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(71) Applicant *(for all designated States except US)*: **NOKIA CORPORATION** [FI/FI]; Keilalahdentie 4, FI-02150 Espoo (FI).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **OLLIKAINEN, Jani** [FI/FI]; Ulvilantie 29/3 D 224, FI-00350 Helsinki (FI). **LEHTOLA, Antero** [FI/FI]; Itäinen Rantakatu 70 B 24, FI-20810 Turku (FI). **KROGERUS, Joonas** [FI/FI]; Kalastajanmäki 7 A 18, FI-02230 Espoo (FI). **RAHOLA, Jussi** [FI/FI]; Holmanpää 1 B, FI-02240 Espoo (FI).

(74) Agent: BERGGREN OY AB; P.O. Box 16 (Annankatu 42 C), FI-00101 Helsinki (FI).

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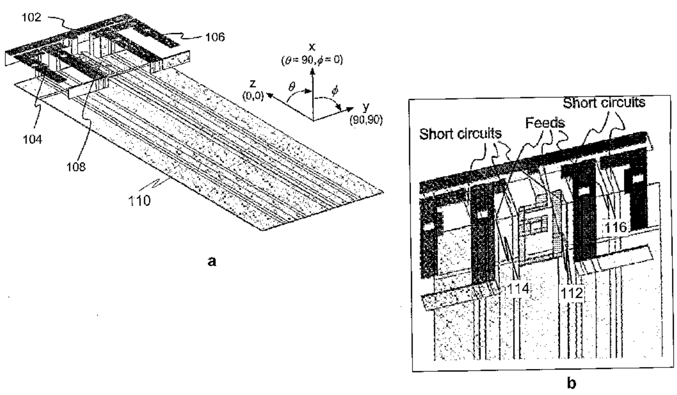

(57) Abstract: The invention relates to a radio antenna (100) and, more specifically, to an internal multiband antenna for use, e.g., in a portable telecommunication device, such as a mobile phone. In particularly the invention relates to an antenna module for a mobile terminal including a non-resonant antenna element (102), two resonant antenna elements (104, 106) each covering at least any one of a first, second, third and fourth frequency band, said two resonant elements are substantially in the same plane and define a planar surface wherein the two resonant elements (104, 106) are each positioned at a corner of the planar surface and the non-resonant element (102) is positioned along an edge of the planar surface.

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MULTIBAND ANTENNA ARRANGEMENT

TECHNICAL FIELD OF THE INVENTION

The invention relates to a radio antenna and, more specifically, to an internal multiband antenna for use e.g. in a portable telecommunication device, such as a mobile phone.

BACKGROUND OF THE INVENTION

Current wireless communication systems utilize several different radio communication standards and operate at many different frequency bands. In this fractured service environment, terminals operating in multiple systems and frequency bands offer a better service coverage than single-band and single-system terminals. One example of a multiband communication terminal is a mobile phone operating for example at four GSM bands, namely GSM850 (824-894 MHz), GSM900 (880-960 MHz), GSM1800 (1710-1880MHz), GSM1900 (1850-1990 MHz) and further at the UMTS band (1920-2170 MHz).

Compact multiband antenna configurations with good performance are needed to realize multiband mobile terminals and/or base stations. Current mobile terminals typically have one multiband antenna and one feed for the GSM bands and another antenna and feed for UMTS. At the same time as the space for the antennas in the mobile terminal is becoming very limited, there is a need to fit more and more antennas inside the terminal, for example to implement mobile antenna diversity.

Antenna diversity can be and is used to improve the performance of radio devices in a multipath propagation environment. In antenna diversity, two or more antennas operating at the same frequency band are used to receive the same information over independently fading radio channels. When the signal of one channel fades, the receiver can rely on the other antenna(s) to offer a higher signal level. Alternatively, it is also possible to combine two or more signals in such a way that interference caused by other transmitting devices reduces. The price for improved performance is, however, increased complexity. Generally, diversity can provide, for example, better call quality, improved data rates, and increased network capacity without the use of extra frequency spectrum. Diversity can also provide longer battery life or duration. When implemented in mobile terminals, the benefits of antenna diversity can be utilized without investments in the network infrastructure. In mobile terminals, the use of multiple antennas for one system can also reduce the effect of the user on the antenna performance.

However, some problems relate also to sizes of antennas. One of the main problems of small antennas is small operation bandwidth. The bandwidth is interrelated with efficiency and antenna size so that one of the mentioned characteristics can only be improved (antenna size decreased) at the expense of others. For example, if a larger antenna bandwidth is needed for a new communication system or for implementing a new antenna function, such as diversity, the simplest way to do this is to increase the antenna size or to trade off some of the total efficiency. However, in small portable radio equipment neither one of the mentioned methods is desirable. Usually, they are accepted only in compelling circumstances.

Fortunately, there are known methods, such as, introducing multiple resonances with resonant matching circuits and parasitic elements, which can be used to increase the operation bandwidth up to a certain limit without degrading the efficiency. However, these methods typically increase the complexity of the antenna.

Furthermore, the performance of a small antenna in a relatively small terminal depends also on the location and orientation of the antenna(s) as well as the size and shape of the terminal. Finding suitable locations for the antenna in the terminal can be at least as important for the performance as the actual antenna structure.

To design compact and efficient internal handset antennas that operate e.g. at four GSM bands (GSM850/900/1800/1900) and the UMTS band is very challenging. The problem becomes even more difficult, if multiple antennas operating at a given frequency band, such as diversity antennas, have to be included in a mobile terminal. If total antenna size cannot be increased when a new antenna or operation band is added, the sizes of the existing antennas must then be decreased, which leads without exception to degradation of the performances of the existing antennas.

Further problems arise when two antennas operating at the same frequency range are placed close to each other because they tend to couple to each other. In diversity and MIMO (Multiple Input Multiple Output) applications, mutual coupling decreases the efficiency of the coupled antennas reducing the improvement from that, which would be possible with perfectly isolated antennas, which can be designed more independently. Furthermore, mutual coupling complicates antenna design as it causes modifications made to one antenna to affect also the others. Large isolation between antennas operating at different bands is also useful because it can allow simplifying the RF front end. However, it can be very challenging to design antennas that have e.g. over 10 dB isolation in the limited space allowed for internal antennas of modern mobile terminals.

In addition low correlation between antenna signals is a prerequisite for the improvement of the radio link performance with diversity or MIMO. Generally, it is not obvious that low correlation can be achieved in the small space allowed for the internal antennas of modern mobile terminals. In current mobile phones, various components such as a camera, speaker or both have often been located at least partly between the internal antenna element and its ground plane. These additional components can degrade the antenna performance. Thus it would be desirable to find antenna solutions that would enable the integration of other components in their proximity with minimal degradation of antenna performance.

Furthermore, the hand of a user can also be problematic for antenna performance, because it typically degrades the performance of mobile phone antennas at the frequency ranges in question (0.8 GHz – 2.2 GHz). The effect is very strong when the hand is at least partly on top of the antenna, and unfortunately it is very common that the user often holds the phone so that the forefinger is on top of the antenna element near the top of the phone. It would be desirable to find antenna configurations in which internal antennas are placed so that the effect of the user's head, hand, or other body parts have a minimal influence on their performance.

Relating to the problems mentioned above, it is known that the bandwidth of a small antenna can be increased using resonant matching circuits and parasitic elements. Moreover, it is known that generally increasing the distance between antennas increases isolation between them. In addition, it is well accepted that the isolation depends on the relative orientation of the antennas.

However, according to the inventors' experience, when additional antennas are added between two antennas to be isolated, whether the isolation increases or decreases depends on the type of the additional antenna as well as its relative orientation to the antennas to be isolated. Hence, it is not obvious that merely locating any antenna or resonator between to antennas automatically increases isolation between them; it may also do the opposite.

SUMMARY OF THE INVENTION

The object of the invention is to provide a compact internal multiband mobile terminal antenna arrangement operating efficiently at all the commonly used cellular communication system bands and further enabling antenna diversity (and MIMO) and simple RF front end solutions. An additional object of the invention is that the compact internal multiband mobile terminal antenna arrangement has a sufficiently low envelope correlation (say $\rho e < 0.7$) between antenna signals for good diversity performance and sufficiently large isolation of about 10 dB or more.

The object of the invention is fulfilled, for example, with an antenna for a mobile terminal comprising a non-resonant antenna element, two resonant antenna elements each covering at least any one of a first, second, third or fourth frequency band, said two resonant elements are substantially in the same plane and define a planar surface wherein the two resonant elements are each positioned at a corner of the planar surface and the non-resonant element is positioned along an edge of the planar surface.

The following abbreviations are used in this document:

CDMA	Code division multiple access
GPS	Global positioning system
GSM	Global system for mobile communications
IFA	Inverted F-antenna
MIMO	Multiple input multiple output
PIFA	Planar inverted-F antenna
PWB	Printed wiring board
RX	Receive

TX	Transmit
UMTS	Universal mobile telecommunication system
WCDMA	Wideband CDMA

An exemplary embodiment of the invention relates to an antenna for a mobile terminal comprising a general ground element, one first separate lower band antenna covering the GSM850/900 frequencies and two second dual-resonant shorted patch antennas covering the GSM1800/1900/UMTS frequencies, wherein each of said antennas comprise a leg portion containing a feed arrangement for feeding the antenna against the ground element.

