



(51) International Patent Classification:

G06F 3/01 (2006.01)

(21) International Application Number:

PCT/IB2020/000520

(22) International Filing Date:

18 May 2020 (18.05.2020)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1906916.0

16 May 2019 (16.05.2019)

GB

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,

(54) Title: ACTUATOR ASSEMBLY WITH SMA

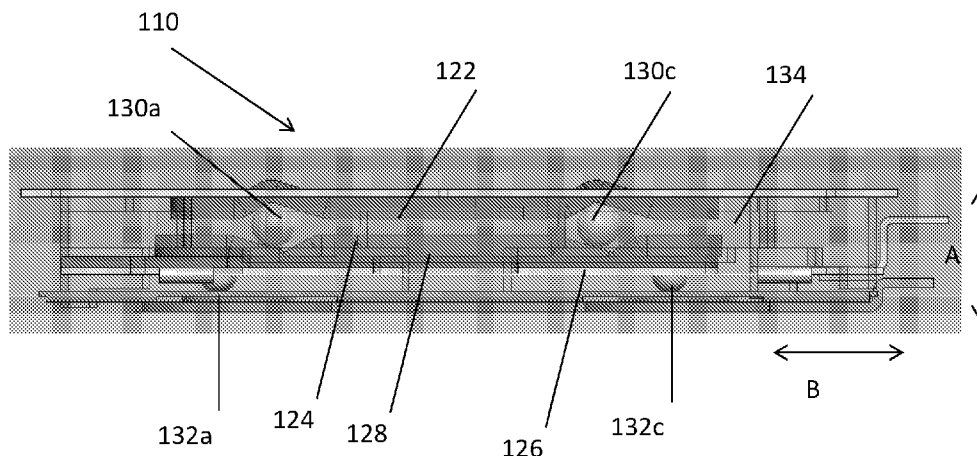


Fig 1b

(57) Abstract: An actuator assembly comprises a static element (134); a moveable element (122) moveable relative to the static element in a first direction; and an intermediate element (124) provided in a spaced relationship with the moveable element, and movable in a second different direction relative to the static element. At least one shape-memory alloy (SMA) wire is coupled to both the static element and the intermediate element so that on contraction the at least one SMA wire moves the intermediate element in the second direction. There is also at least one bearing (130a, 130c) arranged to couple the intermediate element to the moveable element such that movement of the intermediate element in the second direction causes movement of the moveable element in the first direction. Both of the moveable element and the intermediate element comprise at least one groove within which the at least one bearing is located and each groove has an inclined surface which engages with the at least one bearing.

TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Actuator Assembly with SMA

The present techniques generally relate to apparatus and methods for providing haptic feedback in electrical and electronic products, and in particular, relate to actuator assemblies which may be used to provide such haptic feedback and which comprise a shape memory alloy (SMA) actuator.

Consumer electronics devices, such as laptops and smartphones, may employ different types of controls to give users of the devices some feedback indicating that they have successfully pressed a button on the device. This is generally known as haptic feedback, and haptic buttons or controls on a device may provide a tactile sensation to the user to confirm that they have successfully pressed the button/control/switch. A haptic button may be provided as a module or assembly for incorporation within an electronic device by a device manufacturer. However, space within mobile and portable consumer electronic devices is typically at a premium. Haptic buttons are typically located along or near edges of a smartphone or a portable computing device, for example, so that the display screen may be maximised. The ever-decreasing thickness of portable computing devices, and the increasing display screen size, means that there is relatively little free space within a smartphone for haptic buttons. It is therefore, advantageous to produce a haptic button having a low profile, e.g. having a low/small height such that the button is able to be incorporated into the free space along an edge of a portable computing device. However, a low profile button is, by design, not able to move/travel within the computing device as much as ordinary buttons, and therefore, may not be able to provide a satisfying tactile response or sensation to the user.

The present applicant has identified the need for an improved haptic button assembly for electronic devices.

In a first approach of the present techniques, there is provided an actuator assembly comprising: a static element; a moveable element moveable relative to the static element in a first direction; an intermediate element provided in a spaced relationship with the moveable element, and movable in a second different direction relative to the static element; at least one shape-memory alloy (SMA) wire coupled to both the static element and the intermediate element so that on contraction the at least one SMA wire moves

the intermediate element in the second direction; and at least one bearing arranged to couple the intermediate element to the moveable element such that movement of the intermediate element in the second direction causes movement of the moveable element in the first direction, wherein both of the
5 moveable element and the intermediate element comprise at least one groove within which the at least one bearing is located and wherein each groove has an inclined surface which engages with the at least one bearing.

In a second approach of the present techniques, there is provided a haptic assembly comprising a button and an actuator assembly as described above,
10 wherein the button is operably attached to the moveable element whereby movement of the moveable element causes movement of the button in the first direction.

In a third approach of the present techniques, there is provided an apparatus comprising a haptic assembly where the apparatus is any one of: a
15 smartphone, a protective cover or case for a smartphone, a functional case or cover for a smartphone or electronic device, a camera, a foldable smartphone, a foldable tablet computing device, a foldable communications device, a foldable phablet, a foldable image capture device, a foldable smartphone camera, a foldable consumer electronics device, a camera with folded optics, an image
20 capture device, an array camera, a 3D sensing device or system, a servomotor, a consumer electronic device (including domestic appliances such as vacuum cleaners, washing machines and lawnmowers), a mobile or portable computing device, a mobile or portable electronic device, a laptop, a tablet computing device, a phablet, an e-reader (also known as an e-book reader or e-book
25 device), a computing accessory or computing peripheral device (e.g. mouse, keyboard, headphones, earphones, earbuds, etc.), an audio device (e.g. headphones, headset, earphones etc.), a security system, a gaming system, a gaming accessory (e.g. a controller, headset, a wearable controller, joystick, etc.), a robot or robotics device, a medical device (e.g. an endoscope), an
30 augmented reality system, an augmented reality device, a virtual reality system, a virtual reality device, a wearable device (e.g. a watch, a smartwatch, a fitness tracker etc.), an autonomous vehicle (e.g. a driverless car), a vehicle, a tool, a surgical tool, a remote controller (e.g. for a drone or a consumer electronics device), clothing (e.g. a garment, shoes etc.), a switch, a dial, a button (e.g. a

light switch, a thermostat dial, etc.), a display screen, a touchscreen, a flexible surface, and a wireless communication device (e.g. near-field communication (NFC) device).

Implementations of the present techniques will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1a is a perspective plan view of a first arrangement of an actuator assembly;

Figure 1b is a cross-sectional view of the actuator assembly of Figure 1a;

Figure 1c is a perspective side view of a first wedge layer within the actuator assembly of Figure 1a;

Figure 1d is a perspective plan view of a second wedge layer within the actuator assembly of Figure 1a;

Figure 1e is a perspective plan view of the actuator assembly of Figure 1a with some components removed for clarity;

Figure 1f is a plan underside view of the actuator assembly of Figure 1a with some components removed for clarity;

Figures 1g and 1h are perspective underside and plan views of a chassis within the actuator assembly of Figure 1a;

Figure 1i is a plan view of a spacer layer within the actuator assembly of Figure 1a;

Figure 1j is a perspective underside view of a sensor within the actuator assembly of Figure 1a;

Figure 1k is a perspective plan view of a haptic button assembly comprising the actuator assembly of Figure 1a;

Figures 2a and 2b are cross-sectional views of the actuator assembly of Figure 1a before and after activation;

Figures 2c and 2d are close-up views of the actuator assembly of Figures 2a and 2b, respectively;

Figure 3a is a perspective top view of a second arrangement of an actuator assembly;

Figure 3b is a perspective view of a chassis within the actuator assembly of Figure 3a;

Figure 3c is a perspective underside view of a second arrangement of the actuator assembly of Figure 3a with some components removed;

Figure 3d is a perspective view of a spacer within the actuator assembly of Figure 3a;

Figure 4a is a perspective top view of a third arrangement of an actuator assembly;

5 Figure 4b is a perspective view of a crimp layer within the actuator assembly of Figure 4a;

Figure 5a is a side view of a fourth arrangement of an actuator assembly;

Figure 5b is a perspective view of a crimp layer in the actuator assembly of Figure 5a;

10 Figure 5c is a perspective underside view of the actuator assembly of Figure 5a with some components removed for clarity;

Figure 6a is a side view of a fifth arrangement of an actuator assembly;

Figure 6b is a perspective view of a chassis in the actuator assembly of Figure 6a;

15 Figure 6c is a perspective underside view of the actuator assembly of Figure 6a with some components removed for clarity;

Figure 7a is a side view of a sixth arrangement of an actuator assembly;

Figure 7b is a perspective view of a second wedge layer in the actuator assembly of Figure 7a;

20 Figure 7c is a perspective underside view of the actuator assembly of Figure 7a with some components removed for clarity;

Figures 8a and 8b are side and plan views of a seventh arrangement of an actuator assembly, respectively;

25 Figure 8c is a perspective view of a crimp layer of the actuator assembly of Figure 8a;

Figures 9a and 9b are side and underneath perspective views of an eighth arrangement of an actuator assembly with some components removed, respectively;

Figure 9c is a perspective plan view of the actuator assembly of Figure 9a;

30 Figures 10a and 10b are perspective plan and underneath perspective views of a ninth arrangement of an actuator assembly with some components removed, respectively;

Figure 10c is a perspective view of a second wedge layer in the actuator assembly of Figure 10a;

Figure 10d is a side view of the actuator assembly of Figure 10a;

Figure 11a is an underneath perspective view of a tenth arrangement of an actuator assembly with some components removed;

5 Figure 11b is a perspective plan view of the actuator assembly of Figure 11a;

Figure 11c is a perspective plan view of a first wedge layer in the actuator assembly of Figure 11a;

Figure 12a is a perspective plan view of an eleventh arrangement of an actuator assembly with some components removed;

10 Figure 12b is an underneath perspective view of the actuator assembly of Figure 12a with some components removed;

Figure 13a is a side view of a twelfth arrangement of an actuator assembly with some components removed;

15 Figure 13b is an underneath perspective view of the actuator assembly of Figure 13a;

Figure 14 is an underneath perspective view of a thirteenth arrangement of the actuator assembly;

Figure 15 is a schematic side view of two layers of a fourteenth arrangement of the actuator assembly;

20 Figure 16 is a schematic side view of some layers of a fifteenth arrangement of the actuator assembly.

Broadly speaking, embodiments of the present techniques provide actuator assemblies which may be incorporated in haptic button assemblies. The haptic button typically has a low profile while still providing a satisfying tactile response or sensation to a user. Advantageously, the haptic button assemblies may have a profile that, for example, enables the assembly to be incorporated into the free space along an edge of a portable computing device. The haptic assemblies may, for example, be arranged to move the button perpendicularly with respect to the edge of the device.

25 30

The term "bearing" is used interchangeably herein with the terms "ball bearing" and "roller bearing". The term "bearing" is used herein to generally mean any element or combination of elements that functions to constrain motion to only the desired motion and reduce friction between moving parts. In some

embodiments of the present techniques, more than one type of bearing element may be used in combination to provide the bearing functionality. Accordingly, the term "bearing" used herein includes any combination of, for example, ball bearings and rollers. The bearings may be made from any suitable material, e.g. ceramic or another insulating material where they potentially contact metal layers within the assembly or metal where they are isolated from such layers.

Each of the actuator assemblies described herein may be incorporated into any device in which it may be useful to provide a user of the device with haptic feedback. For example, the actuator assemblies may be incorporated into an electronic device or a consumer electronics device, such as a computer, laptop, portable computing device, smartphone, computer keyboard, gaming system, portable gaming device, gaming equipment/accessory (e.g. controllers, wearable controllers, etc.), medical device, user input device, etc. It will be understood that this is a non-limiting, non-exhaustive list of possible devices, which may incorporate any of the actuator assemblies described herein. The actuator assemblies described herein may be, for example, incorporated into or otherwise provided along an edge of a smartphone or on a surface of a smartphone. Each actuator assembly described herein may be provided as a standalone module that may be incorporated into an electronic device during manufacture, and may be adapted to suit the device specifications such that it fits into a casing or external surface of the electronic device. Each actuator assembly may comprise electrical connections, which may couple the assembly to the device's processor(s), chip(s), motherboard, etc., such that the action of the button being pressed may be processed by the device so that the haptic feedback can be provided via the actuator assembly.

The inclined surface of each groove on the intermediate element and the moveable element may be considered to form a wedge and thus each of the intermediate element and the moveable element may be termed a wedge layer. Each of the grooves are aligned to face one another which results in a compact design for the actuator assembly. The intermediate element may be moveable from a rest position to an activated position (e.g. when the SMA wires contract) and/or from the activated position to the rest position (e.g. when the SMA wires cool and/or a restoring force is applied as described below). The at least one bearing may be configured to roll across the inclined surface of the groove on

the intermediate element as the intermediate element moves between the rest and activated positions. The inclined surface of the groove across which the bearing rolls may be termed a ramp or a race.

5 The at least one bearing may also be configured to bear against the inclined surface of the groove on the moveable element as the intermediate element moves between the rest and activated positions whereby the moveable element is moved in the first direction. The inclined surface of the groove on the intermediate element may have a length which is matched to a desired movement of the moveable element. An angle between the inclined surface on
10 the intermediate element and a plane perpendicular to the first direction (e.g. a horizontal plane when the moveable element moves vertically) may define a gearing ratio, e.g. a ratio of movement of the intermediate element to the moveable element.

The inclined surface on the intermediate element may be inclined at a
15 same or different angle to the inclined surface on the moveable element. In other words, the inclined surfaces may be substantially parallel (subject to tolerances in manufacturing).

In some examples, the angle may be approximately between 10 to 25 degrees, for example 17 or 18 degrees. In other examples, the angle may be
20 between 15 and 30 degrees, for example 19 degrees or 23 degrees.

Each groove may further comprise a second inclined surface. In other words, each groove may have a V-shape cross-section. The second inclined surface of each groove may act as an end-stop to control the maximum amount of movement of the bearing. The second inclined surface on the moveable
25 element may act as an endstop to limit the maximum movement across the first inclined surface on the intermediate element when the SMA wire(s) contract. The second inclined surface on the intermediate element may act as an endstop to limit the maximum movement across the first inclined surface on the intermediate element when the SMA wire(s) cool. The second inclined surface
30 may have a steeper angle than the first inclined surface. The angle may be between 0 to 90 degrees from a plane perpendicular to the first direction. A steeper angle may provide a better endstop but increasing the angle reduces the length that a bearing may travel across the first inclined surface. The second inclined surfaces of each element need not be parallel.

In other words, for each groove, the first inclined surface may be inclined at a first angle and the second inclined surface may be inclined at a second angle which is larger than the first angle. The first inclined surface of the groove on the moveable element may be parallel to the first inclined surface of the groove on the intermediate element. Similarly the second inclined surface of the groove on the moveable element may be parallel to the second inclined surface of the groove on the intermediate element. It may thus be possible to form the groove(s) on each element using the same tool. This may be advantageous for controlling the manufacturing tolerances and for improved repeatability of said tolerances.

There may be at least one additional bearing adjacent an opposed surface of the intermediate element to the groove. Such additional bearing(s) may facilitate movement of the intermediate element within the actuator assembly, e.g. against a housing and/or sensor. Each of the intermediate element and the moveable element may comprise at least two grooves, for example, there may be two grooves within which at least one bearing is located. There may be an additional stiffening groove, for example between the grooves within which the bearings are located.

When a groove accommodates a bearing, each groove may locate at least one bearing and may locate two bearings. For each groove, there may be at least three bearings associated with the groove and optionally four bearings. For example, there may be two bearings within the groove and one or two bearings on the opposed surface. Alternatively, there may be a single bearing within the groove and two bearings on the opposed surface. Four bearings for each groove provides improved stability relative to three bearings and may help counteract off-centre loading at a contact surface for the actuator assembly. The bearing(s) in at least one of the grooves on both the intermediate element and the moveable element may further engage with the second inclined surface on the moveable element in the rest position.

Each groove (including a stiffening groove) may extend across a width of the intermediate element or the moveable element respectively. Each groove may be continuous or discontinuous.

At least one of the arrangements described below includes a seal, e.g. to prevent ingress of water and/or dust and it will be appreciated that a seal may

be incorporated in all arrangements. Similarly, the sensor shown in the first arrangement may be incorporated in all arrangement. The sensor may be a contact sensor, a capacitive sensor, an inductive sensor, a force sensor, a pressure sensor, an optical sensor and an ultrasonic sensor.

5 Each of the moveable element and the intermediate element may have a generally constant cross-section. In other words, on the opposed surface of each element to the groove(s), there is a correspondingly shaped projection(s). Each of the moveable element and the intermediate element may be formed from stainless steel, e.g. by pressing and may be pressed using the same tool
10 where the inclined surfaces are parallel.

The actuator assembly may further comprise a resilient element (e.g. spring) which helps to restore the moveable element to the rest position when the SMA wire is not powered. The button itself may assist in resetting the mechanism, for example, while the button is pressed the compliance in the
15 finger (skin) may act as a spring to reset the mechanism. Where incorporated, the resilient element may comprise at least one aperture through which a portion (e.g. the projection) of the moveable element projects. This may help to reduce the overall height of the actuator assembly. Apertures may be incorporated in other layers as described below to help reduce height.

20 Figures 1a to 1k show a first arrangement of an actuator assembly 110 which may be provided within a cavity below a button. As explained in more detail below, movement of the button in a first direction, e.g. as a result of the user activating the button, may be detected by a force exerted on a force sensor or in any other appropriate way by a sensor. The sensor may be coupled to
25 control circuitry (not shown), and the sensor may be configured to communicate with the control circuitry when the button press is detected. The detection by the sensor of a user pressing the button causes the haptic feedback to be generated and applied via the actuator assembly 110.

30 As shown in Figure 1a, the actuator assembly comprises a housing 112 which may be formed from any suitable material, e.g. steel. The housing 112 may be manufactured in any suitable way, e.g. by deep drawing a flat sheet. The housing is covered by a resilient layer 114 which may be a spring or flexure. The overall size of the housing may be small, e.g. 12mm by 3.5mm by 1.9mm. The resilient layer 114 comprises two apertures which locate two projections

116a, 116b on a first wedge layer which is housed in the housing 112. By allowing the projections 116a, 116b to extend beyond the housing 112, the depth of the actuator assembly may be reduced.

Each of the apertures is generally centrally located on a corresponding flap each which is defined in the resilient layer 114 by a corresponding channel 118a, 118b. Each channel 118a, 118b is generally H-shaped with a larger width in the crosswise section of the channel. The resilient layer 114 also comprises a pair of parallel slots 120a, 120b to increase flexibility of the resilient layer 114.

Figure 1b shows the internal components of the actuator assembly 110. Within the housing 112, there is a first wedge layer 122 and a second wedge layer 124 between which there are ball bearings 130a, 130c. A spacer 128 separates the second wedge layer 124 from a crimp layer 126 which engages with an inner surface of the housing 112 via ball bearings 132a, 132c. There is also a chassis 134 supporting various layers as described in more detail below.

The shape of each wedge layer is shown in detail in Figures 1c and 1d. Each wedge layer is an elongate layer which may be made of stainless steel. The first wedge layer 122 comprises a pair of grooves 164a, 164b which extend laterally across the first wedge layer 122. The grooves 164a, 164b have a generally triangular cross-section shape. Each wedge layer has a generally constant thickness and thus each groove defines a corresponding projection 116a, 116b. Similarly, the second wedge layer 124 comprises a pair of grooves 166a, 166b and a pair of generally triangular shaped projections 150a, 150b. The grooves 164a, 164b on the first wedge layer 122 are aligned with the grooves 166a, 166b on the second wedge layer 124 so that the projections project away from each other.

Each wedge layer 122, 124 may be formed by pressing a strip of metal to form the grooves and hence the projections. The wedge layers may be formed within a frame to assist in the manufacturing process. The frames may be attached to the wedge layers by detach tabs 168 which as shown may be provided in pairs, one on either long edge of the wedge layers 122, 124. Once the frame is removed, the detach tabs 168 remain.

As shown in Figure 1e, the grooves in each wedge layer are adjacent one another and a pair of ball bearings 130a, 130b, 130c, 130d is located in each pair of grooves. The ball bearings 130a, 130b, 130c, 130d are provided between

a lower surface of the first wedge layer 122 and an opposed upper surface of the second wedge layer 124. Figures 2a to 2d illustrate the relative movement of the second wedge layer to the first wedge layer which is facilitated by the bearings.

5 Figure 1f shows the detail of the crimp layer 126 which comprises an elongate portion 170 and two pairs of crimps with each pair having a crimp located at opposed ends of the crimp layer 126. A first pair of crimps 138a, 138b is mechanically and electrically connected to a first set of SMA wires 142 and a second pair of crimps 140a, 140b is mechanically and electrically
10 connected to a second set of SMA wires 144. In this arrangement, each set comprises three wires but it will be appreciated that this is merely exemplary and a different number of wires may be included in each set. There is thus at least one SMA wire, and may be at least two SMA wires (one on either edge) in the actuator assembly. A first crimp 138a, 140a in each pair of crimps is
15 connected to one end of the elongate portion 170 of the crimp layer 126 and may be termed a moveable crimp as explained in more detail below. A second crimp 138b, 140b in each pair of crimps is connected to the static chassis 134 and may be termed a static crimp.

 Electrical connections 146, 148 extend from the static crimps and project
20 out through a side wall of the housing as shown in Figure 1a. The whole crimp layer 126, or the portion comprising the crimps, is formed of a material that is suitable for coupling to (e.g. crimping) an SMA actuator wire. For example, the crimp layer may be made from a suitable metallic material, e.g. stainless steel which is gold plated in the crimps and on the electrical connections to improve
25 the electrical connections. Like the wedge layers, the crimp layer 126 may be formed in a frame and detached from the frame before or during the assembly process leaving detach tabs 172.

