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The influence of loudspeaker directivity and orientation on the effective audience area in two-channel stereophonic reproduction

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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SUMMARY

In two-channel stereophonic reproduction, the full stereophonic effect is apparent only to observers who are equidistant from the left- and right-hand loudspeakers; for observers located off centre, sound images intended to appear in the central area of the stage are displaced towards one side. It has been demonstrated by the G.E.C. Research Department that if the left- and right-hand loudspeakers are placed face to face, a central image, instead of being displaced as a whole with lateral movement of the observer, is dispersed, giving a diffuse effect. Consideration is given to the potentialities and limitations of this and other alternative methods of presentation which have been proposed from time to time.

1. INTRODUCTION

Two-channel stereophony, as provided by gramophone records and latterly by broadcasting, is at a disadvantage compared with multichannel stereophony, such as is possible in the cinema, in that the full intended effect is apparent only to observers located within a restricted area in front of the loudspeakers. From time to time, special loudspeaker arrangements to overcome this difficulty have been described in the literature, but these have been only partially successful and the subject has never been fully explored. Early in 1958, Research Department carried out some preliminary experiments utilizing the special directional properties of electrostatic loudspeakers acting as dipoles, but further work in this field had to be deferred pending the solution of the more pressing problems arising in the generation and transmission of stereophonic signals. However, a recent demonstration of two-channel stereophony at the G.E.C. Research Laboratories, in which an unusual loudspeaker arrangement was employed in an attempt to increase the usable listening area, has stimulated interest in alternative methods of stereophonic presentation. In reporting on this demonstration, and on Research Department tests arising out of it, it therefore seems appropriate to discuss the subject in general terms and to review the various alternatives.

2. GENERAL

The principal problem in the presentation of two-channel stereophony arises from the fact that if the observer moves away from the centre line of the system, the sound image in general will be displaced. This displacement, which results from changes in relative level and arrival time of sound from the left- and right-hand

loudspeakers, is greatest for images which are intended to appear in the centre of the stage; images at the extreme left or right of the stage are produced, with present-day microphone techniques, by one or other loudspeaker operating virtually alone, and apart from small displacements arising from wall reflections, their location can be made substantially independent of the observer's position. For this reason, attempts at improving the stereophonic presentation are usually directed at keeping the central images in place, since if the left, right and central stage positions are independent of the location of the observer, the errors in the intermediate positions are not likely to be serious.

3. SYSTEMS EMPLOYING MORE THAN TWO LOUDSPEAKERS

One possible method of reducing the effect of the observer's position is to provide a central loudspeaker, preferably placed forward of the other two,[1] supplied with the sum of the signals in the left- and right-hand channels. In a more elaborate variant on this scheme described by Kuhl,[2] an additional pair of loudspeakers is mounted in the centre of the stage, one, facing half left, supplied from the left-hand channel and the other, facing half right, supplied from the right-hand channel. The performance of both these arrangements necessarily falls short of that achievable with a central loudspeaker connected to a third stereophonic channel. For example a signal which appears in, say, the left-hand channel only, and which should therefore produce a sound on the extreme left of the stage, is in fact applied to both left and centre loudspeakers, thus producing an image at some intermediate point; the effective stage width is therefore less than the distance between the outer loudspeakers. It should, however, be pointed out that even if it were practicable to provide a third stereophonic channel connected to a central loudspeaker, this channel would in principle be redundant, since all the information necessary to indicate the intended image position is already present in the left- and right-hand channels. If it were possible at the receiving end of the system to carry out a running cross-correlation process between the left- and right-hand signals, to extract all components common to both and apply them to a central loudspeaker, a central image independent of the observer's position could be obtained without the transmission of additional information. The equipment required to perform such an operation however would be comparable in its complexity with that used at the transmitting end of the E.M.I. Percival coded stereophonic system,[3] which performs - with only partial success - a somewhat analogous function.

