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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 February 2001 (15.02.2001)

PCT

(10) International Publication Number
WO 01/11716 A1

(51) International Patent Classification[7]: H01Q 1/24

(21) International Application Number: PCT/IT99/00260

(22) International Filing Date: 9 August 1999 (09.08.1999)

(25) Filing Language: English

(26) Publication Language: English

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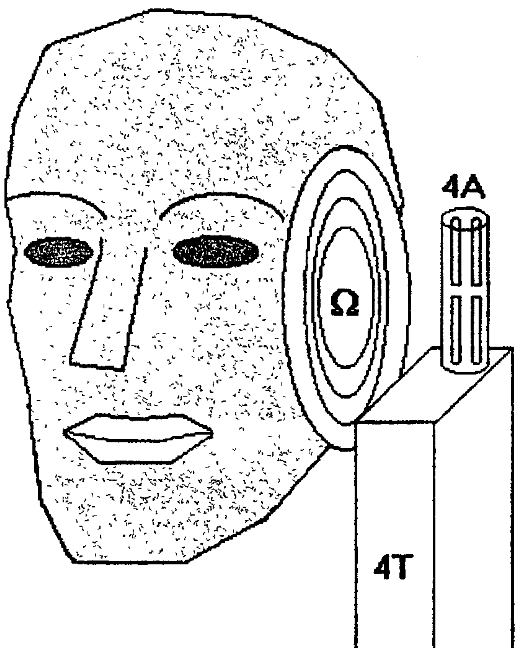
(81) Designated States *(national)*: AE, AL, AU, BA, BB, BG, BR, CA, CN, CU, CZ, EE, GD, GE, HR, HU, ID, IL, IN, IS, JP, KP, KR, LC, LK, LR, LT, LV, MG, MK, MN, MX, NO, NZ, PL, RO, SG, SI, SK, TR, TT, UA, US, UZ, VN, YU, ZA.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*
— *With amended claims.*

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

(54) Title: ANTENNA FOR MOBILE RADIOCOMMUNICATIONS EQUIPMENT



(57) Abstract: A new category of antennas for mobile communications devices specifically designed for reducing the emitted power dissipated within biological tissues of the user of the device. The antenna, operating in a single or a multiple band of frequencies, is constituted by an array of radiating elements fed with relative powers and phases specifically chosen to yield, through superposition effects, a small electric field in a region close to the antenna and normally occupied by biological tissues of the user of the device and thus reducing the SAR within said region.

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ANTENNA FOR MOBILE RADIOCOMMUNICATIONS EQUIPMENT

DESCRIPTION

TECHNICAL FIELD

The present invention relates to a new category of antennas for mobile radiocommunications devices characterized by a low fraction of the radiofrequency power emitted for communication purposes which is dissipated within the tissues of the user's body when the equipment is employed near the body itself. A typical example is that of hand-held mobile phones operating near the user's head.

BACKGROUND ART

In the last years the market of radiofrequency communications devices, such as cellular phones, has had an enormous development. Such wide use of radiofrequency devices close to the human body has raised doubts and concerns about possible adverse effects on health related to the exposure of delicate body tissues to the strong electromagnetic fields generated by such devices. Furthermore, recent studies have shown that, on average, about one-half of the power emitted by hand-held cellular phones is absorbed by the tissues of the user's head (see, for instance, the European Project COST 244), and so such power is wasted from the point of view of radiocommunication.

Present technology has proposed various solutions to the above problem, such as directional antennas realized by means of microstrip or slot antennas, or various kind of absorbing or reflecting structures to reduce the emission in direction of the head.

The physical quantity commonly used to measure the amount of power dissipated within lossy dielectric materials, such as human tissues, is the Specific Absorption Rate, SAR, defined as:

$$SAR(\vec{x}) = \sigma(\vec{x})\rho(\vec{x})^{-1} \, | \vec{E}(\vec{x}) |^2,$$

where $\vec{x}$ is the position in which the SAR is evaluated, $\sigma(\vec{x})$ is electrical conductivity of material in S/m, $\rho(\vec{x})$ is the density of material in Kg/m^3, $|\vec{E}(\vec{x})|$ is the rms value of the electric field strength in the material in V/m. International scientific and engineering associations have fixed limits and guidelines for the SAR values in the human body, see for instance IEEE C95.1-1991 and CENELEC ES 59005.

