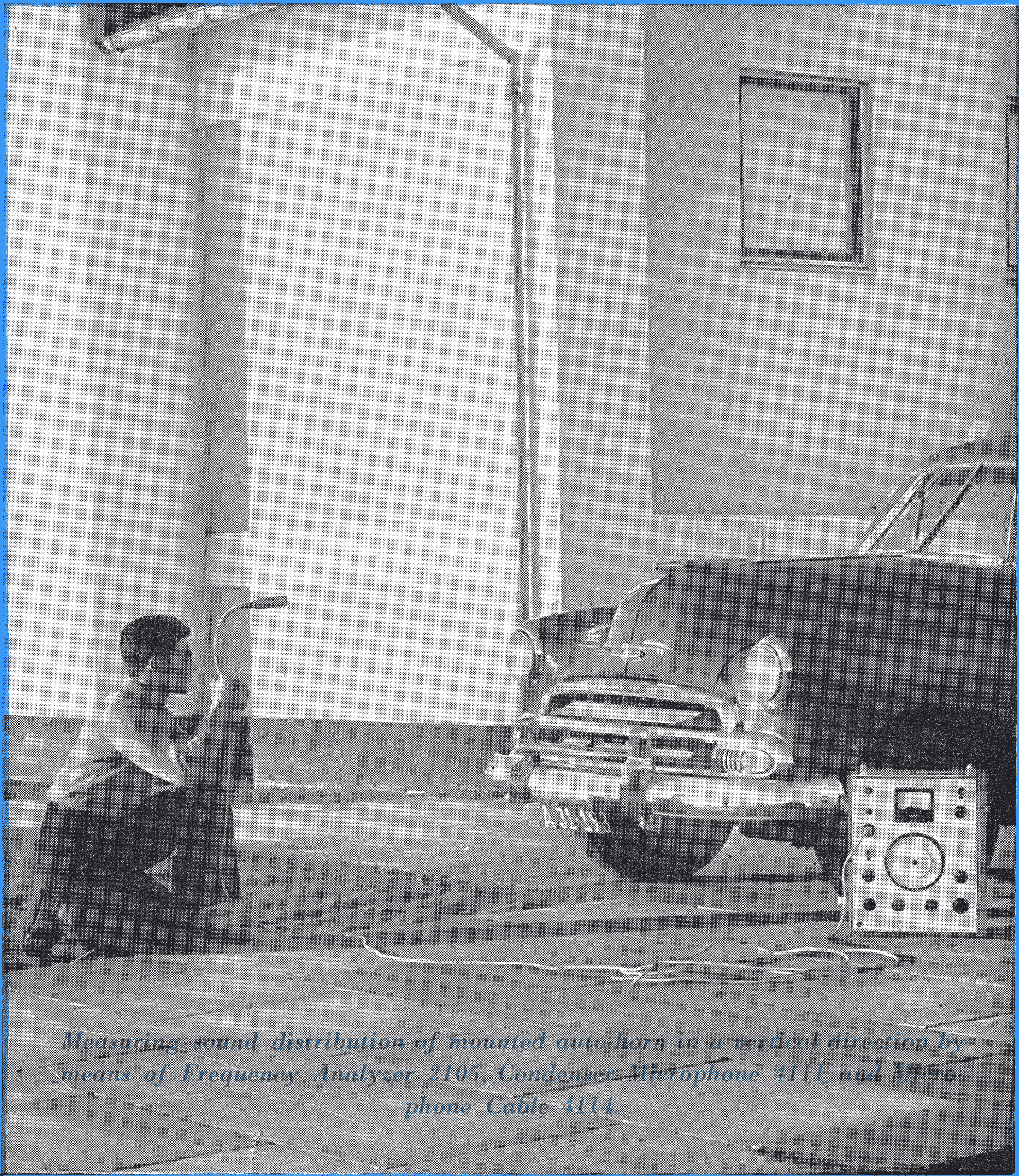
Brüel & Kjær

# Technical Review

## Teletechnical, Acoustical and Medical Research



*Measuring sound distribution of mounted auto-horn in a vertical direction by means of Frequency Analyzer 2105, Condenser Microphone 4111 and Microphone Cable 4114.*

No. 2 April 1953

# Acoustic Measurements on Automobile Horns

## SUMMARY

Suitable measuring equipment for acoustic tests on auto-horns is briefly described. The conditions of quality for auto-horns are laid down, and in the case of three different types of cars measurements have been carried out on the car's sound insulation as a function of frequency, on the horn's sound intensity and frequency composition and the sound's distribution characteristic in both horizontal and vertical direction, as well as the difference in sound intensity between the outside and the inside of the car.

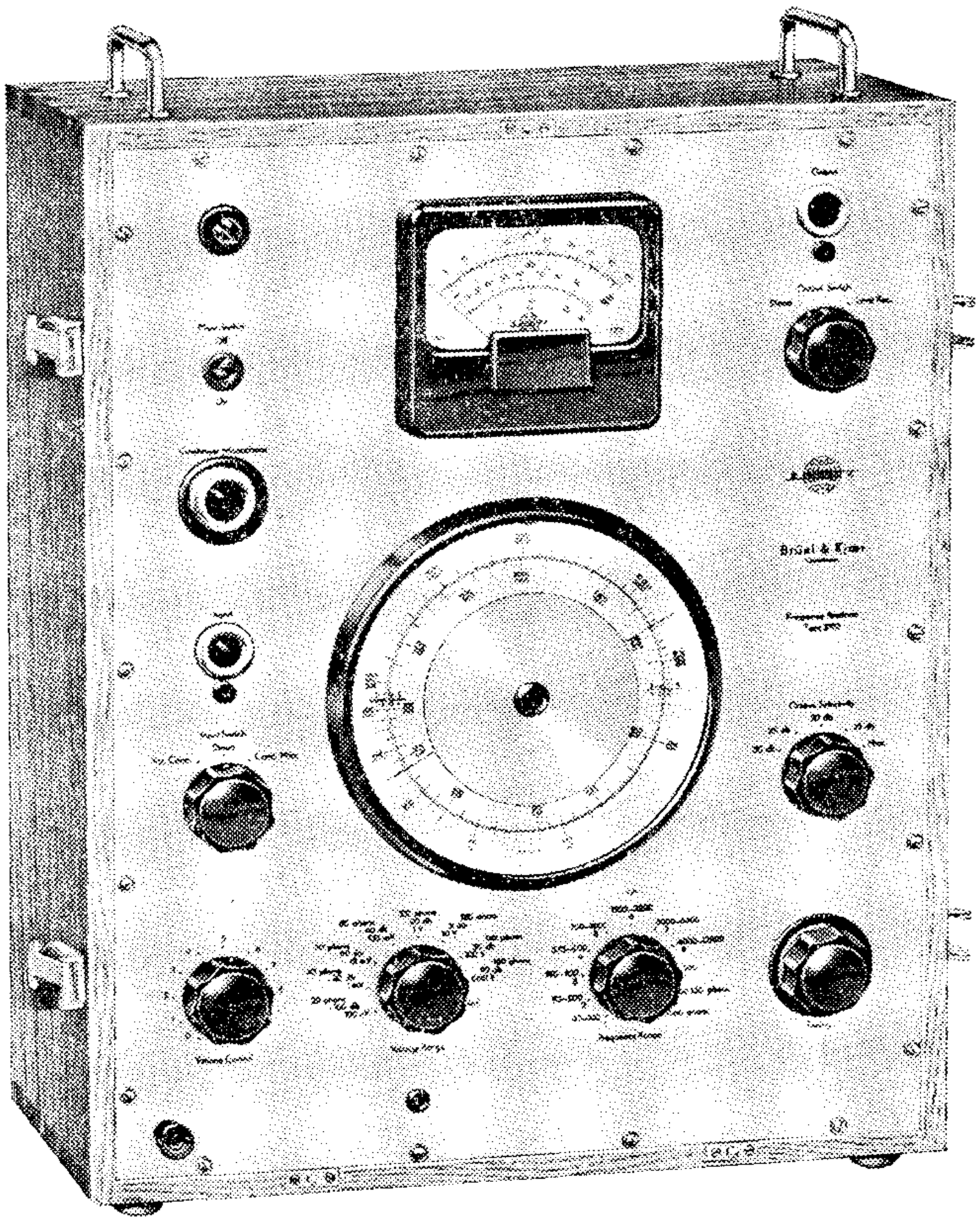


*Fig. 1. Frequency Analyzer 2105.*

Some time ago we had an enquiry from an important European factory producing auto-horns and other automobile components, whether we were in a position to suggest any sensible measuring equipment for acoustic tests on auto-horns. We used the opportunity to look into the available literature and found to our surprise that acoustic literature had only paid very slight attention to these important acoustic problems. We therefore carried out certain investigations, mainly to satisfy ourselves that the measuring instruments recommended by us would most adequately serve the purpose. The most important instrument for these tests turned out to be our Frequency Analyzer type 2105 which, in connection with our Condenser Microphone type 4111, proved its capacity to solve a long series of vital problems in tests on auto-horns.

The Analyzer type 2105 is a selective tube voltmeter, primarily designed for acoustical and electro-acoustical measurements, such as vibration and noise spectrograms, measurements of sound pressure and vibration level etc. The Analyzer operates on the degenerative principle and has a constant percentage band width $\delta$. With most acoustical measurements it is advisable to carry out an analysis with an Analyzer that has a constant percentage band width $\delta$, i. e. one that selects a definite percentage of an octave in preference to an analyzer of the heterodyne type, which selects a definite frequency band. The ear's recognition of frequency is approximately logarithmic, so that whatever the ear discerns as consisting of high frequencies covers a much greater absolute frequency band than that recognized as low frequencies. When, therefore, the ear judges the character of a noise, i. e. judges its spectrogram, it will automatically divide the noise into octaves, and within each octave or part of an octave integrate the total sound pressure, just like a constant percentage band width analyzer, whether it is built, as type 2105 here described, on the degenerative principle, or as an analyzer consisting of filters. A heterodyne analyzer will select a definite, absolute frequency band from the spectrogram, which band width, represented in the logarithmic frequency scale, becomes smaller and smaller as one rises in the frequency range.

