Nov. 27, 1962

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STEREOPHONIC SOUND DISTRIBUTOR

Filed March 10, 1958

2 Sheets-Sheet 1

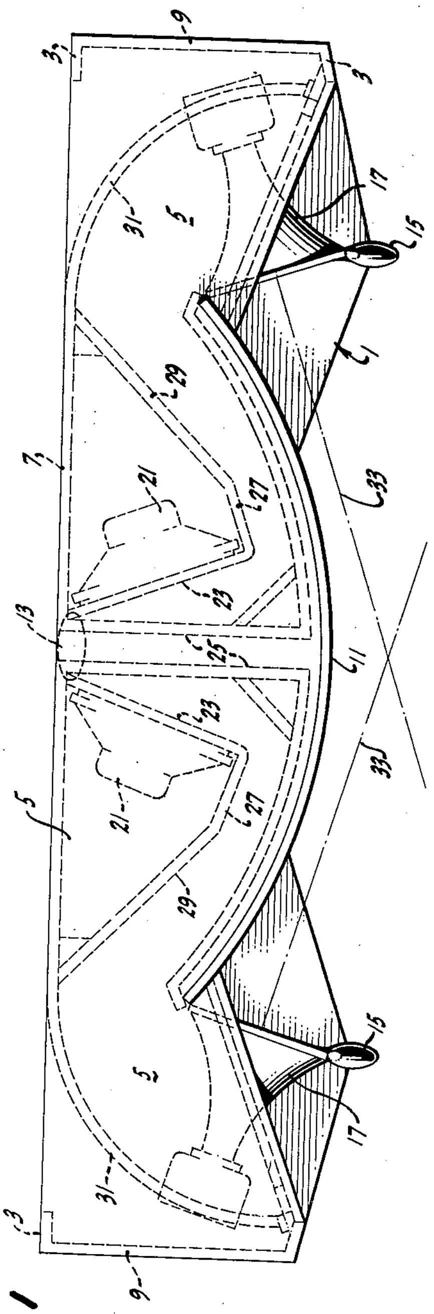

FIG-1

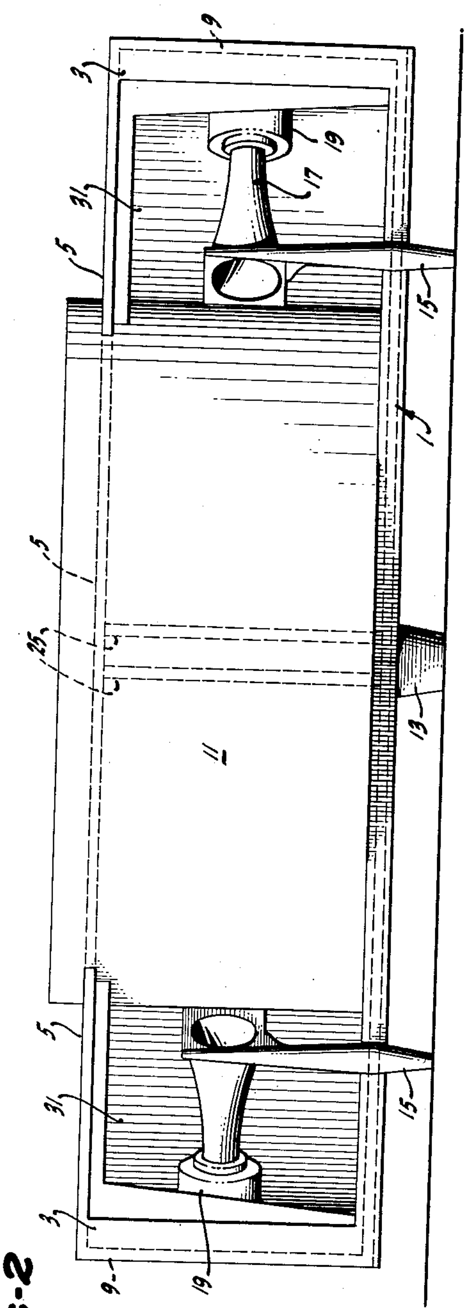

FIG-2

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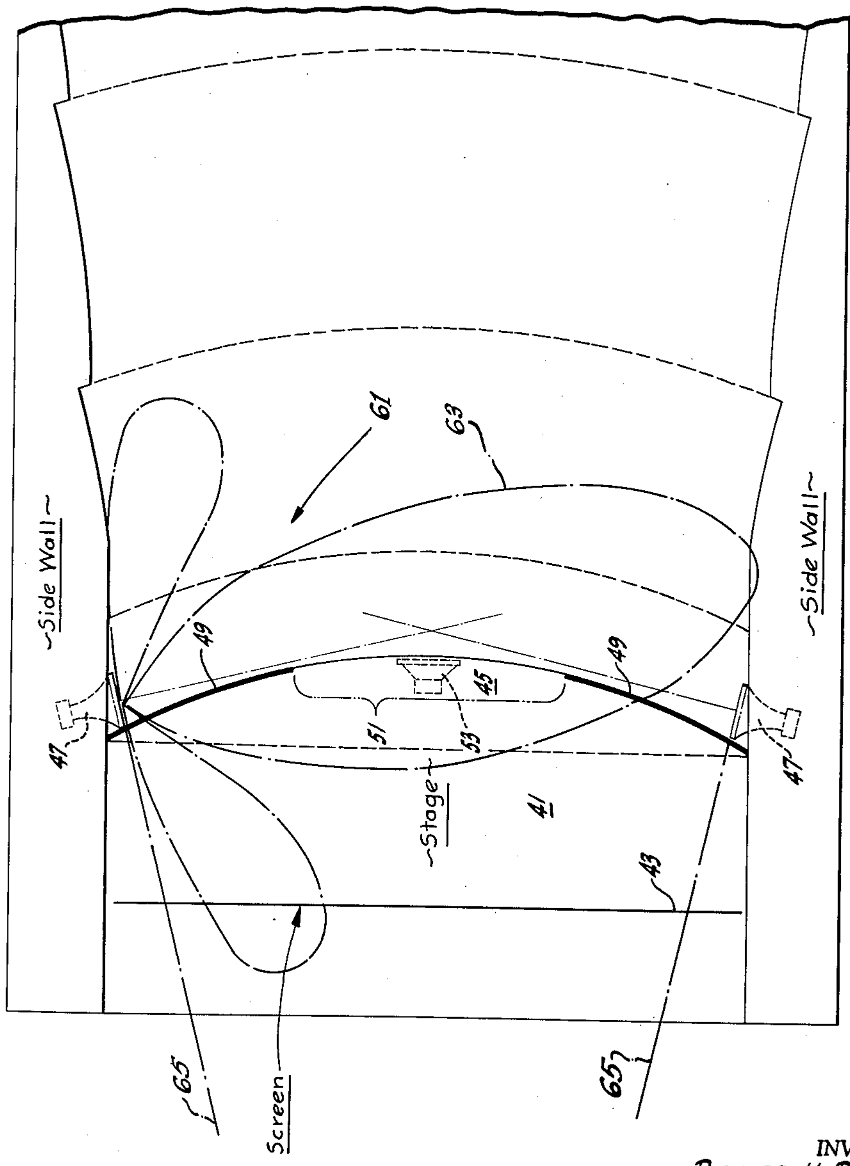

FIG-3

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United States Patent Office

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STEREOPHONIC SOUND DISTRIBUTOR

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This invention relates to stereophonic sound distribution apparatus. The principles involved in its use are applicable to both the pick-up of sound for recording stereophonically and for the projection of sound so recorded. Because its utilization in projection of previously recorded sound is generally so much more widespread than use in the reciprocal manner, the invention will be described primarily as applied to reproduction. It will be understood, however, that because almost all sound reproducers can also be used as microphones for the pick-up of sounds, their characteristics as regards directivity and frequency response being the same when used in either fashion, explanations based upon the radiation pattern of loud-speakers are equally applicable to the sensitivity patterns of microphones.

