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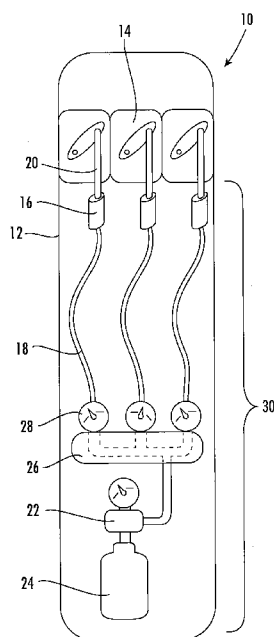


FIG. 1

(57) Abstract: Systems for controlling phase shifters of remote electronic downtilt base station antennas are provided. The base station antenna can include a plurality of phase shifters in a housing that can be coupled to a pneumatic system, wherein the pneumatic system is configured to shift the phase of the base station antenna. The pneumatic system may include gas driven pistons coupled to a gas supply line, wherein the gas driven pistons are configured to reciprocate in response to pressure of a compressed gas in the gas supply line. A linkage between the gas driven piston and the phase shifters is configured to move the phase shifters in response to the gas driven piston to shift the phase of the base station antenna.



SYSTEMS FOR CONTROLLING PHASE SHIFTERS OF REMOTE ELECTRONIC DOWNTILT BASE STATION ANTENNAS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority under 35 U.S.C. § 119 to U.S. Provisional Application Serial No. 62/551,284 entitled *Systems for Controlling Phase Shifters of Remote Electronic Downtilt Base Station Antennas* filed with the United States Patent and Trademark Office on August 29, 2017, the entire contents of which is incorporated by reference herein as if set forth in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to communication systems and components, and in particular, systems for controlling phase shifters of base station antennas.

BACKGROUND OF THE INVENTION

[0003] Base station antennas for cellular communications systems typically include one or more linear arrays of radiating elements such as dipoles that are mounted on, for example, a flat panel. Each array of radiating elements may produce an antenna beam that has desired characteristics such as, for example, a desired beam elevation angle, beam azimuth angle, and/or half power beam width in order to provide cellular service to a specified coverage area. A signal that is to be transmitted by one of the linear arrays of such a base station antenna is divided into multiple sub-components, and each sub-component may be fed through an antenna feed network to a respective one of the radiating elements.

[0004] Based on network coverage requirements, cellular operators may find it advantageous to adjust the vertical elevation angle (i.e., the vertical angle of the antenna with respect to the horizon) or "tilt" of the main beam of a linear array in order to change the coverage area of the antenna. Such adjustment is typically referred to as "down-tilting" as the antenna beam is typically tilted to point at an elevation angle of 0° or less with respect to the horizon such as, for example, an elevation angle of 0° to -10°. The base station antenna may also be electronically down-tilted by controlling the phases of the sub-components of the signal that are transmitted through the respective radiating elements of the linear array that forms the antenna beam in a manner that changes the elevation angle of the main antenna beam. Such electronic down-tilt is typically performed by transmitting a control signal from

a remote location to the base station antenna. In response to this control signal, the base station antenna adjusts settings of adjustable phase shifters that are included in the antenna feed network to implement the phase shifts that down-tilt the main beam of the linear array at issue.

[0005] Electromechanical phase shifters are typically used to implement the adjustable phase shifters that are used to electronically down-tilt the antenna beams of the linear antennas. An example of such an electromechanical phase shifter is the wiper arc phase shifter disclosed in U.S. Patent No. 7,463,190 to Zimmerman. The phase shifter of the '190 patent has a stationary "main" printed circuit board and a mechanically rotatable "wiper" printed circuit board mounted thereon. The amount of phase shift may be adjusted by mechanically moving the wiper printed circuit board to change the position along the arced transmission paths where the wiper printed circuit board capacitively couples to the main printed circuit board. Each of the outputs of the phase shifter may be connected to a respective one of the radiating elements or to a respective sub-groups of radiating elements of the linear array so that a linear phase taper may be applied to the radiating elements (or sub-groups thereof).

[0006] Base station antennas that use electromechanical phase shifters typically include a plurality of Remote Electronic Tilt (RET) units that are used to move the wiper printed circuit boards of the phase shifters. Each RET unit may include one or more motors such as direct current (DC) motors or stepper motors. In some cases a motor may be shared over multiple RET units. Mechanical linkages connect each motor to a respective one of the phase shifters (or to two of the phase shifters when dual polarized radiating elements are used, as the same phase shift is typically applied to the signals of each polarization) so that the motors may be used to move the wiper boards of the phase shifters. The electrical down-tilt is effected by sending a control signal to the base station antenna. This control signal is transmitted over an Antenna Interface Standards Group (AISG) control channel to a RET controller included in the base station antenna. The RET controller includes software that decodes and processes AISG commands that are included in the AISG control signal and, in response thereto, transmits control signals to the individual RET units. The control signals transmitted by the RET controller to an individual RET unit may activate a motor of the RET unit to drive a mechanical linkage to adjust an associated electromechanical phase shifter to apply a desired phase taper to the radio frequency (RF) signals input thereto. Thus, a RET unit is a device that is used to physically adjust a phase shifter of the base station antenna while the RET

controller is a unit that receives AISG commands and controls one or more RET units in response thereto.

SUMMARY OF THE INVENTION

[0007] It should be appreciated that this Summary of the Invention is provided to introduce a selection of concepts in a simplified form, the concepts being further described below in the Detailed Description of the Invention. This Summary of the Invention is not intended to identify key features or essential features of this disclosure, nor is it intended to limit the scope of the invention.

[0008] A first aspect of the present invention is directed to a base station antenna. The base station antenna may comprise a housing, a plurality of phase shifters in the housing, and a pneumatic system coupled to the plurality of phase shifters where the pneumatic system is configured to shift the phase of the base station antenna.

[0009] In some embodiments, the pneumatic system may comprise a container configured to hold a compressed gas, a pressure regulator configured to regulate the pressure of the container, a gas driven piston coupled to a gas supply line where the gas driven piston may be configured to reciprocate in response to pressure of the compressed gas in the gas supply line, and a linkage coupled between the gas driven piston and the phase shifters, where the linkage may be configured to move the phase shifters in response to the gas driven piston to shift the phase of the base station antenna.

[0010] In some embodiments, the base station antenna may further comprise a distribution manifold configured to distribute the compressed gas to a plurality of gas supply lines, where each gas supply line comprises a flow control valve.

[0011] In some embodiments, the gas supply line may comprise flexible tubing.

[0012] In some embodiments, the base station antenna may further comprise a linear position tracker configured to track the position of the gas driven piston relative to the phase shifters.

[0013] In some embodiments, the compressed gas may comprise air or nitrogen.

[0014] In some embodiments, the phase shifters may move in a first direction when more compressed gas is distributed into the gas supply line and the phase shifters may move in a reciprocal direction when less compressed gas is distributed into the gas supply line.

[0015] In some embodiments, the flow control valves may be connected with a controller.