From the purely physical point of view it is, naturally, a matter of indifference which type of analyzer is used, as it is always possible, when the frequency is known, to make the calculation required in changing from one type to the other. There is, however, one great disadvantage of the heterodyne analyzer, and that is the great difference between the spectrogram of a continuous noise and a noise with a line spectrum. A noise spectrum where all frequencies are represented is called a continuous noise spectrum, such as the noise from a typewriter. A line spectrum or a discontinuous spectrum is a combination of sounds where only certain distinct frequencies are represented, such as the spectrum from many musical instruments, which consists of a fundamental tone plus a number of harmonics. Most spectra encountered in industry and practical life will be a mixture of these two. A continuous spectrum can most conveniently be shown by drawing a smooth curve as function of the frequency, whereas a line spectrum is more easily viewed by

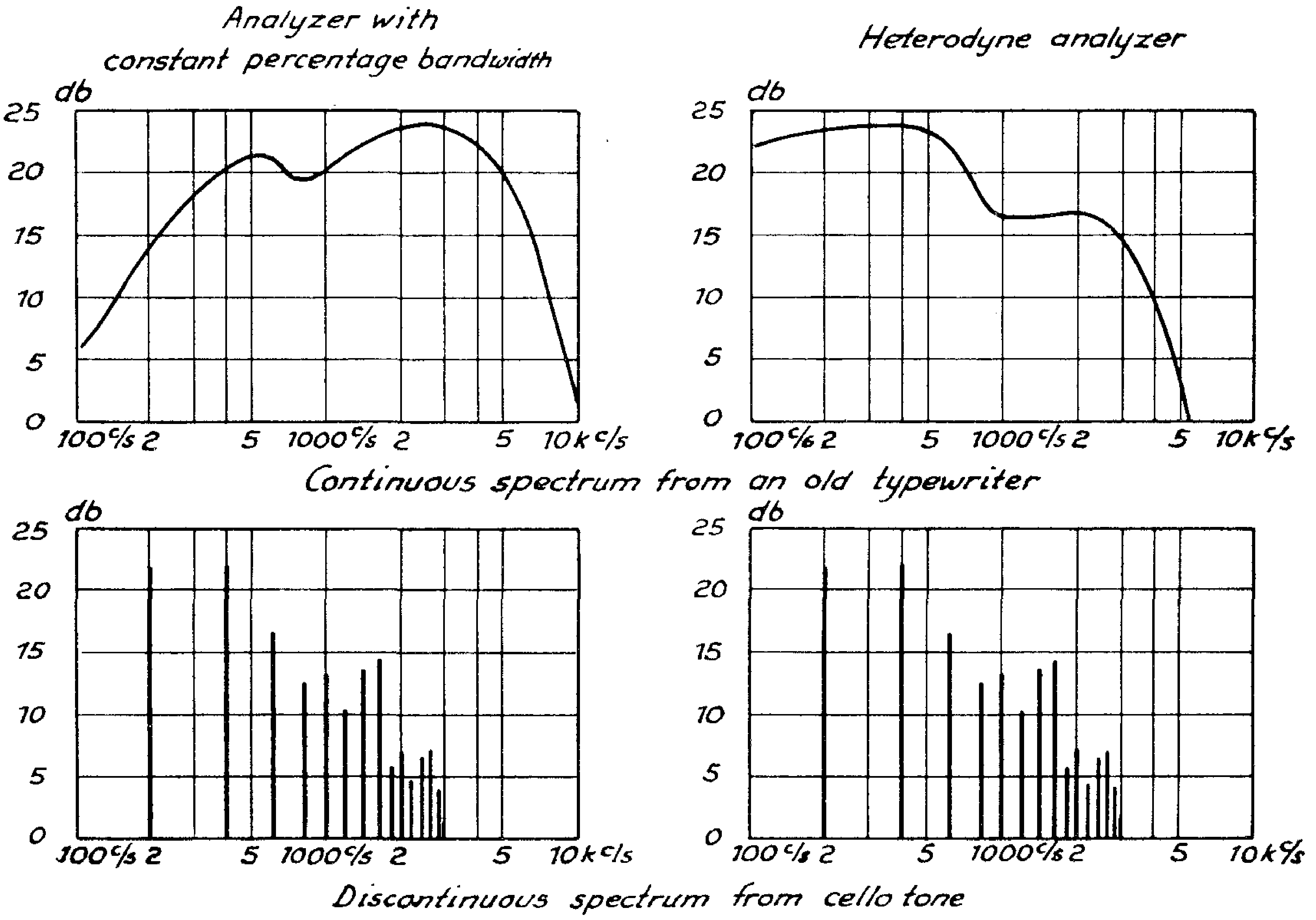


*Fig. 2. Continuous and line spectra measured with Constant Percentage Bandwidth Analyzer and Heterodyne Analyzer.*

drawing a number of lines, each representing a frequency, with the height of the line representing the strength of the frequency. In fig. 2, at the top, is shown a typical continuous spectrum from a typewriter, and below, a line spectrum from a cello. If a continuous noise is analyzed, the constant percentage band width analyzer will give the spectrogram shown on the left, while the spectrogram of the same typewriter, recorded by the heterodyne analyzer, will appear as shown on the right, which differs markedly from the other one. The low end of the spectrogram is considerably accentuated, and the high end is quite compressed. The measured result from the heterodyne analyzer agrees in no way with the real selective appreciation of the noise composition.

The results will be different if the noise consists of sharply defined single frequencies. With the constant percentage analyzer and the heterodyne analyzer, alike, the same values are measured for the harmonic amplitudes, so that the line spectrogram has the same appearance, no matter what type of analyzer is used. As shown in fig. 2, top right, continuous spectrograms measured with the heterodyne analyzer exhibit very great level-differences. As a rule the low frequencies will shown exceedingly great sound pressures, in comparison with the high frequencies. If we are to have any confidence in the high end of the spectrogram, the selectivity should in practice not be less than 80 db. This high selectivity demands a very long time constant in the analyzer, so that for this reason, also, the heterodyne analyzer is slow to work with.

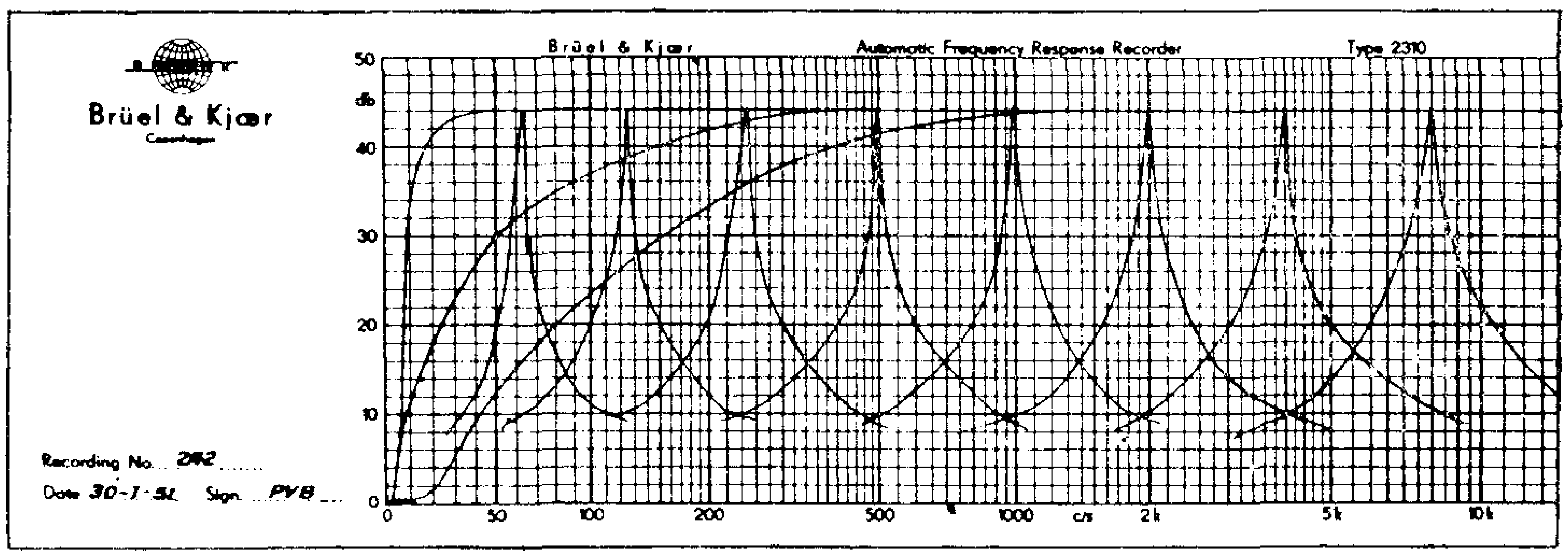


*Fig. 3. Frequency characteristics of the Analyzer type 2105 with different positions of "Frequency Range": Lin., 60—130 phons, 30—60 phons, and ranges 1—8 set on the frequencies 63 — 125 — 250 — 500 — 1000 — 2000 — 4000 — 8000 and 12000 c/s.*

Analysis of a noise varying a little in frequency is almost impossible with a heterodyne analyzer, since the frequency variation at higher frequencies is so great that the frequency lies within the band only part of the time. Therefore, with unstable spectra, too little is measured at the high end of the spectrogram. With a constant percentage analyzer, however, the cutting down arising from frequency variation is the same for both high and low frequencies, so that the balance is correct, and the appearance of the spectrogram is likewise correct. It can be seen that a constant percentage analyzer need not be anything like as selective as the heterodyne analyzer. The less the selectivity that one can employ, the quicker the analyzer will work, and the more stable will be the frequency characteristic shown. For the acoustic analysis of noise it is, simply, required that it should be possible to separate the frequency components of the sound which the human ear is just capable of distinguishing, but the selectivity need not be much greater.

In fig. 3 some typical frequency characteristics for Analyzser 2105 are shown, and in fig. 4 a schematic diagram of this appartus. As we see, the analyzer consists of a pre-amplifier followed by a two-stage linear amplifier, over which a double T-network is used in a feed-back system, so that all frequencies, save the T-link's blocking frequency, will get a very powerful, negative feed-back and as a consequence will be powerfully damped. The only frequency passing through with unimpaired amplification is the frequency completely blocked by the T-network. The frequency is continually adjusted plus or minus half an octave by varying three ganged potentiometers and in steps of an octave by varying the condensers C. After the selective amplifier there follows a one-stage output amplifier with an indicating meter and output terminals for a recording instrument. Connected directly to the Analyzer there may be a Condenser Microphone type 4111, which is supplied from the Analyzer with the requisite voltages, DC to the filament, high tension for the tube and polarisation voltage for the cartridge of the Condenser Microphone. The tubes of the Analyzer's pre-amplifier are also heated by DC in order to get the noise level brought down as far as it is at all possible. The double-T blocking network may be coupled-out, so that the analyzer can work as a linear amplifier; in addition, the various phon characteristics, corresponding to the international standards for noise-level meters, may be coupled-in.