 The elongate portion of the crimp layer 126 comprises a first pair of bearing apertures within which the pair of ball bearings 132c, 132d which are
30 adjacent the static crimps are located. At the opposed end of the elongate portion of the crimp layer 126 there is a second pair of bearing apertures within which the pair of ball bearings 132a, 132b which are nearest the moveable crimps are located. The bearing apertures are generally in the form of elongate circles which allow the spherical ball bearings to roll within the length of the

apertures. The ball bearings 132a, 132b, 132c, 134d facilitate movement of the elongate portion. In this arrangement, there are two pairs of ball bearings, one at each opposed end of the elongate portion. Guide projections 136a, 136b may help ensure that the movement of the elongate portion is controlled to a particular direction. The guide projections 136a and 136b may also optionally be used as end-stop features. Their main function may be to act as an electrical insulation wall between the SMA wires and the live metal parts.

The elongate portion of the crimp layer 126 also comprises a pair of wedge apertures for receiving the projections 150a, 150b of the second wedge layer. As shown in Figure 1b, the projections 150a, 150b of the second wedge layer are slightly sub-flush with the crimp layer 126 and do not extend beyond the crimp layer 126 because of the thickness of the crimp layer and spacer layer which is related to the diameter of the bearings. The elongate portion of the crimp layer 126 also comprises a pair of elongate indentations which extend partially along opposed sides of the elongate portion and each receives a corresponding guiding projection 136a, 136b on the chassis 134.

The chassis 134 is an inner casing which surrounds but is not attached to the first and second wedge layers 124, 126. Figure 1g and 1h shows the detail of the chassis 134 which is generally frame shaped. The chassis 134 comprises a central aperture 154 which extends along most of the length of the chassis 134. The first and second wedge layers are located in this aperture. A pair of guiding projections 136a, 136b extends either side of the central aperture 154 and is received in elongate indentations on the crimp layer to assist in controlling movement of the elongate portion relative to the chassis 134 and to provide electrical insulation between the wires and other parts of the assembly. A pair of heatsinks 181 are located along the edges of the chassis 134 and may assist in cooling the SMA wires after activation.

The chassis 134 also comprises a first end portion 152 which extends along one end of the chassis 134 and which is raised relative to the surface of the chassis 134 around the aperture. The first end portion 152 comprises a first projection 162 which projects from the surface of the first end portion 152. The projection 162 is a locating feature for a force concentrator and for the static crimps. The force concentrator may be glued to the housing. Alternatively, the force concentrator may be floating. There is also a pair of locating stubs 176

which are at the opposed side of the first end portion 152 to the endstop 162. As shown in Figure 1f, the locating stubs 176 are adjacent the detach tabs 172 of the crimp layer 126 and thus help located the crimp layer 126 correctly on the chassis. The first end portion 152 comprises a central divider 174 which as
5 shown in Figure 1f helps maintain the electrical separation between each of the second crimps 138b, 140b which are mechanically connected to the first end portion 152 (e.g. by gluing). The chassis 134 is a static element of the actuator assembly and hence the second crimps may be termed static crimps. The chassis should be able to resist the forces from the wires.

10 The elongate portion of the crimp layer 126 covers the central aperture 154 and extends towards but is not connected to the first end portion 152 on the chassis 134. The elongate portion is a moveable element of the actuator assembly and moves relative to the chassis 134 which may be described as a static element. Thus, the moveable crimps are termed moveable because they
15 are attached to the moveable element. Similarly, the static crimps are termed static because they are attached to the static element. The moveable crimps move relative to the static crimps.

As shown in Figures 1f and 1g, there is a second end portion 178 at the opposed end of the aperture 154 in the chassis to the first end portion 152. The
20 second end portion 178 comprises a raised stub 180 which like the locating stubs has a surface which engages with the force concentrator (which may be floating as explained above). Generally speaking, if an SMA actuator wire is stretched too far (i.e. a certain tension is exceeded), the SMA actuator wire may weaken or become damaged, or even break. This may happen for example in a
25 drop or other extreme event. Therefore, the second end portion 178 may act as a second endstop to restrict the movement of the crimp layer and the second wedge layer so that the at least one SMA actuator wire does not overstretch.

As explained in more detail in relation to Figures 2a to 2d, movement of the crimp layer causes movement of the second wedge layer which is transferred
30 to the first wedge layer (moveable element). The movement of the moveable element may for example be between 10 μm to 500 μm , more preferably between 10 μm to 100 μm and may be in the first direction, which as indicated in the Figures is vertical. More generally, the first direction may be a direction that is perpendicular to the external surface of the resilient layer 114, as indicated by

arrow A in Figure 1b. The elongate portion of the crimp layer and the second wedge layer (optionally with the spacer) may be considered to form an intermediate moveable element which moves in a second direction which is different to the first direction. The second direction may be a direction that is substantially parallel to the external surface of the resilient layer 114, as indicated by arrow B in Figure 1b. The first direction and the second direction may be orthogonal. Movement of the intermediate moveable element in the second direction may cause movement of the moveable element and hence a button in the first direction. That is, movement of the intermediate moveable element may cause the button to be moved in such a way that a haptic effect/sensation is delivered to a user touching the button. The concept of moving intermediate moveable element in one direction to cause movement of the moveable element (and hence button) in another direction may be implemented in a number of ways.

The movement of the various layers may be controlled by applying one or more pulses that deliver power to the at least one SMA actuator wire 142, 144, which in turn control the movement of a button to which the actuator assembly is connected as described below. The pulse rate and the energy per pulse may be varied to deliver different types of haptic sensation. For example, the actuator may be activated multiple times to provide a 'buzz' to the user.

The resilient layer 114 may perform two functions. The resilient layer may function as a return spring which 'resets' the actuator. Thus, the resilient layer 114 may comprise an element which opposes the force of the at least one SMA actuator wire 142, 144. For example, as described above the H-shaped channels 116 shown in Figure 1a define tabs which may each act as a return spring. Each return spring may be arranged to oppose the contraction of the at least one SMA actuator wire 142, 144. The resilient layer may function as a mechanism that constrains the motion of the first wedge layer to be along the first direction (i.e. perpendicular to the external surface of the resilient layer 114, as indicated by arrow A in Figure 1b). The resilient layer 114 may be most compliant along the first direction, less compliant in a first orthogonal direction corresponding to the width of the resilient layer, and least compliant in a second orthogonal direction corresponding to the length of the resilient layer. During actuation, the resilient layer 114 may be loaded by the SMA actuator wire(s)

along the first direction and along the second orthogonal direction. However, movement of the resilient layer 114 along the second orthogonal direction may be insignificant because the resilient layer is stiffest (least compliant) in that direction. The two functions of the resilient layer 114 may be independent of each other.

Each return spring may move the first wedge layer in an opposite direction, i.e. away from the resilient layer 114. This then causes the second wedge layer to move to the left when the wire is not being powered and is not being actively heated (i.e. is cooling). The element which opposes the force of the at least one SMA actuator wire 142, 144 may be any suitable resilient biasing element, and it will be understood that the return spring is only one non-limiting example.

In alternative embodiments, a return spring may not be used. Instead, the force of a user's finger on the button may be sufficient to oppose the contraction of the at least one SMA actuator wire 142, 144 and thereby move the first and second wedge layers. Both the force of a user's finger and the return spring may be used together to return the wires to their original length, particularly if the return spring is relatively weak.

Figure 1h shows the upper surface of the chassis 134 which has various raised areas which are attached (e.g. glued) to a surface of portions of the resilient layer 114 which are not part of the return spring. The attached portions of the resilient layer 114 thus remain static and the shapes of the raised areas match the static portions of the resilient layer. The first end portion 152 has a first raised surface 182, the second end portion 178 has a second raised surface 184 and there are elongate raised strips 186 along each long edge of the chassis 134. Referring to Figure 1a, these static portions of the resilient layer are the strips outside the parallel slots 120a, 120b and the portions on the other side of the wider slot in the H-shaped slots to the tabs having the apertures for the projections of the second wedge layer.

Figure 1i shows the detail of the spacer 128 which is contiguous with the elongate portion of the crimp layer. The spacer 128 comprises a pair of elongate indentations 156a, 156b which align with the corresponding indentations on the crimp layer and receive the guiding projections on the chassis. The spacer 128 also comprises two elongate rectangular apertures 160a, 160b. These apertures

provide space for both the bearings and the projections on the second wedge layer. As with the crimp layer and the wedge layers, the spacer 128 may be formed in a frame and once removed from the frame, there may be detach tabs remaining.

5 Figure 1j shows the detail of one sensor 162 which may be used to detect when a user is pressing the button. The sensor 162 may be a force sensor and may contact a pair of generally circular contact plates which are adjacent the housing. A cantilever plate 188 (also termed a force concentrator) is provided above the force sensor 162. When a button is pressed, the downward force on
10 the button is transferred through the various layers to the cantilever plate 188 which causes it to deform and make an electrical or mechanical contact (as required) with the sensor 162. The downward force required to trigger the sensor is determined by the material and thickness of the various layers and may also be determined by the gearing ratio, e.g. the wedge angle, depending
15 on the arrangement of the layers. For example, if the bearings are assembled to sit at the bottom of the grooves in the rest position, the gearing ratio may not be relevant to the downward force. For example, if the actuator assembly has a stiffness which is significantly higher than the stiffness of a finger, the performance degradation is not significant. Merely as exemplary numbers, the
20 first wedge layer together with the resilient layer may have a combined stiffness of approximately $0.31\text{N}/\mu\text{m}$ which delivers a force of approximately 2 Newtons, e.g. for an angle of approximately 17.5 degrees.

For example, the sensor 162 may be a force sensing resistor. It will be appreciated that this is merely one example of a sensor and any suitable sensor
25 which is able to detect a button press may be used. Other examples include strain gauges, capacitive sensors, electroactive polymers, switches, inductive sensors and piezoelectric films.

Figure 1k shows a haptic button assembly incorporating the actuator assembly 110 described above. A button 100 is separated from the actuator
30 assembly 110 by an optional seal 102. The seal 102 may be a waterproofing and/or dust proofing seal to prevent water and/or dust ingress into the cavity. Generally speaking, a small gap may be provided between the button and a casing of the device within which the button is incorporated. The gap may avoid contact between a surface of the button and a surface of the casing, which may

increase friction and affect the performance of the haptic sensation. However, the gap may then enable liquid and/or dirt to enter the actuator assembly, where it could affect the performance of the assembly. For example, dirt could inhibit the movement of button, the bearings and/or the various layers, while liquid could interfere with any electronic components/circuitry. Thus, the protective seal 102 may advantageously enable a waterproof/dustproof haptic button assembly to be provided. The seal may also seal the assembly against the frame of the electronic device into which the assembly is integrated. This may also prevent water and/or dust ingress in to the electronic device.

The protective seal 102 may be provided across the entire area of the actuator assembly 110. The protective seal 102 may be formed of a flexible material, an elastic material, or a material which exhibits some flexibility/elasticity when it is provided as a thin layer, which enables the protective seal 102 to flex as the button moves. (If the protective seal 102 were not made of a flexible/elastic material, the protective seal may inhibit or limit the motion of the button, which may affect the haptic sensation delivered by the assembly). The protective seal 102 may be formed of an elastomer, for example. The protective seal 102 may be attached to the casing of the device by any suitable technique, such as adhesive, welding, compression or otherwise.

The haptic button assemblies described herein may be incorporated into a variety of different devices, including smartphones and wearables which may be required to meet a particular waterproofing standard. For example, such devices may be required to meet the standard necessary for an Ingress Protection Rating of 67 or 68. An IP rating of 67 indicates the device has some sort of protection that results in the device being dust tight and being waterproof when the device is immersed in up to 1m of water, while an IP rating of 68 indicates the device has some sort of protection that results in the device being dust tight and being waterproof when the device is continuously immersed in more than 1m of water. Accordingly, if the haptic button assemblies are to be incorporated into a smartphone or wearable device with an IP rating of 67 or 68, the seal around the haptic button assembly which seals the assembly in the electronic device also needs to be water and dust proof to the same standard.

In this arrangement, a printed circuit board (PCB) 106 is mounted to one side of the actuator assembly 110 and is connected via the electrical contacts

which extend through the housing as described above. The actuator assembly 110 is supported on a frame 104 which may be resilient and which is attached to the housing of a device in which the button 100 is incorporated, e.g. a mobile phone or the like.

5 Figures 2a to 2d illustrate the change in arrangement of the components when the actuator assembly is actuated (e.g. when a button press is detected as explained in more detail below). Figures 2a and 2c show the rest location of the components and Figures 2b and 2d show the activated location of the components in which a button attached to the actuator assembly has been
10 moved in a first direction. At rest, each end of the first and second wedge layers 122, 124 adjacent the first end portion 152 of the chassis are generally aligned and are set with a relatively large gap from the first end portion 152. Power may be delivered to the at least one SMA actuator wire so that they become hot and contract. The first crimps 138a in each pair of crimps and hence the elongate
15 portion move in a second direction (laterally/sideways) towards the first end portion 152 on the chassis. When comparing Figure 2a with Figure 2b, the lateral movement is to the right in this arrangement.

 The elongate portion of the crimp layer 126 is connected to the second wedge layer 124 by a spacer 128. As the elongate portion of the crimp layer
20 126 is moved towards the first end portion 152, the spacer 128 and also the second wedge layer 124 is moved in the same direction. Thus, as shown in Figure 2b, the second wedge layer 124 is closer to the first end portion 152 than the first wedge layer 122. The movement from the rest to the activated location also means that the grooves on the second wedge layer 124 are moved further
25 out of alignment with those on the first wedge layer 122 (in other words, the bases of each groove are further apart in the activated location than in the rest location).

 Figures 2c and 2d show the detail of the movement of the ball bearings within the grooves in each of the first and second wedge layers 122, 124. Each
30 groove has a triangular cross-section and may thus be considered to have a shallow V-shape. As shown in Figure 2c, each ball bearing 130a engages with three engagement surfaces 190, 192, 196 in the grooves in the rest position. Two engagement surfaces 190, 192 are on the first wedge layer 122 and one engagement surface 196 is on the second wedge layer 124. As shown in Figure

2d, each ball bearing engages with two engagement surfaces 190, 196 in the activation position; one on each wedge layer. Each engagement surface is ramped (inclined) and may be termed a localised ramp. The engagement surface 196 on the second wedge layer 124 and a first engagement surface 190 on the first wedge layer 122 are inclined by the same angle α , in the same direction and are thus substantially parallel to one another. Specifically, the direction in which the engagement surface 196 on the second wedge layer is inclined allows the ball bearing 130a to roll up the engagement surface 196 as the second wedge layer 124 moves towards the first end portion of the chassis. The engagement surface 196 on the second wedge layer may thus be termed a race. For example, the angle α may be approximately 17.5 degrees.

As shown in Figure 2d, as the second wedge layer is moved in the second direction (i.e. laterally), the ball bearing 130a rolls up the engagement surface 196 on the second wedge layer 124. As the ball bearing 130a moves it pushes against the first engagement surface 190 on the first wedge layer 122. This causes the first wedge layer 122 to be moved in the first direction (i.e. vertically). The second engagement surface 192 is inclined at a steeper angle β than the first engagement surface 190 and acts as an endstop to prevent too large a movement. The ratio between the angle, α and the horizontal may be set to provide the necessary gear ratio, e.g. the ratio between lateral movement of the second wedge layer and the vertical movement of the first wedge layer. The length of the slope of the engagement surface 196 is matched to the lateral movement of the second wedge layer 124. The shape of the grooves and the ball bearings thus translate the lateral movement of the second wedge layer 124 into vertical movement of the first wedge layer 122. The tips of the projections 116a, 116b on the first wedge layer 122 are thus moved vertically which may then create the haptic sensation on the button. The second wedge layer 124 also has a surface 194 which does not engage with the ball bearing in normal operation in this example.

In other words, at equilibrium the ball bearing is in a rest position part way up the first inclined surface (ramp). However, it will be appreciated that the ball bearing may be in a rest position in which it engages with all four inclined surfaces. In the arrangement shown, the ball bearing will roll further down the ramp when the user applies a force at the button surface. This will stretch out

the wires to their 'optimum' length (or tension) to on average achieve the maximum stroke capability over temperature. In other words, overstretching of the wires is allowed after assembly. In the other case, a force applied at the button surface does not result in any movement of the wedge layers, but motion
5 can only be generated in one direction on activation of the wires. Here, the assembly must be such that the wires are already at their optimum length (or tension) at equilibrium, otherwise the average stroke capability over temperature may be reduced.

In other words, no overstretching of the wires is allowed after assembly.
10 A similar effect may be achieved by increasing the crimping tension instead of overstretching the wires. It is possible that increasing the tension can be better controlled by defining a gap in the actuator to overstretch the wires. The three surface engagement arrangement may be used in conjunction with increasing the crimping tension while also preventing overstretching the wires in the
15 actuator assembly. The four engagement surface option with increased crimping tension may represent a good balance between assembly complexity and manufacturing tolerances.

This surface 194 is inclined at the same angle as the second engagement surface 192 of the first wedge layer 122, i.e. the surfaces are substantially
20 parallel to one another. When the SMA wires are no longer activated, the return force of the resilient layer forces the first wedge layer 122 back to its rest position. The ball bearing 130a thus rolls down the engagement surface 196 to its rest position. If the return force is too excessive or an additional load is applied at the button surface to cause an "overload condition", the steeper
25 surface 194 of the second wedge layer acts as an endstop to prevent excessive movement of the second wedge layer.

As explained above in this arrangement, the ball bearings 130a are in contact with three engagement surfaces in the rest condition. However, as illustrated in Figure 2b, in the activated position, the ball bearings 130c are only
30 in contact with the two parallel surfaces having an angle of α . Thus, as the second wedge layer moves laterally, the ball bearings roll along the inclined surface on the first wedge layer having an angle of α .

Figures 3a to 3d illustrate a second arrangement of an actuator assembly 210. The assembly 210 in Figures 3a to 3d is similar to the arrangement shown

in Figure 1a, and therefore, for the sake of conciseness, like features are not described. In this example, as shown in Figure 3a, the resilient layer 214 also comprises two apertures each of which is generally centrally located on a corresponding flap and each of which locates one of the projections 116a, 116b on a first wedge layer housed in the housing 112. In this resilient layer 214, the flaps are defined in U-shaped channel 218a, 218b. The resilient layer 214 also comprises a pair of parallel slots 120a, 120b to increase flexibility of the resilient layer 214. It will be appreciated that the different arrangement of slots changes the flexibility of the resilient layer 214.

As shown in Figure 3b, the chassis 234 is a simplified version of the chassis in the first arrangement. As in the previous arrangement, the chassis 234 comprises a central aperture 254 which extends along most of the length of the chassis 134 and a pair of guiding projections 136a, 136b extends either side of the central aperture 254. In this arrangement, the first end portion 252 is a raised rectangular portion having a flat surface.

As shown in Figure 3c, the simplified chassis 234 is attached to a simplified crimp layer 226. As in the previous arrangement, the crimp layer 226 comprises an elongate portion 170, a first pair of crimps 138a, 138b mechanically and electrically connected to a first set of SMA wires 142 and a second pair of crimps 140a, 140b mechanically and electrically connected to a second set of SMA wires 144. The second crimp 138b, 140b in each pair of crimps is connected to the first end portion 252 of the chassis 234, for example each crimp may be glued to an upper surface of the first end portion 252 and/or insert moulded or otherwise attached using standard techniques.

Figure 3d shows the detail of the alternative spacer 228 which is incorporated in this alternative arrangement. In this arrangement, the two elongate rectangular apertures are each separated into a generally square aperture 260a, 260b within which the projections on the second wedge layer are located and two pairs of bearing apertures 258a, 258b, 258c, 258d. The bearing apertures are generally in the form of elongate circles which allow the spherical ball bearings to roll within the length of the apertures. It will be appreciated that this spacer may also be used in other arrangements.

Figures 4a and 4b show a third arrangement of an actuator assembly 310. The actuator assembly 310 in Figure 3a and 3b is similar to the arrangement

shown in Figures 1a and 3a therefore, for the sake of conciseness, like features are not described. Specifically, in this example, as shown in Figure 3a, the resilient layer 214 also comprises U-shaped channel 218a, 218b and a pair of parallel slots 120a, 120b. In this arrangement, the PCB 306 (which may also be
5 a similar device such as an FPC) which controls the actuator assembly 310 is arranged underneath the actuator assembly 310.

Figure 4b shows the consequential change to the crimp layer 326 resulting from the different location of the PCB 306. As in the previous arrangement, the crimp layer 326 comprises an elongate portion 170, a first pair of crimps 138a,
10 138b and a second pair of crimps 140a, 140b. In this arrangement, the electrical connections 346, 348 which extend from the static crimps 138b, 140b project through a base of the housing. Thus as shown in Figure 4b, the electrical connections 346, 348 project downwards.

Figures 5a, 5b and 5b show a fourth arrangement of an actuator
15 assembly 410. The actuator assembly 410 in Figures 5a, 5b and 5b is similar to the arrangement shown in previous Figures and therefore, for the sake of conciseness, like features are not described. In this example, there is also no spacer. However, in this arrangement, the apertures on the crimp layer 426 are larger than those of the arrangement of Figure 5a to allow the projections 150a,
20 150b on the second wedge layer 426 to protrude through and extend beyond the crimp layer 426. The resilient layer 214 also has apertures, like the embodiment of Figure 3a, to allow the projections 116a, 116b of the first wedge layer also to extend through the resilient layer 214.

Figure 5b shows the detail of the alternative crimp layer 426 which is
25 incorporated in this alternative arrangement. In this arrangement, there are two generally square apertures 460a, 460b within which the projections on the second wedge layer are located and two bearing apertures 458a, 458b. In addition to increasing the size of the wedge apertures 460a, 460b relative to the previous arrangement, the bearing apertures are wider than normal and have a
30 larger width than length. This allows each bearing aperture 458a, 458b to accommodate two ball bearings but still allow the ball bearings to roll within the relatively shorter length of the apertures. It will be appreciated that this crimp layer 426 may also be used in other arrangements.

