United States Patent [19]

Rizo-Patron

[11] **3,918,551**

[45] **Nov. 11, 1975**

[54] **SPEAKER SYSTEM**

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[22] Filed: **Oct. 21, 1974**

[21] Appl. No.: **516,186**

[52] **U.S. Cl.** **181/144;** 181/141; 181/147; 181/148

[51] **Int. Cl.²** **G10K 13/00; H04R 7/16**

[58] **Field of Search** 181/141, 144, 145, 146, 181/147, 148

[56] **References Cited**

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Primary Examiner—Stephen J. Tomsky
Attorney, Agent, or Firm—Cooper, Dunham, Clark, Griffin & Moran

[57] **ABSTRACT**

The present invention provides an omnidirectional speaker system comprising an arrangement of substantially open baffled and unbaffled speakers for the reproduction of the full range of audible frequencies, the speakers being of the type having acoustic radiators which produce both front and rear waves of acoustic energy. The speakers are mounted coaxially with axial separations therebetween, and comprise a first pair, each of which is joined to an open baffle, and a third speaker which is unbaffled and coaxial with the first pair of speakers. The third unbaffled speaker is combined with one of the baffled speakers to provide a second pair. The first pair of baffled speakers is mounted so their radiators move in piston-like fashion, and the second pair is mounted so that their radiators move in push-pull fashion. The invention also provides open back cabinets for the speaker system and a lamp type mounting for a pair of high frequency tweeters in face to face, spaced apart, relationship.

10 Claims, 16 Drawing Figures

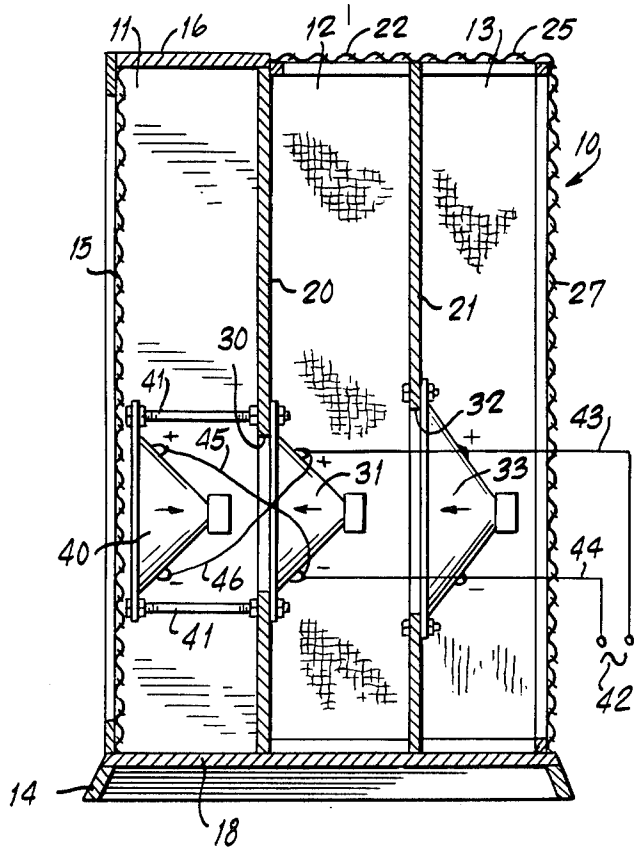


Fig. 1.

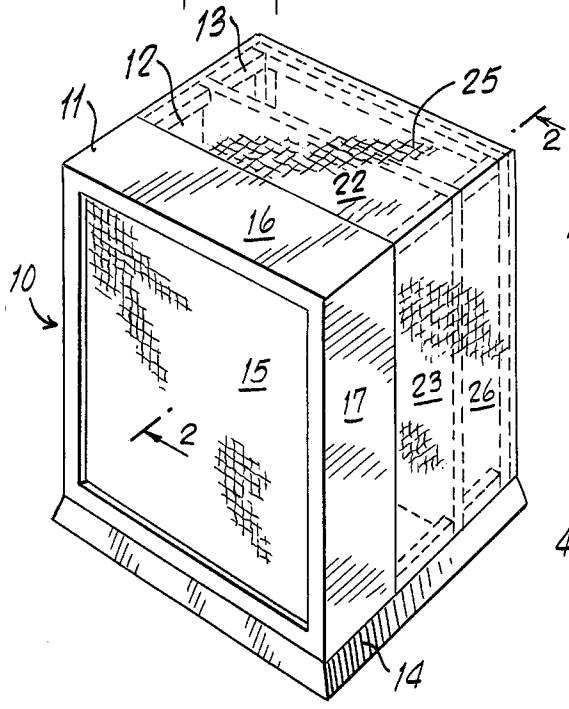


Fig. 2.

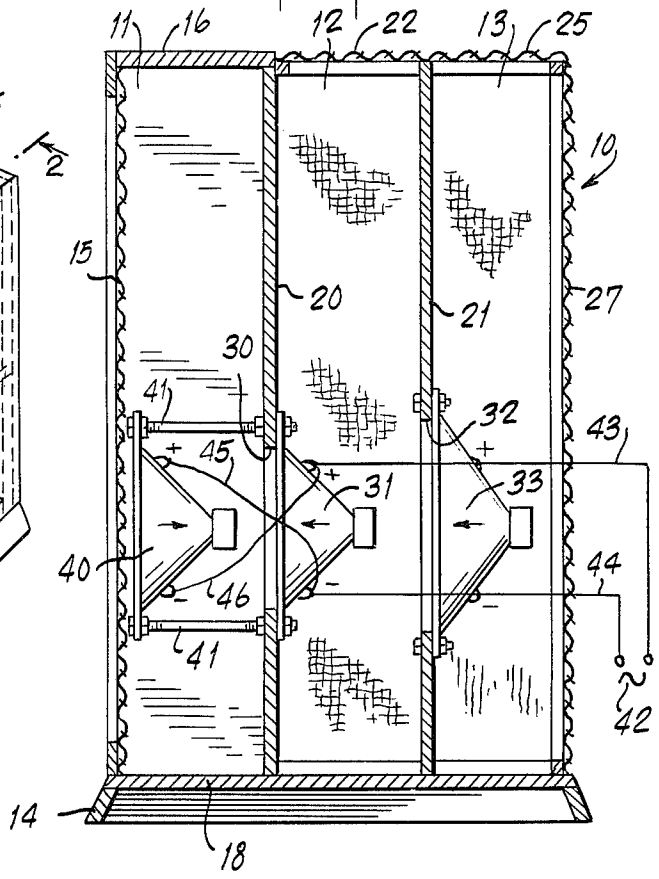


Fig. 3.

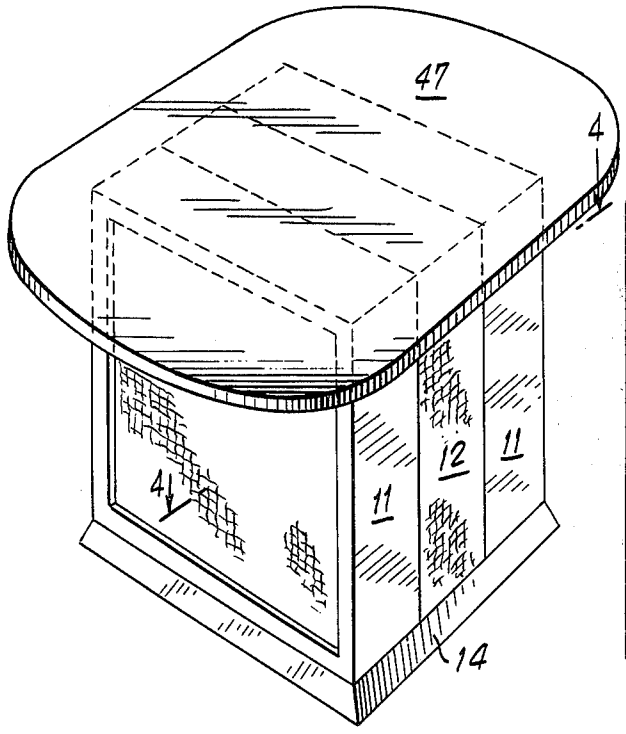
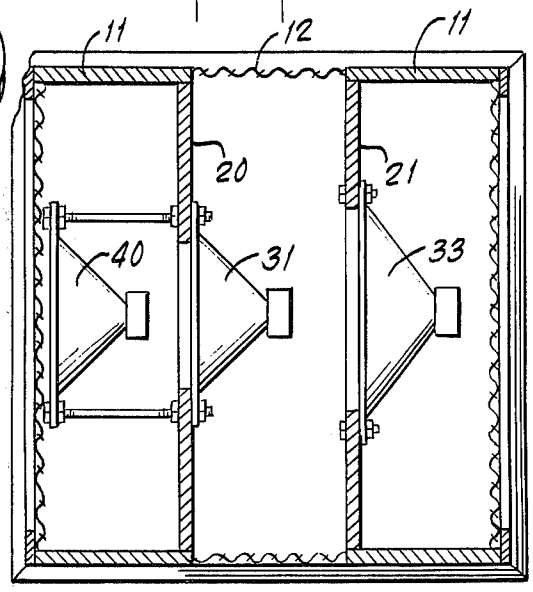


Fig. 4.



