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(54) **A phase shifter**

(57) The present invention is directed to a phase shifter comprising a primary printed circuit board (PCB) having at least an arcuate co-centric unconnected double track printed thereon, and, a secondary PCB having printed thereon at least an arcuate co-centric double track connected by a radially extending link track located at neighbouring ends of the double track; whereby, the secondary PCB is rotatably mounted on the primary PCB such that the arcuate co-centric double tracks on both PCBs partially overlap one another so as to be in electrical communication with one another. The advantage of providing arcuate co-centric tracks on the secondary PCB and the primary PCB is that rotation of the secondary PCB may be used to increase the length of the completed track circuit rather than a translational movement of the secondary PCB. Therefore, no additional area on the primary PCB has to be reserved to accommodate the movement of the secondary PCB. A variable phase shifter and a differential phase shifter may also be constructed in analogous manners.

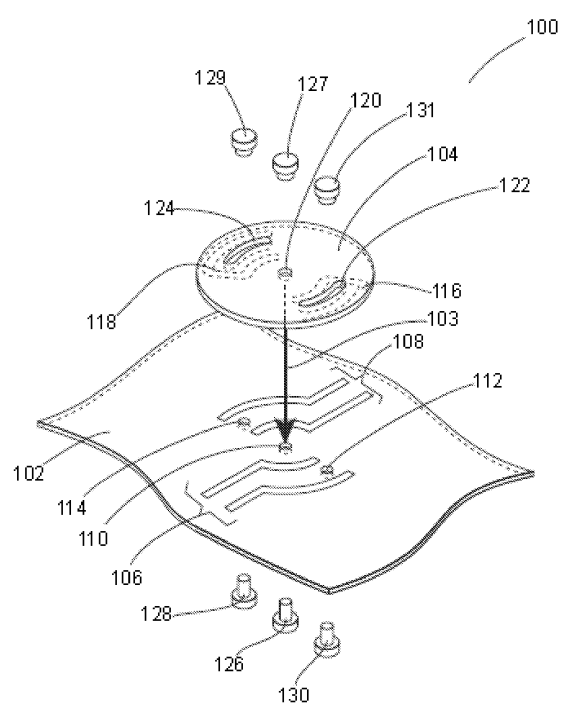


Fig. 1

Description

Introduction

[0001] This invention relates to phase shifters. In particular, this invention is directed towards variable phase shifters for use in variable tilt antennas and differential phase shifters for use in variable tilt antennas.

[0002] An antenna is comprised of one or more radiators which, in conjunction with one another, emit a radiation pattern which typically is comprised of a main beam and a plurality of side lobes. In most antenna arrangements, the main beam and associated side lobes are emitted in duplicate from either side of an antenna. The vast majority of the power of the transmission signal is contained in the main beams and therefore it is of high importance that these main beams are directed towards the coverage area designated for that antenna.

[0003] Variable tilt antennas are useful for deployment in areas which have undulating terrain comprised of valleys, hillsides and/or natural or man-made obstacles for example. The main beam emitted from the antenna can be tilted so that appropriate coverage can be provided down into the valley, up over the hillside and/or around the obstacle. Thus, the effects of the surrounding terrain can be overcome using a variable tilt antenna.

[0004] The main beam in the radiation patterns can also be tilted away from certain geographical areas so as to avoid causing cross-interference with other radiation patterns emitted from nearby antennas, for example in adjacent cells of a cellular network.

[0005] This process of tilting the main beam of an antenna is known as adjusting the vertical radiation pattern (VRP). There are a number of known methods which are currently employed to tilt the radiation pattern of an antenna.

[0006] Antennas may be physically tilted in order to adjust the direction of the main beam into a desired region. However, such manually tiltable antennas are expensive to construct as additional framework components and moving mechanical parts are required in order to permit the radiators which form the antenna to be tilted and moved into the correct positions so as to tilt the radiation pattern emitted from the antenna. The associated maintenance costs are relatively high as the framework comprises moving parts which need to be machined to accurate tolerances and are more complicated to maintain and replace than static component parts.

[0007] Furthermore, the tilting of the manually tiltable antenna may require on site presence of an engineer which is costly to provide. The actual tilting of the manually operable antenna is time consuming, and, even if the manually tiltable antenna only needs to be adjusted during an initial set up stage, it will still be time consuming as various measurements of the radiation pattern emitted from the tilted antenna will need to be taken to ensure that the antenna has been manually tilted to the optimum angle.

[0008] A further disadvantage with manually tilted antennas is whilst that the direction of the main beam emitted from one side of the antenna will be correctly tilted towards the appropriate area, the main beam emitted from the opposing side of the antenna will be tilted in an opposite manner which may be an inefficient use of antenna power. For example, if the antenna is located on a hilltop, one of the main beams emitted from the antenna will be directed downward from the hilltop to cover the appropriate area beneath the hill. However, the main beam can only be directed downward on one side of the hilltop and the main beam emitted on the opposite side of the antenna will be angled skyward which is a waste of transmission power. Moreover, it is possible that the main beam whose direction of emission is not controlled and actively adjusted may cause unwanted cross-interference with signals in neighbouring cells of a cellular network.

[0009] It is also known from the prior art to "electronically" tilt radiation patterns which are emitted from antennas by phase shifting each of a plurality of component signals that are respectively transmitted to the one or more radiators so as to form the radiation pattern emitted from the antenna. The phase shifts are applied to one or more of the component signals by delaying the components signals relative to one another and thus causing a phase shift to be imposed on one or more of the component signals. Delaying of the component signals relative to one another is achieved by varying the length of conducting path that each component signal must flow along relative to each other component signal, before reaching an associated, corresponding radiator in the antenna.

[0010] The conductive paths which the component signals flow along are typically formed by overlapping separate moveable printed conductive tracks so as to create a conductive path of variable length. The printed tracks are usually on printed circuit boards (PCBs). The conductive paths are extended or shortened by the movement of one track relative to the other track, which is to say the movement of one PCB relative to another PCB. The overlapping tracks remain in electrical communication throughout; however, the amount of overlap between the tracks is varied in order to vary the overall operative length of the conductive path.

[0011] Up to now, it has been known to use a sliding trombone type arrangement as disclosed in U.S. Patent Publication Number US2005/0184827 (PALLONE et al.) which describes an input and output transmission line which are printed on PCBs and are not radioelectrically coupled to one another. A mobile radioelectric coupling means comprising a first and second arm formed in a substantially U-shaped coupling circuit connects the input and output transmission lines to form an electric path. The electric path has a variation range between a first position defining a minimal electric path and a second position defining a maximal electric path. The U-shaped coupling circuit moves in a trombone like fashion to extend or decrease the overall path length from the input

transmission line to the output transmission line on the PCBs.

[0012] There are numerous problems with the phase shifters which are used in the variable tilt antenna currently available.

[0013] These types of sliding trombone arrangements for "electrically" tiltable phase shifters are subject to relatively high levels of insertion loss, or attenuation due to the physical layout of the tracks in the arrangement, which result in the use of more track length, and thus an increase in attenuation for a similar phase shift. It is possible to lower the attenuation by reducing the track length of the mobile radioelectric coupling means, however, small movements will result in larger phase shifts and this makes the accuracy of the imposed phase shift harder to control and apply.

[0014] A further disadvantage with the sliding trombone arrangement is that a relatively large amount of circuit board space is required to implement the arrangement. As the tracks on the PCBs are slid towards and away from each other, typically the primary PCB, which comprises the unconnected tracks, remains static whilst the secondary PCB, which comprises the coupling track, is moved in a translational motion. As the secondary PCB needs to move back and forth relative to the primary PCB, an area on the primary PCB must be left free to allow the secondary PCB to slid into and away from this space, thus accommodating the sliding movement of the PCBs relative to one another. In modern printed circuit boards, space is at a premium, and in order to be as cost effective as possible, the PCBs should be as compact as possible. The sliding trombone arrangement is expensive to implement as a result of the need for larger PCBs to be used.

[0015] The provision of translational movement to articulate the coupling circuit relative to the unconnected input and output transmission lines is relatively complicated and requires a mechanism to translate the rotational movement of a motor into a translational directed motion by means of an actuator. This adds to the complexity of the phase shifter and to the cost of constructing the phase shifter.

[0016] It is a goal of the present invention to provide a phase shifter that overcomes at least one of the above mentioned problems.

Summary of the Invention

[0017] The present invention is directed to a variable phase shifter comprising a primary printed circuit board (PCB) having at least one arcuate track printed thereon, and, a secondary PCB having at least one arcuate track printed thereon; whereby, the secondary PCB is rotatably mounted on the primary PCB such that the arcuate tracks on both PCBs overlap one another to be in electrical communication with one another, and, so that the overlap between the arcuate tracks may be varied by rotating the secondary PCB relative to the primary PCB so as to create a variable phase shift.

[0018] The advantage of providing an arcuate track on the primary PCB and on the secondary PCB is that rotational movement of the secondary PCB relative to the primary PCB may be used to increase the length of the completed track circuit rather than a translational movement of the secondary PCB. Therefore, no additional area on the primary PCB has to be reserved to accommodate the movement of the secondary PCB. This allows for a more compact circuit to be made which reduces manufacturing cost, the cost of the PCB material and also reduces the complexity of the phase shifter as a whole.