[0016] In some embodiments, the gas driven piston may be coupled to two or more gas supply lines.

[0017] Another aspect of the present invention is directed to a base station antenna assembly. The base station assembly may comprise a plurality of phase shifters, a container configured to hold a compressed gas, a pressure regulator configured to regulate the pressure of the container, a distribution manifold configured to distribute the compressed gas to a plurality of gas supply lines. In some embodiments, each gas supply line may comprise a flow control valve, a plurality of gas driven pistons each coupled to a respective gas supply line, and a linkage coupled between each gas driven piston and a respective phase shifter, where the linkage may be configured to move the phase shifters in response to the gas driven piston to shift the phase of the base station antenna.

[0018] In some embodiments, the plurality of gas supply lines may comprise flexible tubing.

[0019] In some embodiments, the base station antenna assembly may further comprise a linear position tracker configured to track the position of the plurality of gas driven pistons relative to each respective phase shifter.

[0020] In some embodiments, the compressed gas may comprise air or nitrogen.

[0021] In some embodiments, the phase shifters may move in a first direction when more compressed gas is distributed into the plurality of gas supply lines, and the phase shifters may move in a reciprocal direction when less compressed gas is distributed into the plurality of gas supply lines.

[0022] In some embodiments, the flow control valves may be connected with a controller.

[0023] In some embodiments, each of the gas driven pistons may be coupled to two or more gas supply lines.

[0024] Another aspect of the present invention is directed to a base station antenna. The base station antenna may comprise a housing, a plurality of phase shifters in the housing, a container configured to hold a compressed gas, a pressure regulator configured to regulate the pressure of the container, a distribution manifold configured to distribute the compressed gas to a plurality of gas supply lines, where each gas supply line may comprise a flow control valve, and a plurality of gas driven pistons coupled to a respective gas supply line and a respective phase shifter, where the plurality of gas driven pistons may be configured to move each respective phase shifter to shift the phase of the base station antenna.

[0025] In some embodiments, the plurality of gas supply lines may comprise flexible tubing.

[0026] In some embodiments, the base station antenna may further comprise a linear position tracker configured to track the position of the plurality of gas driven pistons relative to each respective phase shifter.

[0027] In some embodiments, the compressed gas may comprise air or nitrogen.

[0028] In some embodiments, the phase shifters may move in a first direction when more compressed gas is distributed into the plurality of gas supply lines and the phase shifters may move in a reciprocal direction when less compressed gas is distributed into the plurality gas supply lines.

[0029] In some embodiments, the flow control valves may be connected with a controller.

[0030] In some embodiments, each of the gas driven pistons may be coupled to two or more gas supply lines.

[0031] Another aspect of the present invention is directed to a method for shifting the phase of a base station antenna. The method may comprise providing a plurality of phase shifters, a container configured to hold a compressed gas, a pressure regulator configured to regulate the pressure of the container, a distribution manifold configured to distribute the compressed gas to a plurality of gas supply lines, where the plurality of gas supply lines may comprise a flow control valve, a plurality of gas driven pistons coupled to a respective gas supply line and a respective phase shifter, where the plurality of gas driven pistons may be configured to move each respective phase shifter to shift the phase of the base station antenna, and modifying the pressure of the compressed gas to shift the phase of the base station antenna.

[0032] In some embodiments, the method may further comprise a linkage between the plurality of gas driven pistons and a respective phase shifter, where the linkage may be configured to move the phase shifters in response to the gas driven piston to shift the phase of the base station antenna.

[0033] In some embodiments, the plurality of gas supply lines may comprise flexible tubing.

[0034] In some embodiments, the method may further comprise a linear position tracker configured to track the position of the plurality of gas driven pistons relative to each respective phase shifter.

[0035] In some embodiments, the compressed gas may comprise air or nitrogen.

[0036] In some embodiments, the flow control valves may be connected with a controller.

[0037] It is noted that aspects of the invention described with respect to one embodiment, may be incorporated in a different embodiment although not specifically described relative thereto. That is, all embodiments and/or features of any embodiment can be combined in any

way and/or combination. Applicant reserves the right to change any originally filed claim and/or file any new claim accordingly, including the right to be able to amend any originally filed claim to depend from and/or incorporate any feature of any other claim or claims although not originally claimed in that manner. These and other objects and/or aspects of the present invention are explained in detail in the specification set forth below. Further features, advantages and details of the present invention will be appreciated by those of ordinary skill in the art from a reading of the figures and the detailed description of the preferred embodiments that follow, such description being merely illustrative of the present invention.

BRIEF DESCRIPTION OF THE FIGURES

[0038] **Figure 1** is a diagram of a base station antenna according to embodiments of the present invention.

[0039] **Figure 2** is a diagram of the base station antenna assembly of **Figure 1**.

[0040] **Figures 3A** and **3B** show the interaction of a phase shifter and the pneumatic system of the base station antenna of **Figure 1**.

[0041] **Figure 4** is a diagram of a base station antenna according to additional embodiments of the present invention.

[0042] **Figure 5** is a diagram of a base station antenna assembly of **Figure 4**.

[0043] **Figure 6** is a diagram of a base station antenna according to additional embodiments of the present invention.

[0044] **Figure 7** is an enlarged view of the piston of the pneumatic system of **Figures 1-6** according to additional embodiments of the present invention.

[0045] **Figure 8** is a diagram of a base station antenna according to additional embodiments of the present invention.

[0046] **Figure 9** is a diagram of a base station antenna according to additional embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0047] The present invention will be described more particularly hereinafter with reference to the accompanying drawings. The invention is not intended to be limited to the illustrated embodiments; rather, these embodiments are intended to fully and completely disclose the invention to those skilled in this art. In the drawings, like numbers refer to like elements throughout. Thicknesses and dimensions of some components may be exaggerated for clarity.

[0048] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0049] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an", and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising", when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. As used herein the expression "and/or" includes any and all combinations of one or more of the associated listed items.

[0050] Referring now to the figures, a base station antenna **10** according to embodiments of the present invention is illustrated in **Figures 1-7**. In one embodiment of the present invention, the base station antenna **10** comprises a housing **12**, a plurality of phase shifters **14**, and a pneumatic system **30** (**Figures 1 and 2**). The pneumatic system **30** is coupled to the plurality of phase shifters **14** and is configured to shift the phase of the base station antenna **10**. The housing **12** protects the internal components of the base station antenna **10**. Thus, the housing **12** must be formed from a material that can withstand a wide range of environmental conditions. In some embodiments, the housing **12** is formed from steel, aluminum, or the like. **Figure 1** shows the phase shifters **14** and the pneumatic system **30** being located within the housing **12** of the base station antenna **10**. In alternative embodiments, the pneumatic system **30** can be located outside of the housing **12** of the base station antenna **10**.

[0051] The pneumatic system **30** may be used with any base station antenna **10** that utilizes electromechanical phase shifters to electronically down-tilt the antenna beams of the linear arrays. For example, the pneumatic system **30** may be used with the wiper arc phase shifter disclosed in U.S. Patent No. 7,463,190 to Zimmerman, which is incorporated herein by reference in its entirety.