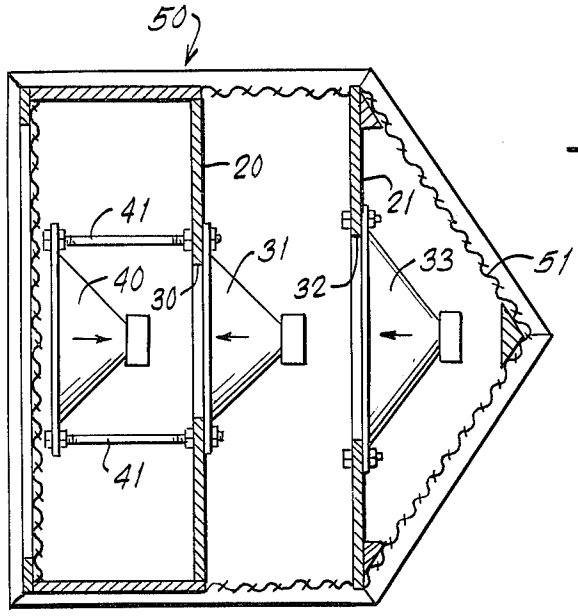


Fig. 5.

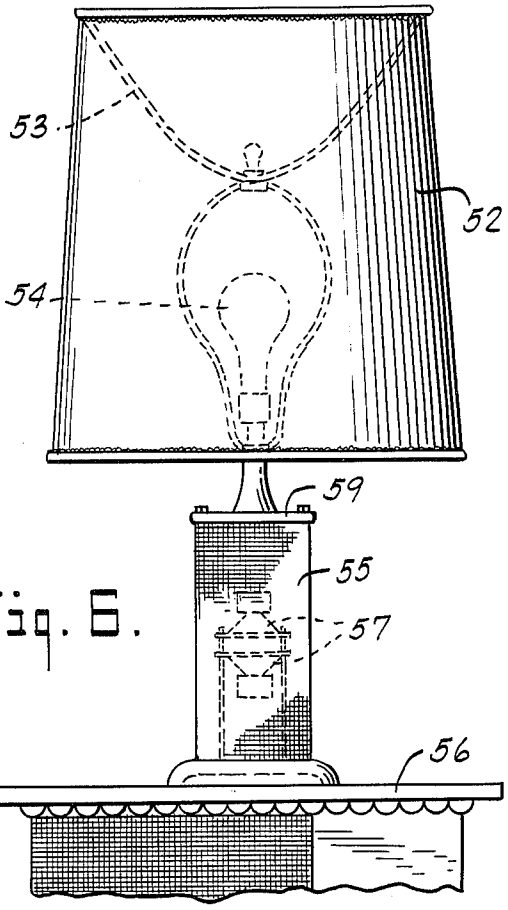


Fig. 6.

Fig. 7.

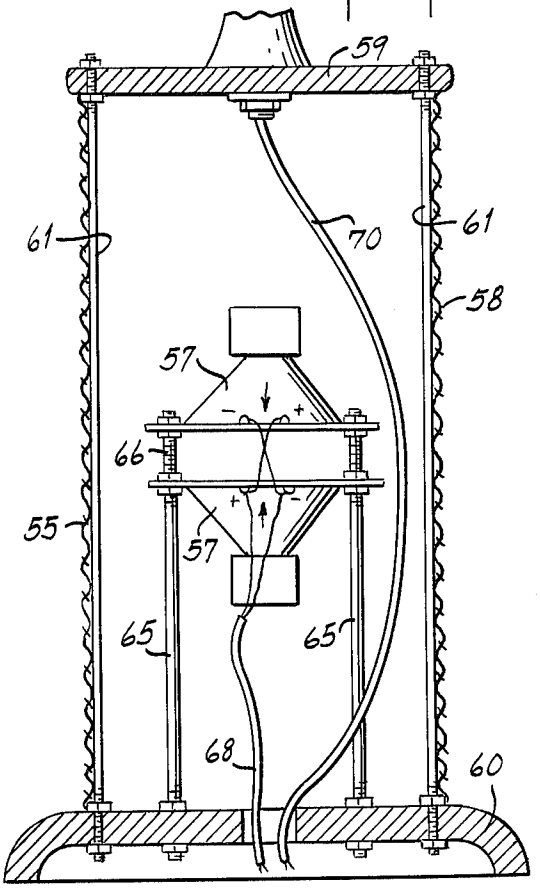


Fig. 8.

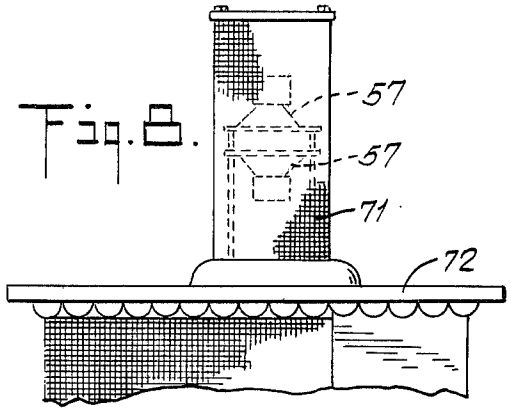


Fig. 9.

