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Cover: Taking measurements with the Heterodyne Voltmeter 2002 on a marine transmitter.

THE HETERODYNE VOLTMETER TYPE 2002 AND ITS APPLICATIONS.

In the following pages a selective and very sensitive tube voltmeter is described, based on the heterodyne principle, with a number of typical and characteristic applications.

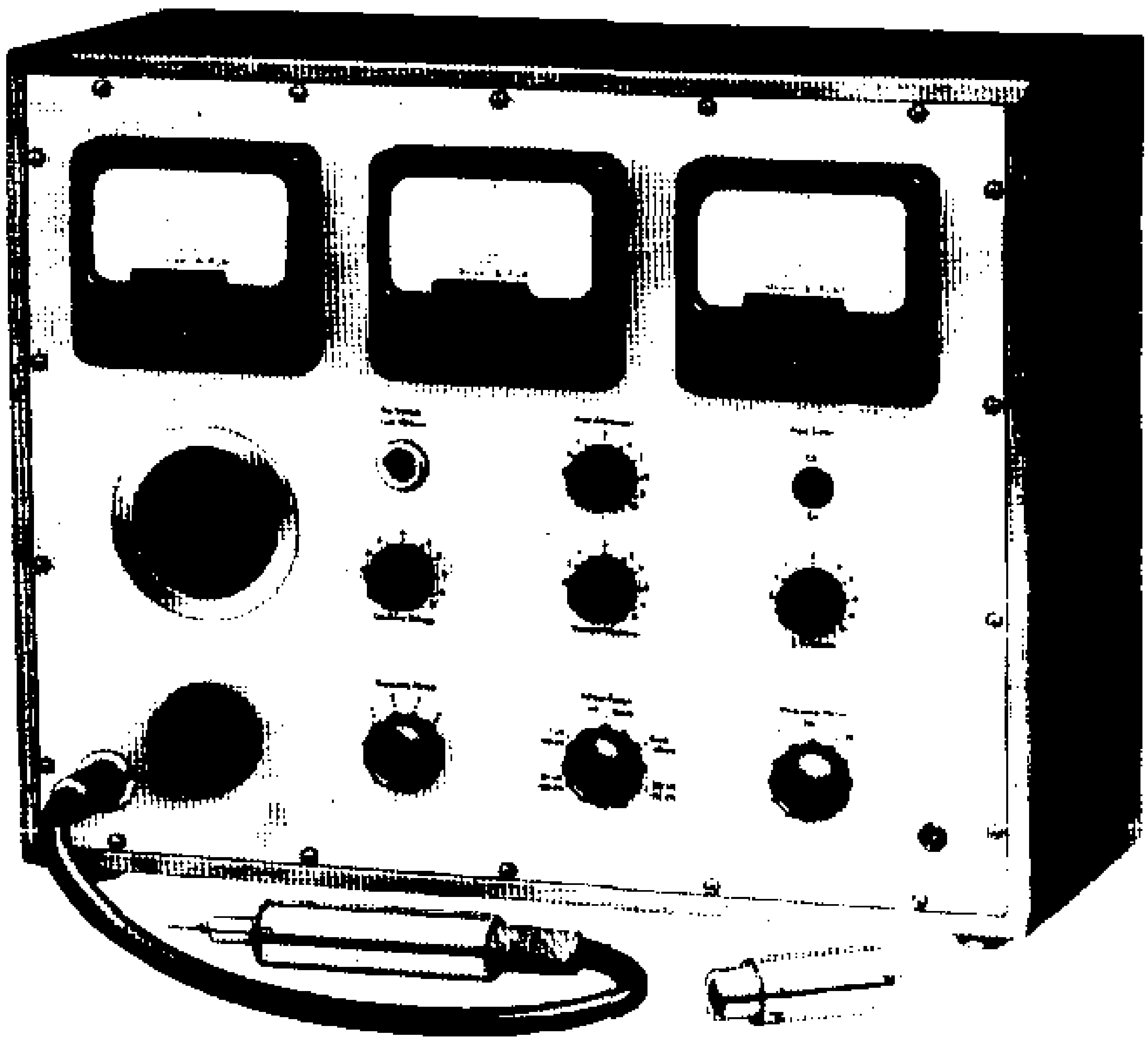

Fig. 1. *The Heterodyne Voltmeter Type 2002.*

The Heterodyne Voltmeter Type 2002 (Fig. 1) can measure small R. F. voltages in the frequency range 20 kc/s to 30.3 Mc/s. The sensitivity of the meter is high, giving a full scale deflection of 10 μV on the most sensitive range. The Heterodyne Voltmeter can also measure the degree of modulation of the R. F. voltage being examined.

This new instrument is much superior to the ordinary sensitive aperiodic tube voltmeter for many different types of measurement. The standard commercially produced tube voltmeter for frequencies up to 30 Mc/s usually has the following disadvantages:

1) Poor sensitivity, as it cannot give full scale deflection for less than 3000—10000 μV, while as already mentioned the Heterodyne Voltmeter gives full deflection for 10 μV on its most sensitive range.

2) If, on the other hand, the sensitivity of the standard, nonselective, tube voltmeter is driven up to maximum, the noise level will be too high. For example, the theoretical noise level of a standard type voltmeter with an input impedance of 5 M Ω in parallel with a capacitance of 5 pF, and a frequency range of 20 kc/s to 10 Mc/s, is 30 μ V, and in practice is always more than this. The noise level of the Heterodyne Voltmeter is of the order of 3—4 μ V.

3) Frequency analysis of R. F. voltages cannot be carried out with a standard aperiodic tube voltmeter.

4) The degree of modulation of an R. F. voltage cannot be measured by means of a standard aperiodic tube voltmeter.

The Heterodyne Voltmeter is in principle a heterodyne radio receiver in which the speaker and diode circuits are equipped with measuring instruments. As it is important that the sensitivity of the Heterodyne Voltmeter be independent of the frequency, tuned circuits are omitted ahead of the mixer stage, thus giving an aperiodic input circuit. Unfortunately, this means that the instrument will not only give a deflection for the carrier frequency, but for the image frequency as well. In the Heterodyne Voltmeter Type 2002 the oscillator frequency is equal to the sum of the signal frequency and the I. F. frequency for the frequency range 20 kc/s to 27 Mc/s. For frequencies lower than the I. F., that is to say, lower than 1650 kc/s, no image frequencies will be produced. For frequencies between 1650 kc/s and 27 Mc/s, the correct signal frequency will correspond to the greater of the two possible frequency modes. For frequencies from 27 Mc/s to 30.3 Mc/s, the lowest mode is selected, and to the indicated frequency must then be added twice the I.F. frequency, i. e., 3.3 Mc/s.

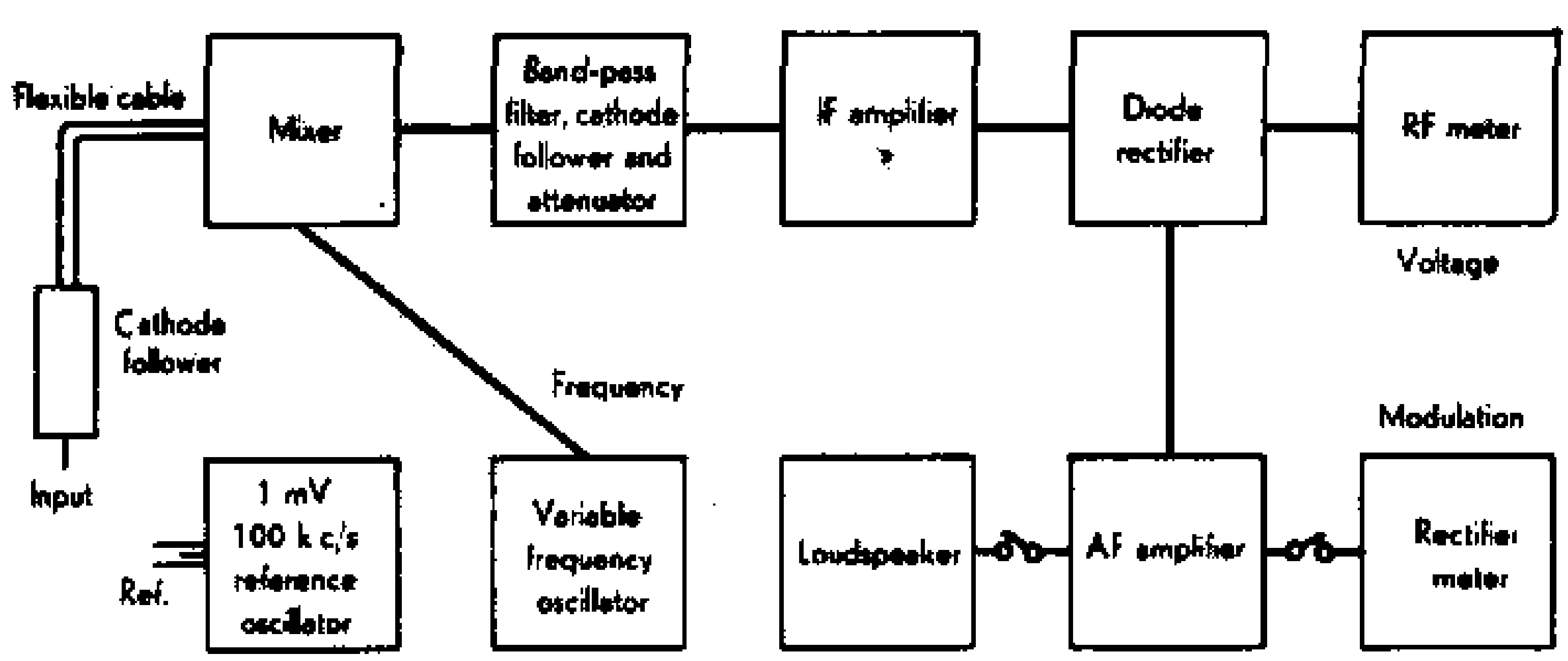

Fig. 2. *Block diagram of the Heterodyne Voltmeter.*

Fig. 2 shows a block diagram of the Heterodyne Voltmeter. The R. F. voltage to be examined is lead via a coaxial plug to the grid of a miniature cathode follower tube placed in a small metal container attached to the plug. The cathode follower serves as an impedance transformer. The input impedance is 5 M Ω in parallel with 12 pF. If the voltage being examined contains a D. C. component, a suitable capacitor must be inserted, or the capacitative attenuator which is available can be used, and in any case must be used for voltages from 0.1 to 10 volts, and which can be used for voltages down to 1 mV. The cathode follower is connected to the Voltmeter via a screened cable and screened multi-pin jack and plug, leading to the mixer tube, a triode-hexode, the hexode section serving as mixer and the triode section as local oscillator. As the conversion conductance of the mixer tube with input voltages whose frequencies lie above 5 Mc/s decreases with increasing frequency, compensation is carried out by mismatching the above mentioned cable. In this way a flat frequency characteristic is obtained, approx. $\pm$ 0.5 db up to 27 Mc/s.

