June 22, 1965 A. F. PETRIE 3,190,389

LOUDSPEAKER CONSTRUCTION

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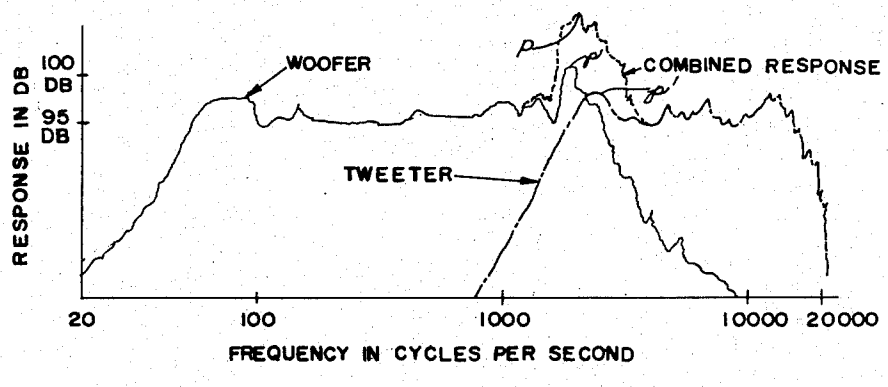


FIG. 1

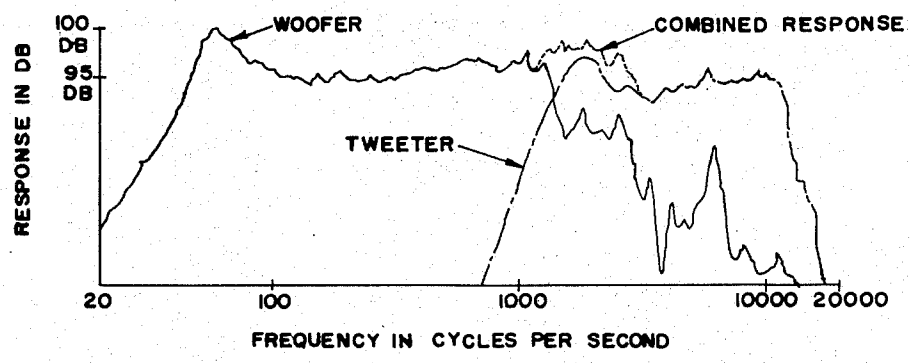


FIG. 2

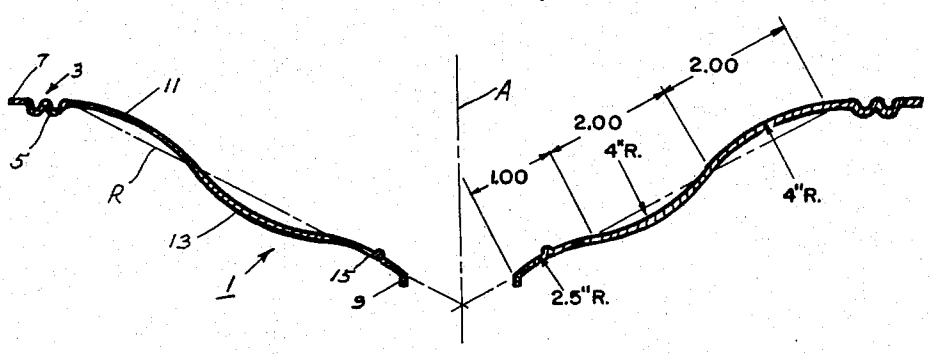


FIG. 3

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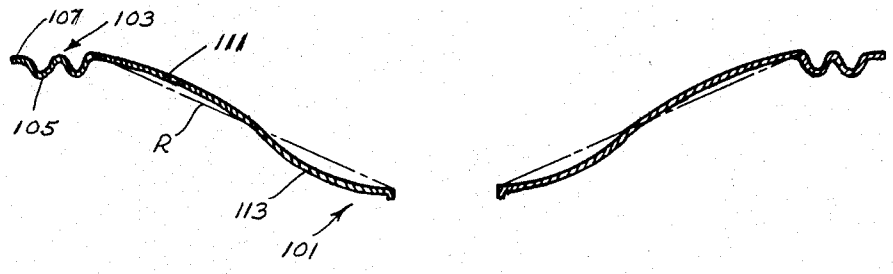


