RESEARCH DEPARTMENT

The design of a low-frequency unit for monitoring loudspeakers

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SUMMARY

The present state in the design of low-frequency loudspeaker units is reviewed and the areas where improvement is desired are indicated. Experimental details are given leading to the design of a 12 in. (305 mm) unit incorporating a vacuum-formed cone of toughened polystyrene with a p.v.c. (polyvinyl chloride) surround, and it is shown by objective and by listening tests that this design is superior to existing units. An analysis of the price indicates that the new unit should not cost any more than those at present in use.

1. INTRODUCTION

Wide range loudspeakers, such as are employed for quality monitoring, generally consist of a low- and high-frequency unit mounted in a cabinet together with a crossover network. In the past colouration* has been so prominent in the reproduction from low-frequency units that the choice of unit has been made on the basis of comparative freedom from this effect rather than on that of power handling capacity. As an example, a 15 in. (380 mm) unit is employed in the type LS3/1 loudspeaker when a unit of smaller diameter would have been chosen if one of the necessary quality could have been found. In addition, owing to the restricted working frequency range of the high-frequency units available, it has been necessary to use low-frequency units beyond the frequency range in which the cone and surround behave as a simple piston, i.e. up to about 500 c/s, and into the region in which the amplitude/frequency response is irregular and dependent on the modes of cone resonance and their degree of damping. Furthermore, in existing loudspeaker units the frequency range over which the response is smooth appears, for reasons not fully understood, to be almost independent of cone diameter and from this aspect there is therefore no advantage to be obtained from employing smaller diameter units.

Cones have generally been made of a paper felt material, but in practice the characteristics of this material, especially the damping coefficient, are not accurately reproducible in large scale manufacture, and therefore the frequency characteristics are variable in the region of resonance modes. In an effort to improve matters some manufacturers have turned to materials having a higher stiffness to weight ratio than is obtainable with felted paper, the idea being to make the cone so stiff and light that the inevitable resonances lie outside the frequency range of interest. For this purpose expanded polystyrene has been employed, generally with a reinforcing skin of some other material such as aluminium. The results are rather disappointing as resonances are found to occur within the middle-frequency band and by its very construction the cone is of such a high mechanical impedance that it is very difficult to secure adequate damping.

In the BBC, the loudspeakers types LS5/1A, LS5/2A and LS3/1A all use a special Goodmans 15 in. (380 mm) diameter low-frequency unit and have a crossover frequency of about 1600 c/s, and some difficulty has been found in obtaining units which will meet the BBC test specification in the 500 to 1600 c/s region where various resonances occur; furthermore, the axial frequency characteristic in this region is not as smooth as could be desired. It was therefore decided to see whether

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* By colouration is meant a characteristic timbre imparted to the reproduced sound by the loudspeaker; it is believed to arise from excitation of mechanical resonances.

it would be possible to make, for future designs, loudspeaker units which would have more uniform and more reproducible characteristics than those of the type at present in use.

One of the difficulties restricting the development of paper cones has been the fact that the cost of a new mould has been in the region of £200, making experimental procedure very expensive. It was therefore decided to investigate the use of thermoplastic materials which can easily be made into cones by vacuum forming. For this process changes in mould shape and even new moulds can be made quite cheaply and easily; furthermore, as the raw cone material is made in the form of flat sheets, it should be very uniform and repeatable.

2. SCOPE OF DESIGN

It was explained earlier that the existing low-frequency units were chosen on the basis that they were relatively free from colouration although in fact they were unnecessarily large. It was therefore decided that the new units should be of 12 in. (305 mm) diameter as this size should afford adequate power handling capacity to meet all requirements. In order to restrict the investigation as much as possible, it was decided to use commercially available chassis and magnet systems, leaving open the choice of voice coil diameter and length, spider constants and the design of the cone and surround; for the latter two items, the influence of shape, thickness and material were to be examined.

3. EXPERIMENTAL DETAILS

During the period of roughly forty years in which moving-coil loudspeakers have been under development, very little has been published on the various factors which influence the frequency characteristics. One factor which is known,[1] however, is that cones with straight sides are much more likely to generate subharmonics than those which have curved sides and it was therefore decided to start with a cone shape having slightly curved sides, as shown in Fig. 1; the voice coil diameter was 2 in. (51 mm).

The primary criterion which was applied to the choice of material was that it should possess a high degree of mechanical damping, for it was argued that since resonance modes were almost certain to occur in the frequency range of interest it was essential that they should be well damped if a uniform frequency characteristic was to be obtained.