The frequency of the local oscillator can be continuously varied in four steps over the whole frequency range, so that the Heterodyne Voltmeter can be adjusted to any frequency within these four ranges, namely, 20 kc/s to 2000 kc/s., 2 Mc/s to 6 Mc/s., 6 Mc/s to 12 Mc/s., and 12 Mc/s to 27 Mc/s. In the anode circuit of the mixer tube there is an I. F. band-pass filter with two tuned circuits, and the mixer is followed by a cathode follower. In the cathode circuit of this tube there is a resistive attenuator, by means of which the sensitivity of the instrument can be varied in steps of 20 db, so that full deflection can be obtained from the following ranges: 10 — 100 — 1000 μV and 10 — 100 mV. A capacitative attenuator, Type 2012, can be attached to the input cathode follower, so that the voltage range can be extended to 10 volts, the input impedance being increased to many thousand MΩ in parallel with 3 pF.

It will be noted that the resistive attenuator is working on a fixed frequency, so that there is no question of frequency dependence, which is a very great advantage. After this stage there is a 3-stage I. F. amplifier with a further 6 tuned circuits, and then a diode rectifier whose load is the meter, indicating the R. F. voltages. The accuracy of the voltage measurements is $\pm$ 0.5 db up to 6 Mc/s, and $\pm$ 1.0 db between 6 and 30.3 Mc/s. If the input voltages are amplitude modulated, the rectified voltage from the diode rectifier will contain the L. F. component from this modulation. The diode rectifier is therefore followed by an L. F. amplifier which can be switched either to a copper-oxide rectifier instrument for measuring the degree of modulation or to a loud speaker, used for tuning to and identification of the signal. The modulation meter is provided with two scales, indicating the degree of modulation in %, with ranges 0 — 31.6 % and 0 — 100 %. The range for the modulation frequency extends from 30 c/s to 1500 c/s with an accuracy of $\pm$ 1 db.

A condition for constant sensitivity is that the oscillator voltage remains constant. It is therefore necessary with each measurement, or at least whenever the measuring frequency is changed, to adjust the oscillator voltage to a fixed value, indicated by a red mark on the modulation meter. Before a series of measurements is carried out, the sensitivity of the Heterodyne Voltmeter must be checked and if necessary readjusted by means of the built-in standard signal generator, which gives an output of precisely 1 mV at 100 kc/s. Any necessary re-adjustment of the sensitivity is made by means of a variable resistor in the cathode of the first I. F. amplifier. As the grid of this tube is connected to the low impedance attenuator, no detuning of any I. F. circuit will occur. The Heterodyne Voltmeter can be operated from a 115 — 127 — 150 or 220 volt A. C. power supply. If it is desired to operate the instrument from a D. C. line or storage battery, a vibrator or rotary converter is required.

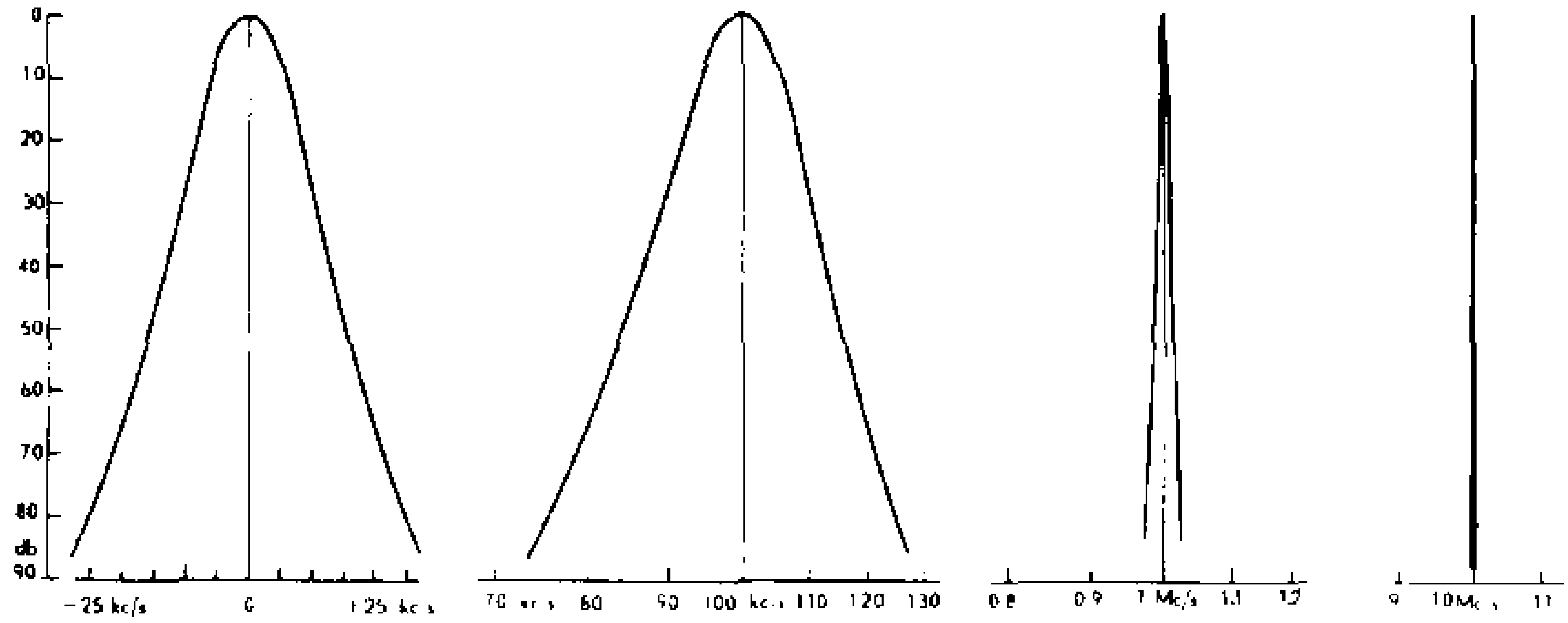

Fig. 3. *Selectivity curves for the Heterodyne Voltmeter. To the left the curve is shown with a linear frequency scale and to the right three sections of the frequency range given in a logarithmic scale.*

The Heterodyne Voltmeter has of course some inconveniences. In some cases when measuring lower frequencies, the selectivity is poor, and conversely, at higher frequencies, the selectivity is great. Fig. 3 shows the selectivity curve of the Heterodyne Voltmeter, at the left with a linear frequency scale, at the right with a logarithmic frequency scale. The relatively great band-width at lower frequencies and the very narrow band-width at high frequencies can clearly be seen. With measurements on the lower frequencies, the lower limit of the R. F. voltages which can be measured with the Heterodyne Voltmeter rises, as can be seen in fig. 4, for the corresponding oscillator frequency approaches the I. F. and tends to block the I. F. amplifier.

