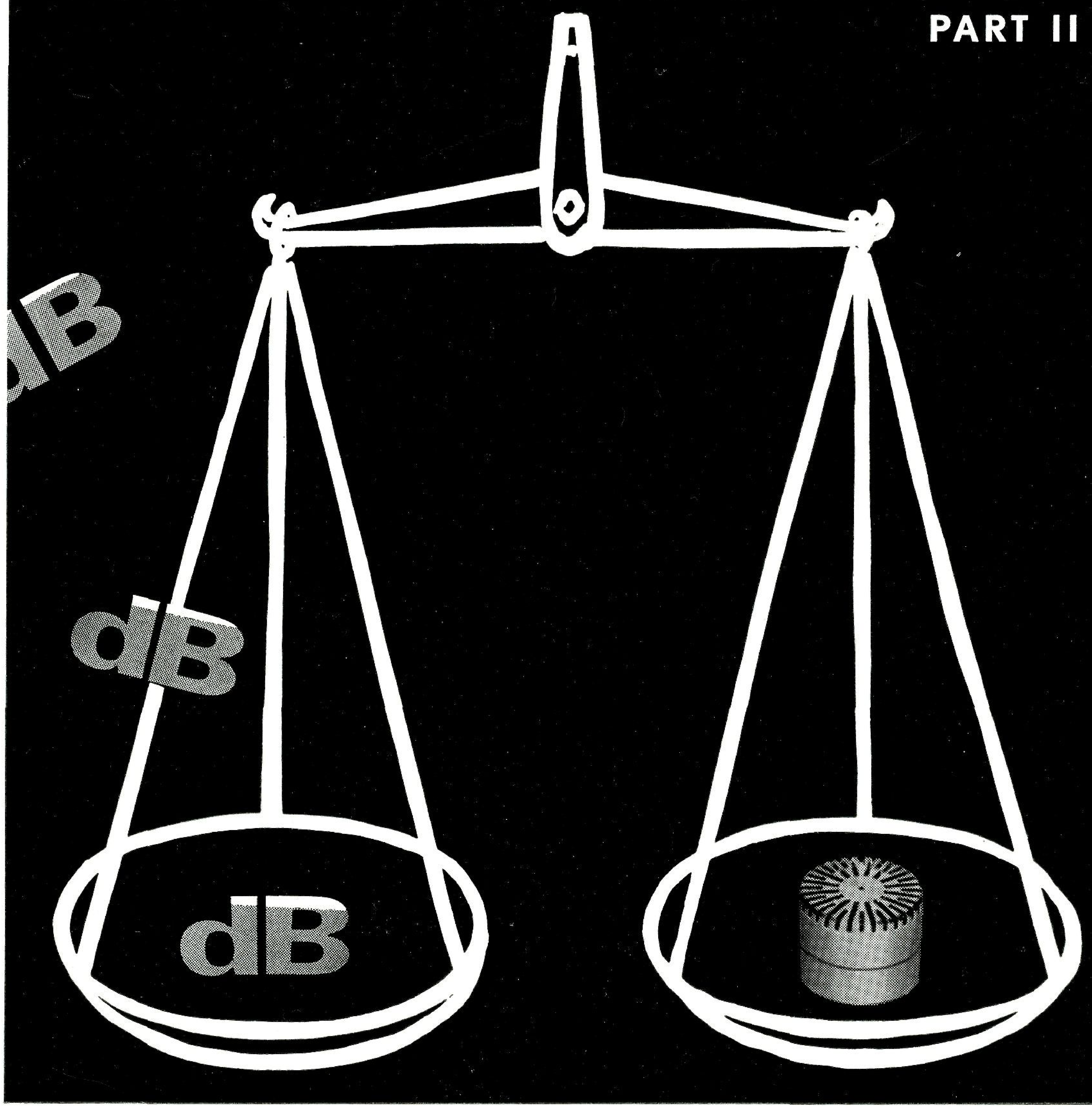
Brüel & Kjær

Technical Review

To Advance Techniques in Acoustical, Electrical, and Mechanical Measurement

THE ACCURACY OF CONDENSER MICROPHONE CALIBRATION METHODS

PART II



No. 1

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TECHNICAL REVIEW

No. 1 – 1965

The Accuracy of Condenser Microphone Calibration Methods. Part II.

by

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Summary.

The object of this investigation is to try to find the accuracy, with which it is possible to calibrate standard microphones.
Throughout this investigation, two standard microphones of the type 4132, i.e. with a flat pressure response curve, and one type 4131 with a flat free field response curve were used as test objects.
The frequency range of investigation has been from 48 Hz (c/s) to 800 Hz (c/s) and it has been assumed that the relative frequency characteristic is flat within this range. The following fundamentally different test methods have been investigated and their uncertainties determined.

1. Rayleigh Disc in Wave Tube.
2. Classic Low Frequency Pistonphone.
3. Double Piston Pistonphone.
4. Thermophone in closed chamber.
5. Smoke Particle Movements in Wave Tube.
6. Disc Lifting Method.
7. Electrostatic Actuator (Slotted and Solid Models).
8. Reciprocity with Capacitor Shunt.

The first three methods listed above have been dealt with in Part I of this investigation, published in Technical Review No. 4 1964.

Thermophone.

The Thermophone was earlier frequently used for the determination of absolute sound pressures. The principle is shown in Fig. 16 and Fig. 17 shows a photograph of the instrument used.
A very thin metal foil is placed inside a cavity, in this case the foil was made of nickel, which can be made into very thin and accurate foils. A DC current with an AC current superimposed is passed through the foil. The resulting pulsated DC current will heat the thin foil periodically and through this heat change the nearest layer of air will also be heated and expand, and in this way produce a sound pressure which can be determined

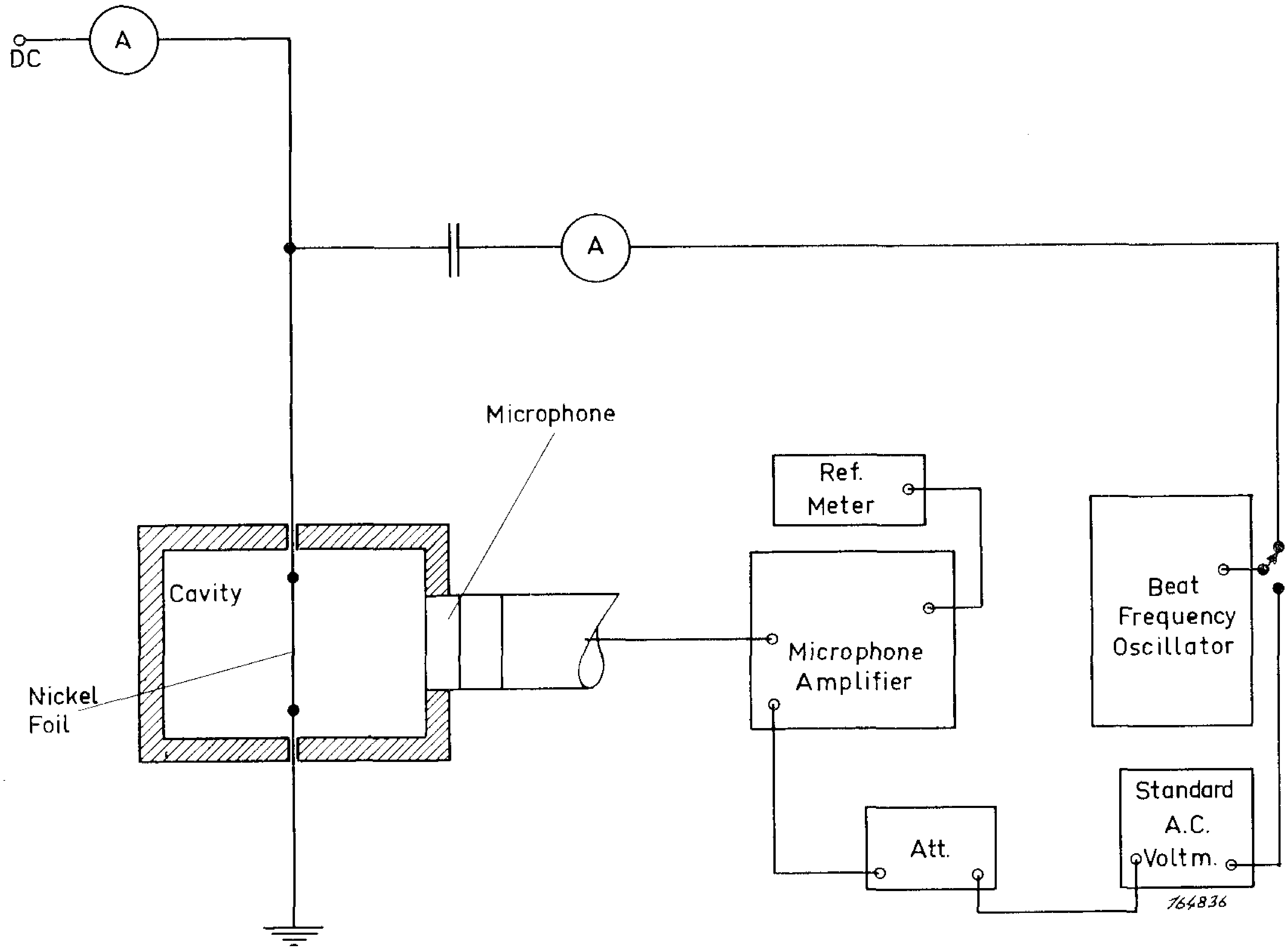

Fig. 16. Principle of calibration with a Thermophone together with the electrical set-up.

Fig. 17. Photograph of the Thermophone made for these tests. A thin nickel foil was used instead of the usual gold foil.

by knowing the volume, the electrical resistance of the foil and the frequency of the current, the heat conductivity of both foil and air and the heat capacitance of foil and air. As can be seen it is a rather complicated formula that has to be used for the sound pressure determination.

Recently, there has been a description of the Thermophone (ref. 11) where it is indicated that an accuracy of o.2 dB could be obtained. It is mainly to look into this statement that the complicated procedure is dealt with in this article.

The most advanced description of the theory for the Thermophone (ref. 12) is made by Riety and here Riety's simplified formula for determination of the sound pressure is used. The sound pressure in the volume is:

$$(8) \qquad p = \frac{2\,R\,I_0\,I_1\,(\gamma - 1)\,10^7}{\omega\,V_0 \left[\left(1 + \frac{X\,\omega}{4\,k\,\alpha} \right)^2 + \left(\frac{X\,\omega}{4\,k\,\alpha} \right)^2 \right]^{1/2}} \ \text{dynes/cm}^2$$

R = Resistance of the nickel foil when heated = o.1304 Ω
I_0 = DC current through the foil (1 Amp.)
I_1 = AC current through the foil (o.1 and o.05 Amp.)
$\gamma = \frac{C_p}{C_v} = 1.402$ for air
$\omega = 2\pi f$; $f = 50$ and 250 Hz (c/s)
V_0 = volume of cavity = 17.75 cm^3
X = thermal capacity of the foil per cm^2 = 1.4×10^{-4} cal/cm^2
k = thermal conductivity of the air in the cavity

$$41 \times 10^{-5} \sqrt{\frac{{}^\circ C + 273}{273}} \ \text{cal/cm}^2$$

$$\alpha = 1.53 \times \sqrt{f} \times \left(\frac{273}{{}^\circ C + 273} \right)^{3/4} \ \text{cm}^{-1}$$

During the test the static pressure was 761 mm Hg and the temperature 19°C, so no correction is made for static pressure and temperature.

The measurements are shown in Table XIV. Only three measurements on each of the three microphones have been carried out.

In general it seems that the obtained sensitivity for the cartridges is found to be a little low compared to that obtained with the pistonphone.

The standard deviation of the measurements can be found by using the average value as a base, in this case one obtains an indication of the accuracy of the actual measurements, i.e. determination of the current, variation in heat conductivity etc., whereas if the standard deviation is calculated out from the value and determined by means of the pistonphone, the found deviation will also include some formula errors, which can be seen to be considerable in this case.

It is very difficult to evaluate the approximations that have been made in the simplified formula (8), so for this method no theoretical calculation of the uncertainty has been made, but it seems that the measured uncertainty from this little experiment indicates very clearly the difficulties involved with the method.

Frequency	AC current	S.P.L.	Microph. 78		Microph. 80		Microph. 85	
			Output mV	Sensi. mV/µbar	Output mV	Sensi. mV/µbar	Output mV	Sensi. mV/µbar
Hz	Amp.	µbar						
50	0.1	1.23	5.10	4.14	5.00	4.06	4.74	3.85
250	0.1	0.116	0.565	4.87	0.545	4.70	0.517	4.46
50	0.05	0.618	2.61	4.22	2.50	4.05	2.37	3.84
Average sensitivity			4.41		4.27		4.05	
Sensitivity with 4220 mV/µbar			4.91		4.46		4.11	
Standard deviation on measurem.			0.33 mV/µbar or 7.6 %					
Standard dev. from true value			0.48 mV/µbar or 11 %					

Table XIV. Results and deviations achieved after calibrating the three microphones using the Thermophone method.