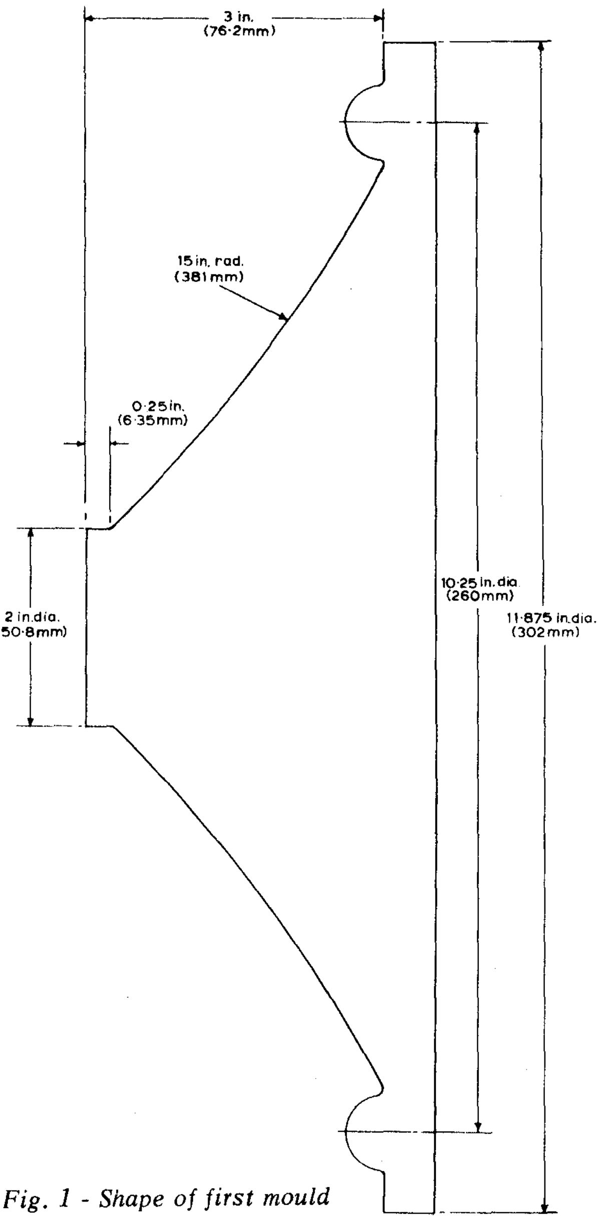

Fig. 1 - Shape of first mould

The first material to be tried was expanded polythene which is available in sheet form in various thicknesses from 1/16 in. (1·6 mm) upwards. This material is very light and is characterised by an extremely high damping coefficient. The first experimental models showed axial frequency characteristics which fell off above 500 c/s owing to insufficient stiffness of the material; this result was not altogether unexpected and steps were taken to stiffen the cone. A coat of polyurethane varnish was applied to each side of the material and as a result the frequency characteristic was extended to about 1 kc/s. It will be noted from Fig. 1 that there is a sharp bend in the cone shape near the voice coil, and it was felt that flexure was taking place at this point. A further mould was therefore made, of the shape shown in Fig. 2, in which the sharp bend was replaced by a gradual curve, and this resulted in a wider frequency range but the frequency characteristic was rather irregular. Coating the cone again with polyurethane would have improved matters but as more promising results had in the meantime been obtained with other materials, further experiments with this material were abandoned.

Concurrently with the experiments described above, tests were carried out on cones made of 0·02 in. (0·6 mm) thick unplasticised polyvinylchloride (p.v.c.), which is a horny type of material and also with a polystyrene material of the same thickness which had been toughened by the addition of a synthetic rubber and possessed a higher degree of damping than did the p.v.c. Cones were made with the mould shown in Fig. 1, and the frequency characteristics were measured with the units mounted in an enclosed cabinet similar in volume to that of the type LS5/1 loudspeaker. These characteristics are shown in Figs. 3 and 4 respectively. It is evident that the high-frequency range covered was in both cases adequate for the purpose in hand and that the additional damping in the polystyrene was advantageous; further experiments were therefore confined to this material.

All the experiments so far described were made on cones having a surround made of the same material as that of the cone and the irregularities which are seen in Fig. 4 above 500 c/s are due to the presence of resonance modes. The cone can be regarded as a transmission line and resonance modes can occur with the wave motion either in a radial or circumferential direction if it is not properly terminated in a resistive surround; as the required impedance for these two directions is different and the termination must occupy a distance small compared with a wavelength, it will be seen that the problem of designing a good termination is difficult.

