Teletechnical, Acoustical and Medical Research

Cover: Production test of filter components with Deviation Test Bridges type 1502.

Some Experiences with The Deviation Test Bridge Types 1502 and 1507.

The Deviation Test Bridge types 1502 and 1507 have been manufactured in ever increasing numbers during the past four years, and much experience has been gained during that period as to the different and extensive fields of use enjoyed by these bridges. We are therefore of the opinion that it is worth while here going into the details of some of the typical and characteristic uses, which may in some case lie outside the field which the bridge was originally constructed to operate in.

The bridge is intended for testing components such as resistors, capacitors and inductors, and will read directly any deviation from the standard. The instrument comprises two arms of a Wheatstone Bridge; the remaining arms are formed by the external standard and the measuring object, and an a.c.-voltage is supplied by a built-in generator. The frequency is 1000 c/s in the Type 1502 Bridge and 50 kc/s in Type 1507 Bridge. The galvanometer voltage is amplified and led to a demodulator circuit together with the generator voltage, and a d.c. meter in this circuit will indicate the deviation.

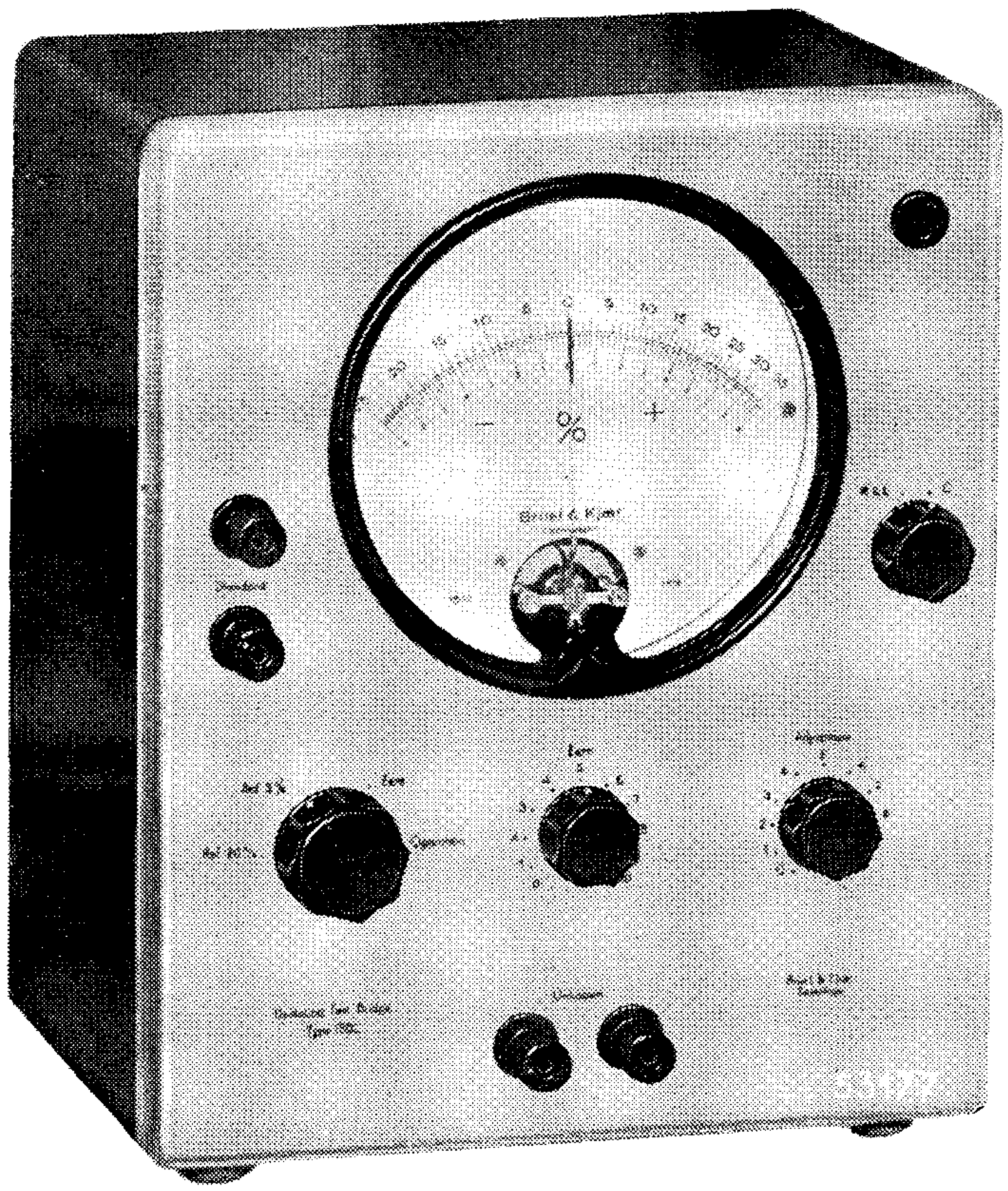


Fig. 1. Photograph of Deviation Test Bridge type 1502.

The bridge has two ranges with full deflections for —7 % to +8 % and —25 % to +33 % respectively, and for adjustment and control it contains a set of resistors, whose ratios are indicated by red markings on the meter scale.

When the deviation indicated is 0 the real deviation is less than 0.1 %, and the full scale accuracy is better than 5 %. The moving-coil instrument is slightly under-critically damped to secure maximum speed, and perfectly protected against overload.
The bridge is to a certain extent insensitive to hum voltages owing to the fact that the modulator responds only to voltages having the generator frequency. However, when the hum voltage is so high as to saturate the amplifier, the gain will decrease and the meter reading will be too low.
When measuring high impedances the meter reading will also be too low, because the bridge is loaded by the amplifier input circuit. This is compensated for within the stated accuracy by increasing the generator voltage according to an adjustment curve, whose values are used instead of the red markings on the scale.
The measuring range for the Type 1502 Bridge covers resistances between 10Ω and 10 MΩ, capacitances between 50 $\mu\mu$F and 10 μF, and self-inductances between 2 mH and 100 H, approximately. For the Type 1507 Bridge, the ranges are 20Ω to 100 kΩ, 25 $\mu\mu$F to 0.1 μF, and 100 μH to 0.3 H. When measuring capacitance the difference between the power factor of the standard and the measuring object should not be too great. This holds good for measurements of inductances too, and here it is furthermore a condition that the reactance at the generator frequency is high in comparison with the resistance, and that no resonance occurs.

Measuring resistance and capacity in production.

Fig. 2 shows a typical set-up for the bridge when measuring resistors and capacitors in factory or stock-rooms. The bridge itself should be placed on a table on the underside of which is stuck a piece of aluminium foil or a thin aluminium plate is fastened, as a screen. As indicated, this screen should be connected to the earth side of the instrument, and the whole then earthed. The whole measuring set-up will in this way be sufficiently screened from hum. The resistor or capacitor is placed in the foot-operated contact device, which is connected to the bridge. With this arrangement it is possible to measure up to 4000 resistors or capacitors per hour. (fig. 2).
When resistors and capacitors can be measured with such speed, it can actually pay every factory which manufactures electrical apparatus to measure all the incoming resistors and capacitors. Two advantages are gained hereby. For the first, an effective control of the elements entering into the production is obtained, so that faults in these components are seized on at the earliest possible stage, and complaints to suppliers made immediately, and for the second, it is possible to purchase components with the greatest tolerances, for example greater than ± 20 %. In most cases this purchase of components with great tolerance is economically advantageous, as resistors and capacitors with large tolerance are considerable cheaper than components with narrower tolerance figures. This price difference in components is alone often quite sufficient to make control measurements on

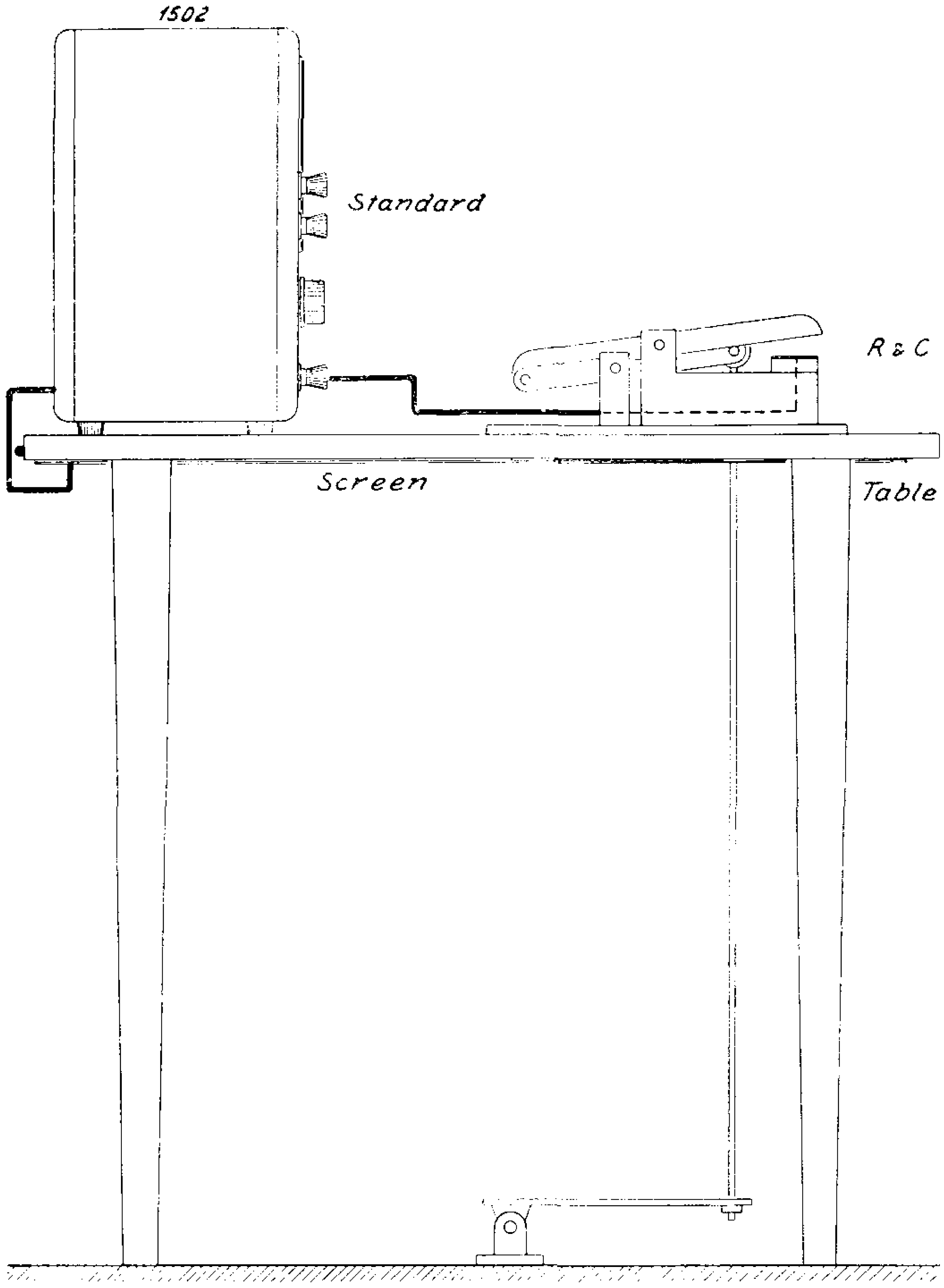


Fig. 2. Set-up foot-operated contact on screened table.

incoming stock items economical. With many constructions there are further problems in special cases when resistors with very narrow tolerances, for example 1 % or ½ %, have to be provided. Instead of ordering resistors with these tolerances it can as a rule pay to order resistors or capacitors with normal tolerance limits and sort out the components delivered oneself, taking out those which can be used for the special purpose in question, and letting the remainder go forward for the ordinary production.

In order that the measuring bridge may be used quickly and conveniently, it is necessary that the normals used be arranged in an intelligent and practical way.

With regard to the stepping of the normals, we would like to mention here that several of our customers have used the so-called "preferred numbers", or the "standardized Renards numbers", which are set forth in table 3. These preferred numbers are based on a logarithmic scale, and therefore give an even distribution of the chosen standard values. A particularly practical distribution is the R-10 series, which divides a decade into 10 equal logarithmic steps. The values seen in the table, 1 - 1.25 - 1.6 - 2 2.5 - 3.15 - 4 - 5 - 6.3 - 8, are inscribed on the normals, whereas the exact value which the normals have is that which is given under "the exact value", i.e., that value, the

40-series	20-series	10-series	5-series	Exact Value	Mantissa
1	1	1	1	10000	000
1.06				10593	025
1.12	1.12			11220	050
1.18				11885	075
1.25	1.25	1.25		12589	100
1.32				13335	125
1.4	1.4			14125	150
1.5				14962	175
1.6	1.6	1.6	1.6	15849	200
1.7				16788	225
1.8	1.8			17783	250
1.9				18836	275
2	2	2		19953	300
2.12				21135	325
2.24	2.24			22387	350
2.36				23714	375
2.5	2.5	2.5	2.5	25119	400
2.65				26607	425
2.8	2.8			28184	450
3				29854	475
3.15	3.15	3.15		31623	500
3.35				33497	525
3.55	3.55			35481	550
3.75				37584	575
4	4	4	4	39811	600
4.25				42170	625
4.5	4.5			44668	650
4.75				47315	675
5	5	5		50119	700
5.3				53088	725
5.6	5.6			56234	750
6				59566	775
6.3	6.3	6.3	6.3	63096	800
6.7				66834	825
7.1	7.1			70795	850
7.5				74989	875
8	8	8		79433	900
8.5				84140	925
9	9			89125	950
9.5				94406	975

Table 3. Table for preferred numbers or Renard numbers standardized in the following countries:
Belgium: NBN 100 (1941), China: CIS No. 1 (1928), Czecho-Slovakia: CSN 1265 (1939), Denmark: DS 132 (1934), Finland: SFS AI (1933), France: X01-001 ENR 962-06 (1940), Germany: DIN 323 (1939), Great Britain: BS 1638 (1950), Holland: N 1270 1271 (1941, Hungary: NM 138 (1950), Italy: UNE 2016 (1942), Japan: IFS 4 (1925), Norway: NS 379 (1940), Sweden: SMS 400 (1932), Switzerland: VSM 10001 (1943), USA: Z 17.1 (1936), USSR: OCT 3530 (1925).

mantissa of whose logarithm is an integral number of times 0.1. For instance the normal with the inscribed value 125Ω should be 125.89Ω and the normal which has inscribed 160Ω, should be 158.49Ω, and so on. The use of logarithmically spaced normals gives a perfectly constant ratio between the individual values, and this ratio is uniform, no matter whether the resistors are 2, 3 or 4 % greater or smaller than the normal. This again means that one can thus construct attenuation series on the basis of the given standard values, as long as one takes components with the same percentage deviation from the standard values. A further advantage with these preferred numbers is, that an attenuator given in decibels is produced automatically, for, as can be seen from the figures, there is exactly 2 db difference between the standard values of the R-10 series, 1 db difference between the values of the R-20 series and ½ db difference between the values of the R-40 series.