By "stereophonic sound" as used herein, is meant sound so projected or distributed that it appears to emanate from more than a single position in space, e.g., so projected that when a speaking actor moves from one side of a stage or screen to the other, or advances or retreats, his voice appears to move with him instead of its location being fixed at a position of a single reproducer, or in the case of an orchestra, the sound of the string section appears to emanate from one side of the stage or room while that of the brasses appears to emanate from the other. It is now recognized that such stereophonic effects add grealy to the illusion of "presence." As the sense of direction from which sound appears to come is almost entirely due to the binaural effect—the difference in phase or loudness of the sound as perceived by the two ears of the auditor—to produce the true sterephonic effect requires, in the case of recorded sound, at least two microphones, picking up sounds that differ in loudness as between their various components, recordings made on two individual sound tracks and reproduction from at least two spaced loud-speakers. With this minimum of two complete sound channels, an auditor located substantially on the median line between the two reproducers obtains an excellent stereophonic effect. If he moves more than a short distance from either side of the median line, however, the point of origin of the sound appears to move with him toward the nearer of the two reproducers and it has been found that to get really good sterephonic sound, the point of origin whereof appears to remain substantially constant when the auditor moves, has required at least three complete sound channels, using an intermediate reproducer located substantially midway between the other two.

Experiment has proved that the binaural effect or sense of directivity is derived almost entirely from the higher frequency components of sound within the audible range. The frequency at which it begins to become apparent is not sharply defined and depends to a degree upon the individual characteristics of the auditor. In general, however, the sense of directivity becomes quite appreciable at frequencies in the neighborhood of 500 cycles per second. It increases gradually with increasing frequency up to substantially the limit of the audible range.

The sense of directivity is due to two cooperating factors. The first of these is differences in loudness of the sound as it reaches the two ears of the auditor; the second is difference in phase. Low pitch sounds of long wavelength are readily defracted, i.e., they cast no sharp

"shadows" so that they are heard nearly as loudly in both ears, even though they may proceed directly toward one side of the head of the listener. Further, the phase difference between the sound striking the two ears is very slight in the case of low pitch, long wave sound. Moreover, ordinarily reproducing installations are mounted at the side of a room which the listener faces, more or less as he would a stage, so that the paths traversed by the sound in reaching his ears are not greatly different in length and the phase difference is still further reduced. The difference in loudness is the more important of the two effects, but they appear to work together up to frequencies where the wavelength of the sound becomes quite short in comparison with the distance between the two ears, at which point the sound shadows become very sharp and the differences in phase become indeterminate.

The broad purpose of the present invention is to provide a sound distributing system which takes advantage of these facts to produce the full sterephonic effect utilizing two channels only, giving to an auditor in any part of an area in front of the projector the illusion that the point of origin of the sound is at a definite fixed position in spite of the fact that he may be located nearer to a transducer on the opposite side of the equipment. Conversely, when used for pick-up purposes the same type of structure will properly distribute the sound between two tracks on which it is to be recorded. Contributory to this broad purpose, among the objects of the invention are to provide a sound distributing structure of minimum size which will give the effects referred to and which is applicable for installation in a living room of ordinary size; to provide a type of structure which can be made of such dimensions as to give the stereophonic effect within a large theater; to provide a sound distributing structure which can be made in unitary form and which is adaptable to the mounting of transducers of various types, in accordance with the tastes and preferences of a purchaser; and to provide sound distributing structures which can be constructed in portable form to become an attractive piece of furniture for installation in any room and that does not require to be "built in" or require structural changes in the room wherein it is installed.

It is well known that electro-acoustic transducers always have some degree of directivity. In general the degree of directivity depends upon the frequency of the sound and the dimensions of the sound radiator or pick-up, as the case may be, the "radiator" as here used being the diaphragm in transducers of the hornless type or the mouth of a horn where one is used. For sounds having wavelengths that are long in comparison with the dimension of the radiator, the directivity is practically nil, i.e., the polar response diagram is either substantially spherical or if the radiator is mounted in a wall or other baffle, hemispherical. As the wavelengths become shorter than the dimension of the radiator directivity becomes more and more pronounced as the ratio of radiator dimension to wavelength increases. Unless special precautions are taken to avoid this effect the polar radiation diagram of substantially any loud-speaker, plotted for frequencies in the upper portion of the audible range, will have an elongated major lobe, the axis whereof is perpendicular to the plane of the radiator. There may or may not be additional minor lobes located on either side of the major lobe, but these are not usually perceptible to a listener. Horn radiators are slightly less directive than open cones but the difference is minor. In non-sterephonic sound distribution systems this directive characteristic has the result that auditors seated on or nearly on the axis of the sound projector will hear the full gamut of the reproduced sound, whereas those sitting materially to one side of the axis will hear the higher reproduced frequencies at decreased relative volume or lose them altogether. In such simple systems, the directive properties of transducers are therefore a disadvantage; in accordance with the present invention the directive properties are utilized to achieve the stereophonic effect.

