New B.B.C. Monitoring Loudspeaker

1. Design of the low frequency unit

by H. D. Harwood, B.Sc.

An outstanding feature of the B.B.C.'s latest studio monitoring loudspeaker is the 12-inch low frequency unit, which has a performance believed to be superior to that of any known commercial product.

THE studio monitoring loudspeaker at present being used by the B.B.C., type LS5/1A, was developed in 1959 and employs a special 380 mm low-frequency unit and two 58 mm high-frequency units. Although some 250 of these have been built, considerable difficulty has been experienced in securing adequate supplies of low-frequency units which meet the tolerances applied. Yet, in spite of the tightness of these tolerances, comments have been made that the sound quality varies from specimen to specimen. Criticism has also been made of the reproduction, although it is conceded to be better than that of any commercially available loudspeaker.

In view of the difficulty in obtaining low-frequency units of adequate quality and reproducibility, an investigation was started in the B.B.C. Research Department into the possibility of producing a thermoplastic cone and these experiments led to the production of the 305 mm unit described in this article (also in a B.B.C. Monograph[1]). The listening tests were so successful that in November 1965 it was decided to commission a new loudspeaker incorporating this unit. It was clear that by employing a 305 mm unit an appreciably smaller cabinet than that of the LS5/1A would suffice, and it was intended that the new loudspeaker should serve both for studios and outside broadcasts.

LIMITATIONS OF EXISTING UNITS

Wide-range loudspeakers, such as are employed for quality monitoring, generally consist of low- and high-frequency units 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 LS3/1A‡ 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 500Hz, 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 units of smaller diameter.

H. D. Harwood, who obtained a physics degree at London University in 1941, started his career in 1938 in electro-acoustics at the N.P.L. There he helped on the first Medresco hearing aid and worked on microphone and loudspeaker calibration. Joining the B.B.C. Research Department in 1947, he has since been engaged on loudspeaker development, microphone calibrations, stereophony requirements and the design of a free field room. He has a number of patents and is author of various B.B.C. Engineering Monographs.

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 B.B.C. the monitoring loudspeakers LS5/1A, LS5/2A,** and LS3/1A all use a special commercial 15 in. (380 mm) diameter low-frequency unit, and have a crossover frequency of about 1,600 Hz, and some difficulty has been found in obtaining units which will meet the B.B.C. test specification in the 500 to 1,600 Hz 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 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.

It was explained earlier that the existing low-frequency units were chosen on the basis that they were relatively free from colouration

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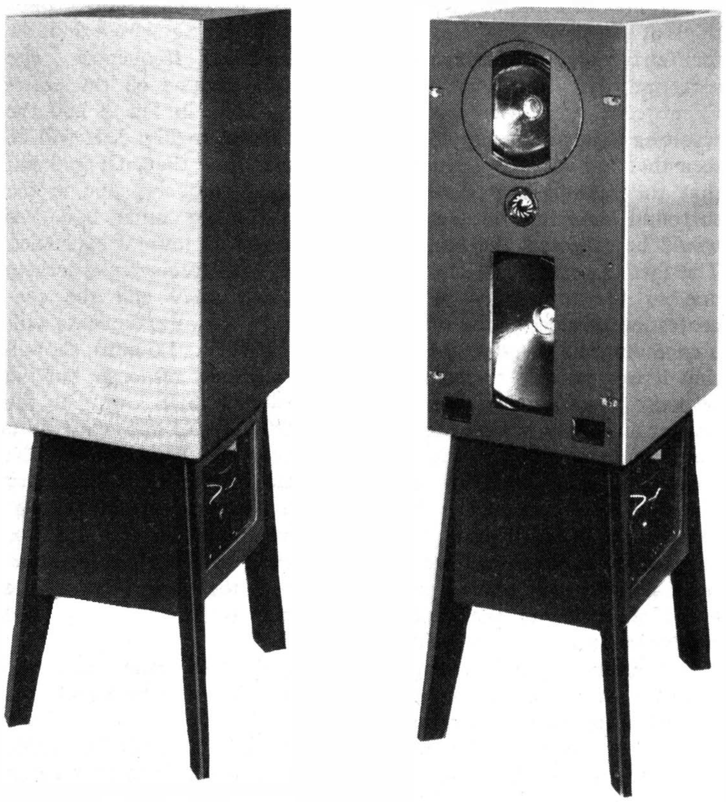
† By colouration is meant a characteristic timbre imparted to the reproduced sound by the loudspeaker; it is believed to arise from excitation of mechanical resonances.

‡ The LS3/1A is used for outside broadcast monitoring and has a small lightweight cabinet. The design is intended to provide the best compromise between quality and portability.

**The LS5/1A is the normal floor-standing version, while the LS5/2A is designed to hang above picture monitors in television control rooms.



The complete studio monitoring loudspeaker (free-standing version) with and without front cover. It is a three-unit design.

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 last-mentioned two items, the influence of shape, thickness, and material were to be examined.

CONE MATERIAL

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,[2] 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(a); the voice coil diameter was 2 in. (50.8 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.

The first material to be tried was expanded polythene, which is available in sheet form in various thicknesses from $\frac{1}{16}$ in. (1.6 mm) upwards. This material is very light and is characterized by an extremely high damping coefficient. The first experimental models showed axial frequency characteristics which fell off above 500 Hz 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 kHz. It will be noted from Fig. 1(a) that there is a sharp bend in the cone shape near the voice coil, and it was thought likely that flexure was taking place at this point. A further mould was therefore made, Fig. 1(b), 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 unplasticized polyvinylchloride (p.v.c.), which is a horny type of material and also with a polystyrene material (Bextrene) 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(a), and the frequency characteristics were measured with the units mounted in an enclosed cabinet similar in volume to that of the type LS5/1A loudspeaker. These characteristics are shown in Figs. 2 and 3 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. 3 above 500 Hz 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.

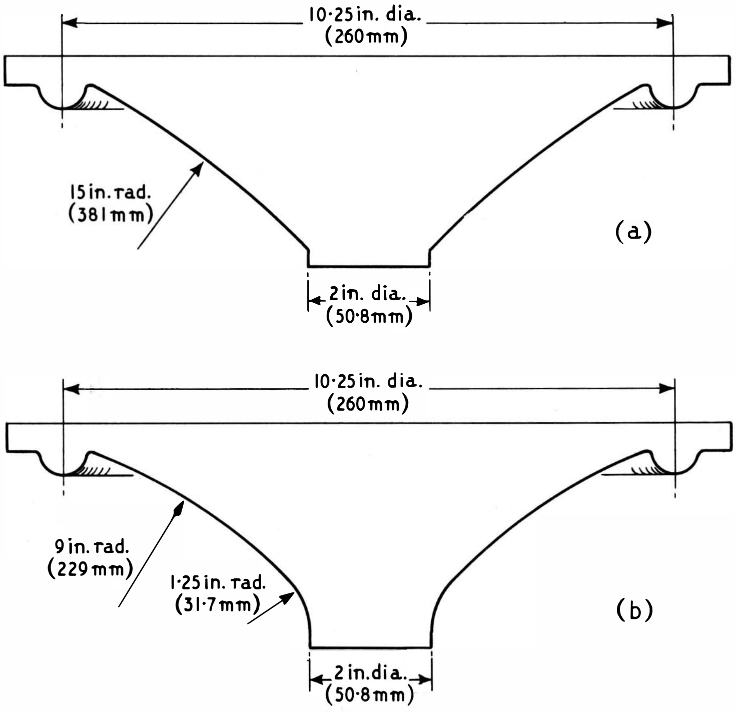
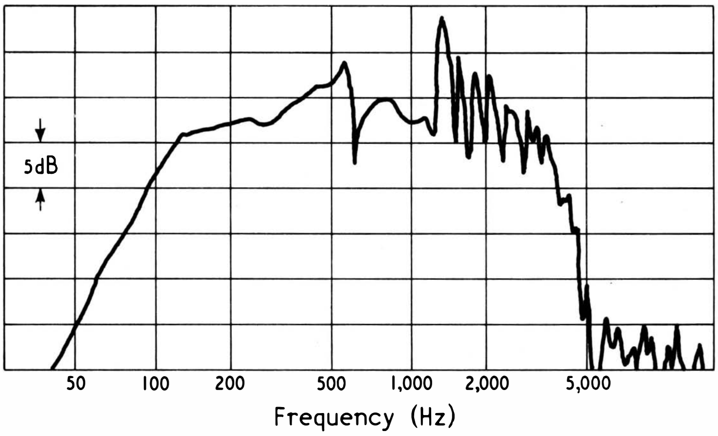


Fig. 1. (a) Shape of first mould; (b) shape of second mould.

Fig. 2. Axial frequency characteristic of unplasticized p.v.c. cone from first mould.



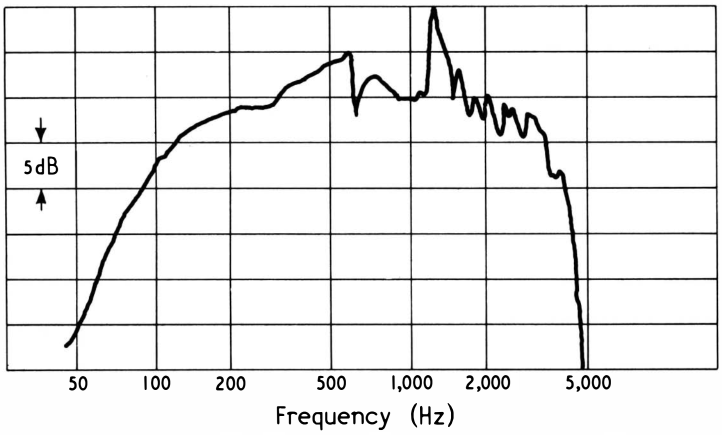
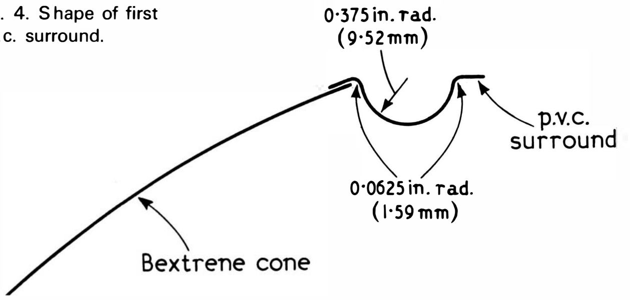


Fig. 3. Axial frequency characteristic of Bextrene cone from first mould.

