4111

INSTRUCTIONS AND APPLICATIONS

Condenser Microphone Type 4111

Specially designed for measurement and calibration applications, this Condenser Microphone features very high stability, a high linear frequency response together with small dimensions.

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DESCRIPTION

The Condenser Microphone type 4111 is particularly designed for measurement applications and has therefore a very high stability and comparatively small dimensions. It is built up of a cartridge directly connected with a cathode follower tube, making it possible without any difficulty to use long cables between the microphone and the following amplifier. The polarization, anode and filament voltages to the cathode follower and cartridge are all taken from the amplifier, which is why only Microphone Amplifier type 2601 and Frequency Analyzer type 2105 or 2109 can be used.

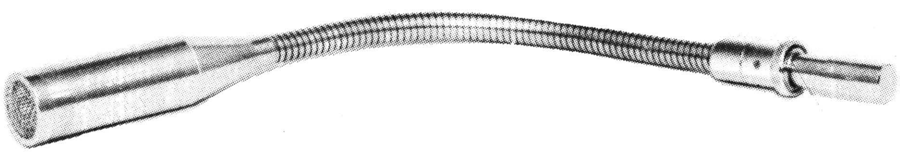

Fig. 1. Photo of Condenser Microphone type 4111.

All the above mentioned apparatus is provided with a special built-in rectifier, which delivers d.c. current for filament to the cathode follower in order to retain a low hum level.

The cartridge is mounted in the end of a tube (diameter 36 mm, length 90 mm), which also contains the cathode follower with components.

Fig. 2 shows an exploded view of the instrument. The other end o. the tube tapers and continues as a self-supporting goose neck with a length of 400 mm. This terminates in a 7-pin plug, directly fitting the socket marked "Condenser Microphone" on the amplifier or analyzer. It is thus possible to mount the microphone directly on the above mentioned 3 pieces of apparatus. By bending the goose neck the microphone can then be placed in any desired position.

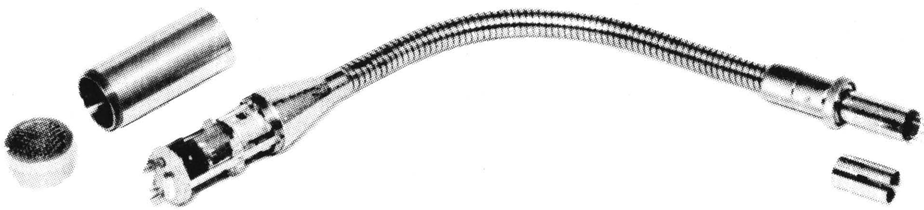

Fig. 2. Exploded view of Condenser Microphone type 4111.

The sensitivity of the microphone, about 2 mV per μbar, is comparatively high, particularly when taking into account its small dimensions and high resonance frequency. The accurate sensitivity of each individual microphone as well as the total frequency response characteristic are shown on a recording in the back cover, made individually for each microphone delivered. Fig. 3 shows an arbitrary example of such a calibration curve. Both the sensitivity (expressed in mV/μbar (= dynes/cm^2) or decibels below 1 volt/μbar) and the frequency response are valid for the sound waves of a free sound field impinging normally on the microphone membrane, with the protective grid removed. (A correction for the influence of this grid, which under routine measurements should be employed in all cases, follows on p. 5). The straight curve from 15 to 20.000 c/s is the response of the cathode follower alone (with a capacity of 5.000 pF across the input). The factor k is the distance of the membrane above the edge of the cartridge, which is a necessary datum when checking the sensitivity by means of the Electrostatic Actuator type 4113 (see p. 24).

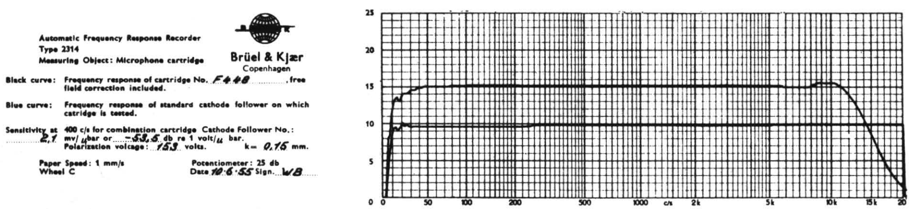

Fig. 3. Example of an individual calibration curve for the microphone fitted with a specified cartridge and with a specified polarization voltage.

The microphone is adjusted so that its frequency response characteristic is as flat as possible for zero angle of incidence. The frequency range is from 20 c/s to 16.000 c/s, of which the range 30 c/s to 10 kc/s is linear to within ± 2 db. The first resonance frequency is about 11 kc/s.

When a microphone is placed in a free sound field, a pressure increase on the microphone membrane is got, compared with the sound pressure of the free travelling sound wave, on account of the scattering effect of the microphone at higher frequencies, dependent on the wave length of the sound and the dimensions of the microphone. This pressure increase for normally impinging sound waves is given in db in fig. 4. In order to obtain a flat response in a free sound field, i.e. a constant electrical output of the microphone versus frequency, for a constant free field sound pressure prior to the introduction of the microphone in the field, the frequency characteristic of the microphone measured under constant pressure conditions, where a constant sound pressure is applied to the diaphragm, must decrease for frequencies higher than 2.000 c/s.

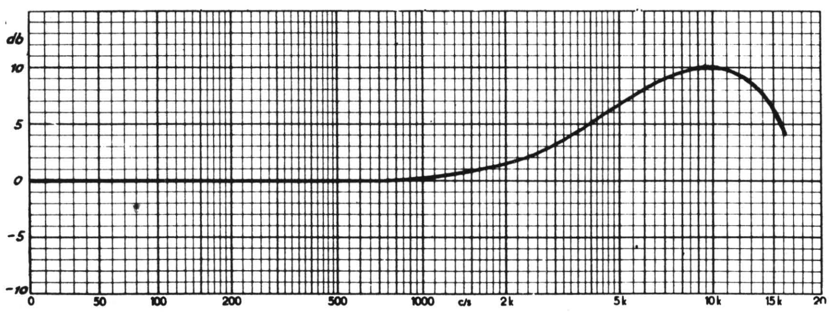

Fig. 4. Pressure increase on microphone diaphragm due to diffraction around a Condenser Microphone type 4111 mounted in a free sound field (with protective grid removed and with the sound waves impinging normally).

The actuator measurement as described on page 24 for the determination of the frequency characteristic simulates such constant pressure conditions. Therefore, if that measuring procedure should be employed for checking the microphone, fig. 4 should be added algebraically to the resulting recorded curve in order to obtain the free field response of the microphone.

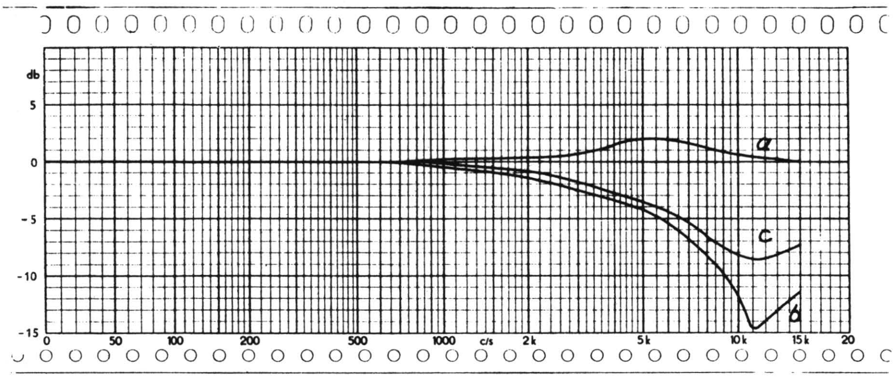

Fig. 5. Corrections to be added to the calibration curve of fig. 3 to find the sensitivity and frequency response under

a) free field measurements, 0 degree (normal) incidence with protective grid,

b) free field measurements, 90^{o} (grazing) incidence, with protective grid,

c) free field measurements, random incidence, with protective grid.

