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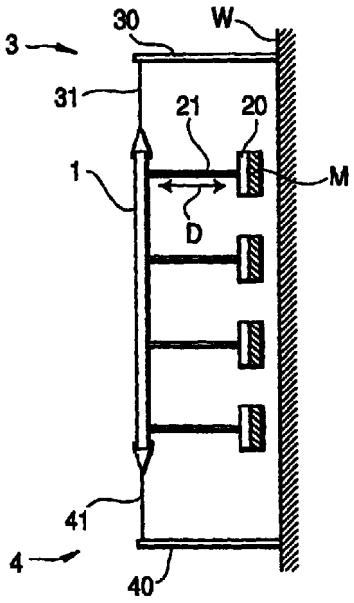
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(54) Acoustic radiator

(57) An acoustic radiator (AR) includes a plate-like member (1) which has elastic properties in a driving frequency band for acoustic radiation. The plate-like member (1) is supported by a support portion (3) into a state where a peripheral portion of the plate-like member (1) is allowed to substantially freely vibrate. A driving portion (2a) is disposed along the peripheral portion of the plate-like member (1). The driving portion (2a) causes the plate-like member (1) to perform acoustic radiation when the driving portion (2a) drives the peripheral portion of the plate-like member (1).

FIG. 2



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to an acoustic radiator which has a plate-like sound generator, and which can be used as a loudspeaker or the like.

[0002] The present application is based on Japanese Patent Application No. Hei. 11-318753, which is incorporated herein by reference.

2. Description of the Related Art

[0003] Various planar loudspeakers have been proposed as an acoustic radiator having a plate-like sound generator. With respect to a planar loudspeaker, many systems have been proposed in which an end portion of a plate-like member is substantially simply-supported or fixedly-supported, and the vicinity of a center portion of the plate-like member is then concentratedly vibrated at one point or plural points. The "simple support" means a supporting form in which a plate-like member is so supported that a portion of the plate-like member in contact with a support member is disabled to move in the thickness direction of the plate-like member, and is allowed to pivot. The "fixed support" means another supporting form in which a plate-like member is so supported that a portion of the plate-like member in contact with a support member is disabled to move in the thickness direction of the plate-like member and also to pivot.

[0004] In the planar loudspeakers, a material having excellent vibration characteristics, such as carbon cloth, has been used as the diaphragms. However, generally, the diaphragm of the planar loudspeaker has ordinarily been vibrated as integrally as possible while suppressing split vibration, so that the vibration is concentratedly applied onto the vicinity of a center portion of the diaphragm. For example, Examined Japanese Patent Publication Nos. Sho. 42-10890 and Sho. 47-6974, and Unexamined Japanese Patent Publication No. Hei. 10-243491 disclose the aforementioned structure of the planar loudspeaker. Premising that a material having excellent characteristics which would be suitable for integral vibration has been used, the development for the diaphragm has been directed mainly to such an improved sound quality that can compare with that of a three-dimensional loudspeaker of the cone type or the like, and therefore the attention has not largely been paid on application to a wide variety of materials.

[0005] Some of planar loudspeakers have been designed so as to positively utilize split vibration of a diaphragm. Even in such the planar loudspeaker, however, a plate-like member has been substantially simply-supported or fixedly-supported as described above. Therefore, the split vibration mode is varied depending on the driving frequency. As a result, the acoustic radiation efficiency is largely varied, so that the frequency characteristics of radiation sound are greatly uneven. This has been investigated in studies by Maidanik et al. and C. E. Wallace. With respect to a rectangular finite panel which is simply-supported by an infinite baffle plate, C. E. Wallace theoretically analyzed acoustic radiation in a split vibration mode and into a far sound field, in "Radiation Resistance of a Rectangular Panel" (JASA. Vol. 51-No. 3). According to this analysis, when a rectangular plate which is simply-supported in a peripheral portion is driven, the acoustic radiation efficiency is varied depending on the numbers of modes appearing in the longitudinal and transverse directions. Specifically, in accordance with the number of modes appearing in the longitudinal direction (or the transverse direction) and that of modes appearing in the transverse direction (or the longitudinal direction), modes are classified into an odd-odd mode, an odd-even mode, and an even-even mode. Then, it is shown that the radiation efficiency is highest in the odd-odd mode, and, in the even-even mode, largest cancellation (cancellation of radiation energies of compressional waves between adjacent modes) occurs and the radiation efficiency is low. Fig. 25 is a graph showing relationships between the mode type and the radiation efficiency in a square plate. From Fig. 25, it will be seen that the radiation efficiency is highest in the 1-1 mode (odd-odd mode), and the radiation efficiency is lowest in the 2-2 mode (even-even mode). As described above, the acoustic radiation efficiency is largely varied depending on the mode of split vibration, and hence the frequency characteristics of radiation sound are markedly uneven.

SUMMARY OF THE INVENTION

[0006] It is an object of the present invention to provide an acoustic radiator which can solve the above-discussed problems of the related art, in which a wide variety of materials can be used as a plate-like member, and which can realize acoustic radiation characteristics that are excellent in evenness with respect to the frequency.

[0007] To achieve the above object, according to the first aspect of the present invention, there is provided an acoustic radiator which includes a plate-like member which has elastic properties in a driving frequency band for acoustic radiation, a support portion which supports the plate-like member into a state where a peripheral portion of the plate-like member is allowed to substantially freely vibrate, and a driving portion which is disposed along the peripheral portion of the plate-like member, and causes the plate-like member to perform acoustic radiation when the driving portion drives the peripheral portion of the plate-like member.

[0008] According to the second aspect of the present invention, it is preferable that the driving portion is placed in an edge side region of the plate-like mem-

ber, the edge side region which extends from an edge of the plate-like member over a distance which is not longer than one half of a distance from the edge to a center of the plate-like member.

[0009] According to the third aspect of the present invention, it is preferable that at least a center portion of the plate-like member is transparent.

[0010] According to the fourth aspect of the present invention, it is preferable that a plurality of the driving portions are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The above and other objects and advantages of the present invention will become more apparent by describing in detail preferred embodiments thereof with reference to the accompanying drawings, wherein:

Fig. 1 is a front view of an acoustic radiator which is one embodiment of the present invention;
Fig. 2 is a side view of the acoustic radiator shown in Fig. 1;
Fig. 3 is a side view of an acoustic radiator which is another embodiment of the present invention;
Fig. 4 is a side view of an acoustic radiator which is another embodiment of the present invention;
Fig. 5 is a side view of an acoustic radiator which is another embodiment of the present invention;
Fig. 6 is a front view of an acoustic radiator which is another embodiment of the present invention;
Fig. 7 is a side view of the acoustic radiator shown in Fig. 6;
Fig. 8 is a front view of an acoustic radiator which is another embodiment of the present invention;
Fig. 9 is a side view of the acoustic radiator shown in Fig. 8;
Fig. 10 is a front view of an acoustic radiator which is another embodiment of the present invention;
Fig. 11 is a longitudinal side section view of an acoustic radiator which is another embodiment of the present invention;
Fig. 12 is a side view showing a structure of attaching a driving source in the acoustic radiator shown in Fig. 11;
Fig. 13 is a longitudinal side section view showing a part of an acoustic radiator which is another embodiment of the present invention;
Fig. 14 is a graph showing acoustic characteristics of a related acoustic radiator;
Fig. 15 is a graph showing acoustic characteristics of an example of the acoustic radiator according to the present invention;
Figs. 16A, 16B and 16C are diagrams illustrating manners of driving a plate-like member;
Fig. 17 is a graph showing acoustic characteristics of a related acoustic radiator;
Fig. 18 is a graph showing acoustic characteristics of an example of the acoustic radiator according to the present invention;
Fig. 19 is a graph showing acoustic characteristics of an example of the acoustic radiator according to the present invention;
Figs. 20A, 20B and 20C are diagrams illustrating manners of driving a plate-like member;
Fig. 21 is a front view of an acoustic radiator which is another embodiment of the present invention;
Fig. 22 is a front view of an acoustic radiator which is another embodiment of the present invention;
Figs. 23A, 23B and 23C are views showing application examples of the present invention;
Figs. 24A, 24B and 24C are views showing application examples of the present invention; and
Fig. 25 is a graph showing relationships between a mode type and a radiation efficiency.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] Hereinafter, preferred embodiments of the present invention now will be described with reference to the accompanying drawings. In the embodiments described below, identical or similar components are denoted by the same reference numerals, and therefore their description may be omitted.

[0013] Figs. 1 and 2 show an acoustic radiator of one embodiment according to the present invention. In the acoustic radiator AR, point-type driving portions 2a are attached at intervals to the rear face of a flat plate 1, and the flat plate is hung from a wall W by support portions 3.

[0014] In the present invention, the characteristic arrangement of the driving portions enables an excellent acoustic radiation efficiency to be obtained over a wide frequency band as described later. Therefore, a wide variety of materials can be used as the flat plate 1. For example, a plate of plastics such as an acrylic resin, a glass plate, a metal plate, a wood plate, or the like may be used. In place that the plate-like member is configured as a flat planar plate as in the embodiment, the plate-like member may have any one of various shapes including a curved face for forming a part of a circular cylinder, a sphere, a cone, or the like. In place of a rectangle, the external shape may have any one of various shapes such as a circle, an oval, and a polygon.

[0015] In this example, each of the driving portions 2a comprises a driving source 20 and a transmission member 21 which extends from the driving source 20 to the flat plate 1. As the driving source 20, an actuator of any one of various types such as the piezoelectric type, the electrodynamic type, the electromagnetic type, the electrostatic type, etc.. In order to dispose such an actu-

ator in a large number of driving portions, the actuators are desired to be small in size and output a high power. Preferably, the actuators may be of the piezoelectric type or the electrodynamic type which can be configured in compact. Alternatively, in place of such point-type driving sources, line-type driving sources may be used as in examples described later. In each of the transmission members 21, one end is coupled to a diaphragm of the driving source 20, and the other end is coupled to the rear face of the flat plate 1, by adhesion, screwing, or the other ways of coupling. Preferably, the transmission member 21 may be configured by a rod-like member which is light and rigid. For example, the transmission member may be made of a resin, a metal, wood, or the like. In Figs. 1 and 2, and figures of the embodiments described below, wirings to the driving portions are not shown.

[0016] The driving portions 2a are respectively placed in plural positions along the peripheral portion of the flat plate 1 so as to perform acoustic radiation by peripherally driving the flat plate 1. The flat plate 1 is vibrated in a direction perpendicular to the face of the flat plate 1 and in each of the positions of the driving portions 2a located at plural points. In Fig. 2, the arrows D indicate the driving directions of the driving portions 2a. Preferably, the vibrating positions on the flat plate 1 may be placed in an edge side region extending from the edge of the plate-like member over a distance which is not longer than one half of the distance from the edge to the center of the plate-like member. The preferable range of the vibrating positions is applicable also to the embodiments described below. The preferable vibrating positions will be described in detail later.