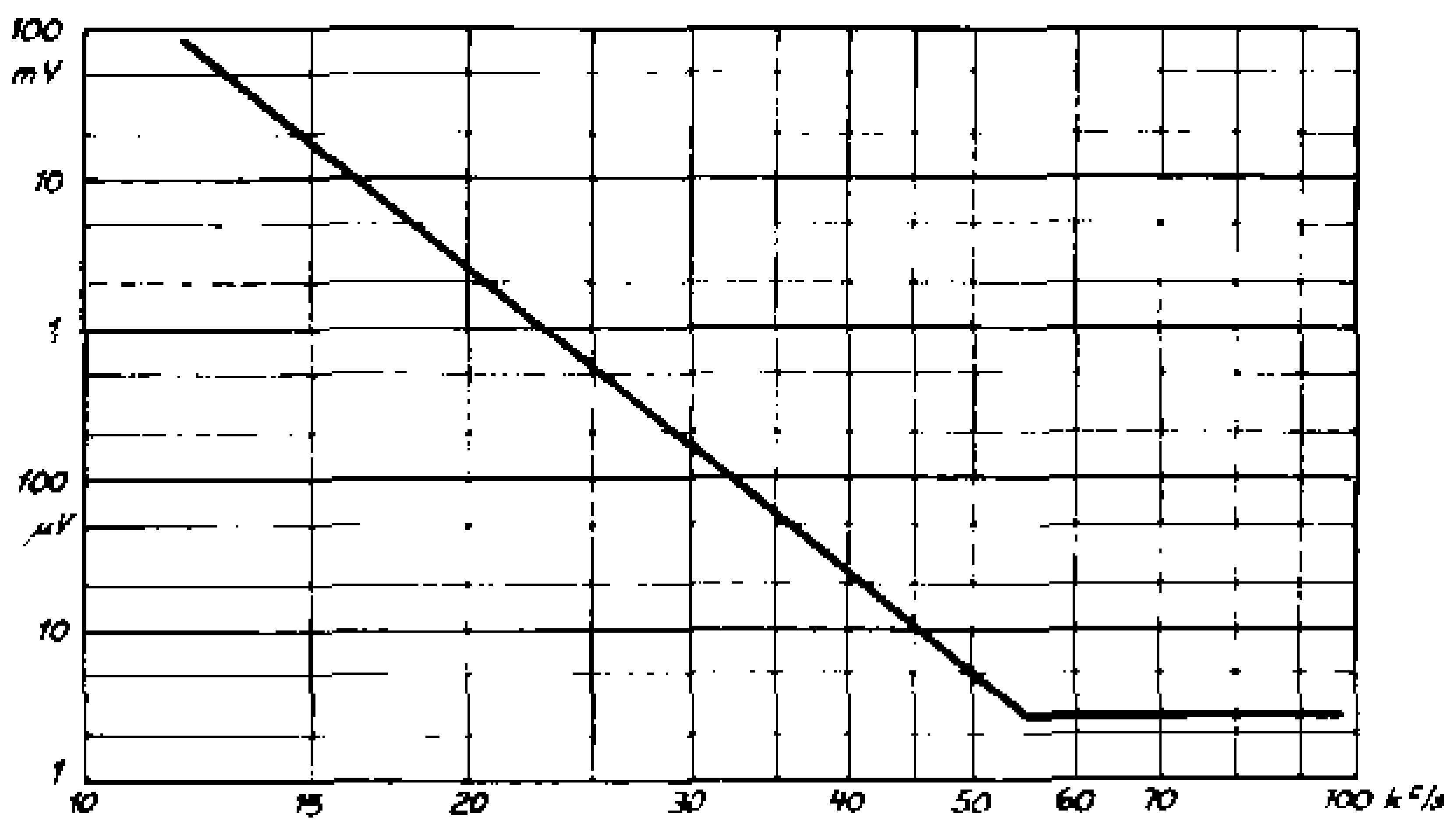

Fig. 4. *Minimum input voltage measurable with the Heterodyne Voltmeter.*

Over a small range around the Intermediate Frequency, the input signal passes the mixer tube without conversion, interfering with the I. F. signal. As the I. F. sensitivity of the instrument is a little higher than the signal frequency sensitivity, the readings in this range will be too high, as is seen from fig. 5. As a consequence of the aperiodic input, the instrument will give additional responses, owing to harmonics of the oscillator frequency and to higher orders of mixing products. Though these responses are considerably weaker than the main signal, care must be taken when analyzing an unknown complex voltage.

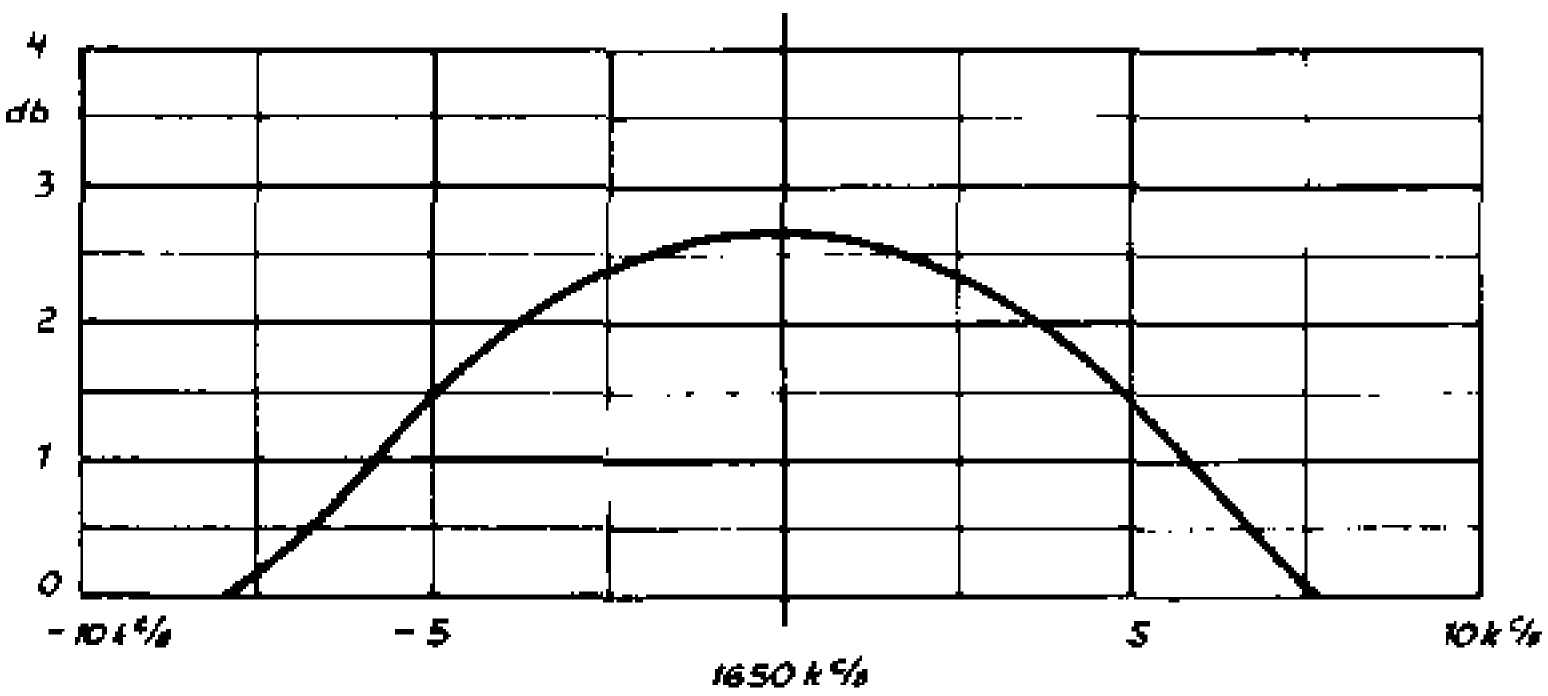

Fig. 5. *Deviation from true value around the I.F. frequency.*

It must be mentioned that input voltages with an amplitude approaching the noise level (3—4 μ V) can be measured by the substitution method, the unknown voltage first being read off on the Heterodyne Voltmeter, then the Voltmeter is connected to a reliable and exactly calibrated signal generator, and the generator's output voltage is then adjusted so as to give exactly the same deflection on the Hetrodyne Voltmeter as before. The precise R. F. voltage can then be read off on the signal generator's attenuator.

In spite of the above mentioned disadvantages, it will be clear from the foregoing that the Heterodyne Voltmeter is an extremely useful instrument in the radio laboratory, and a few examples to show this will now be given:

The Heterodyne Voltmeter is a very handy and practical instrument for the checking of frequency, modulation and particularly output voltages of standard signal generators. The frequencies can be checked by the Heterodyne Voltmeter in connection with a frequency standard, for example a crystal-controlled multi-vibrator. The frequency exactness of the Heterodyne Voltmeter is usually not high enough to permit its use as a frequency standard. It is therefore necessary to check fixed points on the frequency scale by means of a crystal-controlled generator. The output voltages for all the attenuator positions of the signal generator can be read off, for different frequencies, and in this connection it is a great advantage that the attenuator of the Heterodyne Voltmeter works on a fixed frequency, and therefore gives readings which are quite independent of frequency. If the signal generator's attenuator is not absolutely exact, it is quite easy with the help of the Heterodyne Voltmeter to make an error curve, as for example is shown in fig 6. Also, the degree of modulation (usually 30 %) of the signal generator can be checked and adjusted.