The frequency response of fig. 3 was valid in a free sound field with normally impinging sound and protective grid removed. Fig. 5, a, b and c show three corrections which should be algebraically added to this curve or to the corresponding curve valid for the microphone delivered, and placed in the back cover. in order to get the right calibration curve under the following measuring procedures:

1) Free field measurements, 0 degree incidence with protective grid. Fig. 5a indicates the difference in sensitivity for the microphone with and without grid.

2) Free field measurements, 90 degrees incidence with protective grid. Fig. 5b indicates the difference in sensitivity for the microphone with grid under 90 degrees incidence and without grid for normal incidence.

3) Measurements in diffuse sound fields with random incidence. Fig. 5c indicates the difference in sensitivity for random incidence with grid, compared with 0 degree incidence without grid.

These corrections are only dependent on the geometrical form of the microphone, and may therefore be assumed constant, and used for finding the corresponding sensitivity for any microphone delivered, for which the free field 0 degree incidence frequency response is given.

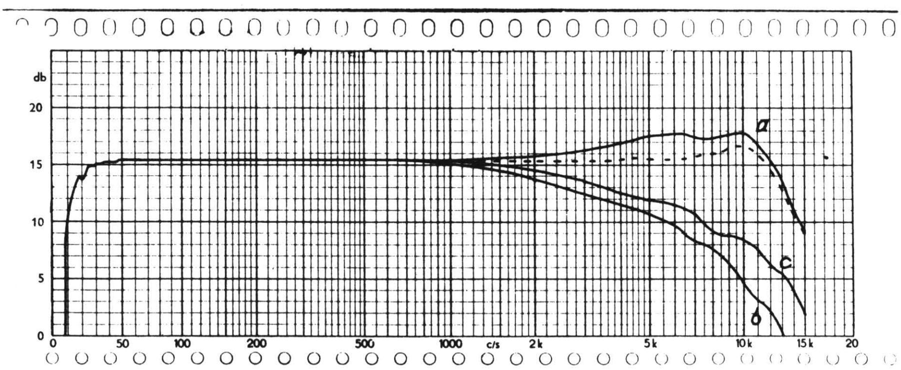

Fig. 6. The corrections of fig. 5, a, b, c, performed on the arbitrary example of a calibration curve of fig. 3.

The result of these three corrections carried out on the curve of fig. 3 is shown in fig. 6, where curve a represents the free field 0^{o} incidence sensitivity as a function of frequency, curve b the free field

90^{o} incidence sensitivity, curve c the random sensitivity.

The directional characteristics (as recorded with the aid of the Polar Diagram Recorder type 2370) of Condenser Microphone 4111 are given in fig. 7 for frequencies up to 9 kc/s. Once again, the geometrical form of the microphone determines the shape of these curves principally, so that they can be used for any type 4111 microphone. The curves are taken with the protective grid mounted on the cartridge.

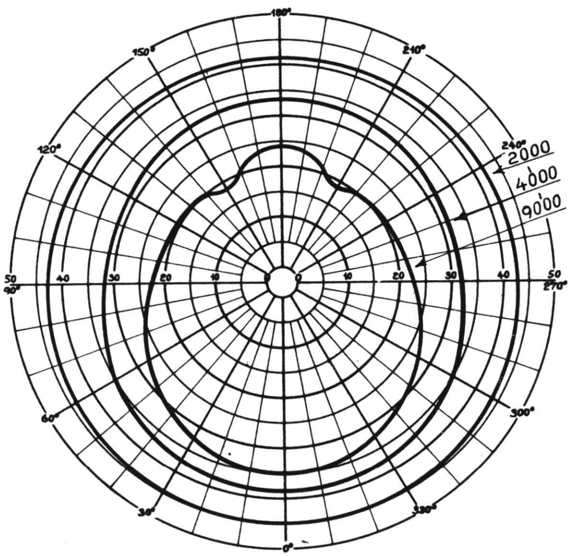

Fig. 7. Directional characteristics of Condenser Microphone type 4111 with protective grid mounted.

The sensitivity s mV/μbar as indicated on the graph in the back cover is the electrical output after the cathode follower for a free sound wave of pressure level 1 μbar, impinging perpendicularly on the diaphragm. This output results initially from the voltage as generated by the cartridge, which is attenuated in two ways. First there is a loss of sensitivity owing to the input capacity of the cathode-follower. This capacity (C_f) is about 10-15 pF and the cartridge capacity (C_c) is around 50 pF. The added capacity of the cathode follower will decrease the sensitivity by the ratio of C_c to $C_c + C_f$. The sensitivity loss owing to this capacity in the cathode follower is around 1 1/2 - 2 db. Secondly, the cathode follower will cause the drop A/A + 1 where A represents the amplification obtainable without feedback; this drop amounts to o. 5 db.

The sensitivity is measured with a polarization voltage as indicated on the calibration curve of the cartridge.

If the microphone is attached to an analyzer the polarization of which is different from that with which the microphone has been measured, a correction for the difference in polarization voltage must be made, the sensitivity being directly proportional to the polarization voltage. The polarization voltage given by the Analyzer type 2105 should be measured with a precision voltmeter with max. 50 µA current consumption. When this is done once for all, the polarization voltage should be marked on the condenser microphone's sensitivity curve, and the condenser microphone's absolute sensitivity should be corrected to the right polarization voltage. If the analyzer's voltage regulator tube V6 is replaced for any reason the polarization voltage must once again be measured.

For practical reasons, the sensitivity is given as defined above, instead of the open circuit voltage of the microphone cartridge when working into an infinite impedance, as required by the American Standard Z 24.4. With the microphone used in combination with Microphone Amplifier 2601 or Analyzer 2105 or 2109, a reference voltage can be put on the input of one of the last instruments. The cathode follower's output is then compared with this reference voltage and gives at once the applied sound pressure with the aid of the microphone sensitivity as defined.

The temperature coefficient for the whole microphone 4111 is less than o.o2 db per degree centigrade in the range -20 to +60° C, while the change in sensitivity caused by a variation in humidity is negligible.

The response is linear up to a voltage output of 20 volts, and the distortion is less than 1% for sound pressure levels up to 120 db above the reference value 2.10^{-4} μbar, and less than 4% for sound pressure levels up to 140-160 db. Higher sound levels will damage the microphone diaphragm.

CONNECTIONS

Microphone Amplifier 2601: The socket for the condenser microphone is here placed on the top of the apparatus, so that the amplifier can act as a stand for the microphone. In order to secure a solid connection between the microphone plug and socket, the plug is provided with a union nut for screwing over the socket. An input switch selects either this condenser microphone or the single pole input on the front side of the apparatus.

