CLSG

CONFIDENTIAL

RESEARCH DEPARTMENT

The design of studio monitoring loudspeakers types LS5/5 and LS5/6

TECHNOLOGICAL REPORT No. PH-13

UDC 621.395.623.842

1967/57

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

CONFIDENTIAL

RESEARCH DEPARTMENT

THE DESIGN OF STUDIO MONITORING LOUDSPEAKERS TYPES LS5/5 AND LS5/6

Technological Report No. PH-13
UDC 621.395.623.842 1967/57

H.D. Harwood, B.Sc.
S.A. Hughes

D. Maurice
for Head of Research Department

This Report uses SI units in accordance with B.S. document PD 5686.

Technological Report No. PH-13

THE DESIGN OF STUDIO MONITORING LOUDSPEAKERS TYPE LS5/5 AND LS5/6

November 1967

Technological Report No. PH-13
UDC 621.395.623.842 1967/57

THE DESIGN OF THE STUDIO MONITORING LOUDSPEAKERS TYPES LS5/5 AND LS5/6

SUMMARY

Details are given of the various factors which have led to the design of two new monitoring loudspeakers suitable for use in studios and outside broadcasts. The loudspeakers are much smaller than those of the present type; a floor-standing model is designated type LS5/5, and one intended for hanging is called type LS5/6. In the course of the design, the questions of bass pre-emphasis and of directivity have been examined in some detail.

The quality of reproduction and the directional properties are appreciably in advance of those obtained for the LS5/1A and the maximum sound level is also higher. The spread in frequency characteristics between development specimens is extremely small, and the level of non-linear distortion is low.

1. INTRODUCTION

The present studio monitoring loudspeaker type LS5/1A was developed in 1959 and employs a special Goodmans 380 mm low-frequency unit and two Rola Celestion 58 mm high-frequency units. Although some 250 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; furthermore, some 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 Research Department into the possibility of producing a thermoplastic cone and these experiments led to the production of the 305 mm unit described elsewhere(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.

2. DESIGN CONSIDERATIONS

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 previously mentioned.

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, 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. 1. 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.

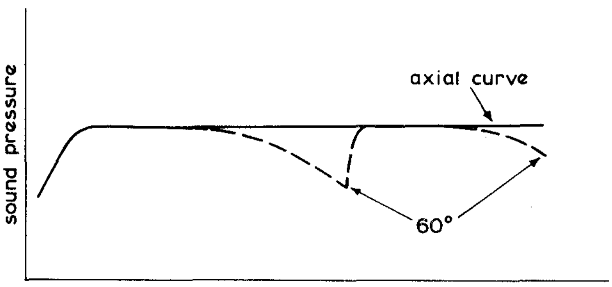

Fig. 1 - Typical frequency characteristics of a two-unit loudspeaker on axis and at 60° from axis

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.

3. BASS EQUALIZATION

3.1. General

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, whilst 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 designs, e.g. the type LS3/1A loudspeaker, it has been carried out in the crossover network, thus enabling a standard amplifier with a 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.

3.2. 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 type PPM/2, the peak occuring 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. 2 and the overall peak levels

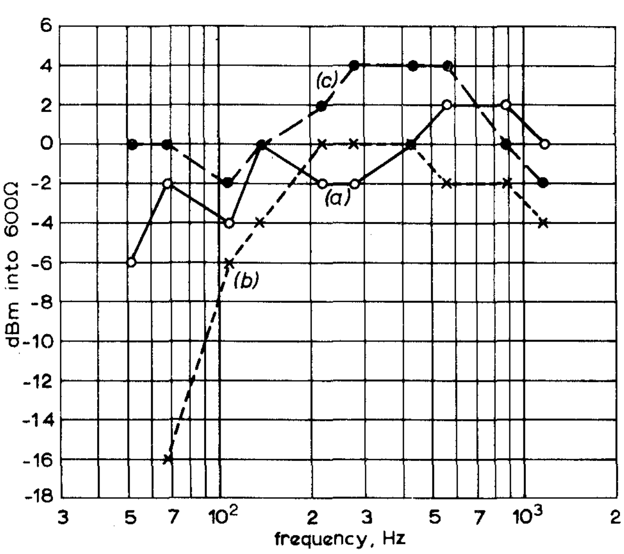

Fig. 2 - Peak levels in octave analysis of programme

Item (*a*) Kramer with Dakotas
(*b*) Mars I
(*c*) Organ Prelude in G

for the whole range of items is plotted in Fig. 3; 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.

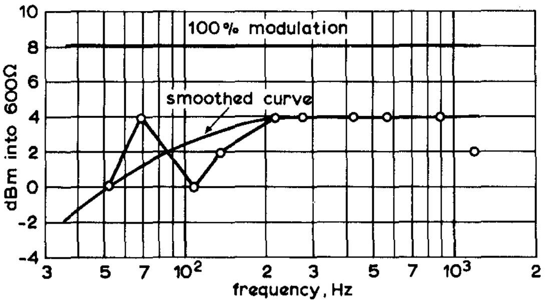

Fig. 3 - Peak octave analysis of programmes, all items

TABLE 1

Effect of Bass Equalization on Peak Level of Programme

programme item (see appendix)	peak levels on PPM/2. (dB above '6') circuit condition (see Fig. 4(*a*))			
	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

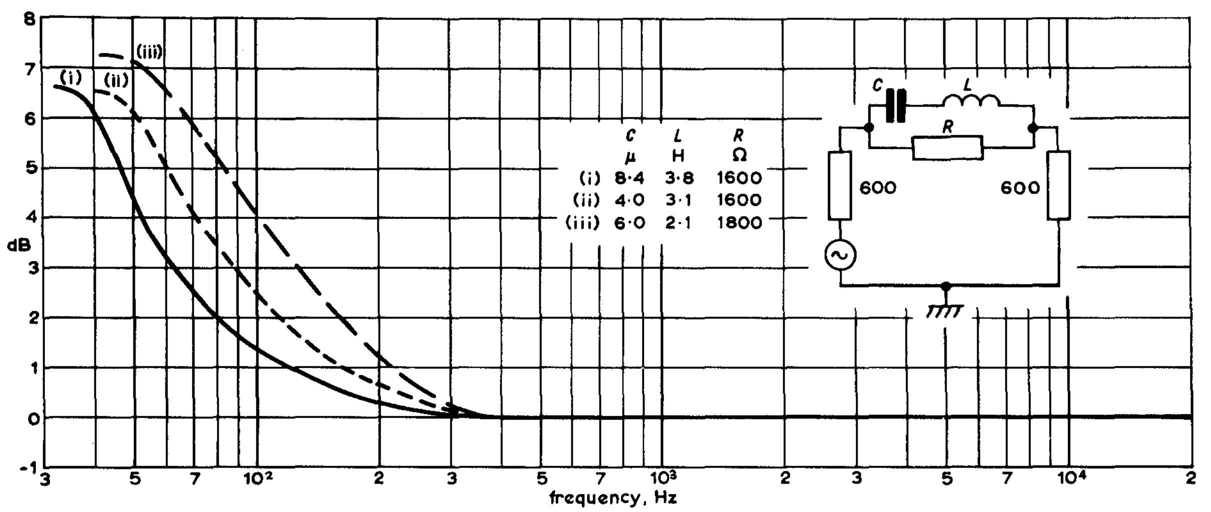

Fig. 4(a) - Response/frequency characteristics of bass-lift circuits

Equalization was designed for the smoothed curve and for two similar but progressively more extreme conditions as shown in Fig. 4(*a*). 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 PPM/2; the results are given in Table 1. It will be seen that the level of item c is increased by 1 dB even by circuit No. (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. 4(*b*), 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

