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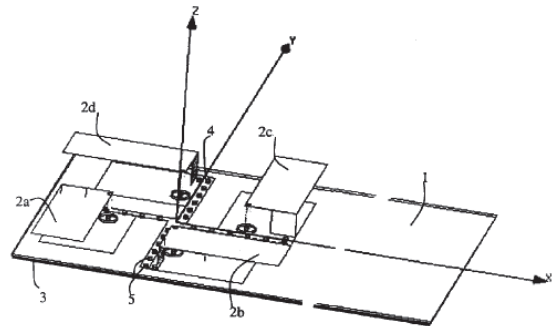
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[54] **Title of Invention**

Four-Plane Inverted-F Antenna System for a Multiple-Input Multiple-Output (MIMO) Wireless Communication Terminal

[57] **Abstract**

The present invention relates to the technical field of multi-antenna systems applied to wireless communication terminals. The invention is characterized in that four shortened planar inverted-F antenna (PIFA) units with respective ground planes are arranged and mounted on the front surface of a printed circuit board (PCB) in four separate quadrants, respectively. Any two adjacent antenna units are arranged to be mutually perpendicular to each other, and the spacing between adjacent antenna units is within a range of 0.1 to 0.5 times the operating wavelength of the antenna units. The antenna units located in the first quadrant and the third quadrant are arranged to be rotationally symmetric with respect to a rotation of  $180 \pm 10$  degrees about the midpoint of a line connecting corresponding points that are identical in their respective geometric positions, and the distance between their respective feed points is greater than 0.25 times the wavelength. The antenna units located in the second quadrant and the fourth quadrant are arranged in the same manner and satisfy the same rotational symmetry relationship and feed-point spacing requirements. At the cross-shaped intersection formed between the antenna units, there is provided a cross-expanded metallic ground plane that is electrically connected to the ground planes of the respective antenna units and includes vias. A metallic layer on the rear surface of the printed circuit board is electrically connected to the cross-expanded metallic ground plane through the vias. Furthermore, on the rear metallic layer of the printed circuit board, corresponding blank regions between the antenna units located in the second quadrant and the third quadrant are provided with slots, such slots being formed by cutting or etching, so as to further improve isolation and performance characteristics of the multi-antenna system. The present invention has the advantages of low mutual coupling, high radiation efficiency, and large system capacity.



1. A four-plane inverted-F antenna system for a multiple-input multiple-output (MIMO) wireless communication terminal, characterized in that:  
the antenna system comprises:  
a printed circuit board (PCB) (1), wherein a rear surface of the printed circuit board is provided with a metallic layer; and  
four ground-plane-shortened planar inverted-F antenna units, wherein each of the planar inverted-F antenna units comprises:  
a conductive ground plane, wherein the ground plane is a metallic patch or a metallic layer attached to a front surface of the printed circuit board and arranged parallel to the metallic layer on the rear surface of the printed circuit board, and wherein a length and a width of the ground plane are less than or equal to 0.2 times a free-space propagation wavelength corresponding to an operating frequency of the planar inverted-F antenna;  
a conductive radiating plane, wherein the radiating plane is arranged parallel to the conductive ground plane, and wherein both a length and a width of the radiating plane are less than 0.25 times an operating wavelength of the antenna;  
a conductive short-circuit plane, wherein the short-circuit plane is arranged perpendicular to the ground plane and electrically connects the ground plane and the radiating plane;  
a conductive feeding post, wherein the feeding post is arranged perpendicular to the ground plane and electrically connects an inner conductor of a radio-frequency (RF) feeder to the radiating plane, and wherein an outer conductor of the radio-frequency feeder is electrically connected to the metallic layer on the rear surface of the printed circuit board;  
wherein a value obtained by subtracting the length of the conductive ground plane from the length of the conductive radiating plane and then dividing the resulting difference by the length of the conductive radiating plane is greater than 0.2;  
The four ground-plane-shortened planar inverted-F antenna units are respectively denoted as (2d), (2a), (2b), and (2c), and are sequentially located in the first, second, third, and fourth quadrants. Among the four ground-plane-shortened planar inverted-F antenna units, corresponding edges of the conductive ground planes of any two adjacent planar inverted-F antenna units that are identical in geometric position are arranged to be mutually perpendicular. A spacing between any two adjacent planar inverted-F antenna units is equal to a perpendicular distance between the respective ground planes thereof, and such distance is within a range of 0.1 to 0.5 times an operating wavelength of the planar inverted-F antenna units. The term “identical edges” refers to edges that are located at identical geometric positions on the respective planar inverted-F antenna units. A spacing between feed points of the planar inverted-F antenna units located in the first quadrant and the third quadrant, and a spacing between feed points of the planar inverted-F antenna units located in the second quadrant and the fourth quadrant, are both greater than 0.25 times the operating wavelength of the planar inverted-F antenna. The planar inverted-F antenna units located in the first quadrant and the third quadrant are arranged to be rotationally symmetric with respect to a rotation of  $180 \pm 10$  degrees about a midpoint of a line connecting respective identical points thereof. The planar inverted-F antenna units located in the third quadrant and the fourth quadrant are arranged to be rotationally symmetric with respect to a rotation of  $180 \pm 10$  degrees about a midpoint of a line connecting respective identical points thereof in the same horizontal plane. The term “identical points” refers to points that are located at identical geometric positions on the respective planar inverted-F antenna units.
2. The four-plane inverted-F antenna system for a multiple-input multiple-output (MIMO) wireless communication terminal according to claim 1, characterized in that:  
a spacing between any two adjacent planar inverted-F antenna units is within a range of 0.1 to 0.5 times an operating wavelength of the planar inverted-F antenna units.

3. The four-plane inverted-F antenna system for a multiple-input multiple-output (MIMO) wireless communication terminal according to claim 1 or claim 2, characterized in that:  
each of the planar inverted-F antenna units further comprises a via-grounded, cross-shaped expanded metallic ground plane, wherein the cross-shaped expanded metallic ground plane is constituted by a metallic layer disposed on a front surface of the printed circuit board, or alternatively is a metallic plane arranged parallel to the front surface of the printed circuit board; the cross-shaped expanded metallic ground plane is positioned at a cross-shaped intersection region between the planar inverted-F antenna units, and each arm or edge of the cross-shaped expanded metallic ground plane is respectively connected to a corresponding one of the planar inverted-F antenna units; and the vias electrically connect the cross-shaped expanded metallic ground plane with the metallic layer on the rear surface of the printed circuit board.
4. The four-plane inverted-F antenna system for a multiple-input multiple-output (MIMO) wireless communication terminal according to claim 1 or claim 2, characterized in that:  
Each of the planar inverted-F antenna units further includes a slot formed in the metallic layer on the rear surface of the printed circuit board, wherein the slot is disposed in a blank region between the planar inverted-F antenna units located in the second quadrant and the third quadrant, and wherein the slot is provided for the purpose of reducing coupling between the antenna units caused by ground currents flowing between the units.

## Four-Plane Inverted-F Antenna System for a Multiple-Input Multiple-Output (MIMO) Wireless Communication Terminal

### Technical Field

The present invention relates to the technical field of multi-antenna antenna systems for wireless communication terminals.