[0019] Furthermore, another advantage of the use of a rotational movement based construction as defined hereinbefore is that it will reduce the amount of attenuation and insertion loss which is suffered by a component signal as it passes along the path created by the arcuate tracks on the phase shifter device. The trombone arrangement as in known from the prior art causes relatively high levels of attenuation and insertion loss when compared to the levels of attenuation and insertion loss caused by a rotational based phase shifter as the length of track required by the trombone arrangement, in order to allow for the same sensitivity of control for applying the phase shift, is greater than the length of track required by the rotational-based movement of the invention in suit.

[0020] The present invention is further directed towards a phase shifter comprising a primary printed circuit board (PCB) having at least one arcuate track printed thereon, and, a secondary PCB having at least one arcuate track printed thereon; whereby, the secondary PCB is rotatably mounted on the primary PCB such that the arcuate tracks on both PCBs overlap one another to be in electrical communication with one another forming a conductive path, and, the overlap between the arcuate tracks may be varied by rotating the secondary PCB relative to the primary PCB so as to impart a variable phase shift on a signal travelling along the conductive path.

[0021] In a further embodiment, the primary PCB comprises a pair of arcuate co-centric unconnected tracks, and the secondary PCB comprises a pair of arcuate co-centric tracks connected by a link track located at neighbouring ends of the arcuate tracks.

[0022] Moreover, as the phase shifter comprises *arcuate* co-centric tracks, as the secondary PCB is rotated, the overlap between inner tracks of the tracks on the PCBs will be increased or decreased to a lesser degree than the overlap between outer tracks of the tracks on the PCBs. This asymmetric overlap of the asymmetrical coupling points from the capacitive coupling minimises the amount of impedance mismatch that will occur over the completed track length. The reduced level of impedance mismatch allows a greater range of phase shift to be achieved. This allows for better impedance control across a wide frequency band and over the range of rotation.

[0023] In a further embodiment, the link track is a radially extending link track.

[0024] In a further embodiment, a plurality of the phase shifters are arranged in series to form a phased array.

[0025] In a further embodiment, some of the phase shifters in the phased array comprise arcuate co-centric tracks of a differing size so as to form a plurality of scaled phase shifts.

[0026] In a further embodiment, a linkage mechanism is used to control the rotation of each of the secondary PCBs relative to the primary PCB.

[0027] In a further embodiment, a plurality of interconnected geared cogs control the rotation of each of the secondary PCBs in the phased array.

[0028] In a further embodiment, each of the secondary PCBs in the phased array further comprise a radially projecting arm; and, each radially projecting arm is pivotably connected to a sliding arm which rotates each secondary PCB as it slides back and forth.

[0029] In a further embodiment, at least two of the radially projecting arms are pivotably connected to the sliding arm at differing lengths from a centre pivot point of the secondary PCB so as to rotate some of the secondary PCBs by differing amounts to form a plurality of scaled phase shifts in the phased array.

[0030] In a further embodiment, the sliding arm is moved back and forth manually.

[0031] In a further embodiment, the sliding arm is moved back and forth by means of a DC motor.

[0032] In a further embodiment, the sliding arm is moved back and forth by means of a stepper motor.

[0033] In a further embodiment, the phase shifter comprises two opposing pairs of tracks on both of the PCBs.

[0034] The advantage of providing two opposing pairs of tracks on both of the PCBs is that by rotating the secondary PCB, both track lengths will be affected equally at the same time. Therefore, if the tracks are used in two separate antenna feed networks, both signals will be affected equally without the need for any complicated linkage mechanism as necessitated by the prior art. That is to say, that by forming two or more conductive paths on the same phase shifter, the extension or retraction of each conductive path on that phase shifter is controlled by the movement of the same secondary PCB. Therefore, no complicated linkage mechanism is required to maintain a synchronous relationship between the various conductive paths on the phase shifter. This facilitates better pattern tracking between two antennas; dual polarised antennas are commonly used in cellular and WiMax networks for diversity and more recently for MIMO communication applications.

[0035] In a further embodiment, the phase shifter comprises a plurality of double tracks on both of the PCBs.

[0036] In a further embodiment, the secondary PCB is mounted spaced apart from the primary PCB such that the double tracks on the PCBs do not contact each other.

[0037] In a further embodiment, the secondary PCB is spaced apart from the primary PCB by a spacer.

[0038] In a further embodiment, the secondary PCB is spaced apart from the primary PCB by a layer of poly-

tetrafluoroethylene (PTFE).

[0039] In a further embodiment, the secondary PCB is spaced apart from the primary PCB by a layer of solder resist.

[0040] In a further embodiment, the secondary PCB is spaced apart from the primary PCB by a layer of lacquer.

[0041] In a further embodiment, the secondary PCB comprises arcuate slots through which lug stops, mounted on the primary PCB, protrude such as to limit the amount of rotation of the secondary PCB relative to the primary PCB.

[0042] In a further embodiment, lug caps are connected atop lug stops mounted on the primary PCB as to maintain an operationally efficient pressure between the secondary PCB and the primary PCB.

[0043] In a further embodiment, the arcuate tracks printed on the PCBs are microstrip tracks.

[0044] In a further embodiment, the arcuate tracks printed on the PCBs are stripline tracks.

[0045] In a further embodiment, the phase shifter is a variable phase shifter such that both of the pair of conductive paths are extended or shortened substantially simultaneously.

[0046] In a further embodiment, the phase shifter is a differential phase shifter such that one of the pair of conductive paths is extended by a distance as the other conductive path is shortened by substantially the same distance.

[0047] The invention is further directed towards a variable tilt antenna comprising at least one phase shifter as described hereinabove.

[0048] In a further embodiment, the pair of opposing tracks conduct a pair of polarised antenna signals respectively.

[0049] In a further embodiment, the at least one phase shifter is connected to at least one radiator in an antenna array by at least one phase cable.

[0050] In a further embodiment, the at least one phase shifter is connected to at least one radiator in an antenna array by conductive tracks printed on a radio frequency (RF) substrate forming the primary PCB.

[0051] The advantage of providing a RF substrate is that a plurality of the tracks can be printed on the primary PCB to form the antenna feed network. The opposing side of the PCB forms the antenna ground plane for the radiating elements on the primary PCB. This obviates the need for any phase cabling which introduces insertion loss and also adds complexity to the production cycle.

Detailed Description of Embodiments

[0052] The invention will be more clearly understood from the following description of some embodiments thereof, given by way of example only with reference to the accompanying drawings, in which:

Fig. 1 is a detailed exploded perspective view of a variable phase shifter in accordance with the present

invention showing hidden parts in phantom lining;

Fig. 2 is a detailed perspective view of a primary printed circuit board (PCB) of the variable phase shifter of Fig. 1;

Fig. 3 is a detailed perspective view of a rotating secondary PCB of the variable phase shifter of Fig. 1;

Fig. 4(a) is an exploded perspective view of a phase shifter employed as a nine-element phase shifter array;

Fig. 4(b) is an enlarged view of a portion of the nine-element phase shifter array of Fig. 4(a);

Fig. 5(a) is a plan view of the nine-element phase shifter array of Fig. 4(a);

Fig. 5(b) is a partial plan view of the nine-element phase shifter array of Fig. 5(a);

Fig. 6(a) is a partial plan view of the 9-element phase shifter array of Fig. 5(a) with a pair of the phase shifters in a neutral position;

Fig. 6(b) is a partial plan view of the 9-element phase shifter array of Fig. 5(a) with the pair of the phase shifters in a rotated position;

Fig. 7(a) is a partial plan view of a further embodiment of a 9-element phase shifter with the pair of the phase shifters in a neutral position;

Fig. 7(b) is a partial plan view of the further embodiment of the 9-element phase shifter array of Fig. 7(a) with the pair of the phase shifters in a rotated position;

Fig. 8 is a detailed exploded perspective view of a differential phase shifter in accordance with a further embodiment of the present invention showing hidden parts in phantom lining;

Fig. 9 is a detailed perspective view of a primary PCB of the differential phase shifter of Fig. 8; and,

Fig. 10 is a detailed perspective view of a rotating secondary PCB of the differential phase shifter of Fig. 8.

[0053] Referring to Figs. 1 to 3 initially, there is provided a variable phase shifter indicated generally by the reference numeral 100. The variable phase shifter 100 comprises a primary printed circuit board (PCB) 102 and a secondary PCB 104. The secondary PCB 104 is rotatably mounted on the primary PCB 102, as indicated by construction line 103, and is held in position by a central

pivot pin 126. The central pivot pin 126 extends through a central hole 110 on the primary PCB 102 and a central hole 120 on the secondary PCB 104 respectively. A central pivot pin cap 127 is connected atop the central pivot pin 126 and the central pivot pin cap 127 ensures that a sufficient amount of pressure is maintained between the primary PCB 102 and the secondary PCB 104.

[0054] The primary PCB 102 comprises a pair of arcuate co-centric unconnected double tracks 106, 108 printed on a topside of the primary PCB 102.

[0055] The secondary PCB 104 comprises a pair of arcuate co-centric double tracks 116, 118 printed on the underside of the secondary PCB 104. Each arcuate co-centric double track 116, 118 comprises an outer arcuate track 105 and an inner arcuate track 107 connected by a radially extending link track 109 between neighbouring ends of the arcuate inner and outer tracks 105, 107.

