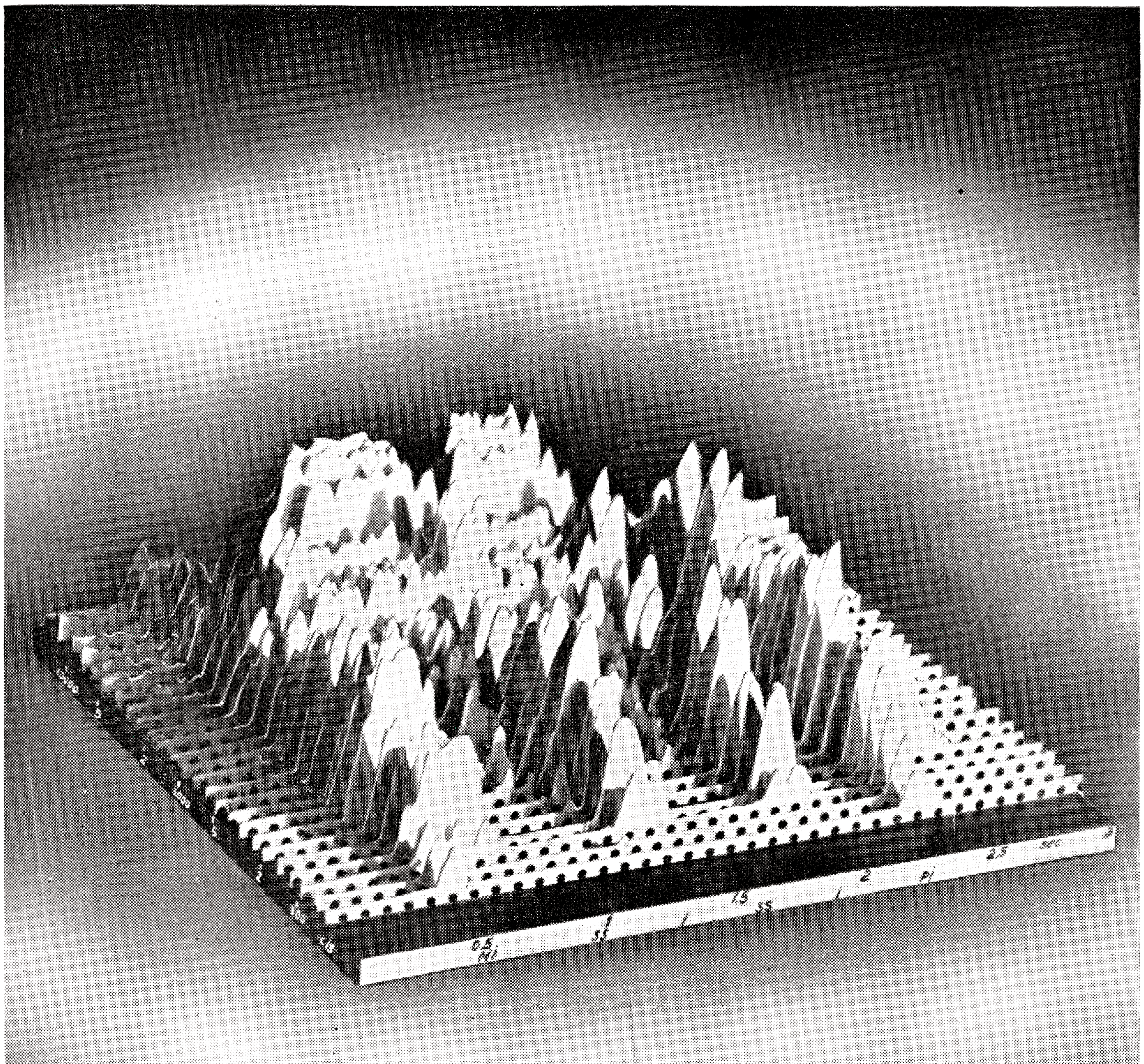
Brüel & Kjær

Technical Review

Teletechnical, Acoustical and Vibrational Research



ANALYSIS OF TRANSIENT SOUNDS

No. 1 January 1954

Cover: Three Dimensional Representation of the analysis of the word "Mississippi" as recorded by the Automatic Spectrum Recorder type 2311, by playing a closed tape-loop containing this word alone on a tape recorder. This method of analyzing any kind of transient sound is described in this number as one of the applications of type 2311. In our cover picture the two double s parts in the word "Mississippi" at the higher frequencies are clearly visible, whereas at the lower frequencies the vocal parts in the word are more distincly shown.

In this issue we continue discussing the application possibilities of the Audio Frequency Spectrometer type 2109 and the Automatic Spectrum Recorder type 2311.

For convenience there follows a list of the applications illustrated in Technical Review, October 1953 and this number.

Noise Measurements with the Audio Frequency Spectrometer type 2109.

In our last number, Technical Review 1953, 4, we discussed the measurement of sound pressure with Condenser Microphone type 4111 as one of the applications of the Audio Frequency Spectrometer type 2109. However, whereas the determination of absolute sound pressure expressed in μbars is useful for many investigations, the sound pressure at different frequencies does not 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 very high frequencies in comparison with the middle frequencies.

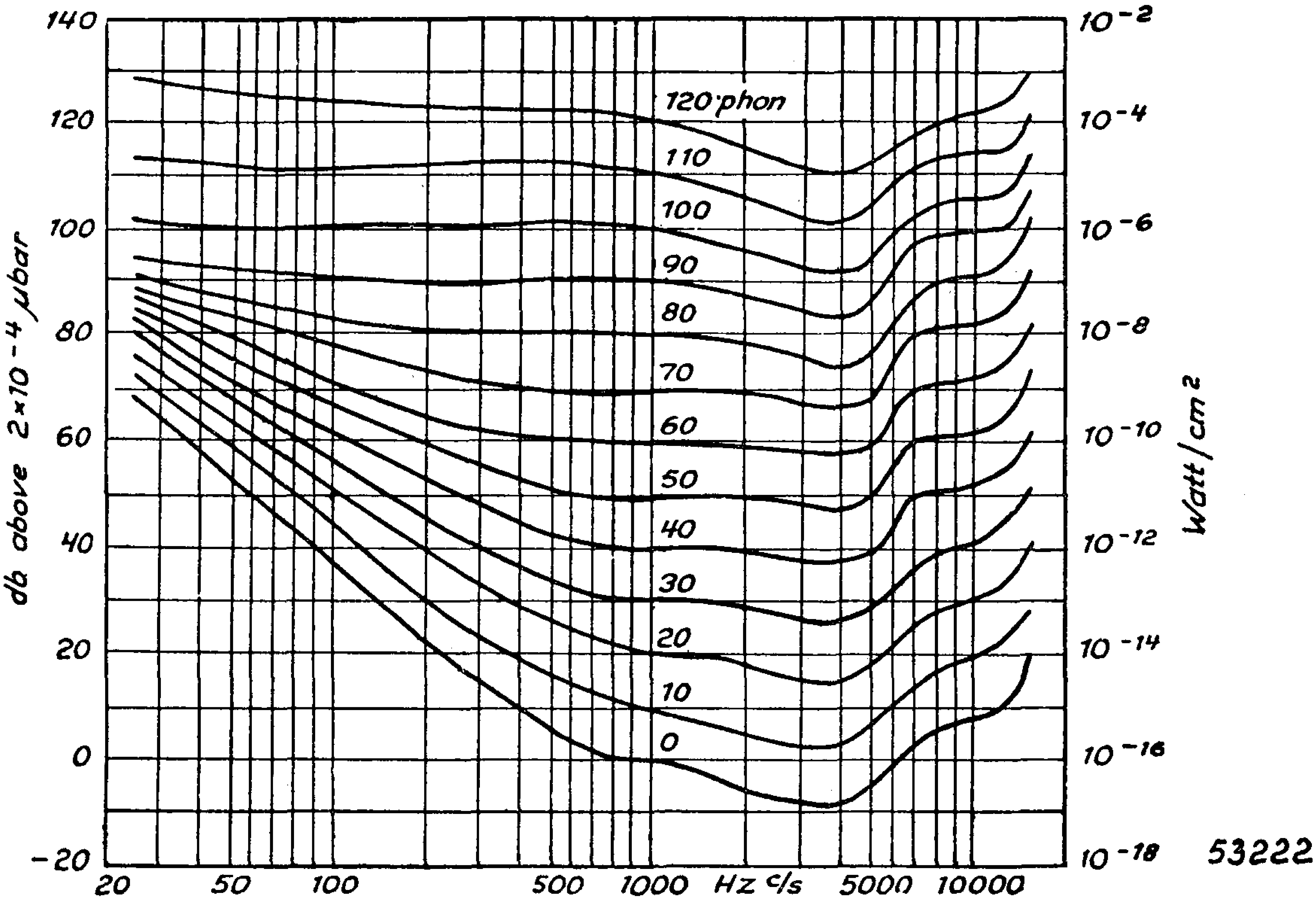


Fig. 24. The sensitivity curves for the human ear (Fletcher and Munson).

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 the sound and the 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} μbars, 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. 24 shows the sensitivity curves of the ear.

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 instrument should have such frequency characteristics that the low and very high frequencies be depressed in a manner corresponding to fig. 24. 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 Z24.3. The various frequency characteristics are drawn in fig. 25 and it will be seen that the deviations are only noticeable for frequencies under 100 c/s, and it is happily the case that the tolerances permitted both for the European and American standards are so great that it is possible to give an instrument frequency characteristics which satisfy both Standards' requirements. 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 Spectrometer 2109 when equipped with a Condenser Microphone type 4111. The Spectrometer is equipped with 4 frequency characteristics for use in noise measuring, which all are shown in fig. 9 last number.

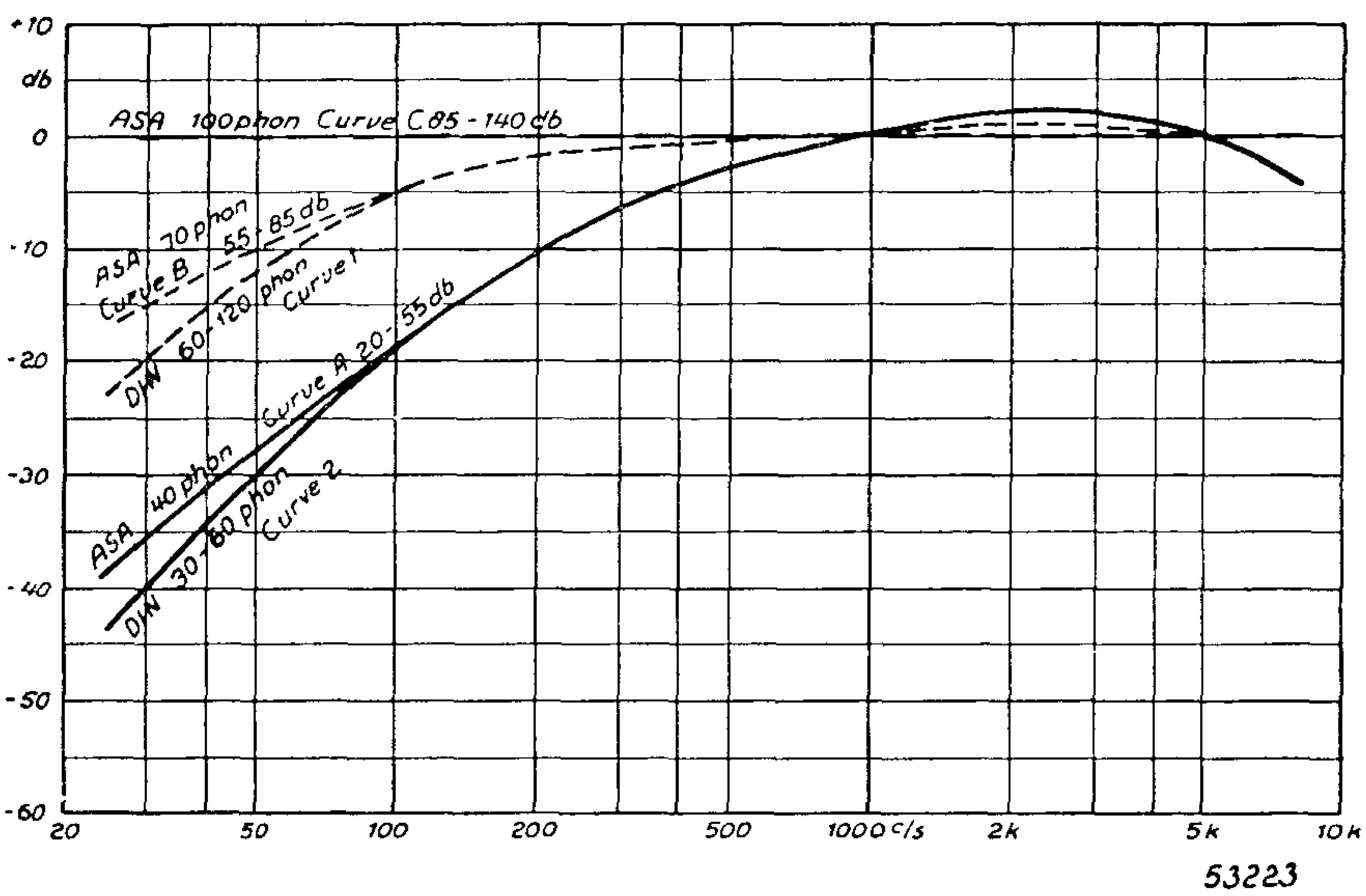


Fig. 25. The standardized frequency characteristics for sound level meters.