Fig. 4. Shape of first p.v.c. surround.



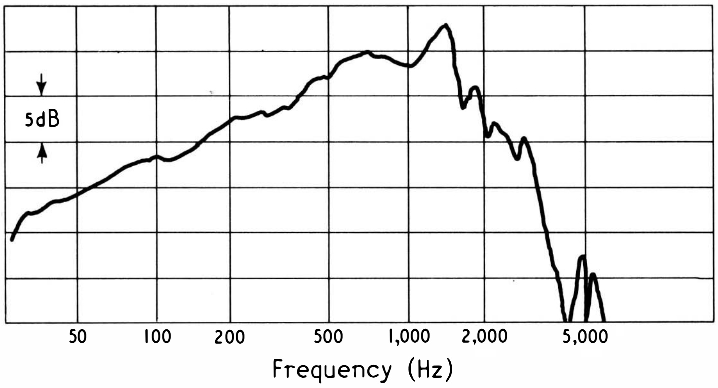


Fig. 5. Axial frequency characteristic of Bextrene cone from first mould, Fig. 1 (a), fitted with p.v.c. surround of shape shown in Fig. 4.

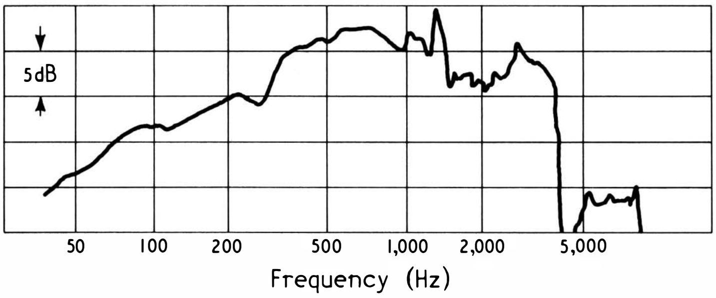
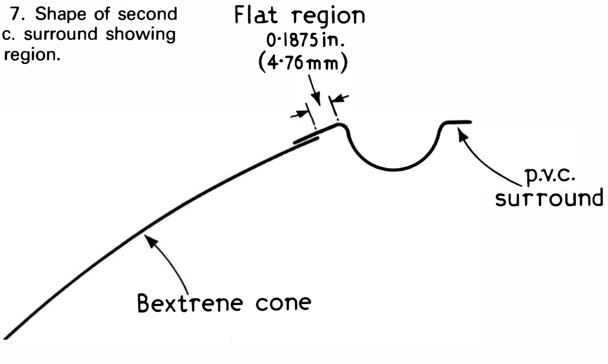


Fig. 6. Axial frequency characteristic of Bextrene cone from second mould, fitted with p.v.c. surround of shape shown in Fig. 4.

Fig. 7. Shape of second p.v.c. surround showing flat region.



The first surround tried was of plasticized p.v.c. 0.02 in. (0.5 mm) thick of the shape shown in Fig. 4, 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. 3 and the resulting axial frequency characteristic is shown in Fig. 5. It will be seen that the curve is considerably smoother than that of Fig. 3 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. (1.0 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, Fig. 1(b). As with the polythene material, the change in shape resulted in an increase in the high frequency response, as shown in Fig. 6. The dip in the curve at 250 Hz 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.

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 Hz. It was finally discovered that with a suitable surround material better damping could be obtained if, as shown in Fig. 7, 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. 8, 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. 9, is appreciably smoother than that obtained from commercial 12 in. (305 mm) units, especially in the region above 500 Hz; the sensitivity is about the same as that of the 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 Hz without obvious amplitude distortion when the waveform was observed on an oscilloscope. Chopped-tone transient response tests[3] showed the unit to be free from serious resonances below 3 kHz.

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 $\pm\frac{1}{2}$ dB from 75 Hz to 1,250 Hz and $\pm$ 1 dB from 30 Hz to 2 kHz. 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.

The cost of materials for the cone and surround is only a few shillings, while the cost of production of these parts is only a small fraction of that of the magnet system. The price of the complete low-frequency unit should be no greater than that of corresponding commercial products.

TESTS

LS5/1A (studio-type loudspeaker).—The 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 adjustable for this purpose. A small dip in the axial response at 1,750 Hz was traced to the effect of the 7 in. (178 mm) wide slot in front of the unit.

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

The two loudspeakers described were given listening tests in a listening room at the B.B.C. Research Department using recordings of

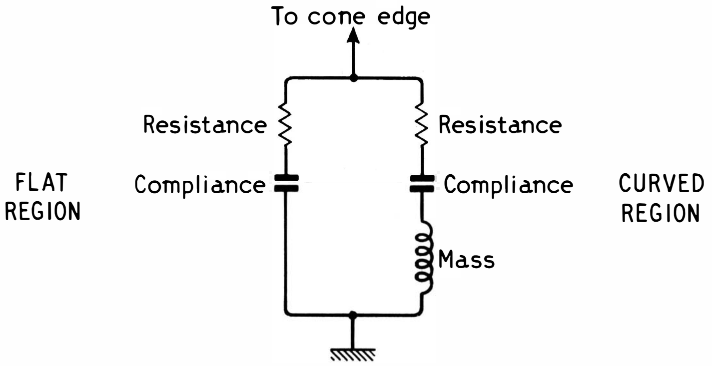


Fig. 8. Mechanical circuit diagram of surround.

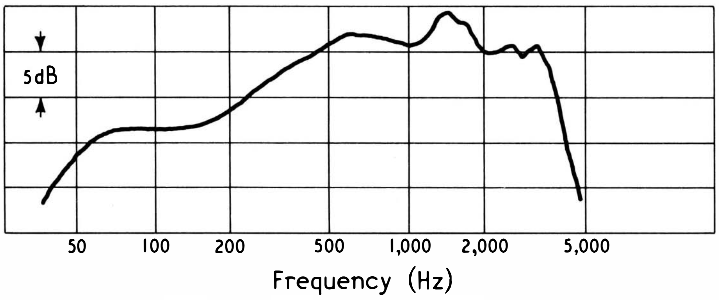


Fig. 9. Axial frequency characteristic of Bextrene cone fitted with p.v.c. surround of the type shown in Fig. 7.

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 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) unit.

(Next month: bass equalization and the cabinet).

REFERENCES

1. "The design of a low-frequency unit for monitoring loudspeakers" by H. D. Harwood. B.B.C. Engineering Division Monograph, No. 68, July 1967.

2. "Speaker Design" by J. Q. Tiedje. *Radio Engineering,* N.Y., 16, No. 1, p. 11, 1936.

3. "A Survey of Performance Criteria and Design Considerations for High Quality Monitoring Loudspeakers" by D. E. L. Shorter. *Proc. I.E.E.,* 105, Pt. B, No. 24, Nov. 1958, pp. 607-625.

We understand that KEF Electronics Ltd., who have made B.B.C. monitoring speakers under licence for several years, are arranging to manufacture the new model when field trials are completed and various technical details have been settled. The company say that production of earlier models will also continue.—Ed.

Books Received

Principles of Television Reception by W. Wharton and D. Howorth. A step-by-step tour through a television set in which basic principles are expanded into block diagrams and these into circuit diagrams that are discussed in detail. After dealing with black and white, colour television is then discussed in its various forms (N.T.S.C., PAL, SECAM). This book should be of value to anyone with some knowledge of electronics who wishes to know some more about this particular branch. Pp. 296. Price 40s. Sir Isaac Pitman & Sons Ltd., Pitman House, Parker Street, London, W.C.2.

Measuring Hi-Fi Amplifiers by M. Horowitz. Explains the basic principles of high-fidelity amplification and the meanings behind manufacturers' data. A comparison of the various instruments available for measuring performance is made and test set-ups for determining various circuit parameters are described. Pp. 159. Price 25s. W. Foulsham & Co. Ltd., Slough, Bucks.

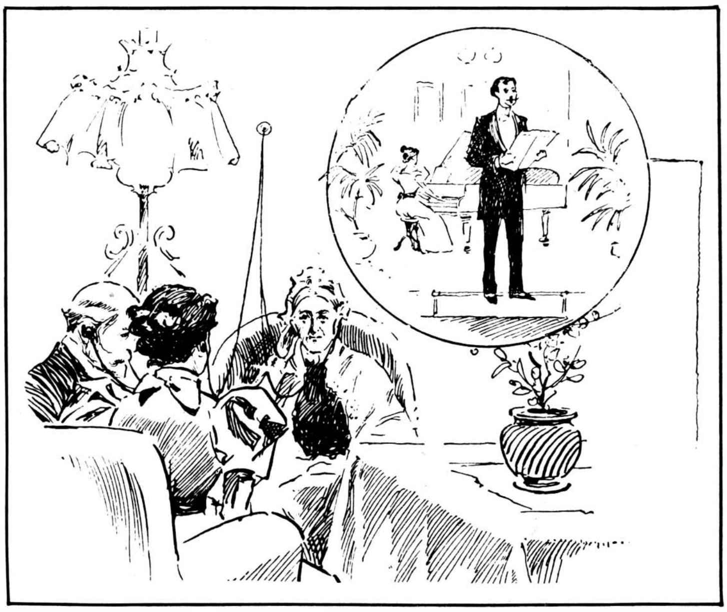
Rapid Servicing of Transistor Equipment by Gordon J. King. Intended for service technicians, students and amateurs, this book provides a guide to the servicing of domestic equipment employing transistors. Initial chapters include theoretical and practical discussions on transistors, how they are biased, operating characteristics and circuitry, signal conditions and testing. The rest of the book is devoted to practical advice on servicing and includes both electrical and mechanical information. Pp. 151. Price 30s. George Newnes Ltd., Tower House, Southampton Street, London, W.C.2.

Mathematics for Electrical Circuit Analysis by D. P. Howson. This book has been written as an introduction to the mathematics required for circuit analysis. Although not complete the material given is thought to be sufficient to cover the needs of second and third year undergraduates taking a light current electrical engineering course. Determinants, matrices and topology to assist in the evaluation of multimesh circuits and the solution of basic differential equations for linear circuits are discussed. Fourier series, Fourier integrals and Laplace transforms are also dealt with. Pp. 170. Price 17s 6d. Pergammon Press, Headington Hill Hall, Oxford.