[0052] In some embodiments of the present invention, the pneumatic system **30** comprises a container **24**, a pressure regulator **22**, a distribution manifold **26**, a plurality of flow control

valves **28**, a plurality of gas driven pistons **16**, and a plurality of gas supply lines **18** (**Figures 1 and 2**).

[0053] The container **24** is configured to hold a compressed gas. In some embodiments, the compressed gas comprises air or nitrogen. The container **24** can be configured to hold other types of compressed gases. The type of compressed gas that may be used depends on a variety of factors, including but not limited to, safety and cost. The pressure regulator **22** is coupled between the container **24** and the distribution manifold **26**. The pressure regulator **22** is configured to regulate the pressure of the compressed gas within the container **24** and the flow of compressed gas to the distribution manifold **26**. In some embodiments, the container **24** is coupled with a secondary gas container **21** (**Fig. 9**). This secondary gas container **21** may act as permanent supply of compressed gas to the container **24** or may be attached by an external port **23** when the container **24** needs to be refilled with compressed gas.

[0054] The distribution manifold **26** is configured to disperse the compressed gas to the plurality of gas driven pistons **16**. The compressed gas is dispersed to the gas driven pistons **16** through a plurality of gas supply lines **18**. Each gas supply line **18** is coupled to a respective gas drive piston **16** and each gas driven piston **16** is coupled to a respective phase shifter **14**. The gas driven pistons **16** are configured to move the phase shifters **14** to shift the phase of the base station antenna **10**. The number of gas supply lines **18** and gas driven pistons **16** may be dependent on the number of phase shifters **14** within the base station antenna **10**. As will be discussed in greater detail below, the gas driven pistons **16** are configured to reciprocate in response to pressure (**P**) of the compressed gas when released into the gas supply lines **18** (**Figures 3A and 3B**).

[0055] Each gas supply line **18** may comprise a flow control valve **28**. The flow control valves **28** are configured to control the flow of compressed gas entering the gas supply lines **18**. In some embodiments, the flow control valves **28** are connected with a controller (not shown). Similar to a RET controller discussed above, a control signal may be transmitted over an Antenna Interface Standards Group (AISG) control channel to the controller connected to the flow control valves **28**. The controller would include software that decodes and processes AISG commands that are included in the AISG control signal and, in response thereto, transmits control signals to the individual flow control valves **28** to control the flow of compressed gas into the gas supply lines **18**.

[0056] The gas supply lines **18** may be formed from a variety of materials that are compatible for use with the type of compressed gas chosen for the pneumatic system **30**, including PVC tubing. Alternatively, because base station antennas contain other electrical

components (not shown), it may be advantageous for the gas supply lines 18 to be formed from a material that can be easily maneuverable within the housing 12 of the base station antenna 10. Therefore, in some embodiments, the gas supply lines 18 comprise flexible tubing.

[0057] The operation of the pneumatic system 30 will now be described. The compressed gas flows from the container 24, through the pressure regulator 22 and into the distribution manifold 26. As the compressed gas flows into the distribution manifold 26, the compressed gas is evenly dispersed based on the number of flow control valves 28 and respective gas supply lines 18. Each flow control valve 28 controls how much compressed gas flows into each respective gas supply line 18. The compressed gas flows through each gas supply line 18 to a respective gas drive piston 16. The gas driven pistons 16 reciprocate in response to pressure (P) of the compressed gas when released into the gas supply lines 18. The phase shifters 14 move as the gas driven pistons 16 reciprocate in response to the pressure (P) of the compressed gas within the gas supply lines 18, thus resulting in a shift of the phase of the base station antenna 10.

[0058] By way of example, and shown in **Figures 3A** and **3B**, the phase shifters 14 move in a first direction when the rod of the gas driven piston 16 extends, thereby rotating the link of the phase shifter 14, *i.e.*, when pressure P is increased in the gas supply line 18 (**Figure 3A**). Conversely, the phase shifters 14 move in a reciprocal direction when the rod of the gas driven piston 16 retracts, thereby rotating the link of the phase shifter 14, *i.e.*, when pressure P is decreased in the gas supply line 18 (**Figure 3B**). The flow control valves 28 keep a constant pressure P within the gas supply lines 18 until the phase of the base station antenna 10 needs to be readjusted. When an adjustment is needed, the flow control valves 28 will either increase or decrease the pressure P flowing into the gas supply lines 18 accordingly.

[0059] Additional embodiments of the present invention are shown in **Figures 4** and **5**. In **Figures 4** and **5**, a base station antenna 110 comprises a housing 112, a plurality of phase shifters 114, and a pneumatic system 130 coupled to the plurality of phase shifters 114. The pneumatic system 130 comprises a container 124, a pressure regulator 122, a gas supply line 118, and a gas driven piston 116. The container 124 is configured to hold a compressed gas. In some embodiments, the compressed gas comprises air or nitrogen. In some embodiments, the gas supply lines 118 comprise flexible tubing.

[0060] The pressure regulator 122 is coupled to the container 124 and the gas supply line 118. The pressure regulator 122 is configured to regulate the pressure of the compressed gas within the container 124 and the flow of compressed gas to the gas supply line 118. In this

embodiment, the pressure regulator **122** may serve as a flow control valve (similar to the one discussed above, *i.e.*, **28**) or a flow control valve **128** may be included. The flow control valve **128** may be connected with a controller **113**. Similar to a RET controller discussed above, a control signal may be transmitted over an Antenna Interface Standards Group (AISG) control channel to the controller **113** connected to the flow control valves **128**. The controller **113** would include software that decodes and processes AISG commands that are included in the AISG control signal and, in response thereto, transmits control signals to the individual flow control valves **128** to control the flow of compressed gas into the gas supply lines **118**.

[0061] The compressed gas flows through the gas supply line **118** to a gas driven piston **116**. The gas driven piston **116** reciprocates in response to pressure (**P**) of the compressed gas when released into the gas supply line **118**. A linkage **120** couples the gas driven piston **116** to each phase shifter **114**. The linkage **120** allows the gas driven piston **116** to move each phase shifter **114** in unison. The phase shifters **114** move as the gas driven piston **116** reciprocates in response to the pressure (**P**) of the compressed gas within the gas supply line **118**.

[0062] The linkage **120** moves in a first direction when the rod of the gas driven piston **116** extends, thereby rotating the phase shifters **114**, *i.e.*, when pressure **P** is increased in the gas supply line **118** (similar to **Figure 3A**). Conversely, the linkage **120** moves in a reciprocal direction when the rod of the gas driven piston **116** retracts, thereby rotating the phase shifter **114**, *i.e.*, when pressure **P** is decreased in the gas supply line **118** (similar to **Figure 3B**). The pressure regulator **122** keeps a constant pressure (**P**) within the gas supply line **118** until the phase of the base station antenna **110** needs to be readjusted. When an adjustment is needed, the pressure regulator **122** will either increase or decrease the pressure (**P**) flowing into the gas supply line **118** accordingly.