The first surround tried was of plasticised p.v.c. 0·02 in. (0·6 mm) thick of the shape shown in Fig. 5, this profile being chosen to allow for fairly large excursions of the cone at low frequencies. The surround was substituted for the integral surround on the polystyrene cone previously used to obtain the curve in Fig. 4 and the resulting axial frequency characteristic is shown in Fig. 6. It will been seen that the curve is considerably smoother than that of Fig. 4 but that the high-frequency response is reduced, probably due to the surround damping out resonance modes; on the other hand, as would be expected, the bass range is extended to lower frequencies. The fact that the axial characteristic rises with frequency is largely due to the directivity increasing with frequency and the concentration of more of the sound energy on the axis. Experiments with a cone material of twice the thickness, i.e. 0·04 in. (1·2 mm), showed that it was possible to recover the high frequency response, but the response was more irregular and the sensitivity lower owing to the greater mass. Cones were then made with 0·02 in. (0·5 mm) material to the second shape mould, shown in Fig. 2; as with the polythene material, the change in shape resulted in an increase in the high frequency response, as shown in Fig. 7. The dip in the curve at 250 c/s was thought to be partly due to a circumferential mode and this was checked by stroboscopic examination. Further evidence was obtained by making a cone with a small turnover at the edge; this had the effect of stiffening the cone edge, thereby increasing the Q and producing an increase in the depth of the dip.

