(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 October 2007 (18.10.2007)

PCT

(10) International Publication Number
WO 2007/118211 A2

(51) International Patent Classification:
H01Q 21/00 (2006.01)

(21) International Application Number:
PCT/US2007/066175

(22) International Filing Date: 6 April 2007 (06.04.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

11/399,627	6 April 2006 (06.04.2006)	US
11/488,216	18 July 2006 (18.07.2006)	US
11/505,548	17 August 2006 (17.08.2006)	US

(71) Applicant *(for all designated States except US)*: **ANDREW CORPORATION** [US/US]; 3 Westbrook Corporate Center, Suite 900, Westchester, IL 60154 (US).

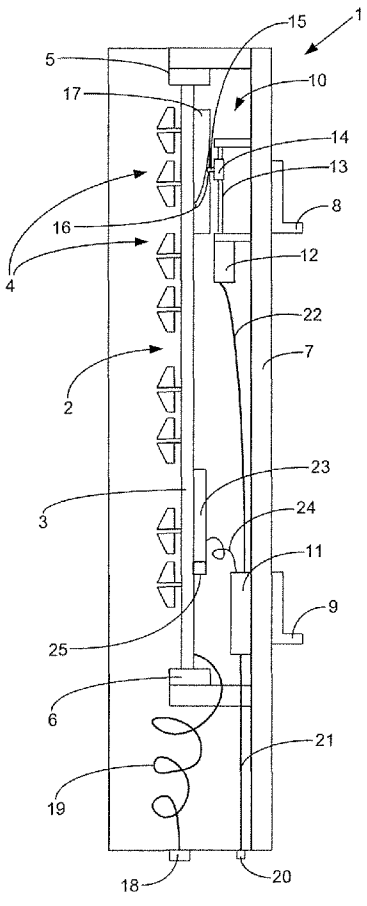
(72) Inventors: **LINEHAN, Kevin, Eldon**; 10001 Broadmoor Lane, Rowlett, TX 75089 (US). **ELLIOT, Robert, Douglas**; 1321 East Bailey Road, Naperville, IL 60565 (US). **ZIMMERMAN, Martin, L.**; 1909 M. Larrabee Street, Unit A, Chicago, IL 60614 (US). **GRAHAM, Peter, Bruce**; Atutahi Cromarty Drive, Martinborough (NZ). **MAILANDT, Peter**; 5502 Golf Drive, Highland Park, Dallas, TX 75205 (US). **MEYER, Louis, John**; 204 Dobbs Road, Shady Shores, TX 76208 (US). **SORELLS, Philip**; 2309 Benwick, Corinth, TX 76210 (US). **GRAY, Andrew, Thomas**; 1400 SE Fancy Free Drive, Apt. 209, Pullman, WA 99163 (US). **YANG, Ching-Shun**; 5 S. 270 Glenoban Drive, Naperville, IL 60563 (US). **DAVIDSON, D.**; 50 Marseille, Laguna Niguel, CA 92677 (US). **WEBB, Bobby**; 1019 Rockerfeller Lane, Allen, TX 75002 (US).

(74) Agent: **KAWULA, Walter, J., Jr.**; Welsh & Katz, Ltd., 120 South Riverside Plaza- 22nd Floor, Chicago, IL 60606 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY,

[Continued on next page]

(54) Title: A CELLULAR ANTENNA AND SYSTEMS AND METHODS THEREFOR



(57) Abstract: There is provided a cellular antenna allowing mechanical azimuth adjustment in combination with adjustment of one or more other antenna attribute such as electrical down tilt, electrical beam width or electrical azimuth adjustment. An integrated control arrangement is provided which can utilize either serial, wireless or RF feed lines to convey communications. A multiband embodiment provides azimuth adjustment for both bands by utilizing mechanical and electrical azimuth adjustment. Systems incorporating such antennas and methods of controlling them are also provided.

WO 2007/118211 A2

MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

A CELLULAR ANTENNA AND SYSTEMS AND METHODS THEREFOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority from U.S. Application Serial No. 11/505,548, filed August 17, 2006, U.S. Application Serial No. 11/488,216, filed July 18, 2006, and U.S. Application Serial No. 11/399,627, filed April 6, 2006, all entitled A CELLULAR ANTENNA AND SYSTEMS AND METHODS THEREFOR.

FIELD OF THE INVENTION

This invention relates to a cellular antenna and systems incorporating the antenna as well as to methods of controlling the antenna. More particularly, although not exclusively, there is disclosed an antenna providing mechanical azimuth adjustment of the beam of the antenna in combination with adjustment with other antenna attributes. There is also disclosed a multi-array allowing independent beam steering of each array.

This invention also relates to a cellular communications antenna including sensors for determining the position and/or orientation of a beam of the antenna. This position and/or orientation information may be utilized locally to control attributes of the antenna or may be communicated to a central controller which may control attributes of the antenna.

BACKGROUND OF THE INVENTION

The applicant's prior application US2004/0038714A1 (Rhodes), the disclosure of which is incorporated by reference, discloses an antenna system providing remote electrical beam adjustment for down tilt, beam width and azimuth.

Systems for effecting mechanical adjustment of antenna beam azimuth are known but have not been well integrated into a cellular antenna. Whilst Rhodes discloses integrated antenna systems providing electrical attribute adjustment (e.g. down tilt, azimuth and beam width) there is a need for an antenna providing good integration

of mechanical and electrical attribute adjustment. There is also a need for independently controlling attributes of multi-array antennas.

When installing cellular communications antennas it has been the practice to orient the antenna with respect to a support structure using a compass and mechanical inclinometer. This may be difficult and precarious at the top of a tower and it may be inconvenient to make an adjustment if later required.

Where an antenna may be oriented by an actuator, devices for measuring the movement have been provided but these may not always provide correct information as to the actual orientation of the antenna due to limited calibration at setup or due to non-linearities. Furthermore, if the orientation of an antenna changes in use (for example due to bird strike) this may not be known by the network operator and network performance may be compromised.

Knowledge of the true position and orientation of an antenna would simplify installation and allow improved control strategies to be employed.

EXEMPLARY EMBODIMENTS

There is provided an antenna allowing mechanical azimuth adjustment in combination with adjustment of one or more other antenna attribute. An integrated control arrangement is provided which can utilize either serial, wireless or RF feed lines to convey communications. Systems incorporating such antennas and methods of controlling them are also provided. A number of embodiments are described and the following embodiments are to be read as non-limiting exemplary embodiments only.

According to one exemplary embodiment there is provided a cellular antenna comprising:

an array antenna rotatably mountable with respect to an antenna support so as to enable azimuth steering of the beam of the antenna;

an azimuth position actuator configured to rotate the array antenna with respect to an antenna support; and

an actuator controller configured to receive control data associated with an address assigned to the actuator controller over an addressable serial bus and

to control the azimuth position actuator in accordance with azimuth control data received.

According to another exemplary embodiment there is provided a network management system comprising a plurality of base station antenna sites, each with a group of antenna systems as described above.

According to another exemplary embodiment there is provided a cellular antenna comprising:

an array antenna rotatably mountable with respect to an antenna support so as to enable azimuth steering of the beam of the antenna having a first array of radiating elements for operation over a first frequency band and a second array of radiating elements for operation over a second frequency band;

an azimuth position actuator configured to rotate the array antenna with respect to an antenna support;

a first feed network configured to supply signals to and receive signals from the first array of radiating elements including an azimuth phase shifter to vary the phase of signals passing through the feed network;

an azimuth phase shifter actuator configured to adjust the azimuth phase shifter; and

an actuator controller configured to receive control data and to control the azimuth position actuator in accordance with mechanical azimuth control data received to rotate the array antenna with respect to an antenna support to alter the direction of the antenna and to control the azimuth phase shifter actuator in accordance with electrical azimuth control data received to adjust the azimuth beam direction of the first array with respect to the azimuth beam direction of the second array.

According to another exemplary embodiment there is provided a method of adjusting beam azimuth for a multiband antenna having a first array and a second array in which the first array has a feed network including one or more variable element for adjusting beam azimuth, the method comprising:

mechanically orienting the antenna so as to achieve a desired azimuth beam direction for the second array; and

setting the variable element so as to achieve a desired beam azimuth for the first array, different to the beam azimuth for the first array.

In another aspect of the present invention, there is provided an antenna allowing electrical and/or mechanical beam steering to provide independent steering of the beams of an integrated multi-array antenna. An integrated control arrangement is provided which can utilize either serial, wireless or RF feed lines to convey communications. Systems incorporating such antennas and methods of controlling them are also provided. A number of embodiments are described and the following embodiments are to be read as non-limiting exemplary embodiments only.

According to one exemplary embodiment there is provided a cellular antenna comprising:

a. a first array of radiating elements configured to develop, when excited, a first beam;

b. a first feed network associated with the first array having one or more first controllable elements for adjusting the azimuth direction of the first beam;

c. a second array of radiating elements configured to develop, when excited, a second beam;

d. a second feed network associated with the second array having one or more second controllable elements for adjusting the azimuth direction of the second beam, wherein the first controllable elements may be controlled independently of the second controllable elements to allow independent azimuth steering of the first and second beams of the arrays; and

e. an antenna housing accommodating the first and second arrays.

According to another exemplary embodiment there is provided a method of azimuth steering the beams of an integrated cellular antenna having a first array of radiating elements arranged in multiple columns and a second array of radiating elements arranged in multiple columns wherein columns of the first array are fed with phase shifted signals such that the azimuth direction of the beam of the first array is oriented in a first direction and wherein columns of the second array are fed with phase shifted signals such that the azimuth direction of the beam of the second array is oriented in a second direction, different to the first direction.

According to another exemplary embodiment there is provided a cellular antenna comprising:

a. an array antenna having first and second arrays of radiating elements configured to develop, when excited, first and second beams respectively, the array antenna being rotatably mountable with respect to an antenna support so as to enable mechanical azimuth steering of the first and second beams;

b. a mechanical azimuth actuator configured to rotate the array antenna with respect to an antenna support;

c. a first feed network configured to supply signals to and receive signals from the first array of radiating elements including a first variable element to vary the phase of signals passing through the feed network;

d. a first variable element adjuster configured to adjust the first phase shifter; and

e. an actuator controller configured to receive control data and to control the mechanical azimuth actuator in accordance with mechanical azimuth control data received to rotate the array antenna with respect to an antenna support to alter the orientation of the antenna and to control the first variable element adjuster in accordance with electrical azimuth control data received to adjust the azimuth beam direction of the first array with respect to the azimuth beam direction of the second array.

According to another exemplary embodiment there is provided a method of adjusting beam azimuth for a multi-array antenna having first and second arrays of radiating elements configured to develop, when excited, first and second beams respectively wherein the first array has a feed network including one or more variable elements for adjusting first beam azimuth, the method comprising:

a. mechanically orienting the antenna so as to achieve a desired azimuth beam direction for the second beam; and

b. setting the one or more variable elements so as to achieve a desired beam azimuth for the first beam, different to the beam azimuth for the second beam.

According to another exemplary embodiment there is provided a method of setting different beam azimuth orientations for first and second beams of a multi-array antenna having first and second arrays of radiating elements in which the first array has a first feed network including one or more variable elements for adjusting beam

azimuth and the second array has a second feed network including one or more variable elements for adjusting beam azimuth, the method comprising:

a. mechanically orienting the antenna so as to orient a line normal to the antenna between desired beam directions for the first and second beams;

b. setting the one or more variable elements of the first feed network so as to achieve a desired beam azimuth for the first beam; and

c. setting the one or more variable elements of the second feed network so as to achieve a desired beam azimuth for the second beam.

According to another exemplary embodiment there is provided a cellular antenna comprising an antenna housing; a plurality of panels of radiating elements relatively rotatable with respect to the antenna housing and azimuth actuators for independently rotating each panel with respect to the antenna housing.

According to another exemplary embodiment there is provided a method of steering the beam of an antenna comprising a plurality of panels of radiating elements relatively rotatable with respect to an antenna housing having azimuth actuators for independently rotating each panel with respect to the antenna housing, the method comprising rotating selected panels with respect to the antenna housing to achieve a desired beam pattern and or orientation.

According to another exemplary embodiment there is provided a cellular antenna comprising:

a. a central panel having a first array of radiating elements;

b. a pair of outer panels of radiating elements rotatably connected to edges of the central panels; and

c. an actuator arrangement for adjusting the relative positions of the outer panels with respect to the central panel.

According to another exemplary embodiment there is provided a method of adjusting beam azimuth for a multi-array antenna having first and second arrays of radiating elements configured to develop, when excited, first and second beams respectively, the method comprising:

a. orienting the first beam to achieve a desired azimuth beam direction for the first beam; and

b. orienting the second beam to achieve a desired azimuth beam direction for the second beam, different to the beam azimuth for the first beam.

In another aspect of the present invention, there is provided a cellular communications antenna including sensors for determining position and/or orientation of the antenna. This allows simplified installation and advanced control strategies to be employed. A number of embodiments are described and the following embodiments are to be read as non-limiting exemplary embodiments only.

According to one exemplary embodiment there is provided a cellular communications antenna comprising:

an array antenna for producing a beam;

an antenna orientation sensor mounted upon or near the antenna and configured to develop a signal characterizing the orientation of the antenna;

an actuator for adjusting an attribute of the array antenna or the beam; and

an antenna controller responsive to the sensor signal and configured to control the actuator to achieve a desired antenna or beam configuration.

According to another exemplary embodiment there is provided a cellular communications antenna comprising:

an array antenna for producing a beam;

an antenna position and orientation sensor mounted upon or near the antenna and configured to develop a signal characterizing the position and orientation of the antenna;

an actuator for adjusting an attribute of the array antenna or the beam; and

an antenna controller responsive to the sensor signal and configured to control the actuator to achieve a desired antenna or beam configuration...

According to another exemplary embodiment there is provided a cellular communications antenna system comprising:

a plurality of array antennas;

a plurality of antenna orientation sensors configured to measure the orientation of each array antenna;

actuators for adjusting an attribute of the array antennas; and

a control arrangement configured to receive orientation information from the orientation sensors and adjust an attribute of the array antennas to achieve a desired antenna configuration.

According to another exemplary embodiment there is provided a cellular communications system comprising:

a plurality of antenna systems as hereinbefore described; and

a central controller in communication with the antenna systems to receive orientation information and send control information to adjust one or more attribute of the antenna systems.

According to another exemplary embodiment there is provided a method of controlling the orientation of a cellular communications antenna having an orientation sensor for measuring the orientation of the antenna and an actuator for adjusting the orientation of the antenna, comprising:

determining the orientation of the antenna; and, if the orientation of the antenna is not within a desired range,

driving the actuator and monitoring the orientation of the antenna measured by the orientation sensor until the orientation of the antenna is within the desired range.

According to another exemplary embodiment there is provided a method of controlling a beam attribute of a cellular communications antenna having an orientation sensor for measuring the orientation of the antenna and an actuator for adjusting a variable element of an antenna feed network of the antenna, comprising:

determining the orientation of the antenna; and

controlling the actuator of the antenna to achieve a desired beam pattern in dependence upon the orientation of the antenna.

According to another exemplary embodiment there is provided in a cellular communications system a method of determining the configuration of a plurality of antenna systems comprising a plurality of antennas having orientation sensors for measuring the orientation of the antennas and position sensors for determining the positions of the antennas, the method comprising:

obtaining position and orientation readings for antennas of each antenna system and communicating the readings to a central controller.

According to another exemplary embodiment there is provided a method of configuring a cellular communications antenna including an orientation sensor for measuring the orientation of the antenna and a position sensor for determining the position of the antenna comprising:

determining the position and orientation of the antenna;

storing position and orientation information in a controller; and

controlling actuators to adjust attributes of the antenna to provide desired beam coverage based on the stored position and orientation information.

According to another exemplary embodiment there is provided a method of controlling coverage in a cellular communications system including one or more base station, comprising the steps of:

a. obtaining information as to the position and orientation of an antenna of the one or more base station;

b. obtaining desired beam coverage information;

c. calculating a desired antenna orientation for the antenna based at least in part upon the desired beam coverage information; and

d. controlling the antenna so that its beam conforms to the desired antenna orientation.

According to another exemplary embodiment there is provided a method of controlling coverage in a cellular communications system including one or more base station, comprising the steps of:

a. obtaining information as to the position and orientation of an antenna of the one or more base station;

b. displaying a virtual projection of the antenna beam onto a virtual topography corresponding to the environment in which the antenna is located;

c. modifying the antenna beam orientation via a user input device;

d. displaying a modified virtual antenna beam in the virtual environment corresponding to modification via the user input device; and

e. controlling the antenna so that the beam conforms to the desired antenna orientation.

According to another exemplary embodiment there is provided a cellular communications system comprising:

a. a central controller:

b. one or more base station, each base station having one or more antenna and a base station controller which provides information as to the orientation of each antenna to the central controller;

c. wherein the central controller controls the orientation of each antenna to achieve a desired coverage.