Analyzers 2105 and 2109: The condenser microphone socket is here placed on the front side of the instruments. In this case the input

Fig. 8. Accessories for Condenser Microphone type 4111.
a) Floor Stand type 4122,
b) Extension Cable type 4114,
c) Spare Condenser Microphone Cartridge MK 0001,
d) Electrostatic Actuator type 4113,
e) Extension Rod type 4115,
f) Support type 4116.

switch selects one of three possible connections: "Condenser Microphone", "Direct Input" - where the coaxial input is directly connected to the grid of the first tube in the apparatus - and "Potentiometer", where a potentiometer is inserted in this last connection. Both instruments are equipped with an indicator allowing reading both in volts, decibels or phons.

To extend the distance between the measuring site and observer or condenser microphone to the indicating instrument, the following accessories are available (see figs. 8, 9 and 10).

Fig. 9. Microphone Amplifier type 2601 connected to Condenser Microphone type 4111 via

a) Floor Stand type 4122,

b) Extension Rod type 4115,

c) Extension Cable type 4114.

<u>Floor Stand type 4122,</u> consisting of two telescopic steel tubes, the lower one mounted on a solid cast iron foot, the movable upper part provided with a ring for fixing the plug housing of Extension Cable 4114 in which the microphone is to be placed. The height from ring to ground can be adjusted between 110 and 200 cm. With the microphone stretched upwards this corresponds with a height between 160 - 210 cm.

Fig. 10. The same as fig. 9 for the combination Analyzer 2105 and Condenser Microphone type 4111. The arrow shows the Support type 4116.

Extension Cable type 4114 of 10 metres length, for those applications where the microphone is held in the hands (for example, in the case of vibration difficulties), suspended or mounted in Floor Stand type 4122. This extension cable has proved to be extremely valuable in many applications.

Extension Rod 4115 and Support 4116. The rod is provided with a toggle joint movable through 90 degrees, and can be used either on Analyzers 2105 and 2109 or on the Microphone Amplifier 2601. The

Support 4116 is used on the analyzers simply for keeping the rod in position. Figs. 9 and 10 show complete set-ups for both Microphone Amplifier 2601 and Analyzer 2105, together with the accessories mentioned. The arrow in fig. 10 indicates the support 4116.

The Condenser Microphone 4111 is usually delivered in a case with place for both microphone and extension rod.

MEASUREMENTS OF SOUND PRESSURE LEVEL

With precision measurements of sound pressure, care must be taken that the microphone is placed in the sound field remote from any disturbing reflecting objects, and the microphone membrane should be directed towards the sound source, as its adjustment curve is based on the sound waves striking the membrane perpendicularly. If it is believed that the microphone amplifier or analyzer itself has a disturbing effect on the sound field, it is recommended to use the Microphone Stand type 4112 or the Extension Cable 4114, with a length of 10 metres.

The Microphone Amplifier 2601 is primarily meant as an amplifier for the High Speed Level Recorder 2304 for recording noise levels, frequency characteristics, measurement of sound insulation, reverberation time, etc. The instrument is therefore not equipped with an indicating meter, although a VT Voltmeter, e.g. type 2407, can be used for this purpose by connecting it to the output. The dynamic range of the microphone amplifier is kept high for these measurements by having the amplifier tubes d.c. heated. Sound levels can be recorded both in decibels and phons, as the instrument also includes the three antisonoric frequency curves for 0-30, 30-60 and 60-130 phons, constructed according to the standards DIN 5045 and ASA Z 24.3, which are very close to each other. (See p. 21).

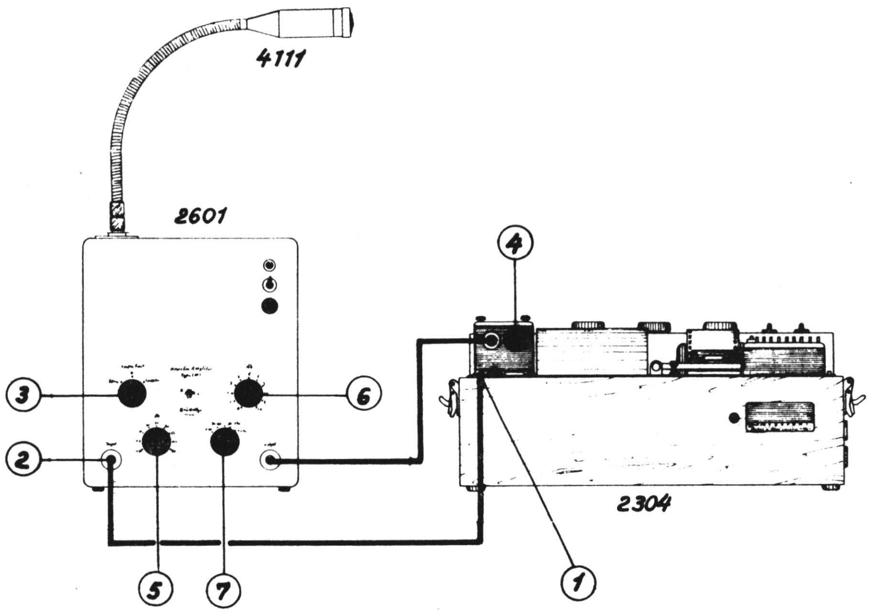

Fig. 11. Recording of sound pressure level or noise level on Level Recorder 2304 and direct adjustment of the combination Microphone Amplifier 2601 - Level Recorder 2304 to obtain calibrated ordinate values on the recording paper.

When the condenser microphone is employed together with the Microphone Amplifier 2601 and the Level Recorder 2304, and a recording of any kind of sound or noise is wanted, together with the absolute values of the sound pressure or noise level, the method of fig. 11 can be used. The 10 mV reference voltage of the level recorder, which value should be checked accurately with a VT voltmeter, is led from the jack below the potentiometer on the instrument (1) to the microphone amplifier input (2) via a screened cable (remember to ground the connection between the two instruments), the input selector of the amplifier being on "Direct". (3). If the same input had been applied acoustically via the condenser microphone, the sound pressure would have been 10/s µbar, in which s is the sensitivity in mV/µbar. This is equal to (20-20. log s) db above 1 µbar, or (94-20. log s) db above the standardized "zero" point of the sound pressure level scale, 2.10^{-4} µbar. If the sensitivity is expressed in -S db re 1 volt/µbar (this value is also given on the recording in the back cover), the reference value of the sound pressure level would be (34 + S) db re 2.10^{-4} µbar. This reference value can be set on any appropriate line of the recording paper by adjusting the input potentiometer of the level recorder (4) or the attenuators of the amplifier (5, 6), which are calibrated in 10 db and 1 db steps. For example, if s were 2 mV/µbar, the reference value would be 88 db above 2.10^{-4} µbar. Set on the 48 mm line of the recording paper, and using a 50 db potentiometer on the level recorder, the ordinate values from 0-50 mm on the recording paper correspond to sound levels between 40 and 90 db above 2.10^{-4} µbar. It is advisable to set the amplifier gain on 60 db and adjust the stylus deflection to 48 mm with the recorder's potentiometer. With unchanged attenuator setting, the ordinate values correspond to the range 40-90 db re 2.10^{-4} µbar, while a 20 db increase in gain, which is available of the total gain of 80 db for Amplifier 2601 extends this range downwards to 20-70 db. The "Zero Adjustment" knob on the recorder is adjusted in the normal way with this direct calibration amplifier-level recorder. For the adjustment, the Frequency Curve Selector of type 2601 (7) should be on linear. As the measurements are being carried out with type 2601 as linear amplifier, the ordinate values will indicate sound pressure levels in db re 2.10^{-4} µbar. Using one of the three weighting networks, automatically transforms the readings into phons. Depending on the prevailing noise level, the corresponding weighting network should be chosen (see also p. 23).

