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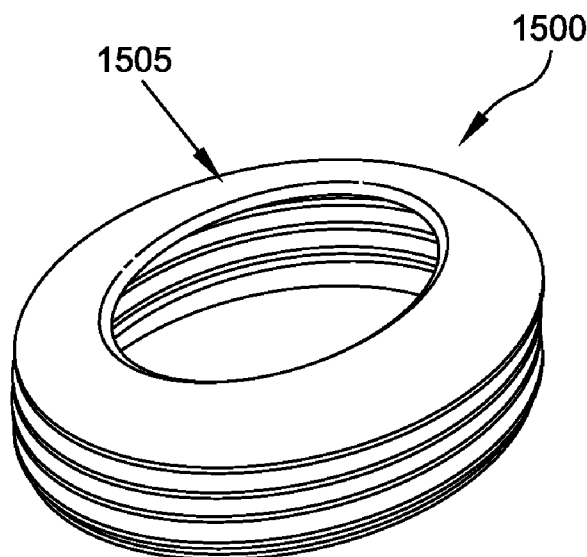
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(54) Title: HIGH TRANSMISSION LOSS HEADPHONE CUSHION



**FIG. 15C**

(57) Abstract: A headset including an earcup having a front opening adapted to be adjacent to the ear of a user, the earcup extending in a radial direction and an axial direction and defining an earcup volume; and a bellows cushion extending around the periphery of the front opening of the earcup and sized to engage the ear of the user, the bellows cushion comprising a plurality of folded segments located at an outer radial portion of the bellows cushion, and configured to be substantially compliant along an axial direction.

## **HIGH TRANSMISSION LOSS HEADPHONE CUSHION**

### **TECHNICAL FIELD**

[0001] This description relates to increasing the mechanical or acoustic impedance of a headphone cushion to reduce the audibility of outside sounds without substantially increasing the axial stiffness of the cushion.

### **BACKGROUND**

[0002] For background, reference is made to commonly owned United States Patent Numbers 4,922,452 and 6,597,792, the entire contents of which are hereby incorporated by reference.

### **SUMMARY**

[0003] In a first aspect, a headset includes an earcup having a front opening adapted to be adjacent to the ear of a user, the earcup extending in a radial direction and an axial direction and defining an earcup volume; and a bellows cushion extending around the periphery of the front opening of the earcup and sized to engage the ear of the user, the bellows cushion comprising a plurality of folded segments located at an outer radial portion of the bellows cushion, and configured to be substantially compliant along an axial direction.

[0004] In some embodiments, the bellows cushion includes a control surface extending along an inner radial portion of the bellows cushion disposed between the earcup volume and the volume of the bellows cushion. The control surface can include an acoustically transparent material or a plurality of audio openings, or a combination of both an acoustically transparent material and audio openings. The control surface can include a fabric or metal mesh material. The bellows cushion can be made of an elastomeric material, such as silicone rubber in one example. The bellows cushion can include an inner foam cushion which is substantially bounded by the bellows cushion. The inner foam cushion can be an open-celled foam material. The headset can also include a

stiffening component attached to an outer radial portion of the bellows cushion, and the stiffening component can include a substantially rigid support ring or a gel layer.

**[0005]** In some embodiments, the headset described above includes one or more drivers inside the earcup. In these embodiments, the headset can further include a microphone inside the earcup adjacent to the driver; and active noise reducing circuitry intercoupling the microphone and the driver constructed and arranged to provide active noise cancellation. The active noise reduction circuitry comprises feedback noise reduction circuitry, feed-forward noise reduction circuitry, or a combination thereof.

**[0006]** In a second aspect, an earcup assembly includes a bellows cushion configured to be substantially compliant along an axial direction and configured for attachment to an earcup, the earcup having a front opening adapted to be adjacent to the ear of a user, the earcup extending in a radial direction and an axial direction, a plurality of folded segments located at an outer radial portion of the bellows cushion; and a control surface extending along an inner radial portion of the bellows cushion and disposed between the earcup volume and the volume of the bellows cushion. The control surface can include an acoustically transparent material and further include a plurality of audio openings. The bellows cushion according to the second aspect can include an inner foam cushion which is substantially bounded by the bellows cushion.

**[0007]** In a further aspect, a headset includes an earcup having a front opening adapted to be adjacent to the ear of the user, the earcup having a radial direction and an axial direction, a baffle disposed within the earcup to define front and rear cavities both contained within an earcup volume, and a bellows cushion extending around the periphery of the front opening of the earcup and sized to engage the ear of the user, the bellows configured to be substantially compliant along an axial direction, a transducer inside the earcup, a microphone inside the earcup adjacent to a transducer, and active noise reducing circuitry intercoupling the microphone and the driver constructed and arranged to provide active noise cancellation. The active noise reduction circuitry can be feedback noise reduction circuitry, feed-forward noise reduction circuitry, or a combination thereof.

[0008] The headsets according to the foregoing aspect may be a substantially toroidal shape, such as, for example, circumaural or is supra-aural.

### DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a diagrammatic view of a headphone assembly on a head.

[0010] FIG. 2A is a perspective drawing of one embodiment of a headphone cushion including a stiffening component and FIG. 2B is plan view of one embodiment of a headphone cushion.

[0011] FIG. 3 is a sectional view of a headphone cushion including a stiffening ring.

[0012] FIG. 4 is a sectional view of a headphone cushion including a high density layer.

[0013] FIG. 5 is a drawing of an outer cover including a high density layer.

[0014] FIG. 6 is a sectional view of an earcup assembly.

[0015] FIG. 7 is a graph of sound attenuation through a headphone assembly including a stiffening ring as measured on a test fixture.

[0016] FIG. 8 is a graph of sound attenuation through a headphone assembly including a stiffening ring as measured on a head.

[0017] FIG. 9 is a graph of sound attenuation through a headphone assembly including a high density layer as measured on a test fixture.

[0018] FIG. 10 is a graph of sound attenuation through a headphone assembly including a high density layer as measured on a head.

[0019] FIG. 11 is a sectional view of a test method for measuring axial stiffness.

[0020] FIG. 12 is a sectional view of a test method for measuring radial stiffness.

[0021] FIG. 13 is a sectional view of a test method for measuring peel strength.

[0022] FIG. 14 is a sectional view of an earcup assembly including active noise reducing circuitry.

[0023] FIGS. 15A – 15D are top, side, top perspective, and bottom perspective views of a bellows headphone cushion.

[0024] FIGS. 16A and 16B are detailed sectional views of two embodiments of a headphone cushion assembly including the bellows headphone cushion of FIGS. 15A – 15D.

[0025] FIG. 17 is a sectional view of an earcup cushion assembly including the headphone cushion of FIGS. 15A – 15D.

### DETAILED DESCRIPTION

[0026] Referring to FIG. 1, there is shown a diagrammatic view one embodiment of a headphone assembly 100 worn by a user on a human head 102 having ears 104. The headphone assembly 100 includes suspension assembly 106, transducer assembly 108, stiffening component 110, headphone cushion 112, audio opening 114, and cover 116. Headphone assembly 100 is shown covering and substantially surrounding ears 104 and accordingly, is referred to as circumaural headphones. Alternatively, headphone assembly 100 may be an on-the-ear (supra-aural) set of headphones. Stiffening component 110 serves to increase the impedance of the outer cover of the cushion thus reducing the sound transmission through headphone assembly 110, thereby improving the isolation from outside noise for the headphones listener. In some embodiments, the stiffening component does not appreciable change the axial stiffness of the cushion so as not to impact the comfort of the headphone assembly to the user. An earcup assembly is formed by the combination of transducer assembly 108, headphone cushion 112, and cover 116. Optionally, stiffening component 110 may be included in the earcup assembly. The earcup assembly may have a substantially toroidal shape to fit over or on the ear 104.

[0027] The stiffening component 110 may be shaped in the form of a support ring that encircles the headphone cushion 112. Cover 116 may extend over the exterior portion of headphone cushion 112. Cover 116 may extend over the interior portion of headphone cushion 112. Interior cavity 118 is formed by transducer assembly 108, headphone cushion 112, and head 102. Headphone cushion 112 may be constructed of open cell foam. If headphone cushion 112 is constructed of open cell foam, audio openings 114 allow the volume of the headphone cushion 112 to combine with interior volume 118.

This combined volume is useful for tuning the audio characteristics of headphone assembly 100. Audio openings 114 are constructed and arranged to furnish additional damping to help smooth the audio response of headphone assembly 100 and control stability when headphone assembly 100 is not being worn. For a description of tuning using audio openings and combined volume, reference is made to US Patents 4,922,542 and 6,597,792.

**[0028]** The bulk density of foam is defined as the density of the foam in its expanded state. In some implementations, headphone cushion 112 may have a bulk density of about 2 to about 6 pounds-mass per cubic foot (pcf). In one implementation, the headphone cushion 112 includes an inner foam cushion having a bulk density of about 5 pcf. In some implementations, the headphone cushion 112 includes a foam having an elastic modulus between 1 and 10 kiloPascals (kPa). In one implementation, the headphone cushion 112 includes a foam cushion having an elastic modulus between about 2 and about 5 kPa. High stiffness foam is useful to reduce sound transmission through headphone cushion 112. However, foam that is too stiff may reduce the comfort of the headphones.

**[0029]** Referring to FIGS. 2A and 2B, in one embodiment of a headphone cushion assembly 200 includes gasket 202, inside cover 204, outside cover 206, stiffening ring 208, and front surface 210. The headphone cushion assembly for only one ear is depicted but it is understood by persons of ordinary skill in the art that headphone cushion assemblies for two ears are included in a set of headphones. Front surface 210 fits against the head of the listener while the headphone is in use. Gasket 202 fits between the headphone cushion assembly 200 and transducer assembly 108 to affect a seal at the interface. Inside cover 204 and outside cover 206 may be one continuous piece of material in some embodiments. Inside cover 204 and outside cover 206 may be made of plastic, leather, leatherette, or leather-like plastic (also known as pleather) material. In FIG. 2A, stiffening ring 208 is attached to the outside of outside cover 206. Alternatively, stiffening ring 208 may be attached to the inside of outside cover 206. Headphone cushion assembly 200 may have a substantially toroidal shape to fit over or on the shape of the human ear. In some embodiments, the headphone cushion assembly 200 further

includes a plurality of openings 212 (FIG. 2B) disposed along the inside cover 204 to expose the underlying foam and thereby increase the effective volume of the earcup by the volume of the underlying foam. In these embodiments, passive attenuation is enhanced and additional damping is provided to help smooth the audio response and control stability of the feedback loop of the active noise reduction system, as more fully explained in commonly owned U.S. Patent No. 6,597,792.

**[0030]** Referring to FIG. 3, there is shown a section drawing of another embodiment of a headphone cushion assembly. In FIG. 3, Headphone cushion assembly 300 includes opening 302, gasket 304, outside cover 306, inside cover 308, stiffening ring 310, headphone cushion 312, and front surface 314. In this embodiment, stiffening ring 310 is attached to the inside of outside cover 306.

**[0031]** The radial stiffness of headphone cushion assembly 300 is measured by compressing one side of headphone cushion assembly 300 in a direction along the radius of its toroidal shape and measuring the force necessary to compress headphone cushion assembly 300 a known distance. Stiffness is calculated by dividing the force by the distance compressed. Likewise, the axial stiffness is calculated in a direction along the axis of the toroidal shape. The radial directions are perpendicular to the axial direction. To achieve high attenuation simultaneously with good comfort, the ratio of radial stiffness to axial stiffness per contact area should be greater than  $10 \text{ cm}^2$ .

