A Low Profile Diversity Antenna for Indoor Ceiling Applications of WLAN Systems

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***Abstract* —This work presents an indoor ceiling diversity antenna for WLAN systems. By integrated the circular patch and circular slot ring antenna together, the wide pattern coverage for indoor communication could be achieved. In order to avoid the bi-directional radiation characteristic of the slot ring antenna, a 20 cm long square reflector was added 10 mm below the slot antenna. The proposed antenna is suitable for indoor ceiling mount applications of WLAN systems.**

I. INTRODUCTION

Nowadays the technique of wireless communication systems is rapidly development. A Wireless local area network (WLAN) links two or more devices, by using some wireless distribution method, usually providing a connection through an access point to the internet. Modern WLANs are based on IEEE 802.11 standards, marketed under the Wi-Fi brand name. In order to acquire better radiation characteristics for the indoor ceiling applications, some literatures proposed the WLAN antenna for ceiling mount application [1-3]. However, the radiation pattern of the antenna was only for broadside radiation. The main drawback of these kinds of antenna is the narrow beamwidth. This drawback limited the receiving/ transmitting phenomenon for the indoor ceiling mount application.

The problem of wireless channel for wireless communication systems is an important issue. Antenna diversity is a well-known technique to enhance the performance of wireless communication systems by reducing the multipath fading and co-channel interference [4-6]. These methods of diversity technique are spatial, polarization and pattern diversities to achieve diversity performance. The designers can employ one or more of these methods, and excellent antenna efficiency, low signal correlation are important parameter for good diversity performance. The apparent diversity gain is computed as (1) in [6]:

$$DG_{app} \cong 10.48\sqrt{1-|\rho_s|^2} \qquad (1)$$

where DG_{app} represents the diversity gain of the proposed design and the ρ_s represents the signal correlation between two diversity antennas. The signal correlation of two antennas is computed as:

$$\rho_s = \frac{\iint_{4\pi} \overrightarrow{F_1}(\theta,\phi)\cdot\overrightarrow{F_2}^*(\theta,\phi)\, d\Omega}{\sqrt{\iint_{4\pi} \overrightarrow{F_1}(\theta,\phi)\cdot\overrightarrow{F_1}^*(\theta,\phi)\, d\Omega \iint_{4\pi} \overrightarrow{F_2}(\theta,\phi)\cdot\overrightarrow{F_2}^*(\theta,\phi)\, d\Omega}} \qquad (1)$$

Where $\overrightarrow{F_1}(\theta,\phi)$ and $\overrightarrow{F_2}(\theta,\phi)$ are the far field radiation of each antenna in diversity antenna system.

In this paper, a pattern diversity antenna system is presented. The pattern diversity antenna system is constructed by excited two types of antennas in different mode of operation individually. We excite fundamental mode of circular patch antenna and high order mode of annular ring slot antenna that make the radiation patterns trend to different depression angle to achieve pattern diversity. This antenna has multi-direction radiation pattern and good average gain at depression angle 45° to 90° (theta 45° to 0°). According to the pattern diversity technique, the signal correlation of two antennas with different radiation is significantly low.

II. INDOOR CEILING DIVERSITY ANTENNA FOR WLAN SYSTEMS

The geometry of the proposed pattern diversity antenna is shown in Fig. 1. The side view of proposal antenna is shown in Fig. 2. The first layer is circular patch, and the second layer is feeding line. The third layer is annular ring slot, and the fourth layer is square ground plane. The dimensions of square ground plane is 200 x 200 mm^2. Due to the radiation pattern of the slot is bi-directional, the square ground plane could reflect the pattern from unwanted direction (-Z) to wanted direction. The dielectric material used between the first layer and the second layer is air having a thickness h_1 = 3 mm. The dielectric material used between the second layer and the third layer is FR-4 having a thickness h_2 = 1.6 mm and relative permittivity $\varepsilon_r = 4.4$. The dielectric material used between the third layer and the fourth layer is air with its distance 10 mm. The height h_3 = 10 mm is near 1/10 wavelength, and it's an advantage for our design.

