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(11) **EP 1 630 898 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:  
**01.03.2006 Bulletin 2006/09**

(51) Int Cl.:  
**H01Q 1/27 (2006.01) H01Q 9/04 (2006.01)**

(21) Application number: **04405541.6**

(22) Date of filing: **31.08.2004**

(84) Designated Contracting States:  
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HU IE IT LI LU MC NL PL PT RO SE SI SK TR**  
Designated Extension States:  
**AL HR LT LV MK**

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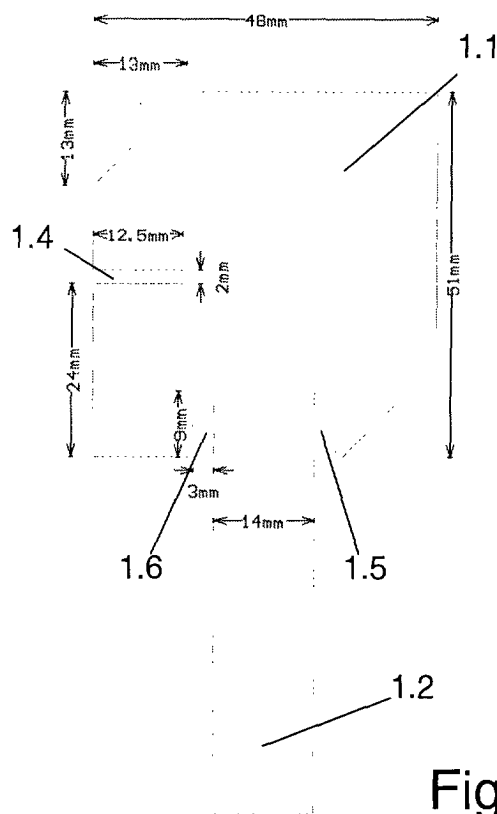
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(54) **Textile antenna**

(57) The antenna comprises a flexible, electrically conductive ground plane and a flexible, electrically conductive antenna patch (1). Textile, non-conductive material is arranged between the ground plane and the antenna patch. The antenna is essentially characterized in that it provides circular polarization or nearly circular polarization, and that it comprises a microstrip feed line (1.2). The ground plane and the antenna patch are preferably made of conductive fabric.



**Fig. 3**

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## Description

### FIELD OF THE INVENTION

**[0001]** The invention is in the field of textile antennas.

### BACKGROUND OF THE INVENTION

**[0002]** Textile antennas are antennas that comprise a textile substrate with a conductive patch and ground plane and may be affixed to or integrated in clothing, furniture or other textile material. They are for example used in connection with wearable computing.

**[0003]** Wearable computing is a new, fast growing field. Steadily progressing miniaturization in microelectronics along with other new technologies enables wearable computing to integrate functionality in clothing allowing entirely new applications. Medical prevention with continuously monitoring the patient's health condition is such an application necessitating sensing devices close to the patient's body. With wearable computing, it has become possible to integrate such sensing devices in the clothing, which offers unobtrusiveness and body proximity. As a next step, patients would benefit if a health condition can be directly communicated to a medical center. The implementation of antennas in textiles is therefore a logical next step.

**[0004]** Further applications of textile antennas include applications in the automotive industry, namely antennas in seats of a car.

**[0005]** Compared with conventional antennas, textile antennas have to fulfill the additional requirement of being drapable. 'Drapability' means that something can be bent in all directions at the same time. A textile has this property in contrast to standard flexible substrates, which usually have a preferred bending direction. Additionally, in wearable applications, a textile antenna must have a flat and planar structure such that it does not affect wearing comfort.

**[0006]** Textile antennas available so far were designed with rectangular patches with probe feed (C.f. P. Salonen and H. Hurme, IEEE Antennas and Propagation Society International Symposium vol. 2, June 2003, pp. 700-703; and M. Tanaka and J.H. Hang, IEEE Antennas and Propagation Society International Symposium vol. 2, June 2003, pp. 704-707). Such antennas provide a linear polarization.