### Background Art

An antenna is a device in a wireless communication system that is used to radiate transmitted signal power and to receive incoming signal power. A planar inverted-F antenna (PIFA) is a typical type of built-in antenna. It comprises a conductive ground plane, a conductive radiating plane arranged parallel to the ground plane, a conductive short-circuit post connecting the ground plane and the radiating plane, and a conductive feeding post connecting a radio-frequency (RF) feeder to the radiating plane. The radiation characteristics of a PIFA antenna are mainly determined by surface currents on the metallic surfaces of the antenna. The radiation pattern of a PIFA antenna is primarily directed toward the outward normal direction of the radiating plane. The width of the main lobe of the radiation pattern is related to the size of the ground plane. The larger the conductive ground plane relative to the conductive radiating plane, the more concentrated the main lobe is in the outward normal direction of the radiating plane. A single PIFA antenna unit has the advantages of small physical size and high radiation efficiency [Kathleen L. Virga and Yahya Rahmat-Samii, "Low-Profile Enhanced-Bandwidth PIFA Antennas for Wireless Communications Packaging," IEEE Transactions on Microwave Theory and Techniques, Vol. 45, No. 10, pp. 1879, October 1997]. However, the radiation efficiency of a PIFA antenna is closely related to the strength of its coupling with the surrounding environment. When a surrounding metallic object is located within one wavelength from a region of the PIFA antenna where strong surface currents exist on the metallic elements, such metallic object may strongly couple with the PIFA antenna. As a result, a portion of the energy radiated by the antenna may be transferred to the nearby metallic object, thereby causing a reduction in the radiation efficiency of the PIFA antenna.

Conventional wireless communication systems generally adopt a single-input single-output (SISO: Single Input Single Output) mode, in which a terminal performs transmission and reception of communication signals using a single antenna to communicate with a single antenna at a base station. A multiple-input multiple-output (MIMO: Multi Input Multi Output) communication mode is a relatively new communication technology, in which multiple antennas on a wireless terminal simultaneously communicate with multiple antennas at a base station. Because it exploits multiple propagation paths having relatively low correlation in the propagation environment for communication, a MIMO communication system, particularly in environments such as urban areas where a large number of reflecting and scattering objects exist, can, in combination with space-time coding techniques, achieve a higher channel capacity than a SISO mode, thereby effectively increasing overall system capacity. Such an increase in system capacity constitutes one of the effective means for resolving the contradiction between the rapidly growing demand for wireless data services and the currently limited wireless access capability of communication networks. Accordingly, MIMO technology is one of the key technologies for next-generation mobile communications [Arogyaswami J. Paulraj, Dhananjay A. Gore, Rohit U. Nabar, and Helmut Bölcskei, "An Overview of MIMO Communications - A Key to Gigabit Wireless," IEEE Proceedings, pp. 198, 2004]. Two major international standards organizations, namely 3GPP and 3GPP2, as well as IEEE, have respectively applied MIMO technology in the UMTS and IEEE 802.11n standards to construct their respective air-interface standards. Wi-Fi systems have also adopted MIMO technology in their wireless interfaces. MIMO technology has broad application prospects in cellular systems, wireless local area networks, and other wireless communication systems.

MIMO technology can be classified into three basic forms, namely diversity, multiplexing, and a compromise between diversity and multiplexing. MIMO diversity techniques, in terms of antenna implementation methods, include spatial diversity, polarization diversity, and radiation-pattern diversity. Spatial diversity is an antenna technology that can be applied to MIMO systems.

When a radio wave propagates from a transmitting antenna to a receiving antenna, multiple propagation paths exist in the propagation environment. Each propagation path has a different propagation distance, and therefore the phases of the arriving waves are different. The strength of the electromagnetic field of the signal at each point in space is the result of superposition of these multiple paths having different phases. At different receiving points, due to differences in multipath phases, the signal amplitude varies significantly, that is, the signal strength exhibits a pronounced spatial distribution. In multipath-rich wireless propagation environments, such as urban environments and indoor environments, the signal amplitude at different points in space can still vary dramatically over distances within one wavelength, meaning that small-scale spatial fading of the signal is very pronounced. Because MIMO antennas employ multiple antenna units to receive diversity at different spatial points, and in combination with space-time coding techniques, the signal amplitudes received by different antenna units at the same time instant are different. After combining, the received signal-to-noise ratio is more stable than that obtained with single-antenna reception, thereby effectively combating small-scale spatial fading and increasing channel capacity. MIMO antennas further employ multiple antenna units to transmit signals. Because signals transmitted by antennas located at different spatial points experience different fading conditions at the receiving antenna on the communication counterpart side, and in combination with space-time coding techniques, the combined received signal-to-noise ratio at the counterpart side is more stable than in a single-antenna transmission scenario. Accordingly, small-scale spatial fading is also effectively mitigated, and channel capacity is thereby increased.

Polarization diversity is an antenna technique that can be applied to MIMO systems. After a wireless signal having a given polarization propagates through a propagation environment, polarization dispersion occurs, such that signal power exists both in the polarization direction identical to that of the transmitting antenna and in a polarization direction perpendicular thereto. Because the orientation of a wireless terminal, particularly a handheld wireless terminal, during operation is random, the polarization direction of the antenna is likewise random. In order to stably receive signal power, a MIMO antenna system may employ antenna units having different polarization directions, thereby obtaining stable received power through polarization diversity.

Radiation-pattern diversity is an antenna technique that can be applied to MIMO systems. In a multipath environment, wireless signals propagate along different propagation paths and arrive at a receiving antenna with different angles of arrival. A single antenna can only receive signals arriving from a portion of all possible directions. Accordingly, by using different antennas having different radiation patterns to perform diversity reception, a larger amount of received signal power can be obtained, thereby counteracting small-scale spatial fading.

Multiplexing is an antenna technique that can be applied to MIMO systems. In a multipath environment, wireless signals propagate along different propagation paths and arrive at a receiving antenna. In a richly scattering environment, such as an urban environment or an indoor environment, the superimposed signals formed by one portion of the incident waves and the superimposed signals formed by another portion of the incident waves exhibit relatively low correlation with each other. Therefore, whether different antenna units are used at different spatial positions, or different polarization directions are employed, or different radiation patterns are utilized for reception, in a richly scattering environment the data links associated with these antenna units are mutually uncorrelated. In combination with multiplexing coding techniques, data can be transmitted in parallel. In this manner, the channel capacity of a MIMO system can increase multiplicatively in proportion to the number of antenna units.

Regardless of which form is used to implement a MIMO antenna, in order for the capacity of a MIMO system to be higher than that of a SISO system, two necessary conditions must be satisfied: (1) the wireless propagation channels between the respective antenna units of the transmitting MIMO antenna and the corresponding antenna units of the receiving MIMO antenna must exhibit low correlation; and (2) if the MIMO antenna units and the propagation channels are jointly regarded as extended channels, the extended channels corresponding to the respective antenna units must likewise exhibit low correlation. In certain MIMO antenna solutions that have already been proposed, these two conditions are achieved by mounting several basic PIFA antennas such that their ground planes are mutually perpendicular. However, such solutions require that the terminal on which the antennas are installed have a sufficiently large physical size so that the spacing between antenna units is sufficiently large, or alternatively require that the number of installed antenna units not exceed two.