Using one of the Analyzers 2105 or 2109, the voltage sensitivity of the analyzer is adjusted in both cases by means of the built-in reference source. The reading of the meter will then be correct, and the measurement can begin. For sound pressure measurements of the total signal over the whole frequency range, the linear frequency characteristic range is again used. As the analyzer meter scale is graduated to show r.m.s. values of the voltage, the sound pressures obtained will also be r.m.s. values. The total sound pressure level can be read off directly in db above the reference value 2.10^{-4} μbar from the meter's db scale, adding to this

a) the phon index of the "Voltage Range"

and

b) a factor $K = 20 \log 5/s$,

in which s is again the sensitivity expressed in mV/μbar. K is about 8 db for most microphones. Some kind of factor has to be included, as the microphone sensitivity is different for each individual microphone. With a microphone whose sensitivity is exactly 5 mV/μbar, a sound pressure of 200 μbar (i.e., a level of 120 db over 2.10^{-4} μbar) will give an input voltage of 1 volt, to which corresponds a scale reading of 0 db and an index value of 120 phons. For microphone sensitivities less than 5 mV/μbar, a positive factor equal to K must be added to the scale reading to account for the smaller deflection with the same sound pressure. N.B. At the meter range knob the index used to determine the sound pressure level in db re 2.10^{-4} μbar is the same as the one used with noise measurements to find the noise level in phons above the hearing threshold (see also p. 20), and therefore expressed in phons. These phon values should be used, and not the db indications which express only the input voltage in db re 1 volt.

When the analyzer is used as a selective instrument, sound levels down to 8 db over 2.10^{-4} μbar can be detected. If, in these measurements, the exact microphone sensitivity, which varies with frequency, is to be used, it is easier to fill in the corresponding K factors, which will also vary, in table 1. In this table the standard frequencies which lie 1/3 octave apart, are used: 20 - 25 - 31.5 - 40 - 50 - 63 - 80 - 100 - 125 - 160 - 200 - etc. up to 16000. With the sensitivity a db less at a certain frequency compared with the sensitivity at 400 c/s, (at which frequency the sensitivity is measured as indicated on the calibration curve), the K factor at that frequency is $(K_{400} + a)$ db.

Fig. 12 indicates how to record sound levels with the aid of Level Recorder 2304 and Analyzer 2105 or 2109, and how to obtain ordinate values on the recording paper strip corresponding to whole ten-folds of db. With the output selector (1) in mid position on type 2105, or "Meter" on type 2109 the range switch (2) is set on "Ref.", the frequency selector on "Linear" (3), and with the sensitivity adjustment the meter deflection is adjusted to the red line (the "Range Multiplier" knob (4) of type 2109 should be on "x 1"). The indication is then 10 db, or expressed as a sound level (10 + range index + K) db, depending on which range will be used during the real measurement. This output is then set to the level recorder input (5). (The output selector

Standard Frequency c/s	K factor	Standard Frequency c/s	K factor
20		630	
25		800	
32		1000	
40		1250	
50		1600	
63		2000	
80		2500	
100		3150	
125		4000	
160		5000	
200		6300	
250		8000	
315		10000	
400		12500	
500		16000	

Table 1.

Table effective for analyzer No. with polarization voltage and Condenser Microphone type 4111 with cartridge F
1) Check analyzer's voltage sensitivity with "Sensitivity Adjust". 2) Measure with the sound waves striking the microphone membrane perpendicularly. 3) Read the db value indicated on the meter and add the corresponding K factor for each frequency, then add the phon index of the "Voltage Range" to find the S. P. L. in db re the reference value 2.10^{-4} µbar (or dyne/cm^2).

of type 2105 or 2109 on "Recorder"). With the aid of the recorder input potentiometer (6), the stylus can be placed on such a value as to give 10-folds of db for 10 - 20 - 50 mm recording paper ordinates. For example, if the measurement will be carried out on the range 100 mV and the microphone sensitivity is 2 mV/µbar, a meter deflection of 10 db corresponds to a sound pressure level (80 + 10 + 8) = 98 db. With the recorder stylus placed on 38 mm and using a 50 db potentiometer, ordinate values from 0 - 50 mm will correspond with sound levels from 60 - 110 db re 2.10^{-4} µbar. Increasing then the analyzer sensitivity by 10 or 20 db will decrease the ordinate values

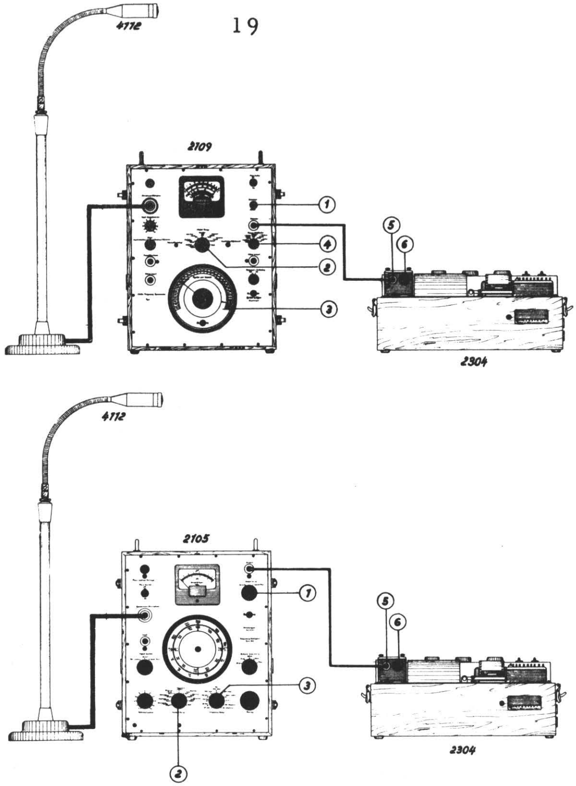

Fig. 12. The same as fig. 11 for the combination of one of the Analyzers 2105 or 2109 and Level Recorder 2304.

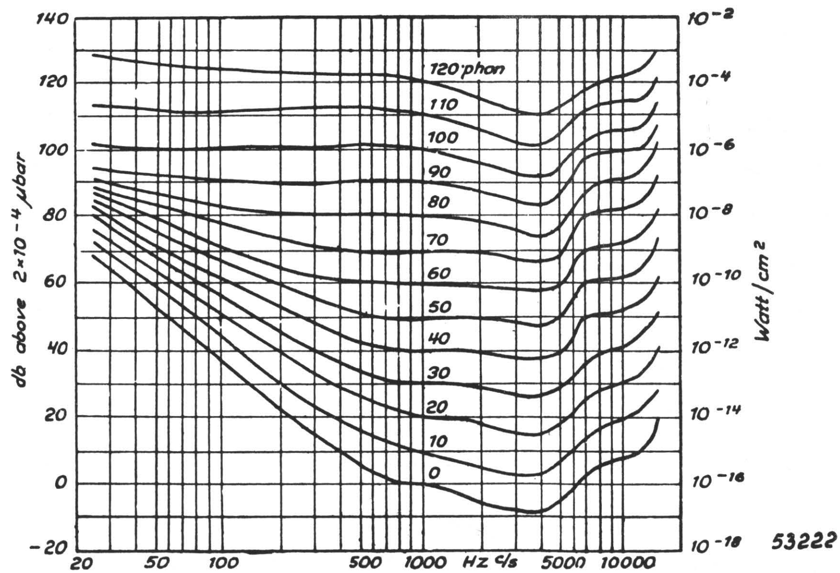

Fig. 13. The sensitivity curves for the human ear (Fletcher & Munson).

by the same amount, and vice versa. The "Zero Adjustment" of the recorder is again adjusted in the normal way as described in the Level Recorder 2304 Manual.