**[0007]** However, it has been found that for some applications relating to wearable computing, the orientation of the textile antenna may vary as a function of time, for example if the person wearing the textile antenna moves. Linear polarization brings about a dependence of the antenna's efficiency on the relative orientation of transmitting (Tx) antenna and receiving (Rx) antenna. In addition, the probe feed causes elements to stick up from an antenna plane, so that it is not practical for wearable computing.

## SUMMARY OF THE INVENTION

**[0008]** It is an object of the invention to provide a textile antenna overcoming disadvantages of prior art textile antennas, and especially to provide a textile antenna that would be suitable for the frequency ranges between around 1.8-1.9 GHz (GSM standard frequencies), about 2.4 GHz (Bluetooth frequency), and other frequencies between 400 MHz and 20 GHz in order to be operable to communicate using already available communication technologies, to provide a textile antenna that is also suitable for being posed on moving objects, and to provide a textile antenna that has a design that makes it cost effective to manufacture and that makes possible to contact it without parts protruding from the plane defined by the antenna, i.e. that may be contacted without parts sticking up from the textile.

**[0009]** This object is achieved by a textile antenna defined in the claims.

**[0010]** The antenna according to the invention comprises a flexible, electrically conductive ground plane and a flexible, electrically conductive antenna patch. Textile, non-conductive material is arranged between the ground plane and the antenna patch as a dielectric textile substrate. The antenna is essentially characterized in that it provides circular polarization or nearly circular polarization, and that it comprises a microstrip feed line.

**[0011]** A microstrip feed line in this context is a strip-shaped conductor structure for feeding the radiating part of the antenna with an AC voltage, being provided on the textile substrate, and meeting the radiating main part of the antenna patch. In a plane configuration, the microstrip feed line is in the same plane as the antenna patch main part.

**[0012]** According to usual definitions, electromagnetic radiation emitted by an antenna is said to be circularly polarized if the axial ratio is smaller than 3 dB. The axial ratio is the ratio between the major axis component of the electric field amplitude and the minor axis component of the electric field amplitude, major axis and minor axis referring to the polarization ellipse. According to the definition used here, 'nearly circular polarization' implicates that the ratio is not greater than 6 dB, preferably not greater than 4 dB.

**[0013]** Of course, antennas for circular polarization have been known for a long time, especially for satellite communication. However, linear polarization is much easier to generate and to handle and is a communication standard. Also, circular antennas are much more difficult to design, and the expected fabrication tolerances implicated that with the shape accuracies achievable for textile material, circular patch antennas are hardly possible to produce. However, it has been found that due to the differences in permittivity  $\epsilon_r$  between usual antenna substrate materials (i.e. Printed Circuit Board Substrates) and textile antennas, the sizes of the patches are considerable greater for textile antennas and that the absolute tolerances are not as strict. Circularly polarized ra-

diation is more insensitive in environments where polarizing reflections may occur.

**[0014]** A further insight of the invention is that it is even possible to provide a circularly polarized antenna comprising a microstrip line feed, although this makes antenna design again more complicated. A microstrip line feed is excellently suited for wearable computing since it lies entirely in the antenna patch plane and does not affect wearing comfort.

**[0015]** According to a preferred embodiment, the antenna patch and preferably also the ground plane are made of an electrically conductive textile, such as a conductive fabric. Conductive fabrics are textiles the threads of which are conductive. For example, the threads of which the conductive fabric is made are plated by a metal or are drenched in conductive ink or the like. Plating or drenching may take place before or after weaving. As an other example, conductive fabrics may be manufactured by imprinting a conductor material on a (non-conductive) already woven or knitted textile. In conductive fabrics, conduction mainly occurs along the threads, so that the electrical resistance is locally highly anisotropic. This is not problematic for linear polarization, where one oscillation mode is sufficient. Yet, it makes calculations of more complex mode schemes in systems comprising conductive fabrics extremely complex. However, it has now been found that for calculation purposes for circularly polarized antennas, the conductive fabrics may be approximated to be plane conductors, especially if the patch has an essentially rectangular shape and if the edges of said rectangle are parallel to threads of the fabric. Otherwise, a higher sheet resistance ( $\Omega/\text{square}$ ) would have to be considered in the computation.