[0056] The secondary PCB 104 further comprises guide slots 122, 124. Lug stops 128, 130 extend through holes 112, 114 in the primary PCB 102 and protrude through the guide slots 122, 124 respectively. The lug stops 128, 130 restrict the rotation of the secondary PCB 104 about the central pivot pin 126 relative to the primary PCB 102. Lug caps 129, 131 are connected atop the lug stops 128, 130. Similarly to the central pivot pin cap 127, the lug caps 129, 131 ensure that a sufficient amount of pressure is maintained between the primary PCB 102 and the secondary PCB 104. A consistent and constant conductive coupling between the tracks 106, 108, 116, 118 on the primary PCB 102 and the secondary PCB 104 may be thus achieved.

[0057] The primary PCB 102 is formed on a substrate 200 that is substantially flat. In the embodiment shown in Figs. 1 to 3, the secondary PCB 104 is substantially circular in form however, it will be appreciated that the secondary PCB 104 does not need to be circular in order for the present invention to be carried out.

[0058] When the secondary PCB 104 overlays the primary PCB 102, the arcuate co-centric unconnected double tracks 106, 108 on the primary PCB 102 overlap with the arcuate co-centric tracks 116, 118 on the secondary PCB 104 respectively to form a pair of continuous conductive paths, the lengths of which are extended or shortened simultaneously by rotating the secondary PCB 104 relative to the primary PCB 102. The conductive paths formed by the tracks 106, 108, 116, 118 may be used for a pair of orthogonal polarised antenna component signals. Similarly to before, the central pivot pin cap 127 and the lug caps 129, 131 ensure that a sufficient amount of pressure is maintained between the primary PCB 102 and the secondary PCB 104 so that the continuous conductive paths which are created by the arcuate co-centric unconnected double tracks 106, 108 on the primary PCB 102 overlapping with the arcuate co-centric tracks 116, 118 on the secondary PCB 104.

[0059] Referring now to Figs. 4(a) and 4(b), there is provided a nine-element phase array indicated generally by the reference numeral 400. The phase array 400 is

formed on a primary PCB substrate 402 upon which is printed a plurality of pairs of opposing arcuate co-centric unconnected double tracks 404A-404H. Each pair of opposing arcuate co-centric unconnected double tracks 404A-404H is associated with a corresponding secondary PCB 104A-104H to form a phase shifter respectively. The nine elements are used for nine antenna component signals and the nine component signals are sent to nine corresponding radiators (not shown) on an antenna. These radiators may be simple dipoles or patch arrays. Eight of the nine component signals are phase shifted by phase shifters according to the present invention.

[0060] The phase shifters may have arcuate tracks 404A-404H of varying arc sizes which will give rise to different amounts of phase shift. For example, a relatively small secondary PCB 104D having arcuate tracks with a relatively restricted arc having a small "diameter" will not extend a conductive path as much as a larger secondary PCB 104A having arcuate tracks with a larger arc length and hence a wider "diameter", when both secondary PCBs 104A, 104D are rotated by the same angular displacement.

[0061] Referring now to Figs. 5(a) and 5(b), there is shown an array 500 of phase shifters comprising eight secondary PCBs 104A-104H on a nine-element array. Each secondary PCB 104A-104H comprises a radially outwardly projecting arm 502 which is rotatably connected to a sliding arm 504. The secondary PCBs 104A-104H rotate, as indicated by reference arrows A, as the sliding arm 504 slides back and forth, as indicated by reference arrow B, in response to an actuator 506. The sliding arm 504 comprises guide slots 508 through which guide pins 510 protrude. These guide slots 508 and guide pins 510 direct and restrict the sliding motion of the sliding arm 504 to one dimension as indicated by reference arrow B. Furthermore, the guide slots 508 and the guide pins 510 may be preferably used in replacement of the guide slots 122, 124 and the lug stops 128, 130 to restrict the rotational movement of the secondary PCBs 104A-104H about their central pivot pins 126 relative to the primary PCB substrate 402 although it will be appreciated that they may be used in conjunction with one another. Guide pin caps (not shown) are also provide in a similar capacity as the central pivot pin cap 127 and the lug caps 129, 131.

[0062] Each radially outwardly projecting arm 502 comprises an elongated slot 514. A lug 512 projects upwardly (out of the page) from the sliding arm 504 and extends through the elongated slot 514. The distance of the lug 512 from the central pivot pin of each phase shifter when the phase shifters are in the neutral position as shown in Figs. 5(a) and 5(b) will determine the angle of rotation imparted to the phase shifters by the movement of the sliding arm 504. This is explained in greater detail below.

[0063] Referring in particular to Figs. 6(a) and 6(b), two phase shifters of the array 500 are shown. The lugs 512 for both phase shifters 100 are positioned at the same distance along the outwardly projecting arm 502

from the centre pivot point 604 of each secondary PCB 104. Thus, both phase shifters will be rotated by the same angular displacement when the sliding arm 504 is moved back and forth, as can be seen in Fig. 6(b).

[0064] As both phase shifters comprise arcuate conductive paths of differing arc lengths (i.e. differing "diameters"), the conductive paths on both phase shifters will not be extended by the same distance as a result of the same angular displacement. Thus, the component signals on the conductive paths of the phase shifters will be phase shifted by different degrees in this embodiment.

[0065] Referring now to Figs. 7(a) and 7(b), the two phase shifters of a second embodiment of an array 700 according to a further embodiment are shown. Both phase shifters are of the same diameter. The lugs 512 for both phase shifters are positioned at different distances along the outwardly projecting arm 502 from the centre pivot point 604 of each secondary PCB 104. The phase shifter on the left side of the array 700 has its lug 512 positioned at a point along the outwardly projecting arm 502 which is further away from the centre pivot point 604 of the associated secondary PCB 104 when compared to the position of the lug 512 for the phase shifter on the right side of the array 700.

[0066] Thus, when the sliding arm 504 is moved left by a predetermined distance both phase shifters will be rotated by different angular displacements, Φ_1 and Φ_2 , as can be seen in Fig. 7(b). In this embodiment, both phase shifters comprise arcuate conductive paths of the same arc length (i.e. the same "diameter"), but as the phase shifters are rotated by differing degrees, the conductive paths on both phase shifters will be extended by different distances. Thus, the component signals on the conductive paths of both of the phase shifters will still be phase shifted by different amounts.

Examples determining the amount of phase shift achieved per degree of rotation of the secondary PCB

1st Example (secondary PCB 104A/104H of Fig. 5(a))

[0067] Let the tracks on the PCBs (102, 104) have a mean radius of 28mm.

[0068] The circumference of the mean circle between the double tracks on the PCB is therefore approximately 176mm ($2\pi.r$).

[0069] This equates to an actual distance of 176mm/360° = 0.488mm per degree

[0070] If the guide slots in the secondary PCB allow for a $\pm 25^\circ$ rotation of the secondary PCB, then a total actual movement of

$$0.48\text{mm} \times 50^\circ = 24.4\text{mm is achievable}$$

[0071] Using a PCB material which has a dielectric constant of 2.2, and with the PCB material operating at

2.5GHz, a 1mm amount of movement is equivalent to a 4.1° phase shift for the component signal travelling along the conductive path formed by the printed tracks on the primary and secondary PCBs,

[0072] Thus, the total amount of possible phase shift is $4.1^\circ \times 24.4 = 100^\circ$ phase shift

[0073] So, at 2.5GHz for a $\pm 25^\circ$ rotation of a dk2.2 material having printed arcuate tracks with a mean radius of 28mm, 1° of angular rotation of the secondary PCB = 4° of phase shift of the signal travelling on the printed tracks, due to each track having a double loop.

2nd Example (secondary PCB 104B/104G of Fig. 5(a))

[0074] Let the tracks on the PCBs (102, 104) have a mean radius of 21 mm.

[0075] The circumference of the mean circle between the double tracks on the PCB is therefore approximately 132mm ($2\pi.r$).

[0076] This equates to an actual distance of 132mm/ $360^\circ = 0.366\text{mm}$ per degree

[0077] If the guide slots in the secondary PCB allow for a $\pm 25^\circ$ rotation of the secondary PCB, then a total actual movement of

$$0.36\text{mm} \times 50^\circ = 18.3\text{mm} \text{ is achievable}$$

[0078] Using a PCB material which has a dielectric constant of 2.2, and with the PCB material operating at 2.5GHz, a 1mm amount of movement is equivalent to a 4.1° phase shift for the component signal travelling along the conductive path formed by the printed tracks on the primary and secondary PCBs,

[0079] Thus, the total amount of possible phase shift is $4.1^\circ \times 18.3 = 75^\circ$ phase shift

[0080] So, at 2.5GHz for a $\pm 25^\circ$ rotation of a dk2.2 material having printed arcuate tracks with a mean radius of 21 mm, 1° of angular rotation of the secondary PCB = 3° of phase shift of the signal travelling on the printed tracks, due to each track having a double loop.

3rd Example (secondary PCB 104C/104F of Fig. 5(a))

[0081] Let the tracks on the PCBs (102, 104) have a mean radius of 14mm.

[0082] The circumference of the mean circle between the double tracks on the PCB is therefore approximately 88mm ($2\pi.r$).