In accordance with the present invention there is provided a sound distributing structure comprising a sound distributing structure comprising a sound reflecting surface in the form of a sector of a cylinder having a vertical axis. The material of the cylinder may be metal, wood, plastic or any other smooth, unyielding material and the total arc subtended by the sector will, in general, be in the range between a quadrant and an octant. On either side of the reflector there are provided means for mounting one or more transducers, the response patterns whereof have an elongated major lobe for frequencies in the upper portion of the aiudible range. The mountings are so positioned that the axes of the major lobes intersect on the median line between the two transducers at or a short distance in front of the reflecting surface, i.e., they intersect at an obtuse angle.

In the usual case, where the transducers are loud-speakers they may take any of the conventional forms. Thus, for example, a single dynamic cone loud-speaker that is relied upon to reproduce all of the frequencies within the range of the apparatus has the necessary sound distribution characteristics as far as the high frequencies are concerned. In other, more elaborate systems, whereing "woofers" are used to reproduce the low frequencies and "tweeters" to reproduce the higher ones, only the tweeter need be mounted as described. In the latter case, however, it is advisable that the cross-over point, at which the sound intensity radiated by woofers and tweeters is equal, should be in the neighborhood of 500 cycles, where directivity becomes clearly perceptible; if the cross-over point is materially higher than this, the woofers also should preferably be directed in the same manner as the high frequency equipment.

The dimensions of the apparatus may vary widely, depending upon the size of the room in which the apparatus is to be used. For general residential use it has been found that a reflecting surface in the neighborhood of five feet wide and from two to two and a half feet high is sufficient to produce the stereophonic effect throughout the largest sizes of living-room ordinarily encountered. In a large and deep theater or auditorium the reflecting surface can be extended across substantially the entire width of the room. In such large structures the central portions of the reflecting surface can be omitted, since reflection does not occur in material degree from this portion of the structure. The woofers can be placed at this point facing directly outward, with perceptibly interferring with the stereophonic effect.

The invention will be better understood by reference to the detailed descriptions of certain embodiments of the invention which follows, the description being illustrated by the accompanying drawings wherein:

FIG. 1 is a plan view of a sound distributing system in accordance with this present invention, embodiment in a cabinet or enclosure adapted for residential use;

FIG. 2 is a front elevation of the distributor illustrated in FIG. 1;

FIG. 3 is a plan view of an auditorium showing the location of a sound distributor in accordance with the invention

The sound distributor illustrated in FIGS. 1 and 2 includes a cabinet or enclosure comprising a base or floorboard **1**, from which there rise corner posts or struts **3** that support a topboard or cover **5**. Closing panels **7** and **9** may be supplied at the back and ends for dust-exclusion and appearance but they are not operational elements of the invention. The major portion of the front of the structure is closed by a convexly curved sound reflector **11**. In the equipment shown this is formed of plywood, bent into the arc of a cylinder having a vertical axis.

The structure is mounted upon three short legs including a center leg **13** at the rear and two front legs **15** at either side. Each of the front legs is carried up to approximately the level of the center of the reflecting surface to form the support for one edge of the horn **17** of a high frequency transducer or tweeter **19**. The other edge of the horn is supported at the edge of the reflector **11**. A hornless cone tweeter could be used mounted with the plane of support of the cone in the same position as the mouth of the horn.

In the apparatus shown, the space within the enclosure behind the reflector is used to form folded horns for low frequency transducers or woofers **21** of the dynamic, free-cone type. As may be seen in FIG. 1, each woofer is mounted on a baffle **23**, extending between the floorboard **1** and the cover **5**. The baffle **23** is positioned at a relatively sharp angle facing a vertical septum **25** that divides the enclosure into two symmetrical halves and forms, in effect, the throats of the folded horns which increase gradually in cross-section from the throat to the edge of the reflector, the latter thus becoming also one edge of the mouth of the horn. The rear walls of each horn are formed by further barriers **27** and **29**, also extending from bottom to top of the enclosure and set at increasingly large angles to the opposing face of the reflector that forms its front wall. The barrier **29** terminates at the read of the enclosure where it is joined by a curved barrier **31** terminating approximately at the strut **3**, to form the opposing edge of the mouth of the horn.