Smoke Particle Method.

A nice method for absolute calibration is to measure the movement of smoke particles in the air, which is a direct way of measuring the amplitude of the air particles.

To get any accuracy out of this method it is necessary to have a fairly large peak amplitude to measure, in other words work with a considerably high sound pressure so that the amplitude can be in the order of at least some tenths of a mm.

The set-up used here is shown in Fig. 18, where the standing wave apparatus Type 4002 is again used with the microphone under test placed at the end of the tube and through two holes in the wall of the tube, a quarter of a wave length from the end, a measuring microscope and a light source was mounted. By filling the air with smoke particles it was possible to have some in focus with the microscope and directly measure the double amplitude.

The natural draught in the tube gave considerable difficulties by moving the particles around, so it was necessary to stop this draught by mounting some gauze around the enclosure where the particle movement was measured. The gauze has of course to be of an open texture so that it has no influence on the particle velocity.

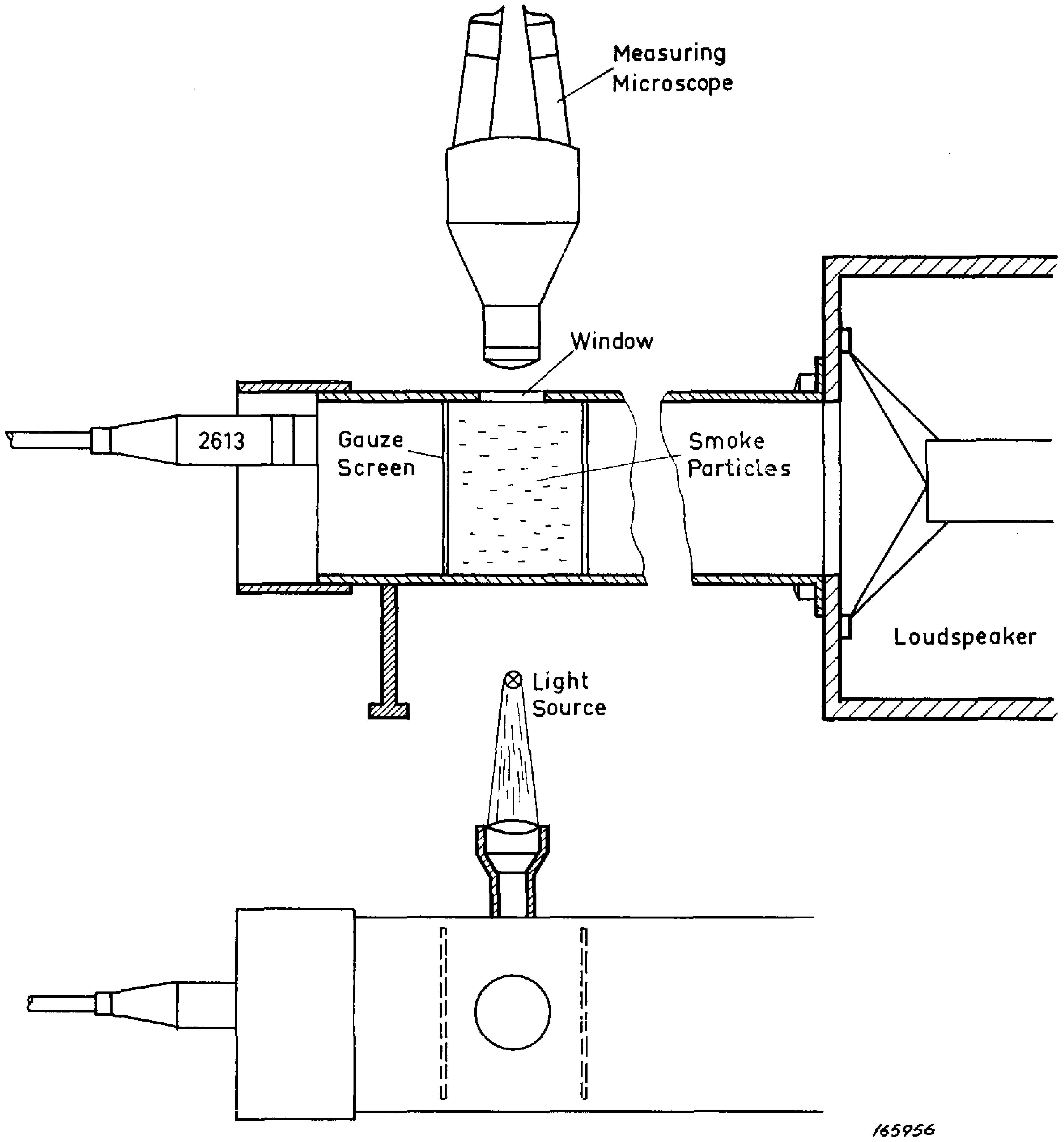

Fig. 18. Drawing of the Smoke Particle in Wave Tube Method

The RMS sound pressure can easily be determined from

$$p = \varrho_0 c \times \frac{\omega A}{2\sqrt{2}} \tag{9}$$

where $\varrho_0 c$ is the characteristic impedance of the air $= 42.86 \times \frac{P_0}{760}\sqrt{\frac{273}{°K}}$ rayls.

During the measurements the static pressure P_0 was 762 mm Hg and the temperature 299°K.
A = the visible length of the particle movement = twice the peak amplitude. The formula is very simple and no uncertainty is introduced by the formula itself.

In Table XV a series of measurements are indicated, which are the results from three different observers. The most difficult thing is to measure the double amplitude with a good accuracy. As can be seen from the results the spread is rather large, suggesting that the whole method is not very accurate. The average value of the sensitivity is found to be a little below the value depicted, indicating that the observers have a tendency to measure double amplitude somewhat too high. The standard deviation is around 13 %, which is a very large spread, so this method cannot be regarded as accurate even if it is very simple and direct.

Micro-phone No.	Sensitivity in mV/μbar			Average value Stand. deviation % deviation
	Observer 1	Observer 2	Observer 3	
78	4.48 5.41 5.98	4.37 4.87 4.66	4.38 3.89 4.55	4.74 mV/μbar Δ = 0.62 mV/μbar or 13 %
80	4.54 4.46 3.56	4.57 3.25 4.89	4.26 4.61 4.14	4.25 mV/μbar Δ = 0.53 mV/μbar or 12.5 %
85	3.78 4.57 4.29	3.91 4.36 3.31	3.08 3.41 4.33	3.90 mV/μbar Δ = 0.53 mV/μbar or 13.6 %

Table XV. Three different observers' results from calibrating the three microphones using the Smoke Particle Technique.

Disc Lifting Method (Gravity Method).

A very simple and direct way of determining a sound pressure can be carried out with the set-up shown in Fig. 19. This method was suggested by K. Kittelsen.

Above a loudspeaker fixed in an enclosure, in this case the B & K Artificial Voice Type 4215, and just above the microphone cartridge which is to be checked, a disc of metal is placed. The disc resting on three small pins practically fills the whole opening at the top of the set-up but does not touch the walls. A photograph of the Artificial Voice, where a special ring has been made to hold the metal disc is shown in Fig. 20.

When the sound pressure is increased to a value where the disc is just lifted, the r.m.s. sound pressure under the assumption that the sound is sinusoidal will be

$$(10) \qquad p = \frac{981 \times m}{\sqrt{2} \times A} \mu\text{bar}$$

where m = the mass of the disc in grammes
A = the surface area in cm^2

In this case the surface area was 2.87 cm^2 for all the discs used.
It is rather easy to determine the exact pressure level where the disc moves away from the support, as after this level the disc will rattle distinctly. On the associated amplifier 2603 it can with repeated tests be checked whether this rattling is started at the same output voltage from the generator.
For these measurements three discs with different masses were used. The corresponding sound pressures are indicated in the following list.

Disc	No. 1	No. 2	No. 3
Mass in grammes	2.7671	3.3878	6.2368
Sound pressure in μbar	670	820	1509

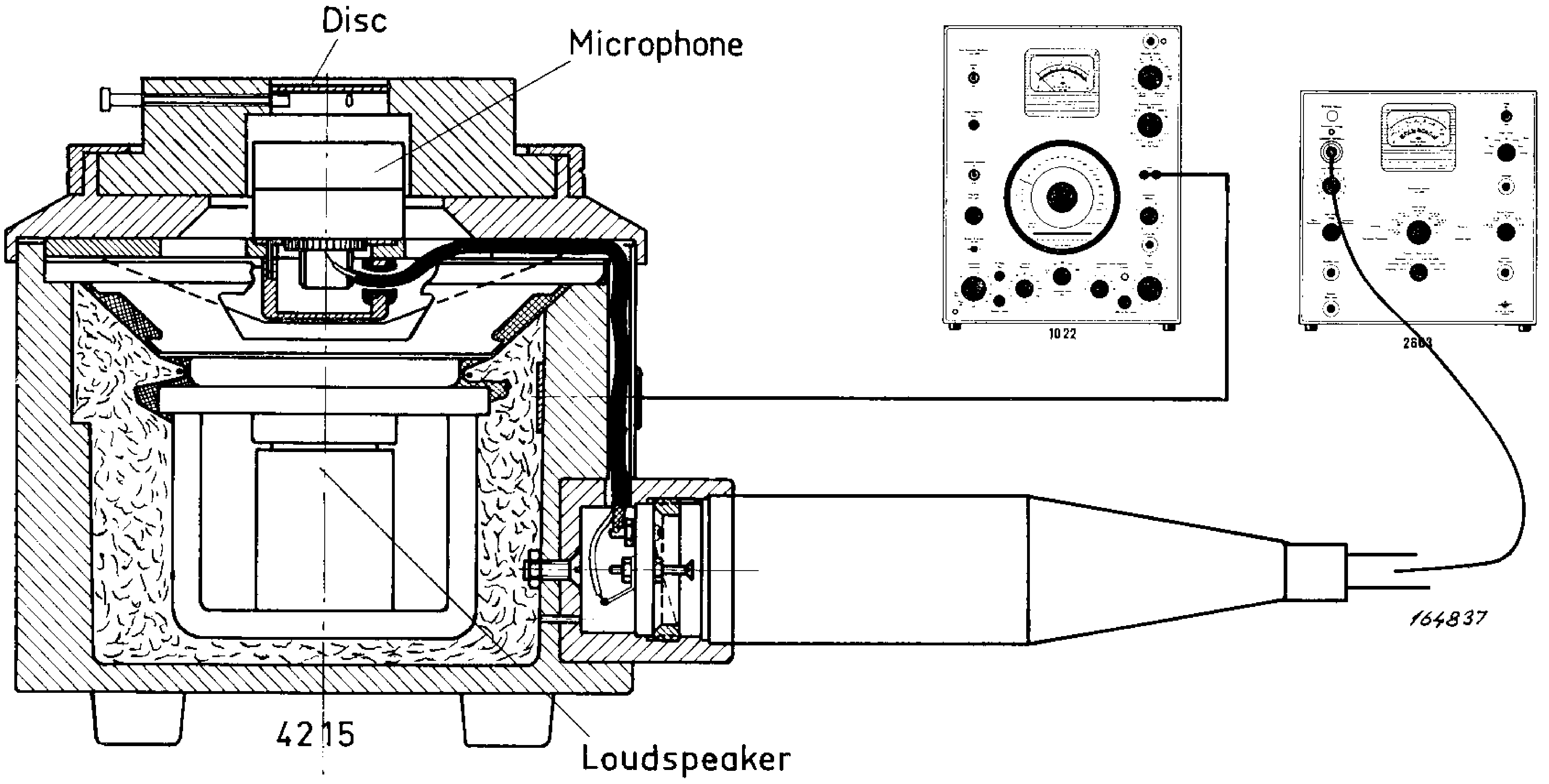

Fig. 19. Principle of the Disc Lifting Method as suggested by K. Kittelsen.

Fig. 20. Photograph of the essential parts used in the Disc Lifting Method.

Table XVI gives a series of measured results for different frequencies, that all had to be fairly low. From the deviation in the results it is possible to deduce with what uncertainty it can be said, when the disc is just lifted from the support points. It can be seen that the standard deviation is around 6 %, which is remarkably low for such a simple calibration method.