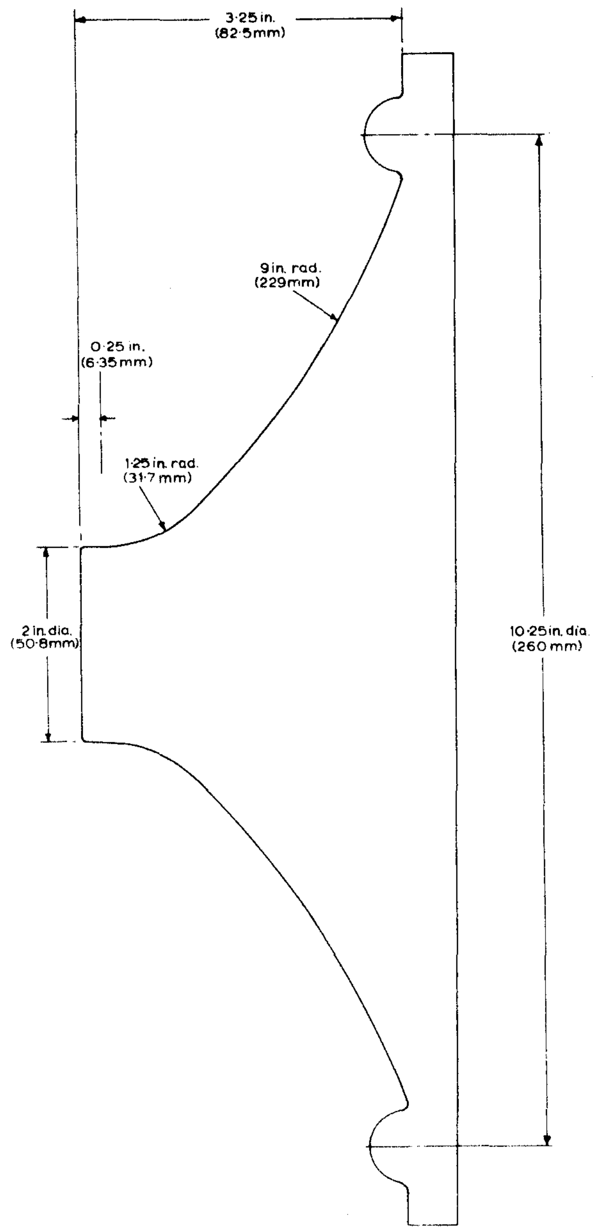

Fig. 2 - Shape of second mould

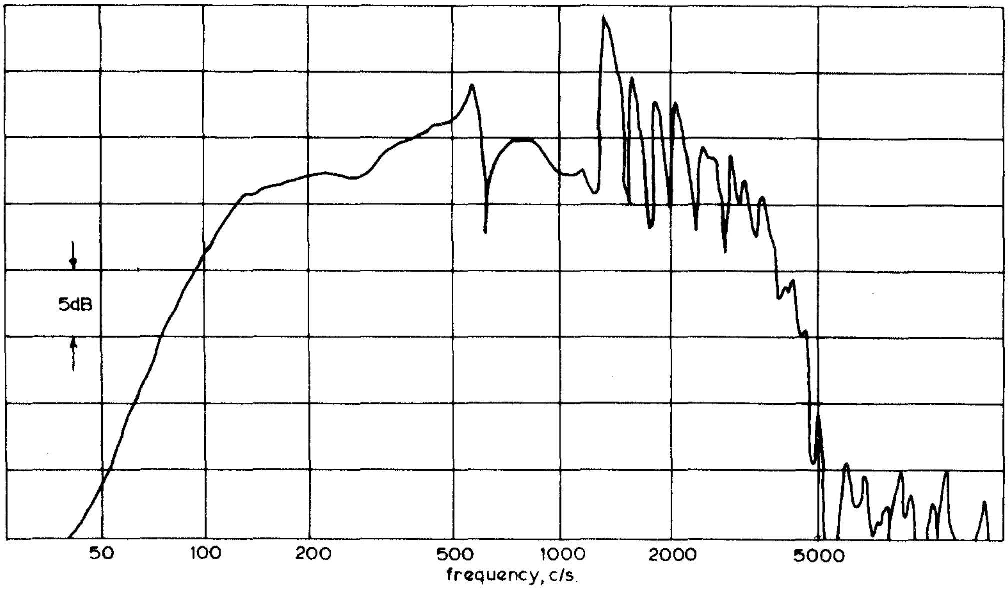

Fig. 3 - Axial frequency characteristic of unplasticised p.v.c. cone from mould No. 1

