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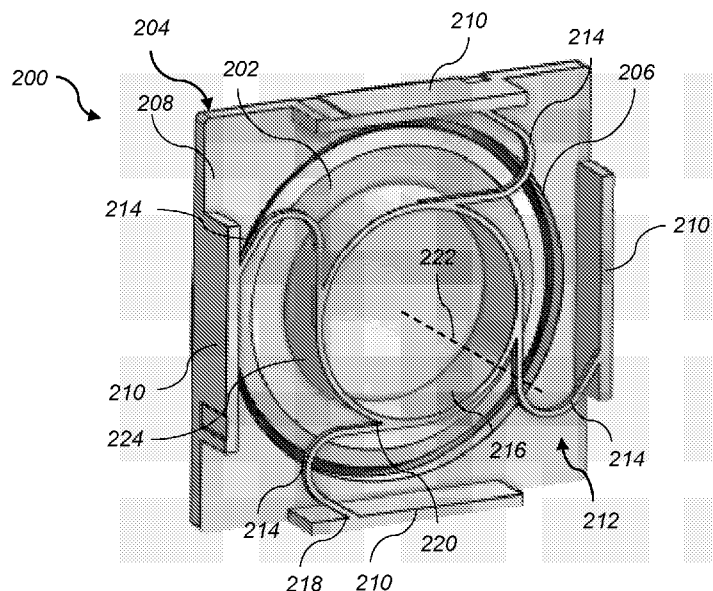


Figure 2

(57) Abstract: There is provided a passive radiator, comprising a frame, a diaphragm attached to the frame by a surround such that the diaphragm can move relative to the frame, and a suspension system comprising at least one flat spring that couples the diaphragm and the frame. There is also provided a playback device comprising a passive radiator, the passive radiator comprising a frame, a diaphragm attached to the frame by a surround such that the diaphragm can move relative to the frame, and a suspension system comprising at least one flat spring that couples the diaphragm and the frame.



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**PASSIVE RADIATOR AND A PLAYBACK DEVICE INCLUDING THE PASSIVE
RADIATOR**

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority to U.S. Patent Application No. 63/510,245, filed June 26, 2023, and to U.S. Patent Application No. 63/510,247, filed June 26, 2023, each of which is incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure is related to consumer goods and, more particularly, to methods, systems, products, features, services, and other elements directed to media playback or some aspect thereof.

BACKGROUND

[0003] Options for accessing and listening to digital audio in an out-loud setting were limited until in 2002, when SONOS, Inc. began development of a new type of playback system. Sonos then filed one of its first patent applications in 2003, entitled “Method for Synchronizing Audio Playback between Multiple Networked Devices,” and began offering its first media playback systems for sale in 2005. The Sonos Wireless Home Sound System enables people to experience music from many sources via one or more networked playback devices. Through a software control application installed on a controller (e.g., smartphone, tablet, computer, voice input device), one can play what she wants in any room having a networked playback device. Media content (e.g., songs, podcasts, video sound) can be streamed to playback devices such that each room with a playback device can play back corresponding different media content. In addition, rooms can be grouped together for synchronous playback of the same media content, and/or the same media content can be heard in all rooms synchronously.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Features, aspects, and advantages of the presently disclosed technology may be better understood with regard to the following description, appended claims, and accompanying drawings, as listed below. A person skilled in the relevant art will understand that the features shown in the drawings are for purposes of illustrations, and variations, including different and/or additional features and arrangements thereof, are possible.

[0005] Figure 1A is a front perspective view of a playback device configured in accordance with aspects of the disclosed technology.

[0006] Figure 1B is a front perspective view of the playback device of Figure 2A without a grille.

[0007] Figure 2 is a rear perspective view of a first embodiment of a passive radiator in accordance with aspects of the disclosed technology.

[0008] Figure 3 is a rear perspective view of a second embodiment of a passive radiator in accordance with aspects of the disclosed technology.

[0009] Figure 4A is a perspective view of a back-to-back configuration of two passive radiators of Figure 3 in accordance with aspects of the disclosed technology.

[0010] Figure 4B is a side view of the back-to-back configuration of Figure 4A.

[0011] Figure 5 is an exploded, perspective view of a third embodiment of a passive radiator in accordance with aspects of the disclosed technology.

[0012] Figure 6A is a perspective view of a back-to-back configuration of the passive radiator of Figure 5 and a transducer in accordance with aspects of the disclosed technology.

[0013] Figure 6B is a partially exploded, perspective view of the back-to-back configuration of Figure 6A.

[0014] Figure 7A is a perspective view of a back-to-back configuration of two passive radiators of Figure 5 in accordance with aspects of the disclosed technology.

[0015] Figure 7B is a partially exploded, perspective view of the back-to-back configuration of Figure 7A.

[0016] Figure 8 is a partially exploded, perspective view of a further back-to back configuration of two transducers that may be operated as passive radiators in accordance with aspects of the disclosed technology.

[0017] Figure 9 is a partially exploded, perspective view of a yet further back-to-back configuration of two passive radiators of a fourth embodiment in accordance with aspects of the disclosed technology.

[0018] Figures 10 to 18 are schematic diagrams illustrating arrangements of transducers and passive radiators within a playback device, in accordance with aspects of the disclosed technology.

[0019] The drawings are for the purpose of illustrating example embodiments, but those of ordinary skill in the art will understand that the technology disclosed herein is not limited to the arrangements and/or instrumentality shown in the drawings.

DETAILED DESCRIPTION

I. Overview

[0020] Embodiments described herein relate to passive radiators for use in playback devices. Further embodiments relate to playback devices including one or more passive radiators. The passive radiators as described in these embodiments may enable greater freedom in design of playback devices, for example by allowing more compactness in playback devices, and/or more flexibility in how a desired or targeted response is achieved. The passive radiators may be easy to tune to give the desired response.

[0021] According to some aspects of the invention, there may be provided a passive radiator comprising a frame, a diaphragm attached to the frame by a surround such that the diaphragm

can move relative to the frame, and a suspension system comprising a flat spring that couples the diaphragm and the frame. The properties of the passive radiator, and particularly the use of a flat spring in the passive radiator, may allow for greater variety and precision in the acoustic design process of the passive radiator and/or playback devices in which the passive radiator is incorporated. Such a passive radiator may have the advantage of being compact whilst maintaining stability. Improved stability in a passive radiator may enable improvements in how much excursion is achievable without distortion from the diaphragm for a given radiating surface area, which may be referred to as an effective surface area, an effective radiation area, or a radiation area. In other words, because of the improved stability, a greater excursion may be achievable from a diaphragm having a smaller radiation area. Improved stability in a passive radiator may enable greater radiation areas to be achieved via diaphragms having greater surface areas and/or more passive radiators. The properties may be selected to allow the passive radiator to be tuned to a particular frequency or frequencies.

[0022] The term flat spring is used herein to refer to an element that provides resilience in a direction parallel to a central axis of the diaphragm of the passive radiator. A flat spring may be a spring that achieves stiffness without overlapping turns, loops, or coils. While the term “flat spring” is used herein, other elements providing resilience in this way may also be used. Similarly, flat springs may have different configurations to those described below and need not themselves be comprised of substantially planar and/or substantially flat elements in directions normal to the direction where resilience is provided. For example, a flat spring may include one or more additional features, such as stiffening ribs, or may have different forms, such as a tubular form or a beam form. Examples of flat springs are described in US provisional patent applications 63/377,652 and 63/503,389, which are incorporated by reference in their entirety herein for all purposes.

[0023] A flat spring may comprise one or more arms. Each arm may comprise a strip of material, which may be flat or substantially flat but may also have other cross-sectional shapes. Each arm may be configured to bend to provide a spring-like behavior. A flat spring may have multiple arms and may be configured to connect to multiple points on the frame. A flat spring may be manufactured from any suitable material including spring steel or thermoplastic. Flat springs may be distinguished from conventional spiders used in passive radiators and loudspeakers as they attach at a small number of discrete points, such as two, three or four points, rather than substantially surrounding a portion of the passive radiator.

[0024] The suspension system may comprise at least two flat springs. The at least two flat springs may be provided in the same plane or in different planes. The at least two flat springs may be evenly spaced about a central axis of the diaphragm, such as an axis passing through a center of the diaphragm and normal to the surface of the diaphragm at that point. Evenly distributing the flat springs may provide improved stability. In particular, evenly spaced flat springs may reduce the impact of, or prevent, rocking modes in the diaphragm. The flat springs may provide improved linearity in the response of the diaphragm.

[0025] The at least two flat springs may be symmetrically arranged. The at least two flat springs may be arranged symmetrically in a plane defined by the flat springs. The at least two flat springs may be arranged symmetrically in two or more different planes. The symmetrical arrangement may include reflection about an axis of symmetry of the diaphragm. Symmetrically arranged flat springs may also provide improved stability by reducing the impact of rocking modes. Symmetrically arranging the flat springs may allow a more compact suspension system in which the flat springs are arranged close to the axis of symmetry, whilst maintaining improvements in stability. In other examples, the at least two flat springs may be arranged asymmetrically. For example, the springs may be arranged asymmetrically when evenly spaced about the central axis. The flat springs may have an asymmetrical form, such

that a spacing results in an asymmetry between flat springs. In some examples, the flat springs may have different sizes. The flat springs may be arranged so that the stiffnesses of the flat springs are balanced around the diaphragm, but in these configurations the flat springs may have differing sizes. For example, two flat springs having a first stiffness may balance a single flat spring having a second stiffness that is double the first stiffness. Differing arrangements of flat springs may enable them to be positioned around other components of a playback device, so that the playback device remains compact without impacting operation.

[0026] The passive radiator may comprise at least one mass coupled to the diaphragm. The diaphragm may be coupled to the suspension system via the at least one mass. Alternatively, the diaphragm may be coupled to the mass separately from the suspension system. In some examples, the diaphragm may comprise the at least one mass, such as when the diaphragm and mass are integrally formed.

[0027] The at least one mass may comprise a first mass having a center of mass positioned on a central axis of the diaphragm, and the suspension system may comprise at least two flat springs that couple the first mass to the frame. The at least two flat springs may be spaced apart from the central axis of the diaphragm. The at least two flat springs may extend from an edge of the mass. Providing a mass and more than one flat spring connecting the mass to the frame may provide improved stability and allow for greater compliance in the suspension system. The flat springs and/or the mass may be tailored to provide specific characteristics for improving the stability of the diaphragm.

[0028] The at least one mass may comprise at least a first mass and a second mass. The flat spring may comprise a first flat spring that couples the first mass to the frame and the suspension system may comprise a second flat spring that couples the second mass to the frame. The first flat spring may be aligned with the first mass in a direction of movement of the diaphragm. The second flat spring may be aligned with the second mass in a direction of

movement of the diaphragm. The first mass and the second mass may be positioned on opposite sides of an axis of the diaphragm. Providing multiple masses and corresponding flat springs allows for variations in arrangements of the suspension system. For example, the masses may be arranged to each side of a diaphragm, rather than centralized. These variations may allow for improvements to compactness of the passive radiator and playback devices including the passive radiator. Multiple masses and flat springs may also allow variations in the response of the passive radiator, by tuning the masses and flat springs to a desired response. Multiple masses and flat springs may also allow for improved response for different shapes of diaphragm.

[0029] The at least one mass may comprise a power supply for a playback device in which the passive radiator is to be incorporated. The at least one mass may comprise another functional component of the playback device in which the passive radiator is to be incorporated. Utilizing functional components of a playback device as the mass may allow the internal volume to be used more efficiently. The playback device may therefore be made smaller, additional components may be introduced, or the size of other components may be increased. This may allow for larger transducers or new functionalities for the playback device.

[0030] According to aspects of the invention, there may be provided a playback device comprising the passive radiator as discussed above, with or without the optional features also described. The playback device may comprise a transducer. The transducer may comprise a diaphragm attached to a frame by a surround such that the diaphragm can move relative to the frame. The frame may be a frame shared with the passive radiator. The transducer may comprise a drive unit, which may also be referred to as a motor. The drive unit may comprise a magnetic element and a voice coil. The transducer may also comprise a suspension system. The suspension system may comprise a spider and/or a flat spring that couples the diaphragm and the frame. The transducer and passive radiator may be housed in an enclosure. In some

examples, the drive unit, diaphragm, and suspension system of a transducer may be arranged concentrically or coaxially. Alternatively, at least one of the drive unit or the suspension system may be offset relative to a central axis of the diaphragm. The transducer may comprise a first drive unit and a second drive unit that are positioned at opposite sides of an axis of the diaphragm. The suspension system of the transducer may comprise a first flat spring and a second flat spring that respectively connect the first drive unit and the second drive unit to the frame.

[0031] In the playback device, the passive radiator may be arranged in a back-to-back configuration. The back-to-back configuration may include the passive radiator and the transducer. In examples where the motor, diaphragm, and suspension system of the transducer are arranged concentrically or coaxially, the flat springs and masses of the passive radiator may be positioned around the drive unit. In examples where the transducer has an offset drive unit and/or suspension system, the transducer and the passive radiator may be arranged so that their respective drive units and/or suspension systems do not interfere with one another. The flat springs and drive units may be symmetrically arranged and may be arranged in an alternating manner. The flat springs and drive units may be symmetrically arranged and arranged in the alternating manner about a central axis of one or both diaphragms. Drive units and flat springs may be arranged in an alternating manner such that each drive unit is positioned between two flat springs and each flat spring between two drive units about the central axis. The drive units and flat springs may be positioned around a periphery of their respective diaphragms. The transducer may have two drive units that may be on opposite sides of an axis of symmetry of the diaphragm of the transducer, and the passive radiator may have two flat springs at opposite sides of another axis of symmetry of the diaphragm of the passive radiator. These axes may be perpendicular. Diaphragms of the transducer and passive radiator may be aligned. A central

axis of each may be aligned. In other examples, the central axes may be misaligned. The diaphragms of the transducer and passive radiator may have different shapes.

[0032] Alternatively, the back-to-back configuration may include the passive radiator and a further passive radiator. The further passive radiator, which may be referred to as a second passive radiator, may comprise a second diaphragm and a second suspension system. The further passive radiator may have the same construction or a different construction to the passive radiator. The further passive radiator may include any of the features of the passive radiators referred to above.

[0033] Back-to-back configurations of a passive radiator with a transducer and/or a further passive radiator may be useful to enable the space within a playback device to be used effectively. Due to the compact nature of the passive radiators described herein, back-to-back configurations may occupy less volume. For example, the back-to-back configurations may be able to occupy volumes previously occupied by only a single passive radiator or transducer. Although back-to-back configurations are described above, in other examples, two transducers, two passive radiators, or a passive radiator and a transducer may be arranged in other configurations, such as front-to-front configurations or back-to-front configurations. Other arrangements of passive radiators and/or transducers are also possible, such as where a plurality of transducers or passive radiators are positioned in series along a face of a playback device and/or are oriented in different directions to one another.

[0034] In the playback device, additionally or alternatively, the transducer may be a first transducer, the playback device may comprise a second transducer. The first and second transducers may be arranged in a back-to-back configuration. One or more back-to-back configurations may be provided in an arrangement of transducers and passive radiators. For example, a first back-to-back configuration of a first and second transducer may be combined with a second and possibly a third back-to-back configuration each comprising two passive

radiators. It will be appreciated that other numbers of transducers and passive radiators may be used depending on the requirements for a playback device. A playback device may comprise an odd number of transducers (e.g. 1, 3, 5, 7, 9) or an even number of transducers (e.g. 2, 4, 6, 8, 10). A playback device may comprise an odd number of passive radiators (e.g. 1, 3, 5, 7, 9) or an even number of passive radiators (e.g. 2, 4, 6, 8, 10). The number of passive radiators may be different from the number of transducers. For example, a playback device which can reproduce a large number of audio channels, such as a soundbar, may have more transducers and/or passive radiators than a playback device for reproducing mono and/or stereo audio.

[0035] The playback device may comprise an enclosure in which the transducer and passive radiator are mounted. The transducer and passive radiator may seal the enclosure. The enclosure may include an internal air volume. A suspension system of the passive radiator may be outside the enclosure, and therefore not in the internal air volume. Where a back-to-back configuration of passive radiators or of a transducer and passive radiator is provided, the back-to-back configuration may be mounted across a vent, gap, or through-hole defined by the sealed enclosure, such that the suspension systems are external to the enclosure.

[0036] The playback device may comprise a drive unit coupled to the diaphragm of the passive radiator. The playback device may be operable in a first mode in which the drive unit is powered and a second mode in which the drive unit is unpowered. The playback device may be configured to operate in the first mode when powered by an external power source and in the second mode when powered by an internal power source. This may allow power savings when operating on the internal power source, such as a battery.

[0037] The playback device may comprise one or more passive radiators that can displace a first volume of air and one or more transducers that can displace a second volume of air. The first volume of air may be at least double the second volume of air. The playback device may

consist of the one or more passive radiators and the one or more transducers. This may result in a useful response from the passive radiators.

[0038] One or more passive radiators of the playback device may have a first radiation area and one or more transducers of the playback device may have a second radiation area. The first radiation area may be at least double the second radiation area. A maximum excursion of the passive radiators may be at least as large as that of the transducers. Including passive radiators having double the radiation area of the transducers may result in the passive radiators displacing twice the volume of air as the transducers.

[0039] One or more passive radiators of the playback device may have a first average maximum excursion and one or more transducers of the playback device may have a second average maximum excursion. The first average maximum excursion may be at least double the second average maximum excursion. A radiation area of the passive radiators may be at least as large as that of the transducers. Including passive radiators having double the average maximum excursion of the transducers may result in the passive radiators displacing twice the volume of air as the transducers.

[0040] While some examples described herein may refer to functions performed by given actors such as “users,” “listeners,” and/or other entities, it should be understood that this is for purposes of explanation only. The claims should not be interpreted to require action by any such example actor unless explicitly required by the language of the claims themselves.