According to an advantageous embodiment of the present invention both of the two second antennas are adapted to cover the GSM1800, GSM1900, and UMTS frequencies. According to this embodiment of the invention the first of said two second antennas can be used as a main (GSM/UMTS) antenna and the second of said two second antennas as a diversity antenna. Alternatively, according to this embodiment the first of said two second antennas can be used as a main GSM antenna and UMTS diversity antenna, and the second of said two second antennas can be used as a main UMTS antenna and GSM diversity antenna.

In addition, if diversity is not needed, the first of said two second antennas can be used as a separate TX antenna and the second of said two second antennas is used as a RX antenna for GSM1800/1900/UMTS according to an embodiment of the present invention. Because said two second antennas (covering GSM1800/1900/UMTS) cover both TX and RX bands, it is also possible to use the antennas for TX and RX diversity as well as for MIMO. Furthermore in the case of separate TX and RX antenna application, it is possible to make the antennas considerably smaller because considerably smaller bandwidths will suffice (e.g. it will be enough to have 280 MHz + 365 MHz instead of 2 x 460 MHz).

Still according to an advantageous embodiment of the present invention the first separate lower band antenna and the first of said two second dual-resonant antennas can be adapted to cover the four GSM bands (GSM850/900/1800/1900) and the second of said two second dual-resonant antennas a separate UMTS antenna. This case also allows a considerable size reduction of two second dual-resonant antennas because of smaller bandwidth requirements. Because of suitable input impedances and large isolation between the first lower band antenna and two second dual-resonant antennas, it is possible to directly combine the separate feeds into one feed port to make the antenna module compatible with currently used RF front ends. Only minor adjustments in the antenna geometry are needed to re-optimize the performance.

Furthermore, by inserting short sections of transmission line between the feeds of the first lower band antenna and at least one of the two second antennas so that the first lower band antenna has optimally high impedance at GSM1800/1900/UMTS bands and said at least one of the two second antennas has optimally high impedance at GSM850/900 bands, the isolation between the ports can be maximized and no optimization is needed after combining the ports.

In addition, the two second antennas can be implemented according to a first embodiment of the present invention by two second dual-resonant coplanar shorted patch antennas. Still, the two second dual-resonant shorted patch antennas can be implemented according to a second embodiment of the present invention by two second dual-resonant stacked shorted patch antennas.

According to a further advantageous embodiment of the present invention the first separate lower band antenna is a T-shaped lower band element. The purpose of the T-shaped lower band element is to excite the longitudinally dipole-like resonant mode of the ground element. The folded T-shaped element itself is non-resonant, but is resonated with a separate matching circuit that provides a suitable parallel inductance and transforms the impedance.

The matching circuit is here realized as a short-circuited section of microstrip line. However, it could also be realized (at least partly) with any other known microwave technology, such as lumped components. According to an embodiment of the invention the matching circuit is located in the center area between the two second dual-resonant shorted patch antennas. It could as well be located closer to one of said two second dual-resonant shorted patch antennas or even on the opposite side of the ground plane, which would free the center area for some other purpose.

Because the first lower band antenna is implemented (according to an embodiment) with a separate feed, a multiresonant matching circuit can be easily added and optimized. However, the feed of the first lower band antenna can be combined with one of the upper band elements so that it is compatible with currently used front end solutions. It should also be possible to design a multiband matching circuit to the first lower band antenna so that it would operate also at GSM1800/1900 bands and perhaps even at the UMTS band, if necessary.

According to an embodiment of the present invention the two second antennas are advantageously positioned essentially symmetrically at the ground element corners. Furthermore the antennas are advantageously positioned as far away from each other as a form of the general ground element allows. In addition the antennas are advantageously positioned as far away from each other as a metal chassis of the mobile terminal allows. Still the first separate lower band antenna can be arranged to extend at least partly outside the general ground element or printed circuit board (PWB), or alternatively to locate totally on top of the general ground element or printed circuit board (PWB).

The present invention offers remarkable advantages over known prior art operating efficiently at all the commonly used cellular communication system bands. Further it for example enables the construction of a compact quad-band GSM and UMTS antenna that includes a tripleband diversity antenna. Alternatively it enables the separation of RX and TX functions of GSM1800/1900/UMTS into separate antennas, which can help simplify the RF front end. The separated TX and RX antennas have as good isolation as possible.

Current mobile terminals typically have only one multiband antenna and one feed for the GSM bands and another antenna and feed for UMTS. The isolation between the TX and RX bands is achieved using switches and filters. Separating the TX and RX functions into separate antennas as in the present invention could provide some of the necessary isolation between the TX and RX bands and enable the use of a simpler and less costly filtering solution in the RF front end.

Further the antenna module according to the invention has sufficiently low envelope correlation ($\rho e < 0.7$) for good diversity performance, and sufficiently large isolation of about 10 dB or more between the signals of the two GSM1800/1900/UMTS antennas can be achieved simultaneously. Moreover diversity antenna has wide bandwidth covering GSM1800/1900 and UMTS bands; 1710 MHz – 2170 MHz and good efficiency.

In addition adding the lower-GSM band element does not considerably increase coupling (decrease isolation) between the antennas. The separation of lower (850/900) and upper (1800/1900) GSM bands into different antennas allows independent optimization of the antennas making it easier e.g. to make the elements for both bands dual-resonant or multiresonant (and more wide-band). Owing to large isolation between lower and upper GSM bands, separate feeds can be easily combined if required by the RF front end architecture.

All antennas are located in a fairly small volume and can be positioned e.g. near the top of a monoblock phone so that they are not likely to be covered by the user's hand. All antennas can be integrated into one antenna module, which simplifies manufacturing (assembly) of terminals. Because all antennas are located close to each other, the transmitters and receivers can also be placed close to each other (integrated) and thus long and lossy RF lines are avoided. Additionally a mobile terminal has only a limited number of good antenna locations, whereupon a compact antenna module with so many antennas saves antenna locations for other, e.g. complementary (or non-cellular) radio antennas.

The invention relates to an antenna for a communication device comprising a non-resonant antenna element, two resonant antenna elements each covering at least any one of a first, second, third or fourth frequency band, said two resonant elements are substantially in the same plane and define a planar surface wherein the two resonant elements are each positioned at a corner of the planar surface and the non-resonant element is positioned along an edge of the planar surface, and further to an antenna module comprising said antenna.

The invention further relates to an antenna module comprising a non-resonant antenna element, two resonant antenna elements covering at least any one of a first, second, third or fourth frequency band, said two resonant elements are substantially in the same plane and define a planar surface and said two resonant elements are each positioned at a corner of the planar surface and the non-resonant element is positioned along an edge of the planar surface, wherein the antenna module couples to a printed circuit board comprising a ground plane and a matching circuit and the non-resonant element, matching circuit and ground plane form a third resonant element covering a fifth frequency range, and further to a mobile terminal comprising said antenna module.

In addition the invention further relates to a method of operating a mobile terminal for a mobile communication network, the mobile terminal having an antenna module and a general ground element, the antenna module comprising a one first separate lower band antenna covering the GSM850/900 frequencies and two second dual-resonant shorted patch antennas covering the GSM1800/1900/UMTS frequencies, wherein each of said antennas comprise a leg portion containing a feed arrangement for feeding the antenna against the ground element, wherein the method comprises the steps of:

- the first separate lower band antenna is used for the GSM850/900 frequencies, and
- at least one of the two second dual-resonant shorted patch antennas is used for the GSM1800/1900/UMTS frequencies.

BRIEF DESCRIPTION OF THE DRAWINGS

Next the invention will be described in greater detail with reference to exemplary embodiments in accordance with the accompanying drawings, in which

Figures 1a & 1b illustrate a first exemplary arrangement for an antenna module according to an advantageous embodiment of the invention,

Figures 2a – 2c illustrate simulated and measured frequency responses of S-parameters for the first exemplary arrangement for an antenna module in free space,

Figures 3a – 3c illustrate examples of simulated 3-D radiation patterns showing total realized gain (dBi) and polarization ellipses for the first exemplary arrangement for an antenna module in free space, Figures 4a & 4b illustrate a second exemplary arrangement for an antenna module according to an advantageous embodiment of the invention,

Figures 5a & 5b illustrate frequency responses of S-parameters for the second exemplary arrangement for an antenna module,

Figures 6a – 6c illustrate examples of simulated 3-D radiation patterns showing total realized gain (dBi) and polarization ellipses for the second exemplary arrangement for an antenna module,

Figures 7a & 7b illustrate geometry of a modified first exemplary antenna module according to an advantageous embodiment of the invention, and

Figures 8a – 8c illustrate simulated frequency responses of S-parameters for the modified first exemplary antenna module in free space.

DETAILED DESCRIPTION

Figures 1a & 1b illustrate a first exemplary arrangement for an antenna module 100 according to an advantageous embodiment of the invention, where the antenna module 100 consists of a separate lower band antenna 102, which is advantageously designed for the GSM850 (824 - 894 MHz) and E-GSM900 bands. In addition, the antenna module 100 comprises two dual-resonant coplanar shorted patch antennas 104, 106. The two dual-resonant coplanar shorted patch antennas 104, 106 are advantageously located symmetrically at the corners of the ground element 110.