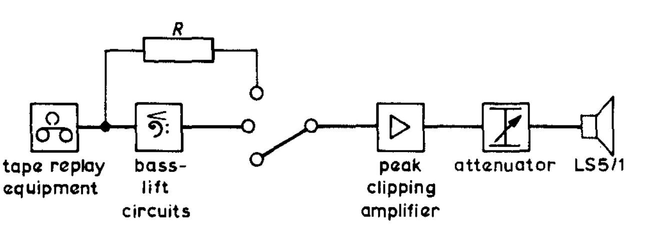

Fig. 4(b) - Circuit used for determination of acceptable distortion with bass-lift circuits

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 No. (iii) of Fig. 4(*a*) distortion was clearly audible on items c and d, i.e. the organ passages, none being noticed on the remainder; when circuit No. (ii) of Fig. 4(*a*) 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.

4. DESIGN DETAILS

4.1. Cabinet

Experience with the type LS5/1A loudspeaker had shown that it had an adequate bass range. Calculations indicated that a similar range would be obtained with the new 305 mm plastic cone unit by employing a cabinet of only 0·085 m^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.

4.2. Use of Slit

The next factor to be dealt with was the directivity of the units. Fig. 5(*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 which may be regarded as approximations to these conditions. Of these, a line source and a circular piston in a baffle may be shown[2] 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

$$R_\alpha = \frac{2J_1\left(\frac{2\pi r}{\lambda}\sin\alpha\right)}{\frac{2\pi r\sin\alpha}{\lambda}}$$

where r is the radius of the piston and 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[3] viz:

$$R_\alpha = \frac{4}{\pi\sin^2\alpha}\cdot\frac{J_1\,kr\sin\alpha}{[(J_1(kr\sin\alpha))^2 + (Y_1(kr\sin\alpha))^2]^{1/2}}$$

$$\times\frac{|R|}{1-|R|^2}\times\exp\left[\frac{2kr\cos\alpha}{\pi}P\times\int_0^{kr}\frac{x\tan^{-1}(-J_1(x)/Y_1(x))\,dx}{[x^2-(kr\sin\alpha)^2][x^2+(kr)^2]^{1/2}}\right]$$

$$\text{where } |R| = \exp\left\{-\frac{2kr}{\pi}\int_0^{kr}\frac{\tan^{-1}(-J_1(x)/Y_1(x))}{x[(kr)^2-x^2]^{1/2}}\,dx\right\}$$

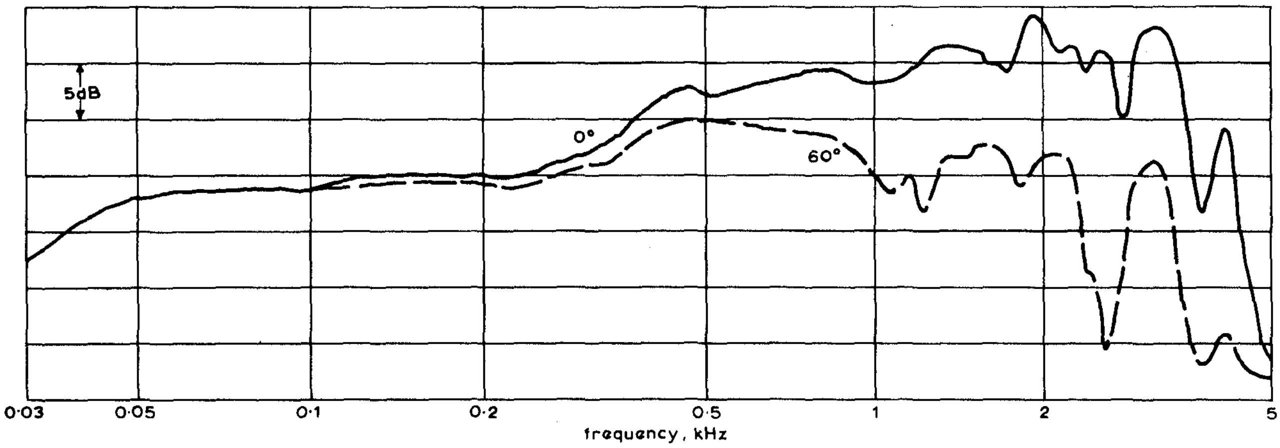

Fig. 5(a) - Response/frequency characteristic of unequalized low-frequency unit without slit at 0° and 60° to the axis

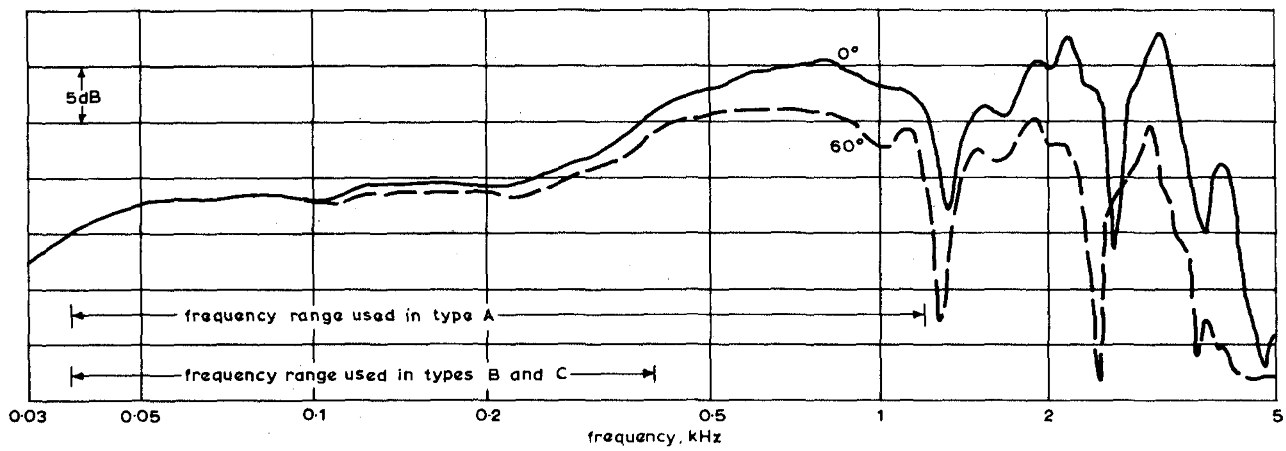

Fig. 5(b) - Response/frequency characteristic of unequalized low-frequency unit with 100 mm slit at 0° and 60° to the axis

