United States Patent [19]

Bauer

[11] **3,903,989**

[45] **Sept. 9, 1975**

[54] **DIRECTIONAL LOUDSPEAKER**

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[52] **U.S. Cl.** **181/144;** 181/143; 181/148; 181/175

[51] **Int. Cl.²**. **H05K 5/00;** G10K 7/00; G10K 11/00

[58] **Field of Search** 181/145, 148, 175, 143, 181/144

[56] **References Cited**

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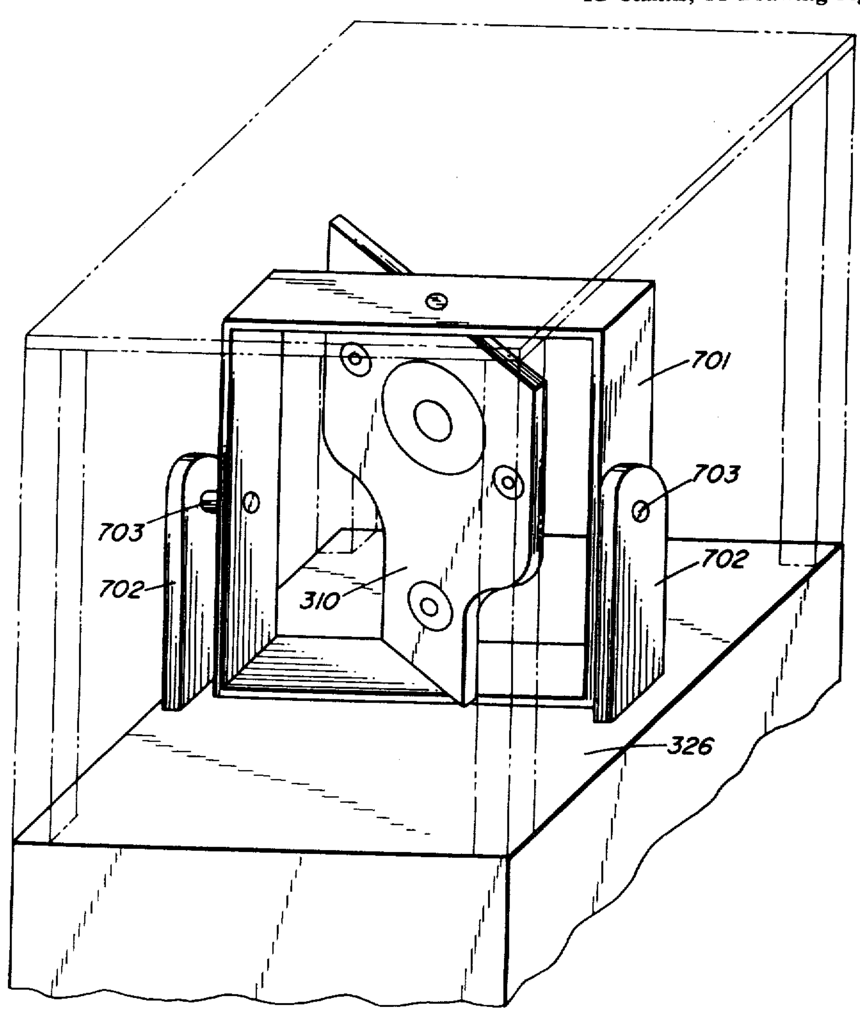
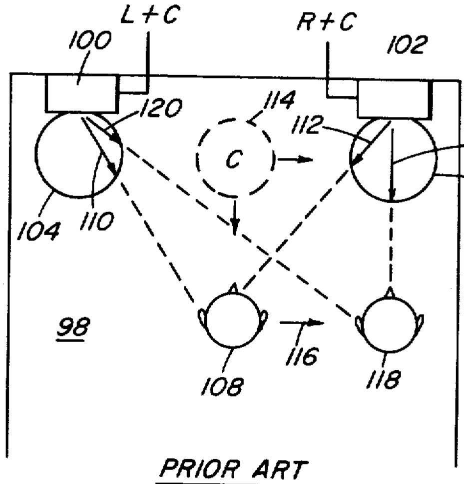
Attorney, Agent, or Firm—Spencer E. Olson

[57] **ABSTRACT**

A loudspeaker system having a cabinet with two compartments, a first of which contains a low-frequency loudspeaker for producing an omnidirectional radiation pattern, and the second compartment, above the first, containing a rotationally adjustable vertically oriented baffle on which are supported additional loudspeaker motors designed to cover the mid- and high-frequency bands of the audio frequency spectrum. The baffle is so shaped and the additional loudspeaker motors located in positions thereon that they operate as high-efficiency gradient or dipole loudspeakers over a significant portion of their respective frequency ranges, whereby the directivity of the loudspeaker system can be controlled by adjustment of the position of the baffle relative to the cabinet.

