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The Application and Generation of Audio Frequency Random Noise

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The Application and Generation of Audio Frequency Random Noise

by

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ABSTRACT

Following the definitions for various forms of random noise, some measuring arrangements for the determination of frequency spectra and amplitude distributions of statistically fluctuating signals are briefly described. After this the amplitude density curves for acoustical noise in workshops, different pieces of music and speech are measured and compared to the distribution characteristics of random noise.

The similarity in the type of distribution indicates that random noise is very useful as a sound source for acoustic and electro-acoustic measurements. A number of sound measuring arrangements utilizing random noise are thus shown and the properties of random noise are compared to the properties of the well-known warble tone sound generator.

Finally the development of a new Noise Generator Type 1402 is described and some examples of its application mentioned.

SOMMAIRE

Après un rappel des définitions du bruit blanc, à spectre continu et du bruit gaussien caractérisé par une densité d'amplitude répartie suivant la courbe de gauss, un dispositif expérimental de tracé automatique de la courbe de densité d'amplitude d'un signal quelconque est décrit. Les résultats obtenus dans un grand nombre de cas montrent que la plupart des bruits acoustiques présentent une répartitition de densité d'amplitude pratiquement gaussienne, d'où l'intérêt d'emploi d'un générateur de bruit gaussien pour les recherches acoustiques. Le spectre de fréquence d'un tel générateur peut être fixé à volonté à l'aide de filtres appropriés et peut être divisé en bande étroites tiers d'octave dans les quelles toute la puissance du générateur est concentrée.

L'article présente un nouveau générateur de bruit spécialement étudié pour les mesures acoustiques et discute brièvement quelques-unes de ses applications: mesure des temps de réverbération, contrôle des hauts-parleurs, études d'isolations acoustiques, etc.

ZUSAMMENFASSUNG

Nach den Definitionen verschiedener Formen des statistischen Rauschens beschreibt der Aufsatz einige Meßanordnungen für die Bestimmung von Frequenzspektren und Amplitudenhäufigkeitskurven. Praktisch gemessene Häufigkeitskurven von Werkstattgeräusch, Musik und Sprache werden der des weißen Rauschens gegenüberstellt. Die Ähnlichkeit der Häufigkeitskurven zeigt, daß das weiße Rauschen eine sehr nützliche Schallquelle für akustische und elektroakustische Messungen ist. Verschiedene Meßanordnungen, die weißes Rauschen verwenden, werden in ihren Eigenschaften mit denen eines gewobbelten Sinusgenerators verglichen.

Abschließend wird die Entwicklung eines neuen Rauschgenerators Typ 1402 beschrieben dazu folgen einige Anwendungsbeispiele.

Audible noise is generally defined as "unwanted sound". This definition refers to everyday life and may, even then, not be strictly correct. The elimination of

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all background noises would, for example, result in a certain feeling of discomfort, and the definition therefore applies only to noise above a certain loudness level. Some particular forms of controlled audio frequency noise are also, as will be outlined in this article, "wanted" because they are very useful for acoustic and electro-acoustic measurement purposes. This is the so-called random noise.

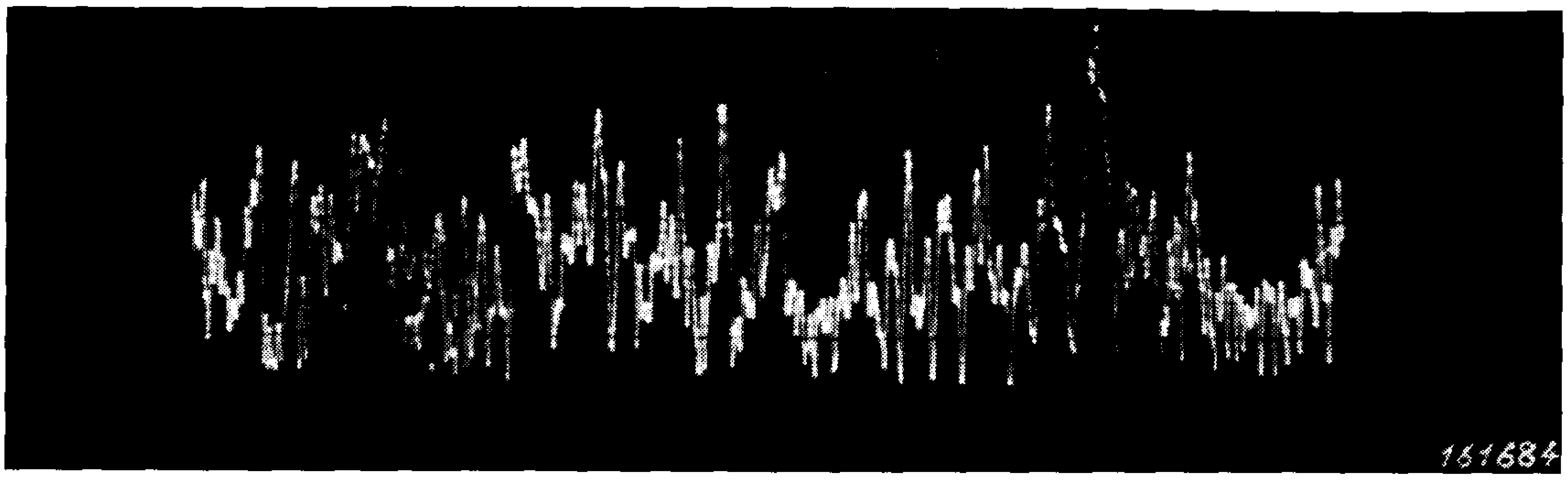


Fig. 1. Time record of random noise.

Random noise may be defined as a sound whose instantaneous amplitudes occur as a function of time, according to a normal (Gaussian) distribution curve. The word random thus refers to the amplitude distribution of the noise and does not specify anything with regard to the frequency composition of the noise. The frequency spectrum may therefore have any shape, and the noise still be random, the randomness being dependent only upon its instantaneous amplitude distribution. Fig. 1 shows a typical time record of random noise.
Similarly the concepts of white noise, shaped noise, and bands of noise may be defined:—

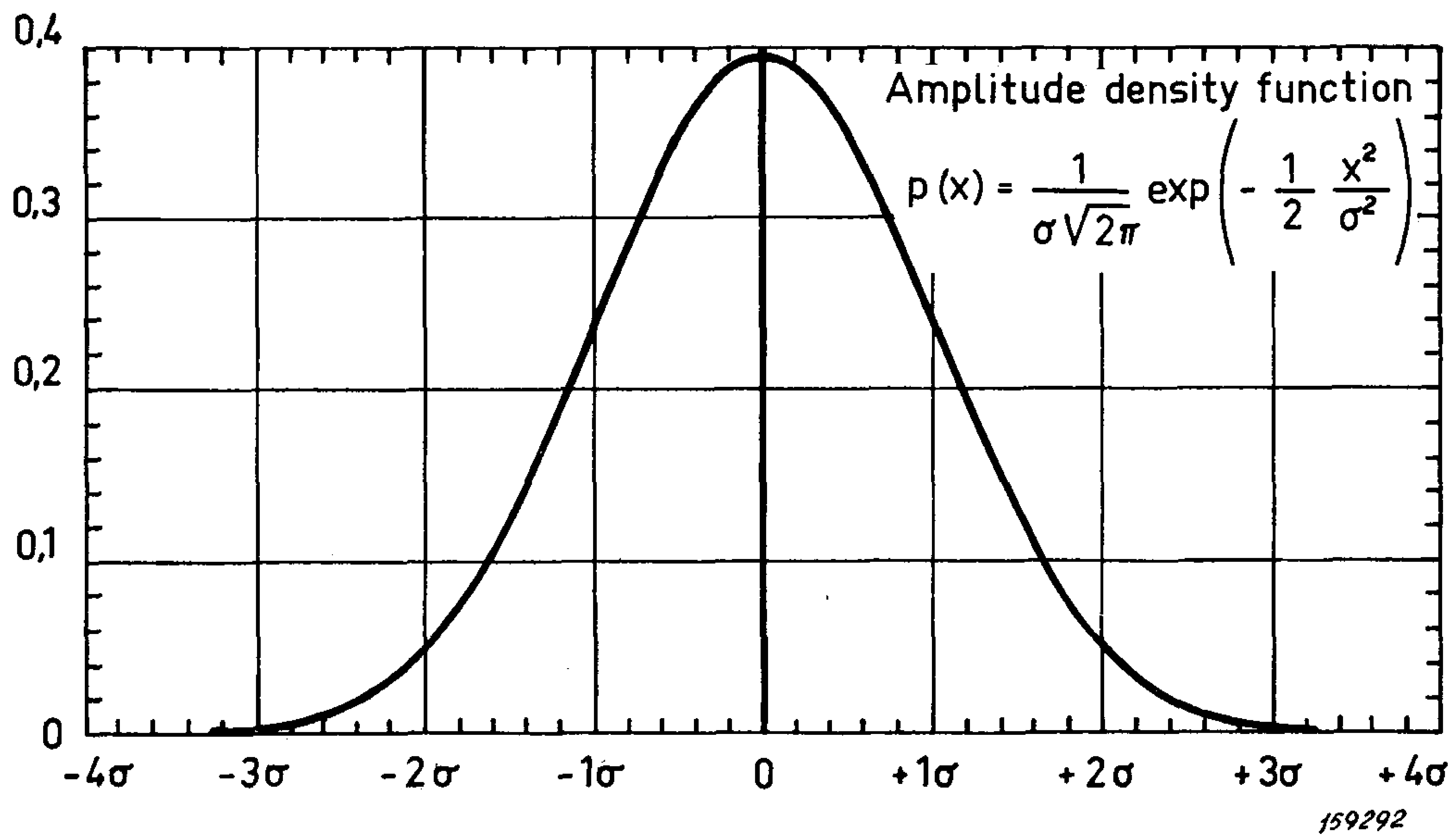
White noise is a sound whose spectrum is continuous and uniform as a function of frequency.

Shaped noise is a sound whose spectrum is continuous but not uniform.

Bands of noise is a sound whose spectrum is continuous and approximately uniform over a certain frequency range.

White noise, shaped noise and bands of noise need not be random. As a matter of fact, most noises occurring in nature are neither white nor random, but may, to a certain extent, be approximated as such. Fig. 2 shows the theoretical shape of the amplitude density (probability density) curve of random noise, while in Fig. 3 various noise spectra are shown, illustrating the above definitions.
From the definitions it can be seen that two typical curves are necessary to characterize a noise signal:—

1. The amplitude distribution (commonly given in the form of an amplitude density curve), and
2. The frequency spectrum of the noise.



$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\frac{x^2}{\sigma^2}\right)$$

Fig. 2. Normalized amplitude density curve of random noise.

Because this paper has been limited to discuss the generation and application of audio frequency noise only, i. e. noise containing frequencies in the audible range from 20 c/s to 20,000 c/s a spectrum which is continuous and uniform within this range will be designated as white.

The frequency spectrum of the noise can be readily measured by means of a frequency analyzer, while the amplitude density curve can be found by means of a variety of more or less specialized measuring instrumentation. A convenient arrangement, which also enables the automatic recording of the amplitude density curve to a logarithmic scale, will be briefly outlined in the following:—

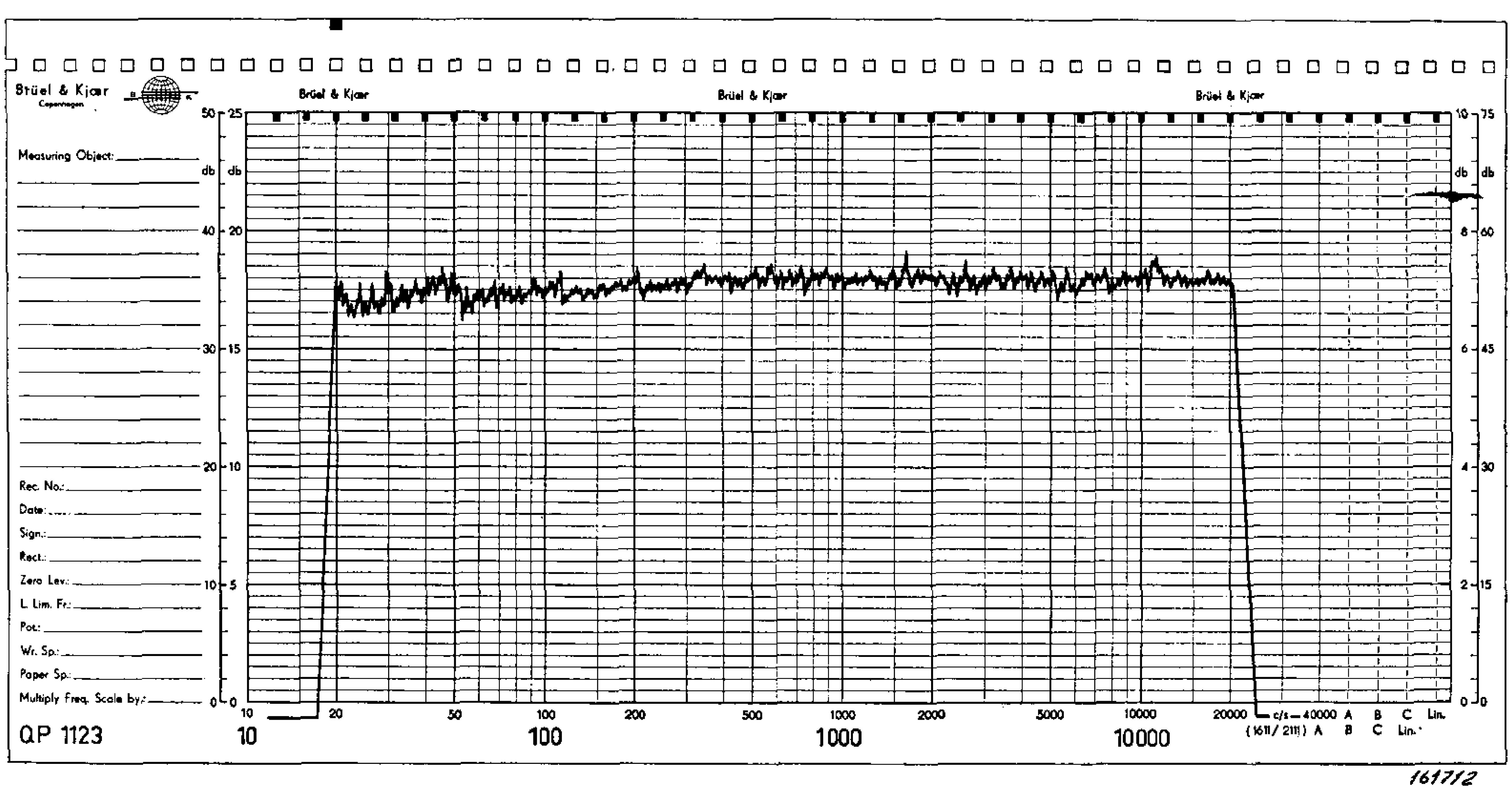
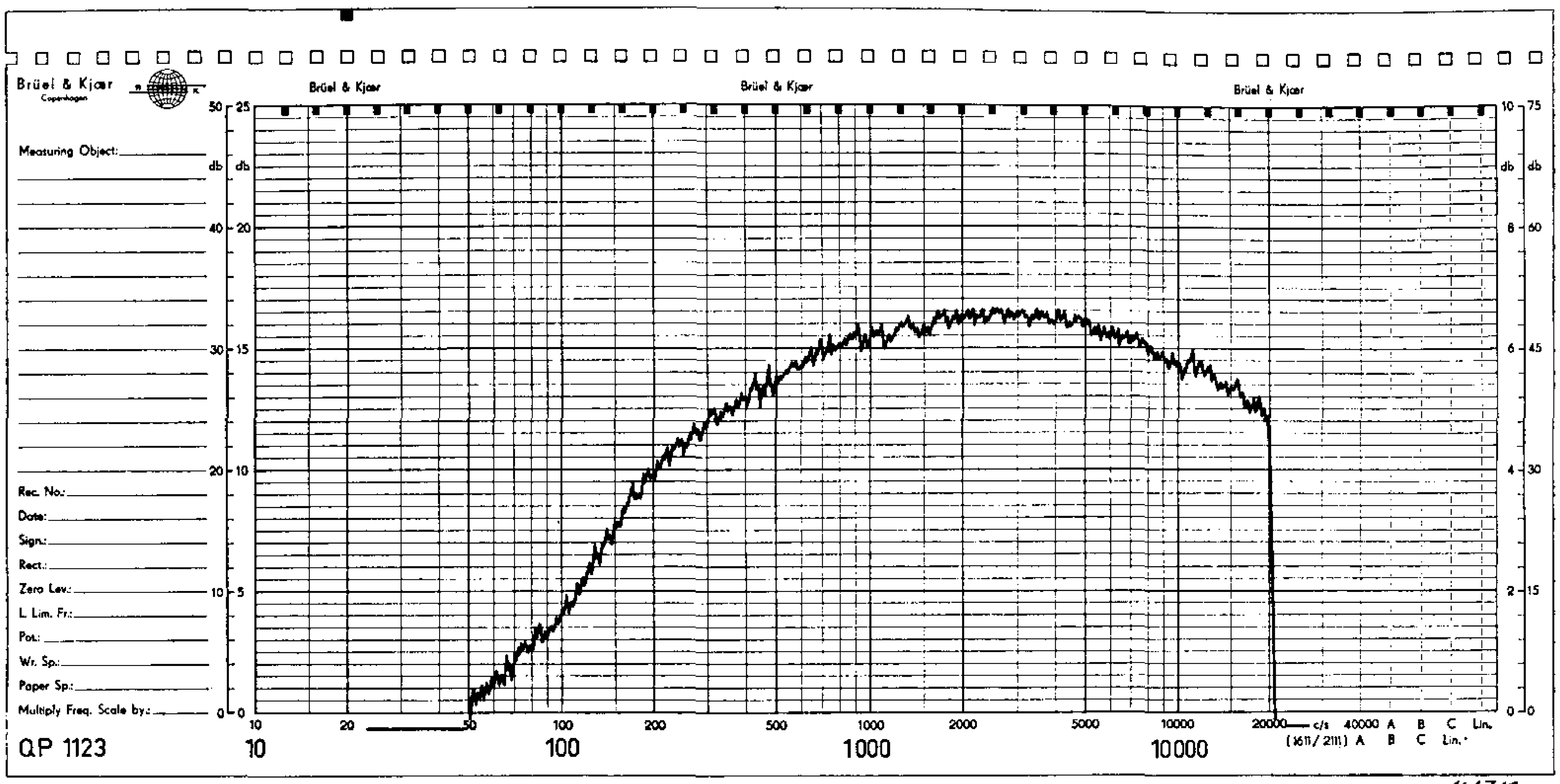