Condenser Microphone type 4111 may be attached to the Analyzer as shown in fig. 1, or the microphone may be connected with the Analyzer through a Microphone Cable, so that there may be a great distance between microphone and Analyzer. Condenser Microphone 4111 has a good linear frequency characteristic, and its sensitivity is constant over a long period of time. The influence of temperature variations on sensitivity is minimal. In fig. 5 is shown a typical sensitivity curve for Condenser Microphone 4111. It will be seen that the microphone is useful over the whole acoustic spectrum from 20 c/s til 16 kc/s. If it is desired to measure the sound pressure of the different frequency components very accurately, the values read off must be corrected with the sensitivity curve for Condenser Microphones. These sensitivity curves are all individually calibrated. For most practical measurements, however, the fre-

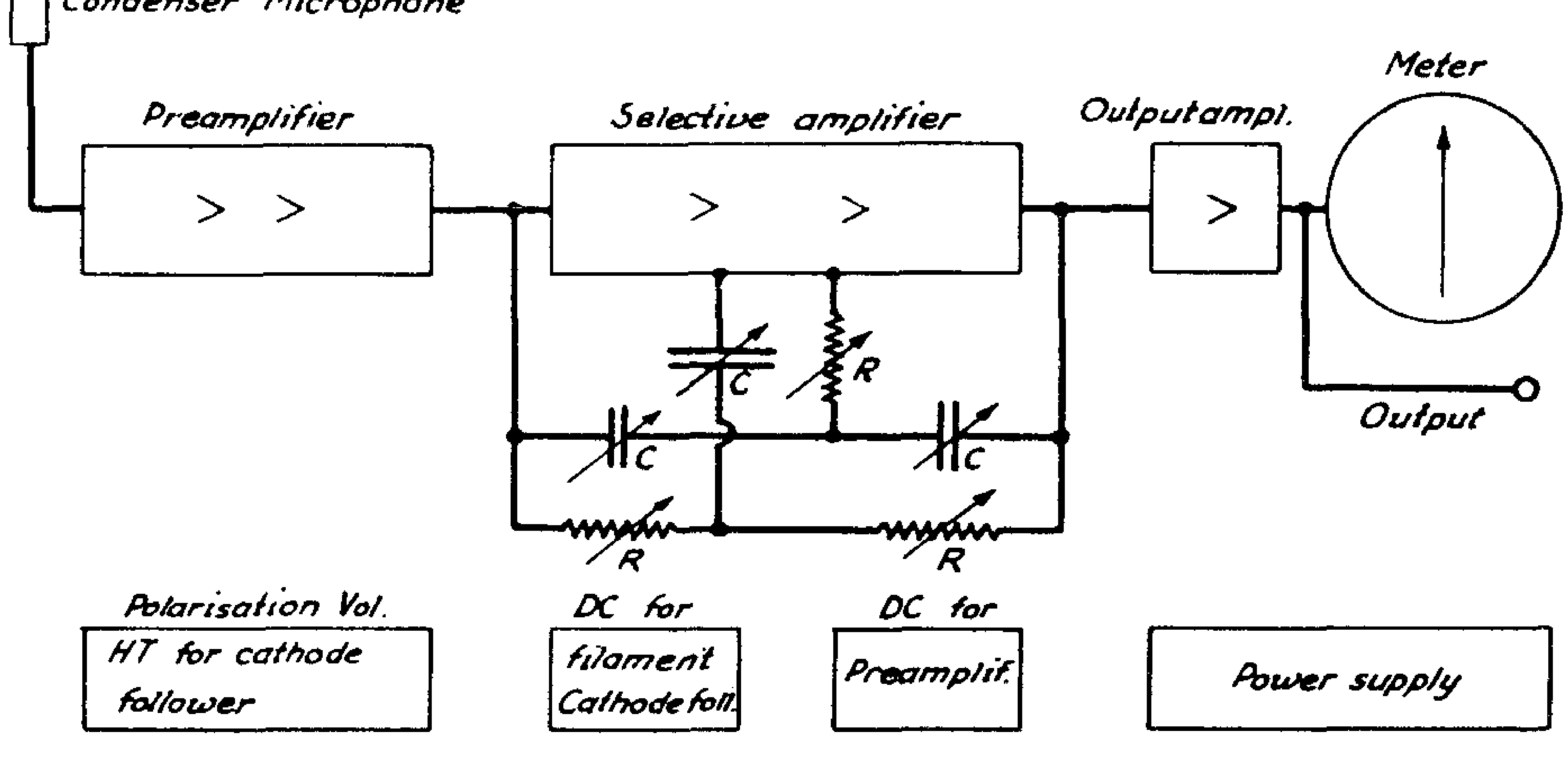


*Fig. 4. Schematic diagram of Frequency Analyzer type 2105.*

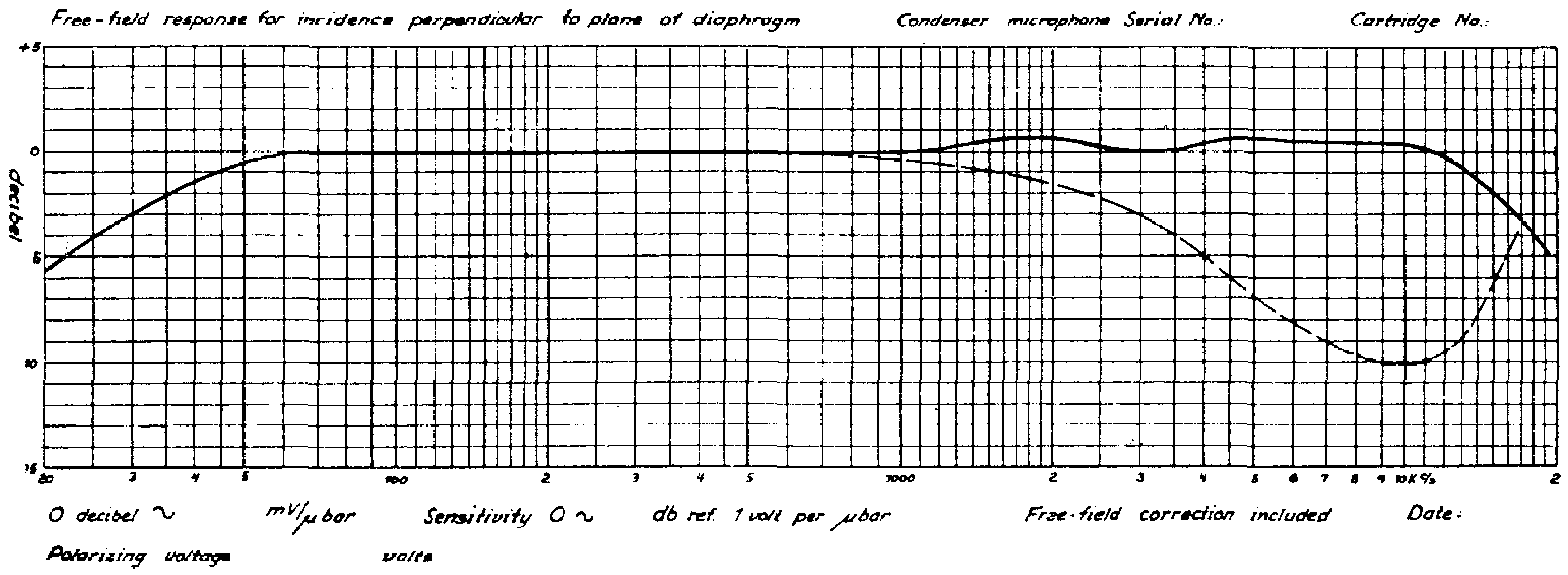


*Fig. 5. Typical sensitivity curve for Condenser Microphone 4111.*

quency characteristic of the Condenser Microphone is so linear that no corrections are needed. On the curve, the absolute sensitivity of the Condenser Microphone, in mV per μbar, is also indicated, and the Analyzer is once and for all adjusted, so that sound pressures of frequency components may be read off directly in μbar or in db with reference to either 1 μbar or the ear's threshold value, which is $2 \times 10^{-4}$ μbar. By inserting the Analyzer's phon characteristics, the noise level, expressed in phons, may be read off directly on the analyzer's scale.

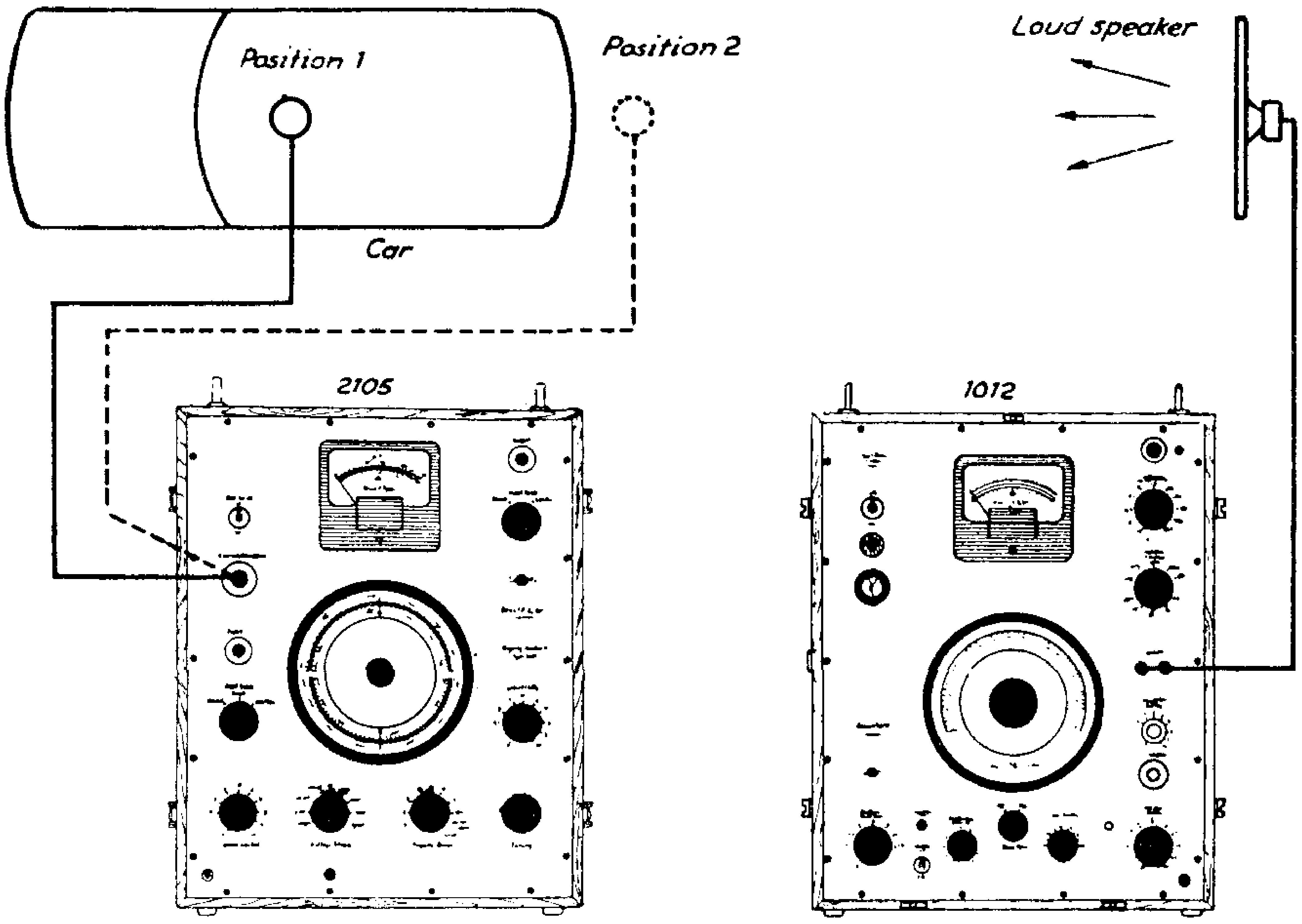
We will now proceed to consider more closely the measurements which are significant, when the acoustic properties of auto-horns have to be examined.