[0063] **Figure 6** shows another embodiment of the present invention. In this embodiment, a base station antenna **210** comprises a housing **212**, a plurality of phase shifters **214**, and a pneumatic system **230** coupled to the plurality of phase shifters **214**. The pneumatic system **230** comprises a plurality of containers **224**, a plurality of pressure regulators **222**, a plurality of gas supply lines **218**, and a plurality of gas driven pistons **216**. Each container **224** is configured to hold a compressed gas. In some embodiments, the compressed gas comprises air or nitrogen. In some embodiments, the gas supply lines **218** comprise flexible tubing.

[0064] The pressure regulators **222** are coupled to a respective container **224** and a respective gas supply line **218**. Each pressure regulator **222** is configured to regulate the

pressure of the compressed gas within each respective container **224** and is further configured to regulate the flow of compressed gas to each respective gas supply line **218**. Accordingly, each pressure regulator **222** also serves as a flow control valve (similar to the one discussed above, *i.e.*, **28**).

[0065] The compressed gas flows through the plurality of gas supply lines **218** to each respective gas drive piston **216**. The gas driven pistons **216** reciprocate in response to pressure (**P**) of the compressed gas in the gas supply lines **218**. The phase shifters **214** move as the gas driven pistons **216** reciprocate resulting in a shift of the phase of the base station antenna **210**.

[0066] The phase shifters **214** move in a first direction when the rods of the gas driven pistons **216** extend, thereby rotating the phase shifters **214**, *i.e.*, when pressure **P** is increased in the gas supply line **218**. Conversely, the phase shifters **214** move in a reciprocal direction when the rods of the gas driven pistons **216** retract, thereby rotating the phase shifters **214**, *i.e.*, when pressure (**P**) is decreased in the gas supply line **218**. The pressure regulators **222** keep a constant pressure (**P**) within the gas supply lines **218** until the phase of the base station antenna **210** needs to be readjusted. When an adjustment is needed, the pressure regulators **222** will either increase or decrease the pressure (**P**) flowing into the gas supply line **218** accordingly.

[0067] In some embodiments, the base station antenna **10** further comprises a linear position tracker **70** (**Figure 7**). The linear position tracker **70** is configured to track the position of a gas driven piston **16** relative to a respective phase shifter **14**. The linear position tracker **70** may comprise sensors or similar feedback devices to communicate the position of a gas driven piston **16** relative to a respective phase shifter **14**. The location of the linear position tracker **70** can vary dependent on the feedback device used. As shown in **Figure 7**, the linear position tracker **70** is coupled to a linkage **20** between the phase shifter **14** and the gas driven piston **16**. Alternatively, the linear position tracker **70** may be integrated with the phase shifters **14** or the gas driven piston **16**. The linear position tracker **70** could also be a separate component of the base station antenna **10**.

[0068] In some embodiments, the base station antenna **10'** may comprise two or more gas supply lines **18'** coupled to each respective gas driven piston **16** (**Figure 8**). Each gas supply line **18'** has differing pressures (**P**) which allow the position of the gas driven pistons **16** to be more accurately controlled. Thus, allowing the adjustment of the phase shifters **14** to be more accurately controlled.

[0069] Methods for shifting the phase of a base station antenna **10** are also provided. In some embodiments, the method comprises (a) providing a plurality of phase shifters **14**, a container **24** configured to hold a compressed gas, a pressure regulator **22** configured to regulate the pressure of the container **24**, a distribution manifold **26** configured to distribute the compressed gas to a plurality of gas supply lines **18**, wherein the plurality of gas supply lines **18** comprise a flow control valve **28**, a plurality of gas driven pistons **16** coupled to a respective gas supply line **18** and a respective phase shifter **14**, wherein the plurality of gas driven pistons **16** are configured to move each respective phase shifter **14** to shift the phase of the base station antenna **10**; and (b) modifying the pressure (**P**) of the compressed gas to shift the phase of the base station antenna **10**.

[0070] Finally, instead of being configured to hold a compressed gas, the container of the pneumatic systems described above could be configured to hold a liquid (*i.e.*, water). In this alternative configuration, the pneumatic system would comprise a plurality of hydraulic pistons. Similar to embodiments described above, the plurality of hydraulic pistons could be configured to move each respective phase shifter to shift the phase of the base station antenna.

[0071] The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.

THAT WHICH IS CLAIMED IS:

1. A base station antenna, comprising:
a housing;
a plurality of phase shifters in the housing; and
a pneumatic system coupled to the plurality of phase shifters, wherein the pneumatic system is configured to shift the phase of the base station antenna.
2. The base station antenna of Claim 1, wherein the pneumatic system comprises:
a container configured to hold a compressed gas;
a pressure regulator configured to regulate the pressure of the container;
a gas driven piston coupled to a gas supply line, wherein the gas driven piston is configured to reciprocate in response to pressure of the compressed gas in the gas supply line;
and
a linkage coupled between the gas driven piston and the phase shifters, wherein the linkage is configured to move the phase shifters in response to the gas driven piston to shift the phase of the base station antenna.
3. The base station antenna of Claim 2, further comprising a distribution manifold configured to distribute the compressed gas to a plurality of gas supply lines, wherein each gas supply line comprises a flow control valve.
4. The base station antenna of Claims 2 or 3, wherein the gas supply line comprises flexible tubing.
5. The base station antenna of any one of Claims 2-4, further comprising a linear position tracker configured to track the position of the gas driven piston relative to the phase shifters.
6. The base station antenna of any one of Claims 2-5, wherein the compressed gas comprises air or nitrogen.
7. The base station antenna of any one of Claims 2-6, wherein the phase shifters move in a first direction when more compressed gas is distributed into the gas supply line,

and wherein the phase shifters move in a reciprocal direction when less compressed gas is distributed into the gas supply line.

8. The base station antenna of any one of Claims 2-7, wherein the flow control valves are connected with a controller.

9. The base station antenna of any one of Claims 2-8, wherein the gas driven piston is coupled to two or more gas supply lines.

10. A base station antenna assembly, comprising:
a plurality of phase shifters;
a container configured to hold a compressed gas;
a pressure regulator configured to regulate the pressure of the container;
a distribution manifold configured to distribute the compressed gas to a plurality of gas supply lines, wherein each gas supply line comprises a flow control valve;
a plurality of gas driven pistons each coupled to a respective gas supply line; and
a linkage coupled between each gas driven piston and a respective phase shifter,
wherein the linkage is configured to move the phase shifters in response to the gas driven piston to shift the phase of the base station antenna.

11. The base station antenna assembly of Claim 10, wherein the plurality of gas supply lines comprise flexible tubing.

12. The base station antenna assembly of Claims 10 or 11, further comprising a linear position tracker configured to track the position of the plurality of gas driven pistons relative to each respective phase shifter.

