western Electric for the pressure increase of a microphone of the same shape.

In some cases it is of interest to know how the microphone will respond to sound waves impinging upon the diaphragm with random incidence. Such a

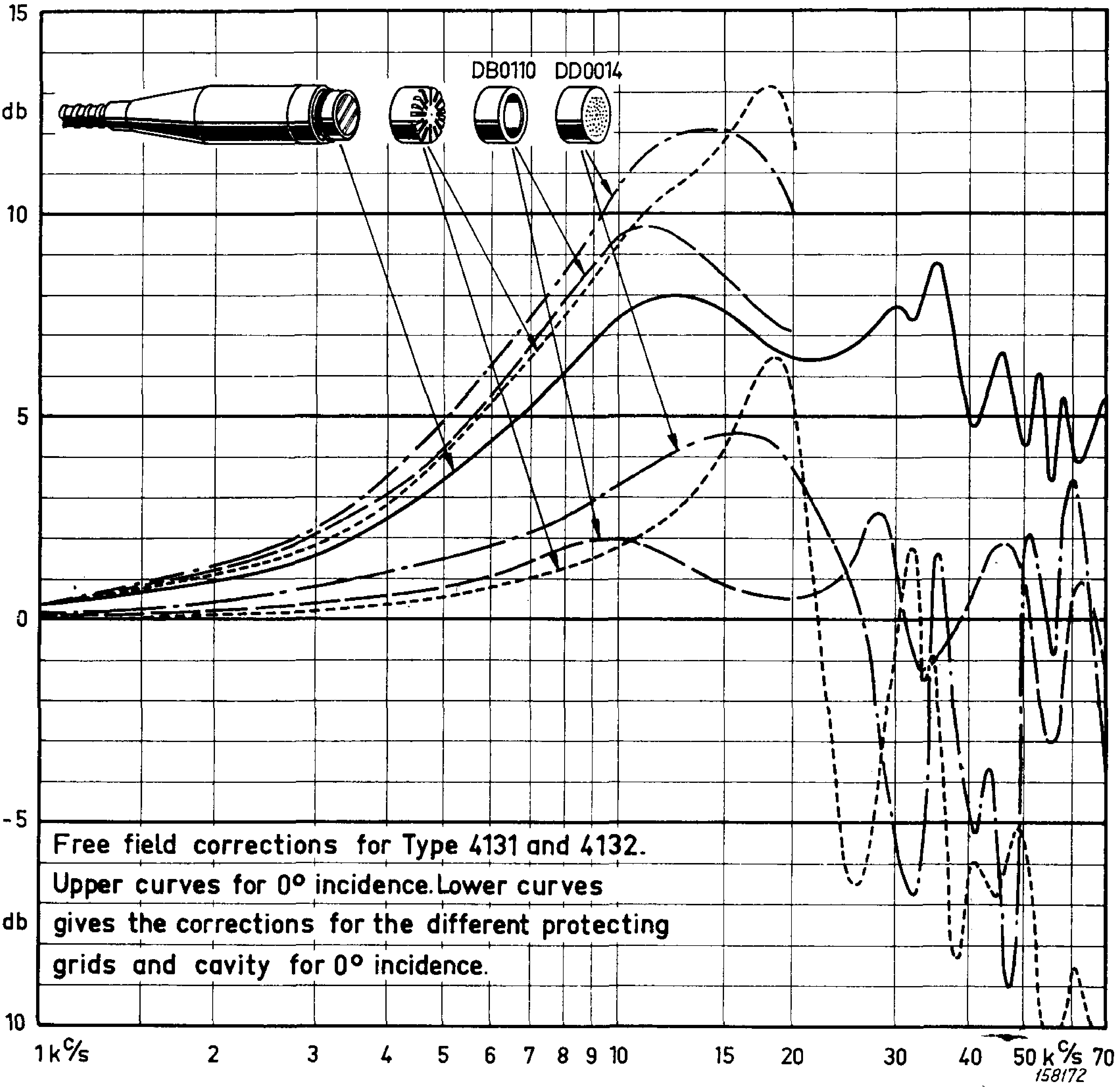

Fig. 21. Free-field corrections (pressure increase curve) for Type 4131 and 4132 with different protecting grids and cavities.

response curve can be calculated according to the outlines given in "International Electrotechnical Commission Draft Specification for Sound Level Meters" and is for the case of 4131 and 4132 plotted in Fig. 19 and 20. These curves are based on the knowledge of the directional sensitivity of the microphone and for the sake of convenience a set of directional characteristics measured by means of Type 4131 and 4132 the Polar Diagram Recorder Type 2370 and the Turntable Type 2371 in connection with the Level Recorder Type 2304 is shown in Fig. 24.