Briefly, the demands that can be made on an acoustically ideal auto-horn are as follows:

The horn should be plainly audible to the drivers for whom the signals are intended, including those inside distant automobiles, without annoying other road users and neighbouring residents. Equally, the horn should not worry the passengers of the car using the horn. Naturally, it is not possible to satisfy these ideal demands, but by suitably shaping the horn, sound-insulating the car and positioning the horn on the car these demands can, nevertheless, be kept in view, and it should then be feasible to achieve better results than modern automobiles have so far shown us.

An investigation of a auto-horn by itself is of little interest, since the placing and installing of the horn on the car is, acoustically, of supreme importance.

A vital test is the measuring of the car's sound insulation, for we must insist when planning the frequency-composition of the auto-horn's sound that the sound has a chance of penetrating into the cars ahead. In fig. 6 is shown how, point by point, we can arrive at the sound insulation by placing at the rear of the car a loudspeaker that is driven by a tone generator with frequency modulation (warble tone) at a number of different frequencies. In the example shown we have chosen frequencies from 100 to 5000 c/s with roughly an octave's interval. First, the sound pressure is measured with the microphone in position 2, that is, immediately behind the carriage, and afterwards moving the microphone inside the car in position 1. The difference in sound pressure, which is here practically expressed directly in db and can, therefore, be read off immediately on the Analyzer's scale, is an expression of the sound insulation. In this sound insulation figure we include, partly, the insulating capacity of the motor body, the windows and the doors, and partly the acoustic absorption of the car itself. The more efficient the car's upholstery, the lower will



| Car | Frequency | 100 | 200 | 500 | 1000 | 2000 | 5000 | c/s |
|---|---|---|---|---|---|---|---|---|
| Ford Consul | Microphone in position 2 | 32 | 33 | 33 | 32 | 37 | 30 | db |
| | Microphone in position 1 | 17 | 17 | 8 | 3 | 13 | 5 | db |
| | Sound insulation | 15 | 16 | 25 | 29 | 24 | 25 | db |
| Volkswagen | Microphone in position 2 | 32 | 34 | 32 | 33 | 36 | 28 | db |
| | Microphone in position 1 | 28 | 30 | 17 | 20 | 27 | 14 | db |
| | Sound insulation | 4 | 4 | 15 | 13 | 9 | 14 | db |
| Chevrolet | Microphone in position 2 | 32 | 35 | 33 | 32 | 40 | 31 | db |
| | Microphone in position 1 | 14 | 18 | 14 | 10 | 16 | 5 | db |
| | Sound insulation | 18 | 17 | 19 | 22 | 24 | 26 | db |

*Fig. 6. Simple measurement of sound insulation of cars by using BFO 1012 with warble tone and loudspeaker as source. To measure the sound pressure Frequency Analyzer 2105 and Condenser Microphone 4111 are used. In the table below is shown the results of insulation measurements for three cars. The figures are given in db over an arbitrary reference value different for each car.*

be the sound level in the car's interior, and the effective sound insulation thus be proportional to the internal absorption.

In the example shown three different cars have been measured; an American Chevrolet model 1951, the German Volkswagen Kleinbus and the English Ford Consul. It will be seen that the sound insulation on the whole is best for the Ford Consul and poorest for the Volkswagen. Common to all the cars is the fact that the insulation increases with higher frequencies, but the rise per octave differs widely. With the method indicated in fig. 6 the insulation can only be arrived at point by point, and this leads to quite considerable errors, since the sound pressure varies greatly owing to different reflections.

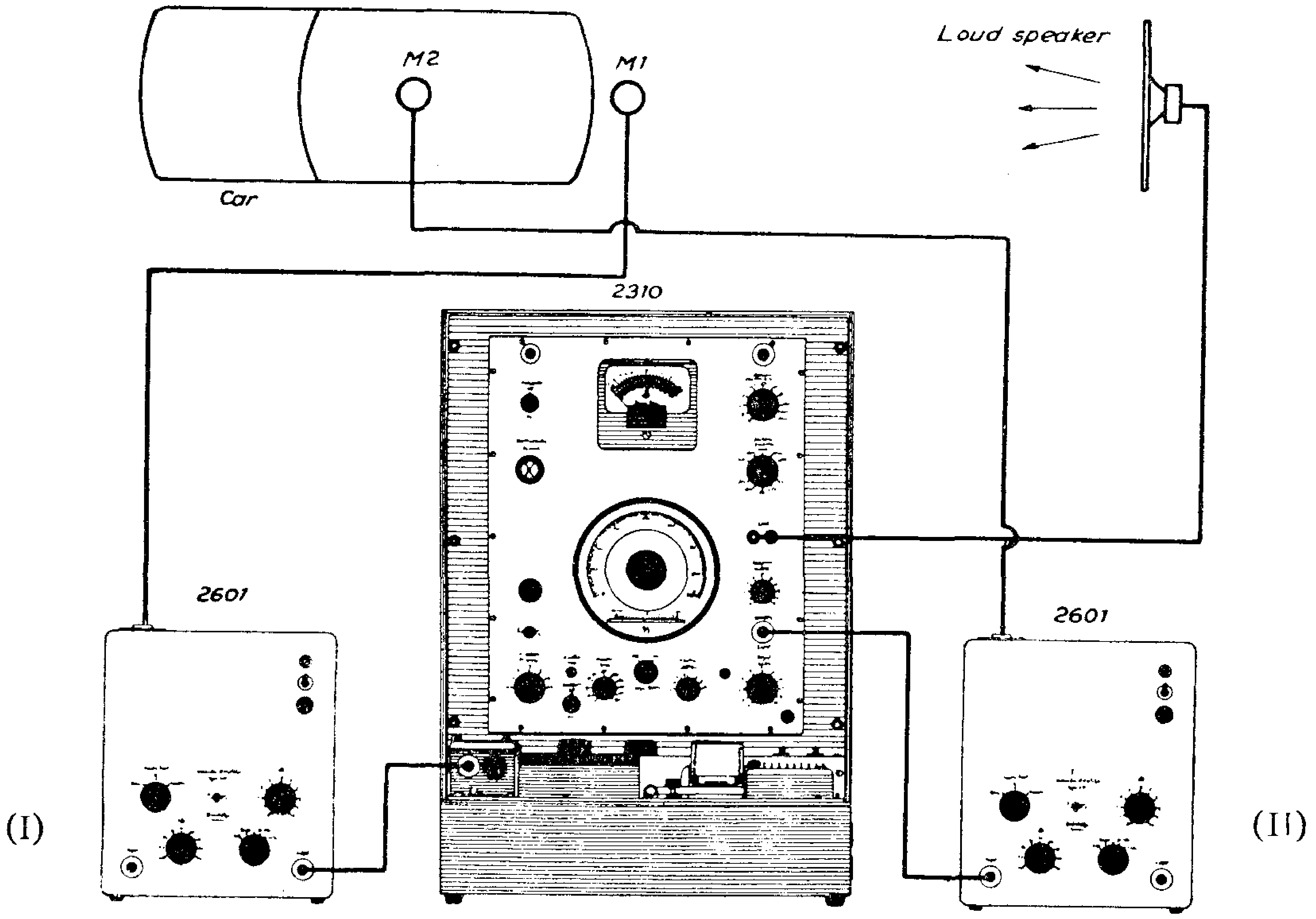


*Fig. 7. Automatic recording of car insulation by using the Automatic Frequency Response Recorder 2310 and two Condenser Microphones 4111 with Amplifiers 2601.*

In fig. 7 is shown a very special method of measuring insulation, where the sound insulation may be recorded directly on a paper strip. For these measurements the Automatic Frequency Response Recorder 2310 is used, comprising a beat frequency oscillator 1012 with warble tone and a High Speed Level Recorder 2331, which records the sound pressure on a logarithmic scale. By means of the Condenser Microphone M2 via Microphone Amplifier 2601 (II) the sound pressure may be kept constant inside the car. By registering the sound pressure at the rear of the car with Condenser Microphone M1, connected via the Microphone Amplifier 2601 (I) to the Level Recorder's input potentiometer, the sound pressure occurring outside the car is recorded. This is directly proportional to the sound insulation, for if the insulation figure rises at a certain frequency, the sound pressure within the car will fall, but this is resisted by the regulating mechanism of the beat-frequency oscillator. The voltage conveyed via M2 to the compressor input will decrease, and the power on the loudspeaker automatically increase, until the voltage transmitted to the compressor input is the same as before. We have, thus, achieved a heightened sound pressure outside the car, tantamount to the increased insulation. If, therefore, we record the sound pressure at the point of M1 as a function of frequency, we get a direct sound insulation curve for the vehicle.