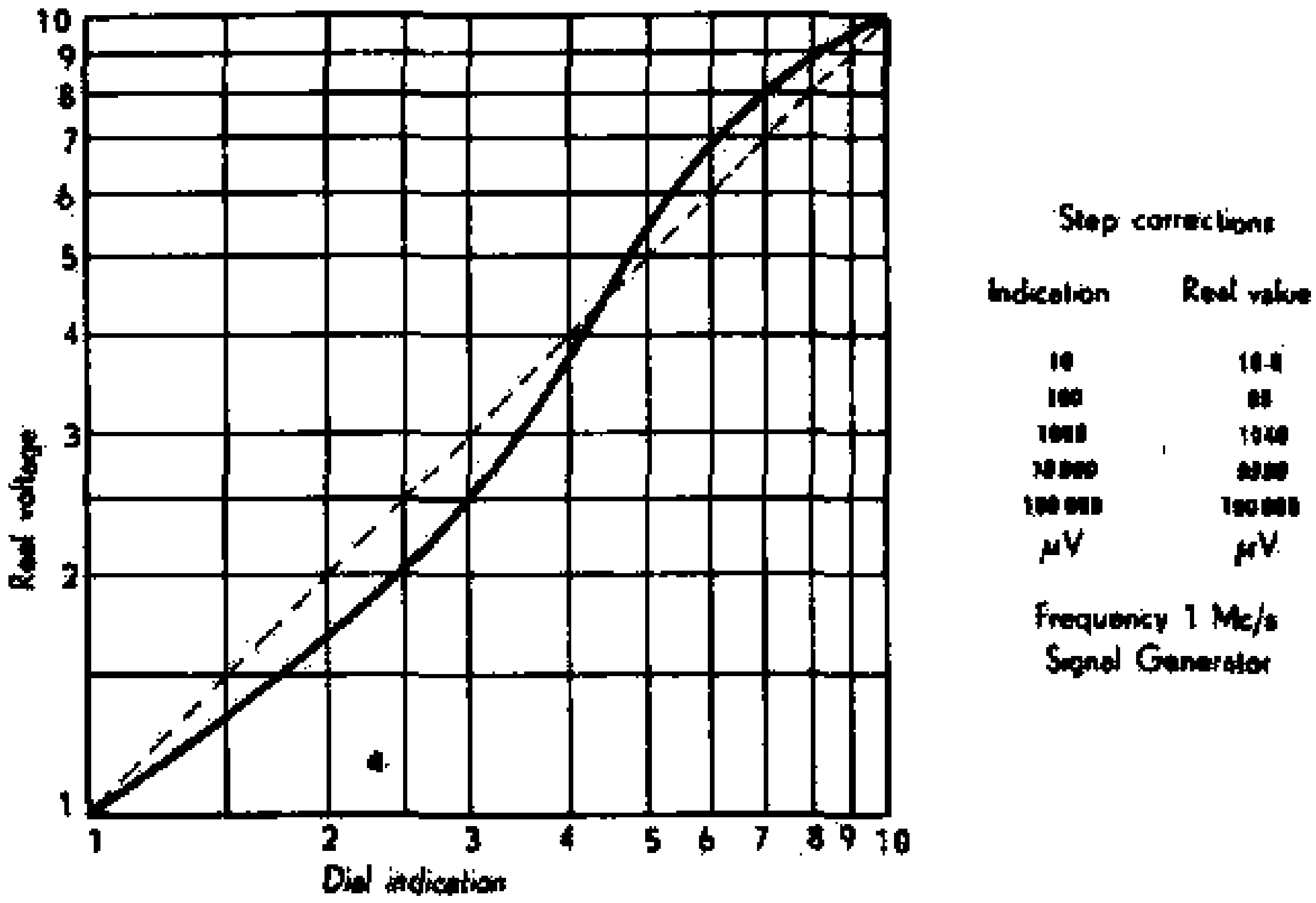

Fig. 6. *Correction curve for a laboratory signal generator.*

A set-up for measuring the degree of distortion from a signal generator can be seen in fig 7, both the main carrier frequency and the harmonics being determined, as seen in the figure. Finally, it might be mentioned that the Heterodyne Voltmeter can be used for the checking of alignment oscillators

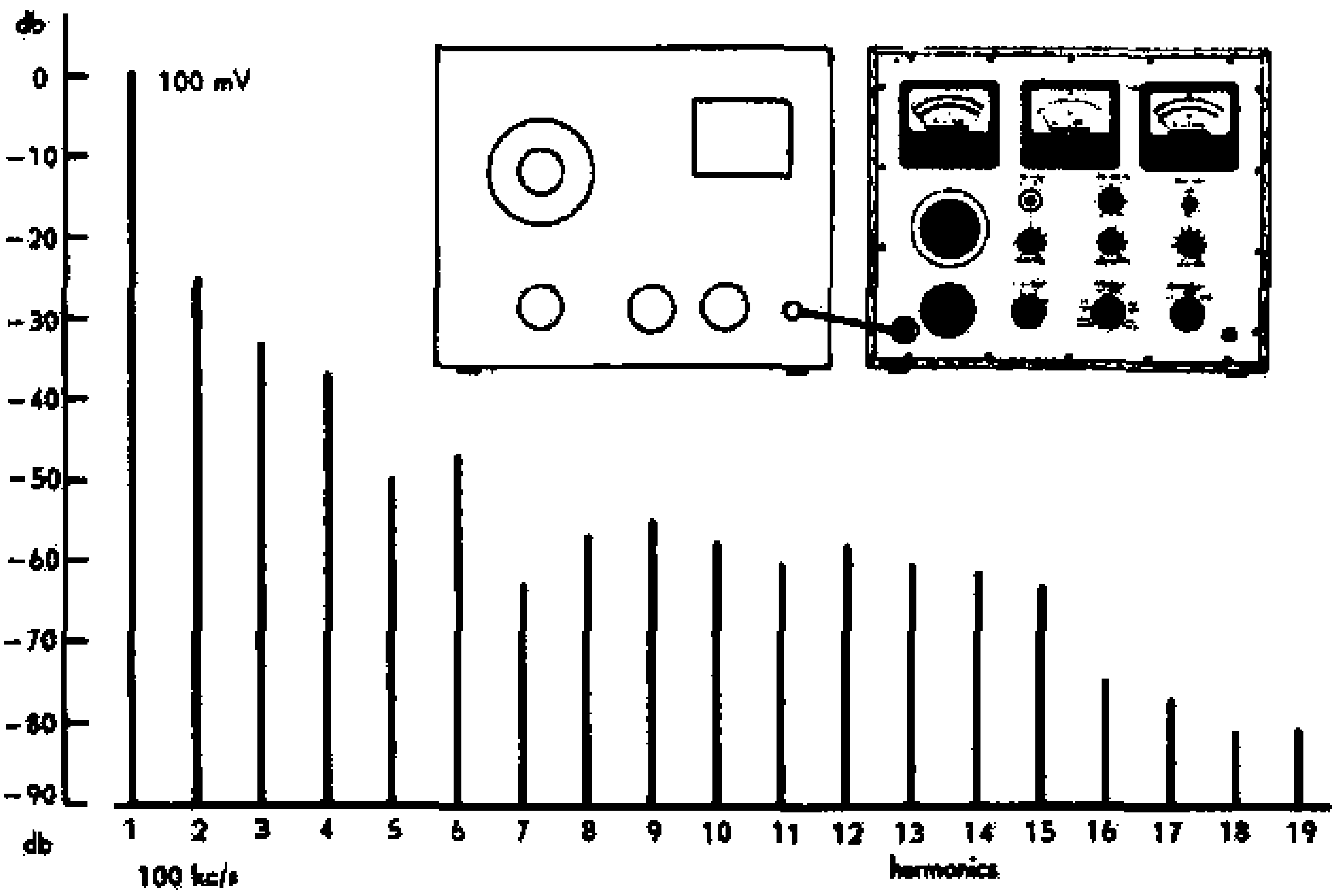

Fig. 7. Measurement of distortion from a signal generator (Laboratory Model MS 11).

as shown for example in fig 8, where the Heterodyne Voltmeter is used to record the frequency spectrum of a multi-vibrator, whose many powerful harmonics are used in aligning the oscillator and signal frequency circuits in radio receivers.

Figure 9 shows a diagram of the potential distribution along a H. F. cable, which connects the central signal generator with the different trimming points in a radio factory. The voltage distribution curve is as a rule dependent on the frequency and should therefore be worked out for all the frequencies which might be of interest. If for example the terminal impedance does not correspond to the characteristic impedance of the

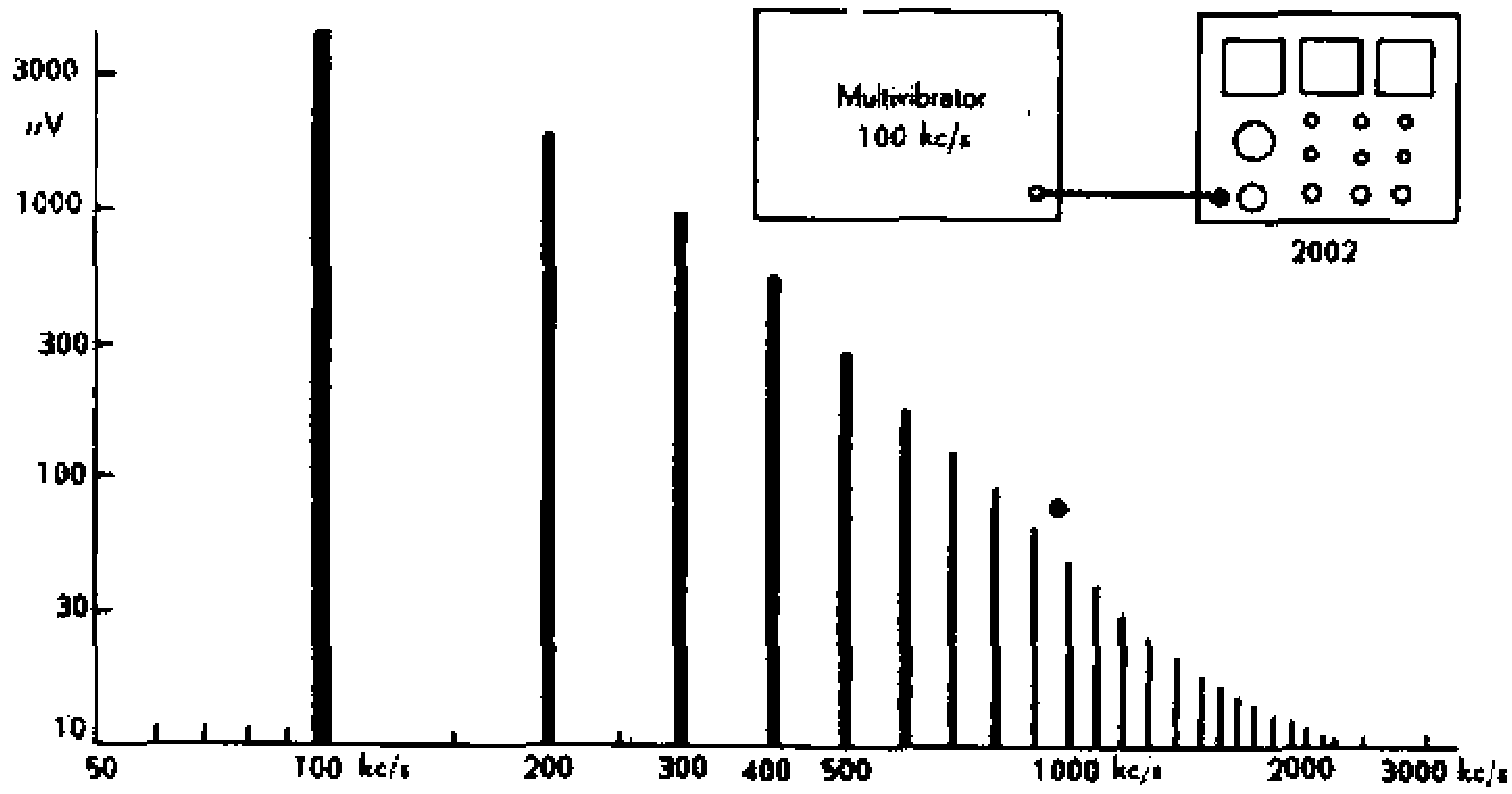

Fig. 8. *Spectrum of harmonics from a multi-vibrator.*

cable, standing waves will be obtained, whose amplitude and position can be measured, as shown in the figure. In a similar way the cables in an antenna distribution system can be checked. The antenna amplifier is fed by means of a signal generator, and with the Heterodyne Voltmeter it is possible to measure the voltages at all the receiver connecting-points throughout the whole building, as shown in fig. 10. At the same time, of course, the antenna amplifier's frequency characteristic and gain are checked.