**[0016]** According to several preferred embodiments, the patch essentially has the shape of an almost quadratic rectangle. 'Almost quadratic' means that the dimensions of the sides differ by not more than 5-20%.

**[0017]** In a first embodiment, the microstrip line contacts the rectangle at one of its corners. In a second embodiment, the rectangle has two truncated corners opposing each other, the microstrip line contacting the rectangle in the middle of one of its edges. In a third embodiment, the rectangle has a centrally located strip-shaped slot, the strip-shaped slot running diagonally with respect to the rectangle (in an angle of about  $45^\circ$  with respect to the rectangle edges or with respect to a coordinate system of the antenna patch plane in which one axis is parallel to the microstrip feed line and the other axis is perpendicular thereto), the microstrip line contacting the rectangle in the middle of one of its edges.

**[0018]** According to some embodiments, the patch comprises at least one strip-shaped indentation in the rectangle. At least one strip-shaped indentation may run perpendicularly to the feed line in order to tune circular radiation. Also, strip-shaped indentations may be provided that run parallel to the microstrip line and effectively extend the microstrip line into the rectangle in order to match antenna input impedance and microstrip feed line

impedance.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0019]** In the following, exemplary embodiments of the invention are described with reference to drawings. In the drawings:

- Fig. 1 shows a photo of a circularly polarized textile antenna according to the invention
- Fig. 2 depicts 3 basic shapes of circularly polarized textile patch antennas according to the invention.
- Fig. 3 depicts the exact shape of an embodiment of a circularly polarized antenna
- Fig. 4 shows a further shape of an embodiment of a circularly polarized antenna
- Figs. 5a and 5b depict axial ratio and input matching values as a function of the frequency of the textile antenna of Fig. 1
- Figs. 6a and 6b show the measured radiation patterns in two orthogonal planes for left-hand and right-hand circularly polarized radiation.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0020]** A photograph of an embodiment of a textile antenna according to the invention is shown in Fig. 1. The antenna comprises an antenna patch 1 on a textile substrate 2, namely on a polyamid spacer fabric with a thickness of 6 mm. This fabric comprises a number of advantages. It is light, has a good drapability and is dimensionally stable in height. Due to its being very light and because it comprises a high fraction of air, its permittivity  $\epsilon_r$  is close to 1. A measurement reveals a permittivity of around 1.15 at a frequency of 2.4 GHz. Underneath the fabric, the textile antenna comprises a ground plane (not visible), which is substantially larger than the patch and spans more than the entire surface of the section of the fabric shown in the photo. In theory, the ground plane's size is such that it may be considered to be infinite in all four directions of the plane defined by the fabric. In fact, the ground plane's size is at least the size of the patch, preferably at least four times or at least eight times its size.

**[0021]** The conductive material of the antenna patch 1 of Fig. 1 as well as of the ground plane is a conductive fabric, namely a nickel-plated woven textile. Nickel shows high resistance against oxidation and corrosion. The antenna patch and the ground plane are attached to the spacer fabric by ammonia-based textile glue. An electrical connection between the microstrip line 1.2 and the ground plane, respectively, and a transceiver electronics is established by conductive two-component glue.

**[0022]** As an alternative to Nickel, other conductive material may be used, for example Copper, Silver, alloys of these materials and of other metals, or any other conductive material. The thickness of the conductive layer is usually around 200 nm to 400 nm, which is smaller than the skin depth in the concerned materials at the above specified frequencies. Thus, by varying the thickness, damping properties may be controlled in a certain range.