In alternative embodiments the dual resonant coplanar shorted patch antennas may be any antenna element, for example it could be a resonant or non-resonant antenna element. A non-resonant antenna element may be made resonant with the use of a matching circuit and coupled to aground plane structure. The use of a dual resonant antenna element is a preferred embodiment as this will allow operation at multiple frequency bands.

The two dual-resonant coplanar shorted patch antennas 104, 106 both cover advantageously the GSM1800, GSM1900, and UMTS frequencies. They could also be used e.g. so that for example antenna 104 is the main (GSM/UMTS) antenna and antenna 106 is the diversity antenna.

Alternatively, antenna 104 could be used as the main GSM antenna and UMTS diversity antenna, whereas antenna 106 is used as the main UMTS antenna and GSM diversity antenna. If diversity is not needed, they 104, 106 could be used as separate TX and RX antennas. In that case, their sizes can be decreased because the required operation bandwidths are smaller.

The lower band antenna 102 comprises advantageously a T-shaped element, which in this implementation extends partly outside the printed circuit board (PWB), and a separate matching circuit 108 that provides a suitable parallel inductance for resonating the antenna and transforms the input impedance level. Alternatively the T-shaped element can also be located totally on top of the PWB. The matching circuit 108 is here realized as a short-circuited section of microstrip line. However, it could also be realized (at least partly) with any other known microwave technology, such as lumped components. In this embodiment, the matching circuit 108 is located in the center area between the two antennas 104, 106. It could as well be located closer to e.g. antenna 104 or even on the opposite side of the ground element 110, which would free the center area for some other purpose, such as a camera or speaker. Because the lower GSM-band antenna 102 is implemented with a separate feed 112, a multiresonant matching circuit can be easily added and optimized. The feed 112 of the antenna 102 can be combined with one 114, 116 of the upper band antennas 104, 106 so that it is compatible with currently used front end solutions.

In this embodiment the largest dimensions of the antenna module 100 are 40 mm × 29.4 mm × 8.2 mm (W × L × H). It occupies a total volume of 9.6 cm^3 (open space between the two dual-resonant coplanar shorted patch antennas 104, 106 has not been subtracted). It may still be possible to make the two dual-resonant coplanar shorted patch antennas 104, 106 more compact and to increase the open space between them. The antenna module 100 in Figures 1a & 1b is attached to a 40 mm × 115.2 mm × 0.2 mm (W × L × H) ground element 110. The top part of the antenna extends 4 mm outside the ground element 110. The total length of the phone model is 119.2 mm. The antennas 102, 104, 106 and the ground element 110 were photoetched from 0.2 mm-thick sheet of tin bronze.

Figures 2a & 2b illustrate simulated and measured frequency responses of S-parameters for the first exemplary arrangement of an antenna module 100 (described in Figures 1a & 1b) according to the embodied invention in free space. Especially a graph 200a in Figure 2a illustrates simulated and measured reflection coefficients (S_{11}, S_{22}, S_{33}) and a graph 200b in Figure 2b simulated and measured couplings (S_{21}, S_{31}, S_{32}) between antennas. Markers on S_{11} curve are at 824, 960, 1710, and 2170 MHz, and markers on S_{22} & S_{33} curve are at 1710 and 2170 MHz. The simulations can be performed, for example, with some commercially available Method of Moments (MoM) based full-wave electromagnetic simulator. A graphs 200a and 200b have x-axes denoting frequency in GHz units and y-axes denoting magnitudes of S parameters in dB units.

The measured and simulated results agree well enough to prove the functionality of the antenna concept. The measured center frequencies of two dual-resonant coplanar shorted patch antennas are slightly too low, but they can be easily corrected by shortening the strips so that at least a 6 dB return loss is obtained over the upper GSM and UMTS frequencies.

Also the simulated and measured couplings between the antennas (a chart 200b in Figure 2b) show the same features. Despite the slight detuning of the upper band, the 10 dB isolation suggested by the simulated result can be obtained also in the measurements.

Figure 2c illustrates a Smith's diagram for the corresponding curves illustrated in chart 200a in Figure 2a.

Figures 3a – 3c illustrate examples of simulated three dimensional (3-D) radiation patterns showing total realized gain (dBi) and polarization ellipses for the first exemplary arrangement of an antenna module 100 (described in Figures 1a & 1b) according to the embodied invention in free space, especially for the first lower band antenna 102 (denoted in Figure 3a as an Antenna 1) at 915 MHz and for the two dual-resonant coplanar shorted patch antennas 104, 106 (denoted in Figures 3b & 3c as an Antenna 2 and an Antenna 3, respectively) at 2110 MHz.

The plots show the total realized gain ($G_{r,\theta}$ + $G_{r,\phi}$) and polarization ellipses in different directions. The arrows in the polarization ellipses indicate the handedness of the polarization. As expected, at 915 MHz the free space radiation pattern of the prototype resembles that of a half-wave dipole, which indicates that the radiation mainly comes from the longitudinally half-wave dipole-like resonant currents of the ground plane. The patterns of the two dual-resonant coplanar shorted patch antennas 104, 106 (Figures 3b & 3c) show that the decorrelation between the antenna signals is mainly due to the different polarizations of the antennas in different directions. The main beams point to slightly different directions, but the effect of this is assumed smaller than that of the different polarizations.

In the Figures 3a – 3c, x-axes denote ϕ in degree units and y-axes denote θ in degree units in the standard spherical coordinate system used for antennas. The orientation of the antenna is given by the coordinate axes in Figures 1a & 1b, where x-axes point to the direction $\theta = 90°$ and $\phi = 0°$, y-axes point the direction $\theta = 90°$ and $\phi = 90°$, and z-axes point to the direction $\theta = 0°$ and $\phi = 0°$ in the standard spherical coordinate system.

Figures 4a & 4b illustrate a second exemplary arrangement for an antenna module 400 according to an advantageous embodiment of the invention, where the antenna module 400 also consists of a separate lower band antenna 402, which is advantageously designed for the GSM850 (824 - 894 MHz) and E-GSM900 bands. In addition, the antenna module 400 comprises two dual-resonant stacked shorted patch antennas 404, 406. The two dual-resonant stacked shorted patch antennas 404, 406 are advantageously located symmetrically at the corners of the ground element 410.

The two dual-resonant stacked shorted patch antennas 404, 406 both cover advantageously the GSM1800, GSM1900, and UMTS frequencies. They could also be used e.g. so that for example antenna 404 is the main (GSM/UMTS) antenna and antenna 406 is the diversity antenna. Alternatively, antenna 404 could be used as the main GSM antenna and UMTS diversity antenna, whereas antenna 406 is used as the main UMTS antenna and GSM diversity antenna. If diversity is not needed, they 406, 406 could be used as separate Tx and Rx antennas.

The purpose of the lower band antenna 402 is to excite the longitudinally dipole-like resonant mode of the ground plane 410. The lower band antenna 402 itself is non-resonant. It is resonated with a separate matching circuit 408, which provides a suitable parallel inductance and transforms the impedance. The matching circuit 408 is here realized as a short-circuited section of microstrip line, but it could be realized also with any other known microwave technology, such as lumped components. In this embodiment, the matching circuit 408 is located in the center area between the two dual-resonant stacked shorted patch antennas 404, 406. The matching circuit 408 could as well be located closer to e.g. antenna 404 or even on the opposite side of the ground element 410, which would free the center area for some other purpose, such as a camera. It should also be possible to design a multiband matching circuit to the first lower band antenna 402 so that it would operate also at GSM1800/1900 bands and perhaps even at the UMTS band, if necessary.

In this embodiment the largest dimensions of the antenna module are 40 mm × 21.5 mm × 8 mm (W × L × H). The upper and lower strips of the two dual-resonant stacked shorted patch antennas 404, 406 are only 3 mm wide. Excluding the matching circuit 410, the antenna module occupies a volume of less than 2.8 cm^3. The volume of one antenna of the two dual-resonant stacked shorted patch antennas 404, 406 is slightly less than 0.8 cm^3. Adding a second of the two dual-resonant stacked shorted patch antennas 404, 406 (diversity antenna) can be estimated to increase the total antenna volume by 38 %. The antennas are attached to a 40 mm × 115 mm (W × L) ground plane 410. Because the first lower band antenna 402 is not on top of the ground plane 410, it increases the total length of the phone model to 118.5 mm.

Figures 5a & 5b illustrate simulated frequency responses of S-parameters for the second exemplary arrangement of an antenna module 400 (described in Figures 4a & 4b) according to the embodied invention. Markers on S_{11} curve are at 824, 960, 2400, and 2500 MHz, and markers on S_{22} & S_{33} curve are at 1710 and 2170 MHz. The simulations can be performed, for example, with some commercially available Method of Moments (MoM) based full-wave electromagnetic simulator. A graph in Figure 5a has x-axis denoting frequency in GHz units and y-axis denoting magnitudes of S parameters in dB units.