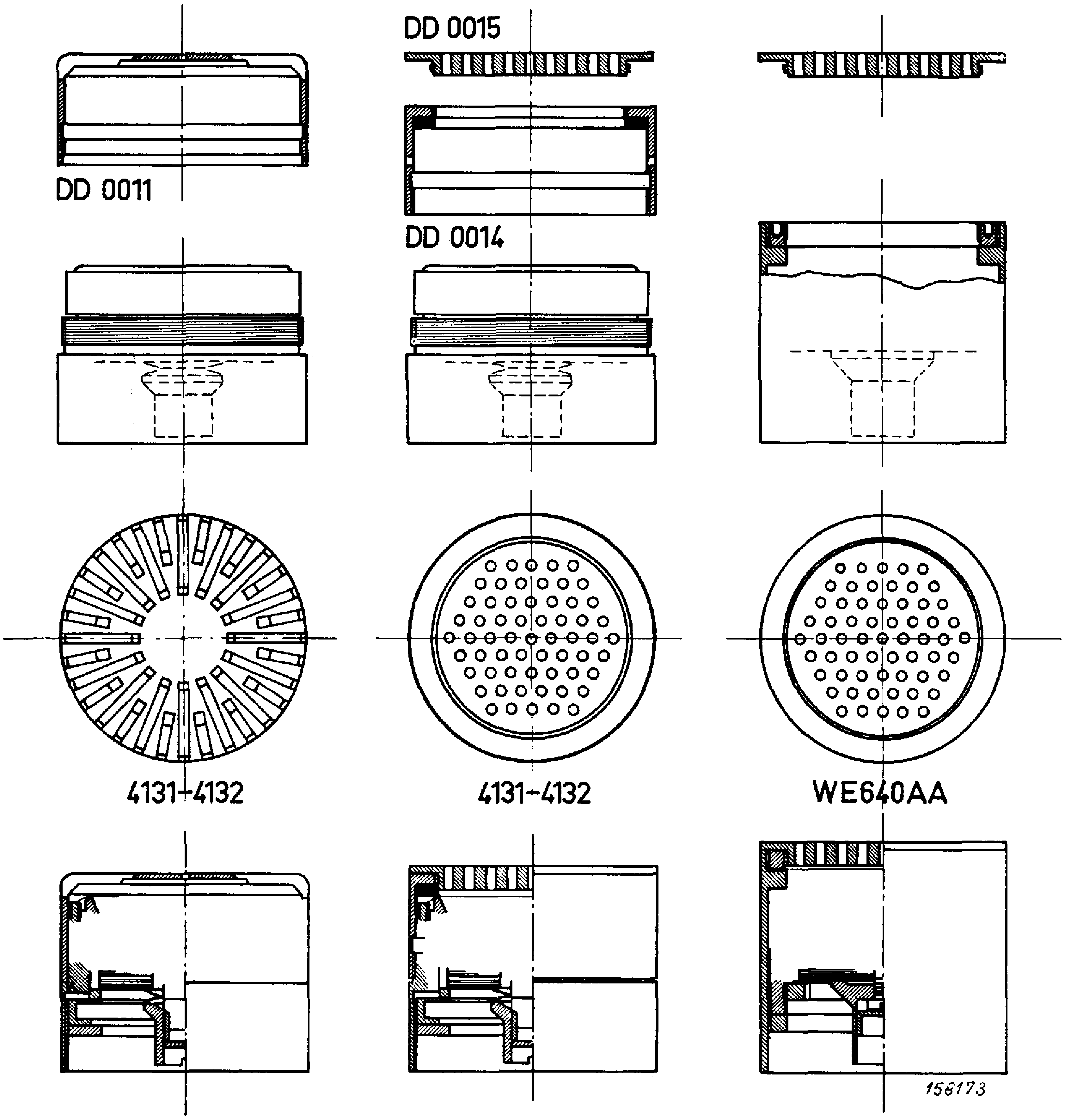

Fig. 22. Microphone Type 4132 with normal protection grid (left), Microphone with special ring and protection plate DD 0014 (middle) and section showing WE 640 AA condenser microphone (right).