13. The base station antenna assembly of any one of Claims 10-12, wherein the compressed gas comprises air or nitrogen.

14. The base station antenna assembly of any one of Claims 10-13, wherein the phase shifters move in a first direction when more compressed gas is distributed into the plurality of gas supply lines, and wherein the phase shifters move in a reciprocal direction when less compressed gas is distributed into the plurality of gas supply lines.

15. The base station antenna assembly of any one of Claims 10-14, wherein the flow control valves are connected with a controller.

16. The base station antenna assembly of any one of Claims 10-15, wherein each of the gas driven pistons are coupled to two or more gas supply lines.

17. A base station antenna, comprising:
a housing;
a plurality of phase shifters in the housing;
a container configured to hold a compressed gas;
a pressure regulator configured to regulate the pressure of the container;
a distribution manifold configured to distribute the compressed gas to a plurality of gas supply lines, wherein each gas supply line comprises a flow control valve; and
a plurality of gas driven pistons coupled to a respective gas supply line and a respective phase shifter, wherein the plurality of gas driven pistons are configured to move each respective phase shifter to shift the phase of the base station antenna.

18. The base station antenna of Claim 17, wherein the plurality of gas supply lines comprises flexible tubing.

19. The base station antenna of Claims 17 or 18, further comprising a linear position tracker configured to track the position of the plurality of gas driven pistons relative to each respective phase shifter.

20. The base station antenna of any one of Claims 17-19, wherein the compressed gas comprises air or nitrogen.

21. The base station antenna of any one of Claims 17-20, wherein the phase shifters move in a first direction when more compressed gas is distributed into the plurality of gas supply lines, and wherein the phase shifters move in a reciprocal direction when less compressed gas is distributed into the plurality gas supply lines.

22. The base station antenna of any one of Claims 17-21, wherein the flow control valves are connected with a controller.

23. The base station antenna of any one of Claims 17-22, wherein each of the gas driven pistons are coupled to two or more gas supply lines.

24. A method for shifting the phase of a base station antenna, the method comprising:

providing a plurality of phase shifters, a container configured to hold a compressed gas, a pressure regulator configured to regulate the pressure of the container, a distribution manifold configured to distribute the compressed gas to a plurality of gas supply lines, wherein the plurality of gas supply lines comprise a flow control valve, a plurality of gas driven pistons coupled to a respective gas supply line and a respective phase shifter, wherein the plurality of gas driven pistons are configured to move each respective phase shifter to shift the phase of the base station antenna; and

modifying the pressure of the compressed gas to shift the phase of the base station antenna.

25. The method of Claim 24, further comprising a linkage between the plurality of gas driven pistons and a respective phase shifter, wherein the linkage is configured to move the phase shifters in response to the gas driven piston to shift the phase of the base station antenna.

26. The method of Claims 24 or 25, wherein the plurality of gas supply lines comprise flexible tubing.

27. The method of any one of Claims 24-26, further comprising a linear position tracker configured to track the position of the plurality of gas driven pistons relative to each respective phase shifter.