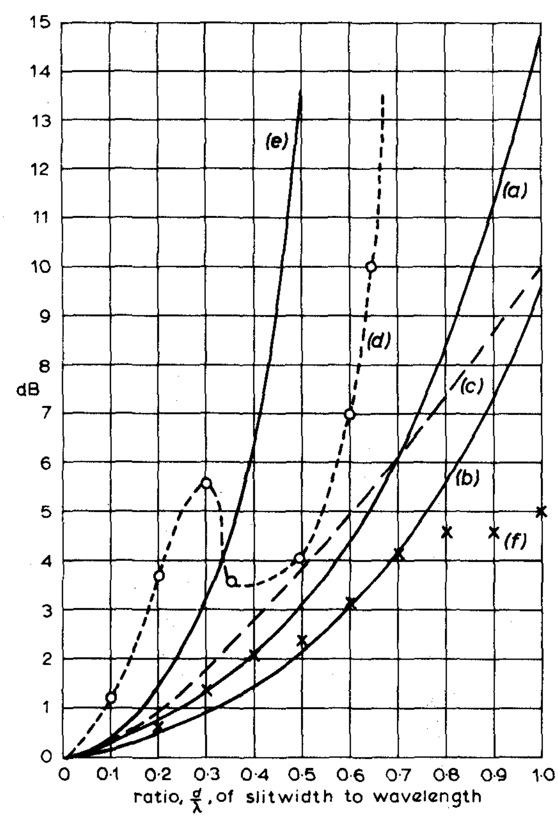

Fig. 6 - Deviation of 60° characteristics from axial characteristics for differing types of source

(*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

and 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. 6 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 λ/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 100 mm slit are shown in Fig. 5(*b*). It may be observed by comparison with Fig. 5(*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. 6 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 180 mm, the width of the slit in front of the 380 mm 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. 6 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 350 mm, 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. 6. 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 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.

* In Reference 3 $Y_1(x)$ is denoted by $N_1(x)$ throughout.

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. 6 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, 100 mm, 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 $\frac{d}{\lambda}$ greater than 0·75 is obscure.

4.3. Details of Units

4.3.1. Bass Unit

As already mentioned, the bass unit employed is the 305 mm plastic cone unit described in Report L-065. A chassis with a more powerful magnet is now available and an increase in sensitivity of about 2 dB over the unit described in Report L-065 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 in Section 4.1 some electrical low-frequency equalization is also necessary. As explained in Section 3, 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

** 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 omni-directional. 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.

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. 4(*a*) 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. 5(*b*).

4.3.2. 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 110 mm diameter unit were already proceeding in Research Department. This unit used a 25·4 mm voice coil and a flared cone of Bextrene type 237, 0·4 mm thick, together with a surround made of p.v.c. 0·5 mm 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. 7, 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 110 mm unit is comparable with that of the bass unit described in Report L-065 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 200 mm diameter unit of increased sensitivity as an alternative design.

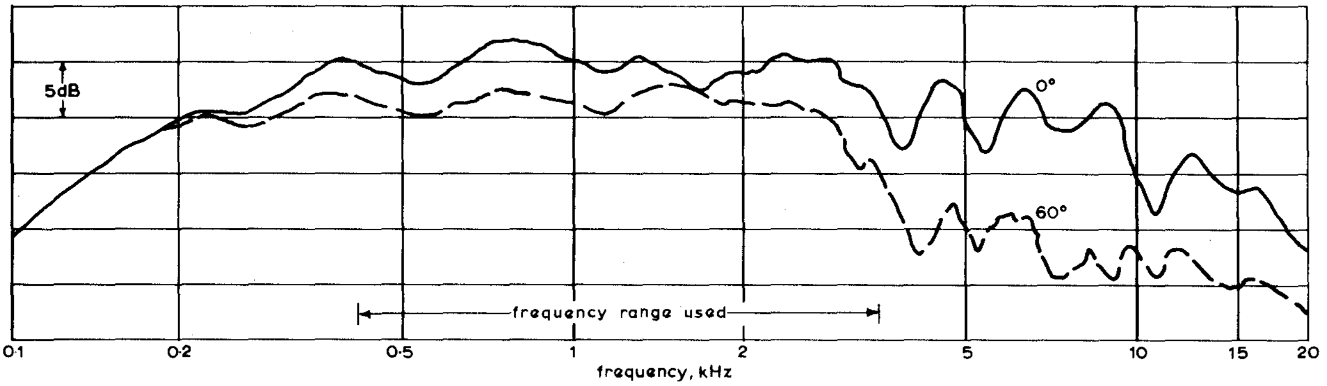

Fig. 7 - Response/frequency characteristics of 110 mm dia. middle-frequency unit at 0° and 60° to the axis

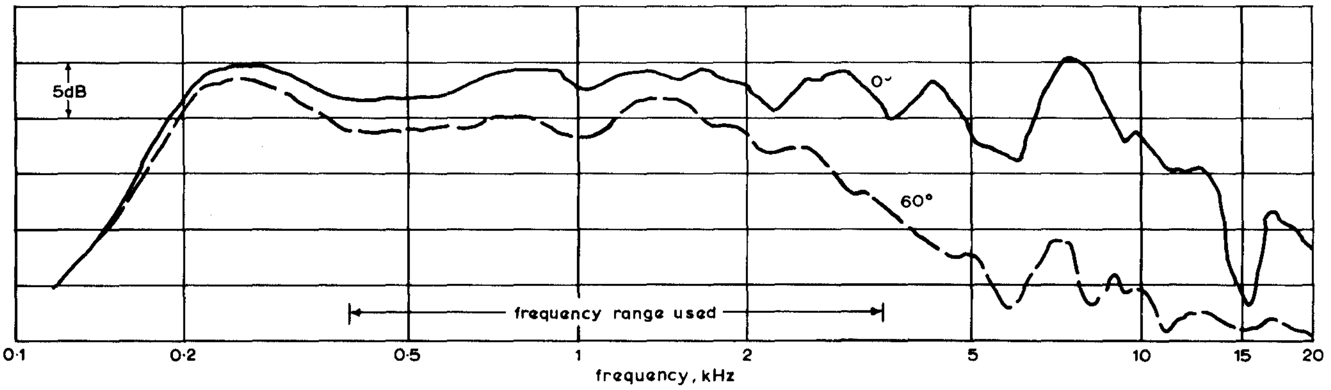

Fig. 8 - Response/frequency characteristic of 200 mm dia. middle-frequency unit without slit at 0° and 60° to the axis

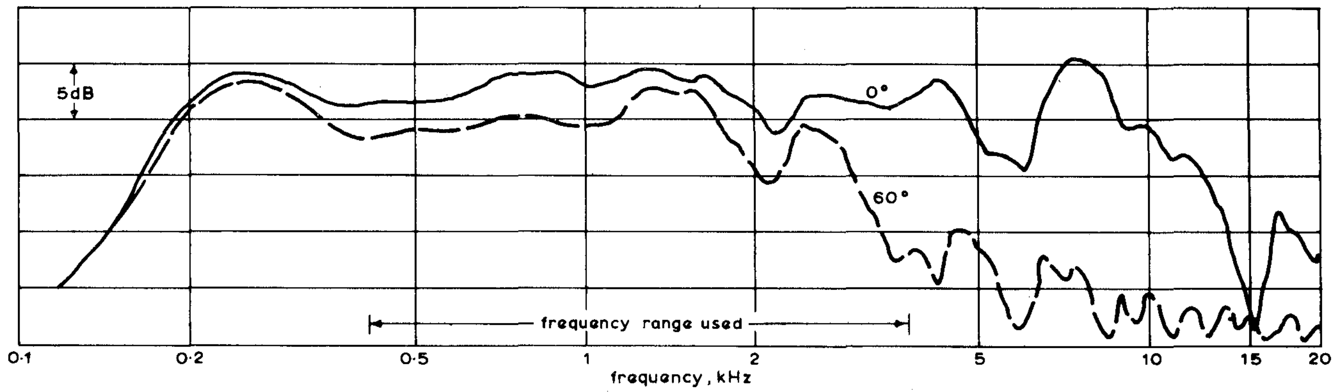

Fig. 9 - Response/frequency characteristics of 200 mm dia. middle-frequency unit with 100 mm slit at 0° and 60° to the axis