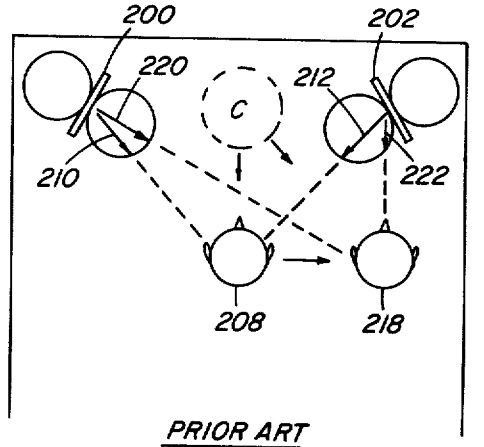
12 Claims, 11 Drawing Figures





PRIOR ART

FIG. 1



PRIOR ART

FIG. 2

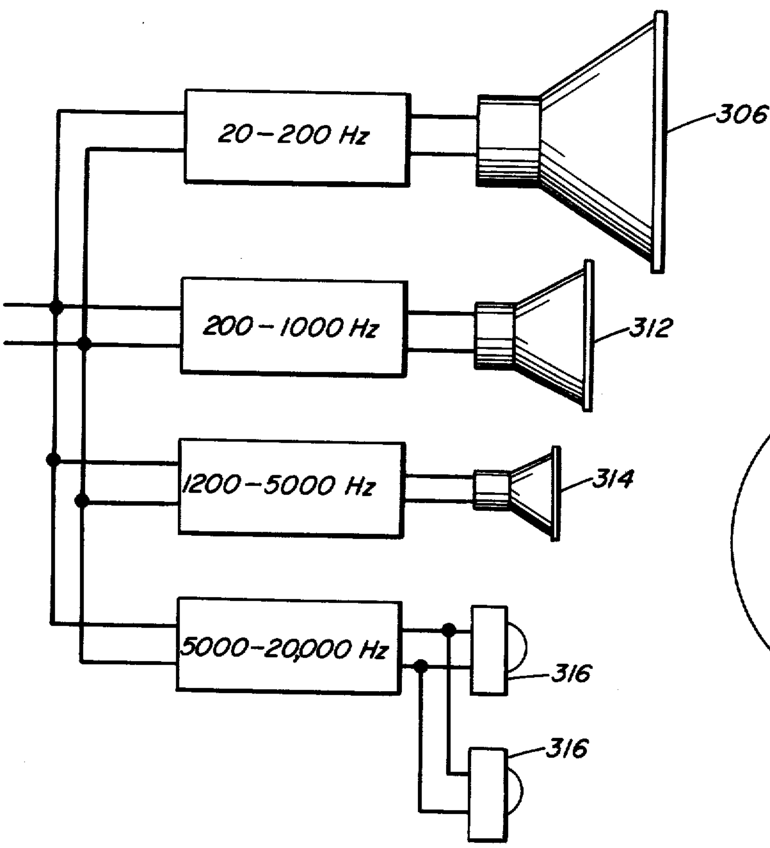


FIG. 5

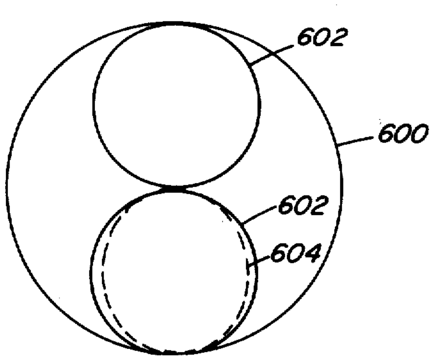


FIG. 6

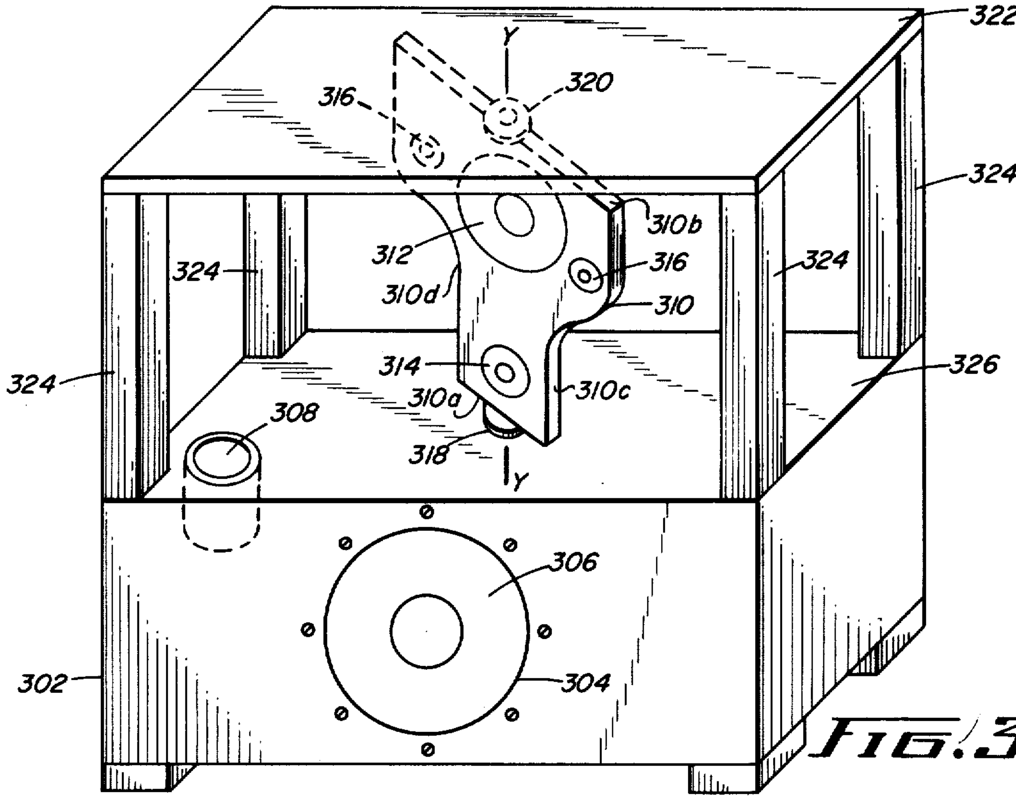


FIG. 3

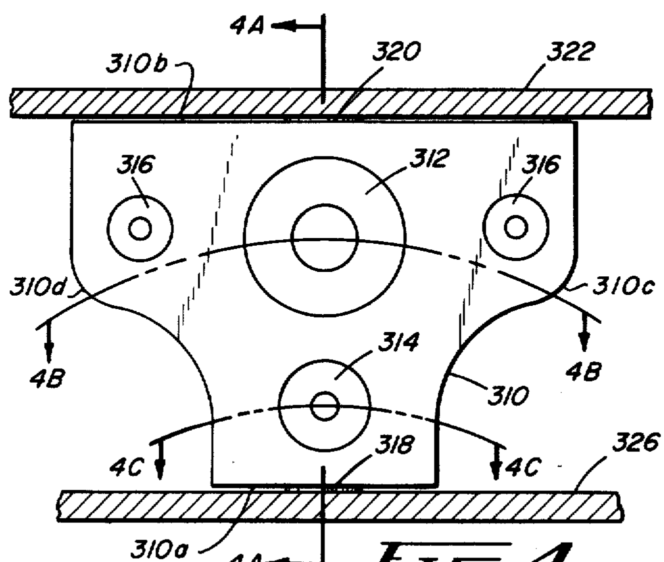


FIG. 4

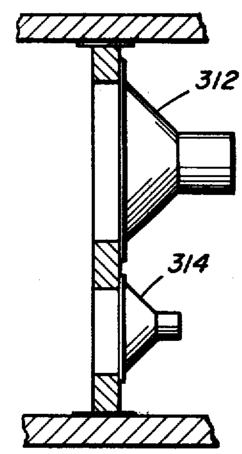


FIG. 4A

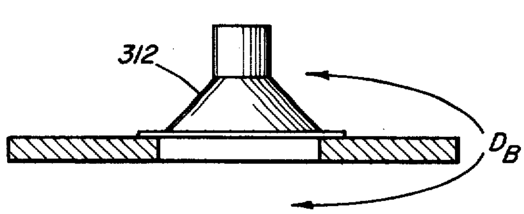


FIG. 4B

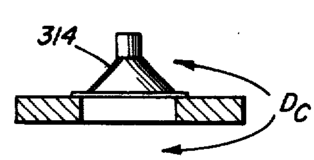


FIG. 4C

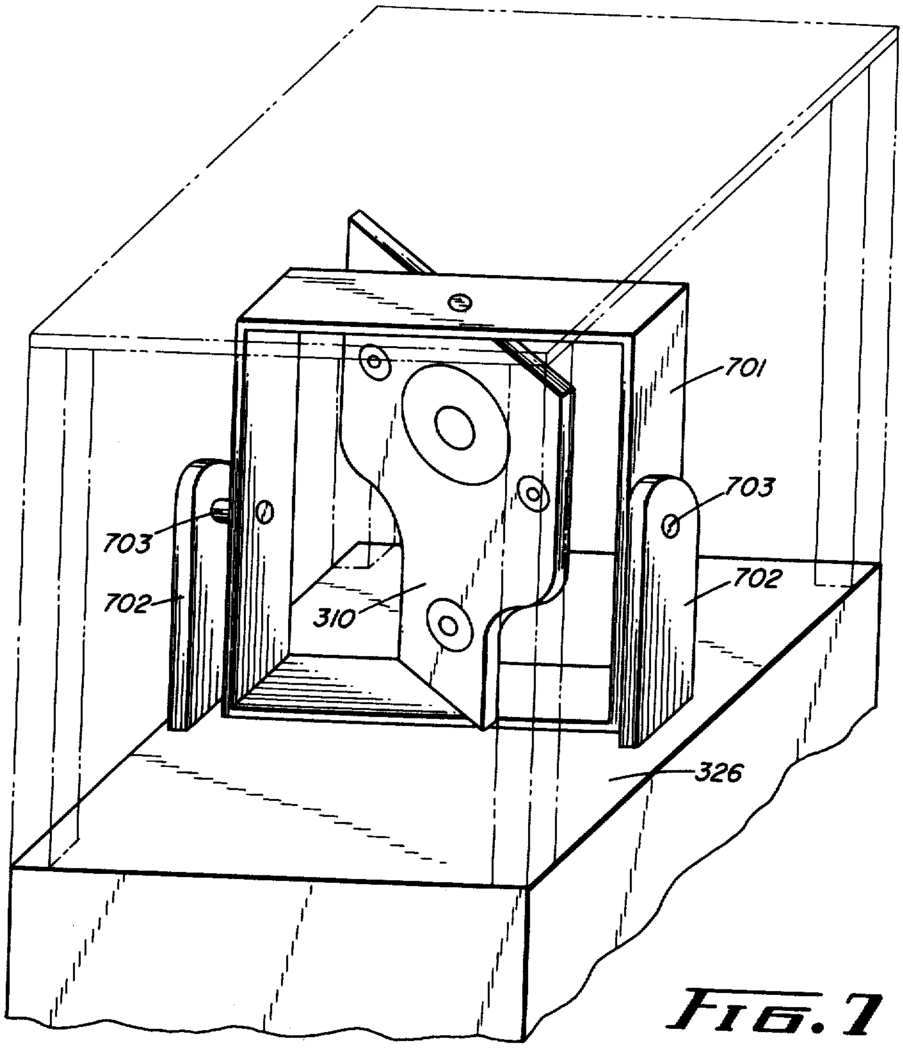

701
703
703
702
702
310
326

FIG. 7

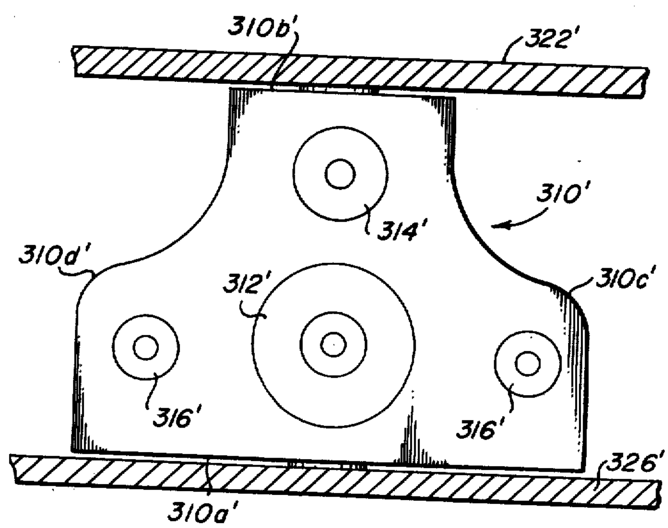

310b'
322'
310'
314'
310d'
312'
310c'
316'
316'
326'
310a'

FIG. 8

DIRECTIONAL LOUDSPEAKER

BACKGROUND OF THE INVENTION

This invention relates to loudspeaker systems, and more particularly to a new and improved loudspeaker arrangement having improved directional characteristics.

