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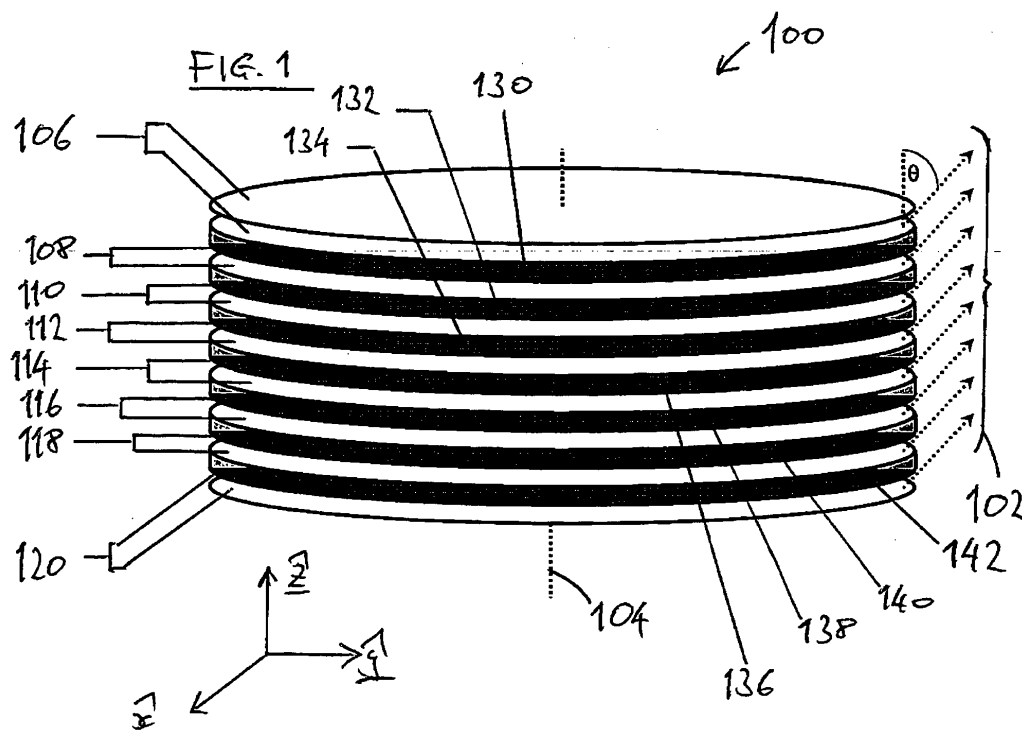
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(54) **Three-dimensional antenna array**

(57) A three-dimensional antenna array (100) comprises a series of pairs (106, 108, 110, 112, 114, 116, 118, 120) of electrically conductive plates, the plates of each pair being connected by a planar array of individual antenna elements forming a two-dimensional sub-group of elements. Radiation emitted by individual antenna elements of a given sub-group is confined to the plane of that sub-group over a confinement area defined by the pairs of plates. The output direction (102) of the array may be controlled by independently controlling the com-

ponents of the direction in the (xy) plane of the sub-groups and normal to the plane. By confining radiation output by any given sub-group of elements to the (xy) plane of that sub-group over a confinement area in that plane, the obstruction of radiation within the array by individual antenna elements, signal feed lines and other components is reduced compared to prior art three-dimensional arrays in which individual antenna elements radiate directly in three dimensions.



Description

[0001] The invention relates to antenna arrays.

[0002] An antenna array is an arrangement of individual antenna elements which allows for radiation transmission in a desired direction (azimuth and elevation), given appropriate phase control of signals applied to the individual antenna elements. Three-dimensional antenna arrays are of interest because potentially they allow for radiation to be transmitted into any one of a large range of directions. An example of a three-dimensional antenna array is described in published patent application DE 2822845, this being an example of a so-called "crow's nest" antenna, in which individual antenna elements are distributed randomly throughout the volume of a sphere in order to minimise production of grating lobes in transmission.

[0003] In practice, the range of output directions achievable using a three-dimensional antenna array is limited because of the requirement to connect signal feed lines to individual antenna elements of the array. The output of a particular element is typically obstructed by signals feed lines to other elements. In the case of a crow's nest antenna, use of a ground plate to fix feed lines presents a significant additional obstruction to output from the array. Further obstruction of the output of individual antenna elements is caused by the presence in operation of other components required for functions such as signal distribution, amplification, power supply, phase control, cooling and mechanical support. Obstruction caused by such components and the signal feed lines also degrades the directionality of the output achievable using such an array.

[0004] The present invention provides a three-dimensional antenna array characterised in that individual antenna elements of the array are arranged in at least two sub-groups, each sub-group comprising a two-dimensional array of individual antenna elements distributed in a respective plane, the planes being substantially mutually parallel, and in that the array further comprises a confining system arranged to confine radiation that may be output by individual antenna elements of any given sub-group substantially to the two dimensions of the plane of that sub-group over a confinement area in that plane, and in that the individual antenna elements of any given sub-group are positioned within the confinement area of that sub-group.

[0005] In an array of the invention, radiation output by any given individual antenna element is not directly radiated into a general direction having three orthogonal components, as in the prior art, but instead the output direction is initially spatially confined to the two dimensions of the plane of the sub-group of elements of which the element is part over a confinement area in that plane. Once the radiation has reached the edge of the confinement area, it may then be directed in a direction having a component normal to the planes of the sub-groups if required. Thus, according to the invention, the emission

of radiation from an element is achieved in two stages: a first stage in which the output direction is confined to two dimensions over a confinement area, and a second stage in which a component of the final output direction, normal to the planes of the sub-groups, is controlled once the radiation is at the edge of the confinement area. For example, the first stage may correspond to controlling the azimuth of the final output beam direction of the array, and the second stage may correspond to controlling its elevation. By initially confining radiation which may be output from a particular element to two dimensions, obstruction of the output of any given element by other elements of the array, and also by signal feed lines to other elements, is reduced compared to prior art three-dimensional arrays in which an individual antenna element can radiate directly in any direction. In an array of the invention, radiation emitted by an individual antenna element can only be obstructed by other elements in the sub-group of which the element forms part, and once the radiation is outside the confinement area of its sub-group it cannot be obstructed by any other element of the array. Radiation is emitted from the array from the edge of the confinement areas.

[0006] In addition to reducing obstruction of one element's output by another element, an array of the invention also allows obstruction by signal feed lines, phase control and power supply components, mechanical support structure, etc to be reduced compared to such obstruction in prior art three-dimensional arrays because such components may be located between the planes of the sub-groups of individual antenna elements.

[0007] The extent to which the planes of the sub-groups of antenna elements are substantially parallel may vary. If the planes are essentially parallel this may simplify construction and operation of an array of the invention. However, adjacent planes may be parallel to within 5° or to within 10°, or to within any angle up to 10°.

[0008] An antenna of the invention provides improved output beam directionality over a greater range of output directions, and with fewer losses, compared to three-dimensional antennas of the prior art.

[0009] Preferably, each confinement area has substantially the same spatial extent in the two dimensions of the planes, and the confinement areas are substantially coincident in the two dimensions of the planes. In other words, the respective confinement areas of the planes coincide in the two dimensions of the planes of the sub-groups, and extend along a third dimension substantially normal to the planes of the sub-groups. This allows independent control of the final output direction of the array in the plane of the sub-groups, and substantially normal to the plane of the sub-groups, allowing for simpler phase-control of the array. The two components of the output direction of the array, parallel and normal to the planes, may thus be controlled substantially independently.

[0010] The confining system is preferably arranged to confine radiation which may be emitted by individual an-

tenna elements of any given sub-group to a substantially circular confinement area in the plane of that sub-group. This allows for simple control of the direction of output of the sub-groups of the antenna in a cylindrical geometry defined by the circular confinement areas.

[0011] Individual antenna elements of any given sub-group are preferably arranged such that a central portion of the confinement area which includes that sub-group is free of individual antenna elements. This allows a common signal feed line, or a group of lines, for a given sub-group to be introduced at the centre of a sub-group, each element in the group being connected to the central portion by a feed line. Such an arrangement reduces obstruction of radiation emitted from one element by other elements in the same sub-group, also reduces obstruction of the output of a sub-group as a whole by signal feed lines passing to elements in the sub-group. Preferably, the centres of each sub-group substantially lie on an axis which passes through the centres of the confinement areas of the planes of individual antenna elements and which is substantially normal to the planes. This arrangement allows a signal feed line, or group of feed lines to be placed along a central axis of the array, for controlling the phase difference within and between sub-groups of individual antenna elements. It may also allow a mechanical support member to be placed along the axis to provide mechanical support for the array.

[0012] In one embodiment, a given sub-group consists of six individual antenna elements, each element being located at a vertex of a regular hexagon having its geometric centre substantially on the axis. With a suitable distance between adjacent elements, the field at the centre of the hexagon may be minimised in operation of the array to a value below that achievable for other arrangements of elements, thus minimising the obstruction of one or more signal feed lines for the sub-group introduced at the centre of the sub-group. Alternatively, any given sub-group may consist of $6N$ individual antenna elements, where $N \geq 2$, each individual antenna element being located at a vertex of one of N concentric hexagons each having its geometric centre substantially on the axis, and wherein each individual antenna element occupies a location on a hexagonal grid such that it has the maximum possible number of nearest-neighbour elements.

[0013] In order to further improve the beam quality achievable from an array of the invention having a hexagonal arrangement of elements, and to reduce losses further, preferably the hexagonal arrangement of elements of the n th sub-group has a rotational offset of $(30^\circ \pm 60^\circ / M) \cdot n$ with respect to that of a first sub-group, the rotational offset of the second and subsequent sub-groups with respect to the first being in the same sense about the axis, where M is the number of sub-groups in the array.

[0014] In embodiments in which sub-groups have a hexagonal arrangement of individual antenna elements, preferably adjacent individual antenna elements of any

given sub-group have a separation such that a radiation null occurs in the centre of that sub-group in operation of the array. This allows one or more signal feed lines for individual elements of a sub-group to be introduced at the centre of the sub-group without obstruction of radiation output by the sub-group when the antenna is operated in transmission.

[0015] The confinement system conveniently comprises a pair of electrically conductive plates connecting the individual antenna elements of a sub-group, each plate lying substantially parallel to and in the plane of the sub-group, and extending over the confinement area of the sub-group. This provides efficient confinement of radiation within the plane of a sub-group of elements by creating parallel-plate line modes during operation of the array. More preferably, the confinement system comprises a plurality of pairs of electrically conductive plates, each pair connecting the individual antenna elements of a respective sub-group and wherein each pair of plates lies substantially parallel to and in the plane of the individual antenna elements of a respective sub-group and extends over the confinement area of that sub-group.

[0016] Adjacent electrically conductive plates of a given pair of adjacent electrically conductive plates may be connected by a shielding layer to enhance radiation confinement and possibly also to provide mechanical rigidity to the array.

[0017] Spaces may be provided within one or more of the shielding layers for accommodating at least one device for performing at least one of phase-control, signal distribution, cooling, signal amplification, power supply and mechanical support.

[0018] A signal generation and phase control system may be integrated within the array, the system being arranged to provide individual antenna elements of any given sub-group with phase-controlled drive signals in use of the array such that constructive interference of radiation occurs for radiation emitted by elements of that sub-group in substantially a single, steerable direction in the plane of that sub-group and/or to provide phase-controlled drive signals to the sub-groups of individual antenna elements in use of the array to effect control of the component of the output direction of the array in a direction normal to the planes of the sub-groups of individual antenna elements.

[0019] Embodiments of the invention are described below, by way of example only, and with reference to the accompanying drawings in which:

- | | | |
|----|----------|---|
| 50 | Figure 1 | shows a perspective view of a three-dimensional antenna array of the invention; |
| | Figure 2 | is a sectional view (yz plane) of the Figure 1 array; |
| 55 | Figure 3 | is a detailed view of a portion of the section of Figure 2; |
| | Figure 4 | is a plan view of a sub-group of individual antenna elements within the |

Figure 1 array;
 Figure 5 is a plan view of the Figure 1 array;
 Figure 6 is another sectional view (xy plane) of the Figure 1 array; and
 Figures 7, 8, 9 are plan views of sub-groups of individual antenna elements within a further embodiments of the invention.

[0020] Referring to Figures 1 and 2, a three-dimensional antenna array of the invention is indicated generally by 100 and referred to a rectangular coordinate system 103. The array 100 comprises eight pairs of electrically conductive, circular discs or plates 106, 108, 110, 112, 114, 116, 118, 120, adjacent discs of adjacent pairs being separated by respective shielding layers 130, 132, 134, 136, 138, 140, 142. The pairs of electrically conductive, circular discs and the shielding layers are substantially parallel and disposed along, and are substantially normal to, a central longitudinal axis 104 such that array 100 has a generally right-cylindrical form.

[0021] A given pair of discs has upper and lower discs; for example pair 106 has an upper disc 106A and a lower disc 106B. Similarly, pairs 108, 118, 120 have upper 108A, 118A, 120A and lower discs 108B, 118B, 120B respectively. The upper 106A and lower 106B discs of pair 106 are connected by six individual antenna elements 107A-F which form a sub-group of individual antenna elements in the xy plane. The other pairs 108, 110, 112, 114, 116, 118, 120 of discs are also each connected by a respective sub-group of six individual antenna elements. The array 100 therefore comprises 48 individual antenna elements arranged in eight planar sub-groups, each having six individual antenna elements. Figure 3 shows an individual antenna element 107A connecting the upper 106A and lower 106B discs of the pair 106.

[0022] A central cylindrical conduit 150 extends along the central longitudinal axis 104 of the array 100 and may be used to accommodate signal feed lines for the individual antenna elements of the array 100 and/or to provide mechanical support for the array 100.

[0023] Figure 4 shows a plan view of the lower disc 106B and the arrangement of the sub-group of individual antenna elements 107A-F on the upper surface of the disc 106A. Each of the elements 107A-F is located at a vertex of a regular hexagon having its centre on the axis 104. The disc 106B has a hole 160 at its centre to accommodate the conduit 150. In practical use of the array 100, signal feed lines extend from the central conduit 150 to each of the individual antenna elements 107A-F. The remaining sub-groups of individual antenna elements are arranged similarly in their respective planes and between respective pairs of discs. The eight sub-groups of individual elements are therefore arranged such the centre of each group lies on the central longitudinal axis 104, the centre of each sub-group being free of individual antenna elements.

[0024] The sub-groups of individual antenna elements have a progressive mutual rotational offset of 22.5°, in

the same sense about the central longitudinal axis 104. Thus, the hexagonal arrangement of the individual antenna elements connecting the pair of discs 118 is offset by 22.5° with respect to the arrangement of elements connecting the pair of discs 120; the hexagonal arrangement of elements connecting the pair of discs 116 is offset with respect to that of pair 120 by 45° in the same sense about the axis 104, and so on. The hexagonal arrangement of elements connecting the pair of discs 106 is thus rotated (i.e. rotationally offset) by 157.5° with respect to that of the elements connecting the pair of discs 120. (Alternatively, the progressive rotational offset between the hexagonal arrangements of adjacent groups may be 37.5°, so that the hexagonal arrangement of elements connecting pairs of discs 118, 116 and 106 are rotated with respect to that of the elements connecting pair 120 by 37.5°, 75° and 262.5° respectively, in the same sense about the central longitudinal axis 104).

[0025] In operation of the array 100, drive signals are provided by signal-generation and phase-control means to each of the 48 individual antenna elements. Radiation emitted by any given sub-group of elements is confined to the xy plane over a circular confinement area which contains the elements and is defined by the circular plates or discs connected by the individual antenna elements of that sub-group. As the general form of the array 100 is that of a right cylinder, and the pairs 106, 108, 110, 112, 114, 116, 118, 120 of plates or discs are substantially parallel and have the same dimensions, the circular confinement areas provided by the plates have substantially the same spatial extent in the xy plane (i.e. they coincide in the xy plane).

[0026] With appropriate phase control of signals supplying the individual antenna elements of the sub-groups, the output direction of the array 100 may be controlled within the xy plane, thus controlling the azimuth of the final output direction (angle $\square$ in Figure 5). Constructive interference of radiation output by the sub-groups of individual antenna elements may take place in substantially a single, steerable direction $\square$ within the xy plane with suitable phase control. Given a suitable choice for the distance between adjacent elements of any given sub-group, a radiation null may be obtained at the centre of each sub-group. This avoids obstruction of radiation by the conduit 150. The direction of radiation output by the array is confined to the xy plane up to the edges of the pairs 106, 108, 110, 112, 114, 116, 118, 120 of plates. On reaching the edges of the circular plates, the output direction of the array may have a component in the z-direction added, given suitable phase-control of feed signals supplying the sub-groups of antenna elements. This allows the elevation of the output direction of the array to be controlled (corresponding to the angle $\square$ in Figure 1).

[0027] The shielding layers 130, 132, 134, 136, 138, 140, 142 may rigidly connected the pairs 106, 108, 110, 112, 114, 116, 118, 120 of plates to provide rigidity to the array 100. Spaces are provided within the shielding lay-

ers to accommodate components for signal amplification, phase-control, and distribution, as well as components for power supply and cooling. In other embodiments, the shielding layers 130, 132, 134, 136, 138, 140, 142 may be substituted by spaces and the conduit 150 may be rigid so that the pairs 106, 108, 110, 112, 114, 116, 118, 120 are supported by the conduit 150.

[0028] Radiation is emitted from the array 100 at the edges of the pairs of plates 106, 108, 110, 112, 114, 116, 118, 120.

[0029] Figure 6 is a sectional view (xy plane) through the shielding layer 130 of the array 100. The shielding layer 130 includes spaces for accommodating phase-control, cooling and amplification devices 105A-F for individual antenna elements 107A-F respectively. Spaces are also provided for accommodating signal feed lines 109A-F, each of which extends from the central conduit 150 to a respective device 105A-F. As the devices 105A-F and feed lines 109A-F are located between the planes of the sub-groups of individual antenna elements associated with pairs of plates 106, 108, they do not obstruct radiation emitted by the individual antenna elements 107A-F during operation of the array 100. The shielding layers 130; 132, 134, 136, 138, 140, 142 shield the devices such as 105A-F and signal feed lines such as 109A-F from radiation emitted by the sub-groups of antenna elements; they may also assist in confining radiation emitted by the sub-groups of individual antenna elements to the respective planes of the sub-groups.

[0030] Figure 7 is a plan view of a lower disc 206B of a pair of discs in a second example array of the invention, and shows the positioning of individual antenna elements in a sub-group of the array. The array is similar in construction to the array 100 of Figure 1, except that each sub-group of individual antenna elements consists of 12 elements, such as 207 and 209, each of which is located at a respective position on a regular hexagonal grid having its centre coincident with the central longitudinal axis 204 of the array. Six elements, such as 207, are each positioned at a respective vertex of regular hexagon having its geometric centre coincident with the axis 204, these vertices being the six closest to the centre of the hexagonal grid. Six further elements, such as 209, each lie at a respective vertex of a second regular hexagon centred on the axis 204, and occupy respective positions on the hexagonal grid such that each element, such as 209, has the maximum possible number of nearest-neighbour antenna elements (i.e. 2).

[0031] Figure 8 shows a plan view of a lower disc 306B of a pair of discs in a third example array of the invention, the array having 18 individual antenna elements in each sub-group. The distribution of elements in the sub-group shown in Figure 8 is similar to the distribution of Figure 7 except that a further 6 individual antenna elements are present, such as 311, each of which lies at a location on a hexagonal grid defined by elements such as 307 and 309, and such that each further element such as 311 has the maximum possible number of nearest-neighbour el-

ements (i.e. 3). Each element such as 311 also lies at a vertex of a regular hexagon having its geometric centre coincident with the central longitudinal axis 304 of the array.

[0032] Figure 9 shows a sub-group of a fourth example array of the invention, the sub-group consisting of 24 individual antenna elements. The distribution of individual antenna elements shown in Figure 9 may be obtained from that shown in Figure 8 by the addition of 6 further elements, such as 413, on a hexagonal grid pattern defined by the 18 elements such as 407, 409 and 411, such that the additional 6 elements, such as 413, each lie at a respective vertex of a regular hexagon and such that they each have the maximum number of nearest-neighbour elements (i.e. 2 in this case).

[0033] A hexagonal sub-group of 30 or 36 elements may be obtained by adding 6 or 12 further elements to the distribution shown in Figure 9, at positions such as 417 or 415, 417 respectively. Further distributions may be obtained by adding further sets of 6 additional elements such that each additional element lies at a location on the hexagonal grid, and at a respective vertex of a regular hexagon, and such that each addition element has the maximum possible number of nearest neighbour elements.

[0034] In other embodiments of the invention, each sub-group may consist of one or more hexagonal arrangements of individual antenna elements as described above, without a progressive rotational offset between the sub-groups.

[0035] In further embodiments, the arrangement of the sub-groups of individual antenna elements may be other than hexagonal. A given sub-group may have a circular arrangement of elements, or a rectangular array or some other distribution pattern. In still further embodiments, the arrangements of elements may differ between sub-groups of the same array.

[0036] In other embodiments of the invention there may be more or less than eight sub-groups of individual antenna elements, although there must be at least two-planar sub-groups. The number of sub-groups may be varied to vary the beamwidth in elevation in which may be achieved using the array 100.

[0037] The array 100 of Figures 1-6 may be an X-band array operating at 10 GHz, with a diameter of 400mm and an inter-element separation of 180mm within each sub-group of elements. In this case the separation of sub-groups in the z-direction may be 15mm.

Claims

1. A three-dimensional antenna array (100) **characterised in that** individual antenna elements of the array are arranged in at least two sub-groups, each sub-group comprising a two-dimensional array of individual antenna elements (107; 207, 209; 307, 309, 311; 407, 409, 411, 413) distributed in a respective plane,

- the planes being substantially mutually parallel, and **in that** the array further comprises a confining system (106, 108, 110, 112, 114, 116, 118, 120) arranged to confine radiation that may be output by individual antenna elements of any given sub-group substantially to the two dimensions of the plane of that sub-group over a confinement area **in that** plane, and **in that** the individual antenna elements of any given sub-group are positioned within the confinement area of that sub-group.
2. An array according to claim 1 wherein each confinement area has substantially the same spatial extent in the two dimensions of the planes, and wherein the confinement areas are substantially coincident in the two dimensions of the planes.
 3. An array according to claim 2 wherein the confining system is arranged to confine radiation which may be emitted by individual antenna elements of any given sub-group to a substantially circular confinement area in the plane of that sub-group.
 4. An array according to claim 3 wherein the individual antenna elements of any given sub-group are arranged such that a central portion of the confinement area which includes that sub-group is free of individual antenna elements.
 5. An array according to claim 4 wherein the centres of each sub-group substantially lie on an axis (104; 204; 304; 404) which passes through the centres of the confinement areas of the planes of individual antenna elements and which is substantially normal to the planes.
 6. An array according to claim 5 wherein a given sub-group consists of six individual antenna elements (107A-F), each element being located at a vertex of a regular hexagon having its geometric centre substantially on said axis.
 7. An array according to claim 5 wherein any given sub-group consists of $6N$ individual antenna elements (207, 209; 307, 309, 311; 407, 409, 411, 413), where $N \geq 2$, and wherein each individual antenna element is located at a vertex of one of N concentric hexagons each having its geometric centre substantially on said axis, and wherein each individual antenna element occupies a location on a hexagonal grid such that it has the maximum possible number of nearest-neighbour elements.
 8. An array according to claim 6 or claim 7 wherein the hexagonal arrangement of elements of the n th sub-group has a rotational offset of $(30^\circ \pm 60^\circ / M) \cdot n$ with respect to that of a first sub-group, the rotational offset of the second and subsequent sub-groups with respect to the first being in the same sense about the axis, where M is the number of sub-groups in the array.
 9. An array according to any of claims 6 to 8 wherein adjacent individual antenna elements of any given sub-group have a separation such that a radiation null occurs in the centre of that sub-group in operation of the array.
 10. An array according to any preceding claim wherein the confinement system comprises a pair of electrically conductive plates (106A, 106B) connecting the individual antenna elements of a sub-group, each plate lying substantially parallel to and in the plane of the sub-group, and extending over the confinement area of the sub-group.
 11. An array according to any of claims 1 to 9 wherein the confinement system comprises a plurality of pairs (106, 108, 110, 112, 114, 116, 118, 120) of electrically conductive plates, each pair connecting the individual antenna elements of a respective sub-group and wherein each pair of plates lies substantially parallel to and in the plane of the individual antenna elements of a respective sub-group and extends over the confinement area of that sub-group.
 12. An array according to claim 11 wherein adjacent electrically conductive plates of a given pair of adjacent electrically conductive plates are connected by a shielding layer (130, 132, 134, 136, 138, 140, 142).
 13. An array according to claim 12 wherein spaces are provided within one or more shielding layers for accommodating at least one device (105A-F, 109A-F) for performing at least one of phase-control, signal distribution, cooling, signal amplification, power supply and mechanical support.
 14. An array according to any preceding claim further comprising a signal generation and phase-control system arranged to provide individual antenna elements of any given sub-group with phase-controlled drive signals in use of the array such that constructive interference of radiation occurs for radiation emitted by elements of that sub-group in substantially a single, steerable direction in the plane of that sub-group.
 15. An array according to any preceding claim further comprising a signal generation and phase-control system arranged to supply phase-controlled drive signals to the sub-groups of individual antenna elements in use of the array to provide control of the component of the output direction of the array in a direction normal to the planes of the sub-groups of individual antenna elements.

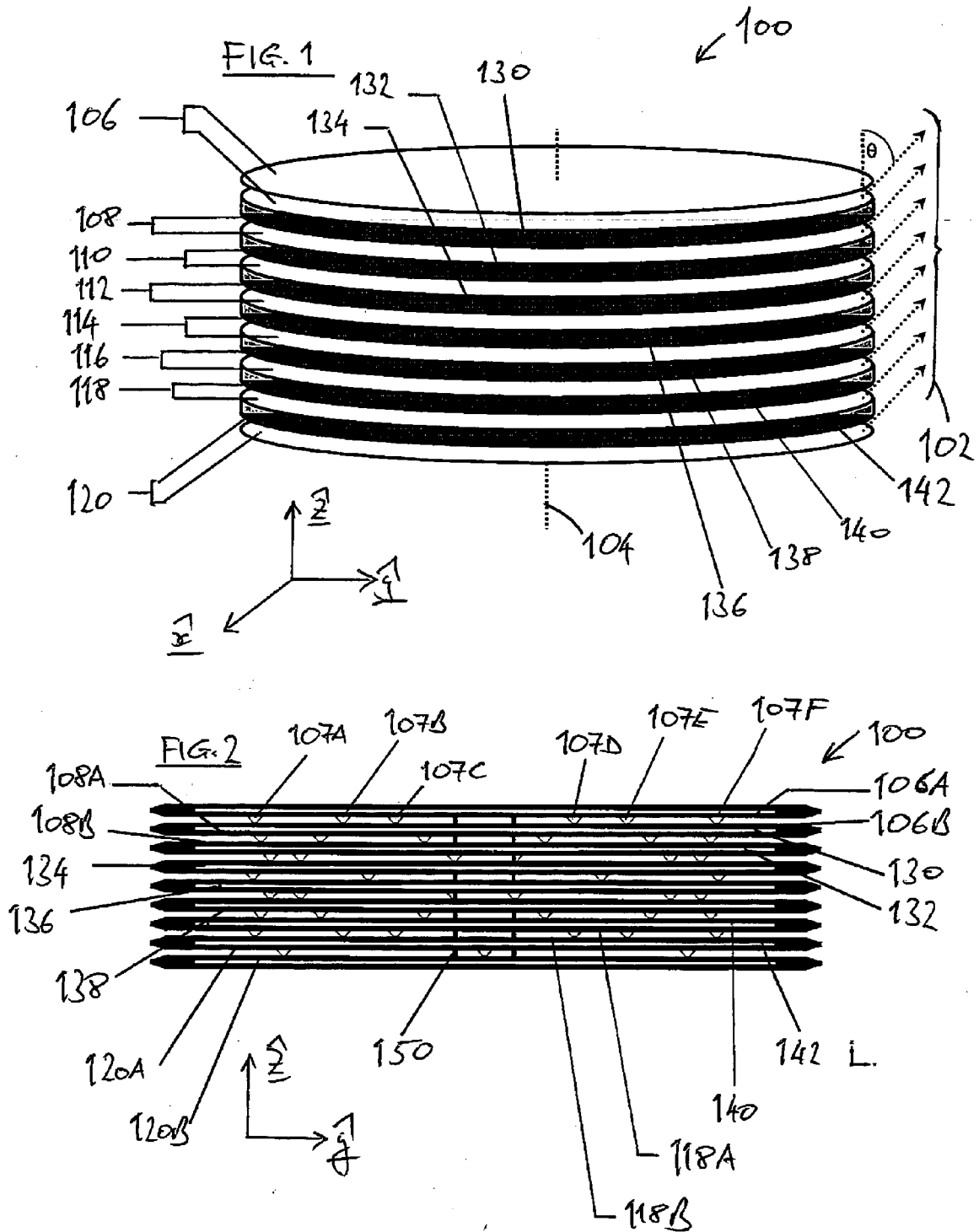


FIG. 3

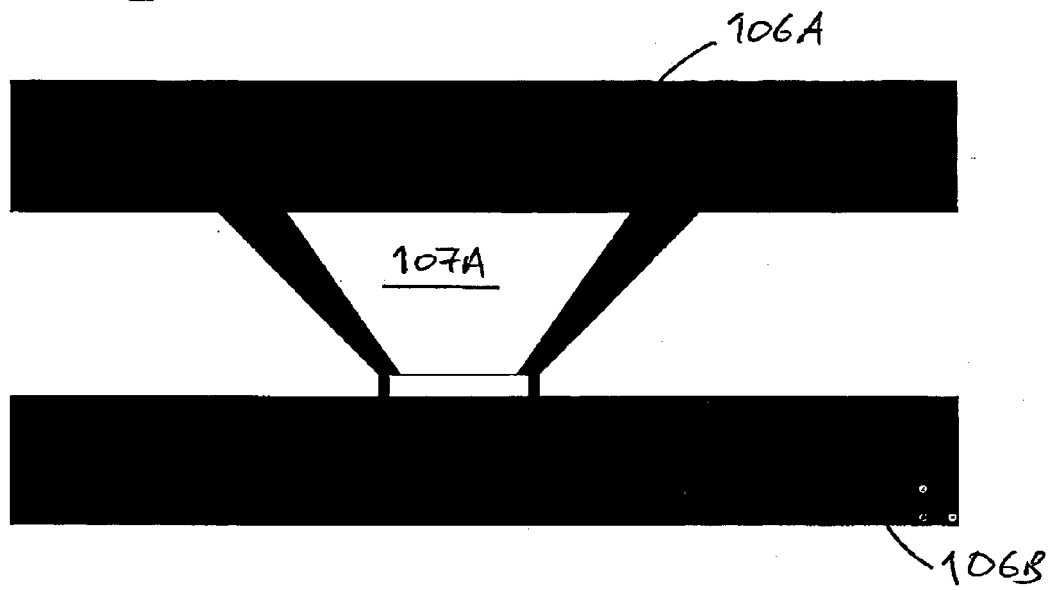


FIG. 5

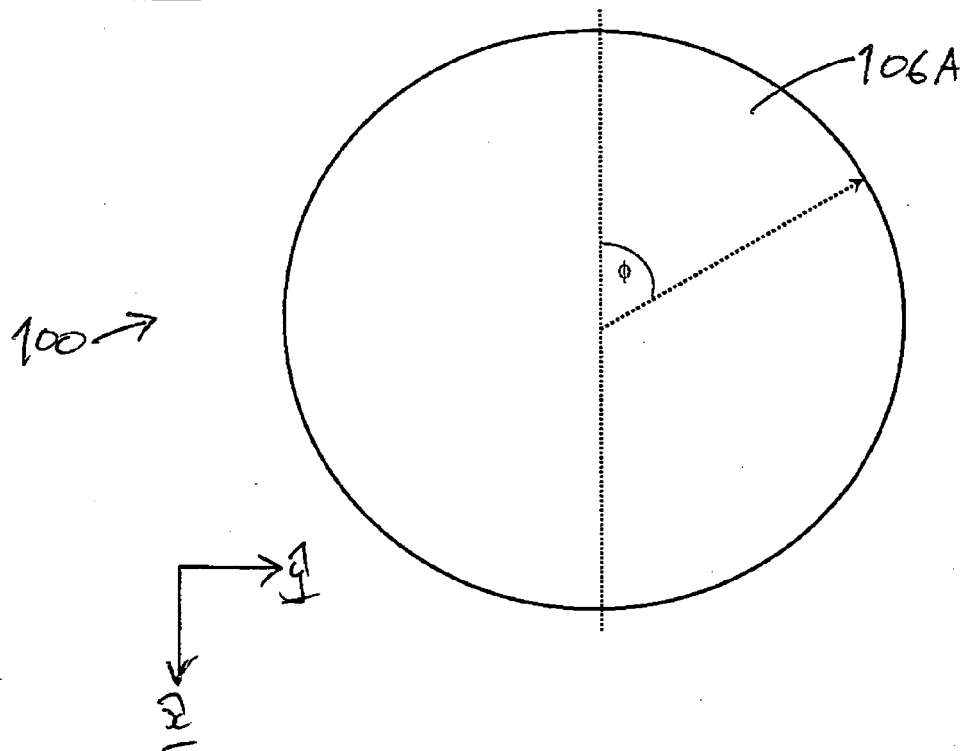


FIG. 4

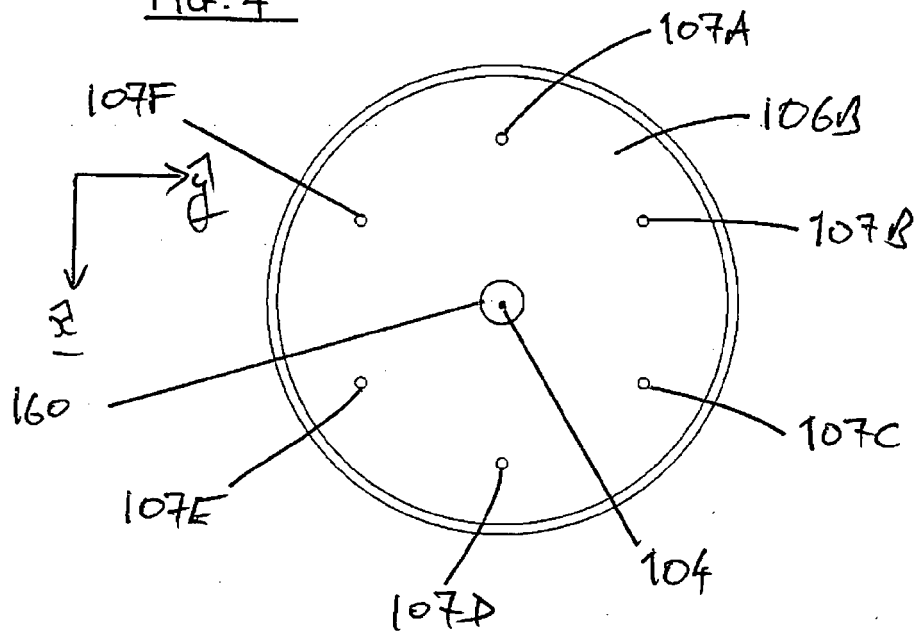


FIG. 6

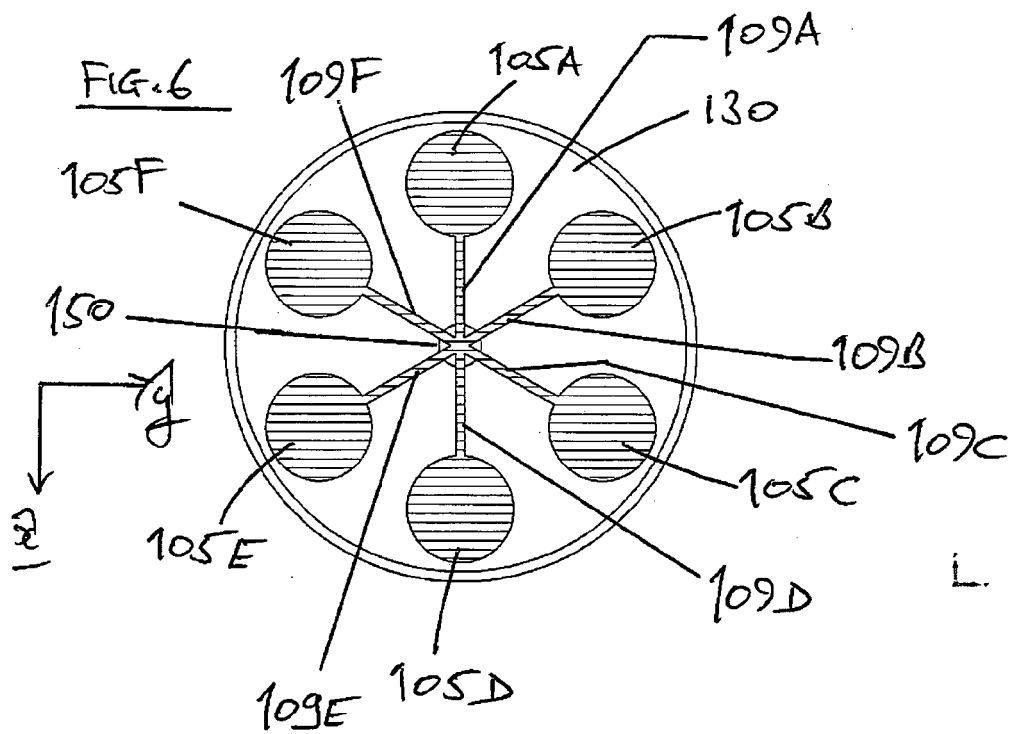


FIG. 7

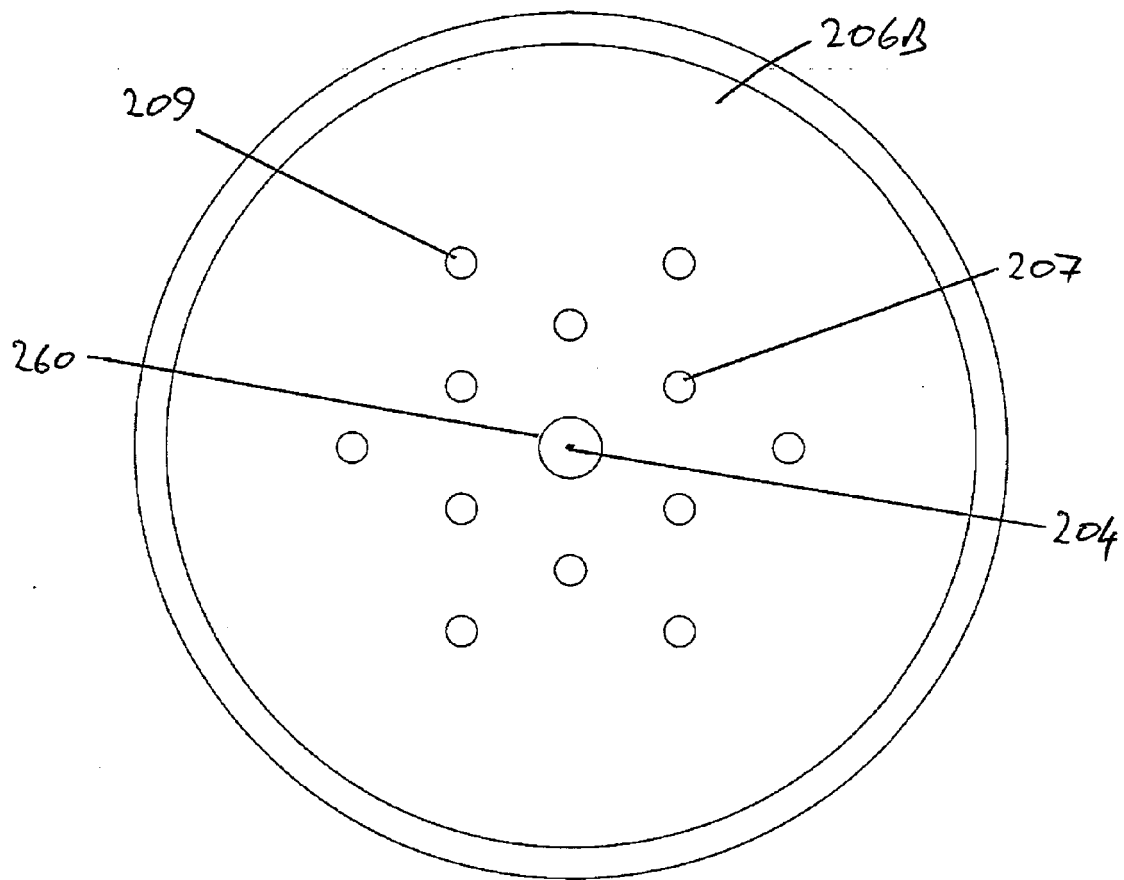
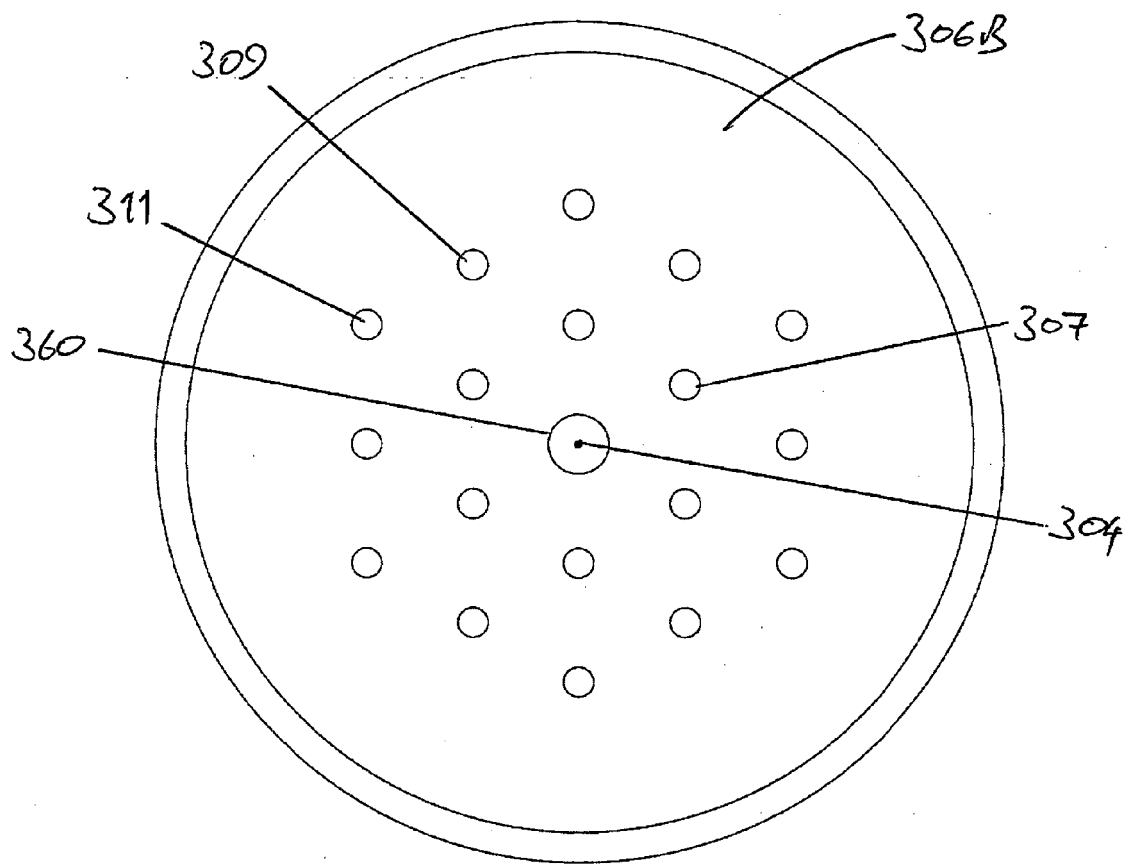
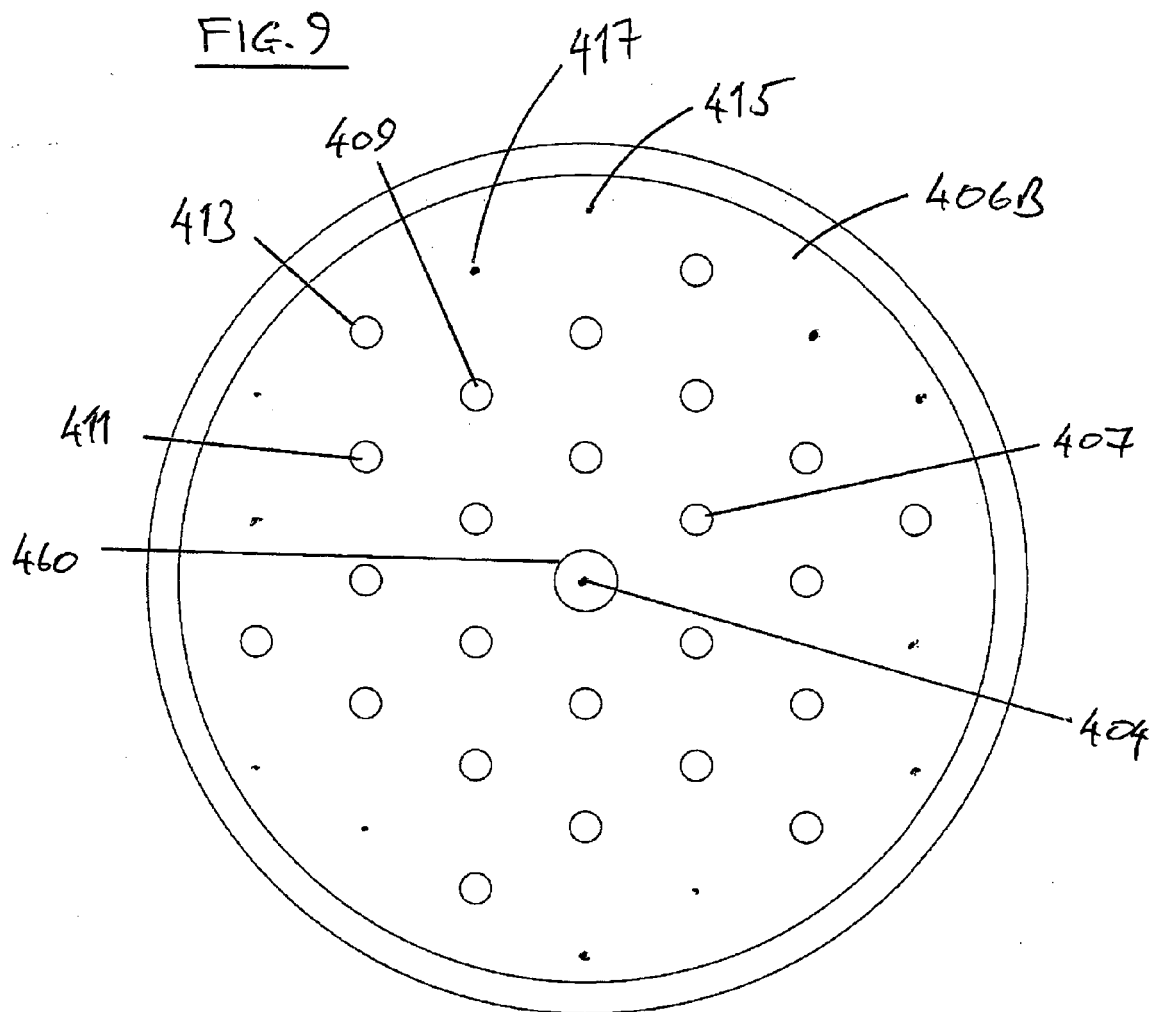


FIG. 8







EUROPEAN SEARCH REPORT

Application Number
EP 13 00 4182

DOCUMENTS CONSIDERED TO BE RELEVANT			
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Place of search The Hague		Date of completion of the search 23 January 2014	Examiner Hueso González, J
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 13 00 4182

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