The cone of the 200 mm unit is made from 0·4 mm thick Bextrene type 730 and as with the 110 mm diameter unit employs a surround of 0·5 mm thick p.v.c. The experience obtained in the design of the surround of the 305 mm 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. 8; 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 in Section 4.2 a slit of 100 mm width is used to effect an improvement in this respect; the resulting characteristics are shown in Fig. 9. The cone was coated on both sides with Plastiflex 1200P to reduce slight colouration in the 2 kHz region and in this regard listening tests show that the reproduction from the coated unit is remarkably "clean".

4.3.3. High-Frequency Units

As already mentioned, the 58 mm high-frequency unit employed in the LS5/1A is made by Rola Celestion. It has a smooth response/frequency characteristic and has proved to be very repeatable in production. At the request of Research Department 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.

Rola Celestion also make a horn-loaded unit for the high fidelity market and this was examined but found to be definitely inferior to the type already in use.

The K.E.F. unit type T15 was also tested and, although this has a more extended axial frequency range than has the Rola unit, the corresponding frequency characteristic is not so smooth and the unit is appreciably more directional at high frequencies.

The frequency characteristics of the improved but unequalized Rola Celestion unit mounted in the cabinet are shown in Fig. 10 at 0° and 60° to the axis.

5. DESIGN OF COMPLETE LOUDSPEAKERS

5.1. General

With the units available three designs were possible. Design A was similar to the type LS5/1A construction and employed the plastic cone 305 mm unit and two of the Rola Celestion 58 mm units;

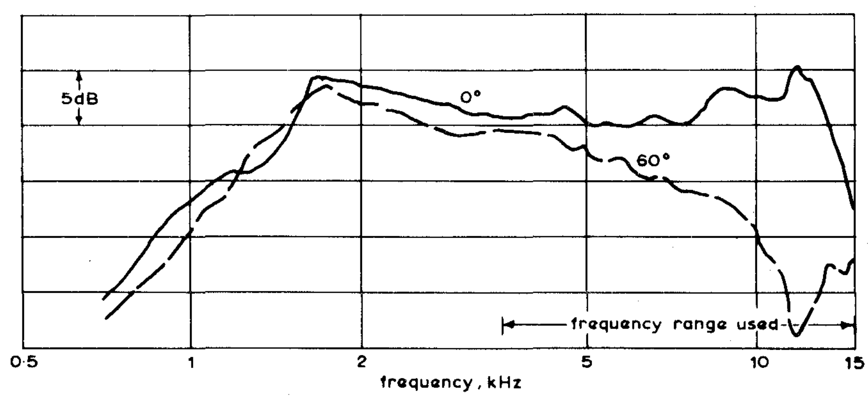

Fig. 10 - Response/frequency characteristics of high flux density Rola Celestion high-frequency unit at 0° and 60° to the axis

type B used the 305 mm unit for the bass, the 200 mm unit for the middle frequencies and a single Rola Celestion 58 mm improved unit for the high frequencies; Type C was similar to type B but used the 110 mm 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.

5.2. Type A Loudspeaker

The design of the type LS5/1A has been described in the Technical Instructions and it is sufficient to mention here that the low-frequency unit is employed up to about 1.7 kHz. Above this frequency two Rola Celestion high-frequency units operate in parallel up to approximately 3.5 kHz above which the output from one is attenuated leaving one only to cover the remaining part of the spectrum. The response/frequency characteristic of the 305 mm plastic cone unit is smoother than that of the 380 mm Goodmans cone used in the LS5/1A and the design of the crossover network is therefore somewhat simpler; a 100 mm slit, described earlier, was fitted over the front of the 305 mm unit. The response/frequency characteristics achieved are shown in Fig. 11 for the horizontal plane. The axial response is smooth but it will be observed that in spite of the 100 mm slit the response/frequency characteristic at 60° in Fig. 11 is not uniform and is rather like that of the LS5/1A in this respect.

5.3. Type B Loudspeaker

In the type B design the 305 mm plastic-cone bass unit is employed up to a frequency of 400 Hz. Above this frequency the 200 mm middle-frequency unit operates up to 3.5 kHz where a change is made to the Rola Celestion 58 mm 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. 12 shows the response/frequency characteristics in the horizontal plane and Figs. 13 and 14 those in the vertical plane above and below the axis. It will be observed that the curves in Fig. 12 are smooth and close together.

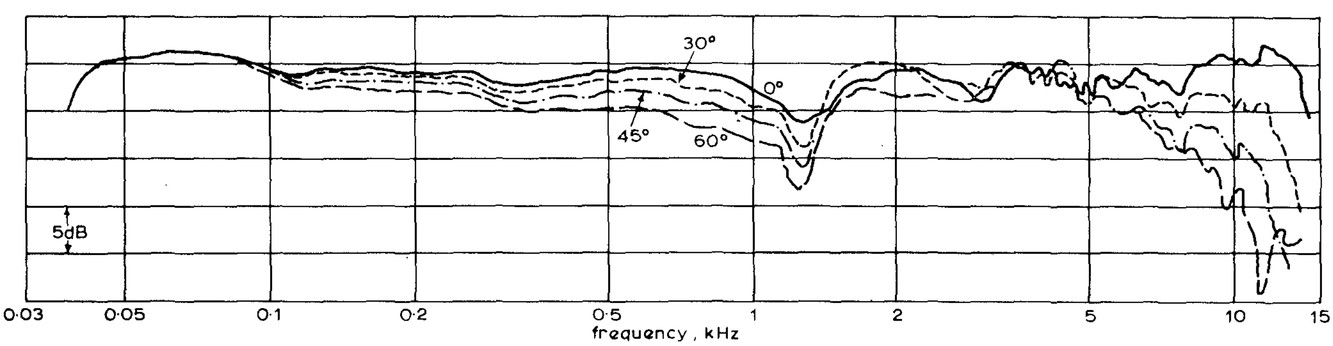

Fig. 11 - Response/frequency characteristics of type A loudspeaker in horizontal plane