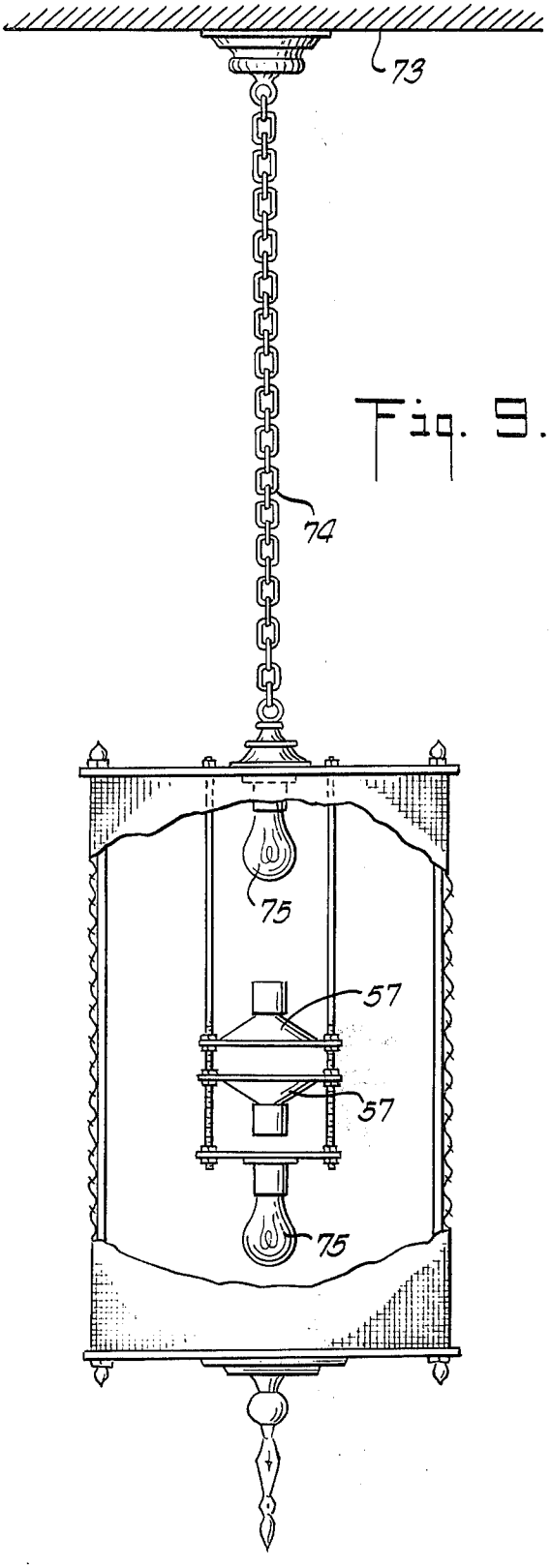
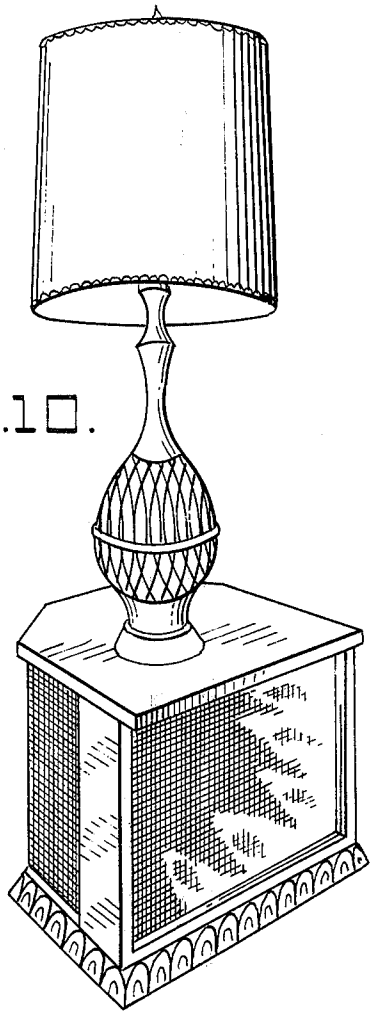


Fig. 10.



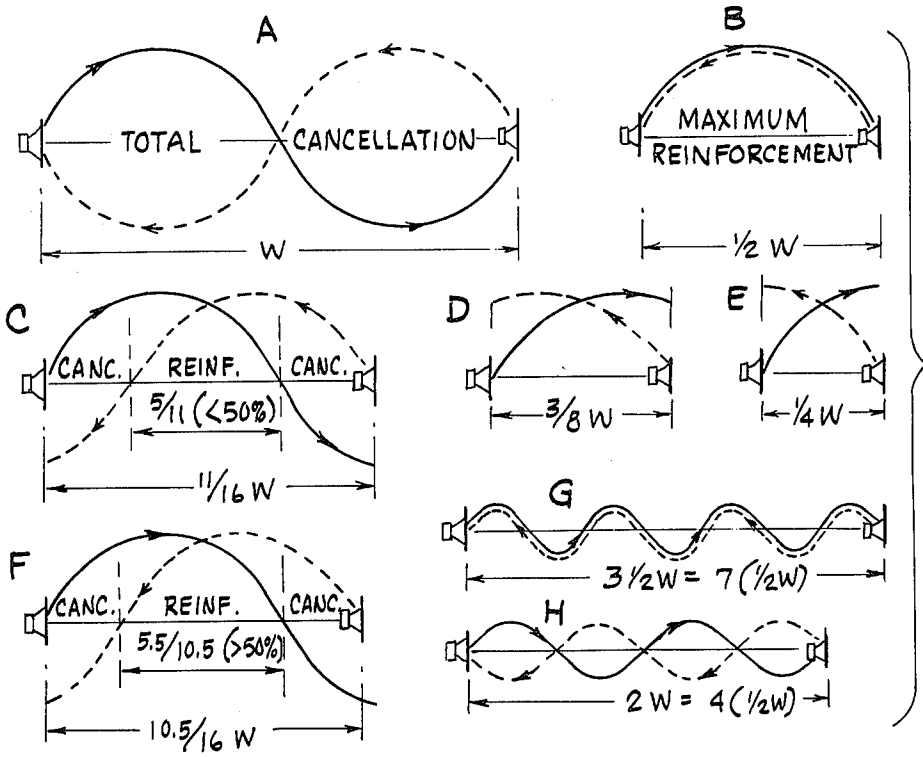


Fig. 11.
(RADIATORS MOVING IN THE SAME DIRECTION AT ANY GIVEN INSTANT)

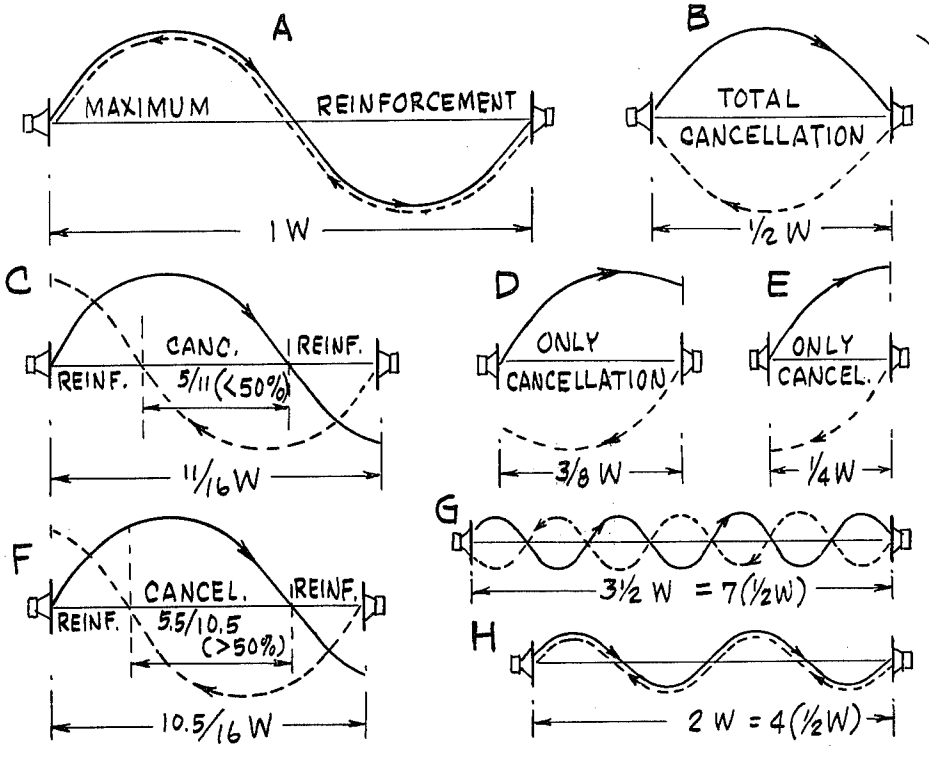


Fig. 12.
(RADIATORS MOVING IN OPPOSITE DIRECTION AT ANY GIVEN INSTANT)

Fig. 13.

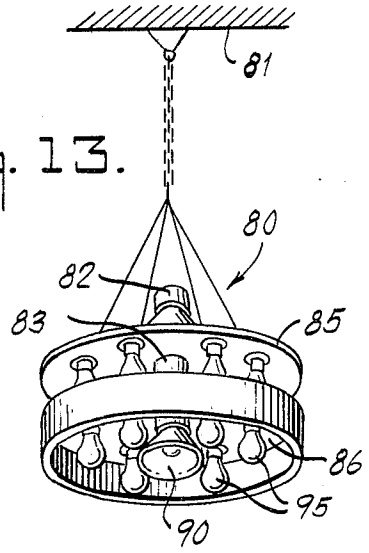
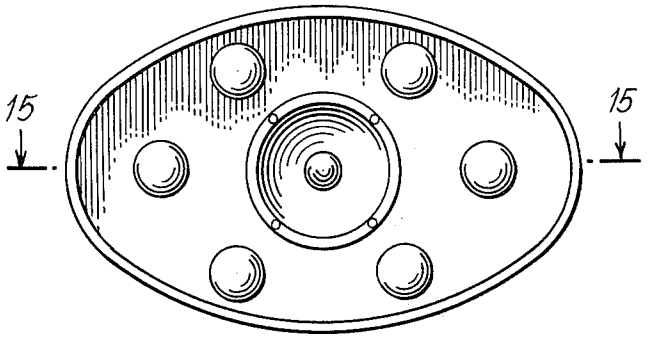


Fig. 14.