Disc No.	Microphone 78		Microphone 80		Microphone 85	
	90 Hz	125 Hz	90 Hz	125 Hz	90 Hz	125 Hz
1	4.85	4.89	4.51	4.39	4.28	4.04
	4.91	4.89	4.46	4.16	4.25	3.96
	4.91	4.93	4.33	4.05	4.28	3.80
2	5.12	4.90	4.49	4.36	4.12	3.94
	4.91	4.81	4.43	4.02	4.12	4.14
	5.06	4.77	4.63	4.36	4.03	4.13
3	4.52	4.50	4.02	3.94	3.54	3.35
	4.94	4.56	4.10	3.83	3.88	3.85
Average values	4.91	4.77	4.36	4.13	4.04	3.89
Average value	4.84 mV/μbar		4.25 mV/μbar		3.97 mV/μbar	
Stand. deviat.	0.18 mV/μbar		0.24 mV/μbar		0.23 mV/μbar	
Rel. uncert.	3.7 %		5.5 %		5.7 %	

Table XVI. The sensitivity in mV/μbar of the microphones determined by the Disc Lifting Method.

Apart from the deviation there also exists the possibility for one-sided errors which will not be found by repeated measurements. If, for instance, the supports are a little greasy and tend to hold the disc to the support, a higher sound pressure is needed to obtain a lifting, and on the other hand if the support is a little oblique so that the disc has the possibility of wriggling, the rattling may occur before the disc as a whole is lifted.

It can easily be seen that a higher sensitivity can be found at 90 Hz than at 125 Hz. This in itself is an indication that there exist one-sided errors with this method, and no doubt the measurements at 90 Hz are more correct than at 125 Hz.

Still lower frequencies were tried, but nothing was really gained with this as then difficulties in obtaining sinusoidal pressure under the disc were introduced.

A modification to the supporting pins was made so that these became more stiff and other values were found as indicated in Table XVII.

The standard deviation is about the same as previously, but the average figure has moved a little up, indicating that the first support used was somewhat elastic allowing the disc to rattle a little before the sound pressure corresponding to the earth gravity was obtained. The latter result should therefore be more correct.

By looking both at the sensitivity found for the microphones and the standard deviation of the results it should be noticed that this very simple method can be carried out with an accuracy of around 0.5 dB.

Mic.	Microphone 78			Microphone 80			Microphone 85		
c/s	90	120	200	90	120	200	90	120	200
D1	5.00	5.08	5.08	4.48	4.57	4.56	4.08	4.20	4.31
D2	5.25	5.05	5.02	4.50	4.51	4.38	4.22	4.14	4.14
D3	4.95	4.85	4.92	4.20	4.32	4.32	3.96	4.14	4.14
mV/μbar	5.00	4.99	5.01	4.39	4.46	4.42	4.08	4.16	4.19
Average mV/μbar Sensitivity	5.00			4.42			4.14		
Standard Deviation %	2.3 %			2.8 %			2.3 %		

Table XVII. The sensitivity of the microphones expressed in mV/μbar again determined with the Disc Lifting Method, but this time with a modified disc support.

Electrostatic Actuator.

The electrostatic actuator has for a very long time been used for the absolute calibration of condenser microphones. The actuator is a slotted, absolutely flat plate which is kept at a small known distance above the microphone diaphragm. When both a DC and AC voltage is applied a force between the actuator and the diaphragm is created simulating a known sound pressure. The slots in the actuator are made in order to give the sound waves free access to an open area, thus simulating free field working conditions.

In Fig. 21 a photograph and sectional drawings of the actuators are shown. This actuator, which was used for the experiments, is the older B & K model which rests on the diaphragm surface exactly at the point where the diaphragm tension head lifts the diaphragm. If this type of actuator is not placed very carefully and accurately on the diaphragm, one of the legs could move out of the supporting line and possibly damage the diaphragm. Therefore the newer B & K actuator is made so that the glass pins now rest on the outer ring of the microphone as shown in the figure.

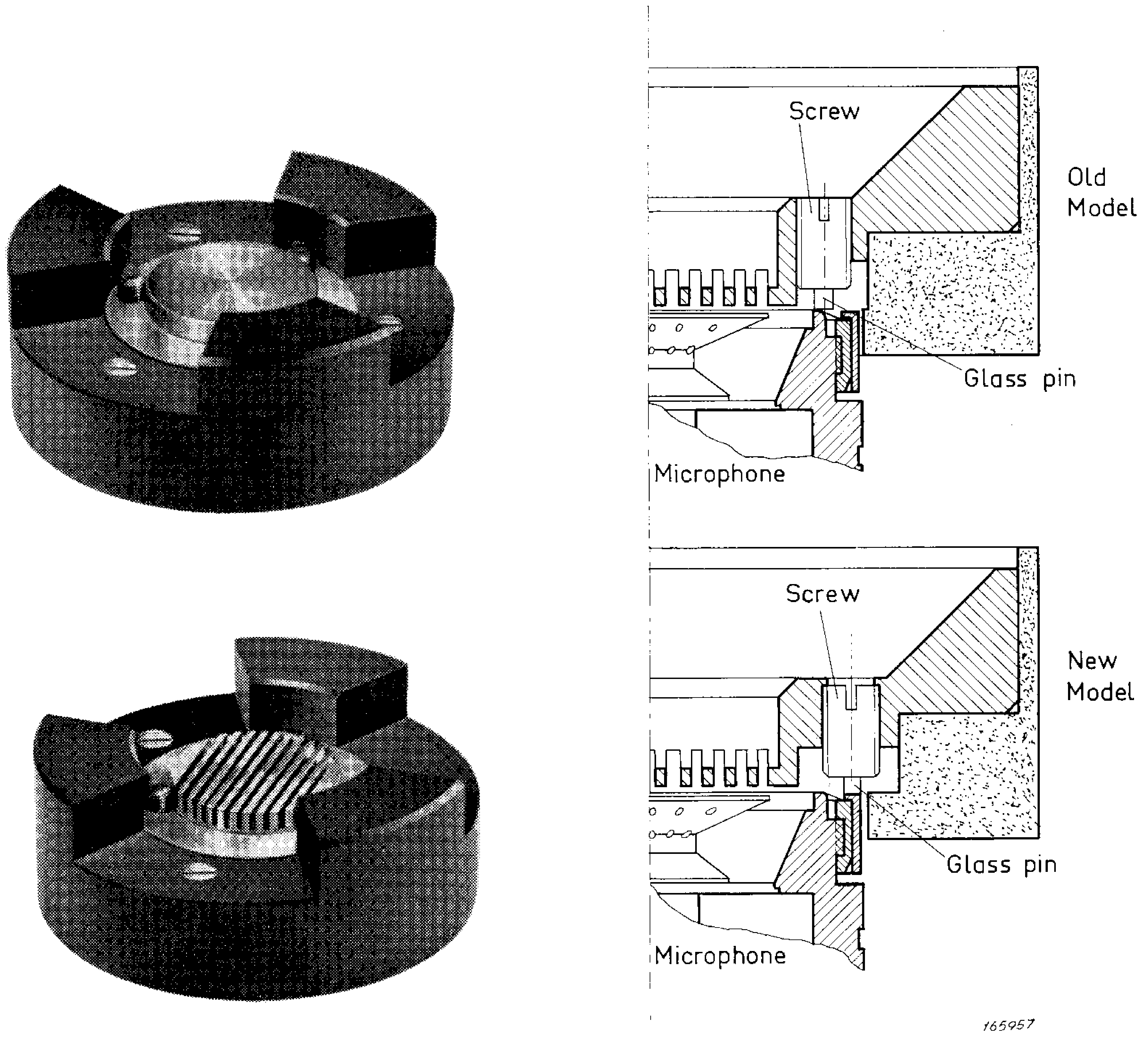

Fig. 21. Photograph and drawings of the Actuators.

Normally, an actuator should be used only for the determination of the frequency response of a microphone and for this purpose it is the best instrument that we have to-day. In these measurements, where the actuator was to be used for the determination of microphone sensitivity, the old model was chosen, as it was easier to measure the absolute distance between the diaphragm and the actuator, simply by measuring the height of the glass pins above the flat surface of the actuator. By adjusting these glass pins, practically any desired distance can be obtained.

The electrical measuring set-up is shown in Fig. 1 and the theory and the practical measurement is described in ref. 13 and 14.

The equivalent sound pressure obtained is

$$p = \frac{8.85 \times E_0 \times e}{10^7 \times d_1^2} \, \mu\text{bar}$$

where E_0 is the polarization voltage, here 800 volts, e is the RMS value of the

AC voltage, here 30 volts, d_1 is the effective distance between the actuator and the diaphragm. Owing to the slots the effective distance is greater than the physical distance. Unfortunately, the necessary correction is not only dependent on the ratio between the width W of the metal bars and the width S of the slots, but also on the distance d. On the B & K actuator W = S and the correction can be taken from Fig. 22.

With accurate mechanical measuring instruments it is possible to determine the average distance d with an accuracy better than ± 0.02 mm. As this uncertainty is by far the greatest of all the uncertainties in the whole set-up, it is in fact this measurement alone that determines the uncertainty of the

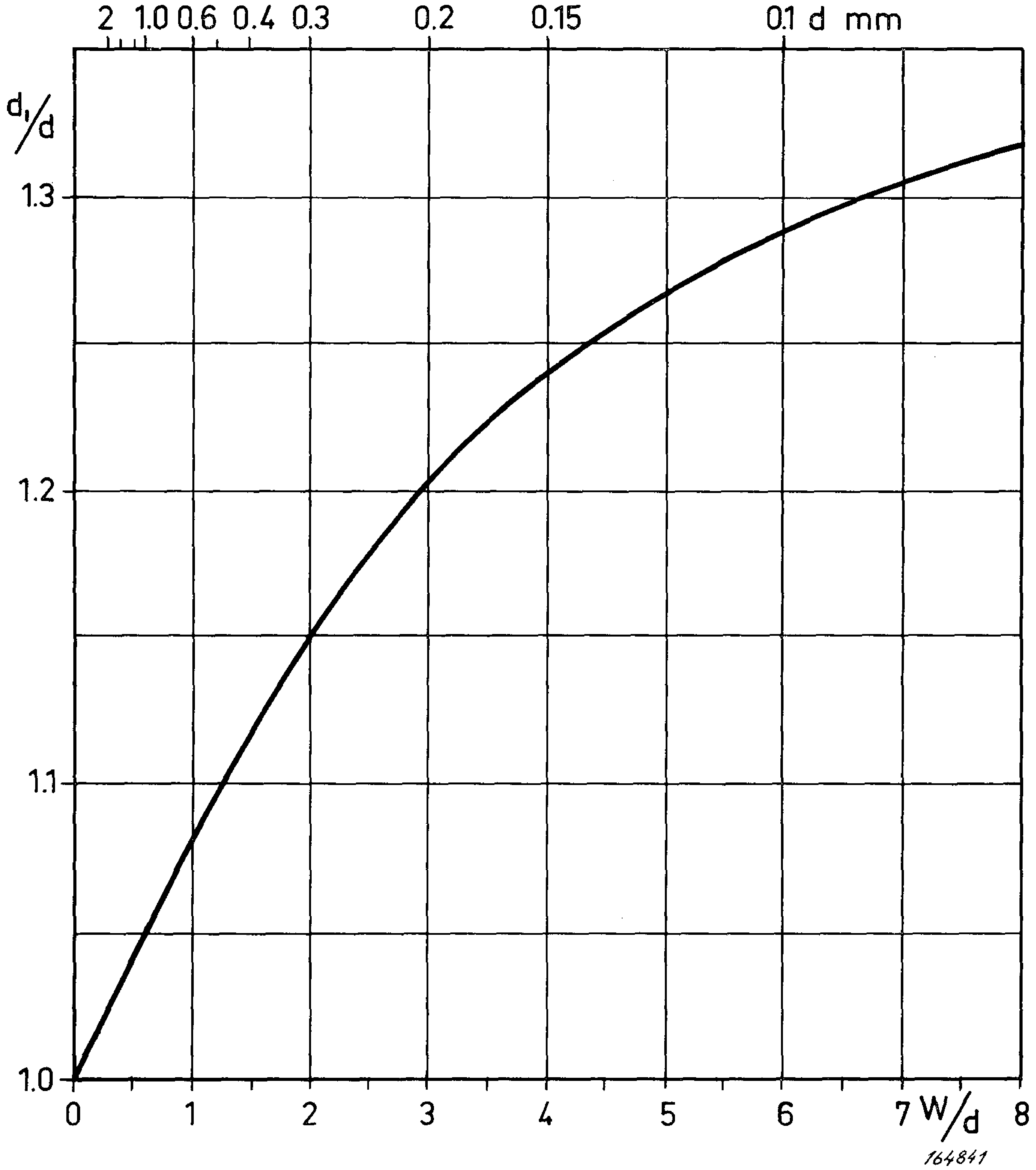

Fig. 22. Effective distance d_1 as function of the actual distance d between the actuator UA 0023 and the microphone diaphragm (W = S = 0.60 mm).

set-up, with the normal distance = 0.4 mm the uncertainty is approx. ± 5 %. This also includes the uncertainty of the correction determined from Fig. 22. In order to check this correction and also to have a well defined actuator, an actuator without slots was used. See Fig. 21 left.