[0017] Each of the driving sources 20 comprises the diaphragm, and a frame which supports the diaphragm so that the diaphragm freely vibrates. Preferably, a mass member M is coupled to the frame so that the mass member M serves as an inertial mass, thereby allowing the vibration force of the diaphragm to be easily directed to the outside.

[0018] In this example, each of the support portions 3 for suspending the flat plate 1 has a suspension rod 30 which extends perpendicularly from the face of the wall W, and a string 31 which is coupled to the front end of the suspension rod 30 and an upper end portion of the flat plate 1. The string 31 is passed through holes formed through the front end of the suspension rod 30 and the upper end portion of the flat plate 1 to be coupled thereto. In this example, the attitude of a lower end portion of the flat plate 1 is held by holding portions 4 so that the flat plate 1 is parallel to the face of the wall W. In the same manner as the support portions 3, each of the holding portions 4 has a holding rod 40 which extends perpendicularly from the face of the wall W, and a string 41 which is coupled to the front end of the holding rod 40 and a lower end portion of the flat plate 1. The string 41 is passed through holes formed through the front end of the holding rod 40 and the lower end portion of the flat plate 1 to be coupled thereto. By this suspension support, the flat plate 1 serving as a sound generator is supported in a state where the peripheral portion of the flat plate 1 is allowed to substantially freely vibrate.

[0019] When the coupling portions between the support portions 3 and the holding portions 4, and the flat plate 1 are set to be closer to the center of the flat plate 1 as indicated by broken lines in Fig. 1, the free vibration of the peripheral portion of the flat plate 1 can be more facilitated. The holding portions 4 are not always necessary for supporting the flat plate 1. In case where the flat plate may be inclined with respect to the wall face, the holding portions 4 may be simply omitted. Otherwise, the holding portions 4 may be omitted in case where the supporting positions of the support portions 3 are adjusted so as to attain a balance with the driving portions 2a, or in case where a balancing weight is attached to the flat plate or the like.

[0020] As shown in Fig. 3, the driving portions according to the present invention may be configured as driving portions 2b in which a transmission beam 22 is interposed between the transmission members 21 and the flat plate 1. In this case, the transmission members 21 may be coupled to the transmission beam 22 by adhesion, screwing, or other ways, and the transmission beam 22 may be coupled to the flat plate by an adhesive agent or the like. According to the configuration, the flat plate 1 is vibrated by a line-type vibrating portion.

[0021] Fig. 4 shows an acoustic radiator comprising support portions which are different from those shown in Fig. 1. Each of the support portions 5 comprises: support rods 50 extending from the back face of the flat plate 1; a basal portion 51 attached to the wall or the like; and rollers 52 attached to the basal portion 51. Although the number of the support rods 50 is appropriately set by taking the size and shape of the flat plate 1 into consideration, four or three support rods may be employed. In order to facilitate the free vibration of the peripheral portion of the flat plate 1, preferably, the positions of the support rods 50 may be set to be closer to the center of the flat plate 1. The material and size of the support rods 50 are determined so that they can support the weights of the flat plate 1 and the driving portions 2a. The support rods are desired to be light, and hence may be made of, for example, a metal, a resin, or the like. The section shape of each support rod 50 may be appropriately determined to have, for example, a circular shape, a polygonal shape, a flat shape, or the like. The size of the basal portion 51 is determined so that its portion has an area which allows the roller 52 to be attached thereto, and that the driving portion 2a behind the flat plate 1 does not abut against the face of the wall or the like. The basal portion 51 is fixed to the wall or the like by adhesion, screwing, or other ways. The rollers 52 are configured as paired rollers which vertically sandwich the corresponding support rod 50. In order to stably support the support rod 50, two or more pairs of the

rollers 52 are usually disposed. The shape of the peripheral face of each roller 52 may be adequately determined so as to stably support the support rod 50. For example, a groove coinciding with the section shape of the support rod 50 may be formed in the peripheral face of the rollers 52. Preferably, the rollers 52 exert a resistance at a degree as low as possible against the movement of the support rod 50 in a longitudinal direction. For example, the roller body may be rotatably attached to a rotation shaft fixed to the basal portion 51, or a ball bearing may be interposed between such a rotation shaft and the roller body.

[0022] Fig. 5 shows an acoustic radiator having supporting portions of another shape. Each of the support portions 6 comprises: a support piece 60 extending from the back face of the flat plate 1; a suspension rod 61 attached to the wall or the like; and a string 62 through which the front end of the suspension rod 61 and the support piece 60 are connected to each other. Preferably, the coupling position of the support piece 60 and the string 62 is placed in a plane which passes through the center of gravity of the total mass of the flat plate 1 and the driving portions 2a (in the case where another member(s) is additionally disposed, the mass of the added member(s) is included in the total mass), and which is parallel to the flat plate 1. According to this configuration, the flat plate 1 can be supported along a vertical plane. In this case, preferably, the number of the support portions is made as small as possible in order to reduce the resistance to vibration of the flat plate 1. To comply with this, the coupling position of the support piece 60 and the string 62 is desired to be higher than a horizontal plane passing through the center of gravity. In this configuration, the total mass of the flat plate and the driving portions (in the case where another member(s) is additionally disposed, the mass of the added member(s) is included in the total mass) is suspended at a position which is higher than the center of gravity, and hence the support piece 60 is required to be disposed only in one or two places of the flat plate. In order to facilitate the free vibration of the peripheral portion of the flat plate 1, preferably, the support piece 60 may be disposed to be closer to the center of the flat plate 1. The number of the support pieces is appropriately set in accordance with the size and shape of the flat plate 1.

[0023] Figs. 6 and 7 show an example in which a driving portion 2c is configured by a line-type driving source 23 and rod-like transmission members 21. As the line-type driving source 23, an electrodynamic element, a piezoelectric element, a piezoelectric film which is folded, or the like may be used. The driving source 23 comprises a diaphragm, and a frame which supports the diaphragm in such a manner that the diaphragm freely vibrates. In the same manner as the previous example, preferably, a mass member is coupled to the frame so that the mass member serves as an inertial mass, thereby allowing the vibration force of the diaphragm to be easily directed to the outside. The transmission members 21 are coupled to the vibrating portion of the driving source 23 and the flat plate 1 by adhesion, screwing, or other ways.

[0024] In the illustrated example, the driving source or the driving portion is configured as an integral continuous member. Alternatively, a plurality of driving portions may be configured by, for example, dividing the line-type driving source in parts along the longitudinal direction. In the alternative, a common driving signal may be supplied to the plural driving portions, or, as described later, different driving signals of plural channels may be supplied to the driving portions.

[0025] Figs. 8 and 9 show an example of the acoustic radiator in which a driving portion 2d is configured by a driving source 23 that is directly coupled to the flat plate 1. In the driving source 23, the vibrating portion is coupled to the flat plate 1 by an adhesive agent. Alternatively, the coupling may be realized by, for example, integral molding of the driving source and the flat plate 1. Also in this example, the flat plate 1 is vibrated in a direction perpendicular to the face of the plate and in the position of the line-type driving source 23 (the directions of the arrows D in the figures). In this example, a frame part (the part surrounding the vibrating portion) of the driving source 23 is coupled by adhesion to a plate-like support portion 25 serving also as a case. The support portion 25 is configured as a case having: a frame part which surrounds the vertical and lateral edges of the flat plate 1 with forming a small gap therebetween; and a facial part which extends from the rear edge of the frame part so as to cover the back face of the flat plate 1. The support portion 25 has a substantially large mass so as to serve as an inertial mass, thereby allowing the vibration force of the driving source 23 to be easily directed to the outside. The support portion 25 serves also as a baffle plate to prevent sound waves radiated from the back face of the flat plate 1 from moving around to the front side. The acoustic radiator may be secured to a wall or the like by fixing the support portion 25 by fixing members such as screws as illustrated, or such other adequate mechanisms that the support portion 25 is hung by strings.

[0026] Fig. 10 shows an example of the acoustic radiator in which, as a driving portion 2e, line-type driving sources 23', transmission members 21', and support portions 25' are disposed. Each of the line-type driving sources 23' is configured in a similar manner as the line-type driving source 23 described above. In this example, the line-type driving sources are placed so that the driving directions D' are parallel to the face of the flat plate 1. In each of the driving sources 23', the vibrating portion is coupled to the flat plate 1 by an adhesive agent. The frame portion (the portion surrounding the vibrating portion) of the driving source 23' is coupled by adhesion to the plate-like support portion 25' serving also as a case. The transmission members 21' are configured in a similar manner as the transmission members 21 described above. In accordance with the driving

directions of the driving source, however, each of the transmission members extends from the vibrating portion of the corresponding line-type driving source 23' toward the flat plate 1, and abuts against the corresponding one of the vertical and lateral edges of the flat plate 1 to be coupled thereto. The support portion 25' is configured as a case having a frame part which surrounds the line-type driving sources 23', and a facial part which extends from the rear edge of the frame part so as to cover the back face of the flat plate 1. In this example, one driving source 23' is disposed along each of the edges of the rectangular flat plate 1, in other words, four driving sources in total are disposed correspondingly to the four edges of the rectangular flat plate 1. Alternatively, another adequate number of line-type driving sources may be disposed as required. For example, two or more separated line-type driving sources may be disposed along each of the edges of the flat plate, or driving sources may be arranged in accordance with the shape of the flat plate. The driving sources 23' vibrates the flat plate 1 in two directions with respect to the face thereof. Therefore, the flat plate 1 vibrates also in the thickness direction to radiate sound. In the case where a plate-like member having a curved face is used in place of the flat plate 1, particularly, vibration in the face direction causes the shape of the curved face of the plate-like member to be varied, and hence vibration in the thickness direction easily occurs. In the same manner as the example described above, the acoustic radiator may be secured to a wall or the like by such adequate mechanisms that the support portions 25' are fixed by fixing members such as screws, or that the support portions 25' are hung by strings. Also in this example, the support portions 25' have a substantially large mass so as to serve as an inertial mass, thereby allowing the vibration force of the driving sources 23' to be easily directed to the outside.