[0083] This equates to an actual distance of 88mm/ $360^\circ = 0.244\text{mm}$ per degree

[0084] If the guide slots in the secondary PCB allow for a $\pm 25^\circ$ rotation of the secondary PCB, then a total actual movement of

$$0.24\text{mm} \times 50^\circ = 12.2\text{mm} \text{ is achievable}$$

[0085] Using a PCB material which has a dielectric constant of 2.2, and with the PCB material operating at 2.5GHz, a 1mm amount of movement is equivalent to a 4.1° phase shift for the component signal travelling along the conductive path formed by the printed tracks on the primary and secondary PCBs,

[0086] Thus, the total amount of possible phase shift is $4.1^\circ \times 12.2 = 50^\circ$ phase shift

[0087] So, at 2.5GHz for a $\pm 25^\circ$ rotation of a dk2.2 material having printed arcuate tracks with a mean radius of 14mm, 1° of angular rotation of the secondary PCB = 2° of phase shift of the signal travelling on the printed tracks, due to each track having a double loop.

4th Example (secondary PCB 104D/104E of Fig. 5(a))

[0088] Let the tracks on the PCBs (102, 104) have a mean radius of 7mm.

[0089] The circumference of the mean circle between the double tracks on the PCB is therefore approximately 44mm ($2\pi.r$).

[0090] This equates to an actual distance of 44mm/ $360^\circ = 0.122\text{mm}$ per degree

[0091] If the guide slots in the secondary PCB allow for a $\pm 25^\circ$ rotation of the secondary PCB, then a total actual movement of

$$0.12\text{mm} \times 50^\circ = 6.1\text{mm} \text{ is achievable}$$

[0092] Using a PCB material which has a dielectric constant of 2.2, and with the PCB material operating at 2.5GHz, a 1mm amount of movement is equivalent to a 4.1° phase shift for the component signal travelling along the conductive path formed by the printed tracks on the primary and secondary PCBs,

[0093] Thus, the total amount of possible phase shift is $4.1^\circ \times 6.1 = 25^\circ$ phase shift

[0094] So, at 2.5GHz for a $\pm 25^\circ$ rotation of a dk2.2 material having printed arcuate tracks with a mean radius of 7mm, 1° of angular rotation of the secondary PCB = 1° of phase shift of the signal travelling on the printed tracks, due to each track having a double loop.

[0095] The above examples show that the mean radius of the arcuate double tracks on the PCBs controls the phase shift achieved per degree of angular rotation imparted to the secondary PCB.

[0096] Referring now to Figs. 8 to 10, wherein like parts previously described have been assigned the same reference numerals, there is provided a differential phase shifter indicated generally by the reference numeral 800. The differential phase shifter 800 comprises the primary printed circuit board (PCB) 102 and the secondary PCB

104. The secondary PCB 104 is rotatably mounted on the primary PCB 102 as before. This is indicated by the construction line 103. Many of the features of the differential phase shifter 800 remain the same as the variable phase shifter 100 shown in preceding drawings including the central pivot pin 126, the central hole 120, the central pivot pin cap 127, the holes 112, 114 in the primary PCB 102, the guide slots 122, 124, the lug stops 128, 130 and the lug caps 129, 131.

[0097] The difference between the differential phase shifter 800 and the variable phase shifter 100 is found in the pattern that is formed by the tracks 802, 804, 806, 808, 810 on the primary PCB 102 and the secondary PCB 104 of the differential phase shifter 800 compared to the printed tracks 106, 108, 116, 118 on the primary PCB 102 and the secondary PCB 104 of the variable phase shifter 100.

[0098] The primary PCB 102 comprises a power input 811 which is input to a power divider indicated by reference numeral 812. By varying the widths of the branches 814, 816 emanating from the power divider 812, the ratio of the division of power can be altered. In this embodiment, the branches 814, 816 are of substantially equal width and thus the input signal is divided substantially equally between the two branches 814, 816. The branches 814, 816 extend into arcuate tracks 818, 820 respectively which are co-centric with but separate from unconnected arcuate tracks 804, 806.

[0099] The secondary PCB 104 comprises a pair of arcuate co-centric double tracks 808, 810 printed on the underside of the secondary PCB 104. Each arcuate co-centric double track 808, 810 comprises an outer arcuate track 105 and an inner arcuate track 107 connected by a radially extending link track 109 between neighbouring ends of the arcuate inner and outer tracks 105, 107. The arcuate co-centric double tracks 808, 810 are arranged so that by rotating the secondary PCB 104 relative to the primary PCB 102, one of the conductive paths formed by the arcuate tracks 806, 808, 820 is extended whilst the other conductive path formed by the other arcuate tracks 804, 810, 818 is shortened.

[0100] A differential output may be thus taken across the differential outputs 824, 826.

[0101] The differential phase shifter 800 may be used in a variable tilt antenna which is designed to operate at low antenna frequencies, below 1 GHz. At these frequencies the spacings between the radiating elements on the antenna need to be relatively large. As the spacing between the elements will be large, it would be uneconomical to printed the radiating elements on a PCB as may be done in the afore-mentioned embodiment, and it is thus envisaged that the differential phase shifter 800 itself will be printed on a PCB but the outputs 824, 826 will be fed to the radiating elements using coaxial cables (not shown). Each output 824, 826 may be fed to the top half radiating elements of the antenna or the bottom half radiating elements of the antenna as appropriate. If the differential shift which is applied to the signal applies a

positive phase shift to the radiating elements on the top half of the antenna and a negative phase shift to the radiating elements on the bottom half of the antenna, then a down tilt of the radiation pattern emitted from the antenna will be achieved.

[0102] As previously described, the secondary PCB 104 is shown in a substantially circular form however, the secondary PCB 104 does not need to be circular in order for any embodiments of the present invention to be carried out.

[0103] In the illustrated embodiments hereinbefore described, the phase shifter 100 has been shown to be double pole phase shifter 100 as the phase shifter comprises a pair of diametrically opposed arcuate conductive paths, one path for two separate signals in an antenna signal. It will be appreciated that a single conductive path may be formed on the phase shifter 100 or a plurality of conductive paths may be formed on the phase shifter 100.

[0104] It will be readily appreciated that although reference has been made to a primary PCB and a secondary PCB throughout many parts of the description hereinbefore and the claims hereinafter, the terms primary and secondary have been used for illustrative and explanatory purposes only and do not limit the construction of the phase shifters in any way. Indeed, the tracks as shown to be printed on the secondary PCB may alternatively be printed on the primary PCB and the tracks shown to be printed on the primary PCB may be printed on the secondary PCB.

[0105] Moreover, although the secondary PCBs have been described as the PCBs which move relative to the primary PCB, either or both of the PCBs, or portions of the PCBs, may be articulated so as to cause movement of the tracks on the PCBs relative to one another.

[0106] In the specification the terms "comprise, comprises, comprised and comprising" or any variation thereof and the terms "include, includes, included and including" or any variation thereof are considered to be totally interchangeable and they should all be afforded the widest possible interpretation.

[0107] The invention is not limited to the embodiments hereinbefore described which may be varied in both construction and detail within the scope of the appended claims.

Claims

1. A phase shifter comprising a primary printed circuit board (PCB) having at least one arcuate track printed thereon, and, a secondary PCB having at least one arcuate track printed thereon; whereby, the secondary PCB is rotatably mounted on the primary PCB such that the arcuate tracks on both PCBs overlap one another to be in electrical communication with one another forming a conductive path, and, the overlap between the arcuate tracks may be var-

ied by rotating the secondary PCB relative to the primary PCB so as to impart a variable phase shift on a signal travelling along the conductive path.

2. A phase shifter as claimed in claim 1, wherein, the primary PCB comprises a pair of arcuate co-centric unconnected tracks, and the secondary PCB comprises a pair of arcuate co-centric tracks connected by a link track located at neighbouring ends of the arcuate tracks so as to form a pair of conductive paths. 5
3. A phase shifter as claimed in claim 2, wherein, the link track is a radially extending link track. 10
4. A phase shifter as claimed in any preceding claim, wherein, a plurality of the phase shifters are arranged in series to form a phased array. 15
5. A phase shifter as claimed in claim 4, wherein, some of the phase shifters in the phased array comprise arcuate co-centric tracks of a differing size so as to form a plurality of scaled phase shifts. 20
6. A phase shifter as claimed in claim 4, wherein, the phase shifters in the phased array comprise arcuate co-centric tracks of a substantially equal size, and, the phase shifters in the phased array are rotated to differing angles to form a plurality of scaled phase shifts in the phased array. 25
7. A phase shifter as claimed in any preceding claim, wherein, the secondary PCB comprises arcuate slots through which lug stops, mounted on the primary PCB, protrude such as to limit the amount of rotation of the secondary PCB relative to the primary PCB. 30
8. A phase shifter as claimed in any preceding claim, wherein, lug caps are connected atop lug stops mounted on the primary PCB as to maintain an operationally efficient pressure between the secondary PCB and the primary PCB. 35
9. A phase shifter as claimed in claim 2, wherein, the phase shifter is a variable phase shifter such that both of the pair of conductive paths are extended or shortened substantially simultaneously. 40
10. A phase shifter as claimed in any preceding claim, wherein, the phase shifter is a differential phase shifter such that one of the pair of conductive paths is extended by a distance as the other conductive path is shortened by substantially the same distance. 45

11. A variable tilt antenna comprising at least one phase shifter as claimed in any preceding claim.

12. A variable tilt antenna comprising the phase shifter as claimed in claim 11 such that the pair of opposing tracks conduct a pair of polarised antenna signals respectively.

13. A variable tilt antenna as claimed in claims 11 or 12, wherein, the at least one phase shifter is connected to at least one radiator in an antenna array by at least one phase cable.