In this paper, we want to use model analysis of antenna to excite different radiation pattern to achieve pattern diversity. We study how to excite high order mode of annular ring slot antenna, that can make the radiation pattern trend to low depression angle (depression angle 45° to 60°) and symmetrical. We study about model analysis of annular ring patch antenna, and the radiation pattern of TM_{21} mode conforms our design target. The maximum current

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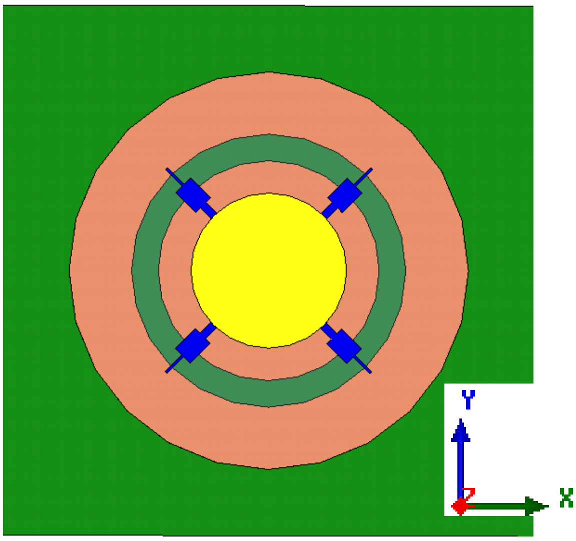


Fig. 1. Indoor ceiling diversity antenna structure.

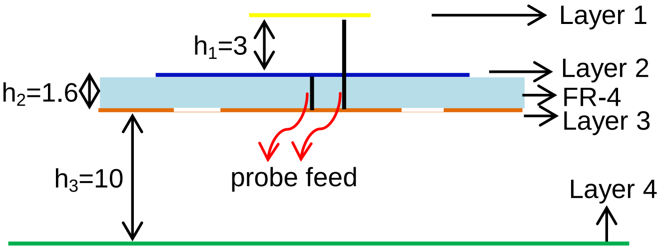
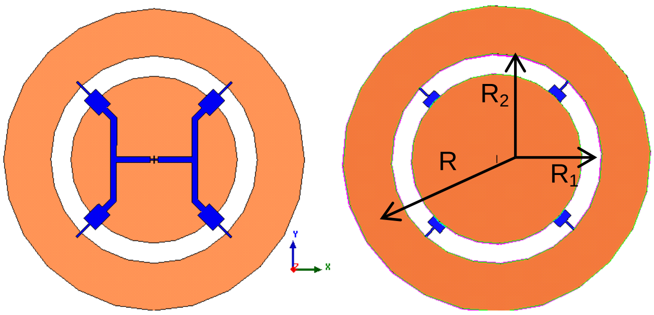


Fig. 2. The side view of indoor ceiling diversity antenna.



(a) (b)

Fig. 3. (a) Top view, and (b) back view of high order mode of annular ring slot antenna.

distribution of TM_{21} mode appears at theta ±45° and ±135°, that can make the radiation patterns trend to low depression angle and symmetrical. According to model analysis of annular ring patch antenna, the annular ring slot antenna is relative annular ring patch antenna. Therefore, we can excite high order mode of annular ring slot antenna to achieve our design target. The annular ring slot is shown in Fig. 3. The inner radius R_1 is 41.5 mm, the outer radius R_2 is 51.5 mm, and the integral radius R is 75 mm. We use probe feed between feeding line and annular ring slot at the center point.

We want to design a symmetrical feeding line, that can equalize power to each termination, and the feeding line is not too long, that can avoid loss too large. The geometry of

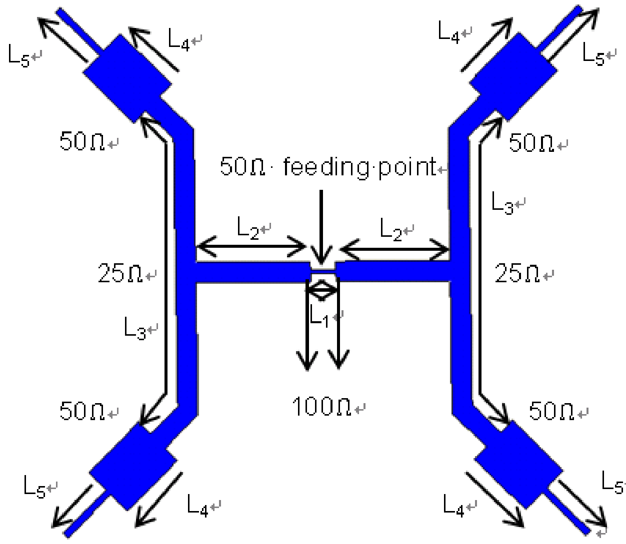


Fig. 4. The feeding line of annular ring slot antenna.