According to another exemplary embodiment there is provided a cellular communications system comprising:

a. a central controller; and

b. one or more base station, each base station having one or more antenna and a base station controller which provides information as to the orientation of each antenna to the central controller;

wherein the central controller includes display means for displaying virtual antenna beams representative of the antenna beams of the base stations superposed on a virtual topology and a user input device enabling a user to manipulate a virtual beam to generate control signals sent to control attributes of the corresponding antenna.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings which are incorporated in and constitute part of the specification, illustrate embodiments of the invention and, together with the general description of the invention given above, and the detailed description of embodiments given below, serve to explain the principles of the invention.

Figure 1 shows a schematic side view of an antenna according to a first embodiment;

Figure 2a shows a schematic side view of an antenna according to a second embodiment;

Figure 2a shows a schematic side view of an antenna according to a third embodiment;

Figure 3a shows a schematic view of a feed arrangement for an antenna of the type shown in figures 1 and 2;

Figure 3b shows a schematic view of a multiband antenna embodiment;

Figure 3c shows a multi-array antenna consisting of a single column low band array and a multi-column high band array;

Figure 3d shows a multi-array antenna consisting of a multi-column low band array and a multi-column high band array;

Figure 3e shows a multi-array antenna consisting of a multi-column low band array and a multi-column high band array including an electrical or optical phase shifting feed network;

Figure 3f shows an antenna consisting of a number of rotatable panels;

Figures 3g to 3l show various configurations of the antennas shown in figure 3f;

Figure 3m shows an antenna having hinged outer panels;

Figure 4 shows a schematic diagram of a cellular base station in which control data is sent via one or more RF feed line;

Figure 5 shows a schematic diagram of a first data communications arrangement for the cellular base station shown in figure 4;

Figure 6 shows a schematic diagram of a second data communications arrangement for the cellular base station shown in figure 4;

Figure 7 shows a schematic diagram of a third data communications arrangement for the cellular base station shown in figure 4;

Figure 8 shows a schematic diagram of a cellular base station in which control data is sent via a serial bus;

Figure 9 shows a schematic diagram of a data communications arrangement for the cellular base station shown in figure 8;

Figure 10 shows a schematic diagram of a cellular base station in which control data is sent via a wireless link;

Figure 11 shows a schematic diagram of a first data communications arrangement for the cellular base station shown in figure 10;

Figure 12 shows a schematic diagram of a second data communications arrangement for the cellular base station shown in figure 10; and

Figure 13 shows a schematic diagram of a network management system.

Figure 14 shows a schematic view of a feed arrangement providing downtilt, azimuth and beam width adjustment.

Figure 15 shows a schematic side view of an antenna according to another embodiment;

Figure 16 shows a schematic diagram of control arrangement for the antenna shown in Figure 14;

Figure 17 shows a schematic view of an antenna system and the beam of one antenna;

Figure 18 shows a schematic representation of an antenna having mechanical beam azimuth, tilt and roll actuators;

Figure 19 shows a schematic view of an antenna system and the beam of one antenna projected onto a landscape; and

Figure 20 shows a schematic view of a cellular communications system.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Attributes of an antenna beam may be adjusted by physically orienting an antenna or by adjusting the variable elements in an antenna feed network. Physically adjusting the orientation of an antenna mechanically maintains a better radiation pattern for the antenna beam than by adjusting a variable element in the feed

network. For down tilt a better radiation pattern is obtained by adjusting a variable element in the feed network than by mechanically orienting the antenna.

Figure 1 shows a side view of a cellular antenna 1 according to a first embodiment. Antenna 1 includes an array antenna 2 having a reflector 3 and a plurality of radiating elements 4 (only some of which are indicated and the number of which may vary). Reflector 3 is rotatable about bearings 5 and 6 so that the array antenna 2 can rotate with respect to antenna support 7. Mounting brackets 8 and 9 allow the antenna to be mounted to a support structure such as a tower.

An azimuth position actuator 10 rotates array antenna 2 with respect to antenna support 7 in response to drive signals from actuator controller 11. Azimuth position actuator 10 may be in the form of a geared azimuth motor 12 driving a threaded shaft 13 which drives a nut 14 up and down as it rotates. Nut 14 has a pin 15 projecting therefrom which locates within a helical groove 16 in semi cylindrical guide 17. As pin 15 moves up and down guide 17 causes the array antenna 2 to rotate about its vertical axis to provide mechanical azimuth steering. It will be appreciated that a range of mechanical drive arrangements could be employed, such as geared drive trains, crank arrangements, belt and pulley drives etc.

In the embodiment shown in figure 1 an RF feed is supplied to connector 18 and a coiled feed line 19 supplies the RF feed to antenna array 2. In this embodiment control signals are provided to serial bus connector 20 and supplied to actuator controller 11 via cable 21. Actuator controller 11 controls azimuth motor 12 via cable 22 and controls one or more actuator adjusting one or more variable element contained within variable feed assembly 23 via cable 24. Both coiled feed line 19 and cable 24 have excess length to enable ease of rotation of antenna array 2.

Variable feed assembly 23 may include a single phase shifter or multiple phase shifters to adjust down tilt. Variable feed assembly 23 may additionally or alternatively include one or more phase shifter or power divider to effect beam width adjustment. Variable feed assembly 23 may also include one or more phase shifter to effect electrical azimuth adjustment. Electrical azimuth adjustment may be provided for a multiband antenna so that the azimuth of the antenna beam of a first array may be adjusted mechanically and the antenna beam of a second array may be adjusted electrically to achieve a desired offset.

Actuator controller 11 may receive status and configuration information from variable feed assembly 23 such as the current position of phase shifters or power dividers or whether an actuator has a fault condition etc. A compass 25 may also be provided to give a real-time measurement as to the azimuth orientation of antenna array 2. The basic reading may be adjusted with respect to true North at the place of installation. This status and configuration information may be supplied from actuator controller 11 to a base station auxiliary equipment controller via a serial cable connected to serial bus connector 20.

In use serial data received by actuator controller 11 will include an address for an actuator controller along with data specifying desired operating parameters. When actuator controller 11 receives data associated with its address it controls actuators in accordance with control data for an attribute to be controlled. For example, actuator controller 11 may receive data for mechanical azimuth with a value of 222 degrees. Controller 11 obtains orientation information from compass 25 and drives azimuth motor 12 so as to rotate antenna array 2 until the compass reading from compass 25 corresponds with the desired orientation. Likewise, controller 11 may receive data for a required down tilt angle. A down tilt phase shifter actuator, such as a geared motor, may drive one or more phase shifter in the feed network until an associated position sensor communicates to actuator controller 11 that the desired phase shifter position has been achieved (see US6198458, the disclosure of which is incorporated by reference). Likewise, beam width actuators and azimuth actuators may be driven by actuator controller 11 to achieve desired values.

In this way, actuator controller 11 can control mechanical azimuth and electrical azimuth, down tilt and beam width in response to commands received from a addressable serial bus.

Figure 2a shows a second embodiment in which all RF signals and control data are received over a single RF feed line. Like integers had been given like numbers to those shown in figure 1. In this embodiment coiled feed line 19 supplies RF feed signals to antenna interface 26 which supplies RF signals to variable feed assembly 23 and extracts and supplies control data to actuator controller 31. As antenna interface 26 is mounted to reflector 3 a flexible control cable 27 is provided to azimuth motor 12. Antenna interface 26 may extract power supplied by an RF feed line to operate actuator controller 23 and it associated actuators. A DC bias voltage may be applied to the RF feed line at the base of a cellular base station tower and

extracted by antenna interface 26 at the top of the tower. This arrangement has the advantage that only a single RF feed line need be connected to each antenna to provide both RF signals and control data.

Figure 2b shows a variant of the embodiment shown in figure 1 where the azimuth position actuator 10a is in the form of a top mounted geared motor which supports antenna array 2 and rotates it. The base of the antenna is maintained in position by bearing 6a secured to the base of the antenna and extending to the walls of the radome 7a.

Referring now to figure 3a there is shown a feed arrangement suitable for adjusting the down tilt and the beam width of the beam of an antenna of the type shown in figures 1 and 2. In this case the antenna includes three rows 38 to 40, 41 to 43 and 44 to 46 of radiating elements although it will be appreciated that any desired number may be employed. RF feed line 28 feeds differential phase shifter 29, which in this example is a variable differential phase shifter. Actuator 30 is driven by actuator controller 31 to adjust the position of the variable differential phase shifter 29 to achieve a desired beam down tilt. Actuators 35 to 37 are driven by actuator controller 31 to adjust power dividers 32 to 34 to adjust antenna beam width.

A number of feed arrangements utilizing a range of different possible variable elements may be employed, some examples of which are set out in US2004/0038714A1 which is incorporated herein by reference. Whilst passive variable elements such as differential phase shifters are shown it will be appreciated that the variable elements could be active elements using PIN diodes, optically controlled devices etc. Figure 14 shows an embodiment including a down tilt phase shifter 200 driven by a down tilt phase shifter actuator 201, power dividers 202, 203 and 204 driven by power divider actuator 205 and azimuth phase shifters 206, 207 and 208 driven by azimuth phase shifter actuator 209 to effect down tilt, beam width and azimuth adjustment of the antenna beam. It will be appreciated that any one or combination of attributes may be adjusted depending upon the application. In a simple application electrical down tilt adjustment may be provided with mechanical azimuth adjustment.

In the multi-array embodiment shown in figure 3b a first array of columns of radiating elements 49 may have a feed network as shown in figure 3a whilst the

second array of columns of radiating elements 48 may have a feed network 48a including phase shifter 48b to vary the phase supplied to the outer columns of radiating elements to effect azimuth beam steering. In this way the beam direction for the first array may be set mechanically by mechanically orienting the antenna and the beam direction for the second array may be offset using electrical azimuth adjustment in the feed network. The arrays may operate in the same or different frequency bands. In the embodiment shown in figure 3b array 49 operates in a higher band than array 48.

Figure 3c shows a multi-array antenna having an array of low-frequency band radiating elements which may, for example, take the form of ring radiators 126, 127, 128, 129 and 130 and an array consisting of three columns 131, 132 and 133 of high frequency band radiating elements which may, for example, take the form of cross dipoles 131a, 132a and 133a. It will be appreciated that the radiating elements may be of any suitable form depending upon the application. Feed network 134 consists of a through line 135 feeding central column 132 and variable phase shifter 136 feeding columns 131 and 133. A mechanical azimuth actuator shown schematically as 137 rotates antenna 125 about its vertical axis to provide mechanical azimuth steering. In use the azimuth direction of the beam of low band elements 126 to 130 may be set by driving mechanical azimuth actuator 137 to orient antenna 125 in the desired orientation. Variable differential phase shifter 136 may then be adjusted to orient the azimuth direction of the beam of the high band elements. A local controller may control mechanical azimuth actuator 137 and an actuator to control variable differential phase shifter 136. This may be based on a local control arrangement or in response to control commands from a central controller.

Figure 3d shows a multi-array antenna 138 consisting of an array of high band elements in the form of three columns of cross dipoles (one of which is indicated at 139) and an array of low band elements in the form of three columns of ring radiators (one of which is indicated at 140) which may be staggered and interleaved as shown. In one embodiment one feed network 141 may be provided to feed the columns of the high band radiating elements so that the central column of high band elements is fed by line 142 directly from RF feed line 143 and the outer columns of high band elements are fed by lines 144 and 145 from the outputs of phase shifter 146 which may be any of a variety of electromechanical or electrical configurations. The RF feed and control arrangement could be any of a variety of configurations.

including those depicted in Figures 5 – 12 of this specification. Mechanical azimuth actuator 147 allows mechanical azimuth beam steering of antenna 138. This embodiment may operate in the same manner as the embodiment described in figure 3c. However, if the low band columns are fed in the same manner as the high band columns (i.e. using a feed network as per feed network 141) then the beams of both the high band and low band arrays may be individually electronically steered. Thus mechanical azimuth actuator 147 may be adjusted to orient antenna 138 in a first orientation and the independent high band and low band feed networks may be used to electronically steer the azimuth beam directions for each array. This allows the antenna to be mechanically oriented to position between the desired beam orientation for each array and for the beam of each array to the offset by electronic beam steering to achieve the designed beam orientations. This may minimize distortion of beam patterns by reducing the amount of electrical azimuth beam steering required. By providing the ability to adjust the orientation of the entire antenna 138 and thus both the high and low band arrays together, and in addition adjustment of the high and low band arrays separately, an infinitude of azimuthal settings of the two beams can be achieved to satisfy traffic and other design parameters. In one exemplary embodiment the high frequency band radiating elements may be in the range of 1710 to 1720 GHz and the low frequency band radiating elements may be in the range of 824 to 960 GHz.

Figure 3e shows a variant of figure 3d in which feed network 141 is replaced by feed network 141a in which active elements are employed to achieve the desired phase shift for the radiating elements of each column. The active elements may be PIN diodes, optically controlled elements or any other suitable active element.

Figure 3f shows an antenna 148 having panels of radiating elements rotatable via actuators 152 to 154 with respect to antenna housing 155. The arrays may be single as shown schematically, or multiple column arrays. This arrangement enables each array of each panel 149 to 151 to be independently oriented with respect to antenna housing 155. Further, antenna housing 155 may itself be rotationally oriented via actuator 156. Figures 3g to 3l illustrate possible configurations of antenna 148. In figure 3g all panels are oriented flat with respect to antenna housing 155. In figure 3h all panels are rotated by the same amount to the left and in figure 3j all panels are rotated by the same amount to the right. In figure 3k the outer panels 149 and 151 are rotated outwardly to broaden the beam of the antenna. In figure 3l the configuration of figure 3k is rotated due to actuator

156 rotating antenna housing 155. Thus the antenna provides azimuth steering and beam shaping by rotation of multiple antenna radiator panels.

Figure 3m shows a variant in which outer panels 210 and 211 of radiating elements are pivotable about joints 213 and 214 to central panel of radiating elements 212. Outer panels 210 and 211 may be independently rotated with respect to central panel 212 by individual mechanical actuators or both may be adjusted via a common mechanical linkage 215. This arrangement allows a wide beam width to be generated using a relatively simple antenna structure.

It will be appreciated that in the above embodiments that different forms of radiating elements may be employed. It will also be appreciated that in each of the above embodiments control may be effected by a local controller or a central controller. Each antenna may provide information as to the configuration and orientation of each antenna and control the antenna locally according to a local control strategy or centrally based on a global control strategy.

Referring now to figure 4 a schematic diagram of an antenna base station 47 having three antennas 68, 69 and 70 is shown. Auxiliary equipment controller 51 includes a connector 52 allowing a laptop 53 to interface with base station auxiliary equipment controller 51.

Figure 5 shows a first embodiment in which a base station controller 55 communicates with a central controller via a backhaul link 54. Commands for controlling antenna attributes are sent from base station controller 55 to auxiliary equipment controller 51. A modulation/demodulation arrangement conveys commands between control interface 50 and antenna interfaces 59 to 61. Base station controller 55 sends RF signals for transmission via RF feed lines 57 to control interface 50. Auxiliary equipment controller 51 sends commands for controlling controllable antenna elements to control interface 50 which superposes control commands onto RF feed lines 56 to 58. Each antenna includes an antenna interface 59 to 61 which extracts the superposed control commands and provides these to controller actuators 62 to 64 which control actuators 65 to 67 of antennas 68 to 70. It will be appreciated that any number of actuators may be controlled and that these may include control motors to adjust the physical position of an antenna, actuators to adjust phase shifters, actuators to adjust power dividers or other adjustable elements. The control data will include an address for an actuator

controller along with control data designating the attribute to be controlled (e.g. down tilt) and a desired value. The actuator controllers may also send status and configuration information to antenna interface is 59 to 61 to be conveyed via control interface 50 to auxiliary equipment controller 51. This status and configuration information may be supplied to a central controller via backhaul link 54.

Figure 6 shows a modified version in which like integers and have been given like numbers. In this case the control interface 71 superposes the control data only on RF line 58. An antenna interface 72 is incorporated within antenna 68 and this provides the control data to actuator controllers 62 to 64 via serial cables 73 to 75. This arrangement reduces cost by only requiring a single antenna interface 72 and for control interface 71 to interface only with one feed cable.

Figure 7 shows an embodiment similar to figure 6 except that the antenna interface 77 is located externally to antennas 68 to 70 at the top of a tower. Actuator controllers 62 to 64 are supplied with control data via serial bus connections 78 to 80. This arrangement has the advantage that a standardised antenna unit 68 to 70 may be employed whether control data either is sent up the tower via an RF feed line or a serial cable.