4. SYSTEMS EMPLOYING TWO LOUDSPEAKERS

For domestic sound reproduction, the use of more than two loudspeakers is open to objection on grounds of inconvenience and cost; any possible refinements of the two-loudspeaker arrangement are therefore of special interest.

It has long been known that if the left- and right-hand loudspeakers are pointed slightly inward instead of forward, their directional properties can be turned to good account in stabilizing to some extent the position of a central image for an observer located beyond the point of intersection of the two axes. Suppose, for example, that such an observer, starting from a central position, moves a little to the right; he then comes nearer to the axis of the left-hand loudspeaker and

further from that of the right-hand one. If the loudspeakers are directional, the level of sound received from the left will increase relative to that received from the right, an effect which by itself would bias the image position towards the left. On the other hand, the sound from the right will reach the observer first, and this difference in arrival time would by itself produce a right bias. Over a certain range of frequency and observer displacement, the two opposing tendencies can combine to keep the image in its proper position.

Unfortunately, the compensating process described above produces in practice a somewhat ill-defined image for the off-centre observer. The relationship between difference in time of arrival and the resulting image displacement depends to some extent on the nature of the sound, so that steady and impulsive sounds are displaced by different amounts.[4] In addition, the directional characteristics of loudspeakers vary with frequency; if therefore the observer moves off centre, the relationship between the levels which he receives from the two loudspeakers is a function of frequency, so that the various components of the stereophonic image, instead of being concentrated at one point, are dispersed. The image presented to an off-centre observer is therefore perceived, not as a clearly located source, but as a sound which is distributed over a certain region on the stage or moves about according to the note being played; these effects are in fact similar in cause and character to the pseudo-stereophonic phenomena which can be produced by applying a monophonic signal to the left- and right-hand channels of a stereophonic system through appropriate electrical networks.[5]

To avoid undue loss of definition in the stereophonic presentation, attempts to compensate for observer movement are usually confined to inclining each loudspeaker axis inwards by 30° to 40°. It may however be argued that from the point of view of the off-centre observer, loss of clarity is preferable to having all nominally central images displaced to one or the other side of the stage, and that the compensation should be carried further. It is therefore of interest to consider what happens when the angle between the loudspeaker axes is increased up to the limiting value of 90°, i.e. where the two loudspeakers face one another across the room.

The directivity of the single-unit type of loudspeaker provided in most domestic equipment increases so rapidly with frequency that at the listening distances normal in stereophonic presentation the change in quality and the decrease in the ratio of direct to reverberant sound experienced by the observer on moving off axis is very noticeable for angles greater than about 45°. For any arrangement involving listening at a still greater angle to the loudspeaker axis, therefore, it is desirable, to avoid an unduly distant effect, to employ loudspeakers having separate high-frequency units of relatively small dimensions, and hence lower directivity, and to operate in a relatively dead acoustic environment.

5. G.E.C. DEMONSTRATION

In the demonstrations of stereophony recently given at the G.E.C. Research Laboratories, both of the above requirements were met. The G.E.C. demonstration room is treated with sound absorbent material on the upper part of the walls and on the ceiling; the resulting acoustic absorption, together with that contributed by the carpet, reduces the reverberation time to well below that of the average listening

room. The loudspeakers used incorporated 8 in (20 cm) low-frequency units, together with high-frequency units similar to those in use in the LSU/12A and LS3/1.[6] No information on the directional characteristics of the G.E.C. loudspeakers is available, but from the geometry of the radiating system it is clear that the directivity pattern must be similar to that of the LSU/12A in the horizontal plane but appreciably narrower in the vertical plane; the high-frequency units were mounted lower than is usual, being about one foot (30 cm) below the ear level of a seated observer. During the demonstration given to members of Electro-Acoustics Group, the loudspeakers were first turned inward by some 80°, and later turned completely inward to face one another without any further change in general effect being evident.