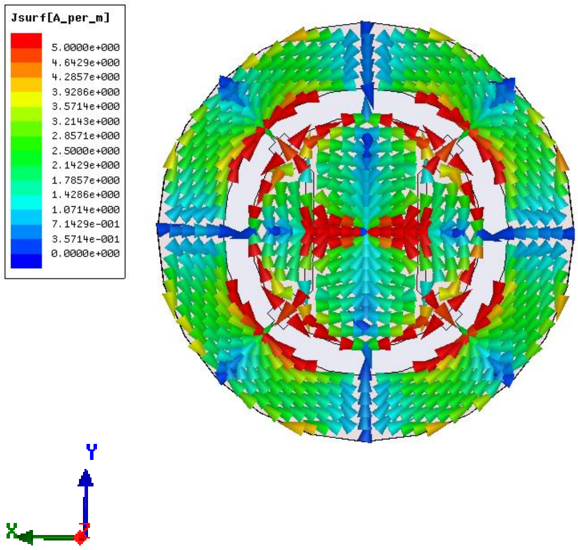


Fig. 5. The current distribution of annular ring slot antenna.

feeding line of annular ring slot antenna is shown in Fig. 4. Using the feeding line to couple with the annular ring slot, and excite the high order mode. The feeding line is separated to four stubs at theta ±45° and ±135°from center feeding point, that can make the radiation patterns trend to low depression angle and symmetrical. The center of feeding line is 50Ω feeding point, L_1 is microstrip line of 100Ω, L_2 = 16.85 mm is a quarter-wave transformer of 100Ω to 25Ω, L_3 is microstrip line of 50Ω, L_4 = 10.5 mm, L_5 = 9 mm, the width of L_4 and L_5 is 8 mm and 1 mm respectively.

The current distribution is shown in Fig. 5. According to the current distribution, it has two half wavelength of current distribution on the half annular ring slot. It can explain that we excite the high order mode of the annular ring slot.

In order to excite the broadside radiation pattern, that can trend to high depression angle (depression angle 60° to 90°).We study model analysis of circular parch antenna. We excite fundamental mode of circular patch antenna, and the configuration is shown in Fig. 6. The radius R_3 is 29.25 mm, and the distance from 50Ω feeding point to center point is 9.25 mm, that 50Ω feeding point is under the center point. We use probe feed between circular patch and the inner circular mental of annular ring slot at the 50Ω feeding point. We use the inner circular mental of annular ring slot as ground plane for circular patch antenna.

The simulation radiation patterns by varying the height h_3 to operate at the 2.45 GHz are shown in Fig. 7. We compare these radiation patterns of annular ring slot by different height h_3 between third layer and fourth layer. It changes from 10 mm (1/10 wavelength) to 30 mm (1/4 wavelength) of the height h_3. These radiation patterns are trend to same depression angle. When the height h_3 is much larger than 10 mm, it will radiate behind the square ground plane a little, so we select the best height h_3 is 10 mm.

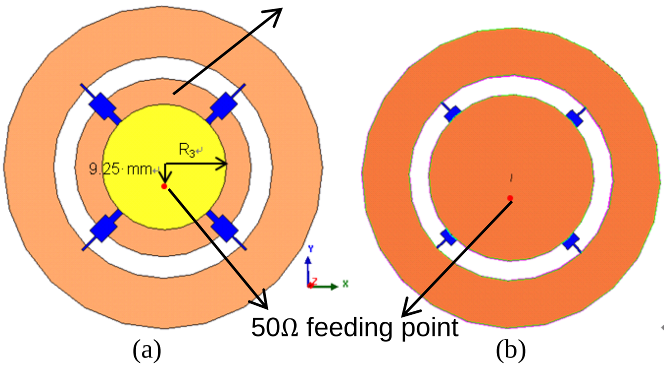


Fig. 6. (a) Top view, and (b) back view of annular ring slot antenna with circular patch antenna.