For antenna terminals having an overall size within 0.5 times the wavelength, solutions in which the ground planes are arranged to be mutually perpendicular may not achieve high radiation efficiency, and problems such as strong mutual coupling and low radiation efficiency may occur. In particular, for handheld mobile terminals, an arrangement in which ground planes are mutually perpendicular requires the antenna units to be disposed along the respective edges of the terminal. This results in ground currents excited on the conductive ground planes interacting strongly with the surrounding environment, such as a user's hand. Due to the influence of the surrounding environment, such an antenna system suffers from problems including unstable impedance matching characteristics and a reduction in radiation efficiency. Because the battery capacity of wireless terminal devices is typically very limited, instability in matching characteristics and degradation in radiation efficiency will significantly increase terminal power consumption and reduce standby time.

On the other hand, mutual coupling between antenna units increases the correlation between transmitted and received information of the coupled antenna units, thereby undermining the fundamental implementation conditions of MIMO communication, namely that the transmitted and received information on data links associated with different antennas must have low correlation. This also constitutes a problem in the application of existing MIMO antennas employing PIFA antenna units in small-sized wireless terminals.

Accordingly, it is necessary to improve the design and arrangement of MIMO antennas so that they can be effectively applied in MIMO systems, and in particular be suitable for use in compact and small-sized wireless terminal devices.

#### Summary of the Invention

The object of the present invention is to provide an improved arrangement method for MIMO antenna units, in particular to enable MIMO antennas that use PIFA antennas as individual units to achieve data links with low correlation among the respective units, thereby increasing the communication capacity that can be achieved by a MIMO system. In addition, the invention aims to reduce mutual coupling among the respective units, so as to improve antenna radiation efficiency and extend the standby time of a wireless terminal, particularly in compact terminal devices in which the spacing between antenna units is within a range of 0.25 to 1 wavelength.

The object of the present invention is to rationally arrange the spatial positions, spacings, and mutual spatial relationships of PIFA antenna units, such that the MIMO antenna system has the following characteristics:

- (1) Low-correlation data links are obtained with a minimum spacing between antenna units, so that the MIMO antenna structure is as compact as possible, particularly within small-sized wireless terminals.
- (2) After the antenna units are installed in a terminal, the antenna units exhibit wide radiation patterns, such that, in a plane passing through the origin with the antenna taken as the origin, the radiation pattern is approximately omnidirectional.
- (3) The radiation patterns of the respective antenna units are complementary to each other, and together form an approximately omnidirectional radiation pattern over a spherical surface, thereby achieving radiation-pattern diversity.
- (4) The main polarization directions of certain antenna units are mutually perpendicular, thereby achieving polarization diversity.
- (5) Mutual coupling among the multiple antenna units is relatively low, thereby realizing low-correlation data links and high radiation efficiency.

The characteristics set forth in items (1), (2), (3), (4), and (5) are all intended to reduce the correlation of transmitted and received information over the wireless links associated with the respective antenna units, and thereby to increase the capacity of the MIMO system.

The characteristic set forth in item (5) is further intended to improve antenna radiation efficiency, thereby reducing the power consumption of the wireless terminal and extending the standby time of the wireless terminal.

The present invention is characterized in that:

the antenna system comprises:

a printed circuit board (PCB) (1), wherein a rear surface of the printed circuit board is provided with a metallic layer;

four ground-plane-shortened planar inverted-F antenna units, wherein each of the planar inverted-F antenna units comprises:

a conductive ground plane, wherein the ground plane is a metallic patch or a metallic layer attached to a front surface of the printed circuit board and arranged parallel to the metallic layer on the rear surface of the printed circuit board, and wherein a length and a width of the ground plane are less than or equal to 0.2 times a free-space propagation wavelength corresponding to an operating frequency of the planar inverted-F antenna;

a conductive radiating plane, wherein the radiating plane is arranged parallel to the conductive ground plane, and wherein both a length and a width of the radiating plane are less than 0.25 times an operating wavelength of the antenna;

a conductive short-circuit plane, wherein the short-circuit plane is arranged perpendicular to the ground plane and electrically connects the ground plane and the radiating plane;

a conductive feeding post, wherein the feeding post is arranged perpendicular to the ground plane and electrically connects an inner conductor of a radio-frequency (RF) feeder to the radiating plane, and wherein an outer conductor of the radio-frequency feeder is electrically connected to the metallic layer on the rear surface of the printed circuit board;

wherein a value obtained by subtracting the length of the conductive ground plane from the length of the conductive radiating plane and then dividing the resulting difference by the length of the conductive radiating plane is greater than 0.2;

The four ground-plane-shortened planar inverted-F antenna units are respectively denoted as (2d), (2a), (2b), and (2c), and are sequentially located in the first, second, third, and fourth quadrants. Among the four ground-plane-shortened planar inverted-F antenna units, corresponding edges of the conductive ground planes of any two adjacent planar inverted-F antenna units that are identical in geometric position are arranged to be mutually perpendicular. A spacing between any two adjacent planar inverted-F antenna units is equal to a perpendicular distance between the respective ground planes thereof, and such distance is within a range of 0.1 to 0.5 times an operating wavelength of the planar inverted-F antenna units. The term "identical edges" refers to edges that are located at identical geometric positions on the respective planar inverted-F antenna units. A spacing between feed points of the planar inverted-F antenna units located in the first quadrant and the third quadrant, and a spacing between feed points of the planar inverted-F antenna units located in the second quadrant and the fourth quadrant, are both greater than 0.25 times the operating wavelength of the planar inverted-F antenna. The planar inverted-F antenna units located in the first quadrant and the third quadrant are arranged to be rotationally symmetric with respect to a rotation of  $180 \pm 10$  degrees about a midpoint of a line connecting respective identical points thereof. The planar inverted-F antenna units located in the third quadrant and the fourth quadrant are arranged to be rotationally symmetric with respect to a rotation of  $180 \pm 10$  degrees about a midpoint of a line connecting respective identical points thereof in the same horizontal plane. The term "identical points" refers to points that are located at identical geometric positions on the respective planar inverted-F antenna units.

a spacing between any two adjacent planar inverted-F antenna units is within a range of 0.1 to 0.5 times an operating wavelength of the planar inverted-F antenna units.

each of the planar inverted-F antenna units further comprises a via-grounded, cross-shaped expanded metallic ground plane, wherein the cross-shaped expanded metallic ground plane is constituted by a metallic layer disposed on a front surface of the printed circuit board, or alternatively is a metallic plane arranged parallel to the front surface of the printed circuit board; the cross-shaped expanded metallic ground plane is positioned at a cross-shaped intersection region between the planar inverted-F antenna units, and each arm or edge of the cross-shaped expanded metallic ground plane is respectively connected to a corresponding one of the planar inverted-F antenna units; and the vias electrically connect the cross-shaped expanded metallic ground plane with the metallic layer on the rear surface of the printed circuit board.

Each of the planar inverted-F antenna units further includes a slot formed in the metallic layer on the rear surface of the printed circuit board, wherein the slot is disposed in a blank region between the planar inverted-F antenna units located in the second quadrant and the third quadrant, and wherein the slot is provided for the purpose of reducing coupling between the antenna units caused by ground currents flowing between the units.