The first lower band antenna covers the GSM850 and E-GSM900 bands with $L_{retn} \geq 6$ dB. When the ground element length is reduced, the size of the first lower band antenna must be increased to obtain the same bandwidth. The first lower band antenna has a resonance also near 2.45 GHz, which is quite poorly matched ($L_{retn} \geq 3$ dB) in the presented embodiment. However, by optimizing the design, it should be possible to obtain $L_{retn} \geq 6$ dB over the Bluetooth (WLAN) band. The two dual-resonant stacked shorted patch antennas cover the GSM1800, GSM1900 and UMTS bands with $L_{retn} \geq 6$ dB. The minimum isolation between these two dual-resonant stacked shorted patch antennas is around 12 dB.

Figures 6a – 6c illustrate examples of simulated three dimensional (3-D) radiation patterns showing total realized gain (dBi) and polarization ellipses for the second exemplary arrangement for an antenna module 400 (described in Figures 4a & 4b) according to the embodied invention, especially for the first lower band antenna 402 (denoted in Figure 6a as an Antenna 1) at 915 MHz and for the two dual-resonant stacked shorted patch antennas 404, 406 (denoted in Figures 6b & 6c as an Antenna 2 and an Antenna 3, respectively) at 2110 MHz.

The plots show the total realized gain ($G_{r,\theta} + G_{r,\phi}$) and polarization ellipses in different directions. In the Figures 6a – 6c x-axes denote ϕ in degree units and y-axes denote θ in degree units in the standard spherical coordinate system used for antennas. The orientation of the antenna is given by the coordinate axes in Figures 4a & 4b, where x-axes point to the direction $\theta = 90°$ and $\phi = 0°$, y-axes point the direction $\theta = 90°$ and $\phi = 90°$, and z-axes point to the direction $\theta = 0°$ and $\phi = 0°$ in the standard spherical coordinate system.

Figures 7a & 7b illustrate geometry of a modified first exemplary antenna module 700 according to an advantageous embodiment of the invention.

The modified first exemplary antenna module 700 illustrated in Figures 7a & 7b is re-designed for the application of separate TX and RX antennas. In this embodiment the antenna module size is decreased to 28.2 mm × 40 mm × 5 mm (length × width × height). The ground element dimensions are 115 mm × 40 mm (length × width). In this embodiment, the T-shaped top part of the antenna does not extend outside the PWB. To compensate for the decrease of bandwidth, the lower band element is made dual-resonant with a series-resonant LC-circuit connected in series with the original antenna feed (see Figure 8c).

Antenna feed 703 is for GSM850/900 TX & RX; feed 702 is for GSM1800/1900/UMTS RX; and feed 701 is for GSM1800/1900/UMTS TX.

Figures 8a - 8c illustrate simulated frequency responses of S-parameters for the modified first exemplary antenna module (described in Figures 7a & 7b) in free space. Especially Figure 8a illustrates reflection coefficients and couplings between antenna elements, Figure 8b reflection coefficients of the antennas on the Smith chart, and Figure 8c a matching circuit for the lower GSM band (port 3).

In this embodiment the impedance bandwidth at the lower GSM band is slightly smaller than required. However, based on the Smith chart of Figure 8b the matching circuit is not optimally tuned, but it is clearly possible to increase the bandwidth so that it covers GSM850/900 bands with at least 6 dB return loss. The desired 6 dB match is achieved at the upper GSM and UMTS bands.

In any of the embodiments outlined above it may be possible that any of these antennas may be frequency tunable so as to cover different frequency bands dependent upon the mode of operation of the mobile communication device.

The invention has been explained above with reference to the aforementioned embodiments, and several advantages of the invention have been demonstrated. It is clear that the invention is not only restricted to these embodiments, but comprises all possible embodiments within the spirit and scope of the inventive thought and the following patent claims. Each feature disclosed in the description, and (where appropriate) the claims and drawings may be provided independently or in any appropriate combination. Especially it should be clear for the skilled person that a mobile terminal, such as a mobile phone, can comprise at least one of the embodiments of the antenna module described in the following patent claims.

Claims

1. An antenna for a communication device comprising a non-resonant antenna element, two resonant antenna elements each covering at least any one of a first, second, third or fourth frequency band, said two resonant elements are substantially in the same plane and define a planar surface wherein the two resonant elements are each positioned at a corner of the planar surface and the non-resonant element is positioned along an edge of the planar surface.

2. An antenna according to claim 1, wherein the non-resonant antenna element is positioned so that it is adjacent to the two resonant antenna elements.

3. An antenna according to claim 2, further comprising a matching circuit coupled to the non-resonant element and a ground plane coupled to the antenna wherein the non-resonant element, matching circuit and ground plane form a resonant element covering a fifth frequency range.

4. An antenna module comprising the antenna of claim 1.

5. An antenna module comprising a non-resonant antenna element, two resonant antenna elements covering at least any one of a first, second, third or fourth frequency band, said two resonant elements are substantially in the same plane and define a planar surface and said two resonant elements are each positioned at a corner of the planar surface and the non-resonant element is positioned along an edge of the planar surface, wherein the antenna module couples to a printed circuit board comprising a ground plane and a matching circuit and the non-resonant element, matching circuit and ground plane form a third resonant element covering a fifth frequency range.

6. An antenna module according to claim 5 wherein the non-resonant element is positioned along an axis parallel to an edge of the printed circuit board.

7. An antenna module according to claim 5 further comprising a support structure wherein said non-resonant element and two resonant elements are located on a surface of said support structure.

8. An antenna module according to claim 5 wherein said non-resonant element and said two resonant elements form a substantially U shaped pattern.

9. An antenna module according to claim 5, wherein both of the two resonant antenna elements are dual-resonant antennas.

10. An antenna module according to claim 5 wherein the first of said two resonant antennas is a main antenna and the second of said two antennas is a diversity antenna.

11. An antenna module according to claim 5, wherein the first of said two resonant antennas is a separate TX antenna and the second of said two resonant antennas is a separate RX antenna.

12. An antenna module according to claim 5, wherein the third resonant element and the first of said two resonant antennas cover the first, second and fifth frequency bands and the second of said two resonant antennas covers the third and fourth frequency bands.

13. An antenna module according to claim 12 wherein the first ,second and third frequency bands are GSM frequency bands and the third and fourth frequency bands are WCDMA frequency bands.

14. An antenna module according to claim 5, wherein a feed of the third resonant element is combined with a feed of at least one of the two second resonant antennas.

15. An antenna module according to claim 5, wherein said two resonant antennas are implemented by two resonant stacked antennas.

16. An antenna module according to claim 5, wherein the non-resonant element is a T-shaped antenna element.

17. An antenna module according to claim 5, wherein the two resonant antennas are positioned symmetrically and coincide with the corners defined by a ground plane.

18. An antenna module according to claim 5, wherein the non-resonant antenna element extends at least partly outside a perimeter defined by the ground plane.

19. An antenna module according to claim 5 further comprising a tuning circuit wherein any one of the two second antenna elements may be tuned to operate at ony one of the first, second, third of fourth frequency bands.

20. An antenna module according to claim 5 wherein the matching circuit is realized as a short-circuited section of microstrip line.

21. An antenna module according to claim 5 wherein the matching circuit is located between the two resonant antennas

22. An antenna module according to claim 5 wherein the matching circuit is located on the opposite side of the ground plane than the antenna elements.

23. A mobile terminal comprising the antenna module of claim 5.

24. A method of operating a mobile terminal for a mobile communication network, the mobile terminal having an antenna module and a general ground element, the antenna module comprising a one first separate lower band antenna covering the GSM850/900 frequencies and two second dual-resonant shorted patch antennas covering the GSM1800/1900/UMTS frequencies, wherein each of said antennas comprise a leg portion containing a feed arrangement for feeding the antenna against the ground element, wherein in the method:

- the first separate lower band antenna is used for the GSM850/900 frequencies, and
- at least one of the two second dual-resonant shorted patch antennas is used for the GSM1800/1900/UMTS frequencies.

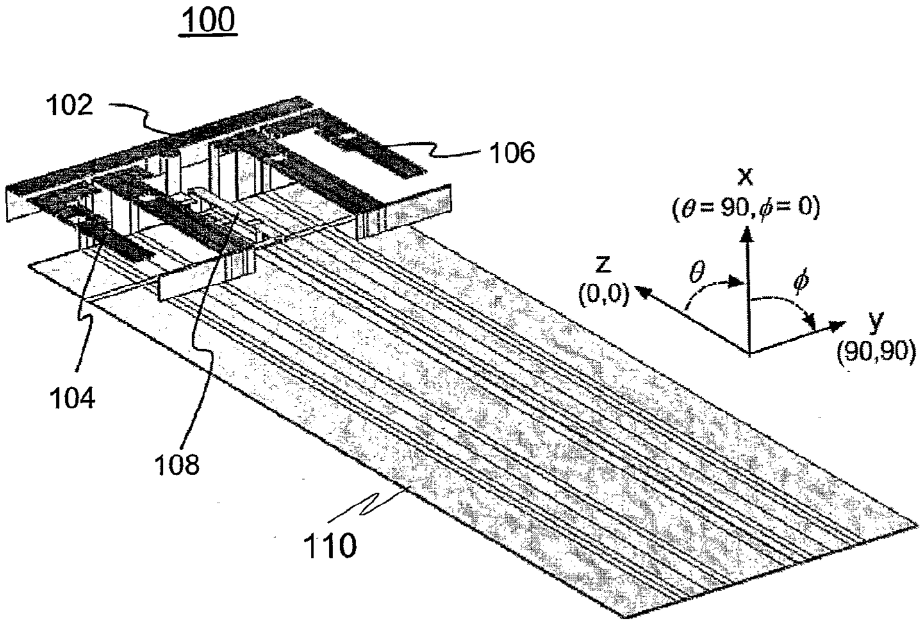

100
102
106
104
108
110
x
(θ = 90, φ = 0)
z
(0,0)
θ
φ
y
(90,90)