It will be noted that in this instance the dual horns thus formed face generally outward; the mouths of the horn forming the radiators have axes pointing generally outward and intersecting rather far in front of the reflector. In the particular apparatus described here this arrangement is dictated rather by mechanical convenience than by stereophonic considerations since the woofers employed cut off at 500 cycles and contribute little to the stereophonic effect. Were the cut-off or cross-over points of the woofers employed higher in frequency, it would be better to carry the horn mouths farther around so that the axes of the radiation patterns would intersect more closely in front of the reflecting surface.

The important feature of the arrangement is the mounting of the tweeters. Those illustrated have elliptical horns, mounted with the major axes of the ellipses in a horizontal palne. Their radiation patterns are therefore much more directive in the horizontal plane than they are in the vertical one (the radiation pattern of one tweeter **47** being shown at **61** in FIGURE 3, with an elongated major lobe **63**). This is desirable as it makes the sound distribution better vertically and more nearly the same for seated or standing auditors or for listeners of different heights. The axes of the radiation patterns of the tweeters are indicated by the dot-dash lines **33**. It will be seen that these axes intersect in the median plane between the two tweeters, a few inches in front of the surface of the reflector. For purposes of illustration, and not by way of limitation, it may be stated that the total chord width of the reflector **11** in the apparatus described is 63 inches, and the point of intersection of the axes of the radiation pattern is about 2 inches in front of the center of the reflector. The total arc subtended by the reflector is about 70°, its radius of curvature being approximately 45 inches. None of these dimensions is critical. A larger arc, corresponding to a shorter radius of curvature of the same width of reflector, results in a deeper zone wherein the stereophonic effect is apparent, a smaller arc makes the zone shallower; on the other hand, a shorter radius of curvature tends to narrow the zone and vice versa.

The positioning of the transducers, particularly as regards to the angle at which they are set, depends in part on the shape of their radiation patterns in the upper region of the audible range. The elongation of the major lobe of these patterns does not begin to become apparent until the size of the radiator exceeds a half wavelength of the radiated sounds. For the purpose of analysis the origin of the sound can be considered as the center of the radiating area. It is therefore clear that the axis of the radiator must be displaced outwardly from the edge of the reflector. Reflection of sound follows the same rules as that of light, in that the angles of incidence and reflection are equal. Considering, for simplicity, that the source of the radiated sound is the center of the horn mouth, it will be seen that the reflection from the surface of the element 11 close to the mouth of the horn will be transverse to the axis of the distribution pattern, while that striking the reflector farther and farther from the horn will become closer and closer to the axis until the point of tangency is reached and no reflection will occur.

The effect of this is to increase the apparent loudness of the sound from the horn to an auditor positioned in front of the distributor and on the same side as the horn. Furthermore, it scatters the beam of sound more widely with respect to people on the opposite side of the equipment. The inverse square law, as to relative intensity of sound at varying distances from the mouth of the horn, still obtains, as long as one considers the actual path traversed by the sound and measures the distance along a single sound "ray."

A pair of crossed directional reproducers, mounted as here shown and described, but without the intervening reflecting surface, will give the stereophonic effect to auditors within a very limited zone centered on the axes of the major lobes of their response diagrams, just as will a single pair of transducers facing outward toward the auditors but like the latter arrangement the zone is highly restricted. The present device both widens and deepens the zone within which the effect is strongly apparent.