The noise measurements themselves are carried out just as described for measurements of sound pressure, but instead of reading off the deflection in mV and converting to sound pressures, the deflection is read off on the instrument's db scale and to this is added the phon value farthest out on "Meter Range" and "Range Multiplier". All the three figures have to be added together. These phon values are so chosen that with a sensitivity of the condenser microphone of 5 mV per μbar no correction is necessary. In general the sensitivity will be less, and a number K must be added to the collected phon readings, where $K = 14 - 20 \log \frac{\text{sensitivity in mV}/\mu\text{bar}}{1\ \text{mV}/\mu\text{bar}}$ This is valid when the spectrometer's sensitivity is adjusted in the usual way. In case many measurements have to be made and it is wished to avoid this correction, the sensitivity of the Analyzer can be increased by K db, on the supposition that K is a small number.

Weighted Spectrograms.

Almost every time a noise level measurement is taken it is necessary to analyze the frequency composition of the noise. However, a curve of sound pressure in μbar against the different frequencies cannot be used directly to judge the most disturbing frequency ranges. The spectrograms must first be corrected to the ear's frequency sensitivity by means of the ear-sensitivity curves of fig. 24. When the spectrogram has been corrected in this way it is described as "weighted" with reference to the ear's sensitvity. It is important that the appropriate level-curve be chosen for the calculations.

An example is shown in fig. 26, where the thin recorded curve shows the sound pressure as a function of frequency, for noise from a grindstone. The total noise was approx. 65 phons, so the 60-phon curve of fig. 24 is used for calculating the weighted spectrum. The calculations are seen above the

weighted Spectrogram	14	35	21	18	36	22	33	42	41	40	45	47	51	50	47	45	46	47	45	52	54	39	32	21	12	7	-5
Subtract ac. 60 phon	22	19	17	14	11	9	7	5	4	3	2	1	0	0	0	0	0	-1	-1	-2	-2	0	5	11	12	15	25
real value db	36	54	38	32	47	31	40	47	45	43	47	48	51	50	47	46	46	46	44	50	52	39	37	32	24	22	20

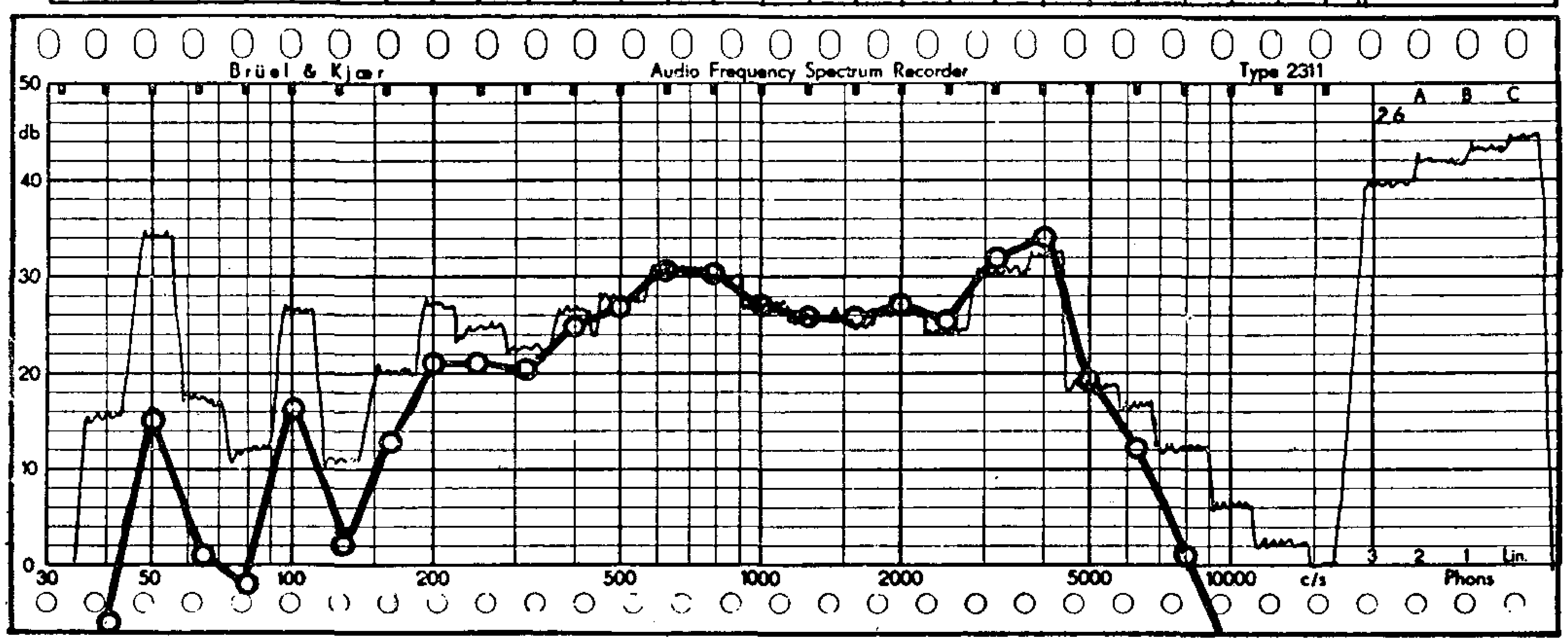


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Fig. 26. Spectrogram of sound pressure in noise from a grinding machine (fine curve) and the same spectrogram weighted with reference to the sensitvity of the ear (heavy curve).

recorded curve, and the result is shown drawn in on the curve as round circles connected by a heavy thick line. It is clearly seen that the noise which, measured in μbar, was strongest at quite low frequencies, was most powerful in the middle range, when judged subjectively, the lower frequencies having less importance for the human ear at the noise level in question.

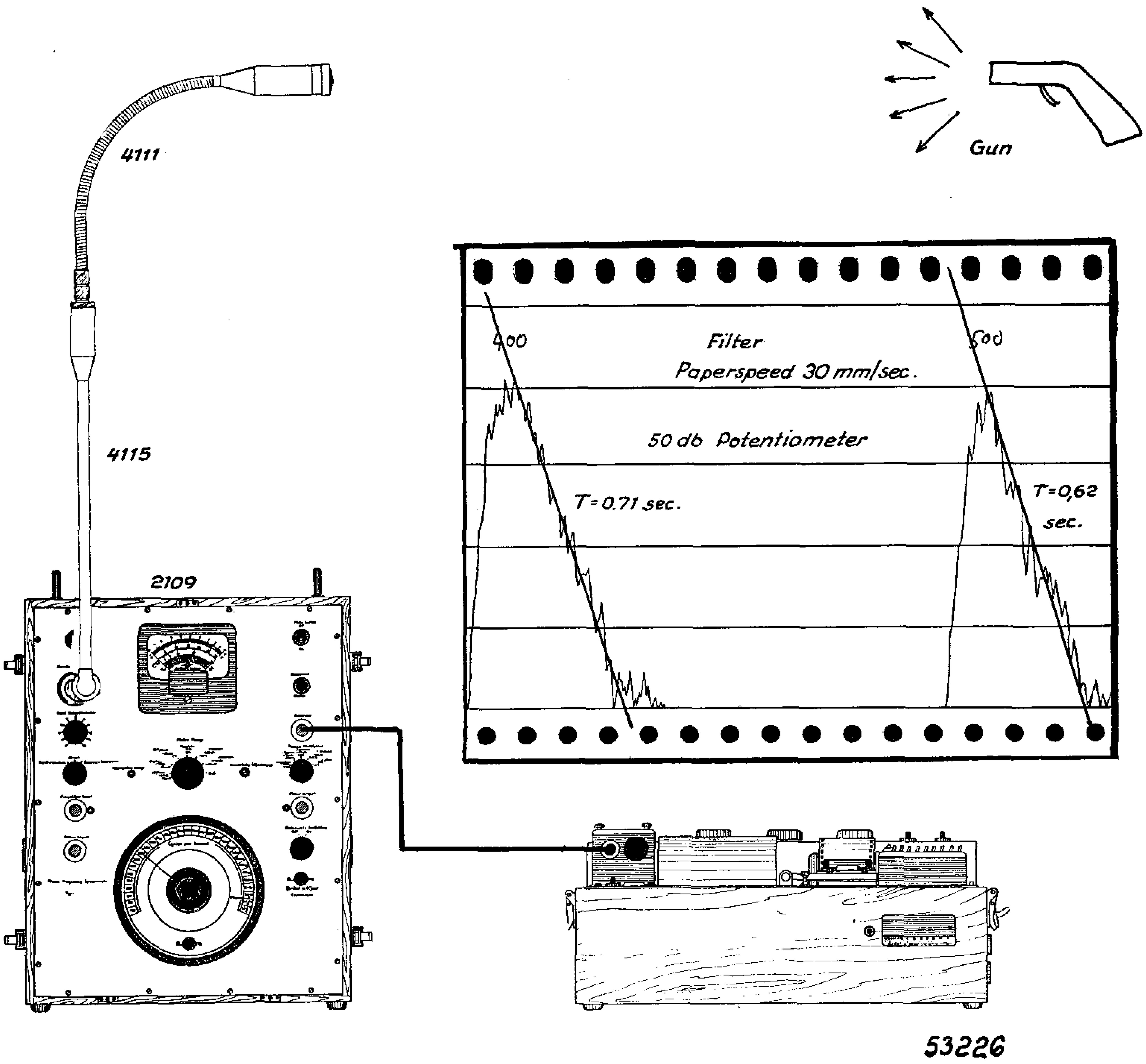


Fig. 27a. Measuring reverberation time with a gun as sound source.

