Sept. 27, 1955 W. C. BENJAMIN 2,718,932

LOUD SPEAKER CONSTRUCTION

Filed June 29, 1954 2 Sheets-Sheet 1

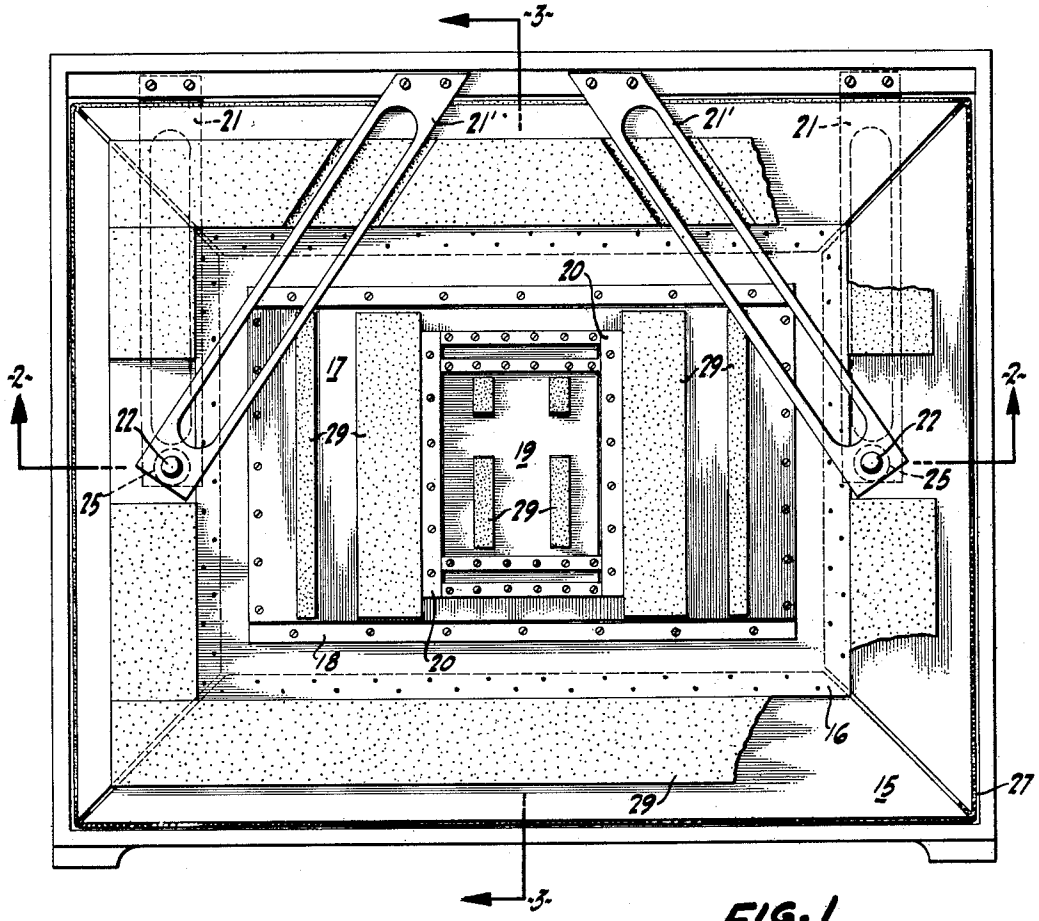


FIG. 1

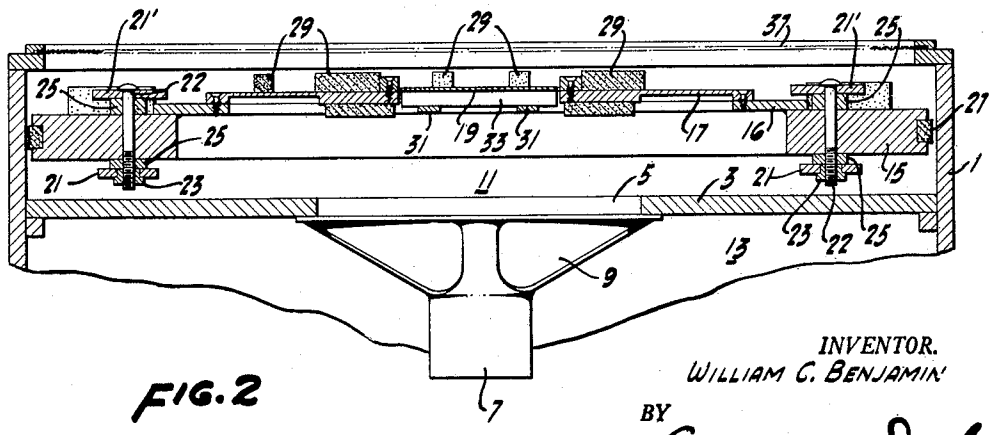


FIG. 2

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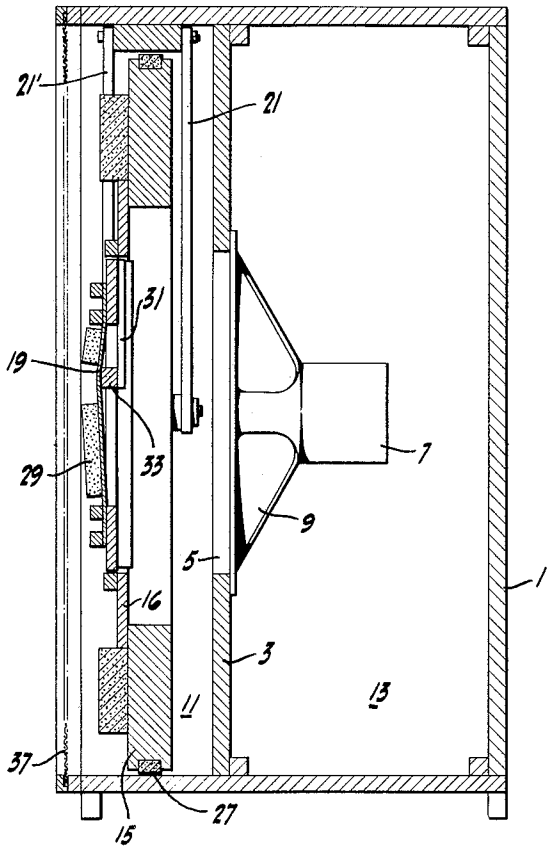


FIG. 3

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LOUD SPEAKER CONSTRUCTION

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5 Claims. (Cl. 181—31)

The invention relates to transducers or sound projectors for high-fidelity sound reproducing systems, and specifically to projectors responsive to the lower frequencies in the audible range.

Because of the difficulty of making loud-speaker units which are equally responsive to all frequencies within the band to which the ear responds, it has become accepted practice in high-fidelity systems to use a plurality of speaker units. One such unit, responsive to the higher frequencies in the audible band, is generally referred to as a "tweeter," while a second unit, responsive to the lower frequencies, is generally termed a "woofer." The two units are interconnected by conjugate frequency selective networks so that substantially all of the low frequency energy from the power amplifier which excites the sound projector units is directed to the low-frequency device while at the higher frequencies all of the energy is fed to the "tweeter." At some intermediate frequency, known as the cross-over point, the energy is divided equally between the two transducing devices.

The reason for this procedure, as is well understood, is the difficulty of coupling the electrical driving mechanism of a transducer to the air in a manner which will be equally effective at all frequencies. In transducers of the class here considered such coupling is effected through a diaphragm; all diaphragms so far produced have a more or less definite resonant frequency, whereat they tend to radiate sound at much higher efficiency than at other frequencies. Furthermore, a diaphragm radiates sound in opposite phase from its front and rear surfaces, and if the waves from the two surfaces meet in opposite phase they tend to cancel. Some sort of baffling means is normally provided to prevent such interference. As the attempt is made to reproduce sounds of lower frequency and longer wavelength the baffle must ordinarily be made of increasingly large dimension, and at the lowest frequencies to which the air will respond the size of the baffle required becomes impractically large.