Fig. 3. Examples of noise spectra: —
(a) White noise (constant spectrum density)



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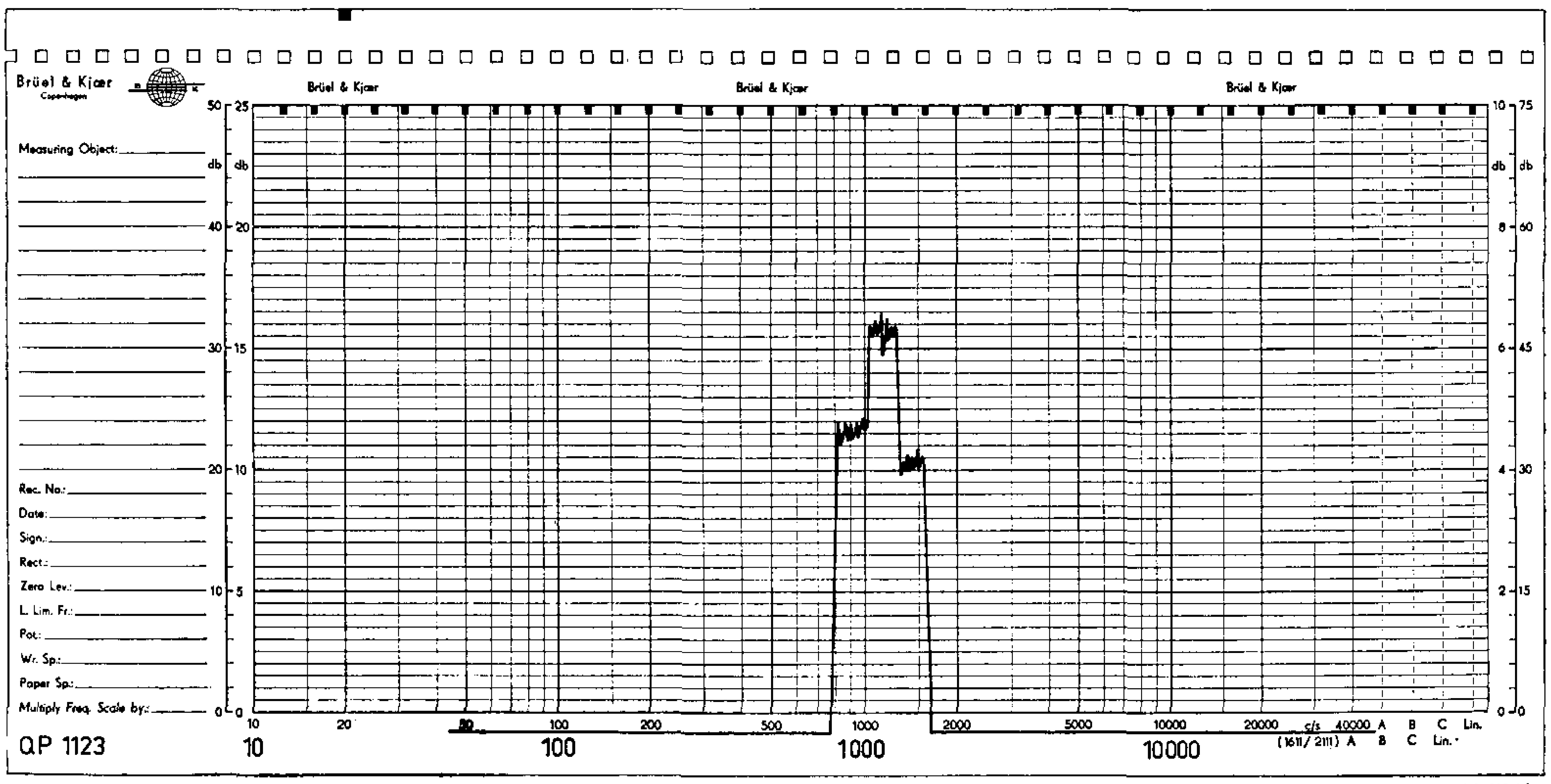
(b) Shaped noise



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(c) Bands of noise (⅓ octave wide)

When the noise to be studied is available in the form of an electrical signal, such as the output from a microphone, vibration pick-up etc., it should be displayed on the screen of a cathode-ray oscilloscope. The light intensity in a differential area of the oscilloscope screen will then be proportional to the length of time that the electron beam is within this area. By measuring the light intensity in such an area with the aid of a photo-sensitive device, e. g. a photomultiplier with a narrow horizontal slit opening, and by moving the slit in the vertical direction with respect to the signal on the oscilloscope screen the amplitude density curve of the noise can be plotted.

In Fig. 4 the principle employed in the measurement is illustrated together with the definitions of amplitude probability and amplitude density. However, instead of moving the slit opening this can be kept in a fixed position with respect to the oscilloscope screen and the signal moved in the vertical direction by means of

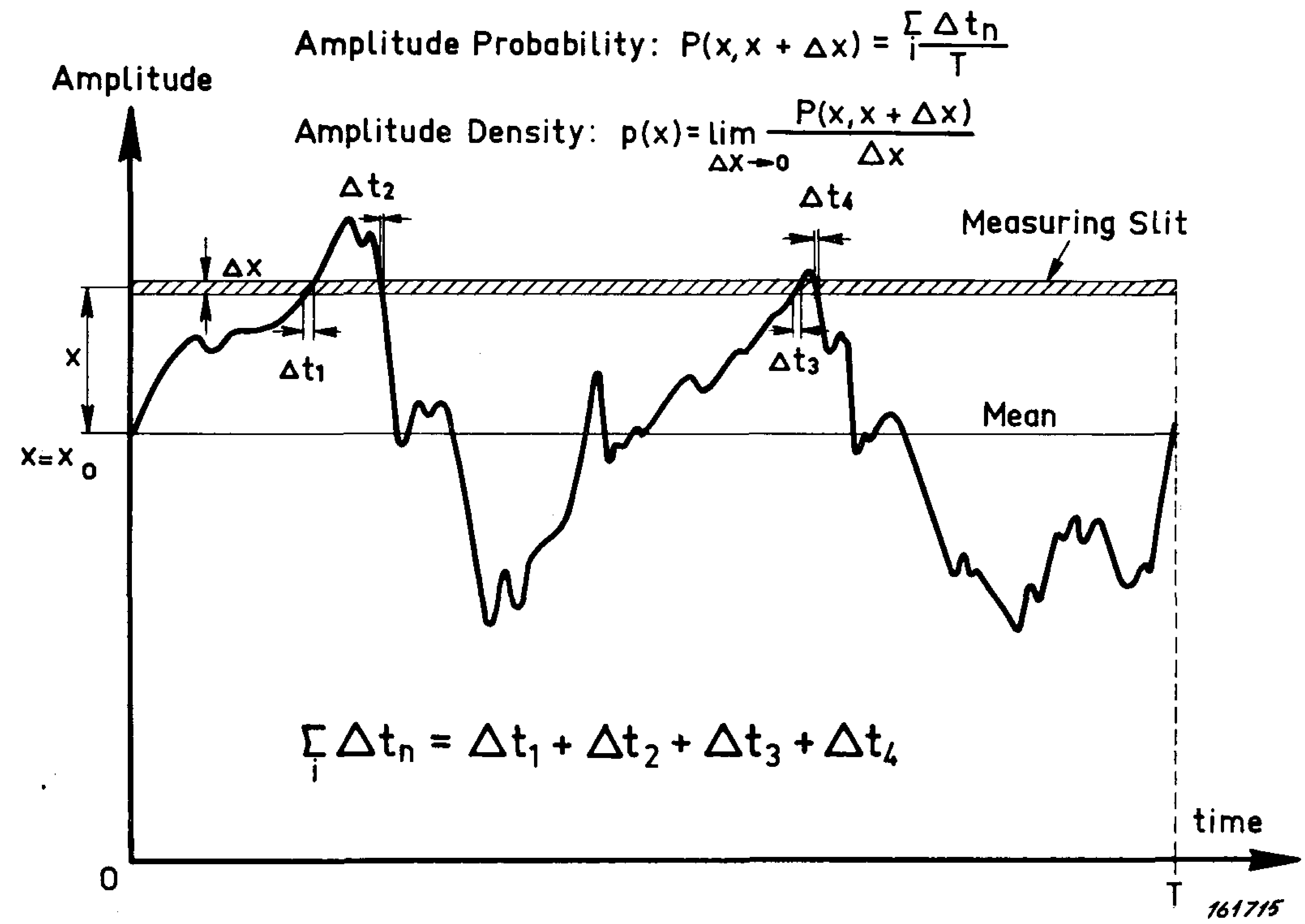


Fig. 4. The fundamental principles involved in the measurement of amplitude density.

Y-position potentiometer on the scope. This gives a simple method of plotting the density curve automatically on a recording device, as the paper drive system of a connected recorder can be used to mechanically rotate the Y-position potentiometer of the oscilloscope, see Fig. 5.

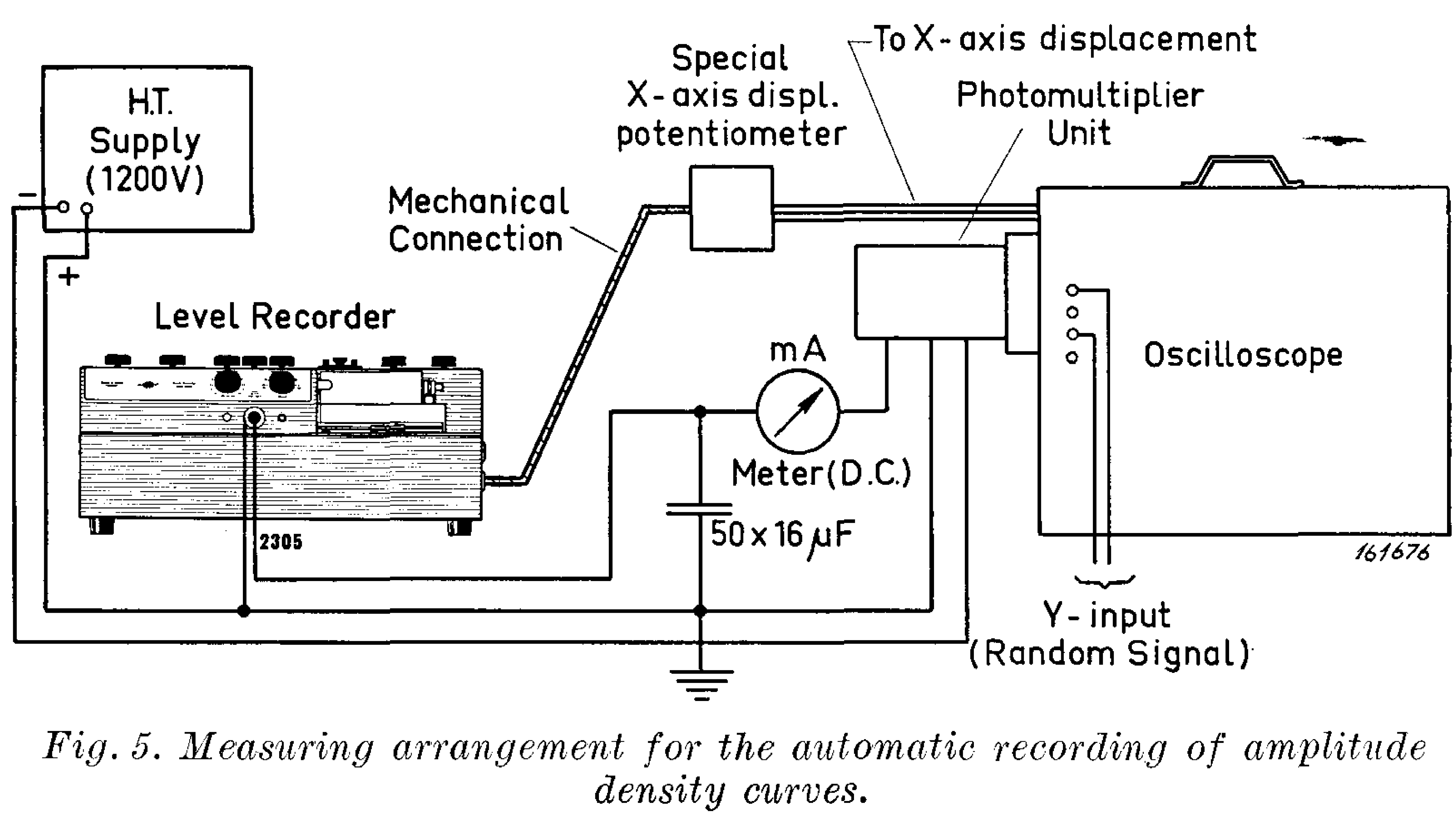


Fig. 5. Measuring arrangement for the automatic recording of amplitude density curves.

In Fig. 5 a Level Recorder Type 2305 is used as the recording device. The recorder can be adjusted to record its input signal to a logarithmic scale, which is a great advantage in this type of recording. The logarithmic scale provides the same relative accuracy over the total recorded amplitude density range and presents the normal (Gaussian) amplitude density curve as a relatively simple mathematical curve (parabola).