FIG. 1a

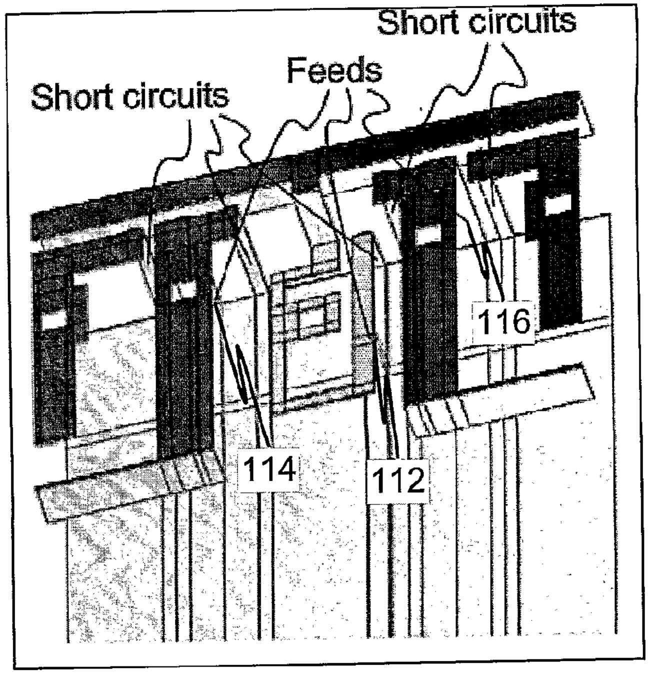

Short circuits
Feeds
Short circuits
116
114
112

FIG. 1b

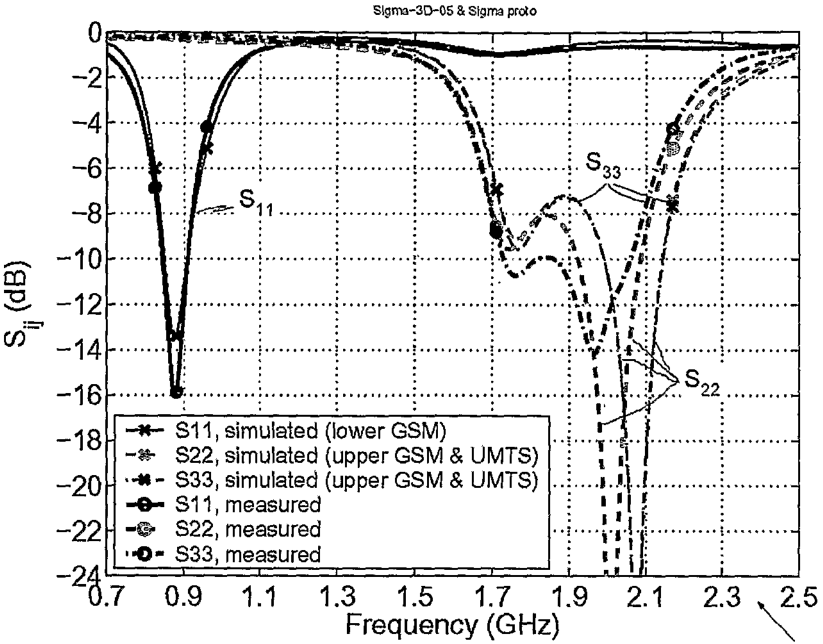


FIG. 2a

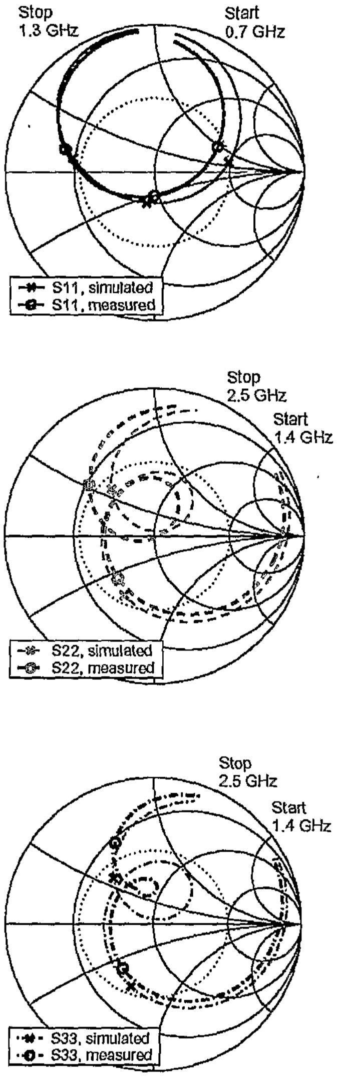


FIG. 2c

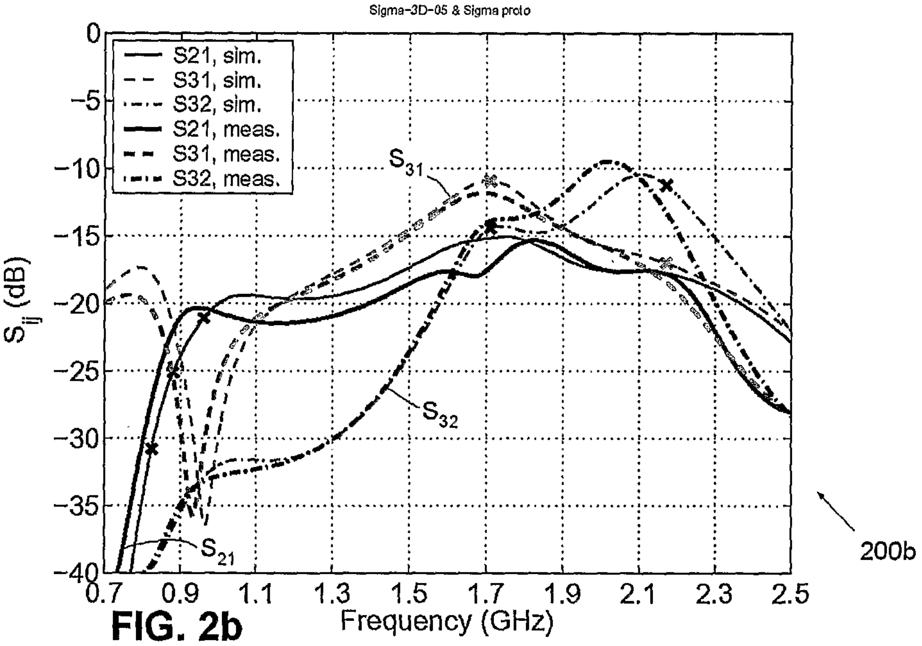


FIG. 2b

Antenna 1 (GSM), *f* = 915 MHz

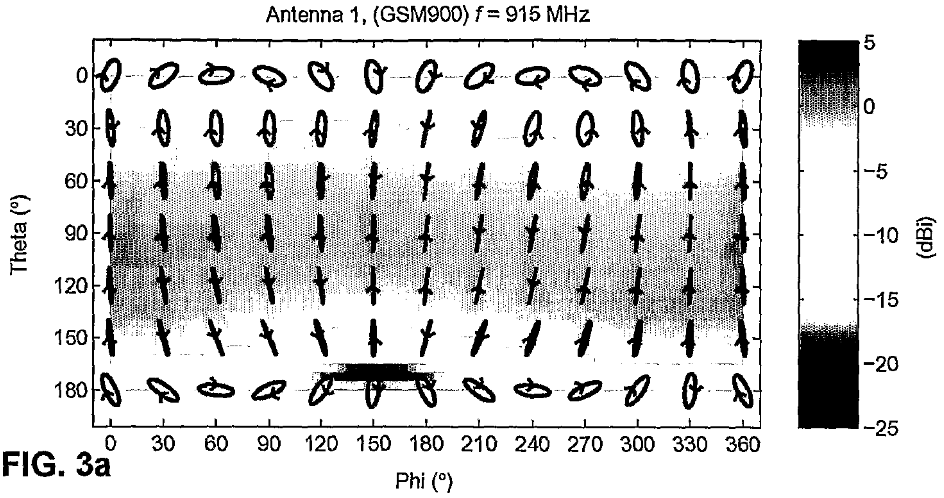


FIG. 3a

Antenna 2 (UMTS), *f* = 2.11 GHz

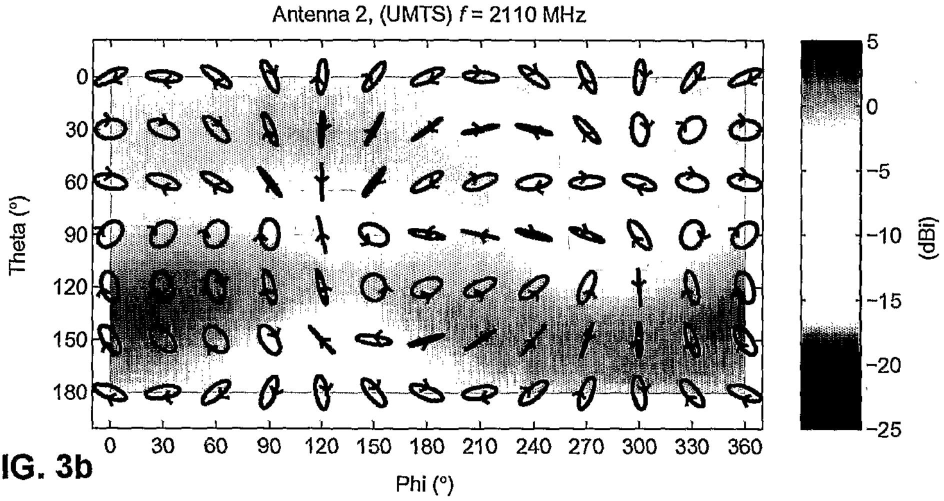


FIG. 3b

Antenna 3 (UMTS diversity), *f* = 2.11 GHz

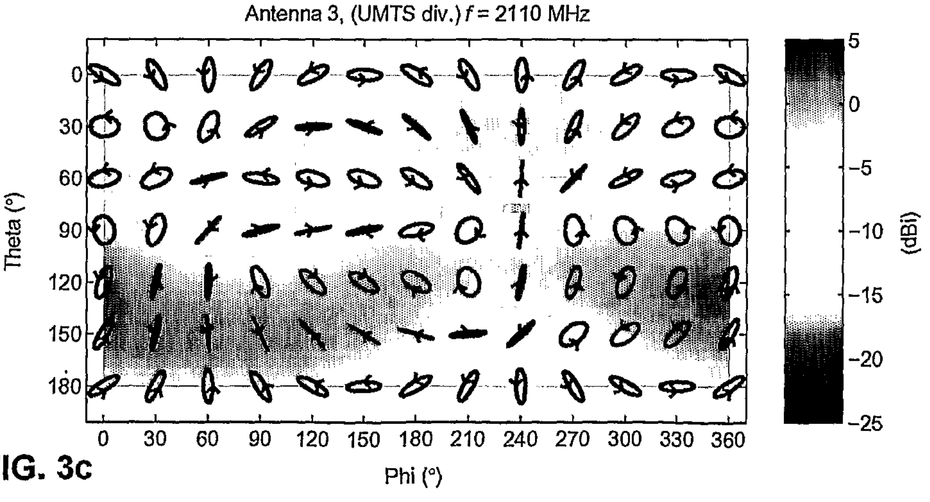


