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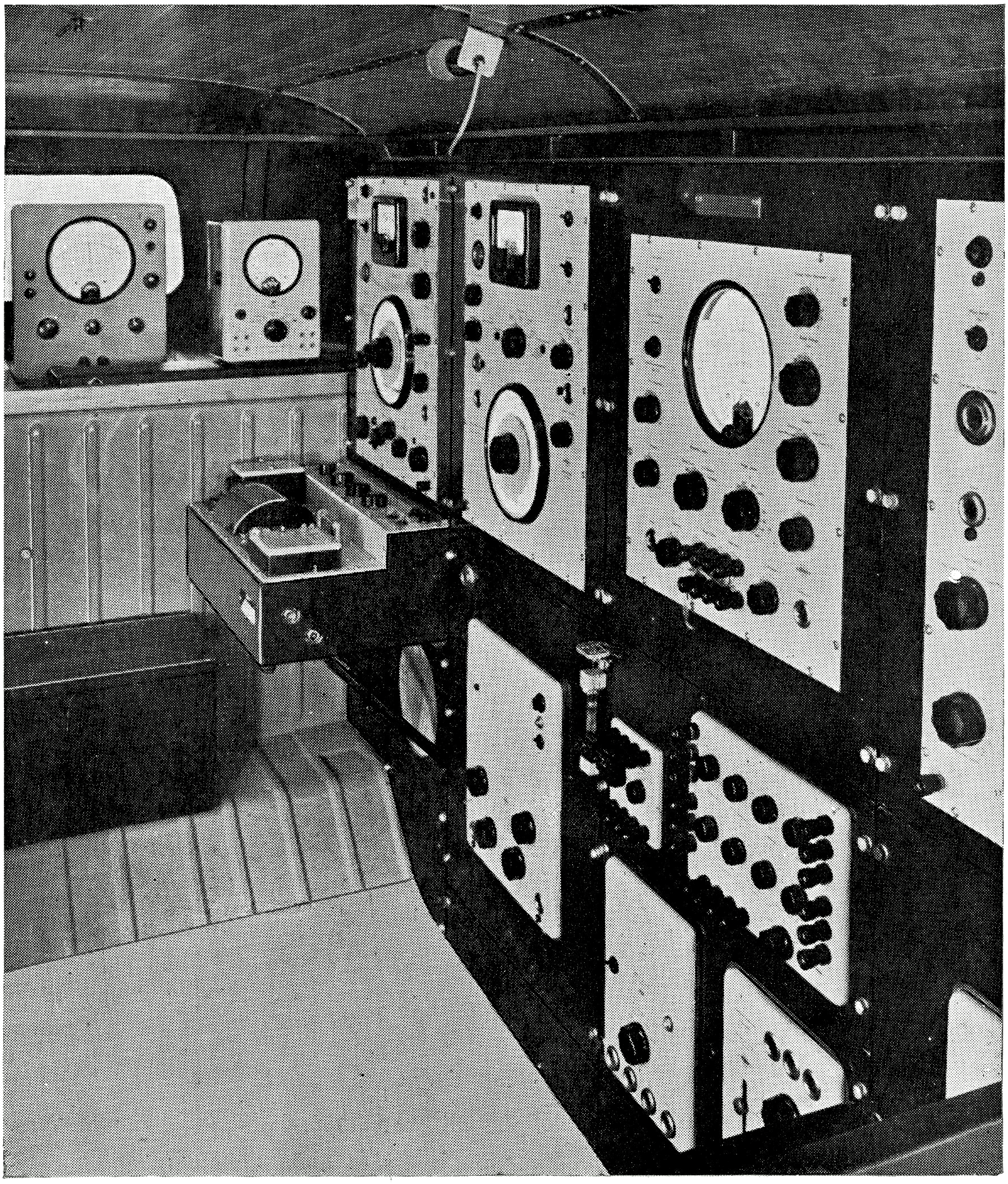
Technical Review

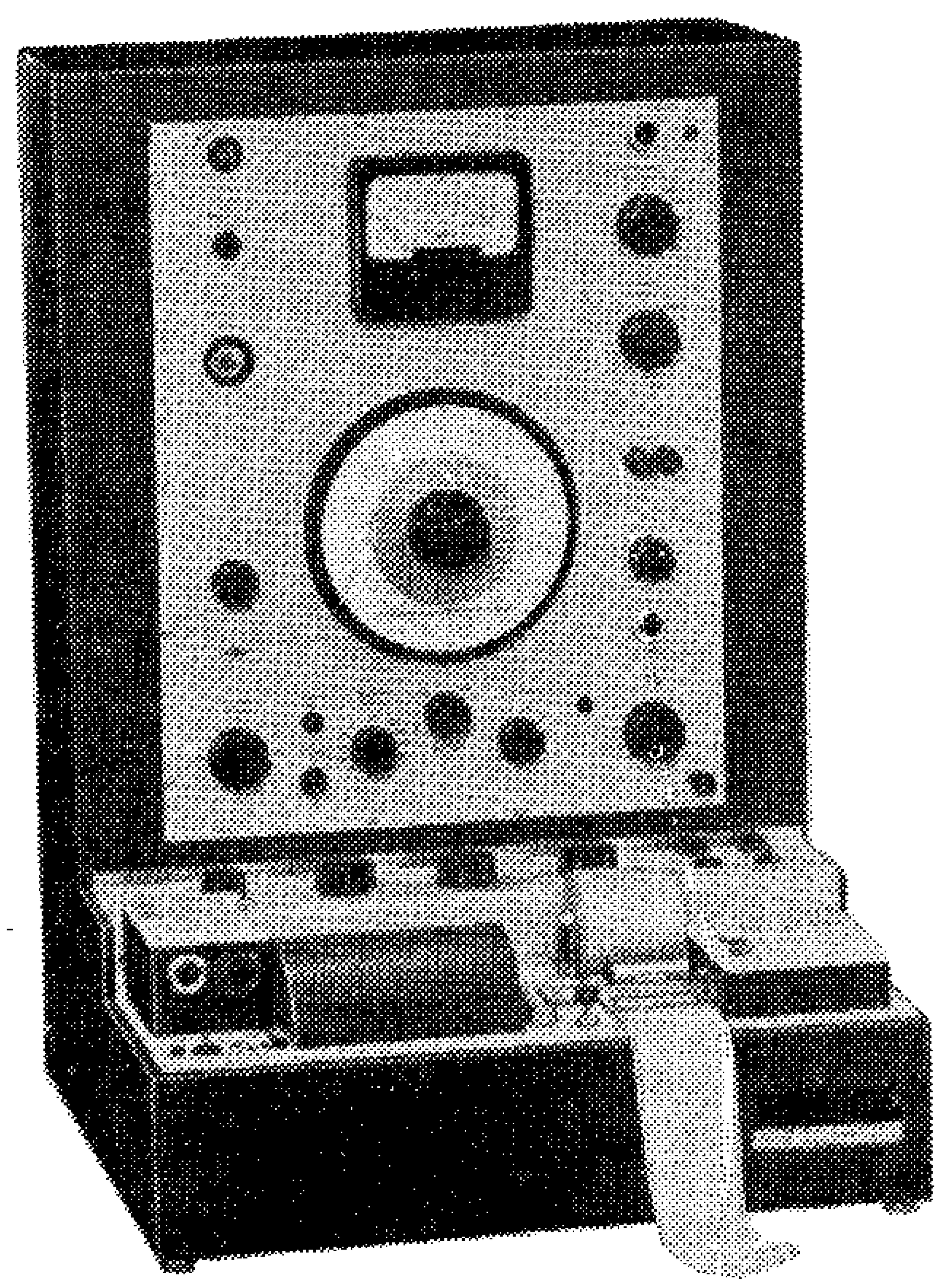
Teletechnical, Acoustical and Vibrational Research



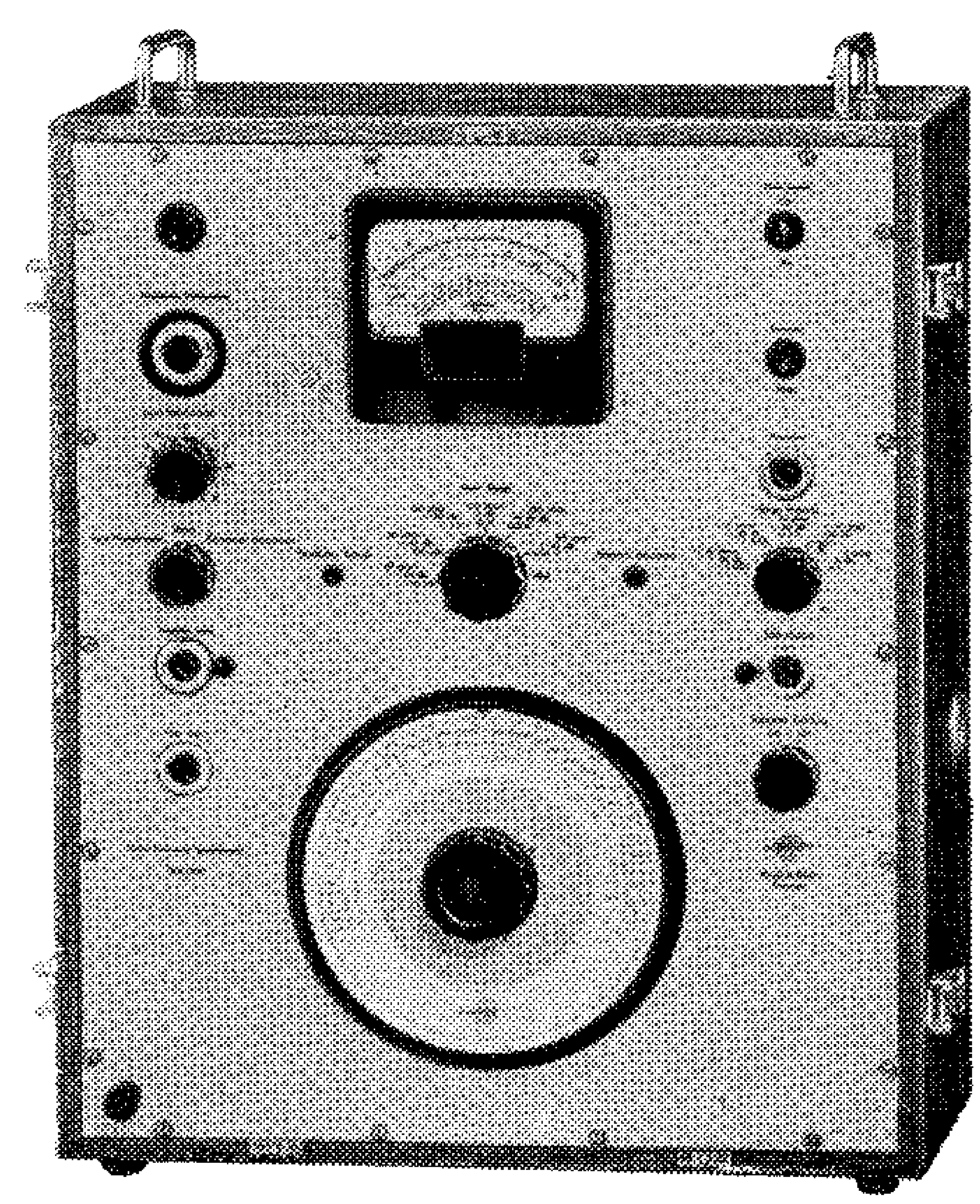
No. 2 April 1954

Our cover: The photo shows the arrangement in our mobile measuring laboratory, of which we will be giving details in a future number

In the center can be seen an Automatic Frequency Response Recorder type 2314, and an Audio Frequency Spectrometer type 2109, both necessary for the measurements described in this number. The same instruments, not rack-mounted are shown below.



2314



2109

Photographs of an Automatic Frequency Response Recorder type 2314 and a Spectrometer type 2109.

Reprint MAY 1959

The Automatic Analysis of Distortion in Sound Reproducing Equipment

by

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and

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SUMMARY

First, we discuss the kind of information which must be obtained so as to judge fully a sound reproducer's tecnical characteristics. Secondly, a review is made of the pros and cons of the two analyzer principles which can be applied to the measument of distortion in sound reproducing equipment where frequency modulation arises. Next, we describe a new semi-automatic measuring method where both the frequency characteristics and the different harmonics in relation to the fundamental can be recorded on one and the same piece of recording paper. Finally, we show how the same apparatus is used for estimating »wow« in sound reproducers.

The quality of a sound reproducing equipment such as a tape or wire recorder, grammophone, dictation machine, sound film equipment and so on, is mainly decided by three different factors:

1. **The linear distortion,** on which depends the ability of the apparatus to reproduce different frequencies in their correct relative amplitudes.