In Figure 5c, the crimp layer (and the housing) has been removed to show the underside of the second wedge layer 424. As in previous arrangements, there are two projections 150a, 150b which extend laterally across the elongate second wedge layer 424. At each opposed end, there is a recess 496 which extends laterally across the elongate second wedge layer 424 and which has a generally rectangular cross-section. Each recess 496 accommodates a pair of ball bearings 132a, 132b, 132c, 132d which facilitates movement of the second wedge layer 424 against the housing (not shown). The incorporation of the recesses 496 together with the larger wedge apertures in the resilient layer and the crimp layer means the height of the actuator assembly may be reduced relative to the previous arrangement.

Figures 6a, 6b and 6c show a fifth arrangement of an actuator assembly 510. The actuator assembly 510 in Figures 6a, 6b and 6c is similar to the arrangement shown in previous Figures (particularly Figure 5a) and therefore, for the sake of conciseness, like features are not described. In this arrangement, like in Figure 5a, the projections 150a, 150b on the second wedge layer 426 to protrude through and extend beyond the crimp layer 526 and the projections 116a, 116b of the first wedge layer also extend through the resilient layer 214. Furthermore, the second wedge layer 426 comprises recesses for the ball bearings which run on the housing as shown in Figure 5c.

As shown in Figure 6b and in line with previous arrangements, the chassis 534 comprises a central aperture 554 which extends along most of the length of the chassis 534. The chassis comprises a first end portion 552 which is a raised rectangular portion having a flat surface and provides a surface to which the static crimps are attached. At the opposed end of the chassis 534 to the first end portion 552, there is a second end portion 578 which is also a raised rectangular portion having a flat surface. As described above, the second end portion 578 may act as an endstop to restrict the movement of the crimp layer and the second wedge layer so that the at least one SMA actuator wire does not overstretch when a force is applied to stretch out the wires, during drop events or during other impact/shock events. Thus, compared to the previous arrangement, this arrangement has a larger endstop.

Figure 6c shows how the crimp layer 526 almost abuts the second end portion 578 in the rest position. In this arrangement, the crimp layer 526 has

reverted to separate apertures for each of the ball bearings 132a, 132b, 132c, 132d which facilitate movement of the second wedge layer 424 against the housing (not shown).

Figures 7a, 7b and 7c show a sixth arrangement of an actuator assembly 610. The actuator assembly 610 in Figures 7a, 7b and 7c is similar to the arrangement shown in previous Figures (particularly Figure 5a) and therefore, for the sake of conciseness, like features are not described. In this arrangement, like in Figure 5a, the projections 150a, 150b on the second wedge layer 626 protrude through and extend beyond the crimp layer 626 and the projections 116a, 116b of the first wedge layer also extend through the resilient layer 214.

Figure 7b shows the detail of the second wedge layer 624. As in previous arrangements, there are two projections 150a, 150b which extend laterally across the elongate second wedge layer 624. At each opposed end, there is a recessed pocket 696 which extends partially across the elongate second wedge layer 624. As shown in Figure 7b, each recessed pocket 696 accommodates a pair of ball bearings 132a, 132b, 132c, 132d which facilitates movement of the second wedge layer 624 against the housing (not shown).

In Figure 7c, the housing and PCB have been removed to show the underside of the crimp layer 626. As in the arrangement of Figure 5b, there are two generally square apertures within which the projections 150a, 150b on the second wedge layer are located and two bearing apertures each of which accommodates a pair of ball bearings 132a, 132b, 132c, 132d. The key difference in the crimp layer when compared to previous arrangements is that the moveable crimps 138a, 140a are closer to the static crimps 138b, 140b. In this arrangement, the moveable crimps 138a, 140a are not at one end of the crimp layer 626 but are aligned with one of the wedge apertures. In other words, the ball bearings 132a, 132b which are close to the moveable crimps 138a, 140a are positioned closer to the end of the crimp layer than the moveable crimps 138a, 140a and may be considered outside the moving crimp area.

Figures 8a, 8b and 8c show a seventh arrangement of an actuator assembly 710. The actuator assembly 710 in Figures 8a, 8b and 8c is similar to the arrangement shown in previous Figures (particularly Figure 7a) and

therefore, for the sake of conciseness, like features are not described. In this example, as in the previous arrangement, the ball bearings 132b which are closest to the moveable crimps 138a are closer to the end of the crimp layer 626 than the moveable crimps 138a. There is also no spacer between the second
5 wedge layer 724 and the crimp layer 726. However, unlike previous arrangements, the tops of the projections 116a, 116b are approximately flush with the resilient layer 714. Similarly, the projections on the second wedge layer 724 do not extend through the crimp layer 726. Furthermore, the ball bearings 132a, 132c are not accommodated in recesses or recessed pockets in
10 the second wedge layer 724.

The detail of the resilient layer 714 is shown in Figure 8b. As in previous arrangement, the resilient layer 714 also comprises two U-shaped channels 218a, 218b and a pair of parallel slots 120a, 120b. There are also two apertures but each of the apertures is smaller than in previous actuator assemblies.
15 Accordingly, a smaller portion of the projections 116a, 116b from the first wedge layer project through the resilient layer 714. Furthermore, the apertures are located closer to either end of the resilient layer rather than relatively centrally as in the previous arrangements.

Figure 8c shows the detail of the crimp layer 726. As in the arrangement
20 of Figure 5b, there are two apertures 760a, 760b within which the projections on the second wedge layer are located and two bearing apertures 458a, 458b. However, in this arrangement, the wedge locating apertures 760a, 760b are smaller and are generally rectangular rather than square. As in Figure 5b, the bearing apertures accommodate two ball bearings. It will be appreciated that by
25 removing the spacer but by reducing the amount the projections extend beyond the resilient layer and the crimp layer, the overall height of the actuator assembly will be approximately the same as some of the arrangements shown previously.

Figures 9a, 9b and 9c show an eighth arrangement of an actuator
30 assembly 810. The actuator assembly 810 in Figures 9a, 9b and 9c is similar to the arrangement shown in previous Figures (particularly Figure 8a) and therefore, for the sake of conciseness, like features are not described. In this example, as in the previous arrangement, the tops of the projections 116a, 116b in the first wedge layer are approximately flush with the resilient layer 814.

Similarly, the projections on the second wedge layer 724 do not extend through the crimp layer 826. However, in this arrangement, the ball bearings 132a and the moveable crimps 138a are now both located close to one end of the crimp layer 826 as in previous arrangement.

5 Figure 9b shows the detail of the crimp layer 826. As in the arrangement shown in Figure 8c, there are two generally rectangular apertures within which the projections 150a, 150b on the second wedge layer are located. In this crimp layer 826, there are individual bearing apertures each of which accommodates a single ball bearing 132a, 132b, 132c, 132d. The moveable crimps 138a, 140a
10 and the ball bearings 132a, 132b which are close to the moveable crimps 138a, 140a are positioned at one end of the crimp layer 826.

Figure 9c shows the detail of the resilient layer 814. Like the previous arrangements (particularly as shown in Figure 3a), the resilient layer 814 comprises a pair of parallel slots 120a, 120b close to the long edges of the
15 resilient layer 814. There are also two apertures, each of which locates one of the projections 116a, 116b on a first wedge layer. However, unlike previous arrangements, the apertures are larger and extend to both ends of the first wedge layer underneath. There are also pairs of parallel slots 820a, 820b which extend towards the central short axis of the resilient layer 814 from the
20 apertures. In other words, the U-shaped channels or H-shaped channels from the previous arrangements have been replaced with the enlarged apertures and pairs of parallel slots. It will be appreciated that this may change the flexibility of the resilient member but it may also remove portions of the resilient member to which the chassis may be fixed.

25 Figures 10a to 10d show a ninth arrangement of an actuator assembly 910. The actuator assembly 910 in Figures 10a to 10d is similar to the arrangement shown in previous Figures (particularly Figure 9a) and therefore, for the sake of conciseness, like features are not described. In this example, as in the previous arrangement, the resilient layer 914 comprises a pair of parallel
30 slots 120a, 120b close to the long edges of the resilient layer 914 and two apertures, each of which locates one of the projections 116a, 116b on a first wedge layer. Pairs of parallel slots 820a, 820b extend towards the central short axis of the resilient layer 914 from the apertures. Unlike the previous

arrangement, the resilient layer 914 comprises a larger end portion 998 which may be bonded to the first end portion of the chassis 934 underneath.

Figure 10b shows the detail of the crimp layer 926. In line with some of the previous arrangements, the crimp layer 926 has an elongate portion 970 in which there are two bearing apertures each of which accommodates a pair of ball bearings 132a, 132b, 132c, 132d. However, unlike the other arrangements, there are no apertures for the projections 950a, 950b, 950c, 950d on the second wedge layer. In this arrangement, there is a first pair of projections 950a, 950b at the end of the second wedge layer 954 closest to the moveable crimps 138a, 140a and a second pair of projections 950c, 950d at the opposed end of the second wedge layer 954. The moveable crimps 138a, 140a and the ball bearings 132a, 132b are aligned with one another and are positioned closer to the centre of the crimp layer 926 than the first pair of projections 950a, 950b. Similarly, the other pair of ball bearings 132c, 132d is positioned closer to the centre of the crimp layer 926 than the first pair of projections 950c, 950d. In other words, the ball bearings 132a, 132b, 132c, 132d are much closer together in this arrangement.

A first end tab 960a of the crimp layer 926 is attached to one end of the second wedge layer 924 and a second end tab 960b is attached to the opposed end of the second wedge layer 924. The first and second end tabs 960a, 960b are connected to the elongate portion 970 of the crimp layer 926 by connectors which are arranged between the respective pairs of projections. The first and second end tabs provide a mechanical connection between the crimp layer 926 and the second wedge layer 924 whereby movement of the moveable portion of the crimp layer 926 due to contraction of the SMA wires as described above also moves the second wedge layer 924.

In this arrangement, the first end portion 952 of the chassis 934 has a larger surface area than some other arrangements. This provides a larger surface area for the contacts to the static crimps 138b, 140b.

Figure 10c shows the detail of the second wedge layer 924. Unlike the previous arrangements in which a groove extends across the width of the second wedge layer to locate the ball bearings, the grooves in this arrangement are discontinuous. There are two slots 954 running parallel to the long axis of the second wedge layer 924 and these slots intersect the corresponding grooves. In

other words, there are effectively two grooves at each end of the second wedge layer and a single ball bearing is located in each groove. Consequently, there are also two pairs of projections as shown in Figure 10d.

Figure 10d shows all the various layers of the actuator assembly 910. In this example, as in the previous arrangement, the tops of the projections 116a, 116b in the first wedge layer project through the resilient layer 914. Similarly, the projections 950a, 950b, 950c, 950d on the second wedge layer 924 extend through the crimp layer 926. The ball bearings 132a, 132b, 132c, 132d are all within the central portion of the crimp layer 926. The larger first end portion 952 and its attachment to the resilient layer 914 are also more clearly shown.

Figures 11a to 11c show a tenth arrangement of an actuator assembly 1010. The actuator assembly 1010 in Figures 11a to 11c is similar to the arrangement shown in previous Figures (particularly Figure 10a) and therefore, for the sake of conciseness, like features are not described. In line with the previous arrangement, the crimp layer 1026 has an elongate portion 1070 and does not have apertures for the projections 950a, 950b, 950c, 950d on the second wedge layer. However, in this arrangement (as in other arrangements), there are two bearing apertures each of which accommodates a pair of ball bearings 132a, 132b, 132c, 132d and each of which is located at an opposed end of the elongate portion 1070. Each of the bearing apertures is formed in a corresponding end tab 1060a, 1060b which is fixed to the second wedge layer 924. A connector joins each end tab 1060a, 1060b to the elongate portion 1070 and as in the previous arrangement, the connectors pass between the respective pair of projections 950a, 950b, 950c, 950d.

The moveable crimps 138a, 140a and the ball bearings 132a, 132b are aligned with one another and are positioned at one end of the crimp layer 1026. Accordingly, the distance between the moveable crimps 138a, 140a and the static crimps 138b, 140b is increased (and hence the length of the SMA wires) relative to the previous arrangement.

Figure 11b shows the detail of the resilient layer 1014. In this example, as in the previous arrangement, the resilient layer 1014 comprises a pair of parallel slots 120a, 120b close to the long edges of the resilient layer 1014. There are also a pair of U-shaped grooves 218a, 218b as in some previous arrangements. However in this arrangement, there are two pairs of apertures, each of which

locates one of the four projections 1016a, 1016b, 1016c, 1016d on a first wedge layer 1022.

Figure 11c shows the detail of the first wedge layer 1022. Unlike the previous arrangements in which a groove extends across the width of the first wedge layer to locate the ball bearings, the grooves in this arrangement are discontinuous. There are two slots 1054 running parallel to the long axis of the second wedge layer 1024 and these slots intersect the corresponding grooves. In other words, there are effectively two grooves at each end of the first wedge layer and a single ball bearing is located in each groove. Consequently, there are also two pairs of projections as shown in Figure 11a.

Figures 12a and 12b show an eleventh arrangement of an actuator assembly 1110. The actuator assembly 1110 in Figures 12a and 12b is similar to the arrangement shown in previous Figures and therefore, for the sake of conciseness, like features are not described. In line with the previous arrangement, the various components are housed in a housing 1112 which is covered by a resilient layer 1114. However, unlike the previous arrangements, no components extend beyond the housing 1112. A PCB (or FPC) 1106 is connected to the base of the housing and extends below the housing 112.

As shown in Figure 12a, the resilient layer 1114 comprises a pair of parallel slots 120a, 120b close to the long edges of the resilient layer 1014 and a pair of U-shaped grooves 218a, 218b as in some previous arrangements. The U-shaped grooves 218a, 218b define a pair of flexible tabs but unlike the previous arrangements there are no apertures in these tabs. The resilient layer 1114 is thus simplified relative to the other arrangements.

Figure 12b shows the detail of the crimp layer 1126 which is similarly simplified. In line with the previous arrangement, the crimp layer 1126 has an elongate portion 1170 having two bearing apertures each of which accommodates a pair of ball bearings 132a, 132b, 132c, 132d and each of which is located at an opposed end of the elongate portion 1170. A pair of moveable crimps 138a, 140a are located at one end of the crimp layer 1126 adjacent a first pair of ball bearings 132a, 132b. A pair of static crimps 138b, 140b are located at the opposed end of the crimp layer 1126 and mounted to a first end portion 1152 of a chassis 1134. Unlike previous arrangements, the crimp layer 1126 does not have apertures for the projections on the second wedge layer.

It will be appreciated that the overall depth of the actuator assembly 1110 is likely to be increased relative to the other arrangement because there is no projection through the upper and lower layers.

Figures 13a and 13b show a twelfth arrangement of an actuator assembly 1210. The actuator assembly 1210 in Figures 13a and 13b is similar to the arrangement shown in previous Figures (particularly Figure 12a) and therefore, for the sake of conciseness, like features are not described. In line with the previous arrangement, no components extend beyond the housing. Thus, as in the previous arrangement, the crimp layer 1226 does not have apertures for the projections on the second wedge layer. This arrangement may also be adapted to weld the crimp layer 1226 to the second wedge layer, e.g. to the bottom of the grooves.

Figure 13b shows the detail of the crimp layer 1226 which has an elongate portion 1270 having four bearing apertures. As shown ball bearings 132a, 132d are accommodated in two diametrically opposed apertures. It will be appreciated that a ball bearing may be located in each aperture. The bearing apertures are in pairs with each pair located at an opposed end of the elongate portion 1270. In this arrangement, the pair of moveable crimps 138a, 140a are not aligned with the first pair of ball bearing apertures but are moved closer to the centre of the elongate portion 1270. A pair of static crimps 138b, 140b are located at the opposed end of the crimp layer 1226. The moveable crimps and static crimps are closer to one another than in the previous arrangement.

Figure 14 show another arrangement of an actuator assembly 1310. The actuator assembly 1310 in Figure 14 is similar to the arrangement shown in previous Figures (particularly Figure 13a) and therefore, for the sake of conciseness, like features are not described. In line with the previous arrangement, no components extend beyond the housing. Thus, as in the previous arrangement, the crimp layer 1326 does not have apertures for the projections on the second wedge layer.

In this arrangement, the crimp layer 1326 which has an elongate portion 1370 with just two small bearing apertures each accommodating a single ball bearing 132a, 132d. The bearing apertures are located at an opposed end of the elongate portion 1370. In this arrangement, the pair of moveable crimps 138a, 140a are aligned with one of the ball bearing aperture. A pair of static crimps

138b, 140b are located at the opposed end of the crimp layer 1326. The moveable crimps and static crimps are thus set further apart than in the previous arrangement.

Figure 15 shows a schematic arrangement for the first and second wedge layers 1422, 1444. In the examples shown above, there are two grooves at opposed ends of the wedge layers. Increasing the length of the actuator assembly increases the distance between the bearings and may result in a larger amount of deflection in the wedge layer(s) for the same load. In this schematic arrangement, which may be incorporated into any of the designs noted above, one or more additional stiffening features 1444 may be used to maintain stiffness. The stiffening feature 1444 may be located centrally between the two grooves. In this example, there is only a stiffening feature on the second wedge layer 1424 but a stiffening feature may also be incorporated on the first wedge layer 1422. There may also be more than one stiffening feature as needed. It will be appreciated that the stiffening feature may be in the form of a stiffening groove which may have a similar shape to the grooves which accommodate bearing(s). A stiffening groove does not accommodate a bearing. Alternatively, the stiffening feature may have any appropriate shape.

Figure 16 shows a schematic arrangement for the first and second wedge layers 1522, 1544 which may be incorporated into any of the designs noted above. In this arrangement, the tops of each groove on the first wedge layer 1522 are welded to the resilient layer 1514 and the bottoms of each groove on the second wedge layer 1524 are welded to the crimp layer 1526. The weld points 1544 are indicated.

Those skilled in the art will appreciate that while the foregoing has described what is considered to be the best mode and where appropriate other modes of performing present techniques, the present techniques should not be limited to the specific configurations and methods disclosed in this description of the preferred embodiment. Those skilled in the art will recognise that present techniques have a broad range of applications, and that the embodiments may take a wide range of modifications without departing from any inventive concept as defined in the appended claims.

CLAIMS

1. An actuator assembly comprising:

a static element;

5 a moveable element moveable relative to the static element in a first direction;

an intermediate element provided in a spaced relationship with the moveable element, and movable in a second different direction relative to the static element;

10 at least one shape-memory alloy (SMA) wire coupled to both the static element and the intermediate element so that on contraction the at least one SMA wire moves the intermediate element in the second direction; and

at least one bearing arranged to couple the intermediate element to the moveable element such that movement of the intermediate element in the second direction causes movement of the moveable element in the first direction

15 wherein both of the moveable element and the intermediate element comprise at least one groove within which the at least one bearing is located and

wherein each groove has an inclined surface which engages with the at least one bearing.

20 2. The actuator assembly of claim 1, wherein the intermediate element is moveable from a rest position to an activated position and vice versa and wherein the at least one bearing is configured to travel across the inclined surface of the groove on the intermediate element as the intermediate element moves between the rest and activated positions.

3. The actuator assembly of claim 2, wherein the at least one bearing is configured to bear against the inclined surface of the groove on the intermediate element as the intermediate element moves between the rest and activated positions whereby the moveable element is moved in the first direction.

4. The actuator assembly of claim 2 or claim 3, wherein the inclined surface of the groove on the intermediate element has a length which is matched to a desired movement of the moveable element.

5. The actuator assembly of any one of the preceding claims, wherein the inclined surface on the intermediate element is inclined at an angle to provide a desired ratio of movement of the intermediate element relative to the moveable element.
6. The actuator assembly of any one of the preceding claims, wherein each groove further comprises a second inclined surface.
7. The actuator assembly of claim 6, wherein the second inclined surface is inclined at a second relative steep angle to provide an endstop.
8. The actuator assembly of claim 6 or claim 7, wherein the first inclined surface of the groove on the moveable element is parallel to the first inclined surface of the groove on the intermediate element.
9. The actuator assembly of any one of claims 6 to 8, wherein the second inclined surface of the groove on the moveable element is parallel to the second inclined surface of the groove on the intermediate element.
10. The actuator assembly of any one of the preceding claims, wherein each of the intermediate element and the moveable element comprise at least two grooves.
11. The actuator assembly of claim 10, comprising two grooves within which bearings are located.
12. The actuator assembly of claim 10 or claim 11, further comprising a stiffening groove.
13. The actuator assembly of any one of claims 10 to 12, comprising at least three bearings associated with each groove in the intermediate element having a bearing located therein.

14. The actuator assembly of claim 13, comprising four bearings associated with each groove in the intermediate element having bearings located therein.

5 15. The actuator assembly of any one of the preceding claims, wherein each groove extends across a width of the intermediate element or the moveable element respectively.

10 16. The actuator assembly of any one of the preceding claims wherein the second direction is perpendicular to the first direction.

17. The actuator assembly of any one of the preceding claims wherein the at least one bearing comprises ball bearings or roller bearings.

15 18. The actuator assembly of any one of the preceding claims, further comprising a seal.

20 19. The actuator assembly of any one of the preceding claims, further comprising at least one sensor selected from the group consisting of a contact sensor, a capacitive sensor, an inductive sensor, a strain gauge, a force sensor, a pressure sensor, an optical sensor and an ultrasonic sensor.

25 20. The actuator assembly of any one of the preceding claims, wherein each of the moveable element and the intermediate element has a generally constant cross-section.

30 21. The actuator assembly of any one of the preceding claims, wherein each of the moveable element and the intermediate element are formed from stainless steel.

22. The actuator assembly of any one of the preceding claims, further comprising a resilient element which restores the moveable element to the rest position when the SMA wire is not powered.