**[0032]** Referring to FIG. 4, there is shown a section drawing of another embodiment of a headphone cushion assembly. To increase the mechanical impedance of the outer cushion cover, a high density layer 400 is attached to the inside of outside cover 306. Outside cover 306 forms a first layer. High density layer 400 forms a second layer. In one embodiment, outside cover 306 has an average area density of less than  $0.03 \text{ g/cm}^2$  and high density layer 400 has an average area density greater than  $0.045 \text{ g/cm}^2$ . The high density layer may be a highly compliant, massive, and dissipative material. The high density layer may be silicone gel. The high density layer may optionally be applied to only the outside of outside cover 306 or to both the inside and outside of outside cover 306.

[0033] Referring to FIG. 5, there is shown a headphone cushion cover before it is spread around a headphone cushion. In this state, the headphone cushion cover is a flat piece of cloth or similar material shown as cover 500. High density layer 400 is shown attached to cover 500. The average area density is defined as the mass per unit area averaged over the area shown in FIG. 5. For example, the average area density of cover 500 is the total mass of cover 500 divided by the area of cover 500 as shown in FIG. 5. The average area density of high density layer 400 is the total mass of high density layer 400 divided by the area of layer 400 as shown in FIG. 5.

[0034] Referring to FIG. 6, there is shown a section drawing of a headphone cushion assembly pressed between top plate 630 and bottom plate 640. Bottom plate 640 is immovable as shown by hash marks 650. Cover 600 covers cushion 670. Outside portion 680 of cover 600 is outside of the headphone cushion assembly and extends from the contact point between cover 600 and top plate 630 to the contact point between cover 600 and bottom plate 640. Inside portion 690 of cushion 600 is inside of the headphone cushion assembly and extends from the contact point between cover 600 and top plate 630 to the contact point between cover 600 and bottom plate 640. Audio openings 660 are also shown in cover 600.

[0035] In one embodiment, the headphone assembly has audio openings in the portion of the cover that extends over the interior surface of the headphone cushion. The audio openings function to acoustically add the volume of the headphone cushion 112 to the interior volume 118 which enhances passive attenuation. The audio openings are approximately 30% of the total surface area of the interior surface of the cover. The approximate volume of the interior cavity is 100 cc, the half-mass of the headphone assembly is 95 g, and the stiffness of the headphone cushion is 100g-force/mm. The approximate volume of the open-cell foam in the headphone cushion is 40 cc, so the combined volume of the interior cavity and headphone cushion is 140 cc.

[0036] At frequencies above the resonance of the axial bouncing mode of the headphone, a second mode of radial, through-cushion transmission may exist – especially in low-impedance cushions with audio openings. Increased radial stiffness through the addition of a stiffening ring, or increased mass and damping through the application of a silicone



gel can improve the cushion's attenuation of outside noise. Increased cushion cover stiffness, mass, and damping generally correlate with higher attenuation. The axial stiffness affects the comfort of the headphones. Low axial stiffness is desired to improve comfort. For a headphone cushion assembly without a stiffening ring, the axial stiffness is approximately 80 gf/mm. For the same headphone cushion with a stiffening ring, the axial stiffness is approximately 100 gf/mm. The stiffening ring increases the radial stiffness much more than the axial stiffness. This difference in stiffness creates headphones that have both excellent comfort and high attenuation of outside noise.

[0037] Referring to FIG. 7, there is shown a graph of measured sound attenuation (in dB) vs frequency (in Hertz) through one embodiment of a headphone assembly while the headphone assembly is mounted on a test fixture. As opposed to the human head, the test fixture is flat so that it does not have leaks between the headphone cushion and the test fixture. Also, the fixture is rigid compared with the much more compliant surface (the skin) of a human test subject. The shapes of the curves in FIG. 7 depend on the physical dimensions and material properties of the headphone assembly under test. Curve 700 shows the sound attenuation through a headphone assembly that has an exterior cover over the headphone cushion, but no interior cover. Curve 702 shows the sound attenuation through a headphone assembly that has both an exterior cover and an interior cover over the headphone cushion. Curve 704 shows the sound attenuation through a headphone assembly that has an exterior cover over the headphone cushion, holes in the interior cover (or no interior cover), and a stiffening ring attached to the outside of the exterior cover. Curve 704 shows the benefit of high attenuation from the stiffening ring above approximately 500 Hz. The attenuation of the headphones with the stiffening ring and holes in the interior cover is approximately equal to the attenuation from the headphone assembly with both inside and outside covers. The advantage of using holes in the interior cover and the stiffening ring rather than interior and exterior covers is that the volume of the headphone cushion can be used to help tune the audio characteristics of the headphones. Since the volume encapsulated by the cushion may be utilized, the headphone assembly may be made smaller and still achieve performance similar to a larger set of headphones that has no holes in the interior cover.

[0038] Referring to FIG. 8, there is shown a graph of measured sound attenuation (in dB) vs frequency (in Hertz) through one embodiment of a headphone assembly while the headphone assembly is mounted on human heads. The curves in FIG. 8 represent data averaged from many individual heads. The set of headphones does not perfectly fit on each head, so leaks occur between the set of headphones and the heads. The shapes of the curves in FIG. 8 depend on the physical dimensions of the heads, and the physical dimensions and material properties of the set of headphones under test. Curve 800 shows the sound attenuation through a set of headphones that has an exterior cover over the headphone cushion, but no interior cover. Curve 802 shows the sound attenuation through a set of headphones that has both an exterior cover and an interior cover over the headphone cushion. Curve 804 shows the sound attenuation through a headphone assembly that has an exterior cover over the headphone cushion, holes in the interior cover (or no interior cover), and a stiffening ring attached to the outside of the exterior cover. Curve 804 shows the benefit of high attenuation from the stiffening ring above approximately 500 Hz.

[0039] Referring to FIG. 9, there is shown a graph of measured sound attenuation (in dB) vs frequency (in Hertz) through one embodiment of a headphone assembly while the headphone assembly is mounted on a test fixture. The shapes of the curves in FIG. 9 depend on the physical dimensions and material properties of the headphone assembly under test. Curve 900 shows the sound attenuation through a headphone assembly that has an exterior cover over the headphone cushion, but no interior cover. Curve 902 shows the sound attenuation through a headphone assembly that has both an exterior cover and an interior cover over the headphone cushion. Curve 904 shows the sound attenuation through a headphone assembly that has an exterior cover over the headphone cushion, holes in the interior cover (or no interior cover), and a high density layer attached to the inside of the exterior cover. Curve 904 shows the benefit of high attenuation from the high density layer above approximately 500 Hz. The attenuation of the headphones with the high density layer and holes in the interior cover is approximately equal to the attenuation from the headphone assembly with both inside and outside covers.

[0040] Referring to FIG. 10, there is shown a graph of measured sound attenuation (in dB) vs frequency (in Hertz) through one embodiment of a headphone assembly while the headphone assembly is mounted on human heads. The curves in FIG. 10 represent data averaged from many individual heads. The shapes of the curves in FIG. 10 depend on the physical dimensions of the heads, and the physical dimensions and material properties of the set of headphones under test. Curve 1000 shows the sound attenuation through a set of headphones that has an exterior cover over the headphone cushion, but no interior cover. Curve 1002 shows the sound attenuation through a set of headphones that has both an exterior cover and an interior cover over the headphone cushion. Curve 1004 shows the sound attenuation through a headphone assembly that has an exterior cover over the headphone cushion, holes in the interior cover (or no interior cover), and a high density layer attached to the inside of the exterior cover. Curve 1004 shows the benefit of high attenuation from the high density layer above approximately 500 Hz.

[0041] Referring to FIG. 11, there is shown a sectional view of a test method for axial stiffness. Force 1100 is applied to moveable plate 1110 which pushes on top plate 1120. Bottom plate 1130 is held immovable as shown by hash marks 1140. Headphone cushion assembly 1180 includes cushion 1150, cover 1160, and attachment plate 1170. Headphone cushion assembly 1180 is pressed between top plate 1120 and bottom plate 1130 during the axial stiffness test. Distance 1195 is the distance between top plate 1120 and bottom plate 1130. Audio openings 1190 are also shown in cover 1160. The steps of the axial stiffness test procedure are as follows. Determine the nominal clamp force of a headset (adjusted for medium size) as the force applied by the ear cushions to parallel plates with outer surfaces spaced 138 mm apart. Place headphone cushion assembly 1180 between top plate 1120 and bottom plate 1130. Apply a series of known forces 1100 to top plate 1120 in the direction perpendicular to top plate 1120. The range of forces 1100 should include the nominal clamp force of the corresponding headset. Record the resulting distances 1195 and forces 1100. Calculate the axial stiffness of the headphone cushion assembly as the slope of the forces 1100 as a function of distances 1195 in gf/mm at the nominal clamp force of the corresponding headset. Determine the contact area of the headphone cushion assembly as the total area of cover 1160 which is in contact with bottom plate 1130 when the nominal clamp force of the corresponding

headset is applied as force 1100. Calculate the axial stiffness per contact area as the axial stiffness divided by the contact area of the cushion in  $\text{gf/mm/cm}^2$ . Forces 1100 should be applied at less than or equal to 100 gf/min. Alternatively, forces 1100 may be applied rapidly if two minutes settling time is allowed before measurement of the forces 1100 and distances 1195.

**[0042]** Referring to FIG. 12, there is shown a sectional view of a test method for radial stiffness. Top plate 1220 and bottom plate 1230 are held immovable as shown by hash marks 1240. Headphone cushion assembly 1280 includes cushion 1250, cover 1260, and attachment plate 1270. Top plate 1220 and bottom plate 1230 have adhesive surfaces to hold headphone cushion assembly 1280 in place between top plate 1220 and bottom plate 1230. Distance 1295 is the distance between top plate 1220 and bottom plate 1230. Indenter 1297 pushes on the headphone cushion assembly in a radial direction. Indenter 1297 is a rigid cylinder with a diameter of 3 mm. Resultant force 1200 pushes back on indenter 1297. Audio openings 1290 are also shown in cover 1260. Before the radial test procedure is performed, distance 1295 must be determined. Using the test setup in FIG. 11, set force 1100 to 150 gf and measure resultant distance 1195. Set distance 1295 in FIG. 12 equal to resultant distance 1195 from the test setup in FIG. 11 with force 1100 equal to 150 gf. The steps of the radial stiffness test procedure are as follows. Clamp headphone cushion assembly 1280 between top plate 1220 and bottom plate 1230. Position the axis of indenter 1297 in the central plane of cushion 1250, and along a direction perpendicular to the curvature of the cover 1260's outer surface when viewed along a direction perpendicular to plates 1220 and 1230. Push indenter 1297 3.8 mm (from the position of initial contact) into headphone cushion assembly 1280. After about 2 minutes settling time, record the resultant force 1200 on indenter 1297. Calculate the radial stiffness of the headphone cushion assembly as the resultant force 1200 divided by the 3.8 mm indenting distance in gf/mm.

**[0043]** Referring to FIG. 13, there is shown a sectional view of a test method for peel strength. Force 1300 is applied to pull up cover sample 1310 from foam sample 1320. Foam sample 1320 is mounted to plate 1330 which is held immovable as shown by hash marks 1340. Cover sample 1310 is a rectangular piece of outer cover material from the

headphone cushion assembly with a width greater than 100 mm and a length greater than 150 mm. Foam sample 1320 is a rectangular piece of foam from the headphone cushion assembly which has a width and length larger than cover sample 1310. Cover sample 1310 is placed over foam sample 1320 such that the inner surface of cover 1310 contacts foam sample 1320. 10 kPa of force is then applied evenly to cover sample 1310 on foam sample 1320 for 2 minutes to allow cover sample 1310 to adhere to foam sample 1320. The steps of the peel strength test procedure are as follows. Using a load cell with a resolution of at least 0.01 N to measure force 1300, peel cover sample 1310 from foam sample 1320 at a rate of 60 mm/min in the direction perpendicular to foam sample 1320. According to one test protocol, cover sample 1310 can be peeled so that the angle between cover sample 1310 and foam sample 1320 remains within 10° of perpendicular. Record average force 1300 as the average force measured over a peel distance of 100 mm. The peel direction should be perpendicular to the direction of gravity. Calculate the peel strength as average force 1300 divided by the width of the cover sample 1310 in gf/mm.