Sound and Vision by P. E. M. Sharp. This Design Centre Publication is intended for the uninitiated who are about to purchase a radio or television receiver or a high-fidelity system and wish to know something about the subject and what is available. The book commences with a description of the technicalities of radio, television and sound and then proceeds to discuss turntables, pick-ups, pre-amplifiers, amplifiers, tuners, loudspeakers, tape recorders and accessories. Following this radio receivers, radiogramophones and television receivers are discussed. During the course of the descriptions, equipment from a large number of manufacturers is introduced. This, however, is not exhaustive. Pp. 64. Price 7s 6d. MacDonald and Co. (Publishers) Ltd., Gulf House, 2 Portman Street, London, W.1.

Semiconductors—Vol. II. Linear Circuits by E. J. Cassignol. This book, from the Philips Technical Library, is divided into two sections. The first deals with the methods of studying linear circuits and discusses the properties of the semiconductors employed in this application. The second section concerns itself in detail with the practical use of linear circuits employing semiconductors. Separate chapters discuss the l.f. amplifier, the video amplifier, the h.f. amplifier, the power amplifier and the d.c. amplifier. The feedback problem is dealt with and a section is included containing a number of practical exercises. Pp. 337. Price 104s. Macmillan & Co. Ltd., Little Essex Street, London, W.C.2.

Understanding u.h.f. Equipment by John D. Lenk. The first chapter contains answers to a series of questions that, in the author's opinion, is most often asked of instructors in the u.h.f. field. Other chapters contain information on specific items of u.h.f. equipment, circuits and components, the emphasis being placed on fundamentals and basic features. In addition comparisons between this equipment and equipment for lower frequencies is made. In the last chapter test equipment and various techniques that are unique to the u.h.f. and microwave field are described and illustrated. Pp. 144. Price 25s. W. Foulsham & Co. Ltd., Slough, Bucks.



This illustration originally appeared in an article by Arthur Mee on the future of "the pleasure telephone" in the *Strand Magazine* in 1898 and is reproduced in Leslie Baily's "B.B.C. Scrapbooks, Vol. 1, 1896-1914" published by Allen & Unwin, price 40s. In the course of his article Arthur Mee prophetically stated "Patti and Paderewski may yet entertain us in our own drawing-rooms, and the luxuries of princes may be at the command of us all. Who knows but that in time we may sit in our armchairs listening of Her Majesty's Ministers".

New B.B.C. Monitoring Loudspeaker

2. Bass equalization: The cabinet: Frequency response characteristics of the units

by H. D. Harwood,* B.Sc.

IN a modern monitoring loudspeaker the choice lies in practice between two- and three-unit designs. In a two-unit loudspeaker one of the difficulties is that the high-frequency units available at present cannot be operated below approximately 1.5 kHz, so that the low-frequency unit must operate in a predictable manner up to about 2 kHz. In the past, reproducible operation of a low-frequency unit above about 500 Hz was not possible but the situation has been changed by the advent of the 305 mm plastic cone described in the March issue.

It is still difficult, however, to maintain the required frequency characteristics away from the axis of a two-unit design. At 1.5 kHz the wavelength of sound is about 220 mm and thus a 305 mm cone has a diameter considerably larger than a wavelength. It follows that the radiation will be directional at such frequencies and that even when the axial frequency characteristic is made uniform the off-axis curves will depart from this condition. On the other hand the high-frequency units used in B.B.C. monitoring loudspeakers, 58 mm in diameter, are small compared with a wavelength, and therefore nearly omnidirectional, up to about 6 kHz. The resulting axial and off-axis characteristics are typified by the curves in Fig. 10. To some extent the difference between the curves can be reduced by fitting a slot in front of the low-frequency unit, but, as will be shown later, this device is by no means wholly successful in overcoming the trouble.

The use of a three-unit system with crossover frequencies in the region of 500 Hz and 3 kHz allows these difficulties to be largely overcome, provided a suitable type of middle-frequency unit can be found. There is the extra advantage that, with a frequency range restricted to the band from 3 kHz upwards, the high-frequency unit will be able to handle a larger programme level than if it had to operate at 1.5 kHz. On the other hand an additional unit and a more expensive and elaborate crossover network are required.

Bass Equalization

In practice the axial frequency characteristics of low-frequency loudspeaker units are not uniform. The reasons for this are that in the middle-frequency range the unit becomes directional, concentrating the sound energy increasingly in the axial direction, while at low frequencies over-damping of the bass resonance takes place, thus producing a bass cut; the resulting rise in axial response above the resonance frequency usually amounts to between 6 and 10 dB. This rise must be equalized electrically and in past B.B.C. designs, e.g. the type LS3/1A loudspeaker, it has been carried out in the crossover network, thus enabling a standard amplifier with a

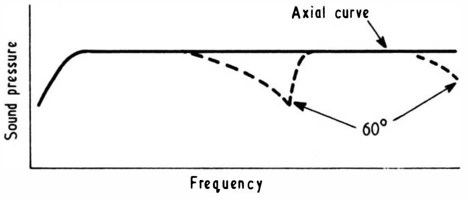


Fig. 10. Typical frequency characteristics of a two-unit loudspeaker on axis and at 60° from axis.

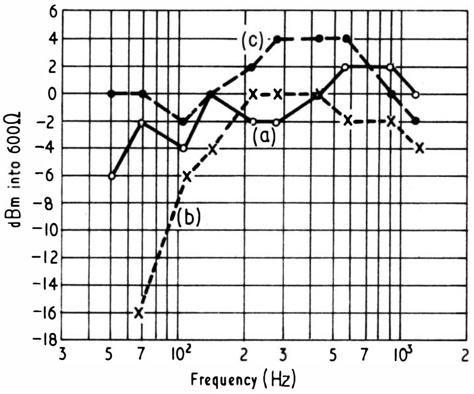


Fig. 11. Peak levels in octave analysis of programme. Item (a) Kramer with Dakotas, (b) Mars 1, (c) Organ Prelude in G.

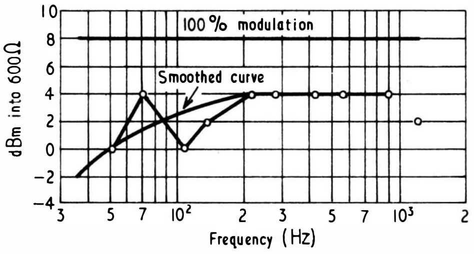


Fig. 12. Peak octave analysis of programmes, all items.

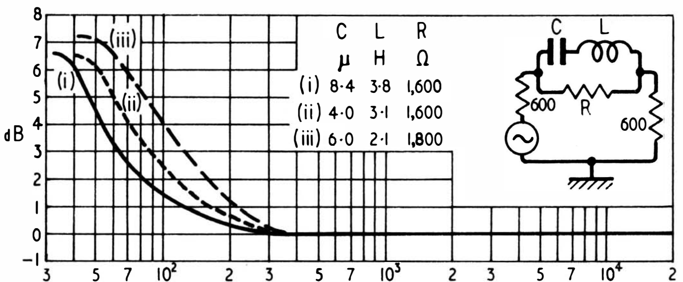
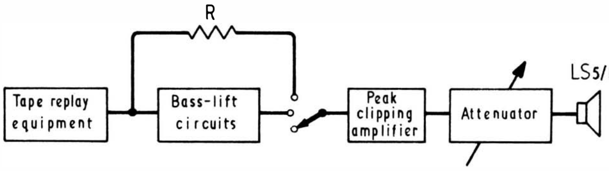


Fig. 13. Response/frequency characteristics of bass-lift circuits.

Fig. 14. Circuit used for determination of acceptable distortion with bass-lift circuits.



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* B.B.C. Research Department.

uniform response frequency characteristic to be used. This method involves a considerable loss of power in the mid-band region: for example, if a 20 watt amplifier is employed and 10 dB of bass equalization is required, only 2 watts are available to drive the loudspeaker in the mid-band region.

An alternative method is to use equalization ahead of the power amplifier, but if an excessive degree of equalization is applied, over-loading of the amplifier will occur first in the bass and once again the usable mid-band power will be reduced. The question therefore arises as to whether the programme spectrum is such that it is possible to apply equalization before the amplifier without causing overloading in the bass. Experiments were accordingly designed to explore this possibility and to determine the optimum shape for the pre-emphasis curve. It will be seen that, in effect, the object of the experiment was to obtain the low-frequency equivalent of the high-frequency pre-emphasis employed in f.m. broadcasting.

Experimental details.—Various types of programme were examined to find those which had the highest power levels in the bass. Eleven recorded items were finally chosen, two of which were organ solos, three were light (pop) music and the remainder orchestral music, the total playing time amounting to about 13 minutes; details of the items are given in the appendix. In all cases the recording was arranged to peak to 6 on a peak programme meter, the peak occurring usually, although not necessarily, during the excerpt chosen.

The spectrum was examined by means of octave filters centred on frequencies ranging from 1 kHz down to about 50-Hz, the peaks in each band of frequencies being recorded by a peak counter reading in steps of 2 dB, due allowance being made for the insertion loss of the filters. Typical analyses are given in Fig. 11 and the overall peak levels for the whole range of items is plotted in Fig. 12; a smoothed curve of the peak spectrum is also shown in this figure. It will be noted that the smoothed curve passes below the point plotted for 68 Hz. This point represents a single note from a bass guitar which stood out considerably above the rest and was therefore ignored in drawing the smoothed curve as it was felt not to be representative.

Equalization was designed for the smoothed curve and for two similar but progressively more extreme conditions as shown in Fig. 13. The recordings were then replayed through the different circuits to see by how much the equalization increased the peak level of the complete programme as read on a peak programme meter; the results are given in Table 1.