NOISE MEASUREMENTS

The determination of absolute sound pressure expressed in μbar is useful for many physical investigations, but the sound pressure at different frequencies does not however immediately give an indication of the human ear's perception of the sound's strength, as the ear is less sensitive to sounds of both low and particularly high frequency in comparison with the middle frequencies. This variation of sensitivity with frequency is very complicated as the absolute sound level also plays an important role. Sounds that seem to the ear to be equally loud are said to have the same subjective strength or loudness. Loudness is expressed in phons. In determining the loudness, the sound is compared with a tone of 1000 c/s whose physical energy is adjusted so that sound and 1000 c/s tone appear to the ear to be of equal strength. The loudness, expressed in phons, of the sound in question is then equal to the physical intensity of the 1000 c/s tone expressed in db above 2.10^{-4} μbar, or what is the same, in db above 10^{-16} watt/cm^2. At 1000 c/s, therefore, phon scale and decibel scale become identical, but at all other frequencies they will be different. Fig. 13 shows the sensitivity curves of the ear. The curves represent averages derived from testing a great number of people.

In order that a sound pressure meter should be able to measure the sound level in phons instead of μbar, it is necessary that the meter

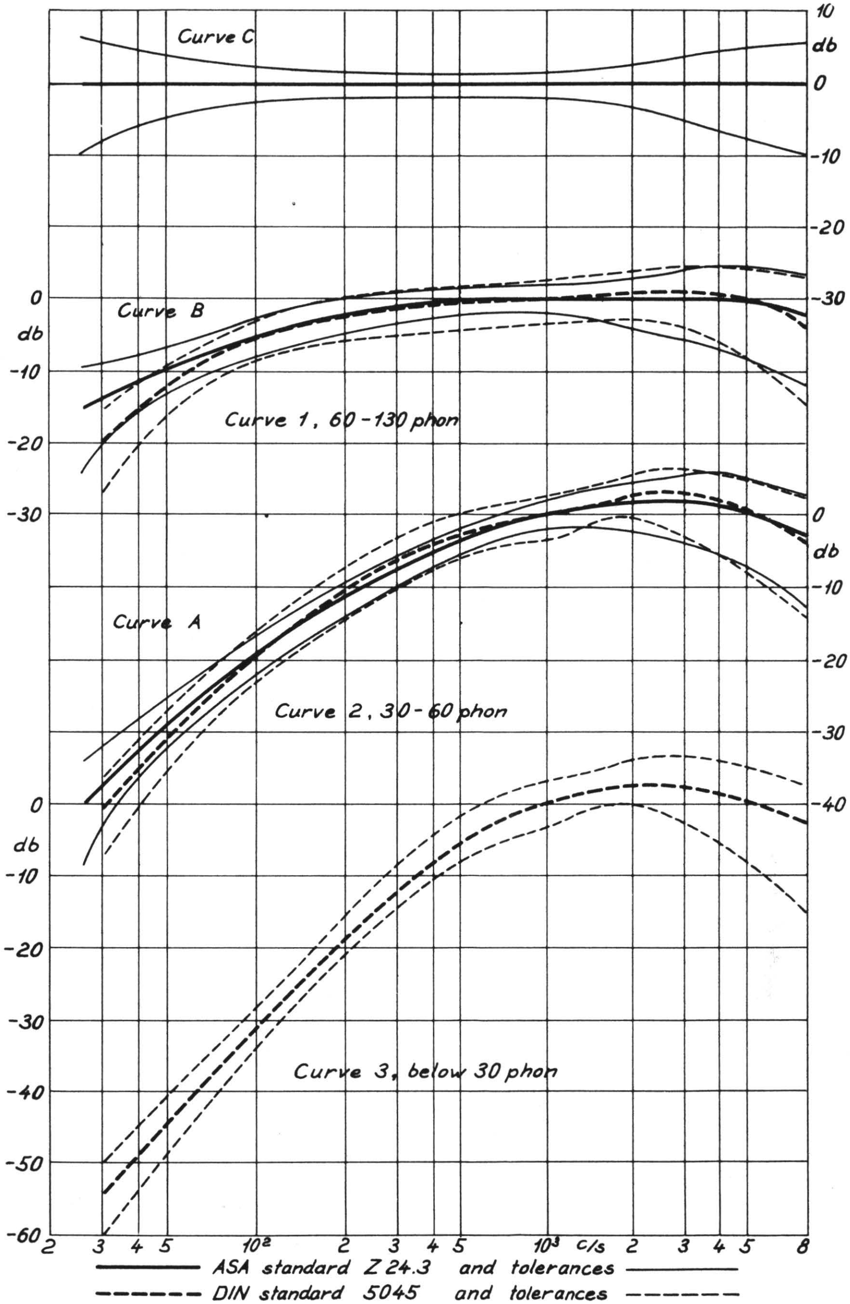

Fig. 14a. Standardized curves for weighting networks to be employed for noise measurements according to the American Standard Association (Z 24. 3) and the DIN standard 5045.

should have such frequency characteristics that the low and very high frequencies be depressed in a manner corresponding to fig. 13. In practice it is sufficient to have three different characteristics each effective in their own level range. In Europe the characteristics set down in DIN 5045 are used, and in America the slightly divergent standards set down in ASA Z 24. 3. The standards set down also contain requirements for the sound level meter's dynamic characteristics, frequency addition and overload safety factor. All these requirements are satisfied within the permitted tolerances in Microphone Amplifier 2601 and Analyzers 2105 and 2109 when equipped with a Condenser Microphone type 4111.

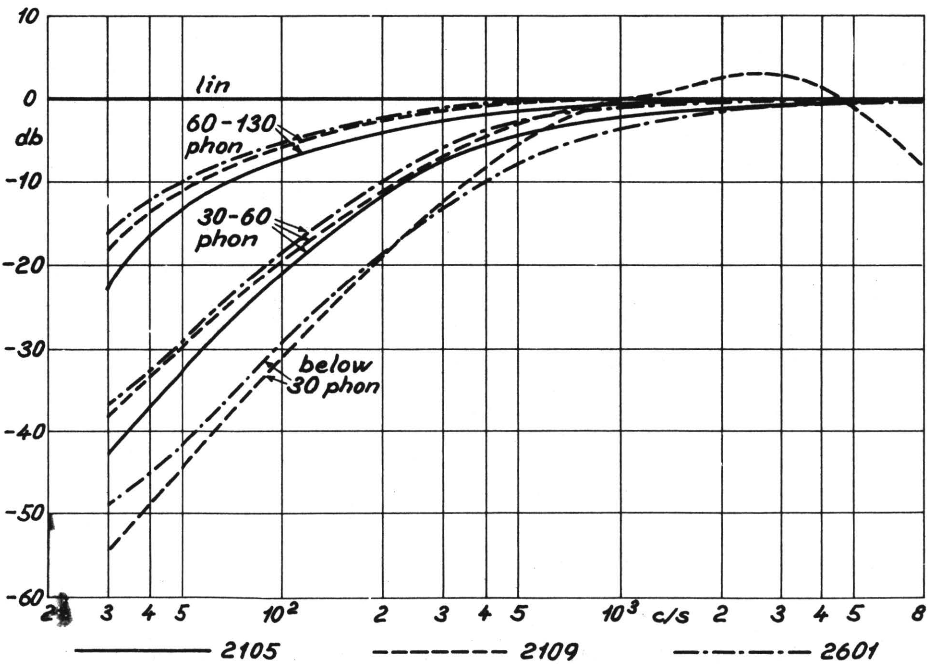

Fig. 14b. Frequency responses of the weighting networks as employed in Microphone Amplifier 2601 and Analyzers 2105 and 2109.