Figure 8 shows an embodiment in which control data is sent up tower 81 from auxiliary equipment controller 82 via serial cable 83 to antennas 84 to 86. An access port 87 is provided to enable a portable controller (e.g. a laptop) 88 to communicate directly with auxiliary equipment controller 82 to effect local control. As shown in figure 9 actuator controllers 89 to 91 and auxiliary equipment controller 82 are interconnected by serial buses 83, 92 and 93. Actuators 194 to 196 are controlled by actuator controllers 89 to 91 in accordance with control data received from auxiliary equipment controller 82. Status and configuration information from actuator controllers 89 to 91 is communicated via the serial bus to auxiliary equipment controller 82.

Figure 10 shows a wireless embodiment in which control data is communicated between a controller 94 and antennas 95 to 97 directly via a wireless link. It will be appreciated that controller 94 may be an auxiliary equipment controller at the base station supporting wireless communication or a portable device such as a laptop with a wireless card etc. Controller 94 may also be remotely located and control antennas 95 to 97 via a long-range radio link.

Figure 11 shows a first embodiment in which a single antenna interface 98 communicates wirelessly with a controller 94 and communicates with actuator controllers 99 to 101 via serial bus 102 to 104 to control actuators 108 to 110. This arrangement allows standard antennas 105 to 107 having serial interfaces to be employed.

Figure 12 shows an embodiment in which actuator controllers 111 to 113 include wireless communication circuits enabling each actuator controller 111 to 113 to communicate directly with a controller 94.

Figure 13 shows schematically a network management system in which a central controller 114 communicates via backhaul links 115 to 119 with a number of base stations 120 to 124. Central controller 114 obtains status and configuration information from each base station controller and sends control data to base stations 120 to 124. Central controller 114 may periodically receive status and configuration information and/or status and configuration information may be sent on request or whenever there is a change. Central controller 114 may adjust antenna attributes according to a schedule, on operator command or actively in response to current operating conditions (e.g. traffic demands etc).

In another embodiment, Figure 15 shows an antenna 311. Figure 16 shows schematically the control arrangement for the antenna. An array antenna 301 is rotatable about bearings 302 and 303 with rotation of the array antenna being controlled by actuator 304. Control data is sent to antenna controller 305 via an addressable serial bus 306, for example.. However, as described in Elliot, control data may be supplied via RF feed line 307 or a wireless link. In this embodiment a global positioning satellite (GPS) receiver 308, for example, supplies position information to antenna controller 305. Antenna controller 305 controls actuators 312 to 313 within feed network 309 to control antenna beam orientation with respect to the array antenna. The actuators 312 to 313 of feed network 309 may adjust phase shifters and or power dividers to adjust the azimuth, downtilt and/or beam width of the antenna beam with respect to the plane of the array antenna as described in Elliot and Rhodes.

In this embodiment an orientation sensor 310 is permanently mounted to the array antenna 301 and develops a signal characterizing the orientation of the antenna.

The orientation sensor may include an electronic compass and/or gyroscope to determine beam azimuth and/or an inclinometer and/or gyroscope to measure beam elevation. Instead of absolute orientation sensors, a relative position determining method may be employed, such as determining relative orientation with respect to another base station (or beacon etc.) by determining the direction in which a narrow beam (RF, laser etc) must be directed to be received by the base station or beacon. Knowing the positions of the base stations relative orientations of the antennas can be determined. The sensor signal from orientation sensor 310 is supplied to antenna controller 305.

According to one embodiment, antenna controller 305 of cellular communications antenna 311 may store desired physical orientation or antenna beam orientation information therein. During operation, based on orientation information from orientation sensor 310 and/or position information from GPS receiver 308, antenna controller may control actuator 304 to achieve a desired azimuth orientation of array antenna 301 or may control actuators of feed network 309 to adjust downtilt and/or azimuth and/or beam width of the beam of the antenna with respect to array antenna 301. For example, a digital compass of orientation sensor 310 may detect the actual orientation of array antenna 301 and communicate this to antenna controller 305. Antenna controller 305 may determine whether the orientation of array antenna 301 is within a permitted range of values stored within antenna controller 305. If it is outside a permitted range antenna controller 305 may adjust actuator 304 to change the physical orientation of array antenna 301 until the sensor signal from orientation sensor 310 indicates an orientation within the permitted range.

Permitted values of antenna attributes may be stored within antenna controller 305 and may be updated via addressable serial bus 306 or another communications channel. The permitted ranges of physical orientation and beam orientation attributes may be stored in a schedule in which these values are set for different periods of time, or for variable traffic, variable foliage or other seasonal changes in capacity or signal obstruction, or other operating conditions. For example, coverage may be required from an antenna in the first region for one period of time and another region for another period of time due to varying traffic demand etc. This schedule can be periodically uploaded from a central controller.

Referring now to figure 17 a schematic view of cellular communications antenna system 314 incorporating the cellular communications antenna shown in figures 15 and 16 is shown. Antenna 318 receives GPS positioning signals from GPS satellites 315, 316 and 317. Using this information the controller of antenna 318 can determine its position. The antenna beam 319 has adjustable beam attributes including beam width 320, beam elevation (referred to herein as beam down tilt) 321 and horizontal beam orientation (referred to herein as beam azimuth) 322. These attributes of the antenna beam may be adjusted so as to provide the desired beam coverage.

Additionally or alternatively the orientation of the antenna may be physically adjusted to alter the coverage of the antenna beam. Figure 18 shows a schematic view of an arrangement for adjusting the physical orientation of antenna 323. Actuators 324, 325 and 326 may respectively adjust beam azimuth 327, roll 328 and down tilt 329. Actuators 324 to 326 may be geared motors which through suitable linkages adjust the orientation of antenna 323 as is well known in the art.

Referring now to figure 19 there is shown the beam 330 of antenna 331 projected onto a landscape. It will be appreciated that by adjusting attributes of physical orientation and/or adjusting attributes of the beam of the antenna, beam width, beam azimuth, beam downtilt, and beam roll may be optimised for desired coverage based upon the measured position and orientation of antenna 331. An image like that shown in figure 19 may be displayed to a user using 2D or 3D display technology. The topography represents the environment in which antenna 331 is located. Obstructions, such as buildings, may also be shown. Current, desired or historical traffic levels may also be indicated (by colour, texture or other visual attributes). Antenna 331 may be superimposed based on information received as to its physical location derived from a GPS unit at the base station. The orientation of antenna 331 may be based upon orientation information from sensors in antenna 331. The shape of beam 330 may be determined based on information as to the configuration of beam shaping elements. It may have a different optical characteristic such as colour or shading depending upon the polarisation of the beam. A user using a virtual reality data glove or other input device may modify beam 330. By grasping the beam with the data glove a user may orient it as desired or by opening and closing fingers, for example, vary beam width. A user is able to observe how modification of the beam affects the virtual beam in the virtual

display, and thus how the real beam would project on the topology. This provides a simple intuitive user interface.

Figure 20 shows a cellular communication system in which a central controller 332 communicates via backhaul links 333 to 335 with base station controllers 336 to 339. Base station controllers 336 to 339 receive position and/or orientation information from antennas 340 to 343 and provide this information to central controller 332. Alternatively, base station controllers 336 to 339 may include a GPS receiver, avoiding the need to provide one in each antenna. Central controller 332 may maintain a database in which the most current position and orientation data is stored, along with historical data if required. Position and orientation information may be sent periodically to central controller 332 or upon request from central controller 332. Central controller 332 may send control commands via base station controllers 336, 337, 338 and 339 to each controller within each antenna to adjust the physical orientation of the antenna and/or antenna beam attributes based upon immediate need, response to predetermined condition changes, or in accordance with a predetermined time schedule, as described above.

In one embodiment when a new antenna is installed it may send position and/or orientation information to central controller 332. Central controller 332 may determine the desired operating parameters for the antenna and send these back to be stored in the base station controller or the controller within each antenna. Each antenna may then control antenna physical orientation and/or beam orientation to satisfy the required operating parameters. Alternatively, the intelligence may be maintained within central controller 332 so that it directly commands each local antenna controller to make an adjustment until it receives position and/or orientation information meeting the required operating parameters. During operation, controller 332 may send a schedule of desired operating parameters to the base station controller or antenna controller providing a schedule of operation for different periods. The schedule may provide for different beam coverage for different periods. Further, central controller 332 may monitor system usage and adjust the mechanical orientation and/or beam attributes to provide desired coverage actively as usage changes.

By regularly monitoring the position and orientation of each antenna, central controller 332 can monitor correct operation of an entire cellular communications network. If, for example, an antenna should encounter bird strike and become

misaligned, central controller 332 can detect the incorrect orientation of the antenna and, if possible, make adjustment or otherwise properly ensure maintenance is performed. Each antenna controller may be programmed so that if a position or orientation parameter is outside a specified range a signal is sent to central controller 332 notifying it of the exception. Controller 332 can then adjust antenna parameters to compensate or indicate that servicing is required.

It will be appreciated that the graphical user interface described in relation to figure 19 may be applied to a system as shown in figure 19 to enable an operator to control all antenna beams across a system via a user interface at central controller 332.

The system enables the position and orientation of each antenna to be communicated to the central controller 332 upon installation. The settings of beam shaping elements such as phase shifters and power dividers may also be provided to central controller 332 to enable the shape of the beam of each antenna to be determined. Controller 332 may also be provided with information as to fixed obstructions (buildings etc.) and variable obstructions (e.g. foliage). Controller 332 may further be provided with information as to projected traffic (e.g. typical traffic profiles for different times of the day or for events such as sports events) as well as real-time information as to traffic (e.g. actual current traffic or traffic over a proceeding period). Controller 332 may then calculate the desired physical antenna position and beam configuration for each antenna required to give the desired coverage in a particular typography. Controller 332 may do this by overlaying antenna position and orientation information onto a topographical map of the area to calculate desired coverage. Controller 332 may take into account information as to usage and system coverage requirements for the area concerned. Controller 332 may operate a wide range of control strategies utilizing the known antenna position and orientation information as will be apparent to those skilled in the art.

Alternatively an operator may control antenna beam orientation and shape using a user interface. An operator may see the topology off or portion of an area to be controlled with base stations superimposed upon the topology. Beams of the antennas may be projected onto the topology based upon information as to each antenna's position and orientation and the settings of the beam shaping elements of each antenna. The pars duration of each beam may be indicated by colour or some other optical attribute. Buildings and other obstructions may also be shown using

visual attributes, such as colour. System traffic may be superimposed upon the topography to show current traffic, historical traffic and/or predicted traffic using colour or some other visual attribute. Where multiple attributes need to be shown in the same space one attribute may be colour and another may be a fill effect such as crosshatching etc. A user may select a beam using an input device (e.g. amounts, virtual reality data glove etc.) and modify attributes of the antenna beam using the input device. For example an operator may grasp a beam using a virtual reality data glove and change its orientation by moving the data glove. The operator may adjust beam attributes such as being width by opening and closing fingers off the data glove. In this way an operator may adjust a beam while visually observing other beams and the coverage of the beam with respect to traffic in a region and how obstructions affect the beam. It will be appreciated at a variety of input devices could be employed utilizing a range of control strategies.

As an alternative to GPS based position location, triangulation methods may also be employed. Each antenna controller may include an RF receiver for receiving transmissions from known locations, such as cellular towers, to calculate the position of each antenna by triangulation.

There is thus provided an antenna providing azimuth and down tilt adjustment which maintains good radiation patterns of the antenna. A common controller enables mechanical azimuth, electrical down tilt, electrical beam width and electrical azimuth actuators to be commonly controlled. An addressable serial bus interface simplifies interconnection of antennas and controllers. Control data may be sent via an RF feed line, serial data cable or wireless connection. For multiband applications the combination of mechanical and electrical azimuth adjustment allows azimuth to be independently adjusted for two or more arrays.

There is also provided an antenna providing dual electrical azimuth beam steering, combined mechanical and electrical azimuth steering, independent mechanical column steering and dual mechanical steering. This allows beam azimuth to be independently adjusted for two or more arrays. A common controller enables mechanical azimuth, electrical down tilt, electrical beam width and electrical azimuth actuators to be commonly controlled. An addressable serial bus interface simplifies interconnection of antennas and controllers. Control data may be sent via an RF feed line, serial data cable or wireless connection.

There is also provided an antenna capable of detecting its position and orientation and communicating this to a local or central controller. The antenna may include means to maintain attributes of the antenna within desired parameters. These may be preset or downloaded. A system of such antennas simplifies installation by only requiring antennas to be mounted in approximate orientations as they may subsequently be adjusted by altering the mechanical orientation of the antenna and/or attributes of the antenna beam. The system enables the precise position and orientation of antennas to be determined at any point in time and employed in a range of control strategies.

While the present invention has been illustrated by the description of the embodiments thereof, and while the embodiments have been described in detail, it is not the intention to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departure from the spirit or scope of the Applicant's general inventive concept.

CLAIMS

1. A cellular antenna comprising:
an array antenna rotatably mountable with respect to an antenna support so as to enable azimuth steering of the beam of the antenna;
an azimuth position actuator configured to rotate the array antenna with respect to an antenna support; and
an actuator controller configured to receive control data associated with an address assigned to the actuator controller over an addressable serial bus and to control the azimuth position actuator in accordance with azimuth control data received.

2. The antenna assembly of claim 1 further comprising a radome within which said array antenna is rotatably supported.

3. The antenna assembly of claim 2 wherein said antenna support includes an antenna suspension structure adapted to provide primary physical support for the antenna at the top of the radome.

4 . The antenna assembly of claim 2 wherein the azimuth position actuator is configured to rotate the array antenna at the top of the radome.

5. An antenna system including at least one array antenna assembly as defined in claim 1 and a control arrangement including a base station controller adapted to develop said addressed control data for transmission to said actuator controller.

6. An antenna system as claimed in claim 5 including a modulation/demodulation arrangement configured to communicate control data between the base station controller and the actuator controller over an RF feed line.

7. An antenna system as claimed in claim 5 including a wireless communications arrangement configured to communicate control data between the base station controller and the actuator controller.

8. An antenna system as claimed in claim 5 including an addressable serial bus connected directly between the base station controller and the actuator controller.

9. An antenna system as claimed in claim 6 wherein the addressable serial bus is an RS485 bus.

10. A network management system comprising a plurality of base station antenna sites, each with a group of antenna systems as defined in claim 5, said network management system including a central controller configured to communicate with individual actuator controllers through the base station controllers of said antenna systems.

11. The network management system of claim 10 wherein said central controller communicates with said base station controllers using an Internet protocol.

12. An antenna as claimed in claim 1, further including:
a feed network configured to supply signals to and receive signals from an array of spaced apart radiating elements of the array antenna, the feed network including a down tilt phase shifter to vary the phase of signals passing through the feed network;
a down tilt phase shifter actuator configured to adjust the down tilt phase shifter;
wherein the actuator controller is configured to control the down tilt phase shifter actuator in accordance with down tilt control data received to adjust the down tilt of the beam of the array antenna.

13. An antenna as claimed in claim 12 wherein the actuator controller is an integrated controller controlling both the azimuth position actuator and the down tilt phase shifter actuator.

14. An antenna as claimed in claim 12 wherein the feed network includes a plurality of down tilt phase shifters to vary the phase of signals passing through the feed network and a plurality of down tilt phase shifter actuators controlled by the actuator controller

15. An antenna as claimed in claim 1, further including:
a beam width phase shifter to vary the phase of signals passing through the feed network;
a beam width phase shifter actuator configured to adjust the beam width phase shifter;
wherein the actuator controller is configured to control the beam width phase shifter

actuator in accordance with beam width control data received to adjust the beam width of the beam of the array antenna.

16. An antenna as claimed in claim 1, further including:
a power divider to vary the power of signals passing through different branches of the feed network;
a power divider actuator configured to adjust the power divider;
wherein the actuator controller is configured to control the power divider actuator in accordance with beam width control data received to adjust the beam width of the beam of the array antenna.

17. An antenna as claimed in claim 1, further including:
a feed network configured to supply signals to and receive signals from an array of spaced apart radiating elements of the array antenna, the feed network including a beam width phase shifter to vary the phase of signals passing through the feed network;
a beam width phase shifter actuator configured to adjust the down tilt phase shifter;
wherein the actuator controller is configured to control the down tilt phase shifter actuator in accordance with beam width control data received to adjust the beam width of the beam of the array antenna.

18. An antenna as claimed in claim 1, further including:
a feed network configured to supply signals to and receive signals from an array of spaced apart radiating elements of the array antenna, the feed network including a power divider to adjust the relative power of signals passing through different branches of the feed network; and
a power divider actuator configured to adjust the power divider;
wherein the actuator controller is configured to control the power divider actuator in accordance with beam width control data received to adjust the beam width of the beam of the array antenna.