It is conventional in loudspeaker systems to divide the audio frequency range of interest between a plurality of individual loudspeaker drivers mounted in a common enclosure, the higher quality systems utilizing a low frequency driver, or "woofer" for the very low frequencies, a smaller driver for the lower mid-range of frequencies, a still smaller driver for upper mid-range frequencies, and one or more "tweeters" for the high-frequency range. Because the wavelengths of the mid- and high-frequency signals are shorter than those of the low frequency signals, the directivity of the mid- and high-frequency signals of any particular drive is sharper than that of the low frequency signals. Accordingly, the sound field produced by an output signal from a given loudspeaker driver is increasingly narrower with increase in the signal frequency, with the consequence that the mid- and high-frequency signals are severely attenuated in directions offset greater than about 30° to 60° from the central axis of the loudspeaker array, depending on the dimensions of the driver and the frequency of the signal. The nature of this problem is described in detail in a paper by applicant entitled "Broadening the Area of Stereophonic Perception" which appeared in the *Journal of the Audio Engineering Society*, Vol. 8, No. 2, pp. 91–94 (1960), and a loudspeaker arrangement representing a solution to the problem is described and claimed in applicant's Pat. No. 3,080,012 assigned to the assignee of the present application. The problem as it applies to quadraphonic reproduction is described in a paper by applicant entitled "Quadrophony Needs Directional Loudspeakers" which appeared in the March 1973 issue of *Audio* Magazine, pages 22, 24, 26 and 30. The present invention being an improvement on the system covered by the aforesaid patent and utilizing the principles described in the articles and patent, portions thereof will here be briefly reviewed as background for a better understanding of the present invention.

