



RESEARCH DEPARTMENT

The Klein-Plessey Ionophone Loudspeaker

Report No. M.018

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**THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION**

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Section	Title	Page
	SUMMARY	1
1	INTRODUCTION	1
2	CONSTRUCTION	1
3	INITIAL MODIFICATIONS	3
4	FREQUENCY CHARACTERISTICS	5
5	TRANSIENT RESPONSE	5
6	DISTORTION AND OVERLOAD	5
7	STABILITY OF OUTPUT LEVEL	7
	7.1. Variation of Output with Tuning Adjustment	7
	7.2. Variation of Output with Mains Voltage	7
8	STARTING	7
9	NOISE	7
10	LISTENING TEST	8
11	RADIO-FREQUENCY INTERFERENCE	8
12	CONCLUSIONS	8

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SUMMARY

A novel type of loudspeaker, known as an "Ionophone", has been tested. In this loudspeaker the conventional vibrating diaphragm is dispensed with and the sound is produced by a modulated r.f. corona discharge. The device is used in conjunction with a horn radiator and its main field of application is therefore in the high-frequency range; smooth response can be obtained up to at least 20 kc/s. In its present state of development the Ionophone suffers from a certain amount of distortion and noise and requires elaborate screening to restrict the electromagnetic radiation from the system. If these defects can be overcome, the loudspeaker could be used with advantage in place of a conventional horn driver unit in high-quality reproducing systems.

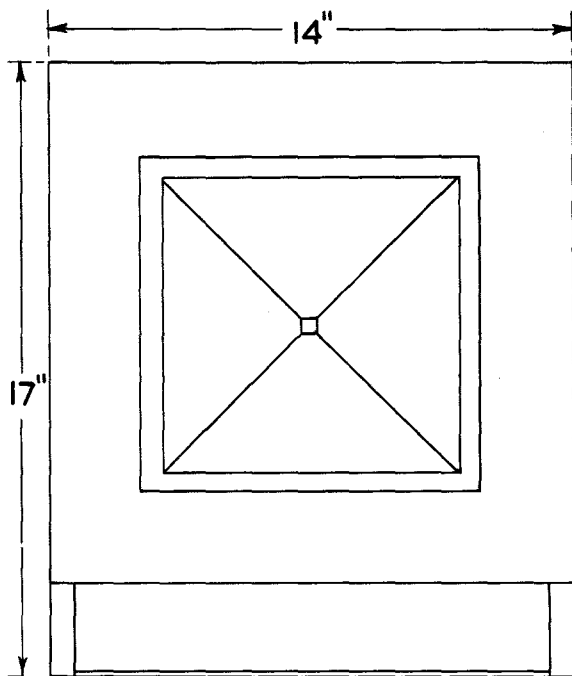
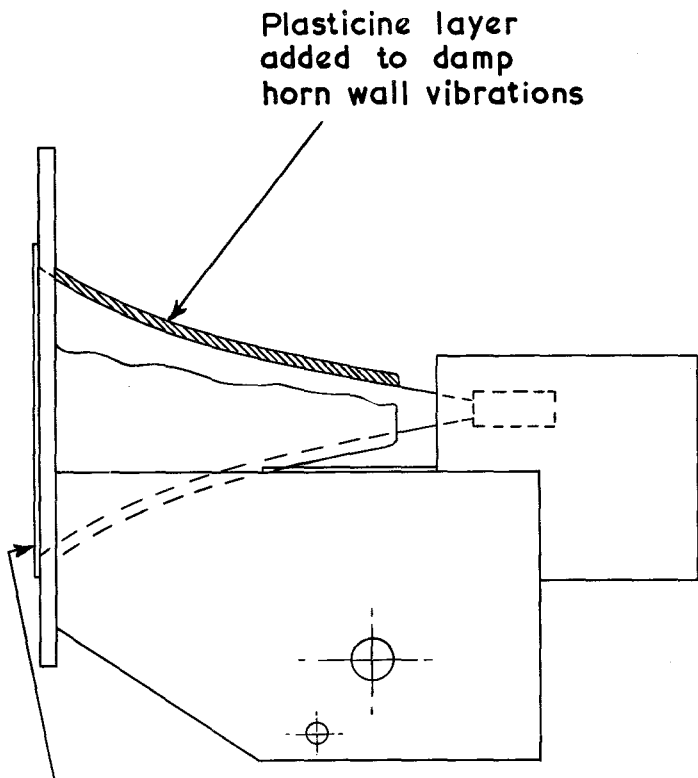
1. INTRODUCTION.