In fig.14a both the American Standard Association and the European DIN standardized curves for weighting networks to be employed in noise measurements are given, together with the permitted tolerances. It follows from this figure that it is possible to satisfy both standards within the different prescribed tolerances. This fact is applied in the microphone amplifier and the analyzers according to the curves of fig. 14b. Both the Microphone Amplifier 2601 and the Analyzer 2109 incorporate the linear frequency characteristic (ASA curve C) and three phon curves, Analyzer 2105 only the linear characteristic and the two upper phon curves of fig. 13.

Noise measurements as well as noise recordings with the aid of Level Recorder 2304 are carried out exactly as described under Sound Pressure Level Measurements, only the appropriate weighting network is connected, depending on the noise level. On the analyzers the noise level is read off in phons as the sum of the meter indication in db + the phon value as indicated at the "Voltage Range" knob + the factor $K = 20 \log \frac{5}{s}$ (or (S-46) db) in which s is the microphone sensitivity in mV/μbar and -S the same expressed in db re 1 volt/μbar. For noise recordings the same procedure can be followed as explained on p. 17 to obtain calibrated ordinate values on the recorder paper. It should be kept in mind, however, that this calibration should be carried out with the instrument on "Linear" and to switch over to the appropriate phon curve afterwards.

CONTROL OF FREQUENCY RESPONSE AND SENSITIVITY OF CONDENSER MICROPHONE 4111

When ordering a Condenser Microphone 4111 one may in addition order

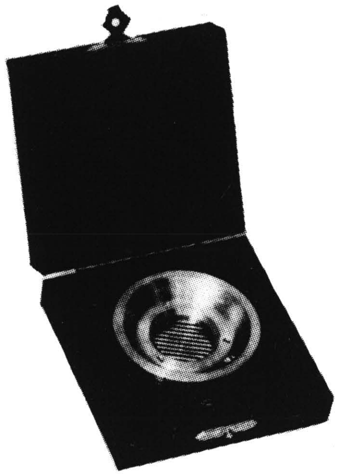

Fig. 15. Electrostatic Actuator type 4113.

an Electrostatic Actuator type 4113 for the control of both the frequency response and sensitivity of the instrument.

This accessory, see fig. 15, consists of a fixed slotted plate which can be placed parallel to the microphone diaphragm, good electrical insulation existing between the two. The distance between the cartridge membrane and the slotted plate is determined by three supporting glass points which may be adjusted by means of a screwdriver from the upper side of the unit. (Normally the screws are sealed at the factory after adjustment).

In fig. 16 the set-up is shown for recording the microphone's frequency response as well as for measuring its sensitivity. A large d. c. voltage E_o, together with a small superimposed a. c. voltage e_{eff}, is applied between the actuator grating and the microphone diaphragm. The d. c. supply is derived from the Calibration Apparatus type 4119 to which instrument the attenuator output of the B. F. O., part of the Audio

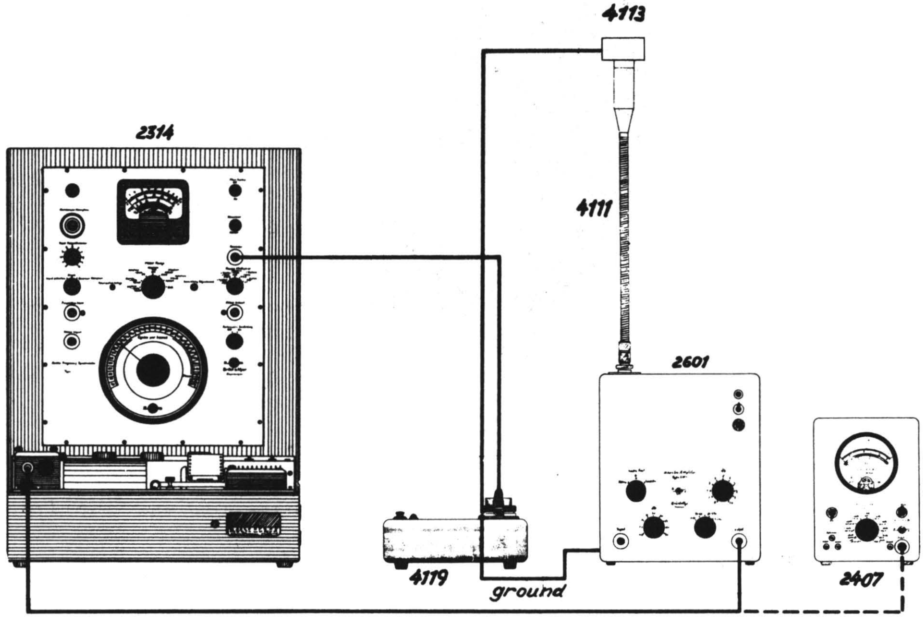

Fig. 16. Recording of a condenser microphone's frequency response by means of the Electrostatic Actuator type 4113.

Frequency Response Recorder type 2314, delivers the a.c. voltage. In case type 4119 is not available any d.c. supply between 500-1000 volts can be employed, connected via a 10 MΩ resistor to the actuator. The B.F.O. is also connected to the actuator, via a 10.ooo pF shielding condenser (see fig. 17).

The electrostatic attractive force resulting from both voltages consists of a large constant part, plus a smaller sinusoidal term of the same frequency as the applied voltage e_{eff}, plus a sine term of double frequency. To keep this last term, which can be regarded as distortion, small, the quotient of d.c. and a.c. voltage should exceed

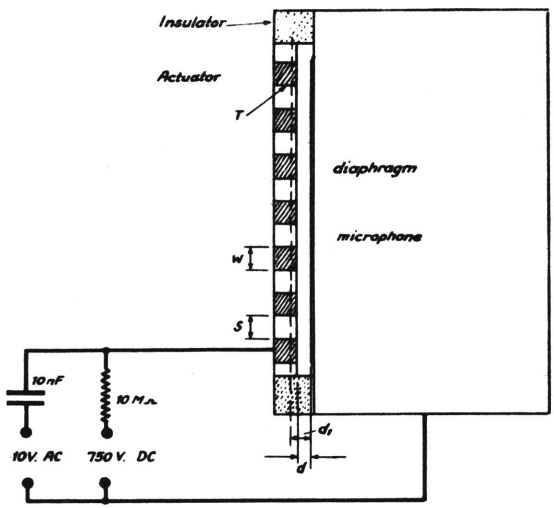

Fig. 17. Principle of the Electrostatic Actuator type 4113.