**[0023]** Instead of plated textiles, also other thin conductive materials may be used, for example metal foils or, especially preferred, conductive paste which may be directly imprinted on the textile.

**[0024]** The conductivity of the conductive patch and ground plane material, if the material is a plated woven or knitted material or an imprint on a textile, is governed by the property of the conductive fabric. The resistance mainly arises from the contact resistance of transitions between crossed threads: The more transitions the current has to make in order to flow between two points, the higher the resistance between these two points. In order to determine a resistance, the path between two points is divided into squares to be crossed (the square sides being parallel to the threads). The resistance is measured in  $\Omega/\text{square}$ . For the material used for the embodiment of Fig. 1, the resistance is about  $5\Omega/\text{square}$ .

**[0025]** As shown in the Figure, the patch 1 comprises a main part 1.1 and a microstrip line 1.2. The main part has an essentially rectangular, almost quadratical shape, with truncated corners 1.3 opposing each other. The microstrip line 1.2 has an arbitrary length and contacts the rectangle 1.1 in the middle of one of its edges. The patch rectangle comprises three strip-shaped indentations 1.4, 1.5, 1.6: The first indentation 1.4 runs from a side of the rectangle towards the interior. The other two indentations 1.5, 1.6 are essentially parallel to the microstrip and effectively extend it into the rectangle. The dimensions of the patch correspond for example to the dimension of the patch indicated further below in Fig. 3.

**[0026]** When an alternating voltage of a frequency between 400 MHz and 20 GHz, for example of a frequency of at least 1 GHz and at most 10 GHz, depending on the patch's dimensions, is applied between the microstrip line 1.2 and the ground plane, a left-hand circularly polarized radio signal is generated. Other antenna sizes and designs would be useable for other frequency ranges, i.e. the MHz frequency range. The radiating edges of the patch are the edge in the main part 1.1 that is contacted by the microstrip line 1.2 and the opposing edge for a first radiation component and the other edges for a second radiation component. The truncated corners set off excitement of the mode causing the second component. The radiation components emitted by these edges (including the truncated corners) superpose in a manner that left-hand circularly polarized radiation is created.

**[0027]** Fig. 2 shows three basic shapes of patches of circularly polarized textile antennas of the invention. The invention is not restricted to these three basic shapes;

rather these are mere examples of shapes on which an antenna design may be based on.

**[0028]** The first basic shape 11 corresponds to the shape of the antenna described with reference to Fig. 1. The main part 11.1 of the patch has the shape of a rectangle with two truncated corners opposing each other. The microstrip line 11.2 contacts the rectangle in the middle of one of its edges. According to the second basic shape 12 the patch essentially has the shape of a rectangle, the microstrip line 12.2 contacting the rectangle at one of its corners. The third basic shape 13 comprises a main part 13.1 being a rectangle with a centrally located strip-shaped slot 13.3, the strip-shaped slot 13.3 running diagonally with respect to the rectangle (i.e. in an angle of about  $45^\circ$  with respect to the Cartesian coordinate system shown in the figure), the microstrip line 13.2 contacting the rectangle in the middle of one of its edges and having an angle of about  $45^\circ$  with respect to the slot 13.3.

**[0029]** All three basic shapes may be supplemented by preferably strip-shaped indentations which are not shown in Fig. 2 and which may be introduced for optimization purposes. More concretely, indentations may be used to amplify radiation components along a particular edge in order to tune the antenna. Further, indentations parallel to the microstrip line - for example of the manner shown in Fig. 1 - may be used to engineer the microstrip line's terminating impedance so that it matches the line impedance (or characteristic impedance) of the microstrip line in order to avoid undesired reflections which reduce the total efficiency of the antenna.