19. A cellular antenna comprising:
an array antenna rotatably mountable with respect to an antenna support so as to enable azimuth steering of the beam of the antenna having a first array of radiating elements for operation over a first frequency band and a second array of radiating elements for operation over a second frequency band;
an azimuth position actuator configured to rotate the array antenna with respect to

an antenna support;

a first feed network configured to supply signals to and receive signals from the first array of radiating elements including an azimuth phase shifter to vary the phase of signals passing through the feed network;

an azimuth phase shifter actuator configured to adjust the azimuth phase shifter; and

an actuator controller configured to receive control data and to control the azimuth position actuator in accordance with mechanical azimuth control data received to rotate the array antenna with respect to an antenna support to alter the direction of the antenna and to control the azimuth phase shifter actuator in accordance with electrical azimuth control data received to adjust the azimuth beam direction of the first array with respect to the azimuth beam direction of the second array.

20. A cellular antenna as claimed in claim 19 wherein the first frequency band is different from the second frequency band.

21. A cellular antenna as claimed in claim 19 wherein the actuator controller is configured to receive control data over an addressable serial bus associated with an address assigned to the actuator controller.

22. A cellular antenna as claimed in claim 19 wherein the first feed network includes a down tilt phase shifter and a down tilt phase shifter actuator responsive to drive signals from the actuator controller to adjust down tilt of the beam of the first array.

23. A cellular antenna as claimed in claim 19 wherein the first feed network includes a beam width phase shifter and a beam width phase shifter actuator responsive to drive signals from the actuator controller to adjust beam width of the first array.

24. A cellular antenna as claimed in claim 19 wherein the first feed network includes a beam width power divider and a beam width power divider actuator responsive to drive signals from the actuator controller to adjust beam width of the first array.

25. A cellular antenna as claimed in claim 22 wherein the first feed network includes a beam width phase shifter and a beam width phase shifter actuator

responsive to drive signals from the actuator controller to adjust beam width of the first array.

26. A cellular antenna as claimed in claim 22 wherein the first feed network includes a beam width power divider and a beam width power divider actuator responsive to drive signals from the actuator controller to adjust beam width of the first array.

27. An antenna as claimed in claim 1, further including a compass attached to the array antenna, such that the compass reading is indicative of the azimuth beam direction.

28. An antenna as claimed in claim 27, wherein the compass sends compass readings to the controller.

29. An antenna as claimed in claim 28, wherein the control signals include a signal specifying a desired azimuth beam direction and wherein the controller is configured to control the azimuth-steering motor based on the compass reading and the desired azimuth beam direction.

30. An antenna as claimed in claim 28, wherein the controller is configured to correct the compass reading for the offset between magnetic and true north.

31. A cellular antenna system comprising:
a central control system and at least two antennas as claimed in claim 1;
wherein the controllers are configured to receive control signals from the central control system over a single addressable serial bus.

32. An antenna system as claimed in claim 31, wherein:
each antenna includes a compass attached to its array antenna, such that the compass reading is indicative of the antenna's azimuth beam direction;
the compass reading is sent to the central control system, which is configured to send control signals to the appropriate controller instructing control of the azimuth actuator to bring the compass reading into agreement with a desired azimuth beam direction.

33. A method of adjusting beam azimuth for a multi-array antenna having a first

array and a second array in which the first array has a feed network including one or more variable element for adjusting beam azimuth, the method comprising:
mechanically orienting the antenna so as to achieve a desired azimuth beam direction for the second array; and
setting the variable element so as to achieve a desired beam azimuth for the first array, different to the beam azimuth for the first array.

34. A cellular antenna comprising:

a. a first array of radiating elements configured to develop, when excited, a first beam;

b. a first feed network associated with the first array having one or more first controllable elements for adjusting the azimuth direction of the first beam;

c. a second array of radiating elements configured to develop, when excited, a second beam;

d. a second feed network associated with the second array having one or more second controllable elements for adjusting the azimuth direction of the second beam, wherein the first controllable elements may be controlled independently of the second controllable elements to allow independent azimuth steering of the first and second beams of the arrays; and

e. an antenna housing accommodating the first and second arrays.

35. A cellular antenna as claimed in claim 34 wherein the first array is designed for operation in a first frequency band and the second array is designed for operation in a second frequency band, and wherein the first frequency band is different from the second frequency band.

36. A cellular antenna as claimed in claim 35 wherein said first controllable elements of said first array are controlled through a first electrical actuator, and wherein said antenna includes an actuator controller which is configured to receive over an addressable serial bus control data associated with an address assigned to the actuator controller.

37. A cellular antenna as claimed in claim 36 wherein the first feed network includes a down tilt phase shifter and a down tilt phase shifter actuator responsive to drive signals from the actuator controller to adjust down tilt of the beam of the first array.

38. A cellular antenna as claimed in claim 36 wherein the first feed network includes a beam width phase shifter and a beam width phase shifter actuator responsive to drive signals from the actuator controller to adjust beam width of the first array.

39. A cellular antenna as claimed in claim 36 wherein the first feed network includes a beam width power divider and a beam width power divider actuator responsive to drive signals from the actuator controller to adjust beam width of the first array.

40. A cellular antenna as claimed in claim 37 wherein the first feed network includes a beam width phase shifter and a beam width phase shifter actuator responsive to drive signals from the actuator controller to adjust beam width of the first array.

41. A cellular antenna as claimed in claim 37 wherein the first feed network includes a beam width power divider and a beam width power divider actuator responsive to drive signals from the actuator controller to adjust beam width of the first array.

42. An antenna as claimed in claim 34, further including an antenna orientation sensor attached to the array antenna, such that the antenna orientation sensor reading is indicative of the azimuth beam direction.

43. An antenna as claimed in claim 42, wherein the antenna orientation sensor sends a compass reading to a controller which controls the controllable elements.

44. An antenna as claimed in claim 43, wherein the controller receives control signals including a signal specifying a desired azimuth beam direction and wherein the controller is configured to control the controllable elements based on the compass reading and the desired azimuth beam direction.

45. An antenna as claimed in claim 44, wherein the controller is configured to correct the compass reading for the offset between magnetic and true north.

46. A cellular antenna as claimed in claim 34 including a mechanical azimuth actuator responsive to control commands to mechanically steer the cellular antenna

relative to an antenna support.

47. A cellular antenna as claimed in claim 46 wherein the mechanical azimuth actuator is controlled by a mechanical azimuth actuator controller configured to receive control data over an addressable serial bus associated with an address assigned to the mechanical azimuth actuator controller.

48. A method of azimuth steering the beams of an integrated cellular antenna having a first array of radiating elements arranged in multiple columns and a second array of radiating elements arranged in multiple columns wherein columns of the first array are fed with phase shifted signals such that the azimuth direction of the beam of the first array is oriented in a first direction and wherein columns of the second array are fed with phase shifted signals such that the azimuth direction of the beam of the second array is oriented in a second direction, different to the first direction.

49. A cellular antenna comprising:

a. an array antenna having first and second arrays of radiating elements configured to develop, when excited, first and second beams respectively, the array antenna being rotatably mountable with respect to an antenna support so as to enable mechanical azimuth steering of the first and second beams;

b. a mechanical azimuth actuator configured to rotate the array antenna with respect to an antenna support;

c. a first feed network configured to supply signals to and receive signals from the first array of radiating elements including a first variable element to vary the phase of signals passing through the feed network;

d. a first variable element adjuster configured to adjust the first phase shifter; and

e. an actuator controller configured to receive control data and to control the mechanical azimuth actuator in accordance with mechanical azimuth control data received to rotate the array antenna with respect to an antenna support to alter the orientation of the antenna and to control the first variable element adjuster in accordance with electrical azimuth control data received to adjust the azimuth beam direction of the first array with respect to the azimuth beam direction of the second array.

50. A cellular antenna as claimed in claim 49 wherein the first arrav is

configured for operation over a first frequency band and the second array is configured for operation over a second frequency band, different to the first frequency band.

51. A cellular antenna as claimed in claim 50 wherein the second array operates over a lower frequency band.

52. A cellular antenna as claimed in claim 49 wherein the second array is a single column array.

53. A cellular antenna as claimed in claim 49 including a second feed network configured to supply signals to and receive signals from the second array of radiating elements including a second variable element controlled by the actuator controller to vary the phase of signals passing through the second feed network to adjust the azimuth direction of the beam of the second array.

54. A cellular antenna as claimed in claim 53 wherein the first array is an array of cross dipoles.

55. A cellular antenna as claimed in claim 53 wherein the second array is an array of ring radiators.

56. A cellular antenna as claimed in claim 55 wherein the first and second arrays are co-located.

57. A cellular antenna as claimed in claim 53 wherein the actuator controller is configured to receive control data over an addressable serial bus associated with an address assigned to the actuator controller.

58. A method of adjusting beam azimuth for a multi-array antenna having first and second arrays of radiating elements configured to develop, when excited, first and second beams respectively wherein the first array has a feed network including one or more variable elements for adjusting first beam azimuth, the method comprising:

a. mechanically orienting the antenna so as to achieve a desired azimuth beam direction for the second beam; and

b. setting the one or more variable elements so as to achieve a desired beam azimuth for the first beam, different to the beam azimuth for the second beam.

59. A method as claimed in claim 58 including obtaining orientation information as to the orientation of the antenna and mechanically orienting the antenna in dependence upon the orientation information.

60. A method as claimed in claim 59 wherein the orientation information is obtained via an electronic compass attached to the antenna.

61. A method as claimed in claim 60 wherein the orientation information is supplied to a remote central controller which provides control commands for orienting the antenna in dependence upon the orientation information.

62. A method of setting different beam azimuth orientations for first and second beams of a multi-array antenna having first and second arrays of radiating elements in which the first array has a first feed network including one or more variable elements for adjusting beam azimuth and the second array has a second feed network including one or more variable elements for adjusting beam azimuth, the method comprising:

a. mechanically orienting the antenna so as to orient a line normal to the antenna between desired beam directions for the first and second beams;

b. setting the one or more variable elements of the first feed network so as to achieve a desired beam azimuth for the first beam; and

c. setting the one or more variable elements of the second feed network so as to achieve a desired beam azimuth for the second beam.

63. A cellular antenna system comprising a central control system and at least two antennas as claimed in claim 49 wherein the actuator controllers are configured to receive control signals from a central control system to control the beam orientations of the antennas.

64. An antenna system as claimed in claim 63, wherein each antenna includes an electronic compass which provides a compass reading indicative of antenna azimuth orientation to the central control system.

65. An antenna system as claimed in claim 64 wherein the central control

system is configured to send control signals to an actuator controller of an antenna to control of an azimuth actuator to bring the compass reading into agreement with a desired azimuth beam direction.

66. A cellular antenna comprising an antenna housing; a plurality of panels of radiating elements relatively rotatable with respect to the antenna housing and azimuth actuators for independently rotating each panel with respect to the antenna housing.

67. A cellular antenna as claimed in claim 66 wherein each column has a single column of radiating elements.

68. A cellular antenna as claimed in claim 66 wherein each panel may be independently rotated to a desired azimuth orientation.

69. A cellular antenna as claimed in claim 66 including an antenna housing actuator for rotating the antenna housing with respect to an antenna support.

70. A method of steering the beam of an antenna comprising a plurality of panels of radiating elements relatively rotatable with respect to an antenna housing having azimuth actuators for independently rotating each panel with respect to the antenna housing, the method comprising rotating selected panels with respect to the antenna housing to achieve a desired beam pattern and or orientation.

71. A method as claimed in claim 70 wherein all panels are aligned in a common orientation.

72. A method as claimed in claim 70 wherein outer panels are oriented away from each other.

73. A cellular antenna as claimed in claim 34 wherein the controllable elements include active phase adjustment elements.

74. A cellular antenna as claimed in claim 73 wherein the active phase adjustment elements include PIN diodes.

75. A cellular antenna as claimed in claim 73 wherein the active phase adjustment elements are optically controllable.

76. A cellular antenna as claimed in claim 49 wherein the first phase shifter is an active phase shifter.

77. An cellular antenna as claimed in claim 76 wherein the active phase shifter includes PIN diodes.

78. A cellular antenna as claimed in claim 77 wherein the active phase shifter is optically controllable.

79. An antenna as claimed in claim 35 wherein the first frequency band is in the range of 824 to 960 GHz and the second frequency band is in the range of 1710 to 1720 GHz.

80. An antenna as claimed in claim 50 wherein the first frequency band is in the range of 824 to 960 GHz and the second frequency band is in the range of 1710 to 1720 GHz.

81. A cellular antenna comprising:

a. a central panel having a first array of radiating elements;

b. a pair of outer panels of radiating elements rotatably connected to edges of the central panels; and

c. an actuator arrangement for adjusting the relative positions of the outer panels with respect to the central panel.

82. A method of adjusting beam azimuth for a multi-array antenna having first and second arrays of radiating elements configured to develop, when excited, first and second beams respectively, the method comprising:

a. orienting the first beam to achieve a desired azimuth beam direction for the first beam; and

b. orienting the second beam to achieve a desired azimuth beam direction for the second beam, different to the beam azimuth for the first beam.

83. A cellular communications antenna comprising:

an array antenna configured to produce a beam and mounted for adjustable orientation;

an antenna orientation sensor mounted upon or near the antenna and configured to develop a signal characterizing the physical orientation of the antenna;
an electrical actuator for adjusting an attribute of the array antenna or the beam; and
an antenna controller responsive to the sensor signal and configured to control the actuator to achieve a desired antenna orientation or beam orientation or configuration.

84. A cellular communications antenna as claimed in claim 83 wherein the actuator adjusts the physical orientation of the array antenna.

85. A cellular communications antenna as claimed in claim 84 wherein the adjustment in physical orientation produces changes in beam azimuth, beam elevation or beam roll...

86. A cellular communications antenna as claimed in claim 83 wherein the actuator adjusts the orientation of the antenna beam with respect to the array antenna.

87. A cellular communications antenna as claimed in claim 86 wherein the beam orientation adjustment comprise adjustment in beam elevation, beam azimuth or beam width.

88. A cellular communications antenna as claimed in claim 83 wherein the antenna orientation sensor includes an electronic compass, inclinometer, or a gyroscope.

89. A cellular communications antenna as claimed in claim 83 including a global positioning satellite (GPS) receiver.

90. A cellular communications antenna as claimed in claim 83 including RF receivers for determining the position of each array antenna by triangulation.

91. A cellular communications antenna as claimed in claim 83 wherein the antenna orientation sensor is permanently fixed to the array antenna.

92. A cellular communications antenna system comprising:
a plurality of array antennas producing beams covering a plurality of cell sectors;
a plurality of antenna orientation sensors associated with said plurality of antennas and configured to respectively sense the physical orientations of said array antennas;
a plurality of actuators for respectively adjusting an attribute of the array antennas; and
a control arrangement configured to receive orientation information from the orientation sensors and adjust an attribute of each of the array antennas to achieve for each antenna a desired antenna orientation or beam orientation or configuration.

93. A cellular communications antenna system as claimed in claim 92 wherein the control arrangement adjusts attributes of the array antennas to match desired attribute values stored by the control arrangement.

94. A cellular communications antenna system as claimed in claim 92 wherein the desired antenna attribute of at least one antenna is selected to achieve one of: system coverage, system usage and desired antenna orientation.

95. A cellular communications antenna system as claimed in claim 92 wherein the control arrangement controls the actuators via an addressable serial bus.

96. A cellular communications antenna system as claimed in claim 92 wherein the control arrangement controls the actuators via a wireless link.

97. A cellular communications system comprising:
a plurality of antenna systems as claimed in claim 92; and
a central controller in communication with the antenna systems to receive orientation information and send control information to adjust one or more attribute of the antenna systems.

98. A cellular communications system as claimed in claim 97 wherein each antenna system supplies orientation information to the central controller.

99. A cellular communications system as claimed in claim 98 wherein each antenna system periodically supplies orientation information to the central controller.

100. A cellular communications system as claimed in claim 98 wherein each antenna system supplies orientation information to the central controller when requested by the central controller.

101. A cellular communications system as claimed in claim 97 wherein each antenna system supplies orientation information to the central controller upon the occurrence of a specified event.

102. A cellular communications system as claimed in claim 101 wherein the specified event is an array antenna orientation outside of a permitted range.

103. A cellular communications system as claimed in claim 97 wherein each antenna system is responsive to commands from the central controller.

104. A cellular communications system as claimed in claim 97 wherein the central controller periodically sends desired attribute information to each antenna system.

105. A cellular communications system as claimed in claim 97 wherein each antenna system includes a position sensor for determining the position of each antenna system and providing position information to the central controller.

106. A method of controlling the orientation of a cellular communications antenna having an orientation sensor for measuring the orientation of the antenna and an actuator for adjusting the orientation of the antenna, comprising:
determining the orientation of the antenna; and, if the orientation of the antenna is not within a desired range,
driving the actuator and monitoring the orientation of the antenna measured by the orientation sensor until the orientation of the antenna is within the desired range.

107. A method of controlling the orientation of a cellular communications antenna as claimed in claim 106 wherein the orientation is one or more selected from the group of Azimuth, vertical orientation and yaw.