2. **The non-linear distortion,** the characteristic of which is that the apparatus produces other frequencies than those present in the original recorded sound. If, for example, the recorded frequency is f, most reproducing equipments will, besides frequency f, also generate frequencies 2f, 3f, 4f, etc., all with certain small amplitudes. The extent of the overtones supplied by the apparatus itself is strongly dependent on both the fundamental frequency and its amplitude, so that in order to supply a complete characteristic of an apparatus, it is necessary to give the different overtones as functions of the fundamental, with amplitude as parameter.

Fig. 1. Necessary data to determine a sound reproducers quality, consisting of:

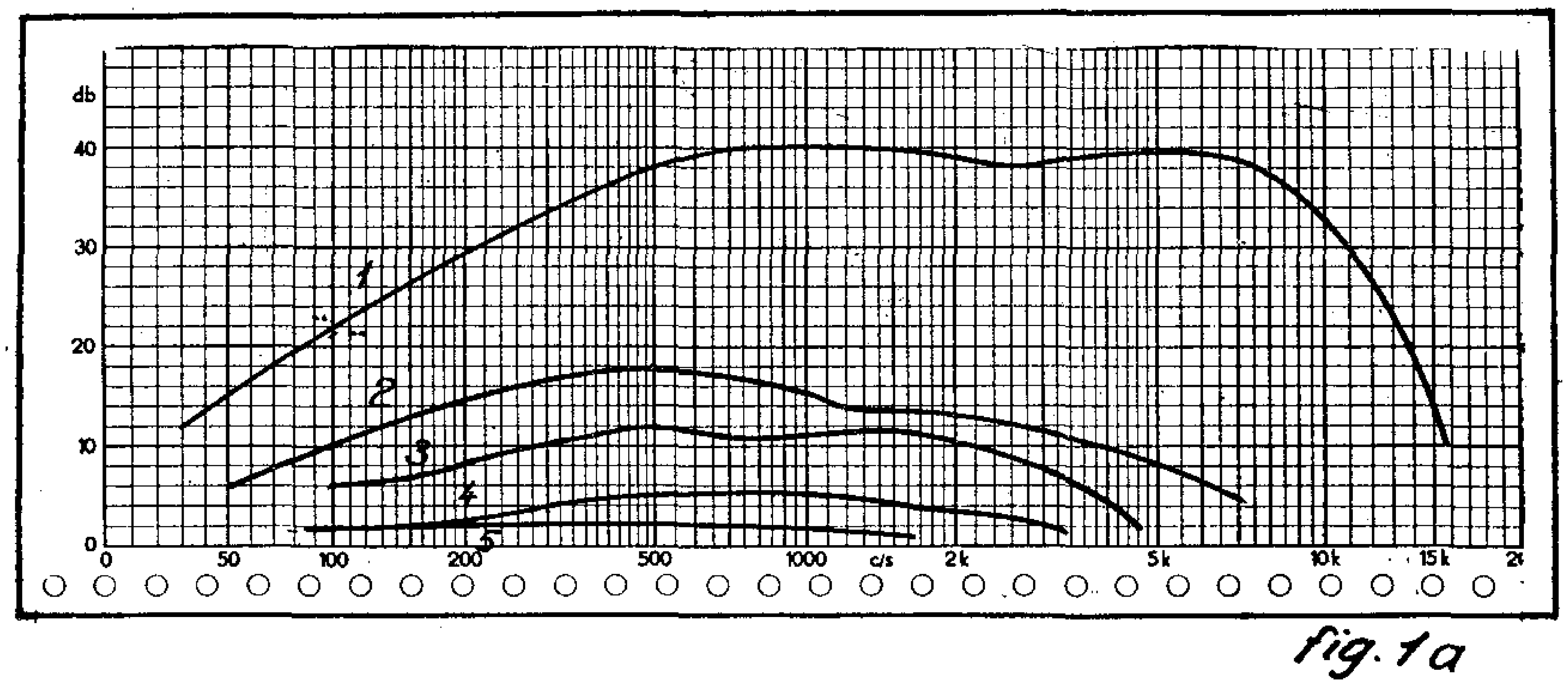


Fig. 1a. The ordinary frequency characteristic (1), plus the different harmonic characteristics (2, 3, 4, 5). All in db.

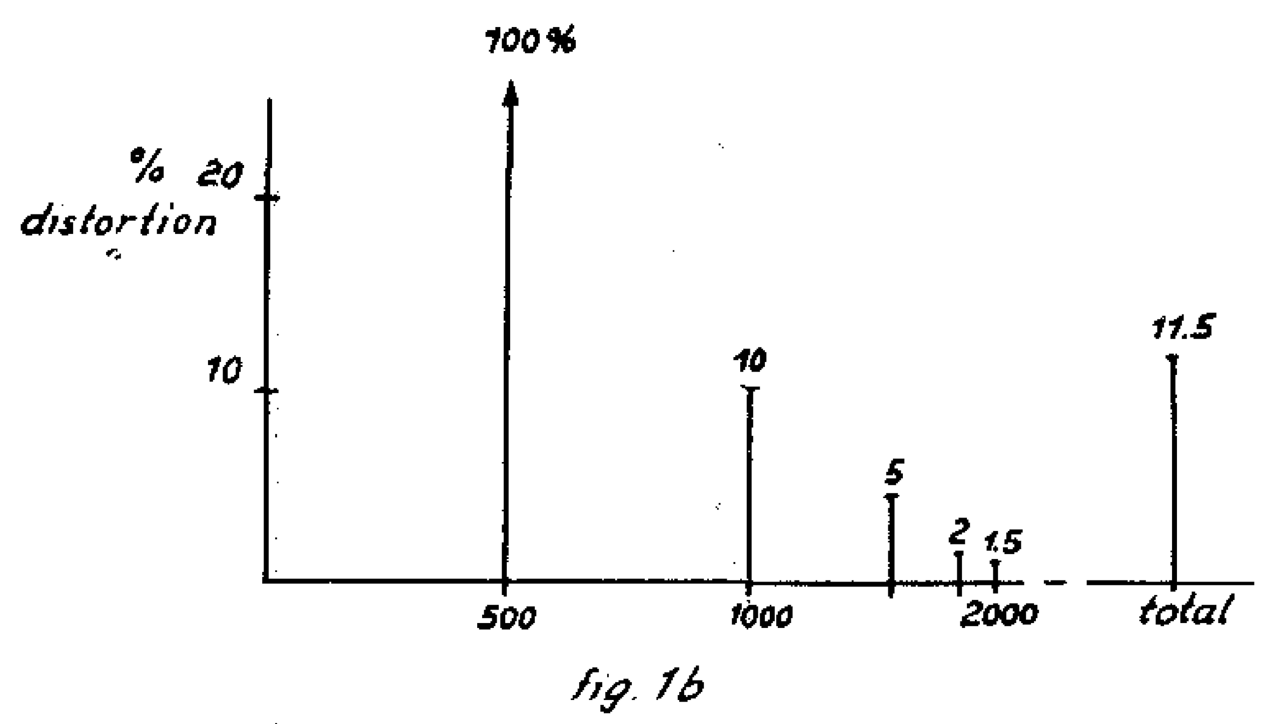


Fig. 1b. The different harmonic components as % of the fundamental at 500 c/s., and the total distortion factor.

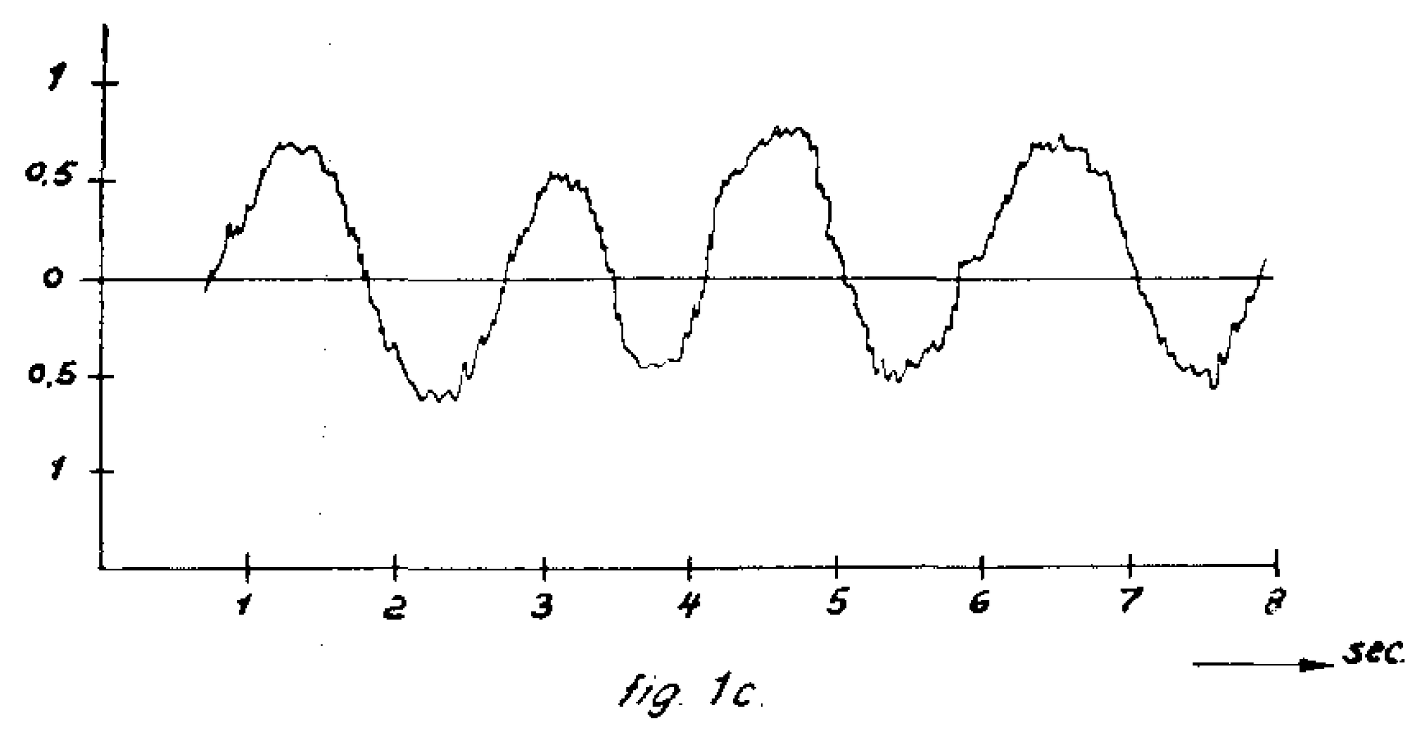


Fig. 1 c. Frequency modulation as a % of recording or playing speed, against time in secs.

3. **The mechanically produced frequency modulation.** All known sound reproducing equipments to date are fitted with one or other type of mechanical driving or transmission system, which causes frequency modulation if the speed of the recording medium during recording and playing should not be perfectly constant. To obtain a complete picture of a sound reproducing equipment, it is therefore also necessary to estimate these possible mechanical faults. For example, the speed deviation could be given as a % of the average speed, as a function of time. Such a curve can often be very irregular with time, but certain periodicities can also appear. As an example of this we could have speed variations in step with the mains frequency when using an underdimensioned a.c. motor, thus producing a varying driving momentum.

The Ideal representation of a sound reproducer's acoustical characteristics.

Fig. 1 shows a typical set of characteristic curves for a sound reproducing equipment. The upper curve in fig. 1 a shows the frequency characteristic, the frequency being given in logarithmic scale on the abscissa, and the amplitude similarly in logarithmic scale on the ordinate, i.e., in a db scale. The curves marked 2, 3, 4 and 5 are the harmonics, drawn as functions of their fundamental frequency, with amplitudes relative to the amplitude of the total signal at these frequencies, i.e., curve 1. The difference in db between curve 1 and 2, 1 and 3 etc., thus directly gives the harmonics expressed in % of the total signal, so that the total distortion can easily be computed by using the well known formula

$$k = \sqrt{d_2^2 + d_3^2 + \cdots} = \frac{\sqrt{E_2^2 + E_3^2 + \cdots}}{E_1}$$

where d_2, d_3, etc. represent the 2nd, 3rd, etc. harmonic distortions expressed in %, or E_2, E_3, etc. represent the harmonic voltages, and E_1 the total signal voltage. In fig. 1 b this is illustrated for the frequency 500 c/s. As can be seen there is a very great variation in the strength of the harmonics as a function of frequency. Similarly, there is a very great difference in the various harmonics for the same fundamental frequency. As a rule, harmonics above the the 5th have no significance in normal reproducing equipment. The higher harmonics are always much weaker than the lower harmonics.

With a sound reproducing equipment of good quality, the linear distortion must be small, i.e., curve 1 should have the same height for all frequencies in the frequency range in which one is interested. The non-linear distortion should also be small, i.e., curves 2, 3, 4, 5 etc. should lie well below curve 1. Furthermore, it is desirable that the "wow", i.e. the degree of frequency modulation, should be small. Fig. 1 c shows a typical "wow" curve of speed modulation, expressed in % of recording or playing speed.