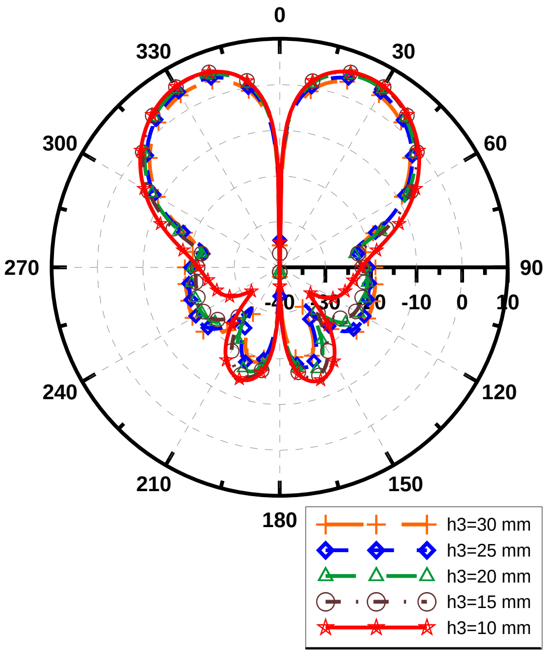


Fig. 7. Simulated radiation pattern for various height of h_3 at vertical-plane of indoor ceiling diversity antenna.

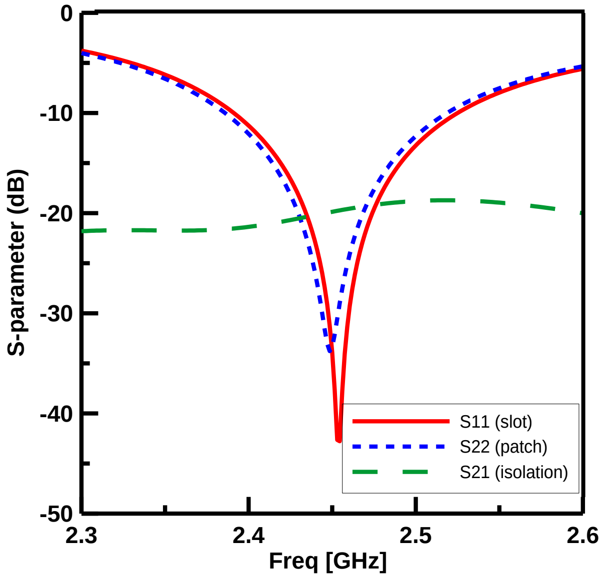


Fig. 8. Simulated S-parameter of indoor ceiling diversity antenna.

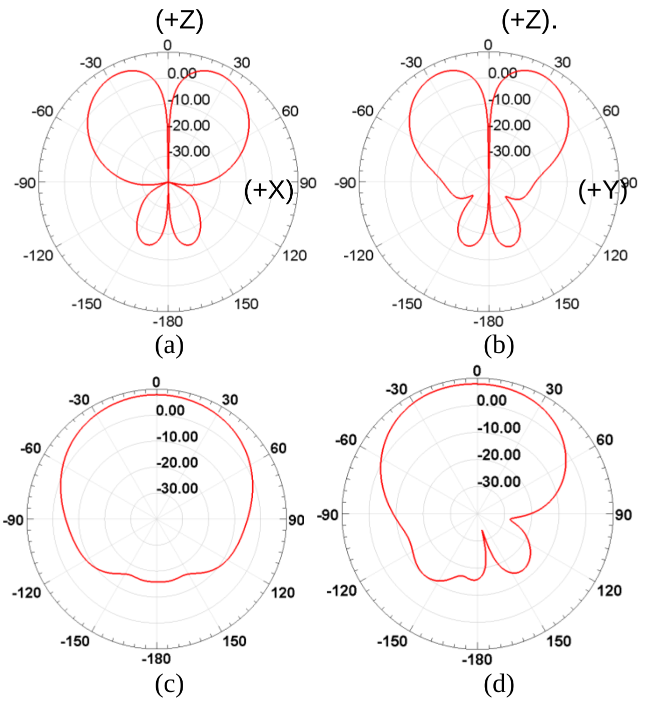


Fig. 9. The 2-D simulated radiation patterns: (a) XZ-plane and (b) YZ-plane of annular ring slot antenna, (c) XZ-plane and (d) YZ-plane of circular patch antenna.