14. A variable tilt antenna as claimed in claims 11 or 12, wherein, the at least one phase shifter is connected to at least one radiator in an antenna array by conductive tracks forming a radio frequency (RF) substrate on the primary PCB. 20

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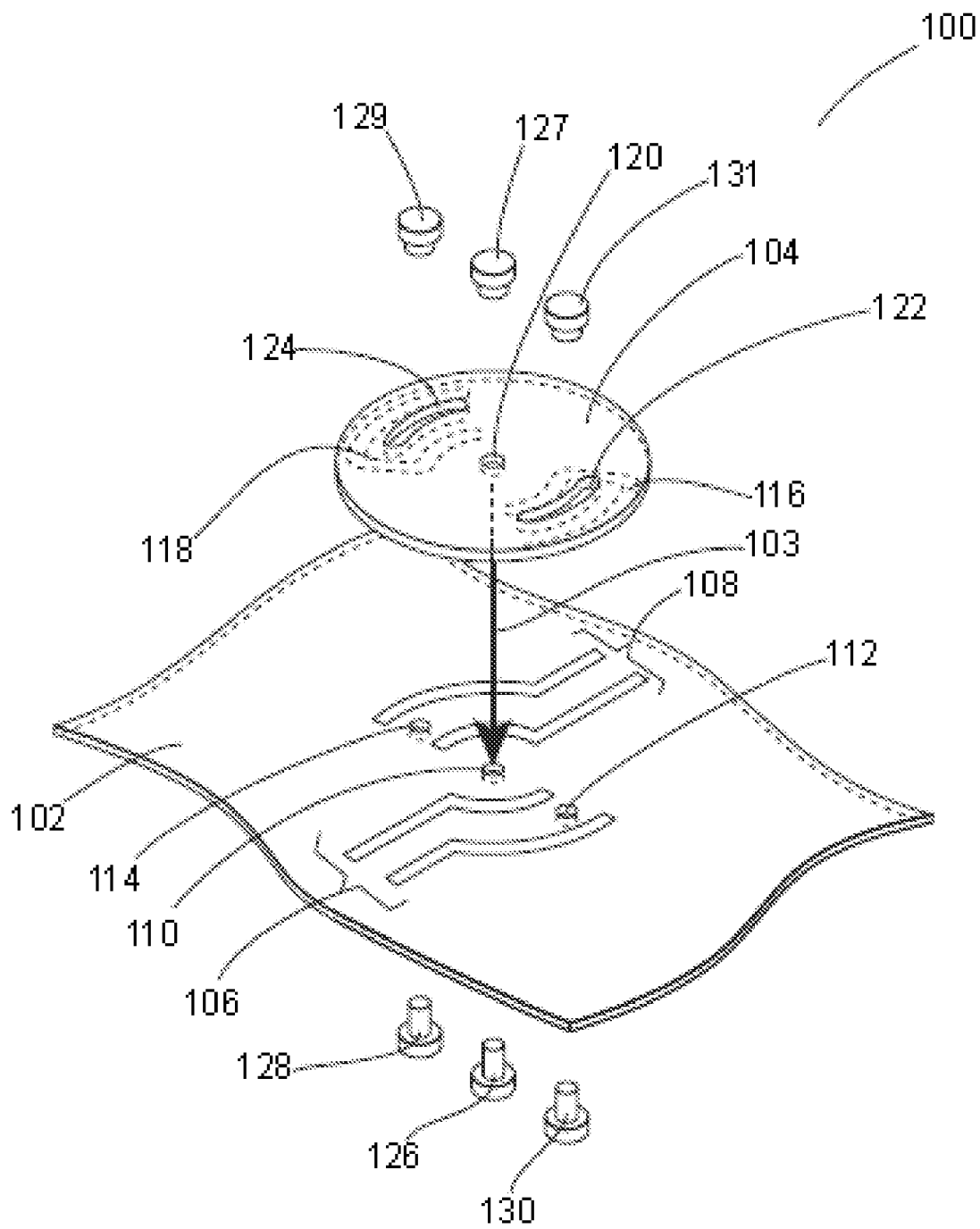