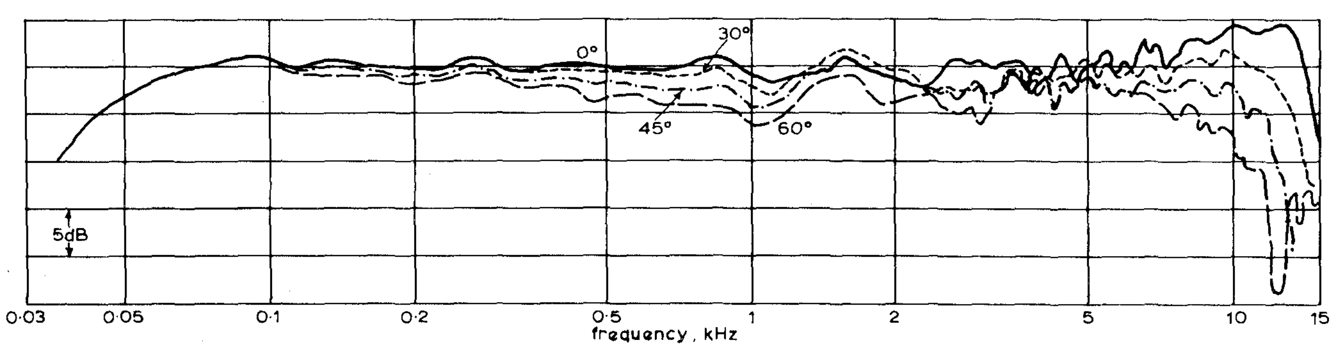

Fig. 12 - Response/frequency characteristics of type B loudspeaker in horizontal plane

5.4. Type C Loudspeaker

This design is essentially similar to that of Type B but employs the 110 mm 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. 15. It will be seen that the curves in Fig. 15 are smooth and except at the highest frequencies very nearly coincident.

6. 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 operational and programme staff, included speech from both dead and reverberant surroundings and recorded and live orchestral items, the latter from Maida Vale 1 studio. For the live music test the loudspeakers were checked in turn both in the Green Room and in the Sound Control Room both of

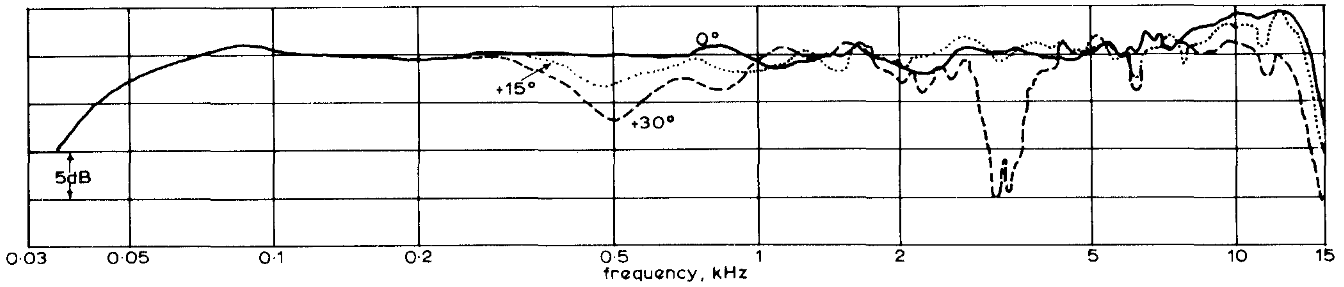

Fig. 13 - Response/frequency characteristics of type B loudspeaker in vertical plane above axis

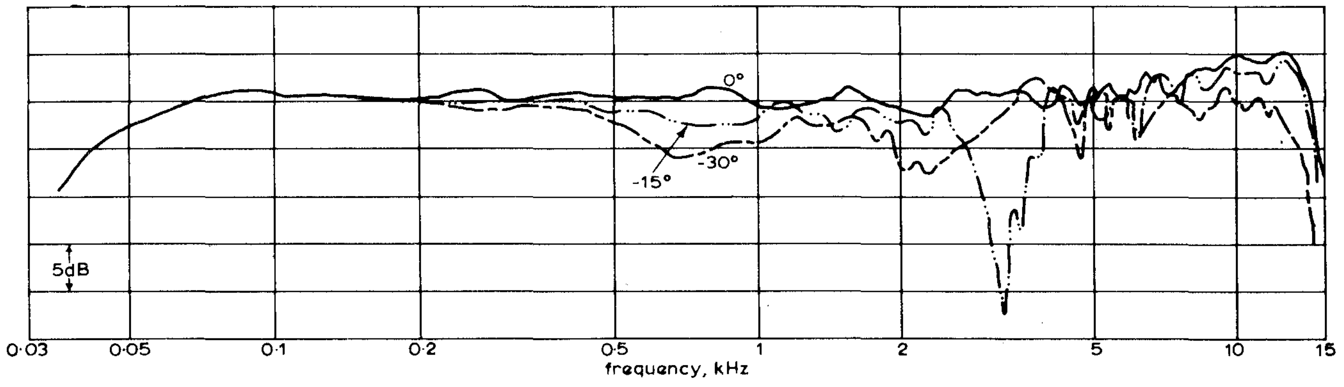

Fig. 14 - Response/frequency characteristics of type B loudspeaker in vertical plane below axis

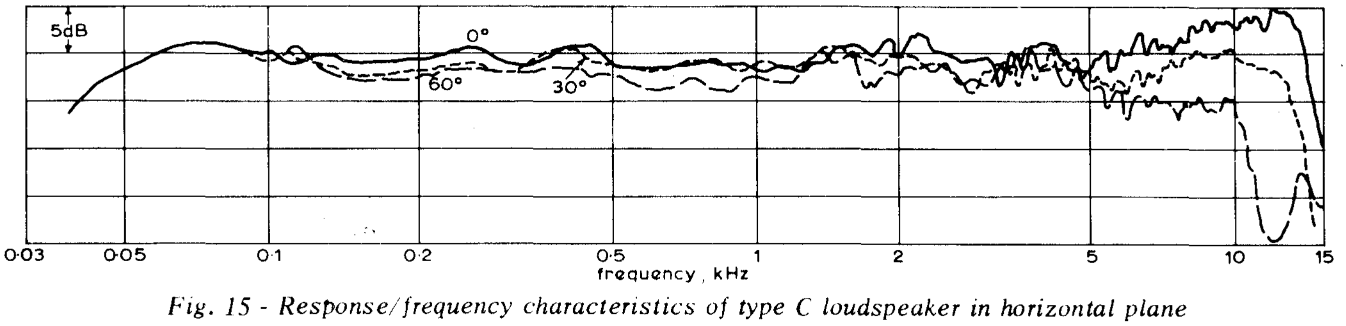

Fig. 15 - Response/frequency characteristics of type C loudspeaker in horizontal plane

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 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 previously mentioned in Section 4.3.2. 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.

7. REPEATABILITY OF THE TYPE LS5/5 LOUDSPEAKER

Some experience of the repeatability of the low-frequency unit has been obtained and was described in Report L-065; there has been considerable production experience with the Rola Celestion high-frequency unit. The 200 mm unit was however handmade 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. 16 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. 17 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.