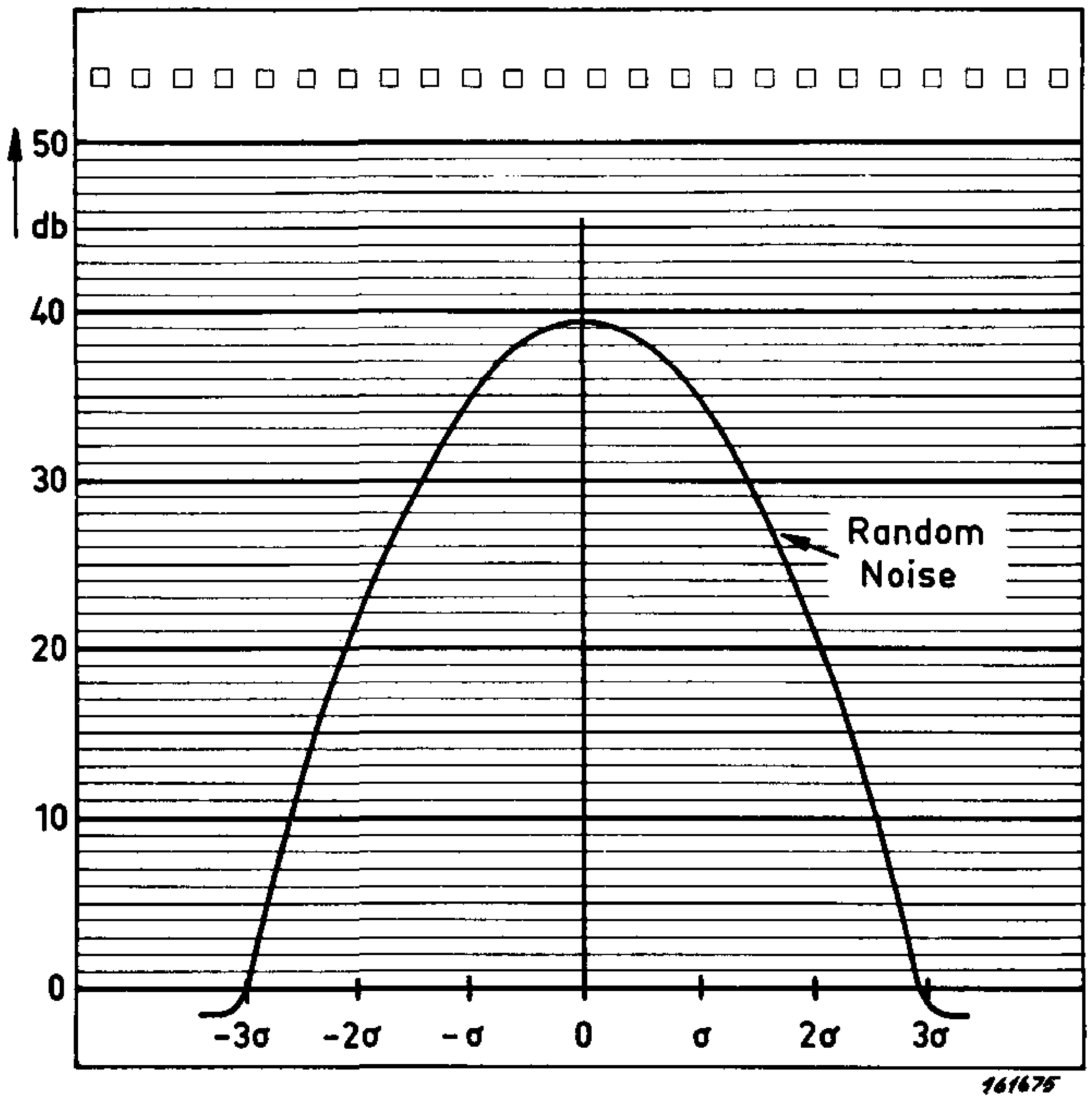


Fig. 6. Amplitude density curve of a practically random signal recorded by means of the arrangement shown in Fig. 5.

Fig. 6 shows the amplitude density curve of a practically random signal as recorded by means of the arrangement shown in Fig. 5. The parabolic shape of the curve is clearly noticed.

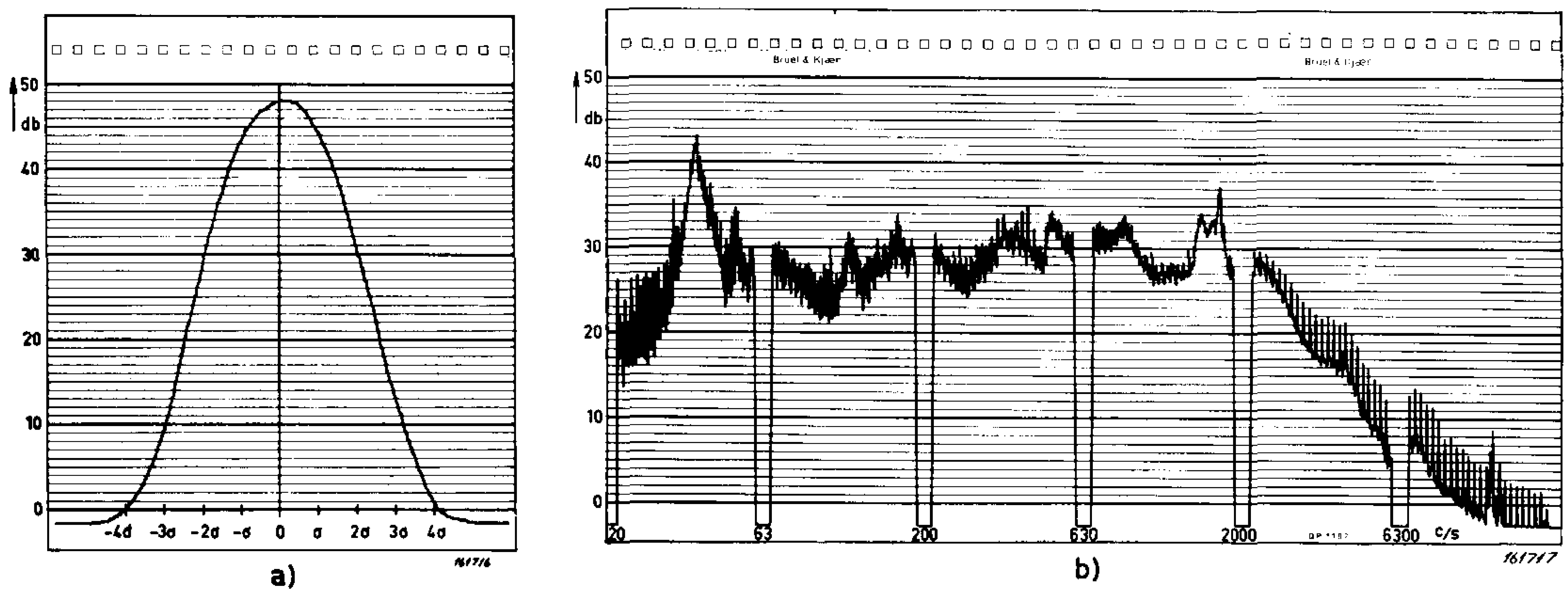


Fig. 7. Analysis of the noise produced in a mechanical workshop.
(a) The amplitude density curve.
(b) The frequency spectrum (measured on constant percentage bandwidth basis).

To investigate the usefulness of random noise as a sound source for acoustic and electro-acoustic measurements, a number of experiments have been carried out at Brüel & Kjær, and the reference literature studied. The main purposes of these studies was to resolve the resemblance between the amplitude distributions of commonly observed sounds and that of Gaussian noise. However, the frequency spectra of the sounds was also measured and found to be of a continuous type although not white.

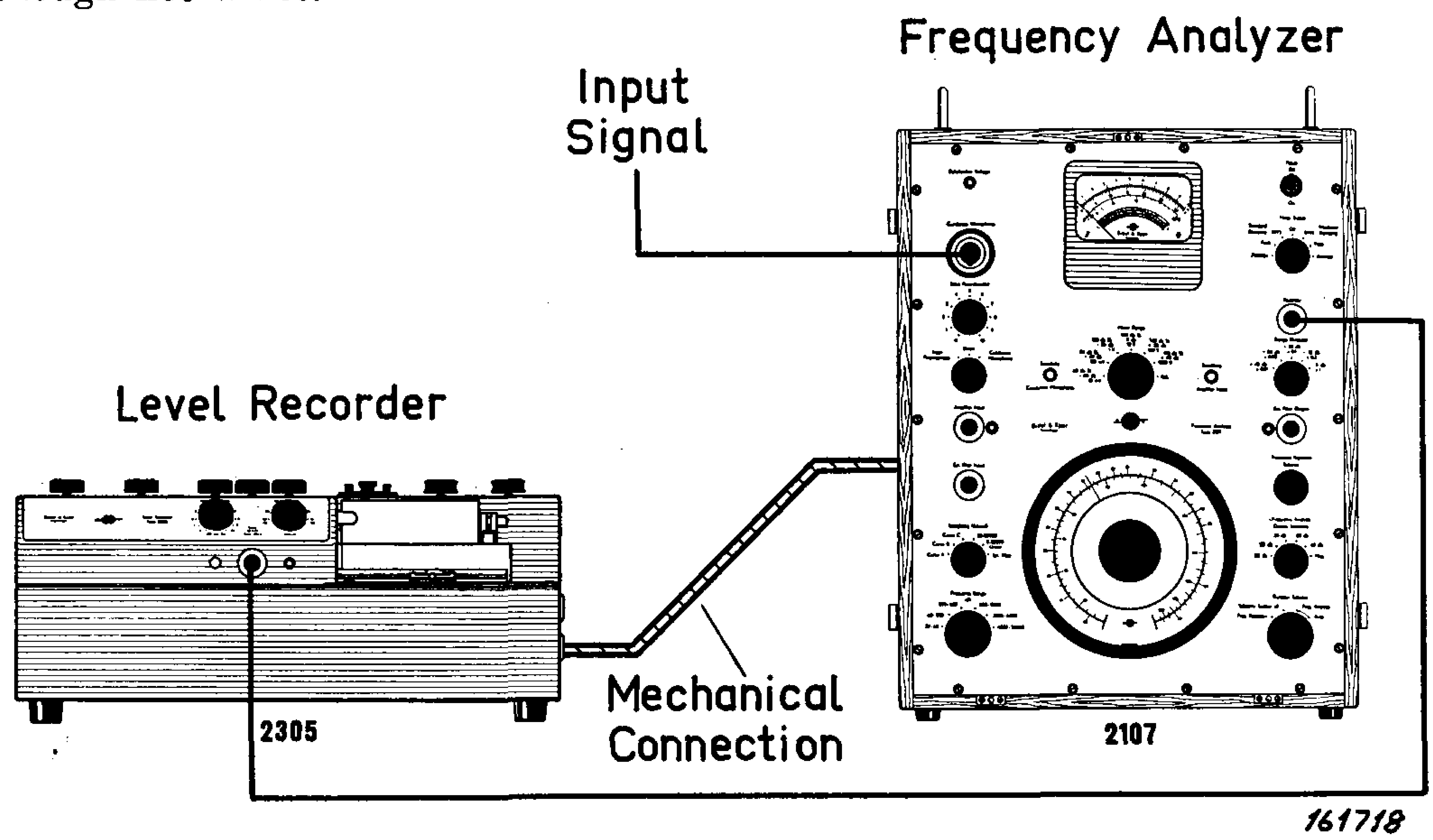


Fig. 8. Measuring arrangement for the automatic recording of the frequency spectrum of complex signals.

Fig. 7 shows the amplitude density curve as well as the frequency spectrum of the noise in a workshop. The frequency analysis was carried out by means of a narrow band constant percentage bandwidth type analyzer (B & K Type 2107) and automatically recorded on the connected level recorder, the paper drive system of which was controlling the sweep of the analyzer, see Fig. 8. In Fig. 9 similar characteristic curves are shown, measured from tape recorded noise from an office where ten people were working.

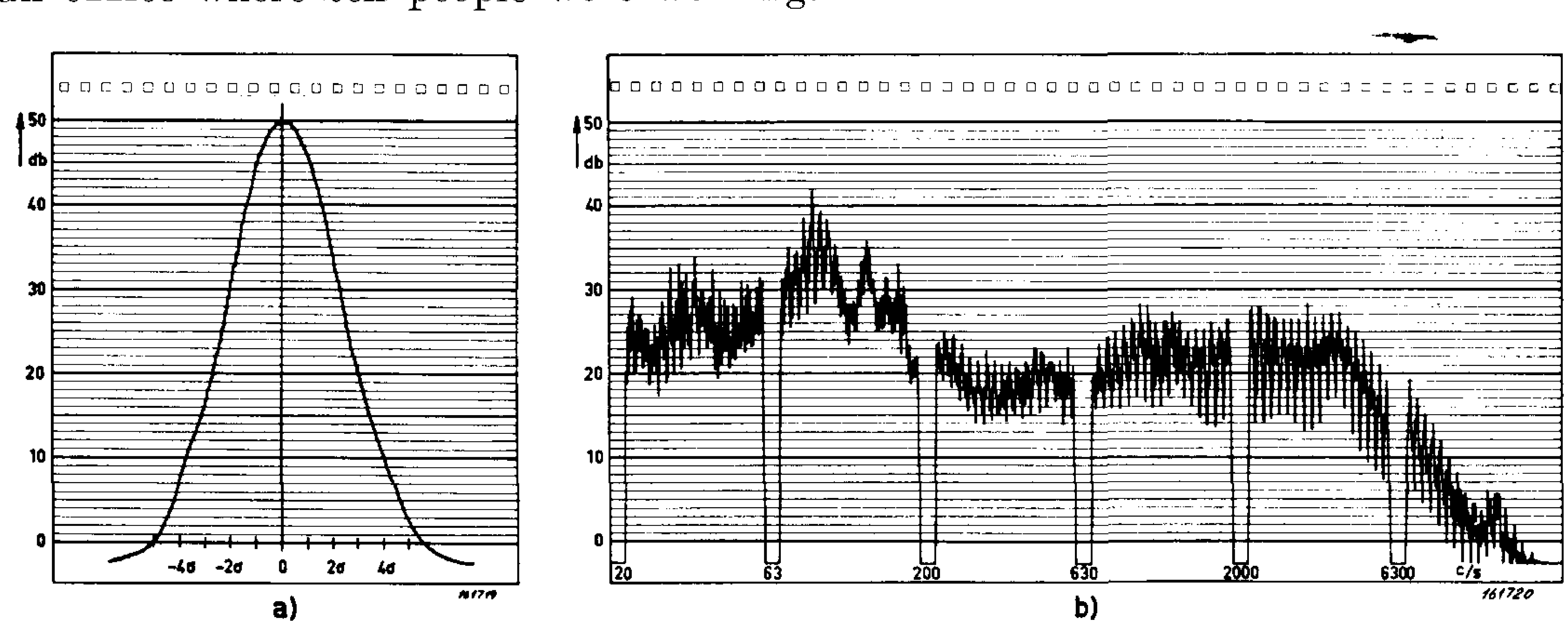


Fig. 9. Analysis of office noise.
(a) The amplitude density curve. *(b) The frequency spectrum.*

The Figs. 10, 11, 12, and 13 show the curves for different pieces of music. The music was played on a high fidelity record player and recorded on tape, then pieces of the tape, chosen at random, were made into closed loops and analyzed. The length of the loops and the time constants of the measuring system were closely matched.