Most electrical amplifiers and recording heads have generally very smooth frequency characteristics, so that when one wishes to establish the characteristics of an amplifier, recording head or playing head, it is only necessary to measure at a few points. However, it is quite another matter if microphone

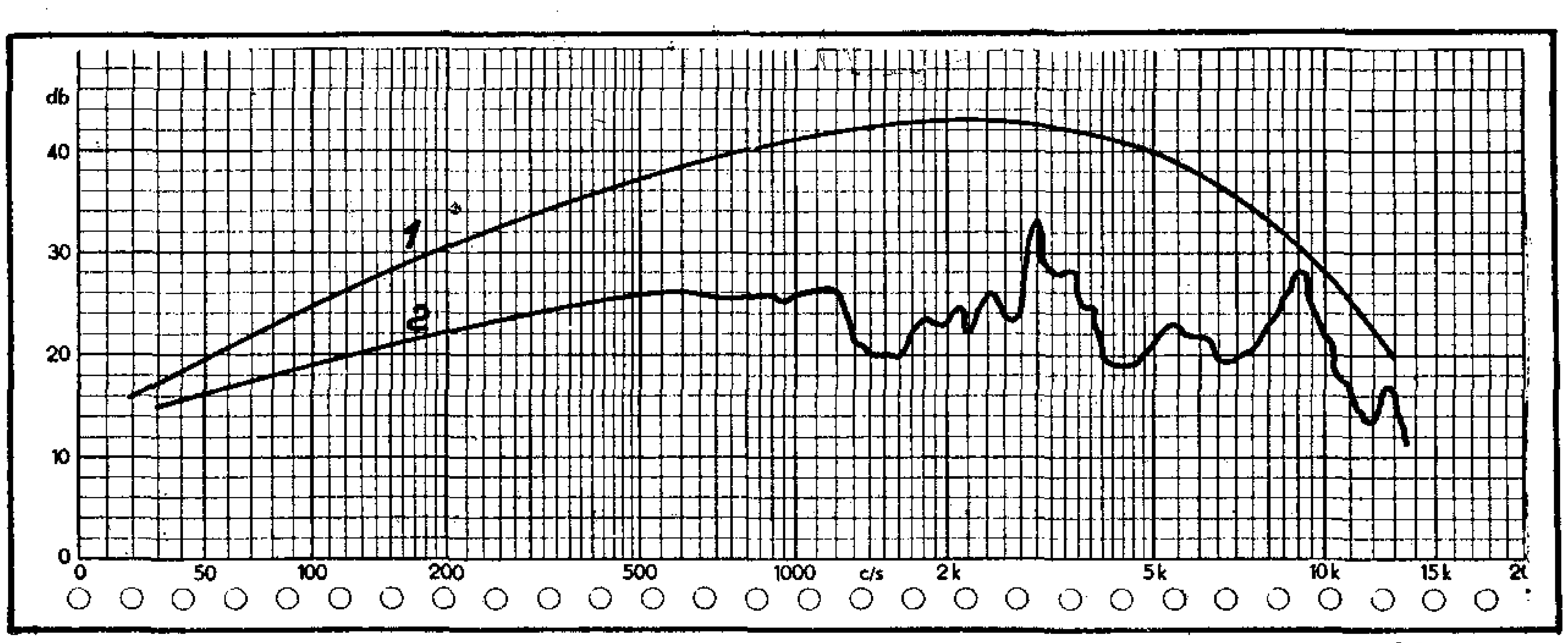


fig. 2.

Fig. 2. Typical frequency characteristics of a tape recorder. Curve 1, electrical input and output. Curve 2, acoustical input and output. The very irregular curve 2 thus includes the frequency characteristics of both microphone and loudspeaker.

and loudspeaker are included in the system. In this case quite irregular curves are obtained, so that an exact and continuous recording as a function of frequency is strictly necessary. An example is shown in fig. 2, where the smooth curve is the characteristic for amplifier plus recording and playing heads alone, i.e., electrical input and output, while the highly irregular curve is taken with acoustical input to the microphone and acoustical output from the loudspeaker or receiver.

With such a measuring result, it is always necessary to state the external conditions, i.e., the way in which the acoustical input and output is applied.

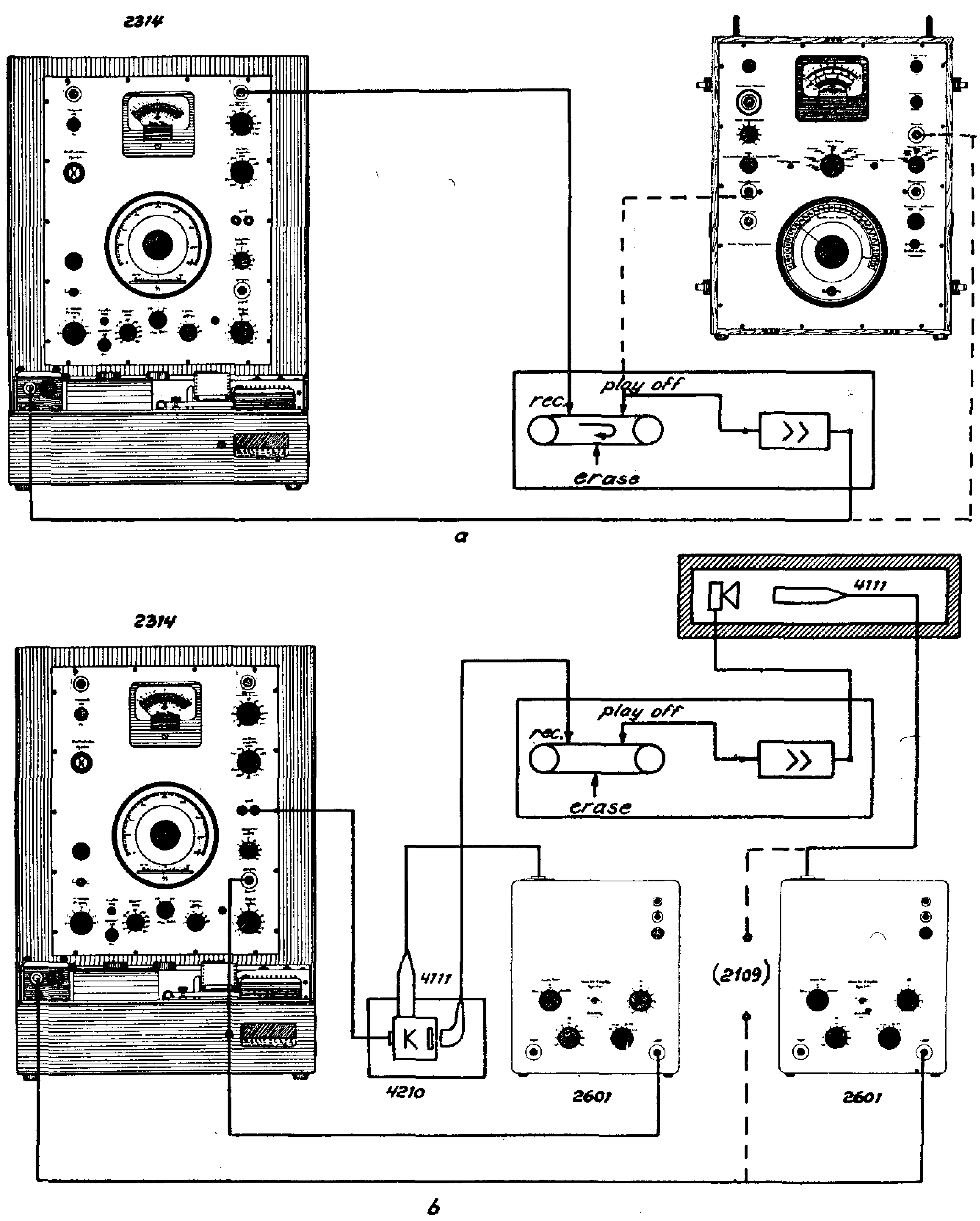


Fig. 3. Set-up for measuring the frequency characteristics and different harmonics of a tape recorder. Above, with electrical input and output. Below, with acoustical input and output. The constant sound pressure on the microphone is obtained with the Artificial Mouth type 4210, and the sound is measured in a anecho room with Microphone type 4111. The tape is spliced in a loop.

Thus, the microphone can be placed in: a), a free field, such as exists in an anecho room, in which case it should be mentioned whether the incident sound waves are perpendicular or parallel to the diaphram of the microphone, b), a diffuse field, where there is random incidence, or c), under conditions of constant sound pressure on the diaphragm with varying frequency. Likewise, the loudspeaker can radiate its energy under free field or diffuse field conditions. Finally, a telephone receiver can be used, in which case a procedure such as the cavity method should be employed. Here, the receiver is mounted on an Artificial Ear consisting of a standardized coupler in which the sound pressure is measured by a calibrated microphone cartridge and cathode follower.

Fig. 3, above, shows how the Automatic Frequency Recorder type 2314, consisting of a beat frequency oscillator and logarithmic high speed level recorder, is connected up to record the frequency characteristic of a tape recorder. The B.F.O. and recording section in 2314 are coupled together so that there is synchronism between the B.F.O.'s frequency and the logarithmic x-axis frequency scale of the preprinted recording paper. The voltages are recorded logarithmically, and so outputs will be measured directly in db. The output terminals of the B.F.O. are connected to the recording head of the tape recorder, and the output from the playing head is normally connected to the level recorder input via the tape recorder's amplifier. (The dotted line in fig. 3 a inserts the third octave analyzer, the use of which instrument will be discussed in detail later.) In this way, the frequency characteristic can be recorded automatically. As a rule, it is an advantage to splice the tape in a single loop. In that case the erasing head must be coupled in, so that the band is clean when it returns to the recording head for recording the next section of the total frequency range, which is thus covered in several loop-traverses,

If the frequency is to be recorded with acoustic input and output, the measuring set-up immediately becomes more complicated, as is seen from fig. 3 b. The B.F.O. here drives the Artificial Mouth type 4210. The sound pressure in front of the artificial mouth is held constant by the aid of Microphone type 4111 built into the artificial mouth, and operating the built-in automatic volume regulator in the B.F.O., via the microphone amplifier 2601. The sound from the reproducing equipment's loudspeaker is measured in an anecho chamber, of minimum size 2×2×3 m, covered internally with sound-absorbing material. A measuring microphone type 4111 is used, either in conjunction with the microphone amplifier type 2601, or the Analyzers type 2105 and 2109.

If the methods described above, which require that the sound heads be independent, so that both recording and playing can take place simultaneously, cannot be used, the difficulty can be overcome by using 2 equipments at the same time, as shown in fig. 4. Apparatus 1 is used for recording, and apparatus 2 for playing, and the loop runs between the two equipments.

With gramophone disc, where a simple erasing of the recording cannot be undertaken, and also where a long time elapses in the process from recording to playing back, it is unavoidably necessary to record first the signal from the B.F.O., using the noiseless switch on the B.F.O. to mark certain definite frequencies on the disc, so that on playing back, the frequency scale can be fixed exactly. When the recording has been made, the disc is played back, and the output recorded on 2314. Paper without a frequency axis is used, and then, when the recording has been made, the frequency axis can be inserted to agree with the impressed signals.

When figs. 3 and 4 are examined, it is seen that a certain time elapses between the recording and the reproduction of a frequency on the same point of the band. Thus, the frequency indicated on the preprinted recording paper will not be correct, if the B.F.O. and the recording paper in 2314 are exactly synchronized. The fault however can very easily be compensated for by letting the paper in 2314 run just that time interval behind the B.F.O.'s frequency scale.