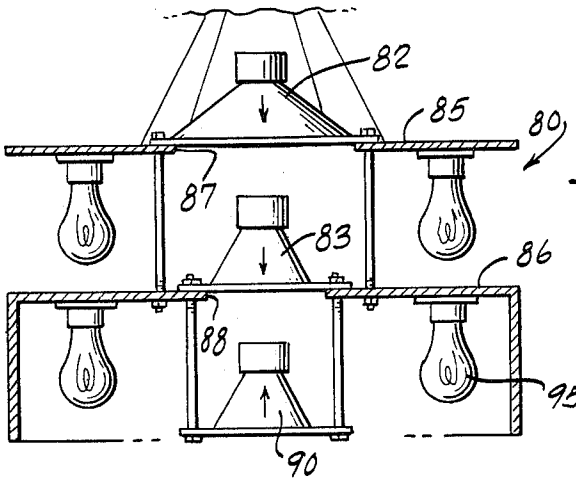
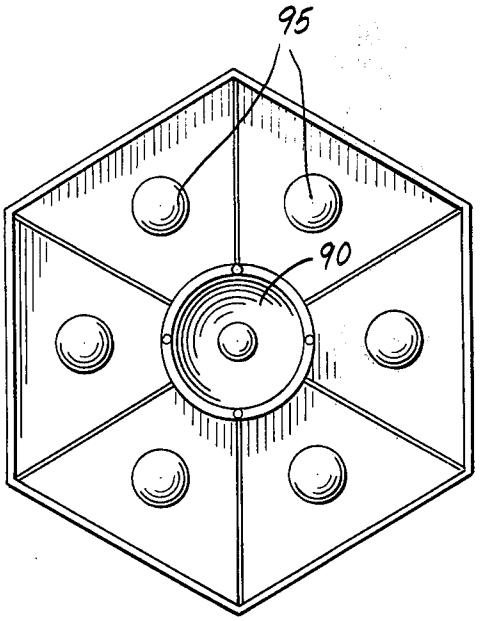


Fig. 15.

Fig. 16.



SPEAKER SYSTEM

This application relates to loudspeaker systems and more particularly to the mounting of the speakers thereof within the concept of my U.S. Pat. No. **3,477,540.** More particularly the present invention illustrates and describes new embodiments which I have found to produce even better acoustic results, and additionally are more esthetic, easier to manufacture and more convenient to use.

An object of the invention is to produce an omnidirectional speaker system which can best be adpated to the requirements of binaural reproduction, while eliminating most of the boominess and the unnaturalness which is characteristic, and physically unavoidable in all types of boxed-in speakers, which have acoustic radiators that produce both front and rear waves of acoustic energy.

In fact, all speaker systems must produce sound by a vibrating membrane or media that puts air in motion and thus gives place to audible waves that reach the listener's ears. Irrespective of the driving systems employed, or the physical principles utilized in causing the air vibration by the transducers (dynamic, electrostatic, electromagnetic, air-motion transformers, etc.) an inescapable and decisive factor is that said sound waves are produced by both sides of the transducer media. It is this characteristic of the last stage of the sound reproducing sequence of operations (including all the previous electronic, electrical and mechanical steps) which constitutes its weakest link. The problem is that the "front" and "back" sound waves produced are out of phase with each other, and so cause their mutual cancellation at all frequencies whose wave length is greater than a critical dimension, which is a function of the limited size of the transducer itself.

Consequently, there is a need for baffling, which increases the effective barrier size or separation between "front" and "back" radiations and thus lowers the frequencies of cancellation.

It is believed that prior attempts to prevent cancellation of the low frequencies by out-of-phase front and back radiations, through means other than open baffling, introduced worse types of distortion into the total system. Such attempts often contemplate the total elimination of the "back" radiation, by preventing it from reaching the listening space, and thus the ears of the listeners. Or, as another alternative, the back waves are permitted to reach the listening space only through some sort of tuned vent in the enclosure wherein the speaker is mounted, after a phase reversal effected by an actual resonance of the entrapped air which cause the vent radiation to come out at least partially in phase with the speaker radiation.

However, the completely sealed or vented boxes, commonly used to achieve these purposes, particularly when they are small, introduce the coloration called "boxed-in" effect, which produces a kind of sound similar to the well known "radio sound", even when glorified by high-powered signals, big magnets, soft suspension, air damping, absorption materials and other expedients. This is why a big speaker box always sounds better than a small one, — other things being equal. But the distortion effects are still there, even in large boxes. The simple physical reason for these effects is that the "back" sound waves, when constricted and made to bounce back and forth within an enclosure until their energy is spent, produce undesirable effects on the vibrating media of the transducer or the air put in motion by it, influencing its vibration and thus distorting the cleanliness of the original signals being reproduced. The resultant undesirable effects can vary, and most high fidelity designs are intended to minimize them; but to a greater or lesser relative degree they are always present, as proven by the fact that no two boxed-in speakers sound exactly alike, no matter how high their quality or the price may be.

The main causes of distortion introduced by boxes of any type thus give rise to a poorer "transient" response and many types of unnatural resonances (cabinet, air, mechanical, etc.), which are acoustically mixed with the sound signals being reproduced, thus changing their original characteristics, their true "timbre" and naturalness, and produce the classical colored "boxed-in" type of sound mentioned before. In this way the transducers become new resonant musical instruments in themselves, instead of neutral reproducers of the original sounds, as their true high-fidelity objective should be.

Other causes of unnaturalness common to boxed-in speakers with the transducers installed on the front baffles of the boxes, are the resulting directional effects in the pattern of sound propagation. Such effects do not correspond to the way in which nature propagates sounds, and are most objectionable in the high frequency range, because of the poor dispersion, and beaming characteristics of the same.

Another common cause of unnaturalness in all speakers where more than one transducer is mounted on a flat baffle, either boxed-in or even on simple open baffles, is the interference resulting between the various drivers. Thus, the off-axis output of one driver interferes with the on-axis output of others causing cancellations and reinforcements, because of different effects at various frequencies, depending on the distances between the drivers. This problem, added to the variations of angular response corresponding to different drivers which vary with frequency, compounds the resulting confusion. As will be noted this problem is common to most state of the art speaker systems.

The main purpose of the present invention of omnidirectional, box-free and truly hi-fi sound reproduction is achieved through a novel use of open baffles for the speakers reproducing low frequencies, and the use of substantially unconfined high-frequency speakers with the superior transients that are characteristic of such speaker systems. This gives rise to a cleaner bass response and a better sound propagation pattern inclusive of the high frequencies, the latter by nature being more directional and difficult to spread out in a natural way.

More specifically, these objects are attained by using a loudspeaker arrangement of several loudspeakers, no two of which are mounted side by side on the same plane of any flat baffle or surface of the mounting ensemble, whereby the transducers are made to propagate their sound waves substantially along the same or mutually perpendicular axes, — the speaker assembly including at least two transducers reproducing low frequencies installed coaxially with an axial separation therebetween, and each mounted by its periphery to an open baffle which may be an open-back cabinet, characterized in that the distance between the low frequency speakers' peripheries is less than the mean di-

ameter of the speakers themselves, thus constituting a roughly spherical omnidirectional sound source. Said basic pair of bass speakers are connected to an audio frequency signal source so as to cause their acoustic radiators to move in the same direction at any given instant. The resultant effect is that sound emanating from the space between the speakers is radiated at right angles to their common axis, reinforced mutually,— this eliminating the "doublet", bi-polar, or figure eight radiation effect corresponding to the sound propagation of a single open baffle or open back cabinet. The resulting radiation resembles rather two figures eight at right angles to each other in almost every dissecting plane, thus approximating a spherical pattern of sound propagation, which is the ideal for producing real omnidirectional and most natural listening effects.