Moreover, to radiate a given amount of sound energy from a diaphragm of given size requires an excursion of the diaphragm which is inversely proportional to the frequency to be radiated, and for very low frequencies the excursion required may be too great to be effectively accomplished.

The above general statements refer to radiation from a diaphragm in free air. If the air is confined, as in a sound chamber or the throat of a horn, so that its pressure can be increased, the energy which can be transferred from the diaphragm to the air can be raised materially. Horns which will pass low frequencies, however, are ordinarily very bulky and are likely themselves to have unpleasant resonances. In general, therefore, it has been found preferable to use directly radiating diaphragms, although this is by no means universal practice.

Generally, also, the effort has been made to make the diaphragms as light as is possible in view of their area, in order to get maximum response.

The present invention comprises a means for transferring the energy available in a loud speaker or transducer unit of the conventional dynamic-cone type through a diaphragm of large size which will radiate such energy at very low frequencies, down to 32 cycles per second, or even to the extreme lower limit of the audible range, which lies somewhere in the octave between 16 and 32 cycles per second.

The projector for effecting this comprises a cabinet completely enclosed on all sides except the front, or radiating, face. While the size of this open side or face is to some degree important, in that it must be large enough to accommodate a diaphragm which will radiate the requisite low frequencies, its dimension may be varied to considerable degree. Projectors have been built, for example, wherein the area of the open face of the cabinet was about seven and a half square feet, the dimensions being approximately 3' x 2'6", but these dimensions are given purely by way of example and are not intended to be limiting. Resiliently suspended within the open face of the cabinet is a composite diaphragm comprising a frame filling substantially the open area and made of very heavy material as compared to ordinary diaphragms. In practice this material has been of fairly light wood, such as white pine, but of 2" by 6" dimensions. Within the frame is a rectangular opening occupying the remainder of the area of the cabinet face, and over this opening there is secured a subdiaphragm which is secured to the frame at its two ends only. The subdiaphragm is of stiffly resilient material, plywood of approximately ⅜ inch thickness having been used for the purpose. If desired the subdiaphragm may also have a rectangular aperture formed within it, over which there is similarly secured a sub-subdiaphragm of still lighter and more compliant nature, e. g., ¼ inch plywood or, preferably, one of the laminated sheet plastics, such as "Micarta" sheet. Any or all of the diaphragms may be loaded to lower their resonant frequencies.

Preferably a seal is provided between the edges of the composite diaphragm and the cabinet. This seal comprises strips of resilient material which substantially fill the gap between the cabinet and diaphragm edges but is secured only to one or the other. The material used for the seal may be, for example, felt or sponge rubber. Since it does not actually connect the parts physically it exerts no limiting action upon the excursion of the diaphragm but does contribute to its damping.

Within the cabinet there is mounted a partition or septum which divides the cabinet into a front chamber, facing the diaphragm, and a much larger rear chamber. Mounted on the septum is a loud speaker unit of the conventional dynamic cone type, or in larger size projectors a plurality of such units. The unit or units used should be of fairly large size, preferably of 10" diameter or over if the projector is to handle the amount of power ordinarily required of high-fidelity reproducers. The distance between the cone and the diaphragm should be short in comparison with the wavelength of sound in free air at the cutoff or cross-over frequency which the projector is intended to radiate.

The above will be more readily understood by reference to the accompanying drawings and the detailed description thereof which follows. In these drawings:

Fig. 1 is a front view of the cabinet and diaphragm, showing the diaphragm construction and its method of suspension;

Fig. 2 is a partial cross-sectional view, in plan, of a projector in accordance with the present invention, the plane of section being indicated by the lines 2—2 of Fig. 1; and

Fig. 3 is a vertical sectional view, taken on the lines 3—3 of Fig. 1, through a sound projector embodying the instant invention.