DISCLOSURE OF THE INVENTION

The present invention represents an enhancement of the antenna design explicitly aimed towards a substantial reduction of the SAR within biological tissues close to the antenna. Such enhancement is achieved by introducing a new category of antennas (henceforth indicated simply as 'antenna') characterized by the possibility of controlling and reducing the electromagnetic field in a chosen region near the antenna itself. Such region will be chosen so that it corresponds to a region occupied by biological tissues of the user during the functioning in the intended or normal operating position of the radiocommunication device on which the antenna is mounted. Other advantages of said antenna are the low production cost, the possibility of working on multiple bands of frequencies, and its small size and weight compatible requirements of small mobile radiocommunications devices. Furthermore, since said antenna reduces the amount of power dissipated within the user's tissues, and therefore is not available for communications purposes, it has the effect of allowing longer talk time or smaller and lighter batteries.

The antenna object of the present invention is characterized (Claim 1) by an array of two or more radiating elements, not necessarily identical or of the same kind, and a feeding network which feeds the radiating elements of the array with powers and phase shifts chosen according to the principle illustrated below to the purpose of reducing the SAR within a specified region occupied by biological tissues during the functioning in the intended use position of the device on which said antenna is mounted. In general, if there are N radiating elements forming an array, the total electric field $\vec{E}(\vec{x},t)$ at a given frequency in a point $\vec{x}$ of the space and at the time t is given by

$$\vec{E}(\vec{x},t)=\sum_{n=1}^{N}V(t)_n\vec{F}(\vec{x})_n,$$

where $V(t)_n$ are the voltages applied to the feeding gaps of the elements of the array, $\vec{F}(\vec{x})_n$ are computable functions which depend on the geometry of the system only, and can be called structure factors. Such structure factors account also of the mutual interaction between the radiating elements and of the objects surrounding the array. A similar expression holds for the magnetic field.

Given the N structure factors, namely fixed the geometry of the array, of the device on which the antenna is mounted and of the surrounding objects, and fixed the total radiated power, it is always possible to find at least one combination of the N voltages $V(t)_1,\ldots,V(t)_N$, by varying independently magnitudes and phases, which minimizes the rms value of the total electric (or magnetic) field in an arbitrary chosen point $\vec{x}$ of the space.

In conventional antennas constituted by an array of elements said structure factors and feed voltages are chosen in order to have the desired radiation pattern at large distance from the antenna, namely to reduce the radiated electromagnetic field in the far-field region in specified directions. On the contrary, in the antenna object of the present invention the structure factors and the feed voltages are chosen in order to minimize or reduce the SAR integrated over a chosen region, indicated as Ω, which is occupied by user's biological tissues in the intended use position of the device mounting said antenna. Otherwise stated, in said antenna, given a certain geometry and the total radiated power, the voltages are chosen so that the quantity

$$\int_{\Omega} \sigma(\vec{x})\rho(\vec{x})^{-1} \,|\, \vec{E}(\vec{x}) \,|^2 \, dV ,$$

is minimized or reduced. The structure factors of the array can be chosen to have a good gain in the directions away from Ω more useful for transmission. For instance, if said antenna is mounted on a cellular phone whose intended use position is near the ear of the user, said region Ω shall be chosen so that it corresponds to the part of the head closer to the antenna.

The SAR reduction achievable by means of said antenna is much larger than that achievable by means of a simple directional antenna which does not radiate in the direction of the region Ω but without near-field control; in fact, the reactive near field for a directional antenna can be relatively high even in directions corresponding to minima in the far-field radiation pattern.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1) Antenna constituted by an array of two radiating elements each in dipolar configuration and feeding circuit.

FIG. 2) Antenna constituted by an array of two radiating elements each in monopolar configuration over a ground plane and feeding circuit.

FIG. 3) Antenna constituted by an array of two radiating elements embedded in a dielectric material.