TABLE 1

Effect of Bass Equalization on Peak Level of Programme

programme item	peak levels on p.p. meter. (dB above '6')			
	circuit condition (see Fig. 13)			
(see appendix)	no bass boost	circuit (i)	circuit (ii)	circuit (iii)
a	−½	−½	−½	−½
b	−½	−½	0	+1
c	0	+1	+2	+3½
d	0	0	0	+1½
e	−1½	−2	−2	−1½
f	−2	−1½	+½	+2
g	−1½	−1	−½	+½
h	−3	−3	−3	−2½
i	−4	−4	−4	−3½
j	−2	−2	−2	−1½
k	0	+½	+1	+1

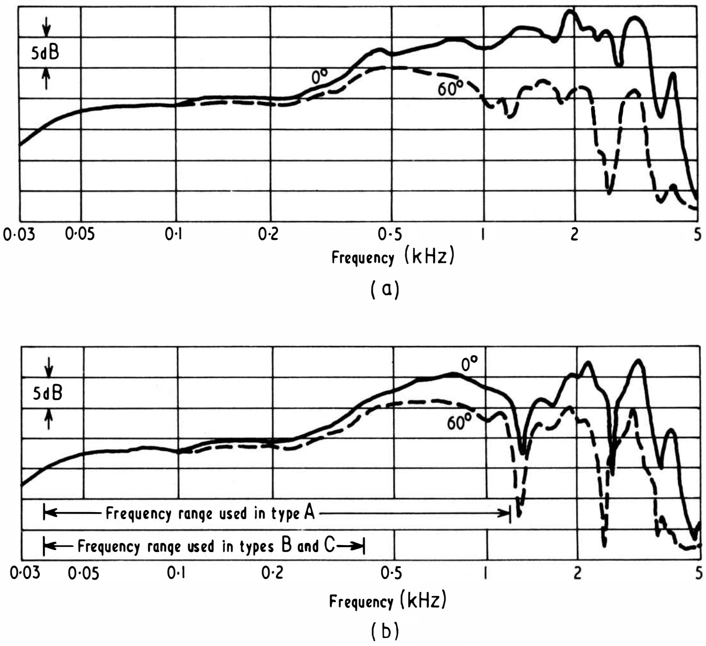

Fig.15. (a) Response/frequency characteristic of unequalized low-frequency unit without slit at 0° and 60° to the axis. (b) Response/frequency characteristic of unequalized low-frequency unit with 100 mm slit at 0° and 60° to the axis.

It will be seen that the level of item (c) is increased by 1 dB even by circuit (i) and it was decided to determine whether this degree of overload at low frequencies would be audible with a typical amplifier using a considerable degree of negative feedback.

A circuit was set up as shown in Fig. 14, in which the peak clipping is arranged to occur in a separate amplifier followed by an attenuator which feeds a loudspeaker amplifier. The gain of the peak clipping amplifier was adjusted so that a 1 kHz signal of +8 dBm from the source was just clipped at the peaks. The bass-lift circuits were inserted in turn ahead of the amplifier and the programme items played through the system, allowance being made for the insertion loss of the circuits. It was found that when using circuit (iii) of Fig. 13 distortion was clearly audible on items (c) and (d), i.e. the organ passages, none being noticed on the remainder; when circuit (ii) of Fig. 13 was inserted, distortion was only just detectable on item (c) and it was therefore concluded that this degree of bass pre-emphasis is permissible. Any equalization required in excess of this must therefore be applied after the power amplifier.

The Cabinet

Experience with the earlier B.B.C. monitoring loudspeaker type LS5/1A had shown that it had an adequate bass range. Calculations indicated that a similar range would be obtained with the new 305mm plastic cone unit by employing a cabinet of only 0.085m^3 internal capacity, that is 60% of the volume used for the LS5/1A.

Measurements were then made with an experimental cabinet to determine the vent resonance frequency giving the best combination of power handling capacity and frequency characteristic; this frequency was found to be 38 Hz, close to that employed for the type LS5/1A. Two types of cabinet were made, one floor-standing and the other for hanging from the ceiling, corresponding to the LS5/1A and the LS5/2A† respectively. The volume and front dimensions of each model were the same.

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†Version designed to hang above picture monitors in television control rooms.

Use of Slit.—The next factor to be dealt with was the directivity of the units. Fig. 15 (a) shows the response on the axis and at 60° from it for the unequalized bass unit in the cabinet. It will be noted that there is an appreciable difference between the two at the higher frequencies. This difference can be reduced by placing a slit in front of the unit; the diffraction from the edges of the slit will make the radiation more nearly omnidirectional in the horizontal plane. There is, however, a limitation to this device: the Helmholtz resonator formed by the mass reactance of the slit and the compliance of the air enclosed between the slit and the cone increases the output to an undesirable extent in the region of the resonance frequency, but acts as a low-pass filter above the resonance, severely reducing the output at high frequencies. The minimum slit width which could be employed without either of these two effects becoming excessive was found to be 100 mm and it would appear at first sight that this width, which amounts to only a third of a wavelength at 1 kHz, should be quite small enough for this purpose.

In the first instance the slit may be regarded as a source having uniform sound pressure all over its area, but with conditions of radiation intermediate between those for free space and those for an infinite baffle and there are three possible configurations
mations to these conditions. Of these, a line source and a circular piston in a baffle may be shown[1] to have directional patterns given respectively by

$$R_\alpha = \frac{\sin\left(\frac{\pi l}{\lambda}\sin\alpha\right)}{\frac{\pi l}{\lambda}\sin\alpha}$$

where R_α is the sound pressure radiated at an angle α between the direction of radiation and the axis, l is the length of the source and λ is the wavelength
and

$$R_\alpha = \frac{2\mathcal{J}_1\left(\frac{2\pi r}{\lambda}\sin\alpha\right)}{\frac{2\pi r\sin\alpha}{\lambda}}$$

where r is the radius of the piston and $\mathcal{J}_1$ is a Bessel function of the first order and first kind. The directional pattern for a piston in the end of a semi-infinite pipe is more complicated[2] viz.:

$$R_\alpha = \frac{4}{\pi\sin^2\alpha}\cdot\frac{\mathcal{J}_1\, kr\sin\alpha}{[(\mathcal{J}_1\,(kr\sin\alpha))^2 + (Y_1\,(kr\sin\alpha))^2]^{\frac{1}{2}}} \times \frac{|R|}{1-|R|^2}$$

$$\times\exp\left[\frac{2\,kr\cos\alpha}{\pi}P\times\int_0^{kr}\frac{x\tan^{-1}(-\mathcal{J}_1(x)/Y_1(x))\,dx}{[x^2-(kr\sin\alpha)^2][x^2+(kr)^2]^{\frac{1}{2}}}\right]$$

where $$|R| = \exp\left\{-\frac{2kr}{\pi}\int_0^{kr}\frac{\tan^{-1}(-\mathcal{J}_1(x)/Y_1(x))}{x[(kr)^2-x^2]^{\frac{1}{2}}}\,dx\right\}$$

and $\mathcal{J}$ and Y are real first order Bessel functions of the first and second kind respectively, according to the usual notation†† and $k = 2\pi/\lambda$.

The calculated response at 60° with respect to that on the axis is shown in Fig. 16 for these cases. As expected it will be noted that for slit widths up to 0.6λ there is not much difference between them (curves (*a*), (*b*) and (*c*)), and for the proposed slit width of $\lambda/3$ considered at 1 kHz, the mean difference between the axial and 60° responses is not more than about 1½ dB

In contrast to this the actual frequency characteristics obtained with a 100mm slit are shown in Fig. 15 (*b*). It may be observed by comparison with Fig. 15 (*a*) that, with the slit, the deviation from the axial response is almost unaltered up to about 700 Hz, although beyond this frequency there is an appreciable change; furthermore at 1 kHz the deviation with the slit is not 1½ dB as calculated but nearly 6 dB. The measured deviation is replotted as curve (*d*) in Fig. 16 and it will be seen that it does not correspond to any of the three calculated cases.

This lack of improvement in directivity with the use of a slit was first noticed during the design of the LS5/1A, when it was found that, reducing below 180mm, the width of the slit in front of the 380mm cone did not bring about a corresponding improvement in the off-axis curves.

One possible explanation which has been examined is that the distribution of energy across the slit is not uniform and the extreme case when all the energy has been concentrated at the two edges has been calculated and is shown in Fig. 16 as curve (*e*). Even under these conditions the directivity is not nearly as great as that experienced in practice with the low-frequency unit for small values of d/λ, where d is the width of the slit; furthermore, measurements show that although the pressure across the slit is not quite uniform it is actually higher in the centre by about 2 dB; in addition the phase change across the slit is also small.

The further possibility arises that re-radiation from the edges of the cabinet might be responsible for the directivity. Taking the width of the front baffle as 350mm, the actual values obtained for the deviation of the 60° curve from the axial for the new values of d/λ are plotted as crosses in Fig. 16. It will be seen that in fact the agreement with the theoretical curves is quite good up to a value of d/λ of 0.75 after

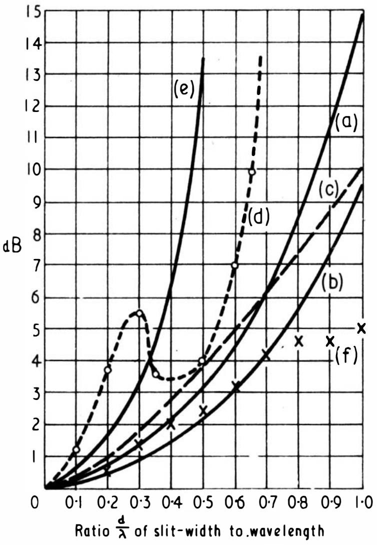
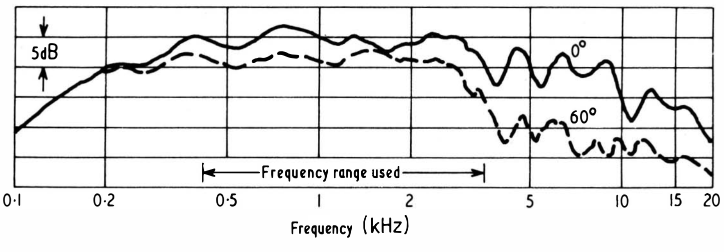


Fig.16 Deviation of 60° characteristics from axial characteristics for differing types of source: (a) line source (calculated); (b) piston source in infinite plane (calculated); (c) piston source at end of pipe (calculated); (d) measured values obtained with slit on low-frequency unit; (e) sound pressure concentrated at edges of slit (calculated); (f) measured values taking d *as front of cabinet.*

Fig.17. Response/frequency characteristics of 110 mm diameter middle/frequency unit at 1° and 60° to the axis.