**[0044]** Referring to FIG. 14, there is shown a sectional view of an earcup assembly with noise reducing circuitry. Reference is made to US Patent 6,597,792, the entire contents of which are hereby incorporated by reference. Driver 1400 is seated in earcup 1410 with driver plate 1420 extending rearward from a lip 1430 of earcup 1410 to a ridge 1440 with microphone 1450 closely adjacent to driver 1400 and covered by a wire mesh resistive cover 1460. Cushion 1470 covers the front opening of earcup 1410 and includes foam 1480.

**[0045]** Referring to FIGS. 15A-15D, there is shown another embodiment of a headphone cushion assembly. A bellows cushion 1500 includes a first surface 1505 configured to engage the face or ear of the user (depending upon whether the cushion 1500 is configured as a circumaural or supra-aural cushion, respectively) and a second surface 1510 generally opposite the first surface configured to attach to an earcup (not shown). The bellows cushion 1500 includes a series of folded segments 1520 positioned circumferentially along an outer radial portion of the cushion 1500. The folded segments 1520 provide additional mass disposed generally along a radial direction 1525 without

substantially increasing stiffness along an axial direction 1530. The additional mass provided by the folded segments 1520 decreases sound transmission through the cushion 1500 without decreasing the compliance or compressibility along an axial direction 1530, and thus maintaining or improving the level of comfort provided by the cushion 1500.

**[0046]** In various embodiments, the number, size, structure, and configuration of the folded segments 1520 can be varied to achieve the desired mechanical and acoustical properties for the bellows cushion 1500, and more specifically, to adjust the stiffness and mass along the radial direction 1525 for increasing passive attenuation, while reducing stiffness along the axial direction 1530 to increase or optimize comfort. The bellows cushion 1500 can be made from an elastomeric material, such as silicone rubber or other suitable material as will be appreciated by a person of skill in the art. The bellows cushion 1500 may be configured to be supra-aural or circumaural.

**[0047]** Referring to FIG. 16A, there is shown a detailed cross-section view of another embodiment of a headphone cushion assembly 1540 including the bellows cushion 1500 and folded segments 1520. In certain embodiments, the headphone cushion assembly 1540 includes an inner foam cushion 1550 which is substantially bounded by the bellows cushion 1500. In some embodiments, the headphone cushion assembly 1540 may be used without the inner foam cushion 1550, or without any internal supporting or dampening structure, relying only on the mechanical and acoustical properties provided by the bellows cushion 1500. The assembly can also include a gasket 1555 to provide a mating surface for attachment to the earcup (not shown). In some embodiments, the headphone cushion assembly 1540 includes a control surface 1560 which provides a predetermined impedance to control transmission of sound between inside of the earcup 118 (FIG. 1) and the internal region of the bellows cushion 1500, shown in this embodiment as substantially filled with the inner foam cushion 1550. In some embodiments, the inner foam cushion 1550 can be open-celled foam, closed-cell foam, or a combination thereof to provide the desired levels of acoustic damping and restoring force to the bellows cushion 1500. The control surface 1560 can be an acoustically transparent material and in some embodiments, can be a fabric mesh or wire mesh. The control surface 1560 may include a plurality of audio openings 1565, as shown in FIG. 16B.

[0048] The mesh or openings in the control surface can function to acoustically add the volume bounded by the bellows cushion 1500 to the interior cavity 118 (FIG. 1) of the earcup, which enhances passive attenuation. Such opening are also shown as in FIG. 2B as elements 212. The control surface 1560 can be joined to a portion of the bellows cushion 1500 with a gasket or adhesive 1570.

[0049] Referring to FIG. 17, there is shown a cross-sectional view of the bellow the headphone cushion assembly 1540 including a cushion cover 1580, which may extend over all, substantially all, or only a portion of the bellows cushion 1500. The cushion cover 1580 may be made of protein leather, or fabric, for example to provide desired aesthetic or tactile properties to certain portions of the cushion assembly 1540.

[0050] In those embodiments of the cushion assembly 1540 including a cushion cover 1580, the audio openings 1565 extend through the cushion cover 1580, and in some embodiments through the control surface 1560. In some embodiments, the audio openings are approximately 30% of the total surface area of the interior surface of the cover. In one embodiment, the approximate volume of the interior cavity is about 100 cc and the approximate volume of the open-cell foam in the headphone cushion is about 40 cc, so the combined volume of the interior cavity and headphone cushion is about 140 cc.

[0051] The bellows cushion 1500 as configured in the headphone cushion assembly 1540 provides increased stiffness and mass along the radial direction 1525, while lowering the axial stiffness (or increasing the axial compliance) along the axial direction 1530 to improve comfort to the user. The plurality of folded segments 1520 provides additional mass along the outer radial portion of the cushion 1500 (along radial direction 1525) and consequently, increases passive attenuation. The folded segments 1520 of the bellows cushion 1500 act like a plurality of springs in a series configuration to yield a low stiffness along the axial direction 1530. Along the radial direction 1525, the comparatively higher cross-sectional mass moment of inertia of the folded segments 1520 increases the stiffness along the radial direction 1525, and consequently, improves the passive attenuation performance. In some embodiments, the bellows cushion 1500 implemented in cushion assembly 1540 provides improvements to the passive attenuation performance at frequencies about 1kHz and higher.

**[0052]** In some embodiments, the bellows cushion 1500 and cushion assembly 1540 are implemented in a headset having active noise reducing circuitry. In various embodiments, the active noise reduction circuitry is feedback, feed-forward, or a combination of feedback and feed-forward noise reduction circuitry.

**[0053]** Various embodiments have been described. Nevertheless, it will be understood that additional modifications may be made without departing from the spirit and scope of the inventive concepts described herein, and, accordingly, other embodiments are within the scope of the following claims.



What is claimed is:

1. A headset comprising:  
an earcup having a front opening adapted to be adjacent to the ear of a user, the earcup extending in a radial direction and an axial direction and defining an earcup volume; and
- 5 a bellows cushion extending around the periphery of the front opening of the earcup and sized to engage the ear of the user, the bellows cushion comprising a plurality of folded segments located at an outer radial portion of the bellows cushion, and configured to be substantially compliant along an axial direction.
2. The headset of claim 1 wherein the bellows cushion comprises a control surface extending along an inner radial portion of the bellows cushion, the control surface disposed between the earcup volume and the volume of the bellows cushion.
3. The headset of claim 2 wherein the control surface comprises an acoustically transparent material.
4. The headset of claim 2 wherein the control surface comprises a plurality of audio openings.
5. The headset of claim 2 wherein the control surface comprises a fabric mesh material.
6. The headset of claim 2 wherein the control surface comprises a metal mesh material.

7. The headset of claim 1 wherein the bellows cushion comprises an elastomeric material.
8. The headset of claim 1 wherein the bellows cushion comprises an inner foam cushion which is substantially bounded by the bellows cushion.
9. The headset of claim 8 wherein the inner foam cushion comprises an open-celled foam material.
10. The headset of claim 1 further comprising a stiffening component attached to an outer radial portion of the bellows cushion.
11. The headset of claim 10 wherein the stiffening component comprises a substantially rigid support ring.
12. The headset of claim 11 wherein the stiffening component comprises a gel layer.
13. The headset of claim 1 further comprising a driver inside the earcup.
14. The headset of claim 13 further comprising:
  - a baffle disposed within the earcup to define front and rear cavities both contained within the earcup volume;
  - 5 a microphone inside the earcup adjacent to the driver; and
  - active noise reducing circuitry intercoupling the microphone and the driver constructed and arranged to provide active noise cancellation.
15. The headset of claim 14 wherein the active noise reduction circuitry comprises feedback noise reduction circuitry.

16 The headset of claim 14 wherein the active noise reduction circuitry comprises feed-forward noise reduction circuitry.

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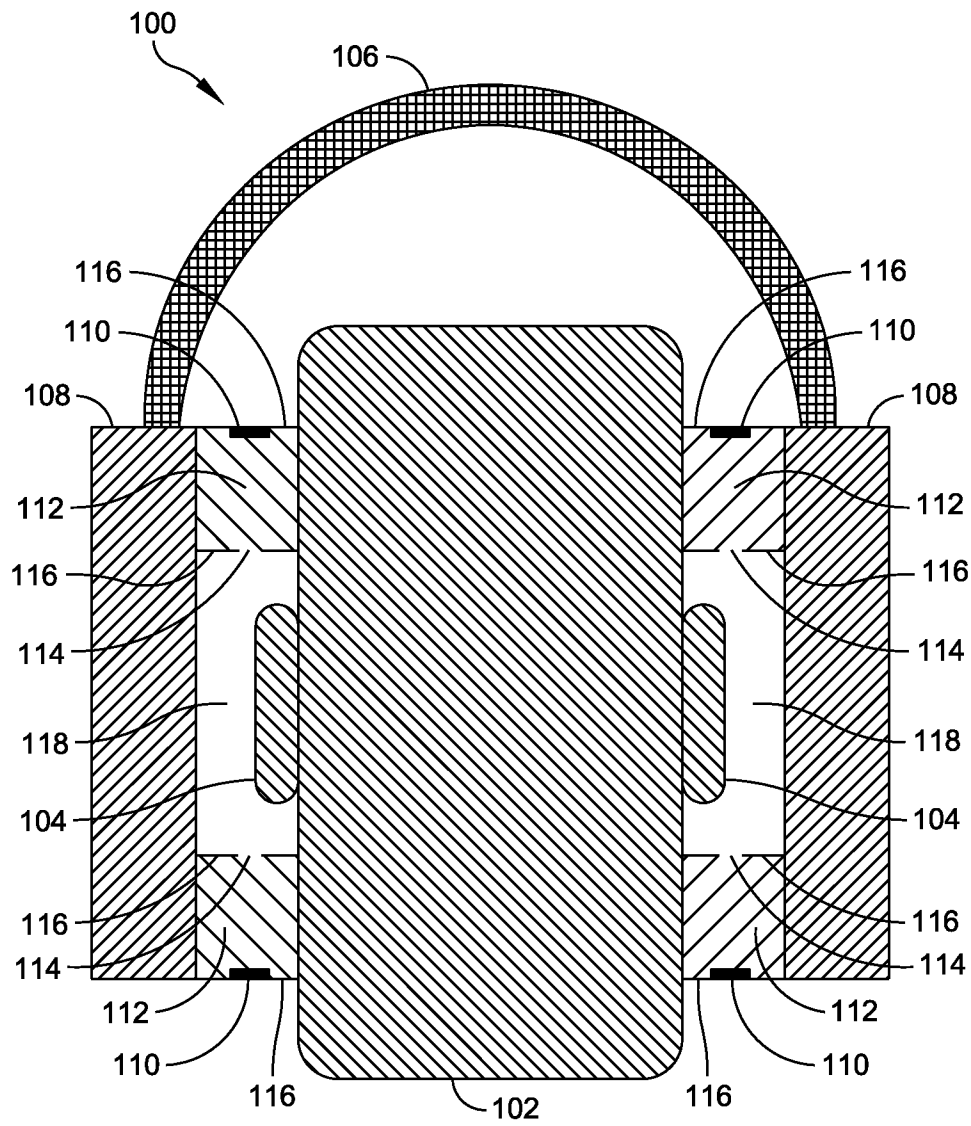