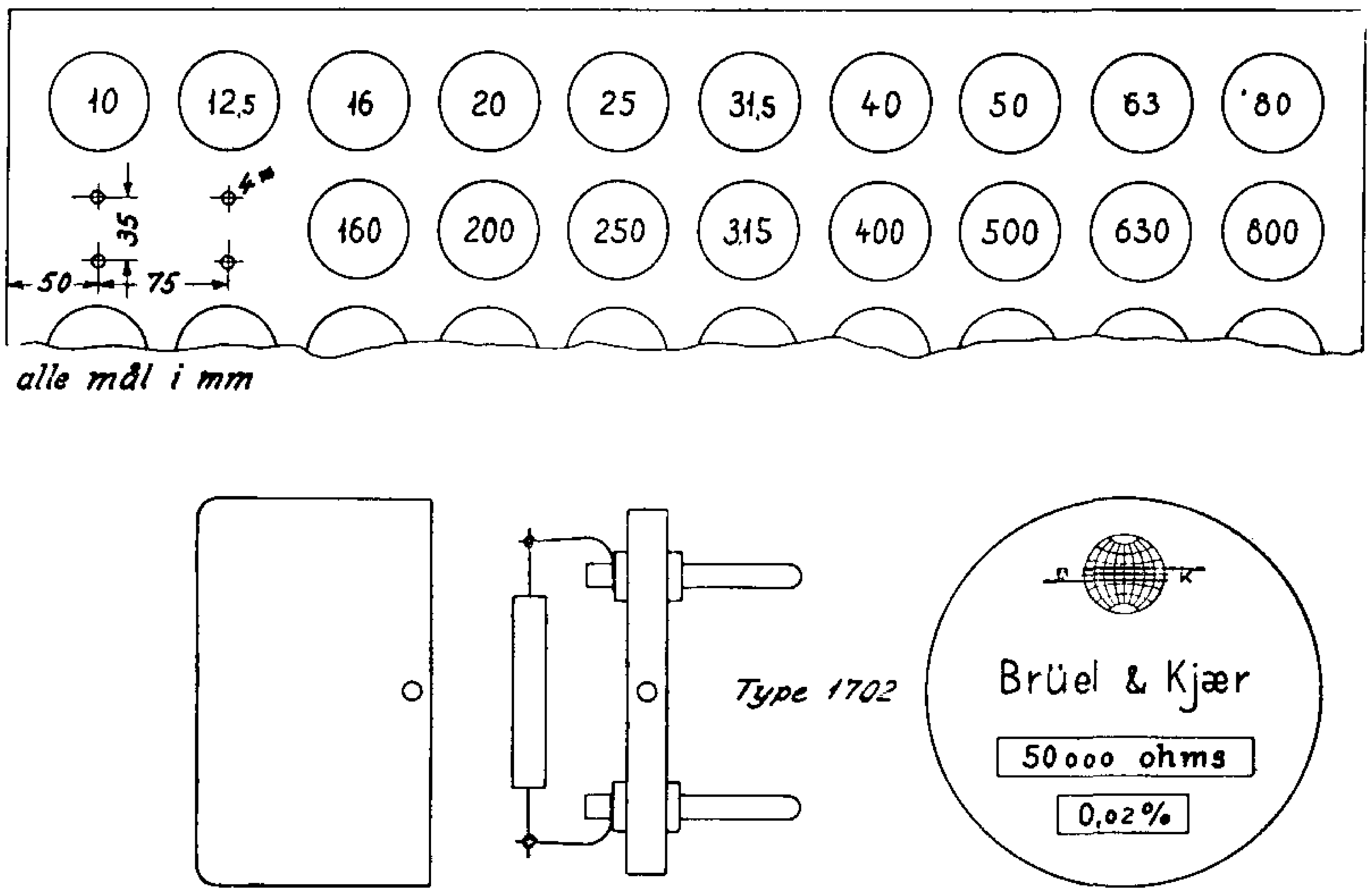


Fig. 4. Practical arrangement for standard resistance values. The standard resistances are placed in our Standard Box type 1702.

Most resistor and capacitor factories have several accepted standard values of their own, but as far as we are aware, no factory has so far gone in for the use of the "preferred numbers", although these are standardized in a considerable number of countries. The factories themselves sort out those of close tolerance as percentage deviations from the accepted standard values.

Fig. 4 shows an example of how one can arrange standard resistors set out according to the normal R-10 series. The abbreviated values are given on the different resistors. The standards are mounted in our Standard Box Type 1702, a round container with banana pins, fitting Measuring Bridges 1502 and 1507. The standards are placed on a strip, so that they sit in their logical sequence. A row of standards covers a decade, and each decade is divided into ten intermediate values.

It is worth while making these standards carefully and attractively, and keeping them in some practical way whereby they may easily be found when

required. A good solution of this last problem is to fix a board to the wall with 4 mm holes drilled at a 35 mm spacing. The holes are made vertically above each other allowing the engraved text to be read in the correct position. In this way an excellent survey of the standards is obtained.
In the production of very small capacity standards the final fine-adjustment should be made on the bridge itself. The standard is placed on "Standard" and the primary on "Unknown", possibly via that jig which would generally be used in the measurements. This manner of procedure ensures capacitative balance in bridge and jig.

Measuring resistors and capacitors in laboratories.

For laboratories where resistors and capacitors are frequently measured, it will be very time saving to set up a couple of measuring bridges of type 1502 or 1507, permanently connected to the resistor and capacitor standards, as indicated in fig. 5.

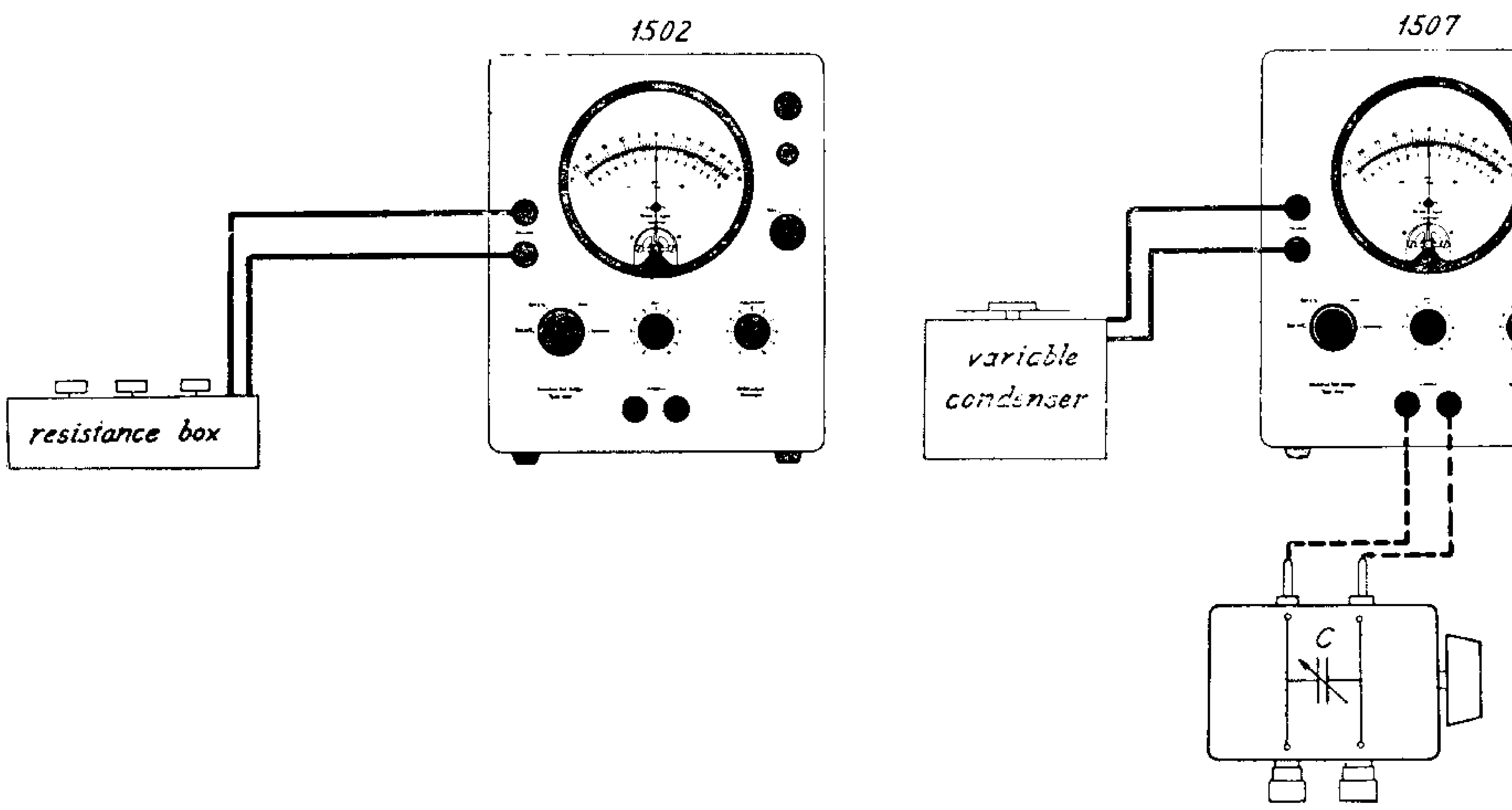


Fig. 5. Resistance box connected to 1502 and variable condenser to 1507.

Resistors are measured on 1502, the unknown being connected to the bridge, and the standard resistor being varied until the bridge is balanced. The unknown resistance can then be immediately found by reading off the value on the resistance box. This form of resistance measurement is much quicker in practice than adjusting a Wheatstone bridge, because meters 1502 and 1507 respond much quicker than the usual mirror- or light spot galvanometer.
Capacitors can also be measured on 1502 in exactly the same way, and in cases where the capacitors are small, bridge type 1507 is used. In order to compensate for the leads to the variable condenser and its minimum capacity, the unknown capacitor can be connected via a small extra measuring box, in which there is a balancing capacity. In this way a quick and very exact measuring of small capacitors can be carried out.

Balance of Coupled Variable Condensers and Potentiometers.

For adjustment of coupled variable condensers the set-up shown in Fig. 6 will be practical. The two stators are connected respectively to the upper

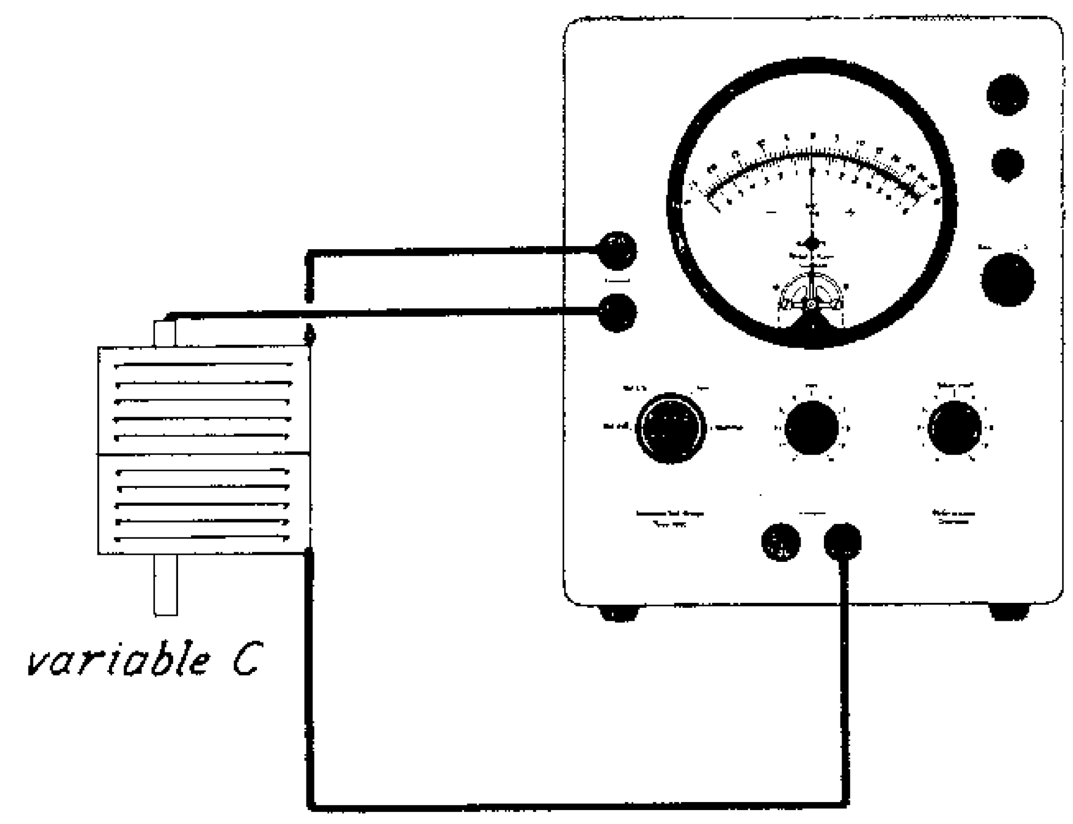


Fig. 6. Matching of variable condensers.

left and lower right terminals of the bridge, while the rotors, which are as a rule connected together, are joined to one of the two remaining terminals. The balance expressed in % deviation may then be checked for all positions of the rotor. A similar set-up can be used with coupled potentiometers and variable resistors.

Checking of Transformers.