In the embodiments of the present invention, a "ground-shortened PIFA antenna unit with vias" having low mutual coupling characteristics is employed. The structure of such an antenna unit is illustrated in FIG. 3.

The respective antenna radiation patterns of the individual antenna units of the MIMO antenna according to the present invention are complementary to one another over a spherical surface, and together can form an approximately omnidirectional radiation pattern. The radiation patterns are shown in FIG. 4, in which the gain in the main radiation directions of each antenna unit is greater than 3 dB.

An advantageous effect of the present invention lies in the small mutual coupling between antenna units, particularly when the spacing between the respective units of the MIMO antenna is within 0.5 times the wavelength. Measured S-parameter values of the reflection coefficients and coupling coefficients of the respective antenna units in the illustrated embodiment are shown in FIG. 5. The transmission coefficient S-parameters between the ports of the respective antenna units are less than -8.5 dB. Accordingly, the data links corresponding to the respective antenna units exhibit good independence. When combined with space-time coding techniques, the MIMO system achieves a larger channel capacity, as has been explained in the literature [Arogyaswami J. Paulraj, Dhananjay A. Gore, Rohit U. Nabar, Helmut Bölcskei, "An Overview of MIMO Communications - A Key to Gigabit Wireless," IEEE Proceedings, pp. 198, 2004].

Another advantageous effect of the present invention is that, in the ground-shortened PIFA antenna unit, the length of the ground plane in which strong current distribution occurs is approximately 0.15 times the wavelength. As a result, the antenna units can be arranged in close proximity to each other, particularly with a spacing within 0.5 times the wavelength, while still maintaining low mutual coupling and high radiation efficiency. The radiation efficiency  $\eta_i$  of the i-th antenna unit of a MIMO antenna can be calculated in accordance with Equation (1):

$$\eta_i = 1 - |S_{ii}|^2 - \sum_{i \neq j} |S_{ji}|^2 \quad (1)$$

In Equation (1),  $S_{ii}$  denotes the reflection coefficient of the i-th antenna unit, and  $S_{ji}$  denotes the S-parameter of the transmission coefficient from the i-th antenna unit to the j-th antenna unit. The smaller the coupling coefficient between antenna units, the higher the radiation efficiency of the antenna. In the embodiment of the present invention, the radiation efficiencies of the respective antenna units are shown in FIG. 6. The average in-band radiation efficiency of the antenna units is greater than 0.8.

#### Description of the Drawings

FIG. 1 is a layout example of the present invention.

FIG. 2 is an implementation diagram of the present invention: (a) without vias; (b) with a cross-shaped expanded metallic ground plane provided with vias; and (c) with a cross-shaped expanded metallic ground plane having ground-plane slots and via grounding.

FIG. 3 is a schematic structural diagram of a ground-shortened planar inverted-F antenna unit provided with vias.

FIG. 4 shows radiation patterns of the respective antenna units of the present invention.

FIG. 5 shows measured S-parameter values of the respective antenna units of the present invention: (a) port data of antenna unit 2a; (b) port data of antenna unit 2b; (c) port data of antenna unit 2c; and (d) port data of antenna unit 2d.

FIG. 6 shows radiation efficiency curves of an embodiment of the present invention.

FIG. 7 shows a specific layout of an embodiment of the present invention: (a) antenna unit dimensions; and (b) antenna system dimensions.

#### Detailed Description of Embodiments

The MIMO antenna designed according to the present invention is mounted on a printed circuit board, and ground-shortened PIFA antennas are used as the individual units of the MIMO antenna. FIG. 1 illustrates an example of an arrangement method of the MIMO antenna. Reference numeral 1 denotes a printed circuit board, and reference numerals 2a, 2b, 2c, and 2d respectively denote MIMO antenna units.

A rear surface of the printed circuit board is provided with a metallic layer (3). Four ground-shortened PIFA antenna units are mounted on a front surface of the printed circuit board, and are formed by a metallic layer on the front surface of the printed circuit board or by a metallic plane arranged parallel to the front surface of the printed circuit board. Identical edges of the ground planes of adjacent antenna units are arranged to be mutually perpendicular. The term “identical edges” refers to edges that are located at identical geometric positions on the respective planar inverted-F antenna units.

According to the design of the present invention, the PIFA antenna unit (2a) is arranged to be perpendicular to antenna units (2b and 2d), and the antenna unit (2c) is arranged to be perpendicular to antenna units (2b and 2d). The antenna units (2a and 2c) are arranged to be rotationally symmetric with respect to a rotation of  $180 \pm 10$  degrees about the midpoint of a line connecting their respective identical points, and the antenna units (2b and 2d) are likewise arranged to be rotationally symmetric with respect to a rotation of  $180 \pm 10$  degrees about the midpoint of a line connecting their respective identical points. The term “identical points” refers to points that are located at identical geometric positions on the respective planar inverted-F antenna units. A three-dimensional structural diagram of the MIMO antenna embodiment is shown in FIG. 2(a).

The spacing between the feed points of antenna units (2a and 2c), and the spacing between the feed points of antenna units (2b and 2d), are both greater than 0.25 times the operating wavelength.

An additional inventive feature of the present design further includes an optional via-grounded cross-shaped expanded metallic ground plane, as shown in FIG. 2(b). The cross-shaped expanded ground plane (4) is constituted by a metallic layer on the front surface of the printed circuit board. The vias (5) electrically connect the expanded ground plane (4) with the metallic layer (3) on the rear surface of the printed circuit board.

The inventive design method further includes an optional configuration in which a slot is formed in the metallic ground layer on the rear surface of the printed circuit board, as shown in FIG. 2(c). The slot (6) disposed between two antenna units serves to reduce coupling caused by ground currents flowing between the antenna units.

The MIMO antenna designed according to the present invention employs ground-shortened PIFA antennas as antenna units. Such antennas are a known improved type of PIFA antenna, and their structure is illustrated in FIG. 3. Each such antenna unit comprises a conductive ground plane (2a-1), a conductive radiating plane (2a-2) arranged parallel to the ground plane, a conductive short-circuit plane (2a-3) arranged perpendicular to the ground plane and electrically connecting the ground plane and the radiating plane, and a conductive feeding post (2a-4) arranged perpendicular to the ground plane and electrically connecting a radio-frequency feeder to the radiating plane.

Dimensional examples of the ground slots, the via-grounded cross-shaped expanded metallic ground plane, and the ground-shortened PIFA antenna units employed in the present invention are shown in FIG. 7, with all dimensions expressed in millimeters.

The ground plane of antenna unit 2a is electrically connected to the metallic layer (3) through vias (2a-5), and the other antenna units are electrically connected by their corresponding vias in the same manner.

The conductive feeding post (2a-4) of antenna unit (2a) electrically connects an inner conductor of a coaxial radio-frequency feeder to the conductive radiating plane, while an outer conductor of the coaxial feeder is electrically connected to the metallic layer (3) on the rear surface of the printed circuit board. The other antenna units are likewise connected to their respective radio-frequency feeders through their corresponding feeding posts. The radio-frequency feeder may be implemented as a coaxial line, a microstrip line, or a stripline.