In fig. 8 is shown three examples from the cars in question. We can note the disturbing influence of the many reflections by the markedly varying course of the recordings. Yet the average insulation will be precisely determined by this automatic method. Since insulation at low frequencies is rather poor, we should in the case of auto-horns endeavour to include components of very low frequency in the sound of the horn. Another characteristic example,

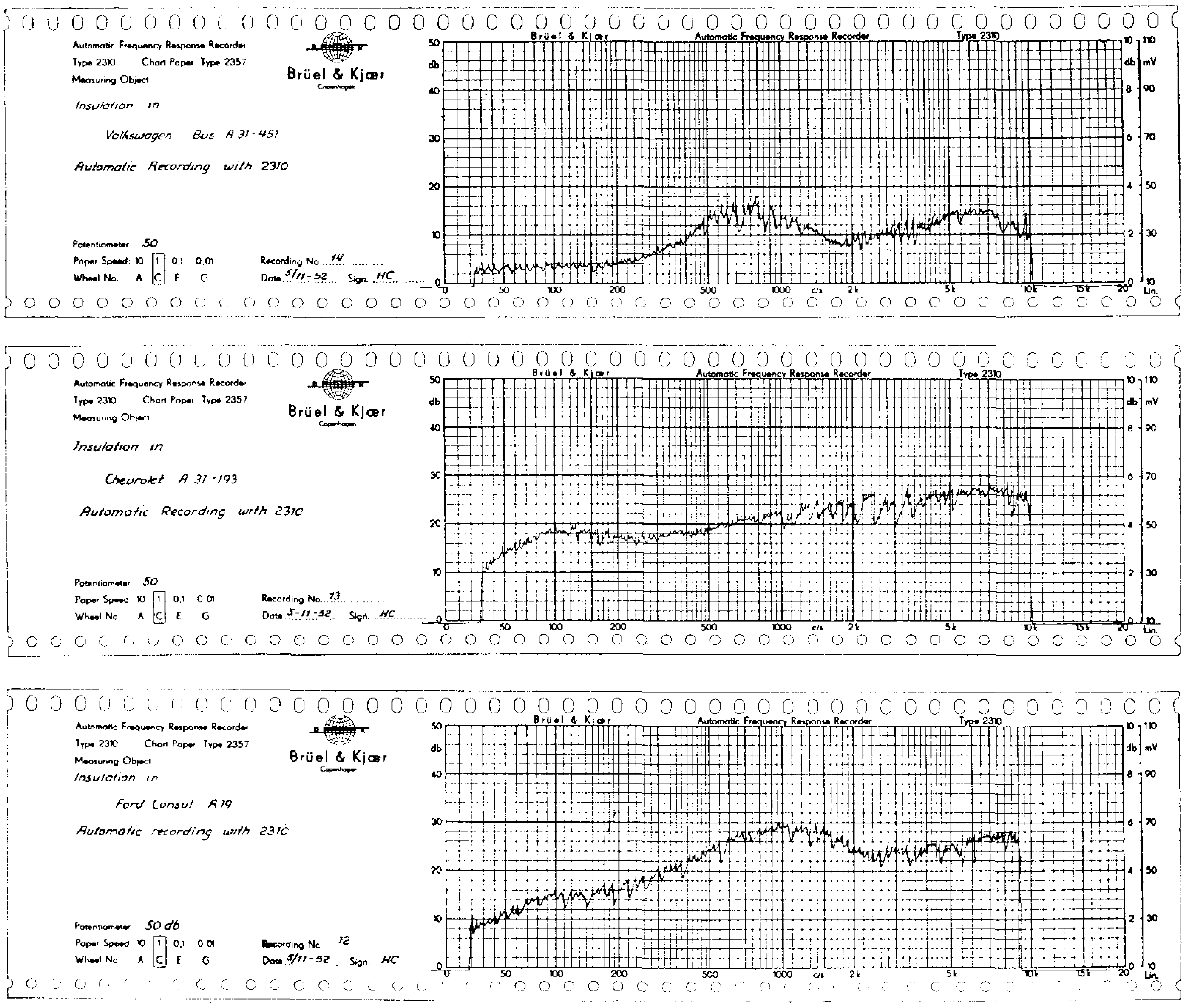
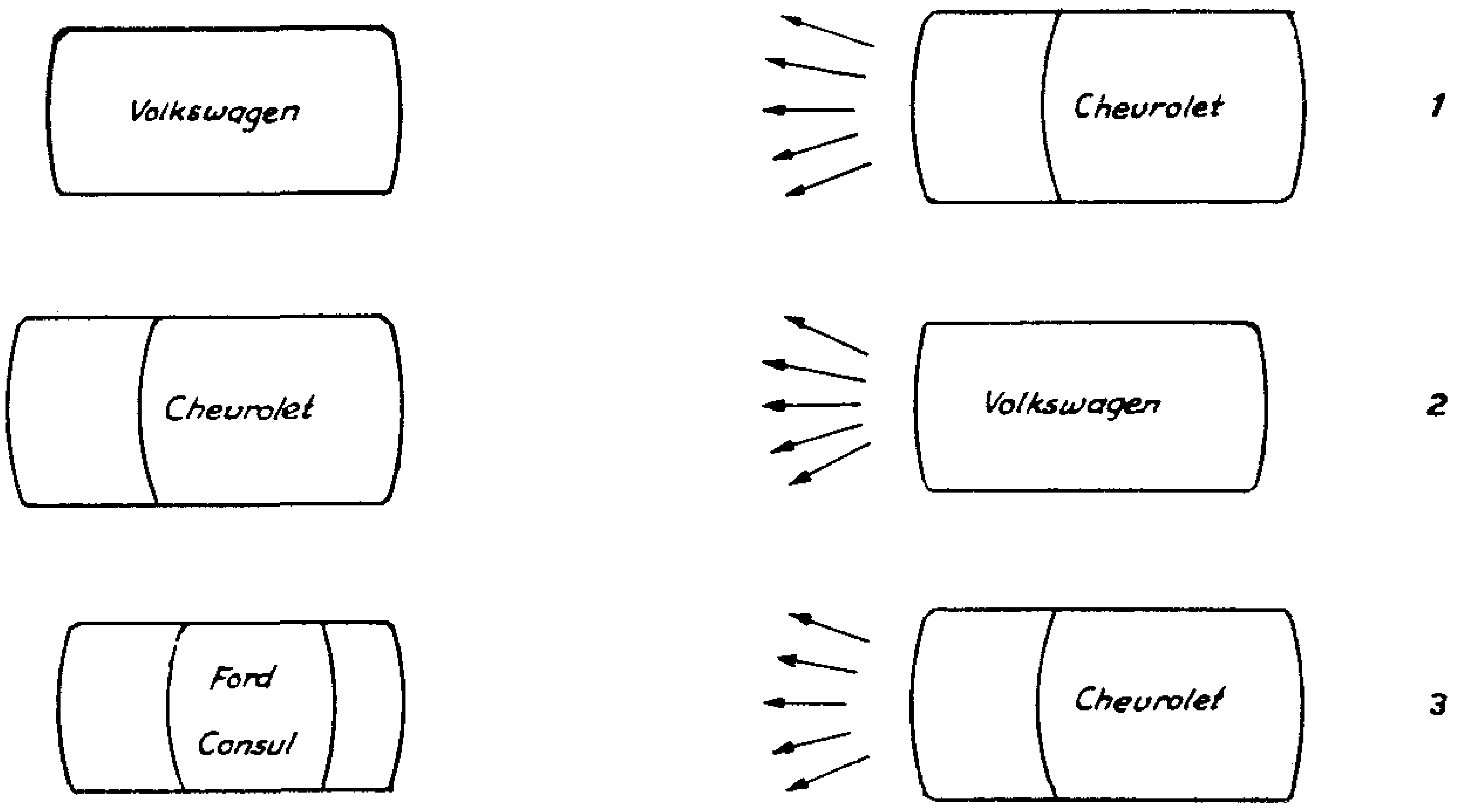


*Fig. 8. Recorded insulation curves for three cars with set-up shown in fig. 7 with automatically controlled constant sound pressure in the car.*

which applies to Volkswagen and Ford Consul, is a local diminution of sound insulation at around 2 kc/s. This means that it would also be an advantage if the auto-horns contained some sound components in this frequency range. This lessening of sound insulation around 2000 c/s is probably due to resonances in the windows.

If there is only an Analyzer with Condenser Microphone available, we may be able to measure the insulation by the method shown in fig. 9, where the sound-source is provided by the horn of another car. The sound pressure is then measured outside and inside the vehicle for the different frequency components given out by the horn of the following car. From the damping of the different components we arrive at the insulation, as shown by the table in fig. 9. The method is highly uncertain, since we are here working with pure tones, and it is also restricted to a very narrow frequency interval, viz. to the frequencies where auto-horns emit a recognisable component. The method must be regarded as a kind of emergency measure.

The frequency composition of an auto-horn is extremely significant. The main part of the sound emitted by an auto-horn may be regarded as a line spectrum. In other words, the sound is made up of distinct frequencies. Fig. 10 shows three examples of auto-horns measured at a distance of 3 m in front of the car. The sound level is measured at the same time, as indicated in the fig. The horn of the Chevrolet car is a so-called double-tone horn, whose sound contains two very powerful components a little below 1000 c/s and lying very



| Analyzer Position c/s | Measurement 1 |  |  | Measurement 2 |  |  | Measurement 3 |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | Sound pressure (µV) |  | Insulation in db | Sound pressure (µV) |  | Insulation in db | Sound pressure (µV) |  | Insulation in db |
|  | in VW | outside | VW | in Chevrolet | outside | Chevrolet | in Consul | outside | Ford Consul |
| Lin. | 2200 | 8000 | 12 | 400 | 4000 | 20 | 900 | 16000 | 25 |
| 60-130 phons | 2000 | 8000 | 14 | 330 | 3600 | 21 | 540 | 15000 | 28 |
| 30-60 | 1800 | 7000 | 14 | 230 | 3000 | 23 | 480 | 14500 | 29 |
| 155 | – | – | – | 1250 | 10000 | 18 | – | – | – |
| 310 | 800 | 2000 | 8 | 37 | 300 | 18 | 420 | 4200 | 20 |
| 465 | – | – | – | 75 | 700 | 18 | – | – | – |
| 620 | 600 | 2600 | 15 | 6 | 60 | 20 | 265 | 4800 | 25 |
| 775 | – | – | – | 11 | 110 | 20 | – | – | – |
| 930 | 1200 | 4700 | 14 | – | – | – | 330 | 9300 | 28 |
| 960 | 750 | 3000 | 14 | – | – | – | 270 | 6000 | 27 |
| 1240 | 970 | 3500 | 12 | 5 | 50 | 20 | 470 | 7000 | 24 |
| 1550 | 650 | 2000 | 10 | 4.2 | 50 | 22 | 225 | 4500 | 26 |
| 1860 | 170 | 500 | 9 | – | – | – | 60 | 900 | 24 |
| 1950 | 280 | 700 | 8 | – | – | – | 125 | 1500 | 22 |
| 2200 | 160 | 500 | 10 | 235 | 3500 | 24 | 100 | 1000 | 20 |
| 2500 | – | – | – | 180 | 1800 | 20 | – | – | – |
| 2800 | 200 | 700 | 12 | 680 | 1500 | 27 | 125 | 1500 | 22 |
| 2960 | 190 | 700 | 12 | – | – | – | 90 | 1400 | 24 |

*Fig. 9. Simple measurement of insulation by using a car horn as sound-source, and the Frequency Analyzer for measuring the sound level outside and inside the car at different frequencies.*

close together. This double-tone horn gives a characteristic modulation at very low frequency which possesses great penetrating power. The Volkswagen horn has a strong basic tone as well as a few less prominent overtones. Ford Consul has a weaker basic tone, as well as some particularly powerful overtones between 2 and 4 kc/s. In the curves shown, the amplitudes appear in a linear scale.