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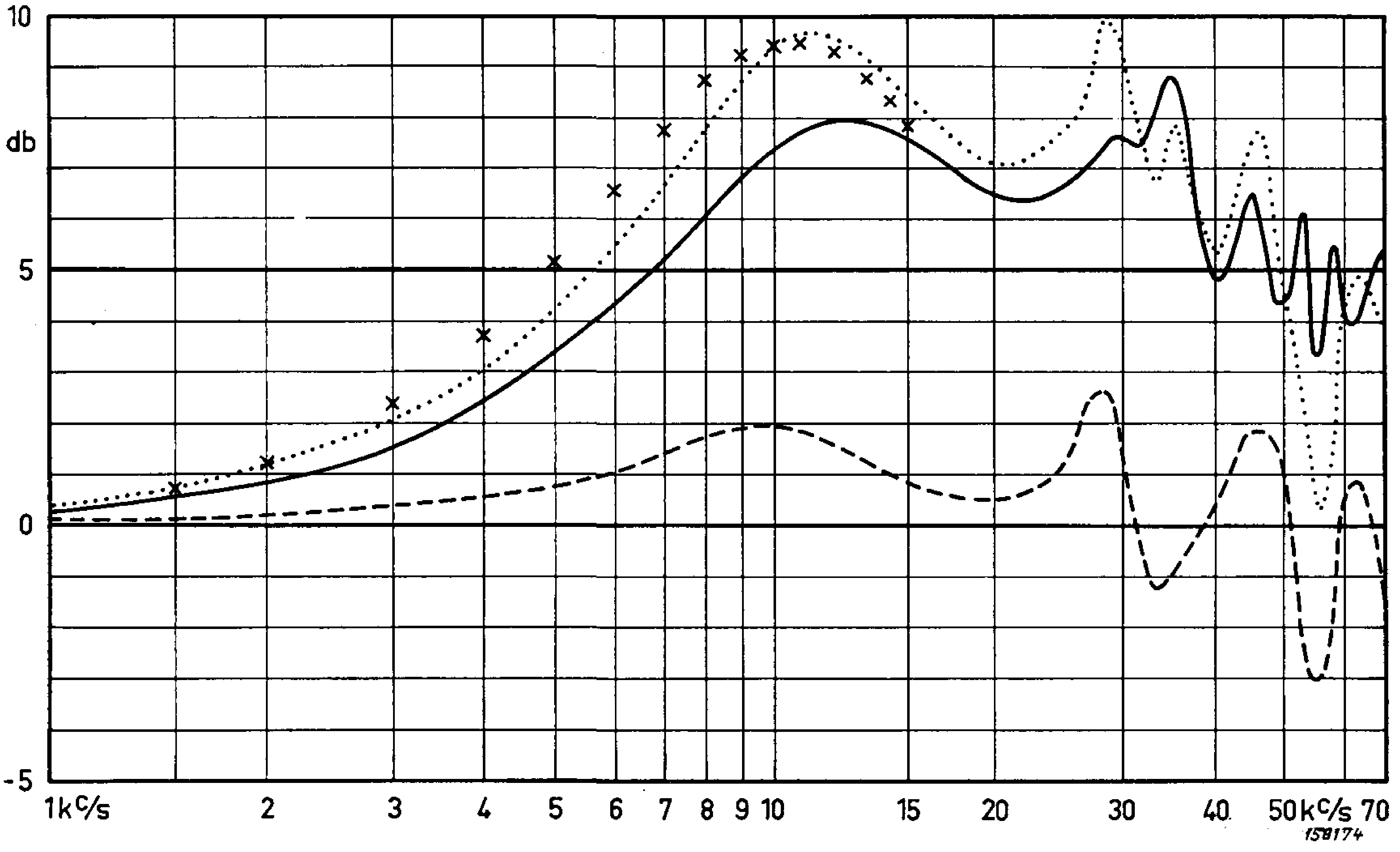