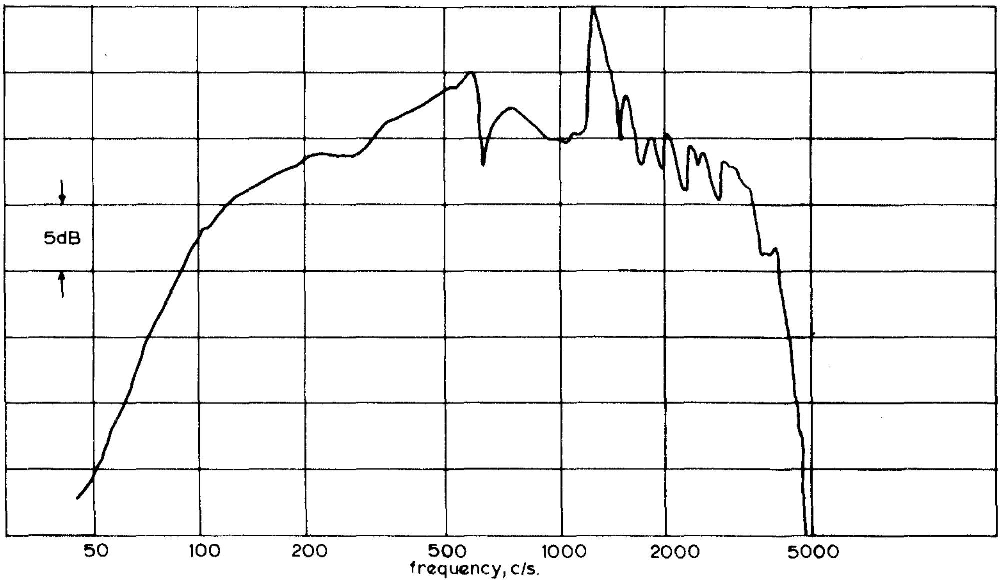

Fig. 4 - Axial frequency characteristic of Bextrene cone from mould No. 1

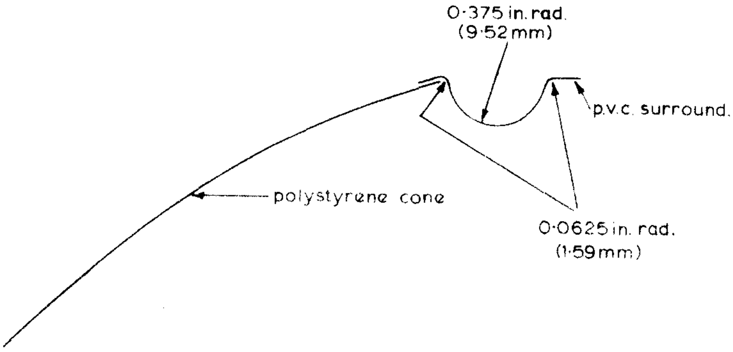

Fig. 5 - Shape of first p.v.c. surround

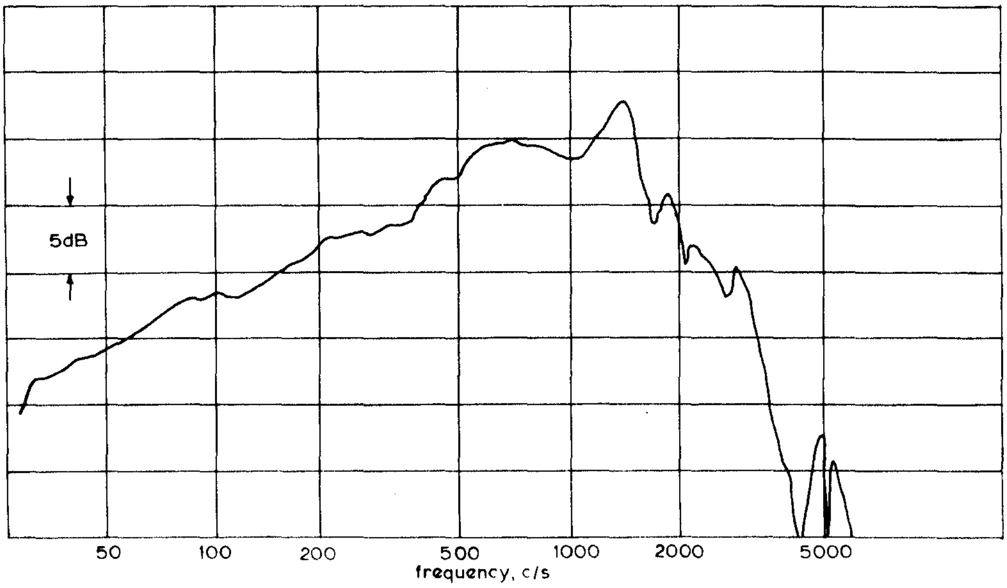

Fig. 6 - Axial frequency characteristic of Bextrene cone from mould No. 1 fitted with p.v.c. surround of shape shown in Fig. 5

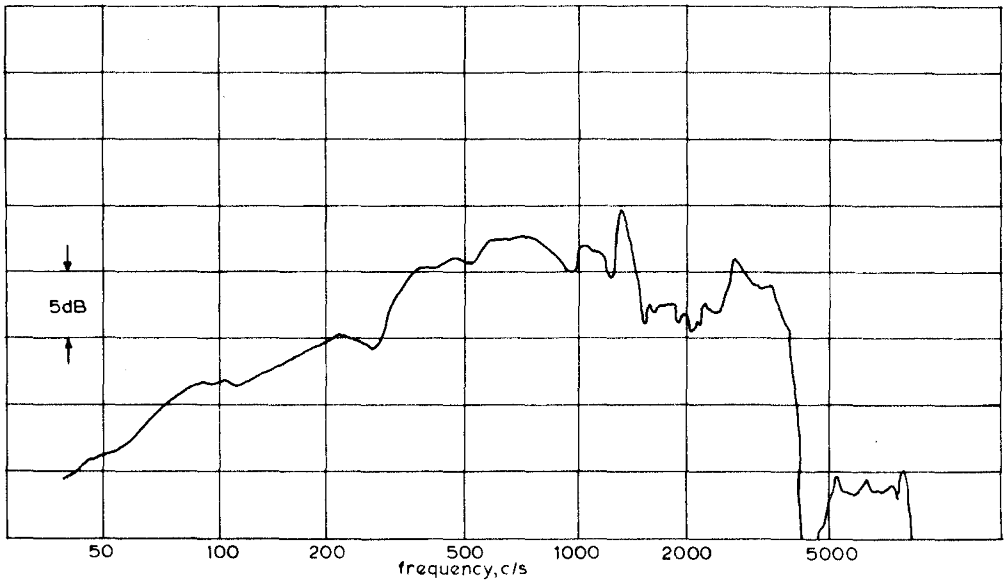

Fig. 7 - Axial frequency characteristic of Bextrene cone from mould No. 2 fitted with p.v.c. surround of shape shown in Fig. 5