FIG. 3c

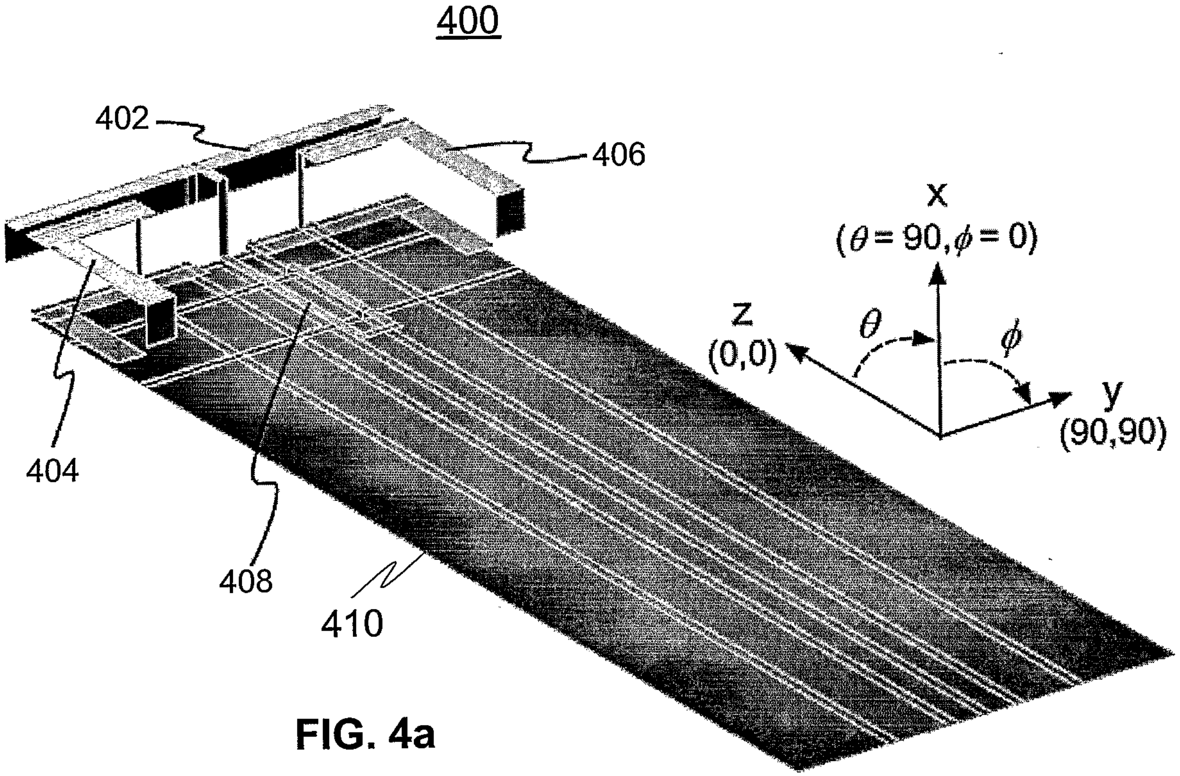

400
402
406
404
408
410
x
($\theta = 90, \phi = 0$)
z
(0,0)
θ
ϕ
y
(90,90)

FIG. 4a

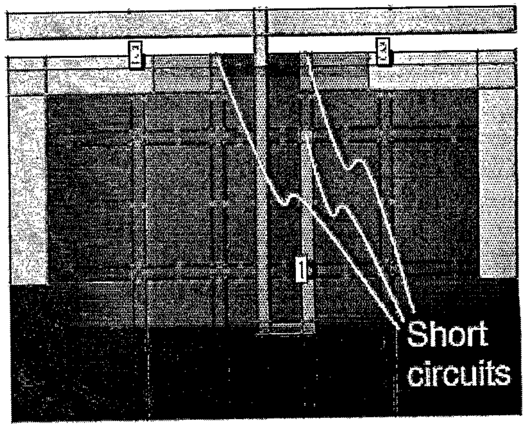

Short circuits

FIG. 4b

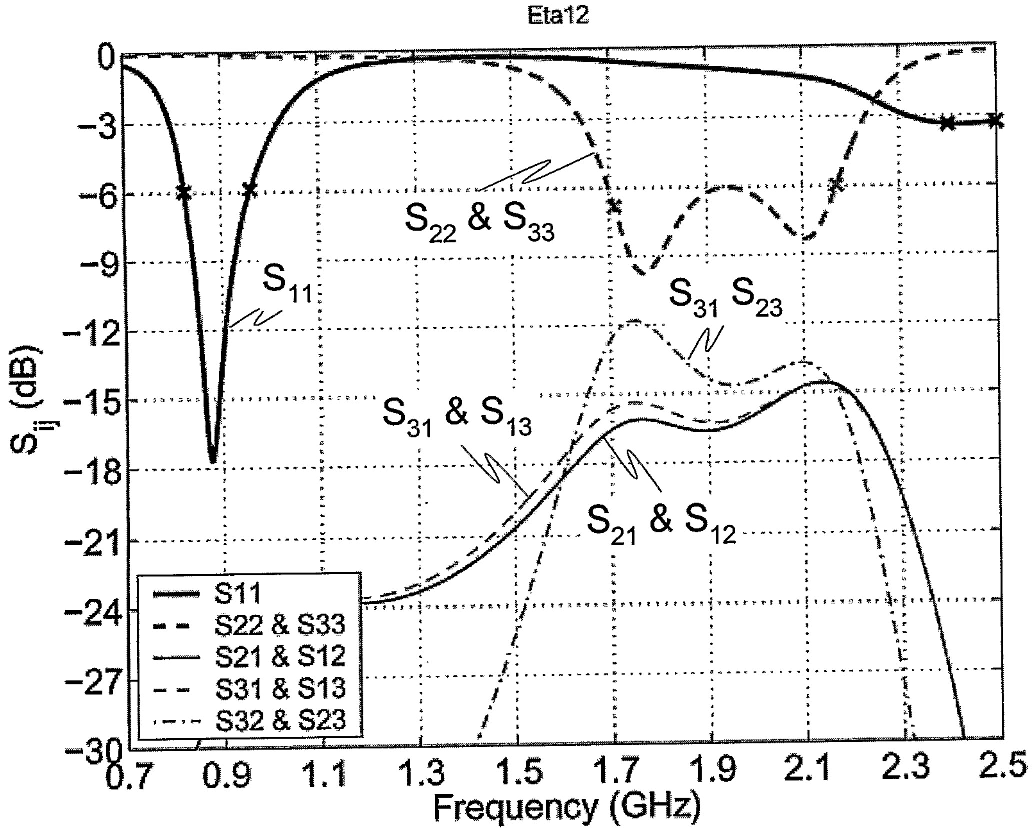

Eta12
S11
S22 & S33
S21 & S12
S31 & S13
S32 & S23
S_{11}
S_{22} & S_{33}
S_{31} S_{23}
S_{31} & S_{13}
S_{21} & S_{12}
S_{ij} (dB)
0
−3
−6
−9
−12
−15
−18
−21
−24
−27
−30
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
Frequency (GHz)