[0027] Fig. 11 shows an example in which the back face of the flat plate 1 in the acoustic radiator shown in Fig. 2 is enclosed by a supporting portion 26. The support portion 26 is configured as a case having: a frame part 26a which surrounds the vertical and lateral edges of the flat plate 1 with forming a small gap therebetween; and a facial part 26b which extends from the rear edge of the frame part so as to cover the back face of the flat plate 1. In the same manner as the example described above, the acoustic radiator also may be secured to a wall or the like by fixing the support portion 25' by fixing members such as screws, or such other adequate mechanisms that the support portion 25' is hung by strings. When the support portion 26 has a substantially large mass, it serves as an inertial mass, so that the vibration force of the driving source 20 is allowed to be easily directed to the outside. Since an inertial mass is provided by the support portion 26, it is not required to couple a mass member to the driving source itself unlike the example shown in Figs. 1 and 2.

[0028] Fig. 12 shows an example of a coupling form between the driving source 20 and the support portion 26 in the example of Fig. 11. In this example, both side portions of the outer peripheral frame which supports the diaphragm of the driving source 20 are fixed to a coupling portion 24, and the coupling portion 24 is fixed to the facial part 26b of the support portion. Preferably, the coupling portion 24 may be provided with a soft member 240 such as sponge in a part which is in contact with the outer peripheral frame of the driving source 20. According to this configuration, the free vibration of the peripheral portion of the flat plate 1 can be more facilitated.

[0029] According to the present invention, it is possible to configure an acoustic radiator in which a plate-like member of a large area is fixed to a structural member of a building, a wall face, or the like. Also in this case, a plurality of driving sources are arranged around the plate-like member so as to perform acoustic radiation by peripherally driving the plate-like member. Fig. 13 shows an embodiment of the acoustic radiator which is attached to a wall face. In this example, an actuator of the electrodynamic type is used as a driving source 2f, a diaphragm (movable portion) 27a of the actuator is fixed to a flat plate 1' by screwing, adhesion, or the like, and a frame (stationary portion) 27b is fixed to a wall face or a wall internal ground member S in a room. As the driving source, alternatively, another actuator of a high output and selected from various kinds of actuators which are suitable for driving a plate-like member of a large area may be used. Preferably, an enclosure plate 28 which extends to the wall face S with forming a small gap between the peripheral edge of the flat plate 1' and the enclosure plate may be formed around the flat plate. Alternatively, a soft member such as sponge or a foam member may be disposed in the gap between the peripheral edge of the flat plate 1' and the enclosure plate 28, or cloth may be spread in the gap. When a gap is formed or the gap is filled with a soft member, suppression of free vibration in the periphery of the flat plate 1' can be eliminated or reduced. The enclosure plate 28 prevents sound waves which are radiated toward the rear side (the side of the driving source) by vibration of the flat plate 1' from moving around to the front side to interfere with those which are radiated toward the front side, or serves as a so-called baffle plate.

[0030] In order to clarify effects of the present invention, a simulation analysis of frequency characteristics of radiation sound was performed in which a flat plate made of an acrylic resin and having a length of 300 nun, a width of 450 mm, and a thickness of 5 mm was used as a sound generator. Hereinafter, this will be described.

[0031] First, conditions of supporting the plate were analyzed. The following two kinds of supporting conditions were employed:

(a) the peripheral portions is fix-supported; and

(b) the plate is hung by strings as shown in Fig. 1 to be supported in a state where the peripheral portion is allowed to substantially freely vibrate.

[0032] In both the cases, vibration was performed by a line-type driving portion which extends in parallel to the peripheral edge of the acrylic flat plate and in a position which is inner than the peripheral edge by 20 mm. It was assumed that the analysis was performed in a frequency band of 50 to 800 Hz in a vibration-sound coupled system, and on a structure having an infinite baffle.

[0033] From the analysis under the support conditions of (a) above, the results shown in the graph of Fig. 14 were obtained. As seen from the graph, a phenomenon that the sound pressure level of radiation sound in a lower-degree odd-odd mode, or namely (1, 1), (3, 1), (1, 3), (5, 1), or (3, 3) produces a large peak clearly occurs. The tendency in the position separated by 1 m from the plate is substantially identical with that in the position separated by 2 m from the plate. Therefore, the characteristics can be deemed as frequency characteristics in a far sound field.

[0034] From the analysis under the support conditions of (b) above, the results shown in the graph of Fig. 15 were obtained. As seen from the graph, when the peripheral portion is allowed to substantially freely vibrate, the energy of radiated sound is lower by about 20 dB than the peak value in the case of (a), but the frequency characteristics are approximately flat. In this case also, the tendency in the position separated by 1 in from the plate is substantially identical with that in the position separated by 2 m from the plate. Therefore, the characteristics can be deemed as frequency characteristics in a far sound field. From the results, it will be seen that, when the frequency characteristics of the vibration source are flat, radiated sound tends to hardly produce prominent peaks and dips.

[0035] Next, effects of the vibrating position in the plate were analyzed. The following three kinds of supporting conditions which are diagrammatically shown in Figs. 16A to 16C were employed as vibration conditions (in the figure, P indicates a vibrating point or a vibrating line):

(p) a center portion of the plate is vibrated (Fig. 16A);

(q) a plurality of points in the peripheral portion of the plate are vibrated (Fig. 16B); and

(r) the whole of the peripheral portion of the plate is vibrated by a line-type driving portion (Fig. 16C).

[0036] In all the cases, the acrylic flat plate was hung by strings as shown in Fig. 1 to be supported in a state where the peripheral portion is allowed to substantially freely vibrate. It was assumed that the analysis was performed in a frequency band of 50 to 800 Hz in a vibration-sound coupled system, and on a structure having an infinite baffle.

[0037] From the analysis in the vibrating positions of (p), (q), and (r) above, the results shown in the graphs of Figs. 17, 18, and 19 were obtained. In Fig. 17, large peaks are at about 225 and 525 Hz, and large dips are at about 95, 185, and 575 Hz. By contrast, in the graph of Fig. 18, small unevenness exists, but there is neither peak nor dip other than a large peak at about 575 Hz and a large dip at about 525 Hz. In the graph of Fig. 19, small unevenness exists, but there is neither peak nor dip other than large peaks at about 95, 525, and 575 Hz.

[0038] As described above, the graphs of Figs. 18 and 19 are flattened as compared with the graph of Fig. 17. It is seemed that these results were obtained because of the following reason. When the whole face of a plate-like member which is supported so that the peripheral portion is allowed to freely vibrate is simultaneously face-vibrated in phase, the entire plate is integrally vibrated (or serves as a rigid body to perform so-called piston motion), and hardly appears the performance as an elastic plate (bending motion). When the vibrating points are reduced, the effect of natural vibration of the plate-like member gradually appears. In a natural vibration mode of a plate-like member in which the peripheral portion is allowed to freely vibrate, vibration is performed under a state where the peripheral edge of the plate is at a loop of vibration. When the vibrating points of the plate-like member are reduced and the center portion is vibrated, the effect of the natural vibration mode largely appears, and a peak of the sound pressure manifestly appears at the natural frequency in the frequency characteristic curve. By contrast, when the peripheral portion of the plate-like member is vibrated, vibration of the peripheral edge of the plate-like member is controlled by the vibrating portion itself. As a result, occurrence of the natural vibration mode is suppressed. Therefore, the vibration speed is smoothly varied with respect to a change of the vibration force which is applied to the peripheral portion of the plate-like member, and frequency characteristics of radiation sound tend to be flattened. In other words, occurrence of the natural vibration mode can be suppressed by vibrating the place where a loop of natural vibration of the peripheral portion of the plate-like member is formed. In the natural vibration mode shown in Fig. 20C, for example, the position which is to be employed as the vibrating position in order to suppress of formation of a loop of vibration in end portions of the plate-like member is in an edge side region extending from the edge of the plate-like member over a distance which is shorter than one eighth of the length of the plate-like member wherein the mode appears. In the natural vibration mode shown in Fig. 20B, the position is in an edge side region extending from the edge of the plate-like member over a distance which is shorter than one sixth of the length of the plate-like member wherein the mode appears. In the case where a vibration mode at the lowest frequency is considered, as shown in Fig.

20A, the position is in an edge side region extending from the edge of the plate-like member over a distance which is shorter than one fourth of the length of the plate-like member wherein the mode appears. In other words, in order to suppress a peak from occurring at the lowest natural frequency, vibration is required to be performed in an edge side region extending from the edge of the plate-like member over a distance which is not longer than one half of the distance from the edge to the center of the plate-like member. Even if a mode may be produced in which a large amplitude appears in the vicinity of an edge portion due to the support which allows free vibration, the amplitude level is in a range which can be controlled by an equalizer or the like.

[0039] As apparent from the analyses relating to the supporting conditions and the vibrating position in the case where the acrylic plate was used, when the sound generator is a plate which has elastic properties in the driving frequency band, the plate is supported in a state where the peripheral portion of the plate-like member is allowed to substantially freely vibrate, and acoustic radiation is performed by driving the peripheral portion of the plate-like member, it is possible to obtain an acoustic radiator having frequency characteristics in which prominent peaks and dips are not produced and which is flattened.

[0040] In the analyses shown in Figs. 14 to 19, all the driving portions are driven by a driving signal of one kind. Alternatively, driving signals of different kinds may be supplied to the driving portions as in the case of a sound source of plural channels. Such driving signals of different kinds can attain a three-dimensional sound field reproduction effect such as sound image localization. Figs. 21 and 22 show examples of an acoustic radiator having a function of receiving such driving signals. In the example of Fig. 21, line-type driving portions 80T, 80B, 80L, and 80R are attached to the upper, lower, left, and right regions of the peripheral portion of the back face of the flat plate 1 configured in the same manner as that of the above-described example. For example, the line-type driving portions may be configured in the same manner as those shown in Figs. 6, 8, and 10. However, the line-type driving portions are separated into regions so that the regions receive different driving signals. Input portions (not shown) for the driving portions are respectively connected to the driving portions so as to independently drive the driving portions.

[0041] In the example of Fig. 22, eight driving portions 81T, 81B, 81L, 81R, 81LT, 81RT, 81LB, and 81RB are attached to the upper, lower, left, and right regions, and their intermediate regions, or upper left, upper right, lower left, and lower right regions of the peripheral portion of the back face of a circular flat plate 1". The driving portions may be configured in various manners such as those shown in Figs. 1 to 5, and 11 to 13. Input portions (not shown) are respectively disposed for the driving portions so as to receive different driving signals and independently drive the driving portions. Namely, the input portions are configured so as to receive 8-channel driving signals.

[0042] In the examples of Figs. 21 and 22, plural driving portions may be disposed for each of the regions. In this case, input portions are disposed so as to receive driving signals which are common in a region and are different among regions. For example, this can be realized by connecting a common input line to plural driving portions for one region.