The Ionophone is a loudspeaker, invented by Siegfried Klein, in which the sound pressure is generated by a radio-frequency corona discharge modulated by the signal to be reproduced. The discharge takes place within a quartz tube which opens into the air through an exponential horn. The Ionophone is made under licence in this country by the Plessey Company, but is not yet in production; this report describes tests carried out on an experimental model.

The salient feature of the Ionophone is its inherent freedom from the defects commonly associated with the presence of a diaphragm. The device could in principle be used to reproduce the whole audio-frequency range, but a horn capable of operating efficiently at low frequencies would be inconveniently large for many purposes. For this reason, the model produced by the Plessey Company is made with a relatively small horn designed to reproduce only frequencies above 800 c/s, and is intended for use in conjunction with a separate low-frequency unit of conventional type. The restriction of the use of the Ionophone to the high end of the audio-frequency band is not a serious disadvantage since it is in this part of the spectrum that the shortcomings of diaphragm-type loudspeakers are most in evidence.

2. CONSTRUCTION.

Fig. 1 shows the appearance and dimensions of the complete equipment, with the exception of the power-supply unit, which occupies a separate chassis. The sheet-metal horn, the nominal cut-off frequency of which is about 700 c/s, has a mouth



Position of horn flange after re-mounting on front of baffle

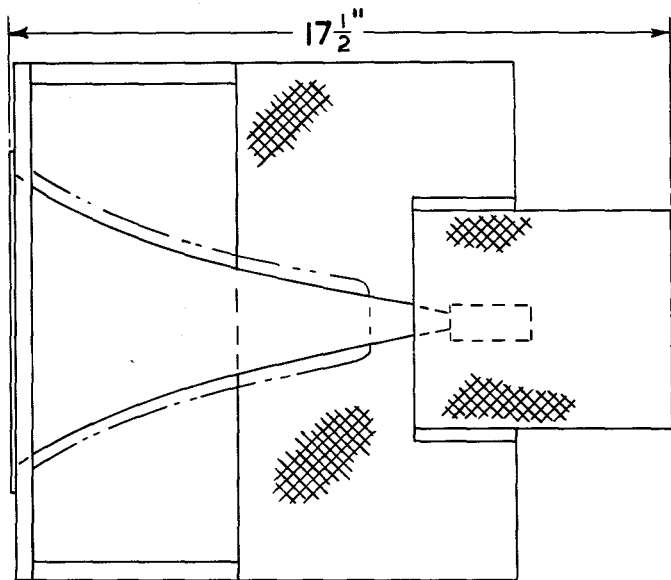


Fig. 1 - General arrangement.

8 in. (20 cm.) square and is mounted on a 14 in. (35 cm.) square plywood baffle supported by the main chassis. The chassis contains an oscillator which provides approximately 70 watts of radio-frequency power to maintain the corona discharge, together with a push-pull modulator. The oscillator is provided with a tuning control brought out at one side of the chassis. A divider network with a nominal cross-over frequency of 800 c/s is connected ahead of the modulator.

Fig. 2 shows the quartz tube in which the sound is generated. The radio-frequency voltage from the modulated oscillator is applied between the platinum point and earth; the earthed ring electrode shown is not essential to the functioning of the Ionophone but serves to stabilize the discharge. The closed end of the tube, in which the corona takes place, becomes red hot after a few minutes operation; the open end, which is attached to the horn, remains cool.