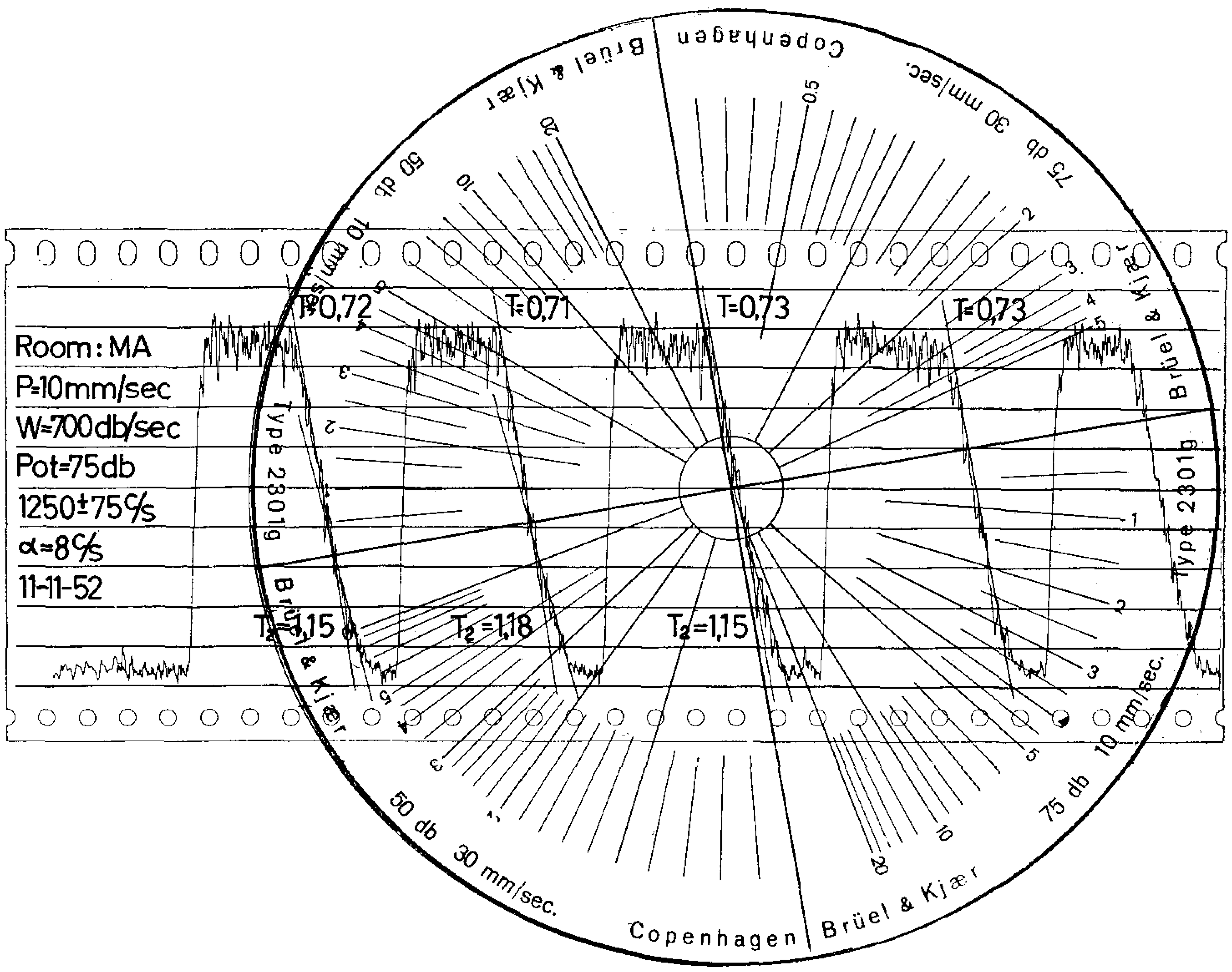
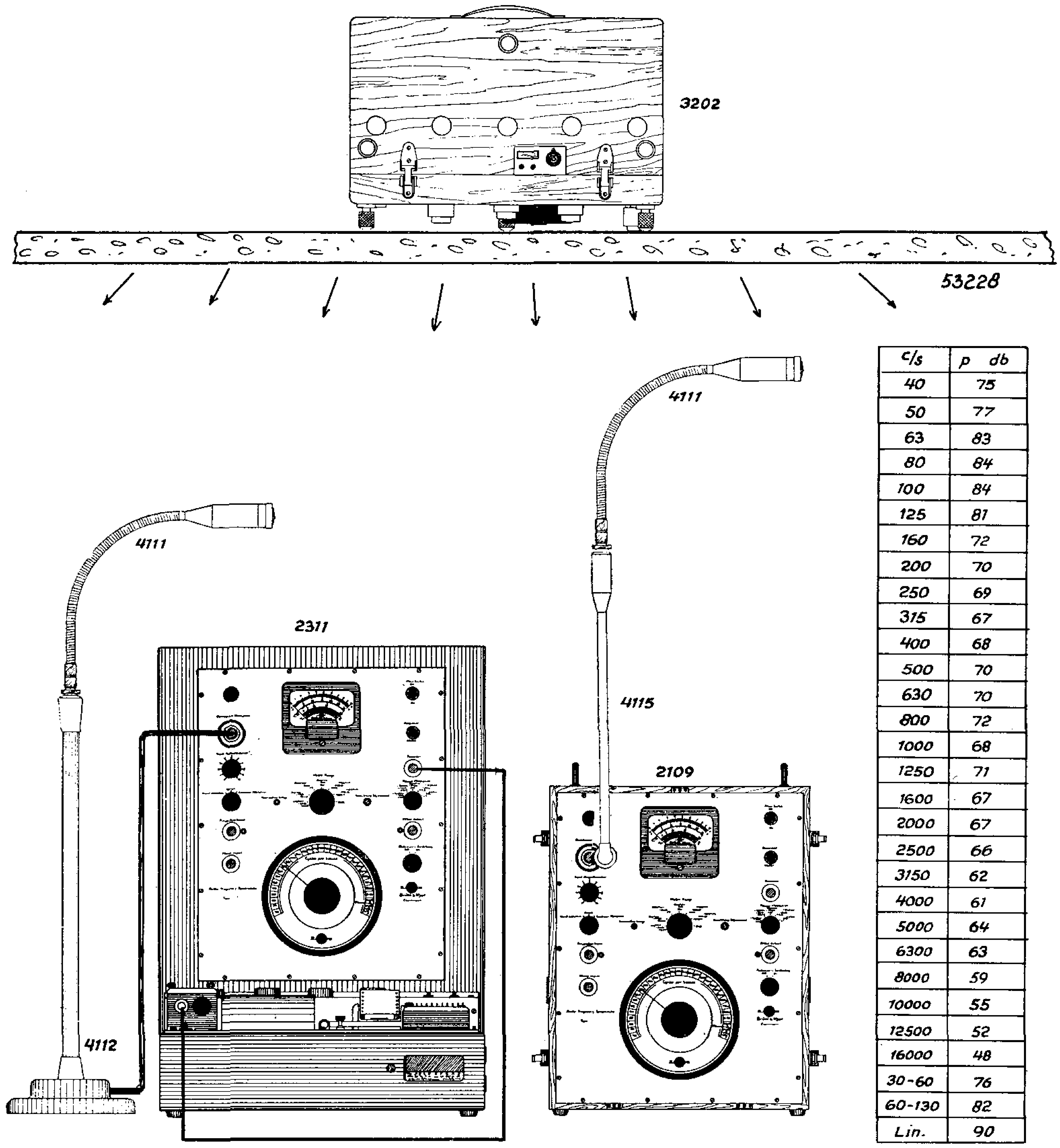


Fig. 27b. Measuring reverberation time with Protractor 2361. Curves taken with BFO Type 1012 with warble tone as sound source.

Measurement of Reverberation Time.

When measuring reverberation time with a gun used as a sound source, it is necessary to have selective amplification when recording the level curves with the Level Recorder Type 2304. The set-up is shown in fig. 27a, where



c/s	p db
40	75
50	77
63	83
80	84
100	84
125	81
160	72
200	70
250	69
315	67
400	68
500	70
630	70
800	72
1000	68
1250	71
1600	67
2000	67
2500	66
3150	62
4000	61
5000	64
6300	63
8000	59
10000	55
12500	52
16000	48
30-60	76
60-130	82
Lin.	90

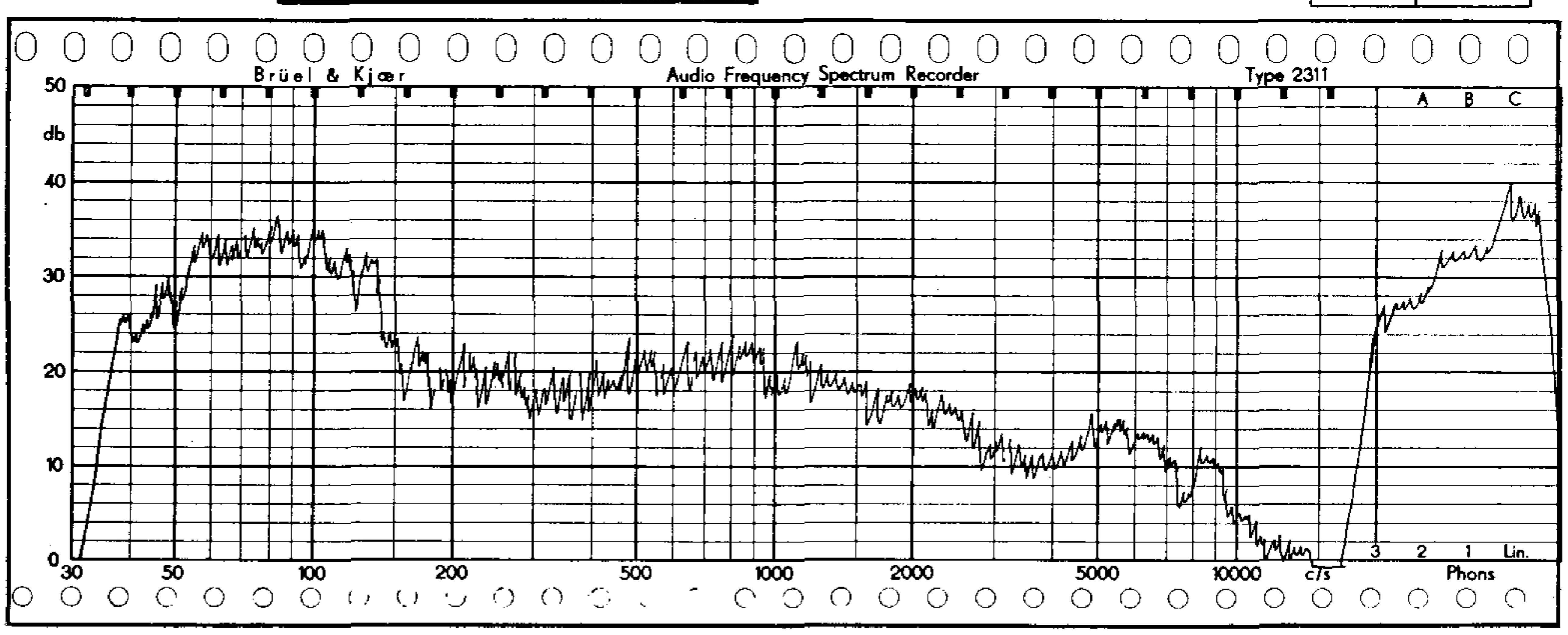


Fig. 28. Measurement and analysis of impact sound.

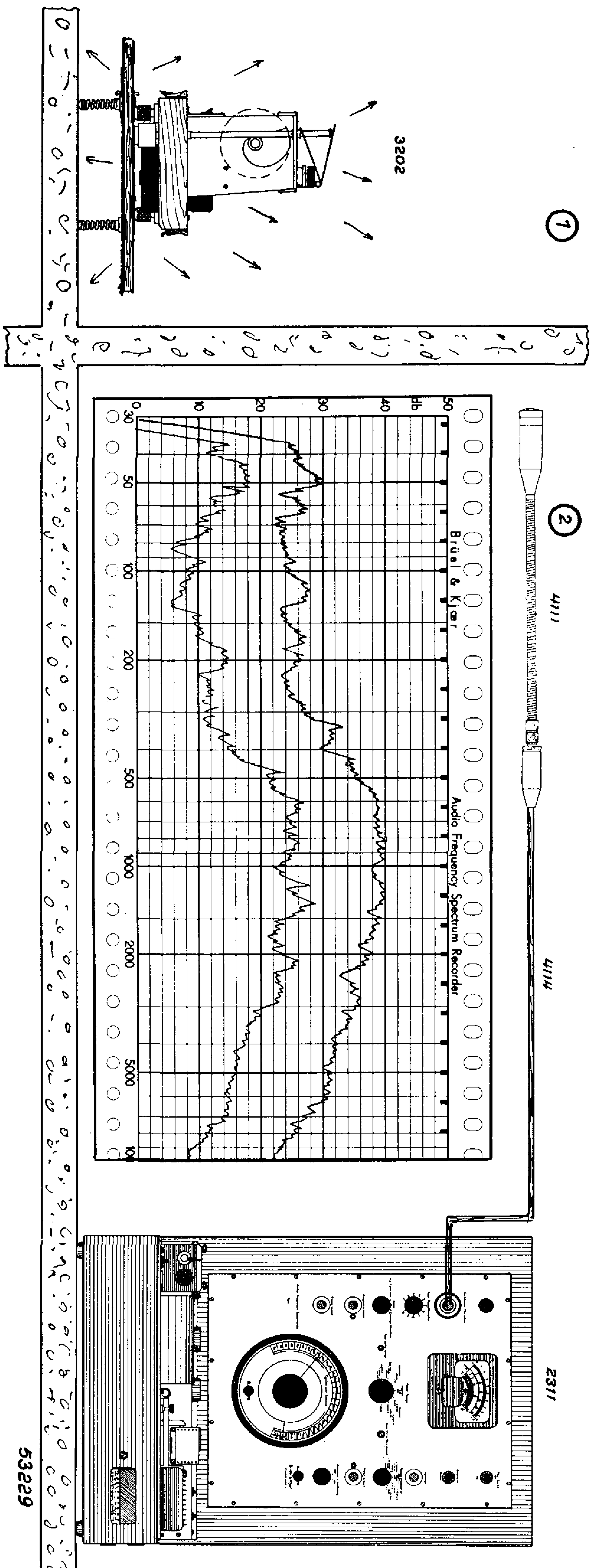


Fig 29. Measurement of airborne sound insulation by using an impact sound generator as "white noise generator".

some typical reverberation curves are also given. It is recommended to take at least 3—4 shots in each frequency band. Also when using a Beat Frequency Oscillator with warble tone as sound source it is strongly recommended to have selective amplification, because it is possible here to record the reverberation curves over a much larger level range than when using a linear amplifier after the microphone. In fig. 27b are shown some typical reverberation curves. When the reverberation curves are recorded over a large level range it often shows up that the reverberation curves are a little curved in the last part, indicating some flutter echo in the rooms. On the figure are shown the two different reverberation times got from the upper and lower part of the curves. At the same time the use of the Protractor 2361 is shown.