The speaker arrangement involved in the present invention produces out-of-phase front and back sound radiations which are separated from each other not only by two open baffles, but also by a sound radiation spread equatorially (perpendicularly to the coaxial speakers), from inbetween the open baffles, that tends to reinforce both the front and back sound radiations of the two main speakers, in spite of the fact that the latter are mutually out of phase. The total result is open baffled, clean, unboxed, omnidirectional sound, with substantial bass response, and with dimensions for the open baffles much smaller than called for theoretically by a single open baffle in order to prevent bass cancellation.

A group of the novel embodiments of the present invention is characterized in that the bass speakers are mounted with their common axis parallel to the nearest reflecting large surface, such as the floor, ceiling, walls, or columns. Another group of embodiments includes intallations far from a large reflecting surface, such as for example hanging from a high ceiling, wherein the coaxial speakers are mounted with their common axis vertical.

In both of said groups of embodiments the main speakers of the coaxial pairs are affixed to two open baffles or shallow open back cabinets, which are supported facing each other by any known means at the approximate proper distance corresponding to the size of the speakers used. The speakers may be normally mounted by any known means, such as with screws, staples, rivets, bolts, nuts, etc. (as described, for example, in my U.S. Pat. No. **3,477,540**). Separator dowels or bolts may also be secured between the front baffles so that they can act as stiffeners for the same, reducing their vibration.

The sides of the cabinets may be covered with any acoustically transparent ornamental cloth or other material wholly, or at least partially, in the areas corresponding to the open spaces in the front and back of the speakers and between the open baffles.

The whole of the cabinets or similar structures when used as floor models, may be topped with finished panels extended horizontally beyond the floor area limits covered by the cabinets supporting the speakers, with a substantial overhang which should be at least sufficient to cover the backs of any speakers mounted on flat open baffles and protruding outside of the space comprised between the front baffles. The resulting speaker cabinets could thus be made to look like tables and used as such, blending their design with the normal interior decor of any listening room. The finished top panels can be of any polygonal or oval shape and combinations thereof, which include polygonal forms with rounded corners.

The table-cabinet tops and the floor act as horizontal baffle extensions at right angles to the rectangular vertical front baffles supporting the speakers. The effective acoustical result is thus equivalent to a greatly increased size of the open baffling available in the system, with a correspondingly extended and clean low frequency response. Hence large systems become possible, without being obnoxious in any listening environment, by combining the speakers' installation with regular pieces of furniture, which are required anyway, such as even large dining tables and the like, where the speakers' mounting cabinet may become simply their supporting structure, instead of just the bare legs.

The sides of the open back cabinets can be the lateral extensions, also vertical and at an angle, to the said vertical front baffles supporting the main speakers pair, and they should have a depth preferably smaller than half of the shortest side of their front baffle.

I have found these floor model embodiments superior to ones having the axis of the bass speakers near and perpendicular to the large reflecting surface constituted by the floor, with respect to bass response, and practically as good as far as omnidirectionality.

In tests using the same large speakers and bent lead-sheet baffles, the floor models with a horizontal axis produced more than **10** decibels of greater bass response when fed with a signal of **40** cycles per second as compared with floor models with a vertical axis and with the lower base speaker near the floor, but with open space on the four sides. The reason for this is believed to be that a large part of the sound energy radiated towards the floor instead of escaping through the said four sides of the open baffle, was reflected upwards **180°** out of phase from the floor, and tended to cancel the bass produced by the lower speaker. This did not happen when the speakers were mounted with their common axis horizontal, provided they were not placed too close to a wall.

The new table-like embodiments are also characterized in that high frequency or small full-range speakers are placed outside, and above the baffled table cabinets, in unconfined acoustic communication with the surrounding air, to enhance the high frequency response and omnidirectionality in the space over the table top panels, while separating their radiation from the one emanating between the baffled speakers. Thus, in order to replace the upward radiation of the latter, a pair of coaxial, unbaffled, small-cone speakers can be installed with their common axis vertical and face to face, only covered with acoustically transparent material, or within an acoustically transparent base of a common light-lamp, which may be of any type such as table or hanging, or ornamental design desired, and placed above a table-cabinet. In such cases the distance between the small speakers should be such that the two cones constitute an approximately spherical sound source.

The phasing and spacing rules to achieve maximum smoothness by controlling the frequency response of the coaxial speakers employed in the new embodiments of my invention are derived by applying the following rather subtle considerations of the phase relationships and resulting effects:

1. An electrical impulse that initially moves the diaphragm of a speaker forward is conventionally called positive.
2. A positive electrical impulse pushes air in front of the speaker and produces a compression wave of the same positive sign.
3. Corresponding to a compression wave in front of a speaker, a "positive rarified" wave is produced in back of it. Similarly, a negative compression wave in front of the speaker corresponds to a negative rarified wave in back of it.
4. Two equal positive compression waves travelling in the same direction reinforce each other (for example, in-phase speakers facing forward from the same baffle, i.e., installed side by side).
5. Two equal and coinciding positive compression waves travelling in opposite directions between coaxial speakers (face to face, back to back, or front to back speakers) cancel each other, producing a "standing" wave.
6. A positive compression wave and an equal positive rarified wave coinciding with each other and travelling in opposite directions produce mutual reinforcement.
7. Consequently, when expressing in a cartesian-coordinates graph the mutual effects of travelling waves in the case of speakers that are installed coaxially face to face, back to back, or facing in the same direction, to obtain cancellation for (+) and (−) waves, and reinforcement for (+) and (+) or for (−) and (−) waves, i.e., in order to express conveniently the physical effects, it is necessary to picture the compression wave trains travelling in one direction and the rarified wave trains travelling in the opposite sense. In the accompanying illustrating diagrams forming part of the drawings (later to be discussed), the compression waves are shown by continuous lines and the rarified waves, travelling in an opposite direction are shown by broken lines.

For a better understanding of the invention reference will now be made to the accompanying drawings, wherein:

FIG. **1** is a perspective view of an open baffled speaker arrangement consisting of a flat open baffle and of an open-back cabinet for mounting two main baffled coaxial speakers facing in the same direction and a third unbaffled speaker coaxially with the baffled pair, supported within the open-back cabinet facing outwards and also in the same direction as said baffled pair.

FIG. **2** is a vertical cross-sectional view taken along the line **2—2** of FIG. **1** and viewed in the direction of the arrows, showing in full lines the pair of main baffled speakers and the third unbaffled speaker coaxial therewith, mounted substantially at the same distance as between the baffled pair. The required electrical connections to cause a pistonwise movement between the radiators of the baffled pair and a push-pullwise motion of the radiators of the speakers mounted on the open-back cabinet are also shown.

FIG. **3** is a perspective view of a table combination with two open-back cabinets instead of one and an open baffle as in FIG. **1.**

FIG. **4** is a horizontal cross-sectional view taken along the lines **4—4** of FIG. **3** and viewed in the direction of the arrows, showing in full lines the pair of main baffled speakers and the third unbaffled speaker coaxial therewith forming two pairs of speakers facing in the same direction, and with substantially the same distance between the speakers of both pairs.

FIG. **5** is a horizontal cross-sectional view of a modified shape of cabinet and showing in full lines the pair of main baffled speakers and the third unbaffled speaker coaxial therewith, with the same relationship between the three speakers forming two pairs as in the previous Figures.

FIG. **6** shows a table lamp construction with the base of the lamp enclosing in acoustically transparent material the high frequency or tweeter speakers, — the lamp being mounted on a cabinet shown as partially broken away.

FIG. **7** is an enlarged vertical sectional view of the lamp base and associated structure showing in full lines the pair of high frequency or tweeter speakers facing each other at a distance smaller than their depth and the electrical wiring required to cause their radiators to move in opposite direction to each other at any given instant (push-pullwise).