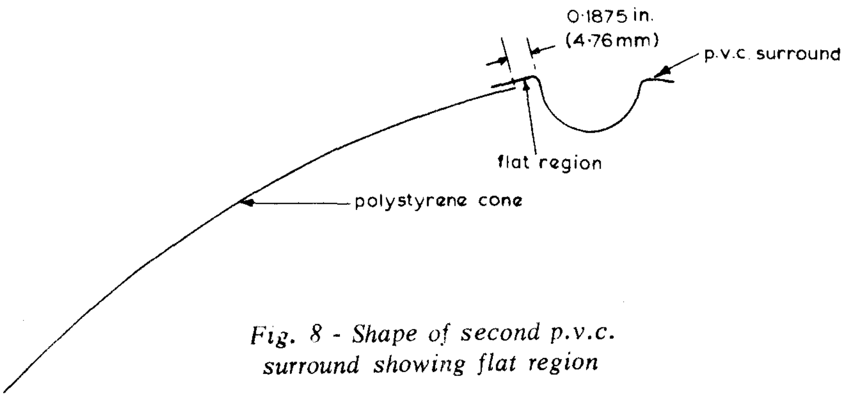

Fig. 8 - Shape of second p.v.c. surround showing flat region

The effects of small changes in the shape of the cone and in the diameter of the voice coil were investigated and it was found that neither of these two factors was critical.

A large number of experiments were then carried out, using surrounds of differing materials, thickness and profile in an attempt to damp out the mode at 250 c/s. It was finally discovered that with a suitable surround material better damping could be obtained if, as shown in Fig. 8, a small flat region was left before the turnover of the surround commenced. This flat region has the effect of introducing a shunt arm, as indicated in Fig. 9, consisting of a resistance and compliance, in parallel with the mass, compliance and resistance of the surround proper. The axial characteristic with this surround, shown in Fig. 10, is appreciably smoother than that obtained from commercial 12 in. (305 mm) units, especially in the region above 500 c/s; the sensitivity is about the same as that of the Goodmans 15 in. (380 mm) unit referred to earlier. The power handling capacity and transient response were then tested. Mounted in a closed cabinet, the unit was able to take the full output of a 25 watt amplifier down to 70 c/s without obvious amplitude distortion when the waveform was observed on an oscilloscope. Chopped-tone transient response tests[2] showed the unit to be free from serious resonances below 3 kc/s.

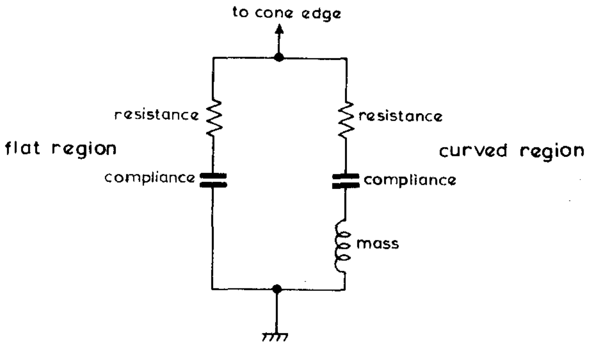

Fig. 9 - Mechanical circuit diagram of surround

Four units were then made to check the reproducibility of this form of construction; the axial frequency characteristics did not differ from one another by more than ±½ dB from 75 c/s to 1250 c/s and ±1 dB from 30 c/s to 2 kc/s. It was therefore decided to design a complete loudspeaker employing a unit of this type for the low frequencies and to carry out listening tests. Manufacturing details are given in the Appendix.

4. TESTS IN LS5/1 AND LS3/1 CABINETS

(a) LS5/1

The Goodmans 15 in. (380 mm) unit in an LS5/1A loudspeaker was replaced directly by the new 12 in. (305 mm) unit. A slight excess of output in the middle frequencies was corrected by means of a resistor which was originally designed to be adjust-