**[0030]** The exact shape of the patch of the textile antenna of Fig. 1 is shown in Fig. 3. The figure includes indications of dimensions. For a textile substrate with the thickness and permittivity of the mentioned textile material (6 mm; the relative permeability may be assumed to be 1 for all discussed embodiments), a microstrip line with a standard characteristic impedance of  $50\Omega$  (ignoring ohmic losses) would be rather wide (28 mm) compared to the patch dimensions. Since such a wide line would restrict the length of the radiating edges, it would then be difficult to achieve circularly polarized radiation. Therefore, the shown embodiment is a  $75\Omega$  system resulting in a feed line width of 14 mm. Nevertheless, the indentations 1.5, 1.6 parallel to the microstrip line making the microstrip line an inset microstrip feed had to be used. These indentations make the circular polarization (CP) operation more difficult, since the necessary excitation of two orthogonal, near-degenerate resonant modes is disturbed by the indentations. This makes the presence of the additional indentation 1.4 being a perturbation slit beneficial.

**[0031]** The exact shape of a patch 21 of a second embodiment of a textile antenna is shown in Fig. 4, which also comprises dimension values. Also this embodiment comprises an indentation 21.4 serving as perturbation slit.

**[0032]** Fig. 5a presents the measured axial ratio at an angle of  $0^\circ$  for the textile antenna of Figs. 1 and 3 as a

function of the frequency. An axial ratio below 3 dB is obtained from 2.29 to 2.36 GHz. The bandwidth of circular polarization according to a first definition (axial ratio below 3 dB) is thus attained with a bandwidth of 3% with respect to a center frequency at 2.32 GHz. Nearly circular polarization according to the definition given above is achieved in the entire considered range between 2.2 GHz and 2.4 GHz.

**[0033]** Fig. 5b shows the measured input matching  $s_{11}$  (solid curve) as a function of the frequency. The smaller the input matching (i.e. the lower the dB value) the higher the accepted power at a particular frequency. It can be seen in the Figure that the accepted power is at a steep maximum around frequencies of 2.2-2.3 GHz. The radiation efficiency, i.e. the ratio between emitted radiation power and the accepted power is usually in the range of 60% to 90%, depending on resistance losses and properties of the dielectric textile substrate.

**[0034]** The solid lines in Fig. 6a and Fig. 6b show the measured radiation intensity for left hand circular polarization as a function of the radiation direction. Figs. 6a and 6b depict the angular dependency in the y-z-plane and the x-z-plane, respectively, if the antenna is in the x-y-plane. Both figures, of course, show a somewhat reduced radiation intensity into a backward (or downward) direction but a relatively broad region with a high intensity in the forward direction. The figures also show the radiation proportion with right hand circular polarization (dashed lines). In the forward direction, the right-hand circular polarization is much weaker (by about 15 dB) than the left-hand circularly polarized radiation. It follows that a high proportion of the power going into the microstrip line is transformed into left-hand circularly polarized radiation in a forward direction.

**[0035]** It has been found that the efficiency of the antenna of Fig. 1 is not critically dependent on environmental parameters such as the surrounding air's humidity. The antenna can be tuned to fulfill the Bluetooth specification, i.e. a frequency range and antenna coverage of around 10 m for 1 mW power and around 100 m for about 20 mW power.

**[0036]** The above described embodiments are by no means the only ways to carry out the invention but may be altered in many ways. Next to the shapes of the patch, of course also the patch and ground plane materials and the textile materials may be varied. In principle, any electrically conductive and drapable material may be used for the ground plane and for the patch. Ground plane and patch may be provided on any textile material. The antenna design (i.e. the patch shape and microstrip width) has to be adapted to both, the textile material's permittivity and its thickness.

## Claims

1. A textile antenna operable to emit electromagnetic radiation of an operating frequency, comprising a

flexible, electrically conductive ground plane and a flexible, electrically conductive antenna patch (1, 21), electrically non-conductive textile material being arranged between the ground plane and the antenna patch, the area of the ground plane being equal to or larger than the area of the antenna patch, **characterized in that** it comprises a microstrip line (1.2, 11.2, 12.2, 13.2) contacting the antenna patch and **in that**, when an alternating voltage of the operating frequency is applied between the ground plane and the microstrip line, the emitted radiation is circularly polarized or nearly circularly polarized.