FIG. 4

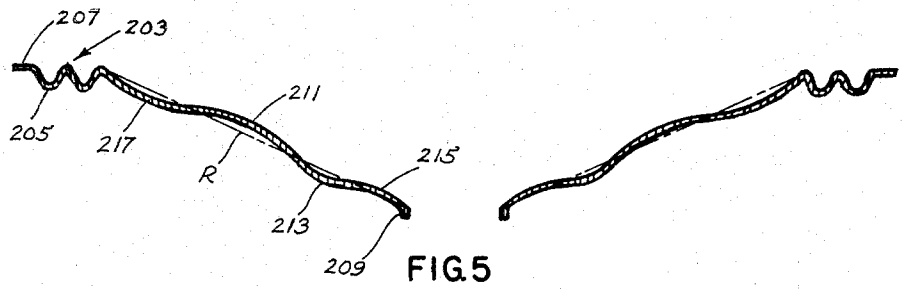


FIG. 5

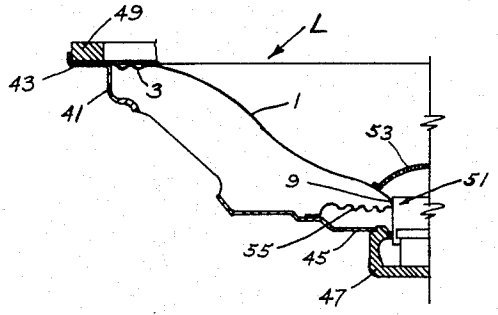


FIG. 6

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LOUDSPEAKER CONSTRUCTION

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7 Claims. (Cl. 181—32)

This invention relates to an improved loudspeaker, and in particular to a cone for low frequency responsive loudspeakers commonly known as woofers.

In order to provide acoustic radiation over a relatively wide band of audio frequencies, it has been customary to employ two loudspeakers, one, known as a woofer, for the low frequencies, and one, known as a tweeter, for the higher frequencies. In what is known as the crossover region, the acoustic radiation efficiency of the woofer tapers off, and the acoustic radiation efficiency of the tweeter increases, in such a manner that the combined acoustic radiation efficiency for the two loudspeakers is substantially constant throughout the crossover region. Although the frequency limits of the crossover region vary considerably in accordance with the design of the loudspeakers and the loudspeaker system, this region generally lies between 1000 and 5000 cycles per second. For optimum operation, it is desirable that the acoustic radiation efficiences of the woofer and tweeter should vary smoothly for a constant input.

Woofer type loudspeakers of the prior art have been designed in such a manner that the radiation efficiency decreases in a particular crossover range. However, in these woofers, it will be found that there is an inherent fluctuation in radiation efficiency within the crossover region. In particular, there appears to be a sharp increase in radiation near the low frequency end of the crossover region. This sharp increase, or fluctuation is detrimental to the smoothness of response of the loudspeaker in which the woofer is incorporated.

To overcome the adverse effects of the inherent fluctuation in radiation efficiency, several prior art approaches have been used. One such approach has been to use a loudspeaker cone in which the decrease in radiation begins at a slightly higher frequency than that desired, and a heavier voice coil and magnetic assembly to initiate the reduction in output at the desired lower frequency. However, this method is relatively expensive, and it has, therefore, been customary in making woofer type loudspeakers, to use a cone wherein, as before, the radiation starts to fall off at too high a frequency, together with a crossover network, which reduces the amplitude of the signals applied to the woofer in the crossover region. Such an arrangement may also achieve the desired radiation characteristics, but such an approach is also considered to be relatively expensive.

Another prior art means for smoothing the response of the woofer in the crossover region, is the use of apex filters. Such filters are generally formed with a sharp ridge located symmetrically to and near the apex of the cone. This ridge will transmit motion to the outer (i.e. larger diameter) section of the cone for low frequencies, but this action decreases as the frequency increases until at higher frequencies substantially all movement is confined to the small section of the cone between its apex and the ridge. One major difficulty with cones of this design is that there is a marked tendency for them to rupture in the vicinity of the ridge. Obviously, the risk of rupturing increases as the loudspeaker is driven harder to provide more output, and, therefore, the safe power rating for the speaker must be reduced to a value below that which would otherwise be expected for a cone of a given size and design.