FIG. 4) Antenna constituted by an array of two radiating elements mounted on a mobile radiocommunication device in the intended use position near the user's head. The shaded zone represent a possible region in which the SAR is minimized.

FIG. 5) Computed radiation pattern in the horizontal plane for the antenna in FIG. 1.

BEST MODE OF CARRING OUT THE INVENTION

A particular mode of realizing the invention (Claim 4) consists of an antenna constituted by an array of two radiating elements, not necessarily identical or of the same kind, with the following characteristics:

a) substantially symmetric with respect to an axis.

b) when each element radiates in free space it shows a substantially omnidirectional radiation pattern with maximum gain in a plane perpendicular to the symmetry axis of the radiator itself.

Such requirements are satisfied, for instance, by dipoles, by monopoles over a ground plane, by helices in the normal mode in monopolar or dipolar configuration (i.e. a dipole in which the two branches are two helices), by conical elements in monopolar or dipolar configuration, by dipoles and monopoles realized as elements printed on a substrate.

The elements of the array are disposed side-by-side, namely with the symmetry axis parallel to each other, and embedded in a dielectric medium, which can also be air. The electrical properties of the material, its form and the characteristics of its surface change said structure factors $\vec{F}(\vec{x})_n$, $n=1,2$, allowing to adjust the antenna characteristics. In particular, the use of a material with relative dielectric constant ε greater than one allows to reduce the dimensions of the array. Simple and convenient forms for the dielectric material in which the array is embedded are that of a cylinder with elliptical section and that of an ellipsoid.

The array of elements in dipolar configuration is illustrated in FIG. 1, the array of elements in monopolar configuration is illustrated in FIG. 2. Elements indicated as 1E in FIG.1. and 2E in FIG. 2 may correspond to metallic cylinders, helices, cones or other forms satisfying the above requirements. In the intended use position the symmetry axis of the radiating elements is approximately parallel to plane tangent to the biological tissue of the user, for instance the head; the plane defined by the two symmetry axis is approximately perpendicular to said tangent plane, see FIG. 4.

The radiating elements forming the array are fed with the voltages, or equivalently powers, and the relative phase which minimize the SAR in the chosen region according to the procedure described above. The region Ω introduced above is chosen to correspond to the part of the user's biological tissues closer to the antenna in the intended use position of the device on which the antenna is mounted. Said procedure can be implemented by means of both calculations, analytical or numerical, and direct measurements. For instance, if the antenna, to be mounted on a cellular phone, is formed by an array of two $\lambda/2$ thin dipoles in air and separated by $\lambda/10$ at the frequency of 1800 MHz and if the user's head is represented by a sphere of dielectric material with $\varepsilon = 44$ and $\sigma = 1$ S/m distant 10 mm from the antenna, then a numerical calculation based on the method of moments shows that the SAR within the sphere is minimized provided that the power which feeds the dipole closer to the sphere is about -13 dB with respect to that which feeds the other dipole, and its relative phase is about +30 degrees. The same calculation shows that the reduction of the integrated SAR with respect to that of a single $\lambda/2$ dipole radiating the same power can be as large as 95%. Moreover, the SAR reduction is effective over a bandwidth larger than 10% without changing feed powers and phase shifts. The expected radiation pattern without the head is illustrated in FIG. 5.

It should also be remarked that the directional emission does not have negative effects on the transmission, since the power emitted towards the user would be absorbed by his/her biological tissues in any case.

The array of radiating elements in the present example are fed by an electronic circuit suitable to split the power in an unequal way between the two feeding lines and to introduce a relative phase shift between the two resulting signals. The circuit is schematically represented in FIG. 1 and FIG. 2, but it can be realized in many different way. Conceptually, said circuit is composed by an unequal splitter (1R, 2R) of the signal coming from the RF generator (1G, 2G), one or more phase shifters (1S, 2S), and the impedance matching circuits (1A, 2A). The above components can be realized by means of both discrete components and transmission lines.