The essential features of this invention are illustrated in the cross-sectional view of the sound projector which is shown in Fig. 3. The device comprises a solid cabinet **1**, closed on all sides except the front. The material of this cabinet will normally be of wood, and it should be sufficiently heavy and rigid so that the walls do not themselves act as diaphragms. Theoretically, however, there is no real restriction as to the cabinet material so long as it is non-radiative of sound; it could be of double, steel-wall construction if the space between the walls were damped by rock wool, fibre glass or other deadening material that would prevent the transmission of any material sound power, or if appearance were not a factor it could be made of heavy composite board such as those marketed under the trade name of "Celotex," "Masonite" or the like.

Mounted within the cabinet **1** and secured thereto close to its open face is a septum or partition **3**. This partition is provided with a central aperture **5** wherein there is secured a conventional dynamic-cone loud speaker unit **7**, the aperture being of substantially the same diameter as the conical diaphragm **9** of the loud speaker unit. The septum divides the cabinet into a shallow front chamber **11** and a much larger rear chamber **13**, the only connection between the two chambers being the aperture for the loud speaker diaphragm.

The composite diaphragm which forms the actual sound radiating member of the projector substantially fills the open front of the cabinet. Its periphery clears that of the septum **3** by a distance sufficient to prevent contact between the two when the diaphragm vibrates, but should not be much further away than this requires. The diaphragm comprises an outer frame **15** of rigid material. In practice the frames used have been formed of 2 x 6 pine, surfaced four sides, making its actual dimensions about 1¾" thick by 5¾" wide, and thus leaving a large central rectangular aperture. The effective size of the rectangular opening within the frame may be reduced by a solid, substantially inflexible inner frame **16**, rigidly fastened to the frame **15** but still leaving a rectangular opening within the inner frame. This, however, is for convenience; a wider outer frame could be used instead. The frame **16** in the device illustrated is of nominally ⅜" plywood. Secured at its opposite ends only over the rectangular aperture, in the frame **16**, is a sub-diaphragm **17** of stiffly resilient material. In practice the sub-diaphragm has been made of plywood, nominally ⅜" thickness, its two ends being screwed to the frame **16**, as shown in Fig. 1, while its sides just clear the edges of the aperture over which it is secured so that it may vibrate without hitting. The edges of the aperture within which the sub-diaphragm vibrates may be reinforced with metal or wood stiffeners **18**.

The sub-diaphragm **17** is also provided with a rectangular aperture and this, in turn, is covered by a sub-sub-diaphragm **19**, also secured at its ends only and of such size that its sides just clear the aperture. Suitable material for this sub-sub-diaphragm is laminated plastic sheet such as is marketed under the names sheet "Bakelite," "Micarata" or "Formica." Plywood of lighter gauge than that used for the sub-diaphragm **17** (e. g., one-quarter inch plywood) is also suitable. Stiffeners **20** may also be secured to the free edges of the aperture in sub-diaphragm **17**.

The entire structure of the composite diaphragm is suspended in the open face of the cabinet by resilient hangers **21** and **21'** best shown in Fig. 1. These hangers may be made of wood or metal, their upper ends being rigidly secured to the cabinet by screws or other suitable fastenings. The hangers are attached to the main frame **15** of the diaphragm in the present instance by bolts **22** and knurled nuts **23**, a washer or separator **25** being interposed between each hanger and the diaphragm so that, in vibrating, the diaphragm is completely out of contact with the hanger. As clearly shown in Fig. 1, the hangers

21 depend vertically from the top of the cabinet, while hangers **21'** are secured at an angle to provide cross-bracing to prevent any tendency of the diaphragm to swing laterally.

A seal **27** closes the gap between the diaphragm and the cabinet. This seal in the particular device illustrated, comprises strips of felt which are cemented to the cabinet but not the diaphragm, although the reverse could equally well be the case. Sponge rubber, solid rubber, or other material of generally similar character could be used for the seal. Its purpose is to maintain pressure within the chamber **11** but not to exert any resilient restraint upon the motion of the diaphragm as a whole.