[0041] In the Figures, identical reference numbers identify generally similar, and/or identical, elements. To facilitate the discussion of any particular element, the most significant digit or digits of a reference number refers to the Figure in which that element is first introduced. Many of the details, dimensions, angles and other features shown in the Figures are merely illustrative of particular embodiments of the disclosed technology. Accordingly, other embodiments can have other details, dimensions, angles and features without departing

from the spirit or scope of the disclosure. In addition, those of ordinary skill in the art will appreciate that further embodiments of the various disclosed technologies can be practiced without several of the details described below.

II. Example Playback Device

[0042] Figure 1A is a front perspective view of a playback device 110 configured in accordance with aspects of the disclosed technology. Figure 1B is a front perspective view of the playback device 110 without a grille 112b. Referring to Figures 1A and 1B together, the playback device 110 comprises a housing 112 that includes side portions 112a, the grille 112b, and a rear portion (not visible in Figures 1A and 1B). A frame 114 is attached to the housing 112 by a plurality of fasteners 116 (e.g., one or more screws, rivets, clips). The playback device 110 also includes electronics (not shown in Figures 1A and 1B), which are housed within the housing 112. The frame 114 is configured to carry a plurality of transducers 118 (identified individually in Figure 1B as transducers 118a-d) and a plurality of passive radiators (identified individually in Figure 1 as passive radiators 120a and 120b).

[0043] The electronics of the playback device are configured to receive audio content from an audio source and send electrical signals corresponding to the audio content to the transducers 118 for playback.

[0044] The transducers 118 are configured to receive the electrical signals from the electronics, and further configured to convert the received electrical signals into audible sound during playback. For instance, the transducers 118a-c (e.g., tweeters) can be configured to output high frequency sound (e.g., sound waves having a frequency greater than about 2 kHz). The transducer 118d (e.g., a mid-woofer, woofer, midrange speaker) can be configured to output sound at frequencies lower than the transducers 118a-c (e.g., sound waves having a frequency lower than about 2 kHz). In some embodiments, the playback device 110 includes a number of transducers different than those illustrated in Figures 1A and 1B. For example, the

playback device 110 can include fewer than four transducers (e.g., one, two, three). In other embodiments, however, the playback device 110 includes more than four transducers (e.g., six, nine, ten). Moreover, in some embodiments, all or a portion of the transducers 114 are configured to operate as a phased array to desirably adjust (e.g., narrow or widen) a radiation pattern of the transducers 114, thereby altering a user's perception of the sound emitted from the playback device 110.

[0045] The passive radiators, 120a, 120b, which may be referred to as passive transducers, are configured to resonate in response to movement of air within the housing 112. The air in the housing 112 is moved by operation of the transducers 118d. Movement of the transducer 118d causes changes in the air pressure that in turn cause movement of the passive radiators 120a, 120b. The passive radiators 120a, 120b can be tuned to specific frequencies or frequency ranges to enhance the frequency response of the playback device 110.

III. Example passive radiators and transducers

[0046] Passive radiators may be used in playback devices for a variety of reasons. For example, they may reduce the amount of movement required by a transducer for a given output sound pressure level from the playback device as a whole. Reducing movement of a transducer may preserve battery life as well as improving the lifespan of the transducer. Additionally, or alternatively, passive radiators may be used to adjust a frequency response of the playback device, such as amplifying a particular frequency range. In some applications, passive radiators are used to increase a low frequency (bass) response of a playback device.

[0047] Passive radiators have been proposed which comprise single- or double- suspension systems. Single suspension passive radiators include a diaphragm with a single suspension in the form of a continuous, compliant surround that flexibly connects the diaphragm to the frame. Single suspension systems are compact and relatively cheap, but it is difficult to provide sufficient linearity, compliance, and/or stability. Double suspension passive radiators comprise

an additional second suspension. These are larger, more expensive, and not as easily tuned to desired frequency responses but generally have greater linearity, compliance, and/or stability than single-suspension passive radiators.

[0048] According to techniques described herein, a passive radiator may include a frame and a diaphragm that is attached to the frame by a surround. The diaphragm may be attached to the frame by the surround so that it can move relative to the frame. The passive radiator may include a suspension system that comprises a flat spring that couples the diaphragm and the frame. The use of a suspension system comprising a flat spring may provide both compactness and stability. Improved compactness may enable greater design freedom for playback devices. Increased stability may allow greater displacement of air relative to the moving surface area formed by the diaphragm and surround. Flat springs may also be tuned to have a particular stiffness, meaning that the response of the passive radiator may be adjusted as desired for the particular implementation.

[0049] As indicated in relation to Figures 1A and 1B, such a passive radiator may be incorporated into a playback device. The playback device may comprise at least one transducer and the passive radiator. The playback device may comprise a plurality of transducers and/or a plurality of passive radiators. Examples of passive radiators are described below in relation to Figures 2 to 13.

[0050] Figure 2 is a rear perspective view of a first embodiment of a passive radiator 200. The passive radiator 200, along with other passive radiators described herein, may be compact and may have beneficial linearity, compliance, and stability characteristics.

[0051] The passive radiator 200 includes a circular diaphragm 202. The diaphragm is mounted in a frame 204 by a surround 206. The surround 206 allows the diaphragm 202 to move relative to the frame 204 and also seals the diaphragm 202 against the frame 204, preventing air from moving between the diaphragm 202 and the frame 204.

[0052] The frame 204 has a front portion 208, including an opening in which the diaphragm 202 and surround 206 are provided. Four frame connection portions, referred to hereafter as tabs, 210 extend perpendicularly from the front portion 208. Each of the tabs 210 extends from a respective edge of the front portion 208.

[0053] The passive radiator 200 includes a suspension system 212, in addition to the surround 206. The suspension system 212 comprises four flat springs 214. The flat springs 214 couple the diaphragm 202 to the frame 204 via a mass 216. The flat springs 214 are provided in a common plane. Each of the flat springs 214 has a first end 218, which connects to a respective tab 210 of the frame 204, and a second end 220 that connects to the mass 216.

[0054] The mass 216, in the embodiment of Figure 2, comprises a uniform ring. The center of mass of the mass 216 is aligned with a central axis 222 of the diaphragm. The central axis 222 of the diaphragm 202 is an axis passing through a center point of the diaphragm 202 and is an axis along which or about which the diaphragm 202 may move in use. The mass 216 is also therefore arranged so that the central axis of the diaphragm is aligned with a central axis of the mass 216, the central axis of the mass 216 being an axis about which the ring is formed. The mass 216 is in contact with, and therefore coupled to, the diaphragm 202. The mass 216 is held in contact with the diaphragm by the flat springs 214.

[0055] The second end 220 of each flat spring 214 connects to an outer surface 224 of the mass 216. The flat springs 214 are evenly spaced about, i.e. even or equally distributed around, a central axis of the diaphragm 202. As the mass 216 is aligned with the diaphragm 202, the flat springs 214 are also evenly spaced about the mass 216. The flat springs 214 are therefore positioned at 90-degree intervals around the central axis. Because the flat springs 214 connect at their second ends 220 to the mass, they are displaced from the central axis of the diaphragm 202.

[0056] In use, air within an enclosure, such as a sealed enclosure of a playback device, in which the passive radiator 200 is provided may be moved by a transducer. The movement of the air may cause movement of the diaphragm 202, and therefore part of the surround 206. The mass 216 is configured to move back and forth with the diaphragm 202 during such movement. The movement of the mass 216 is constrained by the flat springs 214. The diaphragm 202 and surround 206 together form a moving surface area that oscillates at a resonance frequency, thereby generating sound waves at that frequency. Both the resonance frequency and the amplitude of the sound waves may be dependent on characteristics of the surround 206, the mass 216, the suspension system 212, and the diaphragm 202. Particularly, the stiffness of the flat springs 214 and the surround, as well as the mass of the mass 216 and the diaphragm 202 may influence how the diaphragm 202 moves, and therefore the frequency and amplitudes that are attainable.

[0057] Providing a passive radiator that makes use of at least one flat spring may enable a more compact arrangement of components within a playback device while providing stability for the passive radiator, by supporting the mass and diaphragm in the directions in which they may rotate. Providing such support may mitigate unwanted rotational vibration about axes perpendicular to the central axis 222, sometimes referred to as rocking modes, and may enhance the desirable modes of vibration. Preventing rocking modes may improve the efficiency of the passive radiator. Providing a mass whose center of mass is aligned with that of the diaphragm may also ensure greater stability in the movement of the diaphragm. An annular mass such as mass 216 has such an aligned center of mass, is inexpensive, and can be manufactured from cheap and readily available materials.

[0058] The passive radiator of Figure 2, along with the other examples of passive radiators described herein, may have a higher efficiency for the surface area that is configured to move air than a conventional passive radiator. Specifically, due to the increased stability, the

diaphragm may be able to have a greater excursion than would otherwise be possible. As a result, the movement of air may be higher for a given surface area of the passive radiator. This may allow the design of smaller passive radiators for a desired volume of air moved, which in turn may allow for greater freedom in both the physical design and audio design of playback devices incorporating those passive radiators.

[0059] Figure 3 is a perspective view of a second embodiment of a passive radiator 300. The passive radiator 300 includes a circular diaphragm 302. The diaphragm is mounted in a frame 304 by a surround 306. The surround 306 allows the diaphragm 302 to move relative to the frame 304. The surround 306 seals the diaphragm 302 against the frame 304 preventing air from moving between the diaphragm 302 and the frame 304.

[0060] The frame 304 has a front portion 308, including an opening in which the diaphragm 302 and surround 306 are provided, and first and second tabs 310a, 310b extending perpendicularly from the front portion 308 and rearward, relative to the main direction of radiation of the passive radiator 300. The first and second tabs 310a, 310b are arranged to extend from two opposing edges of the front portion 308 of the frame 304.

[0061] The passive radiator 300 includes a suspension system 312, in addition to the surround 306. The suspension system 312 comprises four flat springs 314. The flat springs 314 couple the diaphragm 302 to the frame 304 via a mass 316. The flat springs 314 are provided in a common plane.

[0062] The flat springs 314 are arranged into a plurality of pairs of flat springs, which in the embodiment shown in Figure 3 comprises a first pair 318a of flat springs 314 and a second pair 318b of flat springs 314. Each of the flat springs 314 has a first end 320, which connects to a tab 310a, 310b of the frame 304, and a second end 322 that connects to the mass 316. The flat springs 314 of the first pair 318a connect at their first ends 320 to the first tab 310a. The flat springs 314 of the second pair 318b connect at their first ends 320 to the second tab 310b.

[0063] The flat springs 314 of the first pair 318a and the flat springs 314 of the second pair 318b are arranged symmetrically on either side of a first line of symmetry 324 of the mass 316 and of the diaphragm 302. The first pair 318a of flat springs 314 are also arranged symmetrically to the second pair 318b of flat springs 314 on either side of a second line of symmetry 326 of the mass 316 and of the diaphragm 302 that is perpendicular to the first line of symmetry 324.

[0064] The mass 316 comprises a uniform ring. The center of mass of the mass 316 is aligned with a central axis 328 of the diaphragm. The central axis of the diaphragm 302 is an axis passing through a center point of the diaphragm 302 and perpendicular to the surface of the diaphragm at this point, it forms an axis along which the diaphragm 302 may move in use. The mass 316 is also therefore arranged so that the central axis of the diaphragm is aligned with a central axis of the mass 316, the central axis of the mass 316 being an axis about which the ring is formed. The mass 316 is in contact with, and therefore coupled to, the diaphragm 302. The mass 316 is held in contact with the diaphragm by the flat springs 314.

[0065] While Figures 2 and 3 illustrate circular diaphragms 202, 302 with circular masses 216, 316, these components are not limited to circular forms. Diaphragms may take any suitable shape. For example, rectangular, oblong, or oval shaped diagrams may be incorporated. Similarly, masses may be any suitable shape. A mass may be oblong, oval, square, rectangular, or another shape. A mass may have a different shape to the diaphragm to which it is coupled. In some examples, a mass may be a uniform or non-uniform ring. Alternatively, the mass may be a solid shape. The mass may be a collection of components that together form the mass. The components may be attached to one another to form a coherent mass.

[0066] As in Figure 2, in use, movement of air within an enclosure, such as a sealed enclosure of a playback device, in which the passive radiator 300 is provided may cause movement of the diaphragm 302 and surround 306 at a resonance frequency, resulting in a sound wave at

that frequency. The symmetrical arrangement of flat springs in the passive radiator 300 provides further benefits in compact arrangements for use in playback devices without compromising the stability of the mass and diaphragm. Specifically, while the flat springs are arranged along, e.g., the 'y' axis of the mass (along the line of symmetry 324), stability is also provided in the 'x' direction (along the line of symmetry 326) due to the symmetrical arrangement. Accordingly, the passive radiator 300 can achieve similar output and performance as the passive radiator 200 with flat springs that connect to only two tabs on the frame rather than four. The arrangement of flat springs in the passive radiator 300 allows for back-to-back configurations of the passive radiator with another passive radiator or transducer with a reduced likelihood of the flat springs interfering with one another. A back-to-back configuration may also be referred to as a back-to-back arrangement.

[0067] An example of a back-to-back configuration 400 is shown in the respective perspective and side views of Figures 4A and 4B. The configuration 400 comprises a first passive radiator 402a and a second passive radiator 402b. The first and second passive radiators 402a, 402b are substantially identical, and so only the first passive radiator 402a is described below. The second passive radiator 402b has the same components as the first passive radiator 402a, and these components are labelled with the same reference numerals in Figure 4 where they are visible, except with a 'b' suffix rather than the 'a' suffix associated with the first passive radiator 402a.

[0068] The first passive radiator 402a includes a diaphragm 404a mounted in a frame 406a by a surround 408a that allows the diaphragm 404a to move relative to the frame 406a and seals the diaphragm 404a against the frame 406a. The frame 406a has a front portion 410a including an opening in which the diaphragm 404a and surround 408a are provided. The frame 406a has four tabs 412a (only two are visible in Figure 4A and only three are visible in Figure 4B) that extend from respective edges of the respective front portions 410a, 410b.

[0069] The first passive radiator 402 also has a suspension system comprising four symmetrically arranged flat springs 418a and a mass (not visible in Figures 4A and 4B). These are arranged in the same way as the suspension system 312 and mass 316 are arranged in the passive radiator 300 of Figure 3.

[0070] The first and second passive radiators 402a, 402b are arranged in a back-to-back configuration, such that the four tabs 412a of the frame 406a of the first passive radiator 402a are in contact with the four tabs 412b of the frame 406b of the second passive radiator 402b. In this way the suspension systems 414a, 414b and the masses of the first and second passive radiators 402a, 402b are arranged between the diaphragms 404a, 404b and front portions 410a, 410b of the passive radiators 402a, 402b, and the diaphragms 404a, 404b have their ‘outer’ faces, i.e. the face that is unattached to a mass, facing outwardly. In other words, the first and second passive radiators 402a, 402b are arranged in the back-to-back configuration so that sound is radiated in opposite directions by the radiators 402a, 402b.

[0071] To avoid mechanical interference or impacts between the flat springs 418a of the first passive radiator 402a and the flat springs 418b of the second passive radiator 402b, in this embodiment the first passive radiator 402a is rotated by 90 degrees relative to the second passive radiator 402b, so that the flat springs 418a, 418b of each radiator 402a, 402b are not aligned and so do not vibrate in the same space. The masses of each radiator 402a, 402b are also arranged so that they do not collide, for example one may have a smaller diameter than the other so that they can be arranged in a nested configuration. In other examples, the passive radiators may be rotated by differing amounts relative to one another to avoid collisions between the flat springs.

[0072] Back-to-back configurations such as the back-to-back configuration 400 of Figures 4A and 4B may provide an improved response while occupying a lower volume than two

separate passive radiators. Back-to-back configurations may also enable force cancelling between two passive radiators.

[0073] Figure 5 illustrates a third embodiment of a passive radiator 500, shown in an exploded view. The passive radiator 500 includes a circular diaphragm 502. The diaphragm 502 connects to a first frame portion 504 via a surround 506. The surround 506 allows the diaphragm 502 to move relative to the first frame portion 504. The surround 506 seals the diaphragm 502 against the first frame portion 504 preventing air from moving between the diaphragm 502 and the first frame portion 504. Two further seals 540 are also provided to seal the diaphragm 502 against the first frame portion 504.

[0074] The first frame portion 504 is part of a frame. The first frame portion 504 includes connection elements 530 to connect to at least a second frame portion (not shown in Figure 5) to form the frame. The connection elements 530 extend from a front portion 532 of the first frame portion 504 in which the diaphragm 502 and surround 506 are received. The second frame portion may be part of the first frame portion 504, a frame portion of another passive radiator, a frame portion of a transducer, or a frame portion or portion of an enclosure of a playback device more generally.

[0075] The passive radiator 500 includes a suspension system 508, in addition to the surround 506. The suspension system 508 comprises two flat springs 510. Each flat spring 510 couples the diaphragm 502 to the second frame portion via a respective ring-shaped mass 512 and a support 518. Each flat spring 510 is connected to the first frame portion 504 at a first end by a connector 514, and to the mass 512 at a second end by a lower mass holder 516, arranged to couple the flat spring 510 to its respective mass 512. The flat spring 510 is shaped to follow a circumference of a circle having a diameter that is substantially the same as a diameter of the ring-shaped mass 512 for that flat spring 510.

[0076] The masses 512 are coupled to the diaphragm 502 via the support 518. The support 518 comprises an upper mass holder 520 for each mass 512 and a central portion 522. The central portion 522 is coupled to the diaphragm 502 and extends between the upper mass holders 520 along a diameter 524 of the diaphragm 502. Each mass 512 is sandwiched between the upper and lower mass holders 520, 516. The upper and lower mass holders 520, 516 and the masses 512 are positioned on opposite sides of the diaphragm 502 along the diameter 524, and are positioned to be substantially outside the perimeter of the diaphragm 502.

