Design of a dual-band indoor antenna with orthogonal bi-directional radiation pattern

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Abstract: In recent years, MIMO (Multi-Input Multi-Output) transmission technique has attracted increasing attention, as it can satisfy the need for exponential increase in data traffic for mobile communications, especially when used for indoor areas. In this paper, an antenna design is proposed that can operate in the 2.6 GHz and 3.5 GHz bands and produce an orthogonal bi-directional radiation pattern. Some characteristics of the proposed antenna, such as reflection coefficient (S_{11}), transmission coefficient (S_{21}) and far-field radiation pattern are simulated and evaluated by means of FDTD (finite-difference time-domain) methods. The results show that S_{11} and S_{21} are below -10 dB and -15 dB, and moreover, the MIMO performance can probably be improved because the difference between the two directional gain levels is achieved by approximately 15 dB when four slits are etched into the ground plane.

Keywords: indoor antenna, base station antenna, MIMO, dual band

Classification: Antennas and Propagation

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1 Introduction

In recent years, the MIMO (Multi-Input Multi-Output) transmission technique has attracted increasing attention as it can satisfy the need for the exponential increase in data traffic required by mobile communications, especially for indoor and densely populated areas. In general, base stations use diversity reception to minimize the effect of Rayleigh fading on the received signal. Polarization spatial diversity techniques are the most common forms of diversity reception [1, 2, 3]. Another form of diversity, angular diversity techniques are also effective at mitigating multipath situations [4], because multiple antennas are oriented in different directions, but multiple antennas are required to form such systems. However, for indoor base stations, it is considered that a device must be compact, and its location should be optimized for maximum antenna coverage.

A number of studies on indoor base station antennas have been published in journals and conference papers. According to [5], in 1997 the main design target for an indoor base station antenna and the effect of the ground plane were introduced. A design for a cylindrical monopole antenna was proposed to reduce the physical antenna size [6]. In order to enhance the bandwidth, a dual-sleeve antenna structure and the use of a shorting wire were proposed [7] and [8].

In this paper, we propose a novel compact indoor base station antenna that is designed to operate in the 2.6 GHz and 3.5 GHz bands. The S_{11} and S_{21} are satisfying the requirement of $S_{11} < -10$ dB and $S_{21} < -15$ dB in MIMO system [9] and [10], and moreover, the proposed antenna has an orthogonal bi-directional radiation pattern for each frequency band, which means that angular diversity gains could be improved to a practically useful extent in a multipath environment. Moreover, the MIMO performance can probably be improved because the difference between the two directional gain level can be achieved by approximately

15 dB when we etched four slits into ground plane. The simulation was performed with CST Microwave STUDIO [11].

2 Antenna structure

2.1 Basic principles of radiation patterns

Fig. 1 illustrates the radiation pattern of two isotropic sources in the same phase and opposite phase, and the difference between the two directional gain levels on an orthogonal bi-directional radiation pattern. Fig. 1(a) shows the two isotropic sources separated by a distance d and located along the y -axis. As we know, beam-width and main-beam direction can be controlled by changing the signal amplitude and phase of each antenna [12]. For instance, when two isotropic sources have the same amplitude and phase (Phase difference, $\delta = 0$ -degree), the main-beam of the vector sum of the fields is orthogonal to the x -axis direction. Similarly, when they have the same amplitude but opposite phase (Phase difference, $\delta = 180$ -degree), the main-beam is in the y -axis direction. The vector addition of the fields as mentioned above can be expressed as

$$E = 2E_0 \cos\left(\frac{d}{2} \cos \theta\right) \quad (1)$$

$$E = 2jE_0 \sin\left(\frac{d}{2} \cos \theta\right) \quad (2)$$

where $d = \lambda/2$ and the amplitude of $2E_0$ and $2jE_0 = 1$ are considered as a special case. We should note that the field pattern in the opposite phase given by (2) is a relatively broad figure-eight with the maximum field.

Fig. 1. Schematic of the radiation pattern and image of an orthogonal bi-directional radiation pattern.

According to this concept, when we set the phases of two isotropic sources to be the same or opposite by use of 180-degree hybrid couplers, an orthogonal bi-directional radiation pattern can be formed to extend simultaneously in the x -axis and y -axis directions. However, it should be noted that the overlapping patterns also cause the undesirable high correlated or correlated MIMO signals to affect MIMO performance. Fig. 1(b) shows an image of the desirable radiation pattern. From the image, the difference between the two directional gain level should be large in order

to reduce the overlapping on the orthogonal bi-directional radiation pattern, that meaning the MIMO performance can probably be improved. Therefore, we considered that the difference should be at least 15 dB in order to improve MIMO performance. In next section, the structure of the proposed antenna and the detailed simulation results are shown and discussed.