23. The actuator assembly of claim 22, wherein the resilient element comprises at least one aperture through which a portion of the moveable element projects.

5 24. A haptic assembly comprising
a button and
an actuator assembly according to any one of the preceding claims,
wherein the button is operably attached to the moveable element whereby
movement of the moveable element causes movement of the button in the first
10 direction.

25. An apparatus comprising a haptic assembly of claim 24 where the
apparatus is any one of: a smartphone, a protective cover or case for a
smartphone, a functional case or cover for a smartphone or electronic device, a
15 camera, a foldable smartphone, a foldable tablet computing device, a foldable
communications device, a foldable phablet, a foldable image capture device, a
foldable smartphone camera, a foldable consumer electronics device, a camera
with folded optics, an image capture device, an array camera, a 3D sensing
device or system, a servomotor, a consumer electronic device, a domestic
20 appliance, a mobile or portable computing device, a mobile or portable electronic
device, a laptop, a tablet computing device, a phablet, an e-reader, a computing
accessory or computing peripheral device, an audio, a security system, a gaming
system, a gaming accessory, a robot or robotics device, a medical, an
augmented reality system, an augmented reality device, a virtual reality system,
25 a virtual reality device, a wearable, an autonomous vehicle, a vehicle, a tool, a
surgical tool, a remote controller, clothing, a switch, a dial, a button, a display
screen, a touchscreen, a flexible surface, and a wireless communication device.

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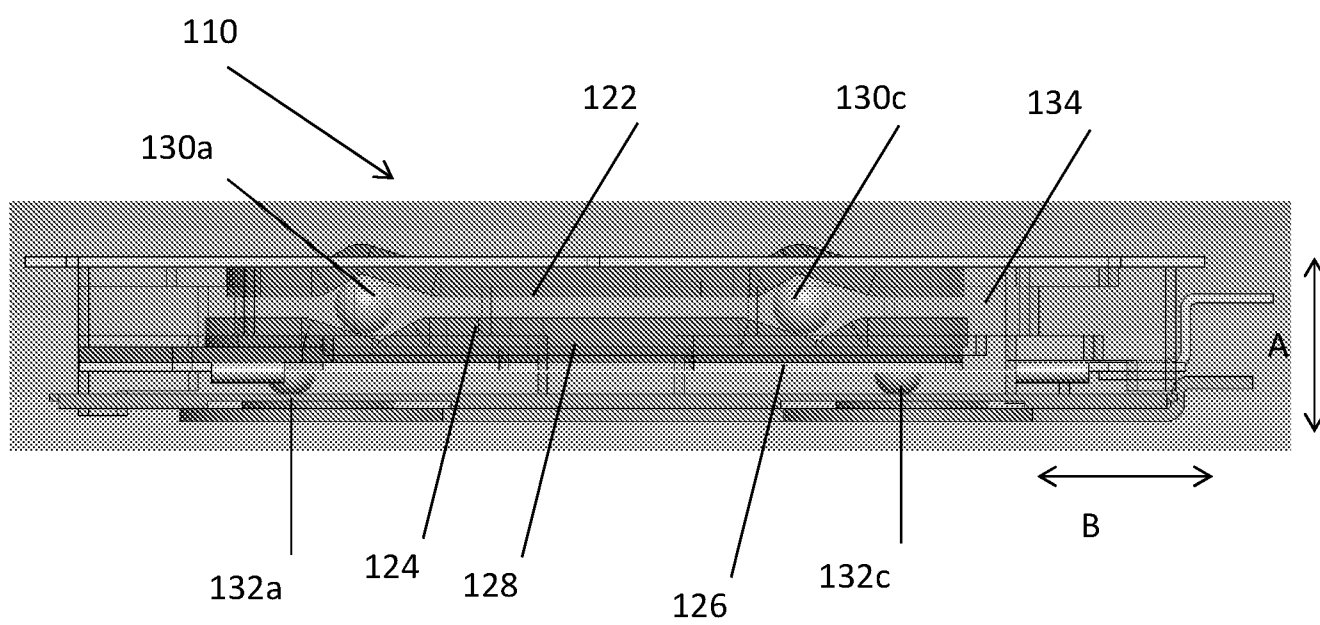
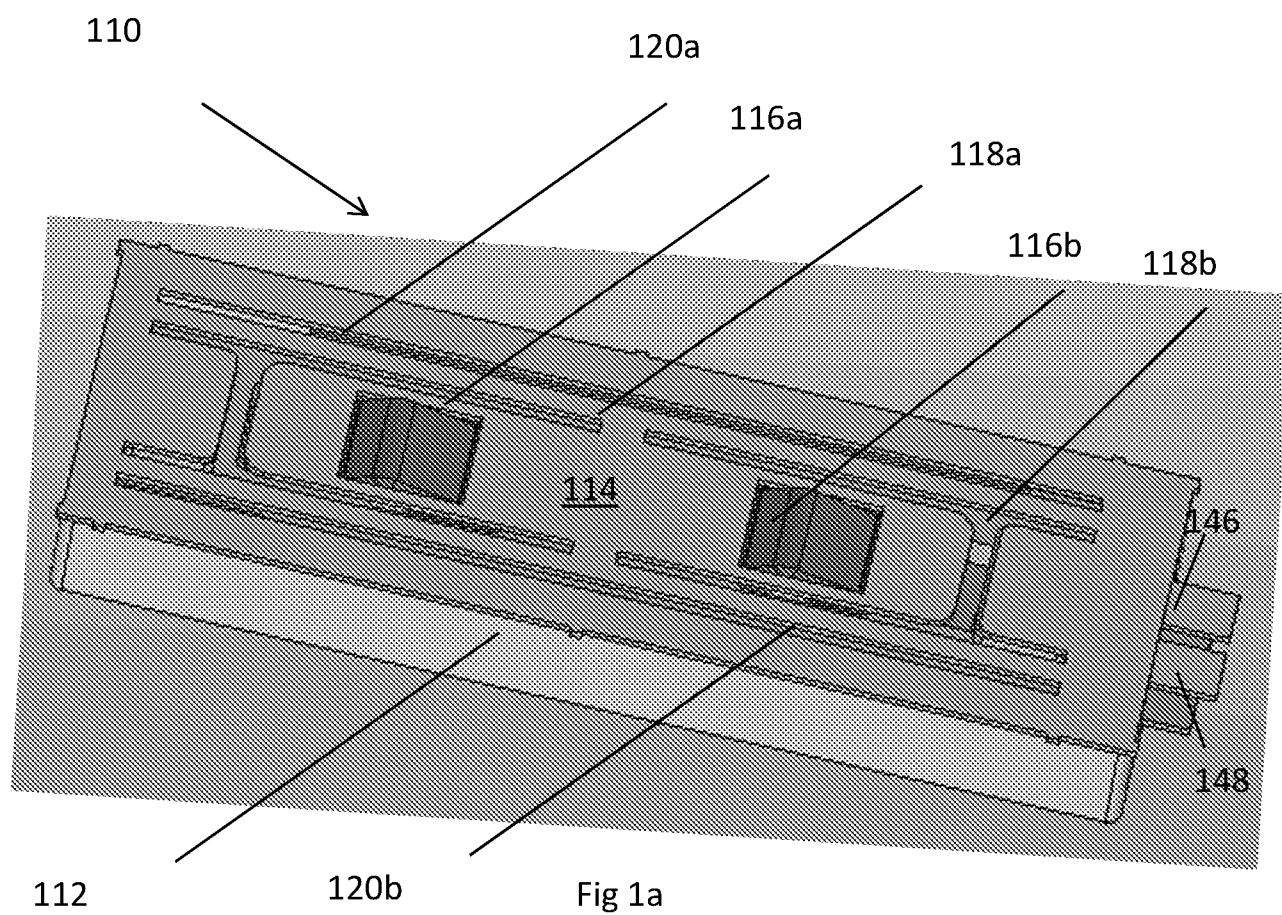


Fig 1b

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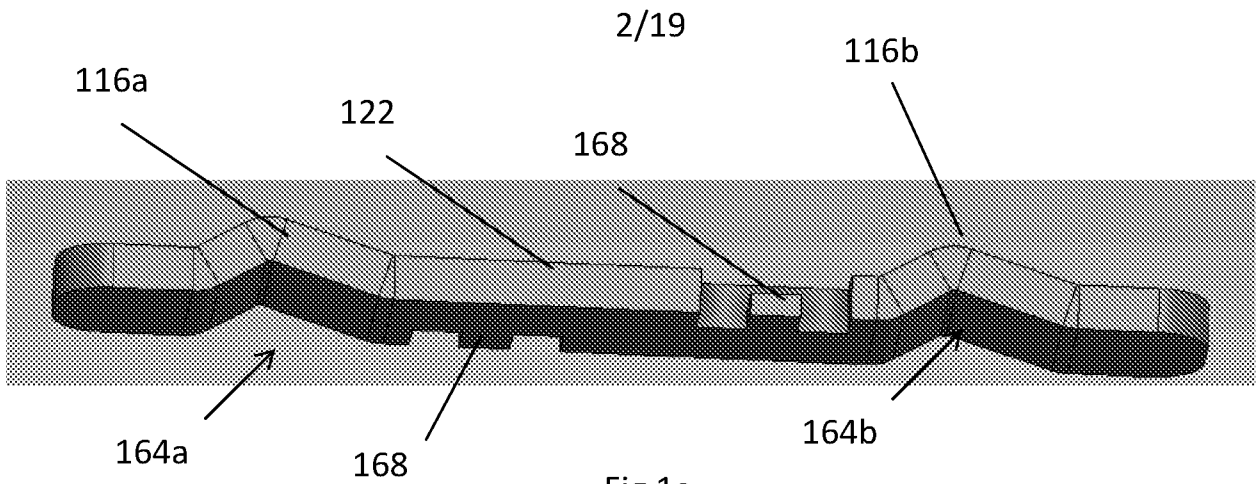


Fig 1c

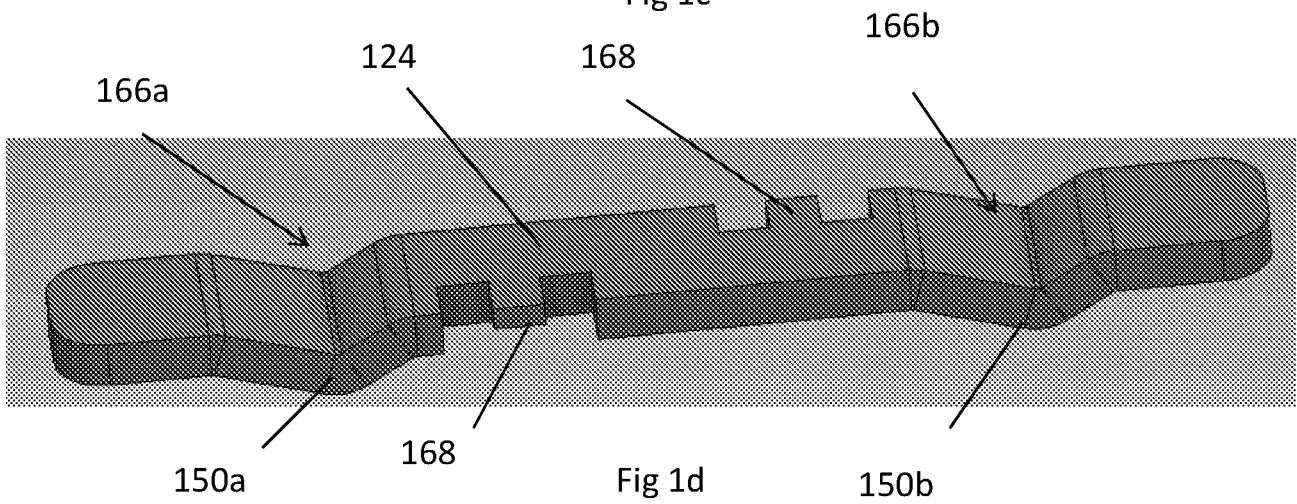


Fig 1d

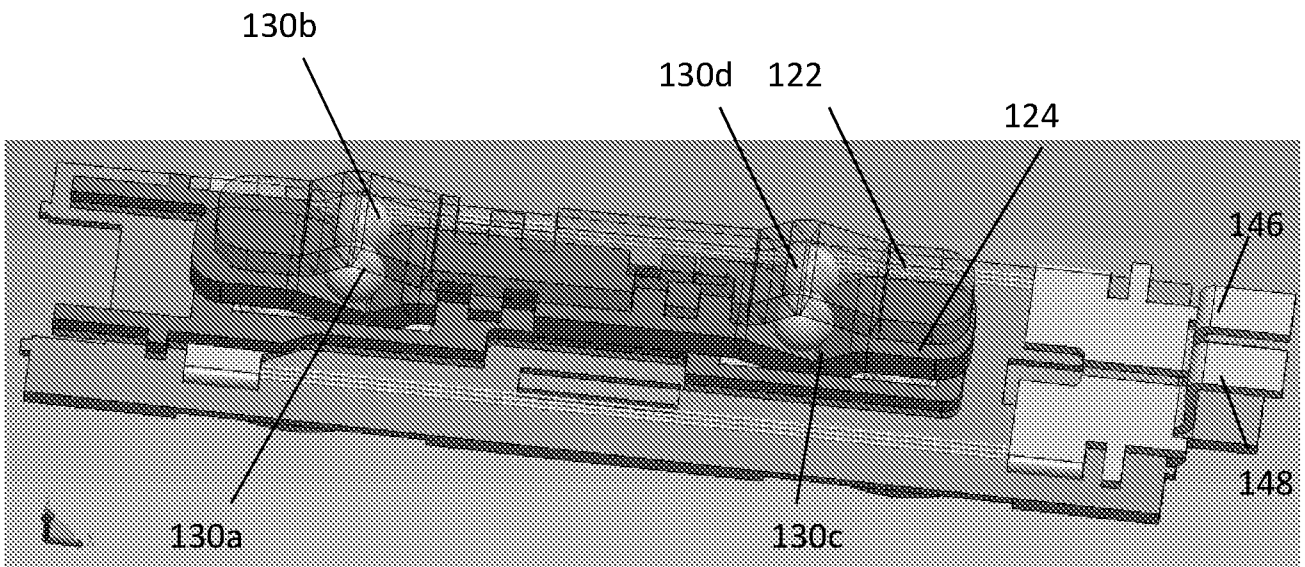


Fig 1e

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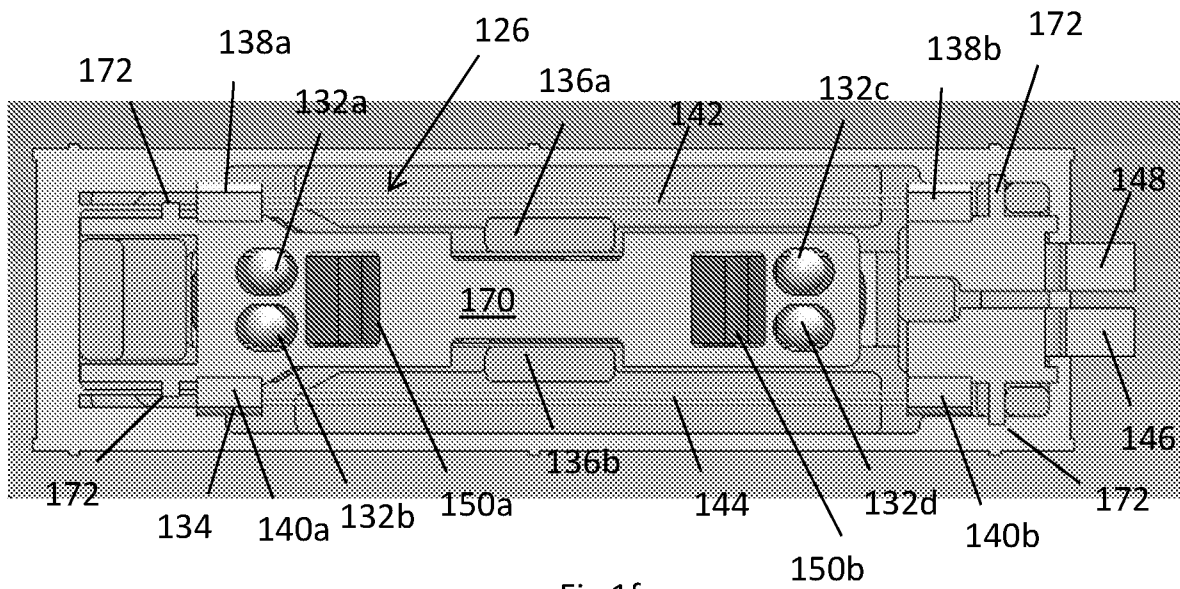


Fig 1f

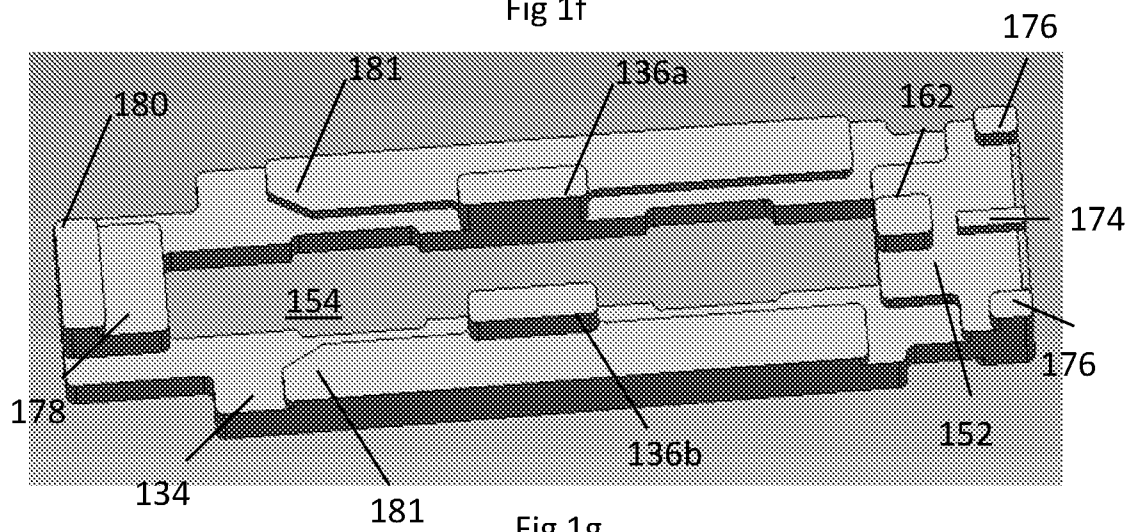


Fig 1g

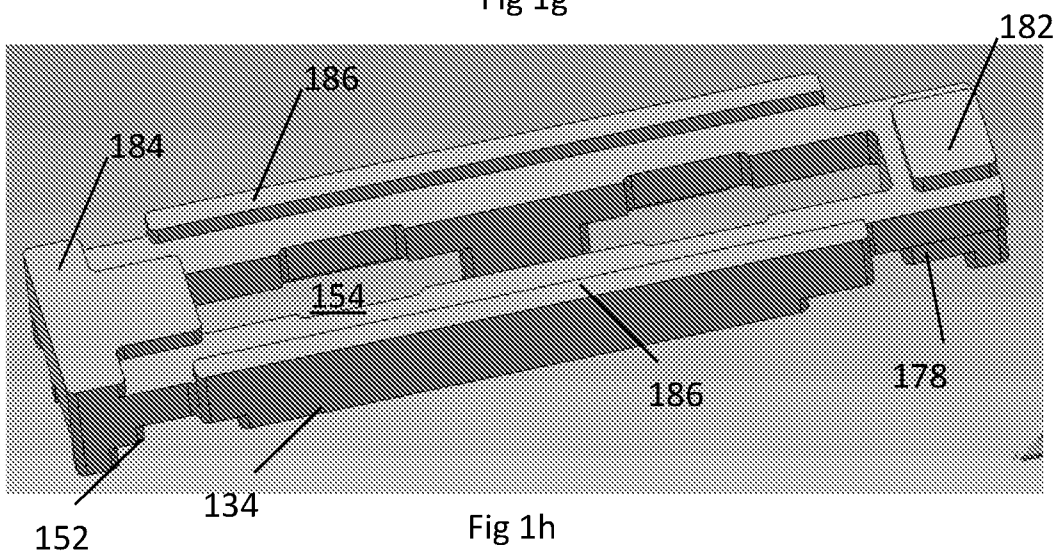


Fig 1h

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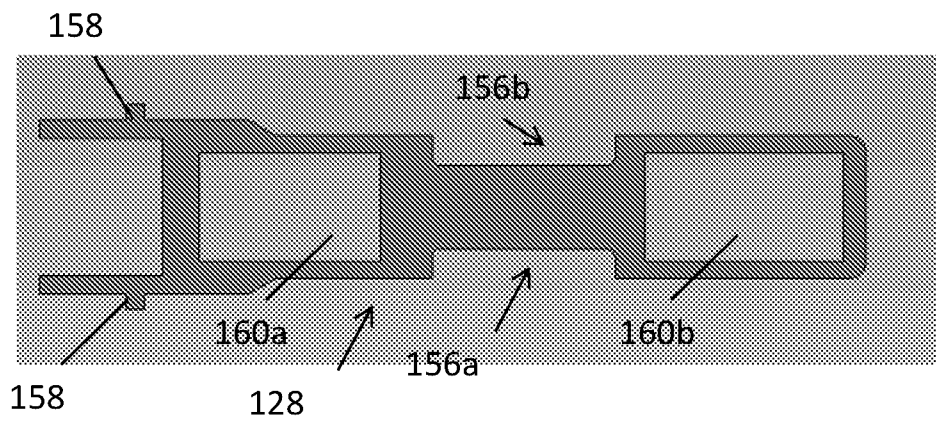