The solid actuator offers the possibility of determining the effective distance d with somewhat greater accuracy, but on the other hand the solid actuator may affect the diaphragm impedance-wise and introduce errors in this way.

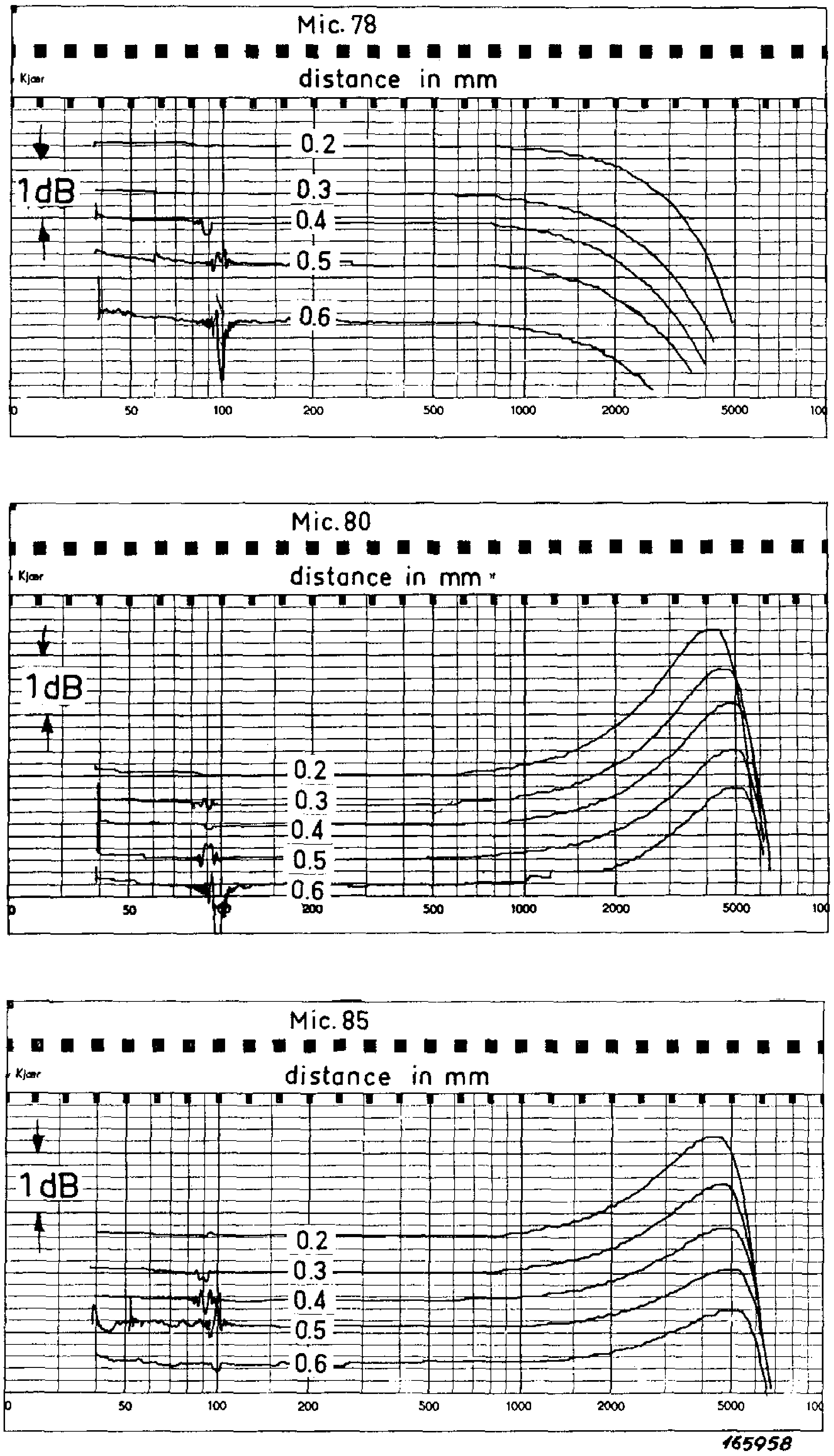

Fig. 23. Frequency response of the same microphone and the same slotted actuator, but with five different distances. No noticeable change of frequency response is experienced between 50—3000 Hz. The relative distance between the curves is not related to the actual distance. Note the large scale of the ordinate.

To determine if any acoustic interaction existed between actuator and microphone diaphragm, a series of frequency response curves with different distances between diaphragm and actuator were recorded. If these curves do not give a different frequency response in a fairly large frequency range, it is a sign that no noticeable coupling between the actuator and the diaphragm takes place. If there was a coupling the response would certainly alter with distance.

In Fig. 23 a series of frequency response curves for the slotted actuator is shown, with a large variation of distance between actuator and microphone. It can be seen that up to frequencies of 3000 Hz there is no noticeable change in response, in other words at frequencies between 60—400 Hz, i.e. in the range where these experiments have taken place, there was no acoustic interaction between actuator and diaphragm of the microphone, not even with the very small distance of 0.2 mm.

Another possible error could be introduced by inaccurate placing of the actuator on the diaphragm, i.e. would it be possible to remove and replace the actuator and still repeat the experiments with a high degree of reproducibility.

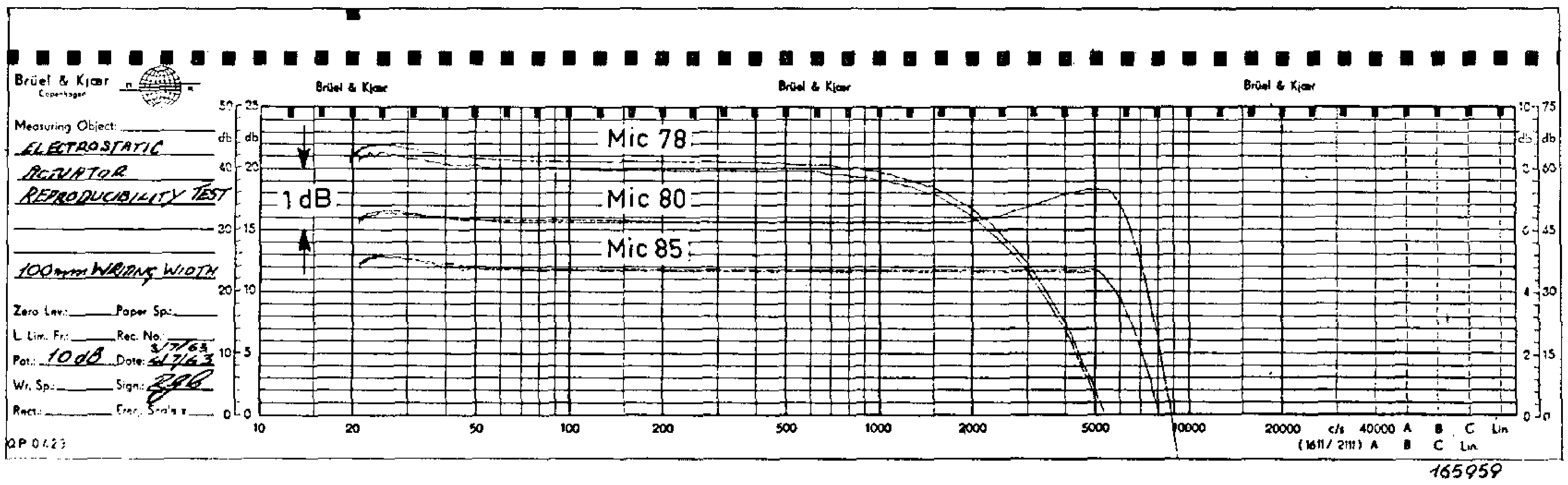

Fig. 24. Reproducibility of the electrostatic actuator. Two curves were run for each microphone with complete resetting each time.

The results of this experiment are shown in Fig. 24 where the same actuator with a distance of 0.4 mm was placed on three different microphones. Two measurements on each microphone were made in such a way that the two other cartridges were tested between each run on the same cartridge.

There was also a time difference of one day between the runs of the curves for the same cartridge. It can be seen with what degree of reproducibility the whole set-up can work from this simple test. It is, actually, within a fraction of a tenth of a dB.

The actual measurements were carried out at eight different distances and at four different frequencies between 60—400 Hz and with both the slotted and the solid actuator on all three cartridges. 800 volts DC and 30 volts AC were used throughout the measurements.

As the frequency response for all three microphones shows, the sensitivity is independent of the frequency in the used frequency range, the average value of the four measurements for each distance is shown in table XVIII.

	d Distance mm	d_1 Effective distance mm	p Equival. SPL µbar	Microph. 78		Microph. 80		Microph. 85	
				Output Voltage mV	Sensi. mV/µbar	Output Voltage mV	Sensi. mV/µbar	Output Voltage mV	Sensi. mV/µbar
Slotted Actuator	0.2	0.241	36.5	1805	4.94	1620	4.44	1530	4.19
	0.3	0.345	17.9	910	5.08	810	4.52	750	4.19
	0.4	0.447	10.6	530	5.00	479	4.52	440	4.15
	0.5	0.548	7.07	341	4.82	311	4.40	281	3.97
	0.6	0.649	5.05	250	4.95	222	4.39	207	4.10
	0.8	0.850	2.94	142	4.82	131	4.45	120	4.08
	1.0	1.050	1.93	97	5.02	91	4.71	80	4.15
	1.2	1.250	1.36	68	5.00	61	4.49	55	4.04
Solid Actuator 800 V DC		0.20	53.1	2635	4.96	2360	4.44	2175	4.10
		0.30	23.6	1120	4.75	1012	4.30	925	3.92
		0.40	13.3	648	4.87	588	4.42	530	3.98
		0.50	8.50	413	4.86	366	4.31	338	3.98
Solid Actuator 30 V AC		0.60	5.91	282	4.77	259	4.21	238	4.03
		0.80	3.32	164	4.94	148	4.46	135	4.07
		1.00	2.12	105	4.96	94.5	4.46	86.0	4.06
		1.20	1.47	75.0	5.10	69.0	4.70	61.0	4.10
Average value of sensitivity				4.93 mV/µbar		4.45 mV/µbar		4.07 mV/µbar	
Standard deviation				0.10 mV/µbar ± 2 %		0.13 mV/µbar ± 3 %		0.08 mV/µbar ± 2 %	

Table XVIII. Results of absolute sensitivity measurements of the three microphones using both slotted and solid actuators at varied distances.

There was only a very small difference between the different frequencies, and there was absolutely no tendency to overweight one frequency by another. The sound pressure level in µbar is determined from the formula, and in the case of a slotted actuator after determination of the effective distance. The average sensitivity and the standard deviation based on the values obtained for the different microphones is given at the bottom of the table.

The standard deviation shows an uncertainty of max. 3 % in the case of microphone 80, and only 2 % in the case of microphones 78 and 85. This is somewhat smaller than expected from the calculated uncertainty, mainly based on the uncertainty of distance measurements, in other words it seems that the estimated 5 % uncertainty on distance can be kept.

Reciprocity Method (C-Shunt).

The reciprocity method is often considered to be the most accurate calibration method existing, and here two versions of this method will be used. One is based on the B & K Microphone Calibration Apparatus Type 4142, where the current through the transmitter is measured as a voltage across a capacitor. The other is a version developed at the acoustical laboratory of the Royal Technical University in Copenhagen, where the current is measured as a voltage across a resistor.

The principle of the reciprocity method is outlined in Fig. 25. A more detailed description of the practical procedure can be found in ref. 14), and for the more theoretical basis in ref 10).