Fig. 1

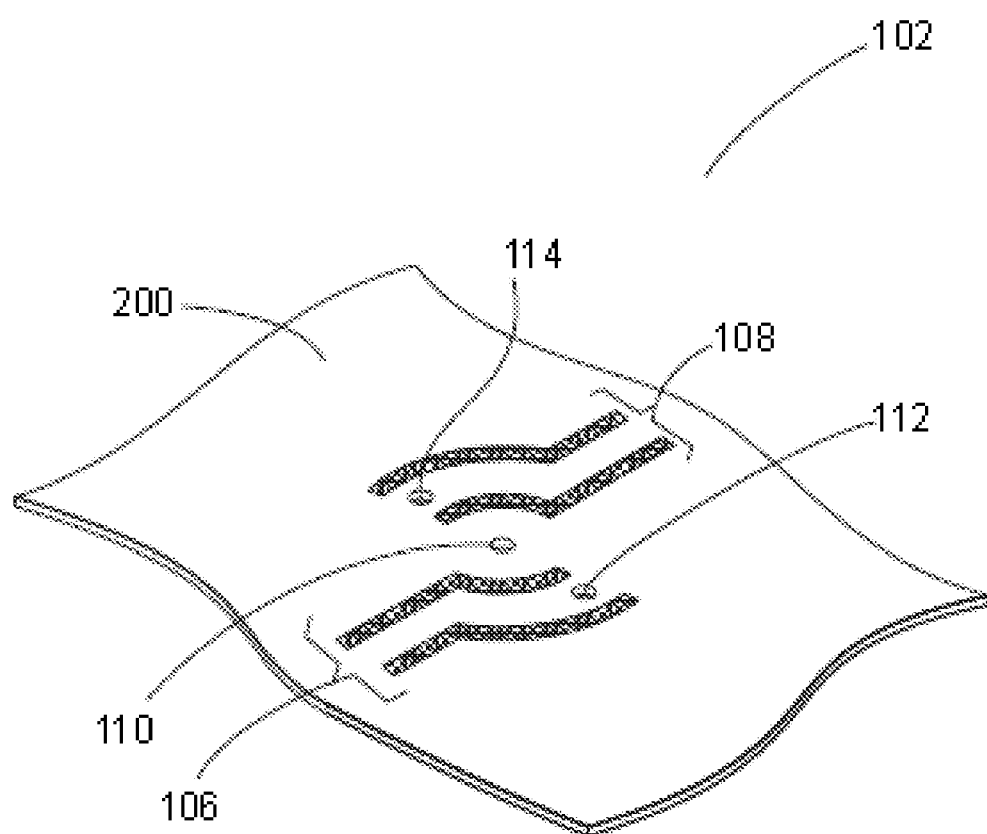


Fig. 2

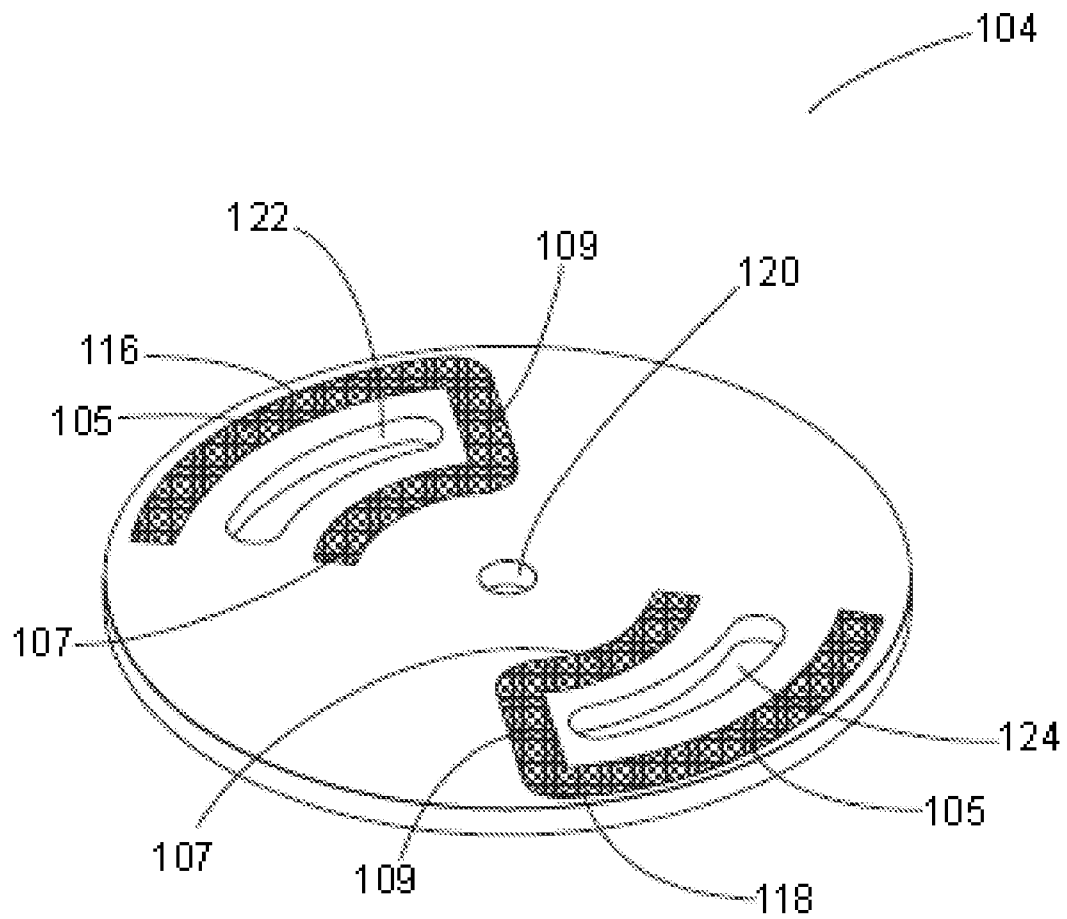
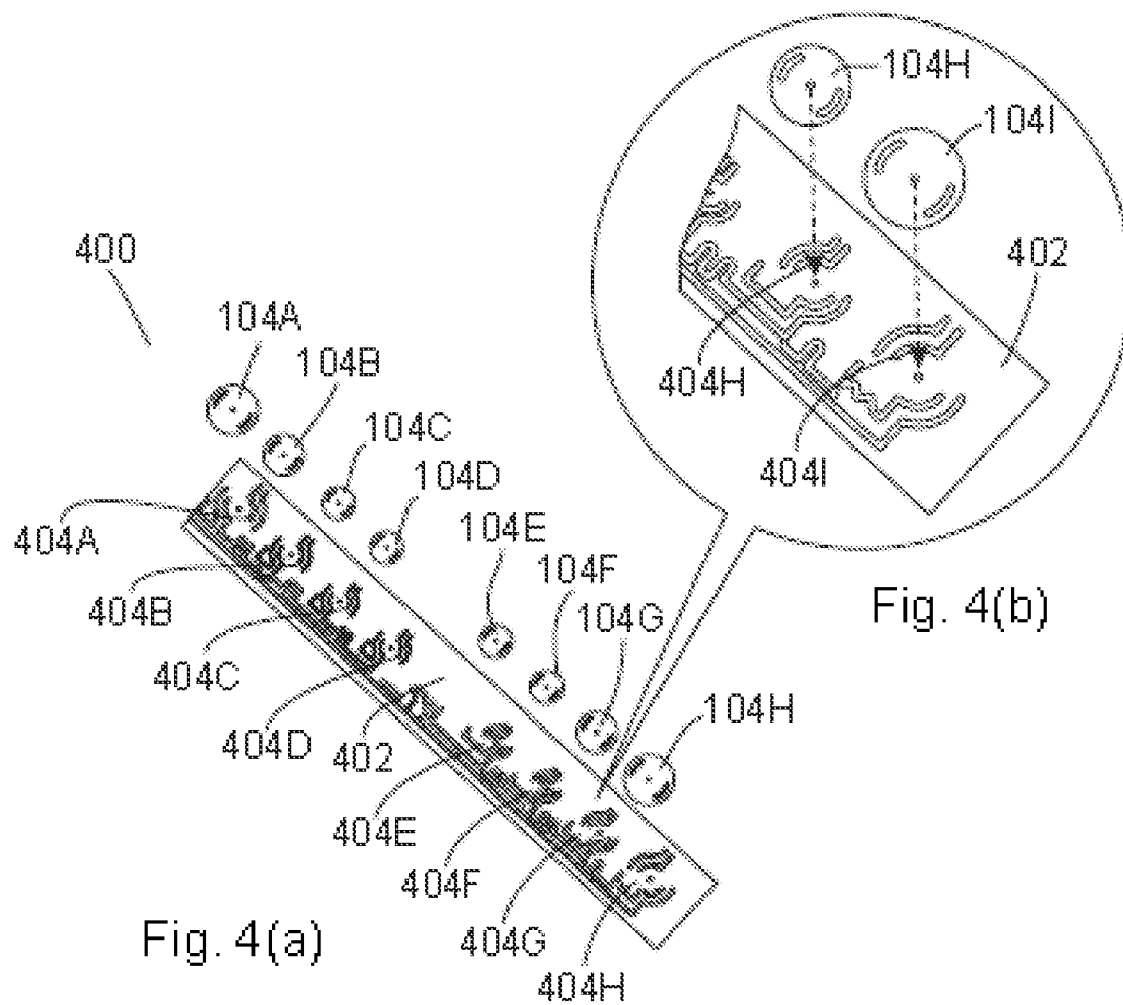


Fig. 3



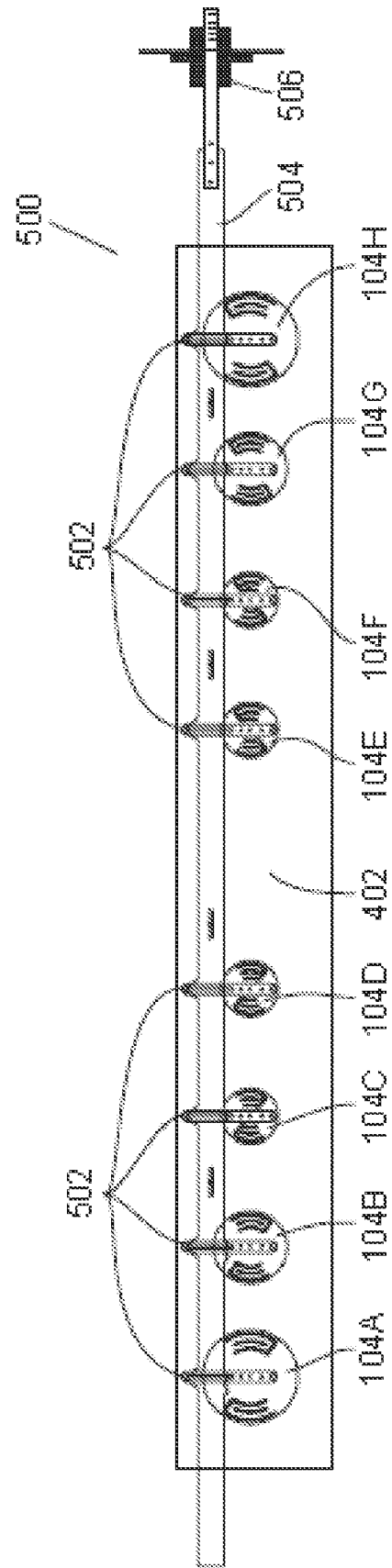


Fig. 5(a)

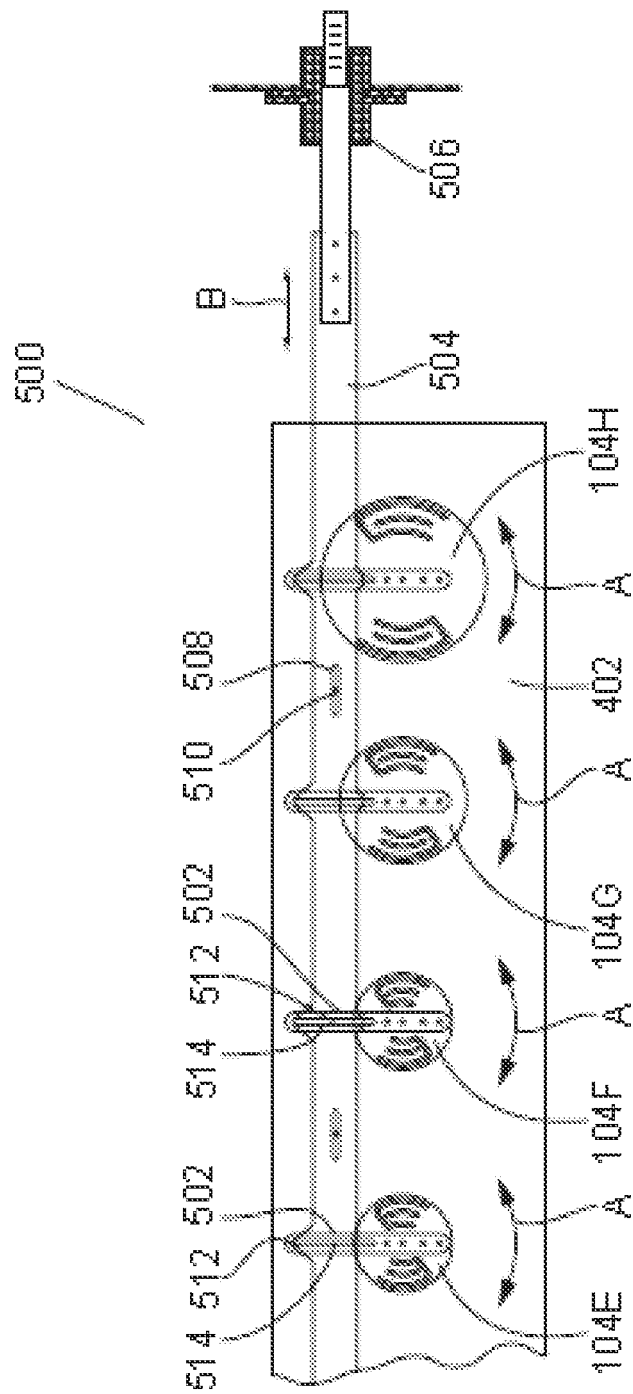


Fig. 5(b)