The feeding circuit can also be realized to achieve the SAR reduction over a larger bandwidth or over two or more separated bands of frequency (dual-band and multi-band): this can be done provided that in the feeding circuit the ratio of the signal splitter and the relative phase shifts change as a function of the frequency or of the operating band, for instance by means of variable power splitters, variable attenuators and variable phase shifters. In the case of dual or multi-band functioning, in general, it is sufficient to change the above parameters (i.e. ratio of the power splitting and phase shifts) depending on the band, and keep parameters fixed within a given band.

INDUSTRIAL APPLICABILITY

The antenna object of the present invention is easily industrially realizable since it does not require particular technologies for the realization neither of the array nor of the feeding circuit. Furthermore, said antenna has a wide industrial applicability since it represents a very effective solution for reducing the SAR in biological tissues of the user of a mobile radiocommunication equipment and, therefore, potentially dangerous effects of the electromagnetic field on user's health.

CLAIMS

1) Antenna for mobile radiocommunication devices characterized by an array of two or more radiating elements fed by signals of relative powers and of relative phases specifically chosen in order to minimize or reduce, through field superposition effects, the SAR due to the emission of the antenna itself in a chosen region which, in the intended use position of the device mounting said antenna, is occupied by biological tissues of the user of the device.

2) Antenna for mobile radiocommunication devices characterized by an array of two or more radiating elements as in Claim 1 in which the array is embedded in a dielectric material.

3) Antenna for mobile radiocommunication devices characterized by an array of two or more radiating elements as in Claim 1 or 2 in which the relative powers and of relative phases are changed according to the operating frequency or band of frequencies in order to minimize or reduce the SAR in the chosen region at that frequency or band of frequencies.

4) Antenna for mobile radiocommunication devices as described the part "Best mode for carring out the invention" and illustrated in FIG. 1 or FIG. 2 of drawings, namely characterized by an array of two radiating elements, not necessarily identical or of the same kind, each one being substantially symmetric with respect to an axis and, when radiating in free space, showing a substantially omnidirectional radiation pattern with maximum gain in a plane perpendicular to the symmetry axis of the radiator itself and said elements forming the array are fed by signals of relative powers and of relative phases specifically chosen in order to minimize or reduce, through field superposition effects, the SAR due to the emission of the antenna itself in a chosen region which, in the intended use position of the device mounting said antenna, is occupied by biological tissues of the user of the device.

5) Antenna for mobile radiocommunication devices as in Claim 4 in which the array is embedded in a dielectric material.

6) Antenna for mobile radiocommunication devices as in claim 4 in witch the array is embedded in a dielectric material shaped like a prism with elliptical base or an ellipsoid.

7) Antenna for mobile radiocommunication devices as in Claim 4 or 5 or 6 in which the relative powers and of relative phases are changed according to the operating frequency or band of frequencies in order to minimize or reduce the SAR in the chosen region at that frequency or band of frequencies.

AMENDED CLAIMS

[received by the International Bureau on 26 October 2000 (26.10.00); original claims 1-7 replaced by new claims 1-9 (2 pages)]

1) Antenna for mobile radiocommunication devices operating on multiple frequency bands characterized by an array of two or more radiating elements in which the relative powers and relative phases are changed according to the operating frequency or band of frequencies in order to minimize or reduce the SAR due to the emission of the antenna itself in a chosen region at that frequency or band of frequencies.

2) Antenna as in claim 1) characterized by an array of two radiating elements in which the first of said elements is closer to the chosen low SAR region than the second and said second element is a monofilar or bifilar short helical antenna and said first element is a monofilar or bifilar linear wire antenna and the two elements are arranged along parallel axis.

3) Antenna as in claim 1) or 2) in which the distance between the elements of the array is smaller than $\lambda/10$, where λ is the larger of the operating wavelengths of the device.

4) Antenna for mobile radiocommunication devices operating in close proximity to the user's body characterized by an array of $N \geq 2$ radiating elements in which, in the intended use position of the device, elements 1...N-1 are closer to the user's body than element N and in which the power feeding the array is divided between the N elements in such a way that most of the power feeds said element N and amplitudes and phases of the powers feeding said elements 1...N-1 are chosen in order to substantially cancel the currents induced in themselves by the electromagnetic field generated by said element N during the functioning of the device.