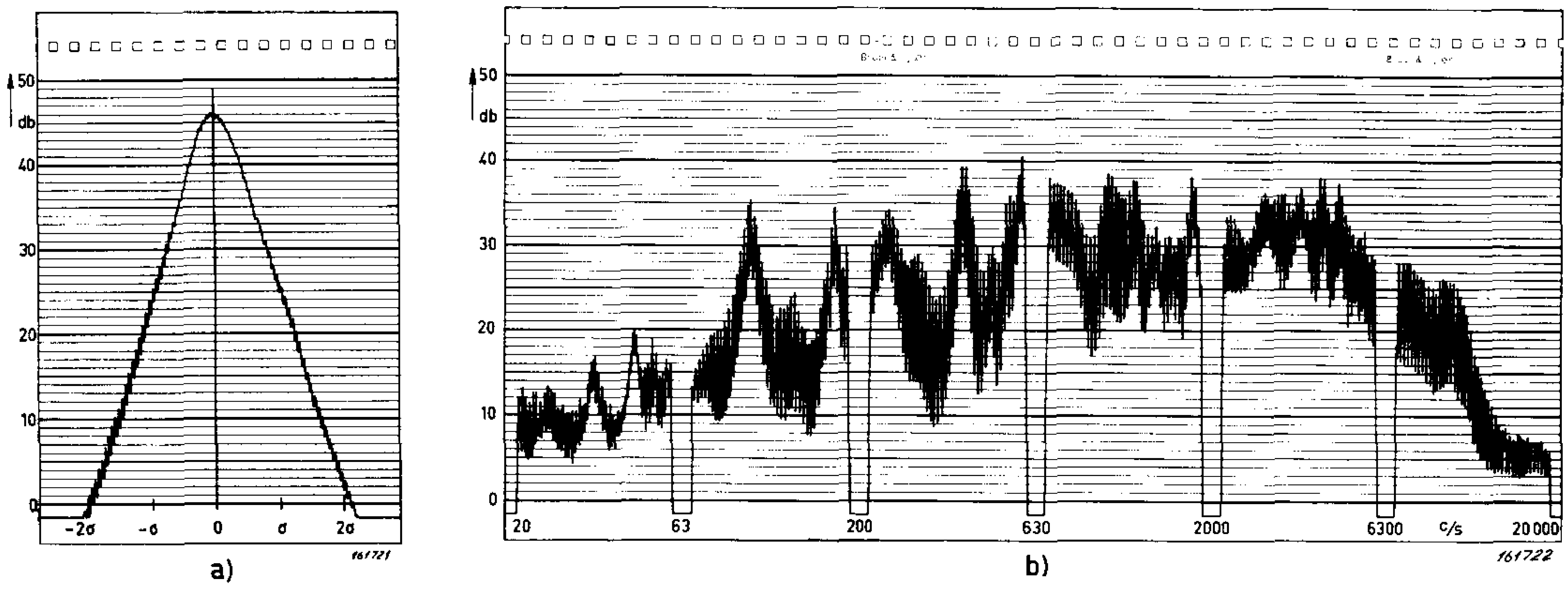


Fig. 10. Analysis of orchestral music. (Vivaldi: Concerto in A minor for two violins and string orchestra).
(a) The amplitude density curve.
(b) The frequency spectrum.

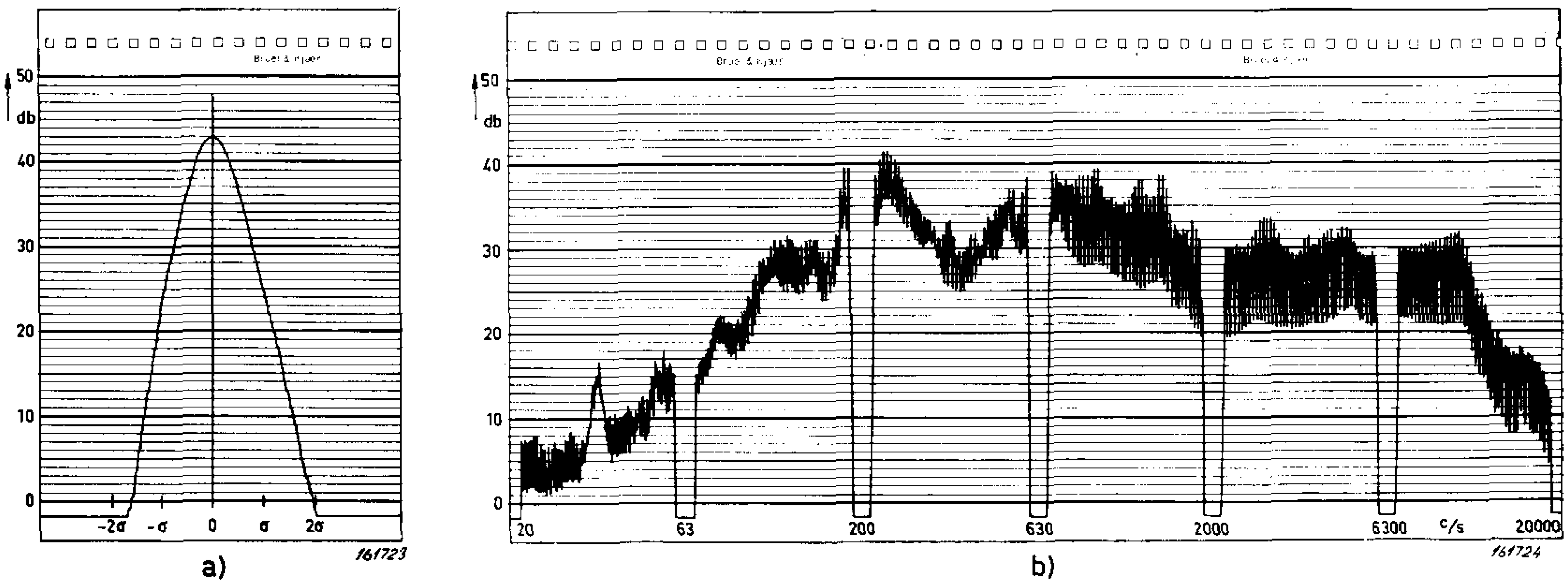


Fig.11. Analysis of dance music. (Dukes of Dixiland: Sheik of Araby).
(a) The amplitude density curve.
(b) The frequency spectrum.

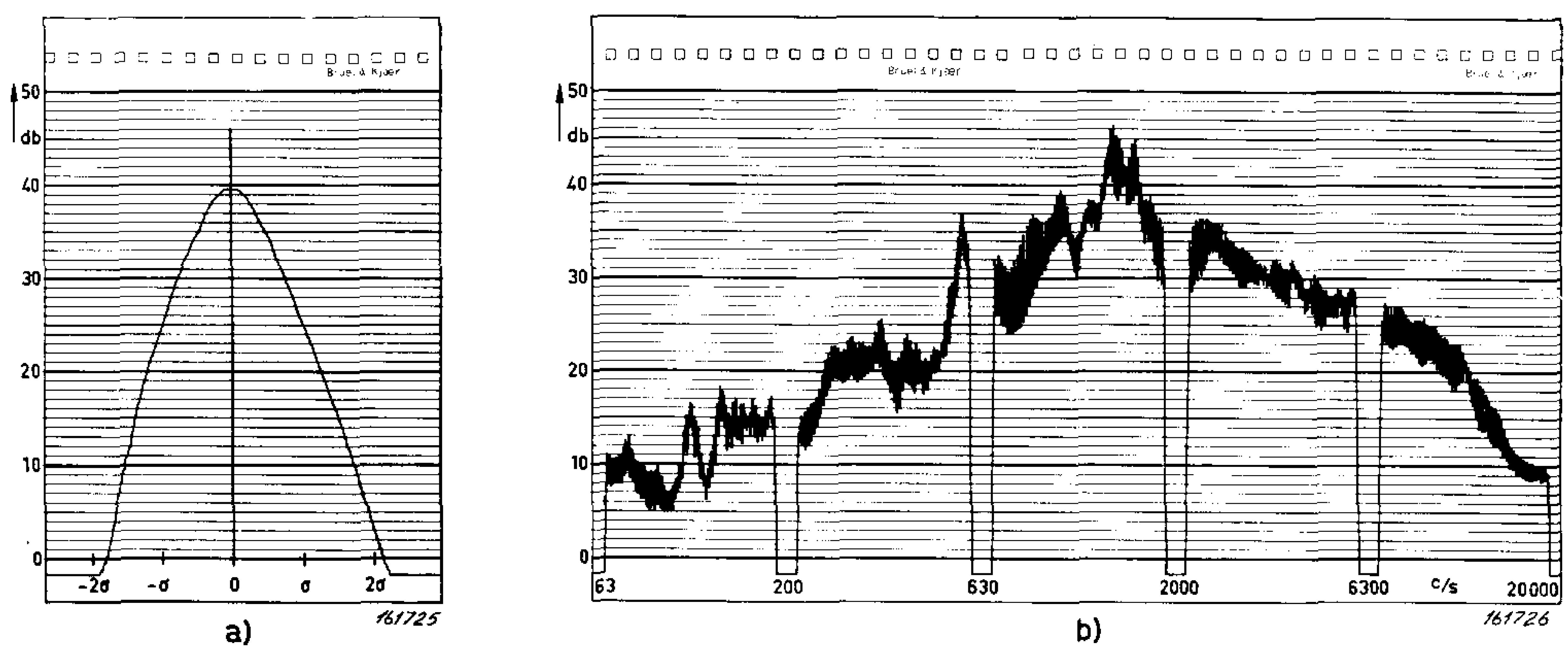


Fig. 12. Analysis of "modern" music (Fats Waller: Pianosolo).
(a) The amplitude density curve.
(b) The frequency spectrum.

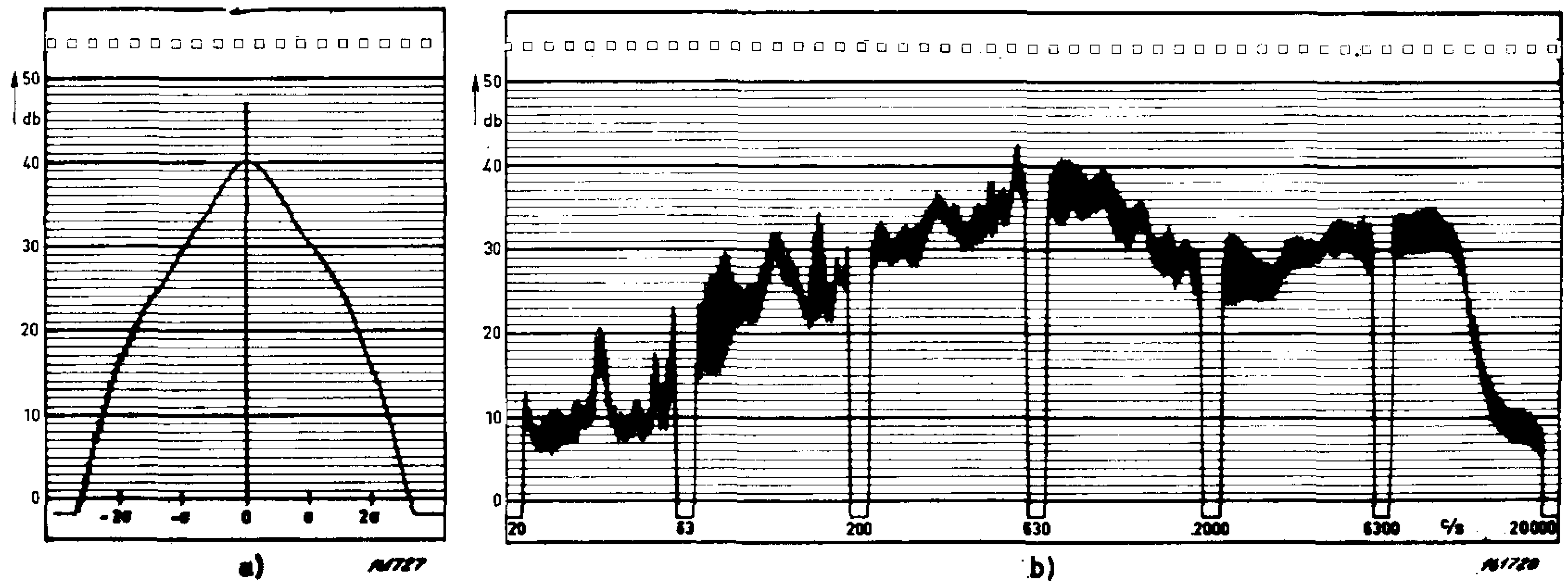


Fig. 13.
Analysis of vocal with orchestra. (Ella Fitzgerald: Stampin' at the Savoy).
(a) The amplitude density curve.
(b) The frequency spectrum.

In Fig. 14 are shown some typical speech curves, and in Fig. 15 some of the amplitude density curves displayed in Figs. 7 through 14 are compared to the

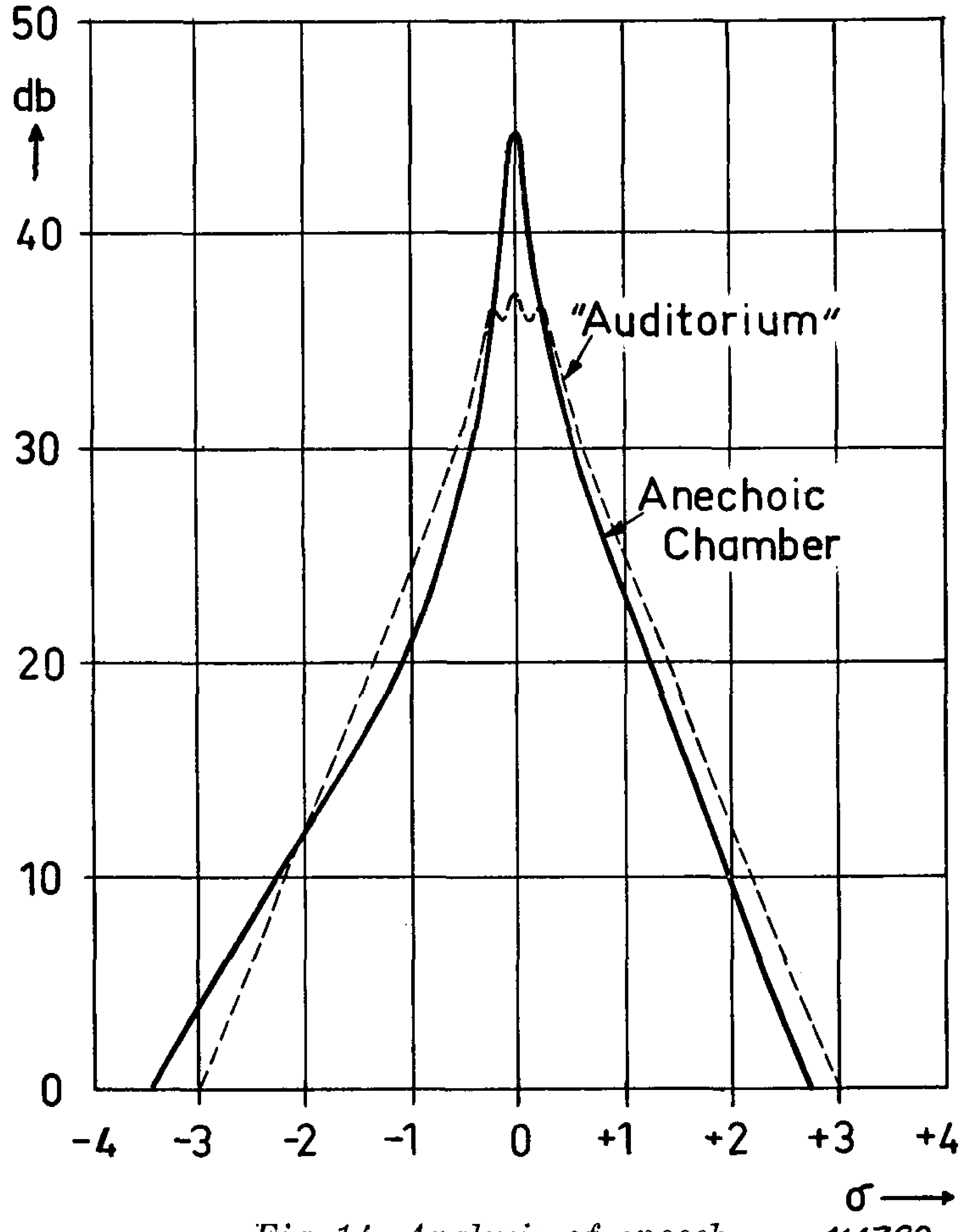
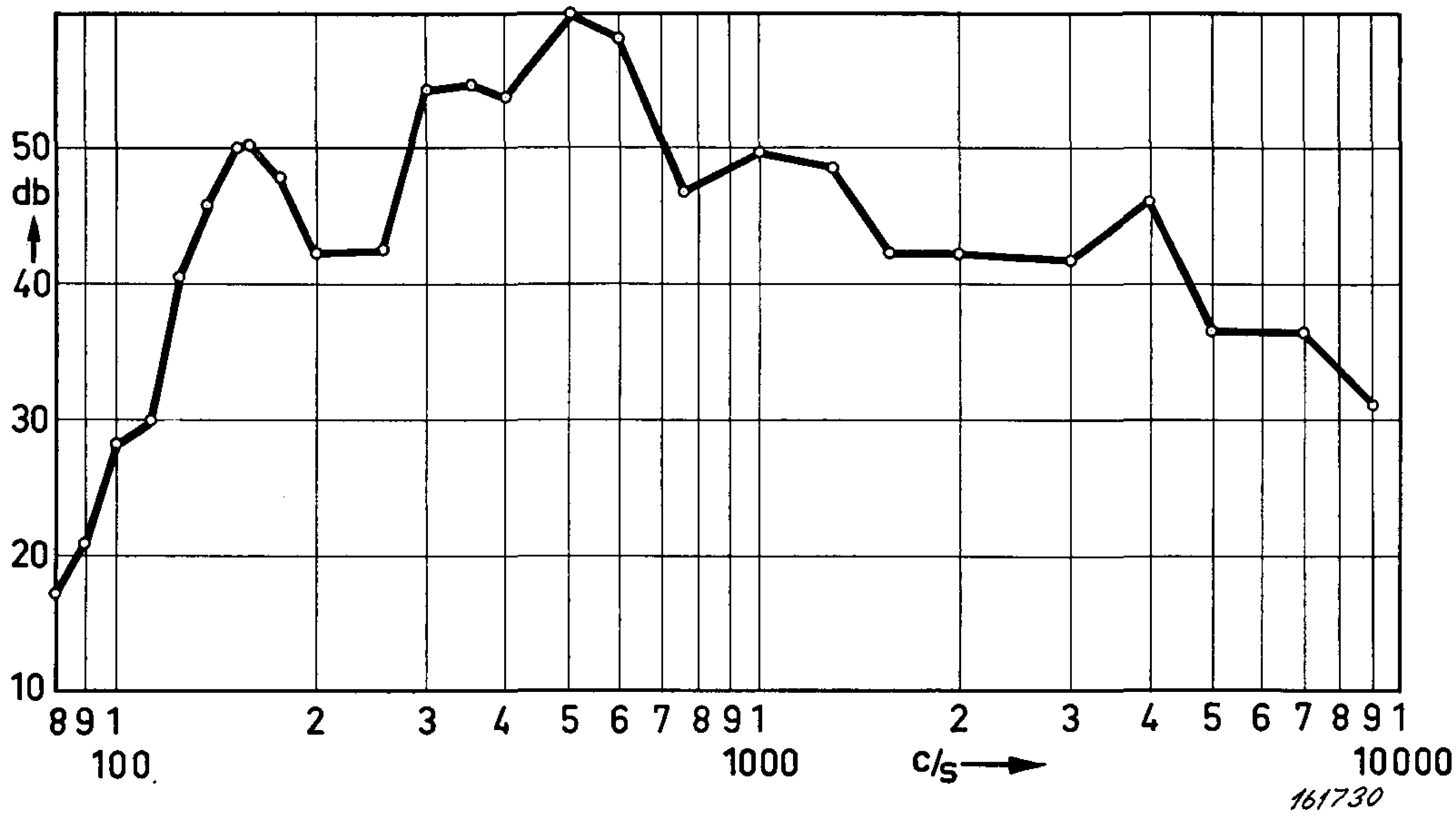