[0043] In the present invention, the driving portions are placed in the peripheral portion of the plate-like member as described above, and hence it is not necessary to dispose a driving portion in a center portion of the plate-like member. In the case of sound reproduction associated with image reproduction, for example, such a center portion may be therefore configured to be transparent so that the portion can be used as an image reproduction area. When an acoustic radiator having a transparent plate-like member made of a resin, glass, or the like is disposed in front of a CRT screen of a television receiver, for example, an image formed behind the plate-like member is allowed to pass therethrough, and acoustic radiation can be superposed on the image. According to this configuration, acoustic radiation from the both peripheral sides enables the listener to listen the sound as if a sound source exists also in the center of the screen in which a driving source does not actually exist and acoustic radiation is performed therefrom. In a practical use, therefore, sufficient directivity from the center of the screen to the front side can be ensured, and a sound image can be localized inside the television screen.

[0044] According to the present invention, an acoustic radiator in which, even when the input level of each point is low, the output level as a whole is made high can be configured by using plural driving sources. Therefore, the driving efficiency of the driving sources can be enhanced.

[0045] Figs. 23 and 24 show various application examples of the acoustic radiator of the present invention. Figs. 23A and 23B show wall-mounted loudspeakers in which an acoustic radiator A1 or A2 can be hung from a wall by a string R. Fig. 23C shows a table loudspeaker in which an acoustic radiator A3 is made stand by a support stand P. Figs. 24A and 24B show various examples in which the present invention is applied to a television receiver arid a personal computer, respectively. An acoustic radiator A4 or A5 is attached to a television receiver or a personal computer so as to cover a CRT thereof. Fig. 24C shows an example in which an acoustic radiator A6 is attached to the door of a refrigerator.

[0046] By using the advantages described above, the acoustic radiator of the present invention can be used as an acoustic radiator such as a loudspeaker in the following various uses:

[0047] Audio product; personal digital assistance; personal computer; television receiver; floor having a

sound generating effect; screen having a sound generating function; poster having a sound generating function; sales promotion display; sales promotion window system; sound generator for an instrument (sound board, music stand); furniture; toy; automobile; hole; stage floor; and hearing aid.

[0048] As described above, according to the present invention, the acoustic radiator comprises: a plate-like member which has elastic properties in a driving frequency band for acoustic radiation; a support portion which supports the plate-like member in a state where a peripheral portion of the plate-like member is allowed to substantially freely vibrate; and a driving portion which is disposed along the peripheral portion of the plate-like member, to allow acoustic radiation to be performed by driving the peripheral portion of the plate-like member, and which vibrates the plate-like member. Therefore, vibrations of end portions of the plate-like member can be controlled by applying vibration to the peripheral portion of the plate-like member. As a result, occurrence of the natural vibration mode is suppressed, and frequency characteristics of radiation sound tend to be flattened. Consequently, acoustic radiation can be performed at an efficiency which is uniformalized over a wide frequency band. Since such uniformalized frequency characteristics can be easily obtained, plate-like members of a wide variety of materials can be applied to the acoustic radiator.

[0049] It is contemplated that numerous modifications may be made to the acoustic radiator of the present invention without departing from the spirit and scope of the invention as defined in the following claims.

[0050] It should be noted that the objects and advantages of the invention may be attained by means of any compatible combination(s) particularly pointed out in the items of the following summary of the invention.

SUMMARY OF THE INVENTION

[0051]

1. An acoustic radiator, comprising:

   a plate-like member which has elastic properties in a driving frequency band for acoustic radiation;
   a support portion which supports the plate-like member into a state where a peripheral portion of the plate-like member is allowed to substantially freely vibrate; and
   a driving portion which is disposed along the peripheral portion of the plate-like member, and causes the plate-like member to perform acoustic radiation when the driving portion drives the peripheral portion of the plate-like member.

2. An acoustic radiator according to item 1, wherein the driving portion is placed in an edge side region of the plate-like member, the edge side region which extends from an edge of the plate-like member over a distance which is not longer than one half of a distance from the edge to a center of the plate-like member.

3. An acoustic radiator according to item 1, wherein at least a center portion of the plate-like member is transparent.

4. An acoustic radiator according to item 2, wherein at least a center portion of the plate-like member is transparent.

5. An acoustic radiator according to item 1, further comprising a plurality of the driving portions which are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

6. An acoustic radiator according to item 2, further comprising a plurality of the driving portions which are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

7. An acoustic radiator according to item 3, further comprising a plurality of the driving portions which are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

8. An acoustic radiator according to item 4, further comprising a plurality of the driving portions which are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

Claims

1. An acoustic radiator, comprising:

   a plate-like member which has elastic properties in a driving frequency band for acoustic radiation;
   a support portion which supports the plate-like member into a state where a peripheral portion of the plate-like member is allowed to substan-

tially freely vibrate; and

a driving portion which is disposed along the peripheral portion of the plate-like member, and causes the plate-like member to perform acoustic radiation when the driving portion drives the peripheral portion of the plate-like member.

2. An acoustic radiator according to claim 1, wherein the driving portion is placed in an edge side region of the plate-like member, the edge side region which extends from an edge of the plate-like member over a distance which is not longer than one half of a distance from the edge to a center of the plate-like member.

3. An acoustic radiator according to claim 1, wherein at least a center portion of the plate-like member is transparent.

4. An acoustic radiator according to claim 2, wherein at least a center portion of the plate-like member is transparent.

5. An acoustic radiator according to claim 1, further comprising a plurality of the driving portions which are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

6. An acoustic radiator according to claim 2, further comprising a plurality of the driving portions which are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

7. An acoustic radiator according to claim 3, further comprising a plurality of the driving portions which are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

8. An acoustic radiator according to claim 4, further comprising a plurality of the driving portions which are placed in at least two plural regions of the plate-like member, wherein the driving portions receives driving signals which are common in a same region, whereas the driving portions receives driving signals which are different among regions.