The Deviation Test Bridge is also a suitable apparatus for checking transformers for amplifiers, hearing aids, etc. The set-up is shown in fig. 7. The

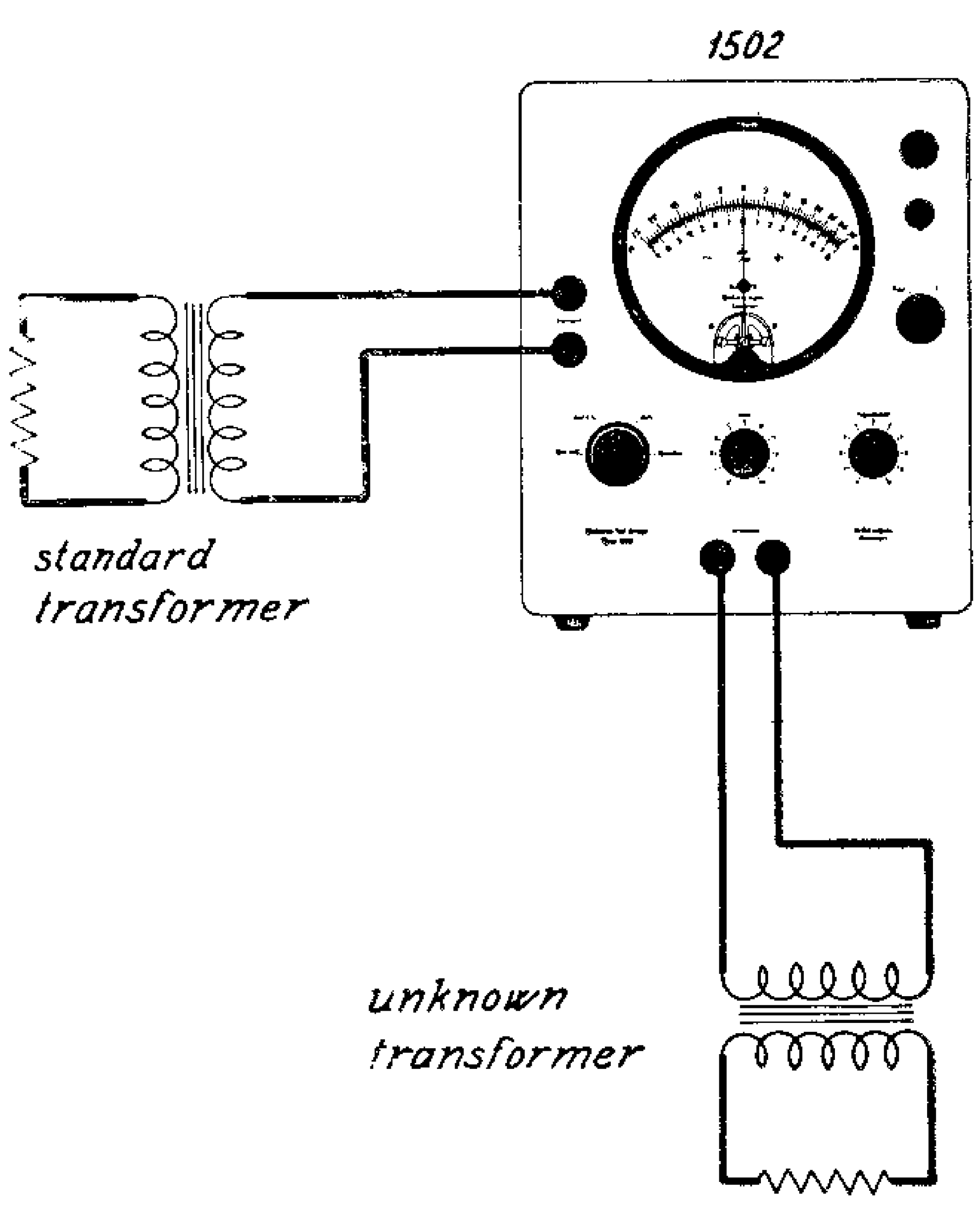


Fig. 7. Production testing of transformers.

transformer with its correct load on the output is connected to the terminals marked "Unknown". A perfect transformer loaded with the same impedance is used as standard, and defects in either coils, turn numbers or laminations may then be observed.

Direct-Reading Measurements of Capacitances.

The Deviation Test Bridge Type 1502 or 1507 may be used as a direct-reading measuring instrument of capacitances. Two equal condensers of

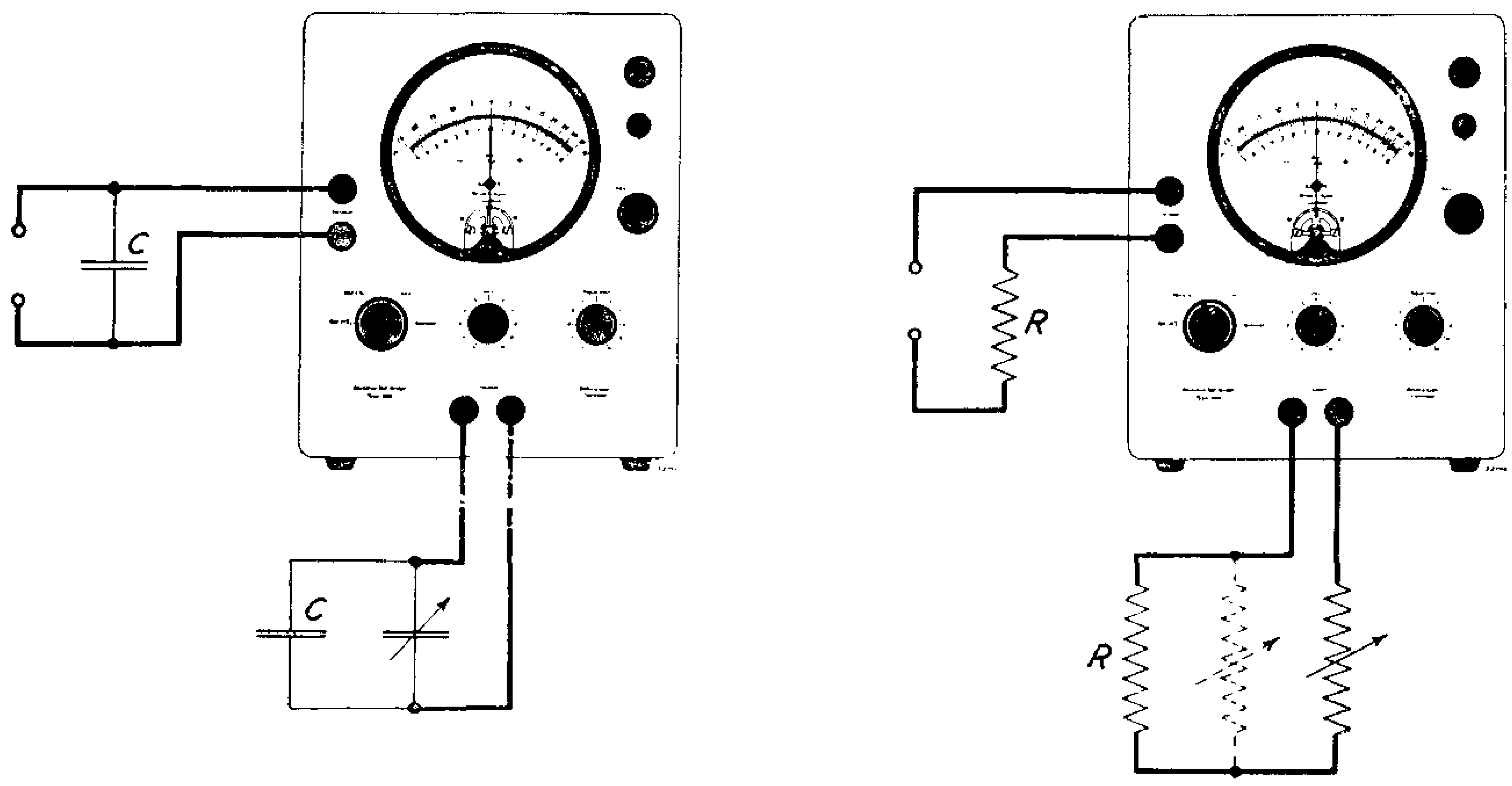


Fig. 8. Direct reading measurements of capacity and resistance values.

exactly known capacitance are, as shown in fig. 8, connected across the "Standard" terminals, one to each terminal. The capacitance to be found is measured as a per cent increase of the fixed known value. By choosing the fixed condensers as pure powers of 10 the direct readings will be simplified. To make the adjustment easier it will be practical to have part of the capacitance on "Standard" placed as a small trimmer condenser.

Fixed Capacitors	Direct Reading Range	Adjustment to Reference %	
		1502	1507
2 × 100 pF	0— 7 pF	5.80	5.42
	0— 33 »	24.1	22.8
2 × 1000 pF	0— 70 »	5	5
	0— 330 »	20	20
2 × 0.01 μF	0— 700 »	5	5
	0— 3300 »	20	20
2 × 0.1 μF	0— 7000 »	5	5
	0—33000 »	20	20
2 × 1 μF	0—0.07 μF	5	
	0—0.33 »	20	
2 × 10 μF	0—0.7 »	5	
	0—3.3 »	20	

The procedure is then as usual: Set zero point and adjustment to reference, then switch to "Operation" and bring the pointer to zero in the middle of the scale by means of the adjustable part of the fixed capacitance. When the fixed condensers are very small the reference adjustment should be done in accordance with the adjustment curves. The following table shows ranges and adjustments to reference for various fixed standards chosen as powers of 10.

Direct-Reading Measurements of Resistances.

In a similar way as for capacitances it is possible to use the Deviation Bridge as a direct-reading ohmmeter. As illustrated in fig. 8 two fixed resistors have to be used analogically to the two capacitances, but the resistance under test has to be connected in series with one of the fixed R. The small adjustable fraction of the other fixed R may be connected either in series or in parallel with R. If series connection is used, the adjustable R need only be a few per cent of the total value of the fixed resistance, while it has to be great compared to the total resistance if connected in parallel.

Fixed Resistance	Direct Reading Range	Adjustment to Reference %	
		1502	1507
2 × 10 Ω	0— 0.7 Ω	5	
	0— 3.3 »	20	
2 × 100 Ω	0— 7 »	5	5
	0— 33 »	20	20
2 × 1 kΩ	0— 70 »	5	5
	0—330 »	20	20
2 × 10 kΩ	0— 0.7 kΩ	5	5
	0— 3.3 »	20	20
2 × 100 kΩ	0— 7 »	5	5
	0— 33 »	20	20
2 × 1 MΩ	0— 70 »	5	
	0—330 »	20	
2 × 10 MΩ	0— 0.7 MΩ	8.02	
	0— 3.3 »	32	

Checking a Tube's Transconductance and Internal Resistance.

For many applications, for example balanced d.c. amplifiers, scaling units for calculating machines and so on, it is important that those tubes which are employed in the construction have definite values with narrow tolerances for both transconductance and internal resistance. Measuring Bridge type 1502 will here give complete satisfaction in the control and choice of suitable tubes.

Fig. 9 shows a typical set-up for measuring a tube's transconductance, the tube being connected respectively as pentode and triode. The indicated resistance values are suitable for tube type 6AU6.

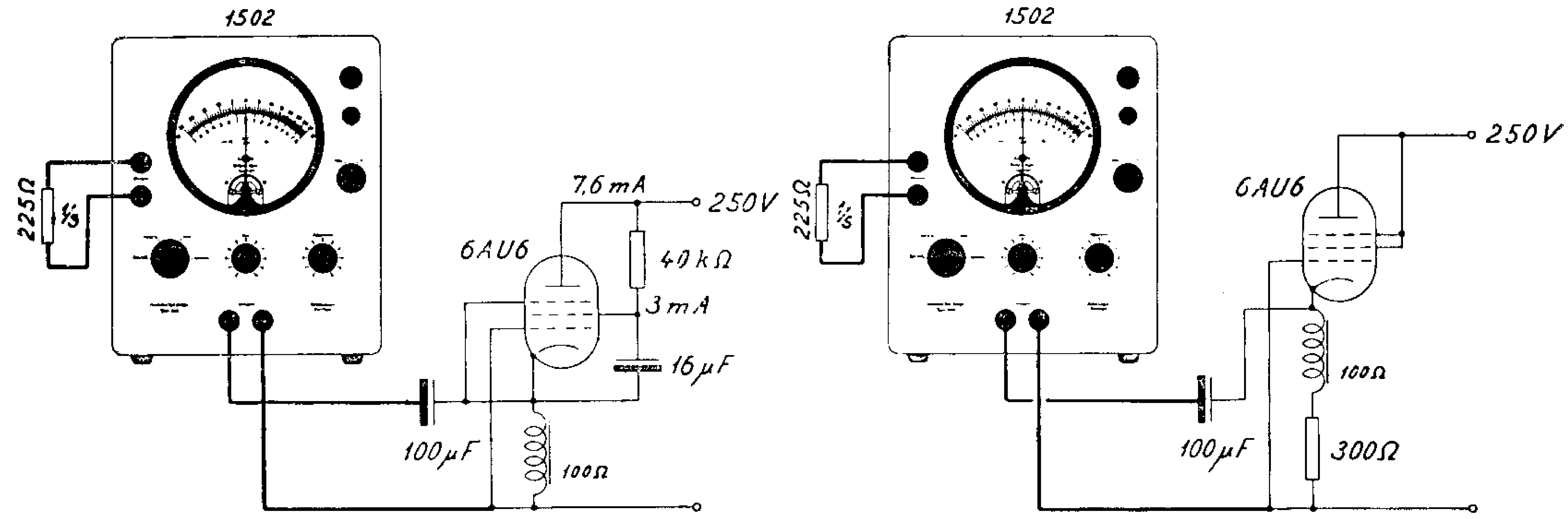


Fig. 9. Measuring transconductance of 6AU6 tube connected respectively as pentode and triode.

If other tube types have to be measured, the components as shown in the diagram must naturally be changed in value to suit. It is important that the choke coil shown in the anode lead of the diagram has an impedance which is great in relation to the tube's reciprocal transconductance at the measuring frequency of 1000 c/s. In the same way, the impedance of the coupling condenser which connects the tube set-up to the bridge (the 100 μF in the diagram) should have a value which is small in relation to the reciprocal transconductance. By choosing the standard resistor as a value of 225 Ω, the bridge pointer will indicate 0 if the 6AU6 tube has the transconductance given in the catalogue.