The product of the sensitivity of the two microphones M_1 and M_2 is found by measuring the ratio between the output voltage e_2 of the cathode follower and the voltage e_c across the capacitor. The main equation is

$$\frac{e_2}{e_c} = M_1 M_2 \times \frac{1.08\,\gamma \times P_0 \times C \times 10^7}{V} \tag{11}$$

where:		Uncertainty:
e_2	= output voltage of cathode follower	
e_c	= voltage across capacitor C	ratio o.1 %
1.08	= standard attenuation in cathode follower (correction has to be made for other values)	o.2 %
γ	= ratio of specific heats 1.402	o.05%
P_0	= Static air pressure (normal 1.013×10^6 μbar) (correction has to be made)	o.1 %
C	= Shunt Capacitor (normal 19.8 μF)	o.1 %
V	= Volume of cavity + equivalent volume of both microphone cartridges in cm^3	o.1 %

Other items which have influence on the accuracy:

C_{stray}	= stray capacitance known to be o.3 pF	o.25%
E_0	= polarization voltage. Normally 200 volts	o.3 %
Ref.	= Error from changing amplifier from cathode follower to voltage across C	o.1 %
C_c	= Uncontrollable variation in cathode follower input capacity	o.1 %
	Uncertainties from reading charts, temperature variation, voltage variation etc.	o.5 %
	Total uncertainty for reciprocity method	o.7 %

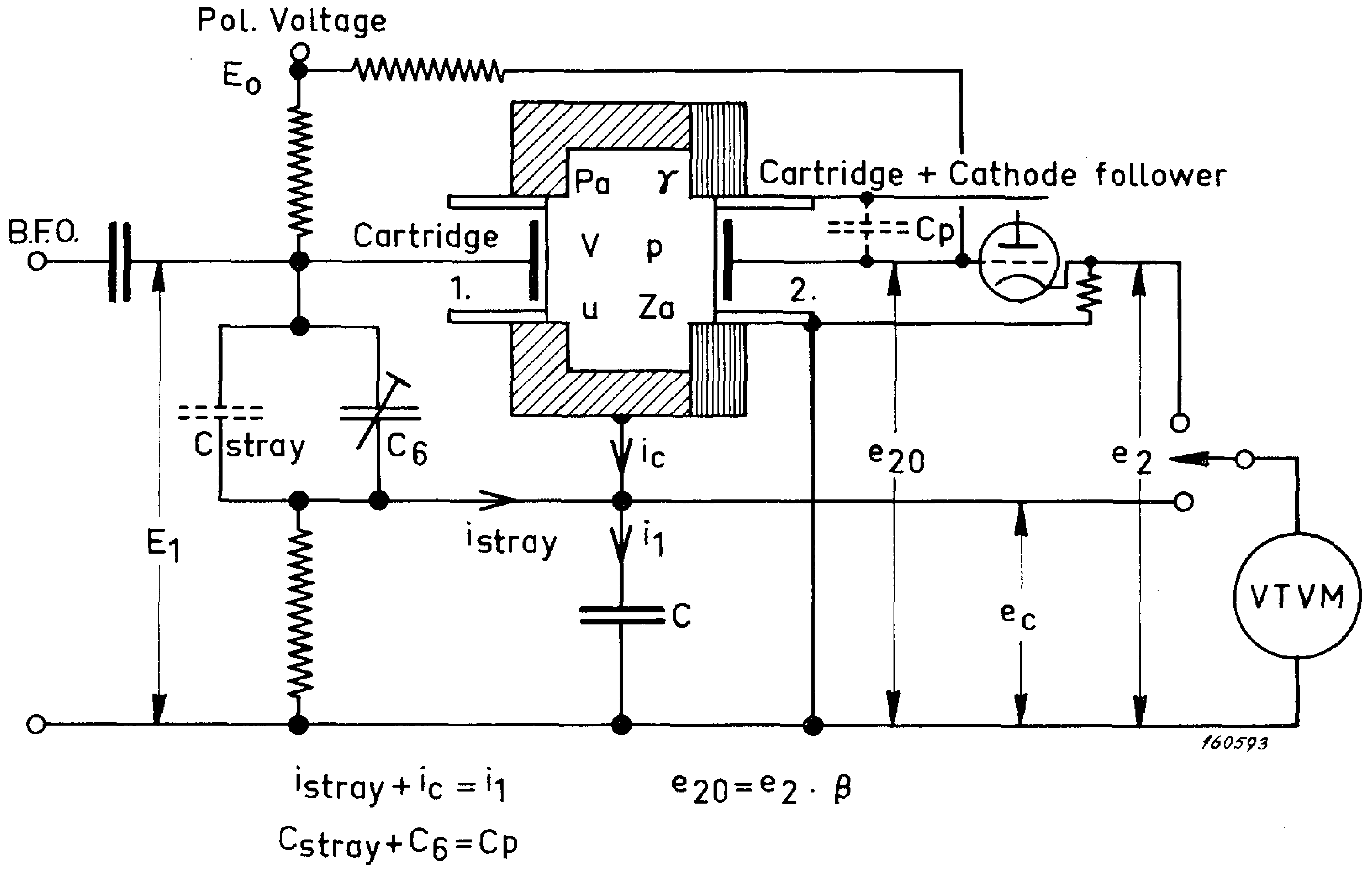

Fig. 25. Reciprocity Method where the current is measured over a capacitor. B & K Microphone Calibration Apparatus Type 4142.

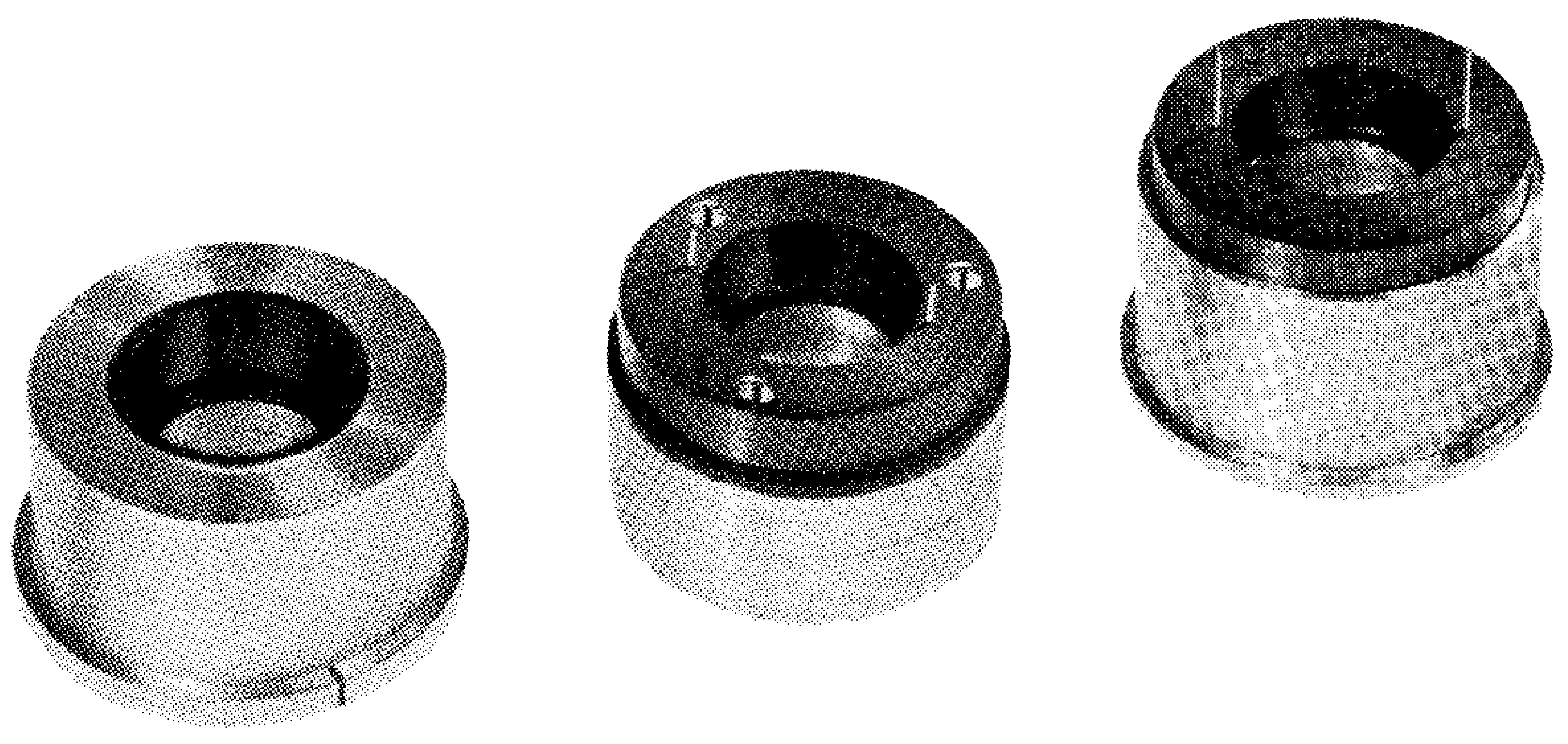

Fig. 26. The three different couplers used for reciprocity calibrations 3 cm³ which is standard on B & K apparatus, 20 cm³ ASA standard Z 24.4 (also applies to B & K Type 4142) and 7.5 cm³ a special B & K version.

Three different couplers have been used, the standard 3 cm^3 and 20 cm^3 couplers which accompany the instrument type 4142 and also a 7.5 cm^3 coupler whose volume has been most carefully measured.

The capacitor C is chosen so that if both microphones have a sensitivity of exactly —50 dB (3.16 mV/μbar) $e_2 = e_c$ when a 3 cm^3 coupler is used. In other words if the two microphones have the same sensitivity deviation from —50 dB the sensitivity can simply be found from

$$-50 + \frac{n}{2} \text{ dB ref 1 volt}/\mu\text{bar}$$

For the 20 cm³ coupler the value will be

$$-40.76 + \frac{n}{2} \text{ dB ref 1 volt}/\mu\text{bar}$$

and with a 7.5 cm³ coupler the value will be

$$-46.03 + \frac{n}{2} \text{ dB ref 1 volt}/\mu\text{bar}$$

In Fig. 26 a photograph of the 3 cm³, 20 cm³ and 7.5 cm³ couplers is shown, where the 20 cm³ coupler corresponds exactly to that described in ASA Z 24.4 (1949).

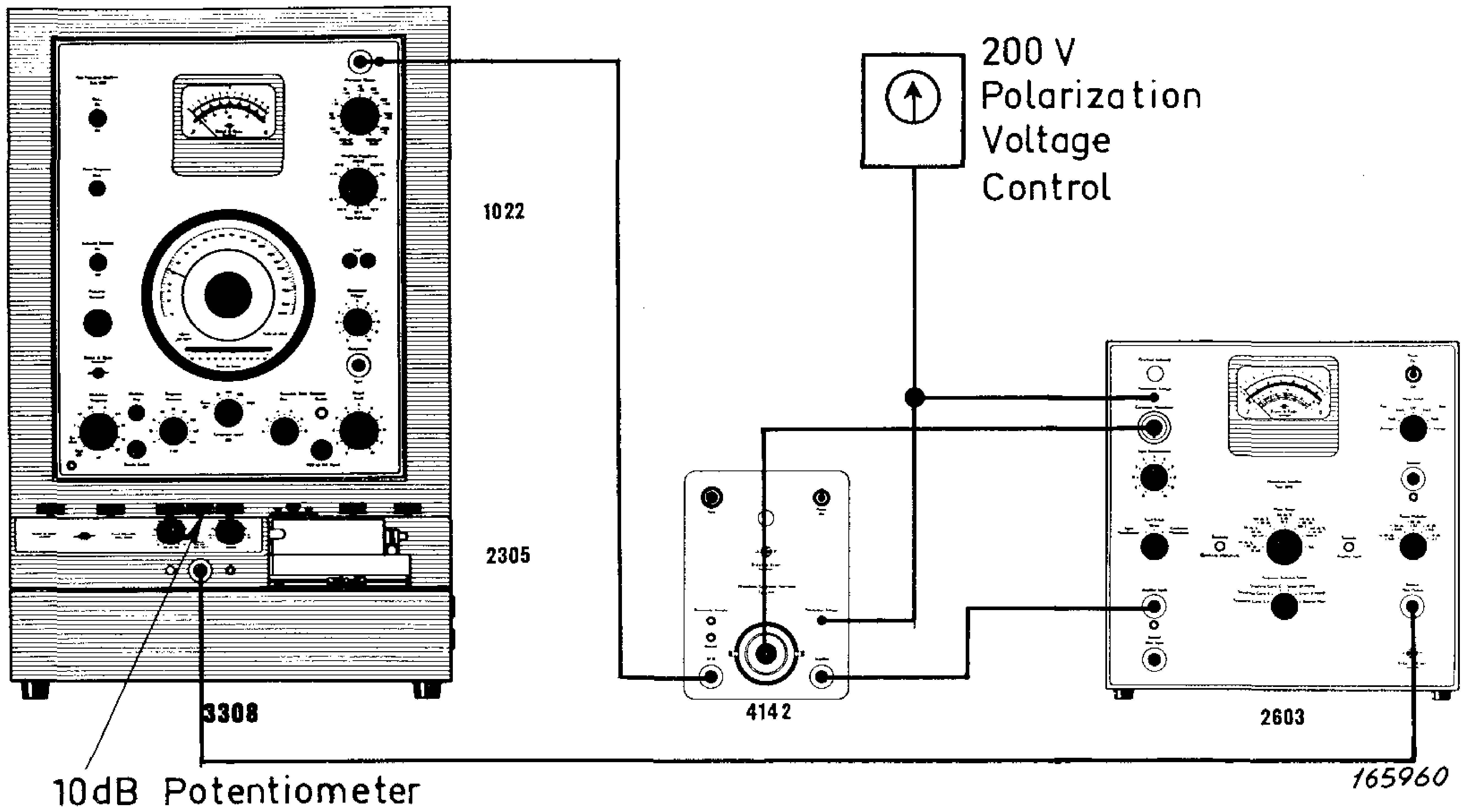

Fig. 27. Set-up for the practical measurements where comparison is made on a Level Recorder with high resolution.