FIG. 1

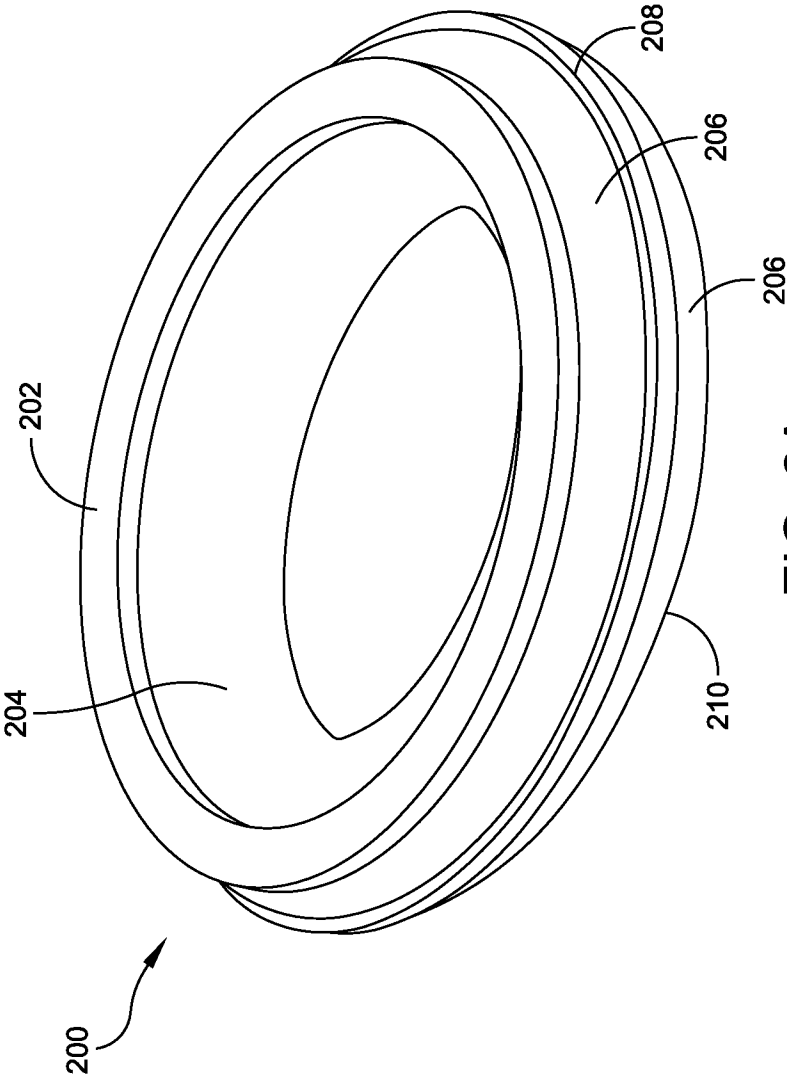


FIG. 2A

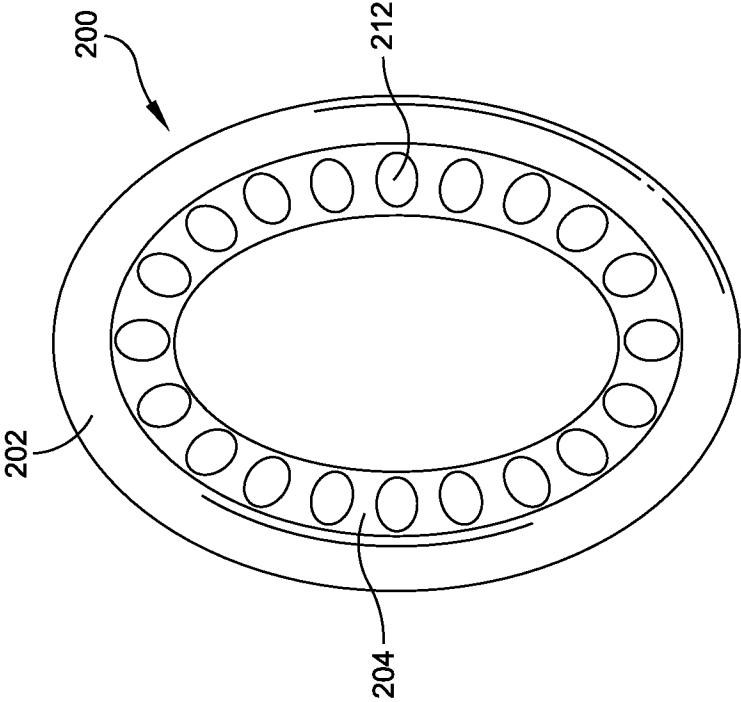


FIG. 2B

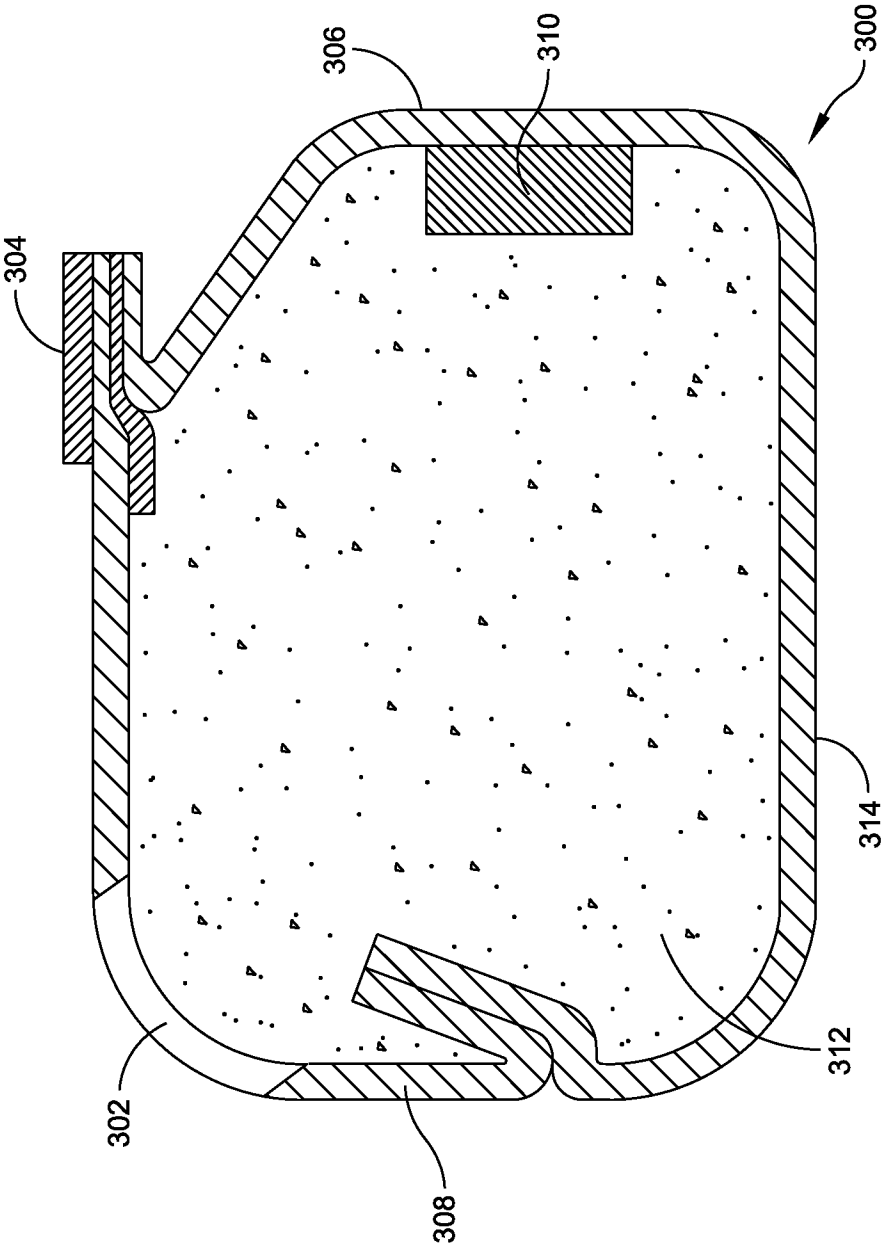


FIG. 3

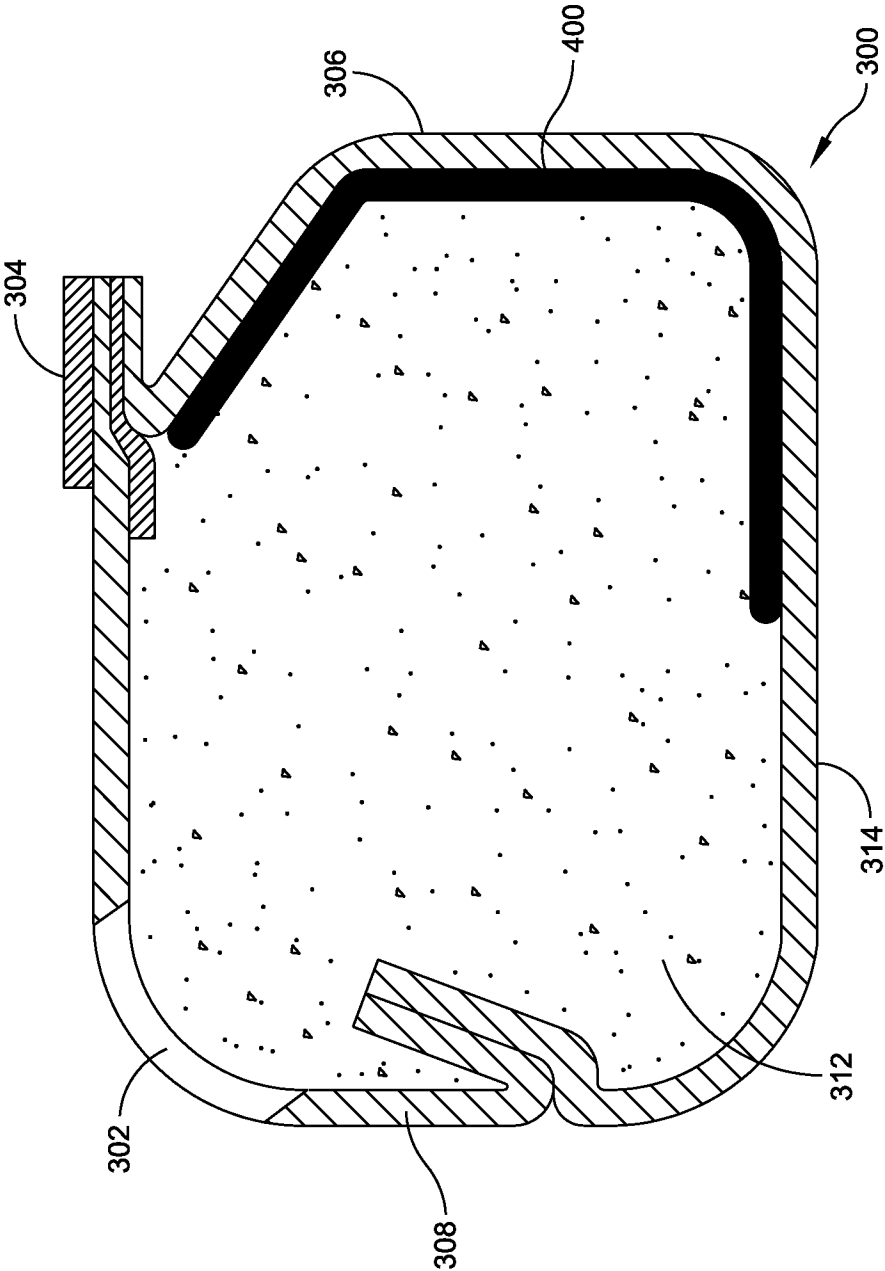


FIG. 4



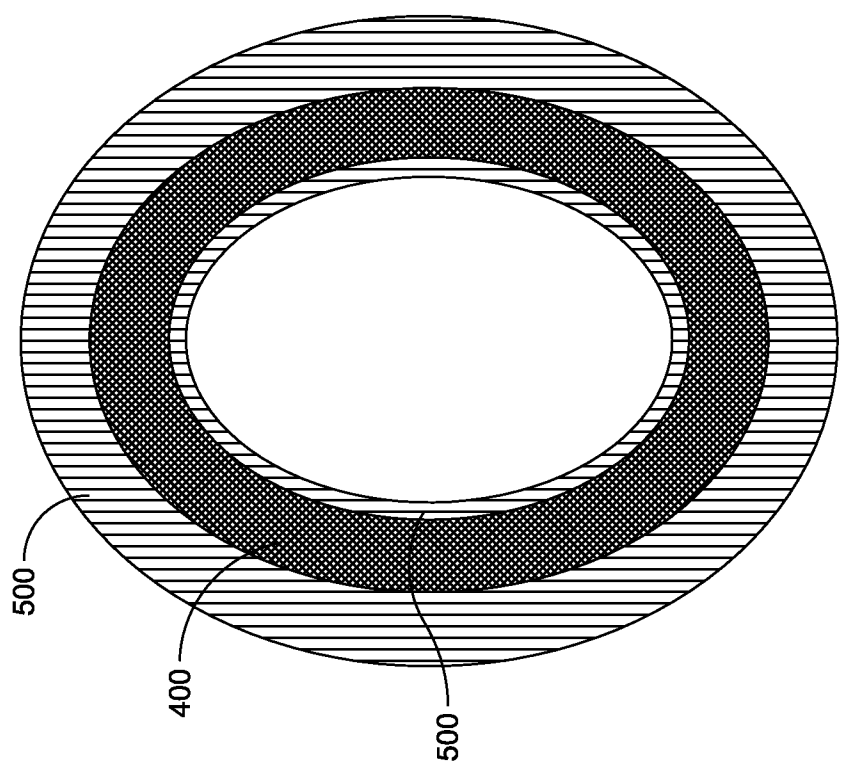


FIG. 5

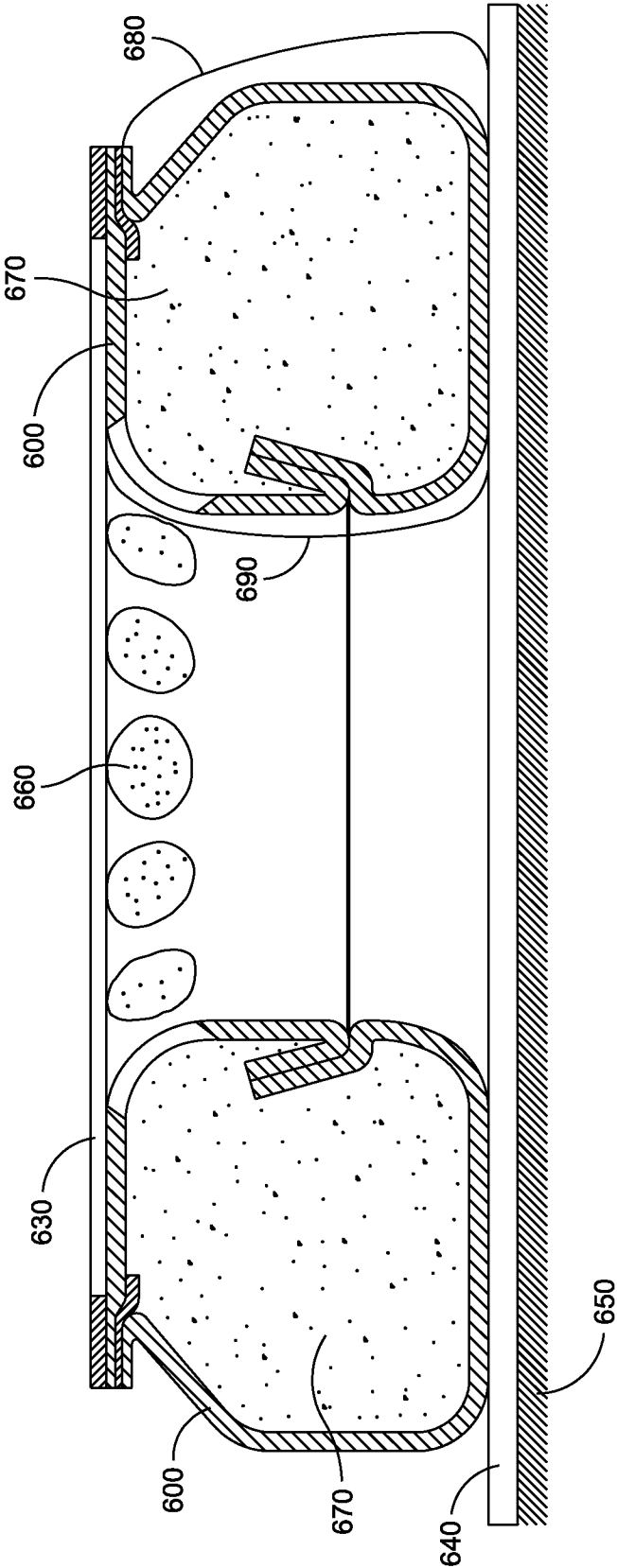


FIG. 6

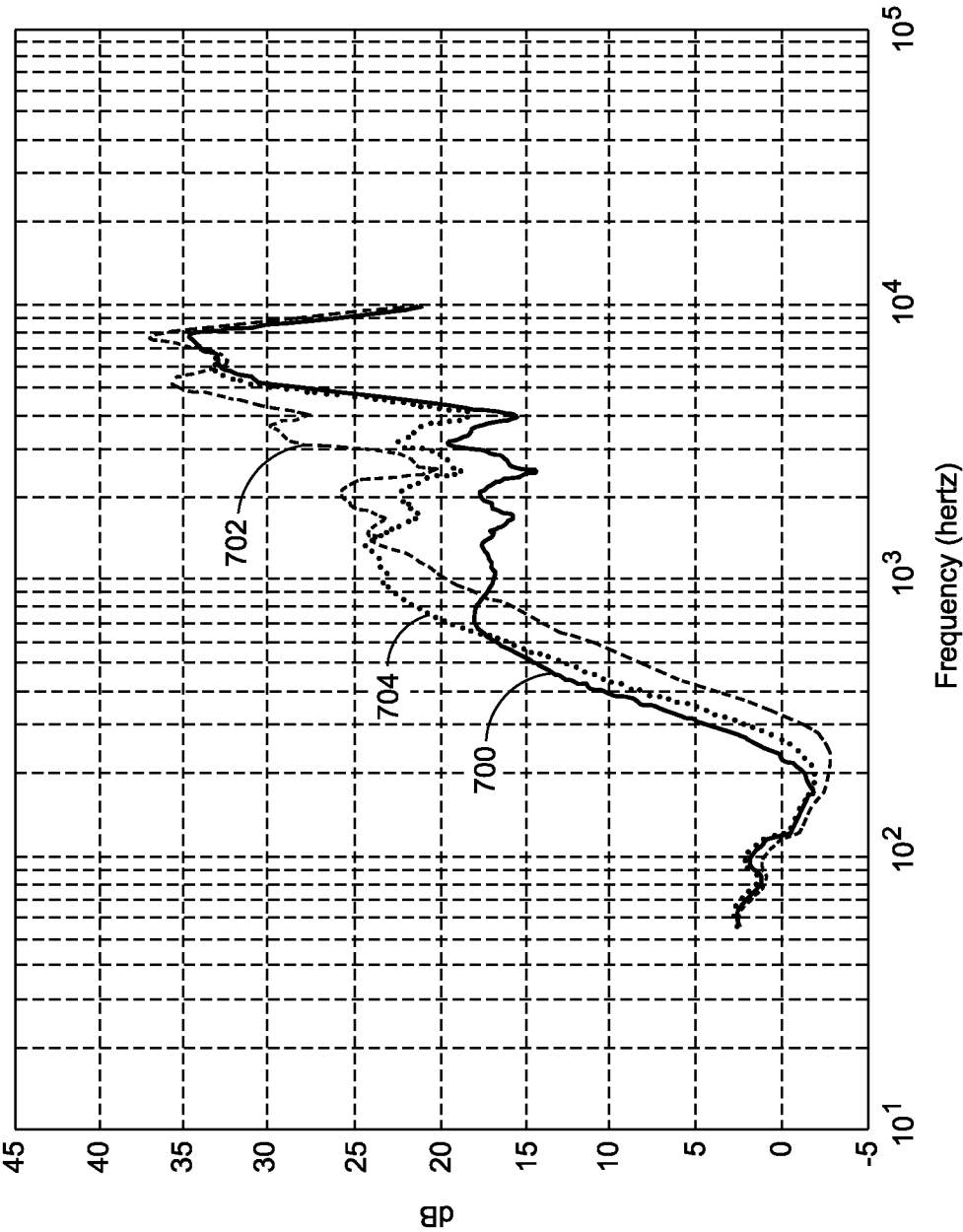


FIG. 7

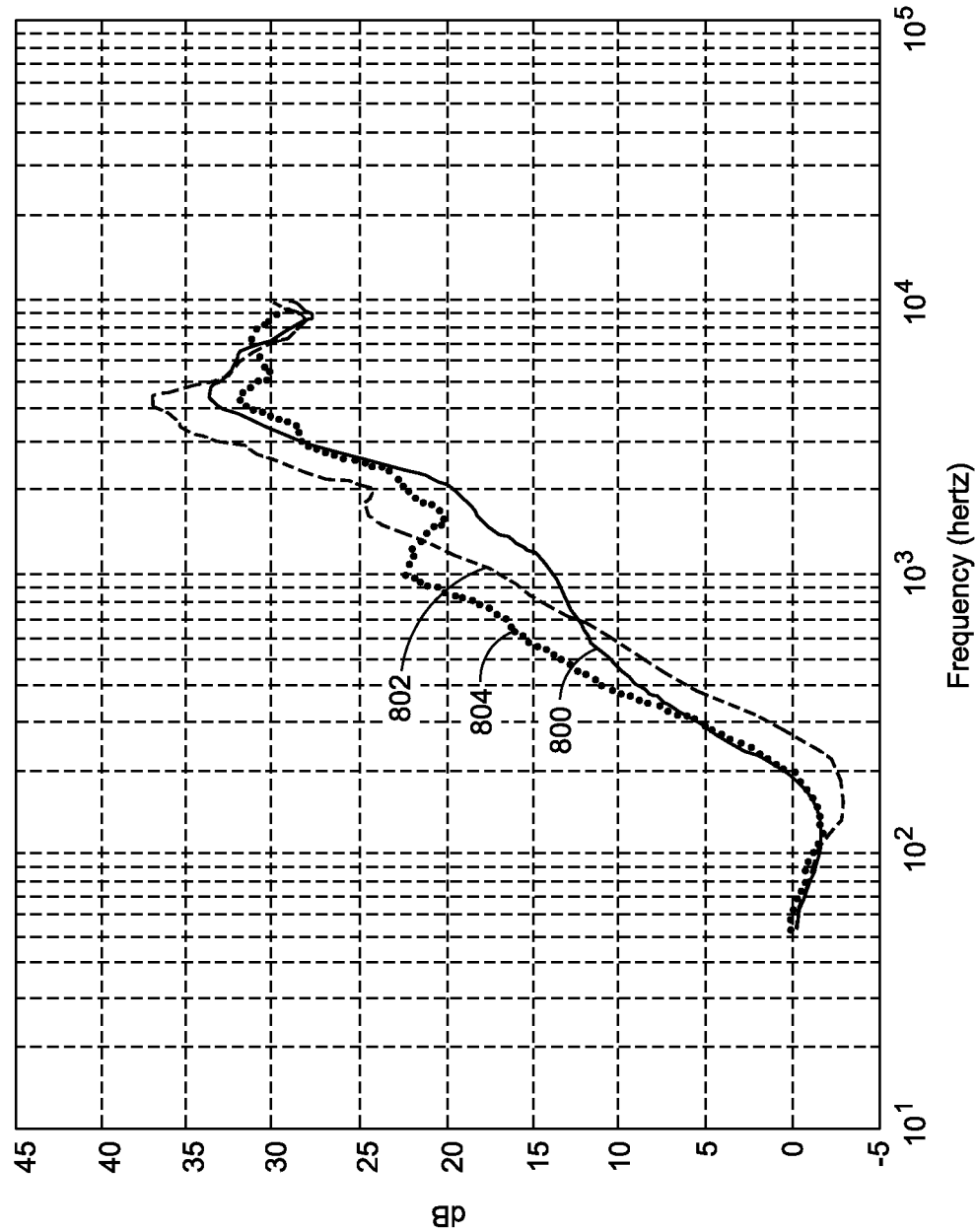


FIG. 8

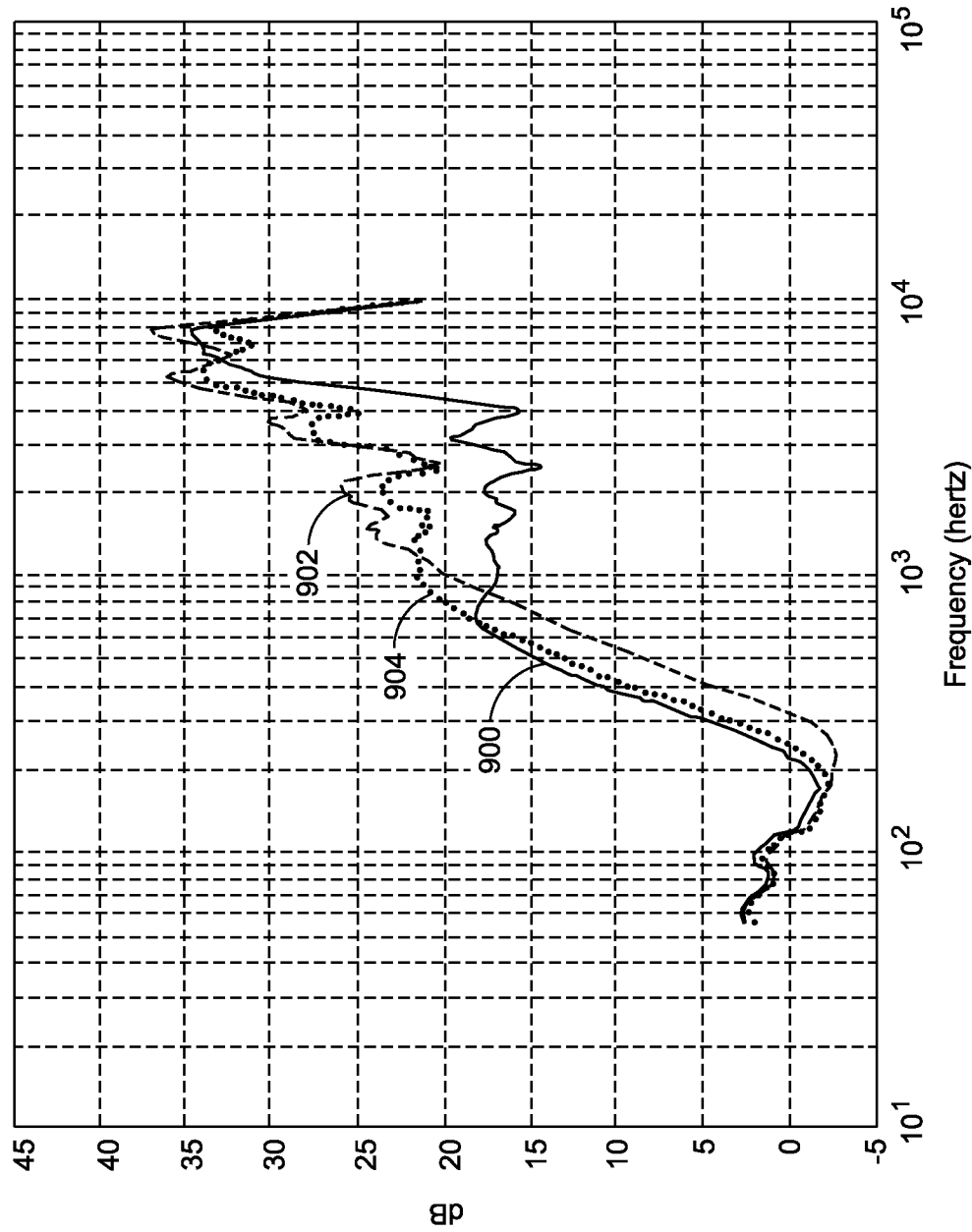