Accordingly, it is an important object of my invention

to provide an improved woofer type loudspeaker that will effectively operate in the vicinity of the crossover region without requiring the use of a relatively heavy voice coil and magnetic assembly, or a crossover network, while also minimizing the danger of the cone rupturing when normal power ratings are applied thereto.

Another object of my invention is to provide an improved loudspeaker of the type responsive to relatively low frequencies, which loudspeaker is of very economical construction and provides a smooth response throughout the range of frequencies for which it is designed to operate.

Still another object of my invention is to provide an improved cone for a woofer type loudspeaker, which is readily manufacturable, sturdily constructed, and efficient in operation.

Briefly, in accordance with my invention, in one embodiment thereof, I have provided a woofer-type of loudspeaker. This loudspeaker includes first and second annular sound radiating sections which are integrated into a generally conical overall configuration. The first sound radiating section has an outwardly concave shape and is disposed on one side of a straight bodied or right circular reference cone. The second sound radiating section has an outwardly convex shape and is disposed on the other side of the reference cone. With such an arrangement, the first and second sound radiating sections are dimensioned relative to each other and arranged relative to the reference cone so that they are capable of providing equal and opposite radiation effects during a predetermined frequency range of operation of the loudspeaker, to substantially improve the performance of the loudspeaker.

The features of my invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following explanation and description, taken in connection with the accompanying drawings, in which:

FIG. 1 shows acoustic response curves for a typical prior art loudspeaker system including a woofer cone, and an associated tweeter cone, with the frequency indicated as a logarithmic function on the abscissa, and the output indicated in decibels on the ordinate;

FIG. 2 shows, similarly to FIG. 1, acoustic response curves for a loudspeaker arrangement in accordance with one form of the present invention;

FIG. 3 is a cross-sectional profile of an improved woofer cone, in accordance with a preferred embodiment of my invention;

FIG. 4 is a cross-sectional profile similar to FIG. 3, of a modified and alternate form of improved woofer cone;

FIG. 5 is a cross-sectional profile similar to FIG. 4 of another modified and alternate form of improved woofer cone; and

FIG. 6 is a side fragmentary view, partially broken away, of an improved loudspeaker employing a woofer cone constructed in accordance with my invention.

Before describing the structure of my improved loudspeaker, a preliminary discussion of some of the important design principles for constructing loudspeakers, is first deemed appropriate. An analysis of the operation of loudspeakers indicates that the basic movement of the loudspeaker cone is back and forth parallel to the axis of the cone. This particular movement is often referred to as piston action, because the entire cone moves as a unit. This action is permitted by suspending the apex and the outer peripheral edge of the cone with compliant sections that permit relatively free movement. Superimposed on the basic piston-like motion of the cone,

there is also a fluctuation of the depth or axial length of the cone which results from the transmission of compression waves along the cone between its apex and outer peripheral edge.

The fluctuating action referred to may be explained more particularly as follows. Let it be assumed that a single frequency is applied to the voice coil of the loudspeaker at any given time being examined. During one half cycle of this frequency, the apex of the cone moves forward (i.e. toward the peripheral edge) so as to place the cone material adjacent thereto under compression, and during the next half cycle the apex moves backward so as to place the cone material under tension. This results in setting up compression waves which flow outwardly from the apex toward the peripheral edge of the cone. When these compression waves reach the peripheral edge they are reflected back toward the apex of the cone. The phase of the reflected compression wave depends on the frequency and speed of the wave in the particular cone material involved.

When the superimposed action just described is such as to foreshorten the cone at the same time as the piston action moves the cone forward, the combined effect will, in a normal cone produce an acoustic radiation that is greater than normal. The two actions are then in phase. Accordingly, when these actions are out of phase, the acoustic radiation is reduced. The greatest change in acoustic radiation will probably be noted when the path length of a quarter of a full compression wave in the cone material is equal to the path length between the apex and the outer periphery of the cone. However, as is well known to those skilled in the art, this is the quarter wave length mode of operation akin to the fundamental note of a closed organ pipe, and other modes of compression waves could exist in the cone material which would cause reinforcements of the piston and superimposed actions at other frequencies.