5) Antenna as in claim 4) with N=2 in which element 2 is a monofilar or bifilar short helical antenna and element 1 is a monofilar or bifilar linear wire antenna and the two elements are arranged along parallel axis.

6) Antenna as in claim 4) or 5) in which the distance between the two elements of the array is smaller than $\lambda/10$, where λ is the larger of the operating wavelengths of the device.

7) Antenna for mobile radiocommunication devices as in claim 1), operating in close proximity to the user's body, characterized by an array of $N \geq 2$ radiating elements in which the relative powers and the relative phases feeding the N-1 radiating elements closer to the user's body are changed according to the operating frequency or band of frequencies in order to substantially cancel the current induced in themselves by the

electromagnetic field generated by element N during the functioning of the device in all operating frequency bands.

8) Antenna for mobile radiocommunication devices as in claim 1) or claim 4) operating on separated frequency bands for transmitting and receiving in which the radiating elements closer to the user's body are characterized by a sharp resonance in correspondence of the transmitting frequency band so that in the receiving band they presents a high impedance mismatch with respect to the transmission line connecting them to the transmitter/receiver electronic circuit of the device in order to reduce the directivity of the antenna in the receiving band.

9) Antenna for mobile radiocommunication devices as in any of the preceding claims in which the array is embedded in a dielectric material.