108. A method of controlling a beam attribute of a cellular communications antenna having an orientation sensor for measuring the orientation of the antenna

and an actuator for adjusting a variable element of an antenna feed network of the antenna, comprising:
determining the orientation of the antenna; and
controlling the actuator of the antenna to achieve a desired beam pattern in dependence upon the orientation of the antenna.

109. A method of controlling a beam attribute of a cellular communications antenna as claimed in claim 108 wherein the beam attribute is selected from the group of beam azimuth, down tilt and beam width.

110. In a cellular communications system a method of determining the configuration of a plurality of antenna systems comprising a plurality of antennas having orientation sensors for measuring the orientation of the antennas and position sensors for determining the positions of the antennas, the method comprising:
obtaining position and orientation readings for antennas of each antenna system and communicating the readings to a central controller.

111. A method as claimed in claim 110 wherein the central controller maintains a database of antenna positions and orientations and controls the antenna systems to achieve a desired coverage.

112. A method as claimed in claim 110 wherein the central controller maintains a database of antenna positions and orientations and sends desired attribute values to the antenna systems.

113. A method of configuring a cellular communications antenna including an orientation sensor for measuring the orientation of the antenna and a position sensor for determining the position of the antenna comprising:
determining the position and orientation of the antenna;
storing position and orientation information in a controller; and
controlling actuators to adjust attributes of the antenna to provide desired beam coverage based on the stored position and orientation information.

114. A method of configuring a cellular communications antenna as claimed in claim 113 wherein the position and orientation sensor is a portable unit that is temporarily secured to the antenna to determine position and orientation and supply the position and orientation information to the controller.

115. A cellular communications antenna comprising:
an array antenna for producing a beam;
antenna position and orientation sensors mounted upon or near the antenna and configured to develop a signal characterizing the position and orientation of the antenna;
an actuator for adjusting an attribute of the array antenna or the beam; and
an antenna controller responsive to the sensor signal and configured to control the actuator to achieve a desired antenna or beam configuration.

116. A method of controlling coverage in a cellular communications system including one or more base station, comprising the steps of:
a. obtaining information as to the position and orientation of an antenna of the one or more base station;
b. obtaining desired beam coverage information;
c. calculating a desired antenna orientation for the antenna based at least in part upon the desired beam coverage information; and
d. controlling the antenna so that its beam conforms to the desired antenna orientation.

117. A method as claimed in claim 116 further comprising the steps of:
a. obtaining information as to the configuration of one or more beam shaping element of the antenna;
b. calculating a desired beam shape for the antenna; and
c. controlling the antenna so that its beam shape corresponds with the desired beam shape.

118. A method as claimed in claim 116 wherein the beam coverage information includes information as to obstructions.

119. A method as claimed in claim 116 wherein the beam coverage information includes information as to current cellular traffic.

120. A method as claimed in claim 116 wherein the beam coverage information includes information as to historical cellular traffic.

121. A method as claimed in claim 116 wherein information is obtained as to the

position and orientation of a plurality of antennas.

122. A method as claimed in claim 118 wherein the some of the plurality of antennas are associated with different base stations.

123. A method of controlling coverage in a cellular communications system including one or more base station, comprising the steps of:

a. obtaining information as to the position and orientation of an antenna of the one or more base station;

b. displaying a virtual projection of the antenna beam onto a virtual topography corresponding to the environment in which the antenna is located;

c. modifying the antenna beam orientation via a user input device;

d. displaying a modified virtual antenna beam in the virtual environment corresponding to modification via the user input device; and

e. controlling the antenna so that the beam conforms to the desired antenna orientation.

124. A method as claimed in claim 123 wherein information as to the configuration of one or more beam shaping element of the antenna is obtained and used to generate the virtual antenna beam.

125. A method as claimed in claim 124 wherein the user input device can modify attributes of beam shape and the antenna is controlled to conform to the attributes set via the user input device.

126. A method as claimed in claim 123 wherein the user input device is a virtual reality data glove.

127. A cellular communications system comprising:

a. a central controller;

b. one or more base station, each base station having one or more antenna and a base station controller which provides information as to the orientation of each antenna to the central controller;

c. wherein the central controller controls the orientation of each antenna to achieve a desired coverage.

128. A cellular communications system as claimed in claim 127 wherein each

base station sends information as to antenna beam shape to the central controller and the central controller controls the beam shape of each antenna.

129. A cellular communications system as claimed in claim 127 wherein each base station includes a position sensor and sends information as to its physical position to the central controller.

130. A cellular communications system comprising:

a. a central controller; and

b. one or more base station, each base station having one or more antenna and a base station controller which provides information as to the orientation of each antenna to the central controller;

wherein the central controller includes display means for displaying virtual antenna beams representative of the antenna beams of the base stations superposed on a virtual topology and a user input device enabling a user to manipulate a virtual beam to generate control signals sent to control attributes of the corresponding antenna.

131. A cellular communications system as claimed in claim 130 wherein each base station controller provides information as to the beam shape of each antenna beam to the central controller.

132. A cellular communications system as claimed in claim 130 wherein each base station controller provides information as to the position of each base station to the central controller.

133. cellular communications system as claimed in claim 130 wherein the user input device is a virtual reality data glove.