Fig. 14. Analysis of speech. 161729
(a) Amplitude density curves of speech in an anechoic chamber and in an "auditorium". (The curves are reproduced from J.A.S.A. 1952, Wilbur B. Davenport jr.: An Experimental Study of Speech-Wave Probability Distributions).



(b) Typical frequency spectrum of a male voice (constant percentage bandwith analysis).

random density curve. For the sake of comparison the amplitude density curve of a sine wave signal is also shown.

The results of the above investigations indicate that various forms of random noise are very excellent sources for acoustical measurement purposes. When used as a sound source for room acoustic measurements, such as reverberation time, sound distribution and sound insulation measurements, the continuous frequency spectrum is an advantage as all room resonances inside a certain frequency band are simultaneously excited. The similarity in amplitude density distributions of random noise and "natural sounds" also ensures that the resonances are excited in a way similar to that occurring in the room under everyday conditions. A simple measuring arrangement for the recording of reverberation decay curves is shown in Fig. 16. The noise generator employed as a signal source supplies a white random noise to the loudspeaker, and the reverberation decay within a certain frequency band is recorded on a level recorder, the desired band being selected by means of a frequency analyzer. With a similar set-up sound insulation measurements can be carried out, Fig. 17.

Sound distribution measurements can be carried out in a simple manner by shaping the noise spectrum, so that it closely resembles the spectrum of the type of sound for which the room is intended (auditorium, concert hall, theatre etc.) and the sound level then measured at different points by means of a sound level meter (no frequency analyzer required).

A disadvantage in using wide-band random noise for room acoustical measurements is that the power often required for this type of measurements is so great that it will, in most cases, be necessary to connect a large power amplifier between the noise generator and the loudspeaker and to use loudspeakers with high power ratings. These difficulties can be overcome by employing narrow band noise as an energy source instead of the wide band noise, as is the case in the set-ups shown in Figs. 16 and 17.

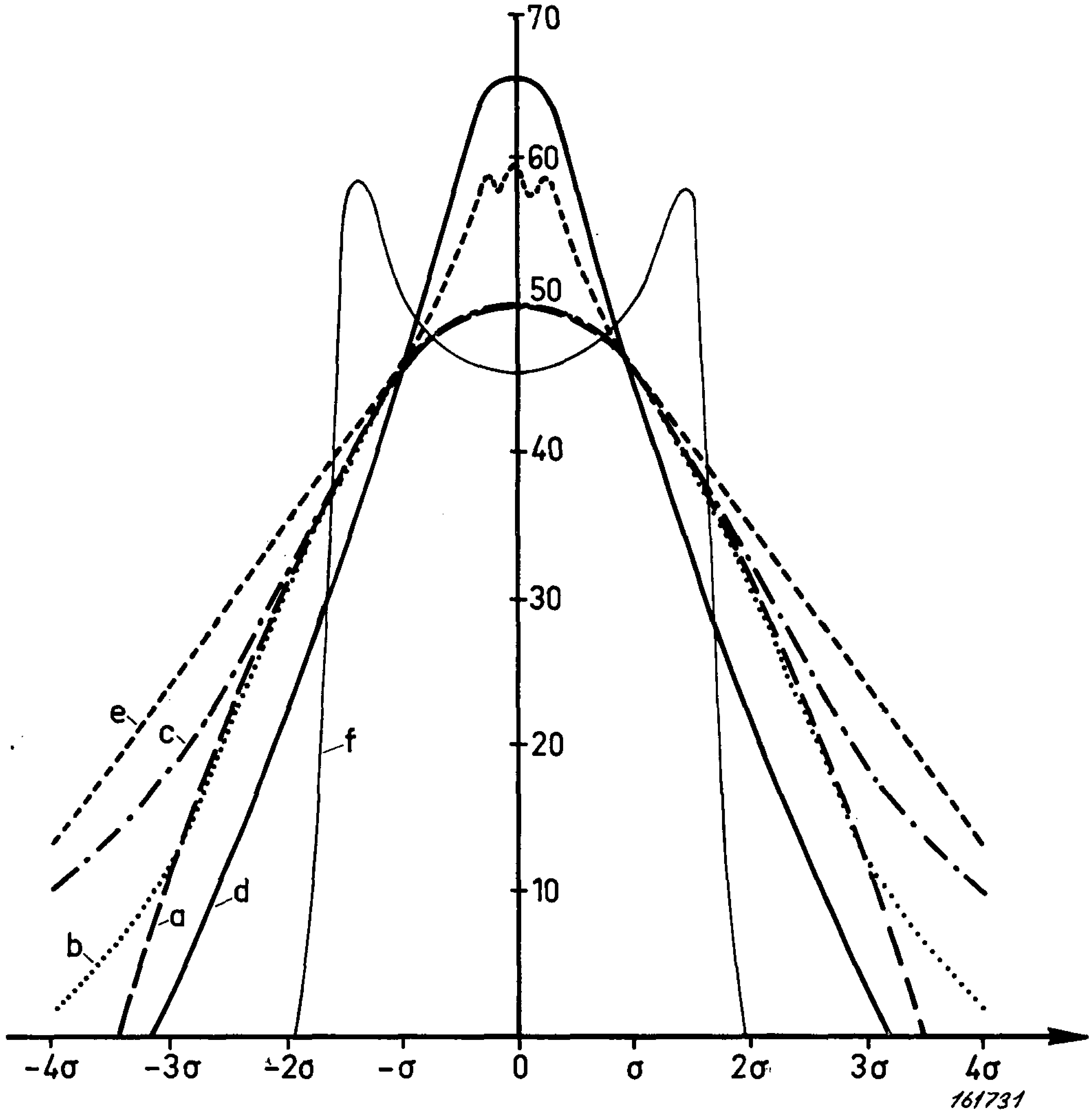


Fig. 15. Comparison of amplitude density curves.
(a) Random noise.
(b) Noise from a mechanical workshop.
(c) Office noise.
(d) Music played by an orchestra.
(e) Speech in an auditorium.
(f) Sine wave.

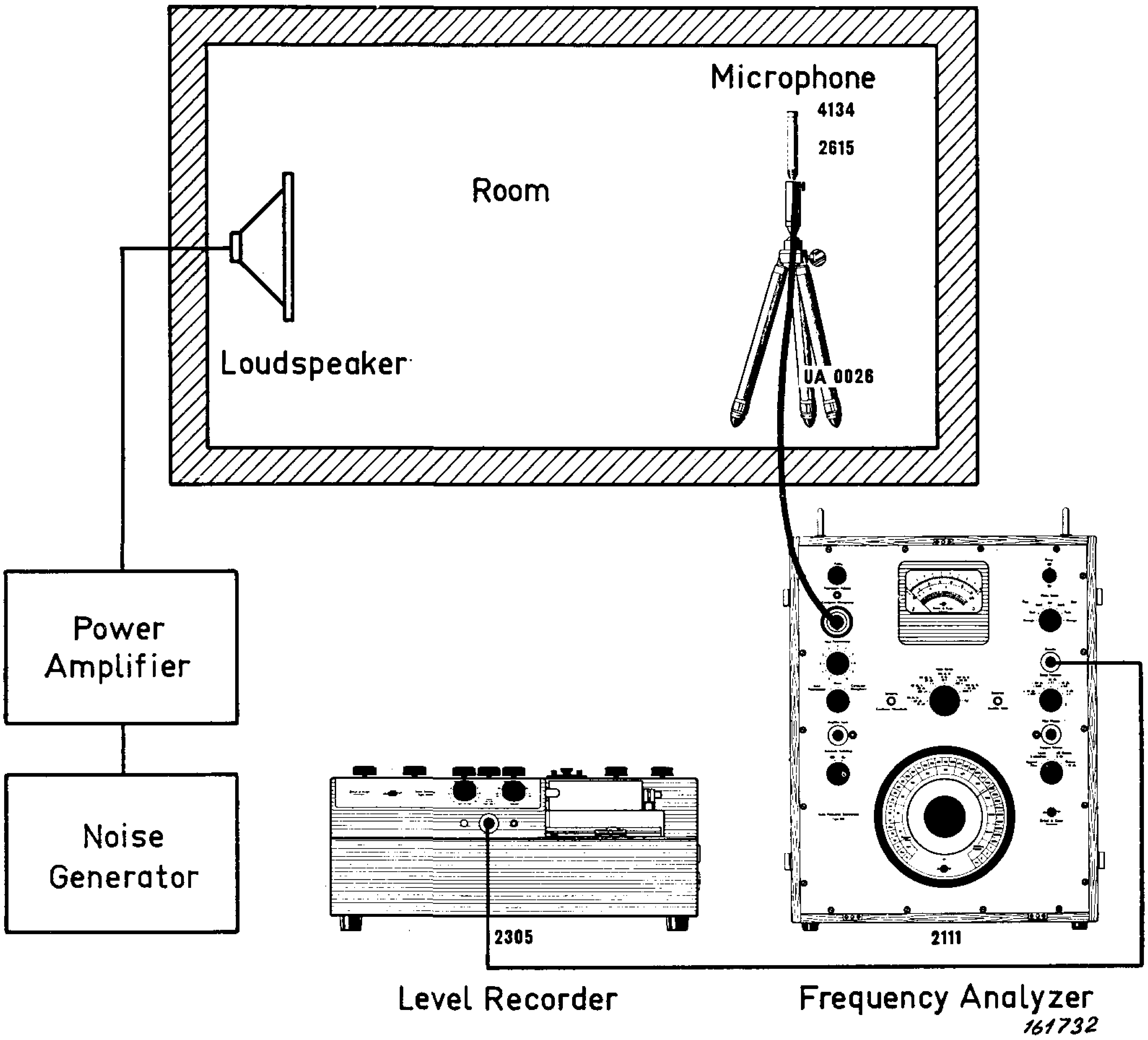


Fig. 16. Typical measuring set-up for the recording of reverberation decay curves.

A noise generator which allows filters to be inserted between the generator and the output stage has been developed by Brüel & Kjær, the maximum output power being of the order of 0.3 watt. It is then possible to utilize the full output power inside a relatively narrow band of noise at a given instant, instead of "spreading" it over the full audio frequency range, whereby no or only a small power amplifier is required between the generator and the loudspeakers. (The power spectral density of white noise is $\frac{\text{Noise Power}}{\Delta f}$ where Δf is the bandwidth of the noise).

Fig. 18 shows two measuring arrangements used for reverberation decay curve recording, where narrow band noise is used as the energy source, and in Fig. 19 examples of two decay curves are shown. The curve shown in (a) was measured with the arrangement in Fig. 16, while curve (b) was recorded by means of the set-up, Fig. 18b. (Note the distinct difference in dynamic range between the two curves, indicating the advantage of the measuring system shown in Fig. 18b).

Before describing the above mentioned noise generator it might be of interest to mention another method of sound generation for acoustic measurement purposes, "the warble tone", and briefly compare this method to the noise band method.

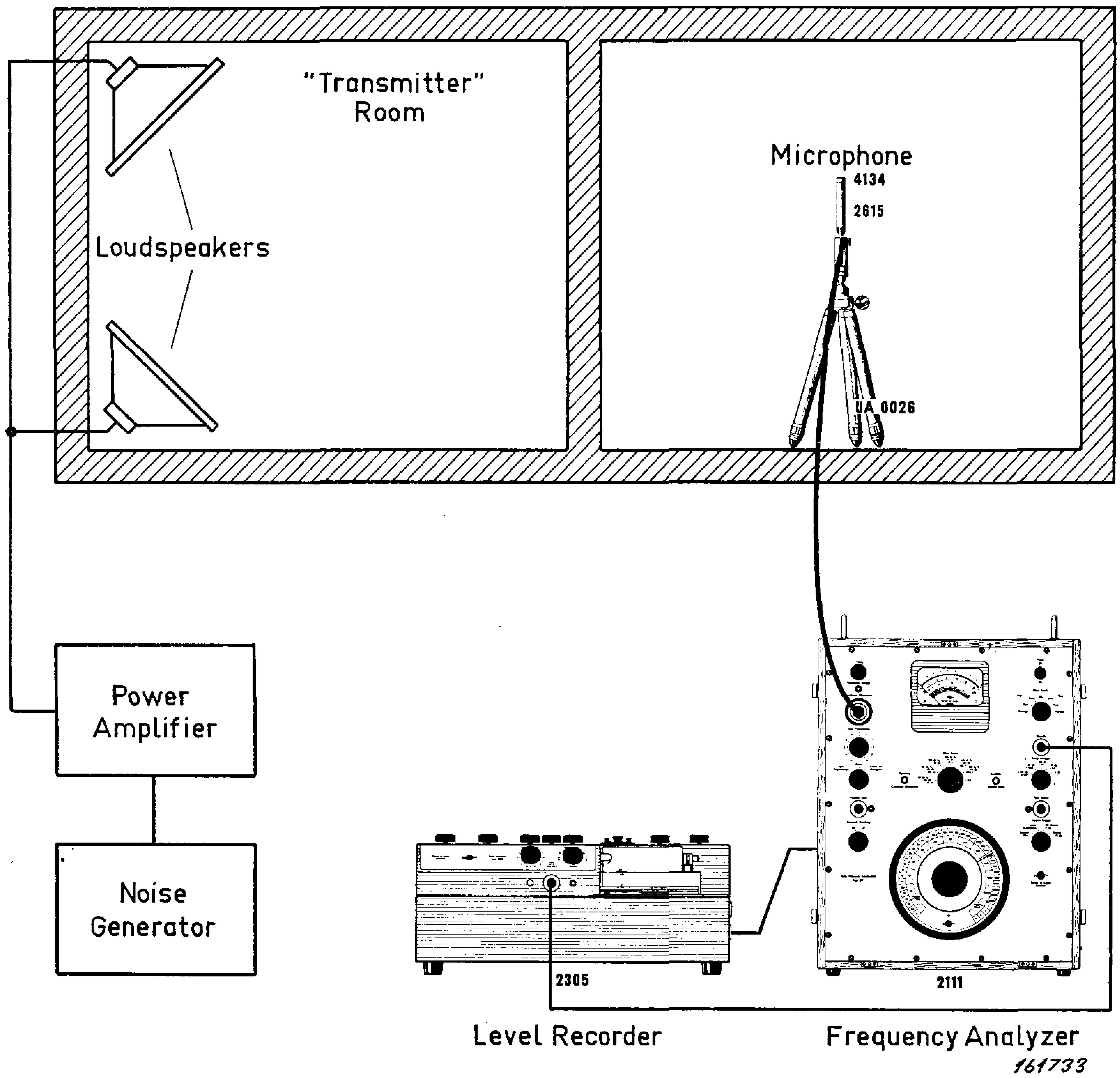


Fig. 17. Measurement of sound insulation.