FIG. 1 of the drawings shows a listening area **98** in which are placed two loudspeakers **100** and **102** carrying a sterophonic program consisting of left and right channel signals, L and R, applied to the respective loudspeakers, together with a center channel signal, C, which is applied equally to both loudspeakers. As has been indicated above, over an important band of middle and high frequencies, where the ear is sensitive to direction, conventional loudspeakers become directional as portrayed by the graphical plots **104** and **106.** The significance of these graphs is that the length of the radius vector from the center of the front of the loudspeaker to the boundary of the graph indicates the strength of the signal being radiated by the loudspeaker in the direction of the radius vector. When a center signal, C, is applied to both loudspeakers, a listener located at position **108,** in front of the loudspeakers and on a line midway between the loudspeakers, is subjected to equal sound pressures from the respective loudspeakers represented by the vectors **110** and **112.** Therefore, the signal C appears to originate from a point midway between the loudspeakers, as indicated by the dashed line circle **114.** However, if the listener moves in the direction of the arrow **116** to a new position **118,** he now receives a lower level signal from loudspeaker **100** than from loudspeaker **102** because of two factors: (1) the radiation in the direction of position **118** from loudspeaker **100** is now represented by the shortened arrow **120,** while the radiation in the direction of position **118** from loudspeaker **102** is as indicated by the longer arrow **122,** and (2) the distance from the loudspeaker **100** to position **118** is greater than the distance from loudspeaker **102,** thus further increasing the relative difference in sound intensity from the two loudspeakers. In short, to a listener at position **118,** the majority of the sounds from the system will appear to arrive from loudspeaker **102**; this destroys the stereophonic sound stage in between the loudspeakers.

It is demonstrated in the aforementioned references that a significant improvement in the positional freedom of the listener can be achieved by providing the loudspeakers with a circular or similar directional characteristic and by positioning the loudspeakers at an angle of approximately 120° with respect to each other as shown in FIG. **2.** Such a circular characteristic can be provided, over a wide range of frequencies by utilizing a dipole action. A dipole directional action is obtained by mounting a loudspeaker driver in a small baffle so as to enable it to radiate equally backwardly and forwardly of the baffle. Since the motions of the sides of the speaker diaphragm are "out-of-phase" with each other there is a directional component axially of the baffle and sound cancellation sidewise of the baffle, resulting in a "cosine" or "figure-8" radiation pattern. It is seen from FIG. 2 that when two dipole loudspeakers **200** and **202** are used for the left and right signals, respectively, when a listener moves away from the center axis position **208** to the off-axis position **218** the radius vector arrow **220** from the loudspeaker **200** is lengthened somewhat, while the vector arrow **222** representing the signal from loudspeaker **202** is shortened, as compared with the lengths of the respective vector arrows **210** and **212** which apply to the on-axis position **208.** Because of the resulting compensatory effect, the listener hears both loudspeakers at approximately the same loudness, and, moreover, the center signal, C, is heard at equal loudness from both loudspeakers and continues to appear to be in the space between the loudspeakers.

It is seen that the above-outlined solution to the difficulty, unless loudspeaker arrangements of the type shown in FIG. **2** of Bauer Pat. No. 3,080,012 are used, requires that the loudspeaker enclosure be placed at an angle with respect to the walls of the room, which reduces the utility of the room space and deleteriously affects the esthetics of the room, particularly when relatively large speaker enclosures are employed; furthermore, the enclosure is apt to be accidentally moved into incorrect placement during household cleaning. It is therefore a primary object of the present invention to provide a loudspeaker system capable of being harmoniously arranged within the listening room while being adapted for adjustment of radiation directivity, thereby to allow the listener to hear the highest quality of sound regardless of the sharp directivity characteristics of the tweeter and mid-range loudspeakers.

SUMMARY OF THE INVENTION

This and other objects of the present invention are achieved by combining in a single enclosure an omnidirectional high-efficiency low-frequency loudspeaker with one or more high-efficiency gradient or dipole loudspeakers which preserve their gradient characteristics over a significant portion of their respective frequency range. The low-frequency loudspeaker is mounted, for example, in the front wall of a substantially sealed compartment and a plurality of additional loudspeakers, designed to cover other portions of the frequency range of interest, are mounted on a baffle vertically supported in a second generally open-sided compartment, the baffle being mounted for rotational adjustment about a vertical axis relative to the cabinet. The baffle is specially shaped and the mid-and upper-frequency range loudspeakers are mounted in positions thereon such that the baffle complements the frequency range of the respective loudspeakers to thereby produce high-efficiency operation of the additional loudspeakers and desirable directional characteristics for the individual additional loudspeakers. Adjustment of the movable baffle supporting the directional loudspeakers permits the loudspeaker cabinet to be placed in the most appropriate place to suit the room decor while orienting the sound field of the gradient loudspeakers in a direction to achieve optimum acoustical performance. The rotationally adjustable baffle together with the gradient loudspeakers supported thereon are confined between parallel planes to further improve the performance and efficiency of the gradient transducer. The baffle may be pivotally supported on the parallel planes, or may be supported in a frame which, in turn, is mounted on trunnions supported on one of the parallel planes, so that the plane of the baffle may be varied universally. The disclosed loudspeaker system can be used alone, and it is particularly useful in pairs in a stereophonic array for achieving the above-outlined objectives, or in a quadraphonic array.