FIG. 1

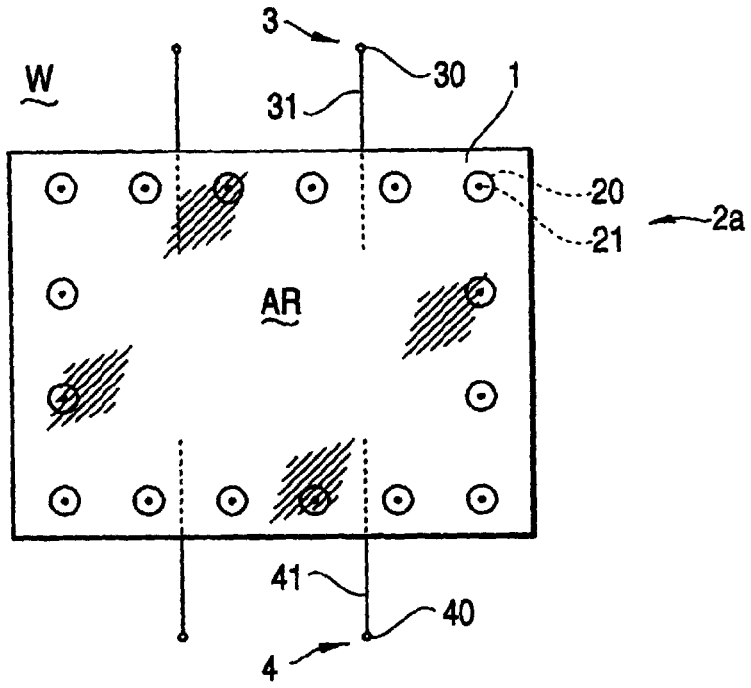


FIG. 2

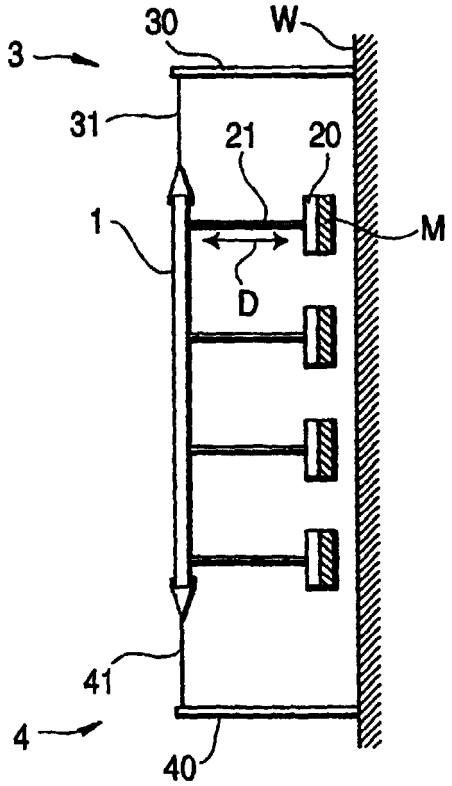


FIG. 3

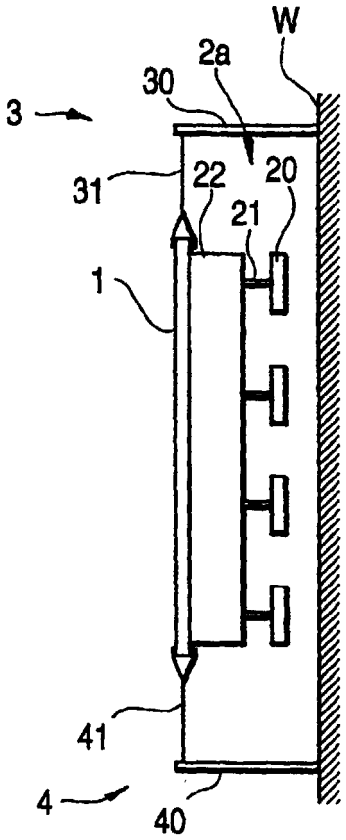


FIG. 4

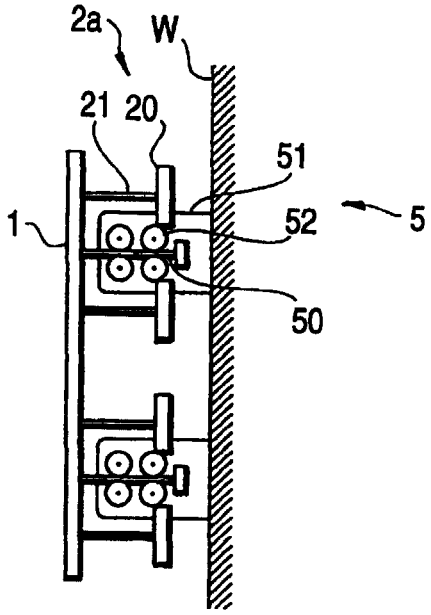


FIG. 5

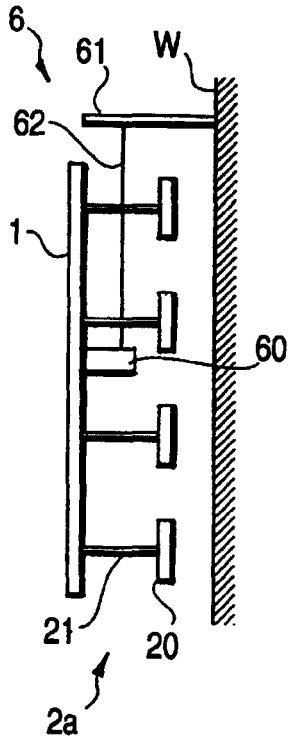


FIG. 6

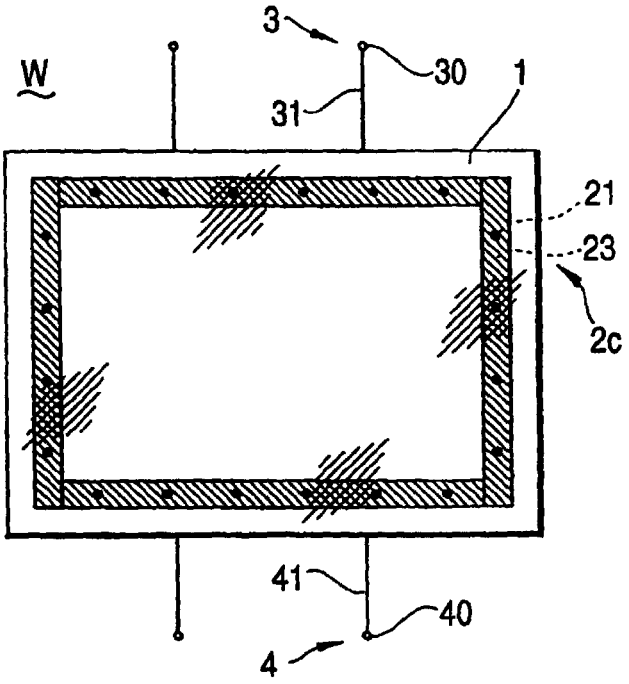


FIG. 7

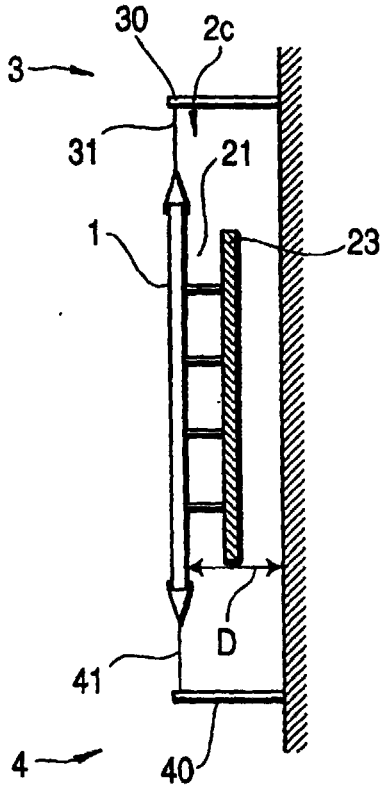


FIG. 8

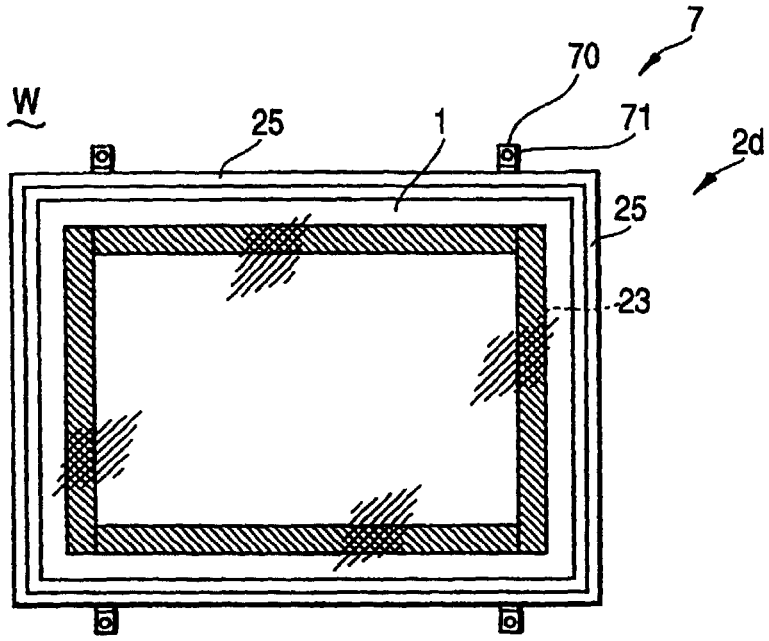


FIG. 9

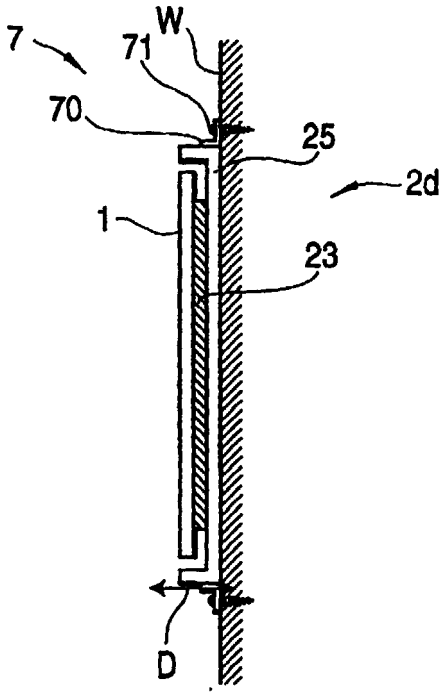


FIG. 10

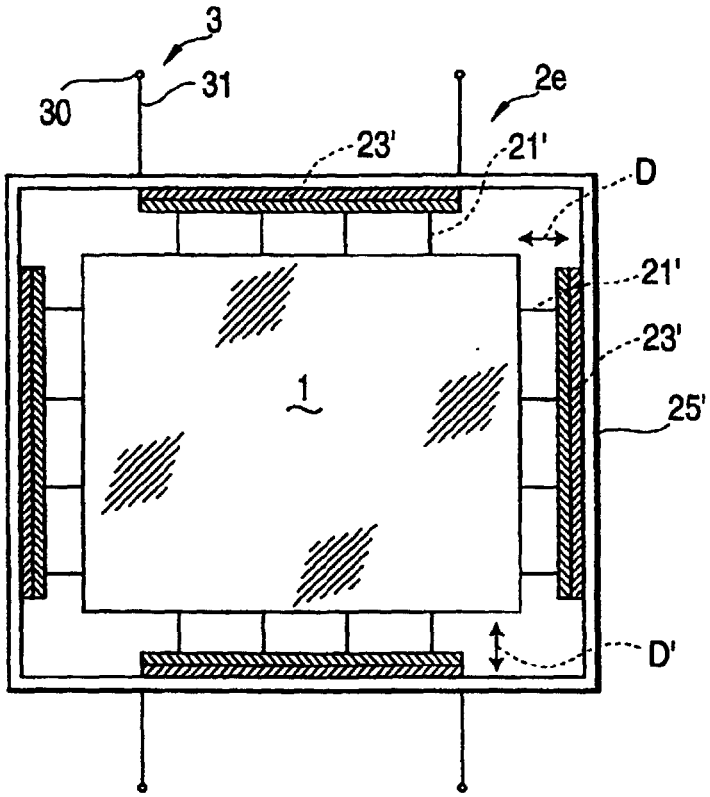


FIG. 11

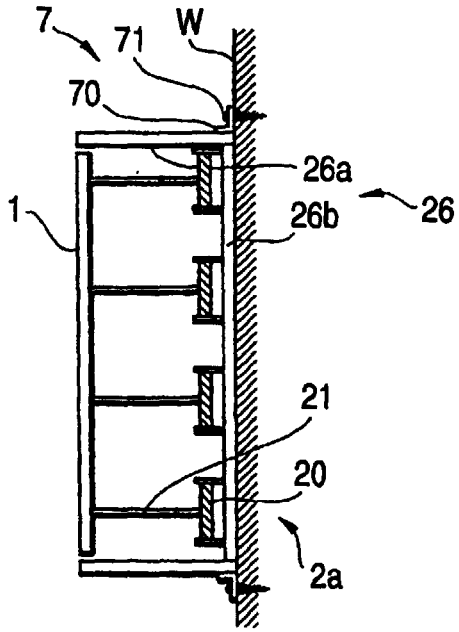


FIG. 12

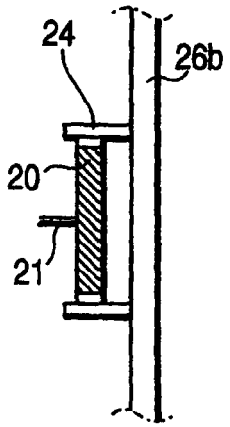


FIG. 13

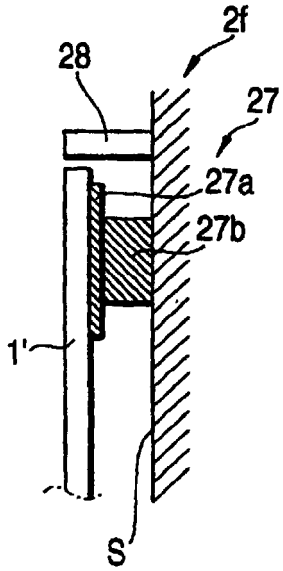


FIG. 14

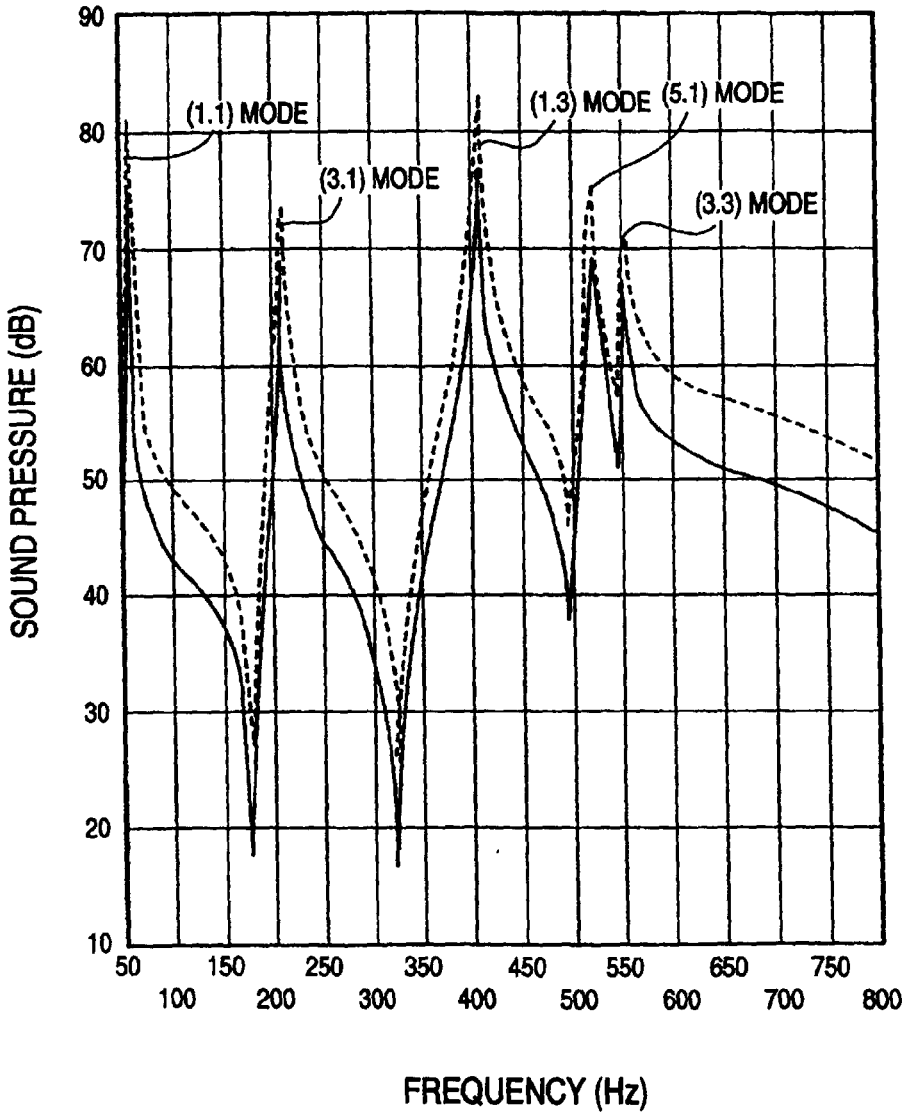

90
80
70
60
50
40
30
20
10