The radio-frequency feeders connected to the respective antenna units are coupled to the transmit and receive ports of the respective radio-frequency chains of the MIMO system.

The MIMO system employs space-time coding techniques.

In the illustrated embodiment of the present invention, the operating frequency range is 2250–2300 MHz. The radiation efficiencies of the respective antenna units are shown in FIG. 6. When the spacing between the antenna units is less than 0.5 times the wavelength, the radiation efficiencies of the antenna units, calculated using the measured S-parameters in accordance with Equation (1), are greater than 75%, with an average efficiency exceeding 80%. The simulated radiation patterns of the respective MIMO antenna units are shown in FIG. 4. The radiation patterns exhibit relatively wide main lobes and are approximately omnidirectional within a given plane. Because the orientations of the respective antenna units are different, the polarization directions of the respective antenna units are also different. Accordingly, the MIMO antenna described above exhibits polarization diversity performance.

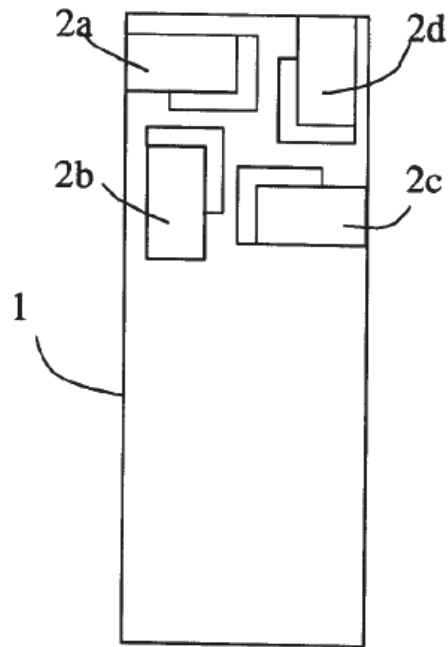


FIG. 1

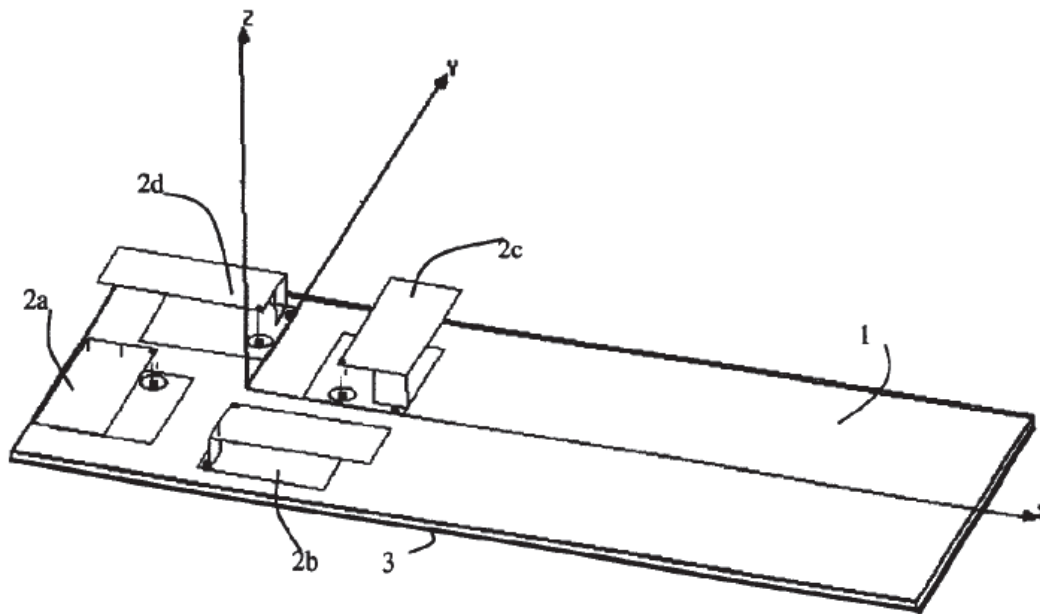


FIG. 2(a)

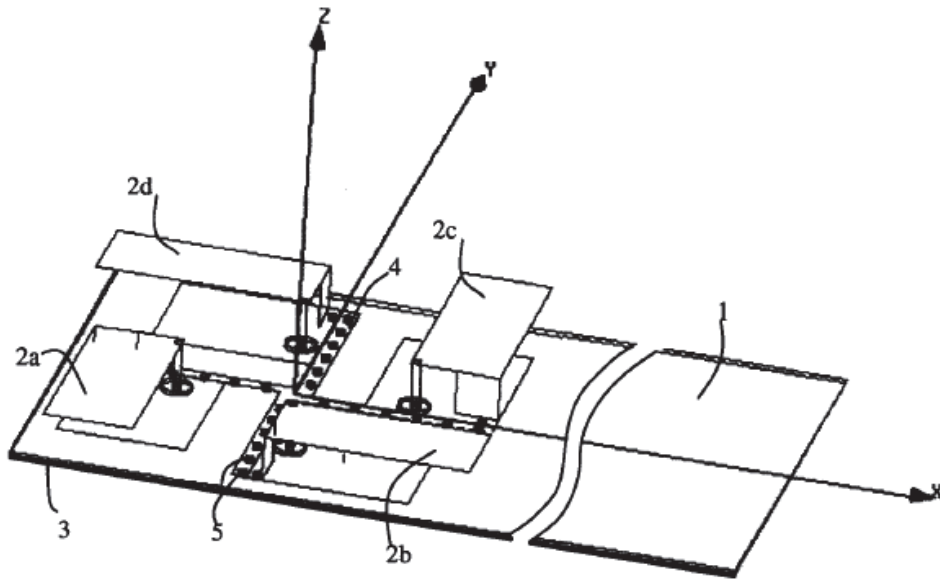


FIG. 2(b)

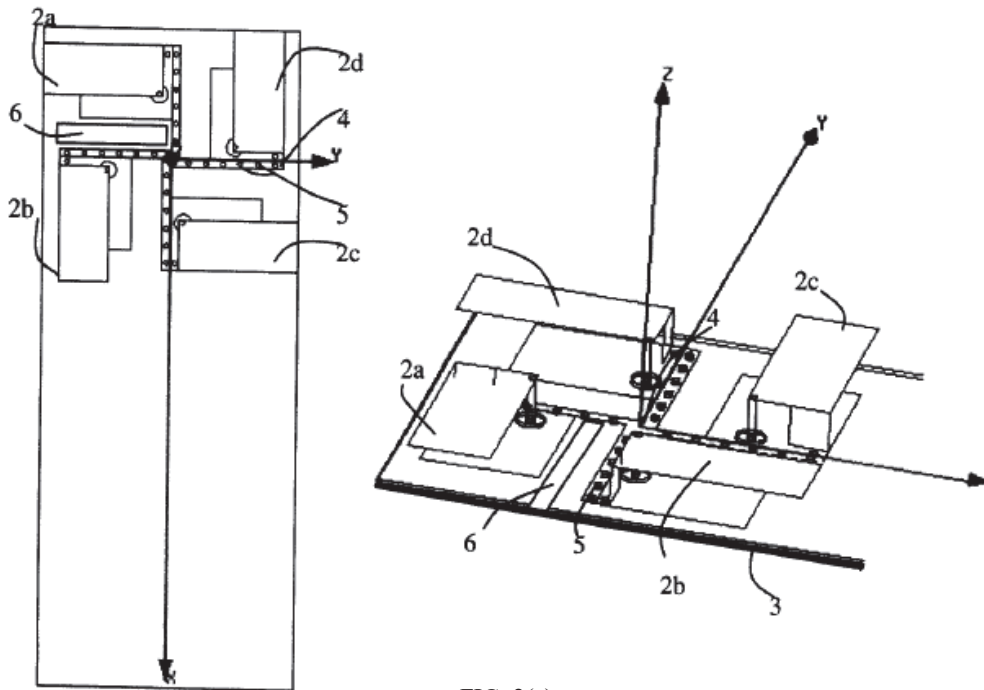


FIG. 2(c)