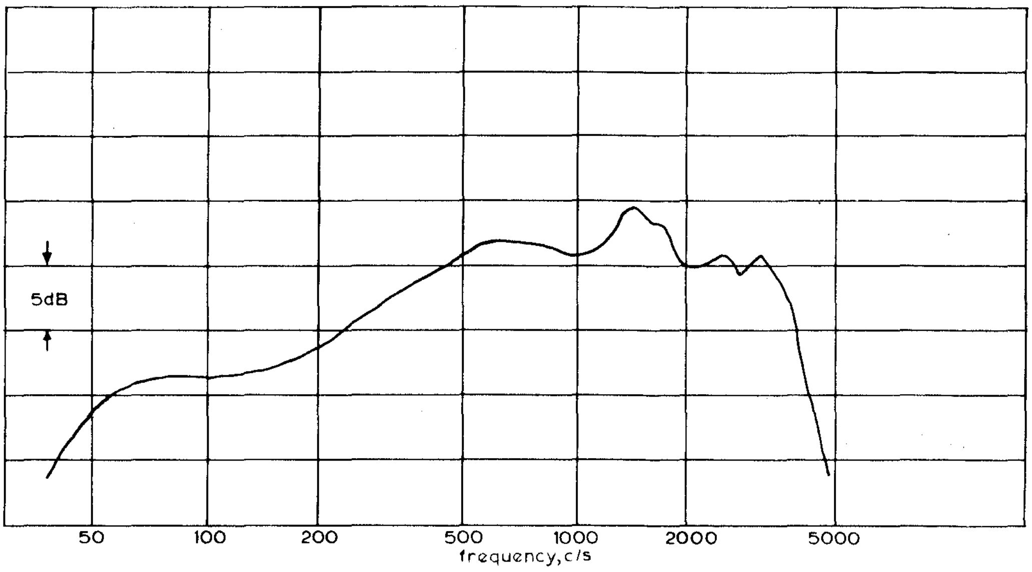

Fig. 10 - Axial frequency characteristic of Bextrene cone fitted with p.v.c. surround of the type shown in Fig. 8

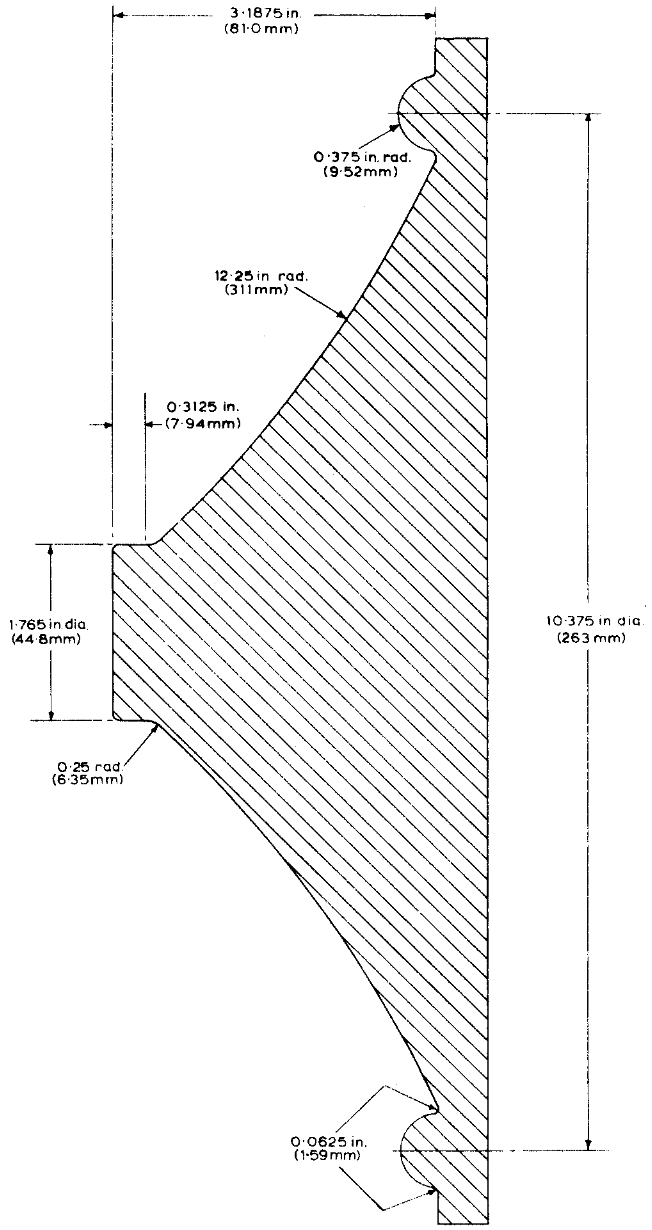

Fig. 11 - Shape of final mould for cone and surround

able for this purpose. A small dip in the axial response at 1750 c/s was traced to the effect of the 7 in. (178 mm) wide slot in front of the unit.

(b) LS3/1

When the Goodmans 15 in. (380 mm) unit in an LS3/1 loudspeaker was replaced by the new 12 in. (305 mm) unit, the response in the region 400 c/s to 800 c/s was found to be somewhat excessive as with the LS5/1 cabinet. To overcome this, it was found necessary to change the values of several components in the crossover network.

5. RESULTS OF LISTENING TESTS

The two loudspeakers described were given listening tests in Kingswood Warren A.F. Section Listening Room using recordings of speech from dead surroundings and recorded orchestral items; they were judged to be significantly superior to their LS5/1A and LS3/1A counterparts and were therefore offered to O. and M. Department for an extended field trial. Reports have been very favourable and in particular comments have been made regarding the freedom from colouration of the bass response compared with the corresponding loudspeakers employing the 15 in. (380 mm) Goodmans unit.

6. COST

The cost of the materials for the cone and surround is only a few shillings, which is a small fraction of that of the complete unit.