In practically all known prior art loudspeaker designs, it will be found that this reinforcement action takes place within the desired crossover range, and its relative effect is especially pronounced because it is superimposed onto the generally lower acoustic radiation of the woofer. Furthermore, the wide fluctuations in acoustic energy radiated by the woofer make it practically impossible to produce a combined output of woofer and tweeter that is uniform. An important aim of the present invention is to overcome the adverse response effects attributable to the fluctuating action of the woofer cone in the crossover region and thereby enhance the smoothness of response of the loudspeaker system.

Referring first to FIG. 3, which is a cross-sectional view of a preferred embodiment of my invention, there will be seen the woofer cone **1**. Cone **1** is symmetrically configured and it includes near its upper and outer end an annular corrugated suspension **3**, shown in profile fashion by FIG. 3. Preferably, cone **1** is made from treated paper having a uniform thickness, and the corrugated suspension **3** comprises a plurality of concentric edge rolls **5** connected to a laterally outermost flange **7**. The lower and inner annular end **9** of cone **1** includes a cylindrical flange, and since it is closest to the axis A of the cone **1**, end **9** is referred to as the apex of the cone. It will be noted further in FIG. 3 that a straight bodied or right circular reference cone R is indicated by dotted lines. The straight bodied and uniformly configured reference cone R is shown to facilitate the description of the present invention and it extends uniformly in straight fashion between the top portion of inner end or apex **9** and the inner end of the corrugated suspension **3**.

With such a cone arrangement as that described above and shown in FIG. 3, in accordance with the principles of my invention, the cone is provided with specially dimensioned first and second annular sound radiating sections **11** and **13** respectively, located between suspension **3** and apex **9**. More particularly, as further illustrated in the preferred embodiment of FIG. 3 the first and second sound radiating sections **11** and **13** are curved in opposite directions relative to the reference cone R. The first section **11** is located on the inner and upper side of the reference cone R, and is conterminous at its upper end with the innermost edge roll of the suspension **3**. The lower end of section **11** is conterminous with the upper end of the second sound radiating section **13**. The second sound radiating section is located on the outer and lower side of the reference cone R, and its lower end is conterminous with the upper end of a third cone strengthening curved section **15** located, as is first section **11**, on the inner and upper side of reference cone R, near to the apex **9**. The lower end of the section **15** is conterminous with the inner end or apex **9** of cone **1**.

From the above description of woofer cone **1**, it will be understood that the annular curved section **11** presents an inwardly convex shape, with respect to the central axis of the cone, and the annular curved section **13** presents an inwardly concave shape, with respect to the central axis of the cone. As further indicated by the dimension lines of FIG. 3, the sound radiating sections **11** and **13** each have the same segmental length, such as, for example, two inches, and the same radius of curvature, such as, for example, four inches. In addition, for the preferred embodiment illustrated in FIG. 3, the segmental length of the smaller cone strengthening section **15** is one half that of the sections **11**, **13**, such as for example, one inch, and the radius of curvature of section **15** may be two and one-half inches.

From further viewing FIG. 3 it will be noted that for the preferred embodiment shown therein, the extent of deviation of the curved section **11** from the reference cone R is the same as the extent of deviation of the curved section **13** from cone R.

With such an arrangement, the relatively concave and convex sound radiating sections **11** and **13** of the cone body have cross-sectional areas which are approximately equal and the extent of their deviations from the reference cone R are also approximately equal. The sections **11** and **13** are thus dimensioned so that they will have equal and opposite radiations in response to compression waves of the cone. Thus, for example, a compresive force component along the center line of the cone causes the sections **11** and **13** to vibrate in opposite directions or phases. Because of the dimensioning and arrangement of the relatively convex and concave sound radiating sections **11** and **13**, they provide substantially equal and oppositely phased radiations which tend to cause cancellation of the relatively high and undesirable frequencies incident to the crossover region for the woofer.

It also will be understood that the area of one of the sections **11** and **13** may be made smaller than that of the other and the deviation of the one section may be made correspondingly greater to also provide substantially the same radiation for the sections **11** and **13**. It will be further realized that the actual relative areas for the sections **11** and **13** are dependent upon the flexibility of the cone material and the amplitude of vibration thereof.

As shown in FIG. 6, the woofer cone **1** embodying one form of invention is illustrated in woofer-type loudspeaker L. The loudspeaker L comprises a frame **41** having an outer rim **43**, and an inner rim or flange **45** to which a magnet assembly **47** is attached.