28. The method of any one of Claims 24-27, wherein the compressed gas comprises air or nitrogen.

29. The method of any one of Claims 24-28, wherein the flow control valves are connected with a controller.

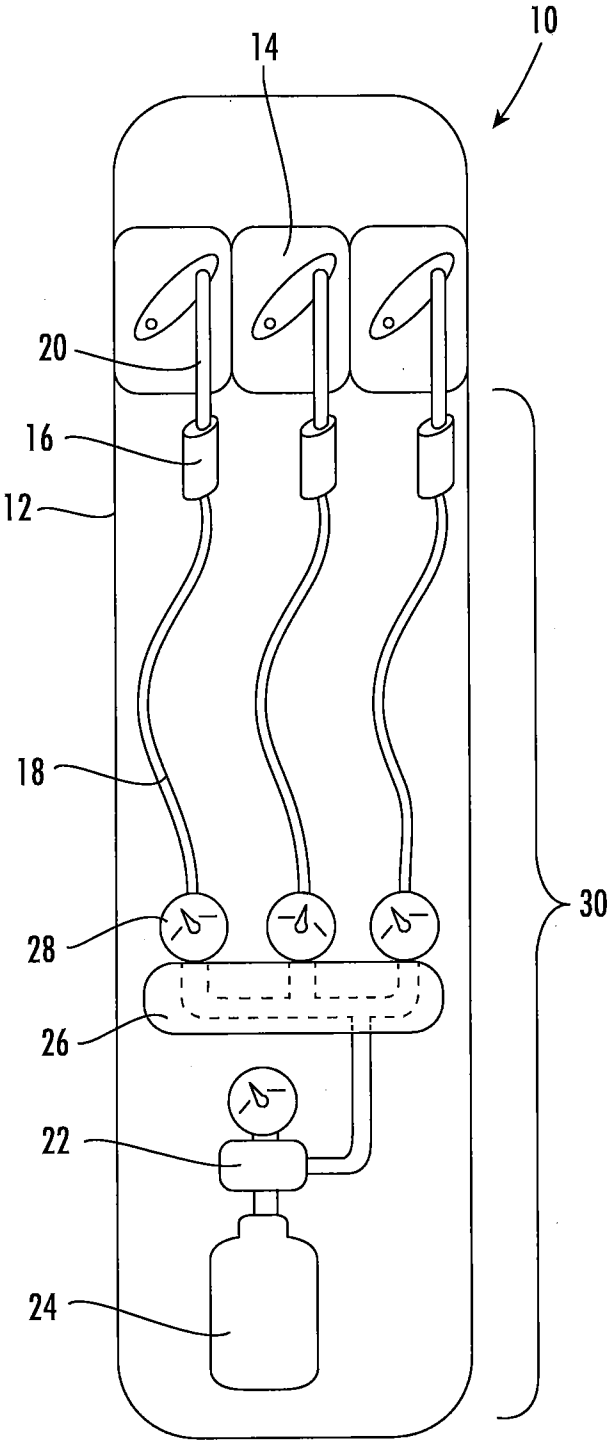


FIG. 1

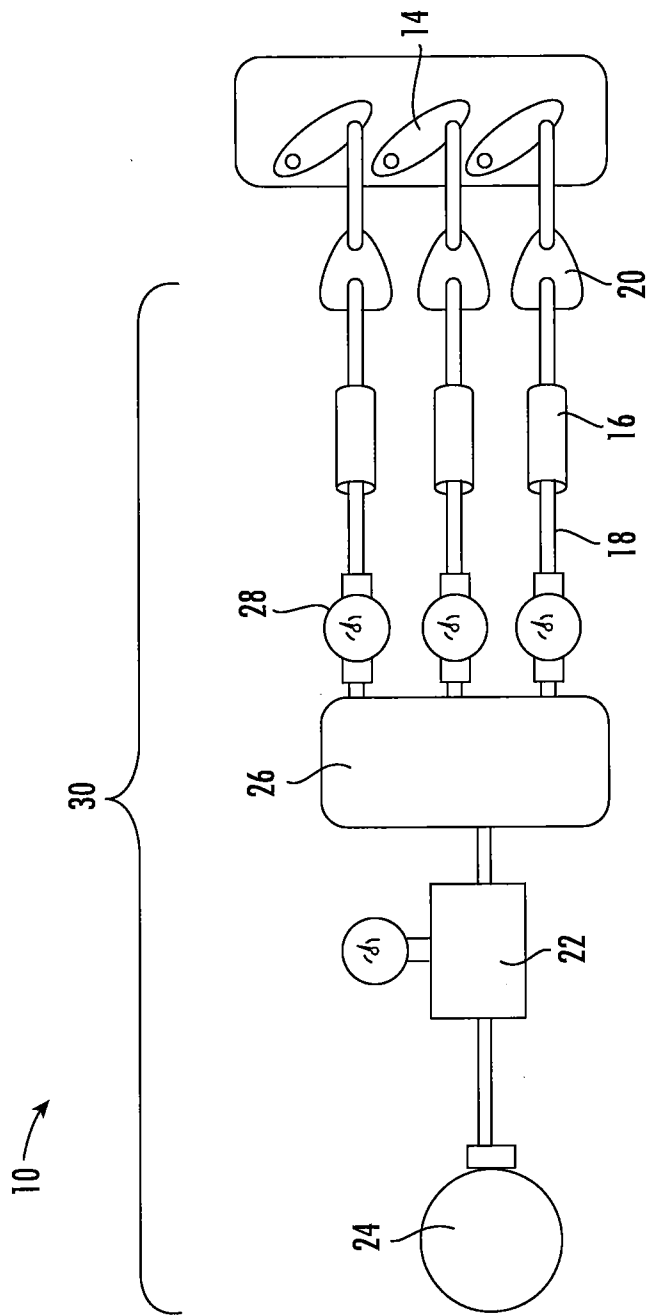


FIG. 2

3/9

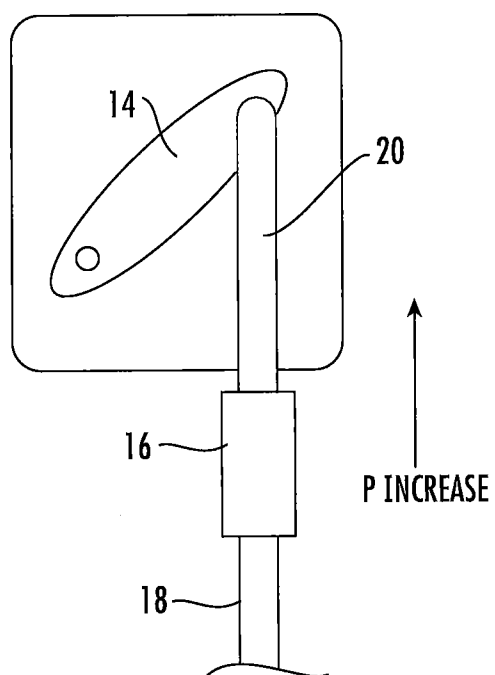


FIG. 3A

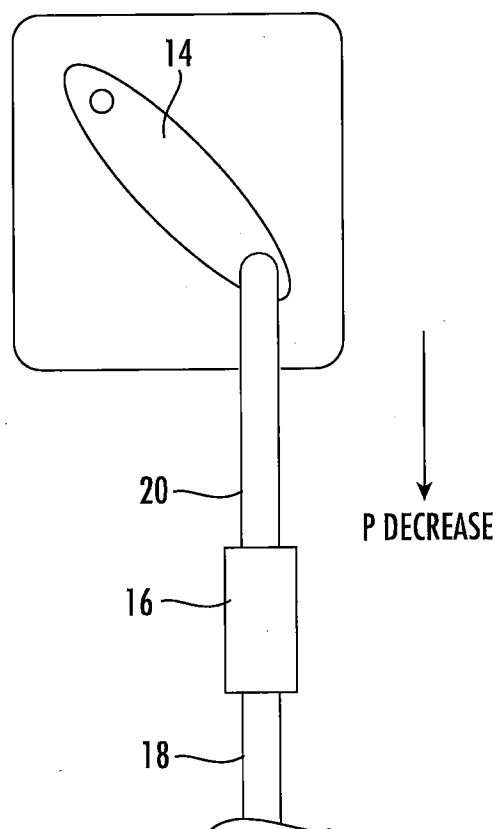


FIG. 3B

4/9

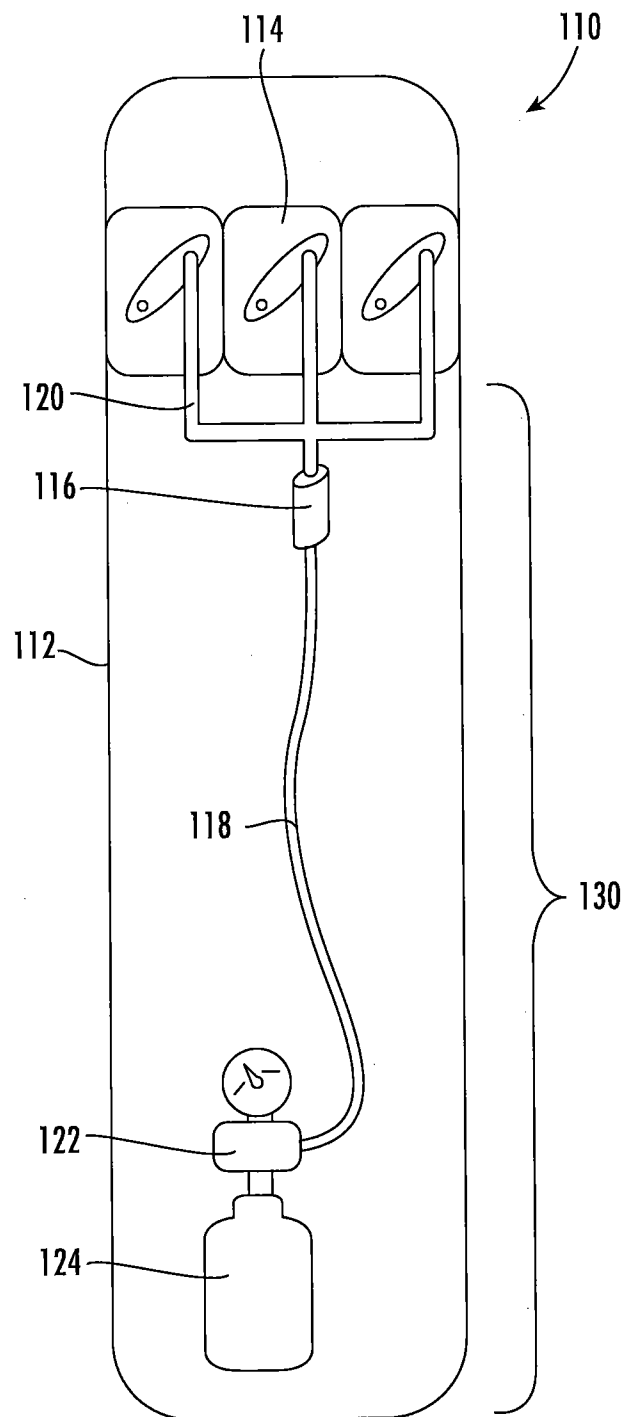


FIG. 4

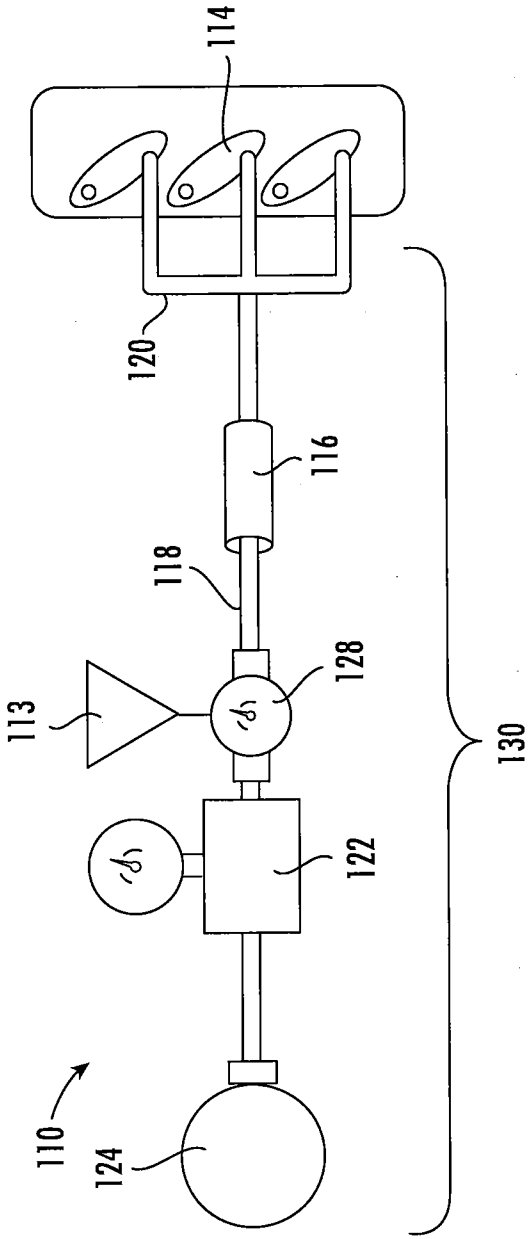


FIG. 5

6/9

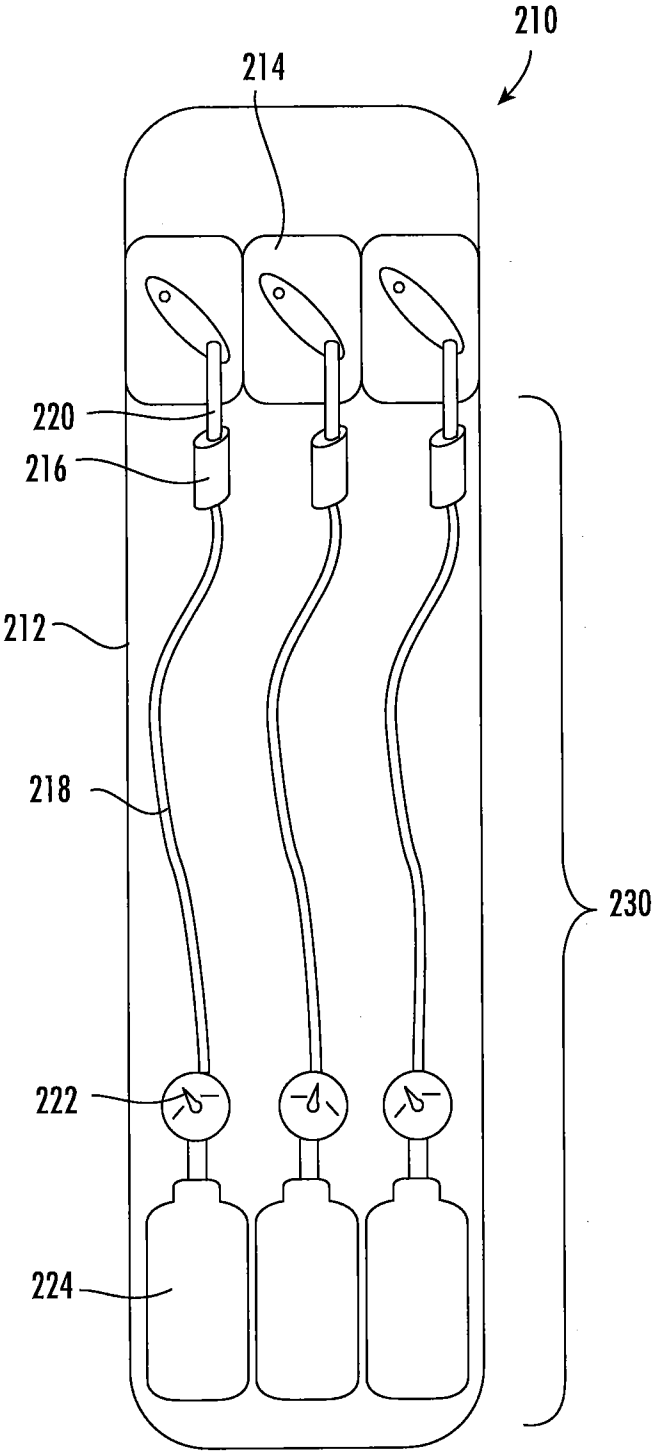


FIG. 6

7/9

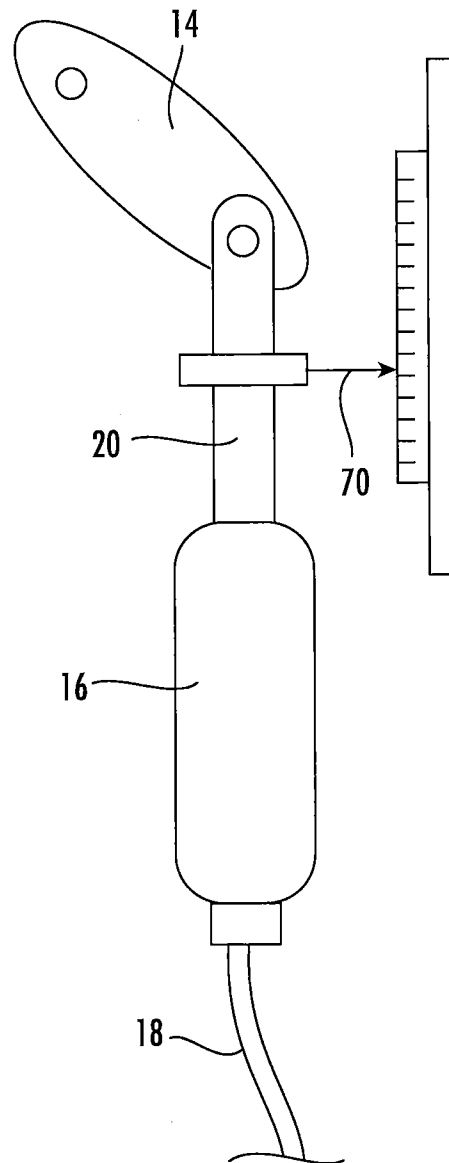


FIG. 7

8/9

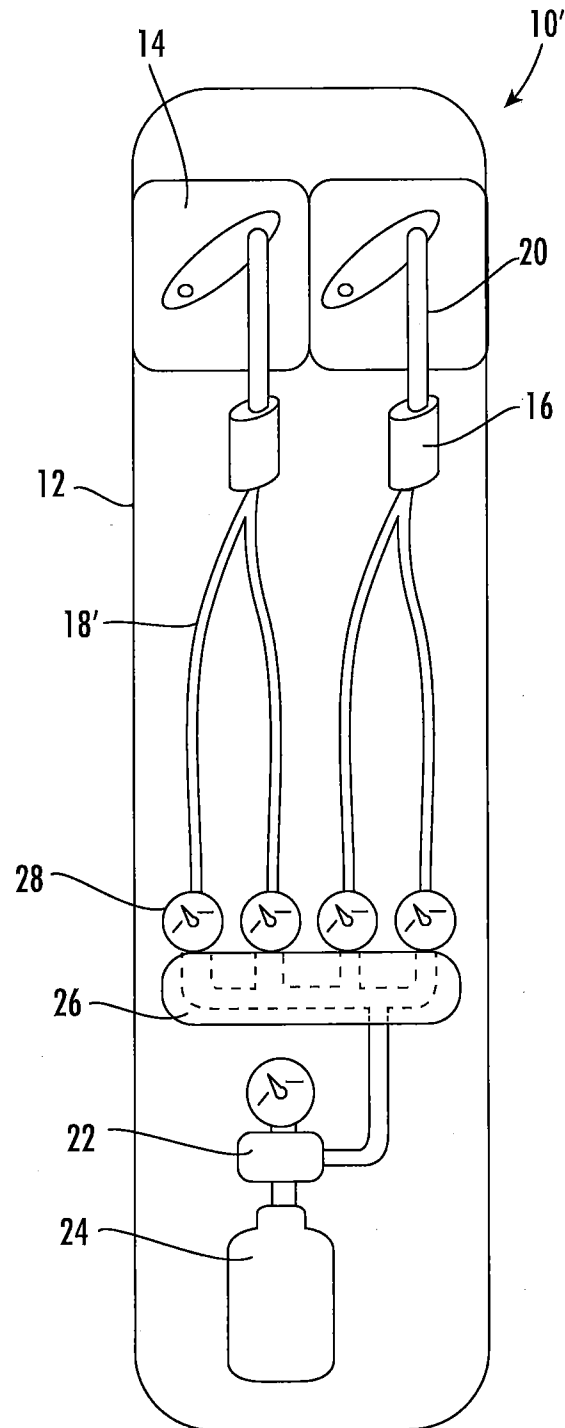


FIG. 8

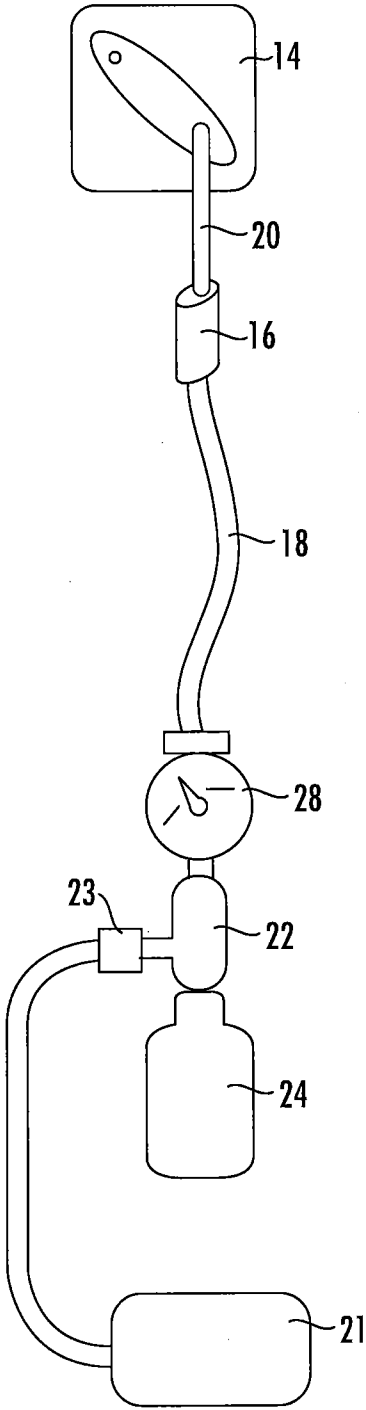


FIG. 9

A. CLASSIFICATION OF SUBJECT MATTER**H01Q 3/36(2006.01)i, H01Q 1/22(2006.01)i**

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)

H01Q 3/36; H01P 1/18; H01Q 21/00; H01Q 3/00; H01Q 3/26; H01Q 3/32; H01Q 1/22