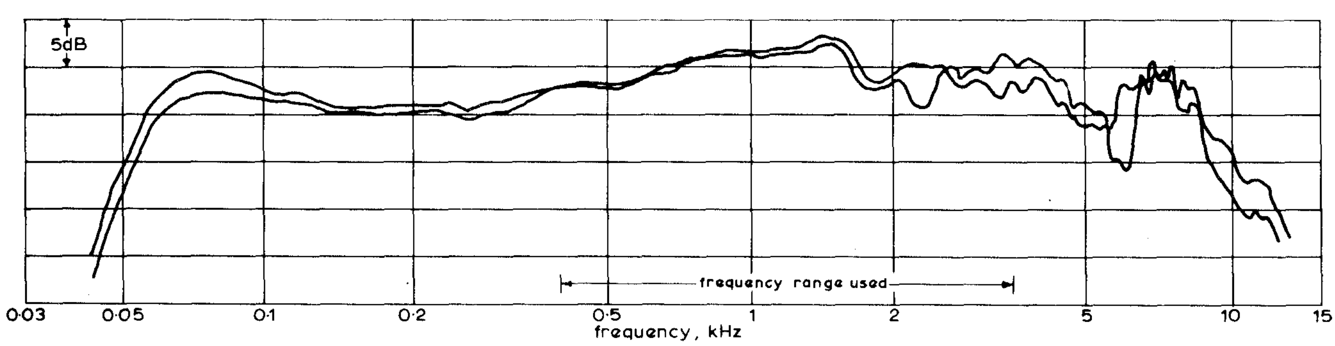

Fig. 16 - Spread in axial response/frequency characteristics of six 200 mm units in large cabinet

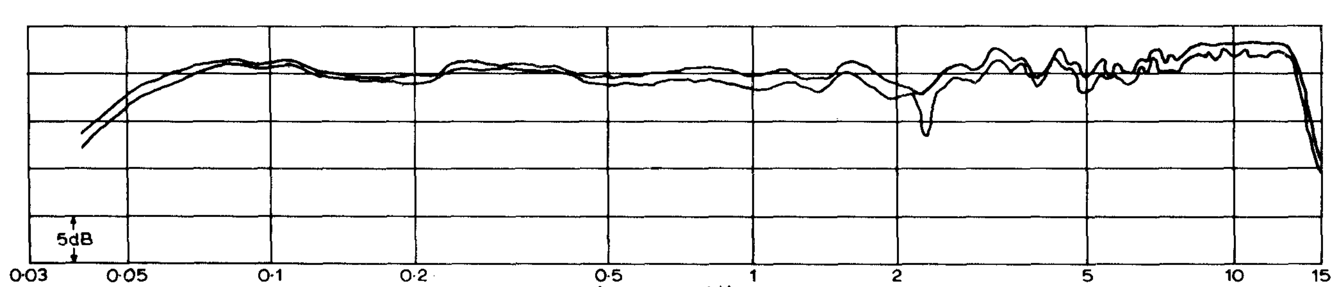

Fig. 17 - Spread in axial response/frequency characteristics of six LS5/5 prototypes