Measurement of Impact Sound.

The sound insulation of a floor for impact sounds is estimated by placing a standardised impact sound generator on the floor, and measuring the sound intensity L in the room below for various frequency bands. In the "Tentative Standards" for these measurements it is recommended to use $^{1}/_{3}$-octave filters for the estimation of the sound pressure, and it is recommended that the results be given in the form of a curve as a function of frequency or in tabular form as shown in fig. 28. The effective tapping level in a specific frequency band will then be given by the equation

$$L_{eff} = L - 10 \log \frac{T}{0.5}$$

where T is the measured reverberation time in seconds in the receiving room in the frequency band in question. If one wishes to express the tapping level by a single figure L_A this can be calculated by means of a known described method, but it is always recommended to take a spectrogram of the sound under the floor in question, as this spectrogram is very important for judging the floor's quality.

Insulation Measurement of Airborne Sound.

For insulation measurements of airborne sound through partitions, doors, windows etc, $^{1}/_{3}$-octave filters are also recommended by the tentative standards mentioned, in the case where white noise is used. According to these standards these measurements should be carried out at the mid-frequencies of the filters of Spectrometer 2109 from 100 to 3200 c/s. The airborne sound insulation of a partition between two rooms is measured with the white noise generator on one side of the wall and the Condenser Microphone plus Spectrometer first in the transmission room and then in the receiver room. From the difference between the two readings the air-borne sound insulation D is found as a function of the frequency, when correction is made for the absorption of the receiver room according to the formula

$$D = 20 \log \frac{p_1}{p_2} + 10 \log \frac{F}{A_2}$$

where F is the area of the wall between room 1 and 2 and A_2 the absorption of the receiver room, both measured in the same units.

If the sound pressure of the noise as a function of frequency is recorded in the two rooms, the sound pressure relation between the two rooms can be directly estimated from the difference between the two curves, and thus the figure for the wall's insulation, D.

When the wall is highly insulating, it is convenient to decrease the amplification of the Spectrometer with the measurement in the transmitter room, which can be easily done, as the amplifier section has very exact attenuators. In fig. 29 the insulation measurement is shown using an impact sound generator as white noise generator, which is possible in those cases where no white noise generator is available. The impact sound generator is in this case placed on a wooden board, which again is placed on springs, so that practically all the sound energy from the impact sound generator is radiated as airborne sound and only a very small amount as impact sound.

Recording and Analysis of Fluctuating Noise.

In many workshops or offices the noise level varies very considerably, and if the noise level is measured in such places by taking a single reading, a serious error will often be made because of these fluctuations in the level, and if one furthermore wishes to take a spectrogram, the fluctuations will be still greater, as the noise variations in a small frequency band are always much greater than the average value from all the frequencies. In such a case it is necessary

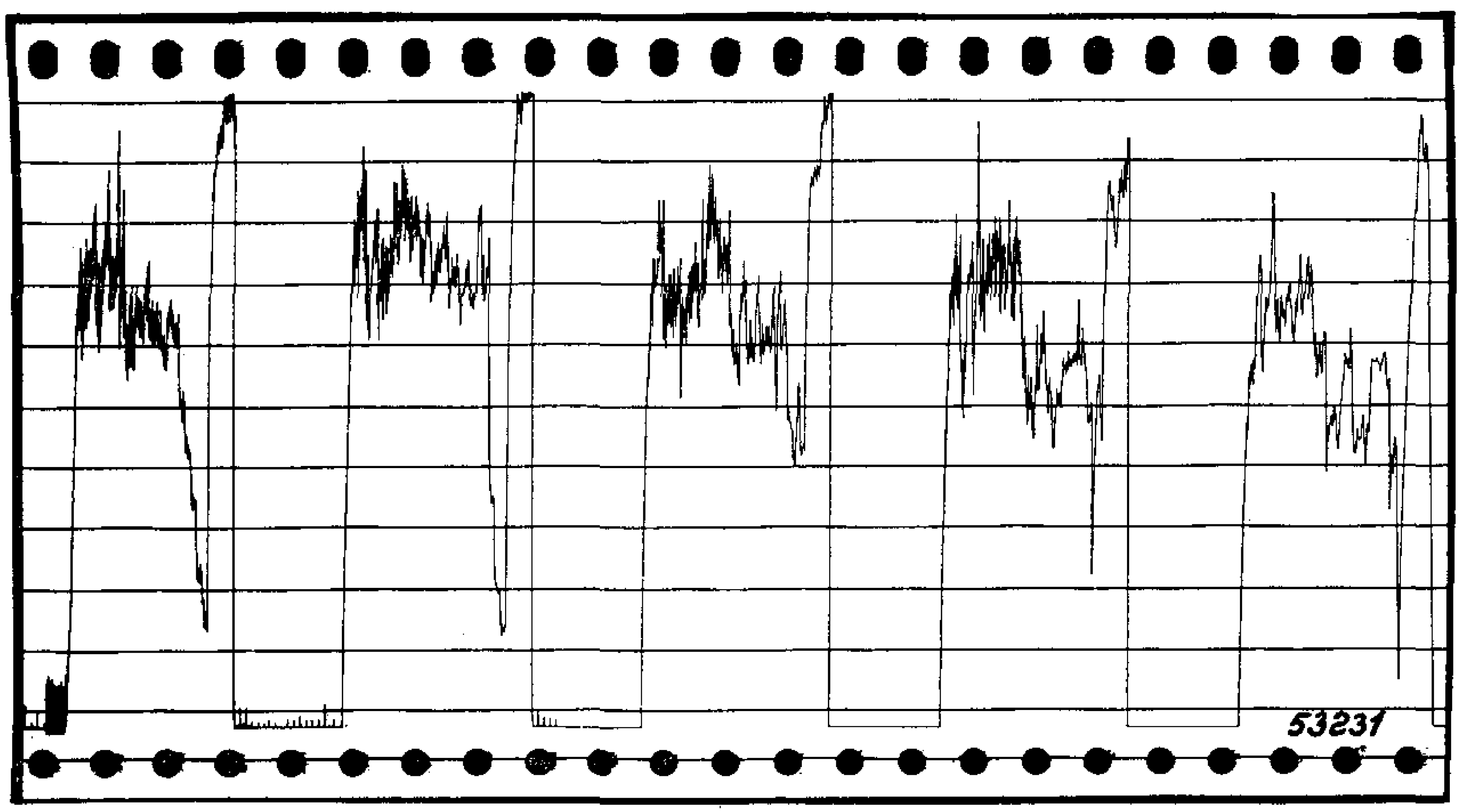


Fig. 30a. Continuous recording of spectrograms and noise levels.

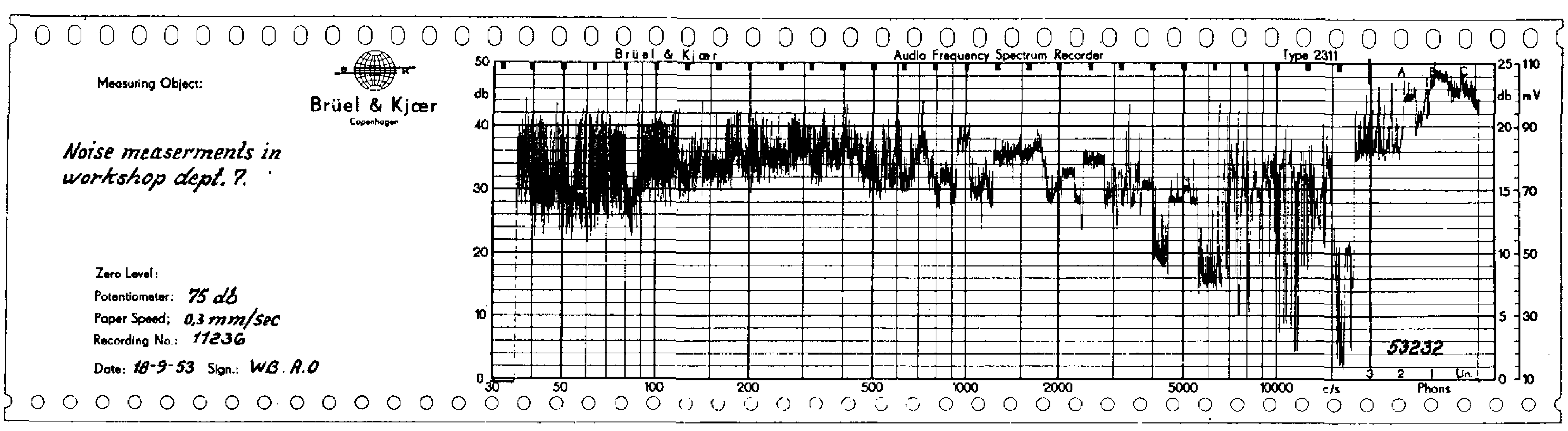


Fig. 30b. Long time recording of spectrograms and noise levels.

to record both spectrograms and noise level over a relatively long period of time, so that a satisfactory average figure can be obtained, and so that the noise peaks can also be observed, which is of particular interest from a health point of view. With the recording equipment consisting of Condenser Microphone 4111 and the Audio Frequency Spectrum Recorder 2311, there are two possible methods to follow. The first way is to take a whole series of spectrograms one after the other, as shown for example in fig. 30a, where the recording of each spectrogram has taken approx. 24 sec. When a long series of these spectrograms has been obtained for a given room or workshop, they can be compared and the maxima for the different frequencies found from them. This method requires much time, and almost as good results can be obtained by using the method shown in fig. 30b, where a spectrogram with a very slow paper speed has been taken in a workshop, i. e., the recorder is allowed to stay on each individual filter a very long time. The curve shown has taken 20 minutes in all to record. In this way the total number of fluctuations is obtained for each filter, and also the maximum sound strength effective in each frequency band. If very precise measurements are desired, these recordings should be repeated over a longer period, for example a whole day, with three recordings per hour.

Direct Recording of Harmonics.

A special application of the Audio Frequency Spectrometer 2109 which is of importance, is in the field of loudspeaker, microphone and hearing aid investigations. With regard to measurements of non-linearity, characterized by the production of harmonics when the system is driven by a constant sinusoidal tone, or, in the case where two or more constant tones are supplied to the system, by the generation of new tones with frequencies corresponding to the sum and difference frequencies, two different methods exist. First, the normal test of measuring the harmonics of the single tone with which the system is driven by means of a wave analyzer. Secondly, the intermodulation measurements either with one fixed and one gliding frequency or with two gliding frequencies with constant difference. Of these two methods the first had, however, this disadvantage, that continuous recordings of the harmonics were impossible, whereas with intermodulation measurements the resulting difference tone produced by the loudspeaker or hearing-aid can be recorded on the Level Recorder, giving consequently more information, especially for the higher frequencies, where bigger peaks and valleys are to be expected for the harmonics, due to the complexity of the vibration pattern of the cone or diaphragm. One of the disadvantages of the more modern intermodulation method on the other hand is the absence of a correlation between the results of the measurements and the distortion of the system. With the combination of Automatic Frequency Response Recorder 2314 (or combination BFO 1012 plus Level Revorder 2334) and the Spectrometer 2109, however, continuous recording of the harmonics in acoustic as well as in electrical systems can easily be performed. The method is demonstrated with the set-up in fig. 31,