The cone **1** is attached to rim **43** by means of its outer suspension **3**. The outermost flange **7** (FIG. 3) of suspension **3** is cemented to the rim **43**, and a gasket ring **49** is cemented thereover. A voice coil winding assembly **51** is suitably attached to cone **1** near apex **9**. A dust cap **53** is attached to the cone **1** in the front of the voice coil assembly **51**, and an inner suspension **55** of impregnated cloth or other suitable material is positioned between the frame **41** and the voice coil assembly or the cone **1** near the apex thereof.

When suitable electrical signals are applied to the wind-

ing of the voice coil, these signals being supplied by an audio amplifier or other suitable source, the signals create an electrical field at the voice coil winding which reacts with the magnetic field so as to cause the cone **1** to vibrate in accordance with the electric signals. This vibration is, of course, in the direction of the axis of the cone. The cone suspensions **3** and **55** insure that the cone will vibrate axially and not laterally.

Turning now to a comparison between the audio response of my improved woofer type loudspeaker and a typical prior art loudspeaker of a similar variety, attention is initially directed to the curves of FIG. 1. As shown therein, the frequency is represented in cycles per second on the abscissa and the response is represented in decibels on the ordinate. The curve of the response vs. frequency for the woofer is indicated by a continuous line, and as indicated, between the frequencies of 1,000 c.p.s. and 10,000 c.p.s. the audio response rises generally to peak *p* and then falls off. The curve of the response vs. frequency for the tweeter is indicated by dot-dash lines, and as indicated, between the frequencies of 1,000 c.p.s. and 10,000 c.p.s. the audio response rises to an initial peak *p'* from whence it fluctuates slightly until it begins to fall off between 10,000 c.p.s. and 20,000 c.p.s. The combined audio response in the vicinity of the crossover region for the woofer and tweeter of the prior art system represented in FIG. 1, is indicated by the dotted line. It will be noted that this combined response peaks to a maximum point P which is substantially above 100 db in the crossover range.

The curves of FIG. 2 illustrate the audio response of a loudspeaker system which includes my improved woofer. As shown therein, the frequency and response are represented in the same manner as FIG. 1. It will be noted that the curve of the tweeter in the vicinity of the crossover region is substantially similar to the similar portion of the curve for the tweeter in FIG. 1. However, it will be further noted that the woofer curve of FIG. 2 does not include any peak *p* such as FIG. 1. In addition, it will be further observed that the response of the woofer in FIG. 2 falls off near the crossover region (with increasing frequency) in a relatively smooth fashion, when compared with the woofer-response curve of FIG. 1. As a result of the smoother response of the woofer of the present invention in the vicinity of the crossover range as indicated in FIG. 2, the combined or total response for both woofer and tweeter becomes relatively flat, thereby eliminating the peak P of FIG. 1. It will thus be seen from a comparison of the response curves of FIG. 1 and FIG. 2, that by providing equal and opposite sound radiating sections in the vicinity of the crossover range for the woofer cone **1**, my improved woofer type loudspeaker provides a substantially improved smoothness in audio response.

FIG. 4 represents a modified form of my invention wherein the cone **101** is of the simplest form, and includes a first sound radiating section **111** and a second sound radiating section **113**. The sections **111** and **113** are dimensioned similarly to sections **11** and **13** of the cone **1** so that they provide equal and opposite radiation in the vicinity of the crossover region and consequent smoothness in the response of a loudspeaker with which the cone **101** is associated. For cone **101**, the sections thereof which have a structural similarity to correlative sections of cone **1** are identified by the same two reference numerals, with the numeral **1** prefixed thereto. It will be understood that the mode of operation of cone **101** in a loudspeaker is substantially the same as that described above for cone **1**.

FIG. 5 represents a second modified form of my invention wherein the cone **201** includes additional curved sections **215** and **217** near its inner and outer ends respectively. Section **215** provides additional strength for the cone near the apex **209** and section **217** provides a relatively smooth edge resonance. Cone **201** includes a first sound radiating section **211** and a second sound radiating section **213**. The sections **211** and **213** are dimensioned similarly to sections **11** and **13** of the cone **1** so that they provide equal and opposite radiation in the vicinity of the crossover region and consequent smoothness in response of a loudspeaker with which the cone **201** is associated. For cone **201**, the sections thereof which have a structural similarity to correlative sections of cone **1** are identified by the same two reference numerals, with the numeral **2** prefixed thereto. It will be understood that the mode of operation of cone **201** in a loudspeaker is substantially the same as that described above for cone **1**.