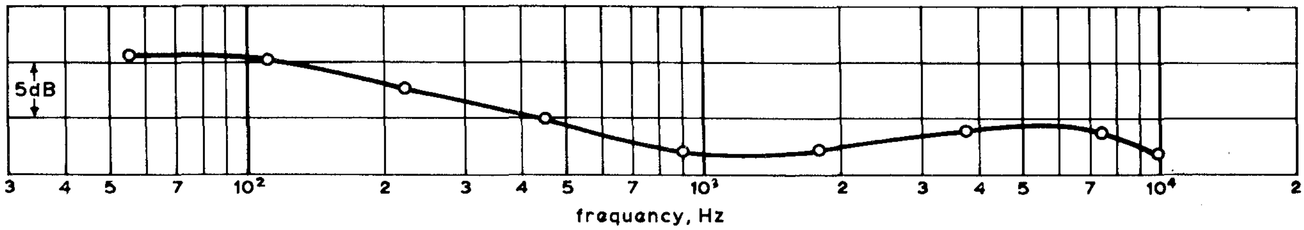

Fig. 18 - Mean spherical response of LS5/5 loudspeaker measured in octave bands

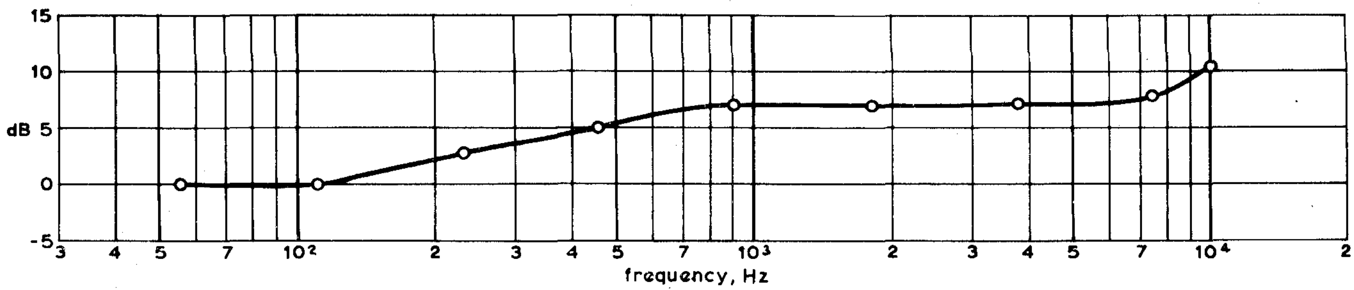

Fig. 19 - Directivity index of LS5/5 loudspeaker measured in octave bands

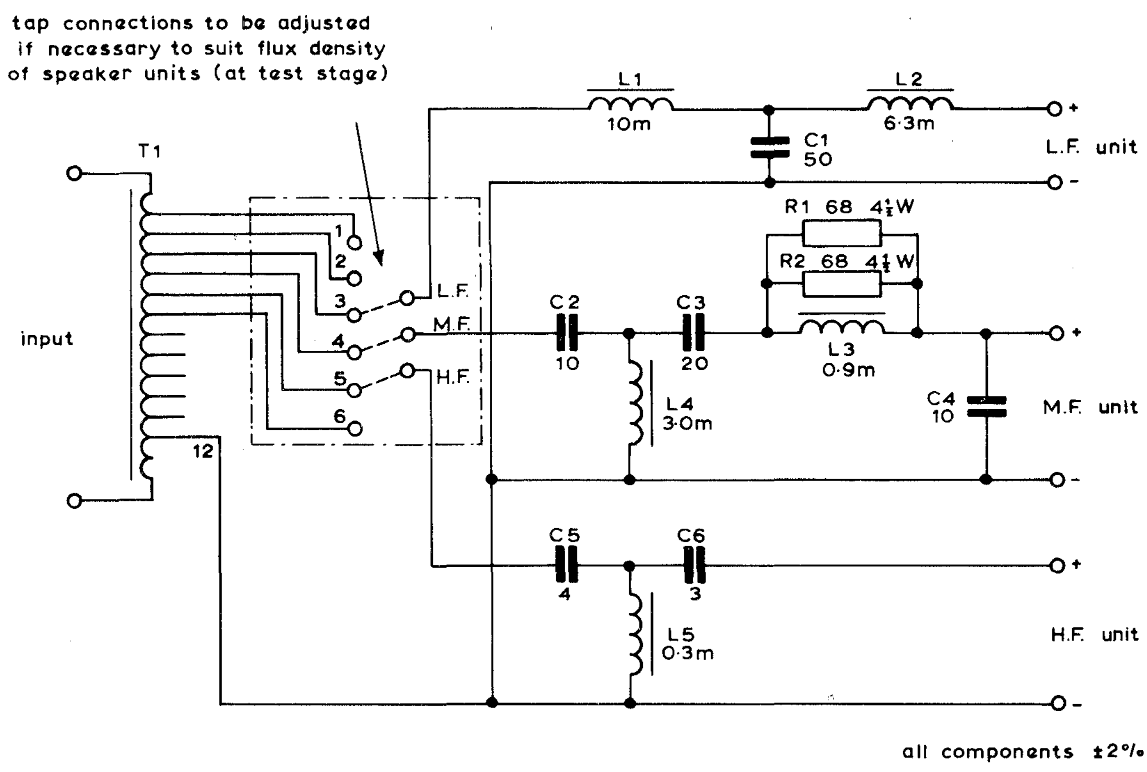

Fig. 20 - Circuit diagram of crossover network of LS6/5 and LS5/6 loudspeakers

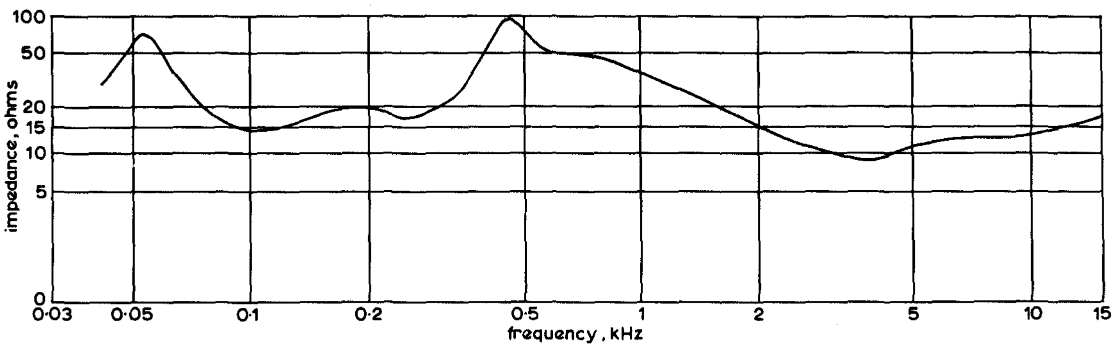

Fig. 21 - Modulus of impedance of LS5/5 and LS5/6 loudspeakers

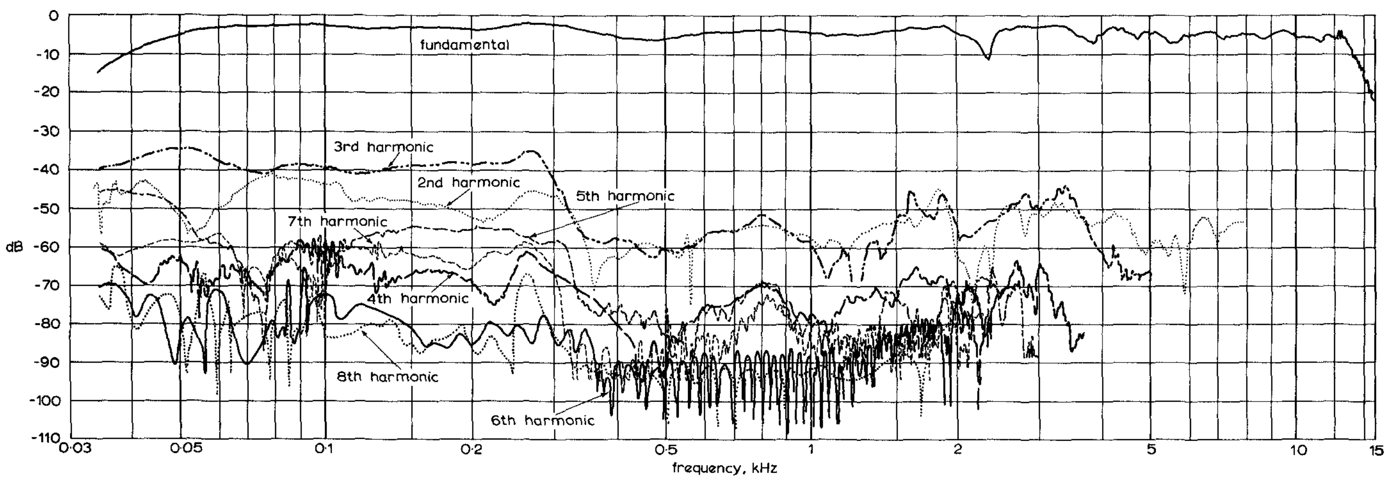

Fig. 22 - Harmonic distortion of LS5/5 loudspeaker measured at 1 N/m² at 1·5 m

8. 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. 18. The corresponding directivity index* is given in Fig. 19; 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.

9. IMPEDANCE AND DISTORTION CHARACTERISTICS

Fig. 20 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. 21 shows the modulus of the impedance of the loudspeaker measured on the 25 ohm tapping of the auto-transformer.

Early tests on the 305 mm unit indicated that it would deliver a higher level of sound without overloading than would the 380 mm unit employed for the LS5/1A loudspeaker. Fig. 22 shows the curves of harmonic distortion measured on the axis of the complete LS5/5 loudspeaker at 1·5 m for a sound level of 1 N/m² and Fig. 23 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[4] designed for this purpose.

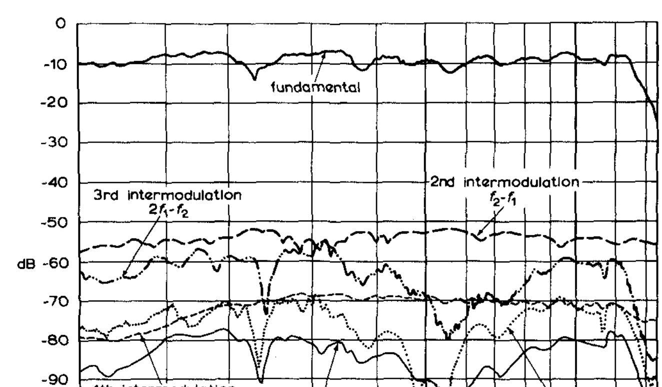

Fig. 23 - Intermodulation distortion of LS5/5 loudspeaker measured at 1 N/m² at 1·5 m

* 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.

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 4 were taken on the type LS3/1 loudspeaker at the same sound pressure and comparison with Figs. 22 and 23 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 (380 mm) low-frequency unit.

10. POWER AMPLIFIER

A commercially produced transistorised power amplifier is used, capable of supplying 25 watts into a 25 ohm load. Associated with it is a pre-amplifier, designed by the BBC Designs Department, which provides the usual balanced bridging input impedance and also the bass pre-emphasis circuits, mentioned in Section 4.3.1, which give a rise of 4 dB at 40 Hz for the LS5/5 and 7 dB at 40 Hz for the LS5/6.

11. DIMENSIONS

The LS5/5 loudspeaker cabinet is approximately 350 mm wide by 430 mm deep by 660 mm high, giving an external volume of 0·1 m^3. It is mounted on a plinth, 520 mm 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; photographs of the two models are shown in Figs. 24 and 25 respectively.