FIG. **8** is an elevational view partially broken away showing a simplified version of the structure of FIG. **6,** without the lamp.

FIG. **9** is a front elevational view, partially broken away of another embodiment of the invention showing how the high frequency or tweeter speakers may be mounted in a hanging lamp.

FIG. **10** is a perspective view of a combined lamp and cabinet structure embodying the present invention.

FIG. **11** illustrates sound propagation and cancellation curves of radiators moving in the same direction at any given instant (pistonwise).

FIG. **12** illustrates sound propagation and cancellation curves of radiators moving in opposite direction at any given instant (push-pullwise).

FIG. **13** shows in perspective a hanging lamp fixture having a pair of baffled speakers facing in the same direction and a third unbaffled speaker coaxially with the baffled pair, as provided by the present invention.

FIG. **14** is a bottom plan view of FIG. **13.**

FIG. **15** is a vertical sectional view taken along the direction of the arrows **15—15** in FIG. **14.**

FIG. **16** is a bottom plan view of a modified version of FIGS. **13** and **14.**

Referring now to the drawings in more detail there is shown in FIG. **1,** in perspective, a speaker cabinet generally indicated as **10,** composed of three sections **11,** 12, and **13,** a supporting base **14,** and a front panel **15** of acoustic cloth or other acoustic transparent material. As seen in both FIGS. **1** and **2,** the section **11** has a rigid top member **16,** rigid side members **17,** a rigid bottom member **18,** and a rigid flat baffle **20,** as well as the acoustic cloth **15** which thereby encloses such section. It will also be noted that section **12** is defined by the rigid flat baffle **20** and a second rigid flat baffle **21** with the top **22** and sides **23** of such section being enclosed only by acoustic transparent cloth. Section **13** is formed by the baffle **21,** a top of acoustic cloth **25,** and sides **26** also of acoustic cloth, and has an open back **27** which is also only enclosed by acoustic cloth.

Baffle **20** is provided with an aperture **30** of sufficient size and diameter to receive a low frequency speaker mounted thereon. Baffle **21** also has an aperture **32** of sufficient size and diameter to accommodate a second low frequency speaker **33** mounted thereon. While the speakers **31** and **33** are mounted on baffles **20** and **21,**

respectively, it will be noted that by reason of the acoustic cloth **22, 25** and **27,** said speakers **31, 32** constitute a pair of open baffled speakers.

Within section **11** there is mounted a third speaker **40** which is unbaffled and is disposed immediately behind the front panel **15** of acoustic cloth. For convenience of assembly, the speaker **40** is supported from the baffle **20** by carriage bolts or the like **41.** Attention is invited to the fact that the unbaffled speaker **40** is spaced a distance from baffle **20** which is substantially equal to the distance between baffles **20** and **21.** Also, all three speakers **33, 31** and **40** are mounted coaxially. The speakers **31** and **33,** constituting one pair, are designed to vibrate together in piston-like fashion as shown by the arrows. The speakers **31** and **40** constituting a second pair are designed to vibrate in push-pull fashion as shown by the arrows. All three speakers **33,** 31 and **40** face the same direction, and there is substantially the same distance between the speakers of both pairs.

An audio source is generally indicated at **42** and has leads **43, 44** suitably connected to speakers **33** and **31** and by cross leads **45, 46** to speaker **40,** — the positive and negative connections to each speaker being shown on FIG. **2.**

In FIG. **3** there is shown a perspective view of a table combination with two open back sections **11** and one open baffle section **12,** — the table having a flat table top **47** of suitable configuration.

FIG. **4** shows in cross-section the basic speaker construction underlying the table top **47** and shows two baffles **20, 21** and two speakers **31, 33** respectively mounted thereon and an unbaffled speaker **40** suitably supported from baffle **20.** Aside from the fact that I have used two sections **11** in FIG. **4** in combination with one section **12** instead of sections **11, 12,** and **13** as shown in FIG. **2,** the remainder of the structure as illustrated in FIG. **4** is the same as shown in FIG. **2** and functions as described with reference to FIG. **2.**

In FIG. **5** there is illustrated in horizontal cross-section a modified form of cabinet **50** which has a triangular open back **51** of acoustic cloth instead of the flat back **27** as shown in FIG. **2.** All other parts shown in FIG. **5** correspond to the parts shown in FIG. **2** and have been similarly numbered.

FIG. **6** shows a table lamp having a lampshade **52,** a lampshade supporting frame **53,** a lamp bulb with socket **54,** and a lamp base **55,** — the lamp base, in turn, being suitably supported on the top of a low frequency speaker cabinet **56** which corresponds to a cabinet as shown in FIGS. **1** and **2.**

The lamp base **55** contains two tweeters or high frequency speakers **57** spaced in face to face relation. The lamp base **55** and the enclosed high frequency speakers **57** are better shown in FIG. **7** which is an enlarged view in vertical cross-section of the lamp base **55.** The lamp base is enclosed by acoustic cloth **58.** The lamp base has a top portion **59** and a bottom portion **60,** and tie rods **61** which space the top and bottom portions from each other. The speakers **57** are also supported from the lamp base **60** by tie rods **65** and are held in spaced face to face relation by rods **66.** An audio frequency source is generally indicated as **68** with the positive and negative as applied to each speaker being shown as illustrated in FIG. **7.** From such illustration it will be understood that the high frequency or tweeter speakers **57** are mounted in push-pull relation and the arrows shown in FIG. **7** so indicate. A cable **70** is shown for supplying electric current to the electric bulb **54.**

In lieu of using an electric lamp and base as shown in FIGS. **6** and **7,** FIG. **8** shows how the tweeter or high frequency speakers **57** can be mounted in an acoustically cloth enclosed member **71,** which, in turn, is mounted on a cabinet **72** which contains the low frequency speakers as illustrated and described with reference to FIGS. **2** and **4.**

FIG. **9** shows how the tweeters **57** may be mounted in a hanging lamp which is supported from the ceiling **73** by a chain **74,** such lamp having light bulbs **75,** — the lighting fixture being enclosed in acoustical cloth **76.**

In FIG. **10** there is shown in perspective a view of a combined lamp and cabinet structure embodying the present invention.

Referring now to FIGS. **11** and **12** it will be noted that FIG. **11** illustrates sound propagation and cancellation curves of radiators moving in the same direction at any given instant, — said radiators moving pistonwise. The graphs of FIG. **11** are obtained in function of the distance between the coaxial speakers, expressed in terms of the wave length *w* of the sound frequencies considered in each graph. It will be noted from FIG. **11** that eight sets of curves or graphs are shown with each set of curves being labeled respectively A through H. The distance between each pair of radiators is indicated in terms of *w* or multiples or fractions of *w*. FIG. **12** illustrates sound propagation and cancellation curves of radiators moving in the opposite direction at any given instant, push-pullwise. The graphs of FIG. **12** are also obtained in function of distance between the coaxial speakers, expressed in terms of the wave length *w* of the sound frequencies considered in each graph. It will also be noted from FIG. **12** that eight sets of curves or graphs are shown with each set of curves being labeled respectively A through H. The distance between each pair of radiators is indicated in terms of *w* or multiples or fractions of *w*.

Without going into the mathematics involved it can be easily appreciated from the graphs that the following conclusions apply:

For electrical connections causing the diaphragms of the coaxial speakers to move in the same direction at any given instant:

1. Maximum reinforcement occurs for frequencies whose wave length is double the distance between the speakers (FIG. **11B**).
2. Maximum reinforcement occurs for frequencies whose half wave length and odd multiples of ½*w* are equal to the distance between the speakers (FIGS. **11B** and **11G**).
3. Total cancellation occurs for all frequencies whose wave length *w* and all multiples of one *w* are equal to the distance between the speakers (FIGS. **11A** and **11H**).
4. Only reinforcements occur for all frequencies whose half wave lengths are longer than the distance between the speakers (FIGS. **11D** and **11E**).
5. For frequencies whose half wave lengths are shorter than the distance between the speakers, alternating reinforcements and cancellations occur, as said distance becomes an odd or even multiple of half a wave length of the correspondingly increased frequencies considered (FIGS. **11G** and **11H**).