With the arrangement described above, which for convenience will be referred to as the face-to-face position, the stereophonic presentation from the point of view of a centrally seated observer was in the main satisfactory, though the quality was rather more reverberant than usual and lacking in high-frequency response. However, because of the relatively high directivity and low position of the loudspeakers, the high-frequency loss for a standing listener was considerable and, perhaps on this account, the stereophonic images observed in a standing position, even on the central axis of the system, were not sharp. For a seated observer, the zone within which the location of nominally central images was sharply maintained was no wider than with the same loudspeakers disposed in the conventional way; outside this zone, however, the central image, instead of simply moving over to extreme left or right with movement of the observer, became progressively dispersed, eventually occupying about half the stage width. Thus, as long as the stereophonic programme included sufficient material originating on the extreme right and left as well as in the centre, the stage was kept well filled for a wide range of listening positions. For observers situated off centre, anomalous movement of sound sources was apparent, chiefly in operatic and dramatic excerpts; whether in such a case the means adopted to keep the stage filled represent the greater or the lesser of the two evils is a matter of individual taste.

6. RESEARCH DEPARTMENT TESTS

Following the demonstration heard at the G.E.C. Laboratories, an attempt was made to reproduce the same effects at Kingswood Warren. Of the two listening rooms available, the less reverberant (that of the Audio Frequency Section) was chosen, as giving conditions nearer to those of the G.E.C. demonstration. The loudspeakers were of the LSU/12A type mounted on turntables to permit rapid re-orientation; as already pointed out, the directional characteristics of these loudspeakers in the horizontal plane are comparable with those of those used in the G.E.C. demonstration. The high-frequency units of the loudspeakers were at the normal height of 3·5 ft (1·1 m) above the floor so that there was little difference in the quality observed by standing and seated observers. Electrical equalization, giving a rise in gain of 4 dB at 10 kc/s, was switched in as required to offset the high frequency loss observed with the loudspeakers in the face-to-face position. On turning the loudspeakers inwards by angles varying between 80° and 90°, the effects previously noted in the G.E.C. demonstration were observed, with the difference that because of the higher proportion of reverberant sound the reproduction was more distant in character, while even the images observed from a central position were blurred.

7. CONCLUSIONS

In assessing the merits of a loudspeaker system for broadcast monitoring, it is necessary to consider the performance as judged in the optimum listening position, i.e. in the centre; if this performance is inferior to that obtainable with the best existing arrangements, the system, whatever its other advantages, is unsuitable for monitoring purposes. In the heavily damped G.E.C. demonstration room the face-to-face loudspeaker arrangement was capable of giving an acceptable presentation for a centrally seated observer. However, in the more realistic environment provided by the Kingswood Warren listening room, which is designed to simulate domestic listening conditions, the result obtained was at its best inferior to that presented to a central observer by a pair of loudspeakers disposed in conventional fashion. The face-to-face arrangement cannot therefore be recommended for broadcast monitoring purposes; its employment by the individual listener is a matter of taste.

From the Research Department experiments with electrostatic loudspeakers, referred to earlier, it would appear that with angles greater than 90° between the loudspeaker axes, better results could be obtained by employing loudspeakers which are directional even at low frequencies, thus avoiding the excessively high ratio of reverberant to direct sound which is a limiting factor in this type of presentation. The achievement of suitable directional characteristics within the aesthetic and economic limitations applying to domestic equipment will however require a much greater research effort than either the Corporation or the radio industry have so far been able to devote to the subject.

Comparison between alternative forms of stereophonic presentation is hampered by the lack of appropriate numerical criteria for the total effect. It would be possible, for example, though only by laborious subjective tests, to assign a figure of merit for the sharpness of an image and another figure for the degree to which the image position approximates to that intended; but the resulting data would still be of limited value, since some observers may prefer a dispersed image to a false position. Whatever criterion is adopted, however, it will always be necessary to distinguish between those reproducing systems which under practical conditions make the stereophonic presentation uniformly good over the listening area and those, like the "face-to-face" arrangement, which make it uniformly bad.

8. REFERENCES

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