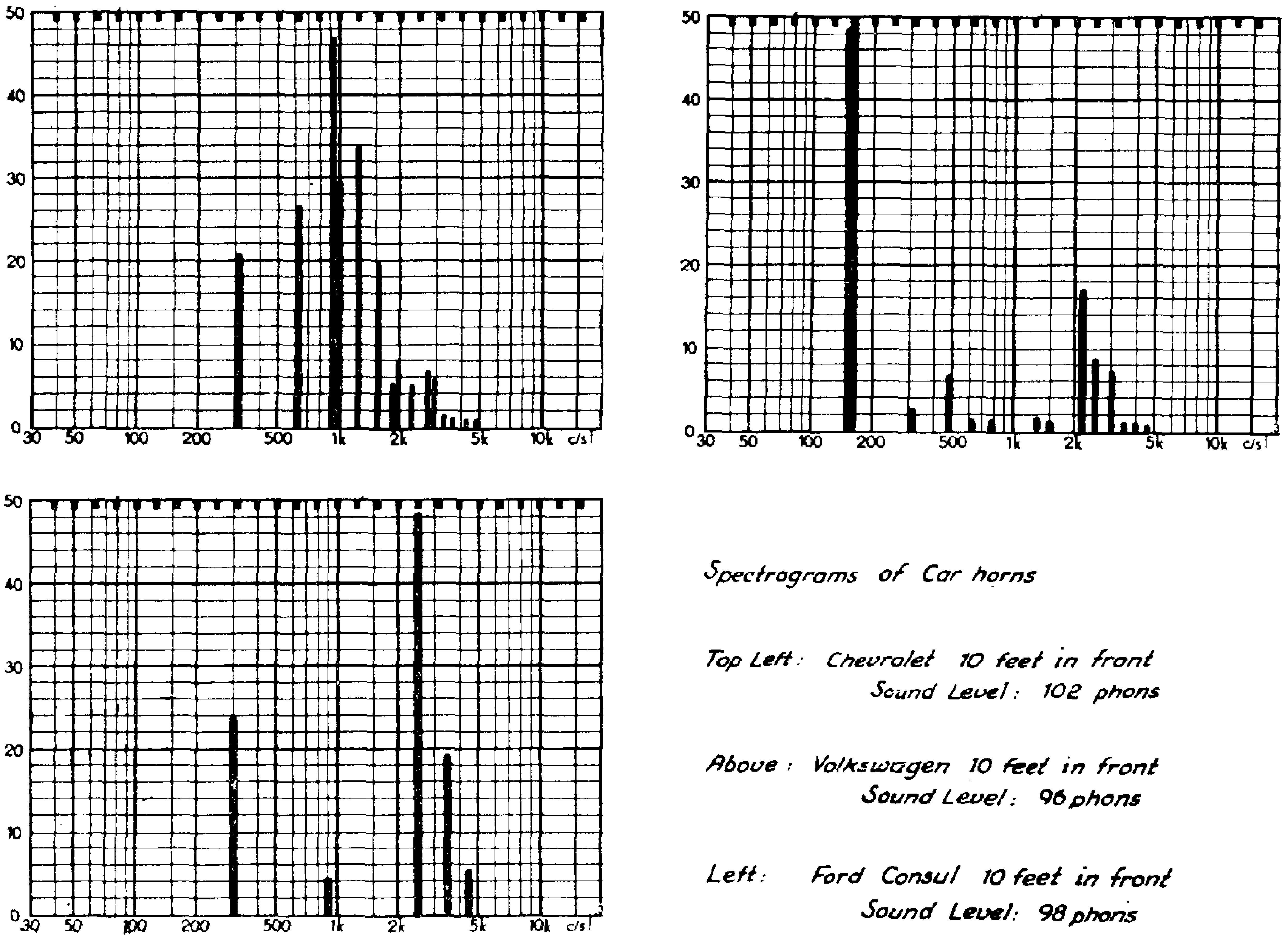


*Fig. 10. Spectrograms for auto-horns measured with Frequency Analyzer 2105 and Condenser Microphone 4111 at 3 metres (10 feet) in front of the car. The weighting characteristic for 30—60 phons (curve A) is used. The sound pressures are given in linear scale.*

The noise in a moving car is also of great interest in this connection, for at the frequencies where the car noises are especially loud the ear will to some extent be deafened, and therefore less receptive to sounds in the neighbourhood of these frequencies. In designing auto-horns we should, therefore, make sure that the frequency composition will differ from that normally occurring in the sound of a running car. In fig. 11 we now see the results of measurements carried out in the three cars referred to.

It will be seen that the Ford Consul has a decidedly powerful tone for a very low frequency about 35 c/s, whereas components for higher frequencies are quite negligible. The Chevrolet car has four moderately strong frequency components, compared with which the Volkswagen has a series of very powerful frequency components at lower frequencies. Now it is fortunate that the human ear is not so sensitive to low frequencies as to medium frequencies, so that the very powerful sound pressures at low frequencies are not so irritating. This is taken into account by adding to the figures a dotted line, representing the "70 phon curve". The components of the noise should therefore be assessed on the basis of this curve. The fig. also indicates the noise level, expressed in phons, found in the running cars. If the horn frequencies of a following car only lie between the indicated noise frequencies in the vehicle itself, however, the human ear is very capable of perceiving the sounds, even if they are 20 or 30 db below the car's own noise level. The spectrograms shown in fig. 11 are measured at a constant speed of 20 m/hr. The strength of individual components varies considerably with the speed.

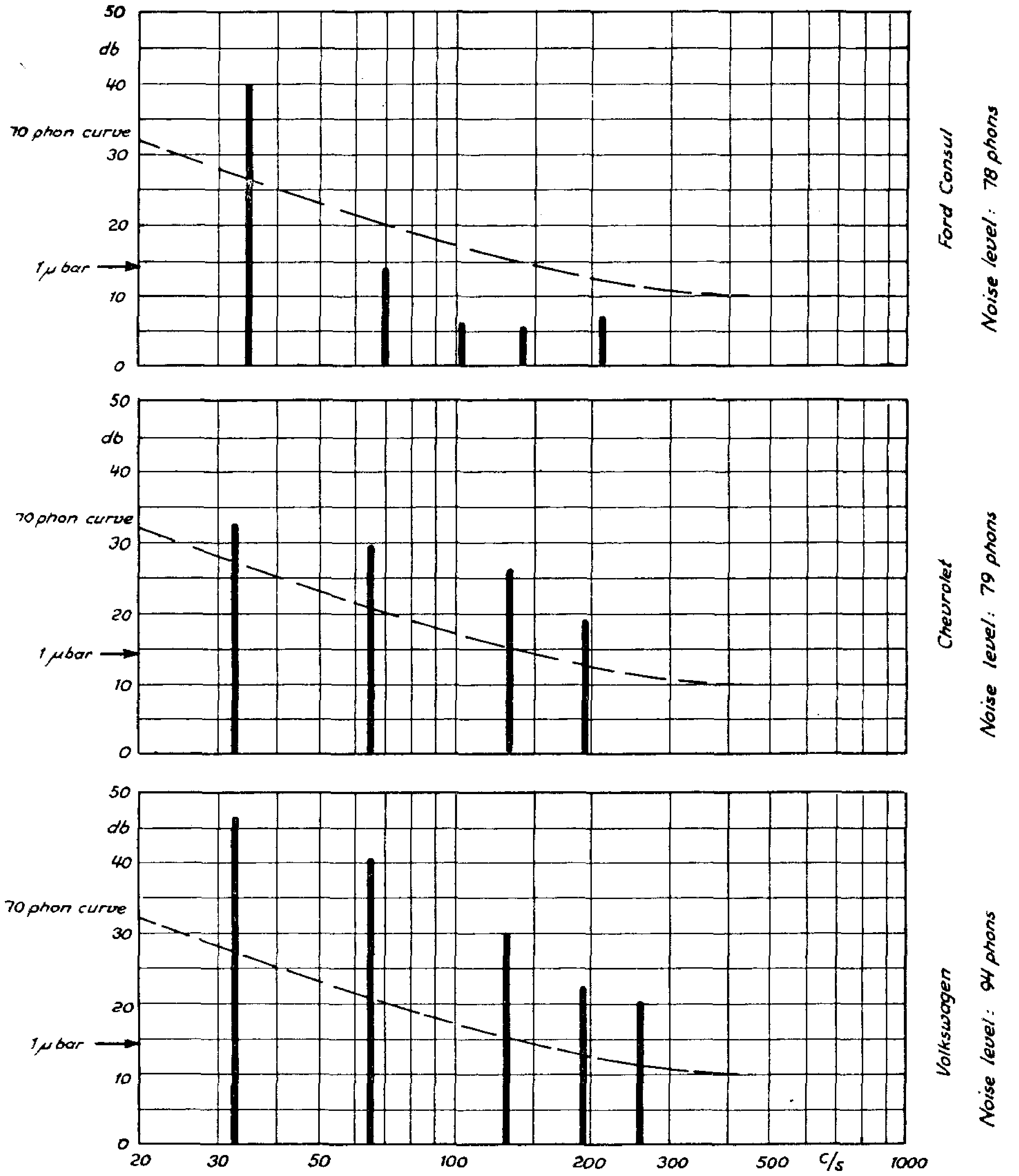


*Fig. 11. Spectrum of noise in the cars when driving at 20 miles an hour. The total noise levels in phons are indicated. The broken curve corresponds to the reciprocal sensitivity of the ear to a pure tone with a level of 70 phons.*

An important point about auto-horns is that they should project the sound mainly forward in the direction in which the car is travelling. The sound thrown upward or sideways must to a large extent be considered lost, and it is not merely lost; it is definitely harmful, since it inconveniences drivers who have no interest in the signalling. A mark of distinction for a good horn, therefore, is that it has a pronounced directional effect forward. A set-up for the recording of directional characteristics can be seen in fig. 12. On a turning platform for locomotives we place the car so that it can be rotated at constant speed. At some distance from this we arrange the measuring device, consisting of a Condenser Microphone and Frequency Analyzer with Level Recorder attached, on which the Polar Diagram Recorder 2370 is mounted. The paper in the Polar Diagram Recorder rotates synchronously with the turning platform, and the sound pressure is recorded directly as a function of