6. When the space between the speakers is between ½w and 1w of a set of frequencies, partial cancellations and reinforcements will occur (FIGS. 11C and 11F).
7. Reinforcements will predominate over cancellations in the space between the speakers for all frequencies whose approximately **43/64** *w* is longer than the distance between the speakers (FIGS. 11C and 11F).

For electrical connections causing the diaphragms of the coaxial speakers to move in an opposite direction at any given instant:

1. Maximum reinforcement occurs for frequencies whose wave length is equal to the distance between the speakers (FIG. 12A).
2. Maximum reinforcement occurs for frequencies whose wave lengths and multiples of their wave lengths are equal to the distance between the speakers (FIGS. 12A and 12H).
3. Total cancellation occurs for all frequencies whose half wave length and odd multiples of ½w are equal to the distance between the speakers (FIGS. 12B and 12G).
4. Only cancellations occur for all frequencies whose half wave lengths are longer than the distance between the speakers (FIGS. 12D and 12E).
5. For frequencies whose half wave lengths are shorter than the distance between the speakers, alternating cancellations and reinforcements occur, but in a reversed way, as said distance becomes an odd or even multiple of half a wave length of the correspondingly increased frequencies considered (FIGS. 12G and 12H).
6. When the space between the speakers is between *w* and ½*w*, of a set of frequencies, partial reinforcements and cancellations will occur (FIGS. 12C and 12F).
7. Cancellations will predominate over reinforcements in the space between the speakers for all frequencies whose approximately **43/64** *w* is longer than the distance between the speakers (FIGS. 12C and 12F).

Appropriate consideration of the above conclusions will make it apparent that requirements for desirable bass response are met by the **180°** out-of-phase electrical connection, as experimentally ascertained and described in my U.S. patent mentioned above, for the coaxial face to face (or back to back) open baffled speakers.

It will also be apparent from the above mentioned conclusions that the requirements for best treble response in the case of face to face tweeters are met by the in-phase electrical connection of the facing tweeters. This arrangement will produce at least some acoustic cancellation at all frequencies lower than about the frequency whose one-half of a wave length is equal to or greater than the distance between the coaxial small speakers. The new result is a relative reinforcement of the high frequencies, which can be experimentally confirmed with FM "white noise" or with high-frequency signals.

Furthermore, such an arrangement provides for a better loading and thus a greater power handling capacity for both small speakers, without the need of sealing off their back radiation as is done with pressurized dome type tweeters, where the same undesirable effects of sound coloration may occur, as discussed before when referring to the back waves of boxed-in speakers.

Consequently, it may be stated that the following novel general rules may always be applied in the installation of open-baffled and unbaffled coaxial speakers.

When the coaxial speakers are mounted in the front baffles of two facing open back cabinets, with their radiators moving in the same direction at any given instant, for best low frequencies reproduction, in order to achieve the best possible damping and power handling capacity it is preferable to use speakers of different sizes and main cone resonances in each coaxial pair.

Conversely, when the coaxial speakers are connected so as to cause their radiators to move in opposite directions at any given instant for each pair considered, it is preferable to use speakers of the same size and main cone resonance characteristics, i.e., identical, in each coaxial pair of "push-pull" speakers.

It will be appreciated that in both cases the rules given will provide for maximum possible mutual cancellation at the cone resonance frequencies of the coaxial speakers, and hence the maximum mutual acoustic damping and power handling capacity. Thus, the desirable characteristics of open baffling such as its inherently superior transients response and better efficiency, are achieved while simultaneously minimizing its principal defects of lack of sufficient bass response and of acoustical loading for maximum power handling capacity, and of the artificial bi-polar radiation, figure eight or "doublet" effects of sound propagation corresponding to all single open baffling systems (such as screen type electrostatics, planar baffles and similar systems).

For whichever connection, however, there will always occur alternating reinforcements and cancellations which for a given separation between the coaxial speakers, are produced at the same frequencies where cancellations and reinforcements, conversely, occur for speakers connected in a reversed way.

Hence, a means becomes easily available to control the undesirable dips and peaks in frequency response curves in a given installation and listening environment. For this purpose it only suffices to have in each system at least two coaxial pairs of speakers installed at the same distance in each pair but connected in a reversed way, so as to cause the radiators of the speakers of one pair to move in the same direction at any given instant and of another pair in an opposite direction to each other at any given instant, in order to smooth the dips and peaks produced by the other pair in their frequency response curve.

Of course, this can be most simply and economically achieved by forming two pairs of coaxial speakers using only three speakers, with the installation of a third unbaffled additional speaker coaxially to the first baffled pair within an open-back cabinet; spacing it at the same distance from the nearest baffled speaker, as the distance between the baffled initial pair, and phasing it so that its diaphragm moves in an opposite direction to the said pair at any given instant, thus acoustically correcting and smoothening the overall frequency response curve, while providing a better damping and power handling capacity to the system, with least chance for "cone break-up" distortion.

Experimentally it was found that when the said added third speaker was installed unbaffled within one of the shallow open-back cabinets, coaxially with the initial baffled pair, connected as just described, and it was a

full range speaker, the bass response of the system was further and unexpectedly improved.

The better and cleaner bass effect produced within the open-back cabinet, between the new coaxial unbaffled speaker and its nearest baffled neighbor was apparently through a push-pull effect, contrarywise of what was needed for the best bass response between the two coaxial openbaffled speakers.

Now, it can be shown that single open baffling, causes not only a figure eight polar radiation with practically complete cancellation of front and back sound waves in the plane of the flat baffle, but also that the phase delaying effect of such baffling produces variable reinforcements and cancellations for the various frequencies reproduced, which reinforcements reach a maximum for an effective baffle size equal to a whole wave length of a frequency being reproduced; but with increased baffle sizes said reinforcements diminish again until for a baffle size of twice said wave length, total cancellation with generation of standing waves is caused, which phenomenon is repeated cyclicly for odd and even multiples of said wave length.

Hence in order to minimize the irregularities in frequency response curves caused by the single baffles themselves I have found it desirable to use in cabinets with two open baffles variable radial sizes for said open baffles, preferably comprised between the practical ratios of **2:1** and **1:1**, which may be "staggered" for best results in the various cabinets of a multi-cabinet system.

The above effect is further facilitated by the adoption of different polygonal shapes for the top panels of the various table cabinets of a multi-channel system, such as rectangular, pentagonal, and hexagonal commonly used presently in regular furniture.

Consequently, it was found that embodiments corresponding to the designs just described (see FIGS. **1** and **4**) are ideal from the points of view of the various basic objectives of this invention, namely: un-boxed, omnidirectional sound, with substantially spherical waves propagation pattern, with no two speakers installed side by side on any one plane, with the possibility of no cross-over electrical networks at all, providing for maximum bass response, efficiency, power handling capacity and automatic acoustical correction of the respective response curve, with a minimum number of speakers used, and according to accepted ornamental furniture designs.

The mentioned types of acoustical compensations by the realtive shapes and sizes of the open baffles used, and the spacing and phasing of the speakers in a multispeaker arrangement are not feasible in systems with speakers mounted on the fronts of boxed-in cabinets of any type, or even of just single open baffles.

Furthermore, different sizes and spacings between the speakers of any opposing pair can control the critical frequencies at which cancellations and reinforcements occur. Thus the spacing of the tweeter speakers in each table-cabinet could be chosen for "staggered" reinforcements and cancellations tending to smooth the overall response.

The tweeter speakers used for all these purposes may be full-range speakers of the type that could not be damaged be being fed with low frequencies. They should preferably be open-back speakers, and their cut-off frequencies would be determined simply by their sizes or respective small open baffles.

If sensitive tweeters susceptible to be damaged when fed with low frequencies are desired, it will suffice to filter off said low frequencies in the respective circuits by the use of appropriate capacitors in series with the tweeters voice coils, in the usual manner.