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††In Reference 2 $Y_1(x)$ is denoted by $N_1(x)$ throughout.

which the loudspeaker is less directional. This value of d/λ corresponds to a frequency of about 700 Hz, the frequency above which it was observed that the slit has an appreciable effect.

It appears therefore that up to 700 Hz** the directivity is largely determined by the width of the cabinet but that above this frequency the width of the slit plays a large part. That it does not fully determine the directivity even then is shown by the fact that the upper part of curve (*d*) of Fig. 16 does not lie in the region of the calculated curves. This discrepancy is further emphasized by the fact that in the final design the smaller middle-frequency unit employs the same width of slit, 100mm, in the same baffle, yet the deviation of the 60° curve from the axial curve at 1 kHz is different from that of the low-frequency unit, the value being 3 dB closer to the theoretical figure. Unexpectedly it appears therefore as though the size of the unit still affects the directional properties in spite of the slit and the exact mechanism accounting for the directivity for the values of d/λ greater than 0.75 is obscure.

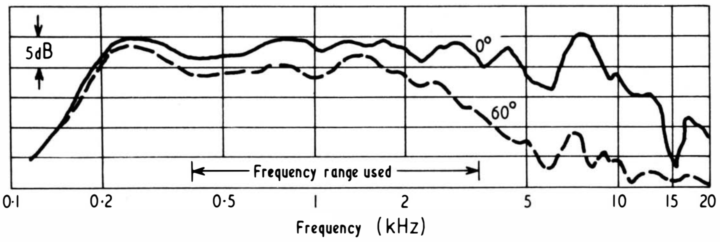
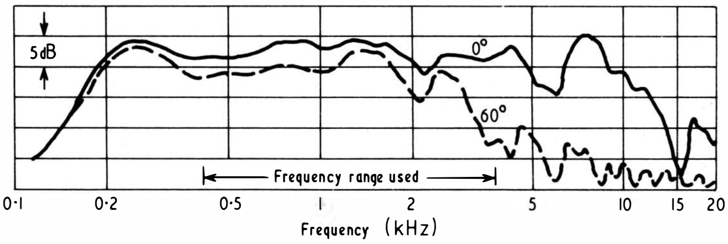


Fig. 18. Response/frequency characteristic of 200 mm diameter middle-frequency unit without slit at 1° and 60° to the axis.

Fig. 19. Response/frequency characteristics of 200 mm diameter middle-frequency unit with 100 mm slit at 0° and 60° to the axis.



Details of units

As already mentioned, the bass unit employed is the 305mm plastic cone unit described last month. A chassis with a more powerful magnet is now available and an increase in sensitivity of about 2 dB is thus possible. Further experience with the unit revealed a slight colouration in the 1.5 kHz region, and this is accentuated with a later material manufactured as a replacement for the type of Bextrene formerly used. It is however completely removed by painting the cone with a layer of polyvinyl acetate damping compound known as Plastiflex type 1200 P, even though this treatment does not cause any appreciable change in the frequency response. (The effect on colouration can easily be demonstrated by applying pink noise (i.e. random noise with equal power per octave) to the unit in a free-field room and making a tape recording of the output before and after painting the cone. The two conditions can then be compared sequentially and the improvement obtained by the treatment is evident.)

In spite of the use of the vent mentioned earlier some electrical low-frequency equalization is also necessary. As explained previously, it is best to apply this equalization mainly as pre-emphasis ahead of the power amplifier and to introduce the remainder in the crossover network. It is expected that, as with the LS5/2A loudspeaker, a further bass lift, amounting to about 3 dB at 40 Hz over that required for the floor-standing model, will be required for the hanging model, and this lift also is conveniently applied ahead of the amplifier. It will be seen from curve (ii) of Fig. 13 that this leaves about 4 dB available for the floor-standing model before the permissible amount of pre-emphasis is exceeded.

The frequency characteristics of the bass unit on the axis and at 60° from it are those already shown in Fig. 15 (*b*).

Middle-Frequency Units.—No satisfactory commercially-produced middle-frequency unit is available, but at the time when the new loudspeakers were commissioned experiments on a 110mm diameter unit were already proceeding in the B.B.C. Research Department. This unit used a 25.4mm voice coil and a flared cone of Bextrene type 237, 0.4mm thick, together with a surround made of p.v.c. 0.5mm thick. The bass resonance, at about 400 Hz, was well damped, the intention being to employ this unit over the frequency range 450 Hz to 3.5 kHz. The frequency characteristics on the axis and at 60° from it are shown in Fig. 17, and it will be seen that over the required frequency range the two are smooth and nearly parallel. Listening tests, however, showed a noticeable colouration in the 1.5 kHz region and chopped-tone tests were therefore applied. In the region 1.2 kHz to 1.7 kHz these tests revealed three resonances with Q-factors of the order of 500, some 40 dB below the steady-state condition. If in phase with the steady-state condition, these resonances represent irregularities of no more than 0.1 dB on the axial curve and can only therefore be measured by chopped-tone techniques. It was however shown that the application of a layer of Plastiflex type 1200P damping compound to both sides of the cone reduced the resonances to a marked extent; furthermore, the use of pink noise and the recording technique mentioned for the bass unit demonstrated a great improvement in the reproduction and the colouration was reduced to a very low level.

The sensitivity of the 110mm unit is comparable with that of the bass unit described last month, but there is a growing demand for even greater sound levels from monitoring loudspeakers; whereas the sensitivity of the low-frequency unit could be increased, that of this middle-frequency unit could not, and it was therefore decided to make a 200mm diameter unit of increased sensitivity as an alternative design.

The cone of the 200mm unit is made from 0.4mm thick Bextrene type 730 and, as with the 110mm diameter unit, employs a surround of 0.5mm thick p.v.c. The experience obtained in the design of the surround of the 305mm unit was applied to this unit and in addition a heavily flared cone was used. The bass resonance frequency in free air is about 50 Hz, but to avoid reaction with the cabinet vent resonance the rear of the unit is confined in a small enclosure. The resulting frequency characteristics on axis and at 60° are shown in Fig. 18; with this unit the operational frequency range is 400 Hz to 3.5 kHz. It will be seen that the axial frequency characteristic over this range is smooth, but that the 60° response diverges from it. As mentioned earlier a slit of 100mm width is used to effect an improvement in this respect; the resulting characteristics are shown in Fig. 19. The cone was coated on both sides with Plastiflex 1200P to reduce slight colouration in the 2 kHz region and in this

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**At the vent resonance frequency the output from the vent is in quadrature with that from the cone but, as most of the energy is radiated from the vent and both sources are very close together, the loudspeaker is omnidirectional. Above this frequency the sound radiated from the vent is rapidly attenuated and the phase difference between the two outputs becomes zero. The vent therefore has little influence on the directivity at any frequency.

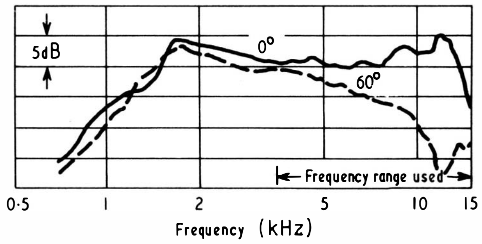


Fig.20. Response/frequency characteristics of high flux density 58 mm high-frequency unit at 0° and 60° to the axis.

regard listening tests show that the reproduction from the coated unit is remarkably " clean."

High-Frequency Units.—The 58mm high-frequency unit employed in the LS5/1A has a smooth response/frequency characteristic and has proved to be very repeatable in production. At the request of the B.B.C. a further model has been produced employing the same diaphragm, and therefore having similar frequency characteristics, but with a stronger magnet giving an increase in sensitivity of nearly 2 dB.

A horn-loaded unit designed for the high fidelity market was also examined but was found to be inferior to the 58mm unit mentioned above. A larger direct radiator was also tested and although this had a more extended axial frequency range than the 58mm unit, the corresponding response curve was not so smooth and the increased size made the unit appreciably more directional at high frequencies.

The frequency characteristics of the improved but unequalized 58mm unit mounted in the cabinet are shown in Fig. 20 at 0° and 60° to the axis.

With the units available three designs were possible. Design A was similar to the type LS5/1A construction and employed the plastic cone 305mm unit and two of the 58mm units; type B used the 305mm unit for the bass, the 200mm unit for the middle frequencies and a single 58mm improved unit for the high frequencies; type C was similar to type B but used the 110mm unit for the middle-frequency range. As it was not possible to determine from a study of the units which would give the best reproduction it was decided to build a prototype of each and carry out final listening tests. The characteristics of the three designs will be discussed in the final part of the article next month.

References

1. " Acoustical Engineering " by H. F. Olson, pp. 36 and 44. Van Nostrand, New York (1957).