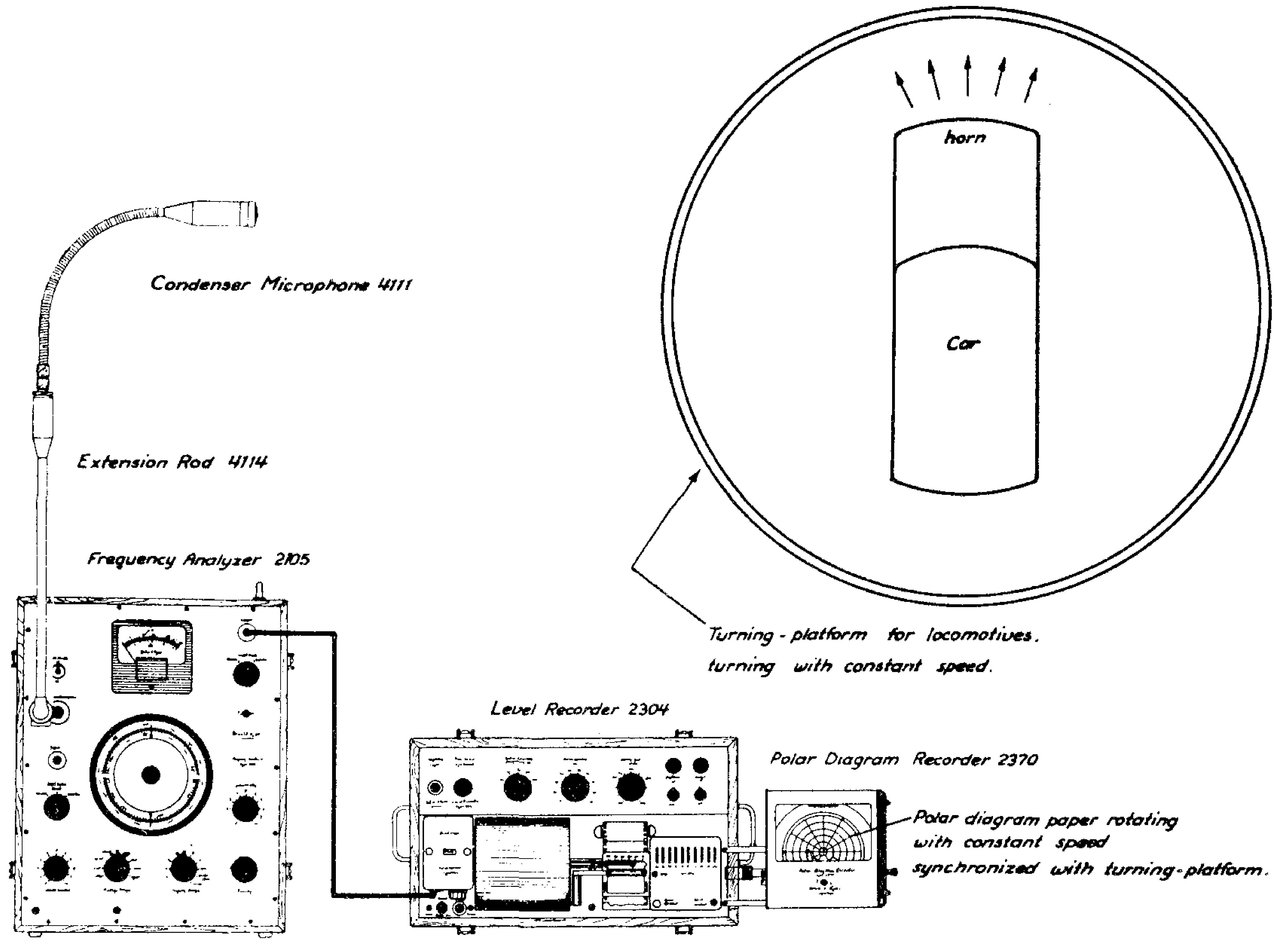


*Fig. 12. Recording directional characteristics of the sound from an auto-horn. A locomotive turnplate is used together with Level Recorder and Polar Diagram Recorder.*

the rotation angle. Fig. 13 a, b and c show the results with the three cars. The measurements are carried through with the Analyzer standing on the 30—60 phon curve, so that the significance of the lower frequencies is lessened. The polar diagrams or directional diagrams show that the Ford Consul has the best directional diagram, while the Volkswagen reveals the poorest directional effect. The scale of the diagrams is linear.

Naturally, the analyzer alone will help us to measure, point by point, the sound emission from the car, by going round the vehicle and placing the instrument in previously marked positions and measuring the sound pressure there. This has been done in the table shown in fig. 14. This last method, however, is uncertain, since reflections from contiguous buildings, trees and such like act very disturbingly on the point-wise measurement. By far the safest method, therefore, is the automatic recording, where all reflections can be recognised.

The vertical direction diagram is also of consederable interest. In fig. 15 we see the measuring set-up, and in fig. 16 the test results from the three cars. Measurements of this kind should preferably be undertaken at quite some distance from the vehicle, so that reflections from the roadway are included in the results. The distance from the front of the car should not be less than 20 ft. In the results shown in fig. 16 the Chevrolet comes out the best.

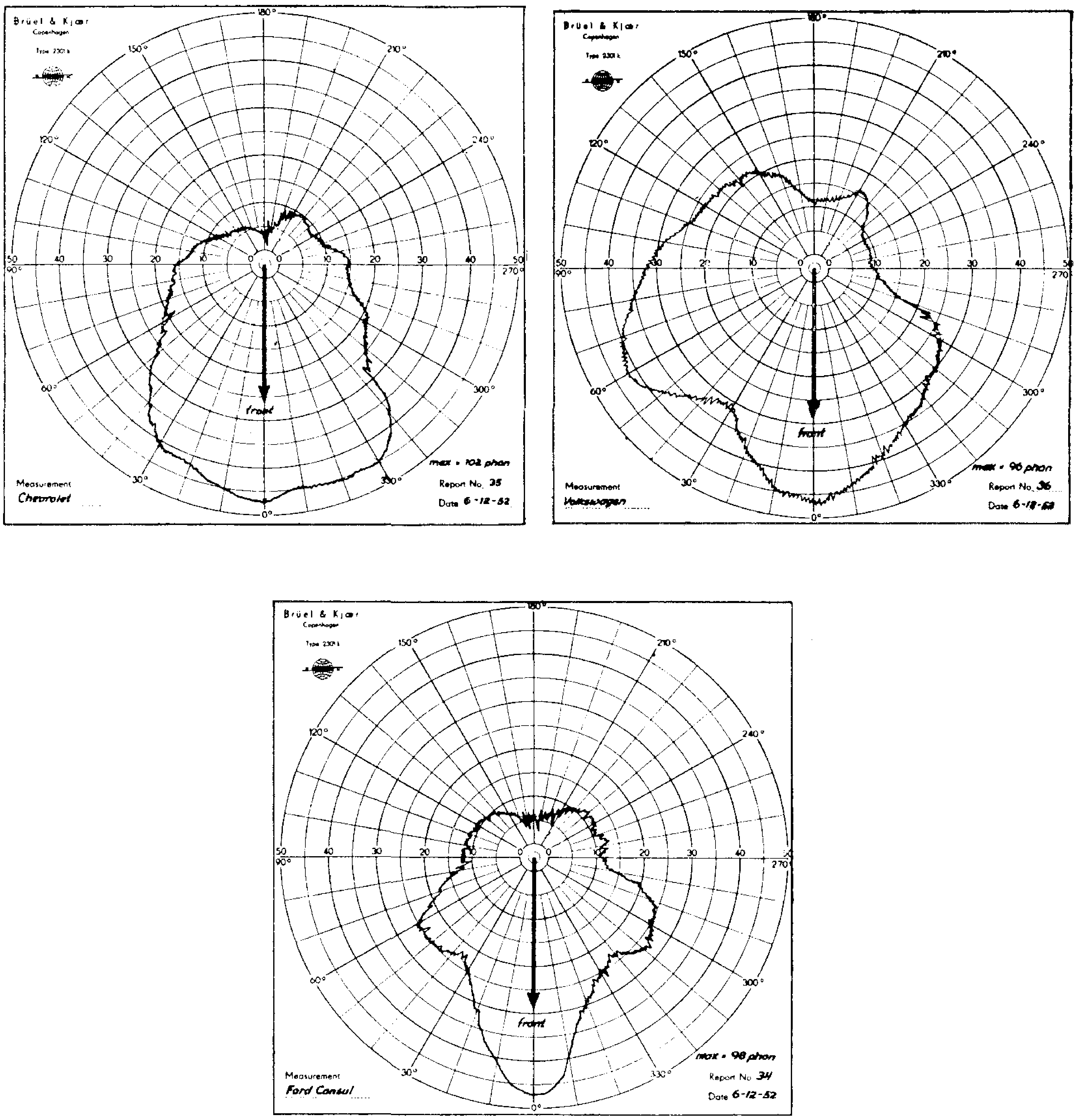


*Fig. 13. Recorded directional characteristics of Chevrolet, Volkswagen and Ford Consul. The sound pressures are indicated in linear scale.*

Finally, it need only be mentioned that Frequency Analyzer 2105 besides measuring and analysing noise is extremely useful for the analysis of vibrations, which may frequently be of importance when suspending auto-horns, or shaping membranes and such like. As vibration pick-ups in such cases the very small crystal pick-ups of type 4303 or 4304 are used.