To evaluate this interval a direct connection between the B.F.O. output and the Level Recorder's input is made (see fig. 4 above), by which an impulse can be precisely marked, but because of the delay in question a second impulse

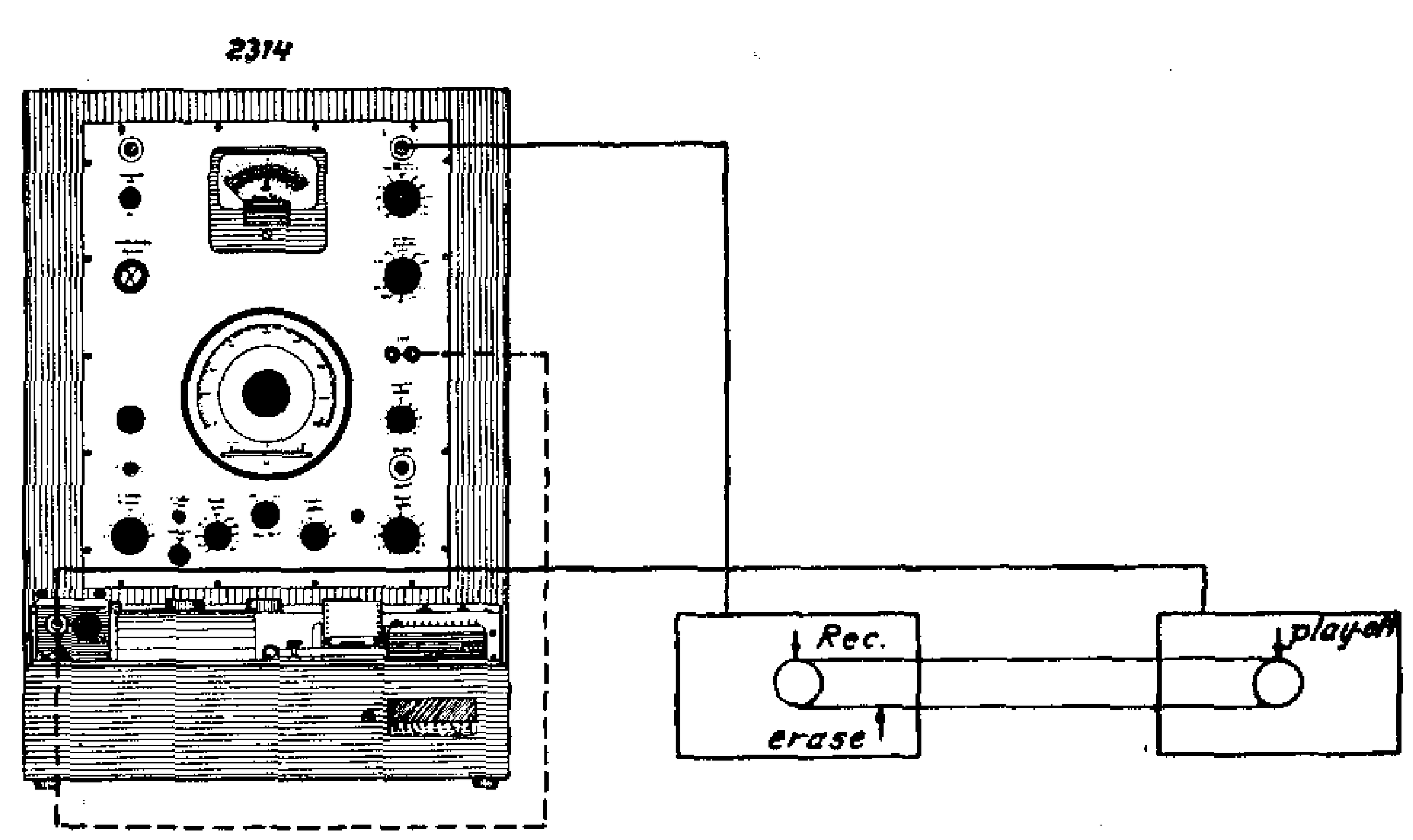


Fig. 4 A.

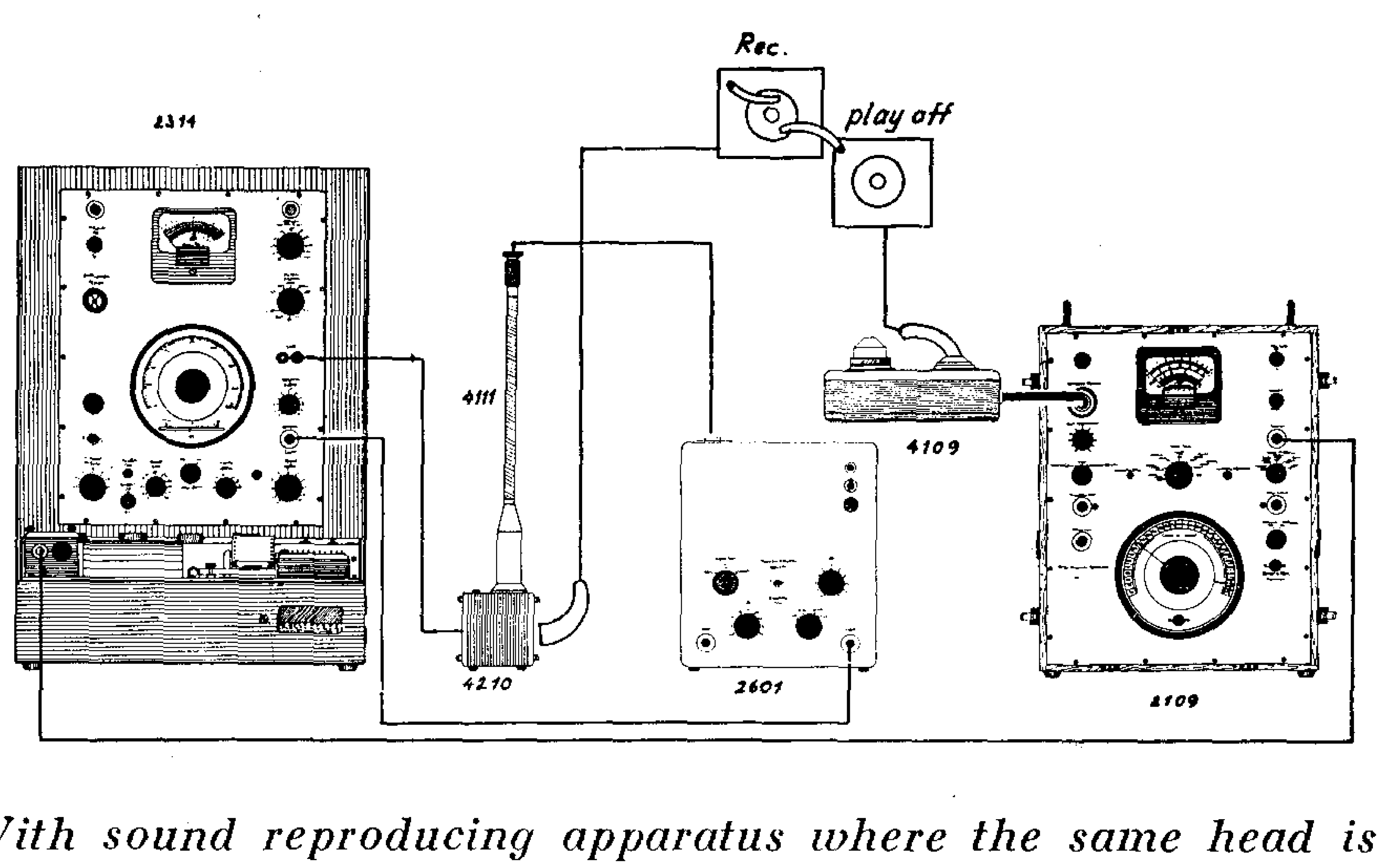


Fig. 4. With sound reproducing apparatus where the same head is used for both recording and playing, two aparatus are used. Above, electrical input and output of a dictation machine, below, with acoustical input and output. Artificial Ear type 4109 is used to pick up the sound from the receiver.

Comparison of two types of analyzers

Up to now, two different types of selective amplifier or analyzer have been constructed: 1) the so-called Constant Percentage Bandwidth Analyzer, and 2) the Heterodyne Analyzer. Type 1 has a bandwidth which is a definite fraction

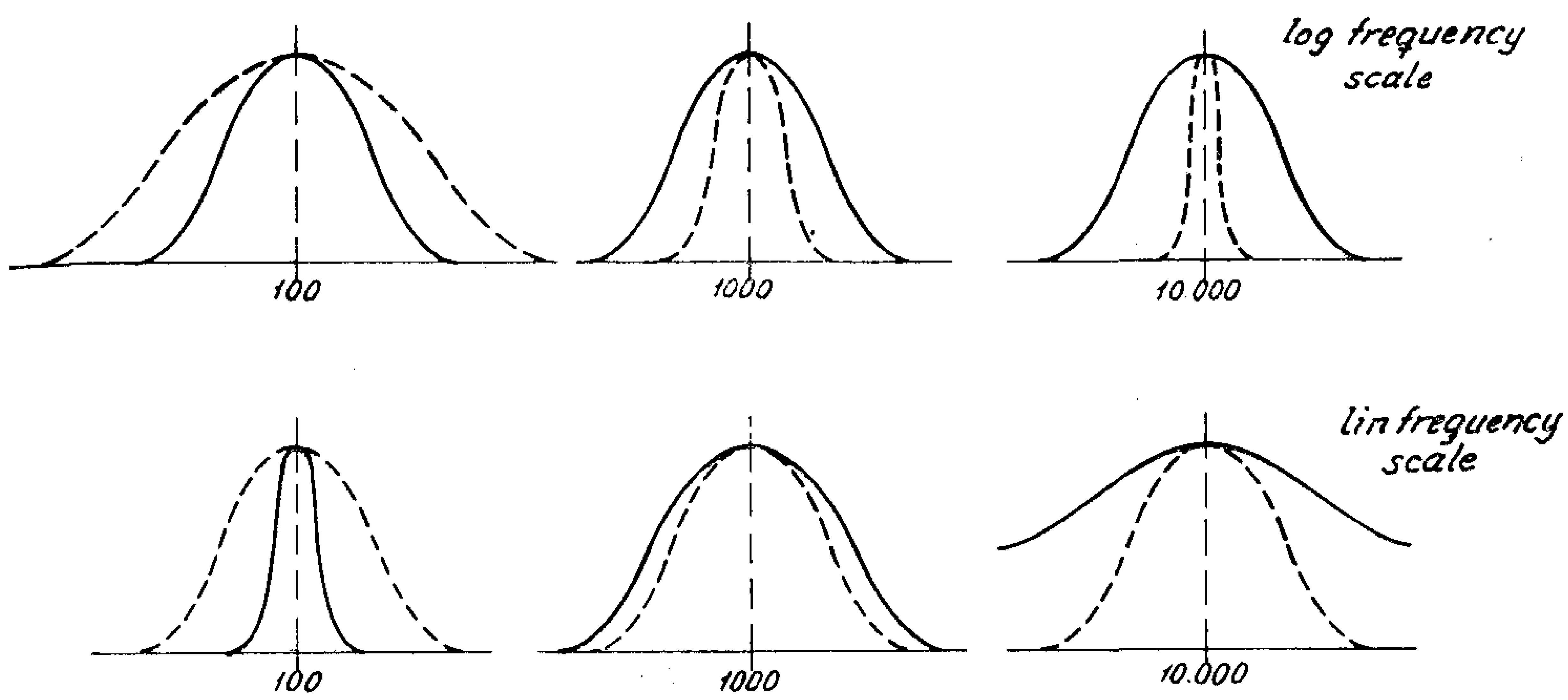


Fig. 6. Typical selectivity curves for the analyzer of Constant Percentage Bandwidth type (full line) and the Heterodyne Analyzer type with 4 c/s bandwidth (broken line). Above, drawn with log. frequency scale, below, with linear frequency scale.

of an octave, or a certain % of the band's middle frequency. To this type of analyzer belong the so-called degenerative R.C. analyzers, as well as those analyzers built with fixed filters.

(Analyzer 2105, of which the principle is indicated in fig. 9, left, belongs to the degenerative RC class; the double-T feed-back circuit has a minimum damping for any chosen frequency ($f = \frac{1}{2 \pi R C}$), so that the selectivity curve of the complete analyzer consists of the well-known clock-shape. Analyzer 2109 is an example of the second mentioned class, with 27 fixed octave filters).