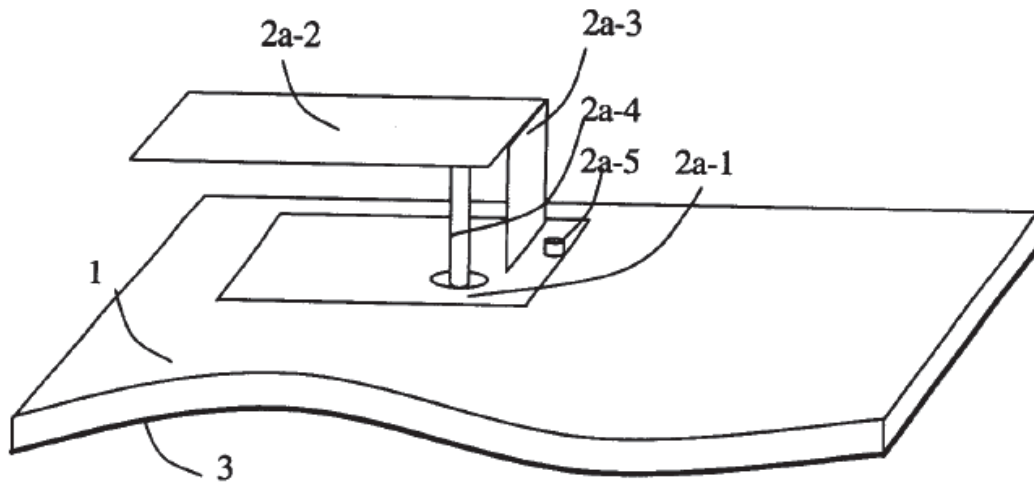


FIG. 3

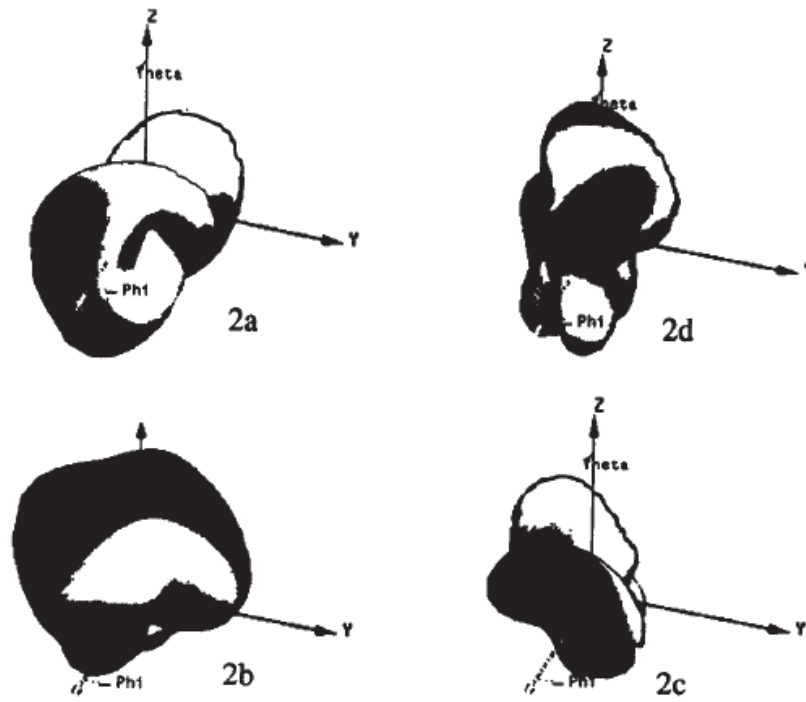


FIG. 4

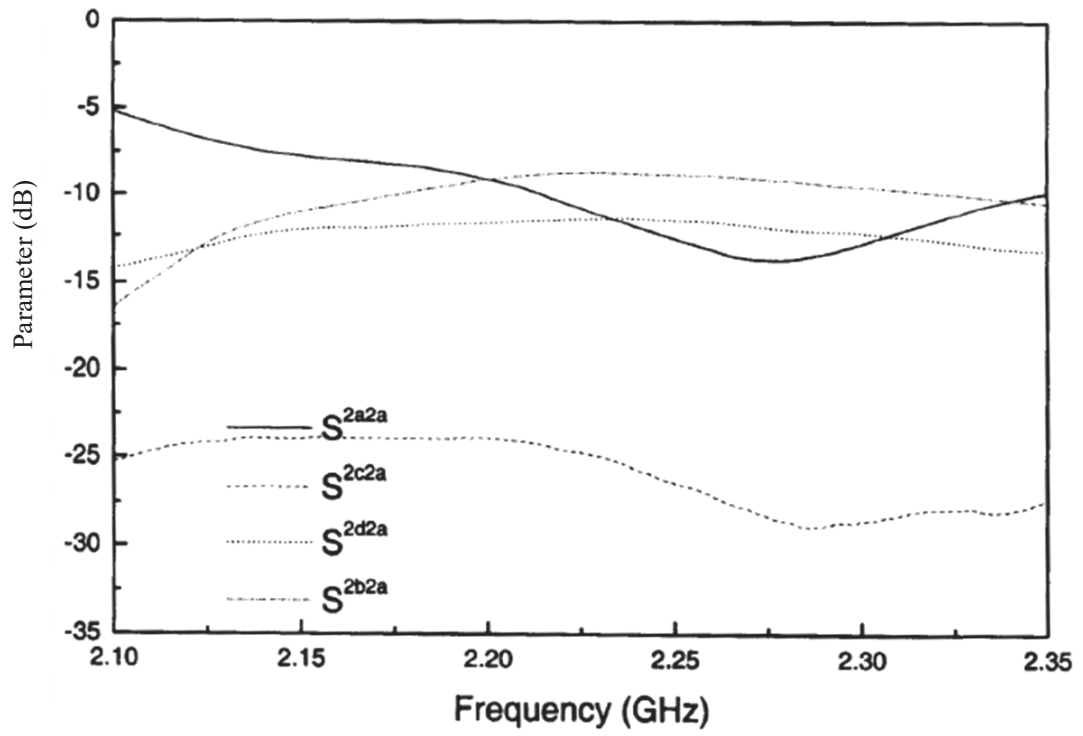


FIG. 5(a)