2. H. Levine and J. Schwinger. *Physical Review*, 73, No. 4, 1948, pp. 383-406.

APPENDIX

Musical Excerpts used for the Experiment on Bass Equalization

Item No.	Title	Type of Music	Length of Excerpt
a	Götterdämmerung (Wagner)	Orchestral	35 sec
b	Schwanda (Weinberger)	Orchestral	55 sec
c	Prelude in G (Pierné)	Organ	I min 41 sec
d	Fiat Lux (Dubois)	Organ	I min 30 sec
e	The Gee Men (Swinger from Seville)	Saturday Club (pop)	I min 41 sec
f	Billy J. Kramer with Dakotas (It's all over now baby blue)	Saturday Club (pop)	I min 12 sec
g	Billy J. Kramer with Dakotas (We're doing fine)	Saturday Club (pop)	I min 30 sec
h	Mars from Planets Suite (Holst)	Orchestral	52 sec
i	Mars from Planets Suite (Holst)	Orchestral	25 sec
j	Jupiter from Planets Suite (Holst)	Orchestral	51 sec
k	Overture: Scapino (Walton)	Orchestral	I min 30 sec

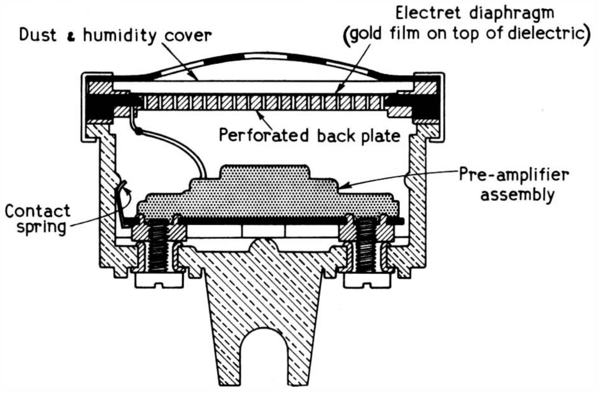
Electret Microphone

A capacitor microphone with a permanent electric charge built in has been developed as an experimental telephone transmitter by Northern Electric Laboratories of Ottawa, Canada. In conventional capacitor microphones the charge is, of course, produced by some kind of voltage source, but in this new transducer it is provided by an electret—that is a dielectric material to which a permanent electric charge has been applied during manufacture. (Electrets can be considered as electrostatic analogues of permanent magnets.) Here the electret takes the form of a 7.6 μm film of a granular polycarbonate material (the capacitor dielectric) metallized on one side with a 0.89 μm layer of gold (one plate of the capacitor). In the microphone this metallized film is placed with its insulating side in contact with the roughened surface of a rigid perforated backplate, which forms the other plate of the capacitor. The film has just enough tension to prevent wrinkles. Thus, when the air pressure on this diaphragm is varied the capacitance is changed and, since the charge is constant and $V = Q/C$, there is a corresponding variation of voltage across the capacitor—the output signal.

The transducer is a high impedance device, so its output is matched to the low impedance of the telephone line, and at the same time amplified, by a 20 dB solid-state pre-amplifier built into the microphone.

One advantage of this technique, regarding its application to telephones is, of course, that no voltage generator is needed for the capacitor microphone. And, because electrets can be made from very thin dielectric films, a higher capacitance per unit area than with conventional capacitor microphones is possible. The rate of decay of the charge is very slow, and the developers say that measurements at temperatures ranging from 90°C to 170°C have indicated that an electret life in excess of 100 years can be expected at normal temperatures. As a competitor to the carbon microphone used in telephones, the experimental microphone has the advantage, according to Northern Electric, that the built-in pre-amplifier requires less current than a carbon transducer.

Construction of the electret microphone.



New B.B.C. Monitoring Loudspeaker

3. Three designs, using different combinations of units

*by H. D. Harwood** B.Sc.

As mentioned last month, three designs of loudspeaker were possible with the units available. Design A was similar to the type LS5/1A construction and employed the plastic cone 305mm unit and two of the 58mm units; type B used the 305mm unit for the bass, the 200mm unit for the middle frequencies and a single 58mm improved unit for the high frequencies; type C was similar to type B but used the 110mm unit for the middle-frequency range. As it was not possible to determine from a study of the units which would give the best reproduction it was decided to build a prototype of each and carry out final listening tests.

Type A Loudspeaker. The design of the type LS5/1A will not be described in detail; it is sufficient to mention here that the low-frequency unit is employed up to about 1.7 kHz, and above this frequency two high-frequency units operate in parallel up to approximately 3.5 kHz. Above this the output from one is attenuated, leaving one only to cover the remaining part of the spectrum. The response/frequency characteristic of the 305mm plastic cone unit is smoother than that of the 380mm cone used in the LS5/1A and the design of the crossover network is therefore somewhat simpler; a 100mm slit, described last month, was fitted over the front of the 305mm unit. The response/frequency characteristics achieved are shown in Fig. 21 for the horizontal plane. The axial response is smooth but it will be observed that in spite of the 100mm slit the response/frequency characteristic at 60° in Fig. 21 is not uniform and is rather like that of the LS5/1A in this respect.

Type B Loudspeaker. In the type B design the 305mm plastic-cone bass unit is employed up to a frequency of 400 Hz. Above this frequency the 200mm middle-frequency unit operates up to 3.5 kHz where a change is made to the 58mm improved unit. As already mentioned, the bass resonance frequency of the middle-frequency unit is about 50 Hz and it is necessary to enclose the rear to prevent it acting as a vent at low frequencies. In order to make use of the sensitivity of the middle- and high-frequency units the high-flux-density version of the low-frequency unit is employed. In this design the relative voltages applied to the units are adjusted by means of an auto-transformer placed ahead of the crossover networks; by this method the relative levels can be adjusted without having to change components in the crossover network as was the case with the LS5/1A. It also has the advantage that the nominal impedance of the loudspeaker can be adjusted to any convenient value to suit amplifiers commercially available. Fig. 22 shows the response/frequency characteristics in the horizontal plane and Figs. 23 and 24 those in the vertical plane above and below the axis. It will be observed that the curves in Fig. 22 are smooth and close together.

Type C Loudspeaker. This design is essentially similar to that of type B but employs the 110mm diameter unit for the middle-frequency range. The lower crossover frequency in this case is about 450 Hz, the upper crossover frequency remaining at 3.5 kHz. As the middle-frequency unit has a bass resonance of about 400 Hz the mechanical impedance at low frequencies is high and it is not necessary to enclose the rear. Owing to the lower sensitivity of this middle-frequency unit there is no advantage in employing the high-flux-density low-frequency unit and the lower-flux-density type is therefore used. As with the type B design, an auto-transformer is inserted ahead of the crossover network.

The response/frequency characteristics in the horizontal plane are shown in Fig. 25. It will be seen that the curves in Fig. 25 are smooth and except at the highest frequencies very nearly coincident.

Listening Tests

The three prototype loudspeakers were given a listening test and compared with a type LS5/1A and a still earlier experimental model known as the R.M.L. which was included because some observers considered it to be superior to the LS5/1A. The tests, which were carried out by experienced members of B.B.C. operational and programme staff, included speech from both dead and reverberant surroundings and recorded and live orchestral items, the latter from the B.B.C.'s Maida Vale 1 studio. For the live music test the loudspeakers were checked in turn in two rooms both of which communicate directly with the studio, and direct comparisons with the live programme were thus possible. The quality of reproduction of all three prototypes was judged an improvement on that from both the LS5/1A and the

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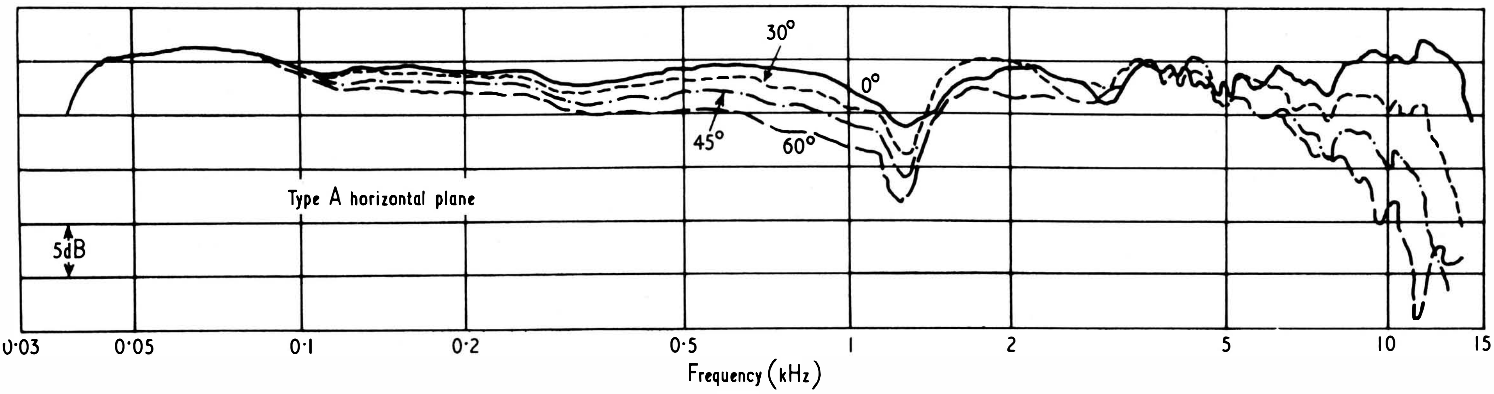
*B.B.C. Research Department.

Fig. 21. Response/frequency characteristics of type A loudspeaker in horizontal plane.