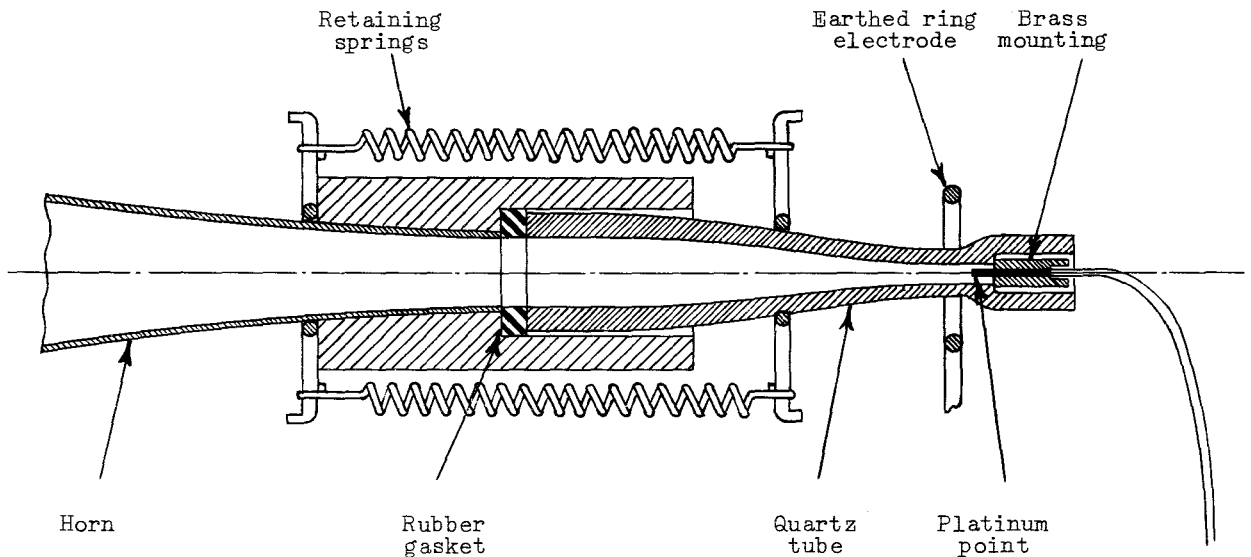


Fig. 2 - Discharge tube assembly.

3. INITIAL MODIFICATIONS.

Measurement of the performance of the Ionophone was hampered at the outset by modulation of the signal by ripple in the H.T. supply and it was found necessary to increase the smoothing. To this end a 6 henry series choke and an 8 μ F shunt condenser were connected ahead of the existing smoothing filter in the power-supply unit.

In addition, the divider network was disconnected and all measurements were carried out with the audio-frequency input applied directly to the modulator.

4. FREQUENCY CHARACTERISTICS.

Fig. 3 shows the frequency characteristics for constant voltage applied to the modulator, measured on the axis of the loudspeaker and at 45° to the axis in the horizontal plane, the signal level being kept low enough to avoid non-linear effects. The measuring microphone was at a distance of 3 ft. (0.9 m.) from the centre of the horn mouth. It will be seen that the axial frequency characteristic shows no serious decline up to 20 kc/s, the highest frequency at which it was possible to measure. With a single horn of the type used, the radiation inevitably becomes increasingly directional with frequency, and the fall in high-frequency response at 45° is therefore to be expected.

Some of the irregularities in the curves of Fig. 3, namely those occurring at 940 c/s, 960 c/s, 1200 c/s, 1450 c/s, 1750 c/s, 1830 c/s, 2450 c/s and 2900 c/s, were found to be due to resonances of the horn walls. To damp the wall vibrations, a layer of Plasticine about $\frac{3}{16}$ in. (5 mm.) thick was applied to the outside of the horn. Fig. 4 shows the axial frequency characteristic of the Ionophone with this modification, the test conditions being the same as for Fig. 3. The irregularities enumerated are no longer apparent.