The warble tone generator normally consists of a beat frequency oscillator, which is frequency modulated by a very low frequency signal. The wave shape of the modulation signal is chosen so that the frequency spectrum of the modulated

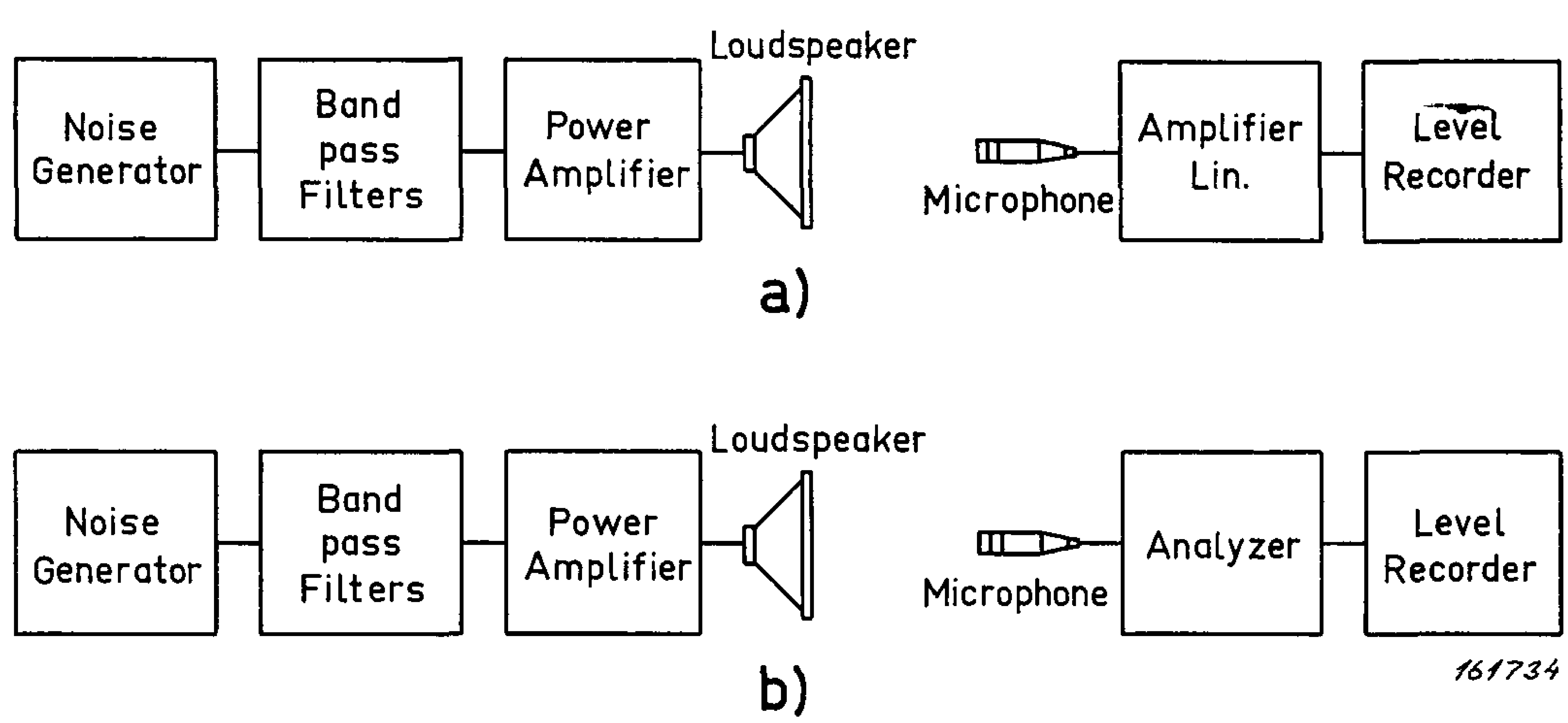
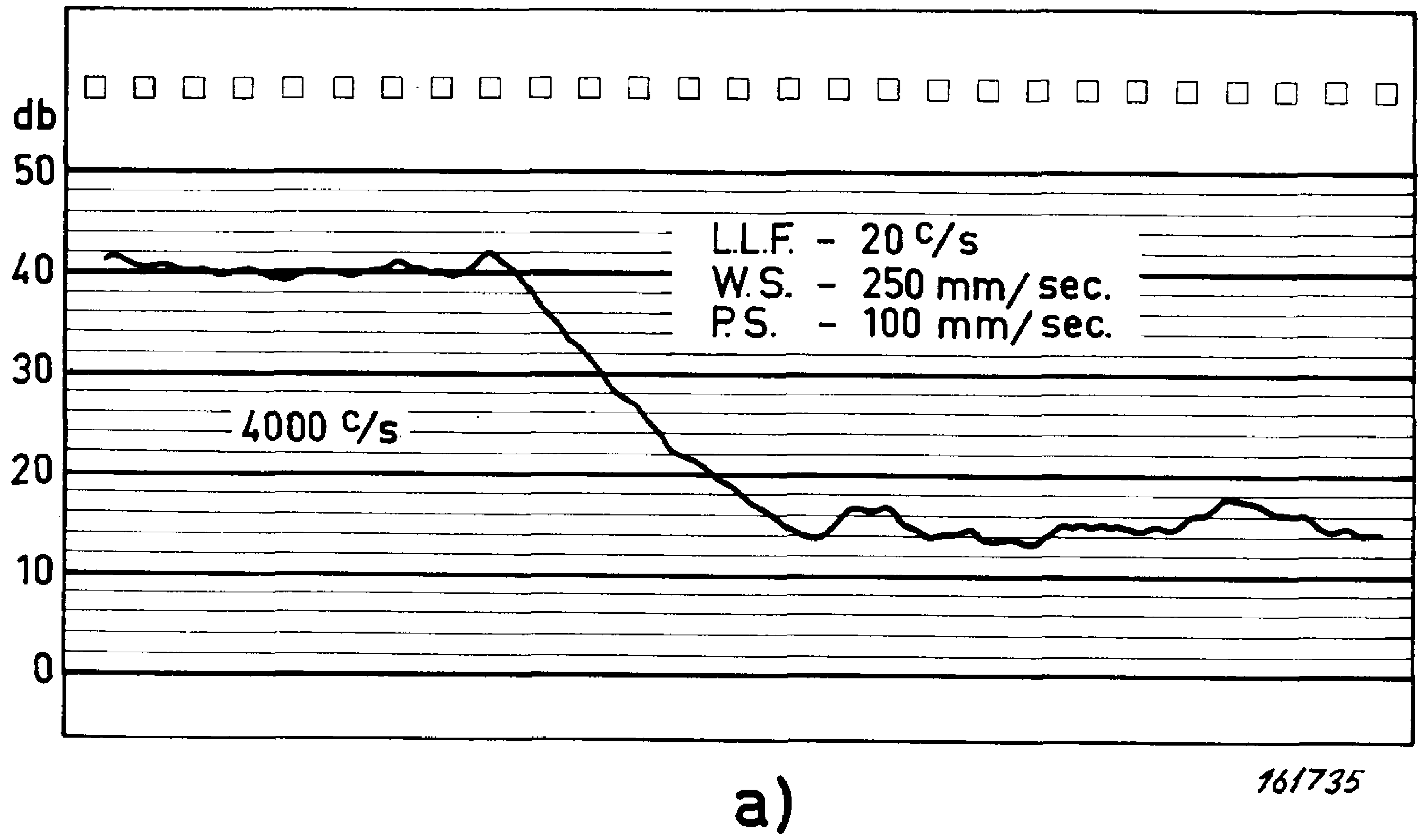


Fig. 18.
Acoustic measuring arrangements using bands of noise for the sound generation.



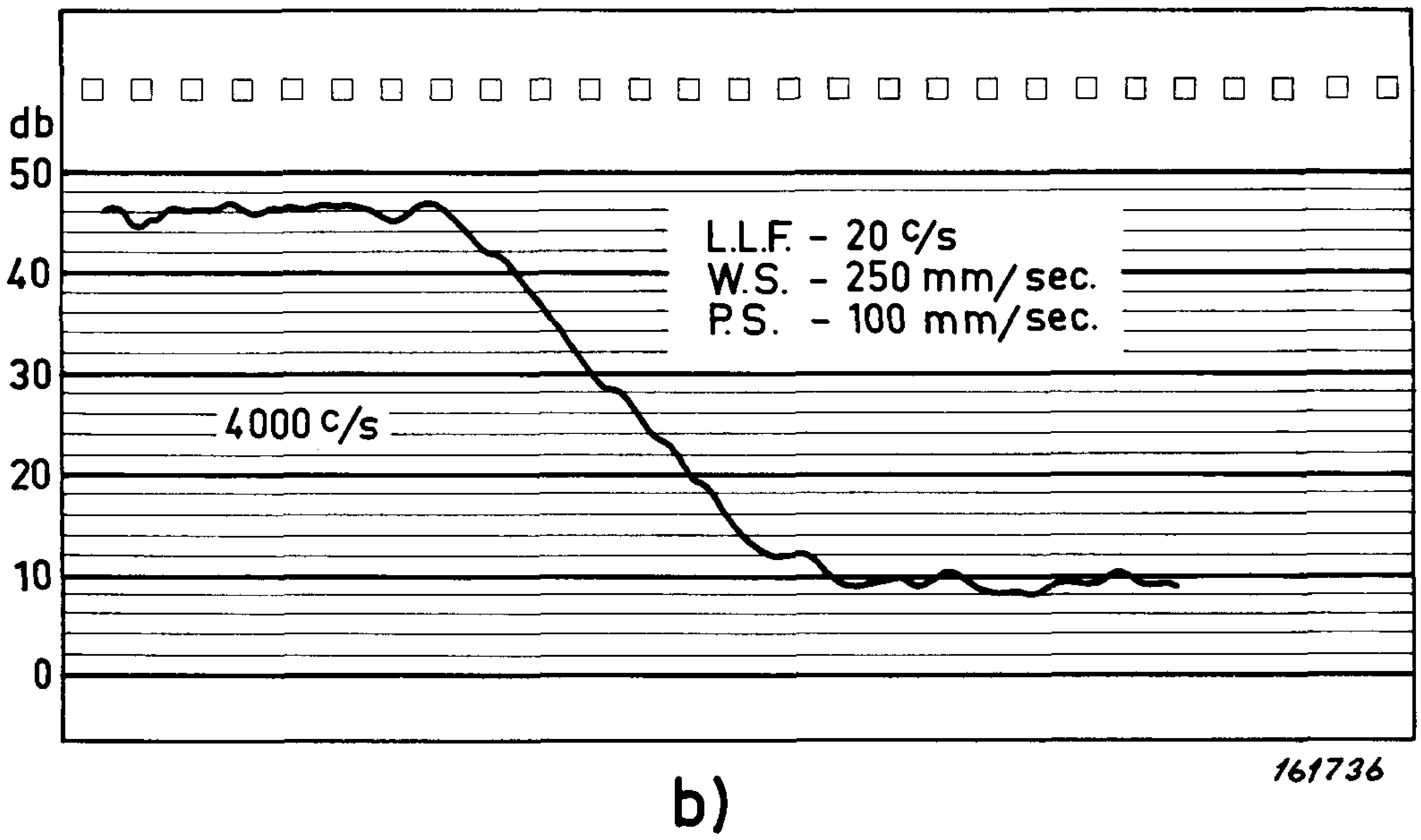


Fig. 19. Typical reverberation decay curves.
(a) Measured by means of the arrangement shown in Fig. 16.
(b) Measured by means of the arrangement shown in Fig. 18b.

signal is as flat as possible inside the band produced by the modulation products, see Fig. 20. If the warble tone generator is swept through the audio frequency range an effect similar to that of a sweeping noise band is produced. However, two distinct differences exist between the two methods of energy generation:—

1. The frequency band of the noise is continuous, i. e. all frequencies inside the band is present *simultaneously* with equal probability, while the warble tone generator generates a discrete frequency spectrum, the distance between the lines in the spectrum being determined by the frequency of the modulating signal.

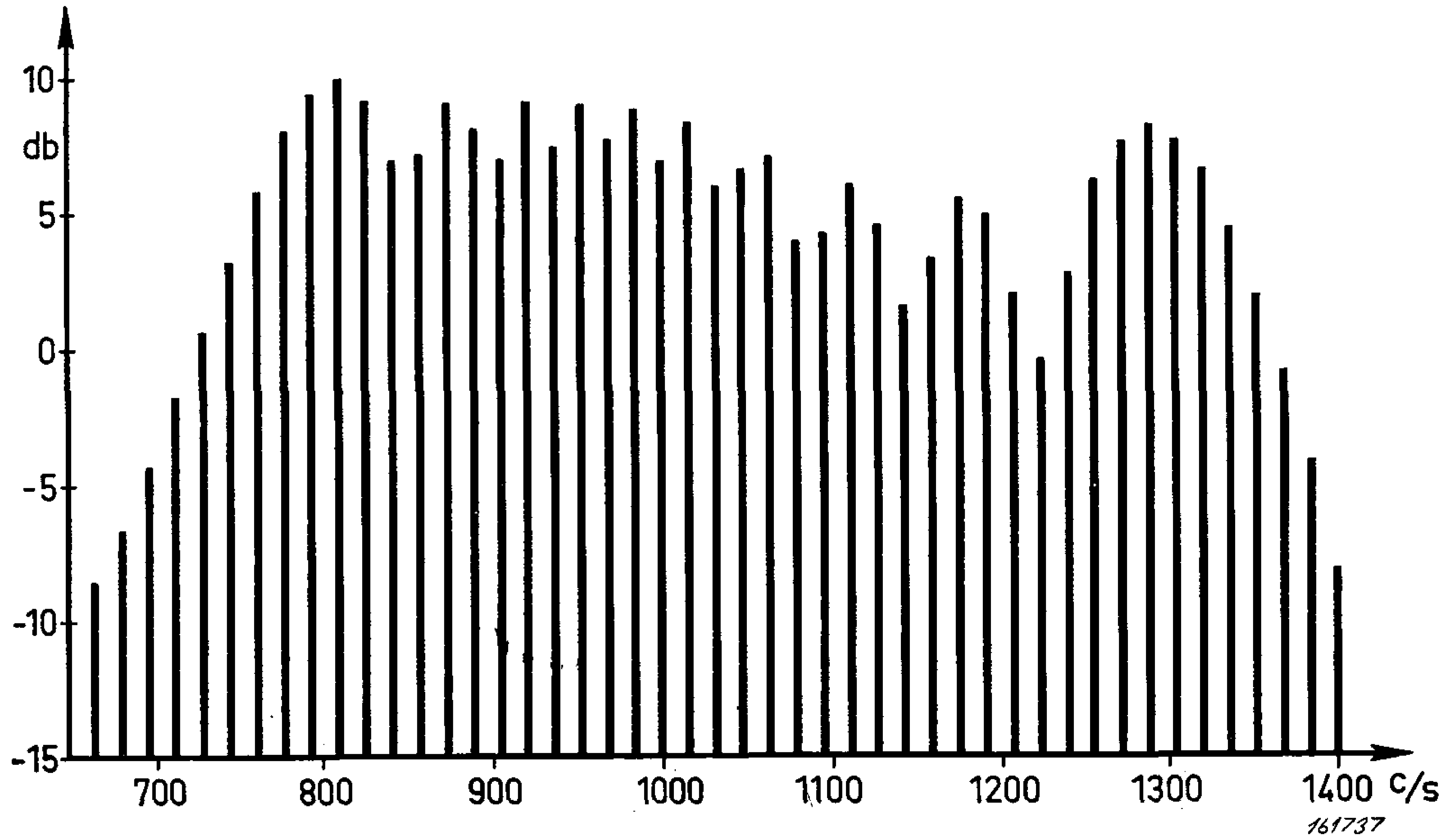


Fig. 20. Typical spectrum of a warble tone produced by a sawtooth-type modulation signal. Modulation frequency 16 c/s, modulation swing 200 c/s.