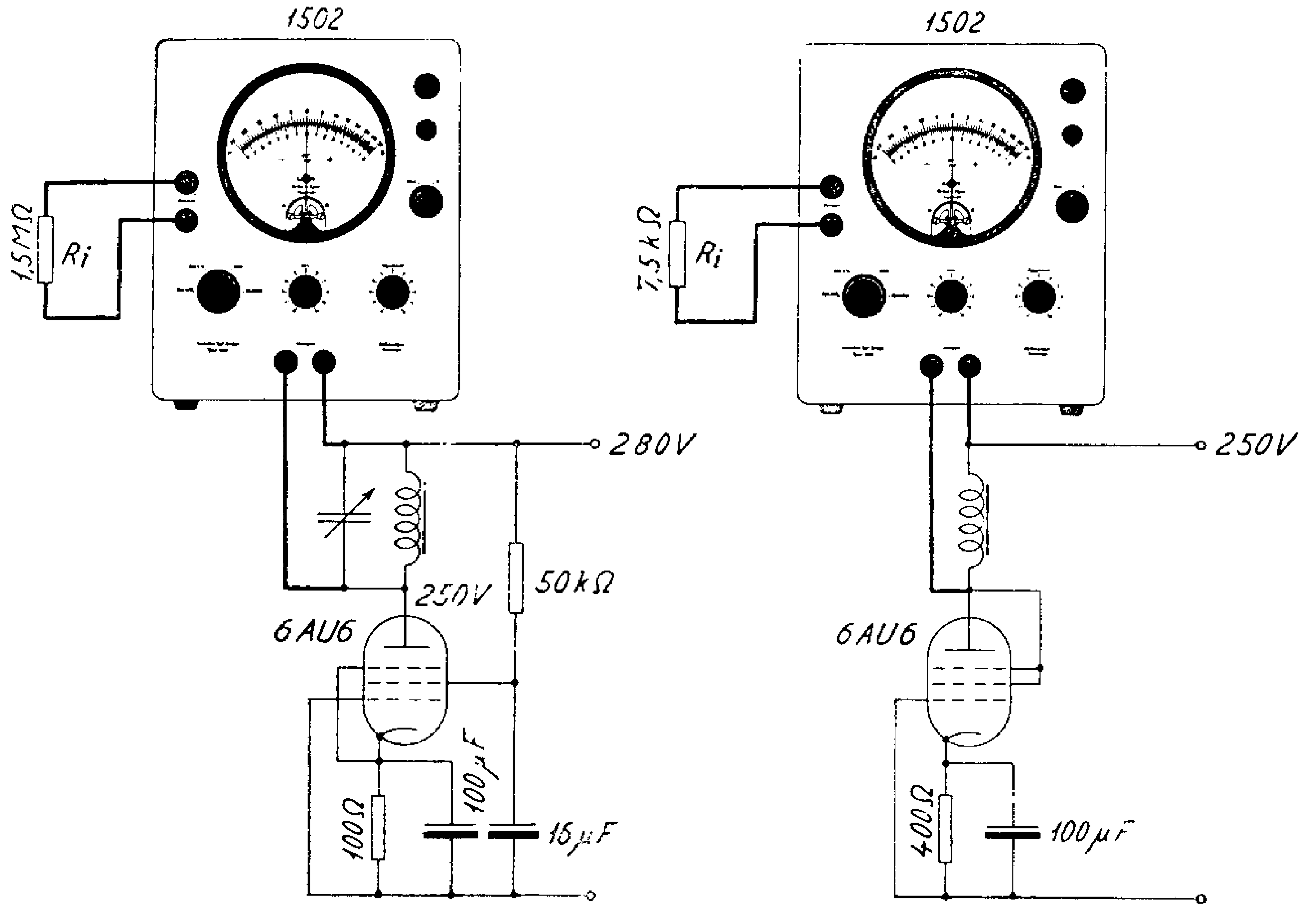


Fig. 10. Measuring internal resistance of 6AU6 tube connected respectively as pentode and triode.

Fig. 10 shows the corresponding set-up for measuring a tube's internal resistance, and here it is important that the impedance in the tube's anode circuit should be much greater than the tube's internal resistance. Therefore, when the tube is connected up as a pentode, it is expedient to produce resonance in the anode impedance. As standard resistance on the bridge

Tube No.	Per Cent Deviation of Transconductance								Per Cent Deviation of Internal Resistance							
	HYTRON	MAZDA A	PHILIPS	RCA	SYLVANIA	TUNGSRAM	MAZDA B	G. E.	HYTRON	MAZDA A	PHILIPS	RCA	SYLVANIA	TUNGSRAM	MAZDA B	G. E.
1.	+10%	+ 8%	+ 4%	÷ 3%	+ 5%	+ 4%	+10%	÷12%	÷14%	÷17%	+ 3%	÷23%	÷25%	÷13%	÷10%	÷ 4%
2.	+ 7%	+11%	+ 7%	+ 3%	+ 2%	÷ 1%	+ 7%	÷ 6%	÷17%	÷ 6%	+10%	÷25%	÷25%	÷ 3%	÷ 9%	÷ 8%
3.	+ 9%	+ 8%	+ 7%	÷ 5%	÷ 1%	0	0	0	÷10%	+ 5%	÷15%	÷25%	÷25%	÷11%	÷ 1%	÷21%
4.	+ 3%	+15%	0	÷ 1%	÷10%	÷ 9%	+11%	+ 8%	÷11%	÷ 1%	÷ 1%	÷25%	÷25%	÷ 9%	÷12%	÷10%
5.	+ 9%	+16%	+ 6%	÷ 3%		+ 4%	+ 8%	÷ 2%	÷10%	÷10%	+15%	÷25%		÷13%	÷ 8%	÷ 5%
6.	+16%	+15%	+ 2%	+ 7%		+ 2%	+ 7%	+ 8%	÷14%	÷11%	+ 9%	÷25%		÷11%	÷ 5%	÷25%
7.	+ 2%	+ 2%	+10%			+ 8%	+15%	+ 1%	÷14%	÷ 4%	+ 1%			÷20%	÷ 7%	÷18%
8.	+13%	+ 8%	÷ 1%			÷ 1%	+ 3%		÷25%	÷17%	0			÷12%	÷ 9%	
9.	+15%	+ 8%	÷ 2%			+ 2%	+10%		÷16%	÷ 2%	+ 5%			÷11%	÷13%	
10.	+14%		÷ 5%			÷ 2%			÷ 9%		+ 5%			÷12%		
Average	+ 9.8%	+10.1%	+ 2.8%	÷ 0 3%	÷ 1%	+ 0.7%	+ 7.9%	÷0.43%	÷ 14%	÷ 7%	+ 3.2%	÷24.7%	÷25%	11.5%	÷ 8.2%	÷13%

TABLE 11

Table 11. Examples of measurement of internal resistance and transconductance of 6AU6 tube connected as pentode.

Tube No.	Per Cent Deviation of Transconductance								Per Cent Deviation of Internal Resistance							
	HYTRON	MAZDA A	PHILIPS	RCA	SYLVANIA	TUNGSRAM	MAZDA B	G. E.	HYTRON	MAZDA A	PHILIPS	RCA	SYLVANIA	TUNGSRAM	MAZDA B	G. E.
1.	+25%	+26%	+19%	+ 8%	+22%	+23%	+23%	+ 4%	÷ 4%	÷ 9%	+ 5%	+17%	+ 8%	÷11%	÷18%	+22%
2.	+20%	+20%	+23%	+18%	+21%	+16%	+24%	+12%	+ 3%	÷ 7%	÷ 6%	÷ 1%	+ 4%	÷ 3%	÷16%	+ 3%
3.	+23%	+25%	+27%	+ 8%	+17%	+19%	+ 8%	+17%	÷ 5%	÷ 9%	÷12%	+20%	+ 4%	÷ 5%	0	÷ 5%
4.	+19%	+26%	+20%	+14%	+ 9%	+15%	+25%	+20%	+ 7%	÷14%	÷ 1%	+ 5%	+15%	÷ 6%	÷15%	÷ 5%
5.	+23%	÷26%	+17%	+ 8%		+27%	+25%	+18%	+ 9%	÷16%	+ 8%	+ 9%		÷10%	÷15%	÷ 5%
6.	+31%	+29%	+18%	+23%		+25%	+22%	+18%	÷ 9%	÷13%	+ 4%	+ 3%		÷13%	÷11%	÷ 4%
7.	+19%	+16%	+22%			+30%	+29%	+21%	+ 7%	÷15%	+ 1%			÷11%	÷13%	0
8.	+26%	+27%	+21%			+21%	+22%		÷ 1%	÷12%	0			÷ 9%	÷ 9%	
9.	+28%	+22%	+13%			+23%	+24%		+ 3%	÷10%	+ 9%			÷ 9%	÷14%	
10.	+19%		+10%			+22%			+ 7%		+14%			÷ 9%		
Average	+23.3%	+18.3%	+19%	+13.2%	+17.2%	+22.1%	+22.4%	+15.7%	+ 1.7%	÷ 10.5%	+ 2.2%	+ 8.8%	+ 7.7%	+ 8.6%	+11.1%	+ 0.8%

TABLE 12

Table 12. Examples of measurements of internal resistance and transconductance of 6AU6 tube connected as triode.

the internal resistance as given in the valve catalogue should be used. Tables 11 and 12 show a list of typical measuring results for tube 6AU6 coupled up respectively as pentode and triode. The tubes used are samples of 7 different manufactures.

Measurement of time constants of integrators.

A factory which made parts for electronic calculating machines was interested in measuring the time constant of integrators. An integrator is simply a series connected resistor and capacitor. The absolute value of the resistor and capacitor making up the integrator is of lesser importance, while it is of great importance to know the product RC with maximum accuracy. The manufacture of integrators was previously carried out by measuring the resistors and capacitors with great accuracy, and thereafter the combination for an integrator was chosen so that the product RC was correct. Thus, though both R and C were measured and then a selection made for the required individual integrator, there was still no final control of the finished article.

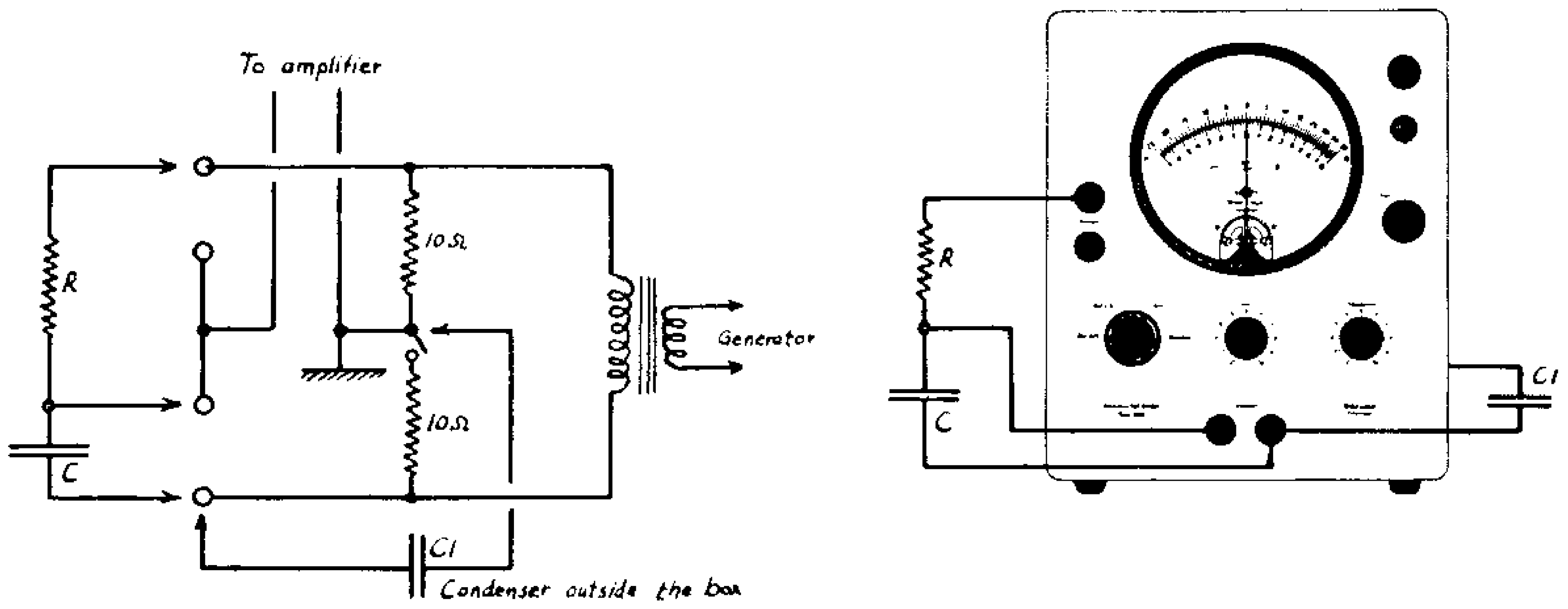


Fig. 13. Testing of integrators.

A Deviation Test Bridge type 1502 was reconstructed as shown in Fig. 13 so that the one built-in 10 Ω balancing resistor was isolated and in its place a large capacitor C1 was connected, placed outside the Deviation Test Bridge. The integrator was connected up as shown, and by varying C1 it was possible to measure a long series of time constants of integrators with a great impedance range.

Special Laboratory Applications.

The Deviation Bridge also finds numerous special applications in laboratories for measuring and controlling physical quantities which are transferable into impedance variations by means of special gauges or pick-ups. Some of the measurements which have been carried out with one of the Bridges are mentioned below.

Measurement	Gauge or Pick-up	Bridge
Mechanical stress in:		
Wood, plastics, etc.	Wire resistance gauge	1502
» » »	Carbon paste on material	1502
all materials	Condenser pick-up	1507
reinforced concrete	Nickel steel permeable pick-up	1502
Force (dynamometer)	Condenser in steel ring	1507
Temperature	Thermistors	1502
Temperature flow	2 thermistors in static balance	1502
Conductance in liquids	Platinum electrodes	1502
» » soils	Standard soil gauge	1502
Small relative movements	Inductive coil pick-up	1507
Liquid levels in tanks	Potentiometer moved by the level	1502
Determination of:		
Extremely small loads	Capacitive micro balance	1507
moisture in cardboards	Capacitive test arrangements	1507
iron in paper, cotton, etc.	Inductive gauge	1507

Automatic Recording of Frequency Irregularity in Rooms

SUMMARY

To save the tedious job to calculate the F.I. (expressed in db/c/s) from a room response curve, two different methods for obtaining direct recording of the F.I. as a function of frequency are developed.
The room response is recorded via a microphone, amplifier and level recorder. On the recorder is fixed a contact strip with 100 silver lamellae which via an electronic scaler registers the total "length" of the room response curve in db. The other method uses the output voltage from the moving coil in the level recorder. This voltage is proportional to the F.I. in db/c/s and recorded on a second level recorder with extremely low recording speed.
The two sets of apparatus have been used for measuring the diffusion effect of three different types of diffusers in a small model room.