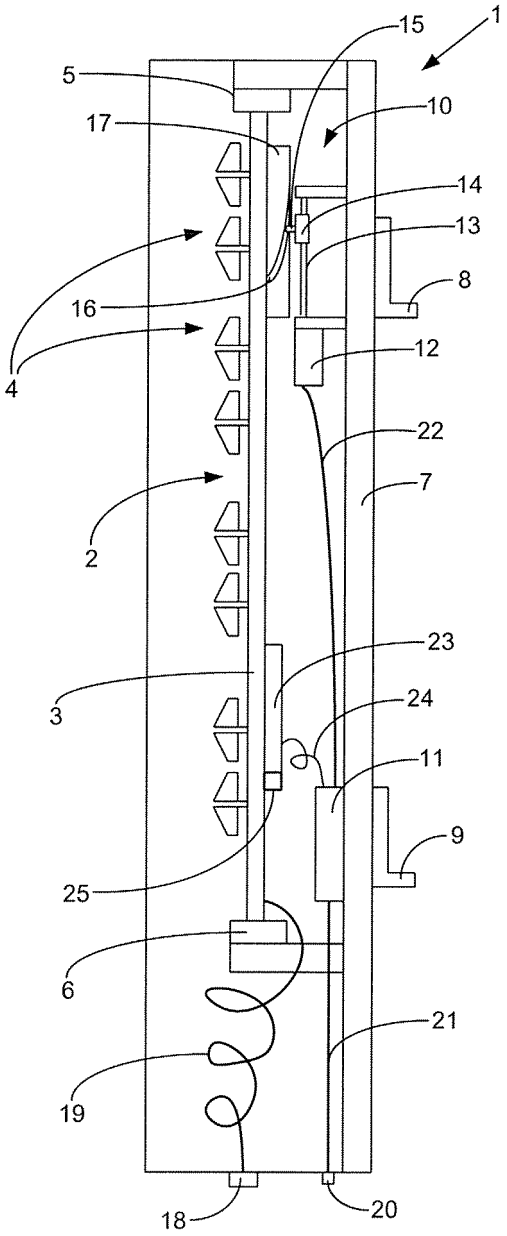


Figure 1

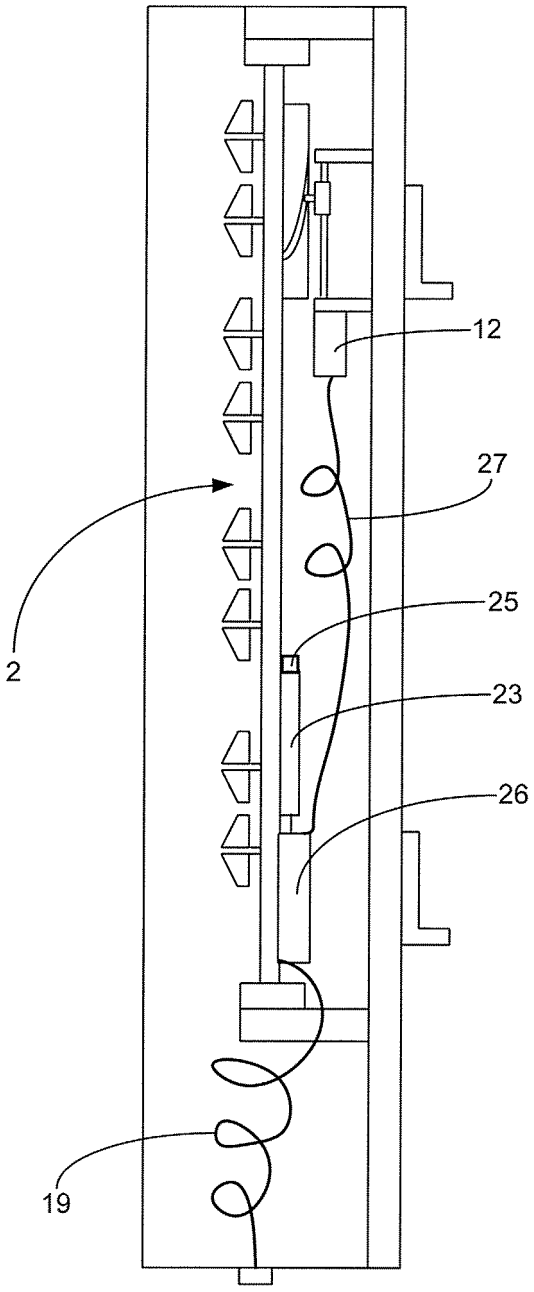


Figure 2a

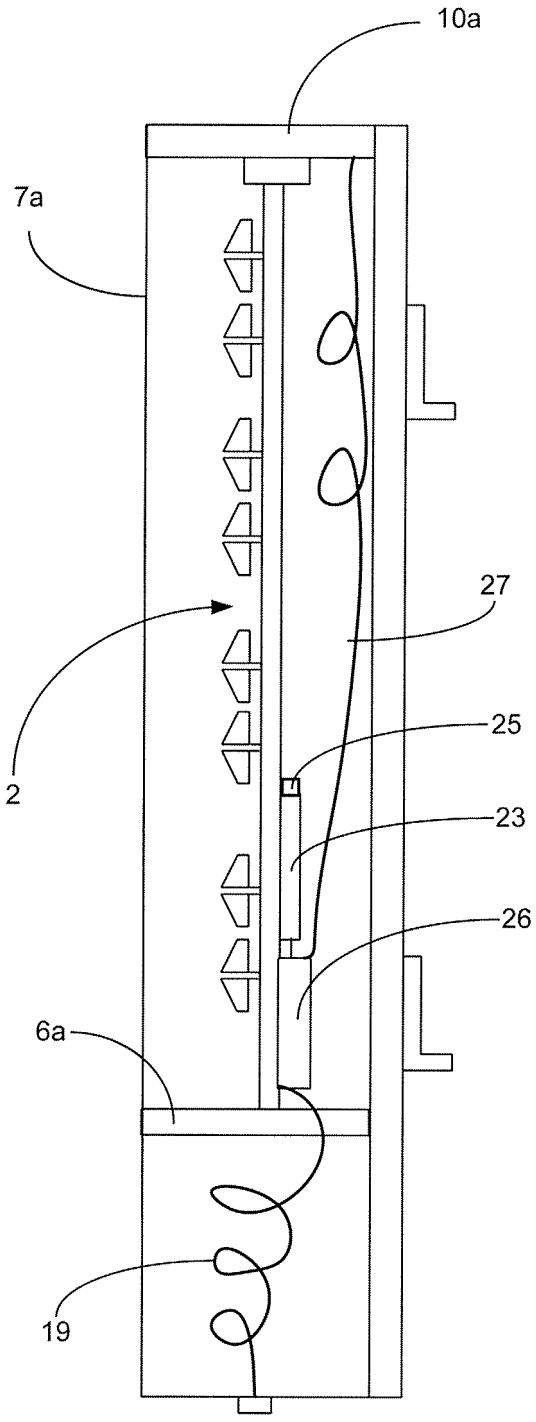


Figure 2b

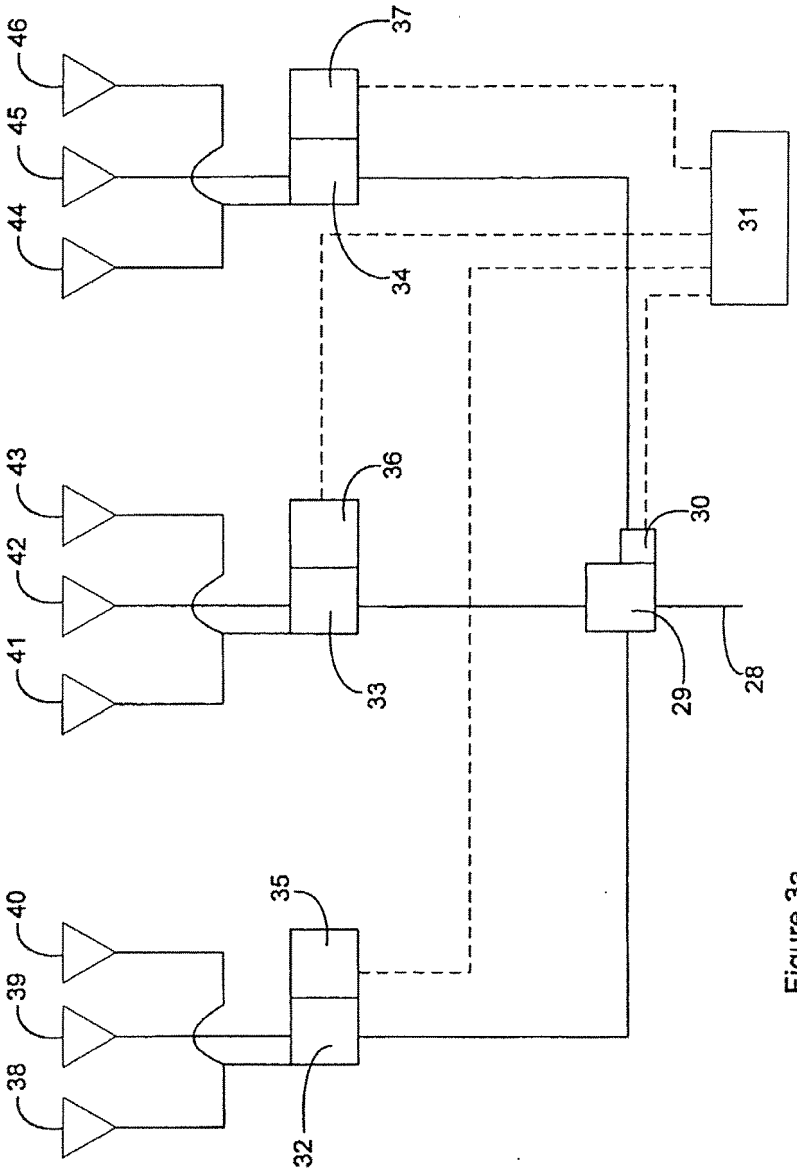


Figure 3a

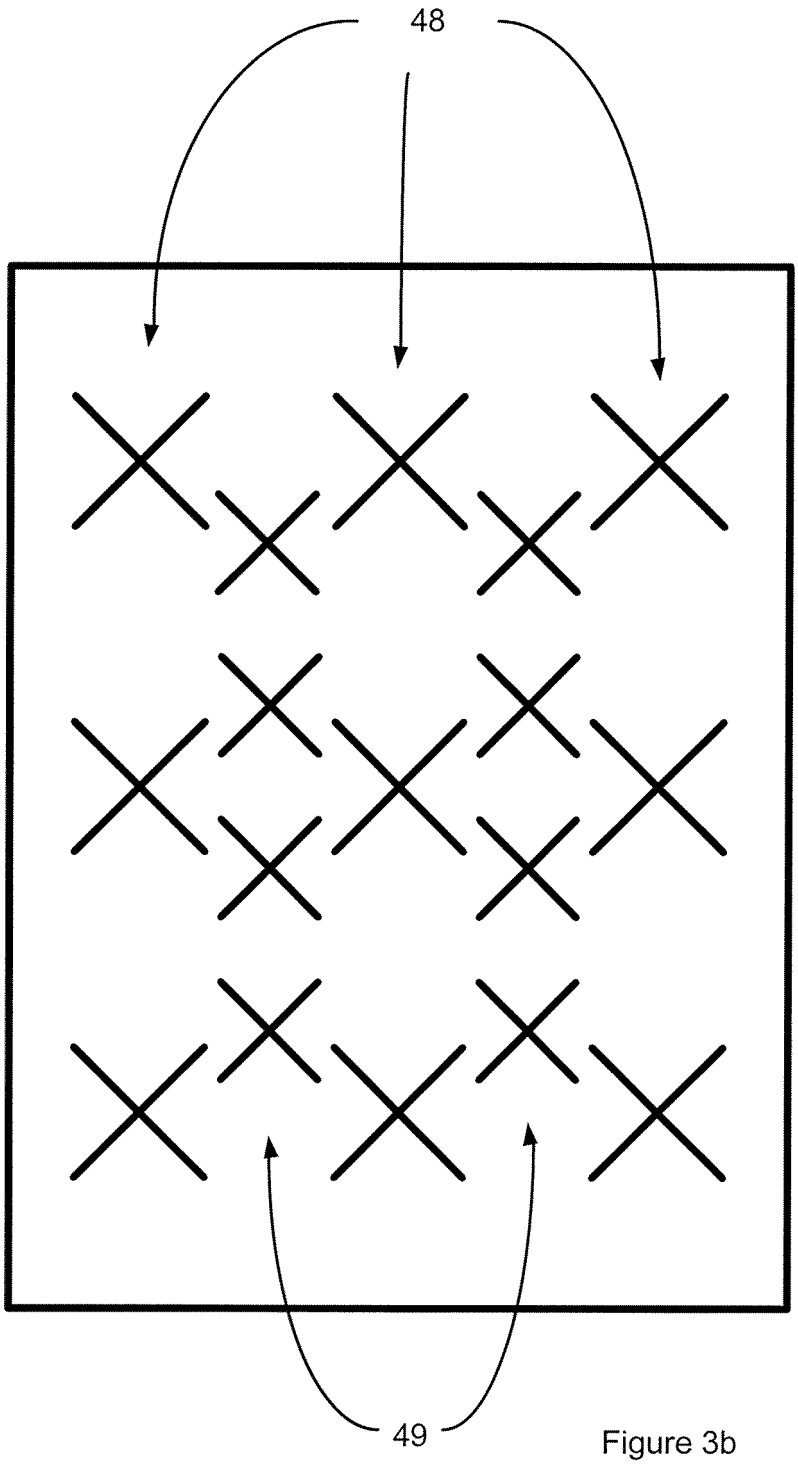


Figure 3b

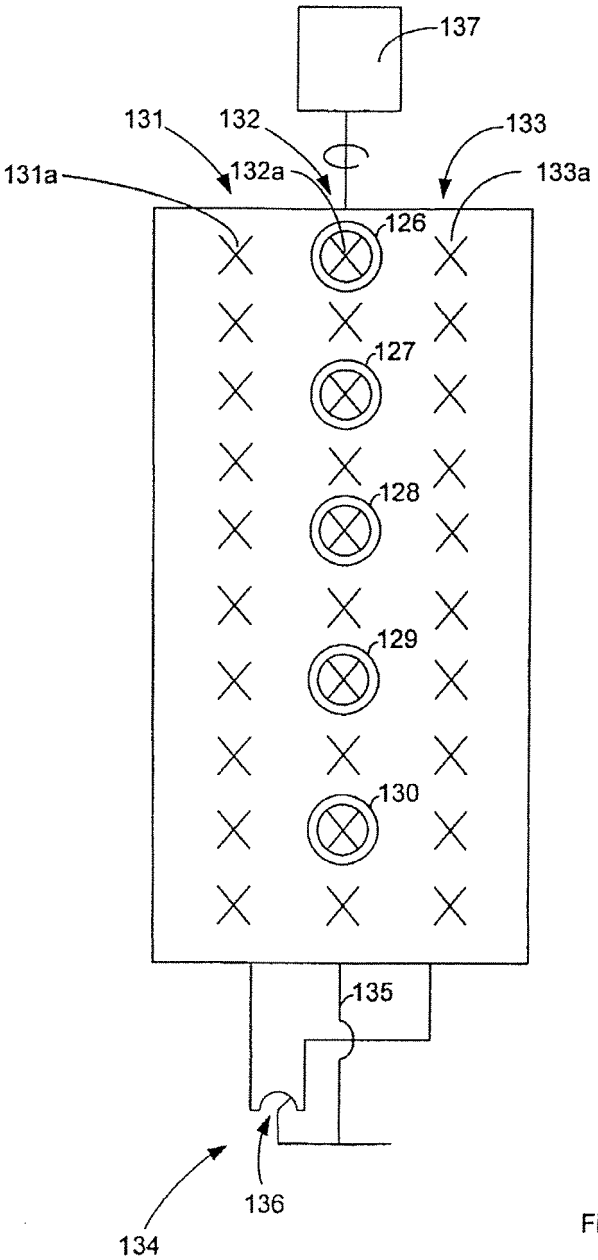


Figure 3c

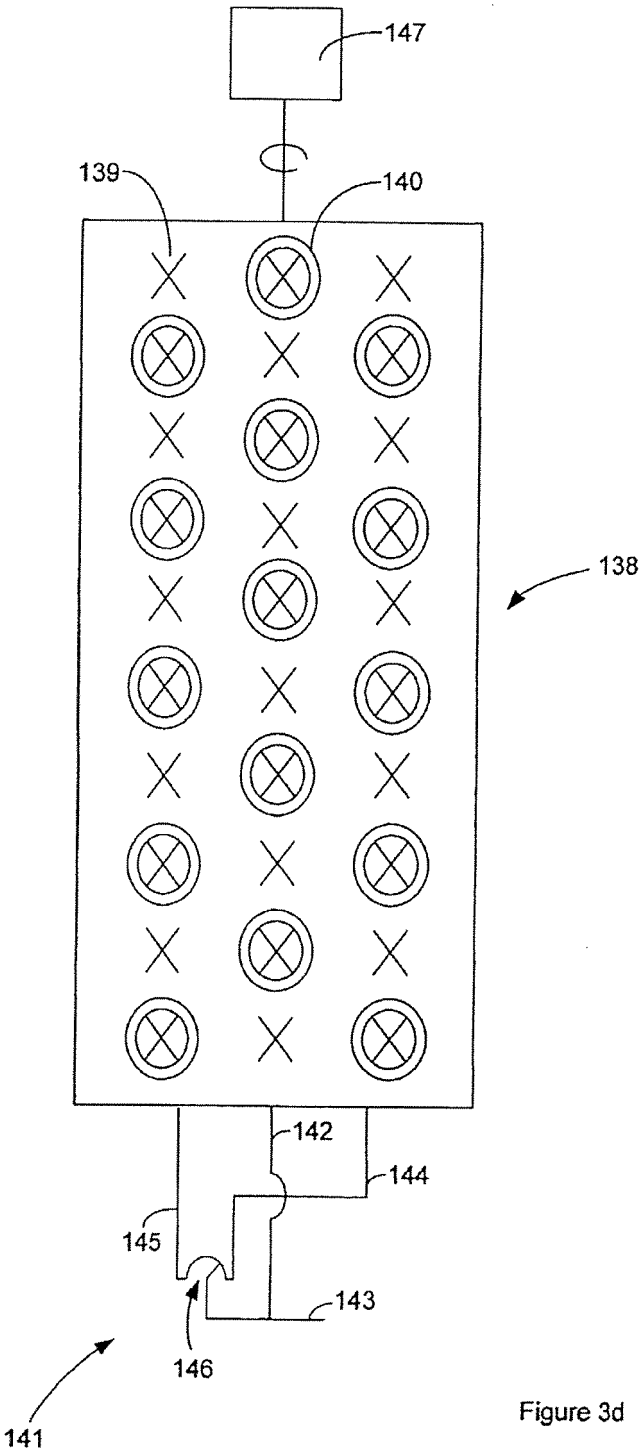


Figure 3d

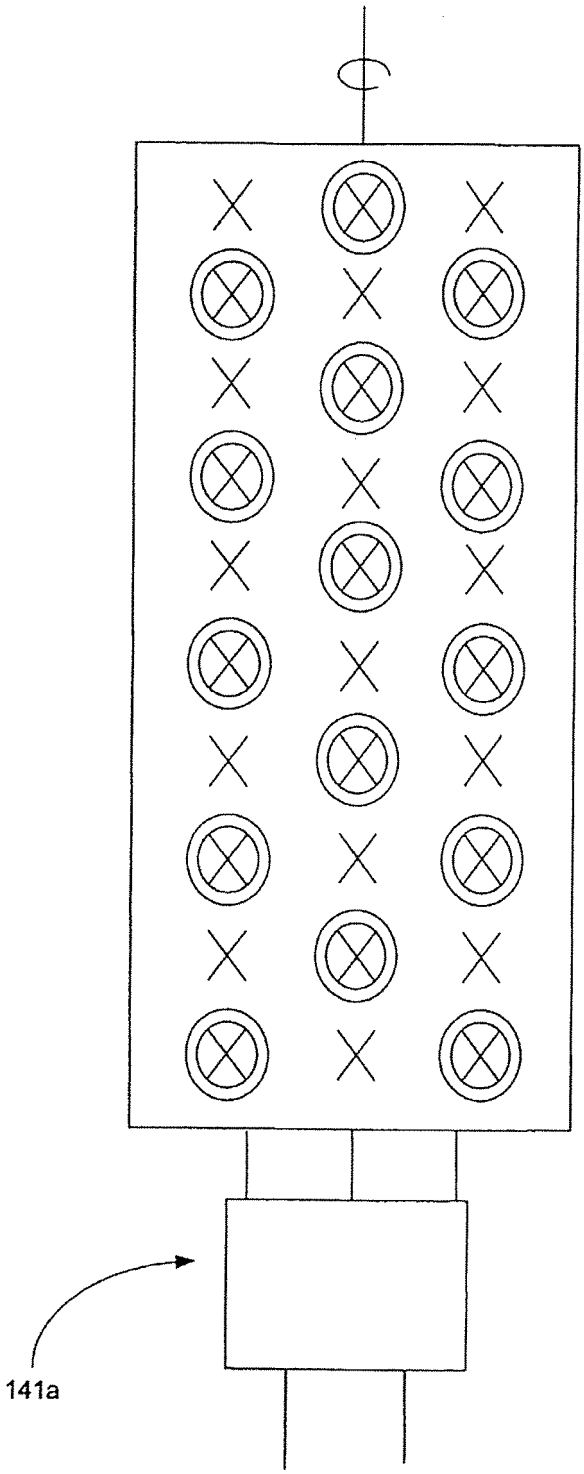


Figure 3e

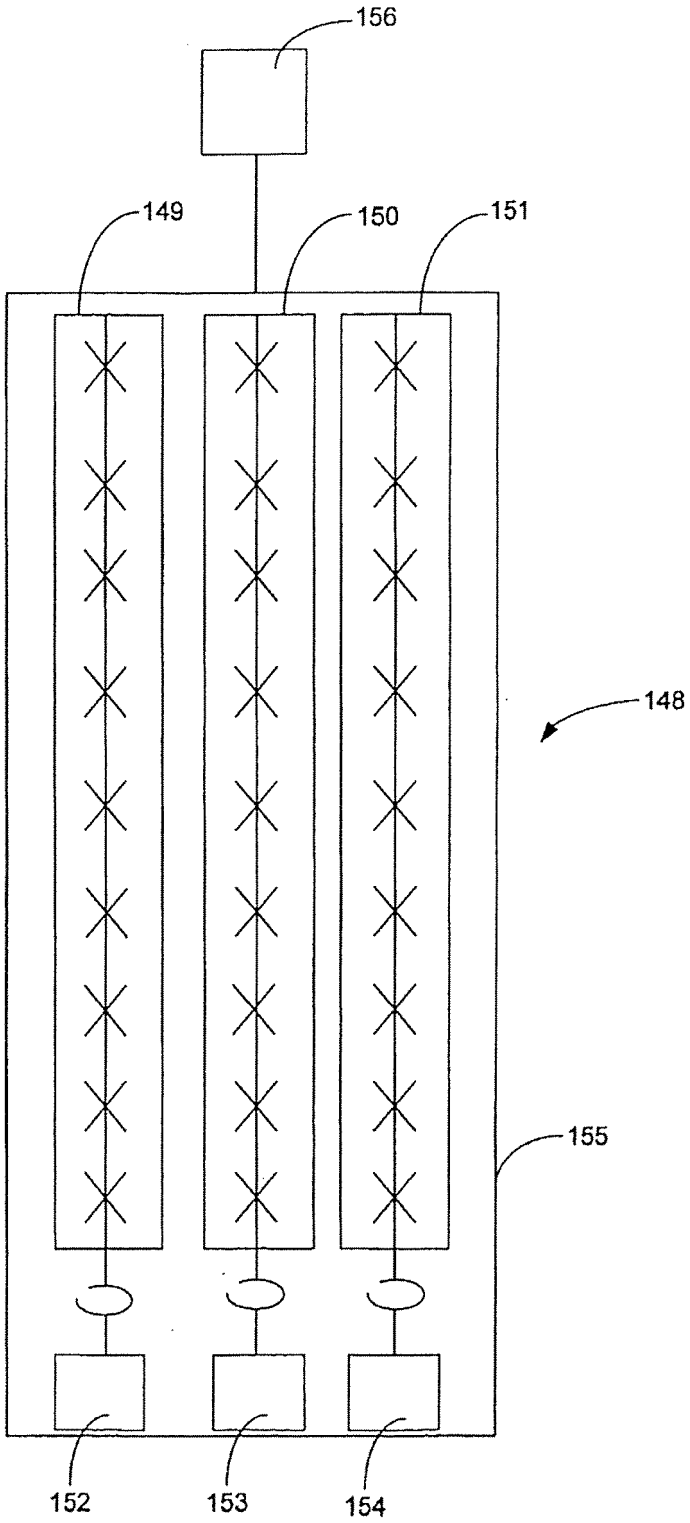


Figure 3f

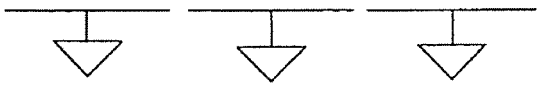


Figure 3g