[0077] In use, movement of the diaphragm 502 due to movement of air within a sealed enclosure to which the passive radiator 500 is mounted is influenced by, and constrained by, the surround 506 and the flat springs 510 in combination with the masses 512. The use of two masses 512 and their distribution to each side of the diaphragm 500 provides benefits in compactness by allowing for reduced mass dimensions relative to a single mass, as well as different arrangements within a playback device. For example, the passive radiator 500 of Figure 5 may be arranged in a back-to-back configuration with a transducer or another passive radiator.

[0078] Figures 6A and 6B show a back-to-back configuration 600 of a passive radiator 602 and a transducer 604. Figure 6A shows a perspective view of the back-to-back arrangement 600, while Figure 6B shows a partially exploded perspective view to demonstrate the orientation and positioning of the passive radiator 602 relative to the transducer 604.

[0079] The passive radiator 602 has the same elements as the passive radiator 500 of Figure 5. These elements are labelled with the same reference numerals as those in Figure 5. The flat springs 510 of the passive radiator are connected to a second frame portion 608 of the transducer 604. The first frame portion 504 and the second frame portion 608 together form a frame 632. The connecting elements 530 of the first frame portion 504 connect to

corresponding connecting elements 630 that extend from a front portion 632 of the second frame portion 608.

[0080] The transducer 604 has a circular diaphragm 606. The diaphragm 606 is mounted in the second frame portion 608 via a surround 610. A support 612 extends across the diaphragm 606. The support 612 couples the diaphragm 606 to two voice coils 614. The support 612 connects to each coil 614 via a coil holder 616. The coil holders 616 and coils 614 are provided at opposing ends of a central portion 618 of the support 612. The central portion 618 is connected to the diaphragm 606 and is fixed to the diaphragm 606 along a diameter 620 of the diaphragm 606. The coil holders 616 and coils 614 are therefore positioned to opposite ends of the diameter 620 of the diaphragm 606 along which the support 612 is positioned. A magnetic element 622 is provided for each coil 614. Each magnetic element 622 is dimensioned to pass through the center of its respective coil 614. Each coil 614 and its respective magnetic element 622 may together form a drive unit for driving the diaphragm 606 according to an audio input signal by passing a current through the coils 614. Movement of the coils 614 is transferred to the diaphragm 606 via the coil holders 616 and support 612. The transducer 604 may take the form of a transducer as described in the international patent application PCT/NL2020/050685, which is incorporated by reference in its entirety herein for all purposes.

[0081] In use, driving the diaphragm 606 of the transducer 604 by passing a current through the coils 614 moves air within the back-to-back arrangement. The movement of the air may cause movement of the diaphragm 502 of the passive radiator 602 to produce sound waves, particularly at frequencies close to the resonance frequency or frequencies of the passive radiator 602. The diaphragm 502 of the passive radiator 602 may move in the same direction as the diaphragm 606 of the transducer 604.

[0082] The masses 512 of the passive radiator 602 are arranged at either end of a diameter 524 of the diaphragm 502 of the passive radiator 602. The coils 614 of the transducer 604 are

arranged to either end of a diameter 620 of the diaphragm 606 of the transducer 604. In the back-to-back configuration 600, the passive radiator 602 and transducer 604 are arranged so that the diameter 526 and the diameter 620 are perpendicular. Such an arrangement enables compactness without interference between the operation of the transducer and of the passive radiator.

[0083] Further improvements in compactness may be achieved using such a back-to-back configuration by designing the passive radiator 602 and transducer 604 to have their maximum excursion occur at different frequencies or across different frequency ranges. At a first frequency or set of frequencies, the transducer 604 may be designed to have a maximum excursion, while the passive radiator 602 may be designed to have a lower excursion at this frequency or frequencies. At a second frequency or set of frequencies, passive radiator 602 may be designed to have a maximum excursion, while the transducer 604 may be designed to have a lower excursion at this frequency or frequencies. The back-to-back configuration may be made more compact in these circumstances because the excursion ranges of the transducer 604 and passive radiator 602 can overlap without collisions between the central portions 618, 522 due to the differing maximum excursions.

[0084] Figures 7A and 7B show a back-to-back configuration 700 of a first passive radiator 702a and a second passive radiator 702b. Figure 7A shows an perspective view of the back-to-back configuration 700, while Figure 7B shows a partially exploded view of the configuration 700 in which one of the passive radiators 702a is shown exploded and the other of the passive radiators 702b is shown unexploded, to demonstrate the relative orientation and positioning of the passive radiators 702a, 702b.

[0085] The passive radiators 702a, 702b have the same elements as the passive radiator 500 of Figure 5. These elements are labelled with the same reference numerals as those in Figure 5, using the suffixes 'a' and 'b' to distinguish to which passive radiator 702a, 702b they belong.

The connecting elements 530a, 530b of the frame portions 504a, 504b connect to form the frame 732. The flat springs 510a of the first passive radiator 702a are connected via their connectors 510a to the frame portion 504b of the second passive radiator 702b, and the flat springs 510b of the second passive radiator 702b are connected via their connectors 510b to the frame portion 504a of the first passive radiator 702a.

[0086] The masses 512a of the first passive radiator 702a are arranged to either end of a diameter 524a of the diaphragm 502a, and the masses 512b of the second passive radiator 702b are arranged to either end of a diameter 526b of the diaphragm 502b. In the back-to-back configuration 700, the first and second passive radiators 702a, 702b are arranged so that the diameters 526a, 526b are perpendicular. This arrangement enables compactness of arrangements of passive radiators.

[0087] Figure 8 shows a further back-to-back arrangement 800. The back-to-back arrangement 800 includes a first transducer 802a and a second transducer 802b. The first and second transducers 802a and 802b are substantially identical, and so only the first transducer 802a is described below. The second transducer 802b has the same components as the first transducer 802a, and they are labelled with the same reference numerals in Figure 8, except with a 'b' suffix rather than the 'a' suffix associated with the first transducer 802a.

[0088] The first transducer 802a, like the transducer 604 of Figures 6A and 6B, includes a circular diaphragm 806a mounted in a frame portion 808a via a surround 810a. The frame portion 808a is part of a frame that also includes a frame portion 808b of the second transducer 802b. The frame portion 808a of the first transducer 802a includes connecting elements 830a that extend from a front portion 832 of the frame portion 808a. The connecting elements 830a connect to corresponding connecting elements 830b of the frame portion 808b of the second transducer 802b to form the frame.

[0089] A support 812a extends across the diaphragm 806a. The support 812a couples the diaphragm 806a to two voice coils 814a. The support 812a connects to each coil 814a via an upper coil holder 816a. The upper coil holders 816a and coils 814a are provided at opposing ends of a central portion 818a of the support 812a. The central portion 818a is connected to the diaphragm 806a and is fixed to the diaphragm 806a along a diameter 820a of the diaphragm 806a. The upper coil holders 816a and coils 814a are therefore positioned to opposite ends of the diameter 820a of the diaphragm 806a along which the support 812a is positioned. A magnetic element 822a is provided for each coil 814a. Each magnetic element 822a is dimensioned to pass through the center of its respective coil 814a. Each coil 814a and its respective magnetic element 822a may together form a drive unit for driving the diaphragm 806a according to an audio input signal by passing a current through the coils 814a. Movement of the coils 814a is transferred to the diaphragm 806a via the upper coil holders 816a and support 812a.

[0090] In contrast to the transducer 604 of Figures 6A and 6B, the first transducer 802a also includes a suspension system 824a in addition to the surround 810a. The suspension system 824a comprises two flat springs 826a. Each flat spring 826a is associated with a respective coil 814a. Each flat spring 826a couples the diaphragm 806a to the second frame portion 808b of the second transducer 802b via the voice coil 814a and the support 812a. Each flat spring 826a is connected to the frame portion 808b of the second transducer 802b at a first end by a connector 828a, and to the voice coil 814a at a second end by a lower coil holder 834a, arranged to couple the flat spring 826a to its respective voice coil 814a. The flat spring 826a is shaped to follow a circumference of a circle having a diameter that is substantially the same as a diameter of the voice coil 814a for that flat spring 826a. Each voice coil 814a is therefore sandwiched between the upper and lower coil holders 816a, 834a.

[0091] The first transducer 802a may be operated as a passive radiator. The voice coils 814a are arranged and dimensioned to function as masses for use in a passive radiator, such as the masses 512 in the passive radiator 500 of Figure 5, when the drive unit is unpowered. The flat springs 826a also perform the same function as the flat springs 510 in the passive radiator 500 of Figure 5. The second transducer 802b may also be operated as a passive radiator in the same way. Depending on a desired effect, one or both of the first and second transducers 802a, 802b may be operated as passive radiators.

[0092] In an example, a playback device incorporating the back-to-back configuration 800 of Figure 8 may be operable in a first mode, in which both the first and second transducers 802a, 802b are actively operated, and therefore function as transducers to generate sound in response to an audio signal. The playback device may also be operable in a second mode, in which the first transducer 802a is actively operated and functions as a transducer while the second transducer 802b is not actively operated and therefore functions as a passive radiator. In some examples, the playback device may also be operable in a third mode, in which both the first and second transducers 802a, 802b are not actively operated and so function as passive radiators. In such examples, the playback device may include a further transducer.

[0093] The mode in which a playback device including the arrangement 800 is operated may be selected by a user. For example, a user may select one of the modes directly by interacting with a user interface element, such as a button on the playback device, or by selecting an option in a control application. Alternatively, or additionally, a selection by the user may cause a particular mode to be implemented indirectly. For example, if the user requests a volume level above a threshold or a particular frequency response, the first mode may be implemented. A particular mode may also be implemented based on the audio being played, for example based on frequency components or genre of the audio.

[0094] Additionally, or alternatively, a mode in which the arrangement 800 is operated is based on how a playback device including the arrangement 800 is powered. The first mode may be used when the playback device is powered by an external power source, such as mains power. The second or third modes may be used when the playback device is powered by an internal power source, such as a battery pack. Alternatively, the use of a particular mode may be linked to a mechanism for supplying power. For example, the first mode may be used when a playback device is mounted on a dock configured to supply power from an external power source, and the second or third mode may be implemented when the playback device is removed from the dock.

[0095] Further details in relation to such back-to-back configurations such as shown in Figure 8 may be found in international patent application PCT/NL2021/050308, which is incorporated by reference in its entirety herein for all purposes. The principles may be applied to similar back-to-back transducer configurations, including those in international patent application PCT/EP2018/079509, which is also incorporated by reference in its entirety herein for all purposes.

[0096] Figure 9 shows a back-to-back arrangement 900 of a first passive radiator 902a and a second passive radiator 902b. The first and second passive radiators 902a and 902b are substantially identical, and so only the first passive radiator 902a is described below. The second passive radiator 902b has the same components as the first passive radiator 902a, and they are labelled with the same reference numerals in Figure 9, except with a 'b' suffix rather than the 'a' suffix associated with the first passive radiator 902a.

[0097] The first passive radiator 902a has a circular diaphragm 904a connected to a frame portion 906a by a surround 908a. The surround 908a allows the diaphragm 904a to move relative to the frame portion 906a and seals the diaphragm 904a against the frame portion 906a. The frame portion 906a is part of a frame that also includes a frame portion 906b of the second

passive radiator 902b. The frame portion 906a includes connection elements 930a that extend from a front portion 932a to connect to corresponding connection elements 930b of the frame portion 906b to form the frame.

[0098] The first passive radiator 902a includes a suspension system 910a, in addition to the surround 906a. The suspension system 910a comprises two flat springs 912a. Each flat spring 912a couples the diaphragm 904a to the frame portion 906b of the second passive radiator 902a via a support 918a. Each flat spring 912a is connected to the frame portion 906b of the second passive radiator 902a at a first end by a connector 914a, and to the support 918a at a second end by a lower coupling 916a.

[0099] The support 918a comprises an upper coupling 920a and a central portion 922a. The central portion 922a is connected to the diaphragm 902a and extends between the upper couplings 902a along a diameter 922a of the diaphragm 902a.

[0100] A mass 924a is connected to the diaphragm 904a. The mass 924a comprises a power source for supplying power to one or more elements of a playback device in which the passive radiator 902a is included. For example, the power sources may supply power to one or more transducers of the playback device. The power source may be a battery or a cell. Using power sources for other parts of the playback device as the mass for the passive radiators may allow more compactness and reduced parts count in playback devices incorporating passive radiators.

[0101] While the passive radiators 902a, 902b are here shown in a back-to-back configuration, in some embodiments, only one passive radiator 902a, 902b may be provided. Although the embodiment of Figure 9 uses a power supply as a mass, in some embodiments other functional components of a playback device may be used as the mass.

[0102] Figures 10 to 18 show schematic diagrams of arrangements of transducers and passive radiators within a playback device. The diagrams of Figures 10 to 18 represent only some arrangements of the possible arrangements of playback devices including the passive radiators

described herein and one or more transducers. Other arrangements may include more or fewer passive radiators and/or more or fewer transducers. Furthermore, for ease of illustration, the figures illustrate the playback devices schematically and in two dimensions. The arrangements of passive radiators and transducers is not limited as such, and so they may be arranged in different planes or at different positions around the playback device as desired.

[0103] Passive radiators may be useful to improve a low-frequency response of a playback device. To achieve a suitable low-frequency response from the passive radiators, it may be desirable to move or displace a volume of air with the passive radiators of the playback device that is double the volume of air displaced by the transducers of the playback device. Displacement of air may be influenced by a moving surface area of a passive radiator or transducer, which may be referred to as a radiation area, and by a maximum excursion of the passive radiator or transducer. Accordingly, a doubling in the volume of air displaced may be achieved by having one or more passive radiators with at least double the radiation area of one or more transducers, for the same maximum excursion, or by having passive radiators with double the maximum excursion for the same surface area. Combinations of differing surface areas and excursions may also achieve a doubling in the air displaced.

[0104] Figure 10 illustrates an example of a first playback device 1000 including at least one passive radiator 1014 and at least one transducer 1004. The first playback device 1000 has four passive radiators 1014 and two transducers 1004. The passive radiators 1014 move at least double the volume of air than the transducers 1004 because they have a radiation area that is at least double that of the transducers 1004 and the same excursion as transducers 1004. This is because their diaphragms are the same size as those of the transducers but there are double the number of passive radiators. In other examples designed to the above principles, it is not necessary to have two transducers and four passive radiators, because any number of

transducers and passive radiators may be provided so long as the passive radiators together move double the volume of air as the transducers, as will be shown in later figures.

[0105] In Figure 10, the two transducers 1004 are provided in a central back-to-back transducer configuration 1002. The transducers 1004 are depicted with their respective diaphragms 1006 and drive units 1008. The drive units 1008 are coaxial with the diaphragms 1006 in this example. Two of the passive radiators 1014 are provided in a left back-to-back transducer configuration 1010 and two of the passive radiators 1014 are provided in a right back-to-back transducer configuration 1012. The left and right configurations 1010, 1012 are provided to each side of the central back-to-back transducer configuration 1002. The passive radiators 1014 are depicted with their diaphragms 1016 and suspension systems 1024. Frames of the transducers and passive radiators are connected to allow air flow between the central transducer configuration 1002 and the left and right transducer configurations 1004, 1006. Arranging the transducers 1006 as in Figure 10 may achieve some force balancing across the playback device 1000. In other examples, the transducers and the back-to-back configurations may be distributed or arranged in any suitable combination.

[0106] Examples of how air may flow from the transducers to the passive radiators are schematically depicted using arrows 1020. The transducers and passive radiators are enclosed in a sealed, air-tight housing 1022 of the playback device 1000, schematically represented in Figure 10 using a solid line. Air moved by the diaphragms 1006 of the transducers 1004 within the sealed enclosure 1022 passes outwardly from between the transducers 1004 and into the volume between the passive radiators 1014, this changes the pressure and that part of the housing 1022 and moves the diaphragms 1016 of the passive radiators 1014.

[0107] Back-to-back configurations referred to in Figures 10 to 18 may be arranged as shown in the examples of Figure 4A, or any of Figures 6A to 9 as appropriate. Alternatively, the passive radiators and/or transducers may be arranged in other back-to-back configurations,

such as any configuration in which rear sides of two passive radiators or transducers face one another, where the rear side of a passive radiator or transducer may be a side at which the suspension system is provided. Alternatively, passive radiators and/or transducers may be arranged in front-to-back or front-to-front configurations such that a front side of a passive radiator or transducer faces either a front side or a rear side of another passive radiator or transducer. Although the transducers in the examples of Figures 10 to 18 are illustrated as having a motor that is centrally aligned with a central axis of a diaphragm, they may have any form, including, for example, displaced motors relative to the central axis of a diaphragm as described in relation to Figures 6A and 6B and 8.

[0108] Figure 11 illustrates a second playback device 1100, in which there are provided a left back-to-back transducer configuration 1102 and a right back-to-back transducer configuration 1104 that each include a transducer 1106 and a passive radiator 1108. Between these transducer configurations 1102, 1104 is provided a central back-to-back transducer configuration 1110 including back-to-back passive radiators 1108. In this transducer configuration, as indicated schematically by arrows 1114, the transducers 1106 may cause air movement in the direction of movement of their diaphragm 1116 by drive units 1118 that moves the diaphragms 1120 of the passive radiators 1108 in their own left and right back-to-back transducer configurations 1102, 1104, as well as moving air laterally in the plane of the diaphragm to move the passive radiators 1108 of the central transducer configuration 1110 therebetween, as indicated schematically by arrows 1122.

[0109] Figure 12 illustrates a third playback device 1200. The third playback device 1200 has a similar arrangement of two transducers 1202 and passive radiators 1204 provided in a sealed enclosure 1216 as the first playback device 1000, in that it has a central back-to-back configuration 1206 of transducers and left and right back-to-back configurations 1208, 1210 of passive radiators. The third playback device 1200 differs from the first playback device 1000

in that the passive radiators 1204 together have a substantially similar radiation area to the transducers. In this example, the radiation area of one transducer is similar to the radiation area of two of the passive radiators, but the average maximum excursion of the passive radiators is double the average maximum excursion of the transducers. This is achieved by each of the passive radiators having a maximum excursion that is double that of a maximum excursion of a transducer. As a result, the diaphragms 1212 of each passive radiator 1206 may be smaller and therefore occupy less surface area in the playback device 1200. The suspension systems 1214 of the passive radiators 1206 are depicted as being larger in Figure 12 than in other figures, and accordingly the suspension systems may be configured to occupy more volume within the enclosure 1216 to achieve the required excursion and the stiffness attributes for said excursion. In other examples, the properties of the suspension system may be varied to maintain a similar volume but to increase the excursion. For example, properties of the one or more flat springs of the suspension system may be varied or the number of flat springs and their arrangement within the suspension system may be varied. Examples of how air may flow from the transducers to the passive radiators are schematically depicted using arrows 1218.