2. The amplitude density curve for the warble tone differs considerably from that of random noise, and thus also from those obtained for "natural sounds", see Fig. 21 as well as Figs. 7 through 14.

Even though the warble tone method is an excellent sound generating method for measurement purposes, and the B. F. O. provides a relatively simple means of automatic level control, the noise band method seems to have certain advantages as outlined above.

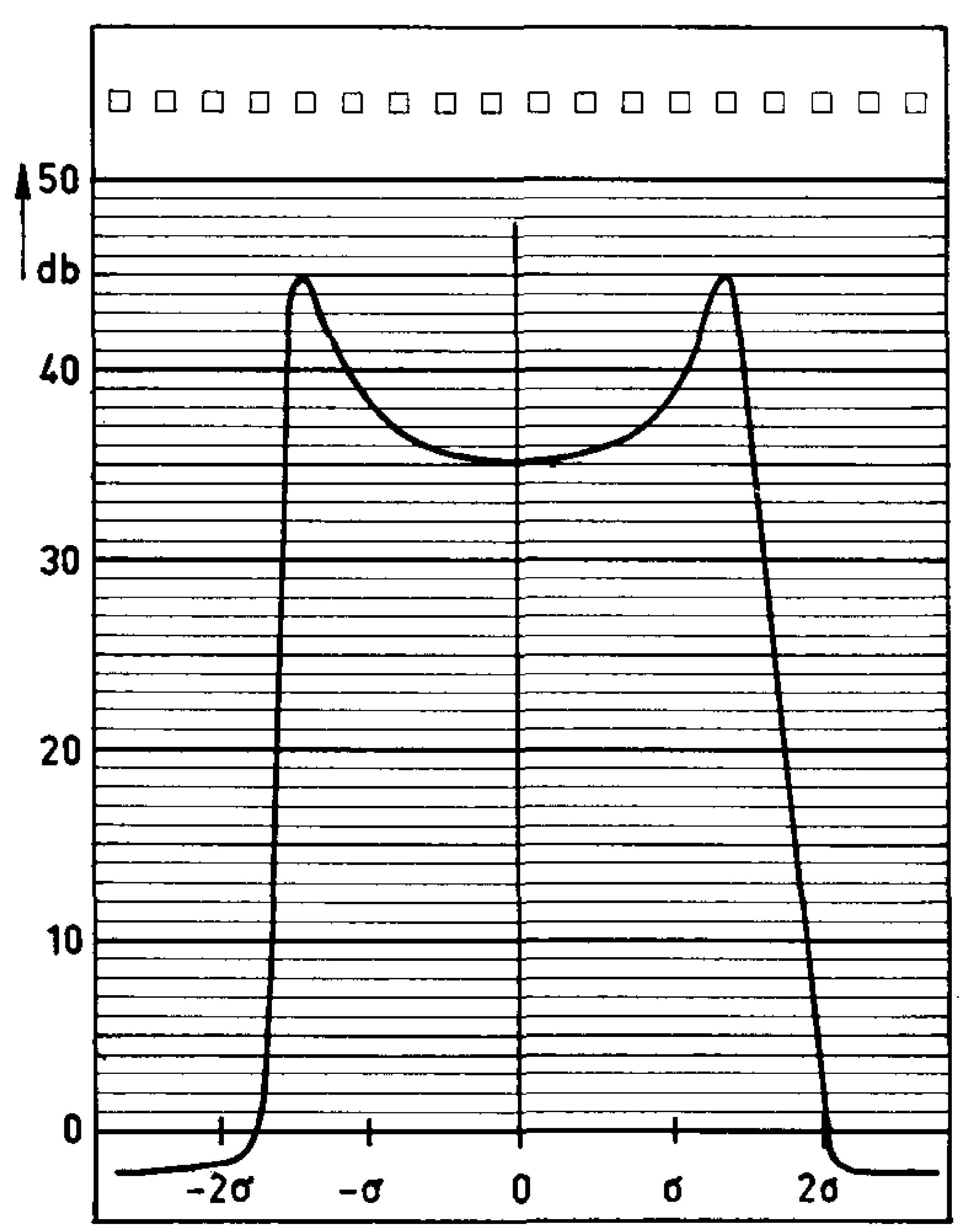


Fig. 21. Typical amplitude density curve of a warbled signal measured by means of the arrangement shown in Fig. 5.

Brüel & Kjær have therefore developed an audio frequency noise generator, Type 1402, with a flat frequency spectrum from 20 c/s to 20,000 c/s to within $\pm$ 1 db. The output power is, as previously mentioned, in the order of 0.3 watt for random noise with a crest factor of 4, i. e. maximum "undistorted" peaks $= 4\sigma$ where σ is the r.m.s. value of the noise. The distortion is less than 0.5 % (un-

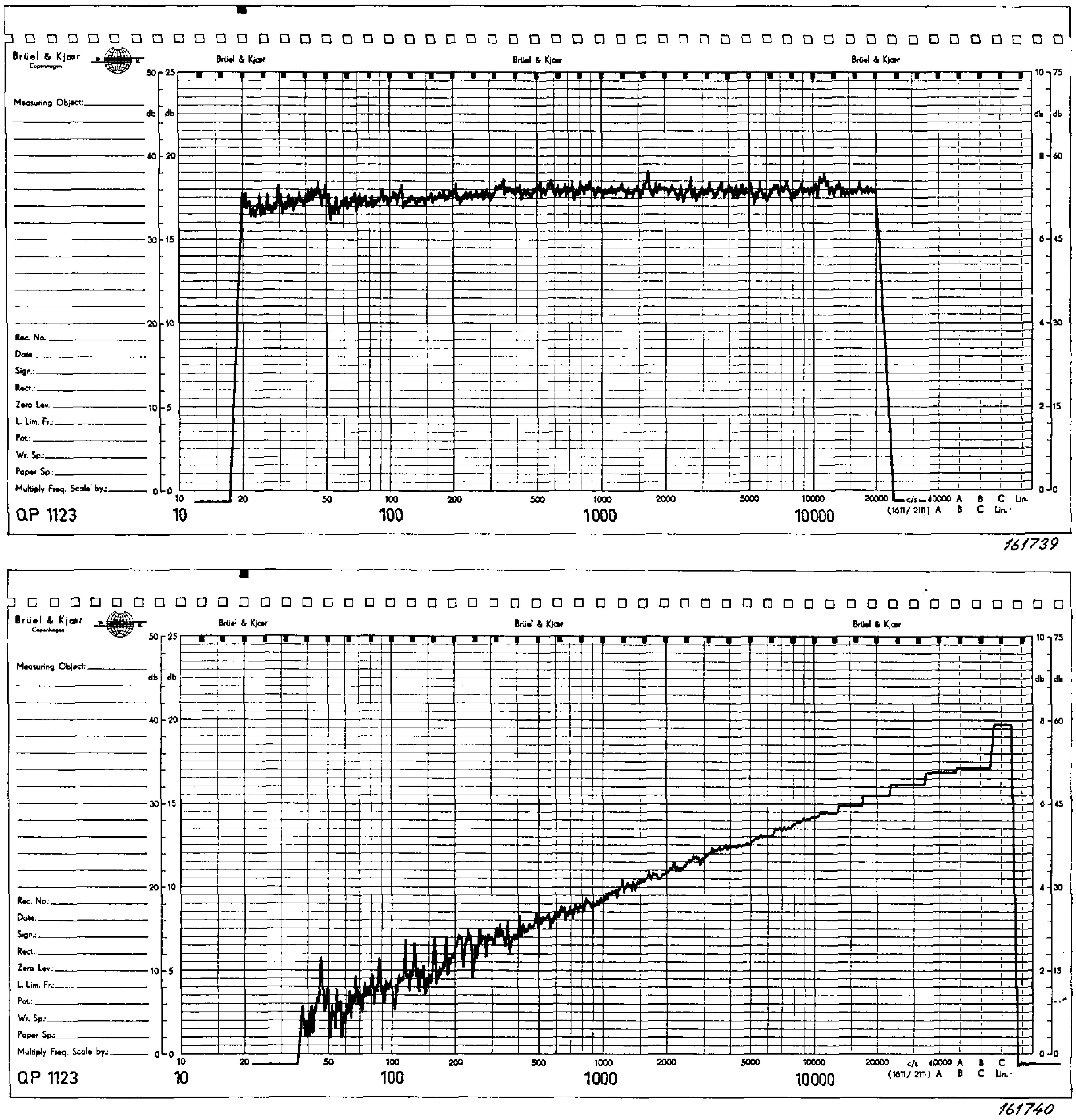


Fig. 22. Analysis of white noise.
(a) By means of constant bandwidth filters.
(b) By means of constant percentage bandwith filters (1/3 octave filters).

loaded) and the maximum available voltage peaks 160 Volts. Various output facilities enable the matching to 6, 60, 600 or 6000 ohms load, as well as an adjustable output voltage by means of a calibrated attenuator. The generator is, in addition, supplied with an "Oscillator Stop" button which disconnects the output signal as required for reverberation decay curve recording. The "Oscillator Stop" function can also be remotely controlled.
To facilitate easy reading of the output noise level the generator includes an indicating meter with interchangeable time constants of 10-3-1 and 0.3 seconds.

The meter measures the r.m.s. value of the noise by means of a special rectifier circuit.

A built-in filter, which can be switched in whenever desired, allows the output signal to drop off with frequency at a rate of 3 db/octave. This filter is included for the reason given below.

As stated beforehand the noise *power* of white noise is proportional to the bandwidth. When filtered through constant percentage bandwidth filters*) the *r.m.s. level* of the noise measured at the output of the filter will thus increase with the center frequency of the filter at a rate of *3 db/octave.* If the built-in weighting filter is switched in circuit a constant r.m.s. level will be measured when the noise is passed through constant percentage bandwidth filters, such as octave and $^1/_3$ octave filters (B & K Filter Set Type 1611), see Fig. 22.

To allow any additional shaping of the output noise spectrum that might be required the generator is supplied with terminals for insertion of external filters between the noise signal amplifier and the output amplifier, see block diagram Fig. 23. The output impedance of the noise signal amplifier is around 10 ohms, and the input impedance of the output amplifier is 100 kΩ.

A great amount of work has been spent on developing a noise generating circuit, the output signal of which has a true Gaussian amplitude distribution of up to 4 times the r.m.s. value ($4\,\sigma$) and which suppresses possible hum components from the mains to a sufficiently high degree.**) The circuit used consists of two zener

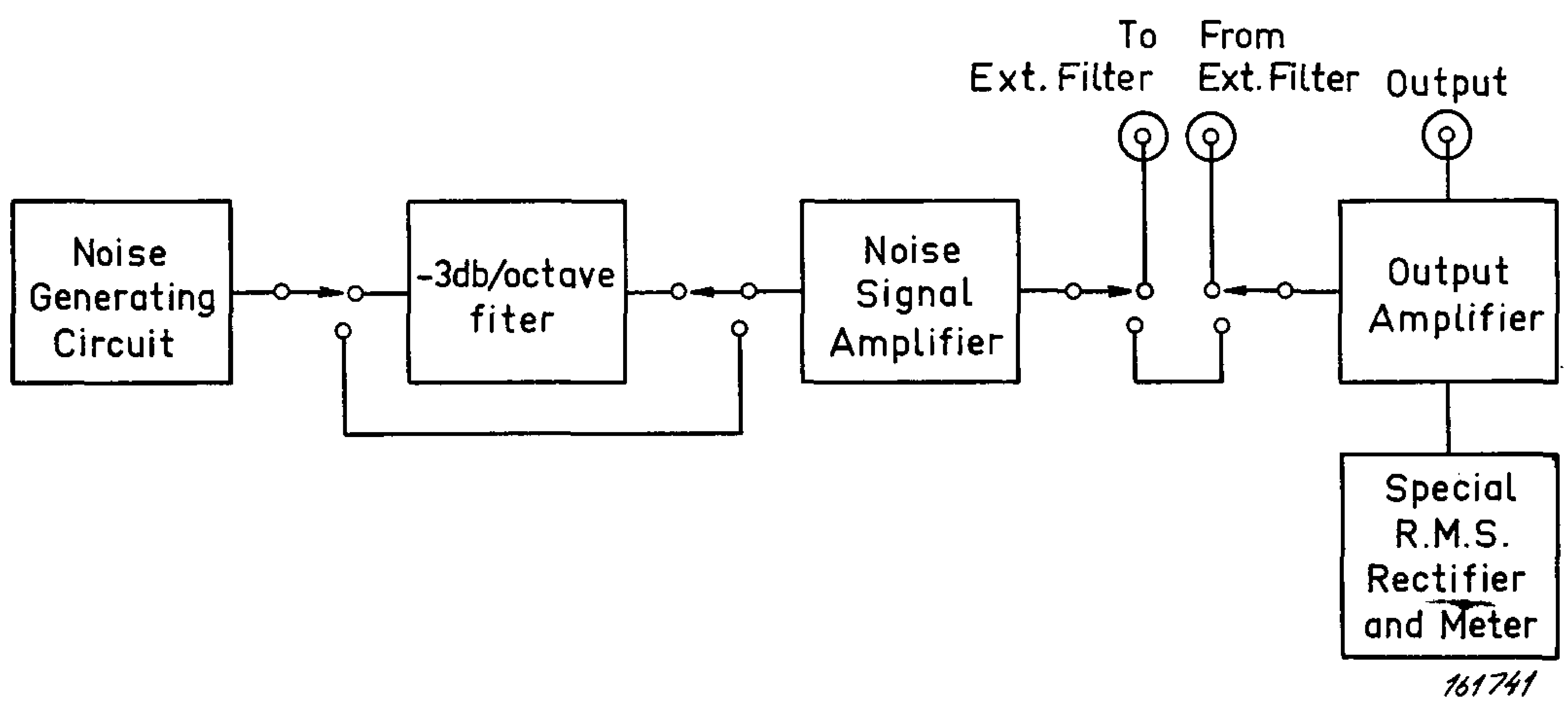


Fig. 23. Block diagram of the A. F. Noise Generator Type 1402.

diodes, and the output noise from the two diodes are superimposed in a balanced amplifier. The use of superposition of the noise from two diodes is necessary, because the amplitude distribution of the signal from one diode alone contains mainly peaks of one polarity.

To allow the measurement of the r.m.s. value of the output from the Noise

*) The bandwidth of constant percentage bandwidth filters are given by the relationship $\Delta f = \alpha f_0$, where f_0 is the center frequency of the filter, Δf the bandwidth, and α a constant.

**) The work was carried out under the leadership of P. E. Møller-Petersen, Brüel & Kjær.

Generator, a special r.m.s. rectifier circuit is used. This type of circuit is first described by Heinz Boucke, Labor für technische Physik, Tübingen, Germany, in 1950, and has later been discussed by Otto Schmid, Schwabisch Gmünd, Germany, Arnold Petersen, General Radio Co., U.S.A., and Carl G. Wahrman, Brüel & Kjær, Denmark. The schematic diagram of the circuit is shown in Fig. 24, and when the ratio between the resistors $\frac{R}{r}$ is correctly chosen, the r.m.s. value of the noise will be indicated on the instrument meter.