The simulation S-parameter is shown in Fig. 8. It has a good impedance matching and isolation within 2.4 ~ 2.484 GHz. According to (1) and (2), good isolation leads better diversity gain. These 2-D simulation radiation patterns of this antenna are shown in Fig. 9. We excites the high order mode of annular ring slot antenna, and the fundamental mode of circular patch antenna, that make the radiation patterns trend to low depression angle, high depression angle respectively and symmetrical.

Tabel. I. The average gain at different depression angle.

Dep. Angle	90	85	80	75	70
Circular patch (dBi)	7.88	7.85	7.76	7.61	7.37
Ring slot (dBi)	-11.7	-3.2	1.92	4.64	6.11
Dep. Ang.	65	60	55	50	45
Circular patch (dBi)	7.02	6.53	5.87	5.04	4.03
Ring slot (dBi)	6.77	6.82	6.36	5.47	4.18

The average gain at different depression angle is shown in Tabel. I. The average gain of circular patch antenna is larger than 7 dBi at depression angle 65° to 90°, and annular ring slot antenna is larger than circular patch antenna at depression angle 45° to 60°.

The simulation of antenna efficiency and radiation efficiency is shown in Fig. 10. The antenna and radiation efficiency of circular patch antenna is higher than 90%, and the annular ring slot antenna is about 80%. There are good antenna and radiation efficiency of the indoor ceiling diversity antenna. The signal correlation of the indoor ceiling diversity antenna is shown in Fig. 11. The signal correlation of the indoor ceiling diversity antenna is smaller than 0.1. The correlation between annular ring slot and circular patch antenna is small. The apparent diversity gain is 10.4 at 2.4 -2.484 GHz. It has a good performance.

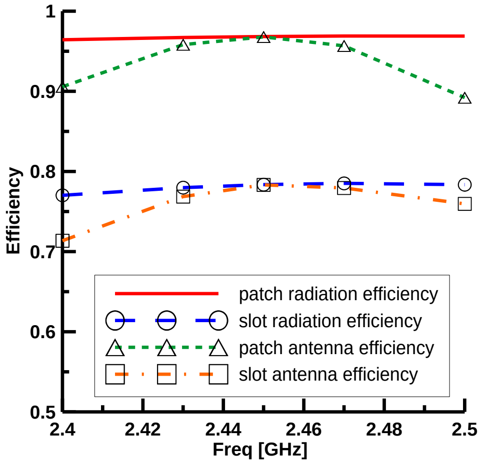


Fig. 10. Simulated antenna efficiency and radiation efficiency.

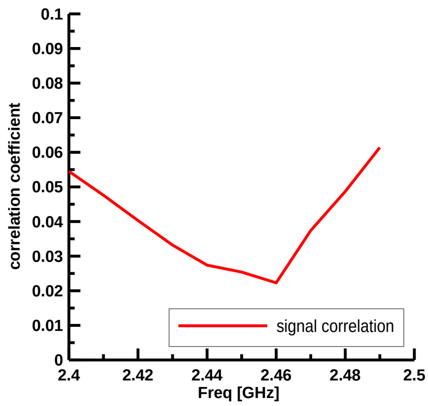


Fig. 11. Signal correlation of indoor ceiling diversity antenna.

III. CONCLUSIONS

In this paper, we excite fundamental mode of circular patch antenna, and high order mode of annular ring slot antenna, that make the radiation patterns trend to different depression angle to achieve pattern diversity, and it has an excellent diversity gain about 10.4. This antenna has multi-direction radiation pattern at depression angle 45° to 90°, that user has a wide coverage range of signal. The average gain is larger than 4 dBi, and the maximum average gain is about 8 dBi at depression angle 45° to 90°.

The signal correlation of this antenna is smaller than 0.1 by using pattern diversity. This antenna has good antenna and radiation efficiency, that antenna and radiation efficiency of circular patch antenna and annular ring slot antenna is much larger than 90% and about 80% respectively. This antenna also has a good isolation about -20 dB at 2.4-2.484 GHz, and low height about 1/10 wavelength.

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