2.2 Antenna structure and simulation result

Fig. 2(a) shows a prototype model of the vertical polarized antenna. Two pairs of monopole antennas, both with a diameter of 2 mm, are mounted on a ground plane and located along the y -axis. 2.6 GHz and 3.5 GHz antenna elements are separated by a distance d_1 of 0.5λ and d_2 of 0.59λ , respectively. The circular ground plane is formed from an indoor base station for practical use, and its diameter and thickness are set to 100 mm and 0.5 mm. In order to improve the input impedance matching, we introduced an L-type matching-pin that is designed to connect the monopole antenna for 3.5 GHz with the ground plane as shown in Fig. 2(b). The height (h) and distance (w) between matching-pin and monopole antenna are 5.5 mm and 1 mm. Four slits are etched into the ground plane and symmetrically arranged to improve the diversity performance of the proposed antenna and the width and length (l) of each slit are 1 mm and 35 mm. Gap feeding is set at the bottom of each antenna. The parameters of w and h can be changed to obtain the optimized result for impedance matching. For the radiation pattern, the optimized result can be obtained by tuning the width and length of slit and d_2 .

Fig. 2. Prototype of the proposed antenna structure.

Fig. 3 shows the simulation results for the S -parameters and far-field radiation pattern. From the results show in Fig. 3(a), when the matching-pin is not used, it can be seen that S_{11} in the 3.5 GHz band does not satisfy the required value of -10 dB, possibly because the antennas are close to each other and the coupling between them becomes strong. S_{21} at 2.6 GHz is -17 dB, which satisfies the -15 dB requirement, but at 3.5 GHz it is -13 dB and needs to be improved. Fig. 3(b) shows the results with the matching-pin, the input impedance in the 3.5 GHz band can be improved ($S_{11} < -10$ dB) and S_{21} at the 2.6 GHz and 3.5 GHz is -15 dB and -24 dB, which satisfies the required -15 dB. The bandwidth of the proposed antenna at 2.6 GHz and 3.5 GHz are 50% and 17%, respectively.

Fig. 3(c) and (d) plot the radiation pattern without four slits. From the result, although the proposed antenna seems to have an orthogonal bi-directional radiation pattern, the difference between the two directional gain levels is 10.8 dB (in the x direction) and 20.6 dB (in the y direction) at the 2.6 GHz, 22.5 dB (in the x direction) and 14.2 dB (in the y direction) at the 3.5 GHz band, so some results need to be improved to satisfy the 15 dB requirement. Fig. 3(e) and (f) show the radiation pattern when the four slits are etched into ground plane. From the results, the difference between the two directional gain levels is 26.1 dB (in the x direction) and 25.6 dB (in the y direction) at the 2.6 GHz band, and 22.8 dB (in the x direction) and 16.9 dB (in the y direction) at the 3.5 GHz band, all results fulfill the 15 dB requirement by the addition of the four slits. For the opposite phase case at 2.6 GHz the difference between two directional gain levels has been improved from 10.8 dB to 26.5 dB (in the y direction), the amount of improvement is approximately 15 dB.

Fig. 3(g) and (h) present the excited surface current distribution, obtained from the simulation of the ground plane of the proposed antenna, for the opposite phase case at 2.6 GHz. Comparison of (g) and (h) shows that when four slits are etched into the ground plane, the current in the x direction is lower than it is without the slits. This is thought to result from currents flowing (I_1 and I_2) along the slits that mutually cancel, making that the main reason for the improvement in the difference between the two directional gain levels in orthogonal bi-directional radiation patterns.

(a) S-parameter (w/o matching-pin)

(b) S-parameter (with matching-pin)

Fig. 3. Simulation results of the proposed antenna

3 Conclusions

In this paper, we propose a novel compact indoor base station antenna with an orthogonal bi-directional radiation pattern for dual-band operation at 2.6 GHz and 3.5 GHz. The simulated results indicate that input impedance in the 3.5 GHz band can be improved by adding a matching-pin, bringing the S_{11} below the required value of -10 dB. Moreover, the MIMO performance can probably be improved because the difference between the two directional gain levels is achieved by approximately 15 dB when four slits are etched into the ground plane. The proposed antenna's structure is simple and compact, which will be useful when designing high-performance base station antennas. In future work, the estimation of MIMO capacity will be implemented and an experiment will be carried out to test the simulated results presented here for the proposed antenna.