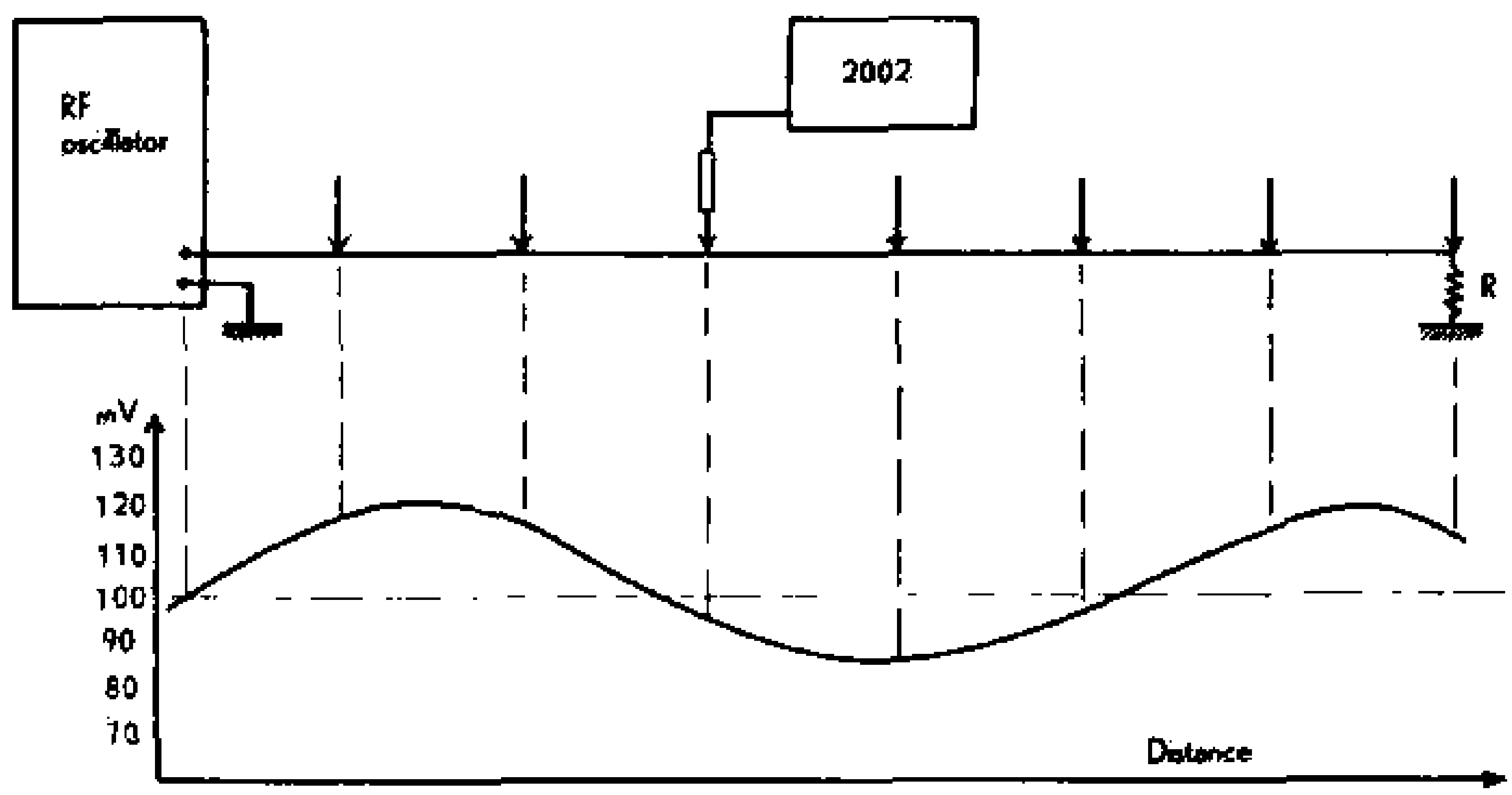

Fig. 9. *Checking an R. F. distribution cable in a radio factory.*

Amongst the easier measurements can be mentioned the recording of the spectrum of broadcast transmitters and fig. 11 shows the long-wave range measured in the neighbourhood of Copenhagen. Fig. 12 shows the noise spectrum from a rotary converter driven by the mains power supply, and fitted with a noise-filter condenser. The noise is measured as picked up on a nearby antenna. The effective height H_{eff} of an antenna for a particular frequency band can be measured by means of the Heterodyne Voltmeter if one knows the field strength A in mV/m at the point in question, produced by a radio station on the appropriate frequency, and one measures the

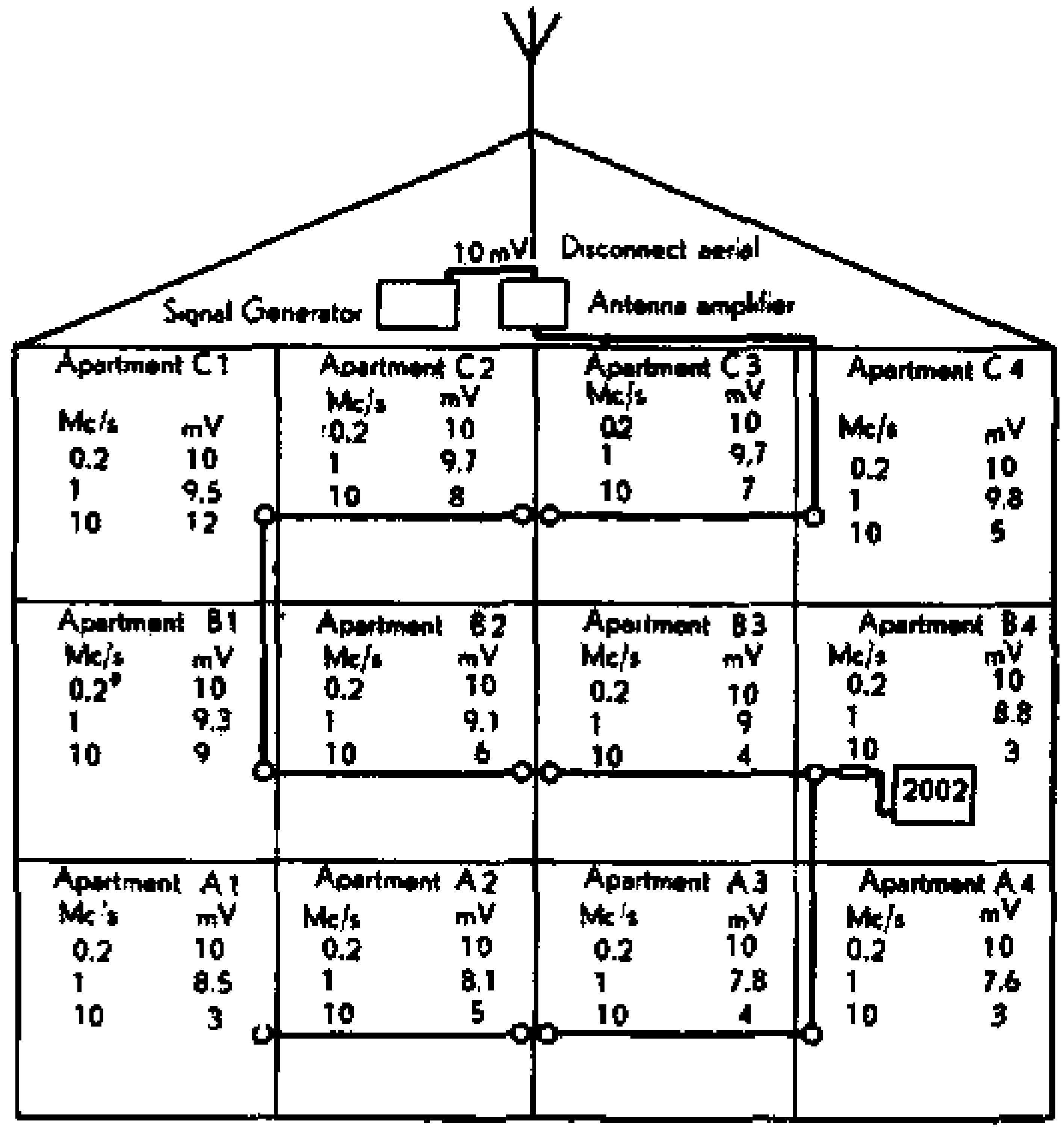

Fig. 10. *Checking of voltage distribution and gain for an antenna amplifier with distribution cables.*

antenna voltage E in mV relative to earth, on the station's frequency (fig. 13). The antenna effective height H_{eff} can the be calculated from the equation