Fig 1i

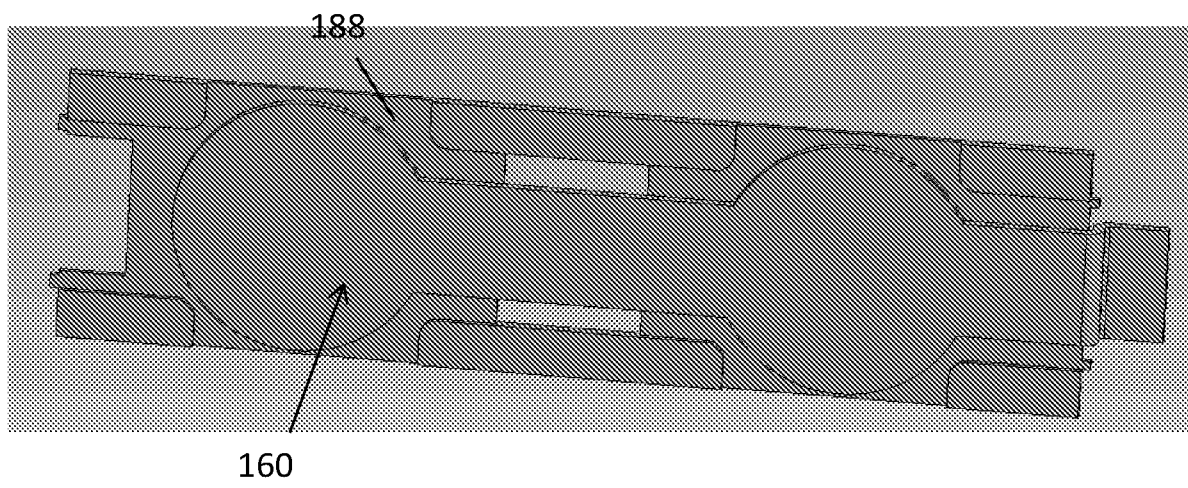


Fig 1j

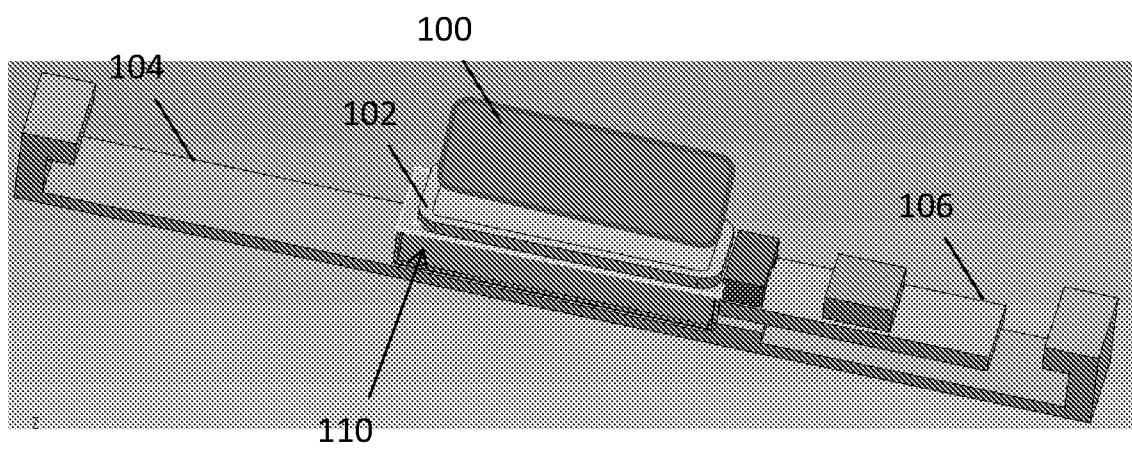


Fig 1k

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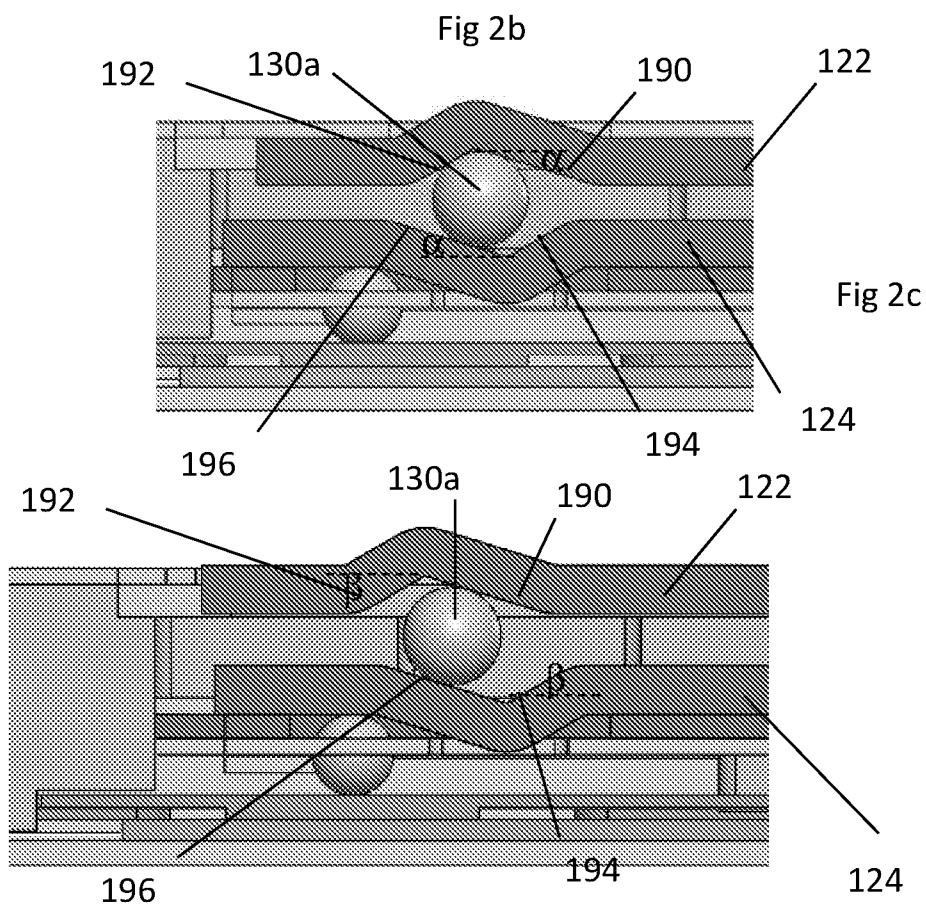
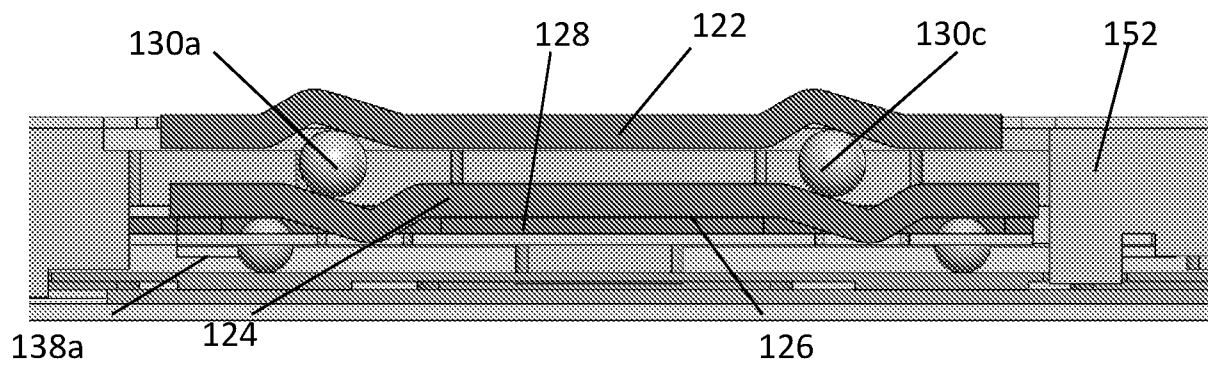
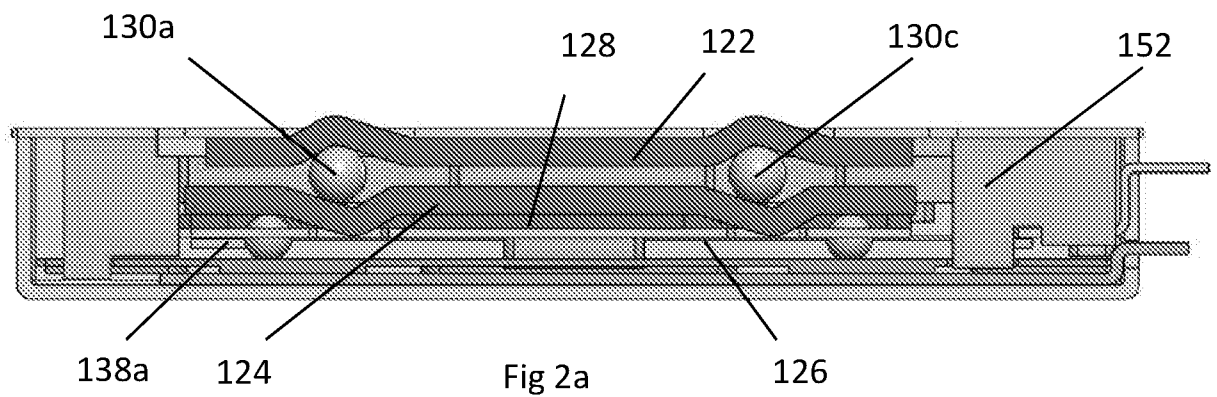


Fig 2d

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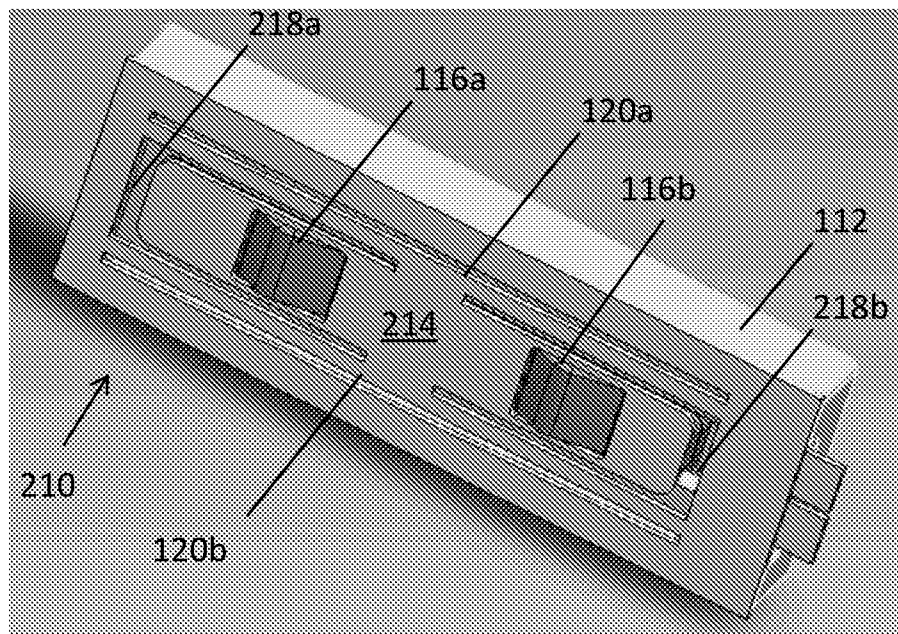


Fig 3a

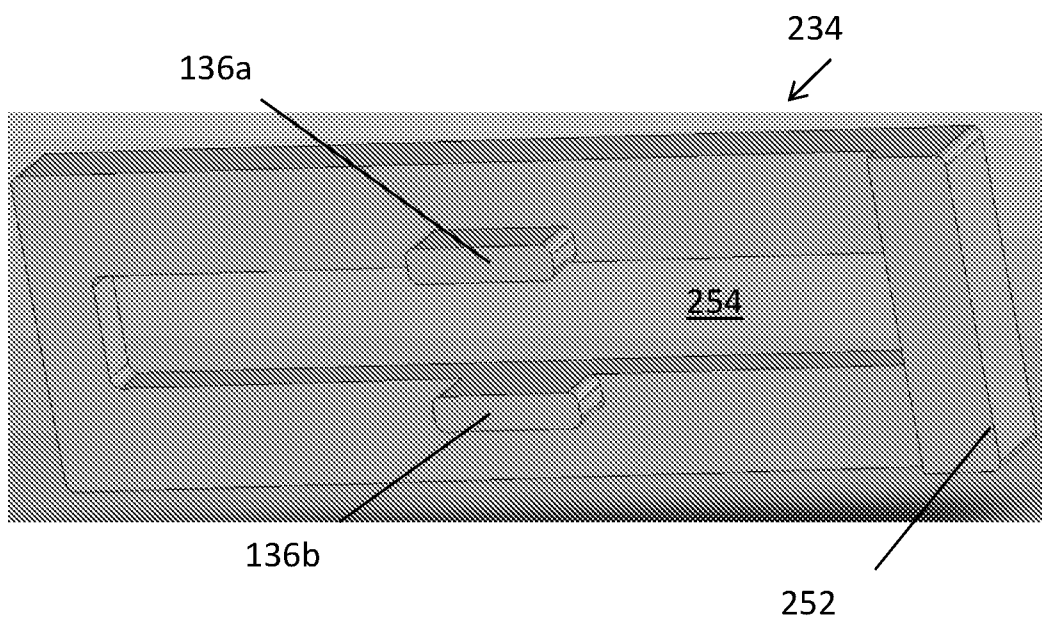


Fig 3b

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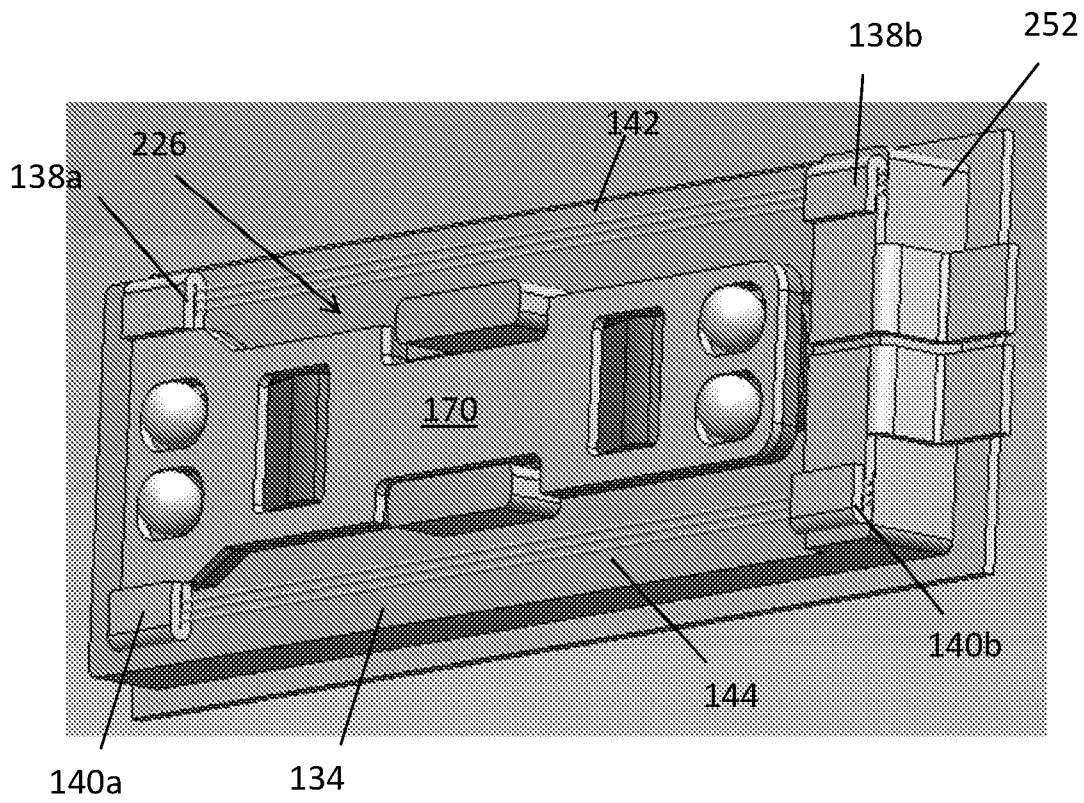


Fig 3c

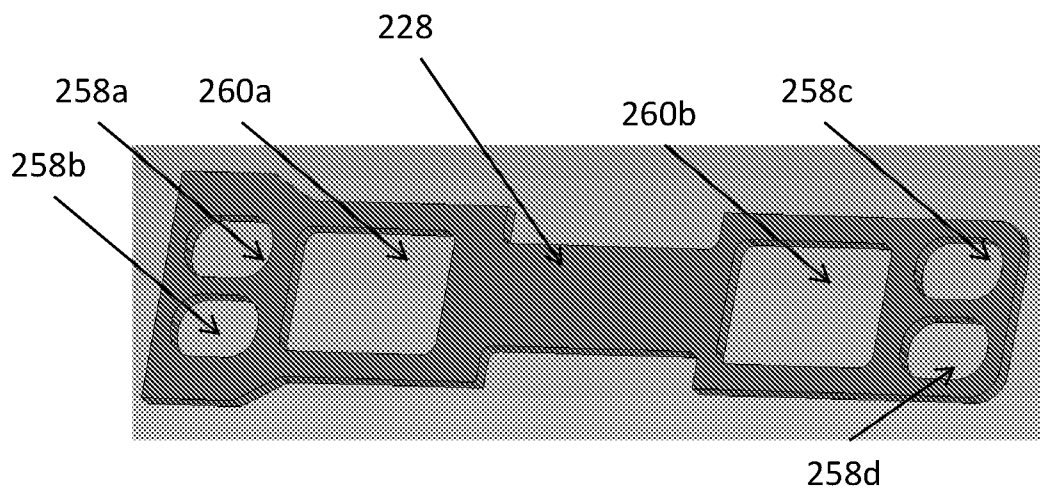


Fig 3d

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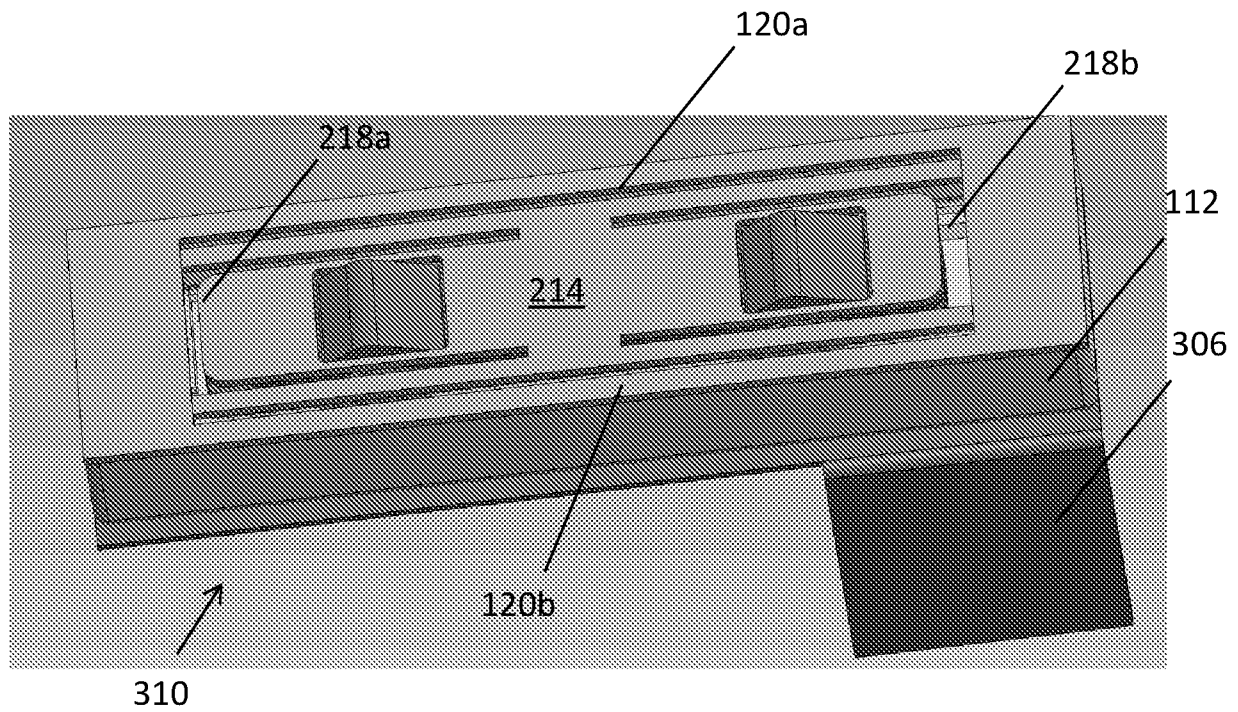