It is to be noted that the method of suspension of each of the elements of the composite diaphragm is such as to permit the relatively wide vibratory excursion without overstressing the material, and that, such being the case, the restoring force on each element where it is deflected is low in comparison with what it would be were it secured around its entire periphery. Since the natural frequency of each of these elements is proportional to the square root of the product of its mass and the restoring force per unit deflection, each successive unit of the vibratory system, considered from the heavy frame inward would have a successively higher natural period of oscillation. The resilience of the hanger **21** is so adjusted that the natural frequency of vibration of the diaphragm as a whole is somewhat below the lowest frequency it is intended to radiate. For example, the natural frequency of this diaphragm may be in the neighborhood of 10 to 20 cycles per second.

The natural frequencies to which the sub- and sub-sub-diaphragms are tuned depends in some degree upon their sizes. Each diaphragm is tuned to a somewhat lower frequency than that at which, because of its size, it will radiate to best advantage. In order to obtain this effect it is generally necessary to load both the sub-diaphragm and the sub-sub-diaphragm, and frequently the outer such loading may be accomplished by screwing or otherwise securing loading blocks **29** to the diaphragms. In the particular device illustrated these blocks are of "Celotex," and are positioned, so that they do not break the sub- and sub-sub-diaphragms into equal parts which will have integral harmonic periods. It should be noted, however, that if these latter elements are made of material having a lower coefficient of elasticity than the wood or stiff laminated plastic which has been described, such loading might not be necessary. It will be recognized that they could be made of either more or less flexible material. Examples of materials which could be used include both stiffer plastics or composite plastic sheets, or more compliant plastics, such, for example, as celluloid. The amount of loading or the necessity for any loading whatsoever depends upon the flexibility of the material used.

The successively smaller radiating elements respond to progressively wider bands. The diaphragm as a whole may respond to perhaps a single octave. However, it is coupled to the sub-diaphragm, which is tuned to a frequency in the lower part of the band which it is primarily intended to cover. It might, at first consideration, appear that there would be a pronounced peak of radiation at the frequency to which the subdiaphragm per se is tuned. Such a peak does not appear because the outer frame to which it is secured is free to move and absorbs much of the energy which would go into the wider amplitude of vibration which marks a resonance peak. The sub-sub-diaphragm, in turn, is tuned to a frequency in the lower portion of its band, as is the case of transfer between the sub-diaphragm and the frame, it imparts energy to the sub-diaphragm at frequencies where the radiation of the latter would otherwise be falling off. Purely by way of example, the frequencies to which the successive elements might be tuned, when considered per se, could be 20 cycles, 80 cycles, and 300 cycles, to form an instrument

whose cross-over point when used in combination with a "tweeter" would be 600 cycles.

A further subdivision of the diaphragm, to make it cover a wider band, is illustrated in Fig. 3. A strut **31** is secured to the sub-diaphragm and projects downward from the lateral center thereof. A block **33**, mounted on the end of the strut presses against the sub-sub-diaphragm at a position which divides it into unequal portions, which are tuned by loading blocks in accordance with the general principles already described.

The distance measured between the diaphragm and the cone **9** of the loud speaker should be short in comparison with the highest frequency to which the projector is designed to respond. The wavelength in air of a 600 cycles tone is a little less than two feet. Considering this the cut-off frequency of the device, the distance between the speaker cone and the diaphragm should not be greater than approximately one foot.

The chamber **11** acts as a transformer which tends to match the impedance of a speaker unit cone through the impedance of the diaphragm as coupled to the outer air. For the lowest frequencies, say those in the neighborhood of 30 cycles, movement of the cone compresses the air in the chamber as a whole. This very greatly increases the resistance against forward motion of the cone and results in the liberation of more energy, which is transferred to the diaphragm as a whole; when the cone is retracted the opposite effect of rarefaction takes place and the differential pressure between the two sides of the diaphragm is again greater, increasing, in effect, the radiation resistance of the diaphragm. At the upper end of the pass-band of the device the distance measured directly from the cone to the periphery of the main diaphragm may be greater than a wavelength, and the outer portions of the diaphragm might therefore tend, could they vibrate at such a frequency, to radiate an out-of-phase wave. The portions of the structure which would tend to do this, however, are essentially non-vibratory at the frequencies where this would otherwise occur. At 600 cycles the inertia of the frame **15** is so great that it vibrates little more than if it were solidly secured to the cabinet. Accordingly substantially all of the energy is radiated as useful sound.