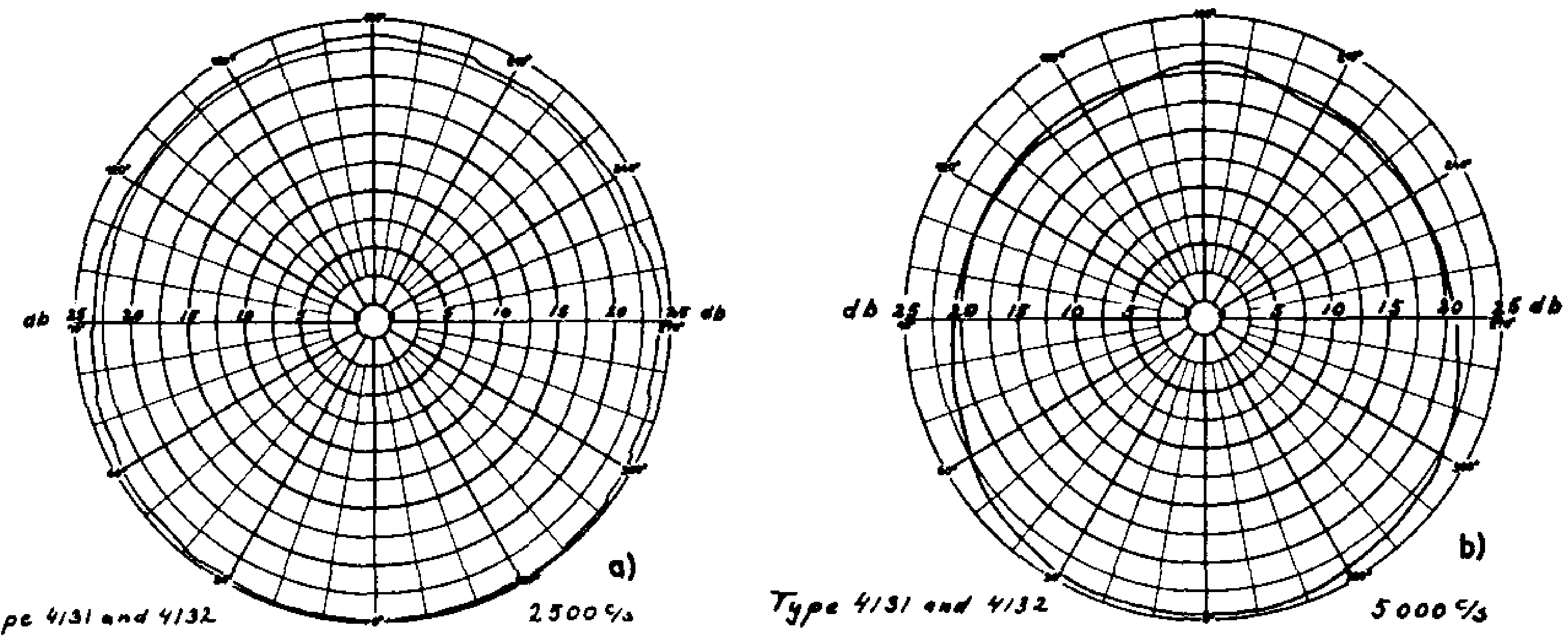
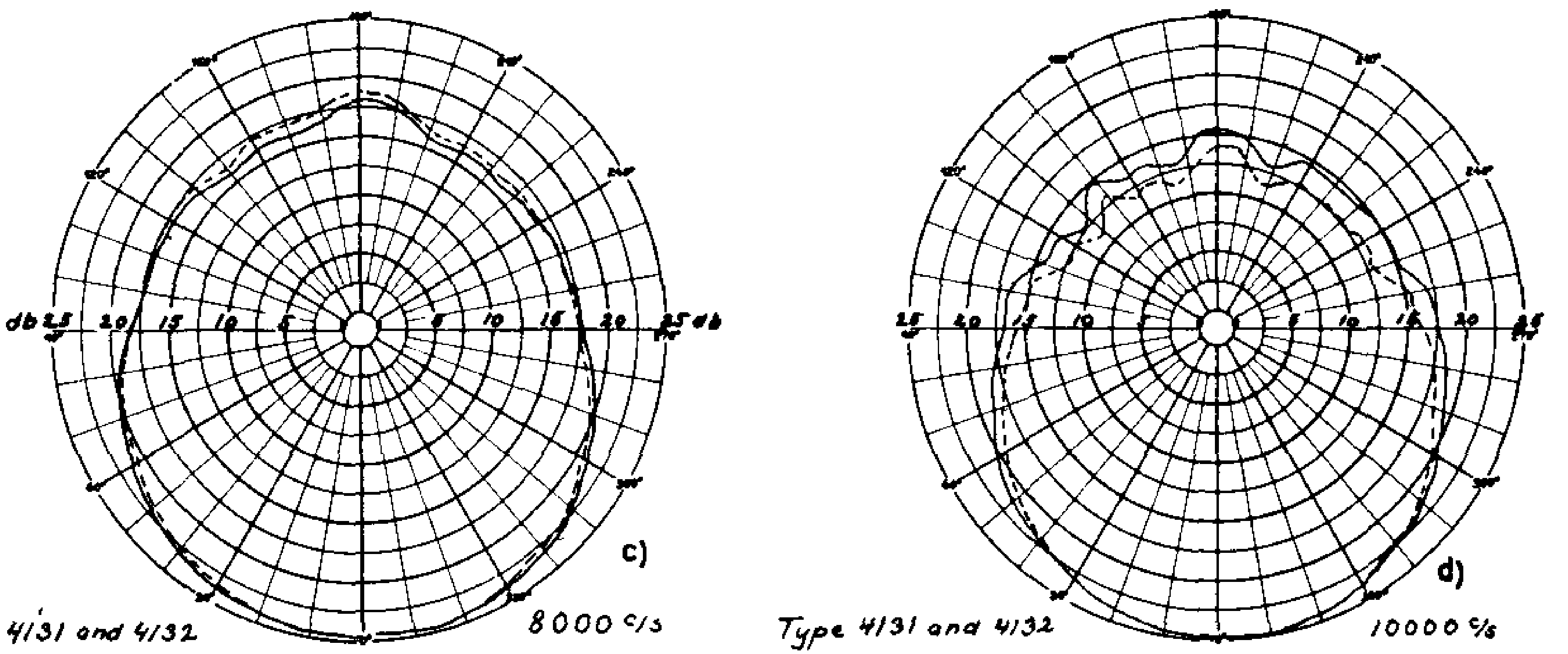