Fig 4a

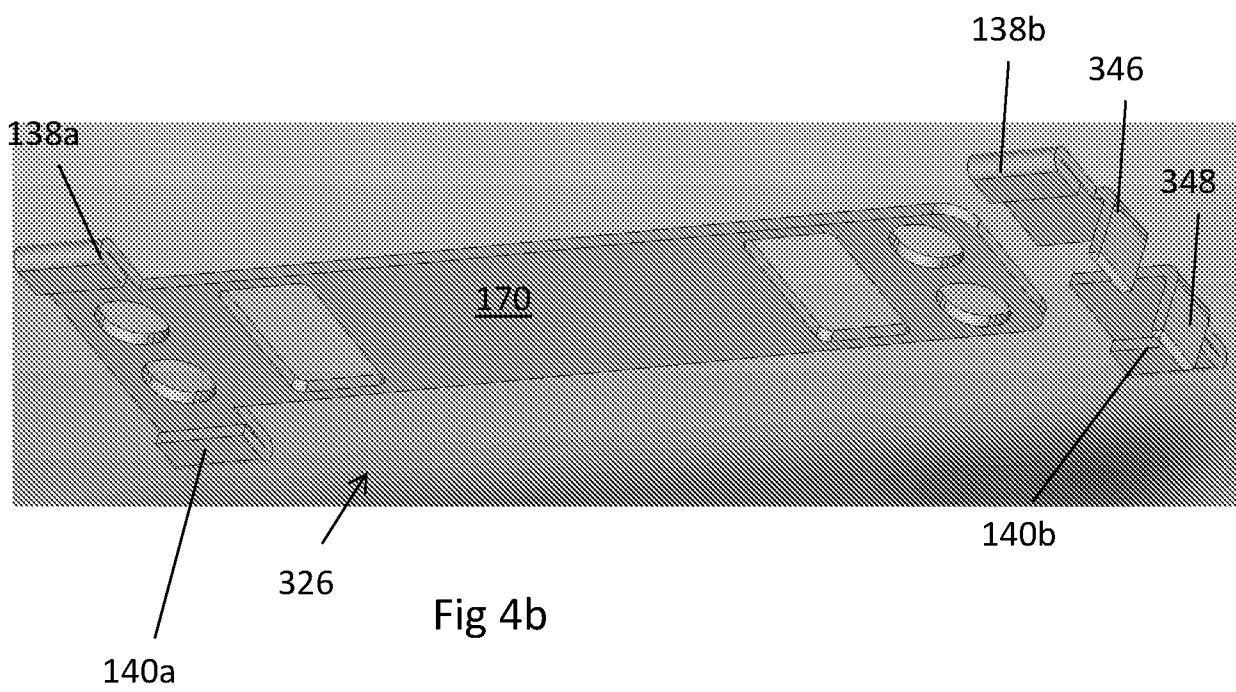
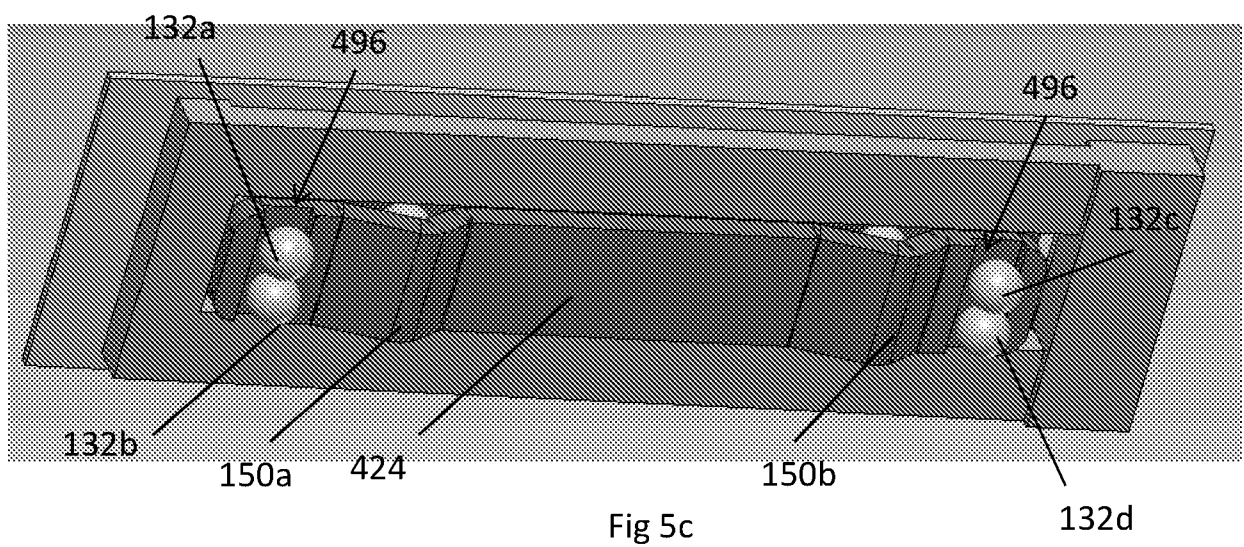
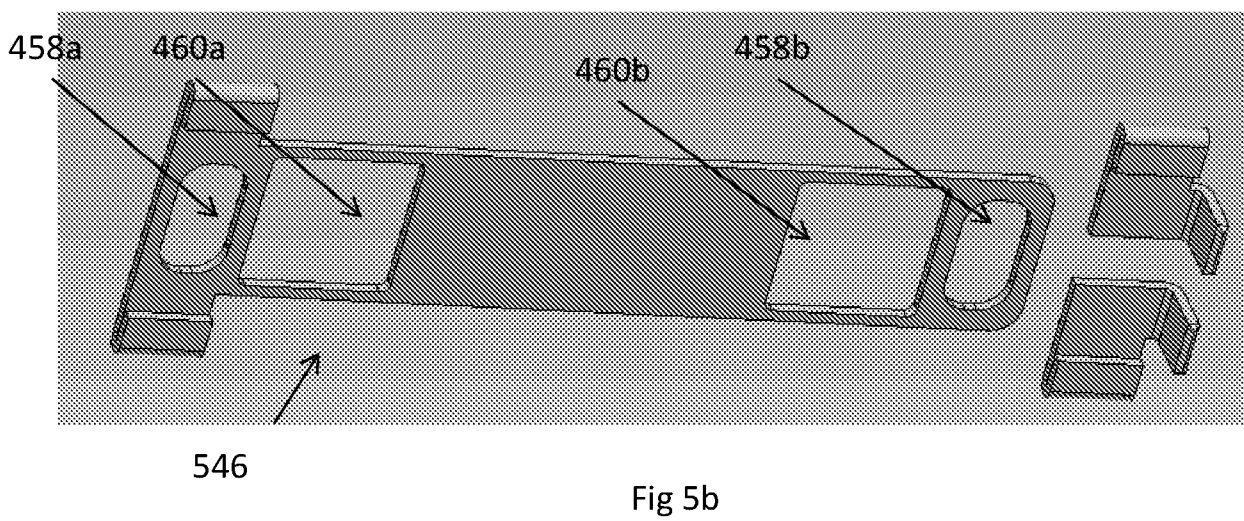
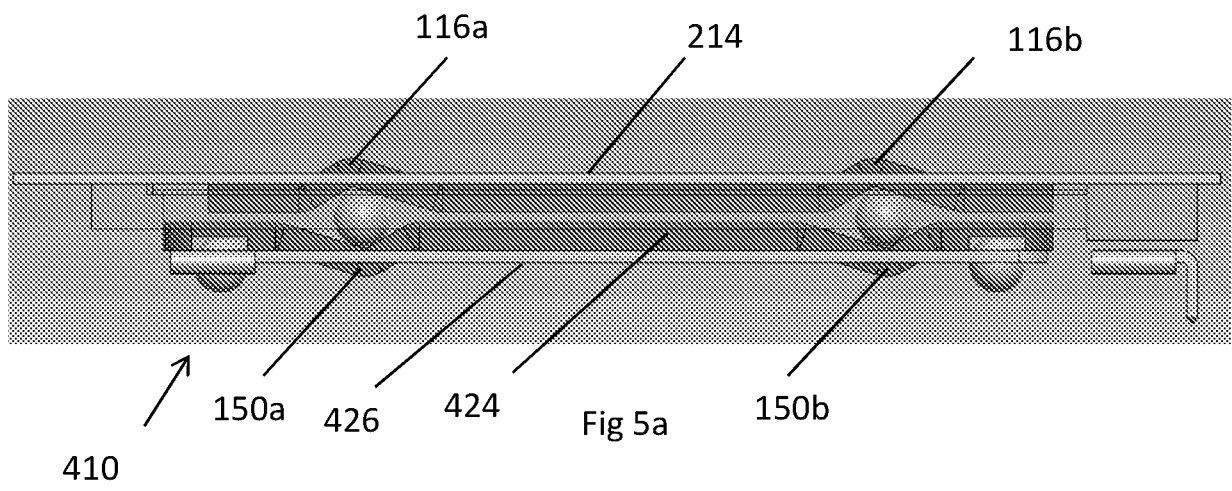
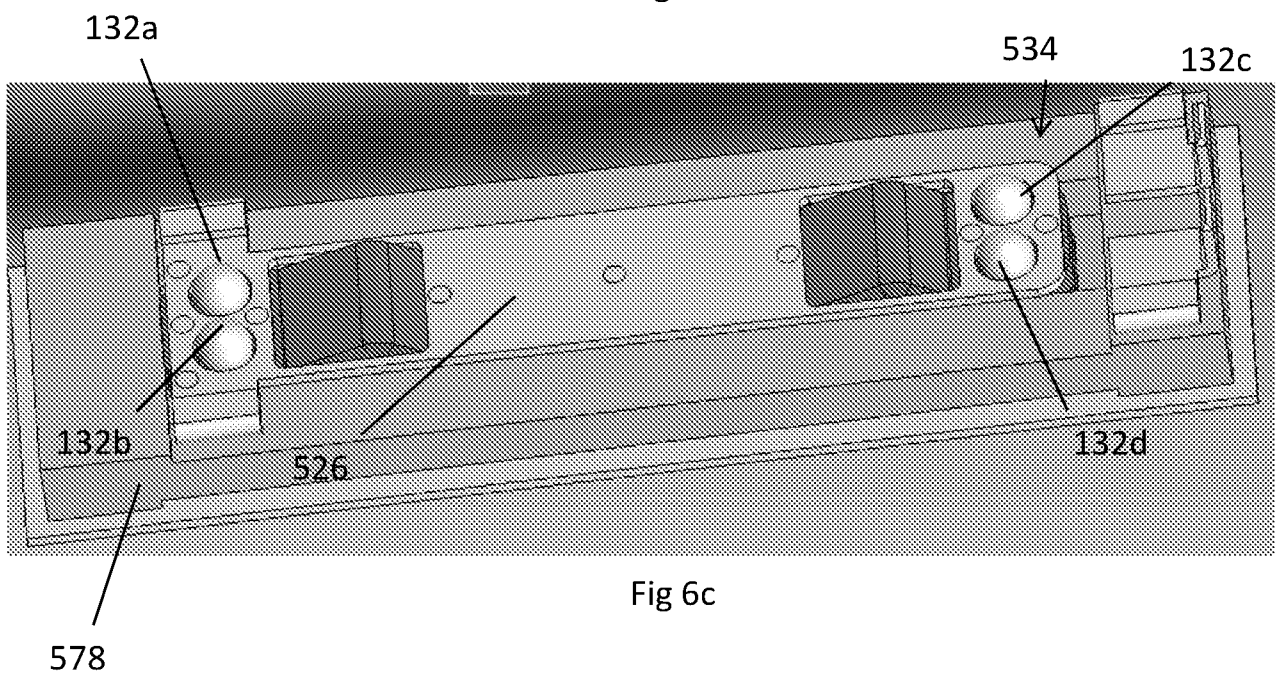
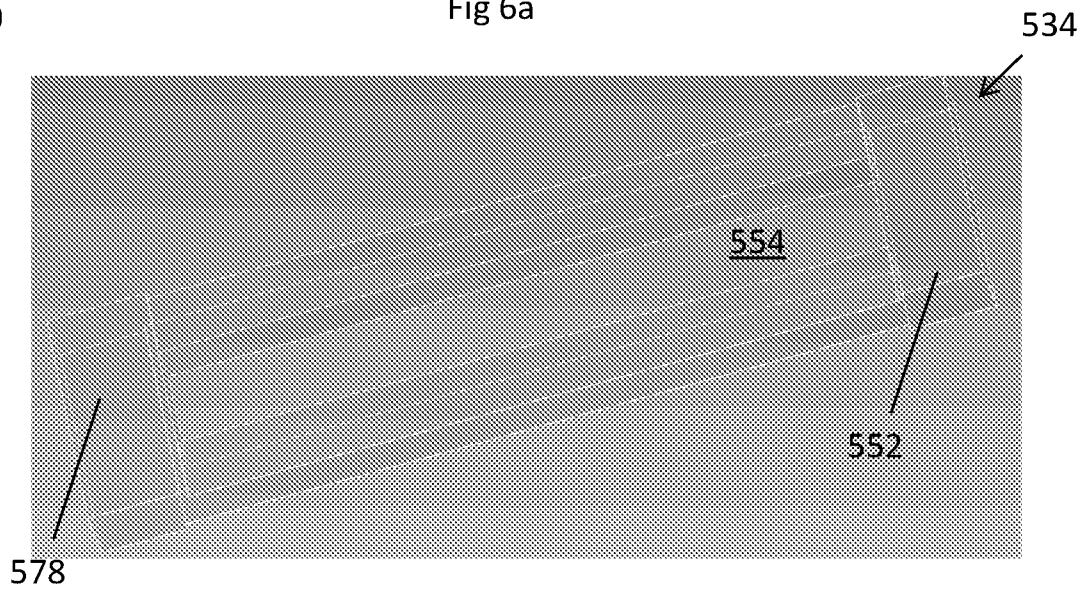
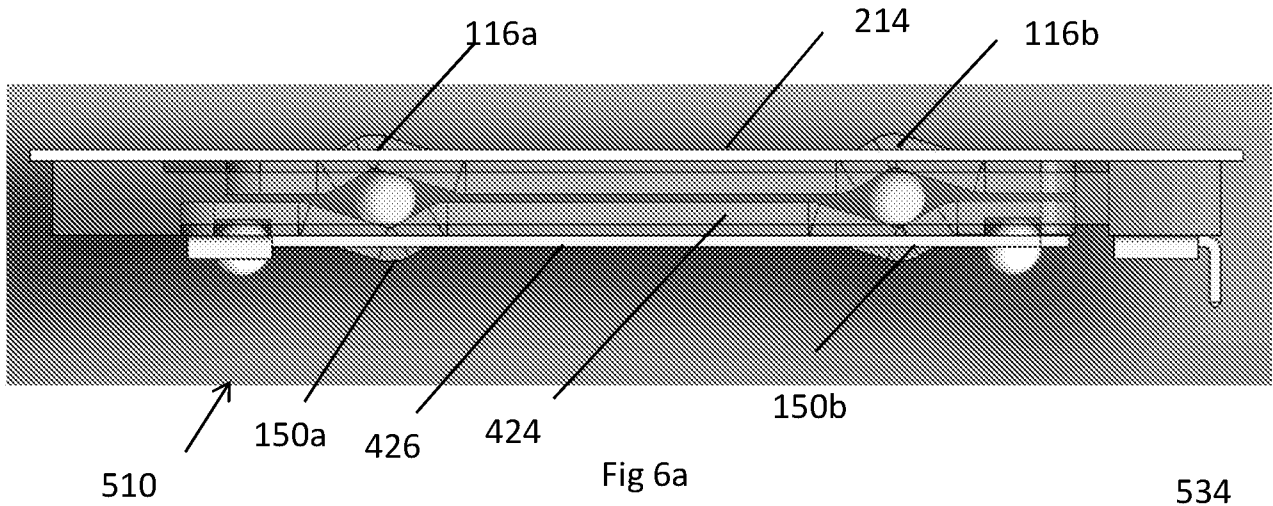