This paper was given by Dr. Per V. Brüel at the International Electro-Acoustics Congress in the Netherlands 1953.

Formerly, a room's acoustic goodness was judged by its so-called reverberation time, i.e., the time taken for the sound to die away in the room, depending on both the room's volume and the sound's frequency. Apart from that, geometric analyses of the sound paths in concert halls and radio studios have been made, so that consideration could be given to the uniform distribution of the sound throughout the auditorium when the room's shape was being decided upon. However, the last ten years have shown, that an examination of a room's reverberation time is not always sufficient; thus, for example, some radio studios with approximately the same size and reverberation time have in practice shown themselves to be widely different acoustically.
Attempts have therefore been made in recent years (see refs. 1, 2 and 3) to find a measuring unit apart from volume and reverberation time which would characterize a room's acoustics. Particular attention has been paid to the sound field's homogeneity, and to this end Bolt and Roop have defined a measuring unit, the so-called "Frequency Irregularity" (FI). To estimate a room's FI, a loudspeaker with a good frequency response, and connected to a B. F. Oscillator, is placed at one end of the room, and a pressure microphone, connected to a level recorder via an amplifier, at the other end.
The B. F. O. is mechanically coupled to the level recorder, so that the record-

1. *Bolt and Roop, J. A. S. A., vol. 22/1950, p. 280.*
2. *Sommerville & Ward, Acustica, vol. 1/1951, p. 40.*
3. *Furrer & Lauber, Acustica, vol. 2/1952, p. 251.*

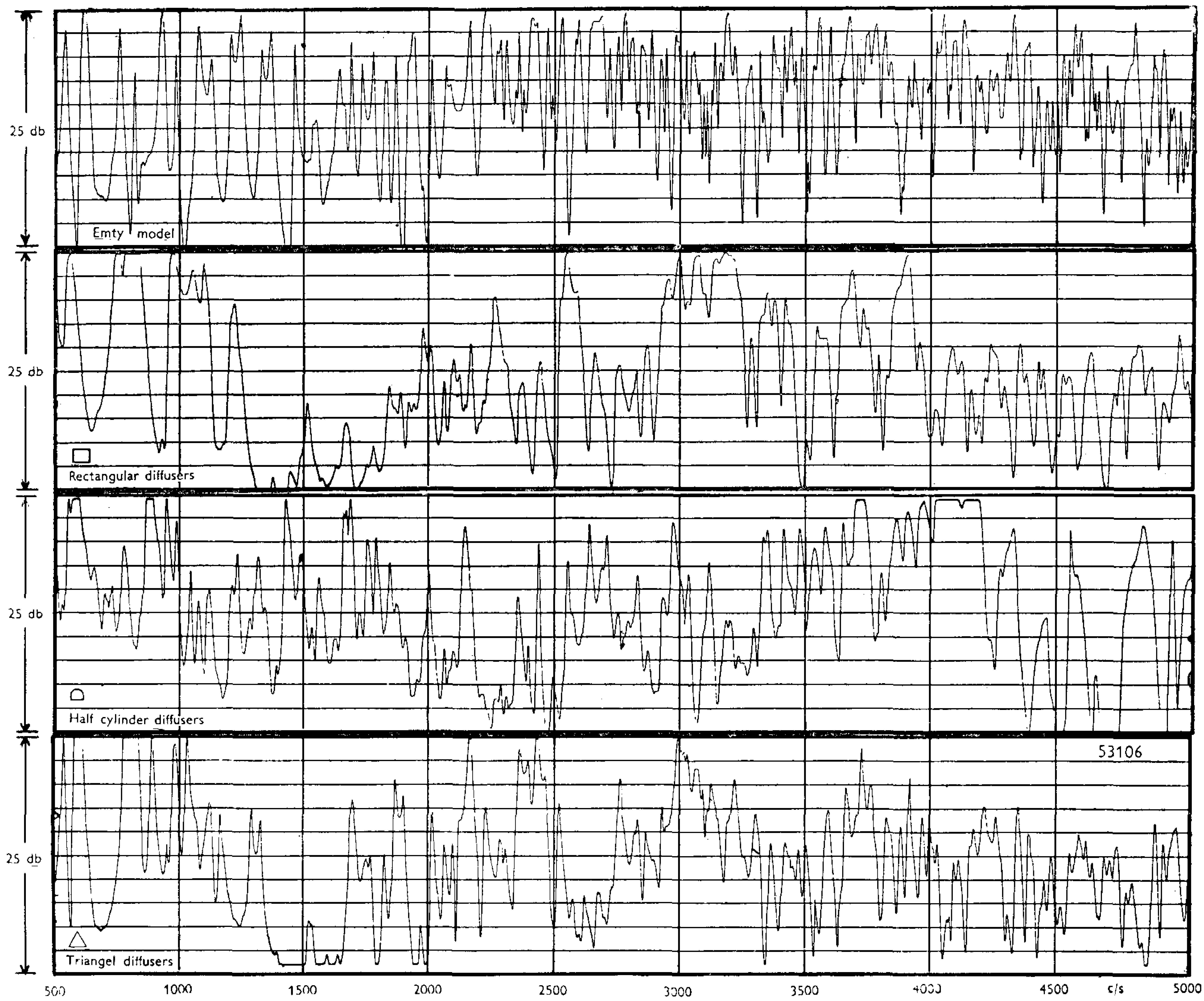


Fig. 1. Frequency Response Curve in a model room, with different diffusers. Above: empty room without diffusers. Below: with diffusers of rectangular, semi-circular and triangular cross section.

ing paper moves synchronously with the frequency variation, and the frequency scale is made linear by using a circular cut in the B. F. O.'s main condenser plates.

The room's frequency response is recorded with a very slow frequency variation of about 1—5 c/s. A typical set of such curves is reproduced in fig. 1. Bolt and Roop define the FI as the total of the differences in db between all the maximum and minimum points of the response curve, divided by the frequency band in question. The unit of FI is therefore db/c/s. The figure for smaller solo studios is about 1—3 db/c/s, and for studios with bad acoustics, 5—10 db/c/s. The value varies with frequency, so the FI has to be given as a curve, as a function of frequency.

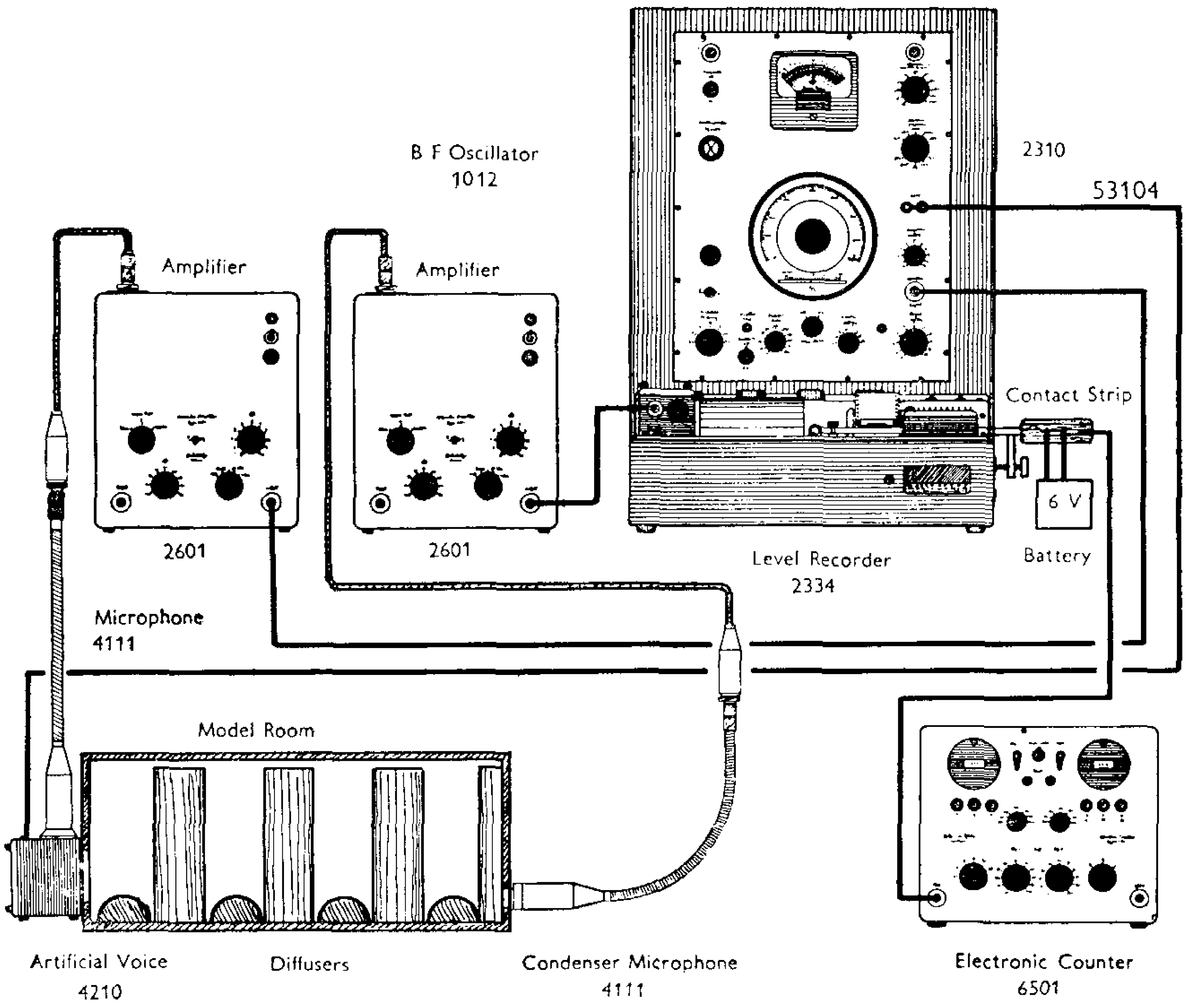


Fig. 2. Measuring set-up with electronic counter and special sound source for the semi-automatic estimation of "Frequency Irregularities".

To record the frequency response of a room is an easy procedure, but to calculate from that curve the FI as a function of frequency is a big job. This paper describes a procedure for automatically recording the FI either of two different methods. The first set-up is shown in fig. 2.
As test room, a small model of a radio studio is used, provided with different