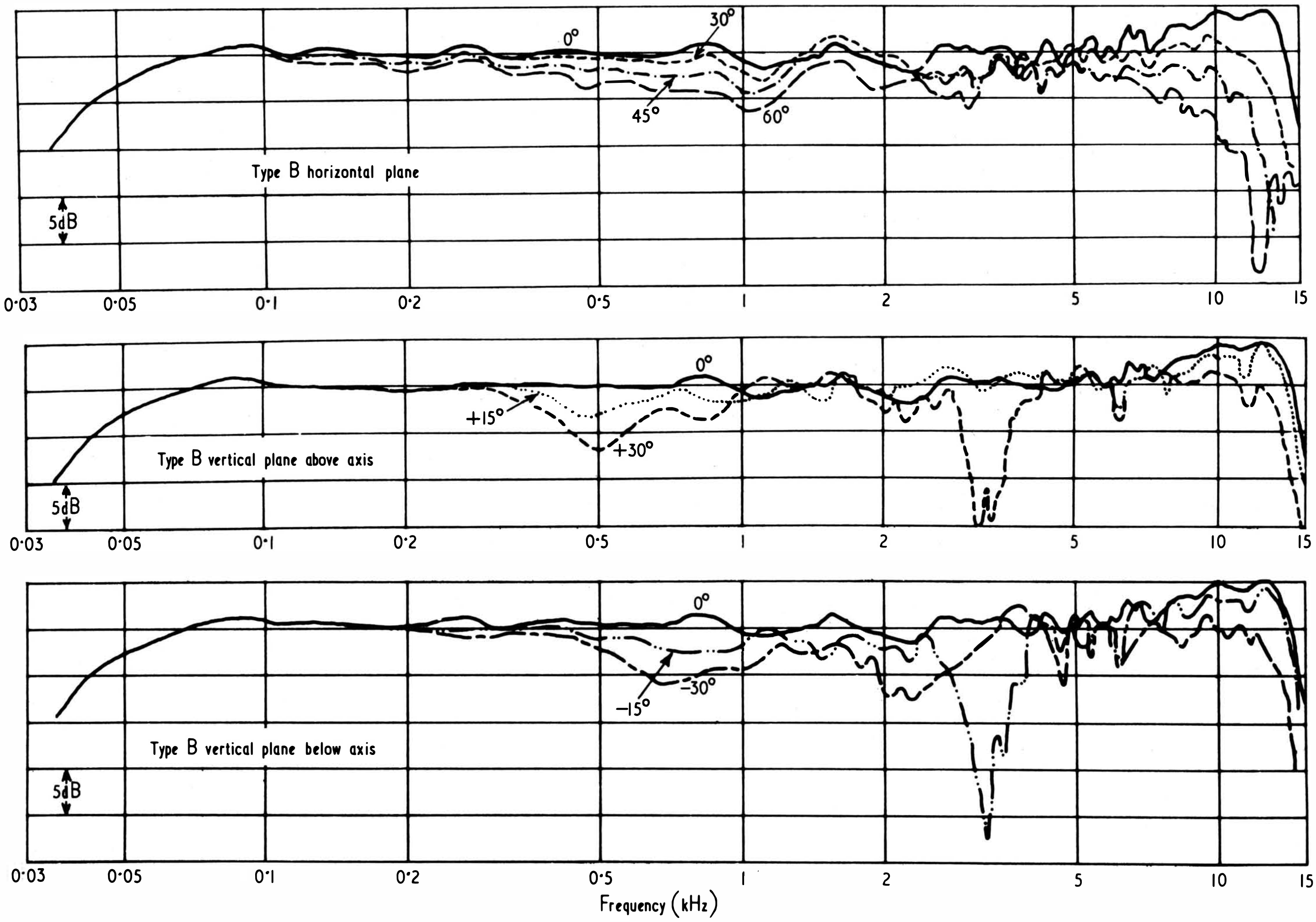


Fig. 22. (top), Fig. 23. (middle) and Fig. 24. (bottom). Response/frequency characteristics of type B loudspeaker in horizontal plane, vertical plane above axis and vertical plane below axis.

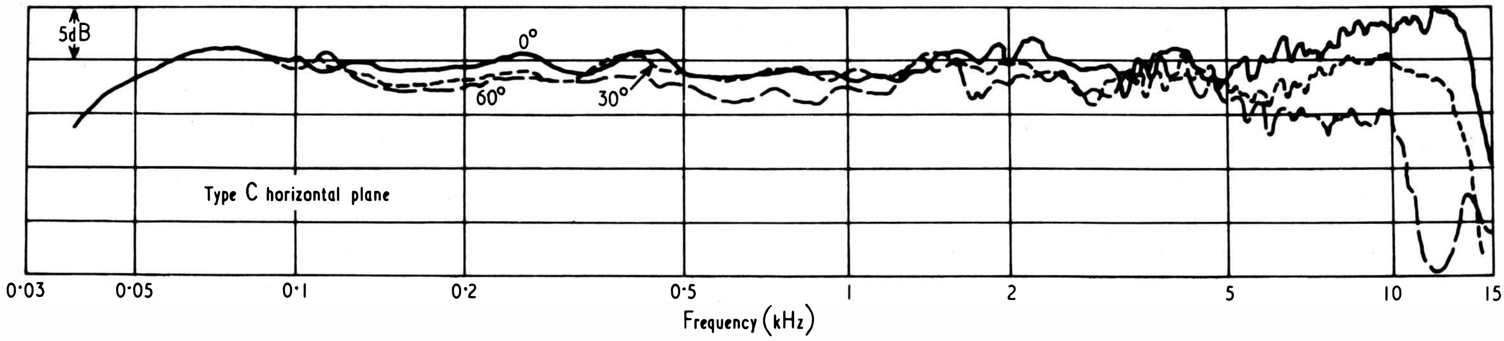


Fig. 25. Response/frequency characteristics of type C loudspeaker in horizontal plane.

R.M.L. It was further agreed by all that the sound quality from the type B loudspeaker was outstanding, being better than that from types A and C but that from the type C was very slightly coloured by the remains of the resonances around the 1.5 kHz region mentioned last month. The wide angle of radiation of type B in the horizontal plane was also favourably commented on.

In view of this verdict the remaining measurements were confined to the type B model. Two variations of this design have been constructed; one, designated LS5/5, is floor based with a rectangular cabinet mounted on a plinth; the other, designed for hanging, is lozenge shaped and is coded LS5/6. In the LS5/6 the vertical positions of the units are reversed with respect to those of the LS5/5, the bass unit being mounted uppermost, as in the LS5/2A. This is done in order to keep the bass unit near to the main reflecting surface in the room, in this case the ceiling.

Repeatability in Production

Some experience of the repeatability of the low-frequency unit has been obtained and was described in reference No. 1 in the March issue. There has been considerable production experience with the 58mm high-frequency unit. The 200mm unit was, however, hand made specially for this prototype and there was no experience of its repeatability in production. To speed up acceptance tests a number of pre-production models of the LS5/5 loudspeaker were built and advantage was taken of this to determine the spread in frequency characteristics likely to be obtained in practice.

Fig. 26 shows the spread in the unequalized axial frequency characteristic of six middle-frequency units measured in the cabinet without the rear enclosure; in the figure the curves were arbitrarily lined up at 750 Hz. It will be seen that the spread is very small over the operating frequency range of 400 Hz to 3.5 kHz.

Fig. 27 shows the spread in axial frequency characteristics of six complete loudspeakers. It should be noted that the trend of the curves is more uniform and the spread is appreciably smaller than that to be expected in practice from moving-coil microphones and even from many electrostatic microphones. In the past, the monitoring loudspeakers have been the least predictable link in the studio chain, but with the introduction of these new loudspeakers this should no longer be so.

Directivity

The variation in mean spherical radiated power as a function of frequency was measured by the use of octave bands of noise. It is shown in Fig. 28. The corresponding directivity index* is given in Fig. 29; the variations of both quantities with frequency are less than those of the LS5/1A and LS5/2A and very much less than those found with any other loudspeaker which has been tested.

Impedance and Distortion Characteristics

Fig. 30 gives the circuit diagram of the cross-over network. The inductors in all cases have Radiometal cores and operate well below the saturation level. Fig. 31 shows the modulus of the impedance of the loudspeaker measured on the 25-ohm tapping of the auto-transformer. In explanation of this curve it should be mentioned that, although the circuit of Fig. 30 appears to be conventional, in fact the L to C ratios employed are not such as to give simple low pass, band pass and high pass filters. These ratios are chosen to give non-uniform pass band characteristics in such a way as to equalize those of the loudspeaker units, e.g. Fig. 15 (b), and so yield a uniform axial frequency response. It is noteworthy that the equalization can be performed by this simple means and without introducing any further components; it does, however, result in the irregular impedance characteristics of Fig. 31. Adjustment for differing sensitivities of units in production is of course made by changing the appropriate tap on the auto-transformer.

Early tests on the 305mm unit indicated that it would deliver a higher level of sound without overloading than would the 380mm unit employed for the LS5/1A loudspeaker. Fig. 32 shows the curves of harmonic distortion measured on the axis of the complete LS5/5 loudspeaker at 1.5m for a sound level of 1 N/m^2 and Fig. 33 gives the corresponding curves for intermodulation tests; these curves include the effect of the variable impedance load on the power amplifier, and were obtained by special apparatus[1] designed for this purpose.

To those unaccustomed to such curves attention is drawn to three points. The first is that the curves, particularly of the higher harmonics, are at least an order more irregular than is that of the fundamental. The second, which is related, is that although the mean level of the curves is fairly clear the average level of distortion cannot be obtained by measurements at spot frequencies. For example, at 83 Hz the level of 8th harmonic is

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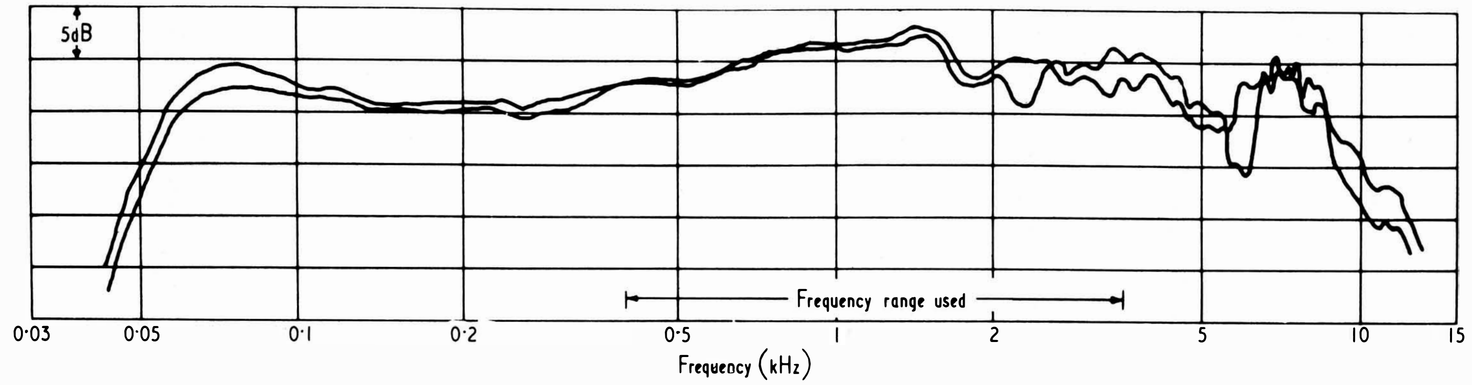
*The directivity index of a loudspeaker is the logarithm to base 10 of the ratio of the sound power which would be radiated if the free-space axial sound pressure were constant over 4π steradians to the actual sound power radiated.

Fig. 26. Spread in axial response/frequency characteristics in six 200 mm units in large cabinet.