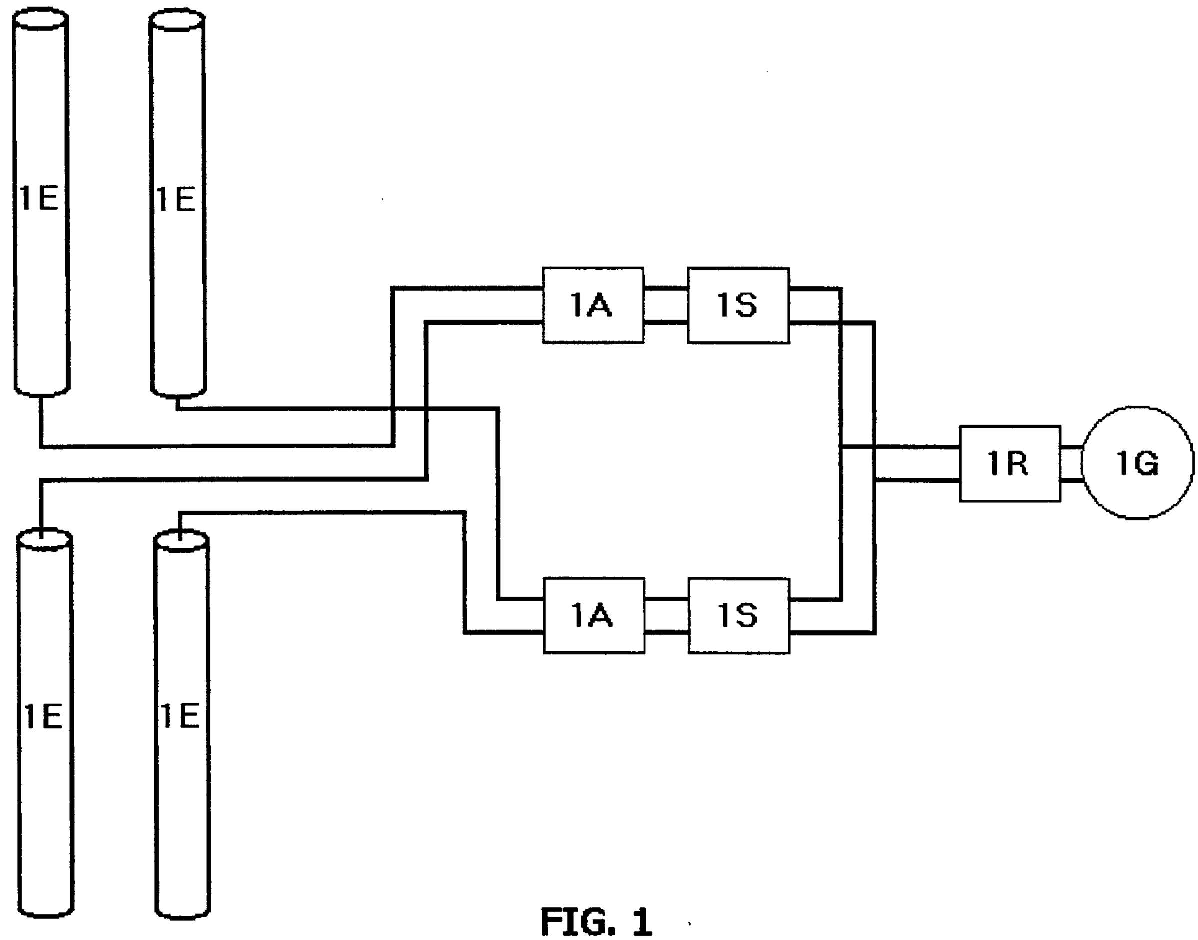

FIG. 1

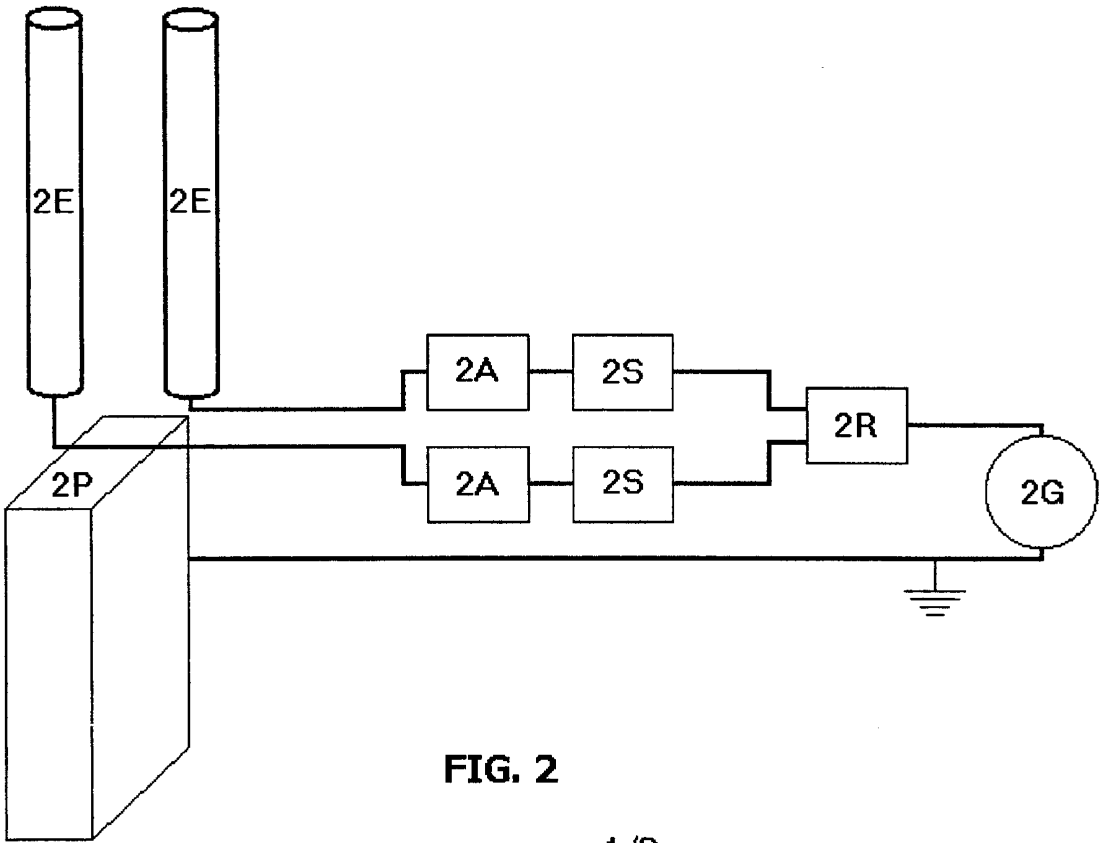

FIG. 2

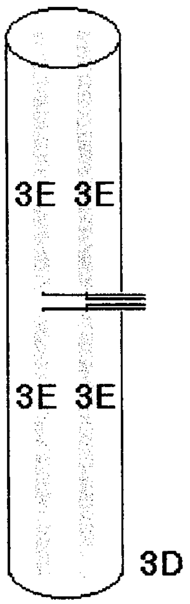

FIG. 3

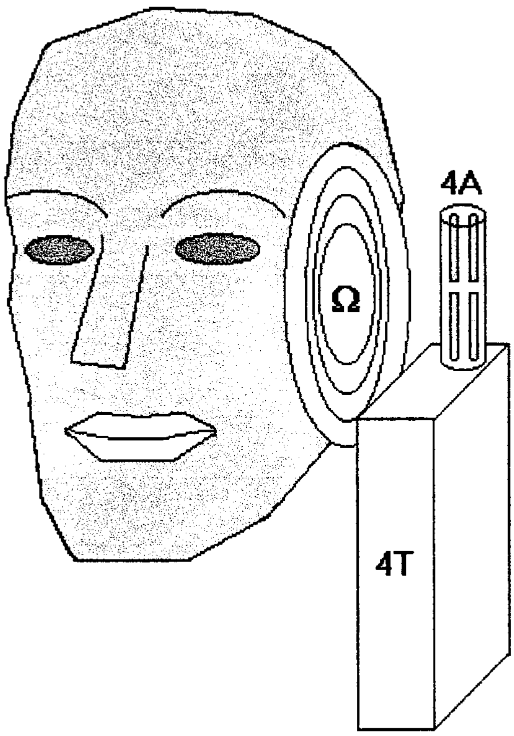

FIG. 4

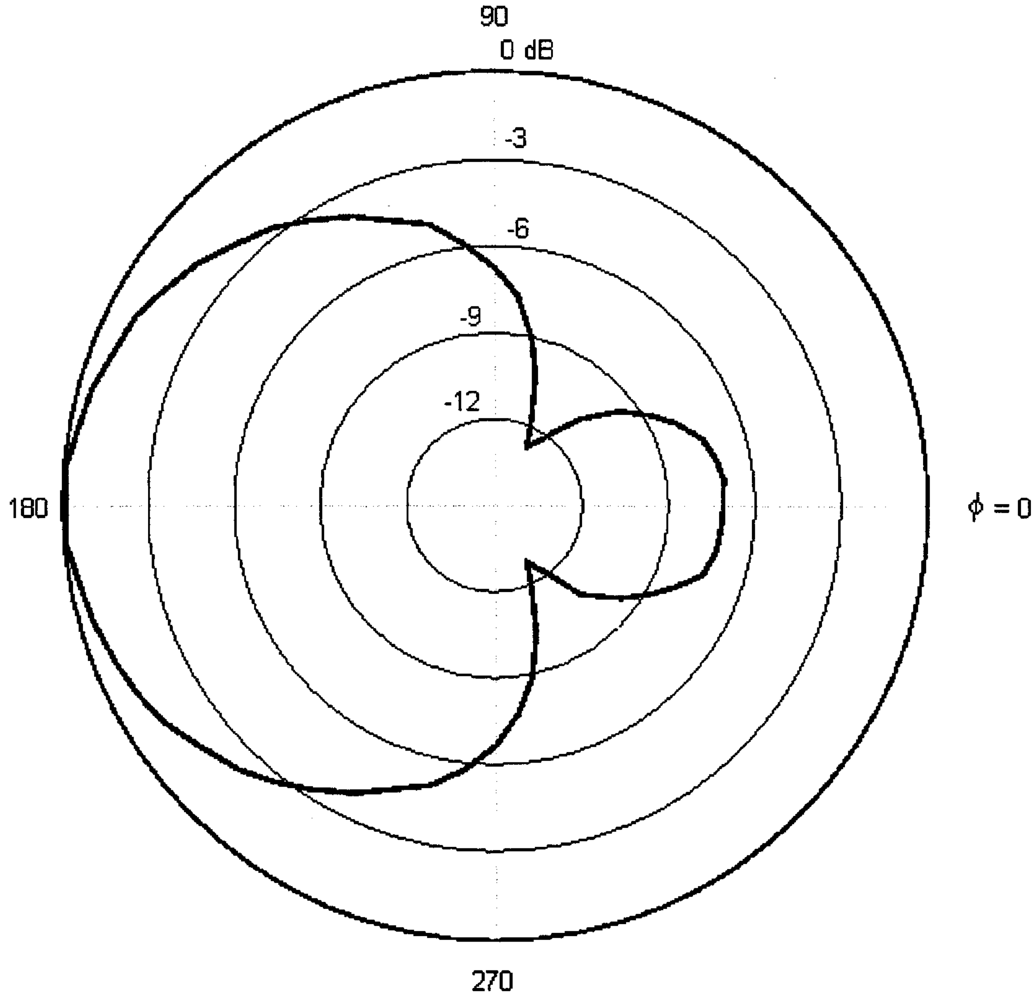

FIG. 5

INTERNATIONAL SEARCH REPORT

Interr. ,onal Application No
PCT/IT 99/00260

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01Q1/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01Q

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 94 14208 A (UNIV BRADFORD ;MCEWAN NEIL JOHN (GB)) 23 June 1994 (1994-06-23) page 9, line 25 -page 12, line 21; claims 9,13-17; figures 16-20	1,4
Y		2,5,6

X	NOGUCHI K ET AL: "DIRECTIONAL ANTENNA FOR PORTABLE TELEPHONES" IEEE INTERNATIONAL CONFERENCE ON UNIVERSAL PERSONAL COMMUNICATIONS,US,NEW YORK, IEEE, vol. CONF. 4, 1995, pages 369-372, XP000689975 ISBN: 0-7803-2955-4 the whole document	1,4