Fig 4b

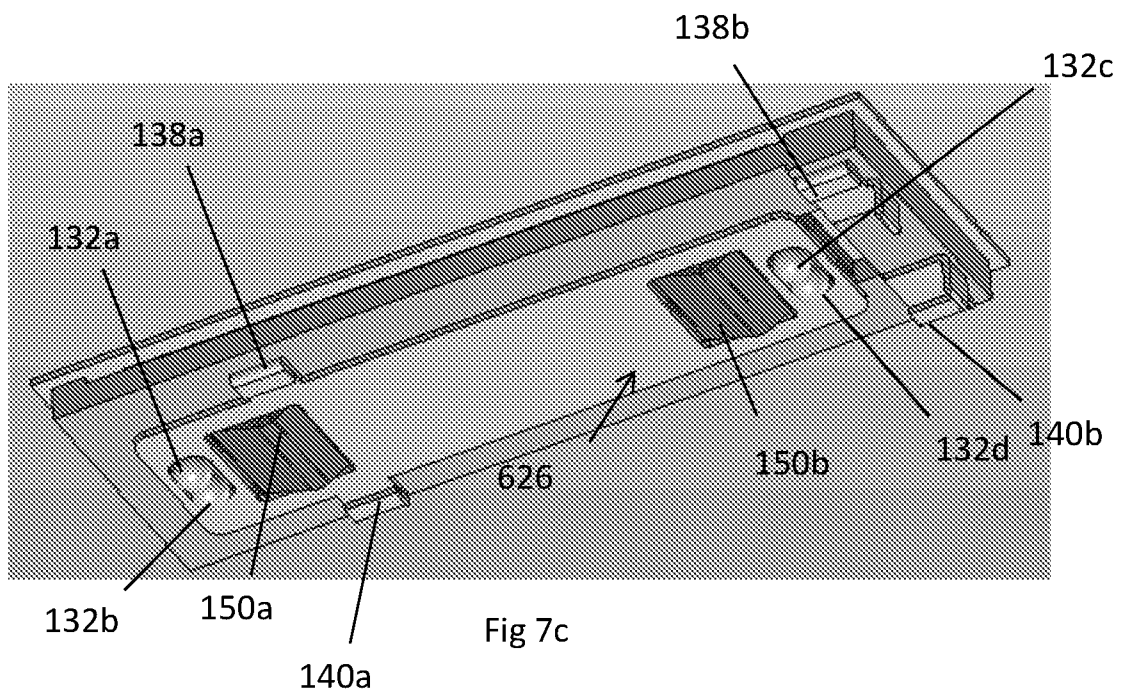
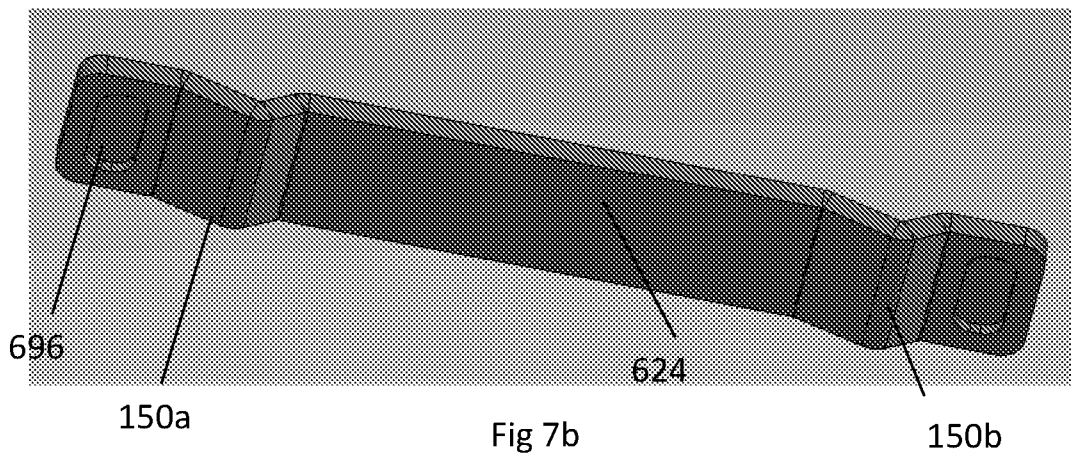
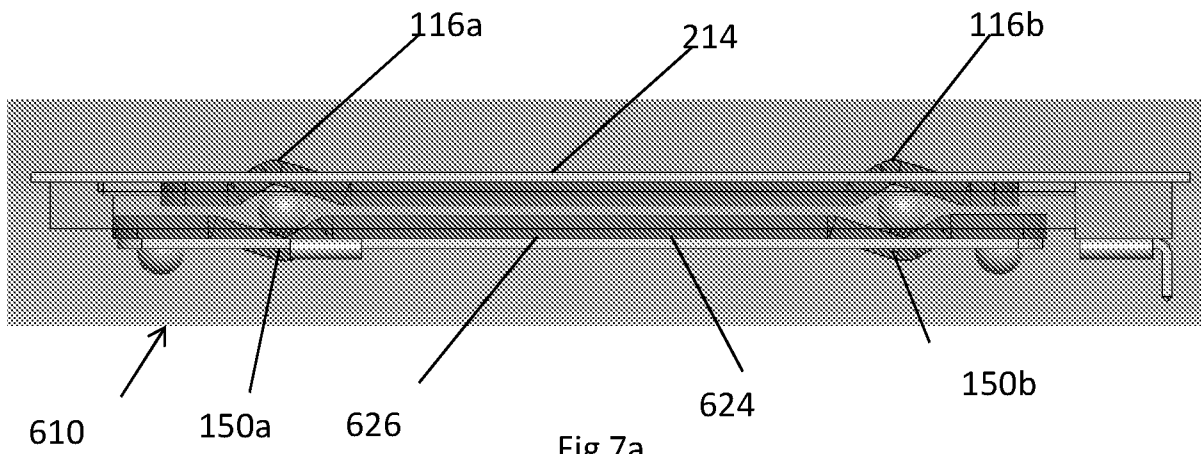
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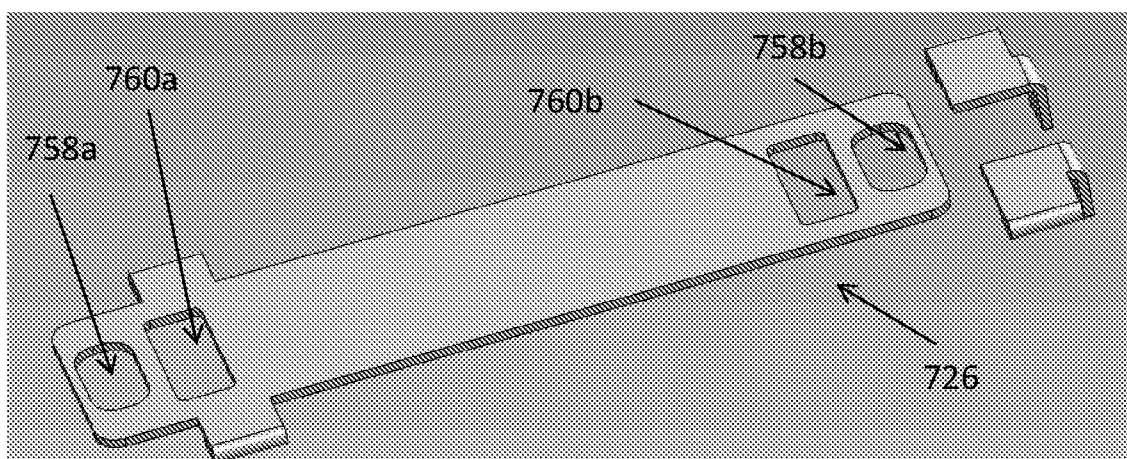
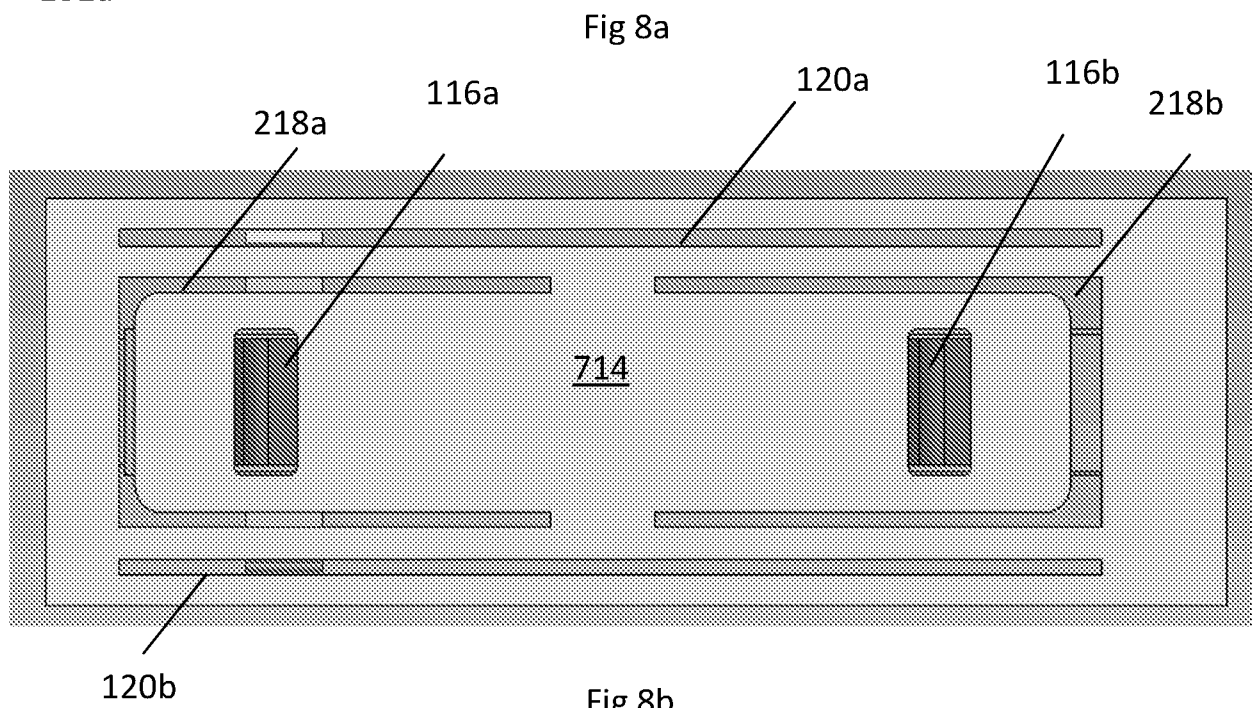
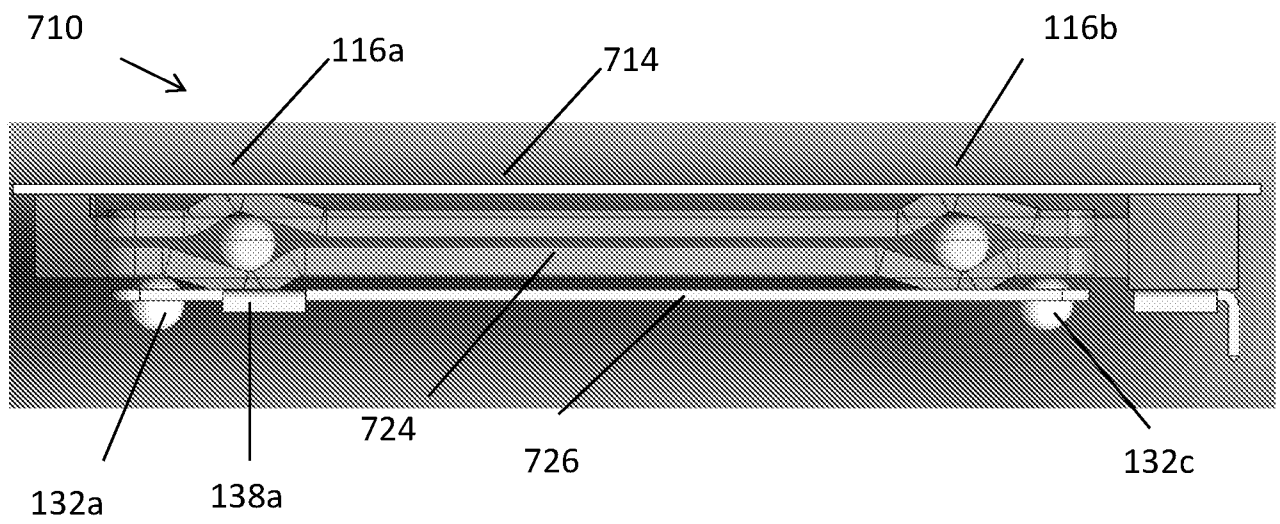
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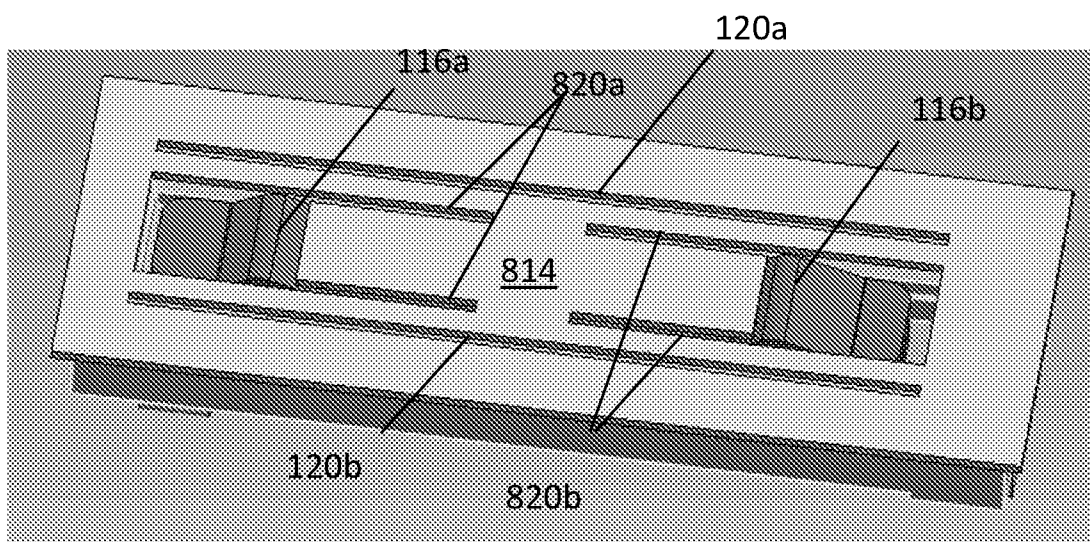
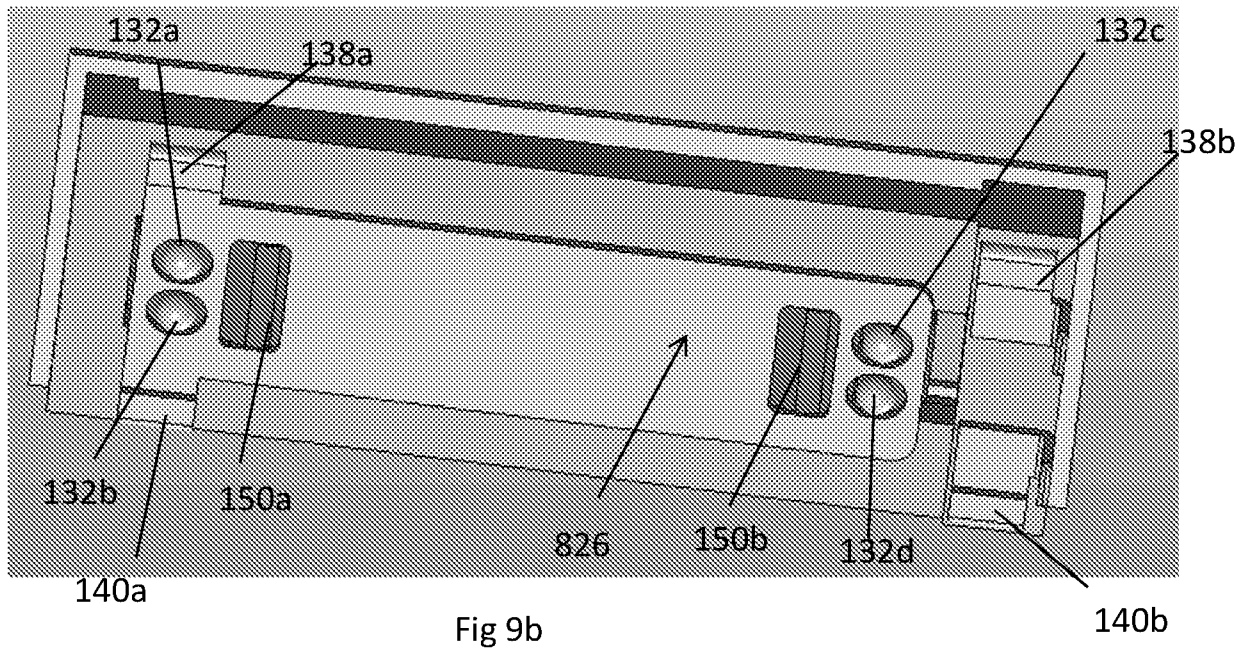
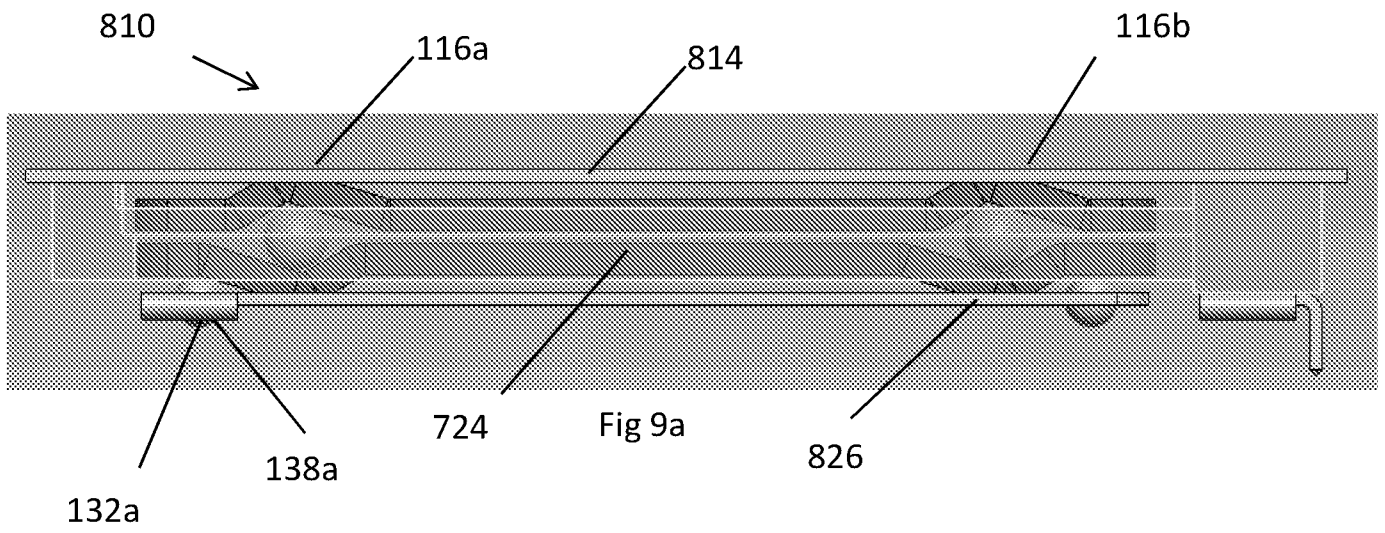
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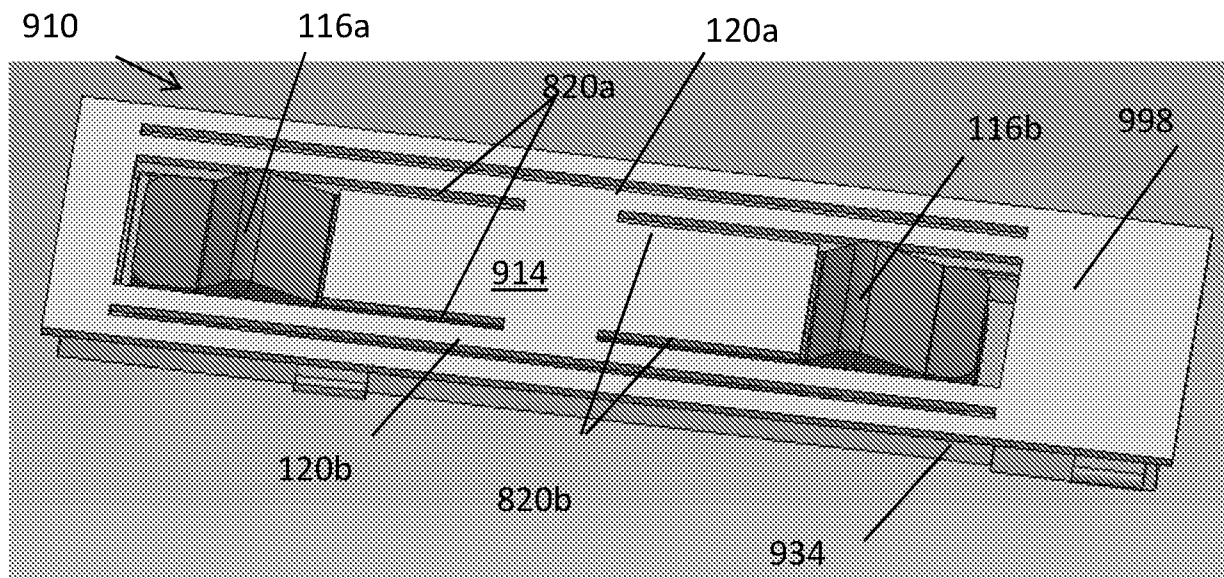


Fig 10a

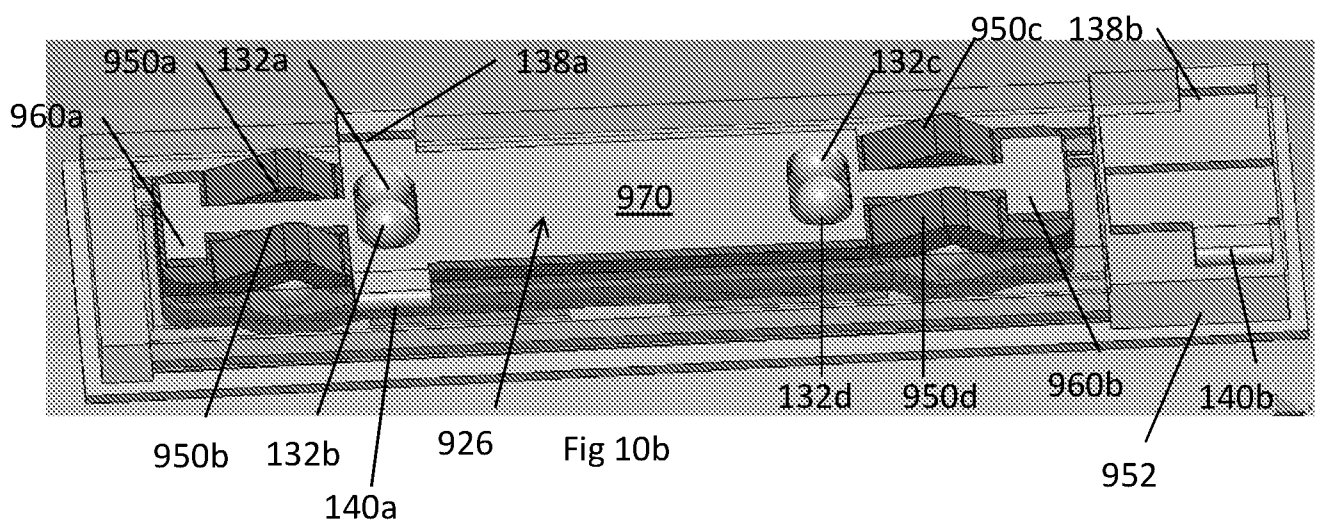


Fig 10b

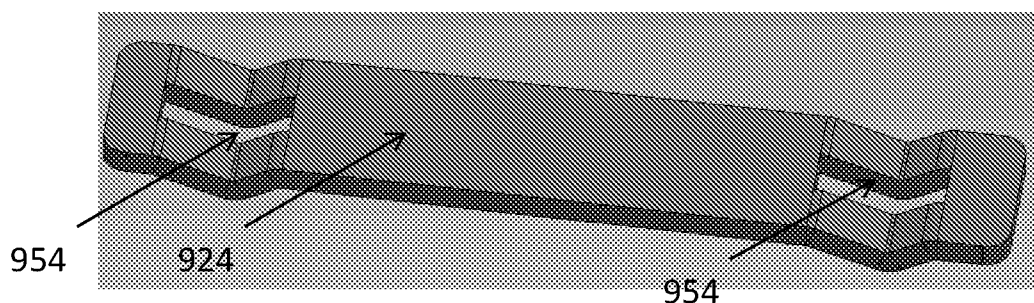


Fig 10c

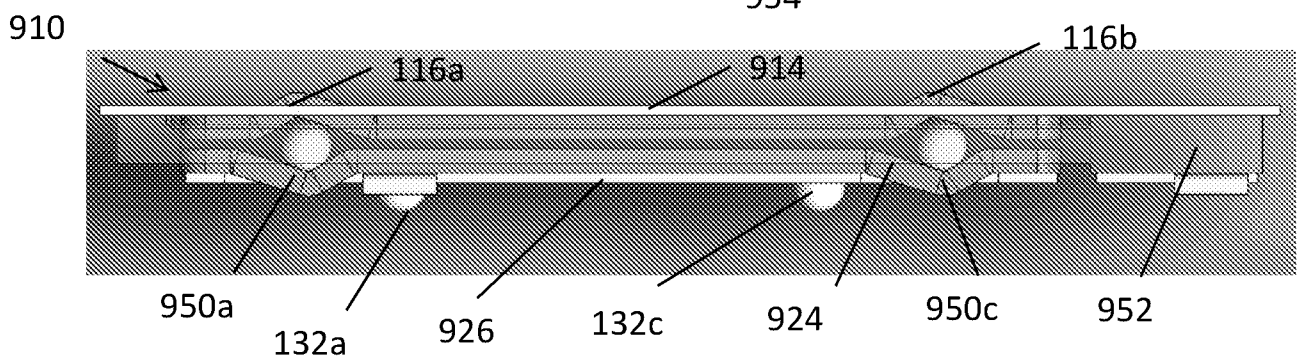
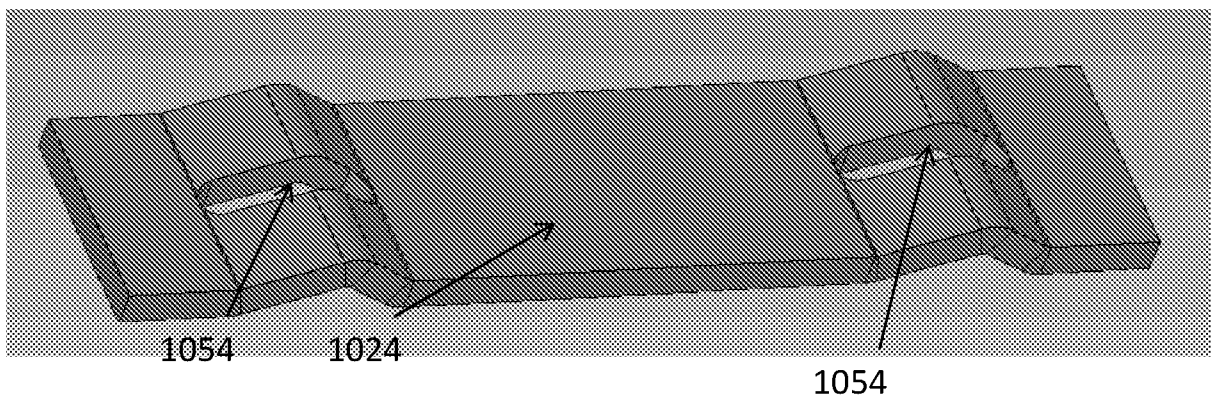
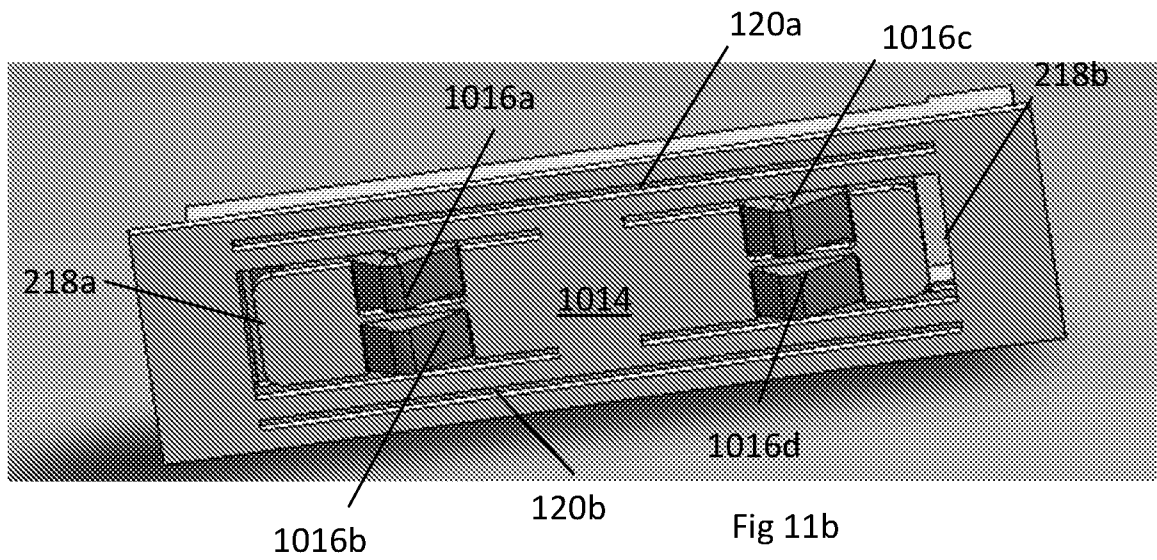
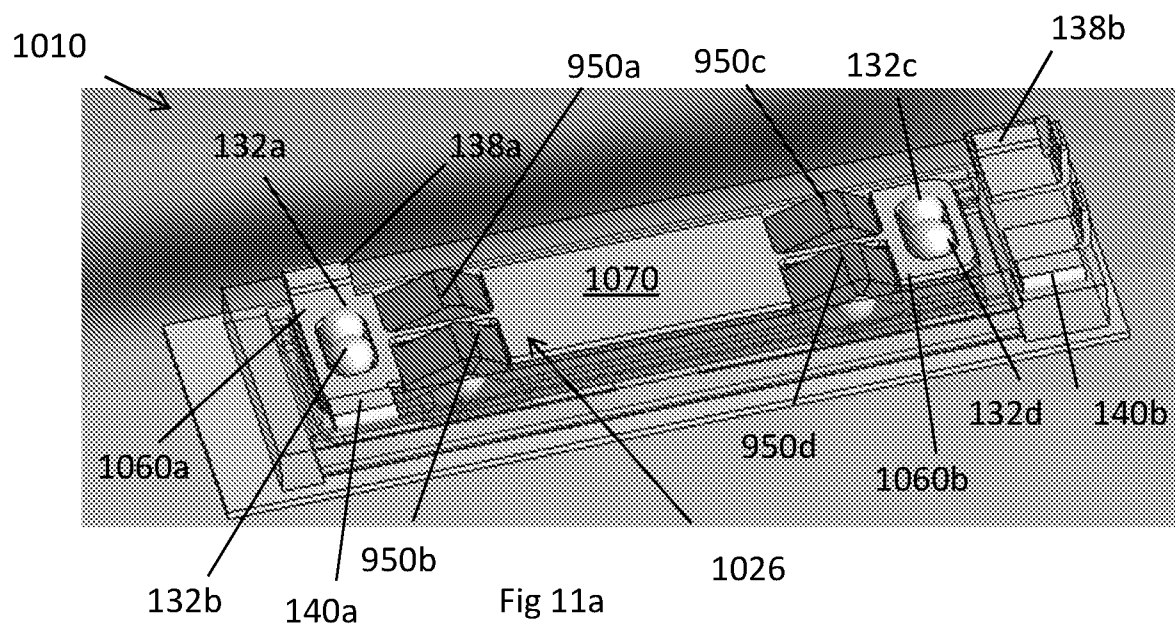