FIG. 5a

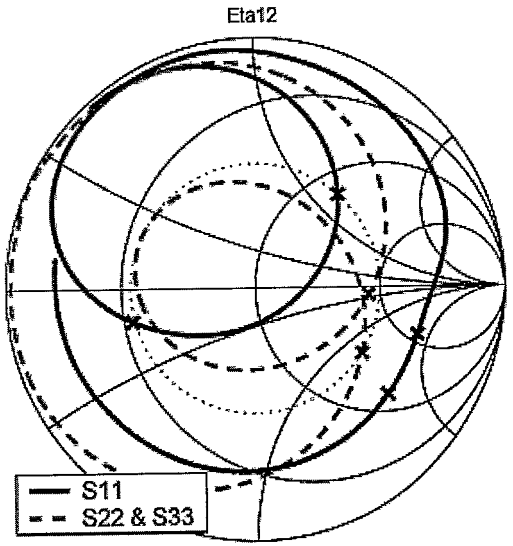

Eta12
S11
S22 & S33

FIG. 5b

Antenna 1 (GSM), *f* = 920 MHz

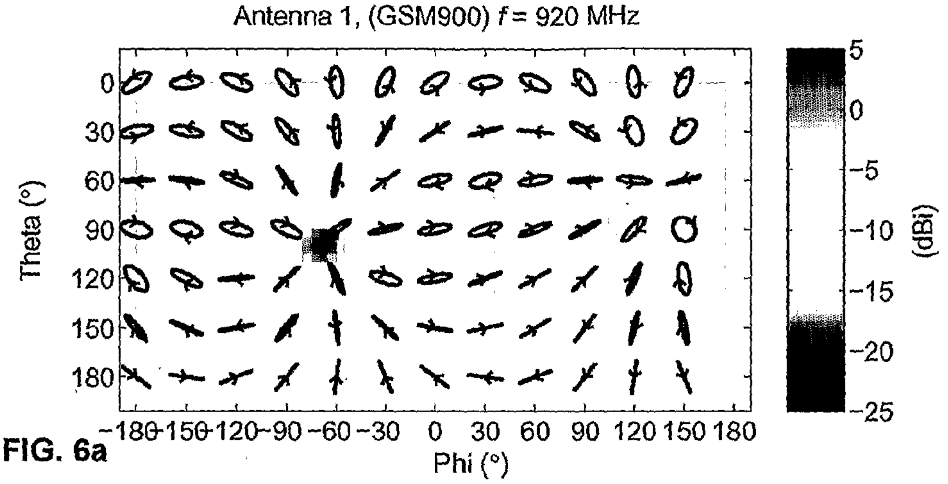


FIG. 6a

Antenna 2 (UMTS), *f* = 2.11 GHz

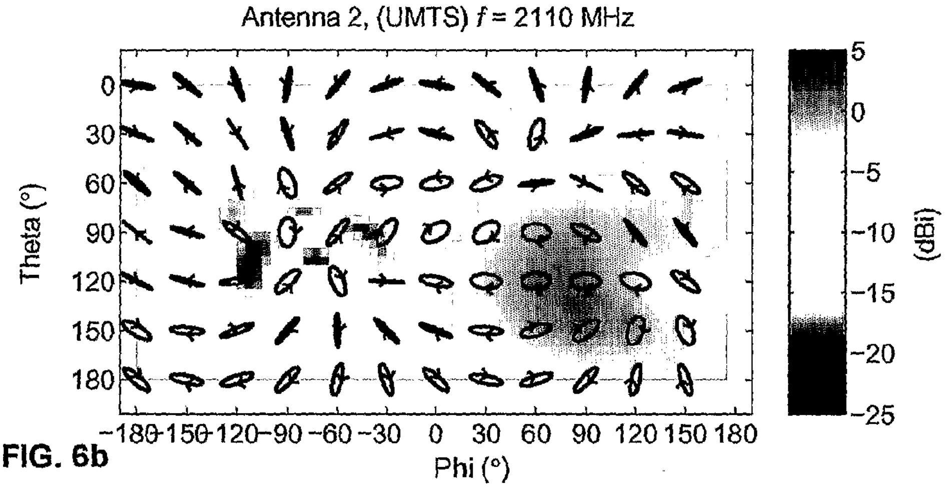


FIG. 6b

Antenna 3 (UMTS diversity), *f* = 2.11 GHz

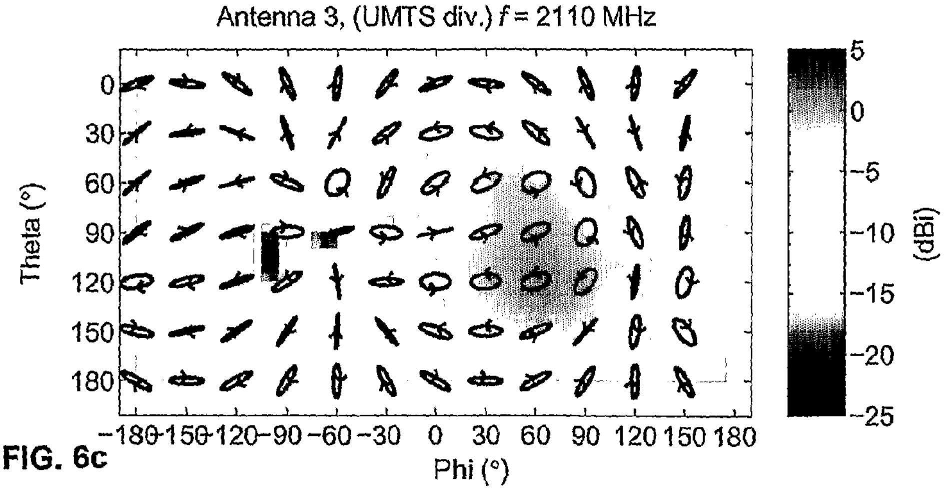


FIG. 6c

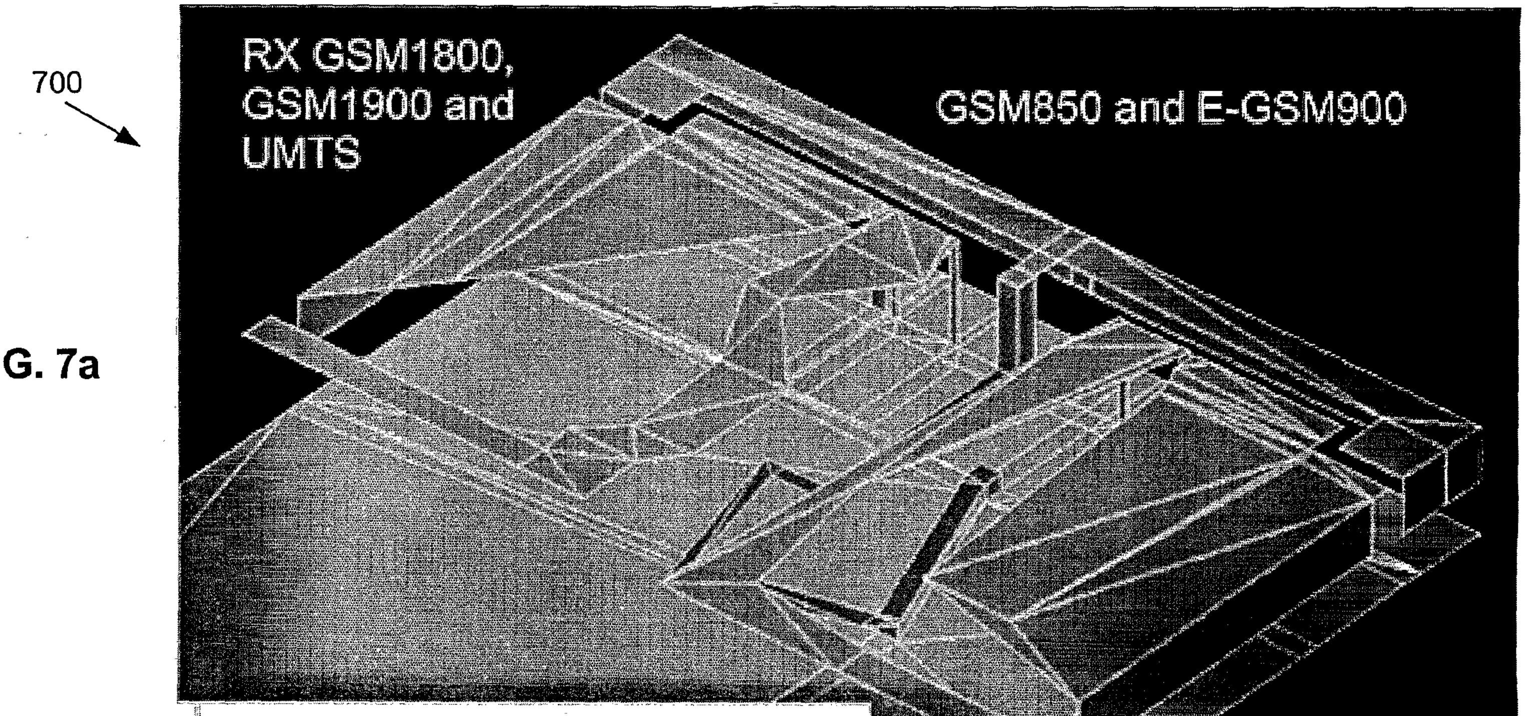

700
RX GSM1800, GSM1900 and UMTS
GSM850 and E-GSM900
TX GSM1800, GSM1900 and UMTS

FIG. 7a

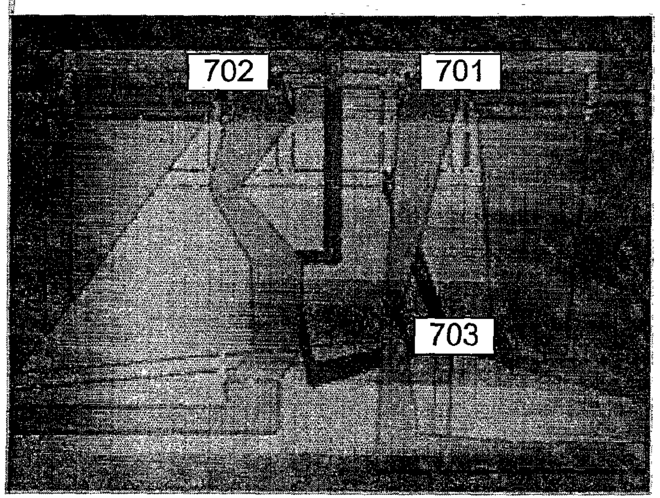

702
701
703

FIG. 7b

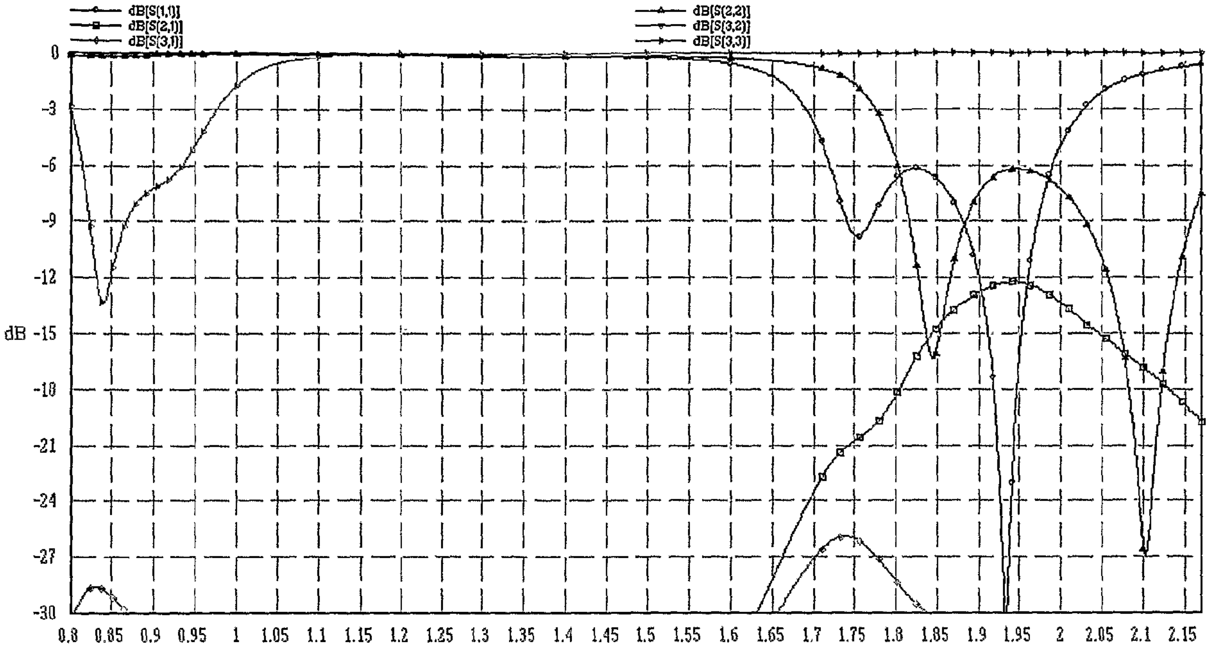


FIG. 8a

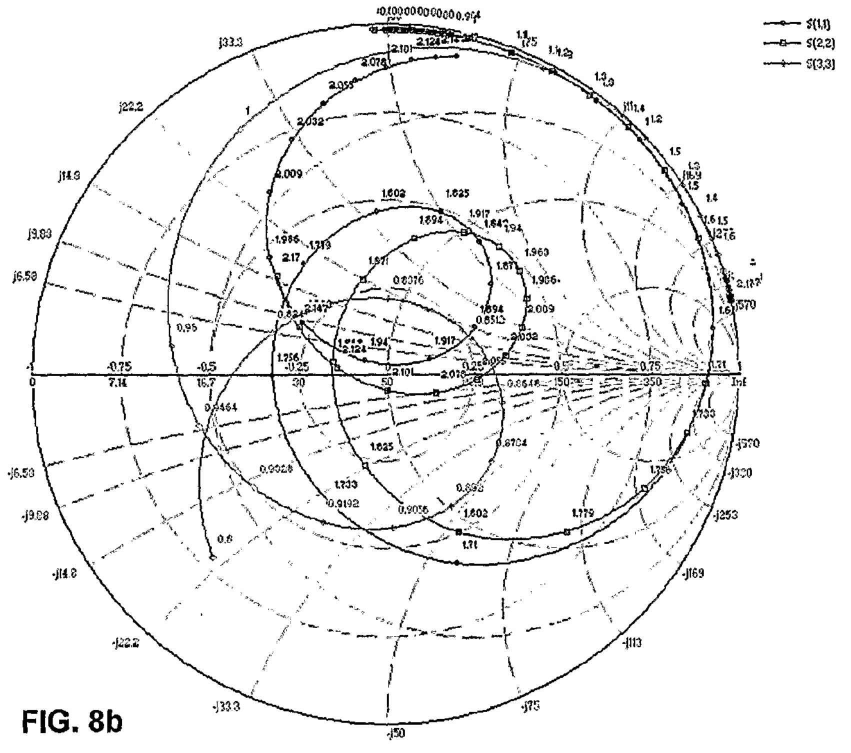
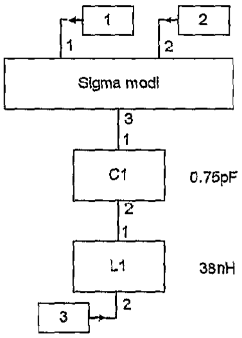


FIG. 8b



Port 3 is advantageously GSM 850/900 (with series resonant matching circuit)

FIG. 8c

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2007/000181

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

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)

IPC8: H01Q

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

DK, FI, NO, SE

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

EPO-internal, WPI, INSPEC, XPIEE, XPI3E, Internet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/0184914 A1 (OLLIKAINEN, J. et al.) 25 August 2005 (25.08.2005), abstract; paragraphs [0043]-[0046], [0052], and [0059]; figures 3, 7, 11, and 12	1-24
A	US 2003/0193437 A1 (KANGASVIERI, T. et al.) 16 October 2003 (16.10.2003), abstract; paragraphs [0063]-[0066]; figures 1-3	1-24