The electrical set-up is shown in Fig. 27. A 10 dB range potentiometer is placed in the Level Recorder, and by using the 100 mm chart width a 5 dB range is obtained over a 50 mm wide wax chart paper. In this way a very high degree of accuracy can be obtained in comparing voltages. The whole measuring set-up was run from a well stabilized power line.

A typical curve is shown in Fig. 28, where the high resolution can be seen. The microphones were rotated so that six recordings were made for each of the three couplers, thus:

78 → 80	85 → 78	80 → 85	78 → 80	85 → 78	80 → 85
e_c78	85 → 80	e_c80	78 → 85	e_c85	80 → 78
80 → 78		85 → 80		78 → 85	
e_c80		e_c85		e_c78	

The static pressure was 985 μbar, polarization voltage 200.2 V and the cathode follower voltage attenuation was 0.8 dB and through a 50 pF capacitor it was 1.35 dB. When these corrections are applied the results given in Table IXX are obtained by utilizing only four rather low frequencies taken from the recorded frequency response curve.

Frequency		100	200	400	800	Hz
Microphone	Coupler					
78	3 cm^3	—46.18 —46.14	—46.18 —46.13	—46.18 —46.13	—46.23 —46.22	dB
	7.5 cm^3	—46.05 —46.13	—46.07 —46.13	—46.11 —46.14	—46.20 —46.23	
	20 cm^3	—46.09 —46.21	—46.11 —46.21	—46.20 —46.23	—46.24 —46.30	
80	3 cm^3	—47.09 —47.07	—47.10 —47.07	—47.08 —47.07	—47.07 —47.06	
	7.5 cm^3	—46.93 —47.04	—46.91 —47.04	—46.91 —47.05	—46.96 —47.02	
	20 cm^3	—47.04 —47.01	—46.96 —47.03	—47.04	—47.07 —47.09	
85	3 cm^3	—47.74 —47.67	—47.74 —47.67	—47.75 —47.65	—47.73 —47.69	
	7.5 cm^3	—47.66 —47.60	—47.65 —47.61	—47.66 —47.62	—47.65 —47.65	
	20 cm^3	—47.66 —47.59	—47.66 —47.60	—47.67 —47.61	—47.71 —47.70	
Average sensitivity (100—400 Hz) of microphone 78:		—46.145 dB 4.92 mV/μbar		standard uncert.	0.051 dB 0.56 %	
Average sensitivity (100—800 Hz) of microphone 80:		—47.032 dB 4.45 mV/μbar		standard uncert.	0.057 dB 0.63 %	
Average sensitivity (100—800 Hz) of microphone 85:		—47.664 dB 4.13 mV/μbar		standard uncert.	0.046 dB 0.50 %	

Table IXX. Calibration results of the three microphones, using the Reciprocity (C-Shunt) Method, with three different couplers and full rotation of the cartridges.

The reversing of the microphone cartridges gives a good overall impression of the spread in the measurements. It can be seen that the standard deviation is somewhat lower than that calculated from the different elements going into the measurements. This is of course also correct as in the calculation there are some one-sided errors which will be found by repetition of measurements, but by using different microphone cartridges, different couplers and different frequencies the limitations of the method can be obtained.

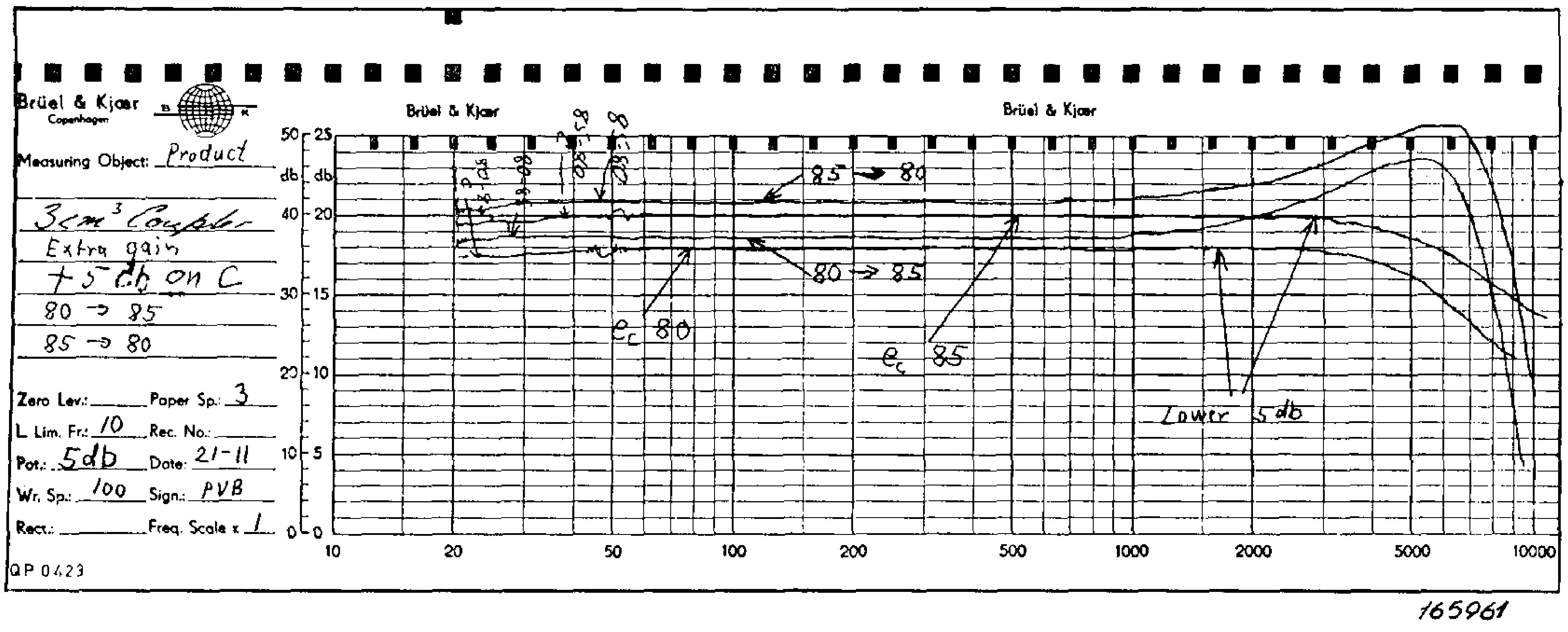
Measuring Object: Product
3cm³ Coupler
Extra gain
+5 db on C
80 → 85
85 → 80
Zero Lev.:
Paper Sp.: 3
L. Lim. Fr.: 10
Rec. No.:
Pot.: 5db
Date: 21-11
Wr. Sp.: 100
Sign.: PVB
Rect.:
Freq. Scale x 1

Fig. 28. A typical recorded curve from the reciprocity method using a C-shunt. 3 cm³ volume.

Reciprocity Method (R-Shunt).

The three microphones used throughout these tests were submitted to the Danish Technical University Copenhagen where they were tested, using the Reciprocity (R-Shunt) method, against the standard used in their Acoustics Laboratory.

The method developed mainly by K. Rasmussen, differs from that previously described by the fact that the current through the transmitter is measured across a small resistor instead of a capacitor. The advantage is that the resistor measurements can be made somewhat more accurately than the capacitor measurements. On the other hand, however, the measuring frequency has to be known with a very high degree of accuracy, whereas the measuring frequency is of minor importance with a capacitor shunt. A much more thorough description of this method will be given by K. Rasmussen in a detailed report at a later date. Rasmussen estimates the absolute accuracy of his calibration set-up to be better than 0.3 %.

With a sound pressure known to this accuracy, see Fig. 29, the three microphones were measured with a precision amplifier and standard voltmeter. Rechecking has been carried out with a voltage and pistonphones, and a comparison measurement has been performed with a high degree of accuracy, but still an uncertainty of 0.1 % for polarization variation, and 0.1 % for

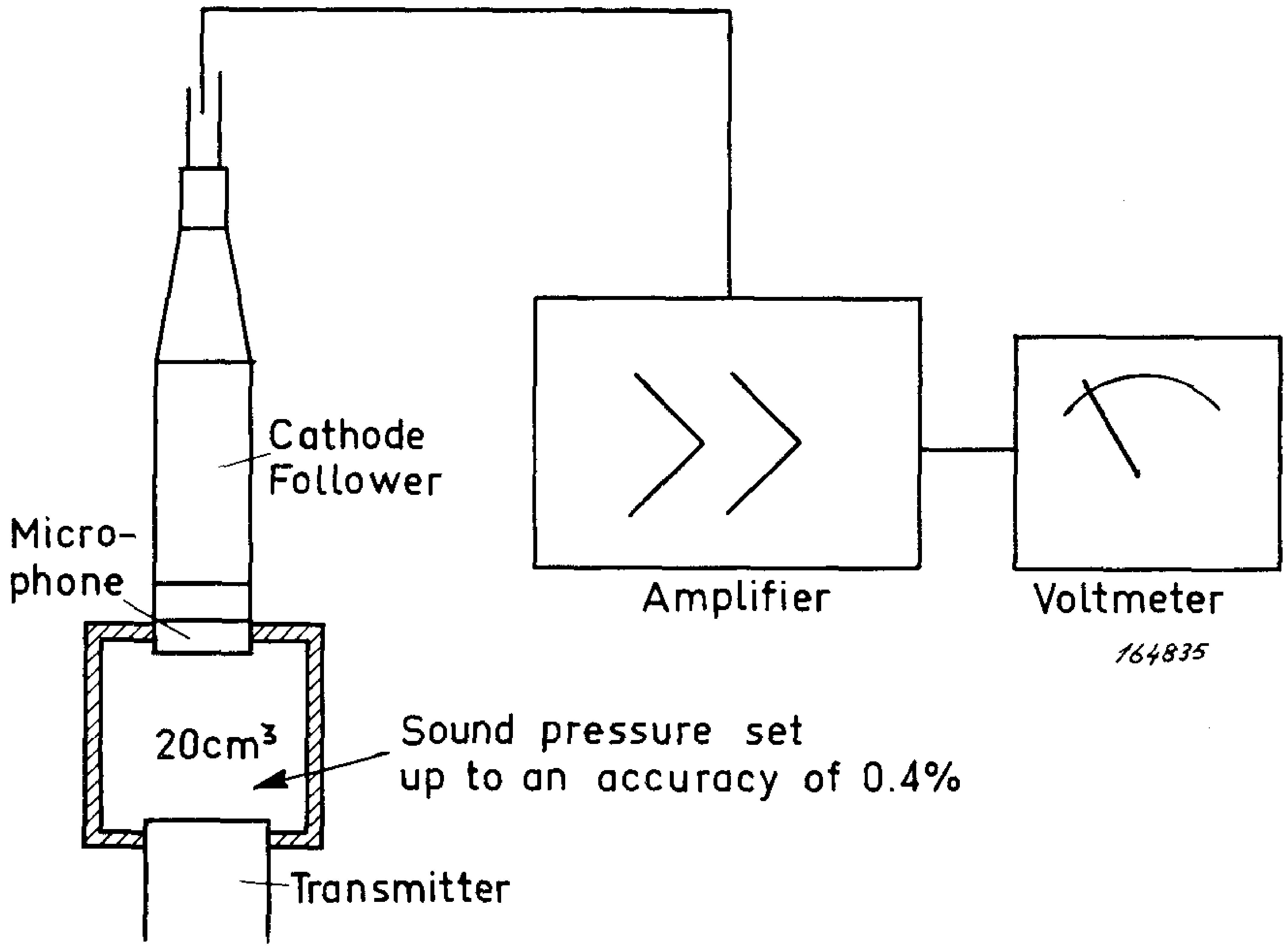

Fig. 29. Method of simple calibration against the standard microphone of the Acoustical Laboratory in Copenhagen.

meter reading errors is to be added, before the three microphones can be calibrated against the Acoustic Laboratory's standard. Even so, however, the total accuracy should be within 0.3 %. The results of the comparison test are indicated in Table XX.

Microphone No.	78	80	85
Voltmeter deflection Volts	10.71	9.59	8.95
Sensitivity mV/μbar	4.93	4.41	4.11

Table XX. Comparison against Acoustic Laboratory's standard microphones, calibrated using the Reciprocity (R-Shunt) Method.

B & K Laboratory Standards.