The Heterodyne Analyzer mixes the incoming signal with one coming from a built-in generator, in a mixing stage. The combination tone of, for example, 50 kc/s is then amplified in a special selective amplifier, often equipped with a crystal filter. In this way an analyzer with a certain fixed bandwidth of, for example, 4 c/s, is obtained, independent of whichever frequency the analyzer is set to. Fig. 6 shows the selectivity curves for these two types of analyzer, expressed in both linear and logarithmic scales, the continuous line being the Constant Percentage Bandwidth Analyzer and the interrupted line corresponding to the Heterodyne Analyzer. By comparing figures 5 and 6, it will be seen immediately that if one is to measure correctly with a Heterodyne Analyzer, it is necessary that the degree of frequency swing at the highest frequency at which one wishes to measure must be within the bandwidth of the analyzer. If, therefore, the heterodyne analyzer has a bandwidth of 4 c/s, and one wishes to measure at 8000 c/s, the maximum frequency modulation in the sound repro-

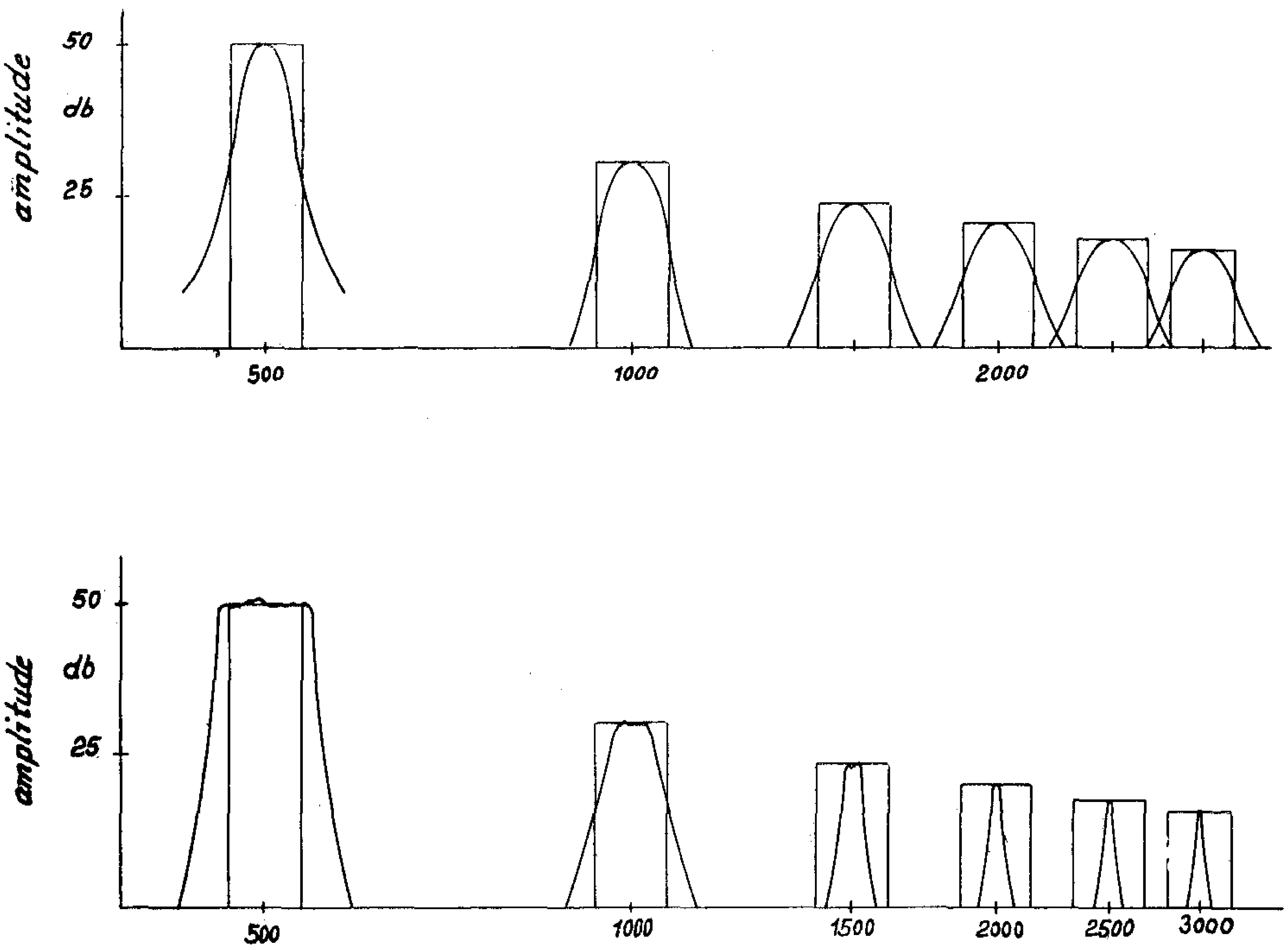


Fig. 7. Fundamental and harmonics with »bandwidth« from a sound reproducing apparatus. The selectivity curves for a Constant Percentage Bandwidth Analyzer (upper figure) and Heterodyne Analyzer (lower figure) have been inserted.

ducing equipment must not be above 0.25 %; a limit which only the very fewest reproducing equipments attain. In practice, therefore, one can say that the Heterodyne Analyzer is unsuited to distortion measurements in sound reproducers where "wow" can exist.

The next question is whether the analyzer with constant percentage bandwidth measures correctly. This is easiest answered by examining fig. 7, where a fundamental with 5 upper harmonics is illustrated. The frequency scale is logarithmic. The frequency modulation produced is indicated for both fundamental and harmonics by the rectangular bands, the amplitudes being given in db, while the selectivity curves of the Constant Percentage Bandwidth Analyzer (top) and the Heterodyne Analyzer (bottom) are shown superimposed on these bands. It is seen at once that for a part of the time the frequency swing on account of the modulation is so great, that the reproduced signal's frequency falls outside the bandwidth of the selectivity curve, and will thus not be measured with its proper value. But, as can be seen, this is likewise the case with the harmonics, so that in fact the relation between the harmonic and the fundamental, that is, the distortion factor, will always be correct, even though the analyzer's selectivity curve is narrower than the frequency swing of the reproducing apparatus. Further, the same illustration shows the selectivity curves with a Heterodyne Analyzer. Here, it is seen that the fundamental is measured with its full amplitude, the whole frequency band falling within the Heterodyne Analyzer's bandwidth, while on the con- bandwith as they increase in number of order. That is to say, that if the distortion factor, or relation between harmonics and fundamental, is calculated on the basis of using a Heterodyne Analyzer, an extremely erroneous result will be obtained. It should, however, be mentioned, that also when working with a Constant Percentage Bandwidth Analyzer one should attempt to adjust the bandwidth so that, if possible, it always covers the bandwidth produced by the

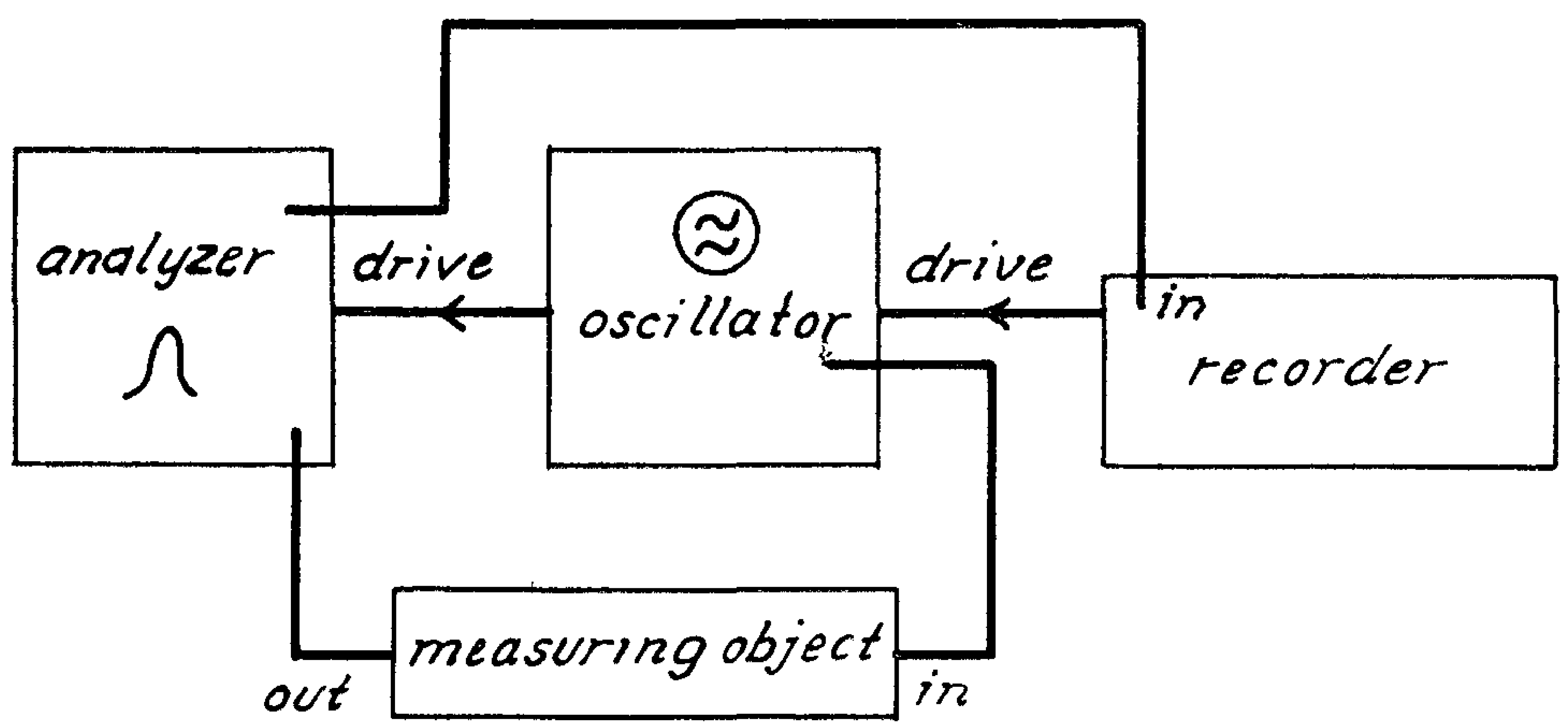


Fig. 8. Ideal measuring set-up for continuous recording of harmonics.

sound reproducing apparatus. If the bandwidth is narrower that that shown in fig. 7, above, the analyzer's meter will show fluctuating readings, which will make exact reading difficult. With the analyzer bandwidth as broad or broader than the modulation bandwidth (wow), however, the meter will be steady as a fixed value.

Automatic analysis of distortion.

If, now, one wishes to record distortion curves as shown in fig 1 a, giving the harmonics as functions of the fundamental in a continuous manner, a set-up such as shown in fig. 8 could be conceived. An oscillator producing practically pure tones is driven by a level recorder, so that there is synchronism between the recording paper and the oscillator's frequency. The level recorder or the oscillator has a mechanical drive to an analyzer of constant percentage bandwidth, whose selectivity curve will thus traverse the frequency range. The measuring object is now coupled in as shown in the figure. First, the frequency characteristic is recorded, the analyzer acting simply as a linear amplifier, so that the set-up of fig. 8 is reduced to that of fig. 3 or 4, as the mechanical drive will be without significance. Then the second harmonic is recorded, by setting the analyzer 1 octave in advantage of the oscillator's frequency: similarly the third harmonic is obtained by setting the analyzer $1^1/_2$ octaves in advance of the oscillator frequency, and so on, the synchronism between oscillator and analyzer being retained all the time. This apparently simple set-up suffers however from the disadvantage that in practice it is very difficult to carry out. One cannot traverse the whole frequency range from 20 c/s to 20000 c/s without using the heterodyne principle in both oscillator and analyzer, and apart from the previously mentioned difficulties of using the heterodyne principle for this kind af analysis, it will be difficult to synchronize the analyzer and oscillator to record the harmonics,

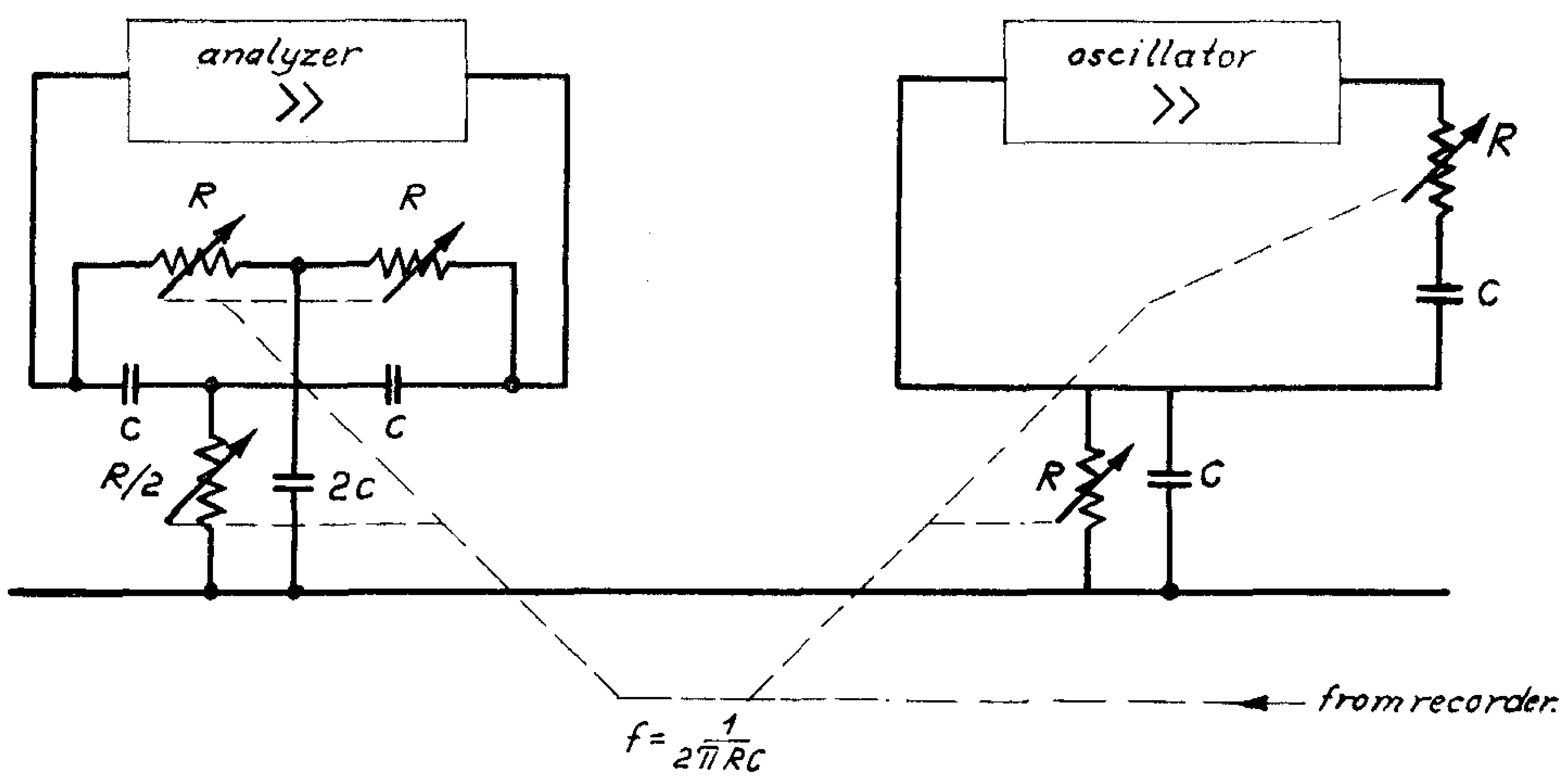


Fig. 9. Simplified and practical set-up where an analyzer of the degenerative type is coupled with an RC oscillator, both controlled by the same tuning.