2. A textile antenna as claimed in claim 1, wherein the antenna patch is made of an electrically conductive fabric.
3. A textile antenna as claimed in claim 2, wherein the antenna patch material is a woven fabric or knitted, wherein the threads are plated.
4. A textile antenna as claimed in claim 2, wherein the antenna patch material is a printed electrically conductive paste.
5. A textile antenna as claimed in any one of the previous claims, wherein the patch essentially has the shape of a rectangle, the microstrip line contacting the rectangle at one of its corners.
6. A textile antenna as claimed in any one of claims 1 to 4, wherein the patch essentially has the shape of a rectangle with two truncated corners (1.3) opposing each other, the microstrip line contacting the rectangle in the middle of one of its edges.
7. A textile antenna as claimed in any one of claims 1 to 4, wherein the patch essentially has the shape of a rectangle with a centrally located strip-shaped slot (13.3), the strip-shaped slot in an angle of 45° with respect to sides of the rectangle, the microstrip line (13.2) contacting the rectangle in the middle of one of its edges.
8. A textile antenna as claimed in any one of claims 5-7 further comprising a strip shaped indentation (1.4, 1.5, 1.6, 21.4) in the rectangle.
9. A textile antenna as claimed in claim 8, comprising two strip shaped indentations (1.5, 1.6) running parallel to the microstrip line and effectively extending the microstrip line into the rectangle.
10. A textile antenna as claimed in any one of the previous claims, wherein the operating frequency is between 1.8 GHz and 2.5 GHz.
11. A textile antenna as claimed in any one of the pre-

vious claims, wherein the line resistance of the microstrip line is between  $50\ \Omega$  and  $80\ \Omega$ .

12. A textile antenna as claimed in any one of the previous claims, wherein the permittivity  $\epsilon_r$  of the textile material is less than 1.7. 5
13. A textile antenna as claimed in claims 11 and 12, wherein the permittivity  $\epsilon_r$  of the textile material is less than 1.45 and wherein the line resistance of the microstrip line is between  $70\ \Omega$  and  $80\ \Omega$ . 10

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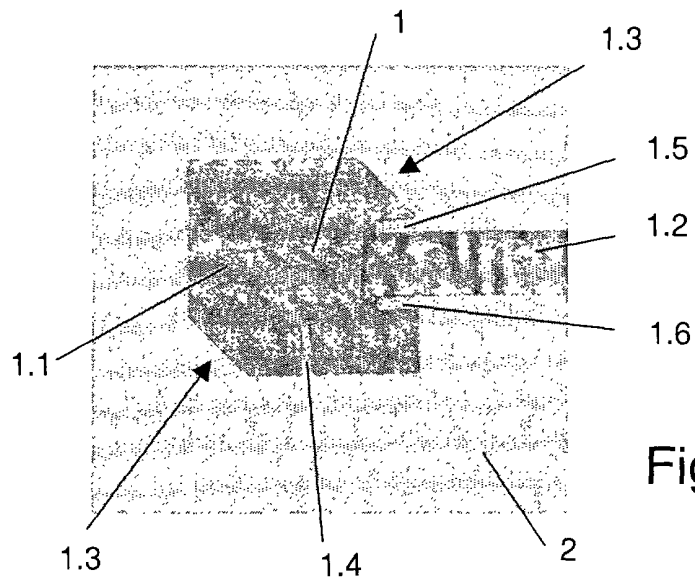