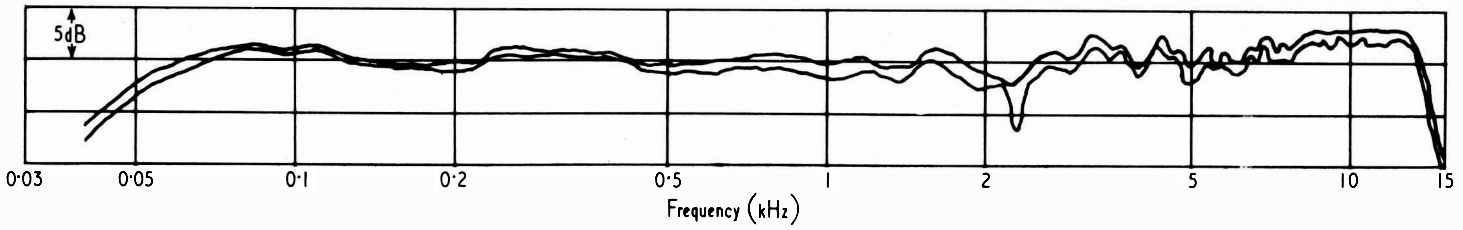


Fig. 27. (Above) Spread in axial response/frequency characteristics of six LS5/5 prototypes.

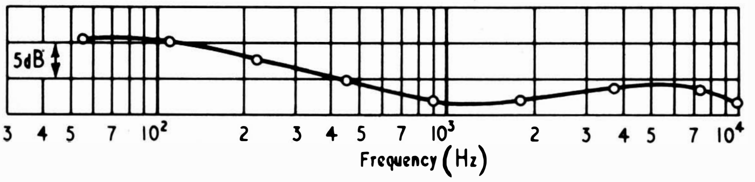


Fig. 28. (Left) Mean spherical response of LS5/5 loudspeaker measured in octave bands.

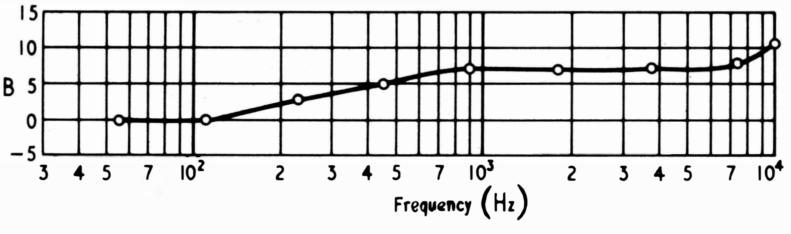


Fig. 29. (Left) Directivity index of LS5/5 loudspeaker measured in octave bands.

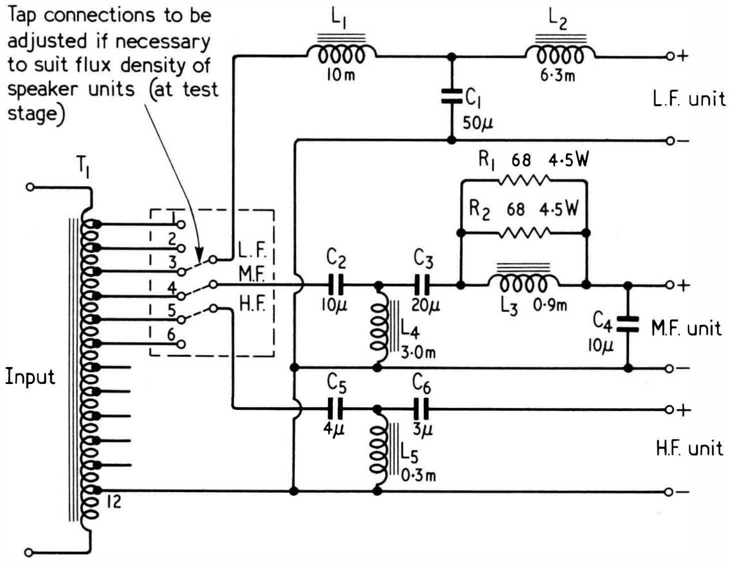


Fig. 30. (Left) Circuit diagram of crossover network of LS5/5 and LS5/6 loudspeakers. All component values are ±2%.

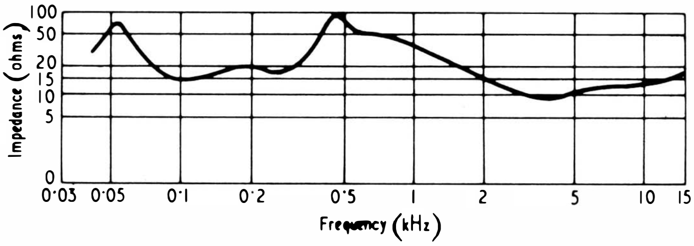
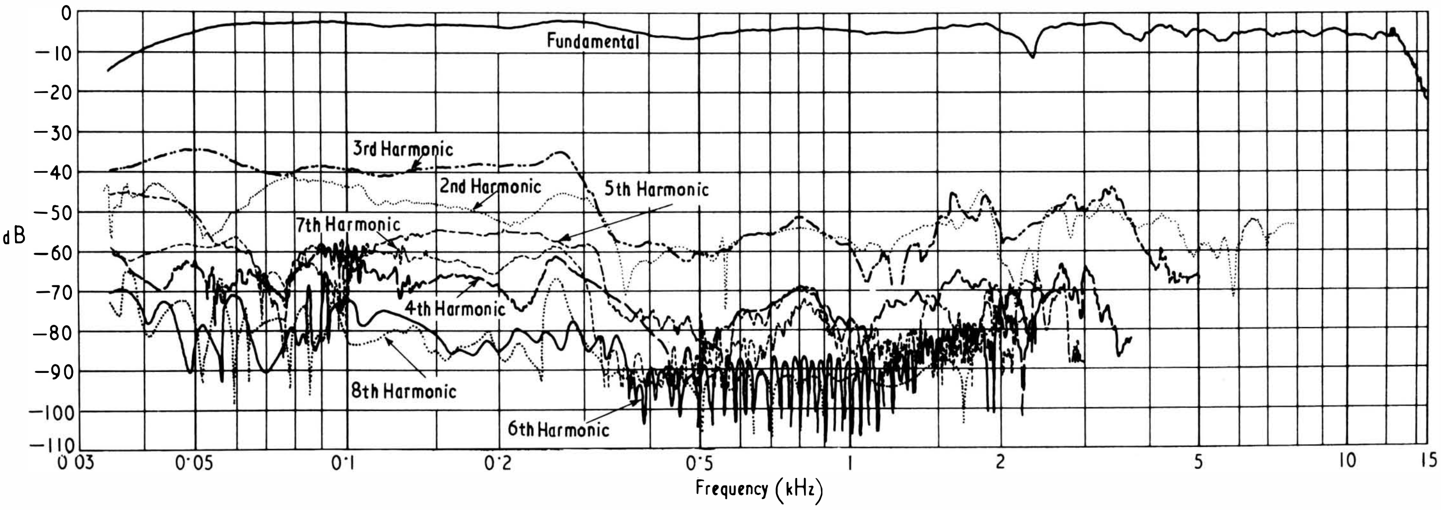


Fig. 31. (Above) Modulus of impedance of LS5/5 and LS5/6 loudspeakers.

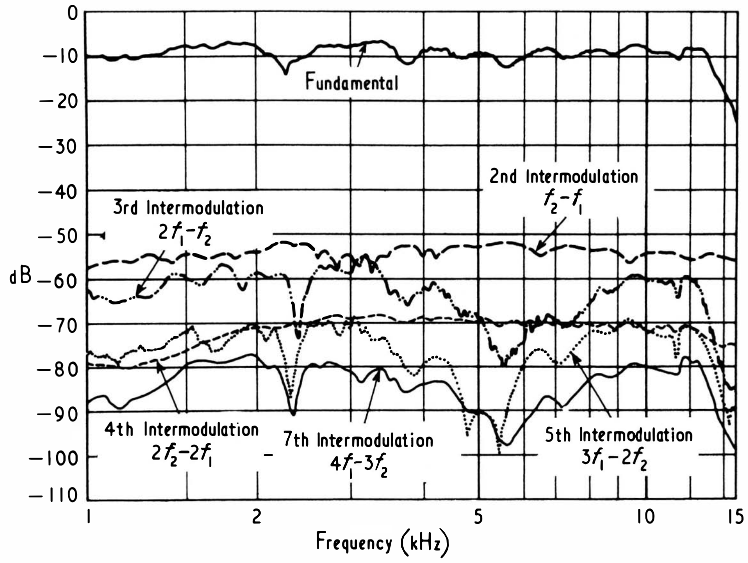
Fig. 32. (Below) Harmonic distortion of LS5/5 loudspeaker measured at 1 N/m² at 1.5m.



8 dB above that of the 6th while 2 Hz farther up the scale the position is reversed to the extent that the 6th is 28 dB above the 8th harmonic, a relative change of 36 dB in 2 Hz! Finally, the levels of distortion shown are inaudible.

The level of the sixth intermodulation product was too low to measure. It will be seen that the distortion levels are quite low even at the lowest frequency at which each unit is used, thus indicating that they are being operated well within their limits. The distortion curves shown in Fig. 14 of reference No. 1 were taken on the type LS3/1 loudspeaker at the same sound pressure and comparison with Figs. 32 and 33 shows that the distortion levels of the new loudspeaker are appreciably lower than those of the old design in spite of the fact that this used a larger (380mm) low-frequency unit.

Fig. 33. (Right) Intermodulation distortion of LS5/5 loudspeaker measured at 1 N/m² at 1.5 m.



Power Amplifier

A commercially produced transistor power amplifier is used, capable of supplying 25 watts into a 25 ohm load. Associated with it is a pre-amplifier, designed by the B.B.C. Designs Department, which provides the usual balanced bridging input impedance and also the bass pre-emphasis circuits, mentioned last month, which give a rise of 4 dB at 40 Hz for the LS5/5 and 7 dB at 40 Hz for the LS5/6.

Dimensions

The LS5/5 loudspeaker cabinet is approximately 350mm wide by 430mm deep by 660mm high, giving an external volume of 0.1m³. It is mounted on a plinth, 520mm high, which houses the power amplifier. The LS5/6 cabinet is of irregular shape but has the same volume as that of the LS5/5.

The weight of the LS5/5 loudspeaker together with the power amplifier is 47kg, that of the LS5/6 without amplifier is 35kg.

Acknowledgements. The author wishes to express his thanks to the Director of Engineering of the British Broadcasting Corporation for permission to publish this article.

Reference

1. "Apparatus for measurement of non-linear distortion as a continuous function of frequency" by H. D. Harwood. B.B.C. Engineering Monograph No. 49, July 1963. keith@snook·eu