The horn of the Ionophone is mounted on the plywood baffle by a flange surrounding the mouth. Originally the flange was screwed to the rear of the baffle so that the inevitable discontinuity in the flare at the horn mouth was somewhat aggravated by the square edge of the wooden surround. After the curve of Fig. 4 had been taken, the horn was re-mounted as shown in Fig. 1, with the flange screwed to the front of the baffle. Fig. 5 shows the axial frequency characteristic of the Ionophone in this state, the test conditions being the same as for Figs. 3 and 4; the effect of the simple change is surprisingly large.

5. TRANSIENT RESPONSE.

Interrupted tone tests carried out before the application of Plasticine to the horn confirmed the presence of the structural resonances already noted. After the application of Plasticine no resonances could be detected throughout the whole frequency range.

6. DISTORTION AND OVERLOAD.

The non-linear distortion of the Ionophone was first investigated by observing on a cathode-ray oscilloscope the waveform of the output from a microphone, the frequency response of which had been equalised electrically to be flat within ± 1 db to 16 kc/s. There was a clearly defined overload point which varied somewhat with frequency. In an endeavour to discover whether the upper limit to the undistorted output was set by non-linear effects in the discharge or by overloading of the modulator or the oscillator, the performance of these stages was investigated. Examination of the circuit showed that the radio-frequency oscillator had originally been modulated on both anode and screen but that additional smoothing had at some time been introduced into the screen supply in such a way as to remove the modulation voltage from this electrode. With the extra H.T. smoothing choke and condenser

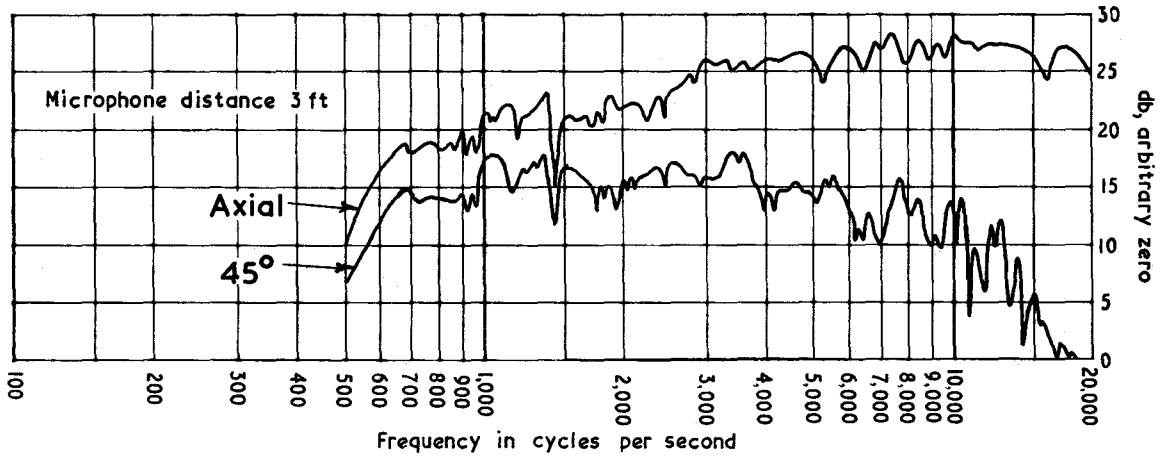


Fig. 3 - Axial and 45° horizontal plane frequency characteristics.