$$E = A \times H_{eff}$$

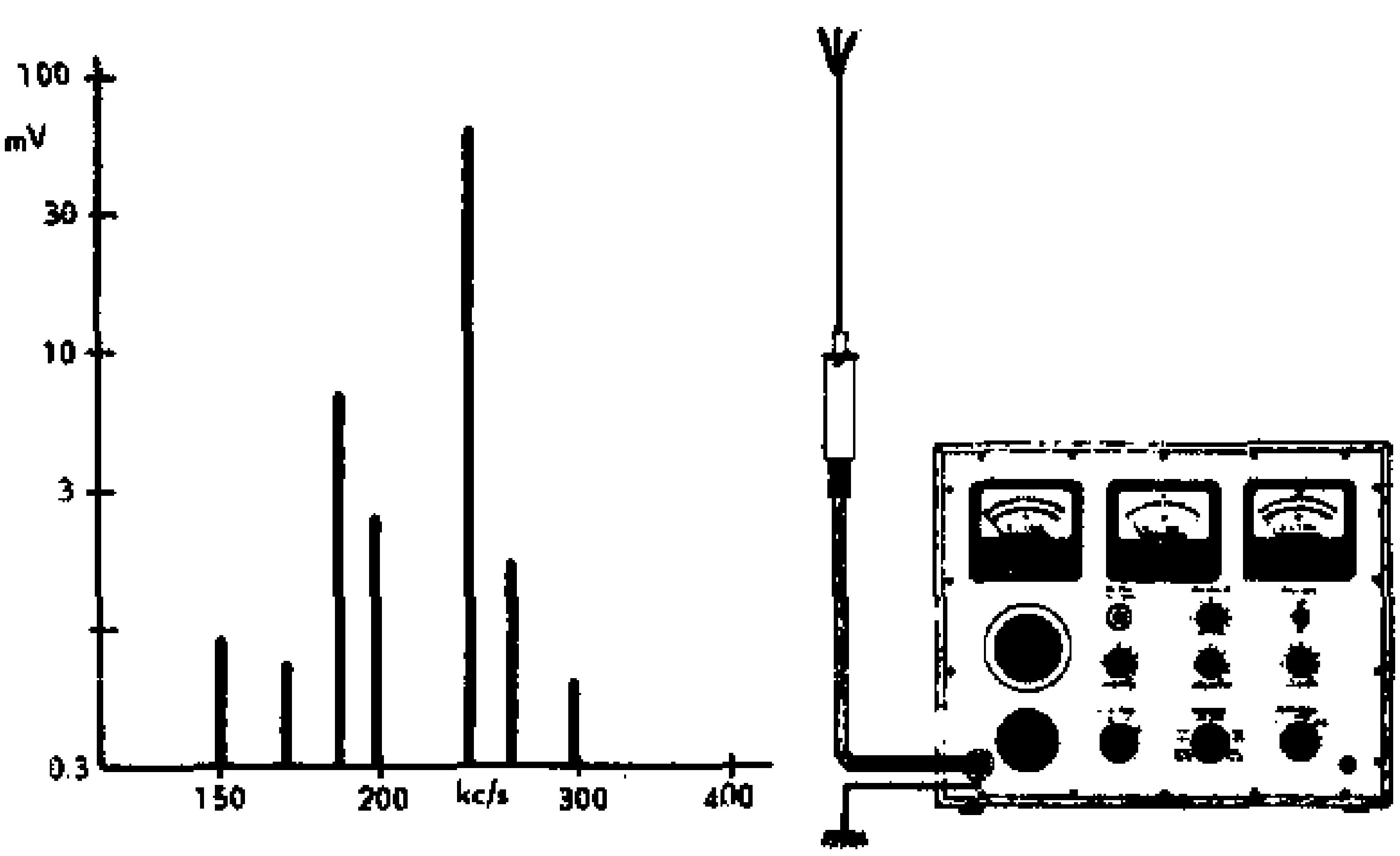

Fig. 11. *Spectrum of broadcasting stations measured in the vicinity of Copenhagen.*

To undertake field strength measurements, a short antenna of between 20 cms and 1.5 metres, depending on the frequency, is attached to the Heterodyne Voltmeter, which is then placed on a suitable stand about 1.5 metres above ground level. The rod antenna's effective height is then found as described above, and the field strength then measured (fig. 14).

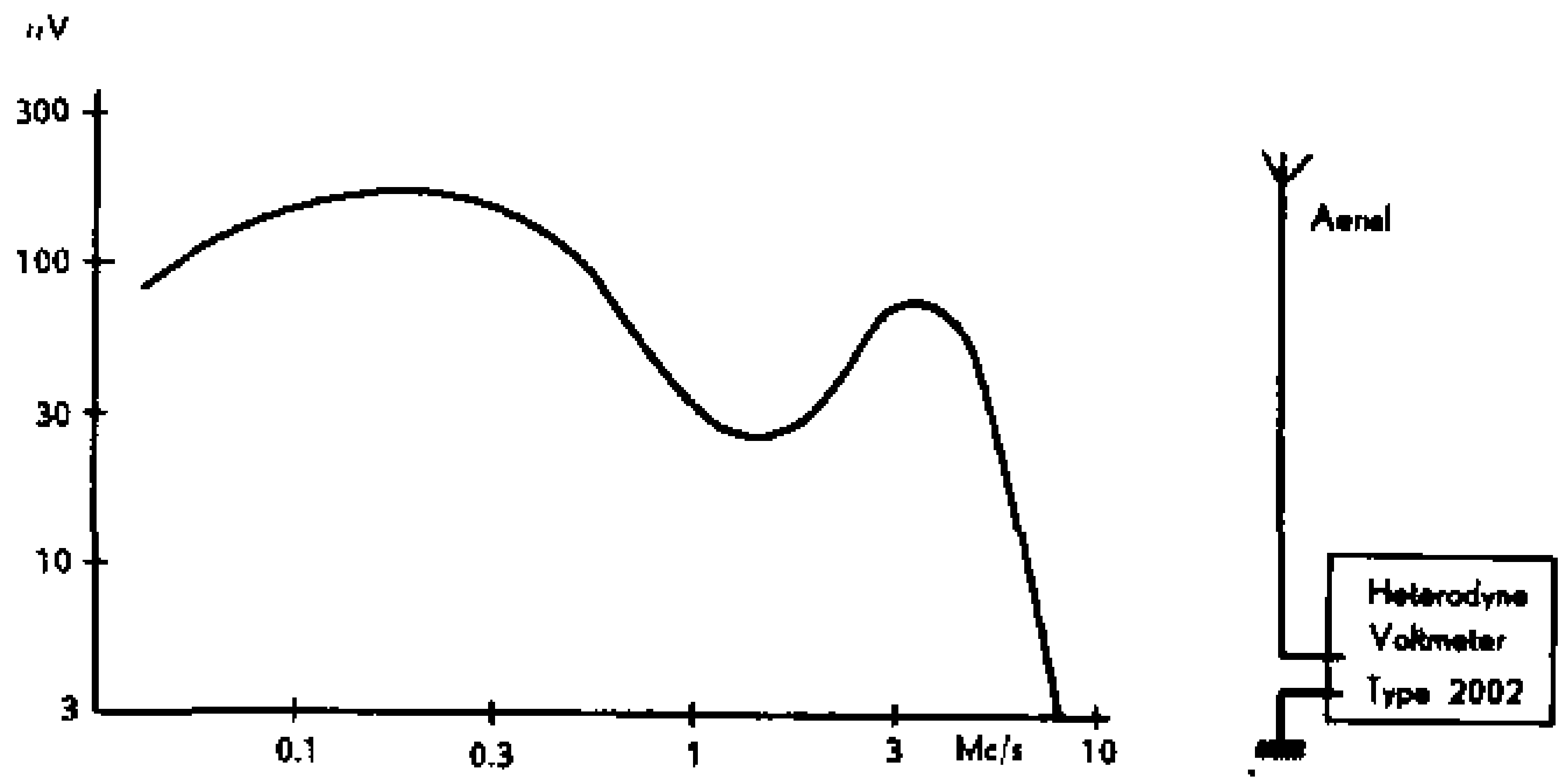

Fig. 12. *The noise spectrum from a rotary converter measured on a neighbouring aerial.*