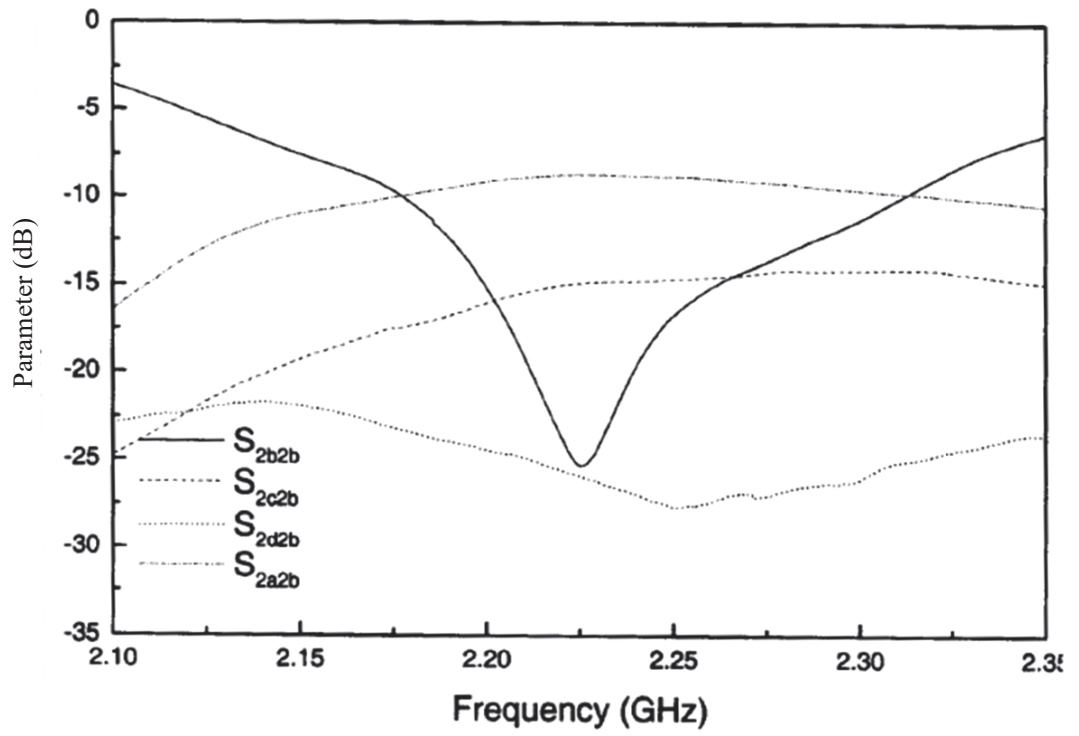


FIG. 5(b)

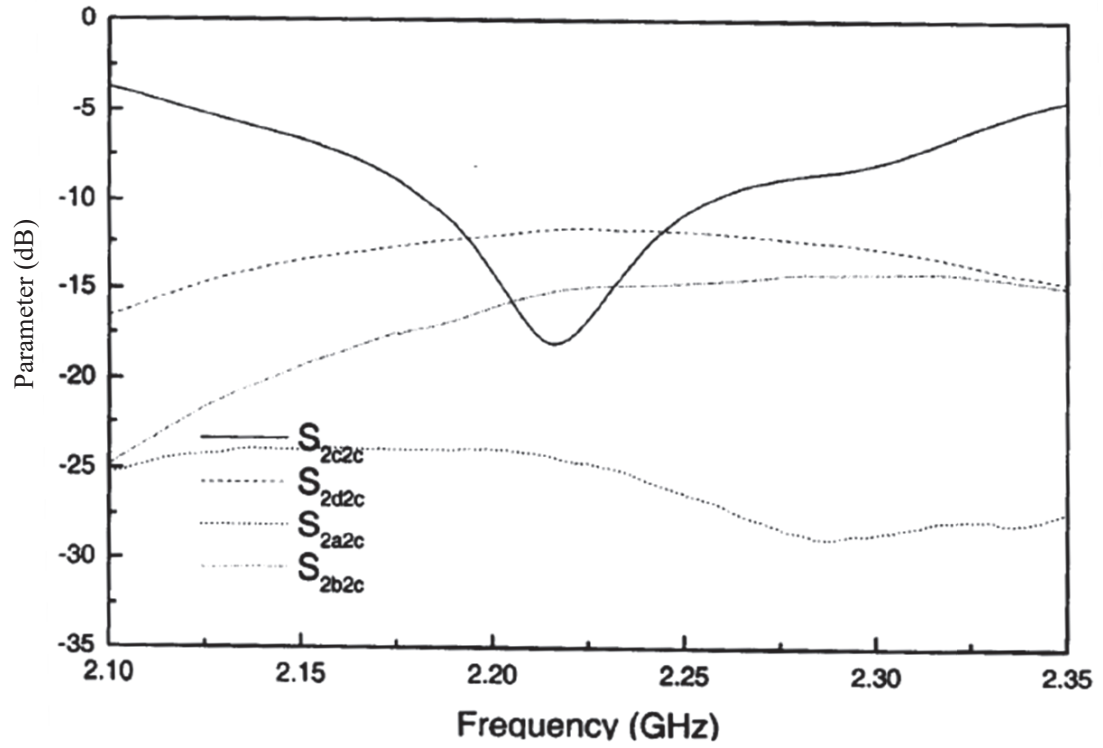


FIG. 5(c)

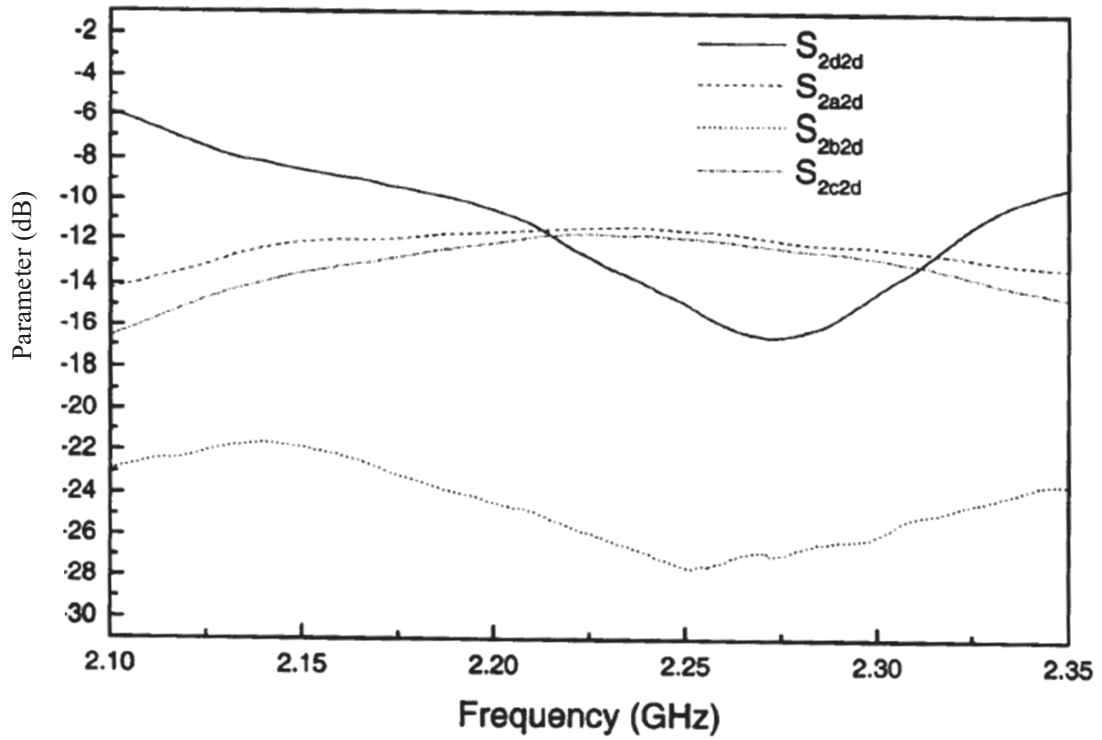


FIG. 5(d)