20. Normally, values between 10-25 volts for e_{eff} will be sufficient. (See Ballantine, Jasa, Jan. 1932 and the manual for the Calibration Apparatus type 4119). For the varying part of the electrostatic force of frequency ω it follows

$$p_{eff} = 8,85 \cdot 10^{-7} \frac{E_o e_{eff}}{(d_1)^2} \; \mu\text{bar} \qquad (1)$$

in which formula the effective sound pressure p_{eff} is given in μbar or dyne/cm^2, E_o and e_{eff} in volts and the distance d_1 in cm. The quantity d_1 in the above formula is not equal to the actual distance between grating and diaphragm (which should be the case for a noneslotted plate with negligible edge-effects) but is related to the distance d by the formula

$$d_1 = \frac{d}{\sqrt{K}},$$

where $$K = 1 - \frac{2 \arctg \frac{S}{2d}}{\pi(1 + \frac{W}{S})} \qquad (2)$$

and in which W is the width of the grill sections and S the width of the slots.

With the voltage e_{eff} taken from a B. F. O. 1012, mechanically coupled to, and driven from a Level Recorder 2304, the complete frequency range 20 c/s - 20.000 c/s can be traversed automatically which results in a recording of the "pressure response" characteristic of the microphone, because with constant voltages E_o and e_{eff} the simulated sound pressure on the membrane p_{eff} is constant. The free-field response, with perpendicularly impinging sound waves for the microphone without protective grid, is then found by adding the curve of fig. 3 to the measuring results. The correction curves of fig. 5 a, b and c should if necessary be added for measurements with normal incidence, 90^o incidence or random incidence, all with employment of the protective cap (see p. 6).

Taking a 25 db potentiometer for these recordings gives results as shown in fig. 18, where the frequency responses of a Condenser Microphone 4111 equipped with three different cartridges and measured with one and the same Electrostatic Actuator are depicted. The relative position of the three curves is irrelevant. The output voltages

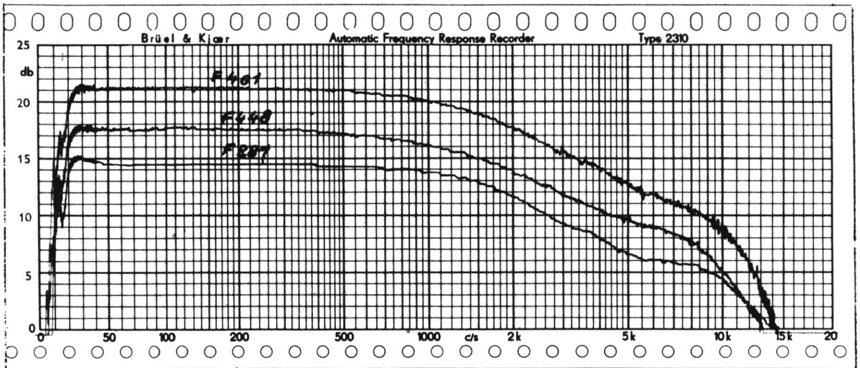

Fig. 18. Pressure response characteristic as taken with Electrostatic Actuator 4113 on three different cartridges.

measured at 200 c/s were 8.o mV for cartridge F401, 9.25 mV for F448, and 20.o mV for F287 (measured with a 2407 VT Voltmeter on the Amplifier 2601 output instead of the recorder). $E_o^{\cdot}$ was 650 volts in this measurement, e_{eff} 10 volts. In order to obtain a flat and even curve for the recording a quiet room should be used to avoid spurious voltages which can be caused by acoustic noise around the place of measurement. The output level should be between 15-25 mV, thus it may be seen that e_{eff} should have been doubled for the measurements on cartridge F401 and F448. A more constant recorder stylus movement would have resulted during the recording, had eff been increased. The curves are only taken with a constant e_{eff} in order to show later on that the biggest output (of the cartridge F287) does not necessarily imply a high sensitivity because the distance k between the cartridge diaphragm to the cartridge edge which supports the actuator, is not constant.

CALCULATION OF SENSITIVITY

The absolute sensitivity of the combination condenser microphone cartridge - cathode follower has only to be determined for one fixed frequency. This measurement together with the total frequency response between 20 and 20.000 c/s found with the actuator, form the necessary data for all future sound measurements with any combination Condenser Microphone 4111 - Amplifier 2601 or Analyzer 2105 or 2109.

In order to find this sensitivity, two basically different measurements can be carried out, viz. with the aid of the Electrostatic Actuator 4113 or by means of the so-called reciprocity technique with the Microphone Calibration Apparatus 4119. The latter of the two procedures, now standardized according to the American Standards Association's standard ASA Z 24.4, is the more accurate of the two and is accepted as laboratory test for our microphones before delivery. Both the principle of this technique and the instructions for performing these measurements on the Calibration Apparatus 4119 are described in our manual 4119.

The Electrostatic Actuator 4113 can be employed both for the independent determination of a Condenser Microphone's sensitivity, based on direct measurements of voltages and lengths (I) as well as for an indirect comparison of a condenser microphone's sensitivity against that of the standard condenser microphone of the factory (II).

I. The necessary quantities for the determination of the eff sound pressure p_{eff} are d_1, E_o, and e_{eff} (see form 1). The microphone output V after the cathode follower is measured in mV on VT Voltmeter 2407, connected to the Microphone Amplifier 2601 output or on the indicating meter of Analyzer 2105 or 2109, functioning as linear amplifier. The quotient of V and e_{eff} then yields the microphone sensitivity s mV/μbar. The accuracy of the measurement of E_o and e_{eff} will be dependent on the measuring equipment employed. With type 2423 Megohmmeter for the measurement of E_o and the reading of the B. F. O. meter for e_{eff}, the accuracy is $\pm$ 2% in both cases. The distance d between the microphone diaphragm and the lower side of the grating is found as the difference of two quantities. A microscope is employed in this measurement, the objective first being focused on the diaphragm and then on the outer surface of the grating; as the thickness of the grating may be measured with a micrometer, the distance d is merely the distance moved by the objective less the grating thickness. It is in the measurements of this quantity d that the greatest inaccuracies occur. Even with true parallelism between grating and diaphragm, errors of $\pm$ o. ol mm in the value of t may occur. The grating thickness is 1 mm in the older type, 2 mm in the new design. The error in the microscope measurements amounts also to $\pm$ o. ol mm on a value of about 1. 3 or 2. 3 mm. The accuracy of the value of d thus becomes $\pm$ o. o2 mm, or on a value of about o. 30 mm for d the error is $\pm$ 7%. The value of the geometric constant K as function of 1/d necessary to calculate d_1, $d_1 = \frac{d}{\sqrt{K}}$, is shown in fig. 19 valid for the Actuator type 4113 with W and S each 1 mm. Even though K is dependent on d, the accuracy of d_1 is about the same as for d, because with decreasing d, K also decreases. The total inaccuracy, however, for the value p_{eff} amounts to$(\pm 2 \times 7 + 2 \times 2) = \pm 18\%$ or ± 1.5 db. For the sensitivity, which is then found as the quotient of the meter reading on VT Voltmeter 2407 in mV and p_{eff} in μbar, the maximum possible error is $\underline{\pm 1.7 \text{ db.}}$

II. The second method for the determination of the microphone sensitivity is based on the indirect comparison with the factory standard. This standard, which is accurately measured by means of the reciprocity technique and of which the sensitivity is known within $\pm$ o.2 db, is used to determine the "electrical" distance d_1 for the combination of a certain actuator and the standard cartridge. The sensitivity of the standard is taken as known data and with the help of formula (1), d_1 is derived, as E_o, e_{eff}, and the output V from the microphone may be measured. The value k, i.e. the elevation of the diaphragm over the cartridge edge of the standard, is then added and the sum $d_1 + k$ is supplied with the actuator (see fig. 20) as a datum peculiar to this unit. When hereafter this actuator is employed with another cartridge of unknown sensitivity and a diaphragm elevation k', this value has only to be subtracted from the supplied value $d_1 + k$ to give the new "electrical" distance d_1', which is applied again in formula (1) to find the effective pressure p_{eff} and hence the required sensitivity s' of the unknown microphone.