Fig. 23. The effective pressure increase owing to the front cavity of DD 0014 (without front cover DD 0015) on microphone 4131 and 4132 (dashed) and the total pressure increase curve for the microphones with this special ring (dotted). As points the pressure increase given by WE for WE 640 AA of similar form are given. 0° incidence.



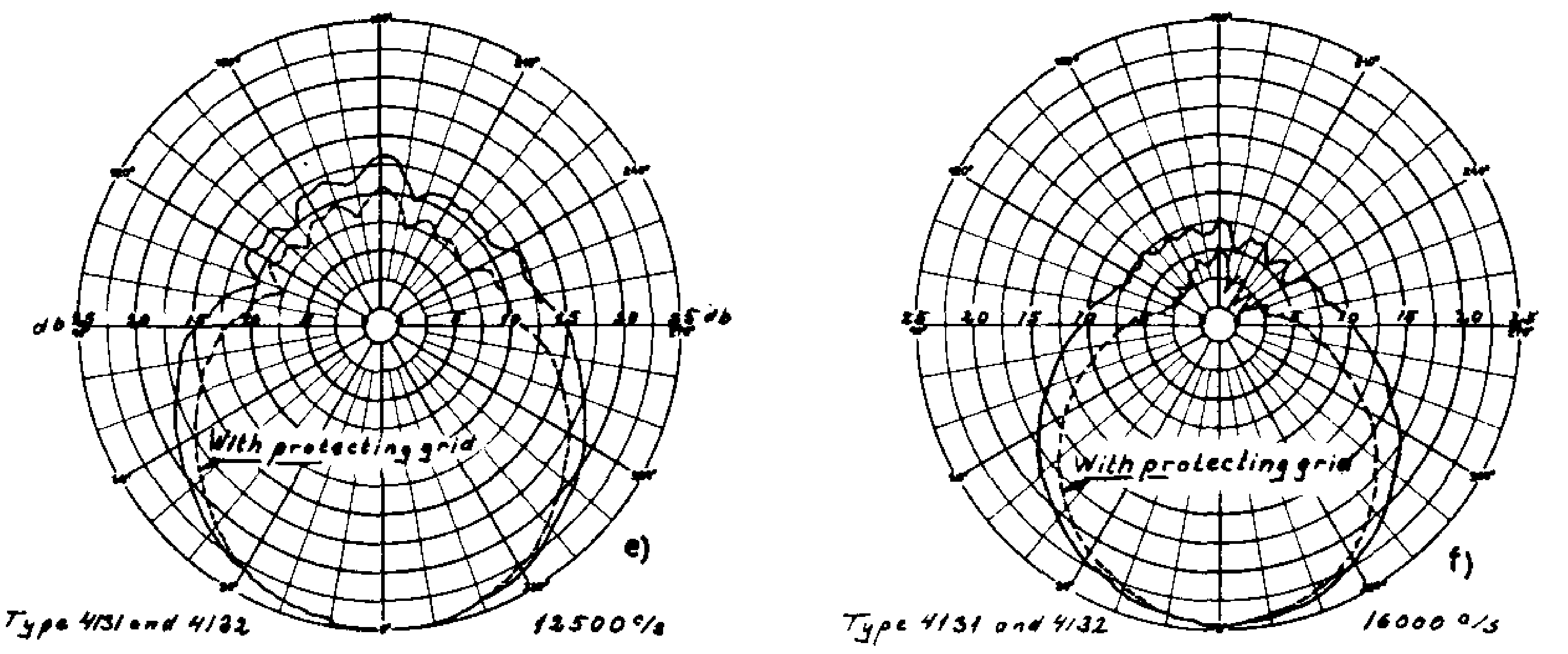
Type 4131 and 4132 2500 c/s

Type 4131 and 4132 5000 c/s



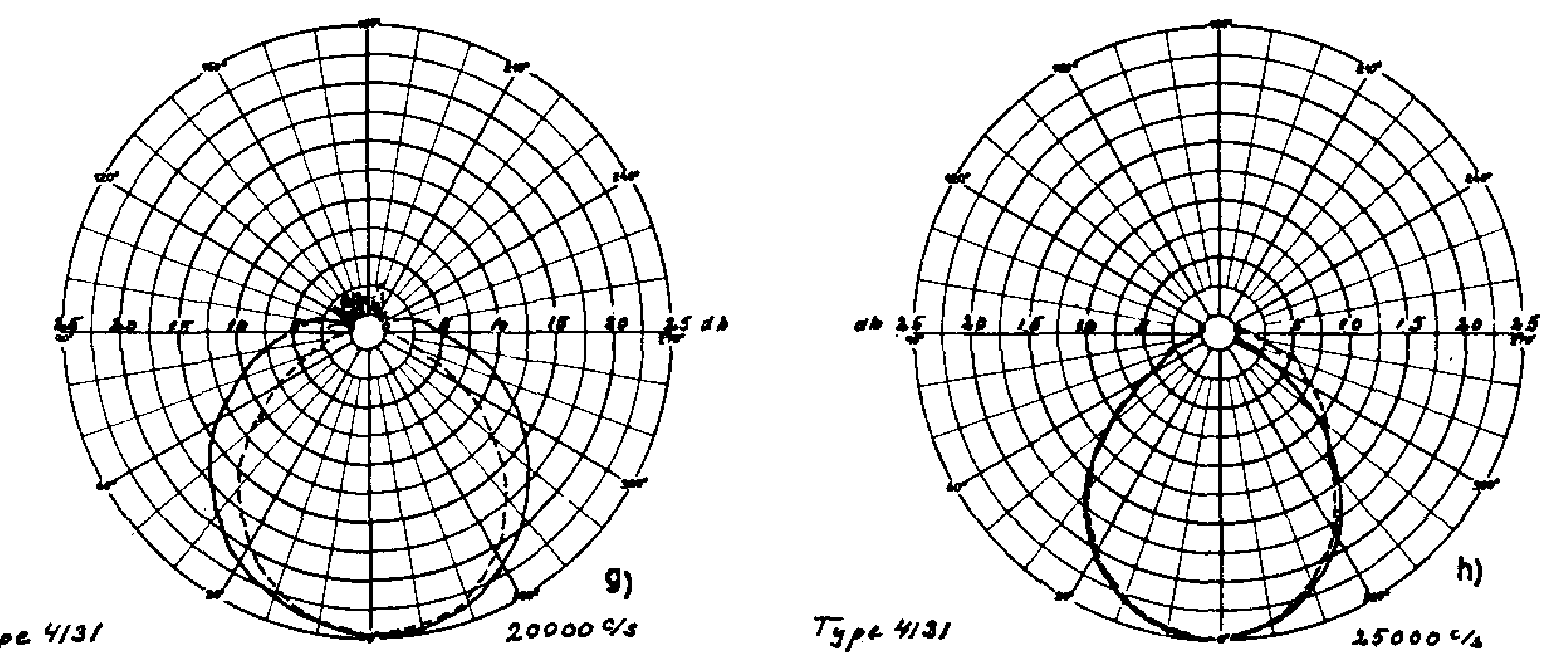
Type 4131 and 4132 8000 c/s
------ With protecting grid

Type 4131 and 4132 10000 c/s
---- With protecting grid



Type 4131 and 4132 12500 c/s

Type 4131 and 4132 16000 c/s



Type 4131 20000 c/s
----- With protecting grid

Type 4131 25000 c/s
----- With protecting grid

158175

Fig. 24. Typical directional characteristics of the Condenser Microphones Type 4131 and 4132.