[0110] The radiation area and/or excursion of the passive radiators is variable and may allow more freedom in the design of the playback device. This is because the properties of the passive radiators can be configured to suit the desired orientations and positionings, and available surface area and volume of the playback device. Furthermore, improvements in stability of passive radiators due to the suspension systems described herein may enable variation in the size of the transducers. For example, because of an improved low-frequency response, smaller transducers may be utilized or transducers with a smaller frequency range. The design freedom is therefore improved even more.

[0111] Figure 13 shows a fourth playback device 1300. The fourth playback device 1300 has two transducers 1302 and two passive radiators 1304. The transducers 1302 are arranged in a

back-to-back configuration 1306, and the passive radiators 1304 are also arranged in a back-to-back configuration 1308. The passive radiators 1304 and transducers 1302 are provided in a sealed enclosure 1310. In this example, each passive radiator 1304 has a radiation area that is at least double the radiation area of each transducer 1302, such that the total volume of air that can be displaced by the passive radiators 1304 is double that of the transducers 1302. Examples of how air may flow from the transducers to the passive radiators are schematically depicted using arrows 1312.

[0112] Figures 10 to 13 illustrate how the parameters of the passive radiators and transducers may be varied to achieve a desirable low-frequency response from each playback device, as well as demonstrating how such considerations may allow for variation in the size of passive radiators and playback devices. Figures 14 to 18 provide further arrangements of playback devices to demonstrate how different enclosures and arrangements may be used to improve design freedom and/or other features of playback devices such as heat dissipation.

[0113] Figure 14 shows a fifth playback device 1400. The fifth playback device 1400 has two transducers 1402 arranged in a back-to-back configuration 1406. The fifth playback device 1400 also has four passive radiators 1404. The passive radiators 1404 are provided in pairs that face each other across two respective vents or through-holes 1410. Accordingly, air within the sealed enclosure 1408 may be moved by the transducers 1402 according to arrows 1414 and may cause resonance in the diaphragms 1412 of the passive radiators 1404. The diaphragms 1412 may cause audio output from the vents 1410 according to the arrows 1416. Such a design may enable more compactness in how the passive radiators and transducers are arranged, as the passive radiators do not occupy area on the outside of the playback device.

[0114] Figure 15 shows a sixth playback device 1500. The sixth playback device 1500 is similar to the fifth playback device 1400 as it includes two transducers 1502 in a back-to-back configuration 1506 and four passive radiators 1504 arranged in two pairs across respective

through holes 1510. However, in the sixth playback device 1500 the passive radiators 1504 are provided in back-to-back configurations 1512, 1514 such that their suspension systems 1516 are outside of the sealed enclosure 1520 and positioned within the through-holes 1510. Such a removal of the suspension system 1516 from the internal volume 1518 of the playback device 1500 may enable the internal volume 1518 to be occupied by other components and/or to be made smaller. Moreover, the shape and configuration of the playback device 1500 may be varied because it no longer needs to accommodate the suspension systems 1516 therein. Providing the suspension system of one or more passive radiators externally to the playback device's sealed enclosure or internal volume may improve heat dissipation without affecting operation or performance of the passive radiators. Air within the sealed enclosure 1520 may be moved by the transducers 1506 according to arrows 1522 and may cause resonance in diaphragms 1524 of the passive radiators 1504. The diaphragms 1524 may cause audio output from the vents 1510 according to the arrows 1526.

[0115] Figure 16 shows a seventh playback device 1600. The seventh playback device 1600 has a sealed enclosure 1606 through which a through-hole 1602 extends. Although shown centrally within the device 1600 in Figure 16, in other examples the through-hole may be positioned at any suitable position within or through the device. In the seventh playback device 1600, two transducers 1604 are provided on either side of the through-hole 1602, such that respective diaphragms 1608 of the transducers 1604 face one another across the through-hole 1602. Motors 1610 of the transducers 1604 are provided within the sealed enclosure 1606. The playback device 1600 also includes four passive radiators 1612 arranged around the sealed enclosure 1606 and configured in two back-to-back arrangements 1614. The passive radiators 1612 may have a form as described in any of the embodiments herein. Air may be moved within the sealed enclosure 1606 by operation of the transducers 1604 so as to resonate the passive radiators 1612, as indicated by arrows 1616.

[0116] Figure 17 shows an eighth playback device 1700. The eighth playback device 1700 has a sealed enclosure 1706 through which a through-hole 1702 extends. In the eighth playback device 1700, two transducers 1704 are arranged in a back-to-back configuration 1708 across the through-hole 1702. Accordingly, motors 1710 of the transducers 1704 are positioned between two diaphragms 1712 and within the through-hole 1702. This results in the motors 1710 being exposed to free air, external to the sealed enclosure 1706, which may result in improved cooling. In other embodiments, a passive radiator and a transducer may be arranged in such a back-to-back configuration across a through-hole, using an arrangement such as that shown in Figures 6A and 6B. The eighth playback device 1700 also includes four passive radiators 1714 arranged around the sealed enclosure 1706 and configured in two back-to-back arrangements 1716. The passive radiators 1714 may have a form as described in any of the embodiments herein. Air may be moved within the sealed enclosure 1706 by operation of the transducers 1704, and such movement of air may result in operation of the passive radiators 1714. Examples of air movement are indicated by arrows 1718.

[0117] Figure 18 shows a ninth playback device 1800. The ninth playback device 1800 has a similar set of features to the first playback device 1000, having two transducers 1804, each having a diaphragm 1806 and motor 1808 each, and four passive radiators 1814, each having a diaphragm 1816 and a suspension system 1824, that are mounted in a sealed enclosure 1822 having an internal volume 1818. The ninth playback device 1800 differs from the first playback device 100 by the arrangement of the transducers 1804 and passive radiators 1814 being arranged such that their respective motors 1808 and suspension systems 1824 are positioned outside of the sealed enclosure 1822. Accordingly, the transducers 1804 and passive radiators 1814 may be considered to be ‘facing’ into the sealed enclosure. Such an arrangement may improve heat dissipation. Air within the sealed enclosure 1822 may flow according to the

arrows 1820. The lack of motor or suspension systems within the internal volume 1818 may allow for smoother air flow around the enclosure 1822.

[0118] While Figures 10 to 18 show playback devices having transducers and passive radiators that are arranged in pairs or specific configurations, in other examples, any number of transducers may be combined with any number of passive radiators in any suitable arrangement. For example, a single transducer and a single passive radiator may be provided in a playback device. In other examples, two transducers may be provided with one, two, three, four, five, or more passive radiators. Example playback devices may include more transducers than passive radiators, more passive radiators than transducers, or the same number of passive radiators and transducers. Passive radiators and transducers may be placed on different faces of the playback device, and may be provided either with their motors or suspension systems inside or outside the playback devices as desired.

[0119] The combination of passive radiators and/or transducers in back-to-back configurations as shown in Figures 6A to 9, and the combinations of back-to-back configurations in arrangements such as in Figures 10 to 17, enables a multi-membrane, single frame architecture for use in playback devices that has a greater packing density than other multi-membrane systems. This is because the membranes of the passive radiators and/or transducers can move in a shared space. Even without arranging the passive radiators and transducers in back-to-back configurations, arrangements of the passive radiators described herein with transducers in playback devices may provide packing improvements or enable greater sharing of space with other componentry within an enclosure. Such arrangements may be the front-to-front configurations as shown in Figures 14, 16, and 18, front-to-back configurations, or other arrangements of passive radiators and transducers, such as individual passive radiators or transducers or differing orientations. The passive radiators described herein lend themselves to achieving improved use of space in any playback device.

[0120] Although the embodiments of passive radiators described above include distinct masses as part of a passive radiator, in some embodiments the diaphragm of a passive radiator may have sufficient mass so that the passive radiator does not require a separate mass. For example, the diaphragm may be formed from a different material, such as glass or metal, and/or may incorporate one or more functional components that add mass. Although circular diaphragms have been discussed in the embodiments above, the skilled persons will appreciate that the same principles can be applied to diaphragms having shapes other than a circle.

[0121] References herein to “embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one example embodiment of an invention. The appearances of this phrase in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. As such, the embodiments described herein, explicitly and implicitly understood by one skilled in the art, can be combined with other embodiments.

[0122] Examples are set out in the following clauses:

[0123] Clause 1. A passive radiator, comprising: a frame; a diaphragm attached to the frame by a surround such that the diaphragm can move relative to the frame; and a suspension system comprising at least one flat spring that couples the diaphragm and the frame.

[0124] Clause 2. The passive radiator of clause 1, wherein the suspension system comprises at least two flat springs that are evenly spaced about a central axis of the diaphragm.

[0125] Clause 3. The passive radiator of clause 1, wherein the suspension system comprises at least two flat springs that are symmetrically arranged.

[0126] Clause 4. The passive radiator of clause 1, comprising at least one mass coupled to the diaphragm.

[0127] Clause 5. The passive radiator of clause 4, wherein the diaphragm is coupled to the suspension system via the at least one mass.

[0128] Clause 6. The passive radiator of clause 5, wherein the at least one mass comprises a first mass having a center of mass positioned on a central axis of the diaphragm, and wherein the suspension system comprises at least two flat springs that couple the first mass to the frame.

[0129] Clause 7. The passive radiator of clause 5, wherein the at least one mass comprises at least a first mass and a second mass, wherein the suspension system comprises a first flat spring that couples the first mass to the frame and a second flat spring that couples the second mass to the frame.

[0130] Clause 8. The passive radiator of clause 7, wherein at least the first flat spring is aligned with the first mass in a direction of movement of the diaphragm.

[0131] Clause 9. The passive radiator of clause 7, wherein the first mass and the second mass are positioned on opposite sides of an axis of the diaphragm.

[0132] Clause 10. The passive radiator of clause 9, comprising a support that couples (i) the first mass to the second mass and (ii) the first mass and the second mass to the diaphragm.

[0133] Clause 11. The passive radiator of clause 10, wherein the support is coupled to the diaphragm along the axis.

[0134] Clause 12. The passive radiator of clause 4, wherein the at least one mass comprises a power supply for a playback device.

[0135] Clause 13. The passive radiator of clause 1, wherein the flat spring comprises a first flat spring and wherein the suspension system comprises a second flat spring that couples the diaphragm and the frame, wherein the first flat spring and the second flat spring are positioned on opposite sides of an axis of the diaphragm, and wherein the passive radiator

comprises a support that couples (i) the first flat spring to the second flat spring and (ii) the first flat spring and the second flat spring to the diaphragm.

[0136] Clause 14. A playback device comprising a passive radiator, the passive radiator comprising: a frame; a diaphragm attached to the frame by a surround such that the diaphragm can move relative to the frame; and a suspension system comprising at least one flat spring that couples the diaphragm and the frame.

[0137] Clause 15. The playback device of clause 14, comprising a drive unit coupled to the diaphragm, and wherein the playback device is operable in a first mode in which the drive unit is powered and a second mode in which the drive unit is unpowered.

[0138] Clause 16. The playback device of clause 15, wherein the playback device is configured to operate in the first mode when powered by an external power source and is configured to operate in the second mode when powered by an internal power source.

[0139] Clause 17. The playback device of clause 14, wherein the suspension system comprises at least two flat springs, wherein the two flat springs are at least one of: evenly spaced about a central axis of the diaphragm; or symmetrically arranged.

[0140] Clause 18. The playback device of clause 14, comprising at least one mass coupled to the diaphragm, and wherein the diaphragm is coupled to the suspension system via the mass.

[0141] Clause 19. The playback device of clause 18, wherein the at least one mass comprises a first mass having a center of mass positioned on a central axis of the diaphragm, and wherein the suspension system comprises at least two flat springs that couple the first mass to the frame.

[0142] Clause 20. The playback device of clause 18, wherein the at least one mass comprises at least a first mass and a second mass, wherein the suspension system comprises a first flat spring that couples the first mass to the frame and a second flat spring that couples the second mass to the frame.

[0143] Clause 21. A playback device comprising at least one transducer; and at least one passive radiator, the at least one passive radiator comprising: a frame; a diaphragm attached to the frame by a surround such that the diaphragm can move relative to the frame; and a suspension system comprising at least one flat spring that couples the diaphragm and the frame.

[0144] Clause 22. The playback device of clause 21, wherein the at least one transducer and the at least one passive radiator are arranged in a back-to-back configuration.

[0145] Clause 23. The playback device of clause 22, wherein the at least one flat spring is offset relative to a central axis of the diaphragm.

[0146] Clause 24. The playback device of clause 23, wherein the at least one transducer comprises a further diaphragm and a motor that is coaxially coupled to the further diaphragm.

[0147] Clause 25. The playback device of clause 23, wherein the at least one transducer comprises a further diaphragm and at least one motor that is offset relative to a central axis of the further diaphragm.

[0148] Clause 26. The playback device of clause 25, wherein the suspension system comprises at least two flat springs and the transducer comprises at least two motors, wherein the at least two flat springs and the at least two motors are symmetrically arranged in an alternating manner.

[0149] Clause 27. The playback device of clause 22, wherein a central axis of the diaphragm and a central axis of a further diaphragm of the transducer are aligned.

[0150] Clause 28. The playback device of clause 21, wherein the at least one passive radiator includes a first passive radiator and a second passive radiator, wherein the first and second passive radiators are arranged in a back-to-back configuration.

[0151] Clause 29. The playback device of clause 28, wherein the first passive radiator comprises a first flat spring and a second flat spring positioned on opposite sides of a first axis of the diaphragm of the first passive radiator, and wherein the second passive radiator

comprises a third flat spring and a fourth flat spring positioned on opposite sides of a second axis of the diaphragm of the second passive radiator, wherein the first axis and the second axis are perpendicular.

[0152]

[0153] Clause 30. The playback device of clause 28, comprising a sealed enclosure in which the at least one transducer and the at least one passive radiator are mounted, wherein the suspension systems of the first passive radiator and of the second passive radiator are outside of the sealed enclosure.

[0154] Clause 31. The playback device of clause 21, wherein the diaphragms of the first and second passive radiators are positioned on opposite sides of a through-hole in the sealed enclosure.

[0155]

[0156] Clause 32. The playback device of clause 21, wherein the at least one transducer comprises a first transducer and a second transducer, wherein the first and second transducers are arranged in a back-to-back configuration.

[0157] Clause 33. The playback device of clause 32, comprising a sealed enclosure in which the first transducer, the second transducer, and the at least one passive radiator are mounted, wherein the first and second transducers comprise at least one motor, and wherein the at least one motor are outside of the sealed enclosure.

[0158] Clause 34. The playback device of clause 21, wherein the diaphragms of the first and second transducers are positioned on opposite sides of a through-hole in the sealed enclosure.

[0159] Clause 35. The playback device of clause 21, wherein a first radiation area of the at least one passive radiator is at least double a second radiation area of the at least one transducer.

[0160] Clause 36. The playback device of clause 35, wherein the at least one passive radiator comprises two passive radiators that together have the first radiation area, and wherein the at least one transducer comprises two transducers that together have the second radiation area.

[0161] Clause 37. The playback device of clause 35, wherein the at least one passive radiator comprises four passive radiators that together have the first radiation area, and wherein the at least one transducer comprises two transducers that together have the second radiation area.

[0162] Clause 38. The playback device of clause 21, wherein a first average maximum excursion of the at least one passive radiator is at least double a second average maximum excursion of the at least one transducer.

[0163] Clause 39. The playback device of clause 35, wherein the at least one passive radiator comprises four passive radiators that together have the first average maximum excursion, and wherein the at least one transducer comprises two transducer that together have the second average maximum excursion.

[0164] Clause 40. The playback device of clause 21, comprising a sealed enclosure in which the at least one transducer and the at least one passive radiator are mounted, and wherein the suspension system is outside of the sealed enclosure.

CLAIMS

1. A passive radiator, comprising:
 - a frame;
 - a diaphragm attached to the frame by a surround such that the diaphragm can move relative to the frame; and
 - a suspension system comprising at least one flat spring that couples the diaphragm and the frame.
2. The passive radiator of claim 1, wherein the suspension system comprises at least two flat springs that are evenly spaced about a central axis of the diaphragm.
3. The passive radiator of claim 1, wherein the suspension system comprises at least two flat springs that are symmetrically arranged.
4. The passive radiator of any of claims 1 to 3, comprising at least one mass coupled to the diaphragm.
5. The passive radiator of claim 4, wherein the at least one mass comprises a power supply for a playback device.
6. The passive radiator of claim 4 or 5, wherein the diaphragm is coupled to the suspension system via the at least one mass.

7. The passive radiator of claim 4, 5 or 6, wherein the at least one mass comprises a first mass having a center of mass positioned on a central axis of the diaphragm, and wherein the suspension system comprises at least two flat springs that couple the first mass to the frame.

8. The passive radiator of claim 4, 5 or 6, wherein the at least one mass comprises at least a first mass and a second mass, wherein the suspension system comprises a first flat spring that couples the first mass to the frame and a second flat spring that couples the second mass to the frame.

9. The passive radiator of claim 8, wherein at least the first flat spring is aligned with the first mass in a direction of movement of the diaphragm.

10. The passive radiator of claim 8 or 9, wherein the first mass and the second mass are positioned on opposite sides of an axis of the diaphragm.

11. The passive radiator of claim 10, comprising a support that couples (i) the first mass to the second mass and (ii) the first mass and the second mass to the diaphragm.