Fig. 1

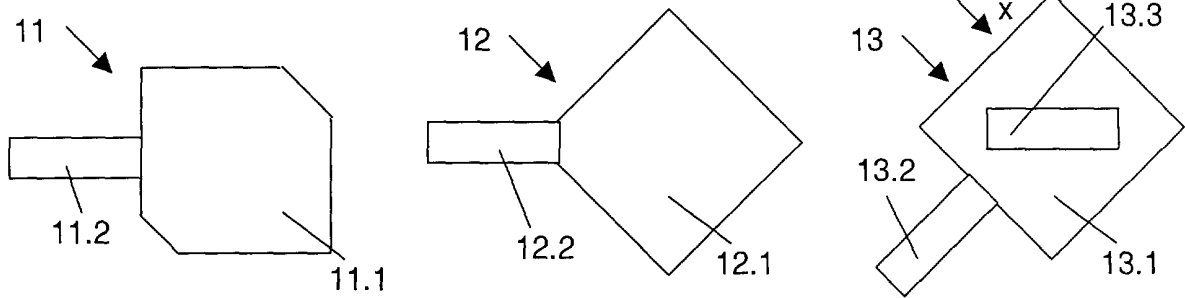


Fig. 2

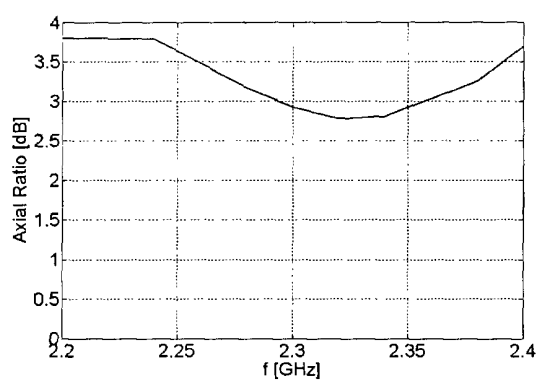


Fig. 5a

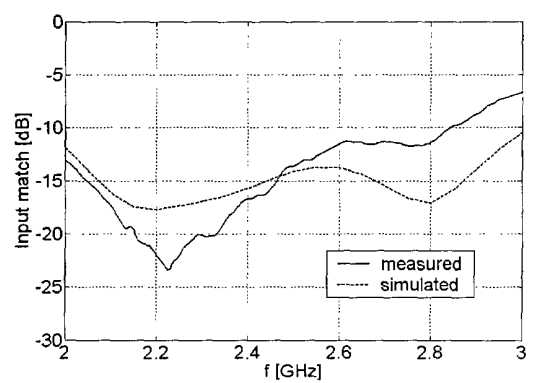


Fig. 5b

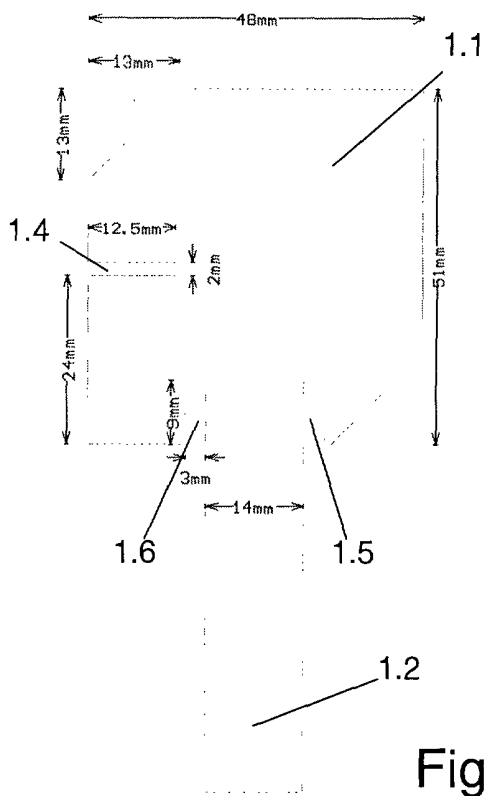


Fig. 3

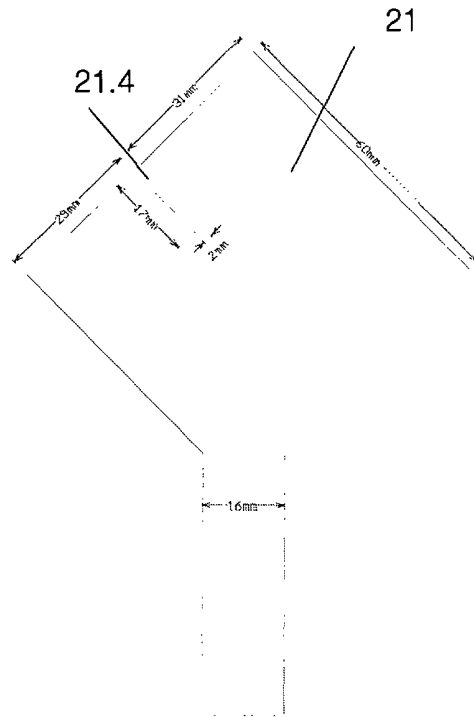


Fig. 4

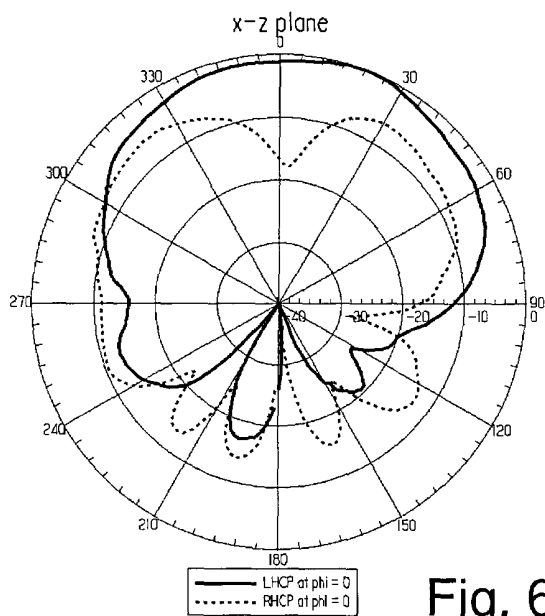


Fig. 6a

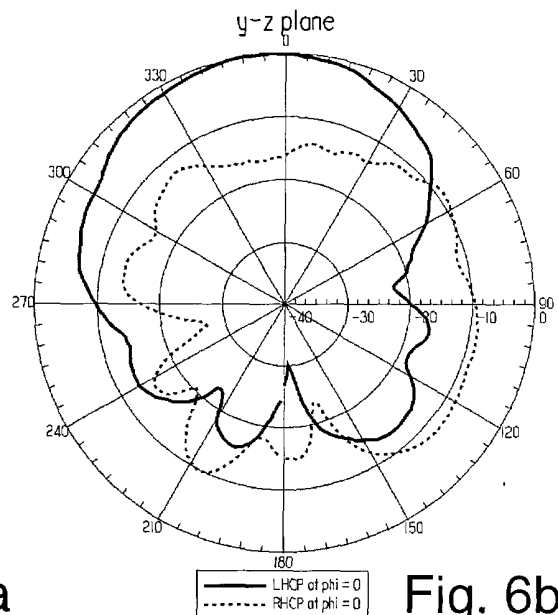


Fig. 6b





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# EUROPEAN SEARCH REPORT

Application Number  
EP 04 40 5541

| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                              |                                              |
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| Category                                                                                                                                                                                                                                               | Citation of document with indication, where appropriate, of relevant passages                                                                                                                                                                                                                                                                        | Relevant to claim                                                                                                                                                                                                                                                            | CLASSIFICATION OF THE APPLICATION (Int.Cl.7) |
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| The present search report has been drawn up for all claims                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                              |                                              |
| Place of search<br>The Hague                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                      | Date of completion of the search<br>28 January 2005                                                                                                                                                                                                                          | Examiner<br>Fredj, A                         |
| CATEGORY OF CITED DOCUMENTS<br>X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document |                                                                                                                                                                                                                                                                                                                                                      | T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>& : member of the same patent family, corresponding document |                                              |

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT  
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EP 04 40 5541

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.  
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28-01-2005

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