FIG. 9

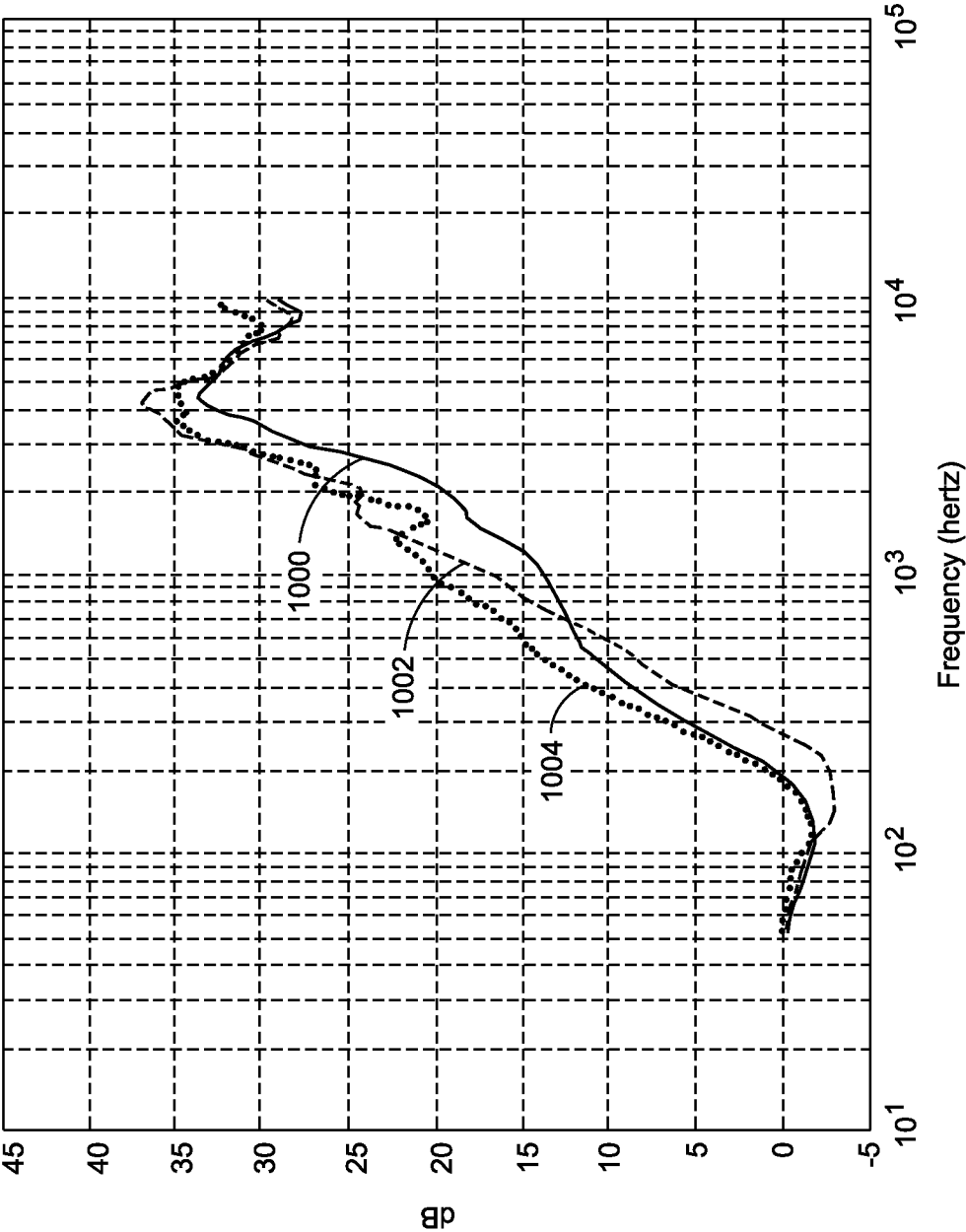


FIG. 10

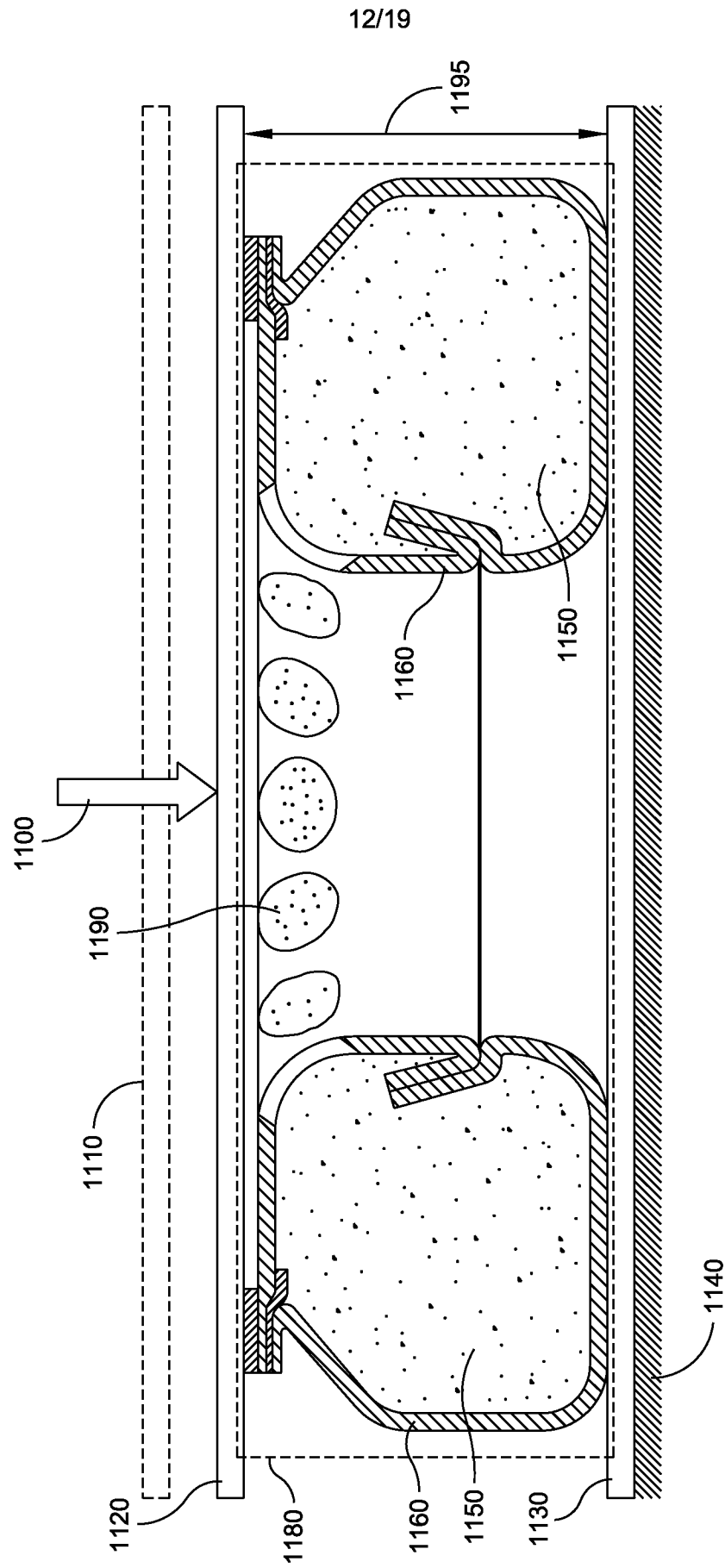


FIG. 11

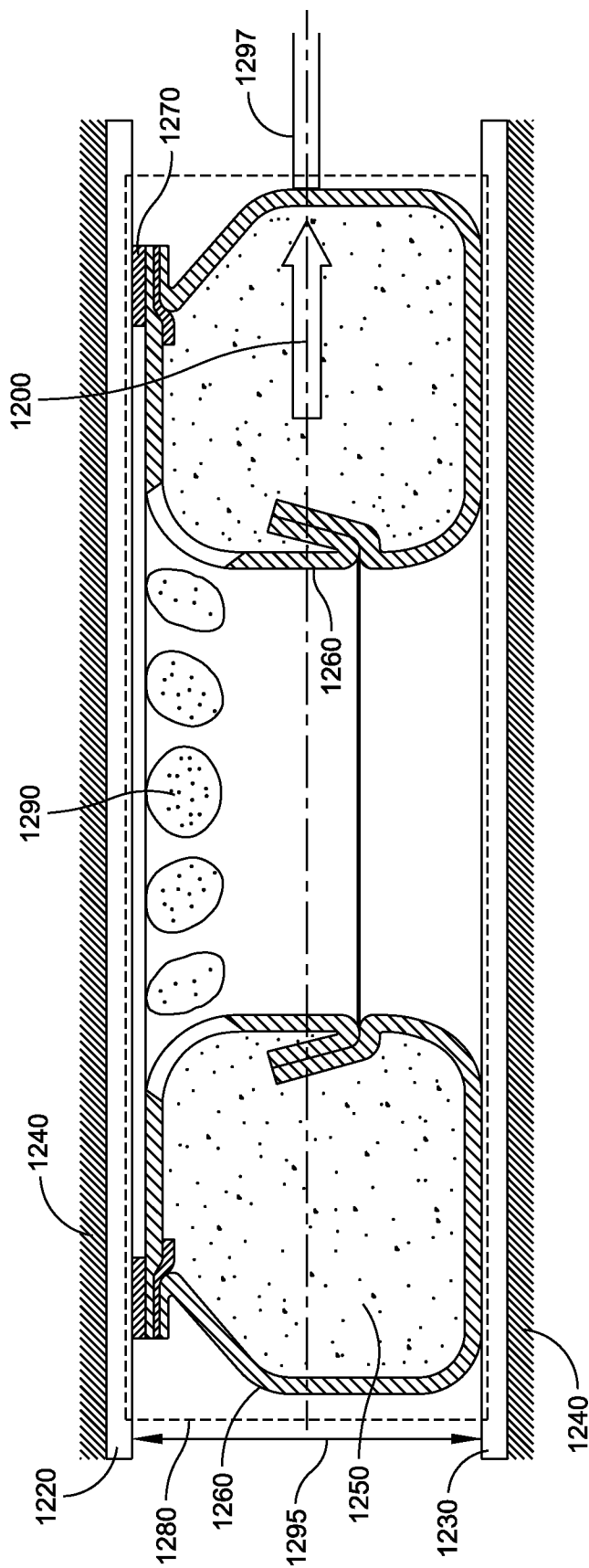


FIG. 12



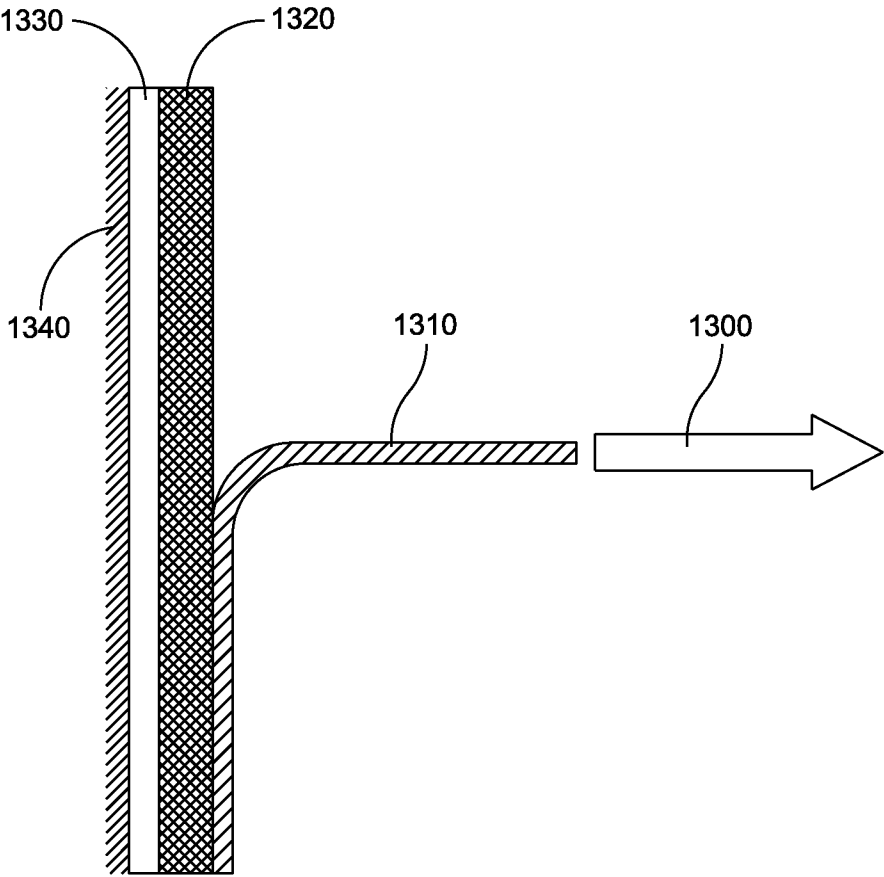


FIG. 13

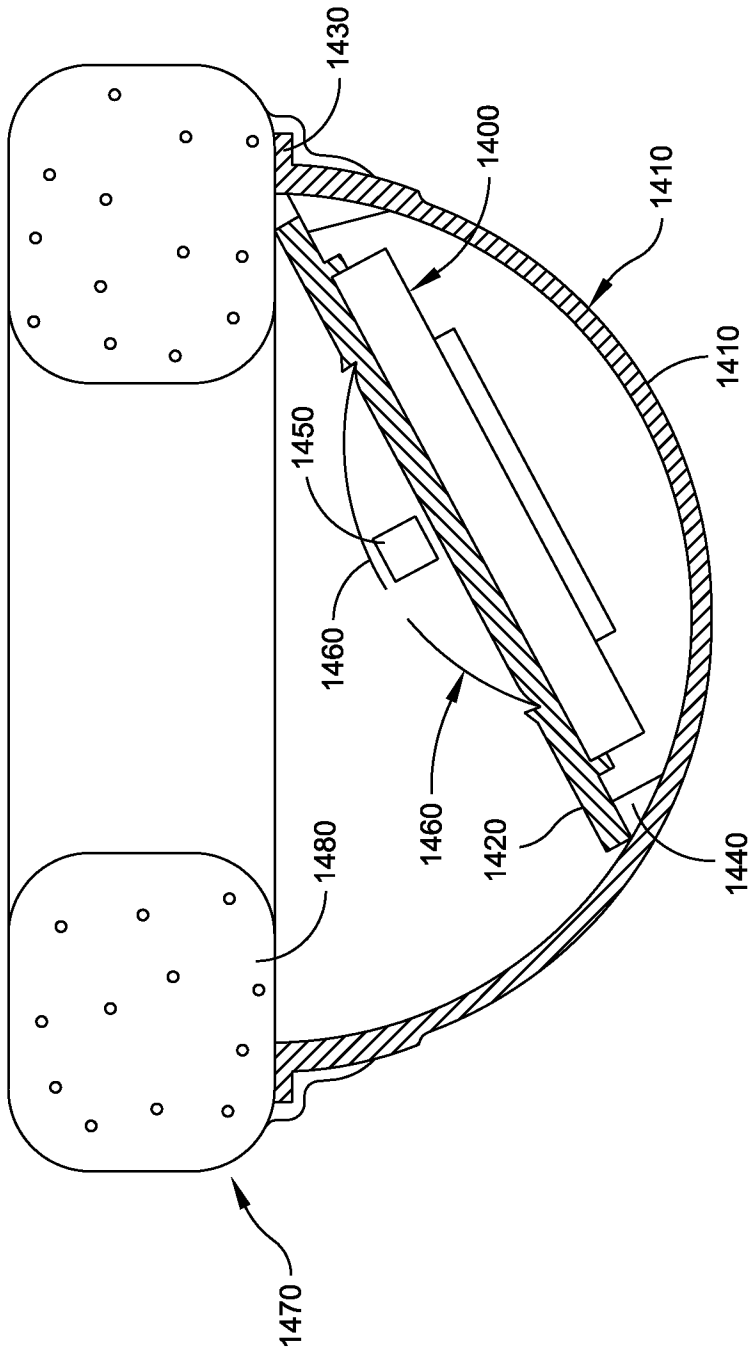


FIG. 14

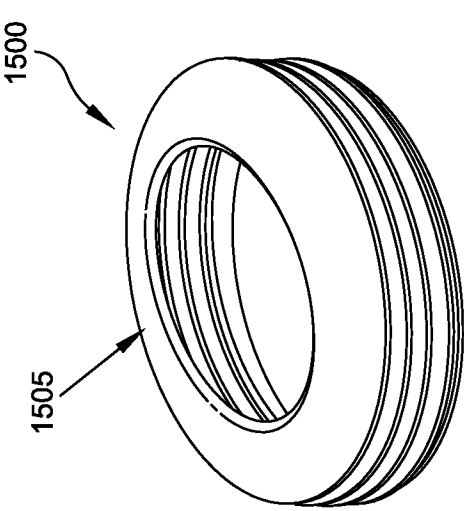


FIG. 15C

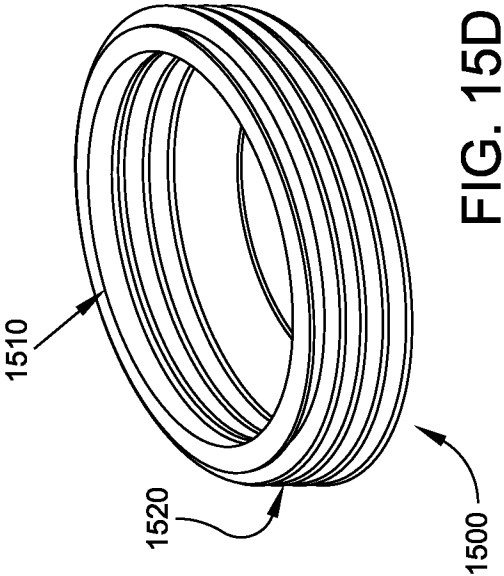


FIG. 15D

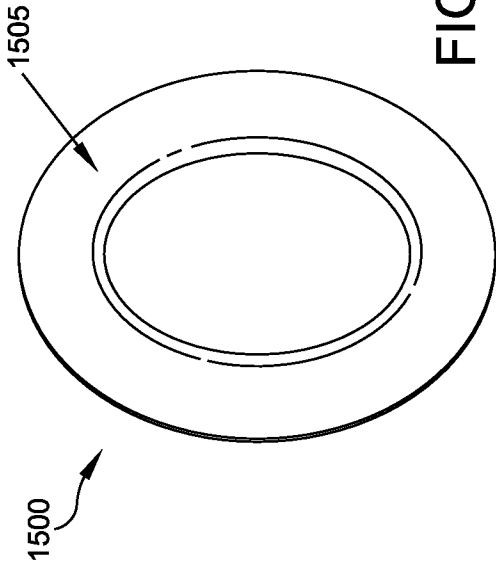


FIG. 15A

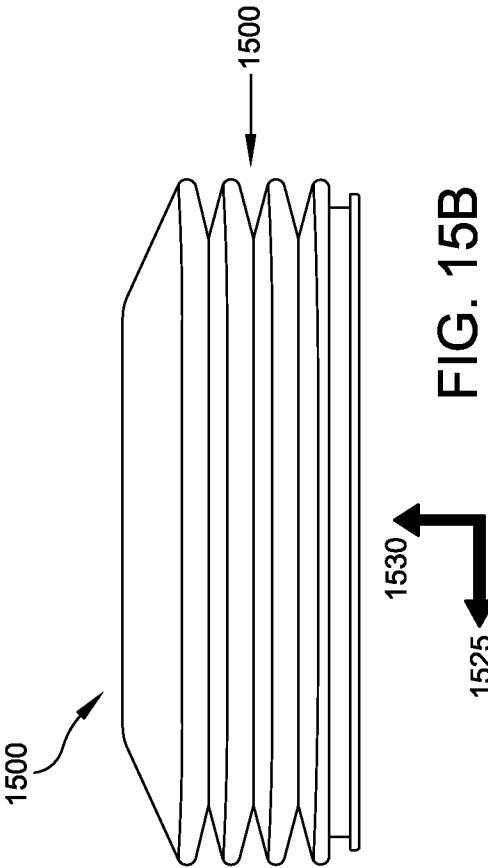