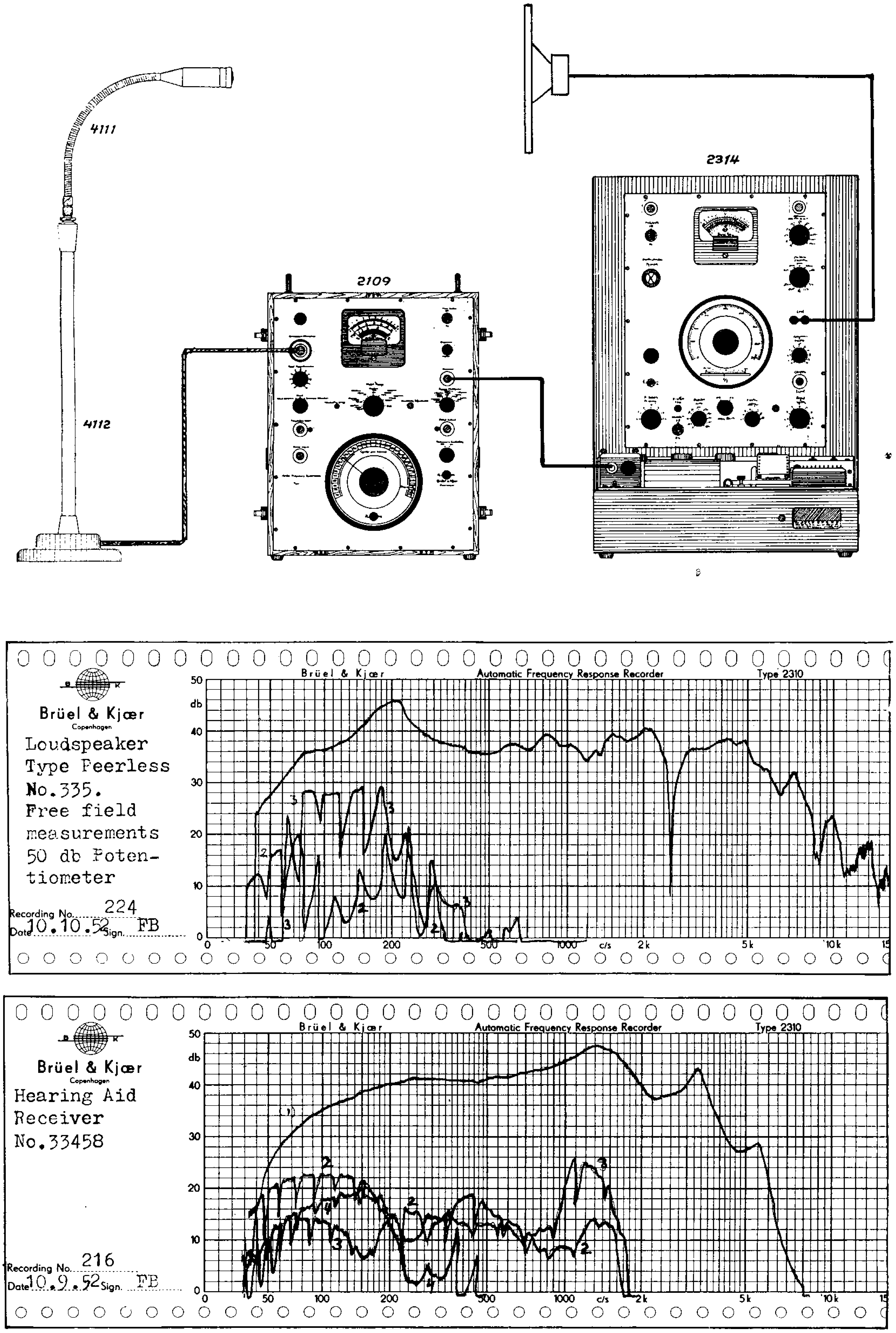


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Fig. 31. Above: recording of loudspeaker's frequency characteristic, and the lowest harmonics. Below: Frequency characteristic and harmonics of hearing aid receiver.

a loudspeaker investigation to be carried out in an anecho room or under free-field conditions.

With the Audio Frequency Spectrometer on linear the normal frequency response curve of the loudspeaker is recorded on paper type 2357 with frequency scale preprinted specially for the 2314 combination. After this the recording paper on the Level Recorder is rolled back, the stylus set on 22.3 c/s and the pointer of the Spectrometer's main scale set on filter 50 c/s. Then,

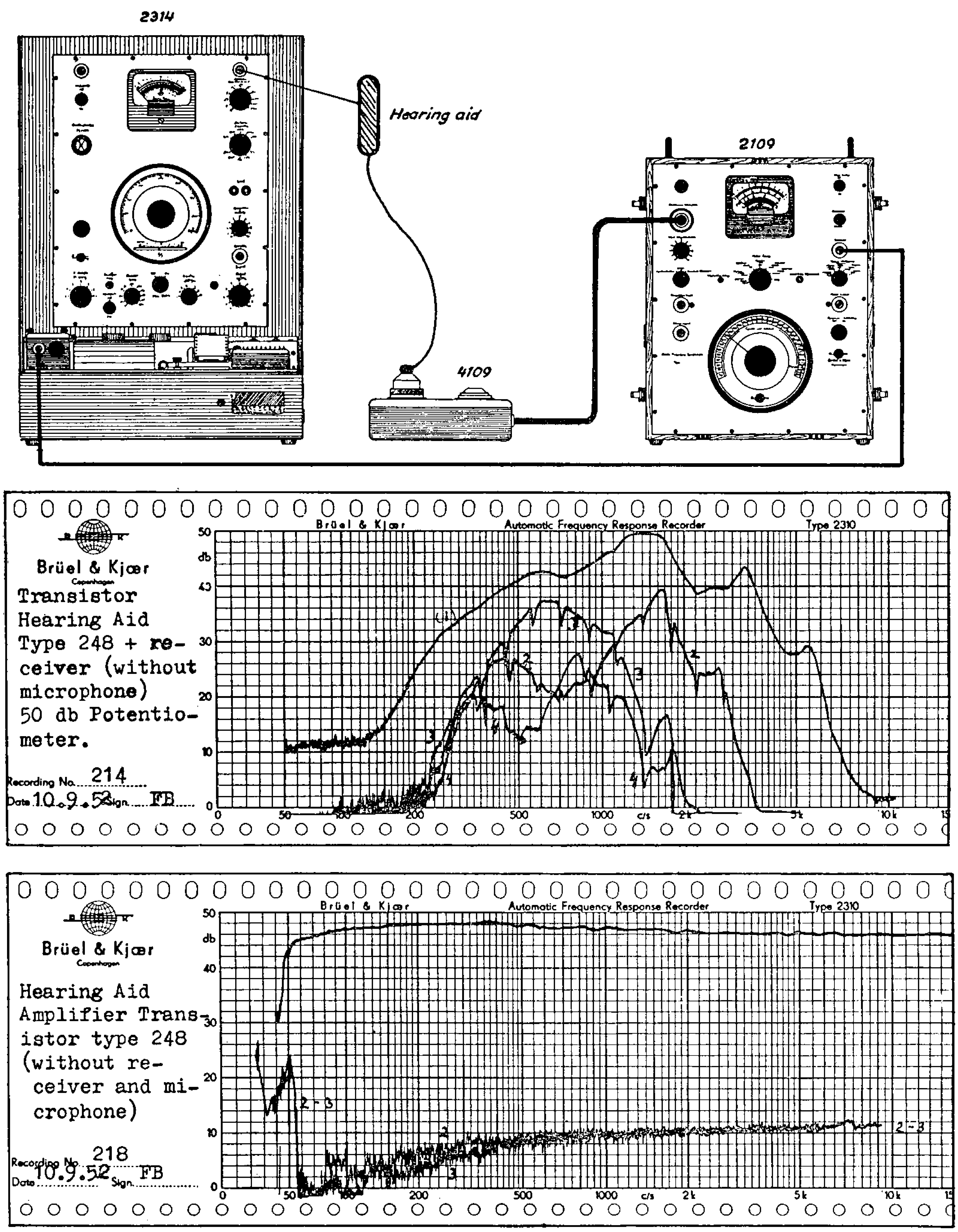

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Fig. 32. Recording of fundamental and lowest harmonics: above, of hearing aid with receiver, and below, of hearing aid amplifier of the transistor type.

while the combination 2314 automatically drives the BFO, the Spectrometer is shifted manually to the subsequent filters according to a table given in our manual for type 2109.

In order to carry out this shift with sufficient precision a relatively long time must be allowed for running through the whole frequency range. For example, 2314 could be suitably adjusted to give a paper speed of 1 mm per second. With this procedure the Spectrometer is continuously one octave in advance of the fundamental generated by the BFO and functions thus as a bandpass filter for the second harmonic of this tone. For the third harmonic the Spectrometer should be $1^1/_2$ octave ahead, for the fourth harmonic two octaves and so on. In the case of a loudspeaker investigation, these recordings can be performed either under constant current or constant voltage conditions, while different measurements are necessary for different acoustical outputs from the loudspeaker.

The curves shown in fig. 31 below are for a hearing-aid receiver and are recorded with an analogous set-up, the loudspeaker being replaced by the hearing-aid receiver mounted on the coupler of the artificial ear 4109 and fed by the BFO 1012 via the attenuator. Apart from the regularly spaced dips of the switching points, these curves show a smooth course of second, third and fourth harmonics with frequency, whereby the second and fourth harmonics show their maxima for lower frequencies but the third harmonic at higher frequency.

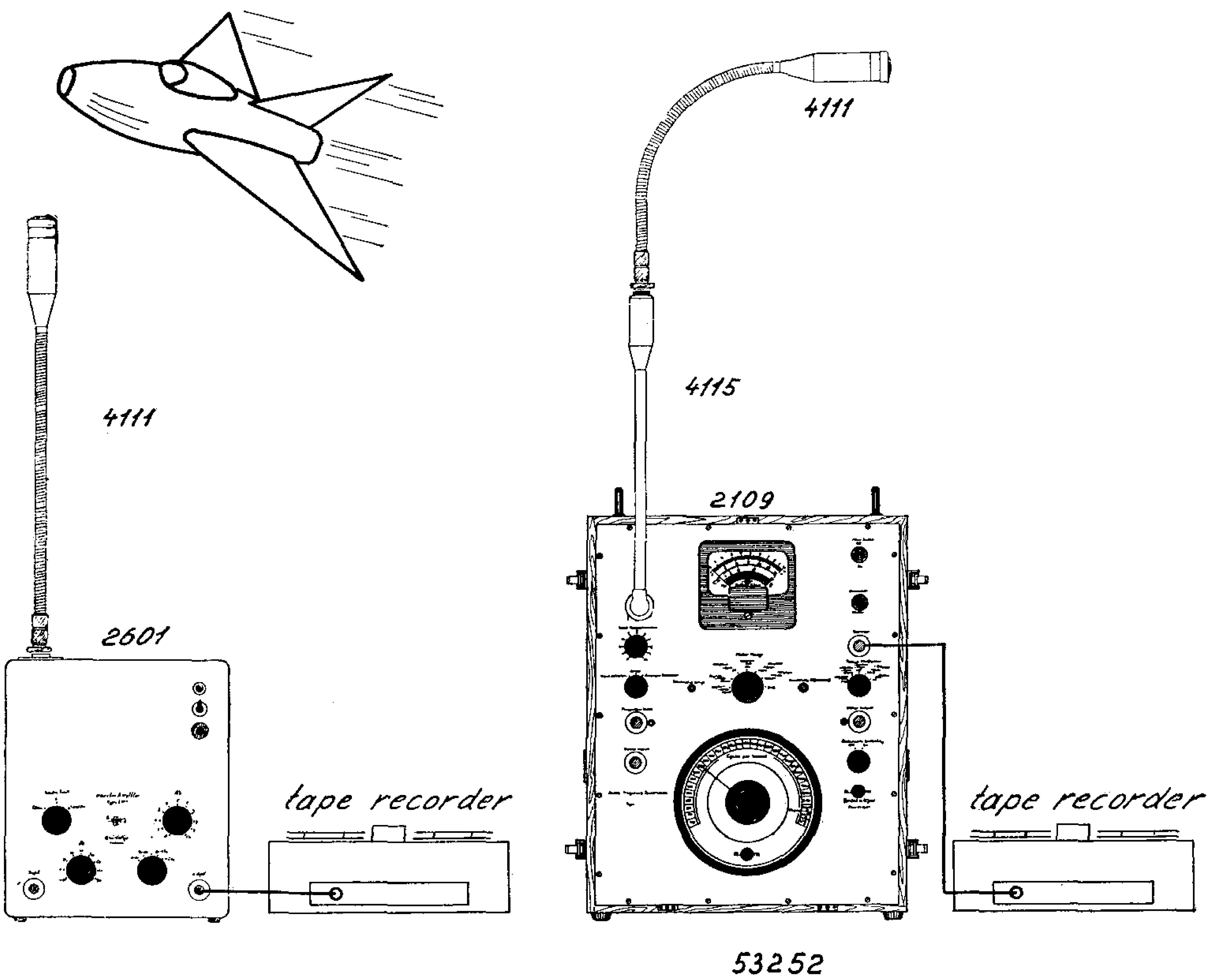


Fig. 33. Recording of transient noise on a tape recorder.