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

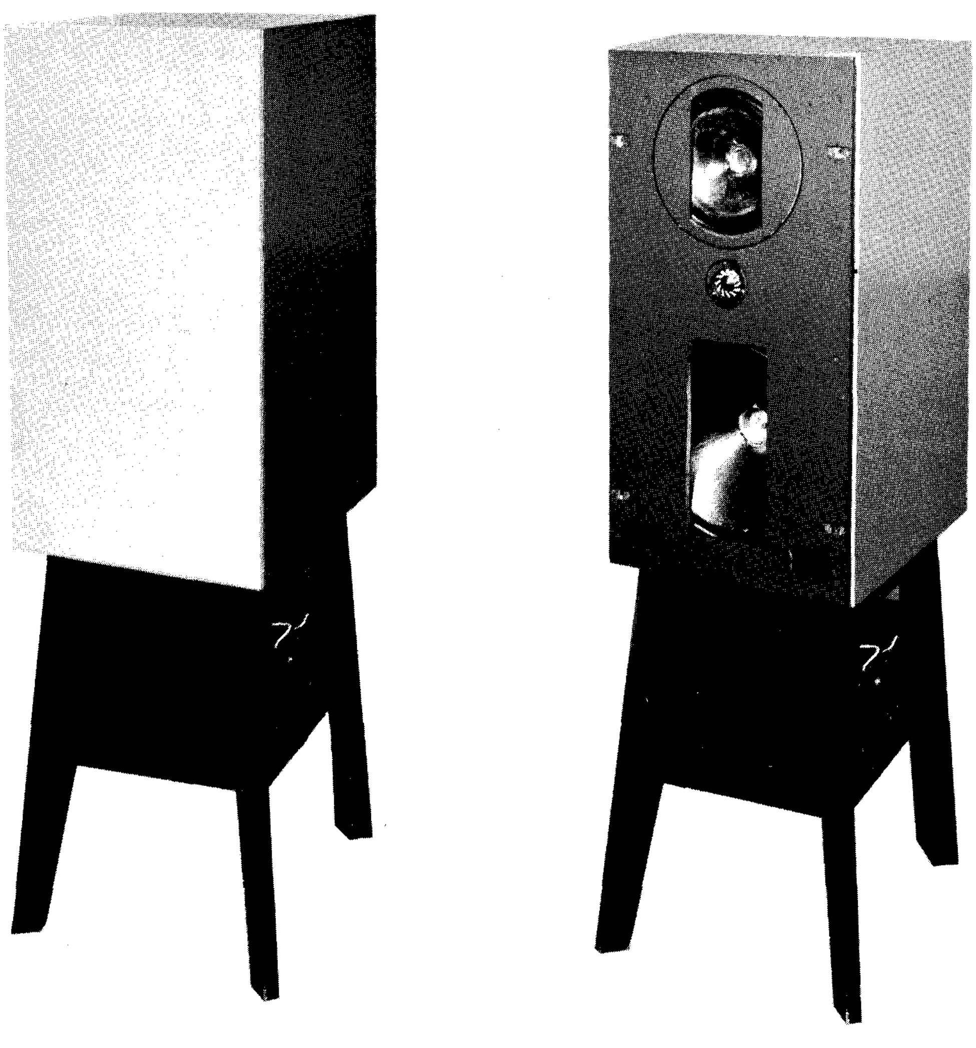

Fig. 24 - Studio monitoring loudspeaker LS5/5 (free-standing version) with and without front cover

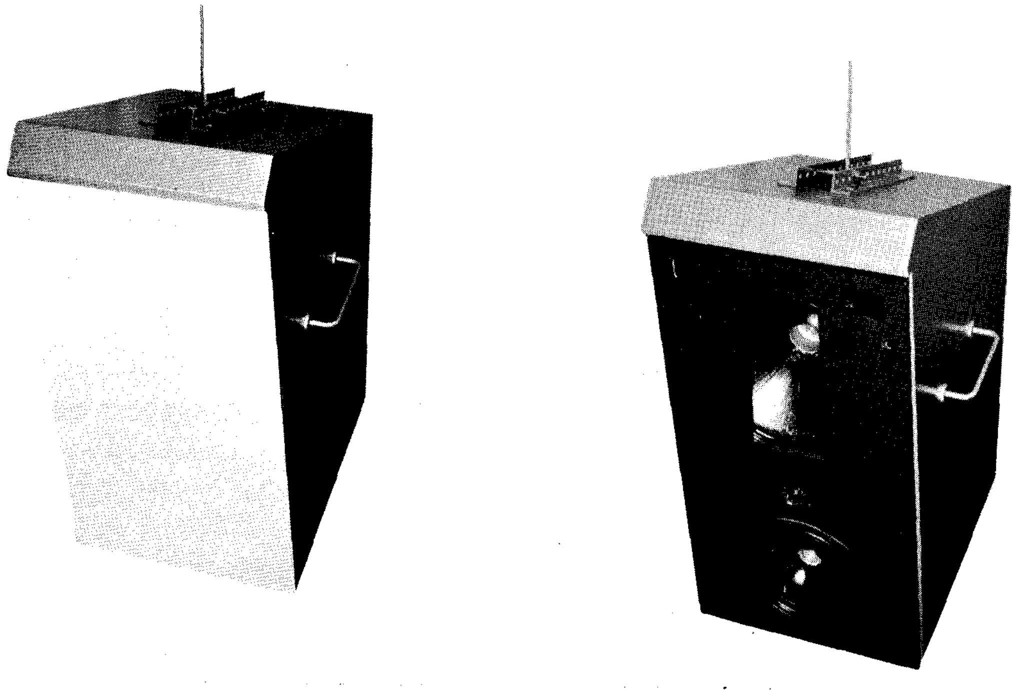

Fig. 25 - Studio monitoring loudspeaker LS5/6 (hanging version) with and without front cover

12. CONCLUSIONS

Details have been given of the considerations which have led to the design of two new monitoring loudspeakers which are suitable for studio or outside broadcast use. The sound quality and directional properties are appreciably in advance of those obtained from the loudspeakers at present in use and the maximum output level is higher. The spread in frequency characteristics between development specimens is extremely small, and the level of non-linearity distortion is low.

13. REFERENCES

1. The design of a low-frequency unit for monitoring loudspeakers. BBC Research Department Report No. L-065, Serial No. 1966/28.

2. OLSON, H.F. 1957. Acoustical engineering, pp. 36 and 44. New York, Van Nostrand.

3. LEVINE, H. *and* SCHWINGER, J. Physical review, 1948, **73**, No. 4, pp. 383 - 406.

4. HARWOOD, H.D. Apparatus for measurement of non-linear distortion as a continuous function of frequency. BBC Eng. Monograph No. 49, July 1963.

APPENDIX

Musical Excerpts used for the Experiment on Bass Equalisation

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	1 min 41 sec
d	Fiat Lux (Dubois)	Organ	1 min 30 sec
e	The Gee Men (Swinger from Seville)	Saturday Club (pop)	1 min 41 sec
f	Billy J. Kramer with Dakotas (It's all over now baby blue)	Saturday Club (pop)	1 min 12 sec
g	Billy J. Kramer with Dakotas (We're doing fine)	Saturday Club (pop)	1 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	1 min 30 sec

JMP

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey