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(71) Applicants:
- **CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE 75794 Paris Cedex 16 (FR)**
- **Université De Nice Sophia Antipolis 06130 Nice Cedex 2 (FR)**

(72) Inventors:
- **FERRERO, Fabien 06160 Antibes (FR)**
- **LIZZI, Leonardo 06100 Nice (FR)**
- **TRINH, Le Huy 06000 Nice (FR)**
- **RIBERO, Jean-Marc 06100 Nice (FR)**

(74) Representative: **Hautier, Nicolas Cabinet Hautier 20, rue de la Liberté 06000 Nice (FR)**

(54) AN ANTENNA APPARATUS HAVING A SELECTIVELY ORIENTABLE DIRECTIVITY

(57) The invention concerns an antenna apparatus having a selectively orientable directivity comprising a first face (101) and a second face (102). The first face (101) comprises at least a first radiating element (200) and a first set of at least three parasitic elements (301, 302, 303), the second face (102) comprises at least a second radiating element (250) and a second set of at least three parasitic elements (351, 352, 353), the apparatus being configured to selectively activate at least some of the parasitic elements (301, 302, 303, 351, 352, 353). The apparatus comprises at least a first electrically-conductive wire (400) and a feed point (500) connected to the electrically-conductive wire (400), the first (200) and second (250) radiating elements being connected together by said electrically-conductive wire (400), said electrically-conductive wire (400) and feed point (500) feeding the first (200) and second (250) radiating elements according to a differential mode.

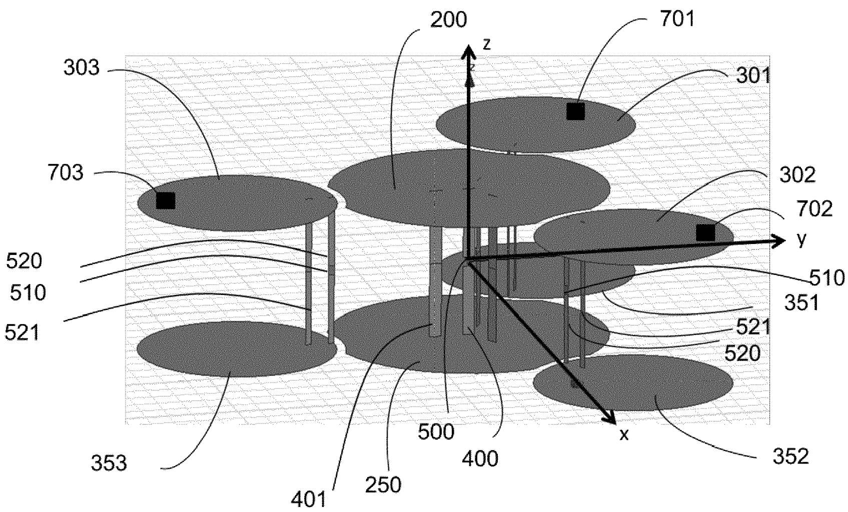

FIG. 2

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to the field of antennas and more specifically to a reconfigurable antenna apparatus for use in a wireless communication system.

BACKGROUND OF THE INVENTION

[0002] The use of a reconfigurable (or a variable directivity) antenna apparatus in communication systems can bring many benefits such as: minimizing interference, reducing the number of network devices, increasing the scope and speed of communication, and improving the coverage of the affected area. However, integration is not straightforward and presents technological challenges that must be resolved.

[0003] Variable directivity antennas that currently exist are based on three different solutions.

[0004] A first solution consists in providing a network of phased radiating elements. The networks of phased radiating elements have a high consumption because of the phase shifters used to control the radiation pattern. In addition, the full coverage of the azimuth plane is often impossible.

[0005] A second solution is based on the use of switched directive antennas having a structure comprising directional elements. These antennas have a very large size. In addition, these antennas do not radiate with an omnidirectional pattern.

[0006] A third type of solution relates to antennas comprising parasitic elements. These antennas often provide tilted diagrams (tilt of the radiation pattern in elevation). In general these antenna apparatuses have a significant thickness.

[0007] It is an object of the present invention to provide a variable directivity antenna apparatus in the azimuthal plane capable of solving at least partially some of the above described problems, and capable of reducing the size thereof.

SUMMARY OF INVENTION

[0008] The present invention concerns an antenna apparatus having a selectively orientable directivity in an azimuth plane (x0y) and comprising a first face and a second face extending in planes parallel to the azimuth plane (x0y) and being arranged one facing the other.

[0009] The first face comprises at least a first radiating element and a first set of at least three parasitic elements surrounding the first radiating element.

[0010] The second face comprises at least a second radiating element and a second set of at least three parasitic elements surrounding the second radiating element.

The apparatus also comprising at least a first electrically-conductive wire and a feed point connected to the electrically-conductive wire, the first and second radiating elements being connected together by the electrically-conductive wire, said electrically-conductive wire and feed point feeding the first and second radiating elements according to a differential mode.

The apparatus is configured to selectively activate at least some of the parasitic elements.

[0011] The proposed solution comprises two symmetrical sets comprising each one a radiating element surrounded by several parasitic elements selectively actionable. Through the use of wire-plate type elements as radiating elements in combination with a differential mode for feeding the radiating elements, this structure is able to control a directional radiation pattern in the azimuth plane without or with a very limited tilt, while keeping a very thin structure.

In addition, the radiating element can provide a perfectly omnidirectional pattern in the azimuthal plane thanks to a central feed when the parasitic elements are not activated.

[0012] The proposed solution has several characteristics that make it an excellent candidate for integration in sensor networks. Indeed, the structure of the compact antenna and the small thickness make it suitable for embedded solutions currently used.

[0013] In addition, control of the reconfiguration of the antenna through variable capacitors requires low energy that allows targeting low-power applications using autonomous nodes.

[0014] For instance, the invention has turned out to be particularly efficient in a network of communicating nodes such as a network of communicating sensors spread in a two dimensions, where the nodes must be individually targeted by the radiation emitted by the antenna apparatus. Through selectively modifying the orientation of the radiation, each node can be targeted.

[0015] The invention is also very advantageous for applications where the antenna apparatus is embedded in a mobile device such as a drone. The drone can for instance selectively orientate the radiation of its antenna apparatus toward a ground control station, enabling thereby a more efficient communication since the power of the transmitted signal is focused on relevant the ground control stations. More data, for instance video, can thus be transmitted by the drone. In addition the transmission distance can be increased without increasing the power consumption or the weight of the drone.

[0016] The small size and weight of the antenna apparatus is particularly advantageous for such applications.

[0017] The differential structure used in the present invention provides a perfectly symmetrical radiation pattern and a pattern not inclined with regard to the azimuth plane, a better compactness since the size is just limited by the radiating elements, and greater robustness to environmental influences. The differential mode used for the antenna radiation makes it independent from any ground plane effect due to the supporting structure. The selective activation of the parasitic elements is performed by reconfigurable capacitors with different states, which provides an additional adjustment possibility for extending the covered frequency bands.

[0018] Therefore, the invention provides an efficient solution that allows a further reduction of the overall space occupied by an antenna without limiting its electrical and communication performances.

[0019] Optionally, the invention may further have at least any one of the following steps and characteristics which may be taken into account separately or in combination.

[0020] Advantageously, the first and second radiating elements are connected together by three electrically conductive wires.

[0021] According to an embodiment, each radiating element is a wire-plate antenna. According to an embodiment, each radiating element comprises a conductive plate and an electrically conductive wire connected to the plate and connected to a differential radiofrequency port. According to an embodiment, each radiating element comprises only the conductive plate and at least one electrically conductive wire connected to the plate and connected to a differential radiofrequency port.

[0022] According to an embodiment, the feed point is located on the first electrically-conductive wire preferably at mid-distance between said first radiating element and said second radiating element.

[0023] According to an embodiment, said first electrically-conductive wire extends perpendicularly to the first and second faces. Thus, the electrically-conductive wires extend perpendicularly to the planes of the first and second faces.

[0024] According to an embodiment, each parasitic elements of the first set is respectively connected to one of the parasitic element of the second set by a second electrically-conductive wire, each parasitic elements of the first set forming thereby with a parasitic element of the second set a pair of parasitic elements; said second electrically-conductive wire connecting the parasitic element of the first and second sets conducting a differential mode.

[0025] According to an embodiment, the first radiating element is respectively connected to the second radiating element by said first electrically-conductive wire and also by an additional electrically-conductive wire. According to an embodiment, each parasitic elements of the first set is respectively connected to one of the parasitic elements of the second set by said second electrically-conductive wire and also by an additional electrically-conductive wire.

[0026] According to an embodiment, the first face and the second face are symmetrical with respect to a geometrical plane parallel to the azimuth plane (x0y) and passing through said first electrically-conductive wire. In particular the pattern defined by the first radiating element and the parasitic elements of the first set and the pattern defined by the second radiating element and the parasitic elements of the second set are symmetrical with respect to a geometrical plane parallel to the azimuth plane (x0y) and passing through the electrically-conductive wire.

[0027] According to an embodiment, the first radiating element and the second radiating element form a differential wire-plate antenna.

[0028] According to an embodiment, the first set of parasitic elements comprises three parasitic elements surrounding the first radiating element and disposed at 120° around the first radiating element.

[0029] According to an embodiment, each one of the first and second faces is configured, in particular the distance between the radiating element and the parasitic elements, so that the first and second radiating elements are electromagnetically coupled to the parasitic elements of the first and second sets respectively.

[0030] According to an embodiment, the distance between the center of first radiating element and the center of each of the parasitic elements of the first set is comprised between 0.15 and 0.3 freespace wavelength λ_0 so that the first radiating element is electromagnetically coupled to the parasitic elements of the first set.

[0031] According to an embodiment, the apparatus comprises variable capacitors connected to each of the parasitic elements of the first and second sets, each variable capacitor is selectively actionable to modify the electromagnetic coupling between each of the parasitic elements and the radiating element to which it is electromagnetically coupled so that the radiation pattern of the antenna apparatus in the azimuth plane (x0y) is modified.

[0032] According to an embodiment, each parasitic elements of the first set forms with a parasitic element of the second set a pair of parasitic elements, the apparatus comprising variable capacitors to simultaneously or independently select each pair of parasitic elements.

[0033] According to an embodiment, the distance between the first and the second faces is set to a distance inferior to sixty millimeters or $\lambda_0/2$ and preferably inferior to 30 millimeters or $\lambda_0/4$, and preferably inferior to 20 millimeters or $\lambda_0/6$, and preferably inferior to ten millimeters or $\lambda_0/12$.

[0034] According to an embodiment, the first and second faces are configured and fed in a differential mode so that the apparatus radiates as an electrical dipole.

[0035] The first and second radiating elements and the wires connected to them form a differential structure.

[0036] According to an embodiment, the first face comprises a first planar supporting member configured to support the first radiating element and the first set of parasitic elements. The second face comprises a second planar supporting member configured to support the second radiating element and the second set of parasitic elements.

[0037] According to an embodiment, the apparatus comprises at least a transversal supporting member extending from the first face to the second face.

[0038] According to an embodiment, the apparatus includes a set of one or more layer(s) between the first and second faces, the set of one or more layer(s) extending from the first face to the second face and being preferably made of a dielectric material. According to an embodiment, each of the radiating elements and each of the parasitic elements comprise a radiating plate.

BRIEF DESCRIPTION OF DRAWINGS

[0039] Further objects, features and advantages of the present invention will become apparent to the ones skilled in the art upon examination of the following description in reference to the accompanying drawings. It is intended that any additional advantages be incorporated herein.

FIGURE 1A and 1B are perspective views of the antenna apparatus according to a non limitative example of the present invention, figure 1B showing the lines of the hidden details.
FIGURE 2 is another perspective view of the antenna apparatus of FIG.1.
FIGURE 3 illustrates a three dimensions radiation pattern obtained with the antenna apparatus of the present invention.
FIGURE 4 is a diagram of radiation pattern characteristics, showing simulation results of the antenna apparatus according to the state (directive/reflective) of the parasitic elements.
FIGURE 5 is a diagram of radiation pattern characteristics, showing additional simulation results of the variable directivity antenna apparatus according to the state (directive/reflective) of the parasitic elements.
FIGURE 6 is a graph showing reflection coefficients (S11 in dB) for different configurations of the radiating pattern.

[0040] The drawings appended herein are given as examples and are not limiting to the invention. These are schematic drawings intended to facilitate the understanding of the invention and are not necessarily at the same scale of the practical applications.

DETAILED DESCRIPTION

[0041] The following detailed description of the invention refers to the accompanying drawings. While the description includes exemplary embodiments, other embodiments are possible, and changes may be made to the embodiments described without departing from the spirit and scope of the invention.

[0042] **Figures 1A, 1B and 2** depict perspective views of the variable directivity antenna apparatus according to the present invention. **Figure 2** depicts the antenna apparatus of FIG.1A and FIG.1B without representing the support member for sake of clarity.

[0043] The antenna apparatus comprises a first face 101 and a second face 102. Advantageously, the first and second faces 101, 102 are arranged one facing the other and in parallel.

[0044] According to a preferred embodiment, the first and second faces 101, 102 are comprised in a plane parallel to the azimuth plane (x0y). The plane x0y is illustrated in figures 1A and 1 B.

[0045] An azimuth is an angular measurement in a spherical coordinate system. The vector from an observer (origin) to a point of interest is projected perpendicularly onto a reference plane; the angle between the projected vector and a reference vector on the reference plane is called the azimuth. In mathematics the azimuth angle of a point in cylindrical coordinates or spherical coordinates is the anticlockwise angle between the positive x-axis and the projection of the vector onto the xy-plane (or x0y plane). The angle is the same as an angle in polar coordinates of the component of the vector in the xy-plane.

[0046] At least one first radiating element 200 and a first set of at least three parasitic elements 301, 302, 303 are provided on the first face 101 of the antenna apparatus. The radiating element 200 comprises a radiating plate and at least a wire to weed the plate with a current. The at least one radiating element 200 is located in the same plane and is surrounded by the at least three parasitic elements 301, 302, 303. The radiating element 200 of the first face 101 is electromagnetically coupled to the parasitic elements 301, 302, 303 of the first set.

[0047] At least, one among the at least first radiating element 200 and the at least three parasitic elements 301, 302, 303 is a wire-plate antenna.

[0048] Preferably, all of the at least first radiating element 200, the at least three parasitic elements 301, 302, 303 are connected such as wire-plate antenna. A wire-plate antenna typically comprises and preferably consists of a metal plate (e.g capacitive top part of the antenna) having arbitrary shape, of a dielectric layer bearing this plate on its upper face and of a ground plane produced by lower metallization of the dielectric layer. The feed for such wire-plate antenna is typically realized by a coaxial line which passes through the ground plane, an inner conductor of which is connected to the ground plane. The particular aspect of such an antenna is that of having a wire connecting the capacitive top part and the ground plane, forming an active metal return to ground. The return-to-ground wire gives rise to a parallel resonance at a frequency less than that of fundamental frequency of a patch.

[0049] Advantageously, the present invention does not require a ground plane contrary to a typical wire-plate antenna. Instead of connecting the metal plate (for instance the first radiating element 200 or the parasitic elements 301, 302, 303) to the ground plane, the present invention replaces the ground plane by another metal plate (for instance another radiating element 250) in order to form a pair of radiating elements connected together by means of a wire; this pair of radiating elements forming a differential antenna.

In radio and telecommunications, a differential antenna consists of two identical conductive elements such as metal wires or rods, which are usually bilaterally symmetrical. The driving current from the transmitter is applied, or for receiving antennas the output signal to the receiver is taken, between the two halves of the antenna. Each side of the feedline to the transmitter or receiver is connected to one of the conductors. This contrasts with a monopole antenna, which consists of a single rod or conductor with one side of the feedline connected to it, and the other side connected to some type of ground. According to an advantageous embodiment, the form of dipole is two straight rods or wires oriented end to end on the same axis, with the feedline connected to the two adjacent ends. Dipoles are resonant antennas, meaning that the elements serve as resonators, with standing waves of radio current flowing back and forth between their ends. So the length of the dipole elements is determined by the wavelength of the radio waves used. The most common form is the half-wave dipole, in which each of the two rod elements is approximately 1/4 wavelength long, so the whole antenna is a half-wavelength long. The radiation pattern of a vertical dipole is omnidirectional; it radiates equal power in all azimuthal directions perpendicular to the axis of the antenna. A dipole antenna presents a balanced input (both terminals have an equal but opposite voltage with respect to ground).

[0050] In order to replace the ground plane, the antenna apparatus according to the present invention comprises, on the second face 102, at least a second radiating element 250 and at least three complementary parasitic elements 351, 352, 353 forming thereby a second set of parasitic elements. The patterns/designs of the first face 101 and of the second face 102 are symmetrical with respect to a geometrical plane passing through a first electrically-conductive wire 400 and located at mid-distance between the two planes containing the first 101 and second 102 faces.

[0051] According to a preferred embodiment, the first radiating element 200 located on the first face 101 and the second radiating element 250 located on the second face 102 are arranged as a pair of radiating elements, forming a dipole. Advantageously, the second radiating element 250 is connected to the radiating element 200 located on the first face 101. The connection is operated by means of said first electrically-conductive wire 400. The apparatus comprises at least a first electrically-conductive wire 400 connected to a feed point 500, the first and second radiating elements 200, 250 being connected together by the first electrically-conductive wire 400. Said first electrically-conductive wire 400 and feed point 500 feed the first and second radiating elements 200, 250 according to a differential mode, meaning that if the first radiating element 200 is fed with a voltage $+V_0$, and the second radiating element 250 has to be fed with $-V_0$. If the first and second radiating elements 200, 250 are connected to a coaxial cable, a balun has to be used between said cable and the radiating antenna element input. A balun is an electrical device that converts between a balanced signal (two signals working against each other where ground is irrelevant) and an unbalanced signal (a single signal working against ground or pseudo-ground). A balun can take many forms and may include devices that also transform impedances but need not do so. Transformer baluns can also be used to connect lines of differing impedance.

In a differential mode, transmission lines are designed and configured with a certain characteristic impedance value. This impedance is established by the ratio of distributed inductance and capacitance in the transmission line. This impedance, if applied as a resistance across the line at the far end, would make voltage and current uniform along the line (except for the small normal power loss with distance). Because this impedance relates directly to opposite flowing currents in each conductor, it is called the differential mode. It deals with the "across" or between conductors characteristics. A conventional two-conductor transmission line, even if one conductor is called the "shield," must have exactly equal and opposite flowing currents into each conductor at each end. Without equal and opposite (differential mode) currents flowing at every point in a transmission line, it will radiate and receive signals. A transmission line with purely differential mode operation would never radiate unwanted energy. It also would not respond to outside radiation or signals.

[0052] According to a preferred embodiment, each parasitic element 301, 302, 303 located on the first face 101 and each complementary parasitic element 351, 352, 353 located on the second face 102 are arranged as a pair of parasitic elements 301, 302, 303, 351, 352, 353, forming dipoles. Each parasitic element 301, 302, 303 located on the first face 101 and each complementary parasitic element 351, 352, 353 located on the second face 102 are connected by means of first and second electrically-conductive wires 520, 521. The first electrically-conductive wires 520 are connected to a variable capacitor to change the behavior of the parasitic elements 301, 302, 303 (reflective or directive). The second electrically-conductive wires 521 electrically connect the parasitic elements 301, 302, 303 to the complementary parasitic elements 351, 352, 353 and are used to reduce the antenna thickness.

[0053] Each parasitic elements 301, 302, 303 of the first set is respectively connected to one of the parasitic elements 351, 352, 353 of the second set by the second electrically-conductive wire 520. Each parasitic element 301, 302, 303 of the first set forms thereby with a parasitic element 351, 352, 353 of the second set a pair of parasitic elements 301, 302, 303, 351, 352, 353. Said second electrically-conductive wire 520 connecting the parasitic elements 301, 302, 303, 351, 352, 353 of the first and second sets conducts a differential mode.

[0054] Each parasitic element 301, 302, 303 of the first set is respectively connected to one of the parasitic elements 351, 352, 353 of the second set by said second electrically-conductive wire 520 and also by an additional electrically-conductive wire 521. The first radiating element 200 is respectively connected to the second radiating element 250 by said first electrically-conductive wire 400 and also by an additional electrically-conductive wire 401.

[0055] The first electrically-conductive wire 400 is used to connect the radiofrequency port and the additional electrically-conductive wire 401 is used to reduce the antenna thickness.

[0056] Advantageously, the first and second electrically-conductive wires 400, 520 conduct a differential mode. The first and second electrically-conductive wires 400, 520 extend perpendicularly to the planes of the first and second faces 101, 102.

[0057] Advantageously, each parasitic element 301, 302, 303 comprises feed means 701, 702, 703. Preferentially, feed means 701, 702, 703 are accessible by the edge of each of said parasitic elements 301, 302, 303. Advantageously, each feed means 701, 702, 703 can be loaded with any type of reactive impedance (inductor, capacitor, stub).

[0058] Variable capacitors 510 are connected to each of the feed means 701, 702, 703, of at least three parasitic elements 301, 302, 303 in order to modify a radiation pattern. According to a preferred embodiment, variable capacitors 510 are located on said second electrically-conductive wires 520.

[0059] The antenna apparatus comprises variable capacitors 510 to simultaneously or independently select each of the at least three parasitic elements 301, 302, 303 as reflective or directive. According to an embodiment, variable capacitors 510 are configured to activate as reflective and directive each of the at least three parasitic elements 301, 302, 303 are PIN diodes (Positive Intrinsic Negative diode) selecting a set of capacitors.

Depending on the intended application, two specific technical solutions can be used, for instance: digitally tunable capacitors (radiofrequency RF component including a series capacitor between the two ports which can be dynamically reconfigured) or low power consumption complementary metal oxide semiconductor (CMOS) RF switches based (RF component).

[0060] According to an embodiment, the first face 101 comprises a first supporting member 103 configured to support the first radiating element 200 and the first set of parasitic elements 301, 302, 303. Similarly, the second face 102 comprises a second supporting member 104 configured to support the second radiating element 200 and the second set of parasitic elements 351, 352, 353.

[0061] The first and second support members 103, 104 comprise each a plate made of a dielectric material, for instance FR4-epoxy substrate. Any type of dielectric substrate (Teflon, Alumina, Duroid, etc.) can be used in this system.

[0062] According to an embodiment, the apparatus comprises at least a transversal supporting member 106 extending from the first face 101 to the second face 102. The supporting member 106 maintains a distance between the first face 101 to the second face 102. The supporting member 106 increases the robustness of the apparatus.

[0063] According to another embodiment, a layer, such as a layer of foam, extends from the first face 101 to the second face 102. Advantageously the supporting member formed by such a layer increases the robustness of the apparatus. According to another embodiment, the apparatus comprises both a transversal supporting member 106 and a layer.

[0064] According to an embodiment, the apparatus comprises a set of one or more layer(s) between the first and second faces 101, 102, the set of one or more layers extending from the first face 101 to the second face 102 and being preferably made of a dielectric material.

[0065] The distance between the first and second faces 101, 102 is advantageously set to a distance inferior to five centimeters and preferably 3 centimeters, and preferably 2 centimeters, and preferably one centimeter. According to a preferred embodiment, the dimensions of the antenna apparatus of the present invention can advantageously reach the size of 60 x 60 x 10 cubic millimeters, e.g. $\lambda_0/2 \times \lambda_0/2 \times \lambda_0/12$ where λ_0 is the freespace wavelength. The wavelength λ_0 of a sinusoidal waveform traveling at constant speed v is given by $\lambda_0=c/f$, where c is called the phase speed (magnitude of the phase velocity) of the wave and f is the wave's frequency.

[0066] Figure 3 illustrates a three dimensions (3D) radiation pattern obtained with the antenna apparatus of the present invention when no parasitic elements are activated. The radiation pattern in three dimensions is shaped like a toroid (donut) symmetric about the axis of the dipole (i.e; the z axis on the figures 1 to 3); the dipole comprising the first and the second radiating elements 200, 250 and said first electrically-conductive wire 400. The radiation is maximum at right angles to the dipole, dropping off to zero on the antenna's axis. Therefore a dipole mounted vertically will be omnidirectional in the horizontal plane, with a modest gain, at the expense of radiation in the vertical direction

[0067] A dipole antenna most commonly refers to a half-wavelength (λ/2) dipole. The physical antenna (not the package that it is in) is constructed of conductive elements whose combined length is about half of a wavelength at its intended frequency of operation. This is a simple antenna that radiates its energy out toward the horizon (perpendicular to the antenna). The patterns shown are similar to those resulting from a perfect dipole formed with two thin wires oriented vertically along the z-axis.

[0068] The resulting 3D pattern looks kind of like a donut or a bagel with the antenna sitting in the hole and radiating energy outward. The strongest energy is radiated outward, perpendicular to the antenna in azimuth (x0y) plane.

[0069] **Figures 4** and **5** are diagrams of radiation pattern characteristics, showing simulation results of the antenna apparatus according to the state (directive/reflective) of the parasitic elements 301, 302, 303. The azimuth plane (x0y) pattern is formed by slicing through the 3D pattern in the horizontal plane, the x0y plane in this case.

[0070] The effectiveness of the antenna apparatus of the present invention is demonstrated through preliminary numerical results for an antenna operating in the 2.45 GHz band (for example, wifi). Thanks to the presence of the three parasitic elements 301, 302, 303, the antenna apparatus is able to reconfigure the radiation pattern in six different directions and also to radiate omnidirectionally (7 configurations). Seven radiation patterns are shown in Figures 3 and 4. It may be noted that the antenna apparatus of the present invention is capable of directing the main lobe in 6 different directions (see patterns C1 to C6 on figures 3 and 4) with a directivity higher than 5 dBi, covering the entire horizontal plane (x0y) with an angular beamwidth of 60°. In addition to these 6 different directions, the apparatus can also radiate omnidirectionally (see pattern C7 depicted on figure 4). In the pattern C7 the azimuth plane pattern is non-directional, which means that the antenna radiates its energy equally in all directions in the azimuth plane.
The antenna apparatus is capable of radiating seven configurations by selectively loading different capacitance of the at least three parasitic elements 301, 302, 303. The following table summarizes the different possible configurations of the radiation patterns according to the radiating mode of the three parasitic elements 301, 302, 303.
For instance, in a first embodiment (configuration 1), the parasitic element 301 among the three parasitic elements 301, 302, 303 is activated as directive whereas the two others parasitic elements 302, 303 are activated as reflective. Variable capacitors of the parasitic elements 301, 302, 303 operate as a plurality of capacitances for changing the loading over the parasitic elements 301,302,303.

		Parasitic element 301	Parasitic element 302	Parasitic element 303
Switching states	Configuration 1 -C1	REFLECTIVE	DIRECTIVE	REFLECTIVE
	Configuration 2 - C2	REFLECTIVE	REFLECTIVE	DIRECTIVE
	Configuration 3 - C3	DIRECTIVE	REFLECTIVE	REFLECTIVE
	Configuration 4 - C4	DIRECTIVE	DIRECTIVE	REFLECTIVE
	Configuration 5 - C5	REFLECTIVE	DIRECTIVE	DIRECTIVE
	Configuration 6 - C6	DIRECTIVE	REFLECTIVE	DIRECTIVE
	Configuration 7 - C7	DIRECTIVE	DIRECTIVE	DIRECTIVE

[0071] The impedance of the antenna apparatus matching within seven possible configurations is shown in Figure 6. At 2.45 GHz, the antenna has a reflection coefficient (S11) values less than -7dB regardless of the configuration considered. When the omnidirectional state is not considered, the reflection coefficient is lower than -8.5dB from 2.4 to 2.48GHz. A -6dB criteria is usually requested for Wireless sensor network application.

[0072] Hence, the antenna apparatus of the present invention allows a reduction of the area occupied by an antenna apparatus as well as an improvement of the bandwidth and of the radiation efficiency of the antenna apparatus; while reducing the power consumption and while enabling a radiation in the azimuthal plane without or with a very limited tilt.

[0073] It should be understood that the embodiments described herein are merely exemplary and that various modifications may be made without departing from the scope of the claims.

Claims

1. An antenna apparatus having a selectively orientable directivity in a plane parallel to an azimuth plane (x0y) comprising a first face (101) and a second face (102) extending in planes parallel to the azimuth plane (x0y) and being arranged one facing the other;
characterized in that the first face (101) comprises at least a first radiating element (200) and a first set of at least three parasitic elements (301, 302, 303) surrounding the first radiating element (200),

the second face (102) comprises at least a second radiating element (250) and a second set of at least three parasitic elements (351, 352, 353) surrounding the second radiating element (250),
the apparatus being configured to selectively activate at least some of the parasitic elements (301, 302, 303, 351, 352, 353);
the apparatus also comprising at least a first electrically-conductive wire (400) and a feed point (500) connected to the electrically-conductive wire (400), the first (200) and second (250) radiating elements being connected together by said electrically-conductive wire (400), said electrically-conductive wire (400) and feed point (500) feeding the first (200) and second (250) radiating elements according to a differential mode.

2. The apparatus according to the preceding claim wherein the feed point (500) is located on the first electrically-conductive wire (400) preferably at mid-distance between said first radiating element (200) and said second radiating element (250).

3. The apparatus according to any of the preceding claims wherein said first electrically-conductive wire (400) extends perpendicularly to the first (101) and second (102) faces.

4. The apparatus according to the preceding claim wherein each parasitic elements (301, 302, 303) of the first set is respectively connected to one of the parasitic elements (351, 352, 353) of the second set by a second electrically-conductive wire (520), each parasitic element (301, 302, 303) of the first set forming thereby with a parasitic element (351, 352, 353) of the second set a pair of parasitic elements (301, 302, 303, 351, 352, 353); said second electrically-conductive wire (520) connecting the parasitic elements (301, 302, 303, 351, 352, 353) of the first and second sets conducting a differential mode.

5. The apparatus according to the preceding claim wherein the first radiating element (200) is respectively connected to the second radiating element (250) by said first electrically-conductive wire (400) and also by an additional electrically-conductive wire (401) and each parasitic element (301, 302, 303) of the first set is respectively connected to one of the parasitic elements (351, 352, 353) of the second set by said second electrically-conductive wire (520) and also by an additional electrically-conductive wire (521).

6. The apparatus according to any of the preceding claims wherein the first face (101) and the second face (102) are symmetrical with respect to a geometrical plane parallel to the azimuth plane (x0y) and passing through said first electrically-conductive wire (400).

7. The apparatus according to any of the preceding claims wherein the first radiating element (200) and the second radiating element (250) form a differential wire-plate antenna.

8. The apparatus according to any of the preceding claims wherein the first set of parasitic elements (301, 302, 303) comprises three parasitic elements (301, 302, 303) surrounding the first radiating element (200) and disposed at 120° around the first radiating element (200).

9. The apparatus according to any of the preceding claims wherein each one of the first and second faces (101, 102) is configured, in particular the distance between the radiating element (200, 250) and the parasitic elements (301, 302, 303, 351, 352, 353), so that the first (200) and second (250) radiating elements are electromagnetically coupled to the parasitic elements (301, 302, 303, 351, 352, 353) of the first and second sets respectively.

10. The apparatus according to the preceding claim wherein the distance between the center of first radiating element (200) and the center of each of the parasitic elements (301, 302, 303) of the first set is comprised between 0.15 and 0.3 freespace wavelength λ_0 so that the first radiating element (200) is electromagnetically coupled to the parasitic elements (301, 302, 303) of the first set.

11. The apparatus according to any of the two preceding claims comprising variable capacitors (510) connected to each of the parasitic elements (301, 302, 303, 351, 352, 353) of the first and second sets, each variable capacitor (510) is selectively activable to modify the electromagnetic coupling between each of the parasitic elements (301, 302, 303, 351, 352, 353) and the radiating element (200, 250) to which it is electromagnetically coupled so that the radiation pattern of the antenna apparatus in the azimuth plane (x0y) is modified.

12. The apparatus according to any of the preceding claims wherein each parasitic elements (301, 302, 303) of the first set forms with a parasitic element (351, 352, 353) of the second set a pair of parasitic elements, the apparatus comprising variable capacitors (510) to simultaneously or independently select each pair of parasitic elements.

13. The apparatus according to any of the preceding claims wherein the distance between the first and the second faces (101, 102) is set to a distance inferior to sixty millimeters or $\lambda_0/2$, where λ_0 is the freespace wavelength, and preferably inferior to 30 millimeters or $\lambda_0/4$, and preferably inferior to 20 millimeters or $\lambda_0/6$, and preferably inferior to ten millimeters or $\lambda_0/12$.

14. The apparatus according to any of the preceding claims wherein the first (101) and second (102) faces are configured and fed in a differential mode so that the apparatus radiates as an electrical dipole.

15. The apparatus according to any of the preceding claims wherein the first face (101) comprises a first planar supporting member (103) configured to support the first radiating element (200) and the first set of parasitic elements and wherein the second face (102) comprises a second planar supporting member (104) configured to support the second radiating element (200) and the second set of parasitic elements.

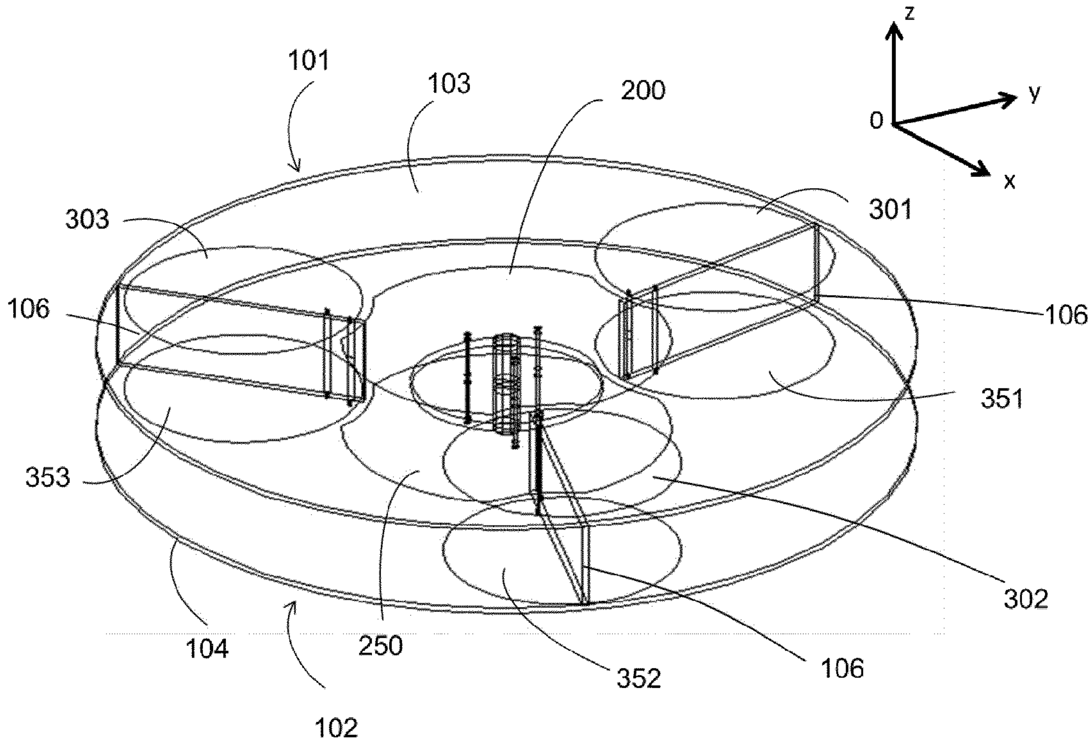

z
y
0
x
101
103
200
303
301
106
106
351
353
302
104
250
352
106
102

FIG. 1A

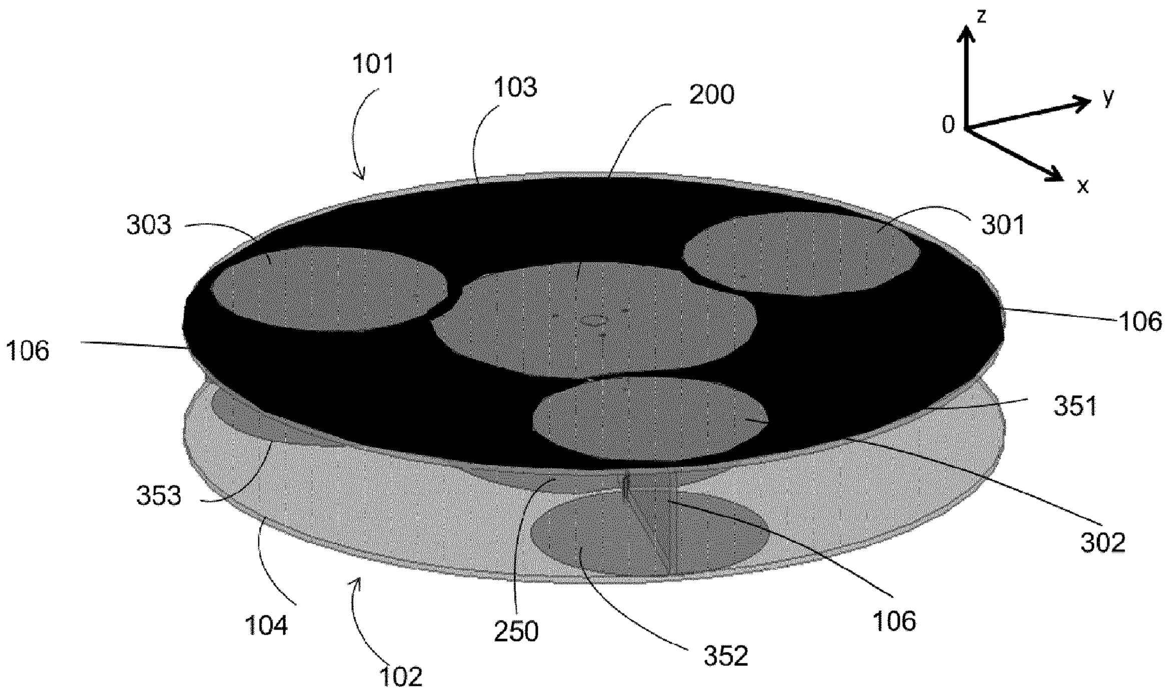

z
y
0
x
101
103
200
303
301
106
106
351
353
302
104
250
352
106
102

FIG. 1B

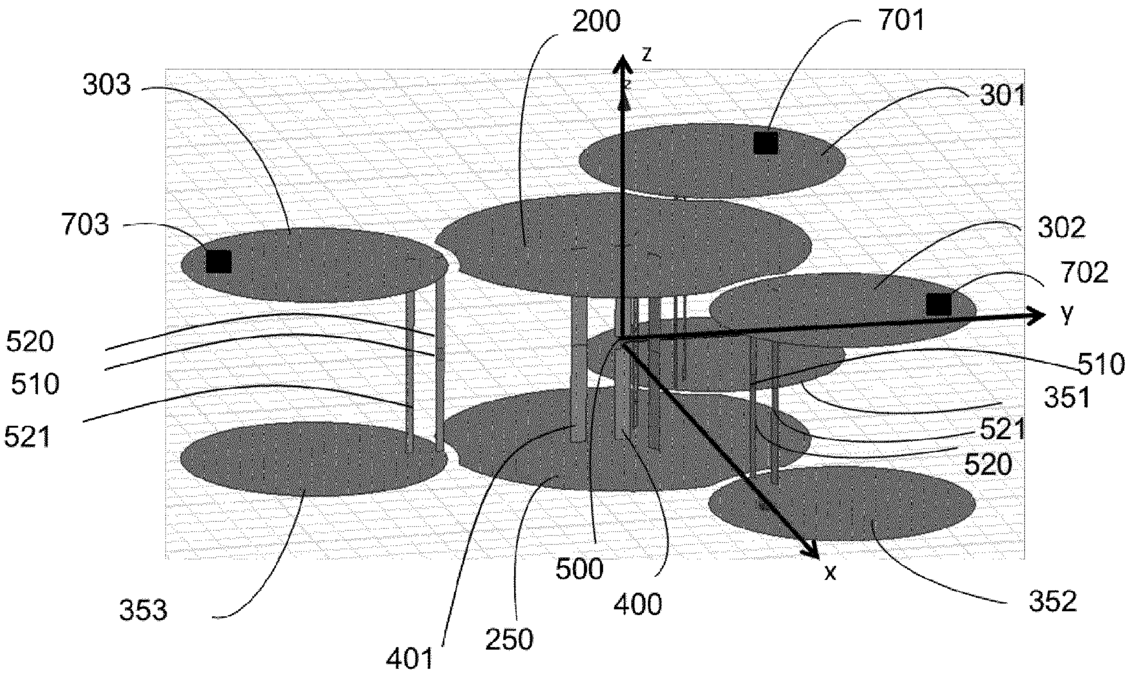

200
701
z
303
301
703
302
702
y
520
510
510
351
521
521
520
353
500
400
x
352
401
250

FIG. 2

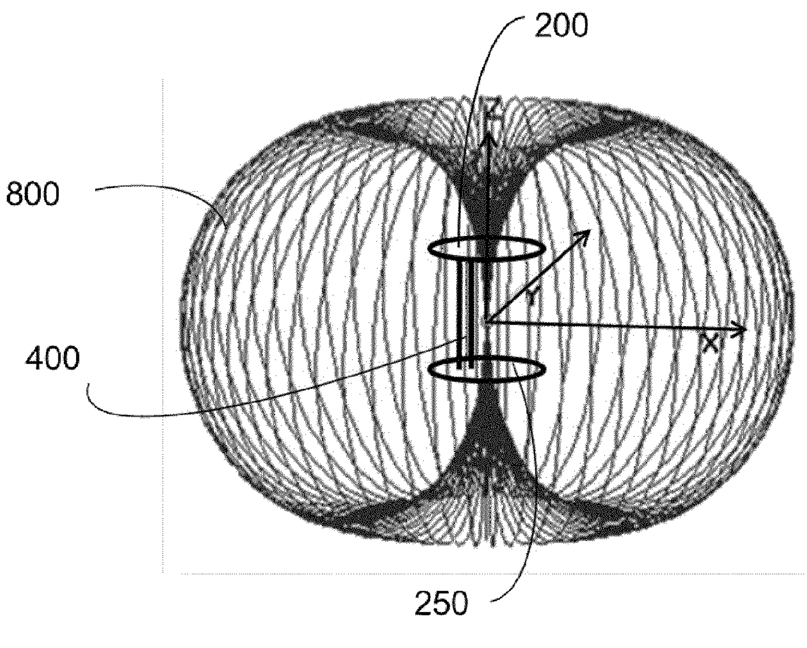

200
Z
800
Y
X
400
250

FIG. 3

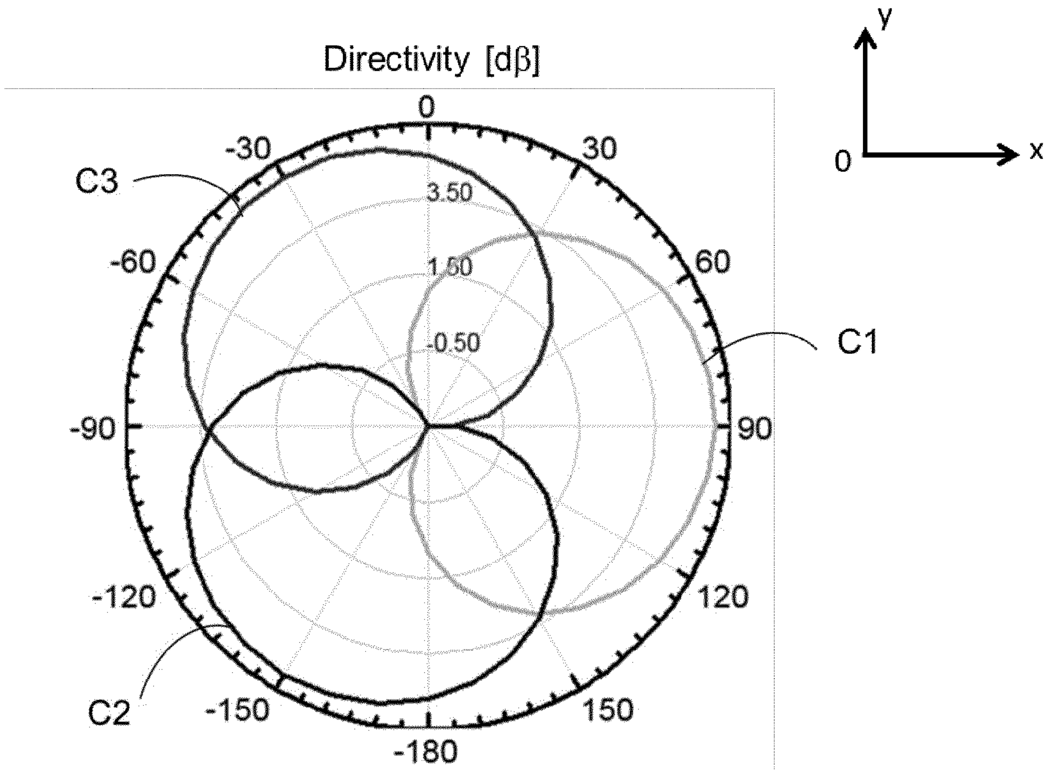

Directivity [dβ]
0
30
60
90
120
150
-180
-150
-120
-90
-60
-30
3.50
1.50
-0.50
C1
C2
C3
y
x
0

FIG. 4

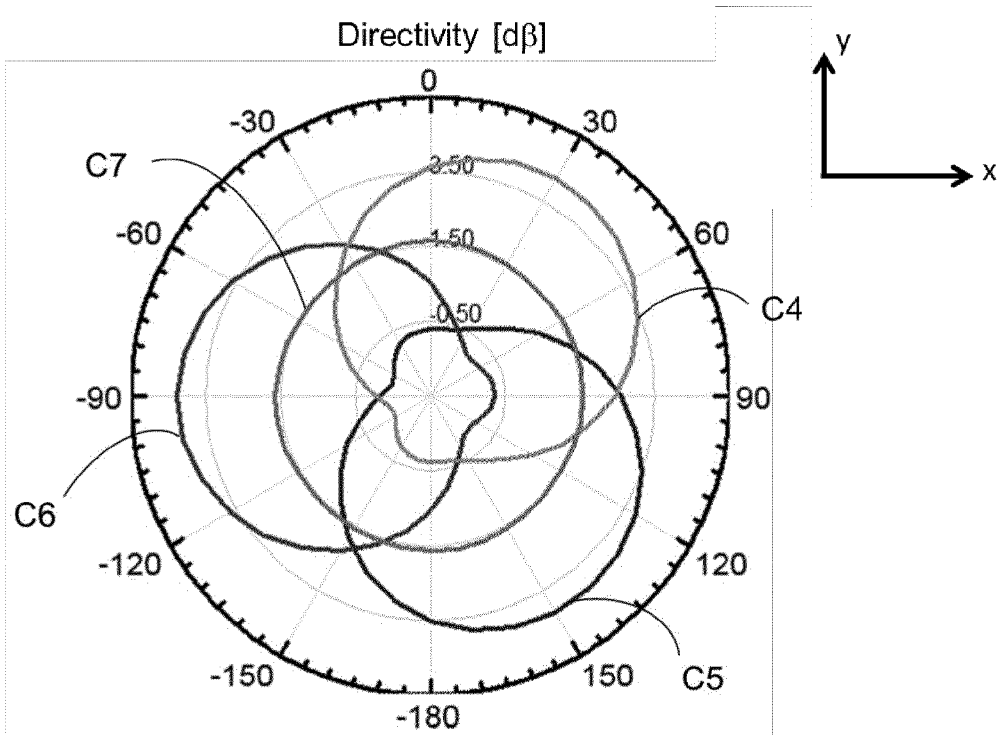
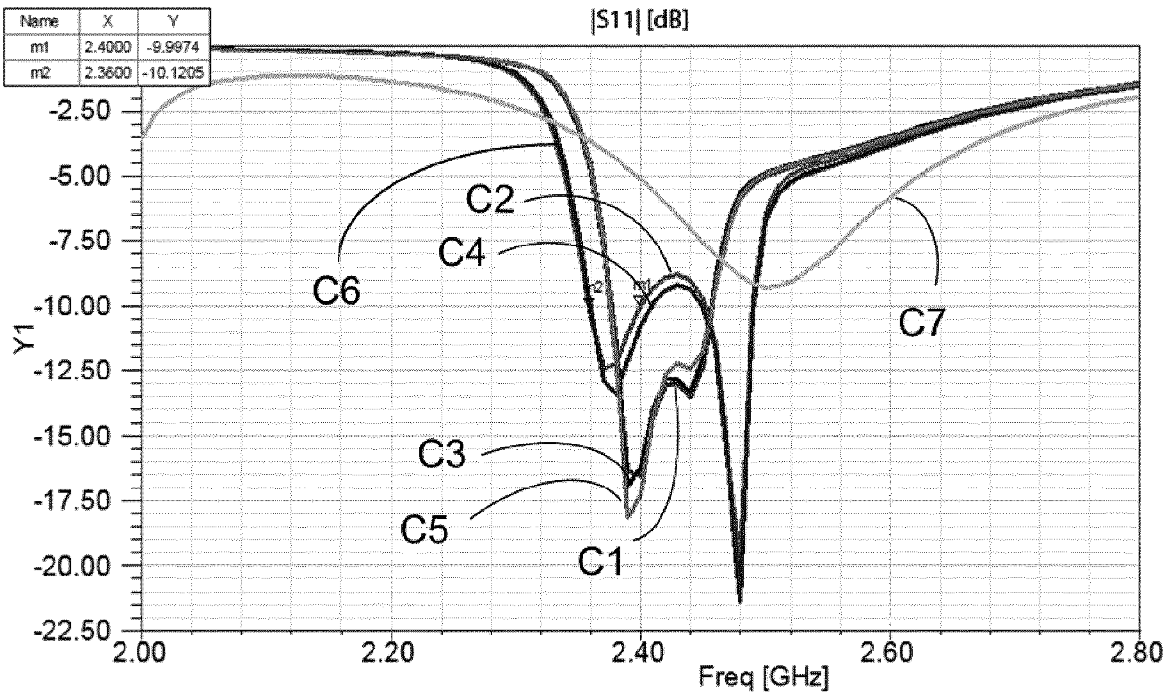

Directivity [dβ]
0
30
60
90
120
150
-180
-150
-120
-90
-60
-30
3.50
1.50
-0.50
C4
C5
C6
C7
y
x

FIG. 5



Name | X | Y
m1 | 2.4000 | -9.9974
m2 | 2.3600 | -10.1205
|S11| [dB]
Y1
-2.50
-5.00
-7.50
-10.00
-12.50
-15.00
-17.50
-20.00
-22.50
2.00
2.20
2.40
2.60
2.80
Freq [GHz]
C1
C2
C3
C4
C5
C6
C7
m1
m2

FIG. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 15 30 6159

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	LIZZI LEONARDO ET AL: "Synthesis of miniature pattern-reconfigurable antennas for smart wireless sensor nodes", 2013 IEEE ANTENNAS AND PROPAGATION SOCIETY INTERNATIONAL SYMPOSIUM (APSURSI), IEEE, 6 July 2014 (2014-07-06), pages 1443-1444, XP032645105, ISSN: 1522-3965, DOI: 10.1109/APS.2014.6905047 ISBN: 978-1-4799-3538-3 [retrieved on 2014-09-18] * the whole document * -----	1-15	INV. H01Q9/28 H01Q3/44
A	JP 2006 340246 A (TOYOTA CENTRAL RES & DEV) 14 December 2006 (2006-12-14) * abstract; figure 6 * -----	1-15	
A	WO 2005/122328 A2 (INTERDIGITAL TECH CORP [US]; CHIANG BING A [US]; CHA INHYOK [US]; LYNC) 22 December 2005 (2005-12-22) * figures 4,5 * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
A	US 2011/080325 A1 (LIVNEH NOAM [IL] ET AL) 7 April 2011 (2011-04-07) * abstract * -----	1-15	H01Q
A	US 2004/266481 A1 (PATEL JAY [US] ET AL) 30 December 2004 (2004-12-30) * figure 17 * -----	1-15	

1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	17 December 2015	Kaleve, Abraham

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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17-12-2015

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2006340246 A	14-12-2006	NONE	
WO 2005122328 A2	22-12-2005	CN 101080846 A	28-11-2007
		EP 1766722 A2	28-03-2007
		JP 4542141 B2	08-09-2010
		JP 2008502226 A	24-01-2008
		TW I307191 B	01-03-2009
		US 2005285784 A1	29-12-2005
		WO 2005122328 A2	22-12-2005
US 2011080325 A1	07-04-2011	CN 102576937 A	11-07-2012
		EP 2483967 A1	08-08-2012
		JP 2013507076 A	28-02-2013
		JP 2014222913 A	27-11-2014
		KR 20120080231 A	16-07-2012
		KR 20150027306 A	11-03-2015
		US 2011080325 A1	07-04-2011
		US 2013201060 A1	08-08-2013
		WO 2011053431 A1	05-05-2011
US 2004266481 A1	30-12-2004	NONE	

EPO FORM P0459

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