DESCRIPTION OF THE DRAWINGS

The construction and principle of operation of the invention will be better understood from the following description, taken in conjunction with the accompanying drawings, in which:

FIGS. **1** and **2**, to which reference has already been made, are schematic plan views of prior art loudspeaker system arrangements;

FIG. **3** is a perspective view of a loudspeaker system embodying the present invention;

FIG. **4** is a fragmentary front elevation view of the adjustable baffle of the loudspeaker system of FIG. **3**;

FIG. **4A** is a cross-sectional view taken along line **4A—4A** of FIG. **4**;

FIG. **4B** is a cross-sectional view taken along line **4B—4B** of FIG. **4**;

FIG. **4C** is a cross-sectional view taken along line **4C—4C** of FIG. **4**;

FIG. **5** is a schematic diagram depicting typical ranges of frequencies covered by the various loudspeakers of the system;

FIG. **6** is a polar plot illustrating the polar patterns of the individual loudspeakers utilized in the system;

FIG. **7** is a fragmentary perspective view of the loudspeaker system illustrating a modification of the system of FIG. **3**; and

FIG. **8** is a fragmentary front elevation view of the adjustable baffle of the system of FIG. **3**, showing an alternative mounting thereof.

DESCRIPTION OF A PREFERRED EMBODIMENT

A preferred form of a loudspeaker system embodying the invention, shown in FIG. **3**, consists of a generally cubical cabinet having two compartments: a lower compartment **302** which is essentially a rectangular shaped box closed on all six sides, constructed of wood or other suitable material, and an upper compartment defined by the plate **326** forming the upper surface of the lower compartment and by a cover plate **322**, also preferably formed or wood, supported at its corners by posts **324**. Thus, the upper compartment is closed at the top and bottom but has generally open sides; acoustically transparent grilles or panels (not shown) may be affixed to the walls of the cabinet for ornamental purposes, and felt or similar sound absorbent material may be applied to the upper surface of the plate **326** and to the lower surface of plate **322**, to minimize sound reflections therefrom.

A conventional woofer or low-frequency loudspeaker driver **306** is supported in a hole **304** in the front wall of the lower compartment **302** so as to constitute, when the lower compartment is completely sealed, an "infinite baffle". Alternatively, and as is shown in the drawing, the lower compartment may be provided with an opening or tube **308** communicating with the upper compartment and proportioned relative to the volume of the lower compartment and the acoustical properties of the loudspeaker **306** to provide the desired low-frequency response. It having been experimentally determined that low frequency sounds up to approximately 200 Hz. do not significantly contribute to the sense of direction, the low-frequency portion of the loudspeaker system is designed to be omnidirectional and to perform most efficiently up to a frequency of about **200**Hz. It will be understood that this frequency is not exact and may be selected to have different values, depending upon the application.

The upper compartment encloses the gradient portion of the loudspeaker system, which consists of a specially shaped planar baffle **310** supported in a vertical position between the upper plate **326** of the lower compartment and the lower surface of the cover plate **322** and mounted on suitable pivots **318** and **320** respectively secured to the top surface of the lower compartment and the under surface of cover plate **322** for rotational adjustment about a vertical axis Y—Y, and upon which are mounted, for movement with the baffle, a desired number of loudspeaker drivers, in this example, four. The baffle **310** has parallel upper and lower edges, the lower edge **310***a* being appreciably shorter than the upper **310***b* for reasons which will become apparent, and the upper and lower edges are joined by curved side edges **310***c* and **310***d* located symmetrically on opposite sides of the axis Y—Y. The illustrated curvature of the side edges **310***c* and **310***d* in effect divides the area of the baffle into two generally rectangular zones of different sizes: a smaller zone defined by the lower edge **310***a* and the generally perpendicular portion of the side edges **310***c* and **310***d* extending approximately one-third the vertical height of the baffle, and a second, larger zone defined by the upper edge **310***b* and the remaining portion of the side edges **310***c* and **310***d*.