X	DE 297 22 794 U (GLATHE JENS ;PETER HEINZ (DE)) 15 April 1999 (1999-04-15) the whole document	1,4

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
22 March 2000	29/03/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Inter. ..ional Application No
PCT/IT 99/00260

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 45893 A (ERICSSON TELEFON AB L M) 15 October 1998 (1998-10-15) page 4, line 23 -page 5, line 14 page 13, line 5-17; figures 2A-3	1,4
X	WO 98 29968 A (AT & T CORP) 9 July 1998 (1998-07-09) page 8, line 15 -page 9, line 2 page 12, line 8 -page 13, line 31; figures 6-9B	1,4
Y	WO 94 28595 A (UNIV GRIFFITH ;LU JUN WEI (AU); KEEFE STEVEN GREGORY O (AU); THIEL) 8 December 1994 (1994-12-08) page 8, line 19 -page 9, line 3 page 10 -page 11; claims 1,9; figures 2,3	2,5,6
A	EP 0 447 218 A (HUGHES AIRCRAFT CO) 18 September 1991 (1991-09-18) column 1, line 1-8,43-55 column 14, line 4 -column 15, line 5; figures 8,9	3,7

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IT 99/00260

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9414208	A	23-06-1994	AU	5658294	A	04-07-1994
DE 29722794	U	15-04-1999	NONE			
WO 9845893	A	15-10-1998	SE	509140	C	07-12-1998
			AU	7089398	A	30-10-1998
			SE	9701322	A	11-10-1998
			US	5990839	A	23-11-1999
WO 9829968	A	09-07-1998	US	5949369	A	07-09-1999
WO 9428595	A	08-12-1994	AU	679992	B	17-07-1997
			AU	6789194	A	20-12-1994
			EP	0700585	A	13-03-1996
			EP	0954050	A	03-11-1999
			JP	10502220	T	24-02-1998
EP 0447218	A	18-09-1991	US	5043738	A	27-08-1991
			CA	2035975	C	17-01-1995
			DE	69119275	D	13-06-1996
			DE	69119275	T	19-12-1996
			JP	2569230	B	08-01-1997
			JP	7046033	A	14-02-1995