Figure 3h



Figure 3j

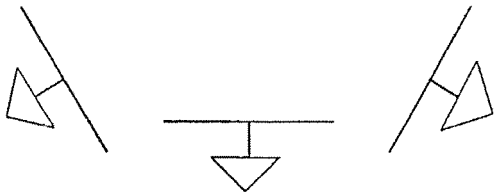


Figure 3k

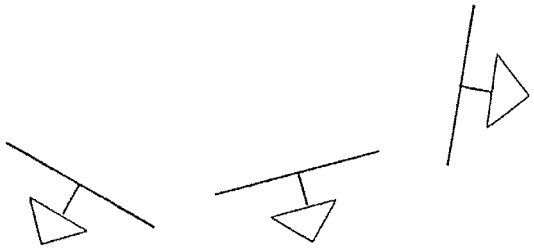


Figure 3L

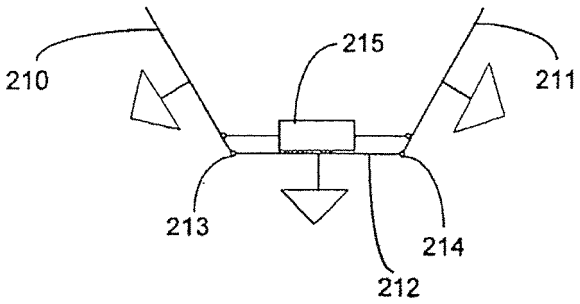


Figure 3m

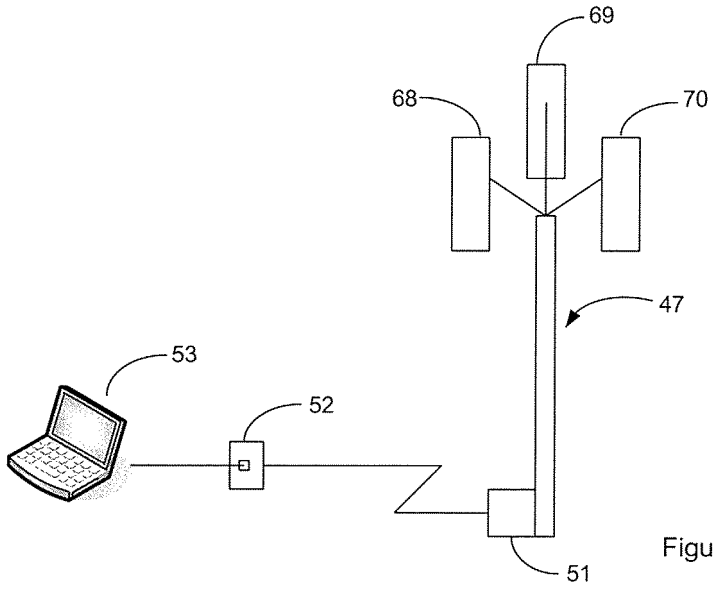


Figure 4

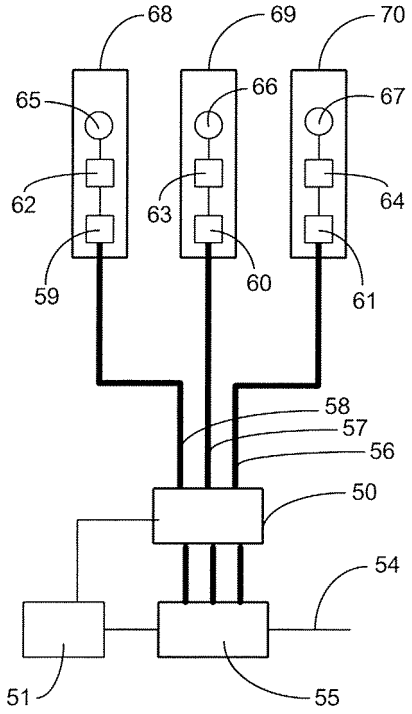


Figure 5

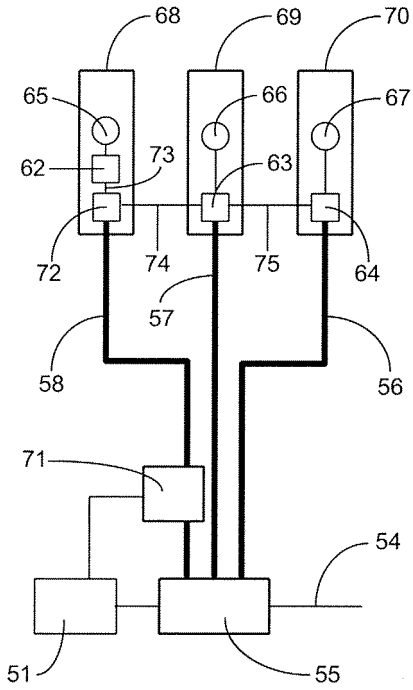


Figure 6

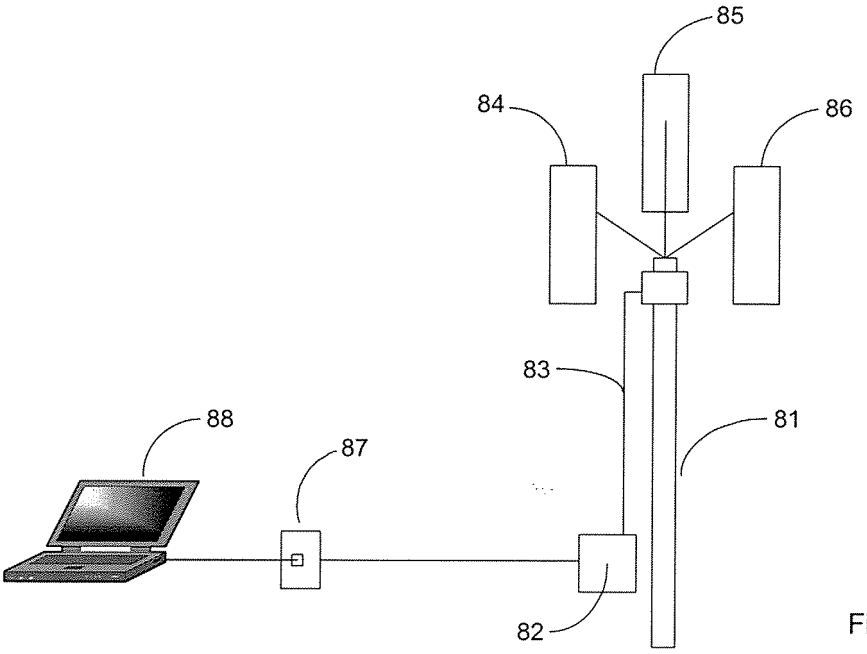


Figure 8

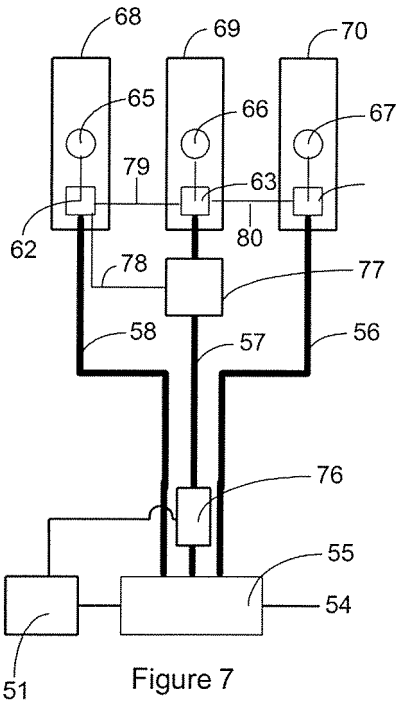


Figure 7

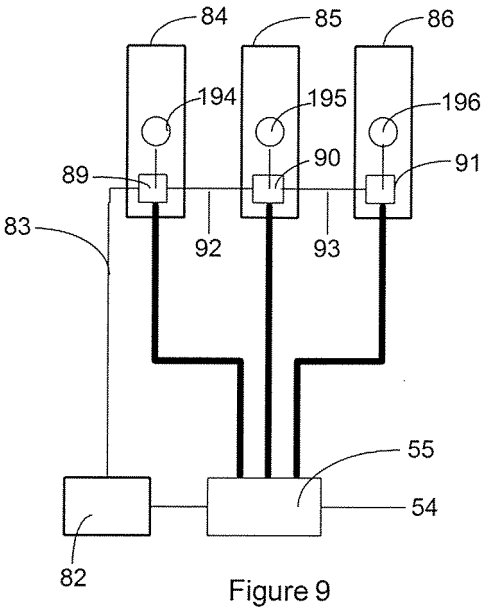


Figure 9

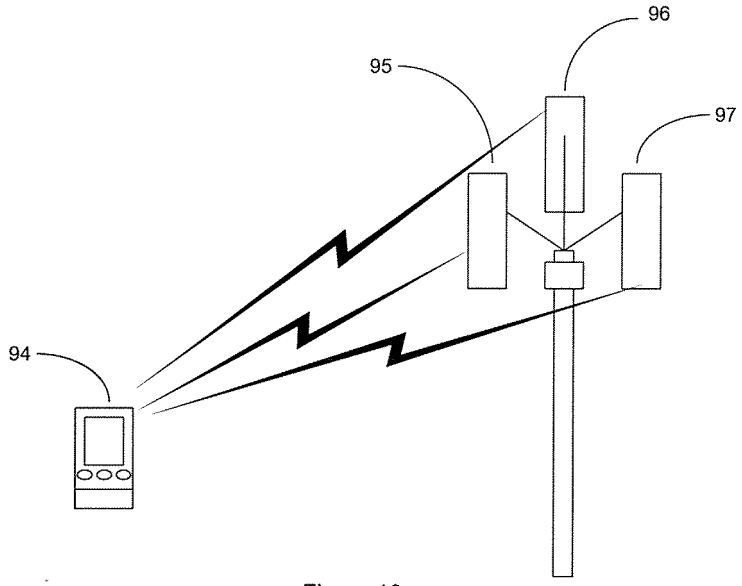