The B & K standard microphones are two fairly old models which are checked from time to time, with both Reciprocity C shunt method and a special, carefully made pistonphone. These standard microphone cartridges are also occasionally checked against various Standard Laboratories own standard. This was recently the case during the Round Robin tests performed by the I.E.C. (International Electrical Commission) (ref. 15), where three B & K microphones were measured, first at the B & K Laboratory then at P.T.B. Braunschweig, E.T.L., Tokyo, N.B.S., Washington, N.P.L., Teddington, L.L. Copenhagen, K.S.M.I.P. Moscow, C.N.E.T. France, back to P.T.B. Braun-

schweig, and finally, on their return the microphones were again tested at the B & K Laboratory. It was found that after having travelled around the world for a year, one of the microphones had changed by 0.1 dB, while the other cartridges had remained unchanged.
It is not the intention to describe the B & K Laboratory Standard Microphones in detail here, but the Laboratory claims that the sensitivity of the microphones is known with an accuracy better than 0.5 %, and that they are able to measure SPL with an accuracy better than 0.6 %.
As mentioned before the microphone cartridges, 78, 80, and 85 have been checked at the B & K Laboratory, the results of which are given in Table II.

B & K Factory Standards.
These are secondary standard cartridges which are regularly checked against the B & K Laboratory primary standards. It is these secondary standards that are used in the factory calibration of all new and repaired cartridges leaving the factory. The factory calibration is claimed to be accurate within 1 %.
Again the sensitivity of the three microphone cartridges used in these tests was rechecked, this time against the normal factory calibration procedure, these results can be seen in Table I.

Conclusion.
The final results of all the measurements are shown in Fig. 30 where all the different methods employed for the three different microphones are directly compared. The standard deviations for the different methods are indicated by the length of the bars in the diagram. In this diagram a check can be used on the average value for the sensitivity of each microphone for the different methods and it can be seen, by using the found uncertainties, if the different methods "cover" each other. If it is not possible to draw a horizontal line running into all the bars, a greater uncertainty for some of the methods than anticipated and found must be present. This is the case for instance for the microphone No. 78 checked with the Thermophone method where the sensitivity value is so low that it cannot be covered by the stated uncertainty. Therefore systematic errors in the Thermophone procedure seem to be greater than this examination of the method has shown.
The most precise measurements are made with the double piston pistonphone and the two reciprocity methods. These methods are compared in Fig. 31. In Table XXI are given the standard deviations for these precise measurements together with three different uncertainties for, setting up a known sound pressure level, determination of sensitivity of a microphone expressed in mV/μbar, and measurements of an unknown SPL.
The pistonphone is primarily a sound pressure source known with high accuracy, and used together with a precision sound level meter a sound pressure level can be measured with very good accuracy, as a major part of the uncertainties in polarization voltage, input capacities in cathode

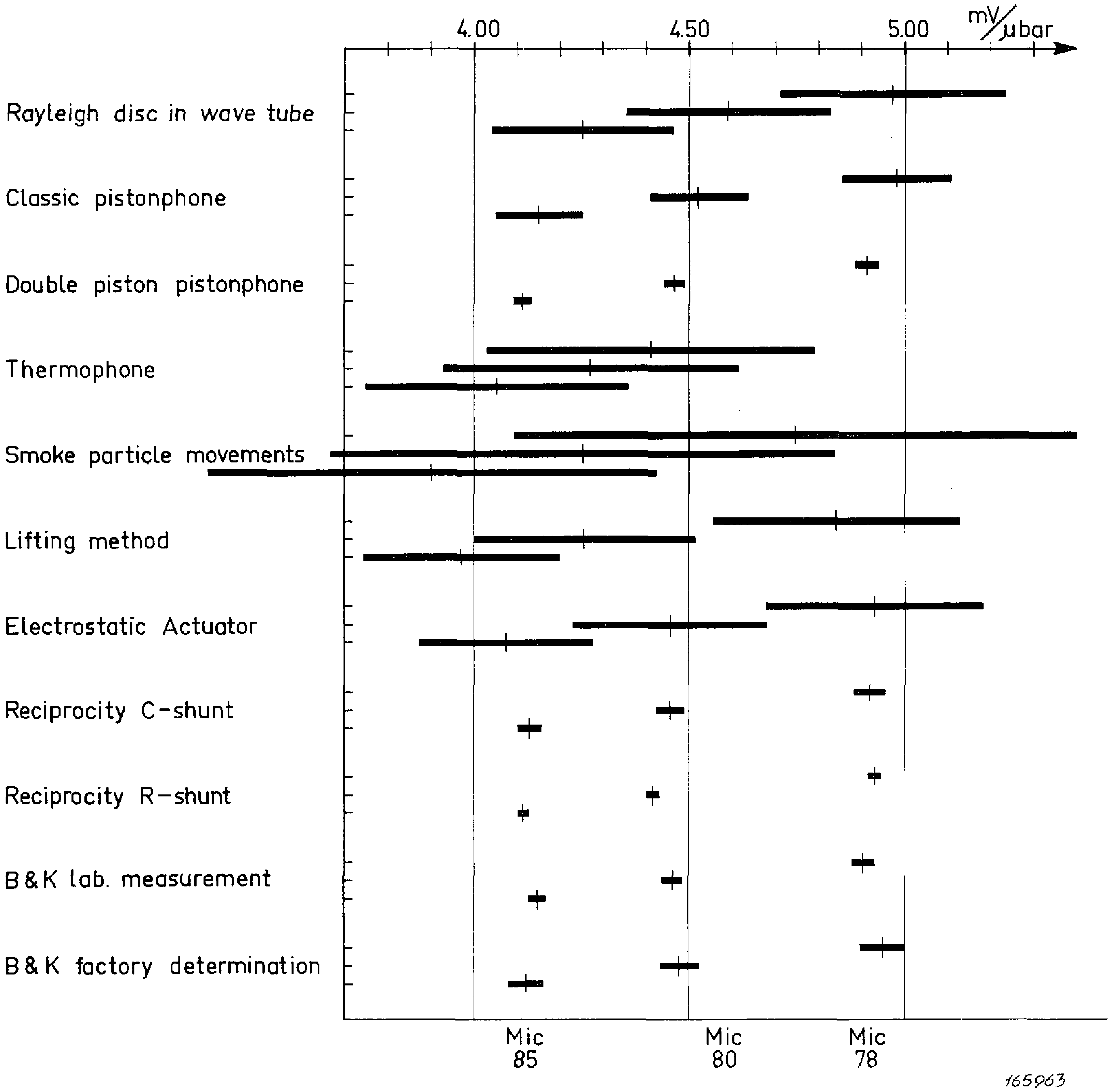

Fig. 30. Direct comparison of sensitivity calibration of the three microphones with nine different calibration methods. The length of the bars indicate uncertainties found for each method.

followers, amplifier gain, meter scale calibration is cancelled out with this method, which strictly compares different SPL's.

The reciprocity method, especially with the R-Shunt, is mainly suited for determining microphone sensitivity and consequently a major part of the above mentioned uncertainties have to be added when a reciprocity calibrated microphone is used for measuring sound pressure levels.

The main result of these investigation, dealing especially with the uncertainties for different calibration methods, is that for measuring sound pressure levels the double piston pistonphone method is the most accurate. However, for the calibration of microphone cartridges, the reciprocity method may be superior. It is also seen that the reciprocity method with R-Shunt is somewhat better than the one with C-Shunt.

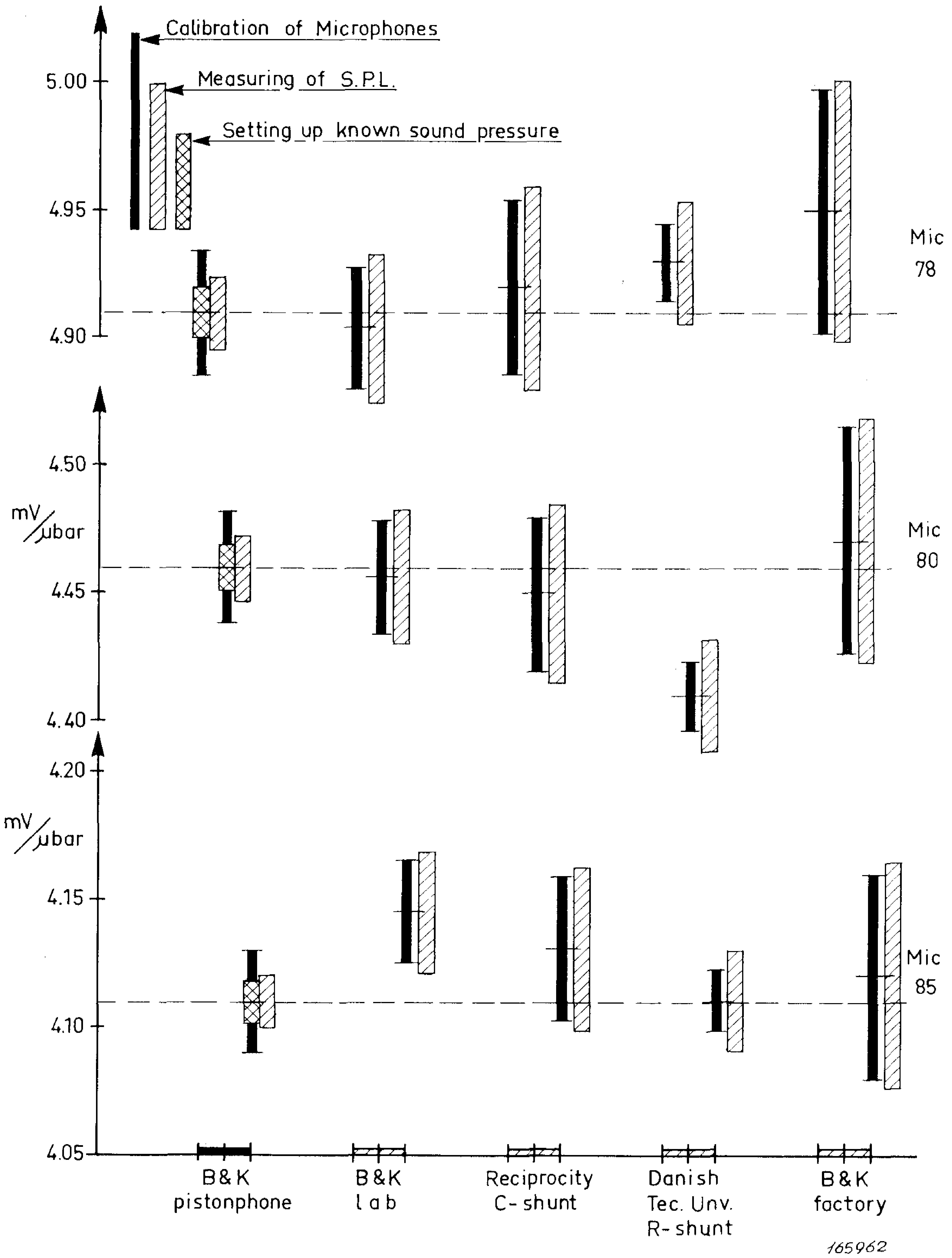

Fig. 31. Comparison of the most accurate calibration methods. The length of the bars indicate the uncertainty for determination of sensitivity, setting up a sound pressure and measuring SPL respectively.

Method	Setting up known sound pressure in μbar	Determination of microphone sensitivity in mV/μbar	Measuring sound pressure level μbar
Double piston pistonphone	± 0.2 %	± 0.5 %	± 0.3 %
B & K laboratory calibration		± 0.5 %	± 0.6 %
Reciprocity C-Shunt B&K Calibration App. 4142		± 0.7 %	± 0.8 %
Reciprocity R-Shunt D.T.U. Copenhagen	± 0.3 %	± 0.3 %	± 0.5 %
B & K factory calibration		± 1.0 %	± 1.1 %

Table XXI. Uncertainties, for the most precise measuring methods used for, setting up a known sound pressure in a chamber, determination of microphone sensitivity, and for measuring unknown SPL.

Selected References.