A loudspeaker driver **312**, designed to cover the lower mid-frequency range of about 200–1000Hz., is mounted in a hole located symmetrically about the axis Y—Y and near the longer upper edge of the baffle. An upper mid-range loudspeaker driver **314**, designed to cover the frequency range of about 1000–5000Hz., is mounted on the baffle directly below loudspeaker **312** so as to be centrally located on the just-discussed smaller zone of the baffle. Two small loudspeakers **316**, tweeters designed to cover the frequency range above about 5000Hz., are symmetrically mounted in the upper larger rectangular zone of the baffle, on opposite sides of the lower mid-range loudspeaker **312**. It is to be understood that these frequency ranges are by way of example and not limitation, and that the specific shape of the baffle and/or the number and location of the loudspeakers upon the baffle need not be symmetrical or as illustrated, but may vary as appropriate for a particular purpose without departing from the spirit of the invention.

Considering the design parameters of the baffle **310** in more detail, the aforementioned Bauer patent teaches that a loudspeaker provided with a small baffle constitutes a suitable dipole radiator for sound energy. It is important to keep in mind, however, that when a loudspeaker is installed in an open baffle, the sounds radiated from the back part of the cone tend to cancel those radiated from the front, making it important that the front-to-back distance defined by the baffle be properly related to the wavelength of the sound being considered so as to avoid undue cancellation. In general, the front-to-back path should be no less than one-sixth wavelength, and no more than three-fourths wavelength; this, in effect, defines that the frequency range handled by a gradient loudspeaker in general should cover a frequency range of approximately 4 to 5:1. It follows that if several loudspeakers, designed to cover different frequency ranges, and to be operated in a gradient manner, are to be mounted on a single baffle, the baffle must be so shaped, and the loudspeakers appropriately placed thereon, that the baffle provides for each loudspeaker the appropriate front-to-back acoustical distance. Applying these considerations to a baffle which will suitably accommodate lower and upper mid-range frequency bands suggested earlier, it is seen that the width of the baffle for the loudspeaker **312**, based on the lowest frequency of 200Hz. (for which the wavelength is 172cm.), should be 172cm./6 = 29cm., or approximately 1ft. On the other hand, for the upper mid-range loudspeaker **314**, for which the lowest frequency is 1000Hz., the width of the baffle should be approximately 2½ inches. It will be understood that these calculations are based on the velocity of sound in air of 34,400cm. per second. Thus, in the illustrative example of FIG. **3**, the upper and lower edges of the baffle are 12 inches and 2½ inches long, respectively, and are joined by side edges that are curved so as to provide the appropriate front-to-back distances for the loudspeakers **312** and **314**. It is, of course, to be understood that these dimensions are appropriate for the frequency ranges assumed for loudspeakers **312** and **314** and would be suitably adjusted for loudspeakers designed to cover different frequency ranges.

The manner in which the loudspeakers **312** and **314** are mounted on the baffle **310** is more clearly seen in the elevation view of FIG. **4** and the cross-sectional views of FIGS. **4A–4C**. It is seen that the loudspeakers are able to radiate freely in both directions of the baffle, thus resulting in approximately equal radiation in both directions to produce the dipole described above. As shown in FIG. **4B**, which is a cross-section taken along line **4B—4B** of FIG. **4**, by mounting the mid-range loudspeaker **312** in the wider portion of the baffle, the desired front-to-back path length D_B for this loudspeaker is obtained, and as seen in FIG. **4C**, which is a cross-sectional view taken along line **4C—4C** of FIG. **4**, the location of the upper mid-range loudspeaker **314** in the narrower portion of the baffle provides the desired front-to-back path length D_C for its freuqncy range.

As regards the tweeter or high-frequency loudspeakers **316**, designs are commercially available which will normally provide the desired directional pattern, approximating a circle of revolution, and which therefore may be used in conventional manner by mounting them in openings in the baffle **310**. That is, the shape of the baffle is not critical to their operation, and therefore they can be mounted at any convenient location on the baffle, in the illustrated example at either side of the lower mid-range loudspeaker **312**.

Another advantageous feature of the structure illustrated in FIG. **3** is that containment of the baffle **310** between the upper surface **326** of compartment **302** and the under surface of cover plate **322** causes the radiation from the gradient or dipole loudspeakers to be guided around the side edges of the baffle board as depicted in FIGS. **4B** and **4C** rather than travelling over the upper edge or under the lower edge of the baffle board, this contributing to the overall efficiency of the loudspeaker system.

As has been suggested hereinabove, to provide substantially uniform radiation of sound over essentially the full audio frequency range, the incoming signal is preferably divided between the four types of loudspeaker motors by coupling it through suitable dividing and frequency compensating networks, as schematically shown in FIG. **5**.

The effectiveness of the described loudspeaker system is graphically illustrated in FIG. **6**, which shows the polar patterns of the individual loudspeakers with the baffle **310** positioned to radiate from the front of the cabinet. The omnidirectional pattern of the woofer or low-frequency loudspeaker **306** is depicted by the circle **600**, the polar patterns of the low mid-range and high mid-range loudspeakers **312** and **314** (which overlap) are in the form of cosine or figure-8 patterns as depicted at **602**, and the polar pattern of the tweeters **316** over their operating range is illustrated as the somewhat narrowed circle **604**. It will be apparent from the foregoing description that by rotational adjustment of the baffle the directionality of the polar patterns **602** and **604** can be rotated relative to the polar pattern **600**, making the loudspeaker system eminently suitable for use in stereophonic and quadraphonic loudspeaker arrays.