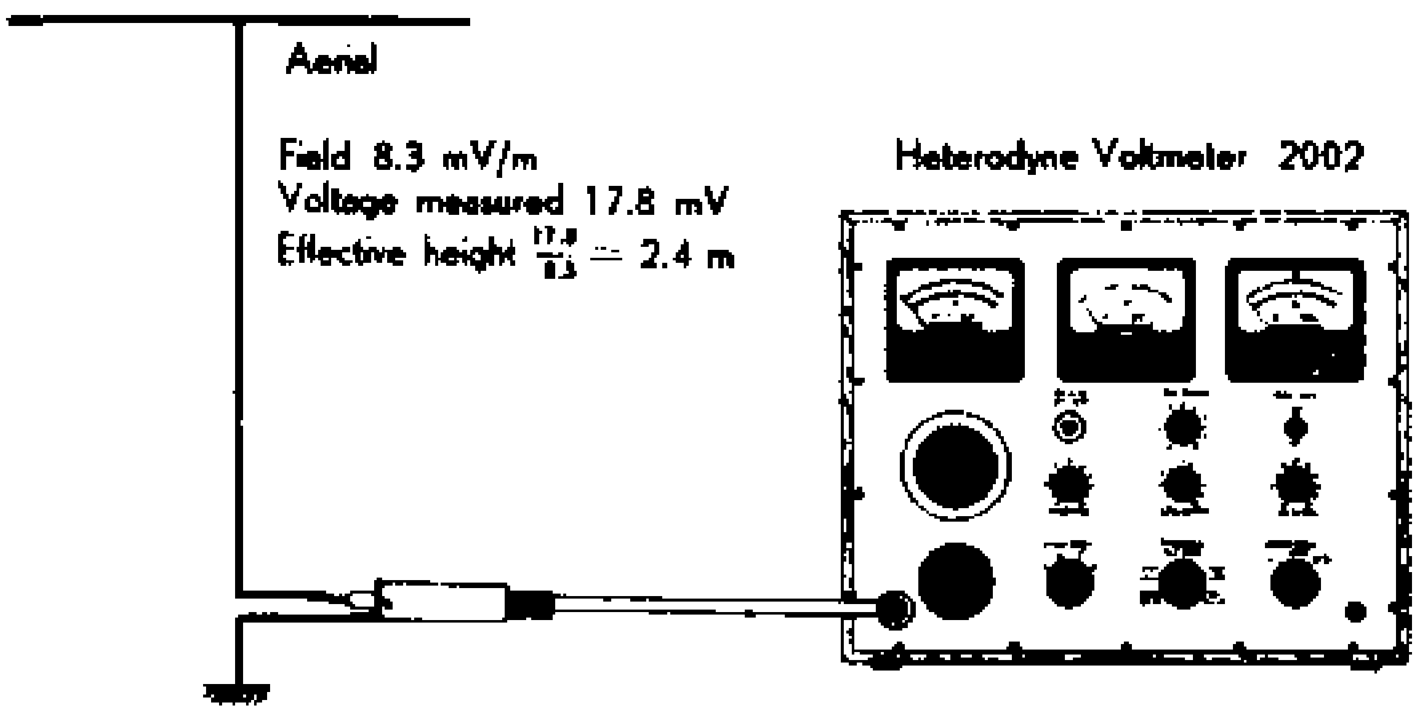

Fig. 13. *Determination of the effective height of an aerial.*

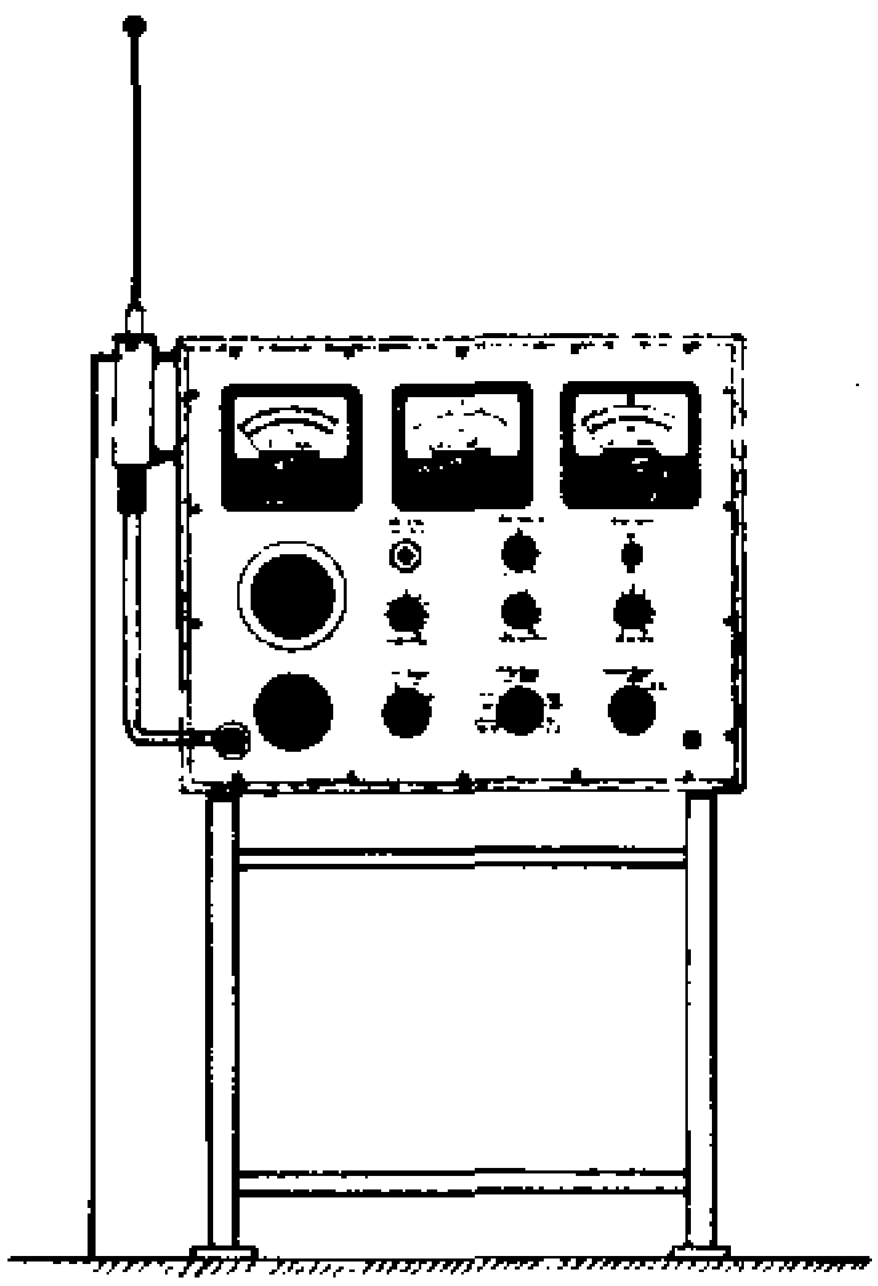

Fig. 14. *Simple method for determination of field strength from wireless transmitters.*

It should be noted that the frequency range being investigated should not lie too far away from that of the station being used to find the effective height, that the method can only be used for the lower frequencies, where the dimensions of the rod antenna are very small in relation to the wavelength, and that the accuracy to be expected is rather poor.

With a set-up such as shown in fig. 15 it is possible to measure variations in the field strength at a permanent antenna (fading). The antenna is coupled to the Heterodyne Voltmeter and the variations in field strength recorded by means of Level Recorder Type 2301, coupled to the Heterodyne Voltmeter's R. F. meter through DC-AC Inverter 4610. The curve shows the antenna voltage from an Italian station in the 41 metre band, measured at Copenhagen. The paper speed was 10 mm/s.

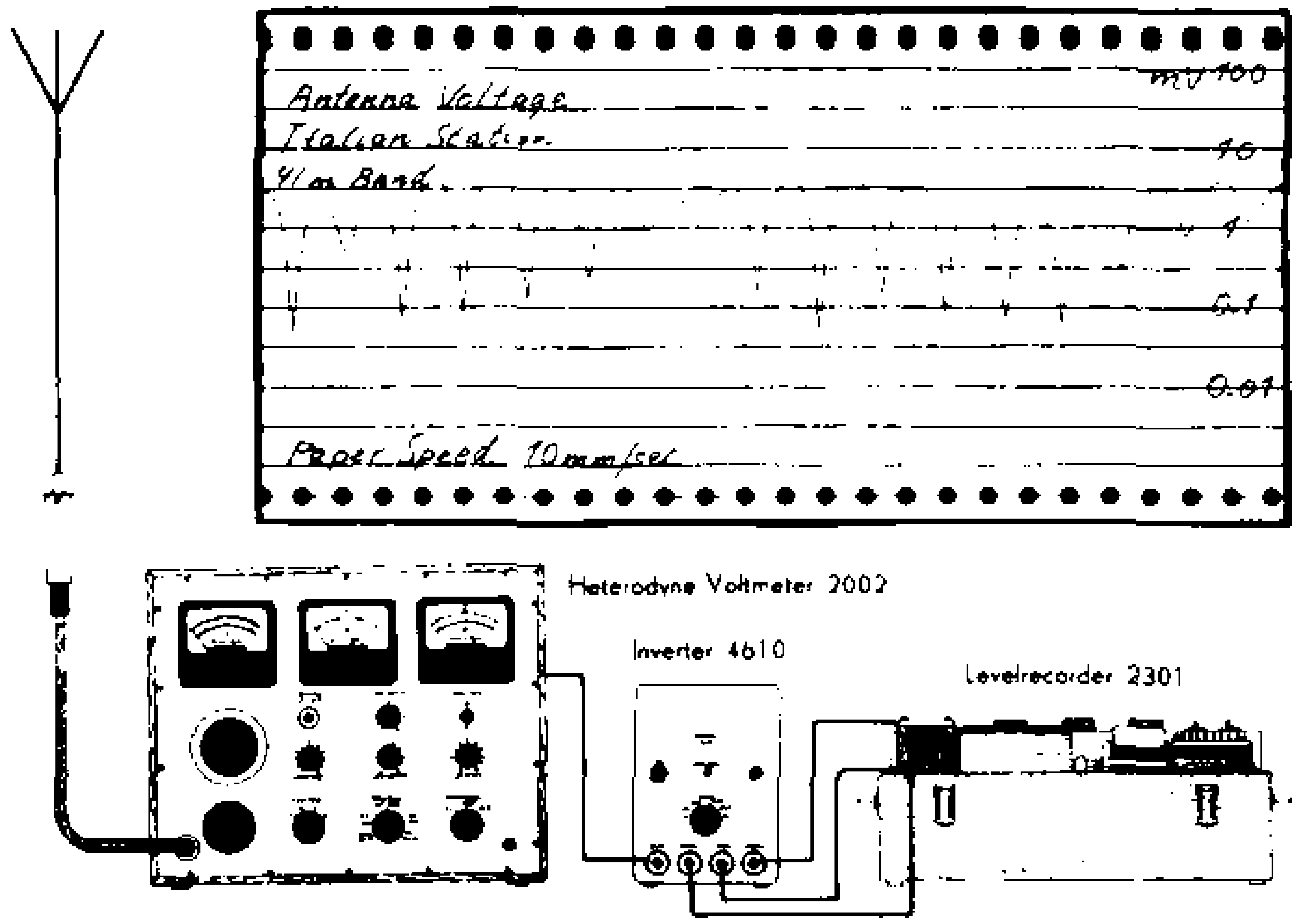

Fig. 15. *Recording of field strength variation (fading) with the Heterodyne Voltmeter 2002, the Inverter 4610 and the Level Recorder 2301.*