unless both frequency scales are purely logarithmic. However, using feed-back for both oscillator and analyzer, as in fig. 9, where both the generated and analyzed frequency follow the relation $f = \frac{1}{2\,\pi CR}$ will allow this synchronization much more easily. If, for example, one wishes to record the 2nd harmonic, one merely choses the condensers in the analyzer to be half as great as those in the oscillator, and if one wishes to record the 3rd harmonic, condensers one third the size are chosen, and so on. Unfortunately, in this case it is only possible to cover a frequency range of about 1 octave at a time, by, for example, varying the resistances shown, 2 in the oscillator and 3 in the analyzer. When it is necessary to go further in the frequency range, the resistances must be returned to their original values and the condensers must be switched, all of which leads to great mechanical difficulties, so that hitherto no commercial apparatus has been constructed according to this principle.

Semi-automatic analysis by $^1/_3$ octave filters.

However, there is still another method for automatically recording harmonics, in that relatively broad fixed filters can be used: Spectrometer type 2109 would thus be suitable. This apparatus contains 27 one-third octave filters which can be coupled in between built-in preamplifier and output amplifier. A switch allows the different filters to be successively coupled in.

Fig. 10 shows the frequency characteristics of the filters in 2109, together with, below, the fundamental at 500 c/s and several harmonics from a sound reproducing apparatus, in relation to the appropriate filters. The measuring principle is that the frequency is automatically varied slowly on the B.F.O. section in 2314, while, as shown in either fig. 3 or 4, the spectrometer 2109 is coupled between the sound reproducing apparatus and the level recording

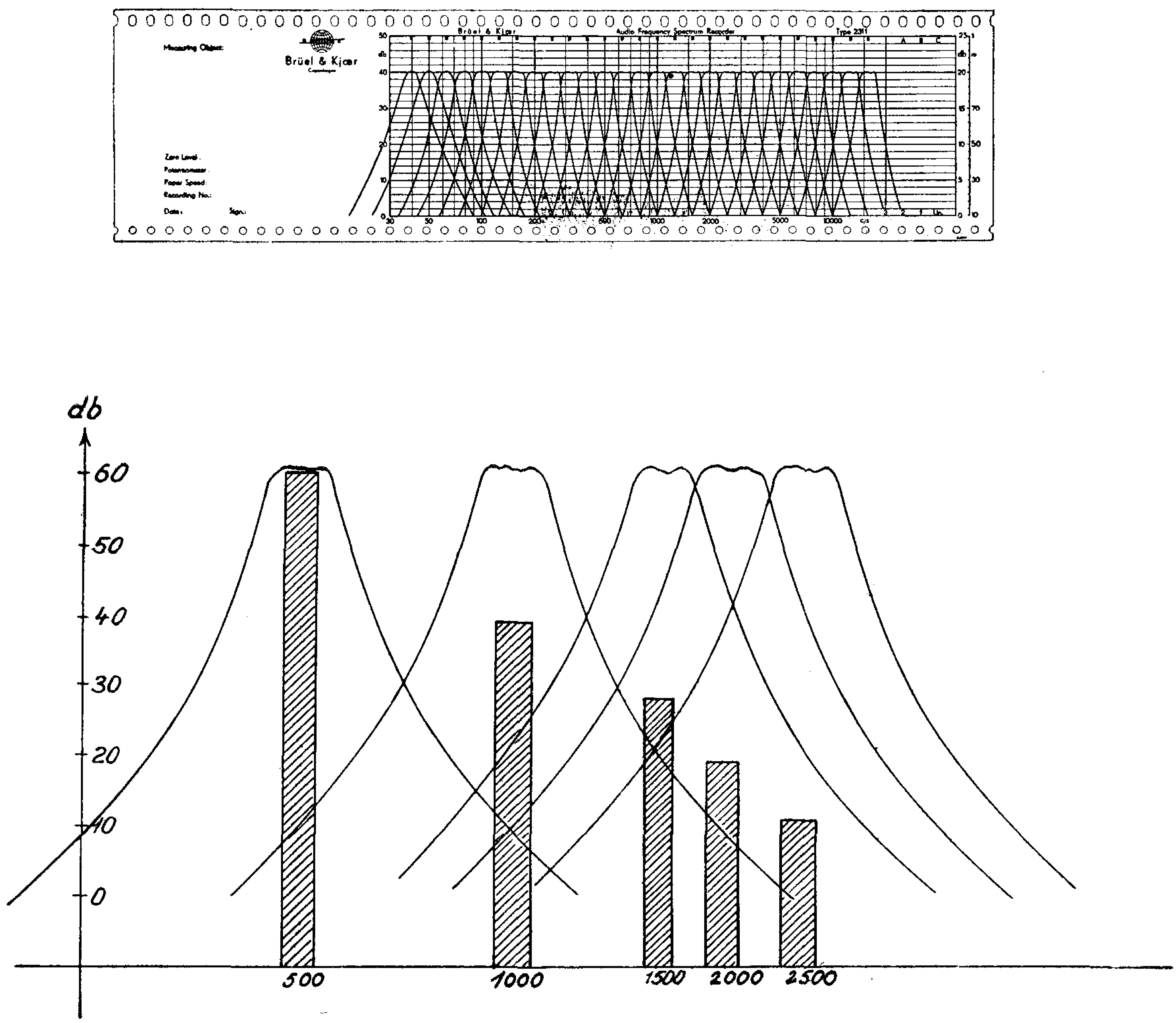


Fig. 10. Above, the frequency characteristics of all the ⅓rd octave filters in Spectrometer 2109. Below: Fundamental at 500 c/s and the harmonics from a sound reproducing apparatus, with the corresponding filters.

section in 2314. If one wishes to record the frequency characteristic itself of the sound reproducing apparatus, the spectrometer 2109 is put on its linear characteristic just as in the last case, whereby the apparatus simply acts as a linear amplifier with a frequency range from 20 c/s to 20000 c/s. When the frequency response has been recorded, the recording paper is rolled back to the starting point and synchronized again with the B.F.O.'s frequency scale. The spectrometer is then switched to its selective position, and care is taken that by precise switching the spectrometer's adjustment is kept exactly 1 octave in advance of the B.F.O.'s frequency, shifting from the one filter to the next at the frequencies given in table 11. The same is repeated for the 3rd harmonic, only this time the spectrometer is kept $1^1/_2$ octaves ahead of the B.F.O.'s frequency, and similarly up to the 5th harmonic. All measurements are carried out with a 50 db potentiometer on the level recorder, and during

Nominal Frequency of filter in c/s	Logarithm of exact center frequency	Exact center frequency of filter in c/s	Exact frequency of separation	Frequencies at which the filters should be switched to record the		
				2nd harmonic	3rd harmonic	4th harmonic
40	1,60	39,811	44,668	22,3 Hz		
50	1,70	50,119	56,234	28,1		
64	1,80	63,096	70,795	35,4	23,6 Hz	
80	1,90	79,433	89,125	44,6	29,7	22,3 Hz
100	2,00	100,000	112,20	56,1	37,4	28,1
125	2,10	125,89	141,25	70,6	47,1	35,3
160	2,20	158,49	177,83	89	59,3	44,4
200	2,30	199,53	223,87	112	74,6	55,9
250	2,40	251,19	281,84	141	93,9	70,5
320	2,50	316,23	354,81	177	118	88,7
400	2,60	398,11	446,68	223	149	112
500	2,70	501,19	562,34	281	187	141
640	2,80	630,96	707,95	354	236	177
800	2,90	794,33	891,25	446	297	223
1000	3,00	1000,00	1122,0	561	374	281
1250	3,10	1258,9	1412,5	706	471	353
1600	3,20	1584,9	1778,3	889	593	444
2000	3,30	1995,3	2238,7	1120	746	559
2500	3,40	2511,9	2818,4	1410	939	705
3200	3,50	3162,3	3548,1	1770	1182	887
4000	3,60	3981,1	4466,8	2230	1490	1120
5000	3,70	5011,9	5623,4	2810	1870	1410
6400	3,80	6309,6	7079,5	3540	2360	1770
8000	3,90	7943,3	8912,5	4460	2970	2230
10000	4,00	10000,0	11220,0	5610	3740	2810
12500	4,10	12589	14125	7008	4708	3530
16000	4,20	15849				

Fig. 11. Table showing the different filters in 2109, with their nominal mid-frequency values in agreement with the Reynard numbers, and the exact frequencies at which the filters should be switched so as to obtain the 2nd, 3rd and 4th harmonics.

measurements the amplification must not be altered at any point in the circuit. As will be seen from the frequency characteristics for th efilters, the analyzer is so selective that it can record a 2nd harmonic which is only 2 ‰ of the fundamental, and the higher harmonics can be found when they are only a fraction of 1 ‰. However, the distortion factor of the B.F.O. used in the 2314 sets a limit to the precision of the measuring method. As a rule, the best distortion factor which can be obtained is approx. 0.2—0.25 %, so that one should not reckon with measuring harmonics whose amplitude lies below 0.5 % of the fundamental in the measuring method here described, but this limit also covers most demands one can make of an analysis of sound reproducing apparatus.

The method given has certain limitations and disadvantages. Thus, the 6th and 7th harmonics fall within the same filter, so that in practice the method can only be used to the 5th harmonic. But, in the case of sound reproducink apparatus, the 2nd and 3rd harmonics are by far the most important, and in any case harmonics over the 5th have no practical significance at all. Another disadvantage is that the method is still not developed to a completely automatic procedure. It is still necessary to shift the filters by hand at certain predetermined frequencies which are read off on the B.F.O.,

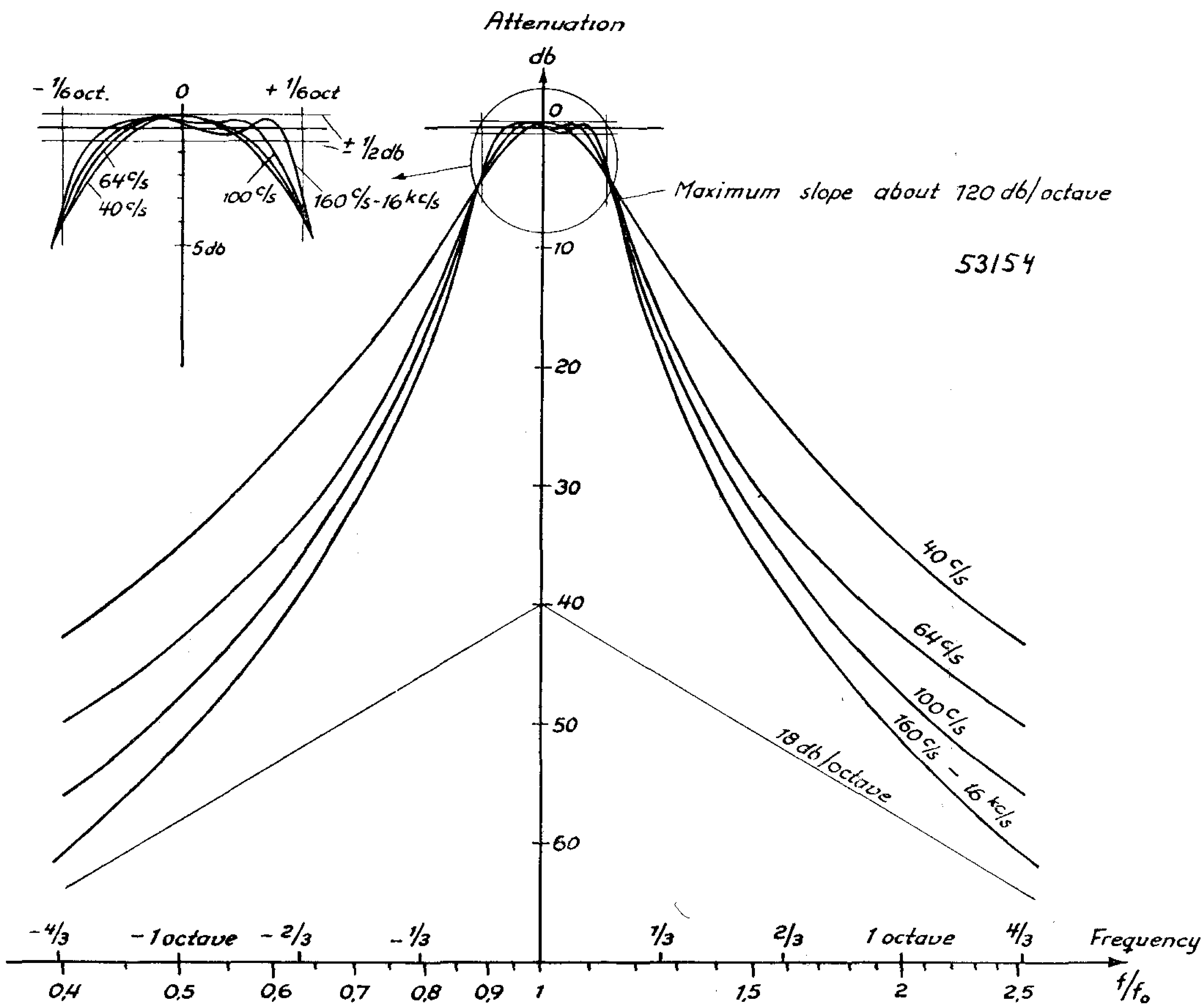


Fig. 12. Detailed picture of the characteristics of a filter in 2109.