The advantage of this method is that it avoids elaborate microscope measurements and that it enables customers to compare their microphones at any time against the factory standard without the necessity of sending the complete microphone or cartridge back to the factory. The accuracy of this method is similar to that obtained in the absolute measurement described above. An example is now considered in detail. The real distance d + k (see fig.20), e.i. the distance between the grating and supporting glass points, is adjusted at the factory to about o. 50 mm. The gratings are then placed over a standard microphone cartridge with a k value o. 14 $\pm$ o. ol mm.

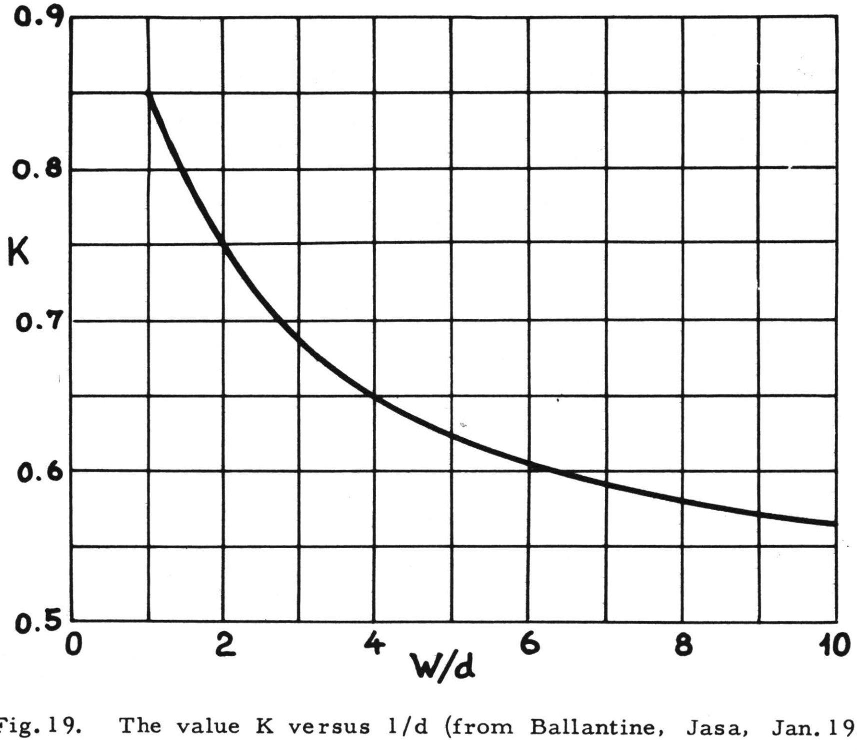

Fig. 19. The value K versus l/d (from Ballantine, Jasa, Jan. 1932).

The distance d_1 follows from a precision measurement in the factory of E_o ($\pm$ 1%), e ($\pm$ 1%), and the resulting output V ($\pm$ 1%). The accuracy of the standard is $\pm$ o. 2 db ($\pm$ 2. 3%). The accuracy in $d_1^{\ 2} = \dfrac{8{,}85 \,.\, E_o \,.\, e \,.\, s}{10^7 \ V}$ is then 5. 3% and in d_1 2. 7%. d_1 is approx. o. 40 mm (o. 43 in this example), the accuracy for d_1

is thus $\pm$ o. ol mm. The new cartridge has a diaphragm elevation $k' = 0.20 \pm 0.01$ mm. The value d_1' is then o. 37 mm $\pm$ o. o3 mm, i. e. a relative error of $\pm$ 8%.

The influence of the theoretical fault which we make by neglecting that the value of κ (fig. 19) has changed and that a smaller real distance d' exists, is negligible compared with the 8% inaccuracy of above.

With the rather extreme difference in k values in this example between the standard and unknown cartridge we have for the real distance in the first case $d = 0.50 - 0.14 = 0.36$ mm. With the aid of fig. 19, this gives for the "electrical" distance d_1

$$d_1 = \frac{0.36}{0.69} = 0.43 \text{ mm.}$$

The new d_1 follows thus $d_1' = 0.43 - 0.06\,(\text{i.e. } 0.14 - 0.20) = 0.37$. In reality we have d'(the new "real" distance) $= 0.50 - 0.20 = 0.30$, so that the "electrical" distance should be

$$d_1' = \frac{0.30}{0.675} = \frac{0.30}{0.82} = 0.365.$$

The introduced error o. oo5 mm can therefore be neglected in the presence of the inaccuracy of $\pm$ o. o3 mm above. With the measurement on the unknown cartridge a new measurement is made of the values E_o', e_{eff}' and V', so that at last the new sensitivity s' is found with a final accuracy of $2 \cdot 8 + 3 = 19\%$ or $\pm$ 1. 5 db. The method employed in the above calculation has been such as to obtain the maximum error which might be encountered, assuming the measure-

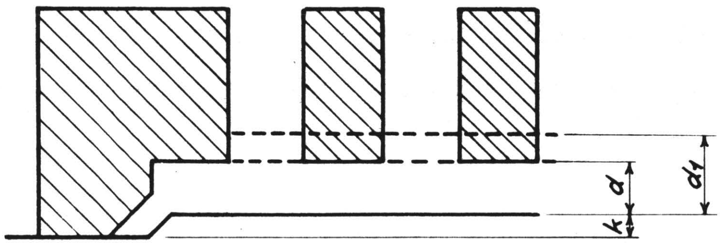

Fig. 20. Indirect comparison with factory standard using the Electrostatic Actuator 4113.

ments to be carried out with precision instruments accurate to within ± 1%. With Analyzer type 2105, Beat Frequency Oscillator type 1012, and DC Voltmeter type 2423, which belong to the 2% accurate class, the final error will be about ± 2 db.

A second point is that the standard cartridge is chosen with a constant k value around the whole edge. The accuracy in this quantity can therefore be assumed to be ± 0.05 mm, which directly increases the final accuracy. The average cartridge, however, cannot be made with this constant diaphragm elevation and the accuracy in k′ is in some cases even poorer than the one used in the error calculation.

The difference in diaphragm elevation also finds expression in fig. 18. The 20 mV output of cartridge F287 does not imply that this cartridge is the most sensitive. In fact the sensitivities of F287 and F446 are both 2.43 mV/μbar. There is, however, a great difference in their k values which indicates in the case of F287 a shorter distance between membrane and grating, and consequently a higher sound pressure for the microphone when equipped with the cartridge F287. Underneath are given values of diaphragm elevation k, (the cartridge F287 was taken as an extreme example), "electrical" distance d_1 (following from the actuator datum $d_1 + k = o.52$), effective pressure p_{eff} (with $E_o = 650$ volts and e_{eff} 10 volts), output voltage V and sensitivity s.

	F401	F448	F287
k	o. 14	o. 13	o. 25 mm
d_1	o. 38	o. 39	o. 27 mm
p_{eff}	4. 05	3. 8	8. 2 µbar
V	8. o	9. 25	20. o mV
s	1. 97	2. 43	2. 43 mV/µbar

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