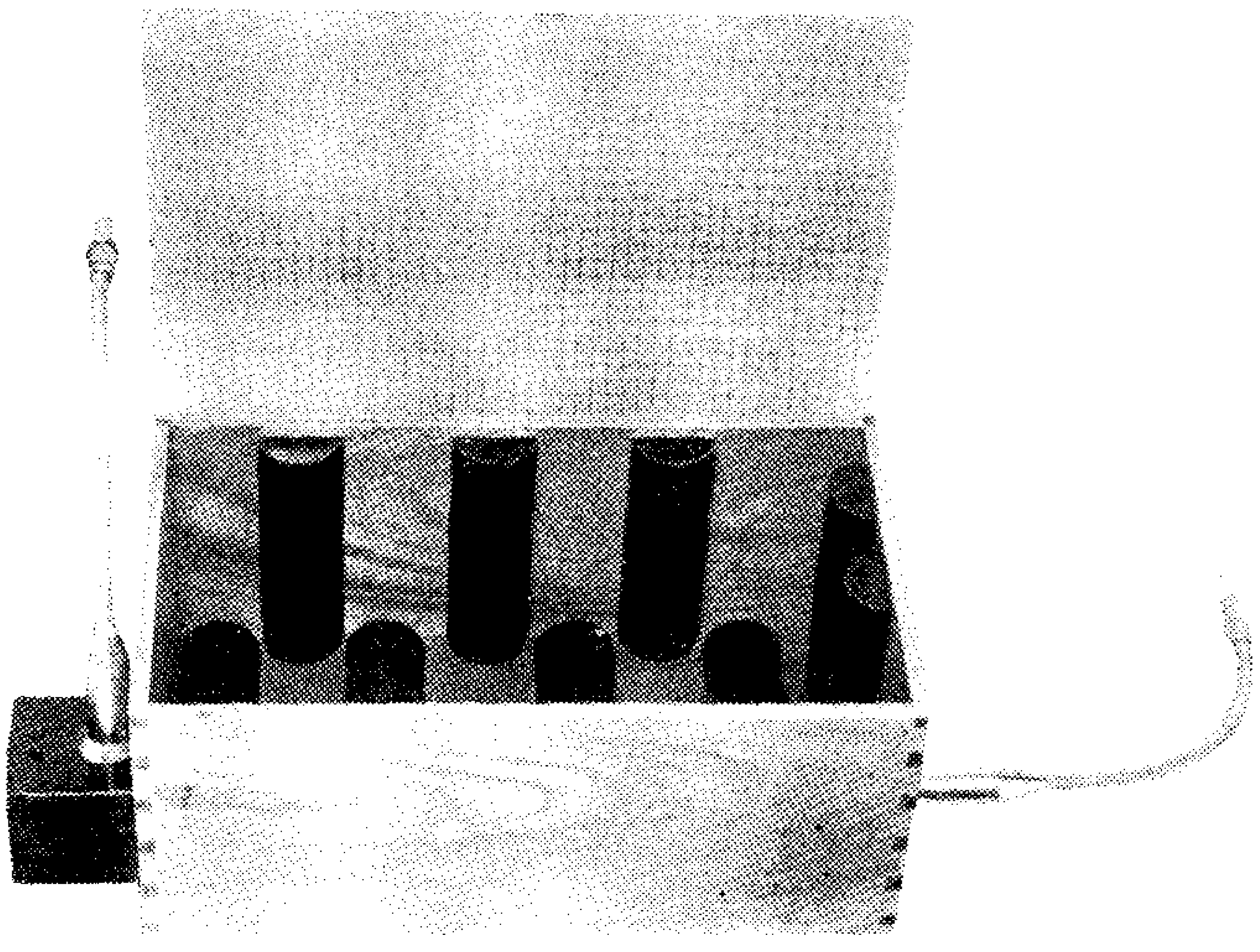
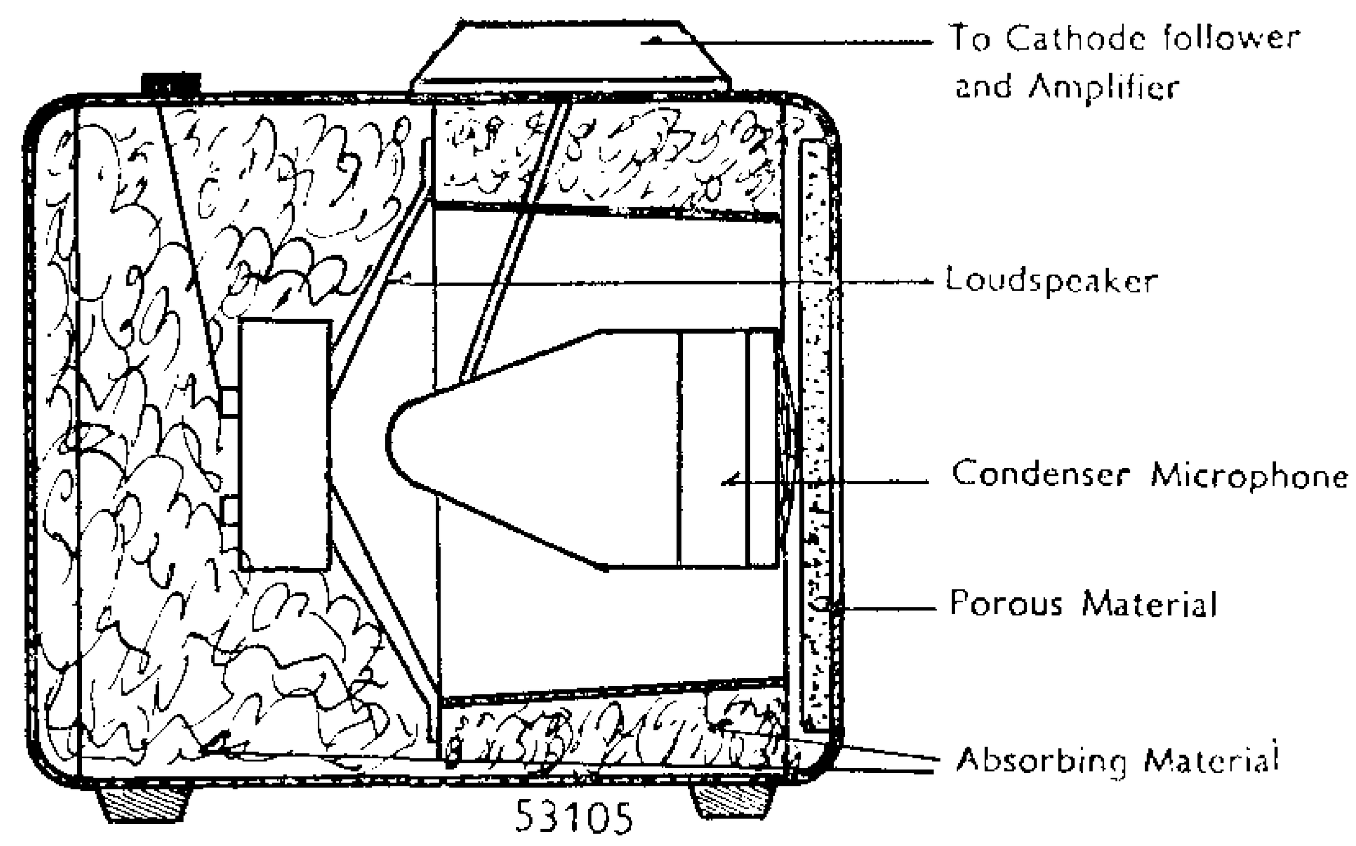


Fig. 3. Photograph of model room and the three types of diffusers used.



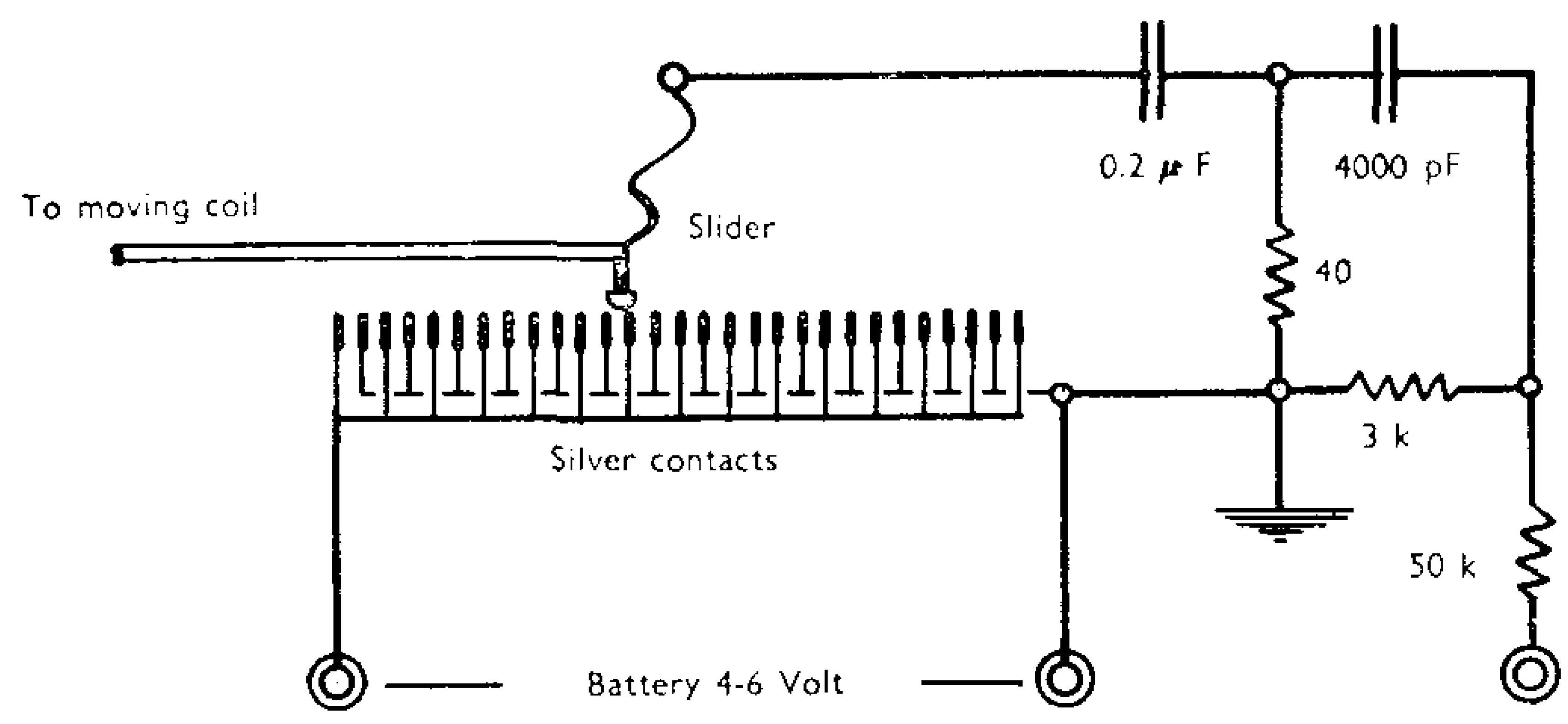


Fig. 4. Cross-section of sound source with flat frequency characteristic and high internal acoustic impedance. Below: principle of the contact arrangement for counting the total length of the frequency curve.

types of diffusers. (Fig. 3.) The normal B. F. O. type 1012 is converted to give a linear frequency scale in the range 500—5000 c/s.

As sound source we use an Artificial Voice consisting of a highly damped loudspeaker and regulating microphone which, via a microphone amplifier and the B. F. O.'s compressor, regulates the loudspeaker sound pressure to a constant value. A thick layer of porous material is placed between the Artificial Voice and the room. This material has a high and purely resistive acoustical impedance, so that, as long as the sound pressure is absolutely constant on one side of the porous layer, the sound emission on the other side will be constant. Owing to the acoustical impedance, a variation of the sound pressure on the room side of the layer will not have any influence on the regulating microphone. In other words, the room response being recorded will be unaffected by irregularities in the sound source characteristic. Fig. 4 shows a cross section of the Artificial Voice provided with the porous material.

At the other end of the model room is placed a condenser microphone connected to a level recorder via an amplifier. The room response is thus recorded as a function of the frequency. The level recorder and B. F. O. are mechanic-

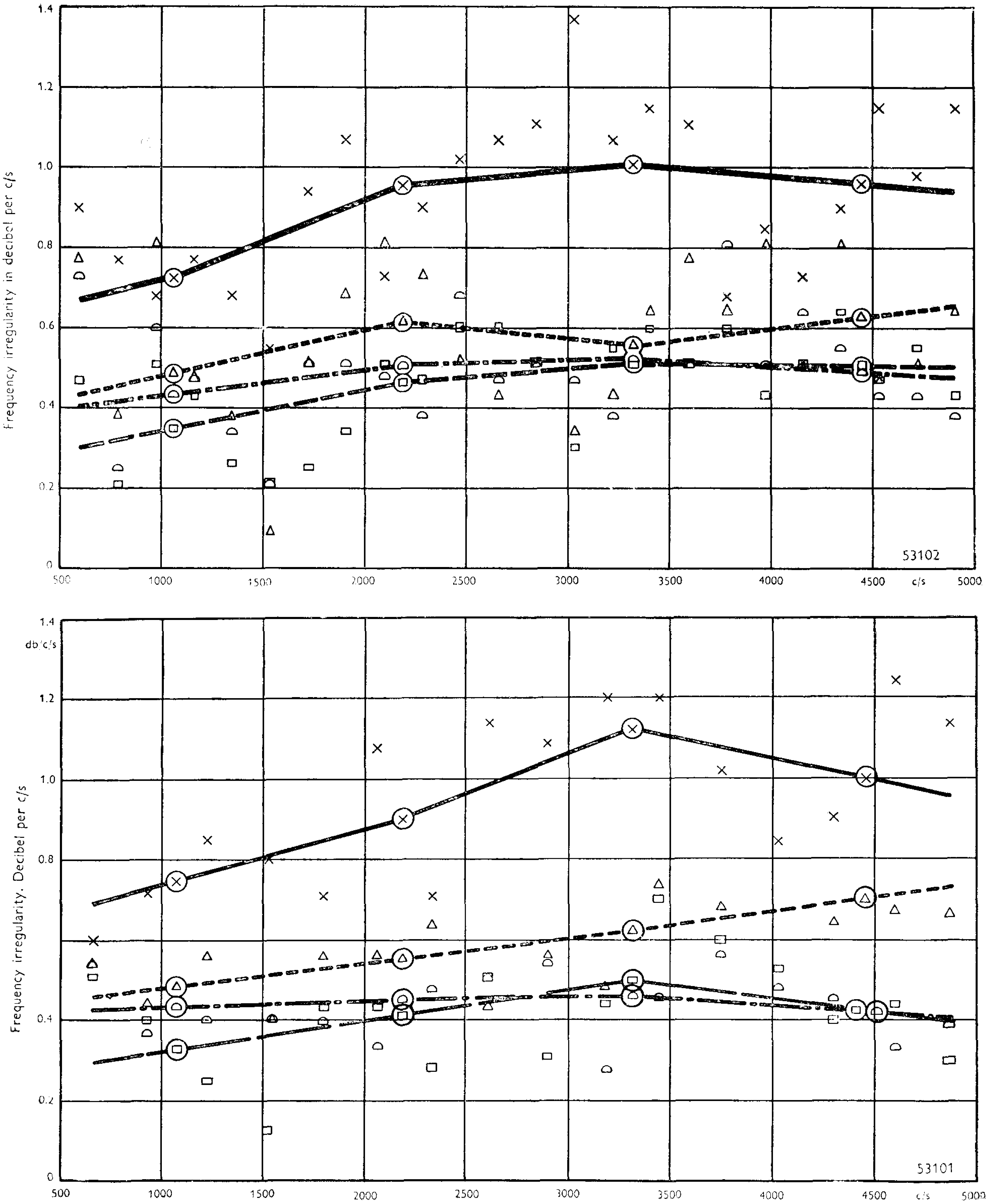


Fig. 5. Measuring results in model room with three different types of diffusers. Curves taken with two positions of the diffusers.
Continuous curve: the empty room.
Dotted curve: triangular diffusers.
Dot and dashed curve: semi-circular diffusers.
Dashed curve: rectangular diffusers.

ally connected by means of a chain drive. The curves shown in fig. 1 are recorded directly from the model with this set-up.

A small contact strip is mounted on the right-hand side of the recorder, and the recorder's slider is coupled to the slider on this contact strip. Each time the latter slider moves one contact, an electrical impulse is obtained which is registered on an electronic counter. In other words, this set-up allows the recording of the total length of movement of the recorder stylus. The B. F. O. sweep is linear in time, so that if the electronic counter is read at regular periods, say 10 secs. or ½ minute, that is, at constant known frequency intervals, the FI in db/c/s can be immediately obtained.

Fig. 5 shows the results from the model room using three different kinds of diffusers. The two sets of curves are for different positions of the diffusers. The points marked with circles are mean values over a wider frequency interval. It is seen that points calculated for small frequency intervals fluctuate very much, so that better results are obtained by calculating the FI over wider intervals. As seen from the curves, the empty room has of course the highest FI. In the low frequency range the best diffusers are rectangular in cross section, and the worst, triangular. At high frequencies, the rectangular are not as good as the semi-circular, but are still better than the triangular. It should be noted that the "Frequency Irregularities" have much lower values measured in a model room than they would have in a full sized studio. The reason is that the reverberation time in a model room is much shorter than in the studio, as the ratio of surface to volume is much greater in the model room. This means that the "goodness" of the natural oscillations will be less in the model room, the peaks and valleys will be less pronounced, and as a result a lower value of FI will be obtained.