Fig. 32 finally shows the distortion for a hearing-aid amplifier (without microphone) plus receiver, and hearing-aid amplifier alone. For the transistor amplifier it will be seen that the second and third harmonics almost merge together into one curve and that this curve lies a long way from the fundamental, which means that the distortion has been slight. The harmonics lie 36—40 db below the fundamental, i.e., the distortion factor has been about 1—2 %. The major part of the distortion of the combination is, as was to be expected, caused by the receiver.

Analysis of Transients.

The Audio Frequency Spectrum Recorder 2311 or the combination of Spectrometer 2109 and Level Recorder 2304 is particularly suitable for the analysis of transients, as a recording is possible with this equipment giving amplitudes as a function both of time and frequency. This kind of analysis has shown itself especially valuable for transients of noise from rockets, guided missiles, low flying aircraft, motor vehicles etc., as well as of the vibrations or noise from periodically working machines, as for example drilling machines, large Diesel engines and so on.

The method is as follows:

The relatively short-duration noise to be analyzed is recorded on a good tape recorder, fig. 33. As microphone the Condenser Microphone 4111 is employed, and as amplifier the Microphone Amplifier 2601 or the Audio Frequency Spectrometer 2109.

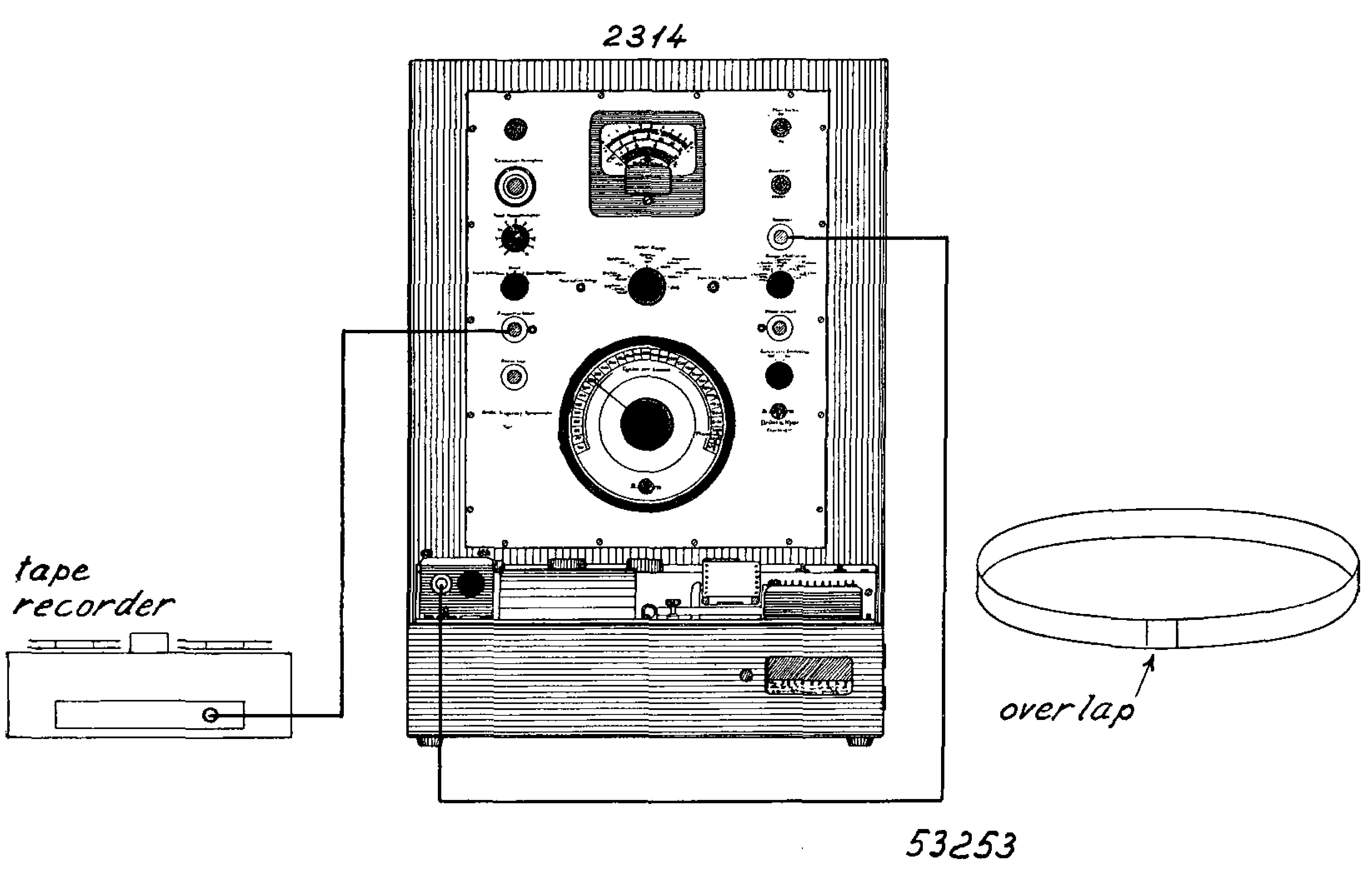
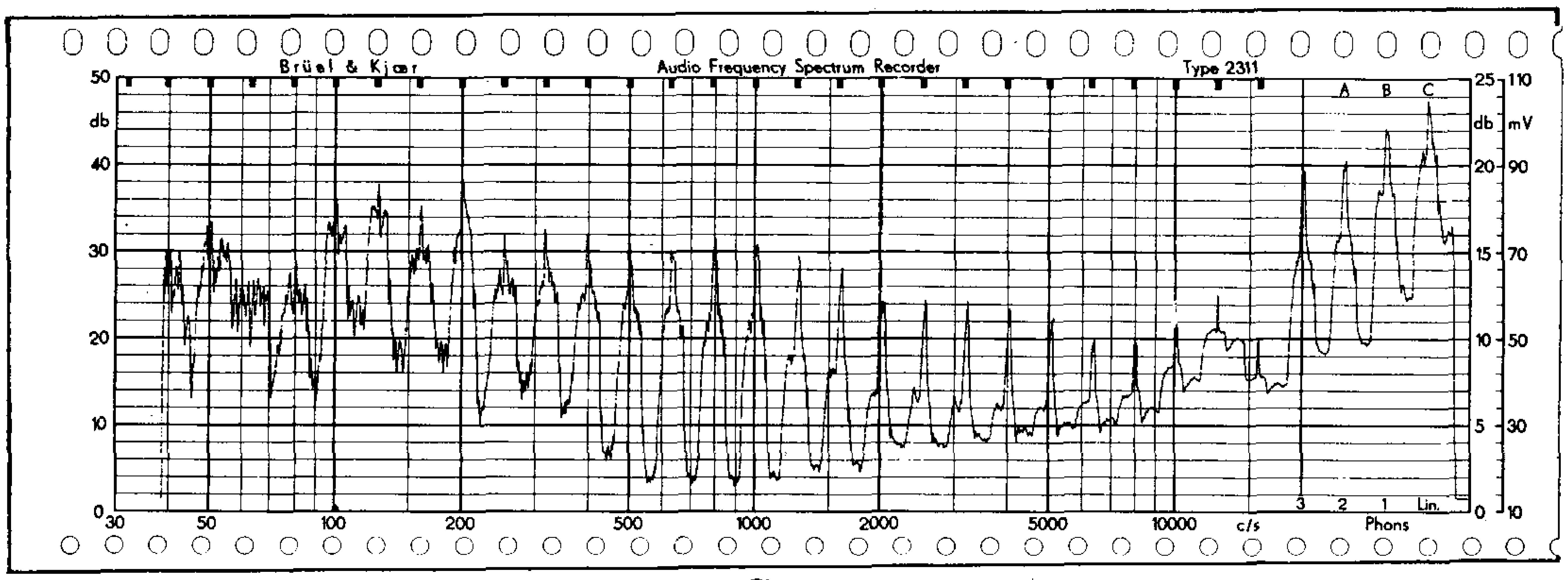
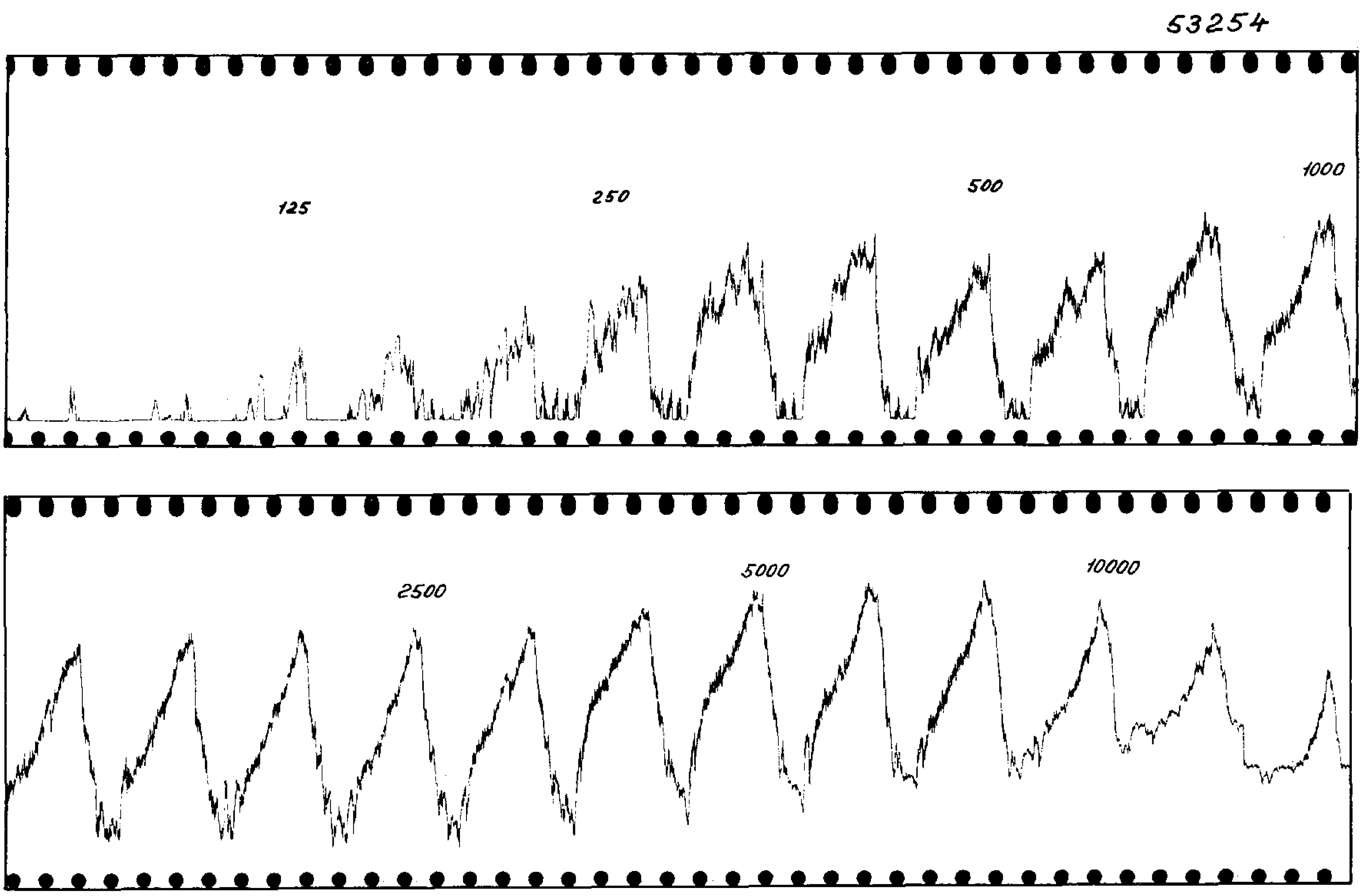


Fig. 34. Playing off a tape-loop for the recording of transient noise.