It will now, therefore, be seen that the present invention provides an improved woofer type loudspeaker that will effectively operate in the vicinity of the crossover region. It will also be realized that my improved woofer type loud speaker is readily manufacturable and low in cost.

While in accordance with the patent statutes, I have described what at present is considered to be the preferred embodiment of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from my invention, and I, therefore, aim in the following claims to cover all such equivalent variations as fall within the true spirit and scope of this invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a loudspeaker of the type responsive solely to relatively low frequencies, a loudspeaker cone comprising an annular apex area of minimum diameter, first and second annular sound radiating sections integrated into a generally conical overall configuration, said first sound radiating section having an inwardly concave shape with respect to the central axis of the cone and disposed on one side of a reference cone, said first sound radiating section being disposed adjacent said apex area, thereby enabling said cone to function as a woofer, said second sound radiating section having an inwardly convex shape with respect to the central axis of the cone and disposed on the other side of said reference cone, said first and second sections being dimensioned relative to each other and arranged relative to said reference cone so that they may provide equal and opposite radiation during a predetermined portion of the frequency range of operation of the loudspeaker, thereby to enhance the smoothness of response of said loudspeaker.

2. In a loudspeaker of the type responsive solely to relatively low frequencies, a loudspeaker cone comprising an annular apex area of minimum diameter and an outermost peripheral edge of substantially greater diameter than said apex area, first and second annular sound radiating sections disposed between said apex area and said peripheral edge, said sections being integrated into a generally conical overall configuration, said first sound radiating section having an inwardly concave shape with respect to the central axis of the cone and disposed on one side of a reference cone, said first sound radiating section being disposed adjacent said apex area, thereby enabling said cone to function as a woofer, said second sound radiating section having an inwardly convex shape with respect to the central axis of the cone and disposed on the other side of said reference cone, said first and second sections being proportioned relative to each other and arranged relative to said reference cone so that they may provide equal and opposite radiation during a predetermined portion of the frequency range of operation of the loudspeaker, thereby to enhance the smoothness of response of said loudspeaker, and a third annular cone section connected to said first sound radiating section, disposed adjacent said apex area and having an inwardly convex shape with respect to the central axis of the cone, said third section being of a substantially smaller length than said first sound radiating section for strengthening said cone and enhancing the durability thereof while enabling said cone to function as a woofer.

3. The arrangement of claim **2** wherein said annular

curved section adjacent the apex area has a segmental length of between 10 percent and 60 percent of the segmental length of said first sound radiating section.

4. The arrangement of claim 2 wherein the deviations of said first and second sound radiating sections are substantially equivalent.

5. The arrangement of claim 4 wherein the linear distances of said first and second sound radiating sections along said reference cone are substantially equal.

6. The arrangement of claim 5 wherein the radii of curvature of said first and second sound radiating sections are substantially equal.

7. A woofer type loudspeaker construction comprising a supporting frame, a cone, and means for suspending said cone in said frame to allow limited movement of said cone along its axis, said cone comprising an apex area and an outer peripheral edge located at the ends of the cone, and first and second annular sound radiating sections located therebetween, said first and second annular sound radiating sections being integrated into a generally conical overall configuration, said first sound radiating section having an inwardly concave shape relative to the central axis of the cone and disposed on one side of a reference cone generally including said apex area, said peripheral edge and said first and second sections, said

first sound radiating section being disposed adjacent said apex area, thereby enabling said cone to function as a woofer, said second sound radiating section having an inwardly convex shape relative to the central axis of the cone and disposed on the other side of said reference cone, said first and second sections being of substantially the same radius of curvature and deviation from said reference cone so that when compressive and tensional forces are exerted upon said cone between its apex and its outer peripheral edge these sound radiating sections provide equal and opposite radiation during a predetermined portion of the frequency range of operation of the loudspeaker, thereby to enhance the smoothness of response of said loudspeaker construction.

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