Figure 10

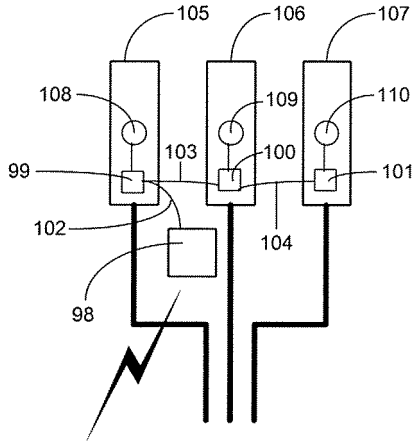


Figure 11

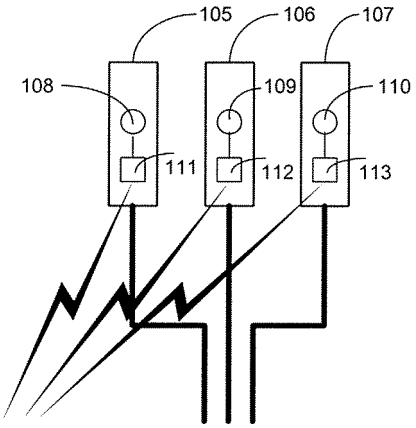


Figure 12

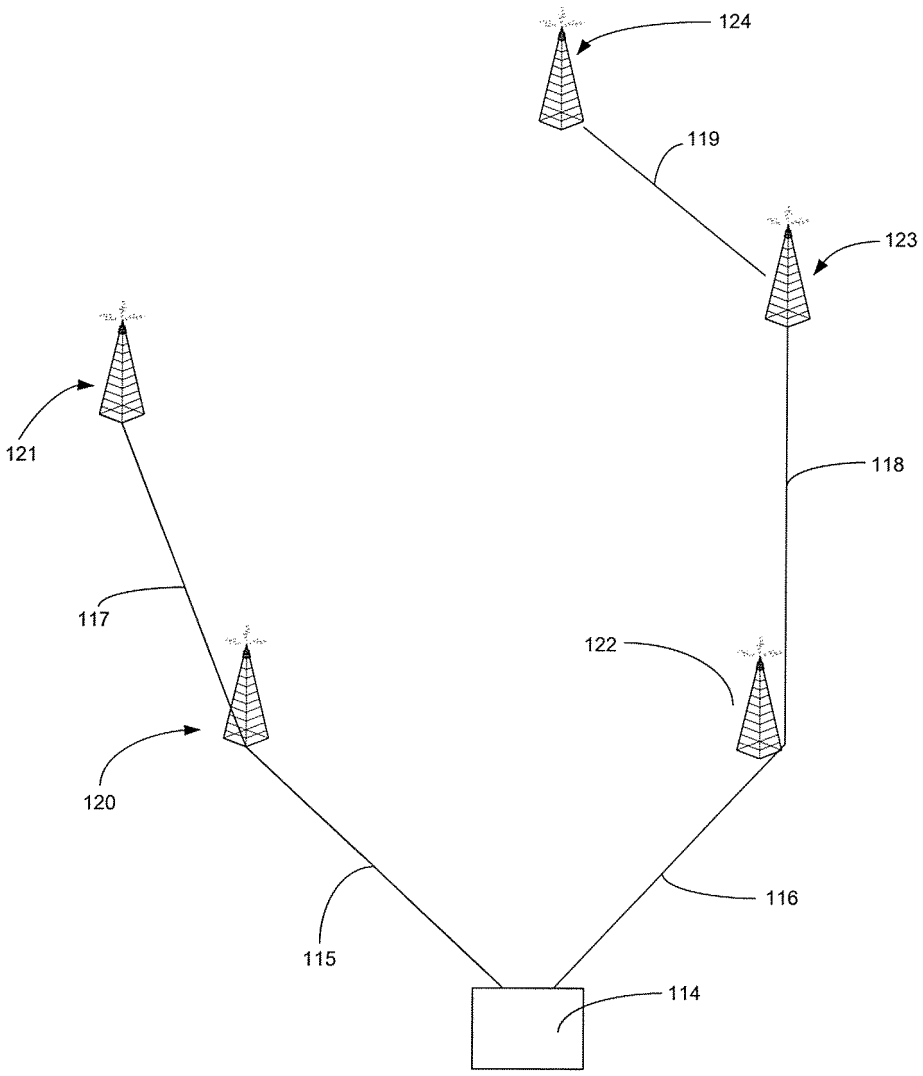


Figure 13

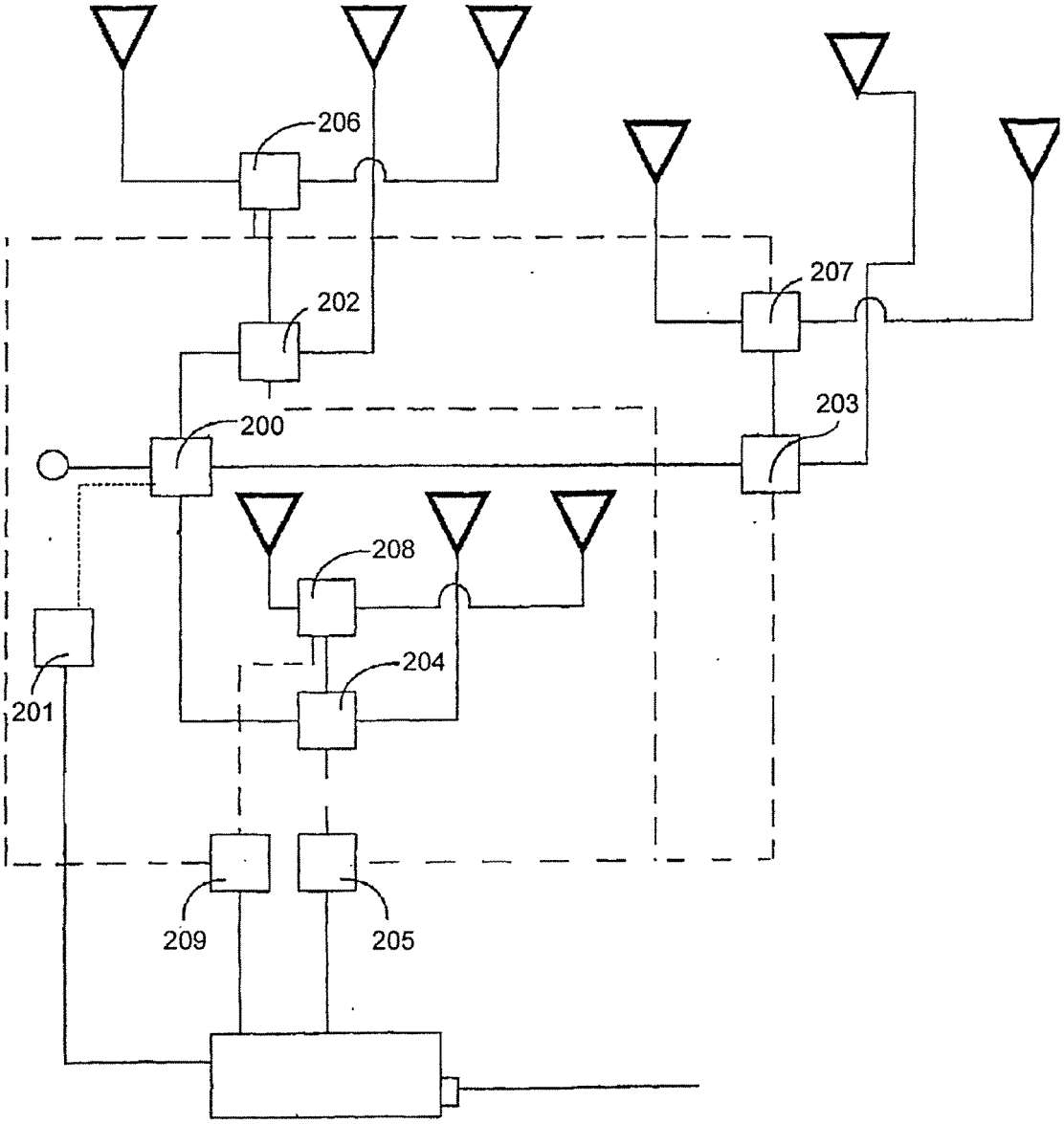


Figure 14

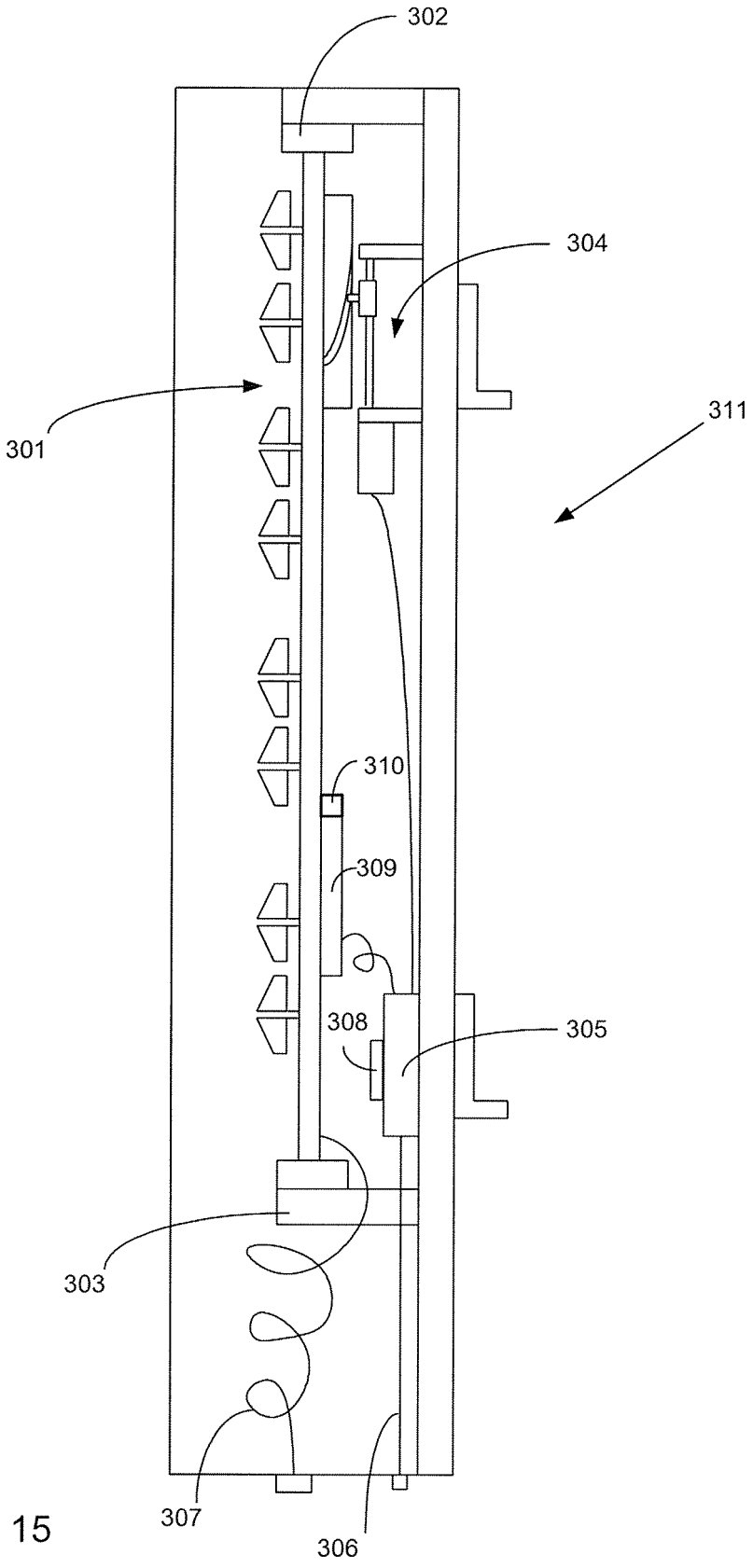


Fig 15

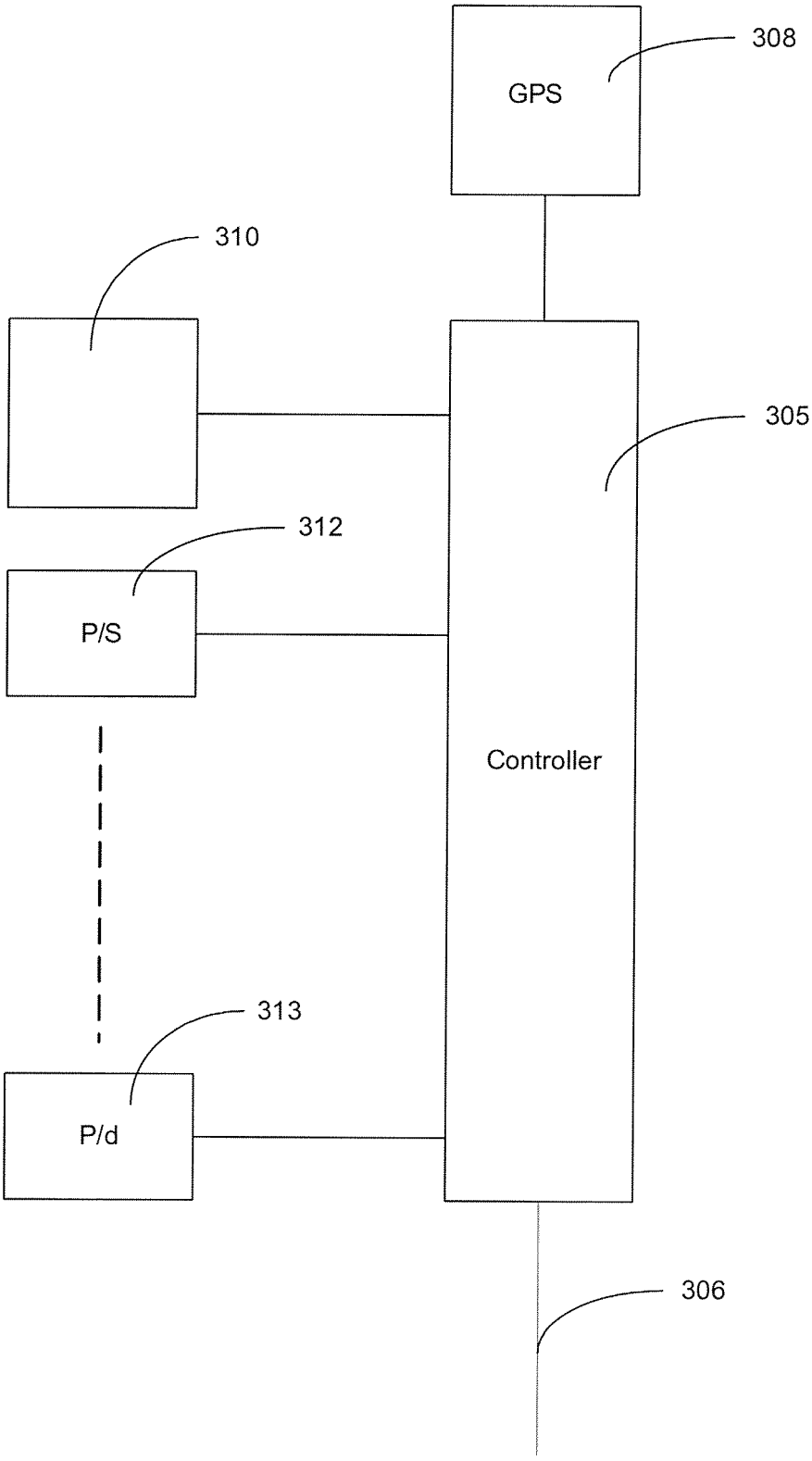


Fig 16

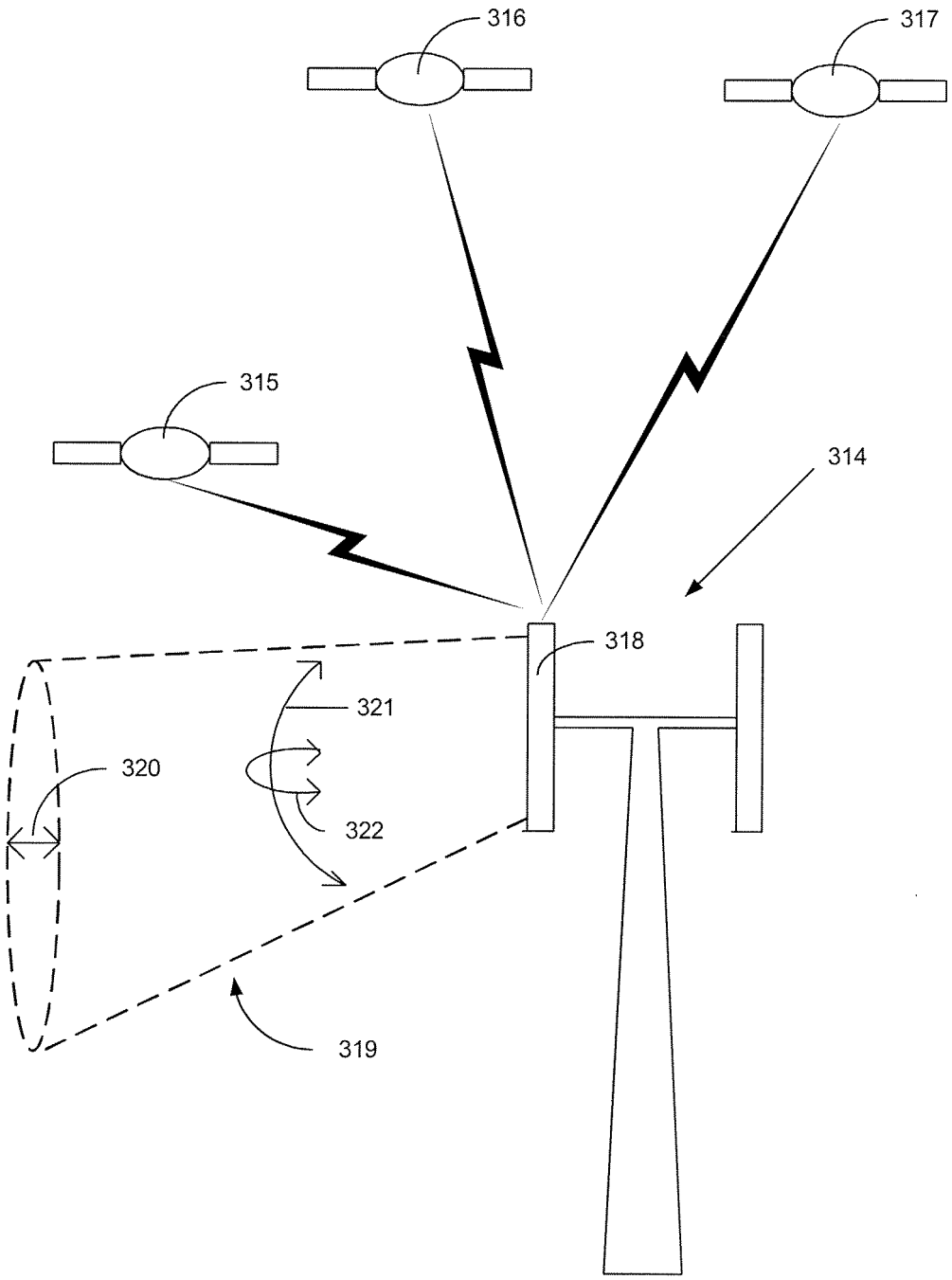


Fig 17

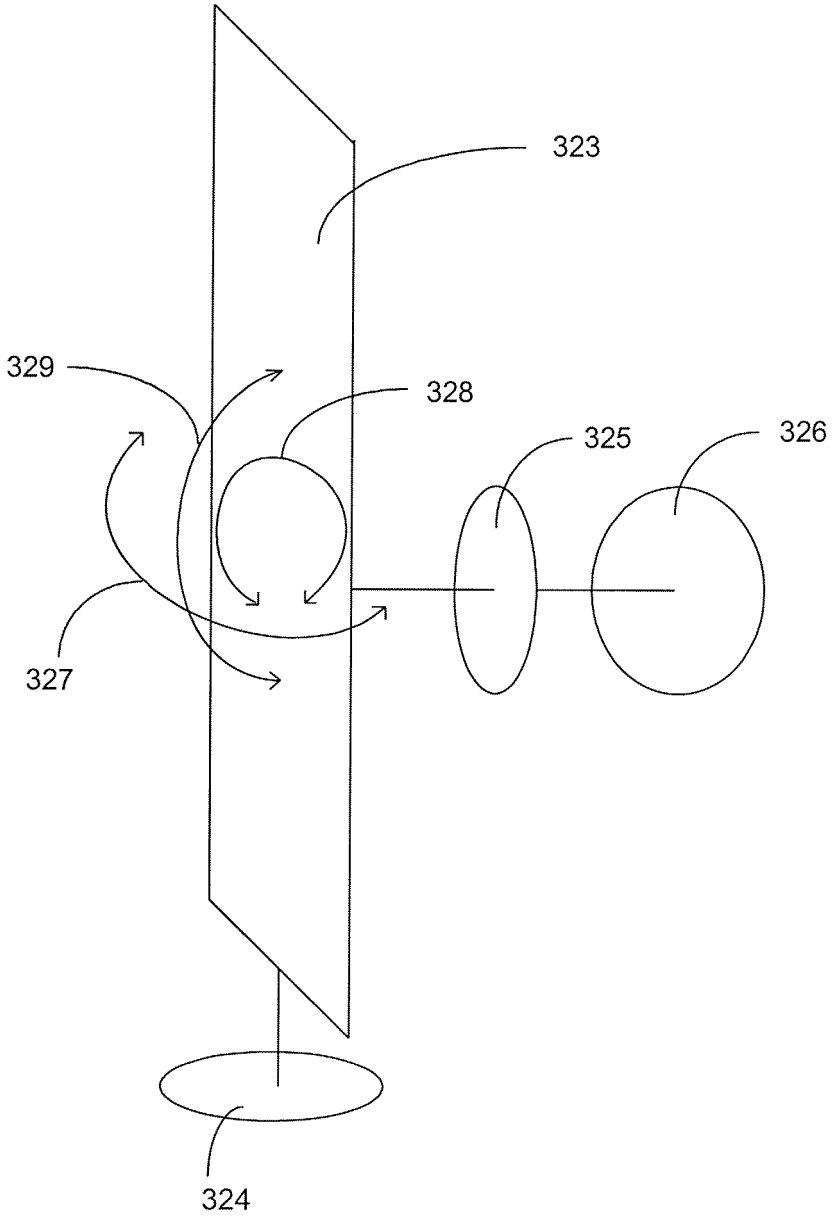


Fig 18

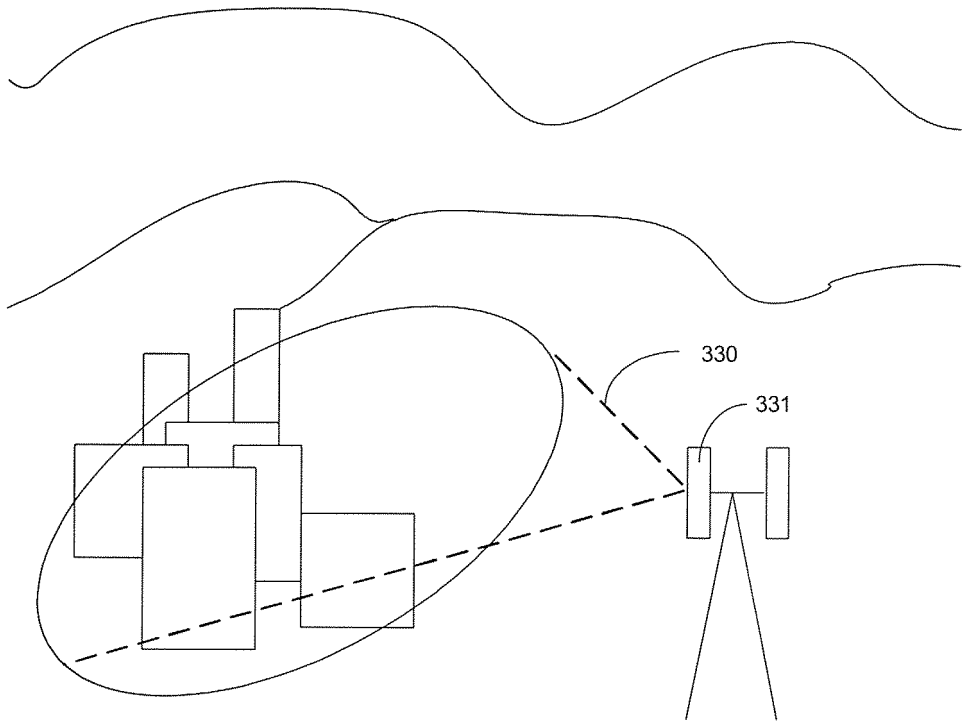


Fig 19

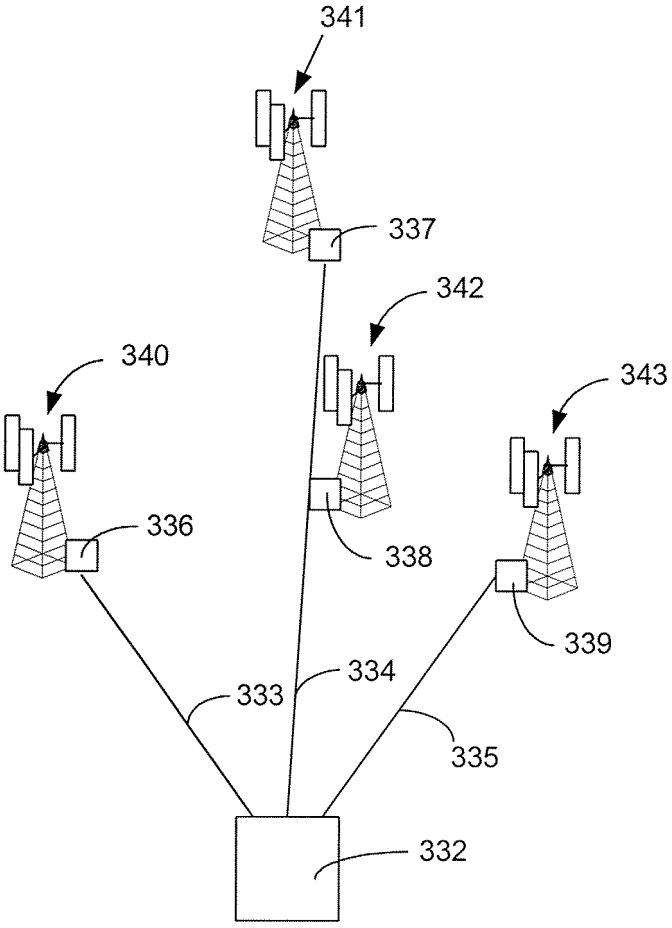


Fig 20