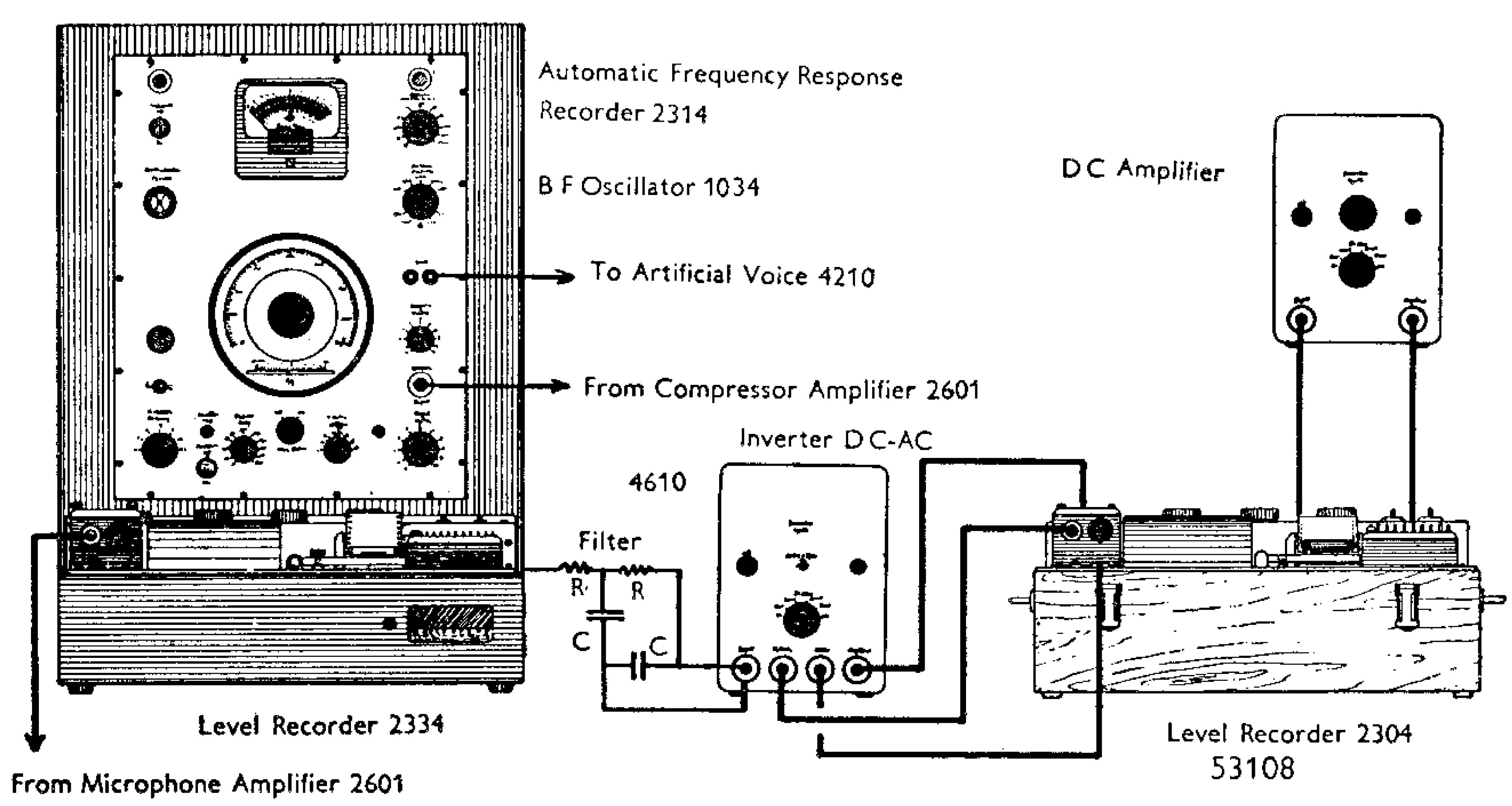


Fig. 6. Principle of the fully automatic set-up for measuring "Frequency Irregularities".

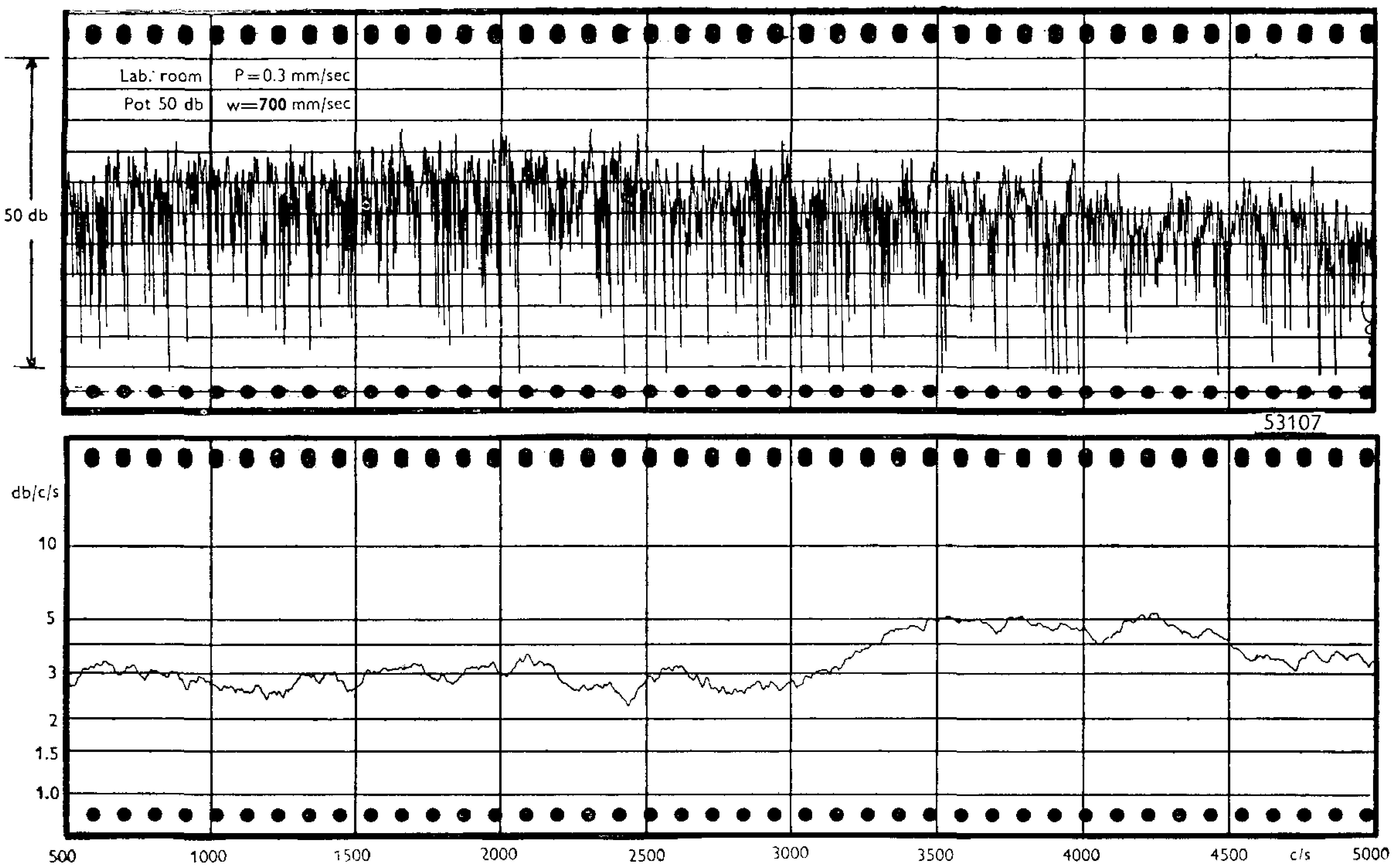


Fig. 7. Frequency Response Curve and curve of "Frequency Irregularities" for a laboratory, recorded with the set-up of fig. 6.

The above method considerably reduces the work of calculation involved in estimating the FI, but it is actually possible to achieve a completely automatic recording of the FI as a function of frequency.

Fig. 6 shows the measuring set-up. The sound source, microphone and microphone amplifier are just as in fig. 2. With this fully automatic method, the feed-back voltage from the driving coil in the recorder is led through a filter, to eliminate possible hum, and then fed to a DC-AC inverter, which converts the slowly varying voltage from the feed-back into 400 c/s a. c., which can then be recorded on another level recorder.

The voltage produced by the feed-back winding in the level recorder's driving coil system is proportional to the speed, and therefore, with a constant rate of frequency variation, proportional to the FI expressed directly in db/c/s.

However, as is clearly indicated in the curves of fig. 5, we are not interested in the instantaneous values of the FI, but on the contrary wish to have them integrated over a relatively broad frequency band. Therefore, in the second level recorder a D. C. amplifier is inserted in its feed-back circuit, whereby the recording speed can be reduced to 1.5 mm/sec., which is quite satisfactory for most room acoustic measurements of FI.

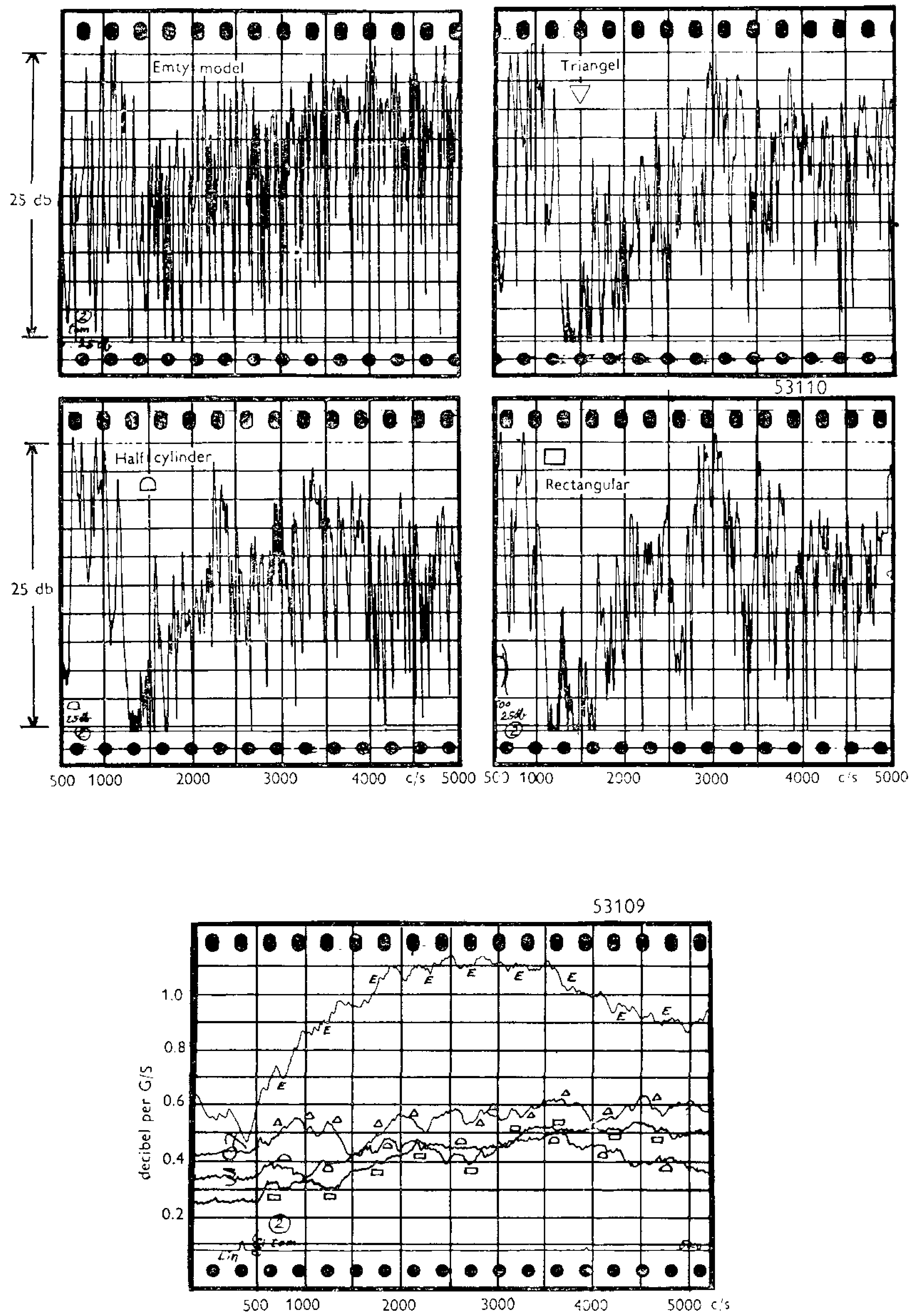


Fig. 8. Frequency Response Curves and "Frequency Irregularities" curves taken in the model room, respectively empty and with the three different diffusers. The "Frequency Irregularities" are recorded below on the same curve paper.