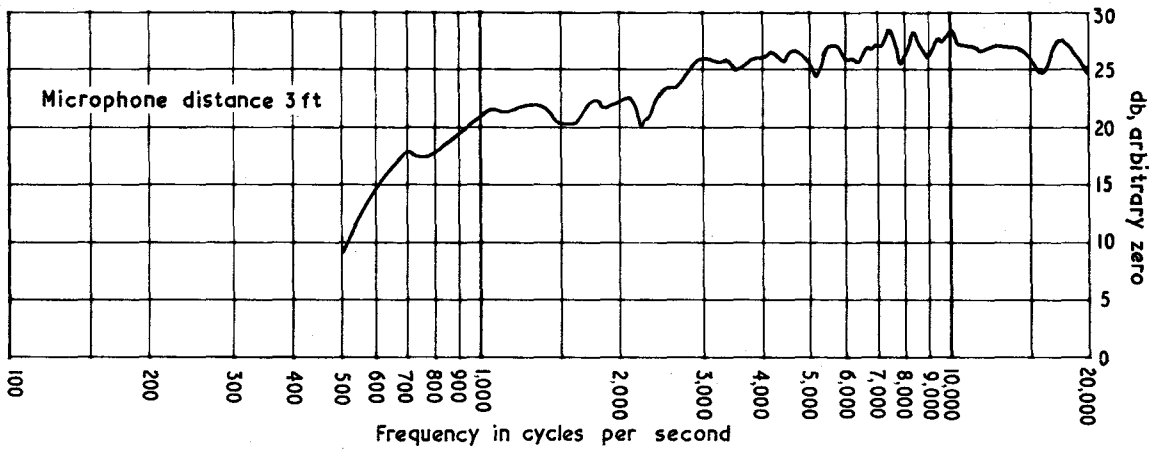


Fig. 4 - Axial frequency characteristic. Approx. $\frac{3}{16}$ in. layer of Plasticine applied to outside of horn.

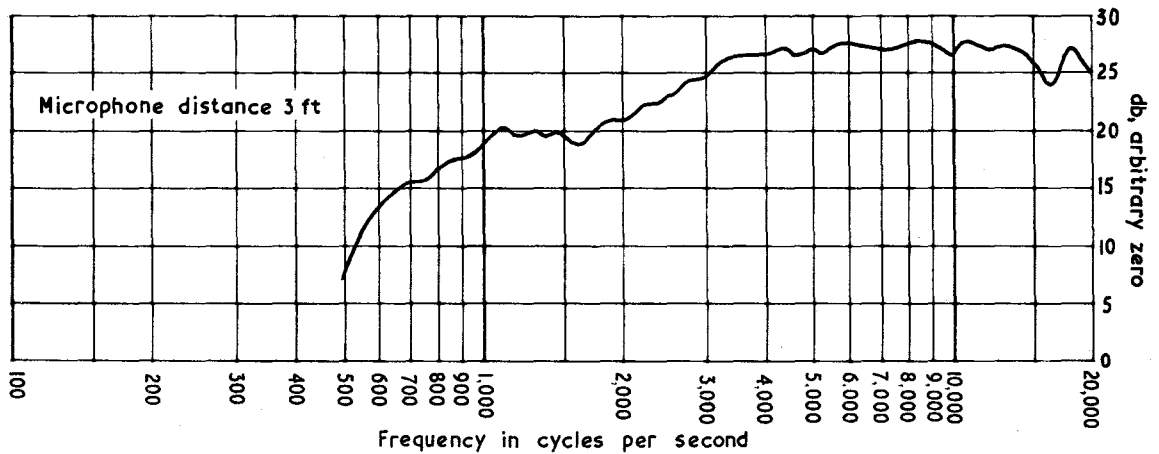


Fig. 5 - Axial frequency characteristic. Approx. $\frac{3}{16}$ in. layer of Plasticine applied to outside of horn. Horn re-mounted on front of plywood baffle.

referred to in section 3 of this report, screen smoothing was found to be unnecessary and was therefore removed. With the screen modulation thus restored, the overload point of the Ionophone was raised by approximately 10 db.