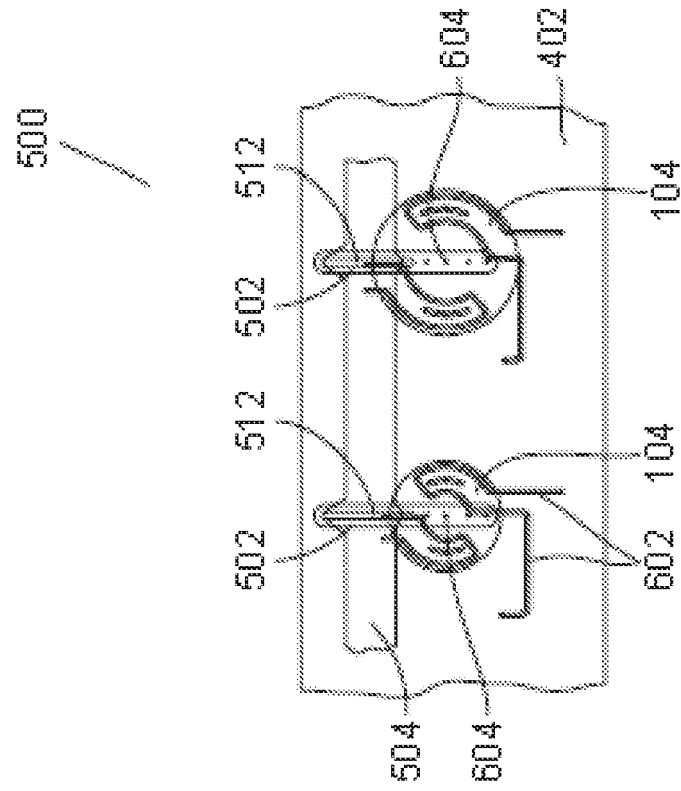


Fig. 6(a)

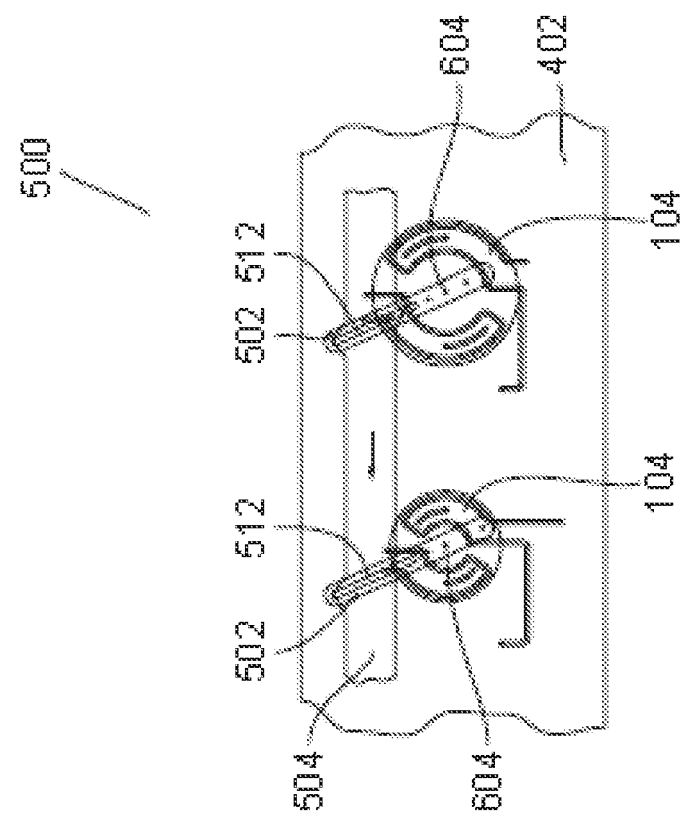


Fig. 6(b)

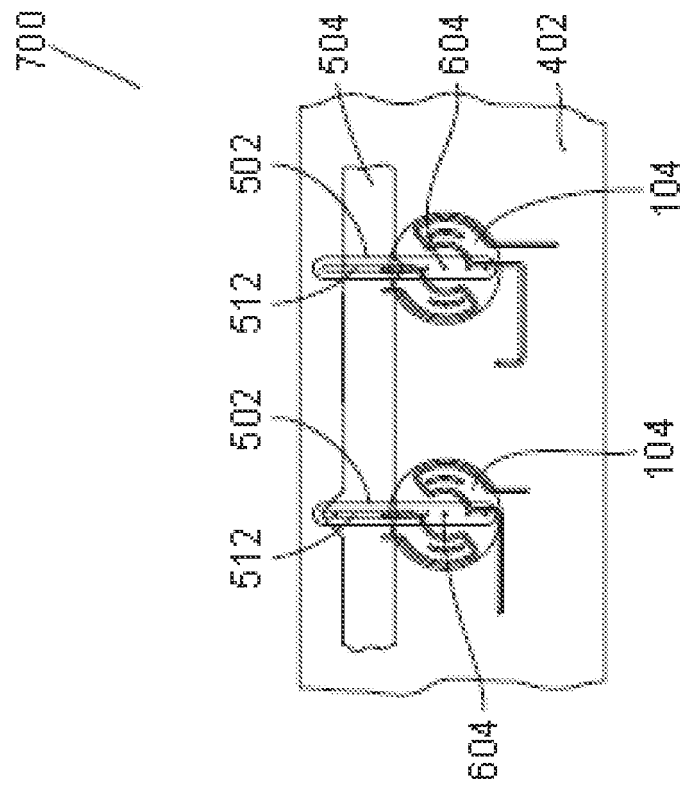


Fig. 7(a)

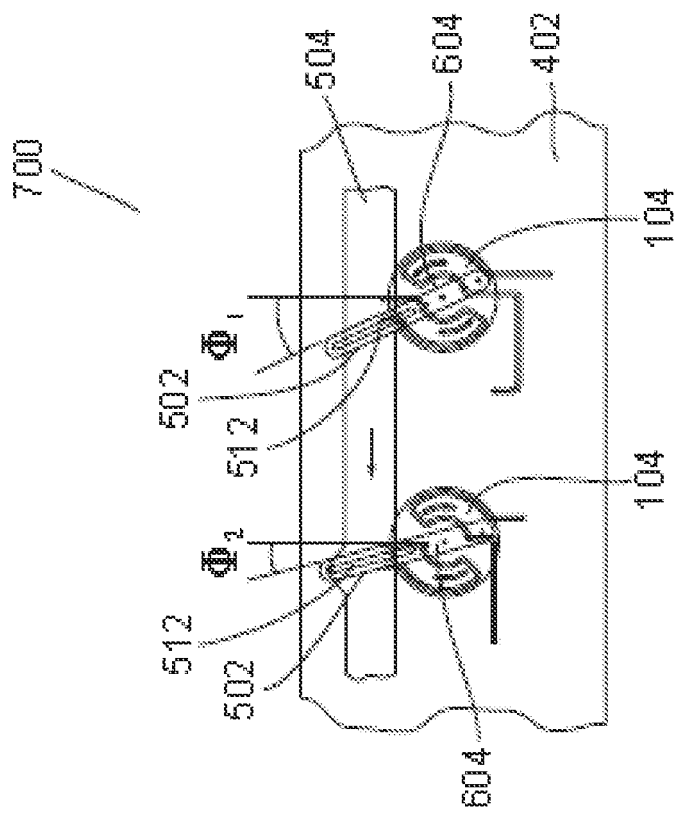


Fig. 7(b)