FIG. 15B

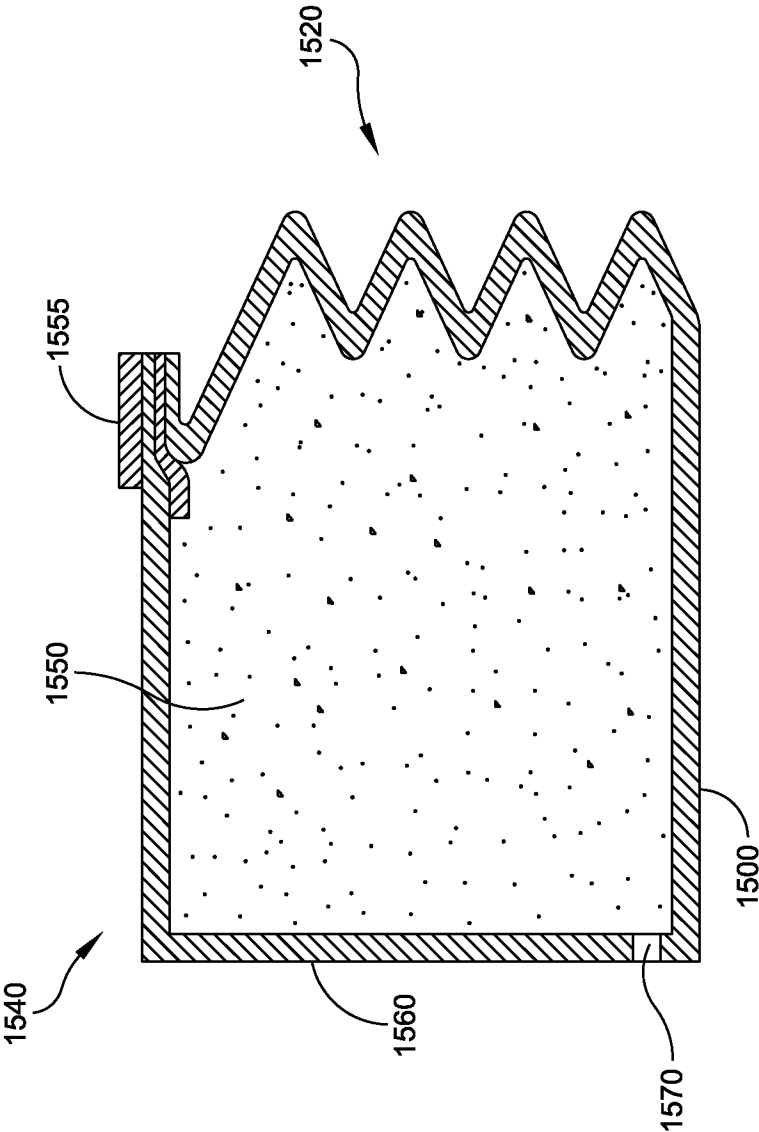


FIG. 16A

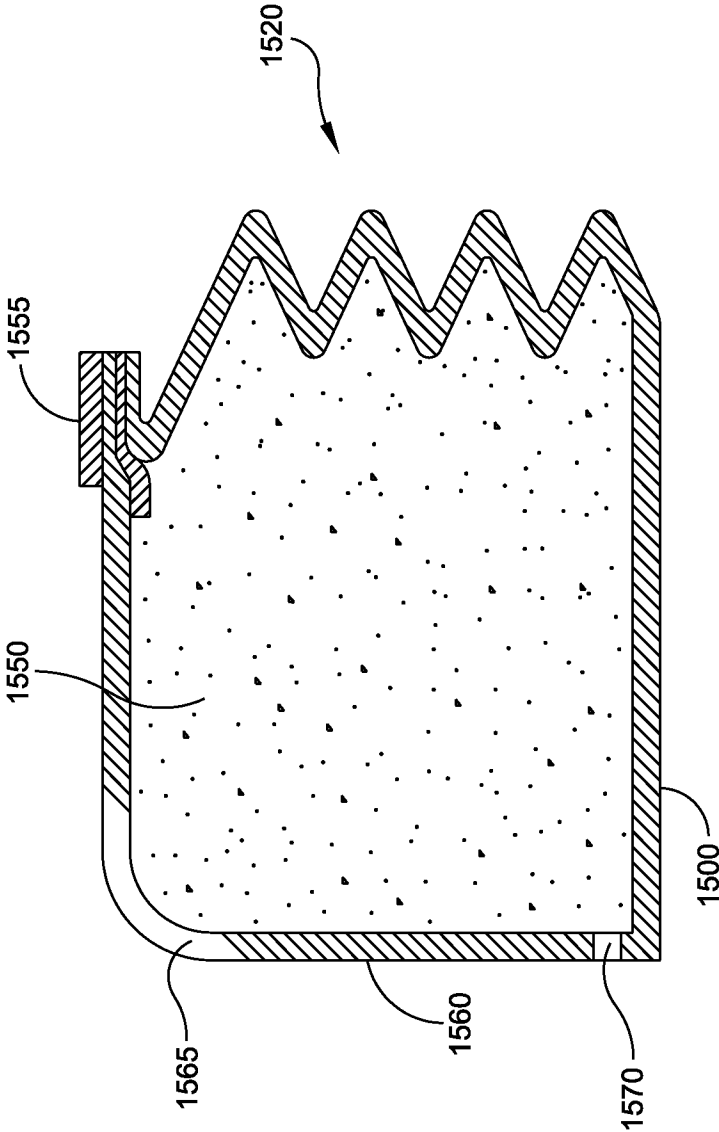


FIG. 16B

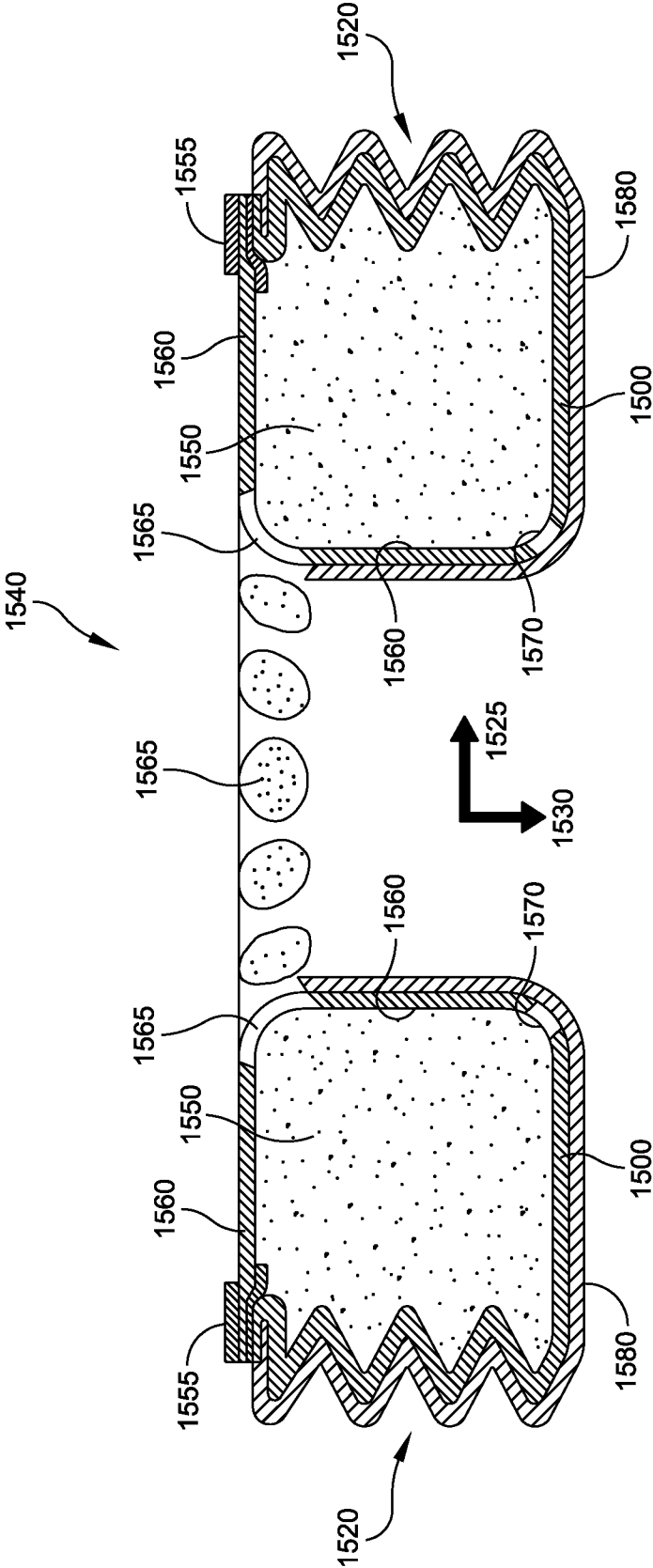


FIG. 17

## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2012/030683

## A. CLASSIFICATION OF SUBJECT MATTER

INV. H04R1/10

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04R A61F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2 336 669 A (BROWN RAY W ET AL) 14 December 1943 (1943-12-14)	1-13
Y	column 1, line 51 - column 3, line 30; figure 1	14-16
Y	----- EP 1 940 197 A1 (SONY CORP [JP]) 2 July 2008 (2008-07-02) paragraphs [0002], [0003], [0021] - [0034], [0118] - [0147]; figures 1,15	14-16
A	----- US 2010/128884 A1 (SAPIEJEWSKI ROMAN [US] ET AL) 27 May 2010 (2010-05-27) the whole document	1-16
A	----- US 2009/110226 A1 (ISHIDA HIROYUKI [JP]) 30 April 2009 (2009-04-30) the whole document	1-16
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Further documents are listed in the continuation of Box C.



See patent family annex.

## \* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

14 May 2012

Date of mailing of the international search report

24/05/2012

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Authorized officer

Kunze, Holger

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2012/030683

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