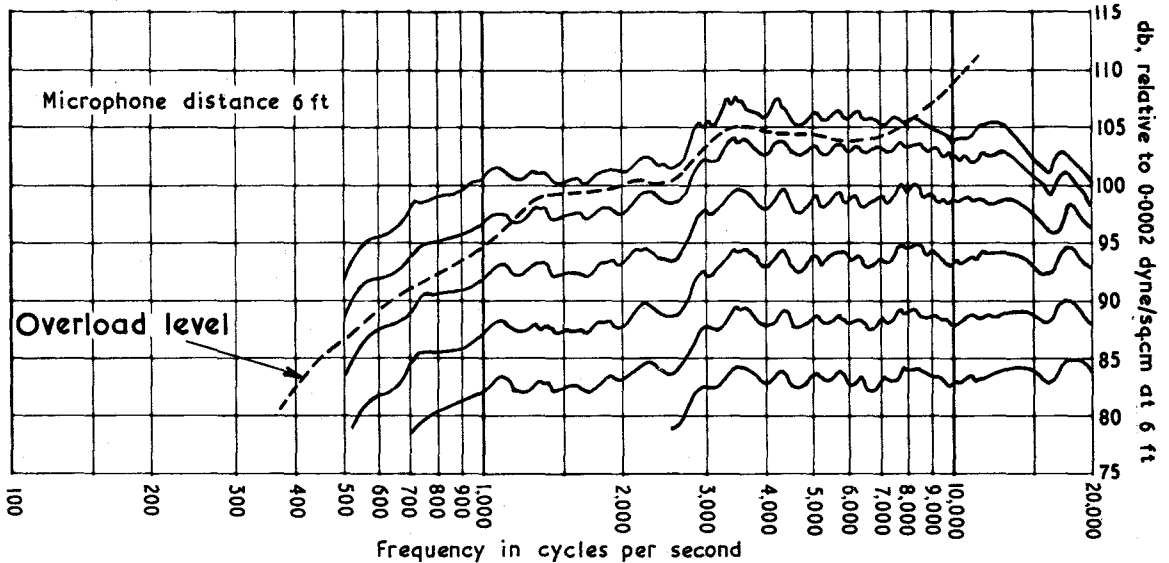


Fig. 6 - Axial frequency characteristics for input levels at 5 db intervals.

The curves of Fig. 6 show the variation in axial frequency characteristic of the Ionophone with input voltage with the circuit in the condition just described. These curves were taken with the microphone position used for certain other measurements, which, for reasons to be given later, were made at a distance of 6 ft. (1.8 m.). At this distance the effects of reflections from temporary fittings in the sound measurement room were appreciable and appear as undulations in the curve for frequencies between 3000 and 9000 c/s.

The dotted line in Fig. 6 marks the level at which the waveform of the sound output, observed on a cathode-ray oscilloscope, shows obvious overloading of the Ionophone. From 1400 to 8000 c/s, this line runs roughly parallel with the frequency response curves, indicating that the overload condition corresponds with a particular level of electrical input rather than with a particular level of acoustic response. The response of the measuring microphone and associated amplifiers falls rapidly above 20 kc/s so that for fundamental frequencies above 8 kc/s, the onset of distortion is partially obscured by attenuation of the harmonics and the apparent rise in overload level at high frequencies may also be due to this cause. The falling off in the overload level at frequencies below 1400 c/s may be attributed to the change in the acoustic impedance at the throat of the horn as the cut-off frequency is approached.

The spacing of the curves in Fig. 6 indicates that in the main, the output of the Ionophone is proportional to the input but some compression is apparent at the higher levels and there are signs of slight expansion at lower levels.

Observation of the modulated radio-frequency envelope from the oscillator suggested that higher undistorted output might have been obtained from the Ionophone if the peak radio-frequency power available had been greater; with the equipment in its present form, the modulation depth is limited to some 25% by clipping of the positive peaks. In view of this limitation, it was not thought worth while to make comprehensive distortion tests. A single harmonic analysis was however carried out at 1000 c/s with a sound level of + 91 db relative to 0.0002 dyne/sq. cm. at 6 ft., the tuning control being adjusted for minimum waveform distortion as observed on a cathode-ray oscilloscope. With these conditions 5.5% second, 0.8% third and 0.3% fourth harmonic were measured. Higher order harmonics were negligible.

7. STABILITY OF OUTPUT LEVEL.

Since the Ionophone in its present form is intended for use in conjunction with another loudspeaker, any variation in sensitivity could have serious effects. Tests were therefore carried out to determine the degree of stability to be expected.