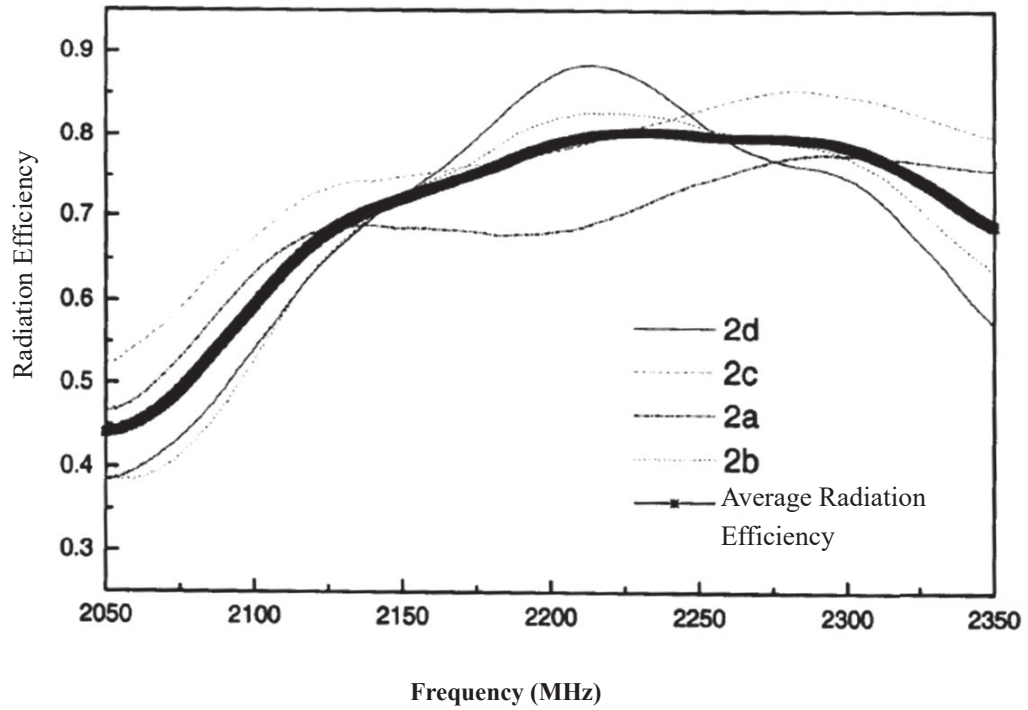


FIG. 6

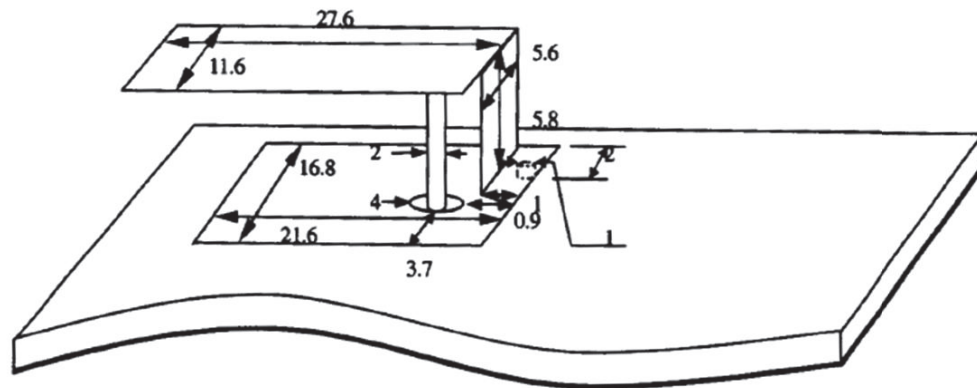


FIG. 7(a)

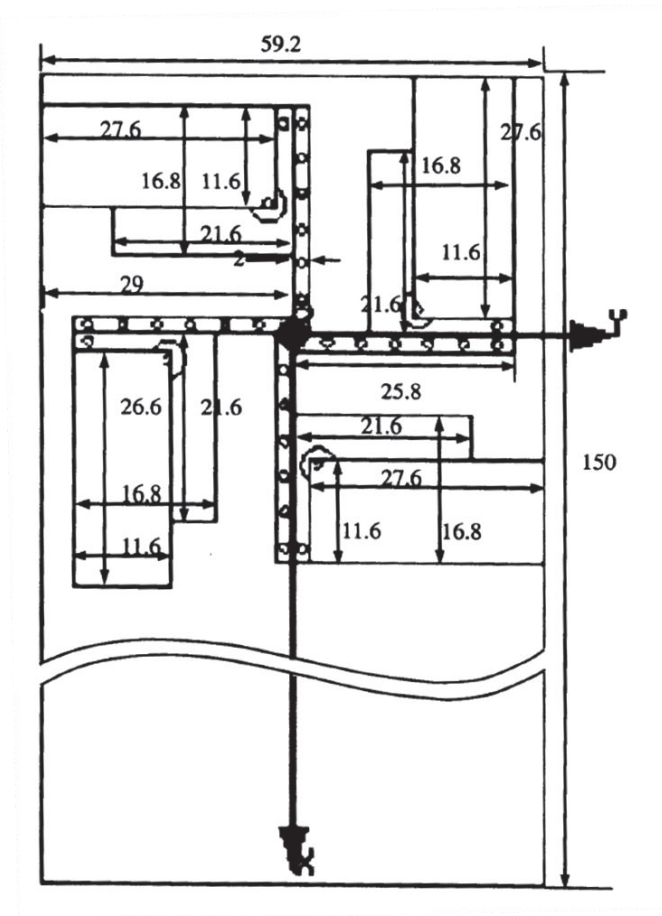


FIG. 7(b)



**Certification of Accuracy of Translation**

**Sun IP Project # 26-437**

**Chinese to English translation of CN1728456A.PDF**

I, Xiongwei Shen, hereby certify that I am fluent in both the Chinese and English languages and that the attached English translation is, to the best of my knowledge, a true and accurate translation of CN1728456A.PDF. The translated text reflects the content, meaning and style of the original text and constitutes a true and accurate translation of the original document. I have been warned that willful false statements and the like are punishable by fine or imprisonment, or both.

**February 1, 2026**

*Xiongwei Shen*

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**Xiongwei Shen**