SOUND PRESSURE (dB)
(1.1) MODE
(3.1) MODE
(1.3) MODE
(5.1) MODE
(3.3) MODE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
FREQUENCY (Hz)

FIG. 15

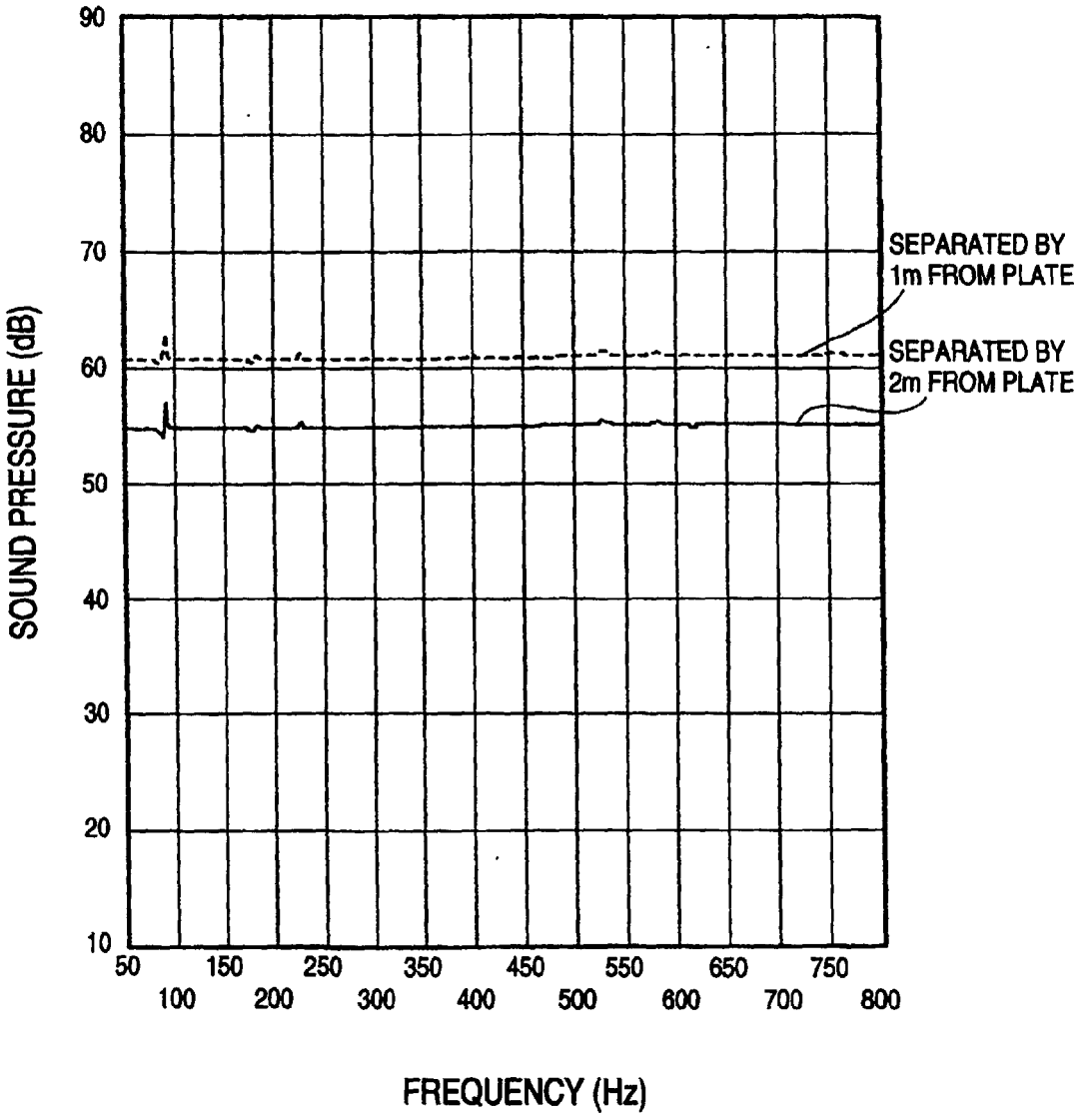

90
80
70
60
50
40
30
20
10
SOUND PRESSURE (dB)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
FREQUENCY (Hz)
SEPARATED BY 1m FROM PLATE
SEPARATED BY 2m FROM PLATE

FIG. 16A

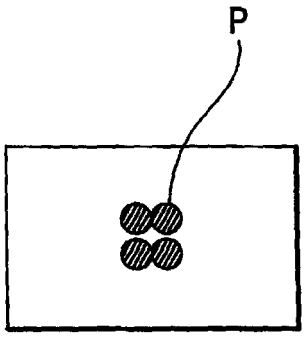


FIG. 16B

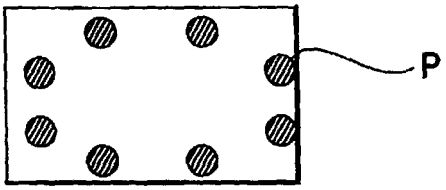


FIG. 16C

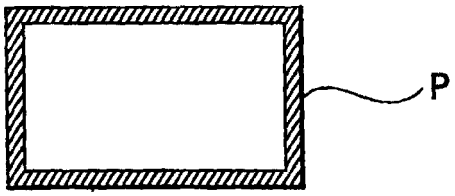


FIG. 17

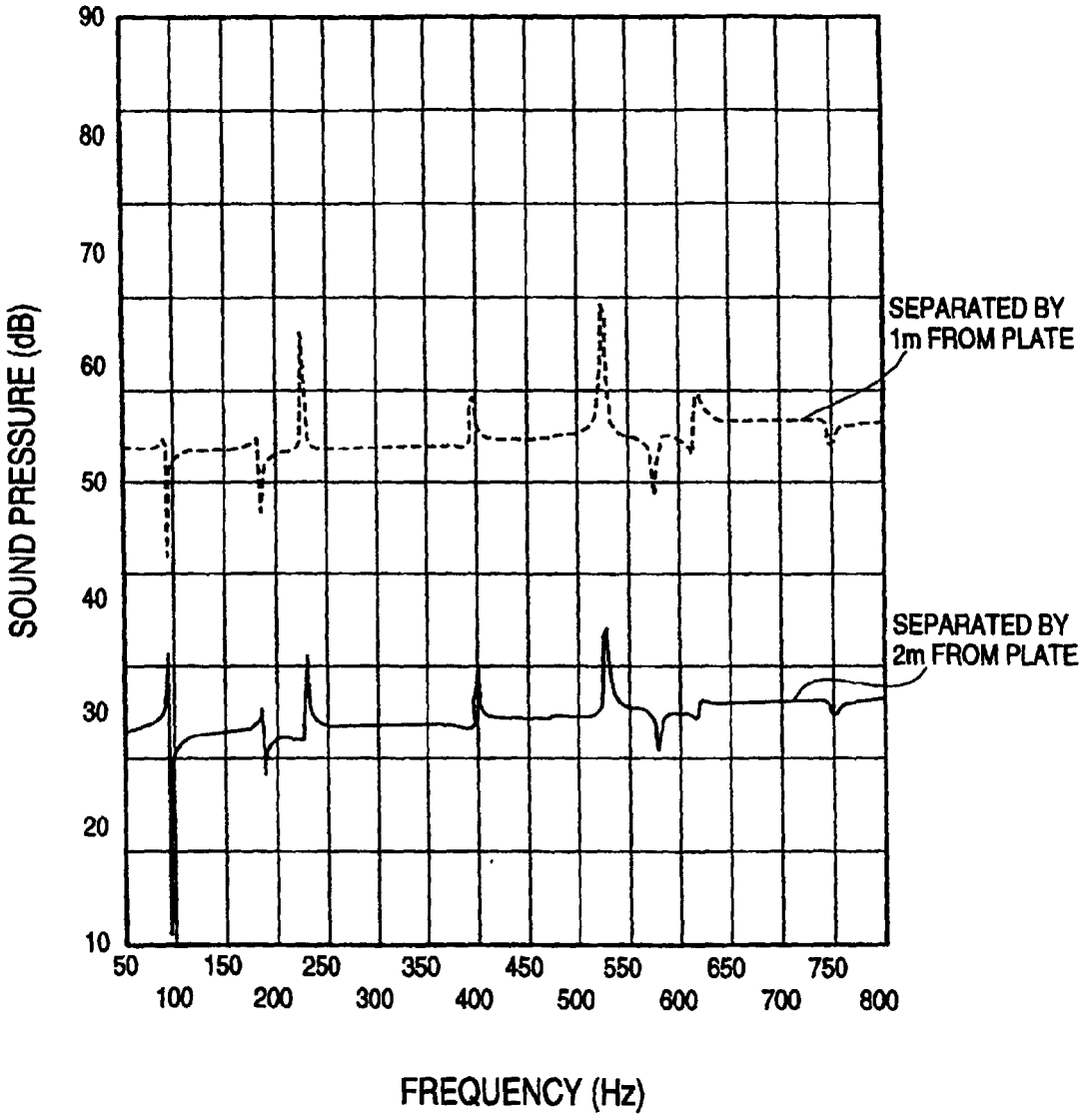

90
80
70
60
50
40
30
20
10
SOUND PRESSURE (dB)
SEPARATED BY 1m FROM PLATE
SEPARATED BY 2m FROM PLATE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
FREQUENCY (Hz)