Fig 10d

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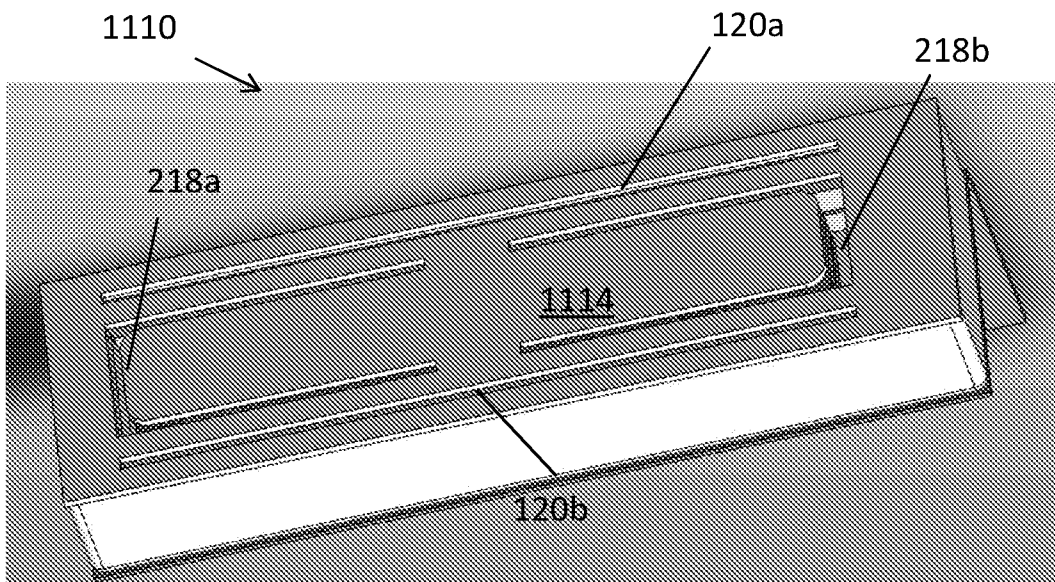


Fig 12a

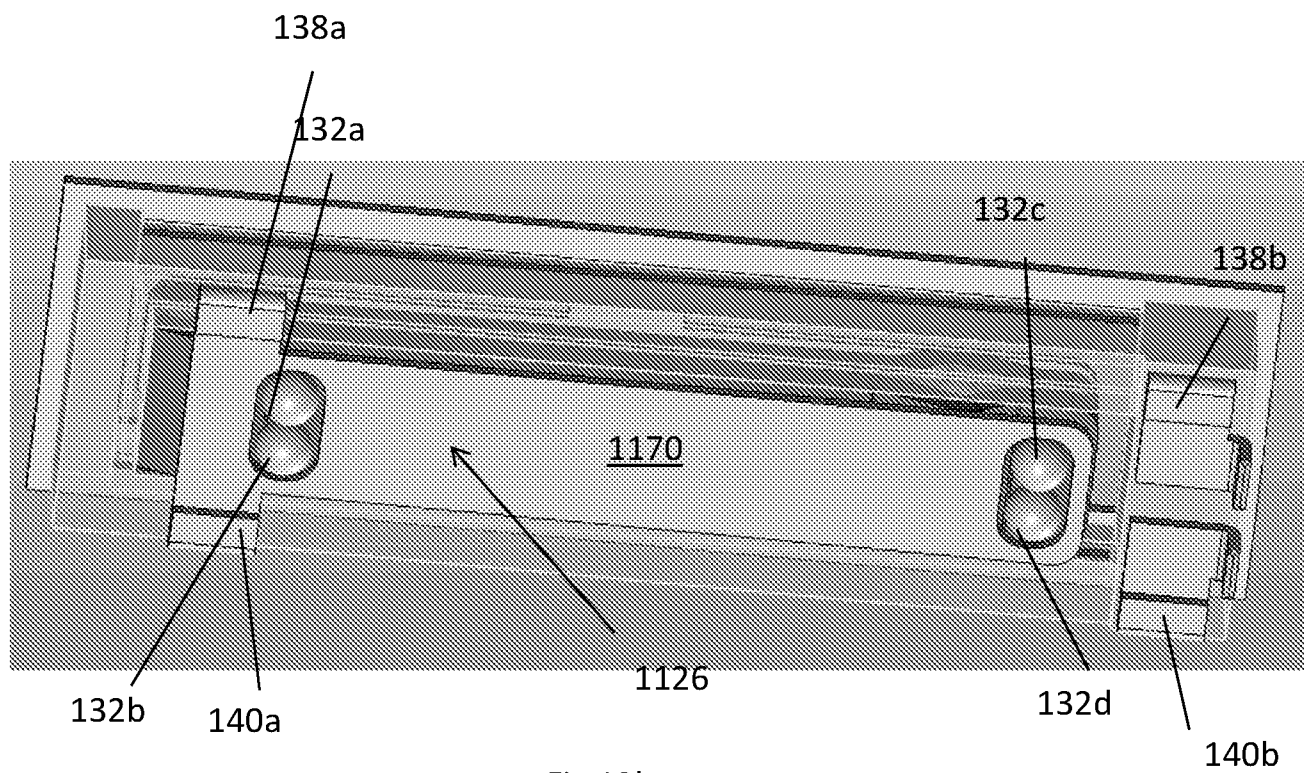


Fig 12b

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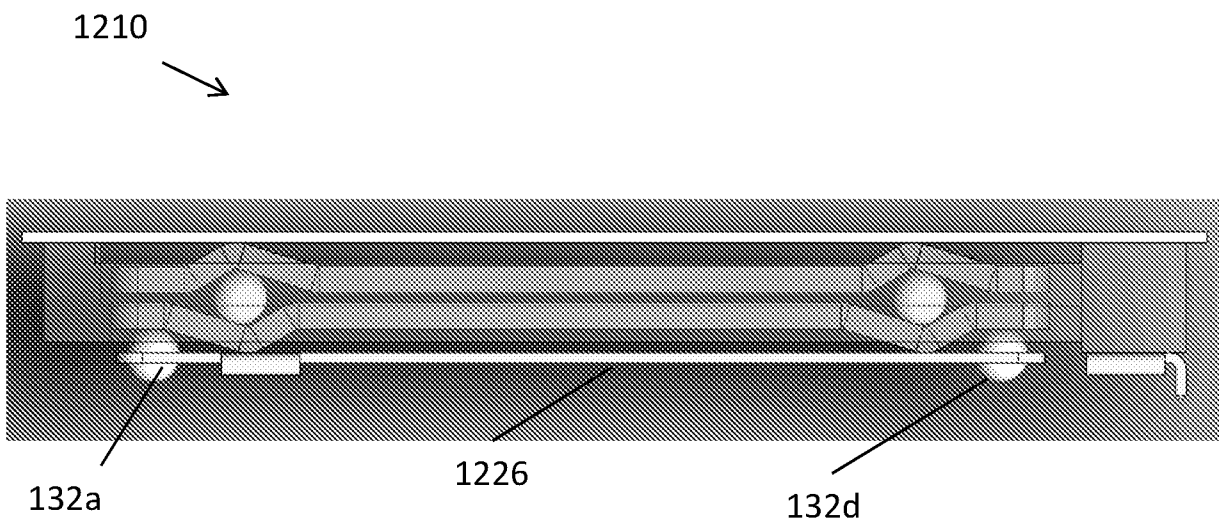


Fig 13a

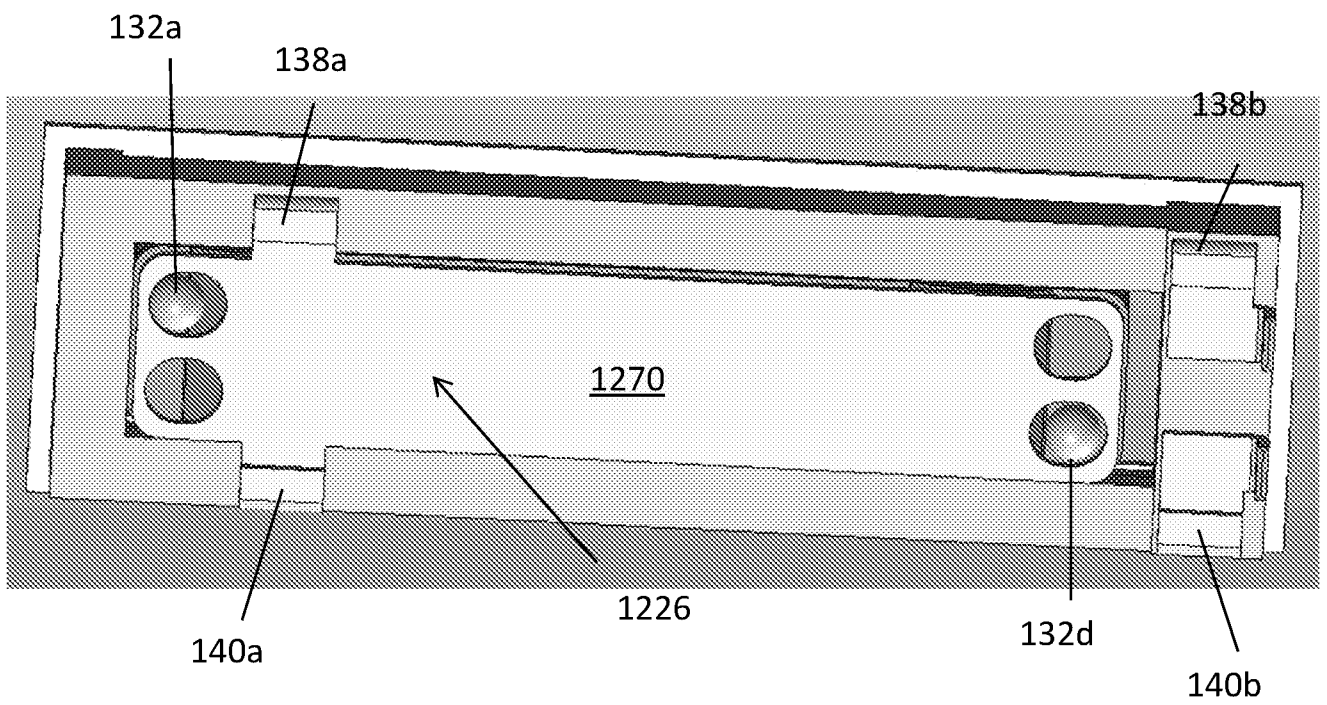
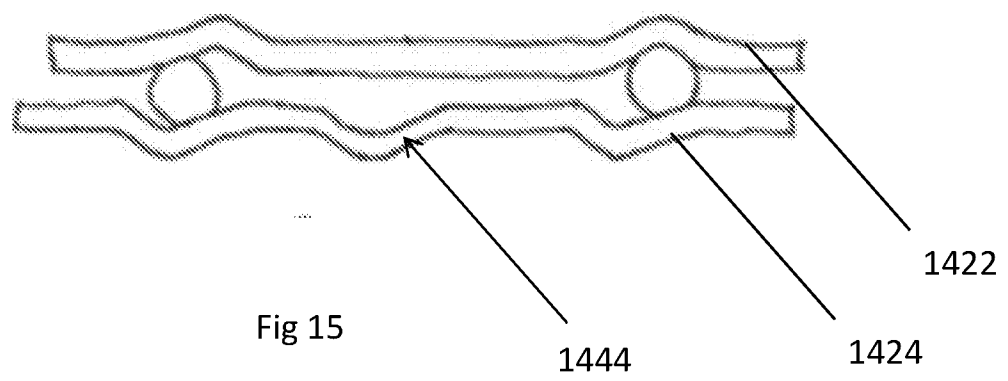
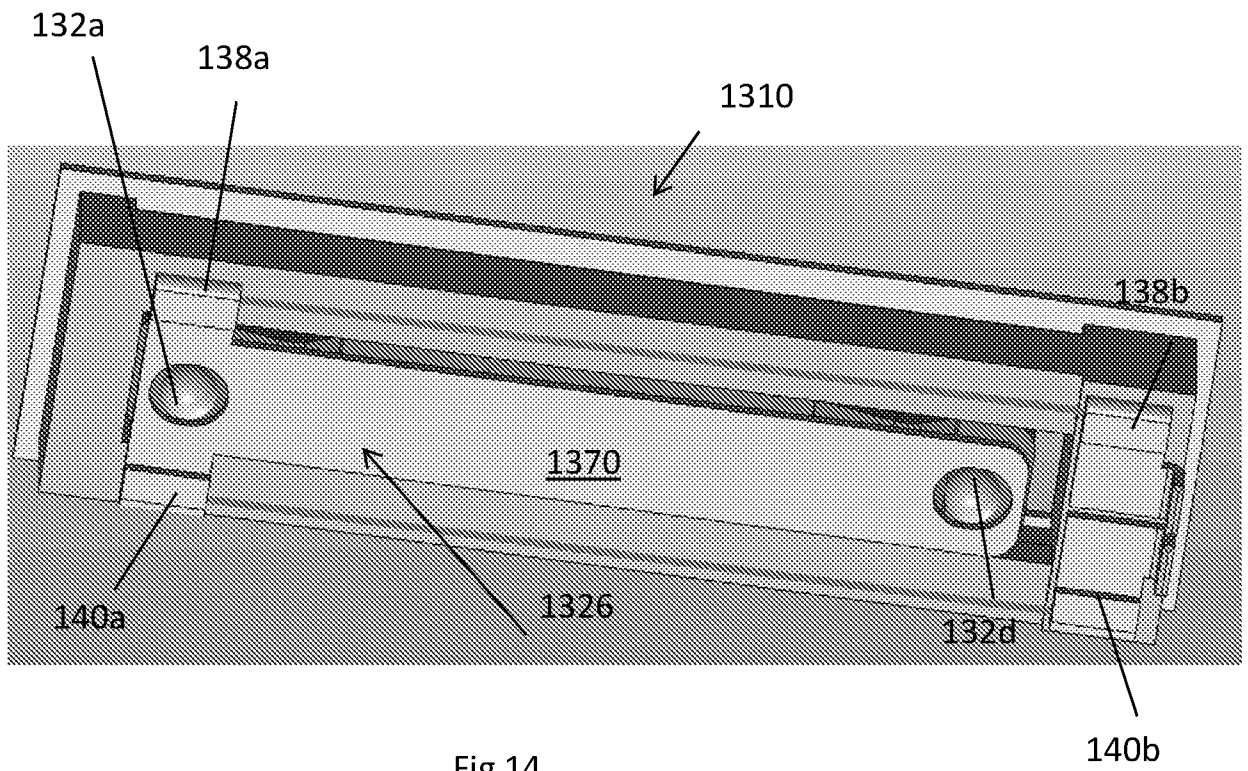


Fig 13b

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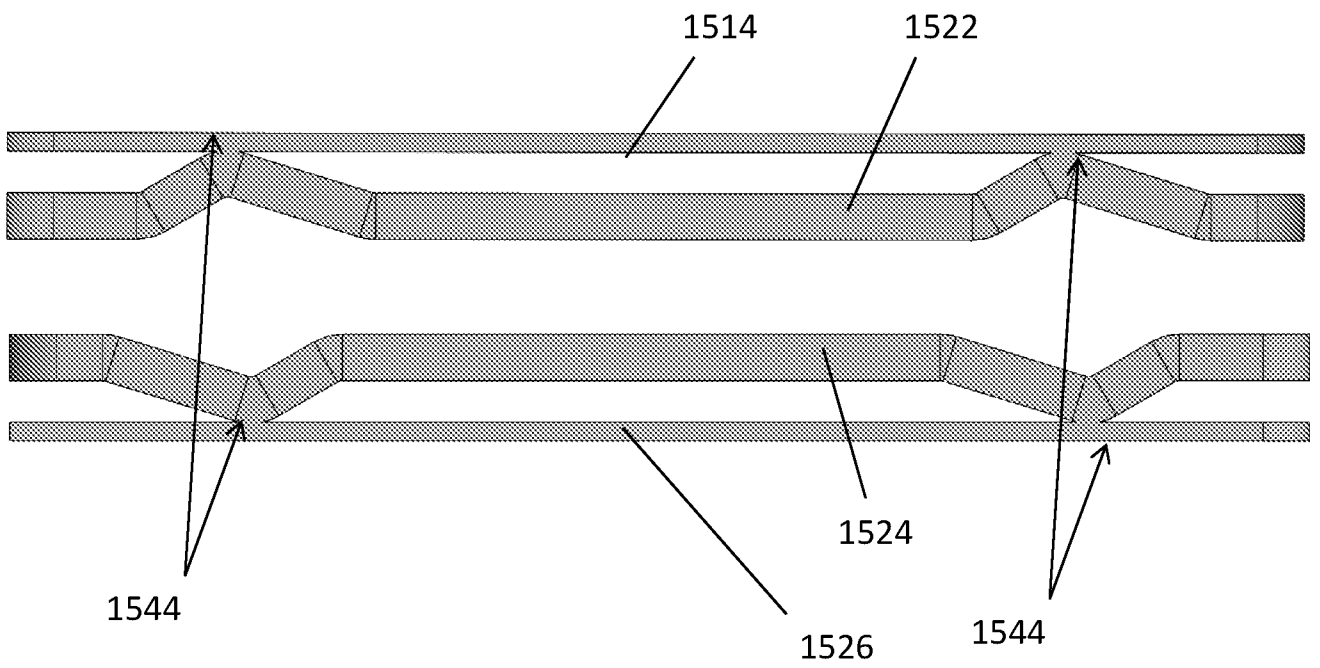


Fig 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/000520

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06F3/01
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2019/073243 A1 (CAMBRIDGE MECHATRONICS LTD [GB]) 18 April 2019 (2019-04-18) abstract page 5, line 33 - page 9, line 35 page 21, line 12 - page 24, line 10; figures 1-16	1-25
A	GB 2 551 657 A (CAMBRIDGE MECHATRONICS LTD [GB]) 27 December 2017 (2017-12-27) abstract; figures 1-12	1-25



Further documents are listed in the continuation of Box C.



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

13 October 2020

Date of mailing of the international search report

21/10/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Liebhart, Manfred

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2020/000520

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2019073243 A1	18-04-2019	GB 2581065 A WO 2019073243 A1	05-08-2020 18-04-2019
GB 2551657 A	27-12-2017	NONE	