The dimensions of the chamber **13**, behind the septum, are not of great importance, provided that the volume is materially larger than that of the chamber **11**. The septum **3** is very rigid, and hence very little energy in reverse phase is transferred between the two chambers; certainly not enough to overcome the wide excursion of the cone **9**. At the low frequencies for which the projector is primarily designed the rarefaction in the chamber **13** produced by forward movement of the cone and the compression resulting from its rearward motion are small in comparison with the reverse effects occurring in the forward chamber. As a result of this the major portion of the energy appears in the forward chamber for transfer to the diaphragm and the amount of energy wasted in the rear chamber is little more than would be effective if the rear side of the diaphragm were exposed to free air. If it proves necessary in a specific shape of cabinet the interior of the chamber **13** may be lined with sound absorbent materials in order to prevent resonance effects. Experiment has indicated, however, that this is seldom necessary; not enough energy is returned to the diaphragm from waves reflected in the rear chamber to cause observable resonance peaks in the output energy. It should be apparent that the structure which has been described is purely illustrative, and that the principles involved in it can be embodied in various other forms. For example, it should be quite evident that for larger power a number of loud-speaker drive-units can be embodied in a single cabinet and used to drive a much larger diaphragm. The materials of which the diaphragm itself is constructed are those which are readily available almost anywhere. However, their exact physical constants cannot be given with any degree of certainty that they would be matched by materials obtained from various sources and answering to the same verbal description. The important features of the invention are not the materials used, but the relative proportioning of the parts, with respect to their mass, elastance and relative size.

For this reason it is proper to recapitulate some of the more fundamental factors entering into the design. First, to be considered are the relative volumes of the front and rear chambers within the cabinet. The rear chamber should be much larger than the front chamber, so that at the lowest frequencies of response, where the wavelengths are long in comparison with the dimensions of the device and the air within the two chambers is rarified or compressed as a whole by the excursions of the diaphragm, the pressure differential due to such excursion within the larger chamber is small in comparison with that occurring within the chamber **11**. This results in the load upon the speaker diaphragm being almost entirely that due to pressure changes on its front surface. This load is so great in comparison with that on a cone speaker of like size in free air, and the radiation resistance is accordingly so high in comparison with the inertia of the cone and the elastance of the support that any natural resonances of the drive unit which might appear if operated in free air are submerged and may be disregarded.

The second important characteristic of the invention is the extremely large mass of the diaphragm as a whole. Past practice has been to make the diaphragms of sound projectors as light as possible, considering the rigidity required to make them vibrate as a whole. In the present case the diaphragm weighs pounds instead of fractional ounces. Accordingly, its excursion is small, but it can radiate large volumes of sound because of its very large size.

Third, the suspension of the diaphragm as a whole is so designed that even in view of its large area and consequent large radiation resistance, it has a definite resonant period, but this period is at or below the lowest audible frequencies. At frequencies where the ear begins to respond, the response of the composite diaphragm is beginning to fall off, but because of the damping due to the radiation resistance it is falling off gradually and not rapidly. The tuning of a diaphragm below audible frequencies is not, per se, new, although achieving such tuning by a structure having a mass of anywhere near that here described is, so far as is known to the present inventor, new.