A	US 2002/0021253 A1 (MURAMOTO, M. et al.) 21 February 2002 (21.02.2002), abstract; paragraphs [0063]-[0066]; figures 10 and 18	1-24
P, A	US 2006/0214857 A1 (OLLIKAINEN, J.) 28 September 2006 (28.09.2006), abstract; paragraphs [0035]-[0037] and [0044]; figures 1 and 9	1-24
P, A	Manteghi, M. et al., "A novel miniaturized triband PIFA for MIMO applications", Microwave and Optical Technology Letters, John Wiley & Sons, Inc., March 2007, vol. 49, no. 3, p. 724-731, abstract; chapter 3; figures 6-8, 12, and 15	1-24

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 04 October 2007 (04.10.2007)	Date of mailing of the international search report 01 November 2007 (01.11.2007)
Name and mailing address of the ISA/FI National Board of Patents and Registration of Finland P.O. Box 1160, FI-00101 HELSINKI, Finland Facsimile No. +358 9 6939 5328	Authorized officer Ville Möttönen Telephone No. +358 9 6939 500

CLASSIFICATION OF SUBJECT MATTER

Int.Cl.
H01Q 5/00 (2006.01)
H01Q 1/24 (2006.01)
H01Q 9/04 (2006.01)
H01Q 9/02 (2006.01)
H01Q 19/00 (2006.01)
H01Q 21/30 (2006.01)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/FI2007/000181

Patent document cited in search report	Publication date	Patent family members(s)	Publication date
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		KR 20060121981 A	29/11/2006
		EP 1719203 A1	08/11/2006
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US 2003/0193437 A1	16/10/2003	None	
US 2002/0021253 A1	21/02/2002	US 6326924 B1	04/12/2001
		JP 2000040916 A	08/02/2000
US 2006/0214857 A1	28/09/2006	None	