12. The passive radiator of claim 11, wherein the support is coupled to the diaphragm along the axis.

13. The passive radiator of claim 1, wherein the flat spring comprises a first flat spring and wherein the suspension system comprises a second flat spring that couples the diaphragm and the frame, wherein the first flat spring and the second flat spring are positioned on opposite sides of an axis of the diaphragm, and wherein the passive radiator comprises a

support that couples (i) the first flat spring to the second flat spring and (ii) the first flat spring and the second flat spring to the diaphragm.

14. A playback device comprising a passive radiator according to any preceding claim.

15. The playback device of claim 14, comprising a drive unit coupled to the diaphragm, and wherein the playback device is operable in a first mode in which the drive unit is powered and a second mode in which the drive unit is unpowered.

16. The playback device of claim 15, wherein the playback device is configured to operate in the first mode when powered by an external power source and is configured to operate in the second mode when powered by an internal power source.

17. A playback device comprising
at least one transducer; and
at least one passive radiator according to any of claims 1 to 13.

18. The playback device of claim 17, wherein the at least one transducer and the at least one passive radiator are arranged in a back-to-back configuration.

19. The playback device of claim 18, wherein the at least one flat spring is offset relative to a central axis of the diaphragm.

20. The playback device of claim 19, wherein the at least one transducer comprises a further diaphragm and a motor that is coaxially coupled to the further diaphragm.

21. The playback device of claim 19, wherein the at least one transducer comprises a further diaphragm and at least one motor that is offset relative to a central axis of the further diaphragm.

22. The playback device of claim 21, wherein the suspension system comprises at least two flat springs and the transducer comprises at least two motors, wherein the at least two flat springs and the at least two motors are symmetrically arranged in an alternating manner.

23. The playback device of claim 18, wherein a central axis of the diaphragm and a central axis of a further diaphragm of the transducer are aligned.

24. The playback device of claim 17, wherein the at least one passive radiator includes a first passive radiator and a second passive radiator, wherein the first and second passive radiators are arranged in a back-to-back configuration.

25. The playback device of claim 24, wherein the first passive radiator comprises a first flat spring and a second flat spring positioned on opposite sides of a first axis of the diaphragm of the first passive radiator, and wherein the second passive radiator comprises a third flat spring and a fourth flat spring positioned on opposite sides of a second axis of the diaphragm of the second passive radiator, wherein the first axis and the second axis are perpendicular.

26. The playback device of claim 24, comprising a sealed enclosure in which the at least one transducer and the at least one passive radiator are mounted, wherein the suspension

systems of the first passive radiator and of the second passive radiator are outside of the sealed enclosure.

27. The playback device of claim 26, wherein the diaphragms of the first and second passive radiators are positioned on opposite sides of a through-hole in the sealed enclosure.

28. The playback device of claim 17, wherein the at least one transducer comprises a first transducer and a second transducer, wherein the first and second transducers are arranged in a back-to-back configuration.

29. The playback device of claim 28, comprising a sealed enclosure in which the first transducer, the second transducer, and the at least one passive radiator are mounted, wherein the first and second transducers comprise at least one motor, and wherein the at least one motor are outside of the sealed enclosure.

30. The playback device of claim 29, wherein the diaphragms of the first and second transducers are positioned on opposite sides of a through-hole in the sealed enclosure.

31. The playback device of any of claims 17 to 30, wherein a first radiation area of the at least one passive radiator is at least double a second radiation area of the at least one transducer.

32. The playback device of claim 31, wherein the at least one passive radiator comprises two passive radiators that together have the first radiation area, and wherein the at least one transducer comprises two transducers that together have the second radiation area.

33. The playback device of claim 31, wherein the at least one passive radiator comprises four passive radiators that together have the first radiation area, and wherein the at least one transducer comprises two transducers that together have the second radiation area.

34. The playback device of any of claims 17 to 33, wherein a first average maximum excursion of the at least one passive radiator is at least double a second average maximum excursion of the at least one transducer.

35. The playback device of claim 34, wherein the at least one passive radiator comprises four passive radiators that together have the first average maximum excursion, and wherein the at least one transducer comprises two transducer that together have the second average maximum excursion.

36. The playback device of any of claims 17 to 25, comprising a sealed enclosure in which the at least one transducer and the at least one passive radiator are mounted, and wherein the suspension system is outside of the sealed enclosure.