News from the Factory

Artificial Voice Type 4215.

Type 4215 is a complete redesign of the Artificial Voice Type 4210, the production of which is now discontinued.

The new unit is cylindrically shaped with thick, heavy walls, thus radiating sound only through its front opening. A built-in socket allows the use of a Condenser Microphone of the type 4132 + 2613 (2612) to keep the sound pressure level in the front opening constant over the frequency range 100 c/s to 7000 c/s. The opening is supplied, furthermore, with an interchangeable coupler, and the maximum sound pressure level which can be produced for acoustic pressure measurements, is higher than 135 db re 2×10^{-4} μbar. Front opening of normal coupler: 38 mm (1½")⌀.

Type 4215 can also be used as a controlled sound source for free-field measurements, a maximum sound pressure level of approximately 115 db being obtainable at a distance of 40 mm from the front opening.

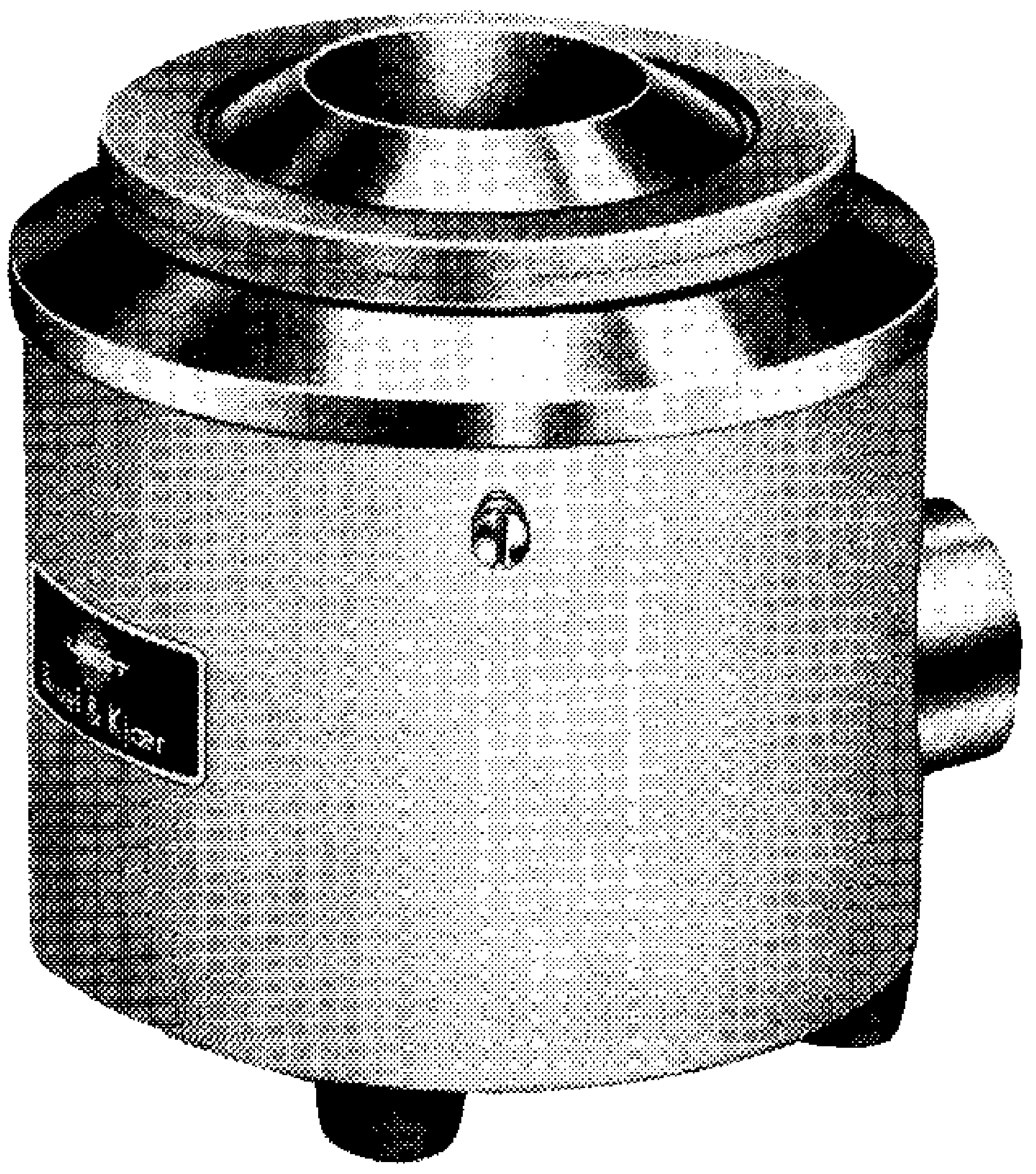


Photo of the Artificial Voice Type 4215.

Calibration Exciter Type 4290.