FIG. 18

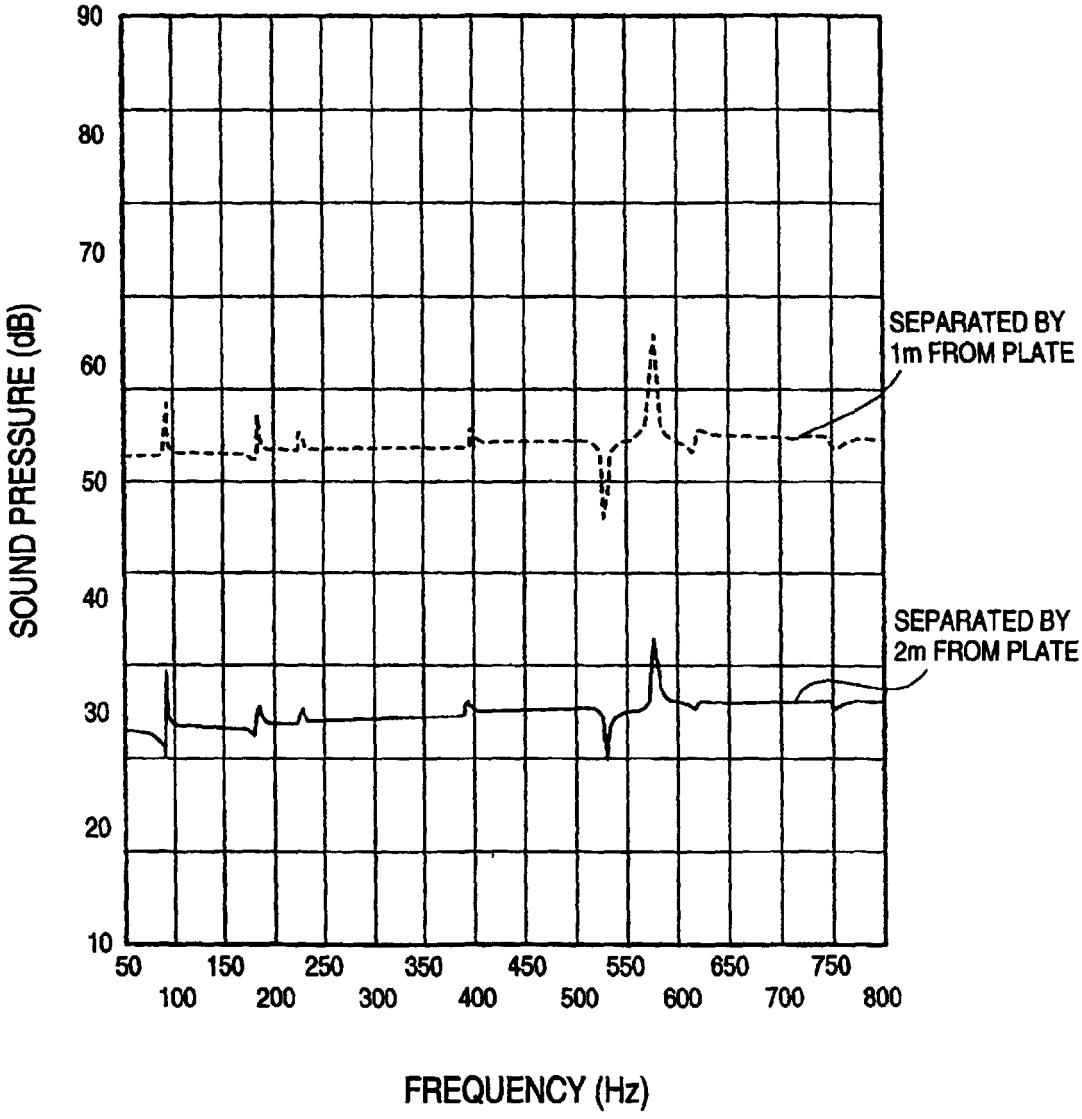

90
80
70
60
50
40
30
20
10
SOUND PRESSURE (dB)
SEPARATED BY
1m FROM PLATE
SEPARATED BY
2m FROM PLATE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
FREQUENCY (Hz)

FIG. 19

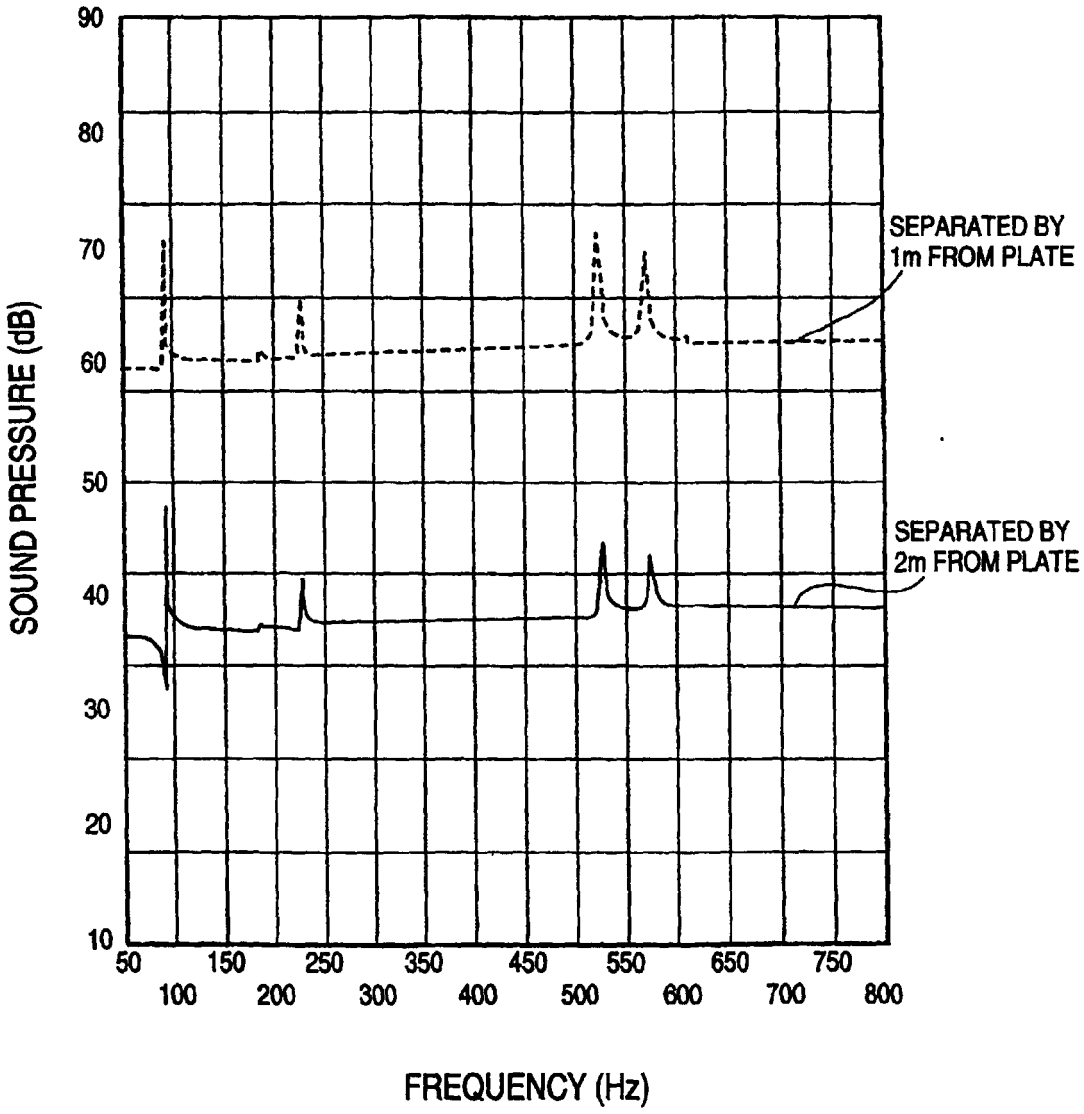

90
80
70
60
50
40
30
20
10
SOUND PRESSURE (dB)
SEPARATED BY 1m FROM PLATE
SEPARATED BY 2m FROM PLATE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
FREQUENCY (Hz)