Fourth, the sub-diaphragm is made resonant to a frequency materially higher than that of the diaphragm as a whole, with the resonant peak at a point at which there is still a material response by the composite diaphragm. The sub-diaphragm, although it also has, when considered by itself, a definite resonant peak, has a high radiation resistance at the frequencies to which it is tuned, and its tuning is accordingly broad. In addition to this radiation damping, the use of such relatively non-resilient materials as "Celotex" for the loading with which the tuning is accomplished adds somewhat to the damping and the breadth of the resonance curve. As the peak of this curve is approached the outer frame is becoming more and more effective as a pure inertia. The resilience of the sub-diaphragm tends to pull the outer frame forward as the sub-diaphragm moves forward. This has two effects; it maintains the amplitude of excursion of the frame at a higher level than it would be if it were a single flat surface, and because of the coupling between the sub-diaphragm and the frame it greatly reduces the response of the sub-diaphragm. The output of sound energy of the sub-diaphragm plus the frame therefore remains substantially constant up to frequencies where the diaphragm as a whole would drop by many decibels.

Fifth, a like interaction takes place between the sub-diaphragm and the sub-sub-diaphragm. Above the frequency of resonance of the sub-diaphragm the response of the diaphragm as a whole falls off very rapidly. The rela-

tionship between the sub-diaphragm and the sub-sub-diaphragm and the frame as the resonant frequency of the sub-diaphragm is approached from below. Again the sound output remains substantially constant.

Sixth, because of the rectangular form of the vibrating diaphragms and the fact that each has at least two free edges, all of the vibrating elements are capable of wide excursions as compared with diaphragms of circular or any other form constrained all the way around. Because of their large size and relative flexibility, they can therefore radiate relatively large amounts of power.

Seventh, in cases where the sub-sub-diaphragm is further divided, either by use of the strut **31** and coupling block **33** or by still further dividing the structure as in connection with the sub-diaphragm and sub-sub-diaphragm, the same principles of the smaller and smaller sub-divisions successively taking over the main radiation load still apply.

Finally, where the frequencies become so high that the distance between the cone of the driving unit **7** and the periphery of the composite diaphragm becomes long in comparison with wavelengths, the inertia of the out-of-phase portions of the structure is so great that these portions practically cease to respond, and there is little out-of-phase energy radiated to cancel that which is delivered from the more actively vibrating portions of the structure.

Structures operating on the principles thus set forth can take many external forms. They can be built into a closet or cupboard which is a part of the building in which they are installed, if desired. More usually the cabinet will be a separate piece of furniture, as in the case here described. Whatever external form the cabinet may take, the composite diaphragm will be concealed by an acoustically transparent gauze or fabric **37**, which, in accordance with customary practice, can be made as decorative or as inconspicuous as may be desired.

Because of the wide number of physical forms in which the invention may be embodied, it should be clear that the specific one illustrated is merely intended to be illustrative of the principles of design here set forth and not to limit the scope of the invention except as such limitations are set forth in the following claims.

I claim:

1. A sound projector for the low and medium frequencies of the audible range comprising a cabinet having an open front and otherwise substantially rigid and unapertured walls, a composite diaphragm suspended in the open front of said cabinet and substantially closing said front and comprising a substantially rigid outer frame having a rectangular opening therein and a stiffly resilient sub-diaphragm covering said opening and secured to said frame on two opposite sides only, a septum within said cabinet dividing it into a front chamber of relatively small volume and a rear chamber of larger volume, and a dynamic-cone type loud-speaker unit mounted in an aperture in said septum, the distance between said unit and said composite diaphragm being less than the wave length in air of sound of the frequency of cut-off of said projector.

2. A sound projector as defined in claim 1 wherein said sub-diaphragm is provided with a smaller rectangular aperture therein and comprising a smaller sub-sub-diaphragm secured over said opening.

3. A sound projector as defined in claim 2 wherein said sub-diaphragm and said sub-sub-diaphragm have successively higher natural frequency of resonance.

4. A sound projector as defined in claim 2 wherein said diaphragm, sub-diaphragm and sub-sub-diaphragm are wooden panels of successively decreasing thickness.

5. A sound projector as defined in claim 1 including strips of resilient material between the edges of said diaphragm and the edges of said cabinet and secured to the edges of only one thereof to provide an acoustic seal.

No references cited.