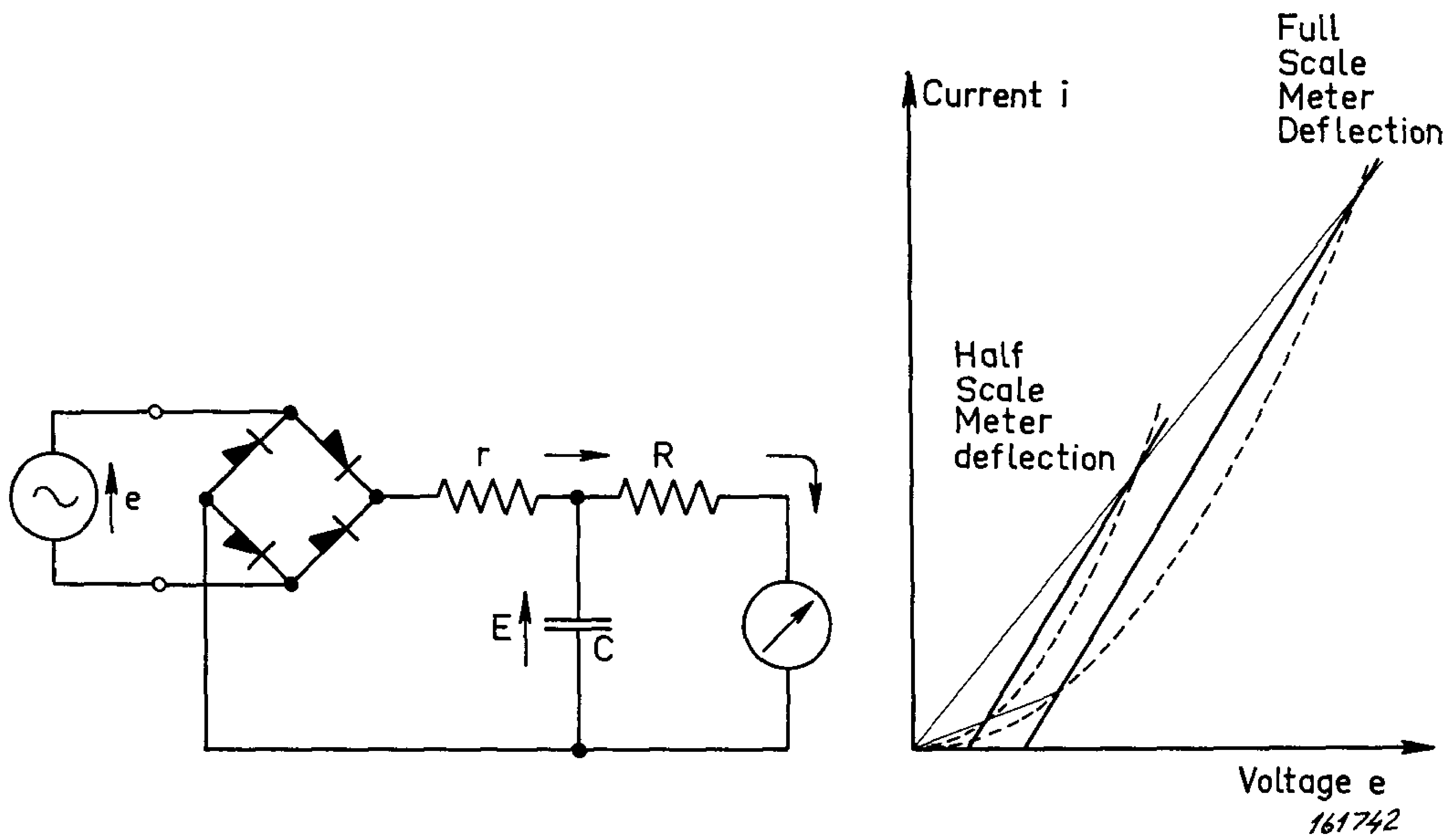


Fig. 24. Basic circuit and operating characteristics of the special r.m.s. rectifier incorporated in Type 1402.

To illustrate the use of the Noise Generator, B & K Type 1402 in a room-acoustic measuring arrangement Fig. 25 shows a convenient set-up for reverberation decay curve recording employing ⅓ octave bands of noise for the sound generation. The arrangement is automatically controlled from the level recorder, so that one decay curve is recorded per $^1/_3$ octave. The on-off switching of the sound, as well as the stepping of the filter switch in the $^1/_3$ Octave Filter Set and the Spectrometer are jointly performed by utilizing the built-in control switches of the recorder.

Audio frequency noise generators are excellent signal sources not only for room-acoustic measurements but also for many other purposes in the field of electro-acoustics. In the measurement of loudspeaker frequency characteristics, for example, it is very convenient to feed the speaker with bands of noise and in this way determine its frequency response. Firstly, the response obtained in this way might give a closer resemblance between the actual performance of the loudspeaker when mounted in a room and used for entertainment purposes, than will a free-field frequency response curve measured by means of a sweeping sine wave. Secondly, the response can be measured under conditions which need not constitute a theoretically completely free field, as the influence of distinct disturbing standing waves are minimized by the simultaneous excitation of many room resonances.

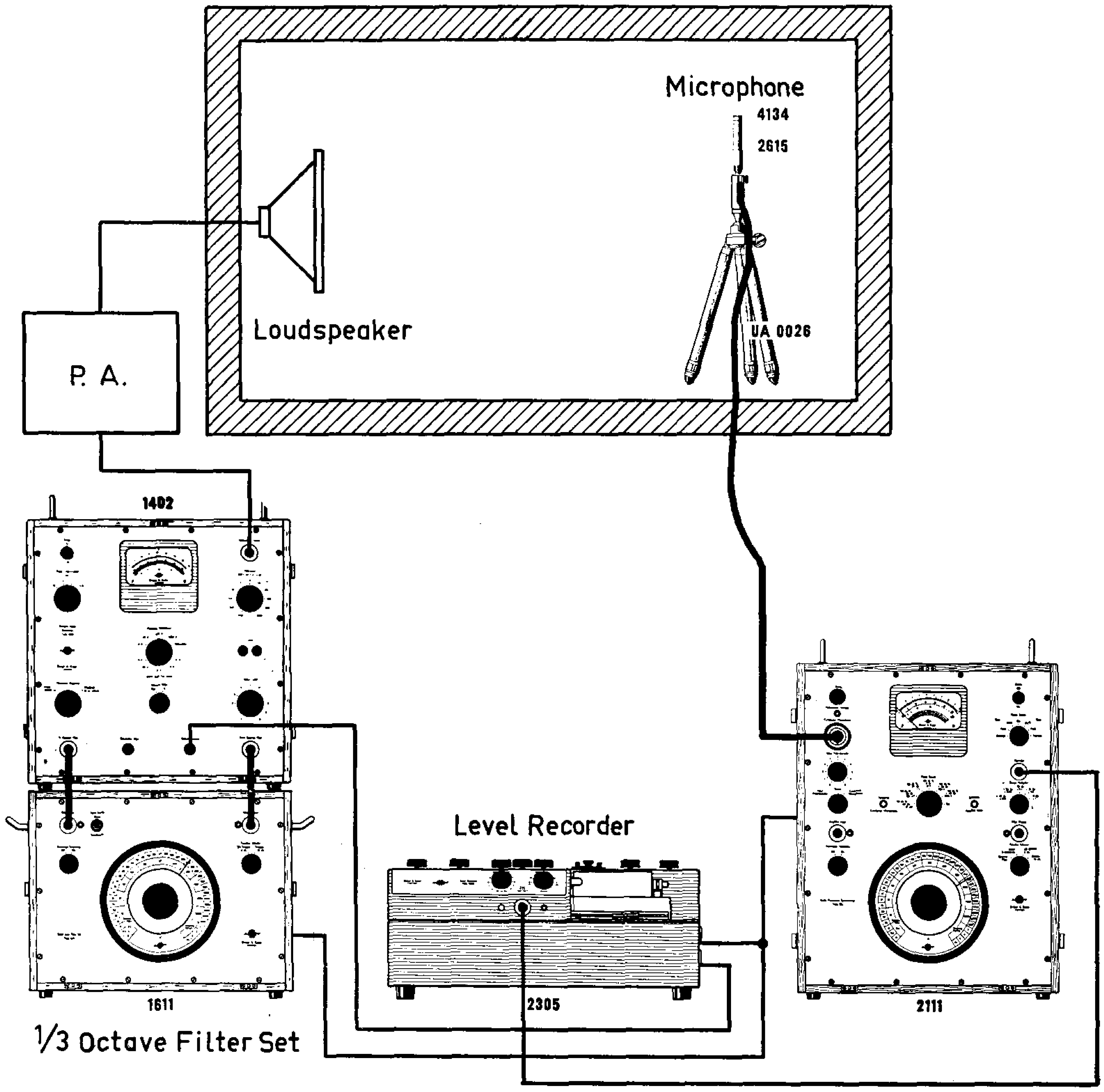


Fig. 25. Measuring arrangement for the automatic recording of reverberation decay curves. The set-up allows one decay curve to be recorded automatically per one-third octave throughout the audio range.

Another example in the use of noise as a signal source for frequency response measurements is the determination of transmission characteristics of telephone lines. By feeding one end of the line with white noise and analysing the frequency spectrum present at the other end, the response can be measured and recorded automatically on a level recorder. In a similar way cross-talk between two channels can be measured and analysed. One of the channels is then fed from the noise generator, while the induced noise spectrum is measured on the other. The Noise Generator is also very useful tool for investigation of many servo-systems and the determination of the equivalent averaging time of complicated wide-band rectifier circuits. (See B & K Technical Review Nos. 4-1960 and 1-1961).

Finally, the use of audio frequency noise in vibration test arrangements should be briefly mentioned. Vibration tests are carried out on automobiles, aircraft, missiles, and components which are intended to operate in a vibrational environment. The specimen to be tested is normally mounted on an electrodynamic shaker which is driven from an electronic signal source via a power amplifier, see Fig. 26. The signal source may consist of a more or less specialized sine wave

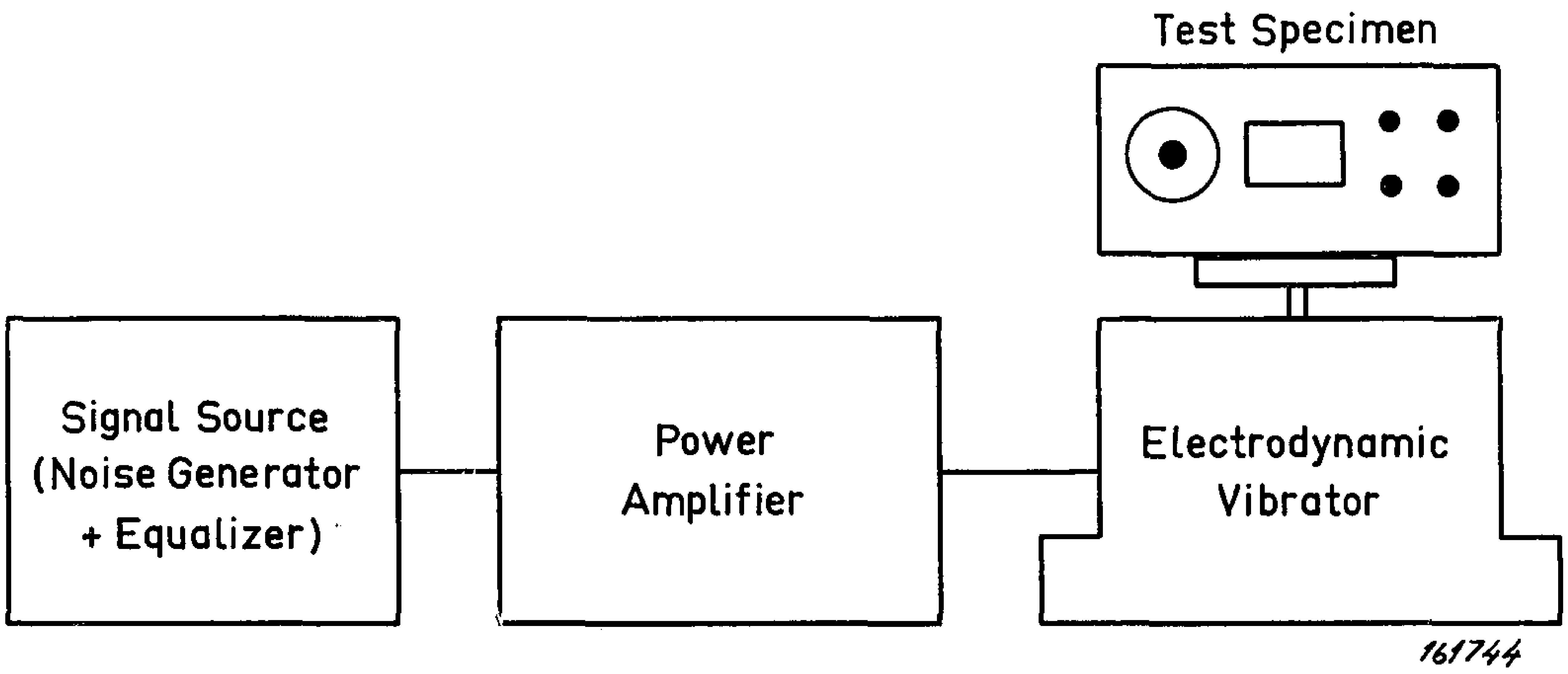


Fig. 26. Typical vibration test arrangement using an electrodynamic shaker as vibration exciter.

generator or of a noise generator. The noise generator is then capable of producing random vibration on the shaker table. Its frequency characteristic may be shaped in various ways, partly to compensate for shaker/specimen resonances, and partly for the production of any desired vibration spectrum. Investigations as to the functioning of the test specimen in a random vibration environment can then be carried out over short or lengthy periods of time.

Selected References:

1. C. G. Balachandran: "Random Sound Field in Reverberation Chambers", J.A.S.A., Volume 31, No. 10-1959.
2. L. L. Beranek: "Acoustic Measurements", John Wiley & Sons, 1949.
3. G.B. Booth: "Random Motion", Product Engineering, Nov. 1956, McGraw Hill.
4. H. Boucke: "Ein neuartiger Effektivwertgleichrichter mit vermindertem Kurvenformfehler". Archiv der Elektrischen Übertragung, 4, (1950) p. 267–270.
5. F. H. Brittain and E. Williams: "Loud Spaker Reproduction of Continuous-Spectrum Input". The Wireless Engineer, January 1938.
6. J. T. Broch: "Vibration Testing of Components. Automatic Level Regulation of Vibration Exciters". B & K Technical Review No. 2-1958.
7. J. T. Broch: "Automatic Recording of Amplitude Density Curves". B & K Technical Review No. 4-1959.
8. J. T. Broch: "Vibration Exciter Characteristics". B. & K Technical Review No. 3-1960.
9. J. T. Broch and C. G. Wahrman: "R.M.S. Recording of Narrow Band Noise with the Level Recorder Type 2305", B & K Technical Review No. 4-1960.
10. J. T. Broch and C. G. Wahrman: "Effective Averaging Time of the Level Recorder Type 2305", B & K Technical Review No. 1-1961.
11. P. V. Brüel: "Sound Insulation and Room Acoustics", Chapman & Hall, 1951.
12. W. B. Davenport jr.: "An Experimental Study of Speech-Wave Probability Distributions", J.A.S.A., Volume 24, No. 4-1952.
13. B. Olney: "Experiments with the Noise Analysis Method of Loudspeaker Measurement", J.A.S.A., Volume 13, July 1942.
14. A. G. P. Peterson: "Response of Peak Voltmeters to Random Noise", General Radio Experimenter, Dec. 1956.
15. O. Schmid: "Grundlagen linearer Effektivwertgleichrichter". Archiv der elektrischen Übertragung, 5, (1951), p. 241-247, and "Zur Theorie des Effektivwertgleichrichters". Archiv der elektrischen Übertragung, 5, (1951), p. 459-463.
16. S. S. Stevens, J. P. Egon, and G. A. Miller: "Methods of Measuring Speech Spectra", J.A.S.A., Volume 19, No. 5-1947.
17. H. Thiede: "Schallvorgänge mit kontinuierlichem Frequenzspektrum", E.N.T., Band 3, Heft 3-1936.
18. C. G. Wahrman: "A true R.M.S. Instrument", B & K Technical Review No. 3-1958.

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