It should be realized that the stereophonic effect is an auditory illusion having subjective as well as objective aspects. Both aspects are important. Objectively, the effect will vary to some extent with the radiation pattern of the transducers used, as well as with the size of the structure in comparison with the size of the room in which it is to be used, the degree of convexity of the reflecting surface and the angle between the axes of the transducers at their point of intersection. It is this latter factor that is most important, although there is a considerable degree of latitude even as to this parameter. It has been found that the planes 65 (FIGURE 3) of the sound radiators—the mouths of the horns or the mountings of the cone diaphragms—should make a sharper angle at their point of intersection than do the radii of the reflector drawn from its reflective edges, where it intersects the planes of the radiators. The axes of the transducers should therefore come very nearly tangent to the surface of the reflector, as shown in the drawing. Once a type of transducer has been determined upon and mounted in approximately the relationship shown in the drawing, very little experiment will indicate the angle giving the widest zone wherein the stereophonic effect is apparent. In general, too obtuse an angle of intersection between the axes of the transducers narrows the zone of stereophonic perception less than does too acute an angle. Thus, if the two transducers are set with their planes more nearly parallel so that their axes become tangent to the surface of the reflector or even intersect in the reflector surface on the median line, good stereophonic results can still be obtained throughout nearly as wide a zone as if set as shown, whereas if the transducers are set so that their radiating planes are on radii of the reflector, the latter has little effect and the zone of stereophonic effect becomes nearly as limited as if the reflector were absent. The differences between transducers are, however, minor and the general arrangement shown has been proved to be satisfactory even with relatively large differences in scale. What may be called the "stereophonic zone" occupies an area extending laterally two to three times the length of the structure and somewhat more than this distance directly in front of it. With the dimensions here shown this is sufficient to fill even a very large living room.

In the experimental determination of the best arrangement for a given size and curvature of reflector the same signal, preferably of mixed frequency, is supplied to both high-frequency transducers. The resulting sound should appear to come from the mid-point of the structure to an observer at a distance of from one to three times the separation of the transducers in front of the device, and at a distance to one side of its median line at least as great as that of the transducers. If the transducer axes intersect at too obtuse an angle the sound will appear to come from the farther of the two; if the angle is too acute it appears to come from the nearer one. The range of adjustment for any curvature of reflector is quickly and easily found and the stereophonic effect, for sounds of unequal intensity from the two transducers follows.

The stereophonic effect becomes gradually less apparent, of course, as the distance from the sound distributor increases. At extreme distances where the total angle subtended by the entire structure becomes only a few degrees, the differences in both phase and loudness of the sounds as they strike the two ears of the auditor become very slight indeed and the whole arrangement becomes, in effect, a "point source" of sound. At normal listening distances, however, the arrangement has the property of apparently separating the sound sources more widely than the transducers themselves are separated.

It follows from what has been stated above that a relatively small device such as has been described in connection with FIGS. 1 and 2 is not suitable for a large sized auditorium or theater. To increase both the width and the depth of the stereophonic zone so as to fill a theater an arrangement such as is shown in purely diagrammatic form in FIG. 3 can be adopted. This figure shows the plan of a typical motion picture theater, indicating the position of the stage 41, the plane of the screen 43 and the curved apron 45 projecting forward from the stage.

In many theaters the edge of the apron is substantially the curvature best adapted to the present invention, which makes it relatively easy to install a curved reflector following its curvature. The high frequency transducers **47** can be mounted on either side of the apron at the base of the reflector **49**, preferably pointing somewhat upward to take advantage of the full height of the reflecting surface, it being noted that relatively little directive effect is observable in the vertical plane and the bottom of the reflecting surface will in some instances be in an orchestra pit below the level of all of the auditors in the theater. To the extent that the high frequency transducers are directive in the vertical plane their upward slant makes substantially no difference as to directivity as this affects stereophonic reception but does prevent undesired reflections from the opposite side of the orchestra pit or any other nearby objects.

In this instance the reflector **49** is interrupted in the center beyond the point at which the transducer axes approach it most closely, leaving a gap between their edges, the points indicated by the bracket **51**. The woofers can be mounted in this gap if desired, or they can be mounted above and either side of the screen without destroying the stereophonic effect, provided the cutoff is sufficiently low, not above approximately 500 cycles. Alternatively, they can be mounted in the same position as shown for the tweeters **47** if they radiate any material energy in the upper portion of the band of audibility.