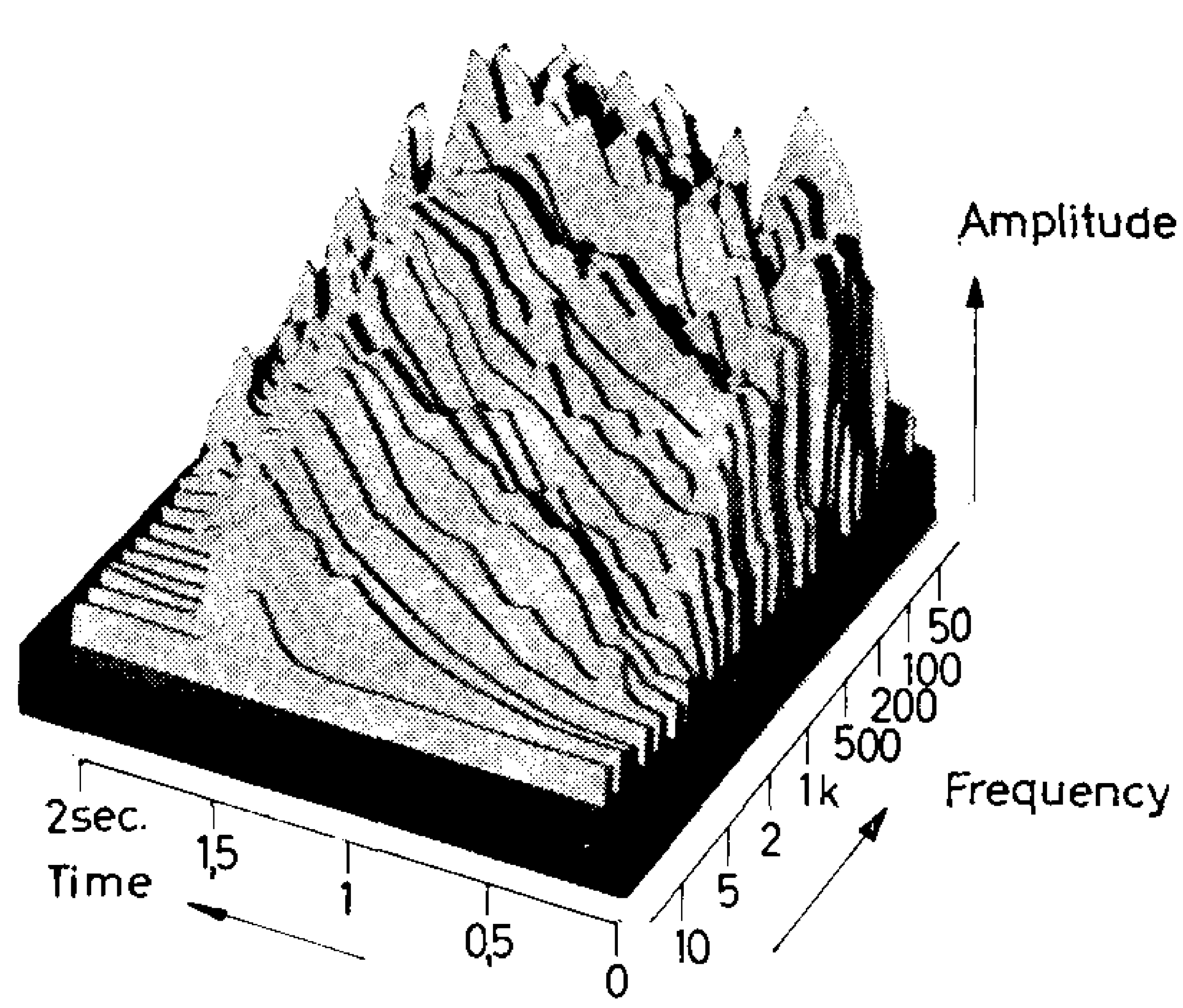


a



b

Fig. 35. Transient analysis of
a) a bang made in a small room,
b) a passing motorcycle suddenly stopping,
c) as b, but in a 3-dimensional representation.



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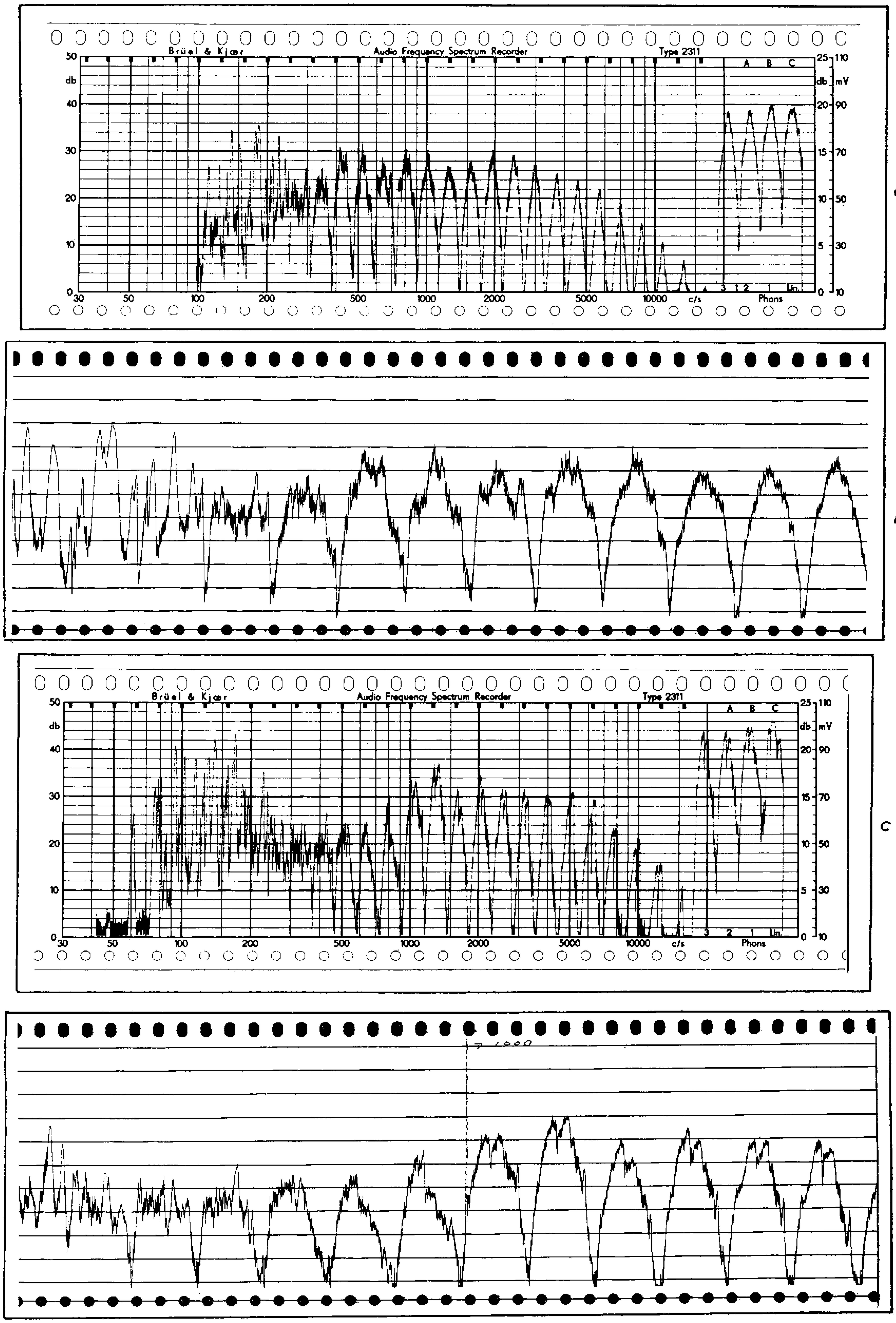


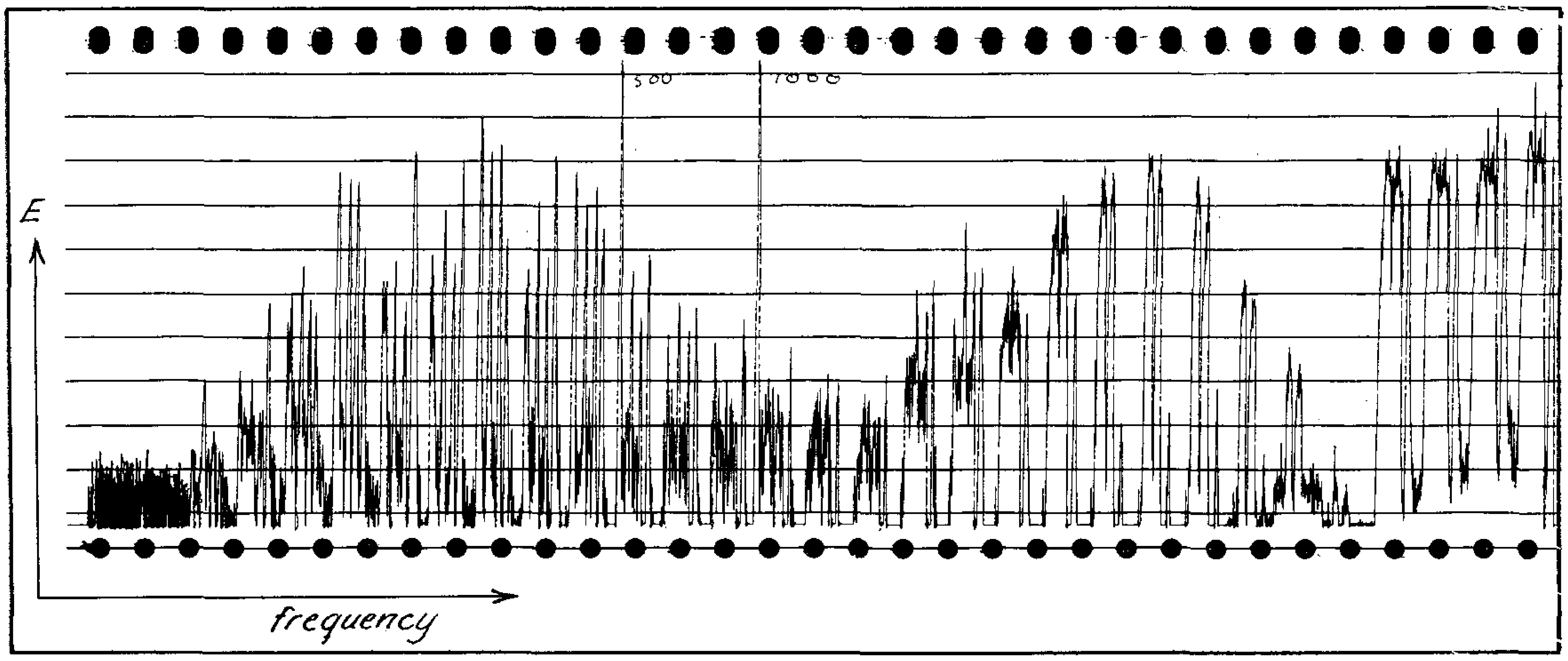
a

b

c

d

Fig. 36. a) Noise of an automobile recorded at motor.
Loop 91.5 cm, wheel C, P = 1 mm/s, W = 300 db/s.
b) as a. P = 3 mm/s.
c) noise of an automobile recorded at exhaust-pipe.
Loop 91.5 cm, wheel C, P = 1 mm/s, W = 300 db/s.
d) as c. P = 3 mm/s.