The Calibration Exciter Type 4290 is a vibration exciter with built-in control accelerometer: It is intended for checking the high frequency response of

small accelerometers such as Type 4308 and 4309, and provides a constant acceleration level from 50 c/s to 30 kc/s. The maximum attainable acceleration level of the vibrating unit (unloaded) is 1 g* at frequencies lower than 800 c/s. At higher frequencies the maximum acceleration level is o.1 g*.
1 g* = 981 cm/sec^2.

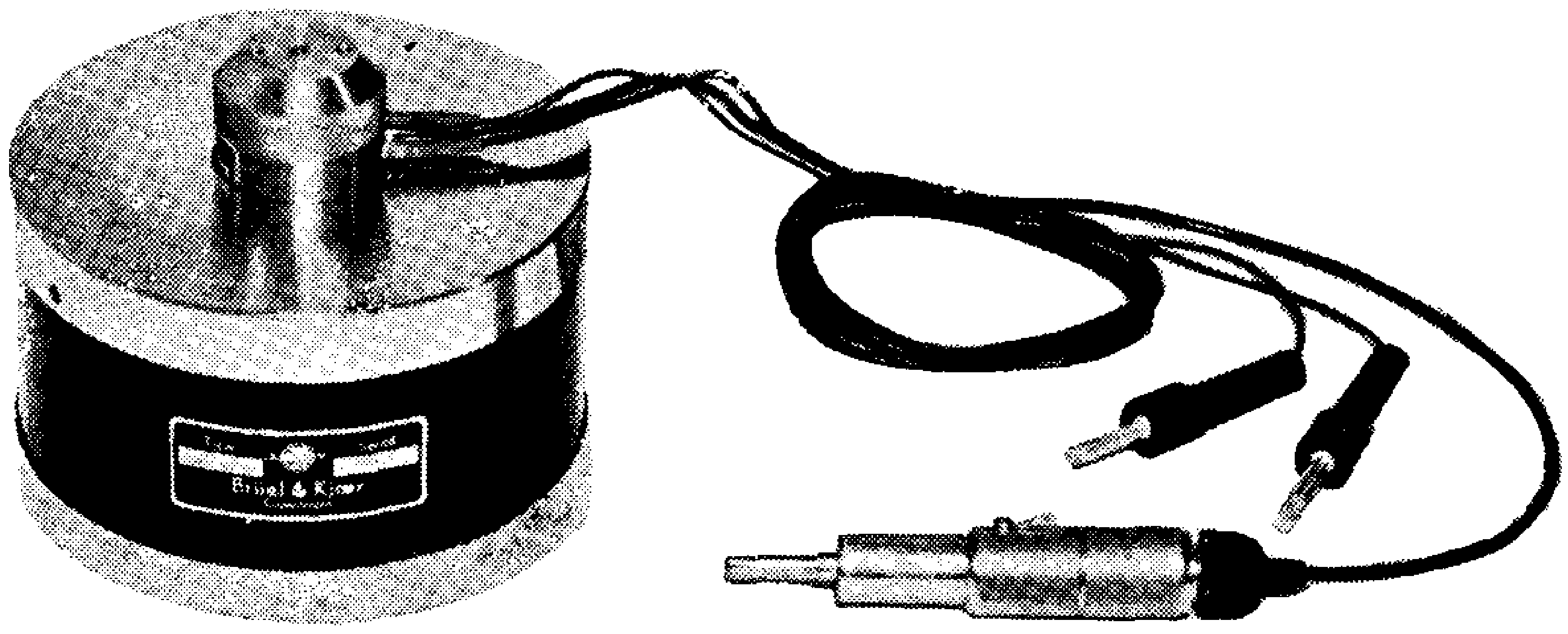


Photo of the Vibration Exciter Type 4290.

Frequency and Distortion Measuring Bridge Type 1607.
Type 1607, which attenuates a single frequency by more than 80 db, is a redesign of Type 1602 Frequency and Distortion Measuring Bridge. The frequency range, however, of Type 1607 is 20 c/s to 20ooo c/s instead of the 47 c/s to 12500 c/s range of the Type 1602.
The new unit is designed, furthermore, for direct connection to the "Filter Input" and "Filter Output" terminals of the Microphone Amplifier Type 2603. The combination 1607 + 2603 is very well suited for distortion measurement, featuring a high input impedance and a true R.M.S. measuring meter.