FIG. 20A

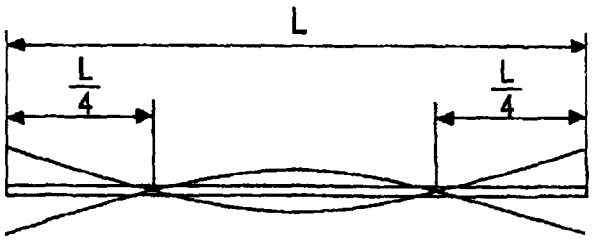


FIG. 20B

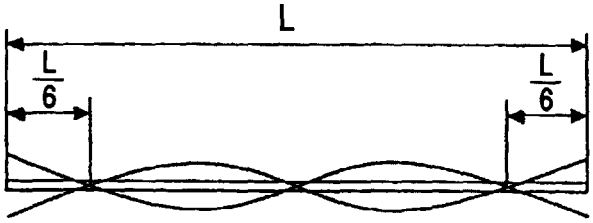


FIG. 20C

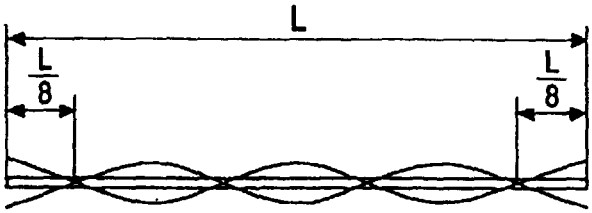


FIG. 21

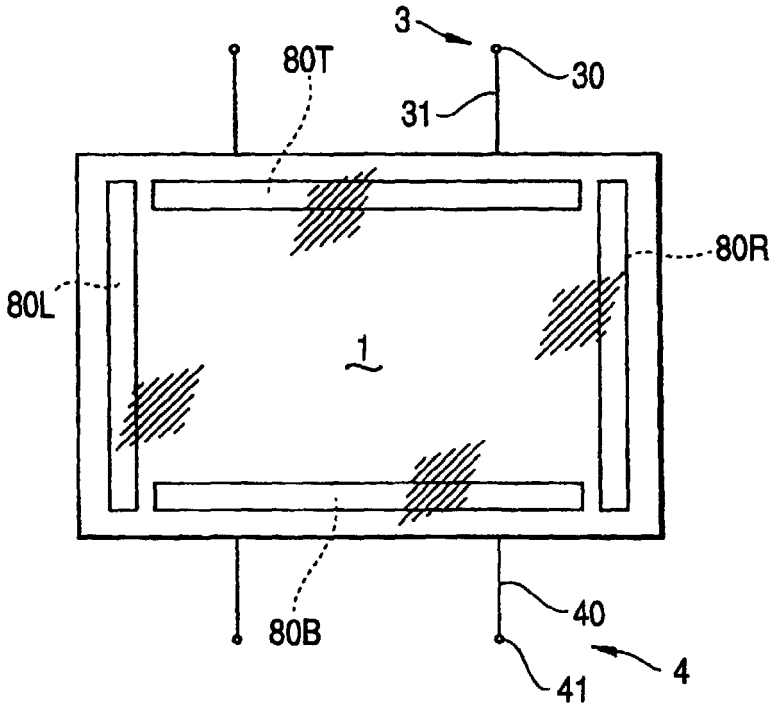

3
80T
30
31
80R
80L
1
80B
40
4
41

FIG. 22

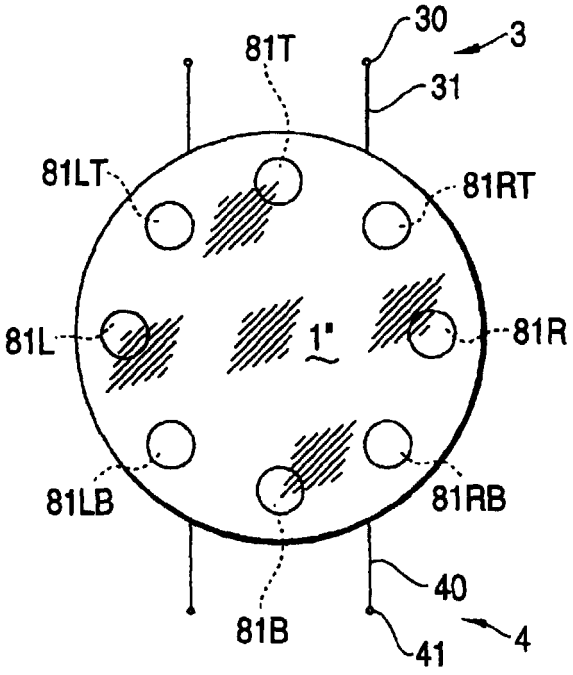

30
3
81T
31
81LT
81RT
81L
1"
81R
81LB
81RB
40
81B
4
41

FIG. 23A

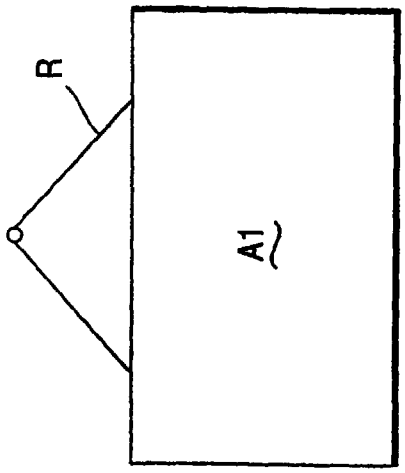


FIG. 23B

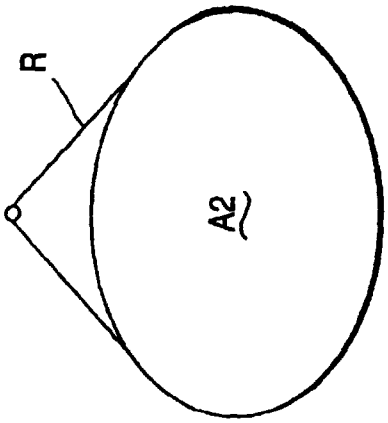


FIG. 23C

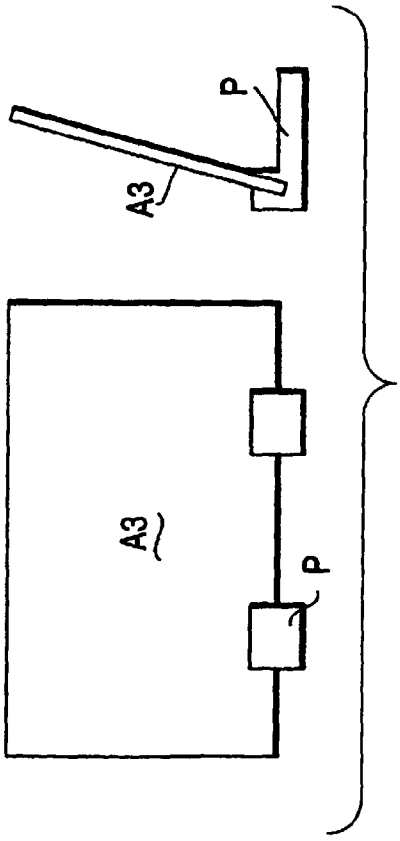


FIG. 24C

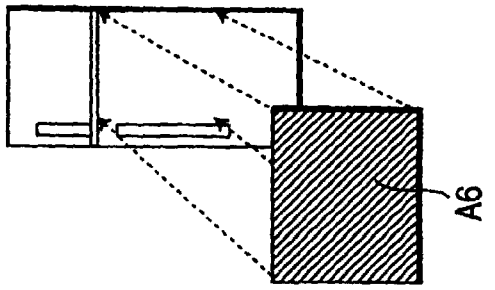


FIG. 24B

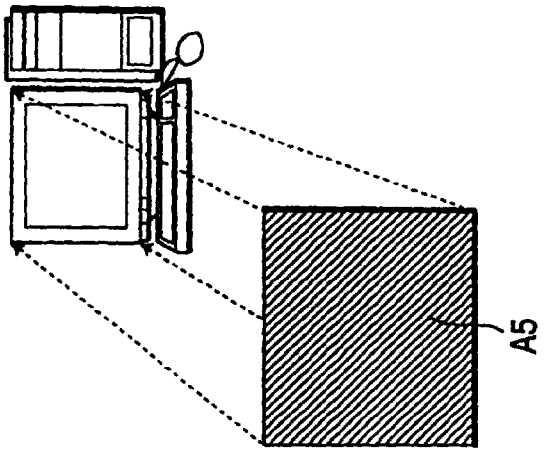


FIG. 24A

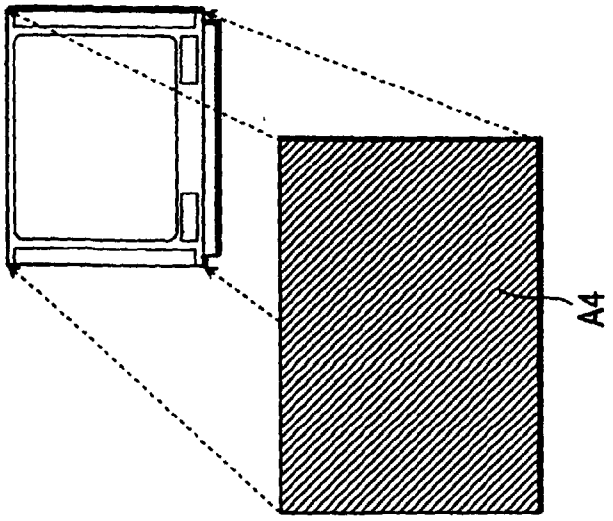
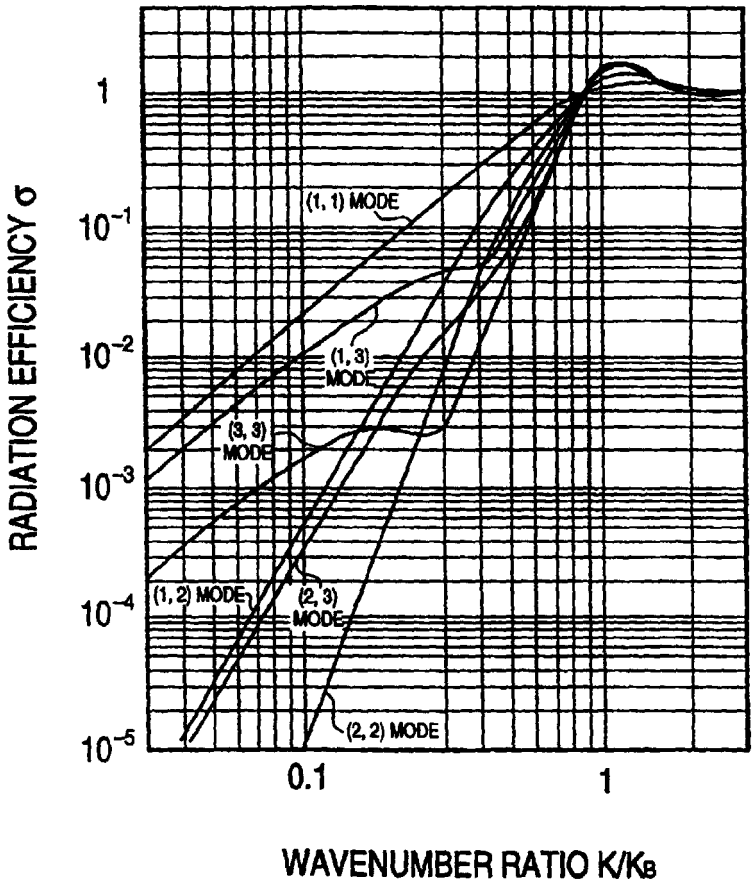


FIG. 25


RADIATION EFFICIENCY σ
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0.1
1
WAVENUMBER RATIO K/Kb
(1, 1) MODE
(1, 3) MODE
(3, 3) MODE
(1, 2) MODE
(2, 3) MODE
(2, 2) MODE