Although the baffle **310** in the preferred embodiment is mounted with its longer edge **310***b* adjacent the cover plate **322**, it is possible to invert it as shown in FIG. **8** so that its wider portion will be down and the narrower portion adjacent the cover plate. This alternative position of the baffle gives somewhat less satisfactory operation, however, because the upper mid-range loudspeaker **314** would tend to be shielded from the listener whose ears would normally be at a level higher than the level of the cover plate 322. It is also within the contemplation of the invention to mount the loudspeaker driver in planes other than the planes of the baffle 310 and to construct the baffle itself so as to be non-planar; however, in the interest of simplicity and ease of manufacture, the illustrated construction is to be preferred.

It will now be obvious to ones skilled in the art that the loudspeaker system illustrated in FIG. 3 is subject to significant modification without departing from the spirit of the invention. For example, the cabinet may be only as long as it is deep. Another modification, illustrated in FIG. 7 and especially applicable to this modified cabinet construction is to pivotally mount the baffle 310 in an open rectangular frame 701 having a height corresponding generally to the spacing between the plates 322 and 326, which, in turn, is pivotally supported by trunnions 703 journalled in a pair of supports 702 which are affixed to the top plate 326 of the lower enclosure. This alternative form of mounting the baffle permits the plane of the baffle and, accordingly, the directivity of the radiation pattern produced by the loudspeaker drivers mounted thereon, to be varied universally, including the possibility of laying the cabinet over on one of its sides. In the latter situation, the frame 701 would be rotationally adjusted to lie in a plane parallel to the floor so as to maintain a substantially vertical orientation of the baffle 310.

While in the system as described and illustrated dynamic or moving coil drivers are used, the advantages of the invention can also be realized with other types of drivers, for example, of the capacitor or electret type, especially for the dipole element.

I claim:

1. A directional loudspeaker system comprising:

a cabinet having a substantially closed lower compartment having a baffle board at the front thereof and a separate generally open-sided upper compartment,

a first loudspeaker driver for the low frequency range mounted on the front baffle board of said lower compartment to cause sound emanating therefrom to be essentially omnidirectional,

a generally planar baffle having substantially parallel upper and lower edges of unequal length joined by side edges supported vertically within said upper compartment and mounted for rotational adjustment relative to the cabinet about a generally vertical axis, and

at least a second loudspeaker driver for a frequency range above the frequency range of said first loudspeaker driver mounted on said baffle at a location as to constitute with a portion of the baffle a dipole radiator having an angle of directivity generally perpendicular to the plane of said baffle,

whereby the angle of directivity of said second loudspeaker driver can be varied relative to the cabinet as desired.

2. The system of claim 1 wherein

the side edges of said baffle are symmetrically spaced from said vertical axis, and wherein

said second loudspeaker driver is for the lower midrange of frequencies and is mounted on said baffle centrally between the side edges and generally adjacent the longer of the other two edges, and

a third loudspeaker driver for the upper midrange of frequencies is mounted on said baffle between the side edges and generally adjacent the shorter of the other two edges.

3. The system of claim 2 further including fourth and fifth loudspeaker drivers for the high range of frequencies mounted on said baffle one on each side of said second loudspeaker and generally adjacent the longer of said other two edges.

4. The system of claim 2 wherein the upper edge of said baffle is longer than the lower edge.

5. The system of claim 3 wherein the upper edge of said baffle is longer than the lower edge.

6. The system of claim 2 wherein the lower edge of said baffle is longer than the upper edge.

7. The system of claim 3 wherein the lower edge of said baffle is longer than the upper edge.

8. The system of claim 2 wherein the side edges of the baffle joining the upper and lower edges are curved so as to define with the shorter edge a first generally rectangular zone having dimensions such that said third loudspeaker driver together with said first zone of the baffle functions as a dipole radiator at the upper midrange of frequencies, and to define with the longer edge a second generally rectangular zone having dimensions such that said second loudspeaker driver together with said second zone of the baffle functions as a dipole radiator at the lower mid-range of frequencies.

9. The system of claim 8 further including fourth and fifth loudspeaker drivers for the high range of frequencies mounted on said baffle in said second zone one on each side of said second loudspeaker driver.

10. The system of claim 8 wherein the upper edge of said baffle is longer than the lower edge.

11. The system of claim 8 wherein the lower edge of said baffle is longer than the upper edge.

12. The system of claim 1 wherein the means for supporting said baffle comprises an open frame mounted for rotational adjustment about a generally horizontal axis, and means for pivotally supporting said baffle on said frame for rotational adjustment about a generally vertical axis.

* * * * *