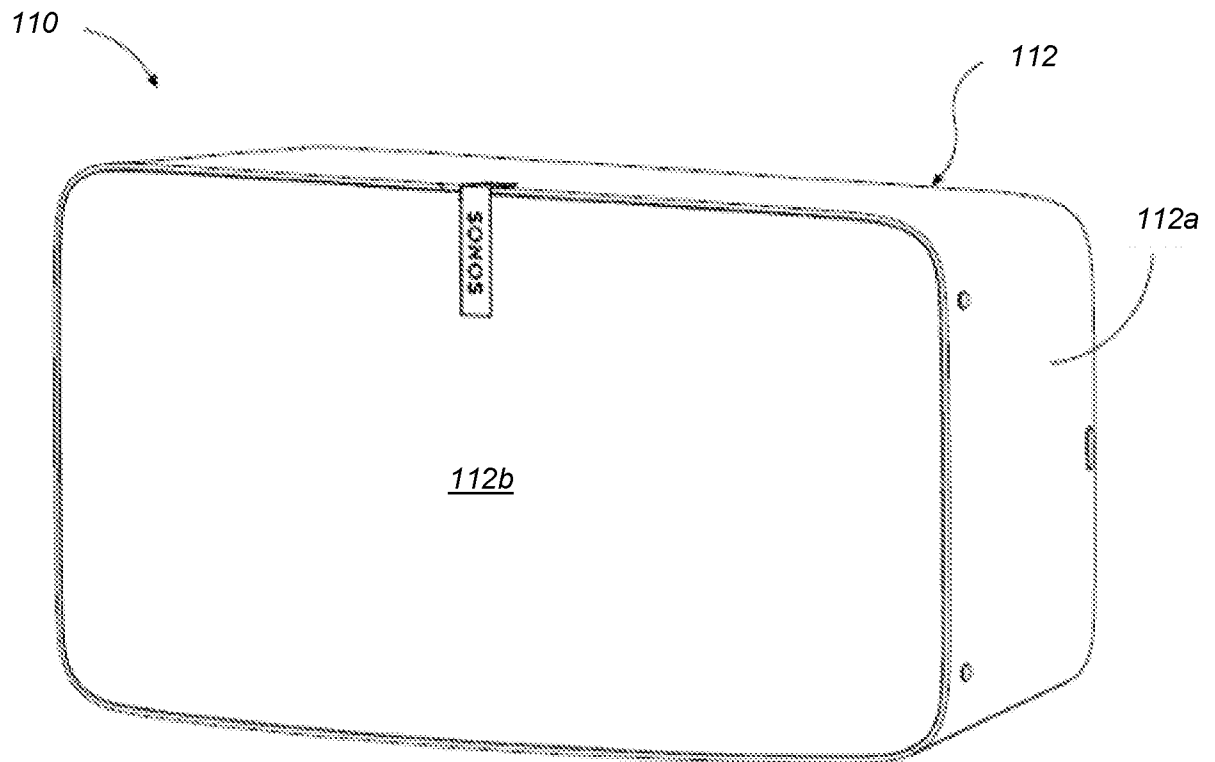


Figure 1A

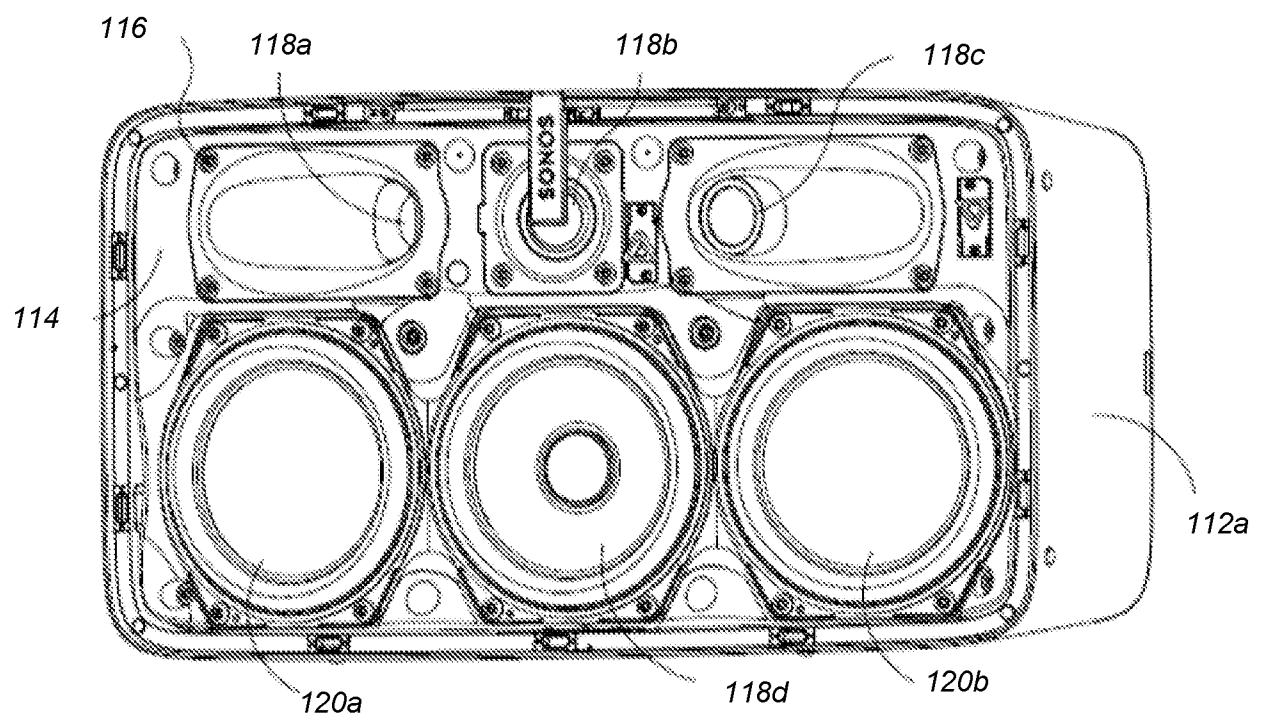


Figure 1B

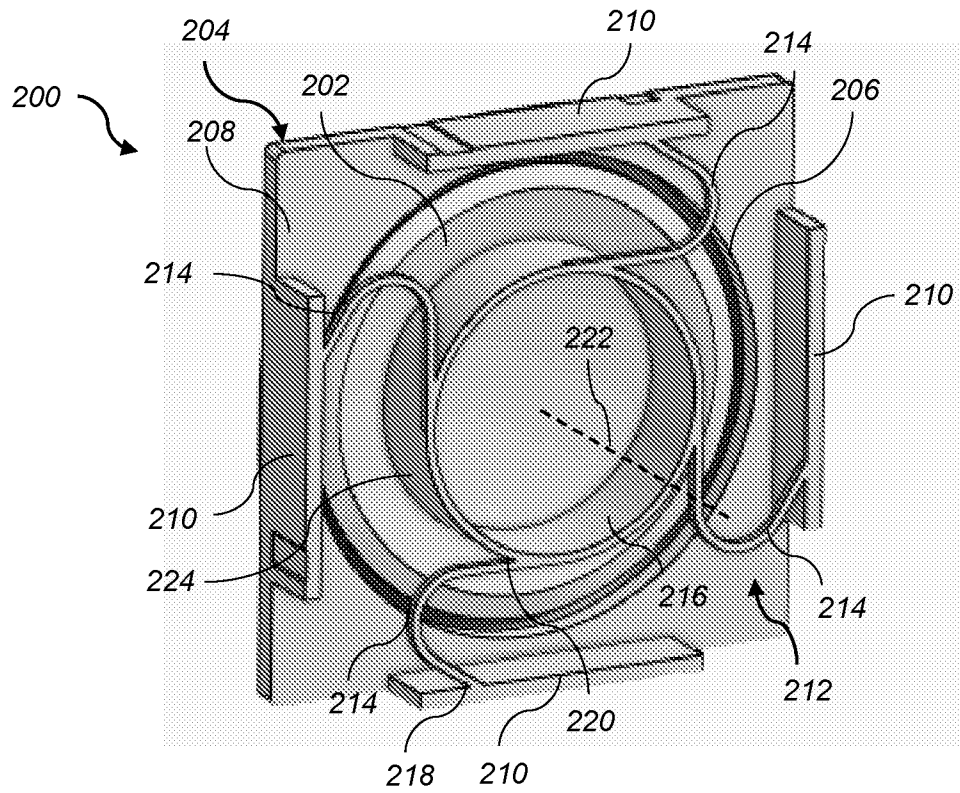


Figure 2

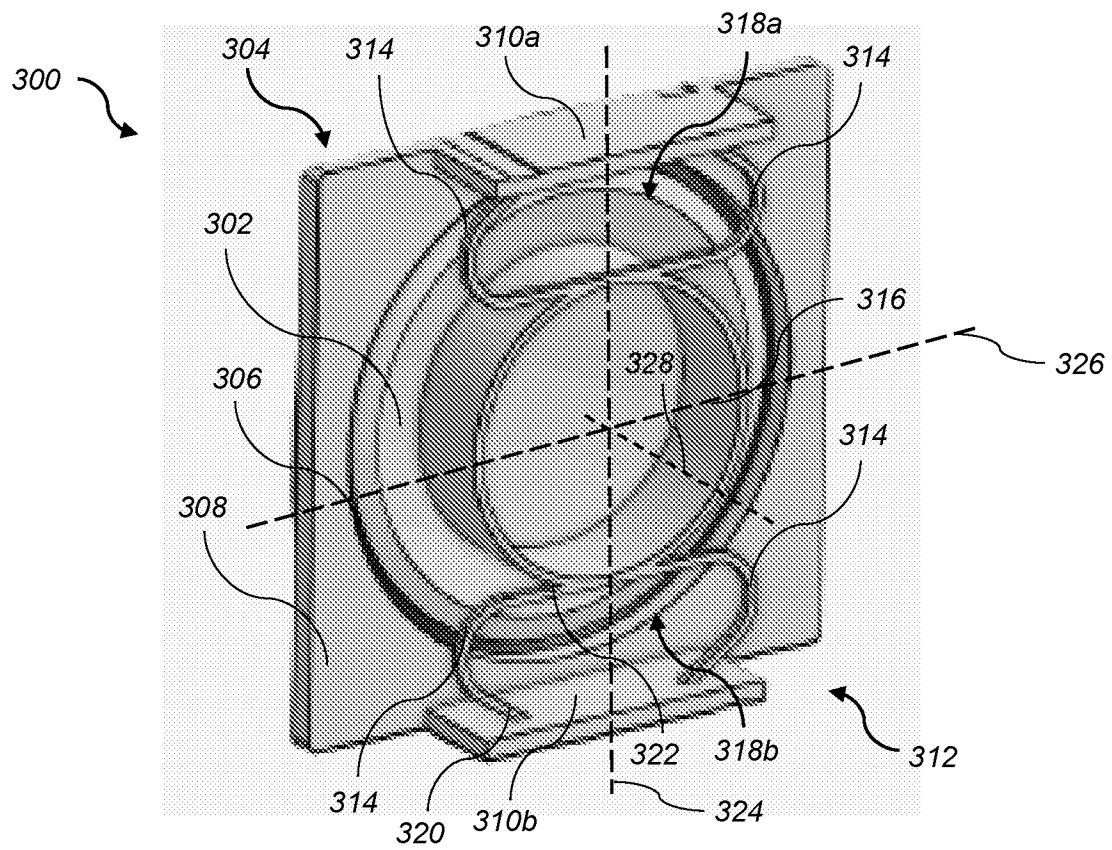


Figure 3

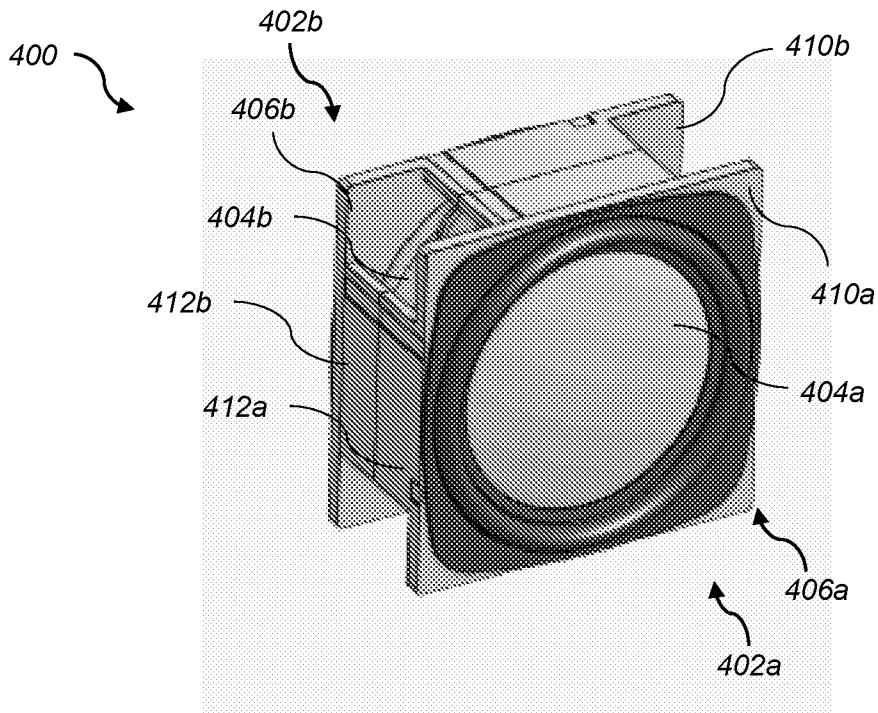


Figure 4A

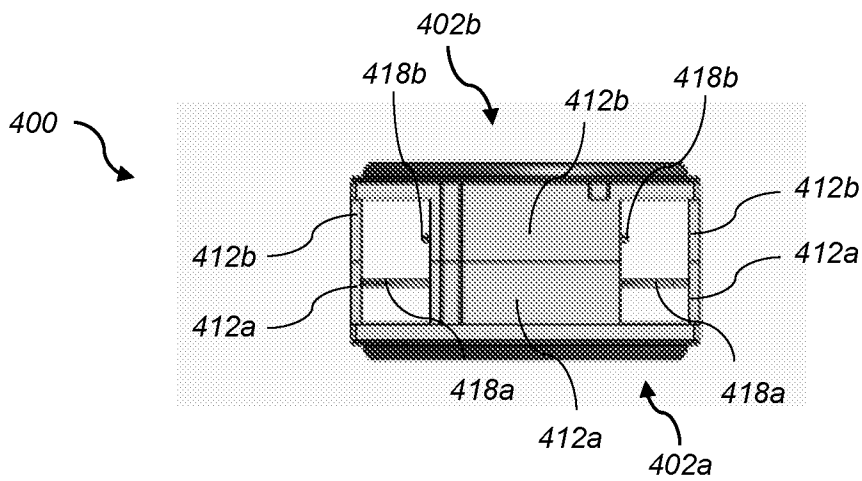


Figure 4B

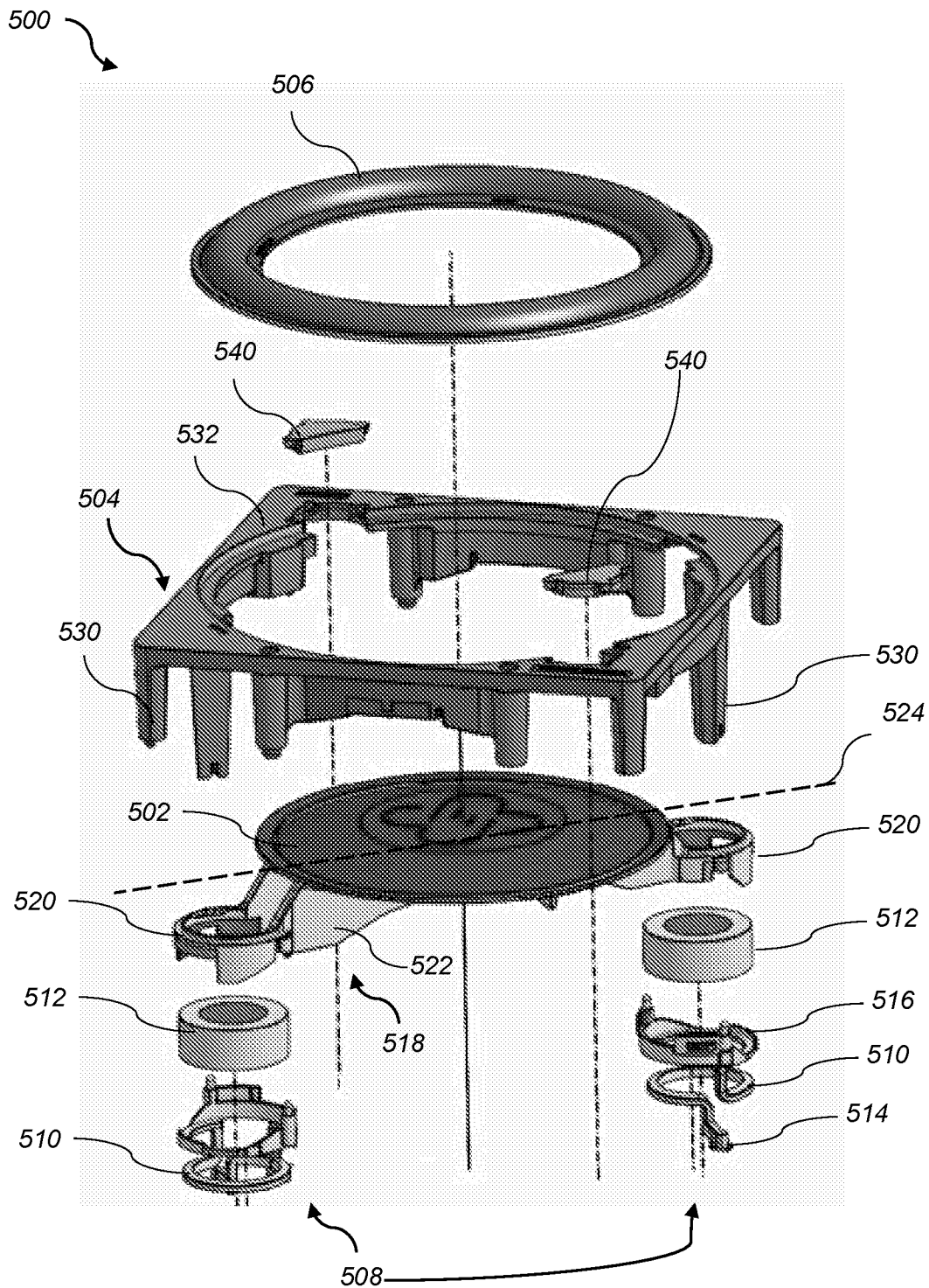


Figure 5

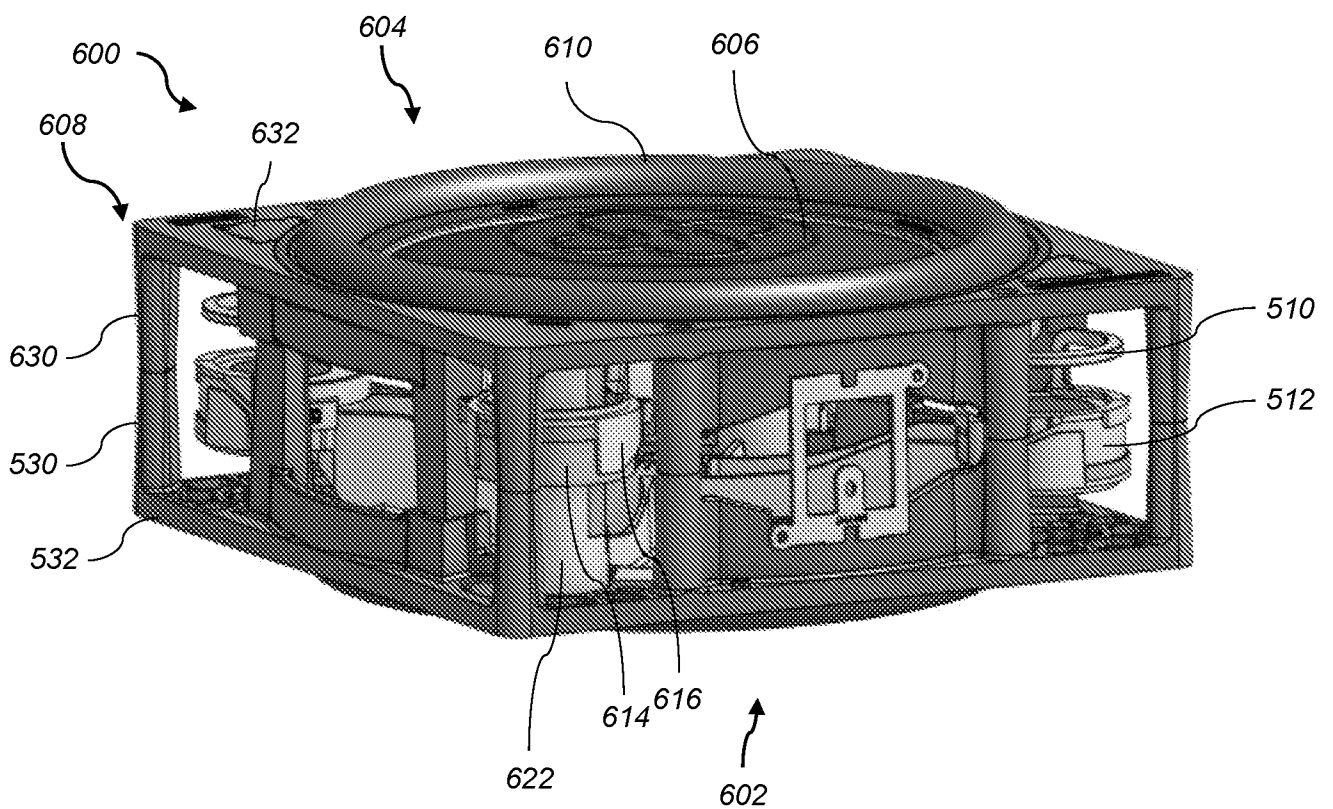


Figure 6A

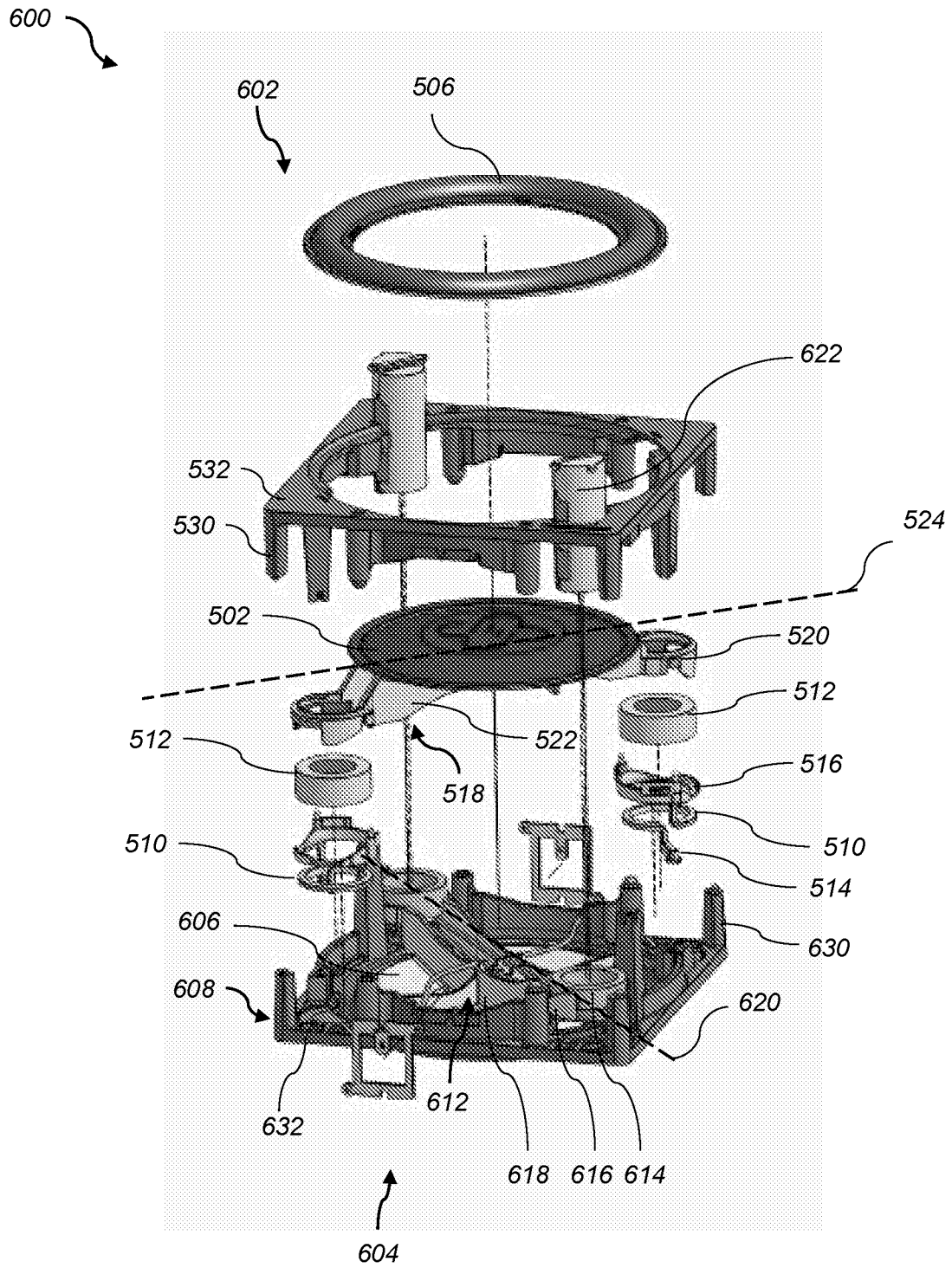


Figure 6B

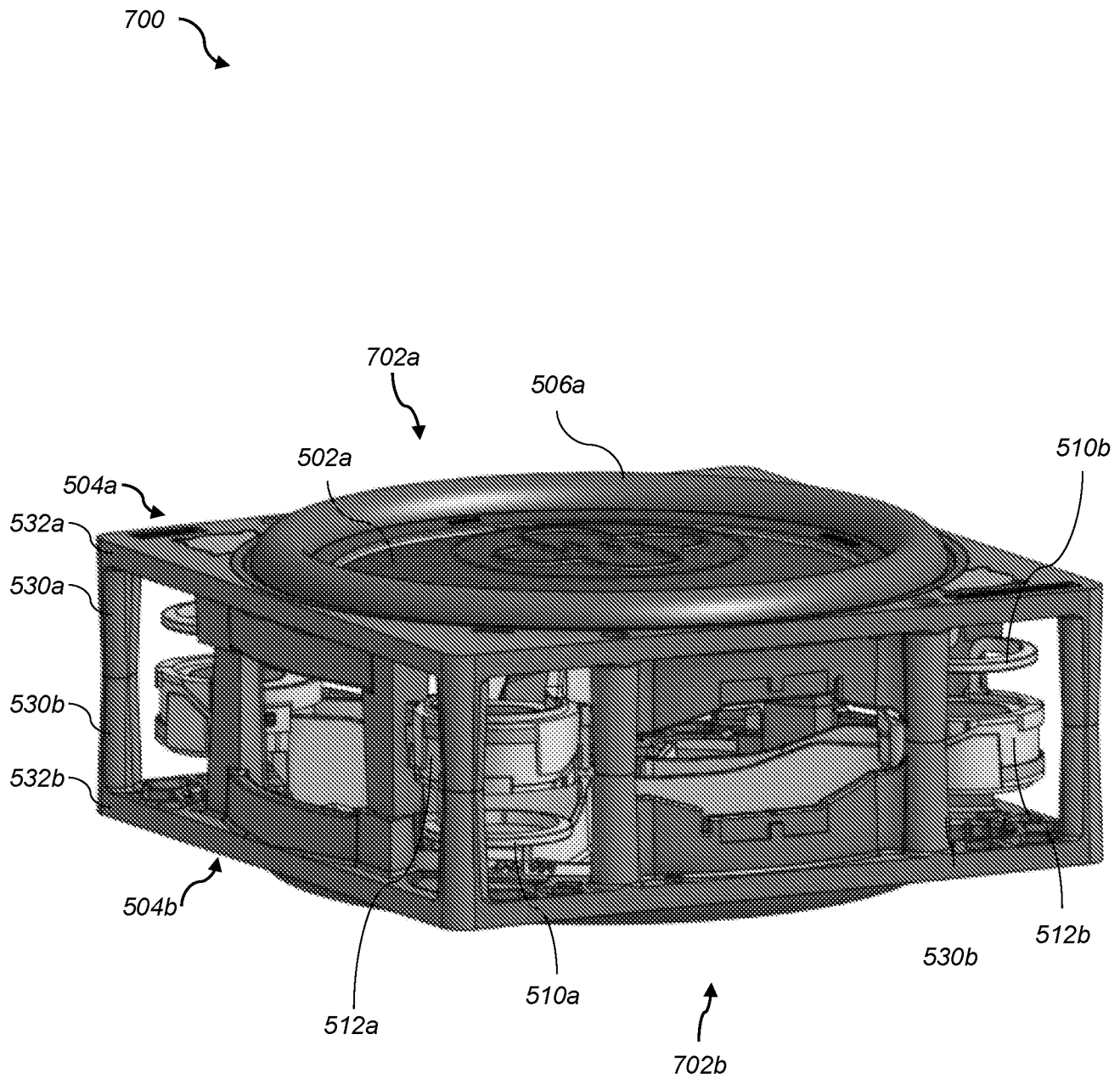


Figure 7A

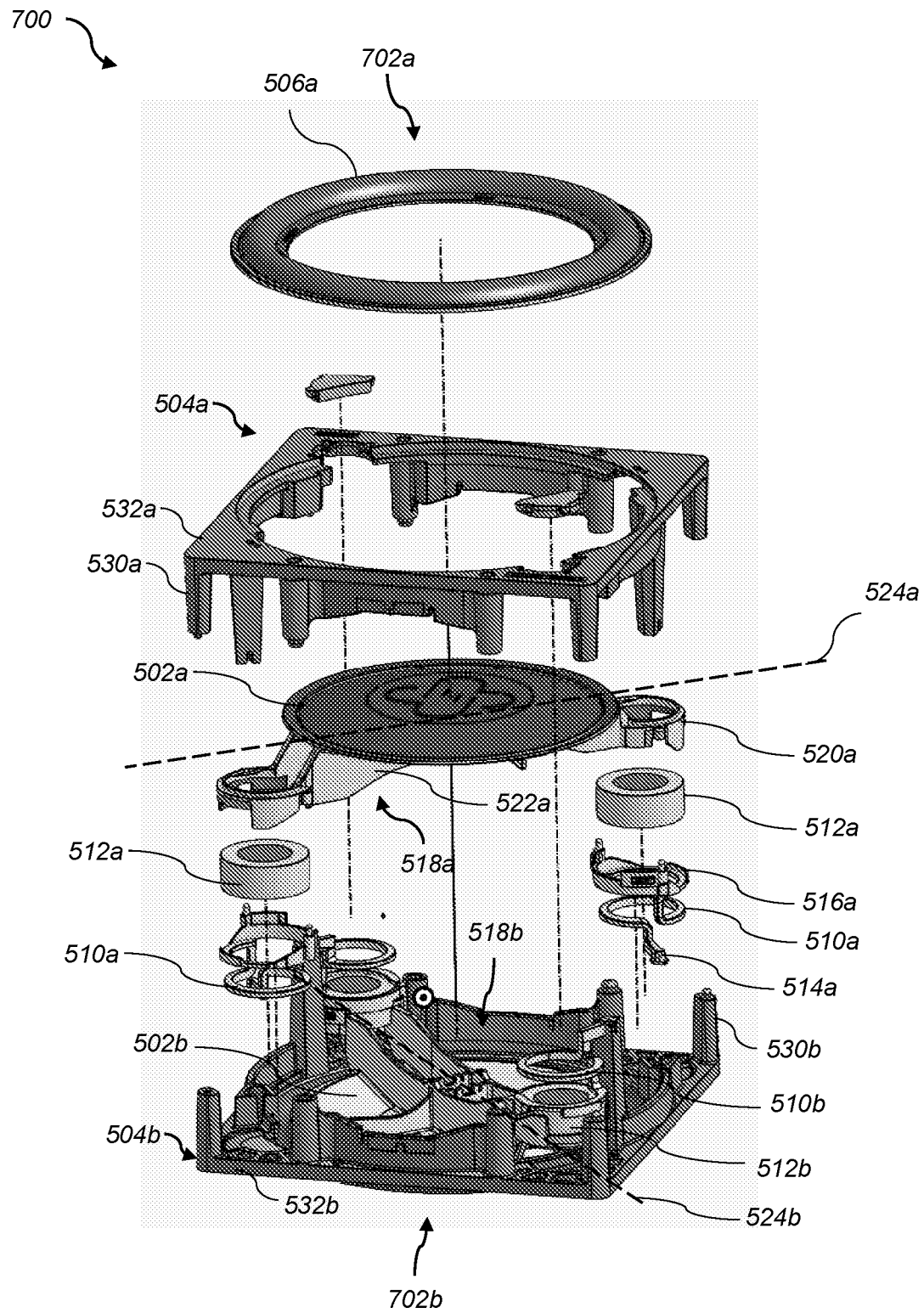


Figure 7B

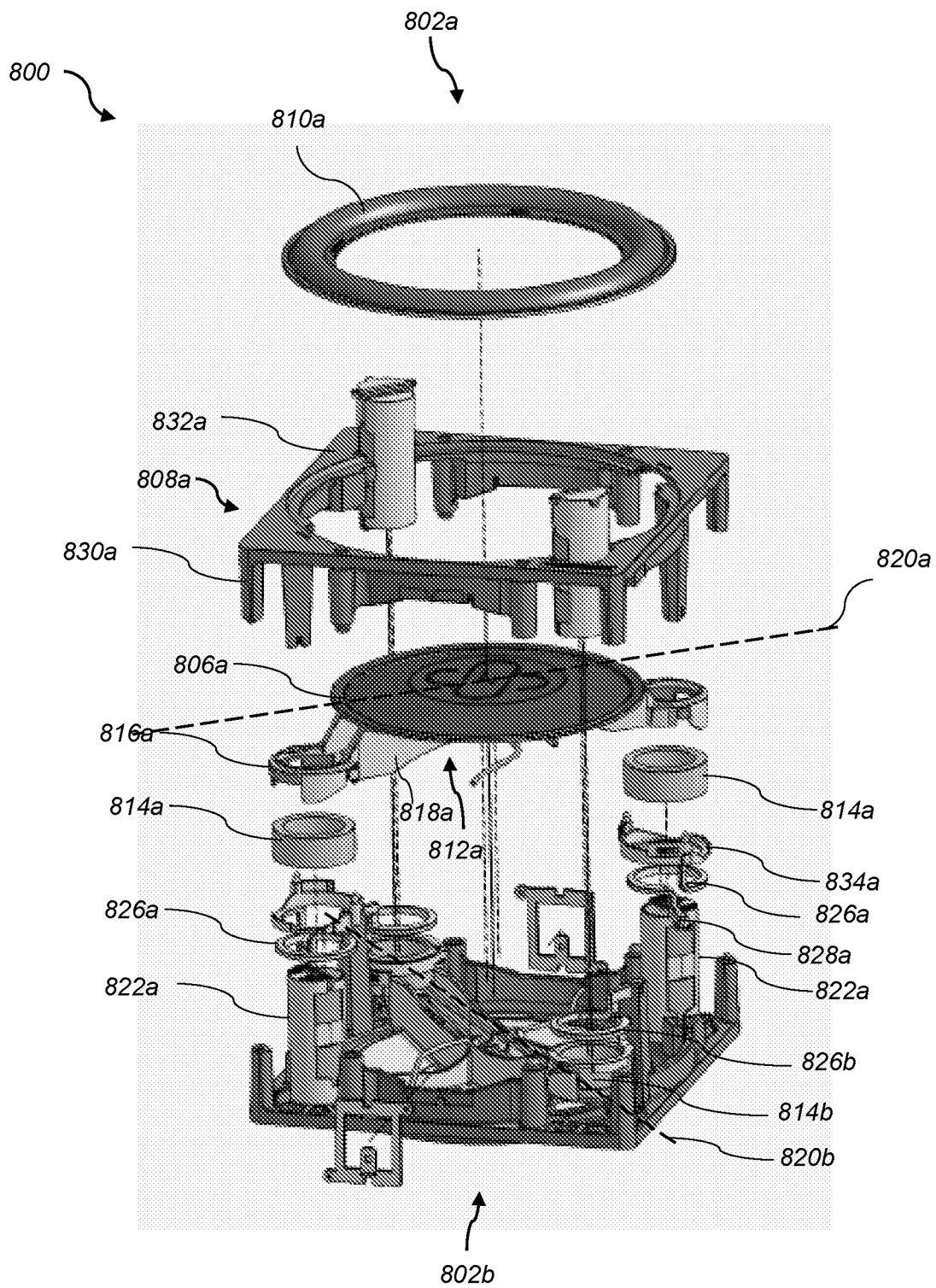


Figure 8

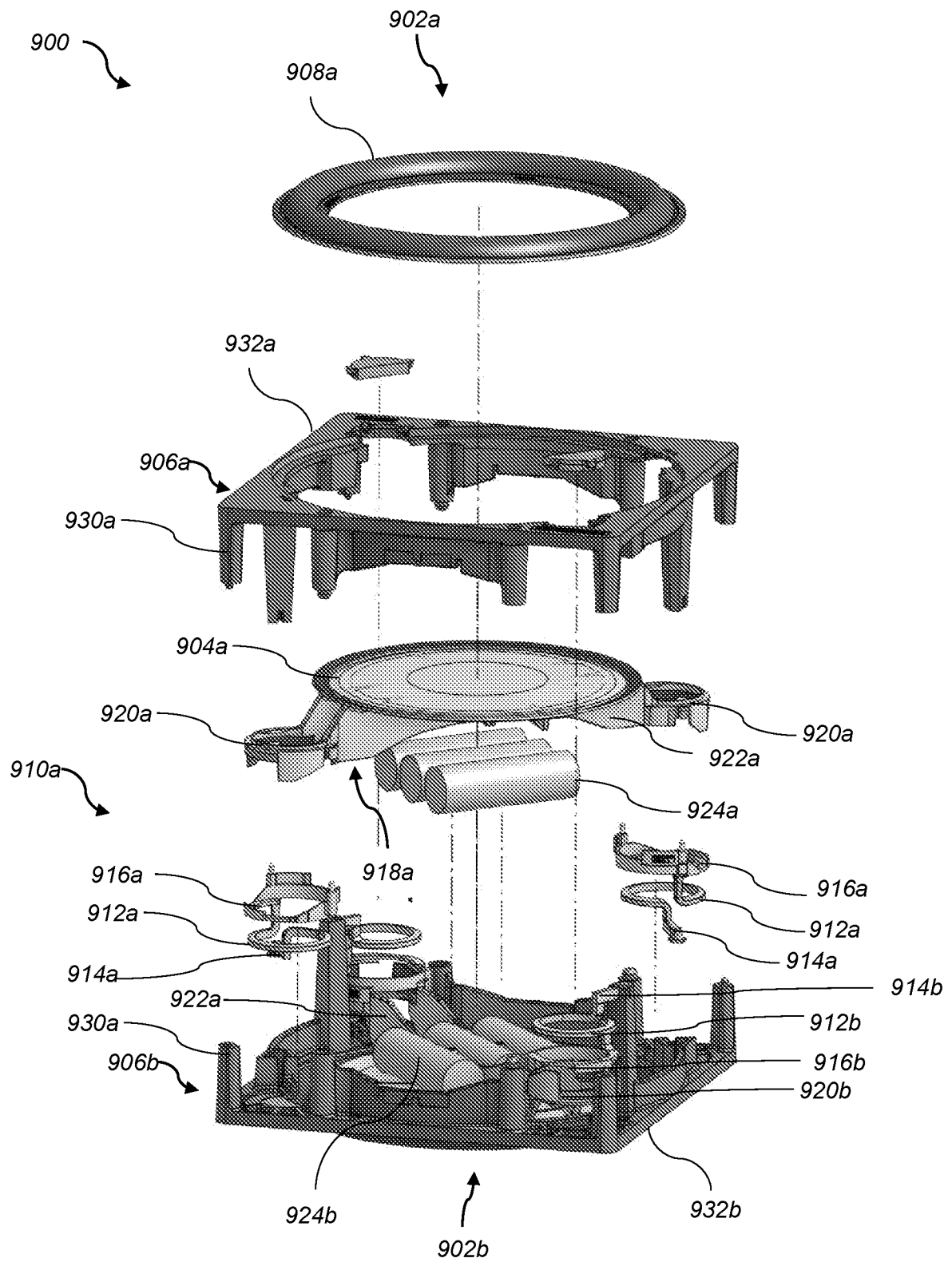


Figure 9

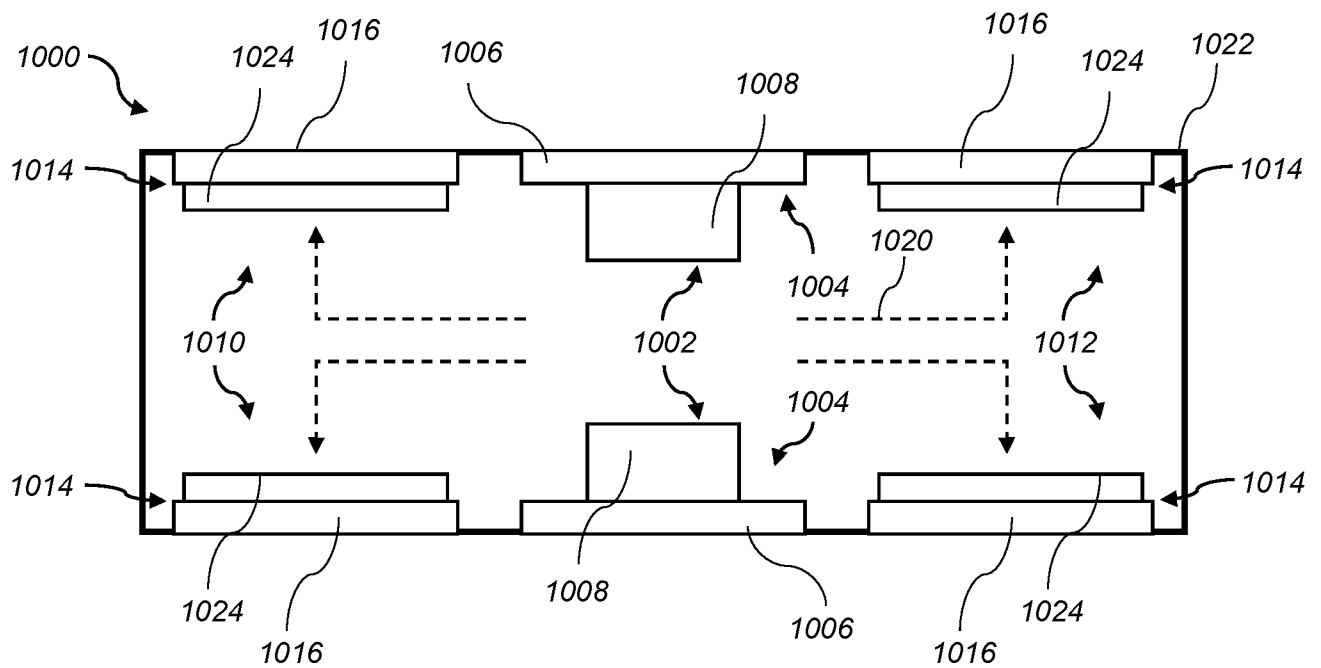


Figure 10

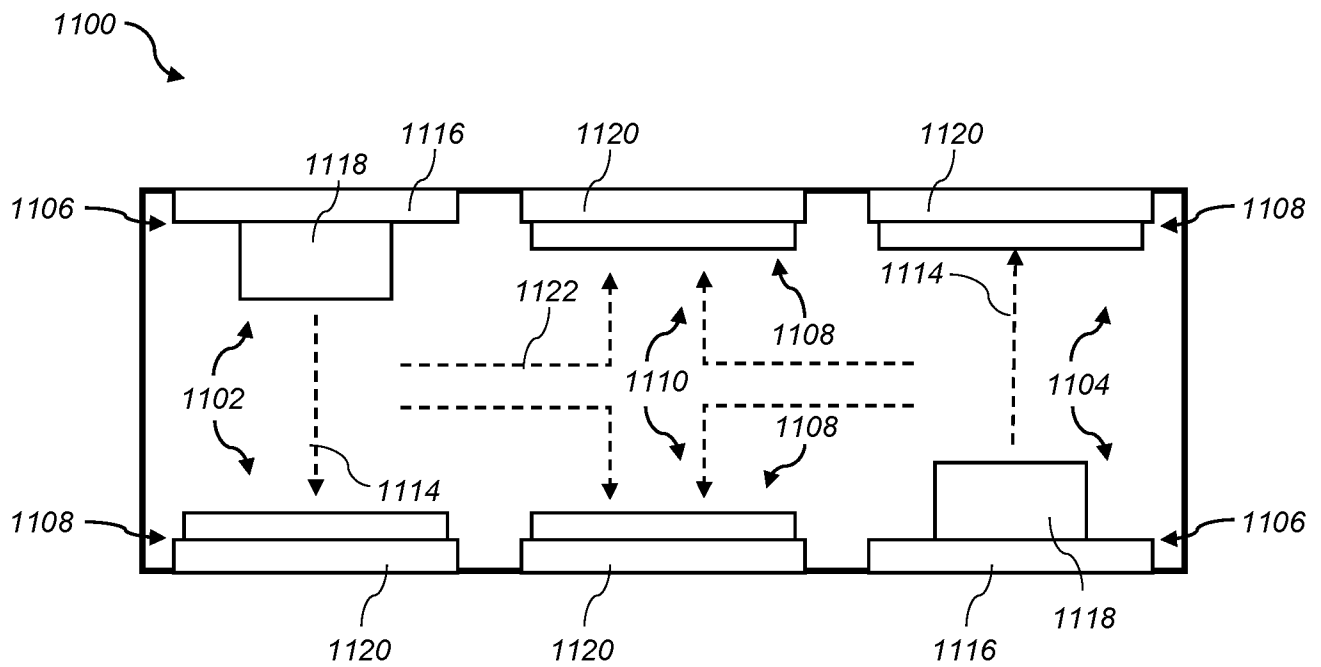


Figure 11

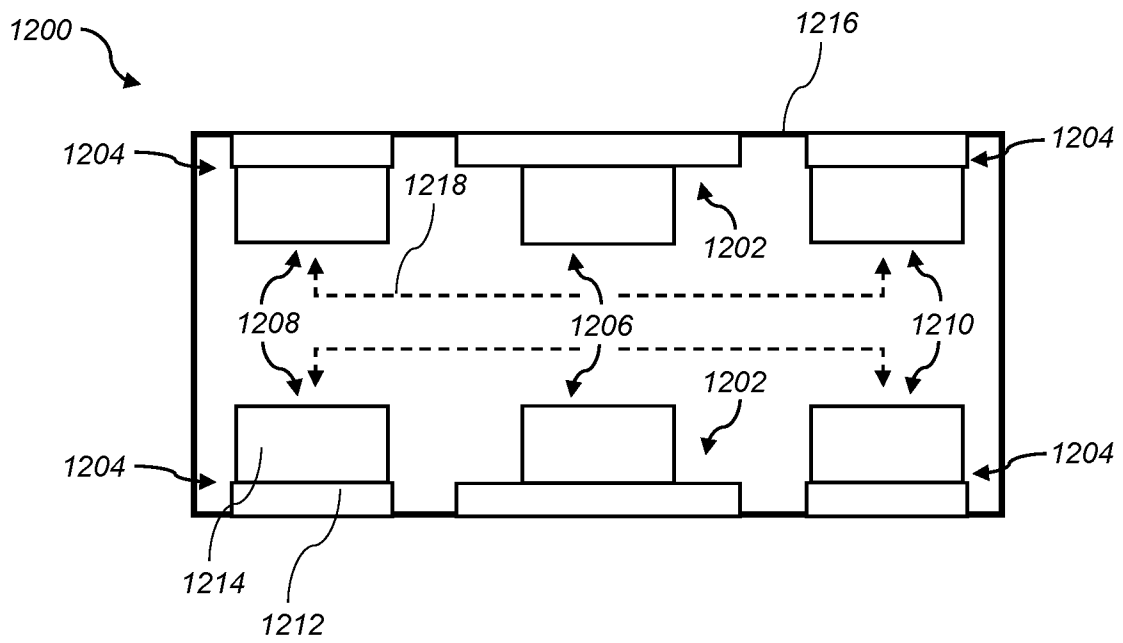


Figure 12

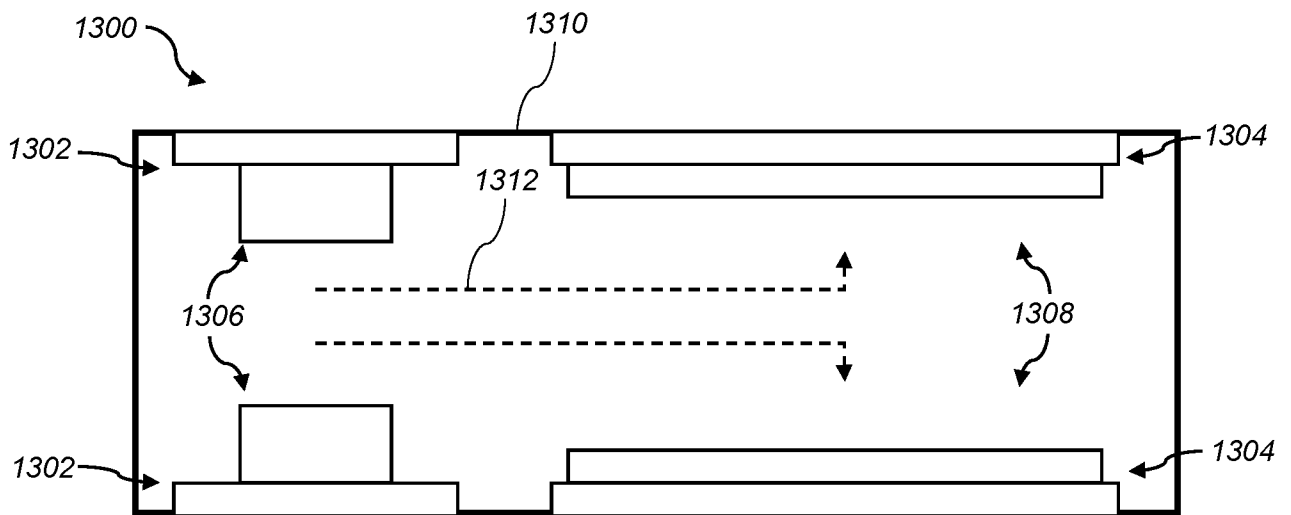


Figure 13

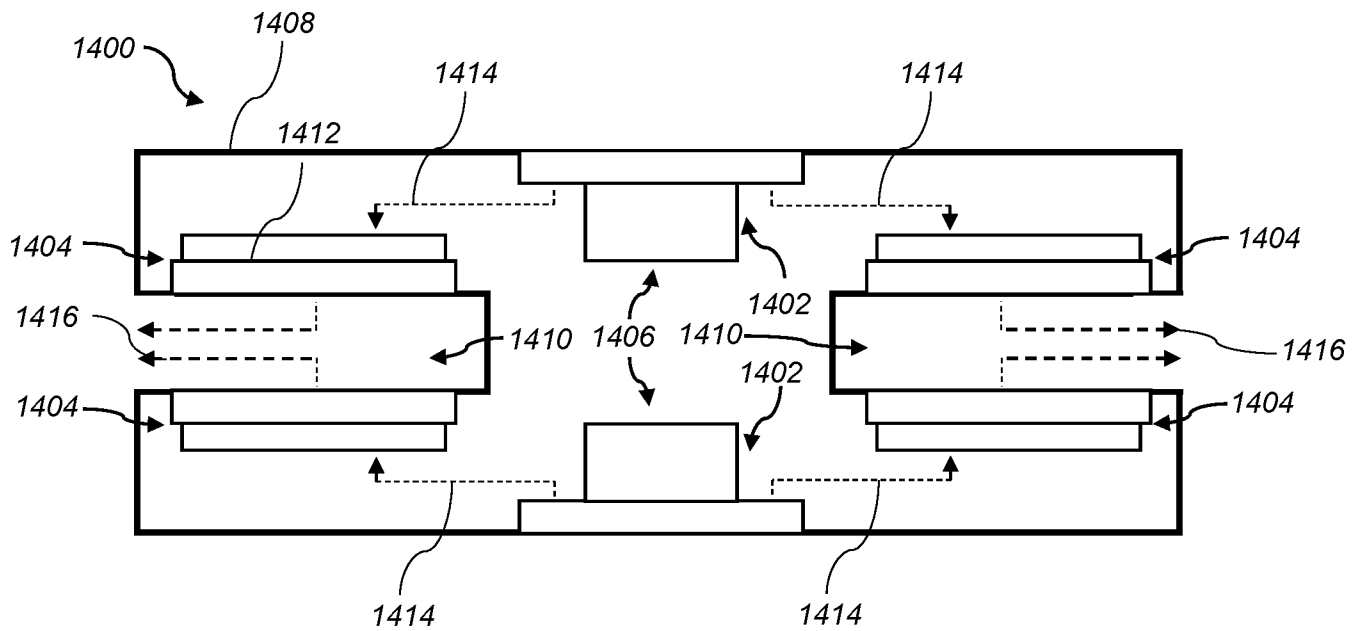


Figure 14

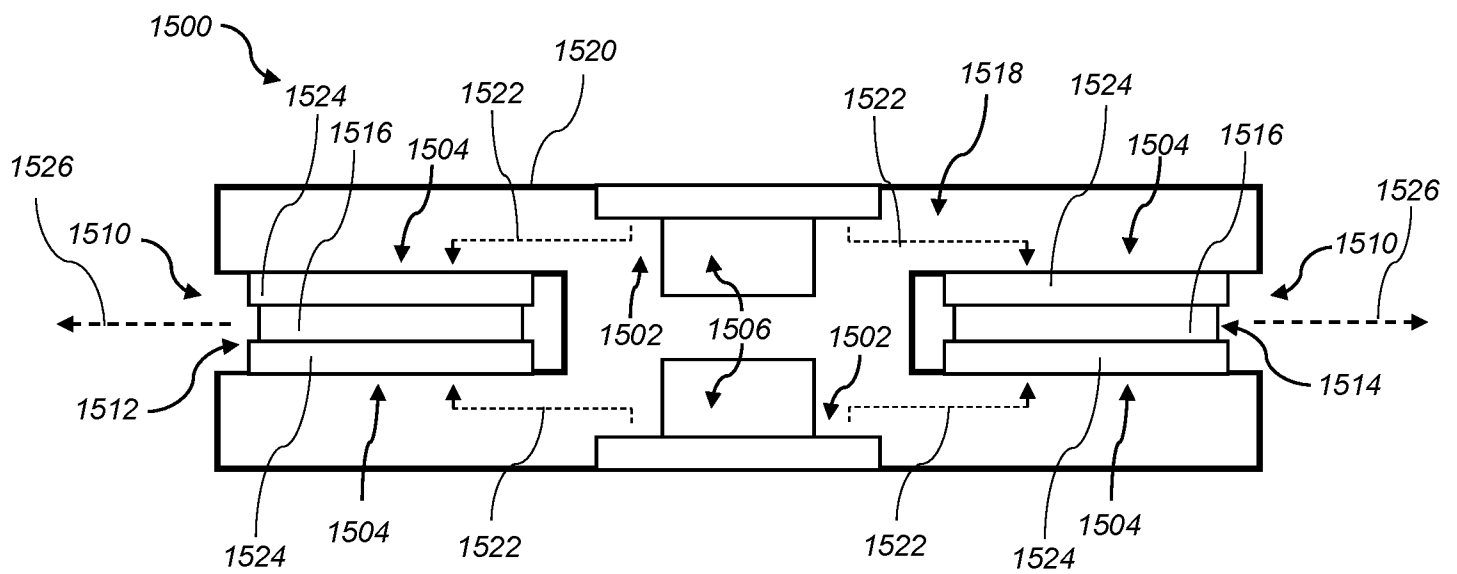


Figure 15

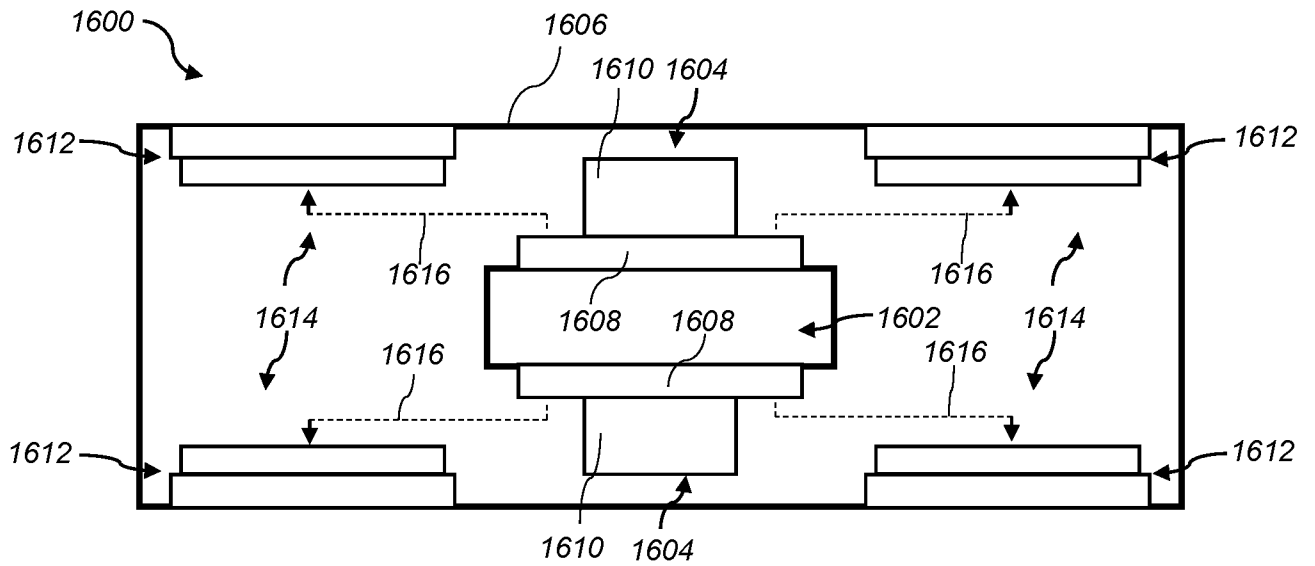


Figure 16

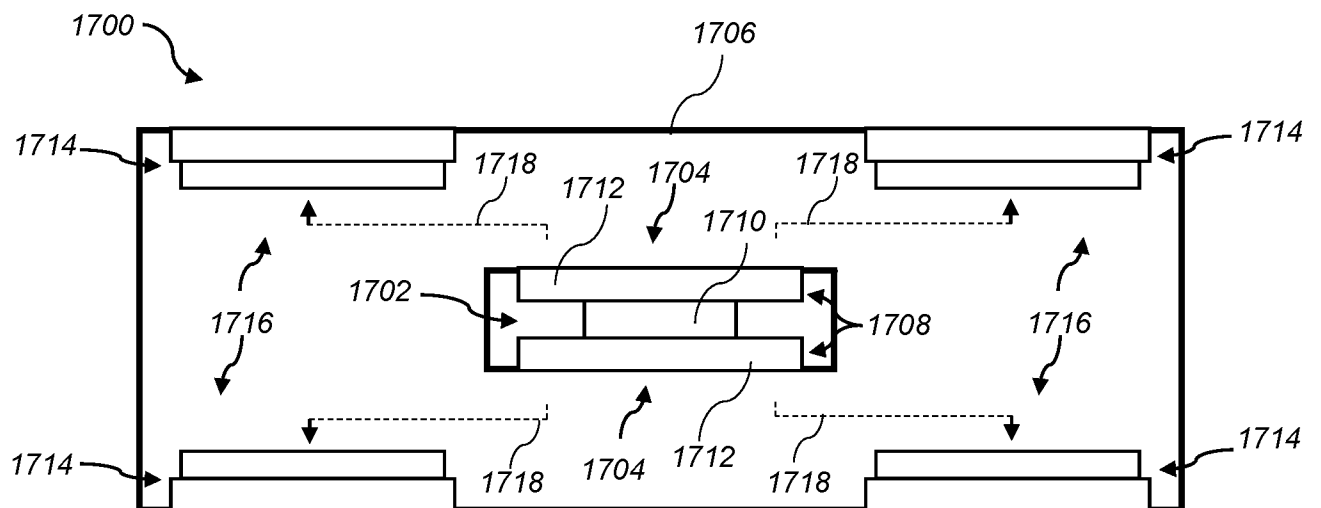


Figure 17

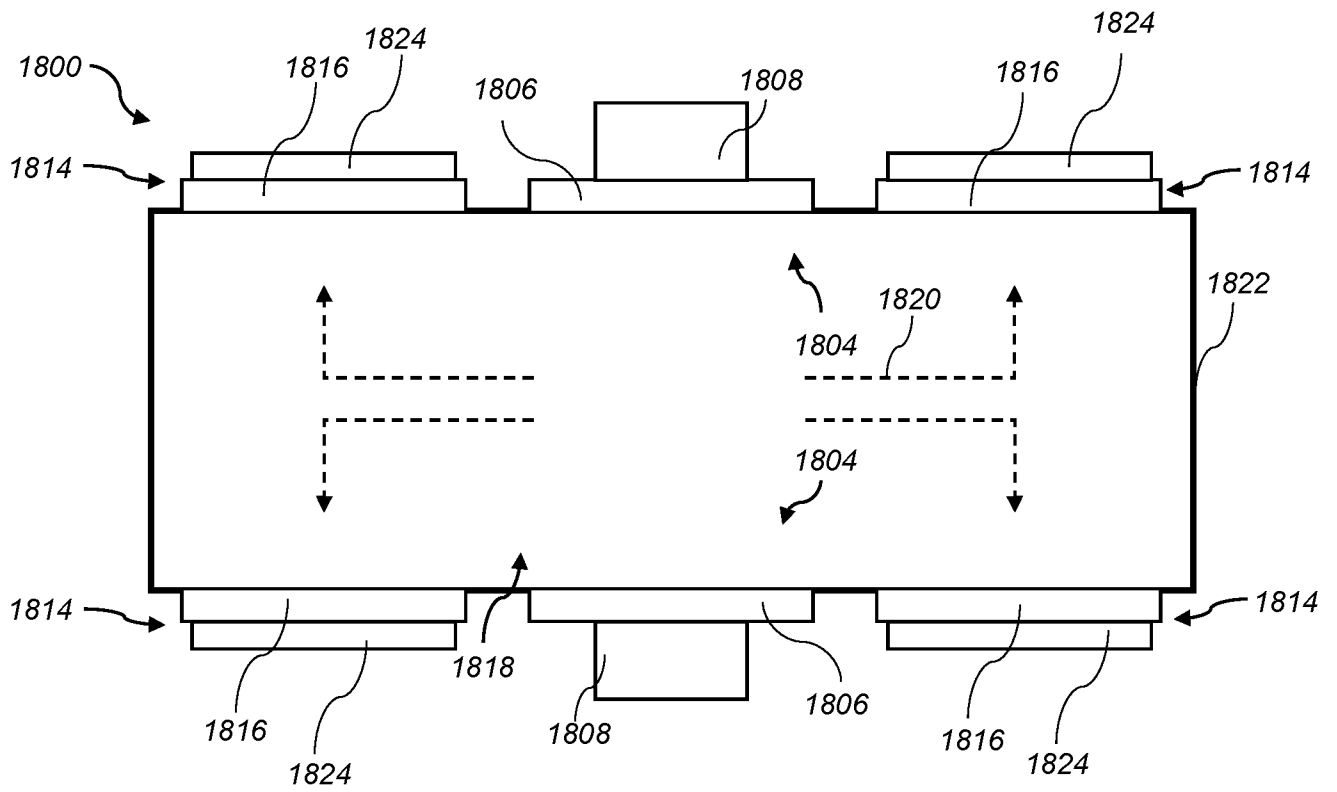


Figure 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2024/035436

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 34, 35
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:
1 - 12, 14, 17 - 19, 23 - 25, 28, 31 - 35

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/035436