Hence by controlling the shapes, sizes, open baffling and spacing of the speaker systems of this invention it is possible to obtain more economically better overall response curves than with conventional systems using more expensive and complicated electrical designs.

The possible total absence of cross-over networks in the embodiments of the invention is desirable because of the resulting simplification and elimination of artificial electrical sources of peaks and dips in frequency response. Transient response is also definitely benefited by the lack of cross-over networks.

A further definite improvement in the overall bass response and naturalness of a sound reproduction system is achieved by the use of two open-baffled cabinets as described before for each monophonic channel. A better coupling with the surrounding air in the listening space is obtained, which results in considerably better bass response and even greater feeling of ambiance and realism in the reproduction of sound.

For this purpose it is necessary to connect two open baffled table-cabinets in parallel to each monophonic signal. Adequate impedance matching should be assured in each case, according to the characteristics of the speakers and amplifiers used.

By using two open-baffled cabinets in each monophonic channel of a stereo system in the manner described, a remarkable depth effect is obtained for the sound reproduction which can best be described as three-dimensional stereo or binaural sound, resulting in a very realistic ambiance in the listening space, even without the need of four channels, as is presently done with the so-called quadriphonic systems. Of course, said four quadriphonic channels can also be advantageously reproduced by four open-baffled cabinets omnidirectionally and with no boominess, hence with a greater naturalness than by directional boxed-in speakers.

In this manner there occurs a kind of mutual acoustic damping also in the listening space among the various speaker cabinets of a system, producing as an overall result a smoothness, naturalness and realism not possible to achieve with conventional prior art systems. If to these advantages are added the almost spherical omnidirectionality and superiority of the clean transients corresponding to each open-baffle mounting, while not sacrificing a deep, true non-resonant bass, and a truly efficient dispersion of high frequencies, with only acoustical mutual damping and smoothening of response curves of each unit and among the various units, it will be understood why the new embodiments of the present invention produce a different kind of sound from the all too generalized boxed-in types with their characteristic boominess, unnatural highs and directional propagation patterns of sound waves as well as their artificial resonances derived from the many echoes of the "prisoner" back waves; and thus from the resultant "glorified radio sound" of even some of the most expensive prior art systems.

Referring now to the embodiment of the invention shown in FIGS. **13, 14,** and **15,** it will be noted that a hanging light fixture **80** is supported from the ceiling **81,** which has two open baffled speakers **82, 83** which

are coaxial and whose radiators move in the same direction as indicated by the arrows. The open baffled speakers **82, 83** are respectively supported by baffles **85, 86** having suitable apertures **87, 88** disposed therein to accommodate such speakers **82, 83.** Also, an unbaffled speaker **90** is coaxially mounted in approximately equal distance from speaker **83,** as the distance between speakers **82** and **83,** so as to provide a push-pull pair of radiators. The lighting fixture includes a plurality of electric bulbs **95.**

It will be understood that the embodiment shown in FIGS. **13, 14,** and **15** functions substantially the same as the embodiment shown in FIG. **2.**

FIG. **16** merely shows an alternative configuration for the hanging lamp fixture of FIGS. **13, 14,** and **15** as viewed from the bottom and showing the unbaffled speaker **90** and the light bulbs **95.**

It will be understood that the above embodiments are only illustrative of the scope of the invention, and that many other detailed shapes and arrangements are possible without departing from its novel teachings as described, which could be adopted by the men skilled in the art.

What I claim is:

1. An omnidirectional speaker system comprising an arrangement of substantially open baffled and unbaffled speakers for the reproduction of the full range of audible frequencies, said speakers being of the type having acoustic radiators which produce both front and rear waves of acoustic energy, mounted coaxially with axial separations therebetween, and wherein the speakers of a first pair are joined to two open baffles having their front surfaces, where the speakers are mounted, perpendicular to their common axis, with said speakers electrically connected to an audio frequencies signal source so as to cause their radiators to move in the same direction, pistonwise, at any given instant; characterized in that at least three speakers are provided to constitute at least two pairs of speakers, the speakers of each pair being spaced at substantially the same distance coaxially from each other in both pairs; in that the second pair of coaxial speakers is formed by mounting the third unbaffled speaker coaxially with the baffled pair, thereby using one of the baffled speakers as a common member of both pairs; and in that the speakers of the second pair are electrically connected so as to cause their radiators to move in an opposite direction to each other, push-pullwise, at any given instant.

2. A speaker system according to claim **1,** characterized in that the speakers are full frequency range.

3. A speaker system according to claim **1** characterized in that the speakers forming said first pair, with their radiators moving pistonwise, are of different cone resonance frequencies; and in that the speakers forming said second pair, with their radiators moving push-pullwise, are of the same size and substantially of the same cone resonance fequencies.

4. A speaker system according to claim **1,** characterized in that at lest one of said open baffles is the front baffle of a shallow open-back cabinet, facing the other flat open baffle, with lateral sides that are at an angle with said front baffle and away from the said other flat open baffle; in that the said third unbaffled speaker is mounted substantially within said open back cabinet, facing outwards from the same; in that the said three coaxial speakers are all facing in the same direction; in that the two equal axial separations between the flanges of the three speakers are substantially greater than the depth of the speakers used and smaller than their mean diameters; and in that the depth of said lateral sides is determined by said axial separation of the speakers, so as to cause the flange of said third unbaffled coaxial speaker to be substantially flush with the outer rim of said lateral sides, which in turn are at most about half the shortest length of the extended diameter of the speakers mounted on the front baffles, measured along their surfaces to both their opposing edges, thereby determining the limiting range of the corresponding dimensional parameters of the said speakers system cabinet.

5. A speaker system according to claim **4,** wherein said front baffles are supported perpendicularly and near to a large sound reflecting surface such as a floor, ceiling, wall, column and the like, characterized in that said open baffled coaxial speakers are mounted with their common axis parallel to said reflecting surface.

6. A speaker system according to claim **5,** wherein said open baffled cabinets are floor standing models, and both said flat front baffles are rectangular, characterized in that the cabinets are topped with finished panels with a substantial overhang that extends beyond the depth of said lateral sides and front baffles at least on one side of the cabinet and sufficiently to cover the back of the coaxial speaker mounted on the flat open baffle, facing into the open back cabinet where the other two coaxial speakers are mounted; and in that the speakers system structure is thereby constructed as a table type cabinet, finished according to a decorative design, and usable also as a table and the like.

7. A speaker system according to claim **6** characterized in that said finished panels on top of the table floor cabinets are of polygonal shapes, with at least four sides, such as rectangular, pentagonal, hexagonal, heptagonal, octagonal and the like.

8. A speaker system according to claim **6,** characterized in that said finished panels on top of the table floor cabinets are of oval shapes, such as rectangular and polygonal with rounded corners, elliptical and the like.

9. A speaker system according to claim **4,** wherein said front baffles are supported far from a large sound reflecting surface such as a ceiling and the like, characterized in that said open baffled coaxial speakers are mounted with their common axis perpendicular to said reflecting surface, such as hanging from a ceiling with said front baffles supported horizontally; in that said front baffles can be of polygonal and rounded shapes; and in that the supporting structure is constructed as a lamp, which can be completed with lights for illuminating purposes, finished according to a decorative design and used also as an ornamental lighting lamp.

10. A speaker system according to claim **6** wherein at least a pair of small open back equal sized cone speakers are mounted outside of each said table cabinets, substantially unbaffled, coaxially and face to face with each other, characterized in that they are connected electrically to an audio frequencies signal source mutually in phase, thereby causing their radiators to move in opposite direction to each other at any given instant, push-pullwise; in that their axial separation is substantially smaller than the depth of each speaker; in that said separation is adjusted at different compensating depths, thus staggering the reinforcements and cancellations of high frequencies among the various cabinets of multiple-cabinets systems; in that

said pairs of coaxial speakers are mounted with their common axis vertical above the horizontal finished panels of the said table like cabinets; and in that they are at most only covered with ornamental acoustically transparent materials, thereby in substantially unconfined acoustic communication with the surrounding air of the listening space, within cage-type household ornaments, such as provided by said type of bases of common table light lamps, hanging light lamps and the like.

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