Certain body makers have for some unexplained reason mounted the horn almost in the middle of the car behind the engine, so that the sound filling the vehicle must be exceedingly powerful, when the horn is in use, while it becomes difficult for the sound to reach out beyond the radiator part. In order to judge these conditions the sound intensity of the horn three metres ahead of the car is compared with the sound intensity inside the vehicle. Fig. 17 shows the result of these measurements, which were made with Analyzer and Condenser Microphone. In this instance the spectrum obtained from in front of the car

| Direction | 0° | 30° | 60° | 90° | 120° | 150° | 180° | 210° | 240° | 270° | 300° | 330° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chevrolet | 102 | 96 | 77 | 71 | 63 | 61 | 57 | 65 | 65 | 70 | 76 | 100 |
| Volkswagen | 96 | 81 | 92 | 83 | 74 | 70 | 60 | 65 | 60 | 60 | 76 | 85 |
| Ford Consul | 98 | 76 | 76 | 63 | 61 | 59 | 56 | 59 | 63 | 63 | 76 | 76 |

*Fig. 14. Results of simple directional measurements with Analyzer 2105 and Condenser Microphone 4111.*

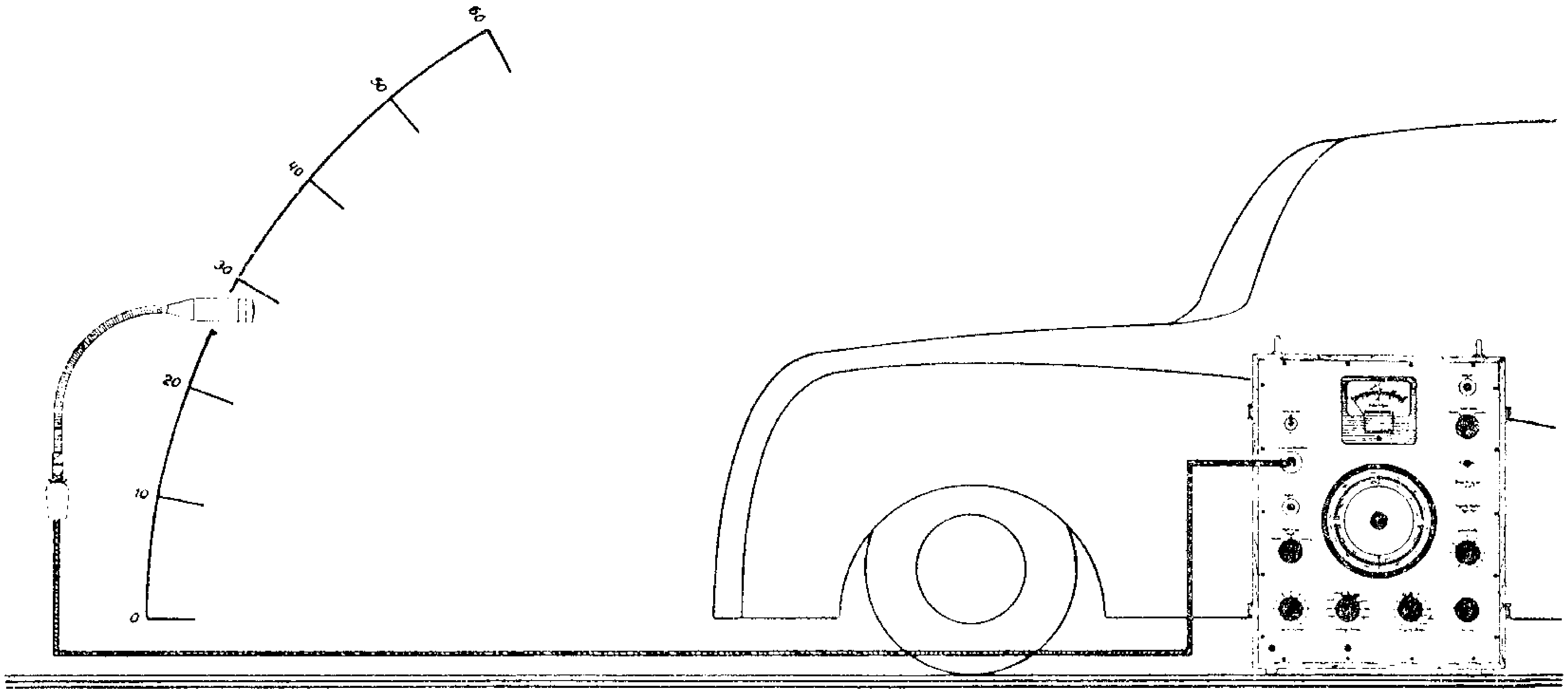
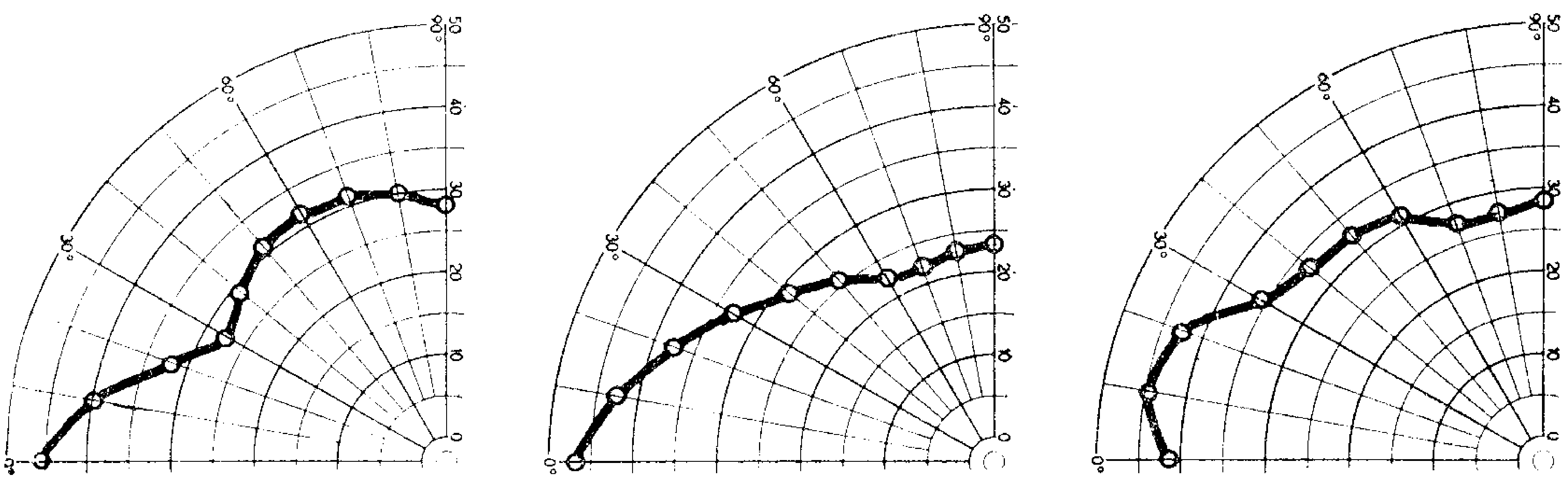


*Fig. 15. Measurement of vertical directional characteristics.*



Volkswagen Chevrolet Ford Consul

*Fig. 16. Results of three measurements of vertical directional characteristics. Linear scale used for the sound pressure.*

is represented in logarithmic scale and expressed in db. Actually, the spectra are approximately identical with those shown in fig. 10. For each type of car the spectrum from the interior is indicated by the thin, solid line. Naturally, the spectrum of the interior is also a line spectrum corresponding accurately to that measured outside, but as is apparent, with different damping of the different frequencies. We observe that the Chevrolet car shows a marked difference between external and internal sounds, which suggests that the horn has been sensibly placed here. In the Ford Consul the disparity is considerably less marked, as regards the low frequency components, whereas conditions in the Volkswagen are quite extraordinarily unequal. Some components are decidedly

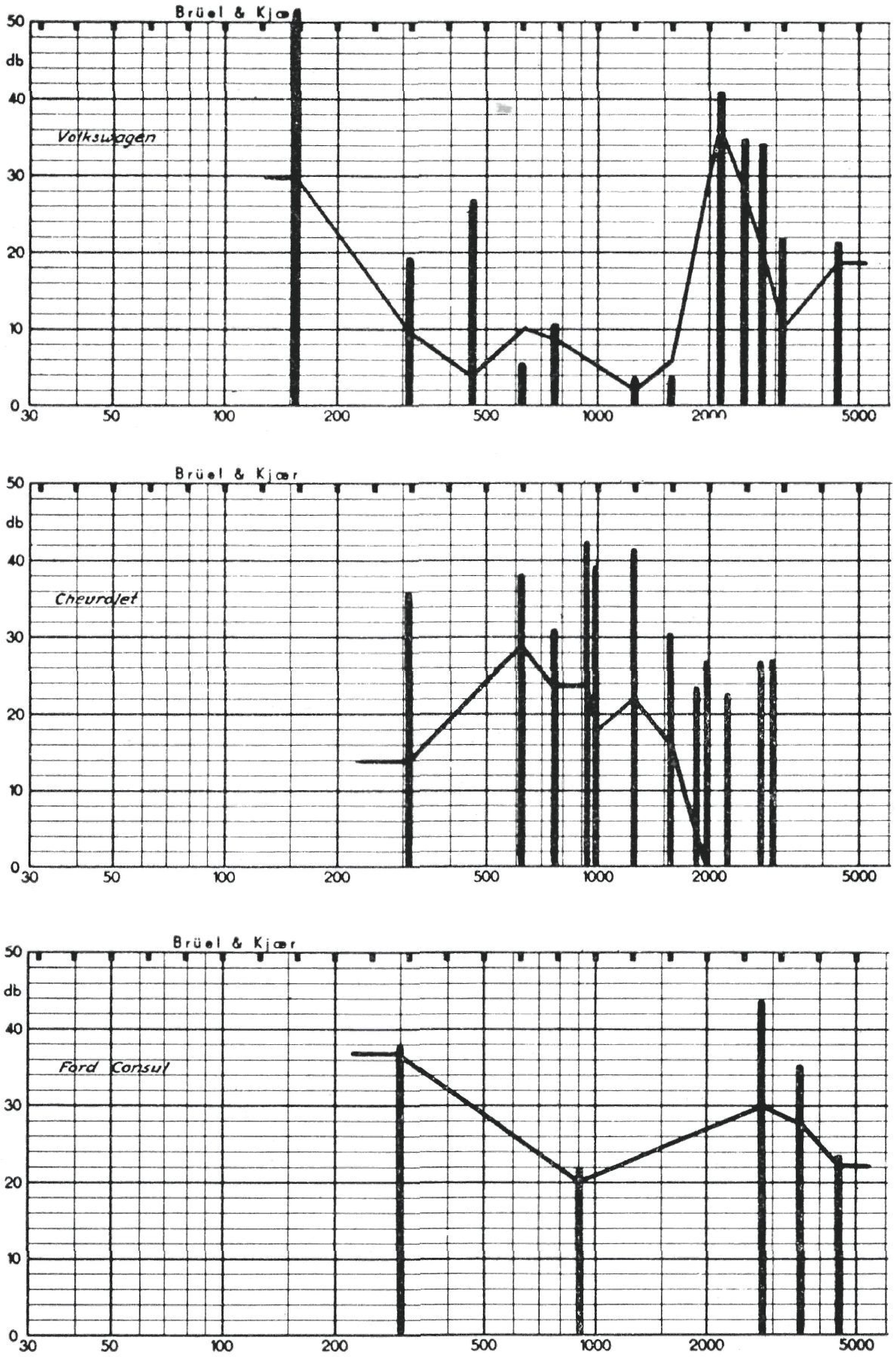


*Fig. 17. Spectrograms of auto-horns 10 feet in front of the car, where the sound pressure is shown in decibels (solid, vertical lines) and spectograms of the same sound measured inside the car (fine line curve).*

more powerful, when measured outside, while other components are actually weaker, i. e. these frequency components are stronger inside the vehicle. It can hardly be doubted that considerable improvement could be effected in these conditions by finding a sensible place for the horn and suspending it in suitable rubber shock-absorbers.

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