7.1. Variation of Output with Tuning Adjustment.

The working range of the tuning control was limited by extinction of the corona at one end and by bad distortion of the sound output at the other. Adjustment between these limits produced a change in sensitivity of 1 db. It was noted that the highest sensitivity and lowest distortion were obtained with a tuning adjustment close to that which extinguished the discharge.

7.2. Variation of Output with Mains Voltage.

Variation of the mains voltage caused a total change of sensitivity of 1.3 db over the range from 250 to 220 volts. For this test the tuning control was set for minimum distortion with the mains voltage at 240. Variation of mains voltage in either direction caused a decrease of sensitivity.

8. STARTING.

The Ionophone, as supplied, normally requires adjustment of the tuning control after switching on to initiate the discharge; only on infrequent occasions does it start without this adjustment.

9. NOISE.

The Ionophone generates a high-pitched background noise which is similar in character to that from a cellulose disc recording; in addition, faint whistling, frying and arcing sounds are heard. The noise is sporadic in character and it was not possible to make a quantitative estimate; but the background would probably be considered quiet enough for domestic use. In addition to the noise heard during pauses in programme, there appeared to be a component which rose and fell with the amplitude of the signal.

10. LISTENING TEST.

For the purpose of a listening test it was necessary to combine the output of the Ionophone with that of a suitable low-frequency loudspeaker. An LSU/10 was used for this purpose, the high-frequency speech coil of the coaxial unit being disconnected. The Ionophone was placed on top of the LSU/10 cabinet and the low- and high-frequency units were thus separated by some 20 in. (0.5 m.). The axis of the Ionophone was therefore inclined so that it intersected the axis of the low-frequency unit at a point, approximately 6 ft. (1.8 m.) in front of the loudspeakers, considered to be the normal listening position, and the relative levels applied to the two units were based on frequency characteristics measured with the microphone placed at this point. For convenience, this microphone position relative to the loudspeakers was also used, as already indicated, in obtaining the curves of Fig. 6 in the measurement room.

The 6 db/octave divider network incorporated in the Ionophone was found unsuitable for the present purpose and a 12 db/octave network with the same cross-over frequency was constructed. Equalising circuits were also added, making the overall axial frequency response at 6 ft. flat within ± 3 db up to 20 kc/s.

The listening tests were carried out both with live material from London studios and with live speech and effects from a non-reverberant room, using in the latter case a microphone equalised up to 16 kc/s.

The high-frequency response was clearly extensive but it was in no way obtrusive, and there was a high degree of realism in the reproduction. The high-frequency radiation was, however, concentrated into a beam so narrow that the full frequency range could only be heard simultaneously by a few listeners.

The undistorted output level was barely adequate for the room, 1850 cubic feet (520 cubic metres) in volume, in which the listening tests were conducted and overloading was apparent on some loud vocal passages. It was estimated that the overload point would need to be raised by at least 6 db before the Ionophone could be used for monitoring purposes.

11. RADIO-FREQUENCY INTERFERENCE.

The carrier frequency of the Ionophone tested was approximately 42 Mc/s. In spite of attempts by the makers to screen the unit, sufficient radio-frequency energy was radiated to cause serious interference with television receivers on the premises. To enable tests to be continued the screening was improved by enclosing the whole Ionophone within a perforated brass box provided with a front of acoustically transparent open-mesh wire gauze.

12. CONCLUSIONS.

The results of the tests suggest that the Ionophone has great potentialities as a high-quality reproducer. A number of improvements will, however, be necessary before these potentialities can be fully realised.

The corona discharge should be made self-starting. The noise level must be reduced if the loudspeaker is to be used for programme monitoring, in the course of which the signal/noise ratio of other equipment has to be assessed, and the maximum undistorted output should be increased by at least 6 db. The horn used with the Ionophone is very directional at high frequencies; to obtain full benefit from the increased range of the loudspeaker, some form of radiator giving wide-angle distribution is highly desirable. Finally, the electromagnetic radiation from the Ionophone must be rendered innocuous by judicious choice of the operating frequency and careful attention to screening.