The whole apparatus is adjusted by giving the first level recorder a uniform change of level, for example by means of a B. F. O. with a logarithmic scale shifting frequency quite slowly, and with a small condenser in series with the level recorder's potentiometer. The voltage will then vary logarithmically, that is, will give a linear db scale as a function of time. On the second level recorder a horizontal line should then be recorded. By comparing the slope

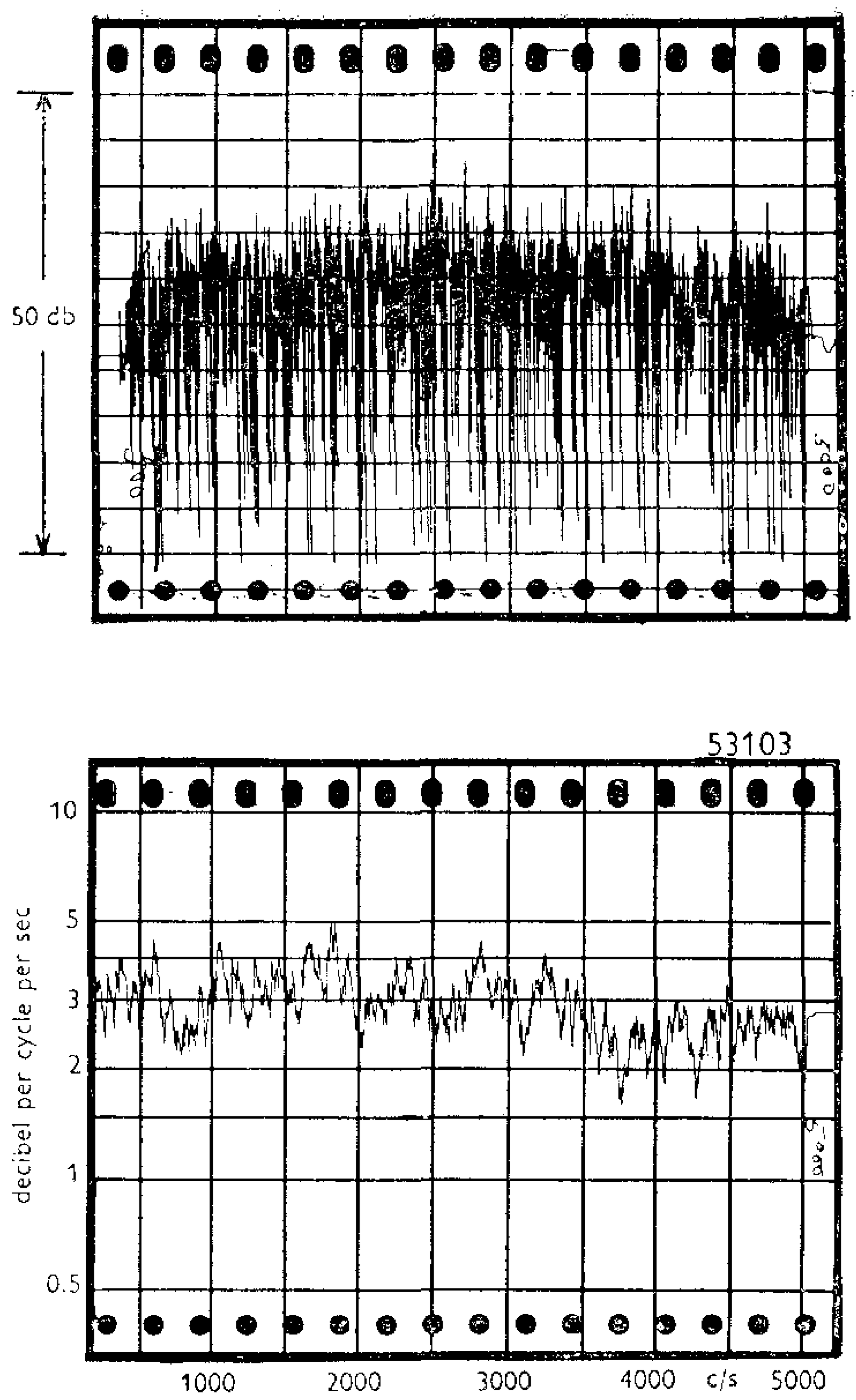


Fig. 9. Frequency Response Curve and "Frequency Irregularities" curve taken in an ordinary sitting room. The total recording period was 40 minutes.

of the line on the first recorder with the horizontal line on the second, the whole system can be adjusted.

Fig. 7 shows a typical result from an acoustically relatively good room. The frequency range from 500—5000 c/s is traversed in about 20 minutes.

Fig. 8 shows the automatic recording in the small model room with the three types of diffusers. On the whole, the results agree with those taken by means of the electronic counting method.

DISCUSSION.

After this paper was given, Professor Dr. R. Bolt gave a short summary of a theory published in J.A.S.A., vol. 22, p. 280: Bolt and Roop "Frequency Response Fluctuations in Rooms". Dr. Bolt showed the results in form of the curves in fig. 10. In order to eliminate the influence of the size and absorption of the room there has been chosen dimension-less parameters for frequency and damping. The ordinate is a quantity nearly proportional to the FI and the abscissa is mostly depending on the frequency. It will be seen that there is a maximum around 0.2 and that this maximum is higher and more pronounced the less diffusing surfaces there are in the room. Below the "frequency" 0,04 and above the "frequency" 0.8 the FI decrease rapidly. In other words it is only of interest to measure the FI within this band.
At lower frequencies the number of normal modes of vibration is so small that the possibility for interference is only slight and consequently the FI is small. As the number of modes of vibration does not change much one can not below this frequency limit expect any improvement of the room's acoustical quality by building in various diffusers. Above the indicated high frequency limit a big number of modes of vibration will be found in the room and the sound pressure variation will therefore be small owing to the statistical levelling.
In practice it is of special interest to find the frequency where the FI have their maximum. That is where the unit of abscissa

$$\mu\sqrt{K\varepsilon} = 0.15 \text{ to } 0.25$$

For judging the quality of a room the FI should be measured in this frequency range.

$$\mu = \frac{f\sqrt[3]{V}}{c} \quad \text{where } f = \text{frequency}$$

V = room volume

c = sound velocity

$$K = \frac{k\sqrt[3]{V}}{2\pi c}, \text{ where the damping constant } k = \frac{c\sum S\alpha}{8\,V}$$

$\sum S\alpha$ is the total absorption in the room which can be obtained by measuring the reverberation time T and inserting in Sabine's reverberation formula.

ε is a factor depending on the position of the microphone and loudspeaker in the room. When both M and L are placed in a wall, $\varepsilon = 1$; when both M and L are at least ¼ wavelength from the walls, $\varepsilon = 1/8$; and when either L or M is placed in the wall and the other is free, $\varepsilon = \frac{1}{\sqrt{8}}$

Dr. Bolt tried the theory on the results given in fig. 5 where the FI maximum is approximately at 3000 c/s. The particulars of the model room are as follow: $V = 0.57 \cdot 0.32 \cdot 0.23 = 42 \cdot 10^{-3}\ m^3$, $T = 0.15$ sec; therefore $\sum S\alpha = 45 \cdot 10^{-3}\ m^2$, $k = 45\ sec^{-1}$ and $\sqrt[3]{V} = 0.348$ m, which give $\sqrt{K} = 8.5 \cdot 10^{-2}$ and $\mu = 3.07$.

In the model room the loudspeaker is placed freely and the microphone in the wall so that $\sqrt{\varepsilon} = 0.6$.
The maximum from fig. 5 then has the dimension-less frequency $\mu \sqrt{K \varepsilon} = 0.16$, and is with this value in accordance with Bolt and Roop's theory.

An extension of the concept of Frequency Irregularity was proposed by Professor Dr. W. Furrer. (3) The definition of Bolt and Roop does not count for the difference between curves with a few considerable fluctuations and those with a greater number of small fluctuations in the same frequency range. Dividing however the FI by the number of "peaks and valleys" in the frequency interval under consideration, gives according to Furrer a more appropriate quantity for indicating the homogeneity of the sound field. In this way the definition of "diffusion" becomes $D = \frac{FI}{n}$

For the measurement of this quantity the device as sketched in fig. 4 was given the following slight modification, as shown in fig. 11. On the slider running over the lamaellae of the contact strip, a slipping contact C is mounted, which is only able to move between the fixed contacts A and B on very small distance from each other, and slips through with continuous movement of the slider in any direction. The turning points of the slider, that means of the frequency response curve as well, will thus be registered as impulses on a second electronic counter. Taking Electronic Counter 6501 for this (using both channels), both the total length of the frequency curves and the number of "peaks and valleys" can easily be read off, the quotient of which gives D.

This Frequency Irregularity Computor is now manufactured as type 4430.

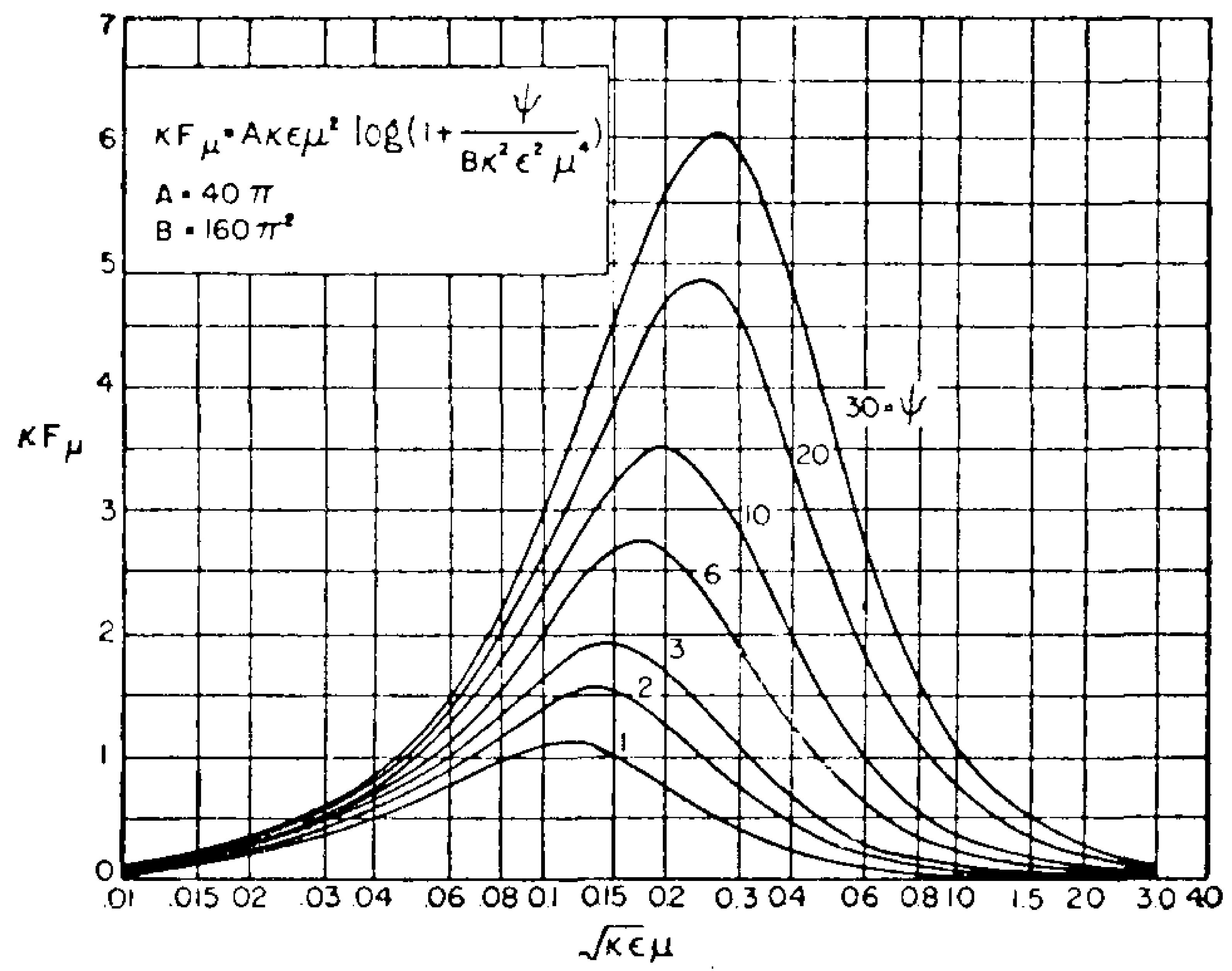


Fig. 10. Generalized plot of frequency irregularity functions from approximate theory from Bolt and Roop.

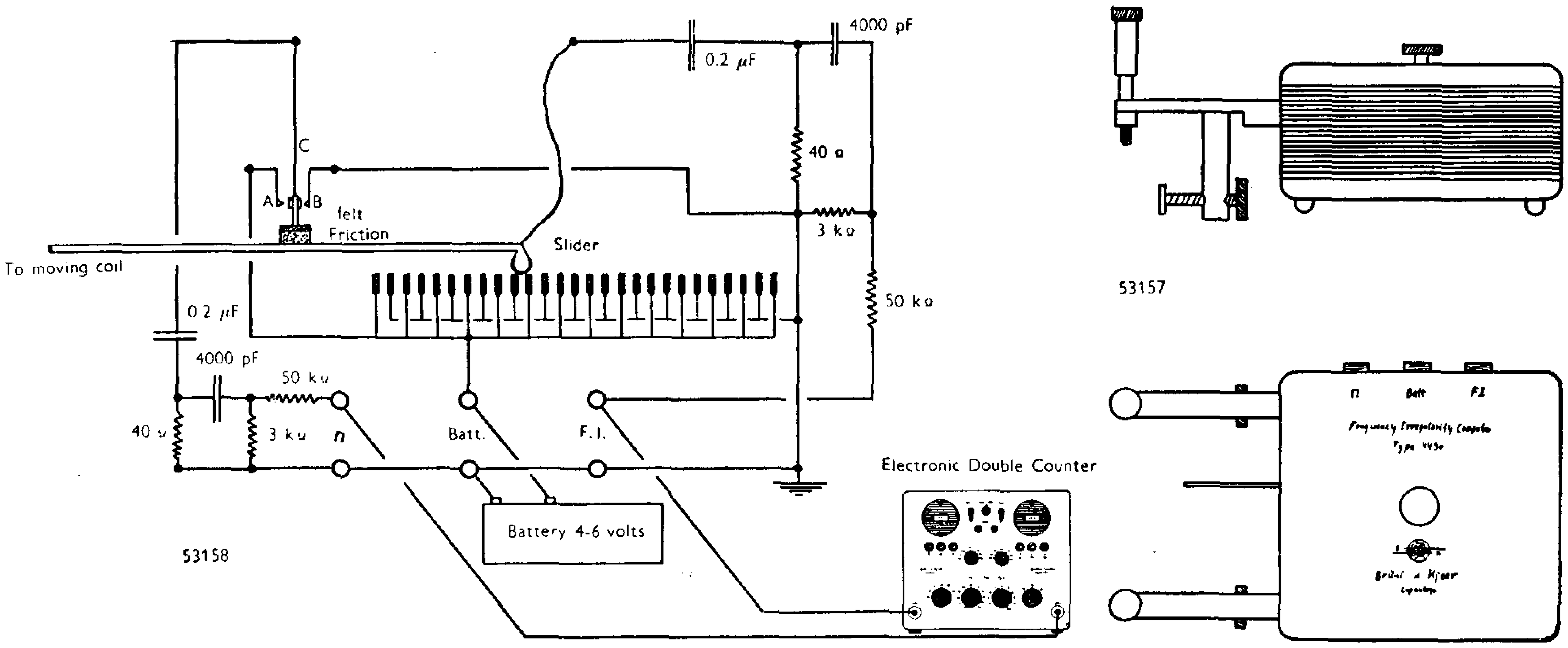


Fig. 11. Sketch of Frequency Irregularity Computor type 4430.

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