a

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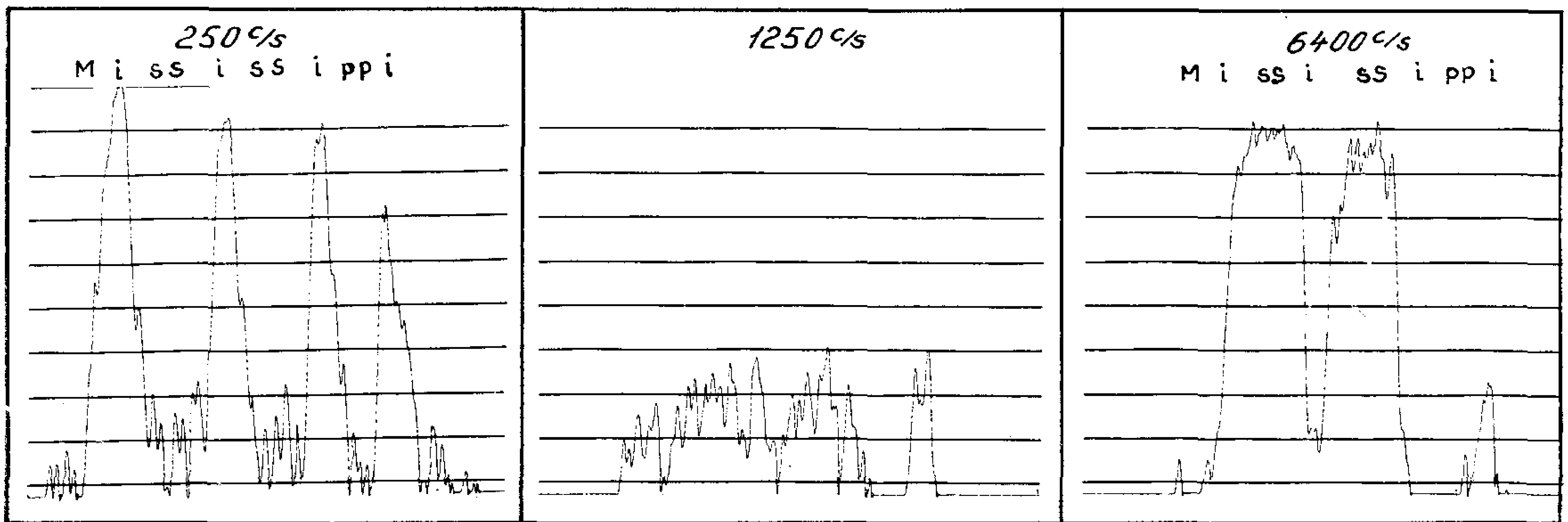
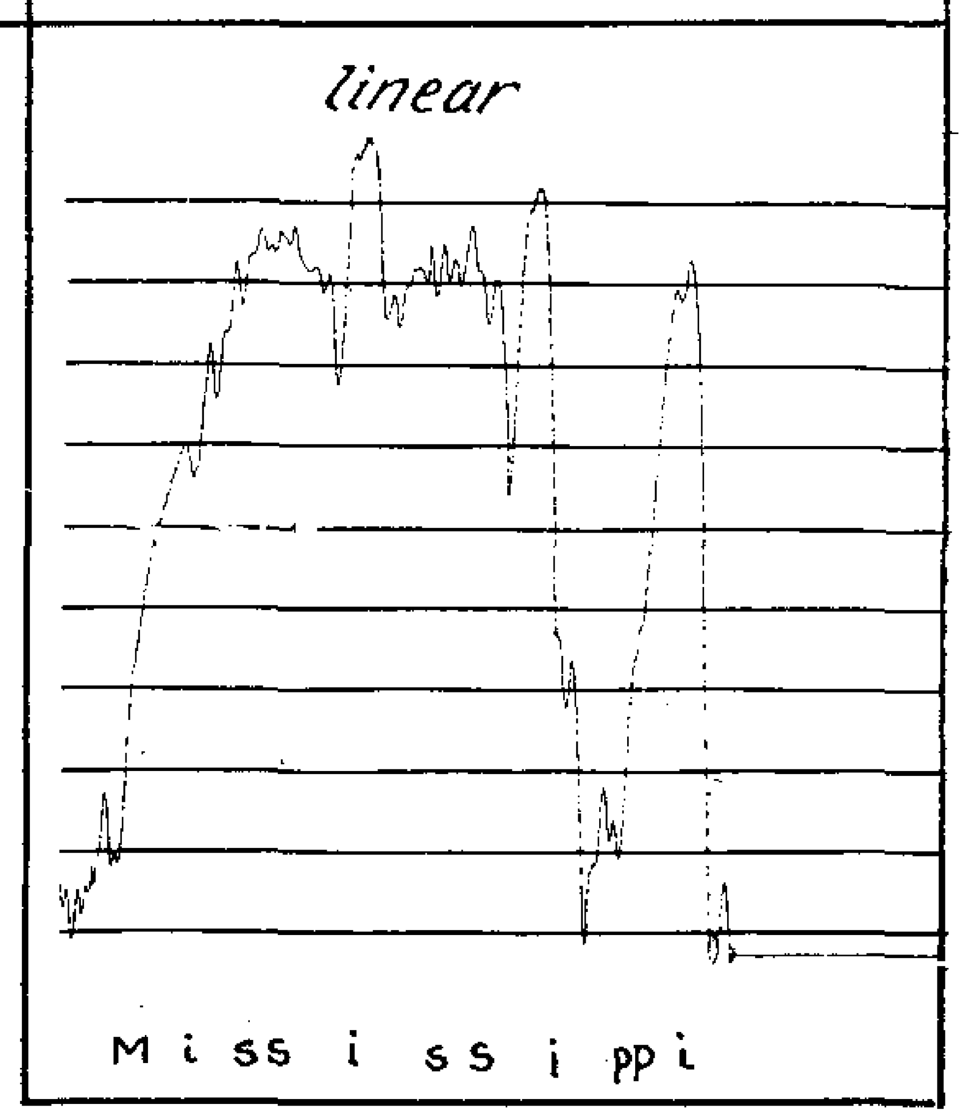


b.



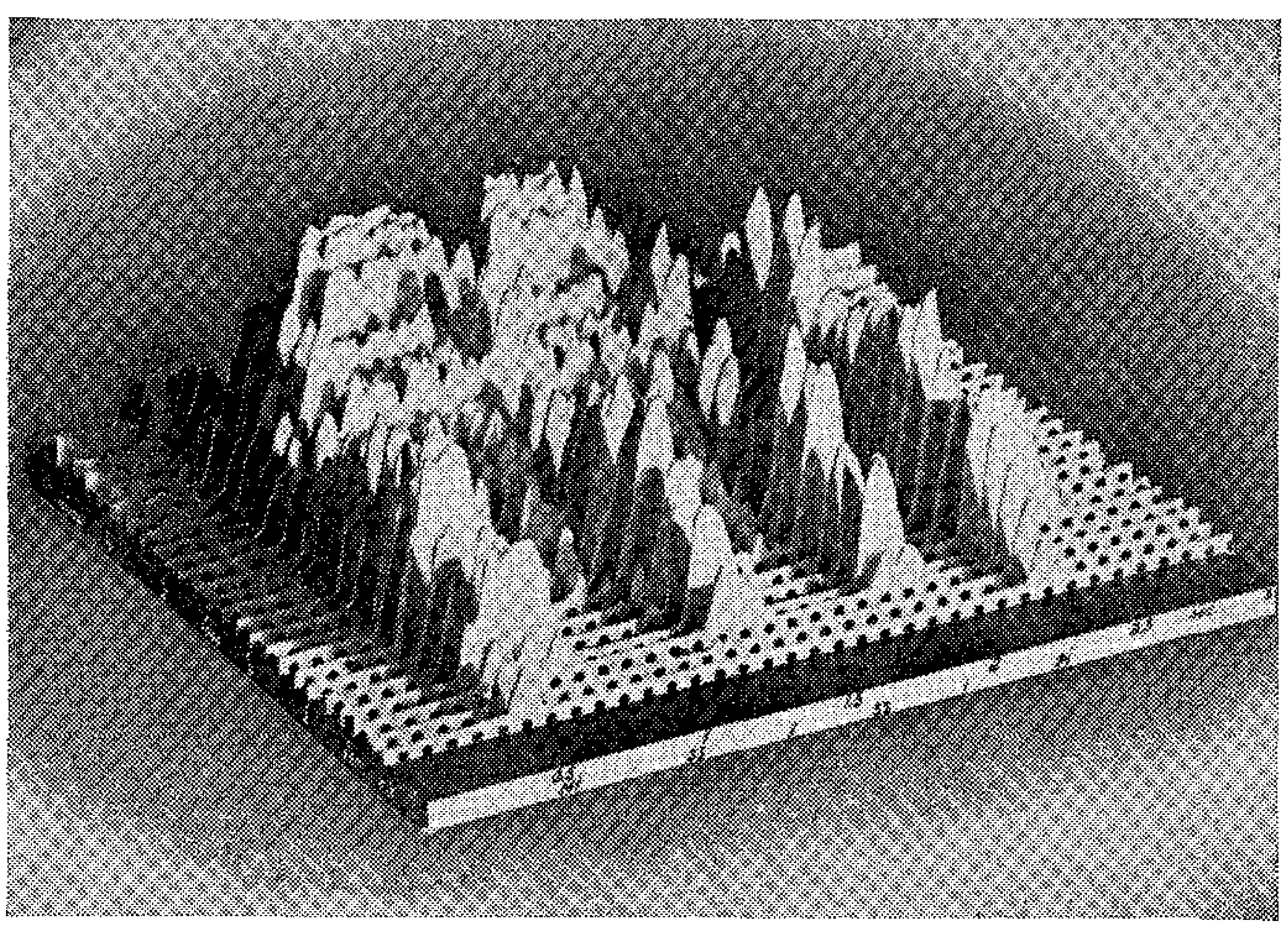


Fig. 37. Analysis of the word "Mississippi"

a) P = 3 mm/s W = 500 db/s

b) P = 30 mm/s W = 1000 db/s

c) P = 100 mm/s W = 1000 db/s

After this, that part of the tape containing the noise one is interested in is cut out, folded as a loop and the ends glued together. The length of the loop should now be accurately synchronized with the time it takes for the Spectrometer to switch from one filter to the other, for those cases where type 2109 is automatically driven by the Level Recorder when the loop is played off again on the tape recorder.

This synchronizing is discussed in our manual 2109, and only recommended in case preprinted recording paper type 3601—3603 is used. The result of such a recording of all the filters together on 133 mm paper length effaces of course the details of the transient noise as recorded by each filter separately. Taking a higher paper speed will yield more details, as can clearly be seen from the different examples, and is easier performed with manual switching of the filters. For this purpose the tape is touched at a small distance from where the ends are glued together by a point magnet, so that a clicking noise is heard when playing off.

In fig. 35, 36 and 37 a series of characteristic examples of analyses of different sounds is shown, made in the way described.

Fig. 35a shows the transient analysis of a bang made in a small room. The over-all energy distribution of this noise is to be seen together with the course of the amplitude for each filter. The tape loop was in this case 30.5 cm long and synchronized with the combination wheel B and paper speed 3 mm/sec., so that the paper type 3603 with its preprinted frequency scale could be made use of. The writing speed is 300 db/s.

Fig. 35 b is a recording without synchronization, the loop being so long that the whole phenomenon of a passing motorcycle stopping suddenly could be recorded. W = 300 db/s. P = 3 mm/sec. With a paper speed of 10 mm/s the length of the recording per filter is sufficiently extended to make a 3-dimensional representation possible by cutting out each filter recording and placing these curves parallel behind each other perpendicularly to a third axis representing frequency. Fig. 35 c shows a picture of such a 3-dimensional noise spectrogram.

Fig. 36 gives 2 noise-analyses, one recorded at the motor of an automobile, the other at the exhaust-pipe. In both cases a synchronized as well as an extended recording was made (the latter only partly given here).

Fig. 37 shows the analysis of the word "Mississippi". Fig. 37 a gives the energy distribution, fig. 37 b some particular filters recorded with 10 times higher paper speed, showing clearly for the high frequencies the two double s parts, whereas for the lower frequencies this item vanishes completely, but on the other hand the vocals show up distincly. Lastly, fig. 37 c shows the cover photo again of the three dimensional representation analogous to picture 35 c. The "valley" between the low and high frequencies running parallel to the time axis is clearly to be distinguished, as well as the necessary pause before the plosive consonant p, resulting in the gap, just in front of the "pi" ridge, parallel with the frequency axis.

Vibration Measurements and Analyses.

The A.F. Spectrometer and Automatic Spectrum Recorder are also very suitable for analysis and automatic spectrum recording of vibrations generated by machine parts, rotating as well as fixed, different wall constructions in buildings, vibrating parts in ships, etc.

The advantages of the 1/3 octave filters compared with the constant-percentage bandwidth principle, as applied in Frequency Analyzer type 2105, which is also suitable for vibration analysis, are to be found in the very quick overall estimation of the energy distribution of a vibrating object. With automatic recording, type 2311 yields, if necessary in 24 seconds, all information about the complete vibration spectrum, showing the position of the different resonant frequencies and the total vibratory energy in each 1/3 octave band. With the constant bandwidth analyzer it is impossible to cover the whole frequency range in a continuous measurement, it does not give direct information about the real energy distribution, but on the other hand allows the resonant frequencies to be determined very accurately.

Vibration measurements can be carried out with our Vibration Pick-up 4303 or 4304 and our Integration Network 1605 or 1604. The networks can be switched for connecting 3 different vibration pick-ups, whereas a second knob switches for acceleration-, velocity and deflection-amplitude measurements. The vibration pick-ups are piezo-electric pick-ups with a sensitivity for type 4303 of about 80 mV per 1000 cm/sec^2 and for type 4304 of about 20 mV/1000 cm/sec^2. The pick-up type 4303 can be used up to 1600 c/s and has a basic resonance frequency at about 2200 c/s. At this frequency the sensitivity is increased approx. 15 db. Type 4304 can be used up to 5000 c/s and has resonance at 6500—7000 c/s. The lower frequency limit is lower than that of the spectrometer.

Vibration Pick-up 4304 and Integration Network 1604.

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