and it is impossible to avoid a little dip in the curve when shifting the filters, when recording the harmonics. If one shifts too late or too soon, the dip will be greater. However, these dips arise at regular intervals, so that it is perfectly easy to distinguish these irregularities from the real fluctuations in the curve. Although the step to a completely automatic switching of the filters is not a great one, it will be impossible to avoid dips in the curves registering the harmonics, even with automatic switching.

Lastly, the question may arise of the influence of "wow" on this measuring procedure. With the B.F.O.'s traversing of the frequency range, the harmonics produced by the measuring object will also scan the fixed selectivity curves of the filters. If the filters had ideal flat-topped selectivity curves, each completely covering $1/3$ octave, the existence of wow produced by the measuring object would show no signs in the recorded harmonic analysis. However, as the curves are not ideal but have pronounced flancs, the wow will appear as an amplitude modulation at the separation points between the filters. However, considering fig. 12, which shows a detailed picture of the filter characteristics of Analyzer 2109, reveals that with a wow of less than 2 %, these variations will coincide with the dip which will be registered even with total absence of wow. Practical measurements corroborate this.

Using steepness of filter to measure "wow".

Fig. 12 shows too that the majority of filters have a maximum steepness of side of 120 db/octave, and this characteristic immediately suggests their use, if necessary, in measuring "wow". For example, as shown in fig. 13, a sound recording apparatus can be supplied with a constant tone of such frequency, as to coincide with a particular filter's maximum side slope. The slightest speed modulation in the sound reproducing apparatus will produce a corre-

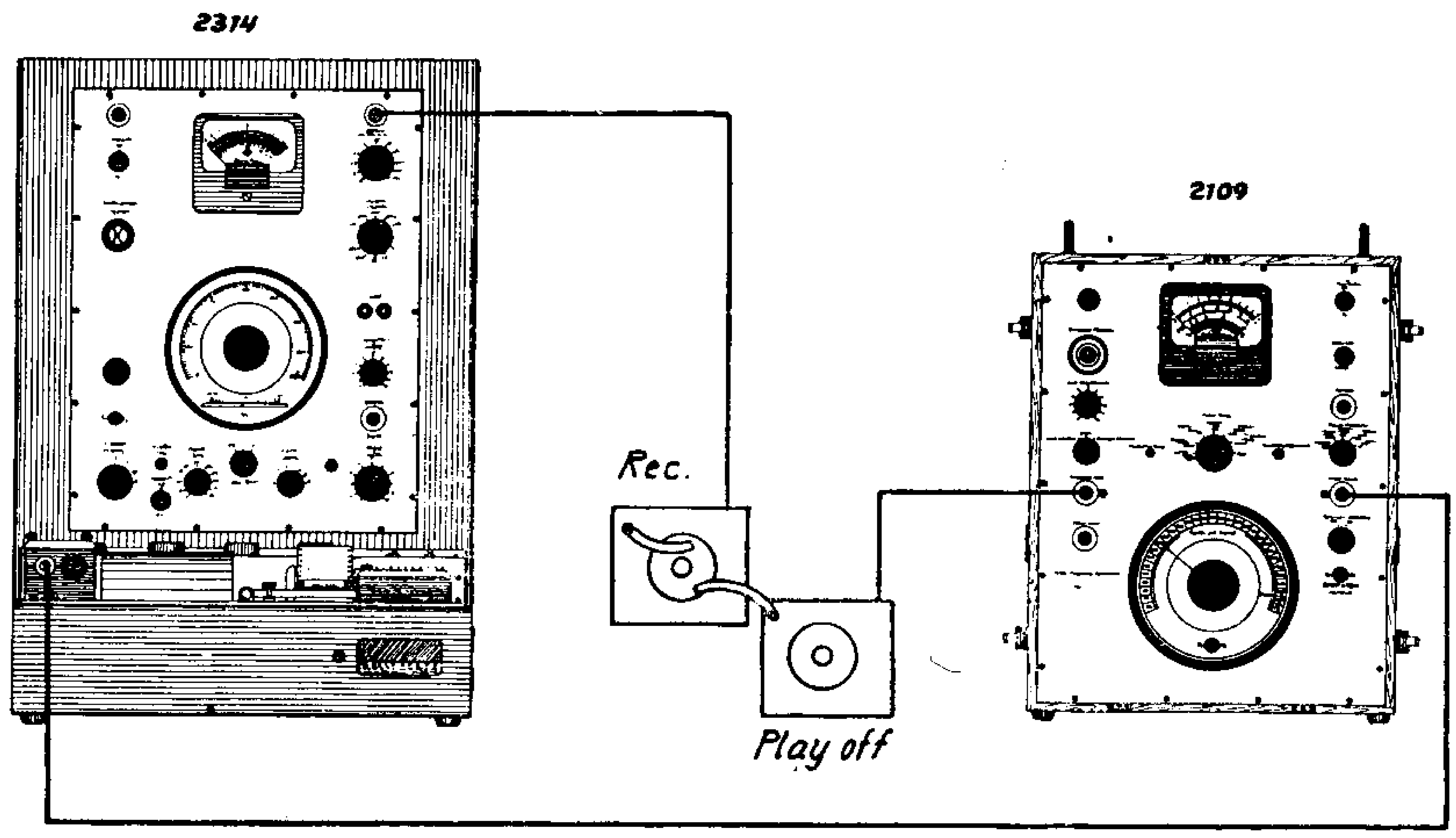
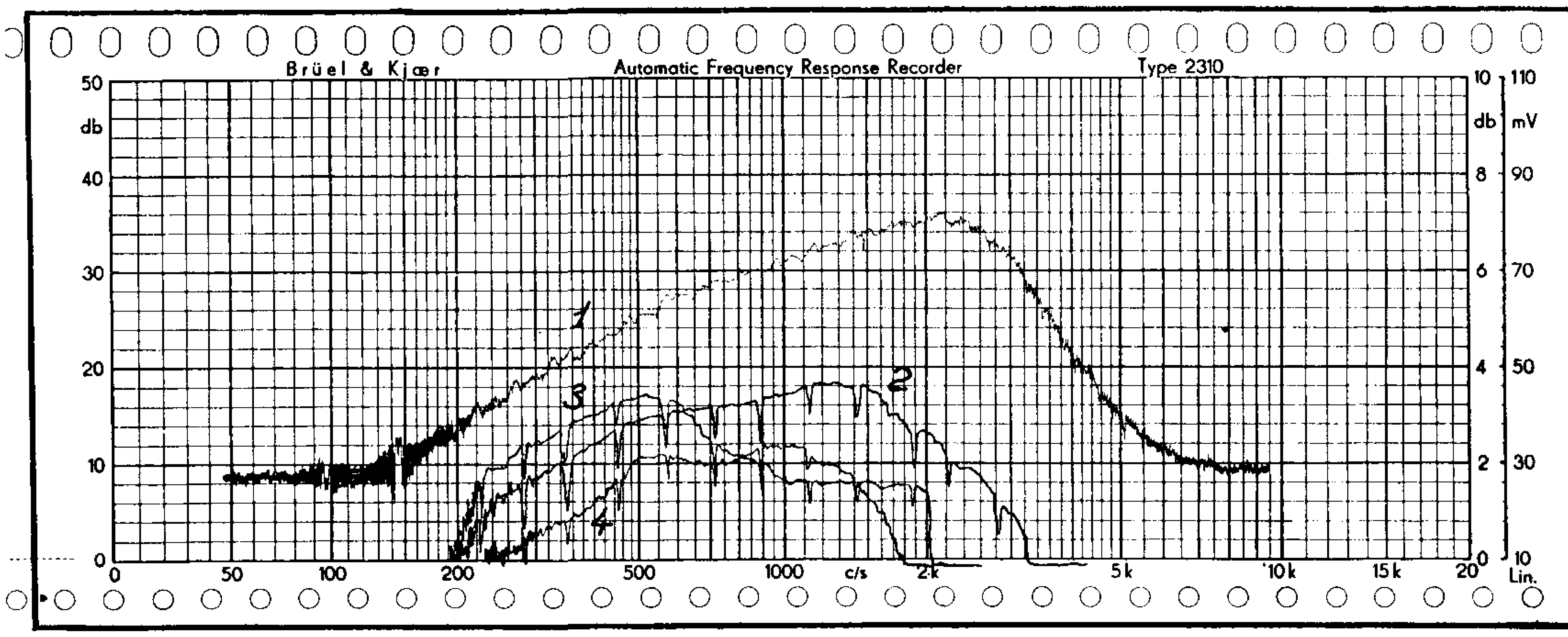


Fig. 13. Principle for the measurement of »wow« in a sound reproducing equipment, using the analyzer 2109.



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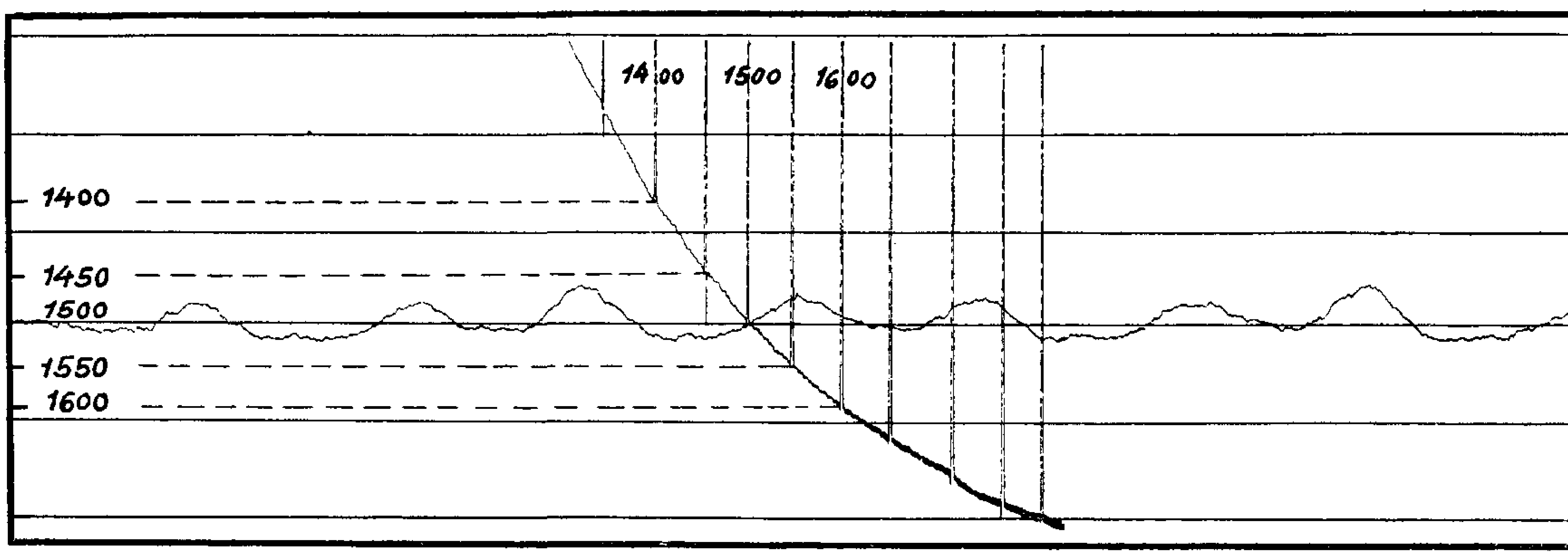


b

Fig. 14. Example of measurements of frequency characteristic and harmonics on a dictation machine, carried out semiautomatically as described in the text, with at the same time a record of the »wow« value, as carried out in the set-up of fig. 13.

sponding frequency modulation, and this in turn will produce a powerful amplitude modulation of the signals passed by the filter. By recording these on the level recorder of 2314, a direct record of the speed modulation of the sound producing equipment will be obtained. It is useful to choose a relatively high frequency for these measurements. On the other hand, the frequency should not be higher than that it is within a relatively flat region of the frequency characteristic of the sound reproducing apparatus, for if one works on a very steep part of the characteristic, the slope of this characteristic will be added to the filter's slope, and allowance must be made if this is the case.