The Heterodyne Voltmeter is extremely useful for more detailed investigations of radio receivers, for example, the measurement of oscillator and I F. voltages. Fig. 16 shows a sketch of a set-up to measure the radiation from a radio receiver to its antenna. If the coupling between the oscillator and antenna circuits in a superheterodyne receiver is too close, voltages at the oscillator frequency may be present between the antenna terminal and earth, producing radiation from the receiver antenna which can be very disturbing for nearby receivers. This condition is particularly disturbing with common-antenna systems. Because of this, regulations are set down in several countries for the maximum voltage a receiver may be allowed to produce in a standardized dummy antenna. In Norway, for example, the

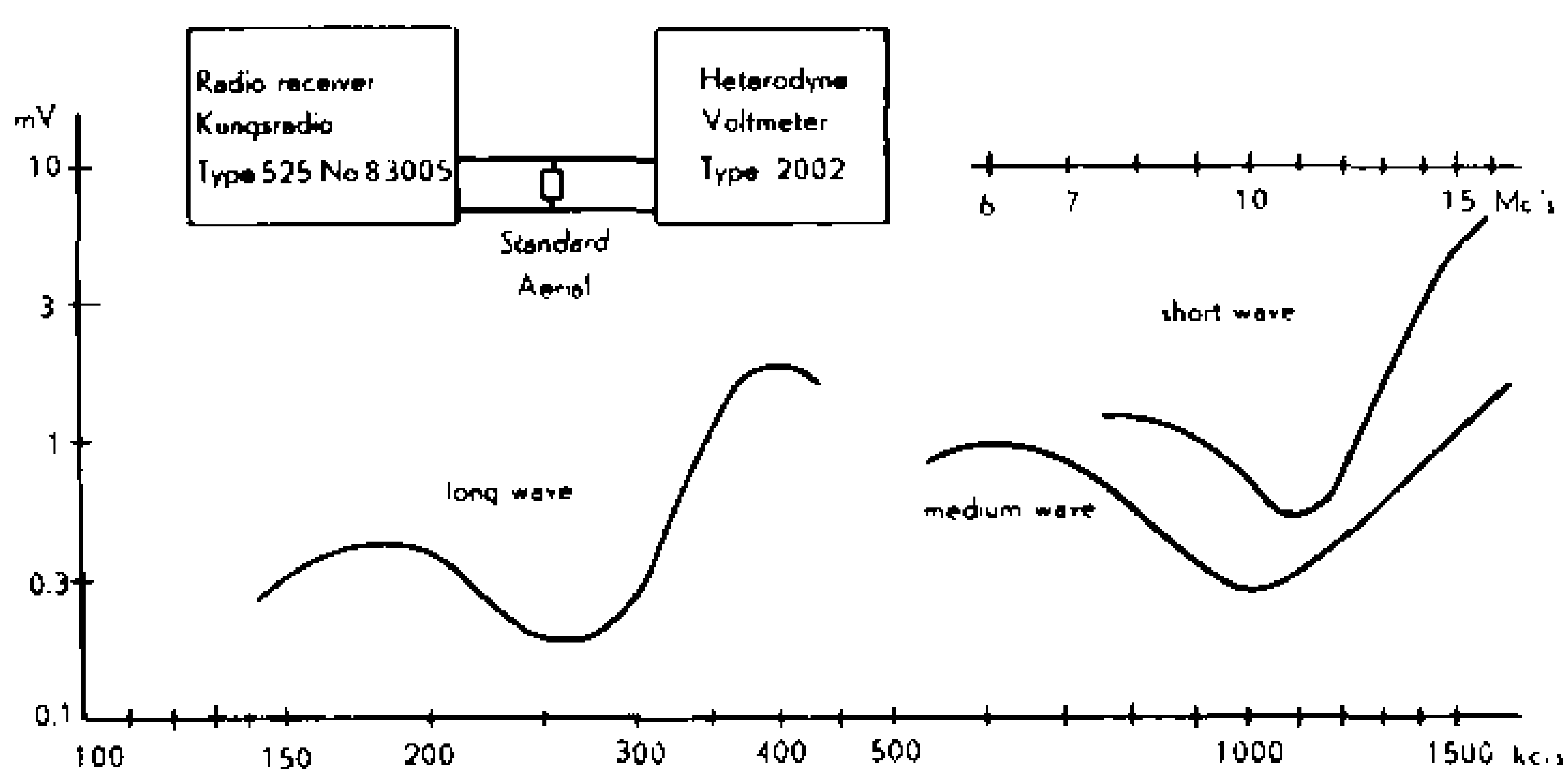

Fig. 16.

Oscillator frequency voltages measured on the aerial terminal of a receiver with one stage R. F. amplification (Kungsradio type 5251 No. 83005).

maximum is 1 mV for frequencies below 1600 kc/s, and a maximum of 100 mV for higher frequencies. The Heterodyne Voltmeter is particularly well suited for the measurement of such small voltages. Television receivers can also be investigated by means of the Heterodyne Voltmeter, particularly in the circuits after the mixer stage, where an I. F. of between 8 and 30 Mc/s is normally employed.

The Heterodyne Voltmeter can naturally also be used in the investigation of the output from the different stages in radio transmitters, for example the modulator and master oscillator stages.

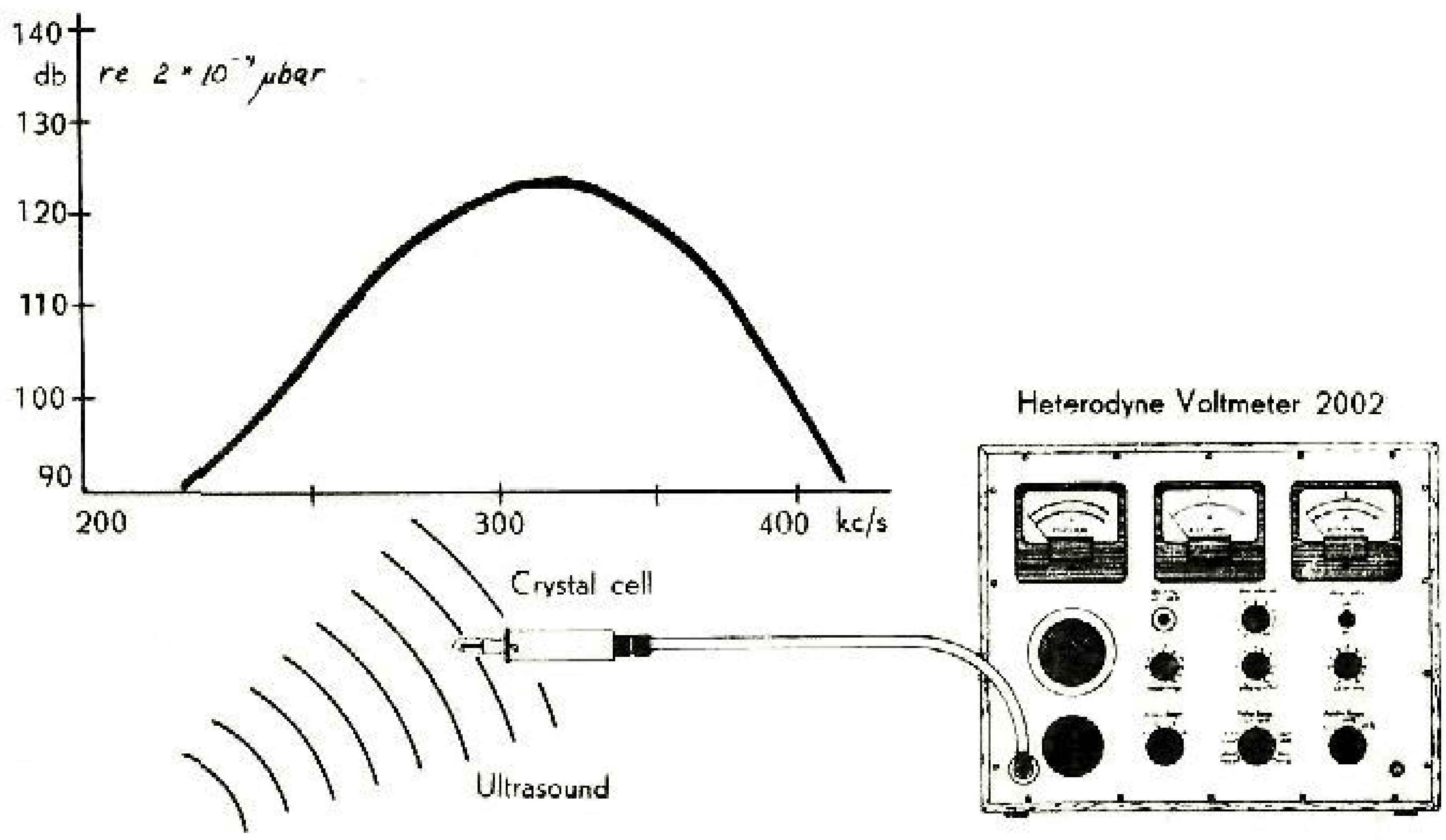

Fig. 17. ***Measurement and analysis of airborne ultrasound.***

Within the field of industrial applications of ultrasonics, the Heterodyne Voltmeter can also be used, as ultrasound is becoming accepted as covering the range from the limit of the audible up to approx. 10 Mc/s.
The Heterodyne Voltmeter, in combination with a minute crystal of Rochelle Salt (1 × 1 × 1 mm), has been used to measure the ultrasound from jet motors. The problem here is to reduce the dimensions of the microphone down to the point where its resonance frequency rises to between 0.5 and 1 Mc/s. Its sensitivity is of course in this way much reduced, but the very high sensitivity of the Heterodyne Voltmeter is of great help in connection with this problem. Fig 17 shows a typical result.

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