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: base station antenna, phase shifter, pneumatic system, housing, shift

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009-0135074 A1 (CHING-SHUN YANG et al.) 28 May 2009 See paragraphs [0010]-[0015]; claim 1; and figures 1-4.	1-4, 10-12, 17-19 , 24-26
A	US 2008-0024385 A1 (MARTIN ZIMMERMAN) 31 January 2008 See paragraph [0040]; and figure 1.	1-4, 10-12, 17-19 , 24-26
A	US 2008-0316133 A1 (RAMON GUIXA ARDERIU) 25 December 2008 See paragraph [0016]; and figure 2.	1-4, 10-12, 17-19 , 24-26
A	US 2011-0063049 A1 (EDDIE R. BRADLEY et al.) 17 March 2011 See paragraph [0009]; and figure 2.	1-4, 10-12, 17-19 , 24-26
A	US 2014-0139401 A1 (HUAWEI TECHNOLOGIES CO., LTD.) 22 May 2014 See paragraph [0007]; and figure 1.	1-4, 10-12, 17-19 , 24-26



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

27 November 2018 (27.11.2018)

Date of mailing of the international search report

27 November 2018 (27.11.2018)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



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INTERNATIONAL SEARCH REPORTInternational application No.
PCT/US2018/045764**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

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

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 5-9,13-16,20-23,27-29
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/045764

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009-0135074 A1	28/05/2009	EP 2232633 A1 EP 2232633 A4 US 8085211 B2 WO 2009-070623 A1	29/09/2010 12/03/2014 27/12/2011 04/06/2009
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US 2014-0139401 A1	22/05/2014	CN 102263313 A EP 2731191 A1 EP 2731191 B1 US 9614281 B2 WO 2013-013565 A1	30/11/2011 14/05/2014 05/09/2018 04/04/2017 31/01/2013