At the same time, the material inhomogeneities of the recording medium itself, for example a varying thickness of the tape, might produce variations in voltage which are independent of frequency modulation. These two influences can be compensated for by using a limiter or by overloading the spectrometer's preamplifier. This, however, also overloads the output amplifier. Therefore, one can take the output from the filter across a high terminal impedance.

The quoted slope of 120 db/octave corresponds to 1.6 db per 1 % frequency modulation. If a 10 db potentiometer is used on the level recorder in 2314, one will with certainty obtain fully legible results for a "wow" of 0.6 ‰ modulation. Fig. 14 shows some results of measurements according to the methods described here, on a dictation machine of American manufacture. Fig 14 a shows the frequency characteristics plus the 2nd, 3rd and 4th harmonics, recorded continuously. Fig. 14 b shows the result of a wow-measurement, where on the same recording paper, the right hand slope of the filter has also been recorded, to obtain a calibration of the amplitude of the "wow". The dictation machine belongs to the very cheapest price class, and as can be seen from the curves its quality as a sound reproducer is correspondingly poor.

In this short account of a new measuring method, it has not been possible to describe the different characteristics or give a closer description of the various types of apparatus used in these measurements, and so the reader is referred to the following list of references, where the apparatus mentioned are further described:

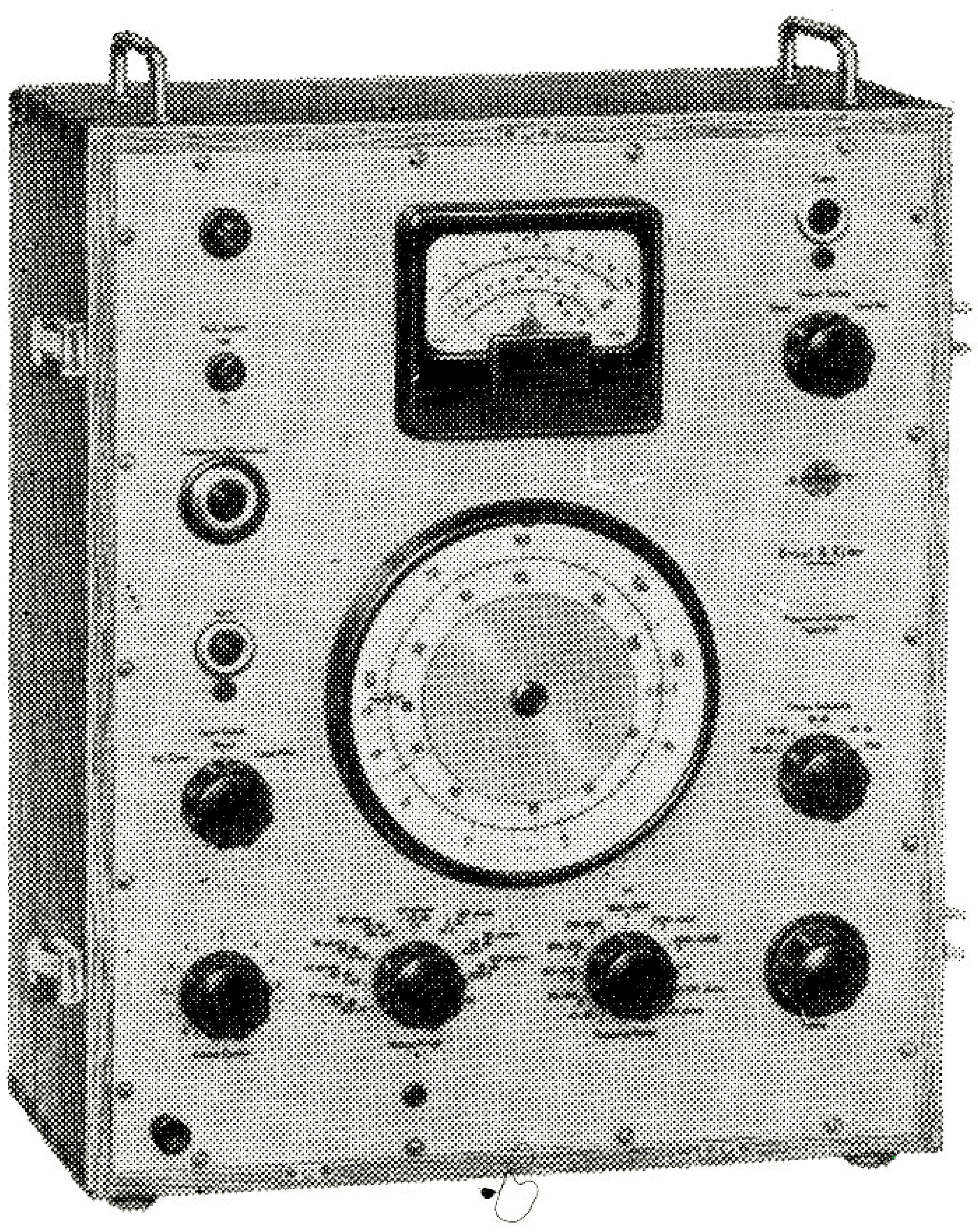
Manuel for Use: Spectrometer type 2109
and Automatic Spectrum Recorder type 2311

» » » Analyser type 2105

» » » Level Recorder type 2304

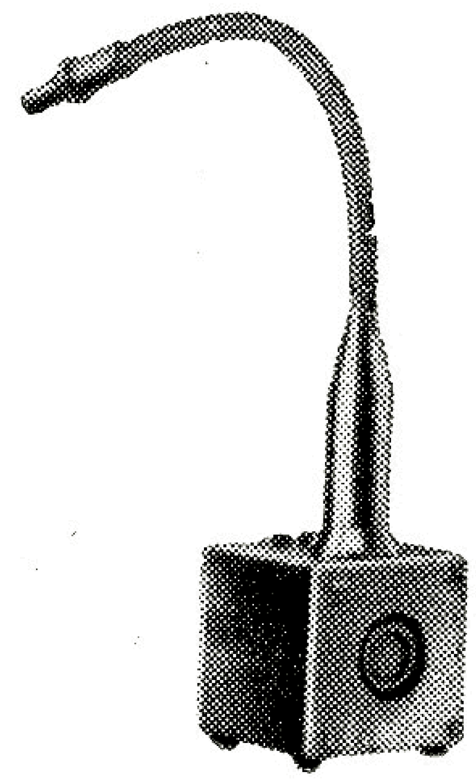
» » » Artificial Ear type 4109

Photographs of a Frequency Analyzer type 2105, a Microphone Amplifier type 2601, an Artificial Voice type 4210 mounted together with Measuring Microphone type 4111 (cathode follower mounting), and an Artificial Ear type 4109.

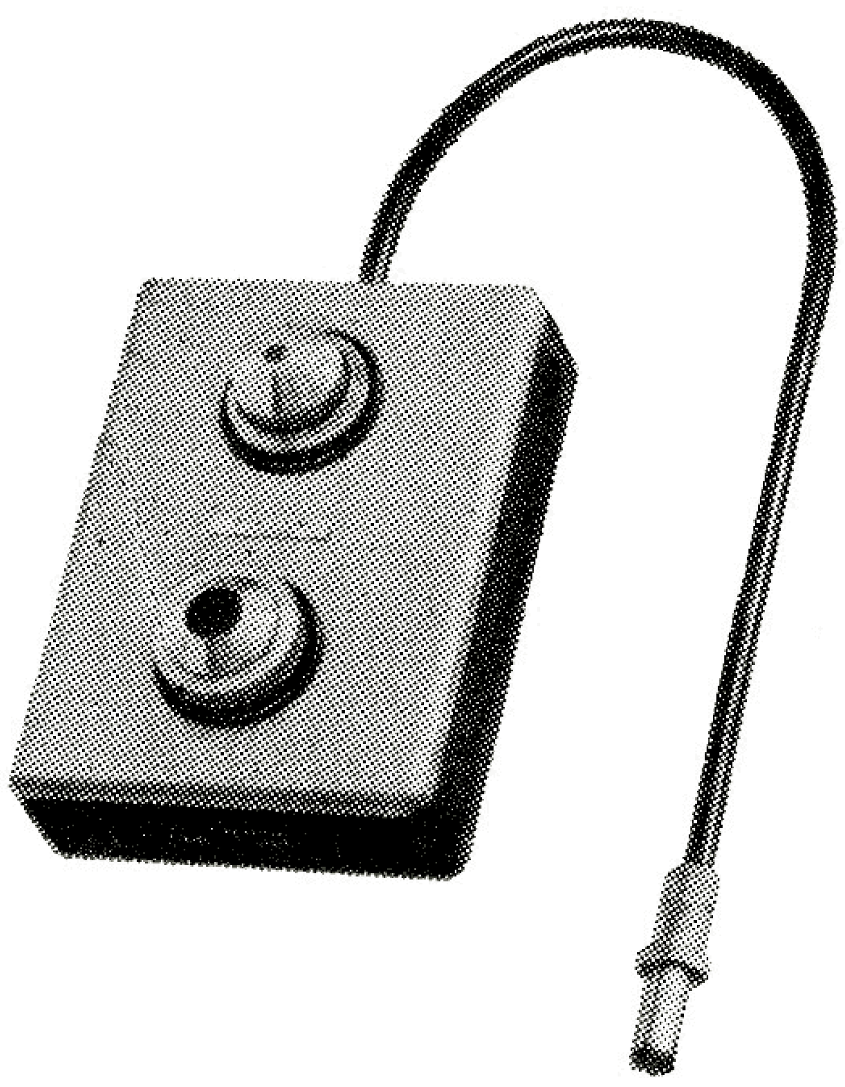


2105

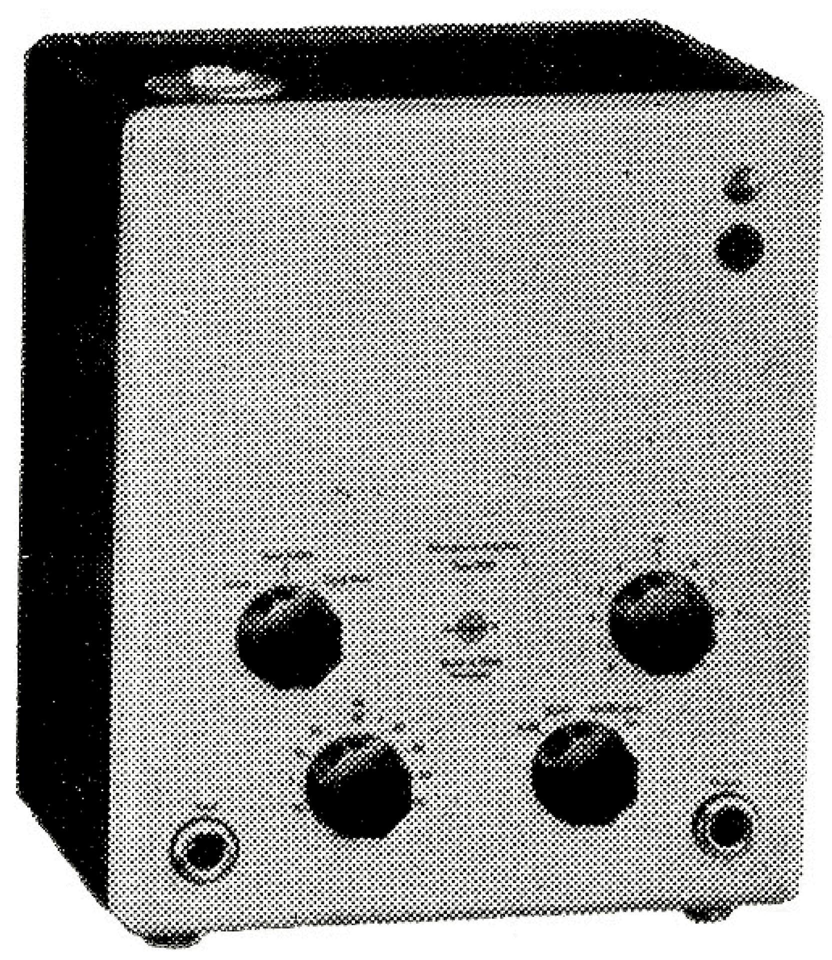
4111



4210



4109



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