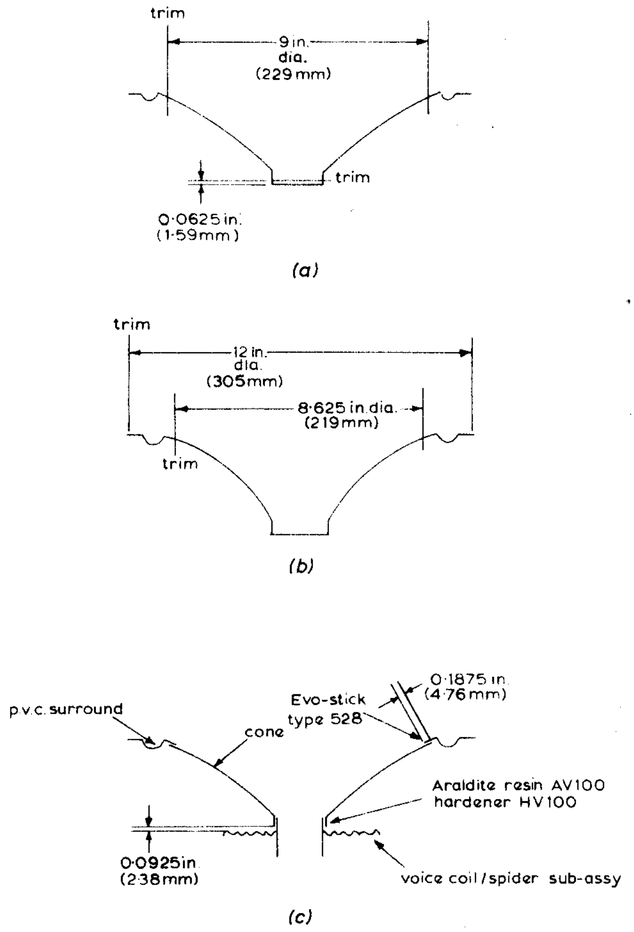

Fig. 12 - Assembly of cone, surround and voice coil

7. CONCLUSIONS

Experiments have been described which have led to the production of a 12 in. (305 mm) low-frequency unit of performance believed to be superior to that of any known commercial product. The cost of production of the cone and surround is only a small fraction of that of the magnet system and the price of the complete unit should be no greater than that of corresponding commercial products.

8. REFERENCES

1. TIEDJE, J.Q. 1936. Speaker Design, *Radio Engng*, N.Y., 1936, **16**, 1, p. 11.

2. The development of high-quality monitoring loudspeakers : a review of progress, Research Department Report No. L-041, Serial No. 1958/31.

APPENDIX

MATERIALS

The cone is made from Bextrene sheet type 234/2437, 0·02 in. (0·5 mm) thick, obtainable from Messrs. BX Plastics Ltd., Higham Station Avenue, Chingford, London, E.4. The surround is made from Nappatex 0·02 in. (0·5 mm) thick, obtainable from Commercial Plastics Ltd., Berkeley Square House, Berkeley Square, London, W.1.

COMPONENTS

Chassis and Magnet System

The chassis and magnet system is made by Goodmans Industries Ltd., Lancelot Road, Wembley, Middlesex.

Voice Coil/Spider Sub-Assembly

This also is made by Goodmans Industries Ltd.

Cone

The cone is shaped by vacuum forming, employing a drape process to the mould whose shape is given in Fig. 11. Prior to forming, the material is heated for 20 seconds by a radiant heater which, at the working level, gives a temperature of 180°C at the front and 160°C at the rear of the sample. After cooling, the cone is removed and trimmed as shown in Fig. 12(*a*).

Surround

The surround also is shaped by vacuum forming using a mould of the profile given in Fig. 11. The heating time, for the same radiant heater as described above, is 18 seconds. After cooling, the surround is trimmed as shown in Fig. 12(*b*).

ASSEMBLY

Voice Coil/Spider Sub-Assembly to Cone:

These components are mounted on a jig to ensure concentricity and are fixed together with Araldite resin type AV 100 and hardener type HV 100. The position of the voice coil former on the cone is indicated in Fig. 12(*c*).

Cone to Surround:

The position of the cone relative to the surround is also indicated in Fig. 12(*c*); a thin layer of Evostick type 528 is used as the adhesive.

Cone Assembly to Chassis:

The cone sub-assembly is mounted in the chassis with the voice coil concentric in the magnet air gap. The surround and spider are fixed to the chassis by adhesive or clamps. If all previous assemblies have been correctly carried out, the spider should be undeflected.

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