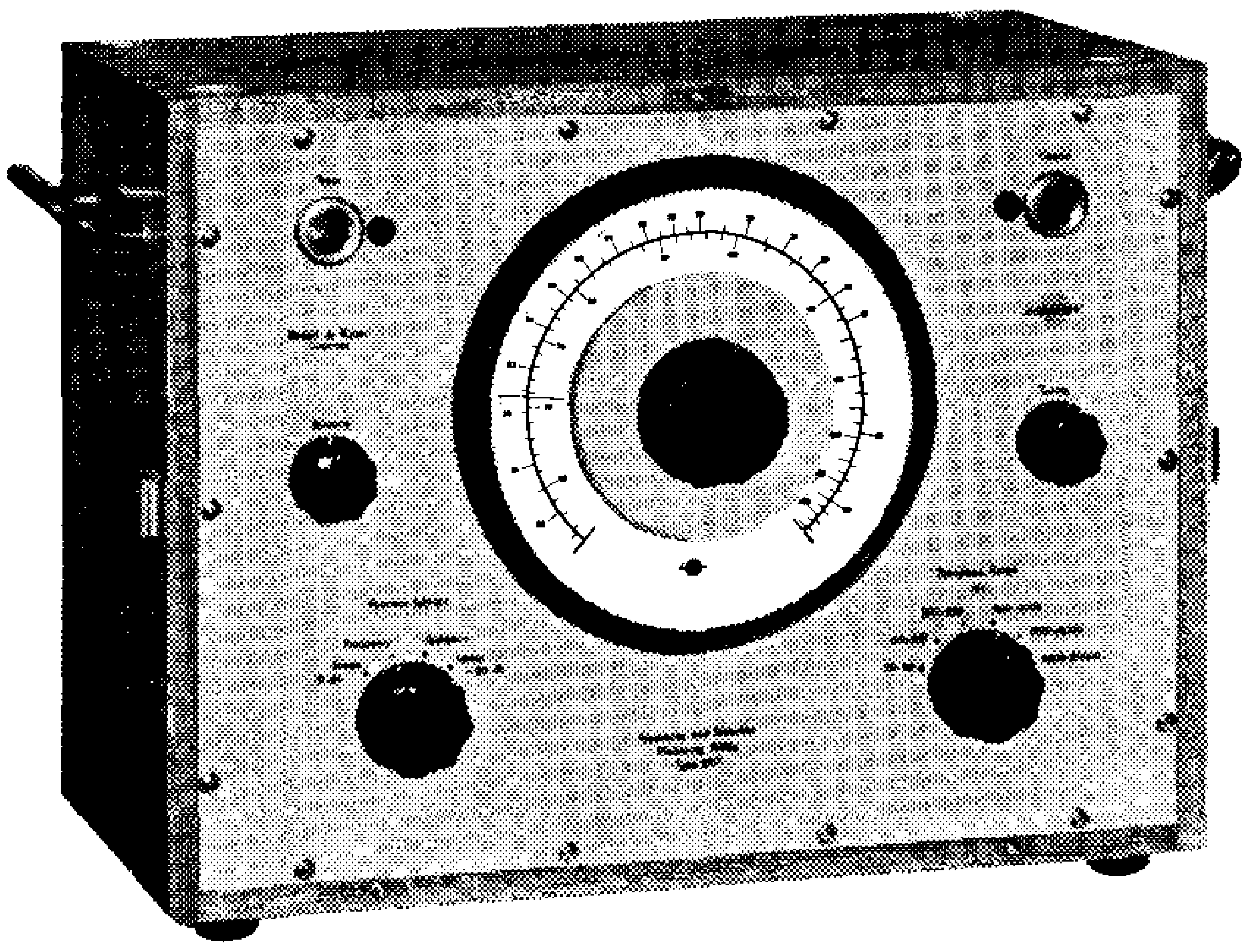


Photo af the Frequency and Distortion Measuring Bridge Type 1607.

Recording Paper QP 3614, QP 3615 and QP 3616:
Because the frequency range for selective measurements with the introduction of the Spectrometer Type 2110 and the Extension Filter Set Type 1619 now covers frequencies from 14 c/s to 35 kc/s, it has been found necessary to

introduce a new series of preprinted, frequency calibrated recording paper. This paper is calibrated from 10 c/s to 40 kc/s and is available in three different qualities:

QP 3614	White paper for ink writing
QP 3615	White waxed, black paper for sapphire stylus
QP 3616	Red waxed, transparent paper also for sapphire stylus writing. This paper allows blue prints to be made of the recorded curve.

By using QP 3616 and making blue prints, only the recorded curve will appear on the print, because the recording paper will be transparent only where the sapphire stylus has scratched away the wax. To obtain the frequency and amplitude scales on the print, it is necessary to use the Photographic Negative QF 0003 and use "double copying".

Photographic Negative QF 0003 is a film containing the same scales as QP 3614-15-16, but in negative.

Modification of Microphone Amplifier Type 2603 and Audio Frequency Spectrometer Type 2110.

To facilitate simple adjustment of the Type 2110 Spectrometer and Type 2603 Microphone Amplifier for sound measurements in conjunction with the B & K Condenser Microphones, separate sensitivity adjustment controls are now provided for the direct input ("Amplifier Input") and the "Condenser Microphone" input.

This means that when the Amplifiers are specially adjusted for sound measurements, this adjustment does not influence their sensitivity adjustment when used as voltmeters or as ordinary electronic amplifiers.

However, when the Amplifiers are used to calibrate Condenser Microphones by means of the Microphone Calibration Apparatus Type 4119 or 4141, it is essential that the sensitivity of both the "Direct" and the "Condenser Microphone" inputs are identical. To do this, the pointer of the meter should be set to the red line on the meter scale by adjusting the controls marked "Sensitivity Condenser Microphone" and "Sensitvity Amplifier Input" with "Meter Range" switch set to "Ref.", and the input switch in both the respective input positions.

The facilities for separate sensitivity adjustments are included on instruments with serial numbers from:

Type 2110	Serial nr. 32028
Type 2603	Serial nr. 32348

A further improvement to the Microphone Amplifiers Type 2603 of higher serial numbers than 35527 has been made by the introduction of printed circuitry.

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