It should be evident that the invention may be embodied in numerous ways other than the two typical ones described. For example, in motion picture theater constructed without the typical stage apron or orchestra pit of theaters intended for stage productions, an entirely separate reflecting structure can be installed below or even above the screen. At the other end of the dimensional scale more compact structures than that here illustrated can be used; a considerably portion of the width of the equipment shown in FIGS. 1 and 2 is taken up by the mouths of the woofer horns. If, for example, a single cone-type transducer is employed in each channel instead of the high and low frequency units illustrated, these units being mounted in the positions occupied by the tweeters in the figures, the length of the equipment will be shortened materially, since in this case it is only necessary to provide enough space behind the transducers to baffle and absorb the waves from the back of the cones without setting up unpleasant resonances.

The greater the width of the reflector, the larger the area in which the stereophonic effect is apparent. As the effect is an illusion the sense of position or apparent position of the sound source as reported to the ear of the listener will be rejected if strongly negatived by his other senses; he may sense that the sound to which he is listening emanates from either side of the wall of the room which he faces, but he will tend to reject the idea that it comes from more widely separated points than these. The effect is subjective and differs as between auditors. Tests indicate that most subjects, listening with closed eyes, obtain a sense of source position extending beyond the limits of the curved reflector; therefore, in a small room reflector narrower than that here described—approximately five feet—will give fairly satisfactory results. The minimum width that will give a satisfactory illusion to most subjects appears to be in the neighborhood of three feet but because the effect is subjective and varies with different subjects no definite limits can be set.

The directive properties of both binaural hearing and transducer response or radiation are most apparent in the upper portion of the audible range, as has already been pointed out. Very few sounds are pure tones, however, and most sounds recognized as being in the low frequency range are accompanied by harmonics or nonharmonic overtones in the upper, directive range. A listener in most cases recognizes the composite sounds as single entities, and will assign their direction relative to himself as that from which the high frequency components appear to come. Therefore, although it is preferable that the transducers used begin to show directivity at approximately 500 cycles this frequency has been arbitrarily considered herein as the approximate lower limit of the "upper audible range," very marked effects, quite satisfactory to nearly all auditors, can be achieved even if the elongation of the major lobe of the response pattern of the transducers used does not become pronounced until the frequencies radiated become considerably higher than this.

For these various reasons the examples here given are not intended to limit the scope of the invention, but rather to serve as illustrations of typical applications thereof. All intended limitations on the scope of the invention are set forth in the claims.

What is claimed is as follows:

1. A stereophonic sound distributor comprising a sound reflecting member having a convex reflecting surface disposed as the arc of a cylinder about a vertical axis, and a pair of similar electro-acoustic transducers mounted substantially symmetrically at opposite sides of said surface, said transducers each having a directional response pattern including an elongated major lobe and being so mounted that the axes of said major lobes intersect substantially in the medium plane between said transducers in front of said reflecting surface.

2. A stereophonic sound distributor comprising a sound reflecting member having a convex reflecting surface disposed as the arc a cylinder having a vertical axis and subtending an angle within the range between 450 and 90°, and a pair of similar electro-acoustic transducers mounted substantially symmetrically at opposite sides of said surface, said transducers each having a directional response pattern including an elongated major lobe and being so mounted that the axes of said major lobes intersect substantially on the medium plane between said transducers and in front of said convex surface.

3. A stereophonic sound distributor comprising a sound reflecting member having a generally convex surface, and means for mounting a pair of loud speakers symmetrically at opposite sides of said surface with one loudspeaker of the said pair thereof located at each side of said surface so that the axes defined by perpendiculars extending from the centers of the radiators of such loudspeakers intersect at an obtuse angle substantially on the median plane between said loudspeakers and proximate the said generally convex surface.

4. A stereophonic sound distributor comprising a sound reflecting member having a convex reflecting surface disposed as the sector of a cylinder having a vertical axis and subtending an arc in the range between 45° and 90°, and means disposed symmetrically at opposite sides of said sound reflecting surface for supporting a pair of loudspeakers whereby one loudspeaker of the said pair thereof is at each side of the reflecting surface so that the planes of the radiators thereof intersect behind said surface at a smaller angle than that subtended by it and that the axes of said radiators as defined by perpendiculars directed from the centers thereof intersect in front of said convex surface in front of its median plane.

5. A sound distributor as defined in claim 4 wherein the ang'e subtended by said sound reflecting member is in the range between 65° and 75°.

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