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04R1/28 H04R7/20
ADD. H04R1/10

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

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/157900 A1 (LITOVSKY ROMAN [US] ET AL) 21 July 2005 (2005-07-21)	1-6,14, 17-19, 23-25, 28,31-33
A	paragraphs [0022] - [0024], [0030]; figures 2A-4A -----	7-12
X	US 2017/085980 A1 (CHOU YEH-FENG [TW]) 23 March 2017 (2017-03-23)	1-3,14, 17-19, 23-25, 28,31-33
A	paragraphs [0016] - [0018]; figures 1,2 -----	4-12
X	US 2022/417651 A1 (BACKMAN JUHA [FI]) 29 December 2022 (2022-12-29)	1-4, 6-10,14, 17-19, 23-25, 28,31-33
A	paragraph [0049]; figure 9 -----	5,11,12

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Further documents are listed in the continuation of Box C.

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See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"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

"&" document member of the same patent family

Date of the actual completion of the international search

27 September 2024

Date of mailing of the international search report

05/12/2024

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2024/035436

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005157900 A1	21-07-2005	CN 1642356 A	20-07-2005
		CN 101969594 A	09-02-2011
		EP 1555849 A2	20-07-2005
		JP 4726500 B2	20-07-2011
		JP 2005204320 A	28-07-2005
		US 2005157900 A1	21-07-2005
US 2017085980 A1	23-03-2017	NONE	
US 2022417651 A1	29-12-2022	CN 114339536 A	12-04-2022
		US 2022417651 A1	29-12-2022

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12, 14, 17-19, 23-25, 28, 31-35

Passive radiator having stable diaphragm (I)

2. claim: 13

Passive radiator having stable diaphragm (II)

3. claims: 15, 16, 20-22

Playback system with increased flexibility in choosing the output characteristics and with improved frequency characteristics

4. claims: 26, 27, 29, 30, 36

Playback devices having optimised frequency characteristics and occupied space.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 34, 35

Claims 34 and 35 mention the parameter "average maximum excursion" of a radiator/transducer. However, this parameter is neither defined in the claim nor is unanimously recognised in the field.

Moreover, the used denomination of the parameter appears ambiguous, since it simultaneously refers to an average and to a maximum value of the same parameter (excursion) of an assessed device (radiator/transducer), for which the working/functioning conditions have not been specified.

Since the description of the present application does not provide any further detail for a potential clarification and a meaningful interpretation of the above-objected terminology, the search of the claims 34 and 35 cannot be meaningfully performed.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.3), should the problems which led to the Article 17(2) PCT declaration be overcome.