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11. P. Brun: "L'Estalonnage absolu des microphones a condensateur par la méthode du Thermophone au departement acoustique du C.N.E.T. p. 397 Acustica vol. 12 (1962).
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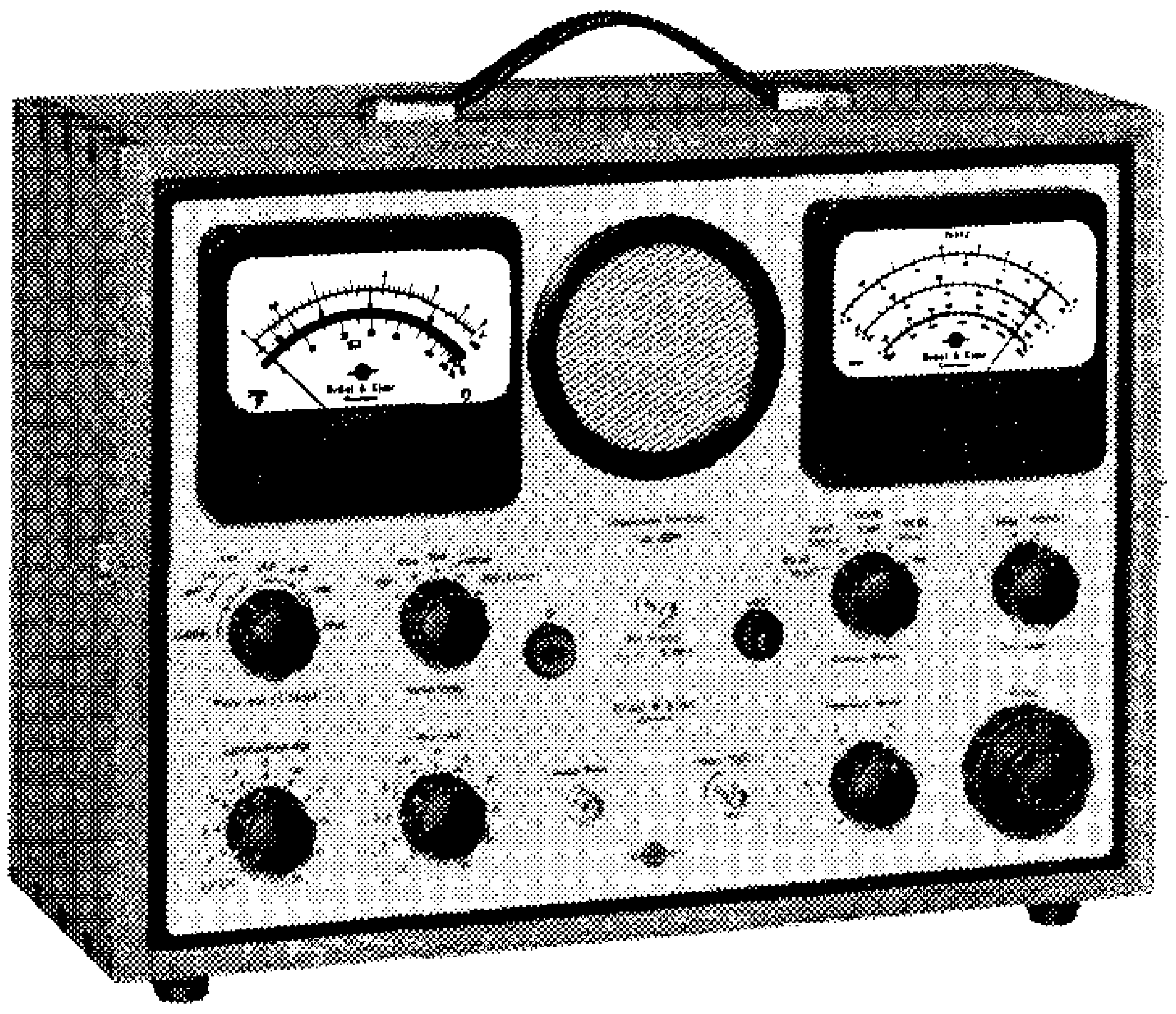
13. S. Ballantine: "Techniques of Microphone Calibration". Vol. 3, p. 319—360 (1932).
14. "Microphone Calibration Appratus Type 4142". B & K Instructions and Applications Vol. BB 4142 p. 26—34.
15. H. G. Diestel and M. Grützmacher: "Summary of Results of the Calibration of Microphones in the Round-Robin Test 1963/64". IEC/TC 29.

News from the Factory



Type 2006.

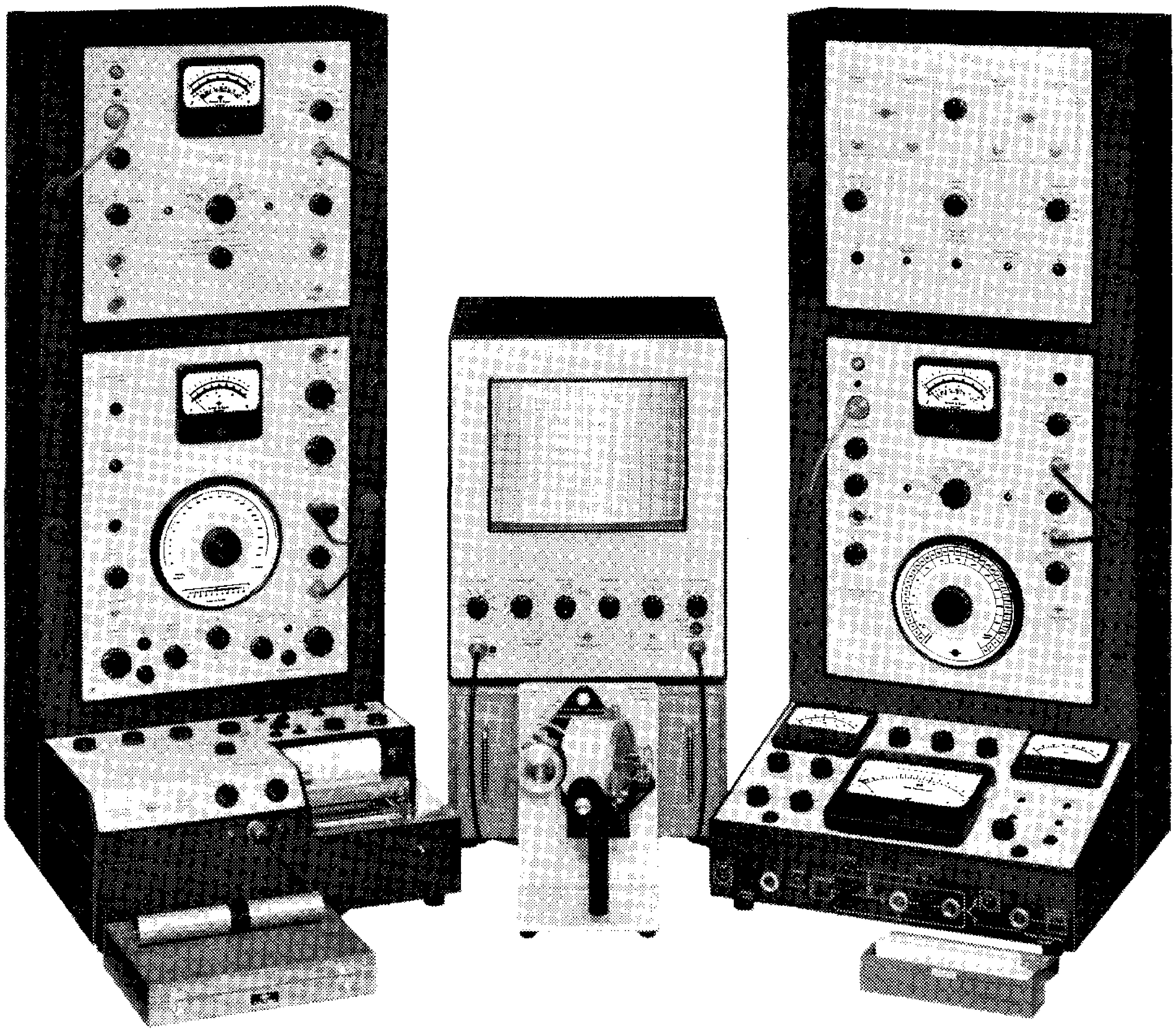
New Heterodyne Voltmeter Type 2006.
is an ideal measuring instrument for measurements in the radio frequency and V.H.F. ranges.

It is a portable, light weight unit capable of selective measurements at all commonly used AM, FM and TV frequencies and incorporates the following excellent features:

1. High sensitivity: 2 μV to 50 V.
2. Wide frequency range 40 kHz (kc/s)—230 MHz (Mc/s).
3. Two different bandwidths 5 kHz (kc/s) and 400 kHz (kc/s).
4. High impedance, small dimension input probe or standard 75 Ω input.
5. Low noise level approximately 1 μV.
6. Direct reading AM and FM modulation meter.
7. Built-in reference voltage for calibration.
8. Built-in loudspeaker audible control.
9. Battery or mains operated. Built-in nickel-cadmium storage battery and charging unit.
10. Fully transistorized except for the special input probe.

The Voltmeter is particularly designed to measure the amplitude of high frequency signals and determine the frequency as well as the percentage modulation. The measured frequency is indicated on a meter scale. A second meter indicates the amplitude of the measured R.F. voltage and the percentage modulation, the loudspeaker provides an audible signal check.

It is especially useful in radio laboratories for selective measurements on radio receivers and transmitters, radar and television I.F. circuits, and for the control of signal generators and coaxial carrier frequency systems. The high input sensitivity also permits many weak signal measurements to be carried out such as the measurement of receiver antenna voltages.
A further important application consists in measurements on antenna amplifiers and distribution systems for TV receivers.



Type 3350.

New Electroacoustical Transmission Measuring Systems Type 3350 and 3351.
The Electroacoustical Transmission Measuring System Type 3350 has been designed for **objective measurements** of reference equivalents of complete subscriber's telephone sets or single parts thereof, and furnish easily reproduceable values. The measuring system consists basically of the following instruments:

The Beat Frequency Oscillator Type 1022 (modified),
The Microphone Amplifier Type 2603,

The Audio Frequency Spectrometer Type 2112,
The Level Recorder Type 2305,
The Frequency Response Tracer Type 4709,
The Reference Equivalent Meter Type 4901,
The Power Supply Type 4902,
The Artificial Mouth Type 4216,
The Condenser Microphones Type 4132 and 4134,
Two Cathode Followers Type 2615,
The Pistonphone Type 4220 and
The Telephone Receiver Test Head Type 4903.

With the Electroacoustic Transmission Measuring System it is possible to measure sending, receiving and side-tone reference equivalents by indicating the 0.6 or 1st power of the integrated r.m.s. value measured over the 200—4000—200 Hz (c/s) range varied logarithmically in 1 sec. Furthermore, it is possible to measure the "noise modulation products" in carbon microphones at frequencies above 5000 Hz (c/s), using a high-pass filter to suppress the sweep-frequency signal. The measured signal can then be read off on the Audio Frequency Spectrometer. This instrument can also be used for non-linear distortion and noise measurements.

Carbon microphone resistance is readily measured and a wide choice of DC voltages and feeding coil-impedances are available.

The frequency response curves are displayed on the Frequency Response Tracer Type 4709 or permanently recorded on the Level Recorder Type 2305.

The reference equivalent is defined as the attenuation (dB or Np) to which a certain reference system has to be adjusted in order to obtain the same gain as that of the system under test. This is negative if the supplementary attenuator has to be inserted in the system under test, but positive if it has to be inserted in the standard circuit.

Measurements are performed with equal speech levels at the input of both systems and without the presence of distorting networks in the reference system.

The SFERT*) has an acousto-electric index of 26.6 mV/μbar while its electroacoustic index at the ear is 37.5 μbar/V. The overall transmission equivalent is accordingly unity.

A second version of the Electroacoustic Transmission Measuring System is produced as **Type 3351.**

Type 3351 is designed for measurements on parts of a telephone system, e.g. for **production control measurements**, while Type 3350 is specially designed for laboratory investigations and measurements on complete telephone systems.

The main difference between the two Systems is the types of instruments used in their build up. As Type 3351 is well suited for production control

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*) Fundamental European Reference System for Telephone Transmission.

measurements, a Frequency Response Tracer Type 4709 may be found convenient for checking the frequency response of the test object, but then this must be ordered separately together with Type 3351.

Basically the Electroacoustic Transmission Measuring System Type 3351 consists of the following instruments:

The Beat Frequency Oscillator Type 1022,
The Microphone Amplifier Type 2603 (2 pieces),
The Reference Equivalent Meter Type 4901,
The Power Supply Type 4902,
The Artificial Mouth Type 4216,
The Condenser Microphones Type 4132 and 4134,
Two Cathode Followers Type 2615,
The Pistonphone Type 4220.

By means of the Electroacoustic Transmission Measuring System Type 3351 it is possible, as with Type 3350, to measure sending, receiving and side-tone reference equivalents by indicating the 0.6 or 1st power of the integrated r.m.s. value measured over the 200—4000—200 Hz (c/s) range varied logarithmically in 1 sec and "noise modulation products" in carbon microphones. However, because there is no Audio Frequency Spectrometer included in the Measuring System Type 3351, it is not possible to measure the non-linear distortion in a microphone or earphone cartridge.

For production control measurements of microphone or earphone cartridges special holding devices are supplied with the Electroacoustic Transmission Measuring System Type 3351. The cartridges are fixed in a standardized position in front of the artificial mouth or ear, and it is a simple matter to change the cartridges.

The special holding devices can very easily be adjusted to fit all normal types of cartridges.

Type 3351 is supplied with transparent covers to protect the instruments.

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