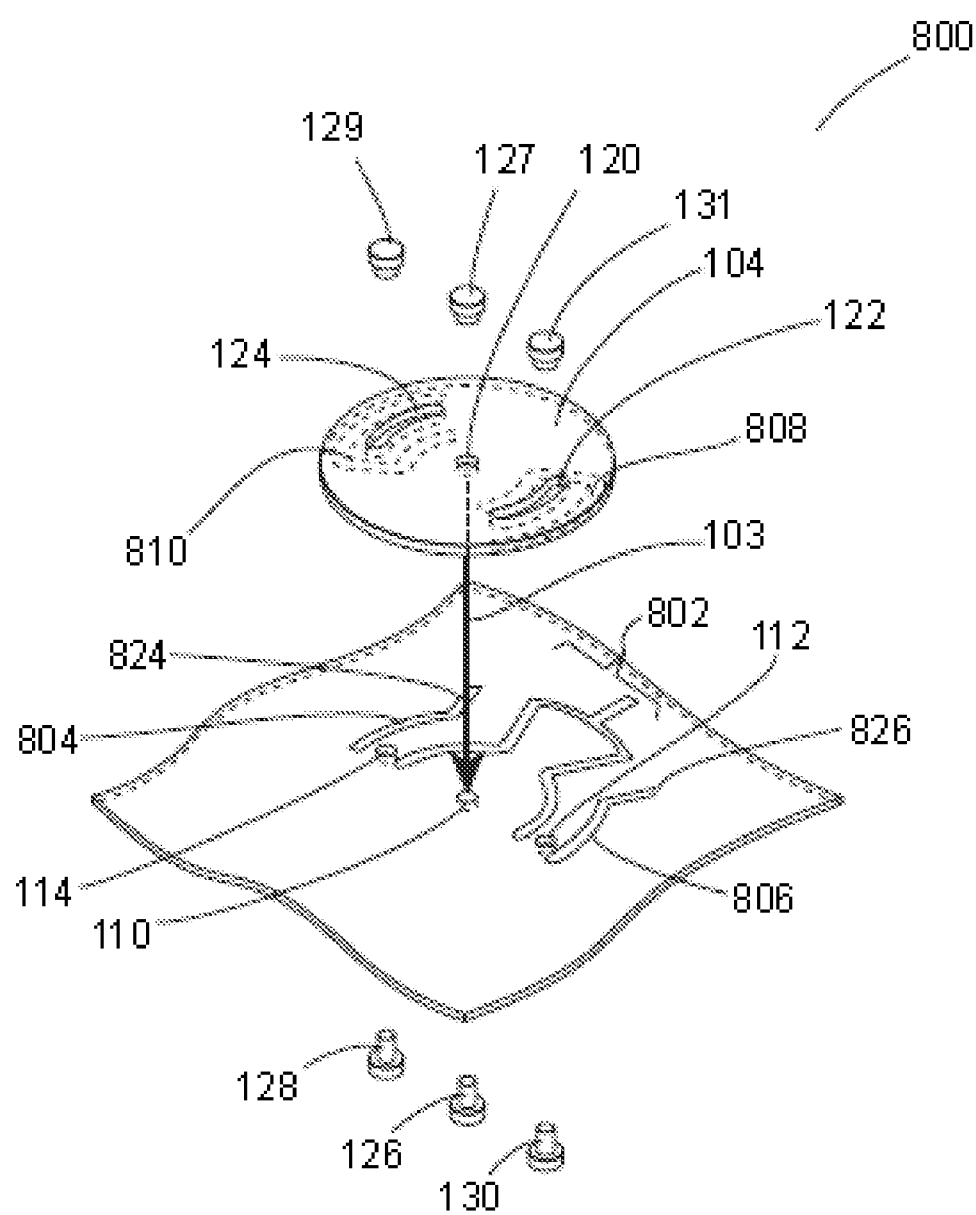


Fig. 8

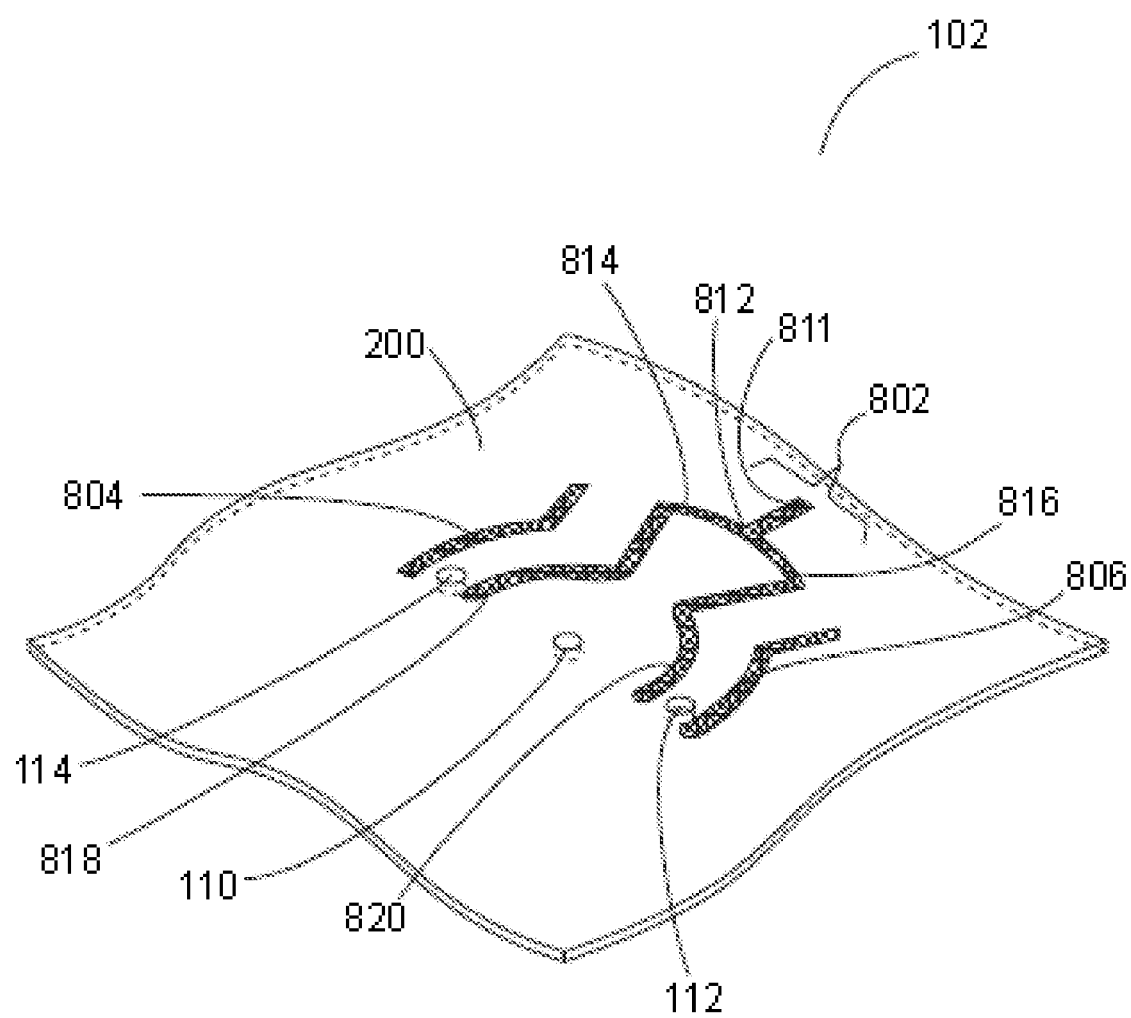


Fig. 9

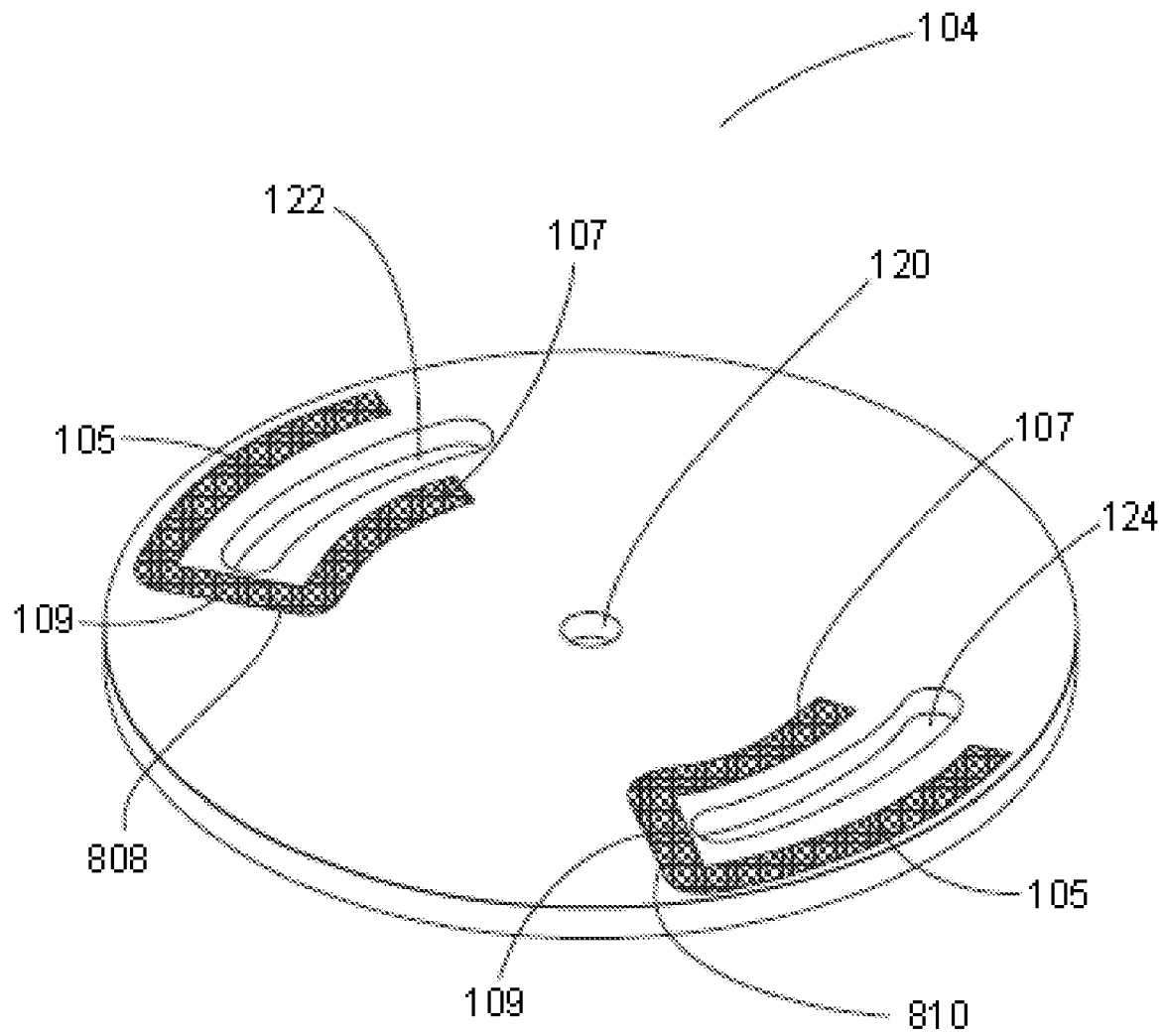


Fig. 10

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 20050184827 A, PALLONE [0011]