TRIPLE POLARIZATION ANTENNA EMPLOYING CAPACITOR LOADED MONOPOLE ANTENNA AND NOTCH ANTENNA FOR MIMO SYSTEMS

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1. *Introduction*

Recently, wireless LANs have proliferated widely and small wireless LAN terminals such as the PDA-type or PCMCIA-type have become popular. As the popularity of broadband communications has increased, the demand for wireless LANs with higher data transmission speeds has increased. Multi-Input Multi-Output (MIMO) systems are effective in enhancing the data transmission speed of wireless communication without expanding the frequency bandwidth, and wireless LAN systems, which achieve data transmission speeds of greater than 100 Mbits/sec by employing MIMO technology, have become the topic of investigations [1]. MIMO systems use many antennas, however, there is a problem when it comes to small MIMO terminals because the spacing between neighboring antenna elements becomes narrow. This causes a high degree of coupling between antennas, which increases the antenna correlation and adversely affects the MIMO channel capacity.

To achieve low antenna correlation characteristics in a compact configuration, the implementation of a triple orthogonal polarization antenna was studied [2]. However, a thinner and smaller antenna is necessary for the small wireless LAN terminals because the antenna size should not affect the portability of the terminal.

In this paper, we propose a small triple-polarization antenna with a low profile for small MIMO terminals, which has six ports, constructed in the size of a PCMCIA card. In the proposed configuration, two orthogonal notches are configured around the corner of a rectangular ground plane on a dielectric substrate. The short ends of the two notches are close to each other. Also, a top loaded monopole antenna employing a circular plate capacitor is configured around the ends of the two notches. The short ends of two notches and the end of monopole must be close to each other in order to reduce the coupling between three antennas. We achieved an antenna array with the six ports, which can be implemented within a PCMCIA card by employing two sets of these three antennas.

To evaluate the validity of the proposed antenna in MIMO systems, we studied the coupling level between the ports, and measured the channel capacity using a fabricated antenna.

2. *Configuration of Proposed Triple Polarization Antenna*

Figure 1 shows the configuration of the proposed triple polarization antenna at 5.2 GHz. This antenna is configured on a dielectric substrate, and the microstrip feedlines are configured on the backside of the substrate. In the figure, the numbers #1 to #6 indicate the port numbers. The size of the substrate is 54 mm x 30 mm, which is generally the size of the protruding portion of a PCMCIA wireless LAN terminal when the terminal is attached to a PC. The thickness of the substrate is 0.8 mm and the dielectric constant of the substrate is ε_r = 2.2. The two orthogonal notches are configured at one corner of the rectangular substrate, and the short ends of the notches are placed close to each other. The top loaded monopole antenna is configured near the ends of the notches as well. The reason why three antennas are placed closely is that this arrangement yields a low degree of coupling between them because the observed polarizations of the three antennas at this point are orthogonal to each other. Two sets of these three antennas are configured at the two corners of the substrate. The spacing between the two notches on the same long side of the rectangular substrate is 0.38 λ_0 (λ_0: wavelength in a vacuum), and the spacing between the two monopoles is also 0.38 λ_0. A

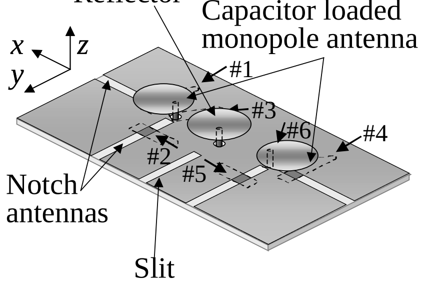

Fig. 1 Proposed antenna.

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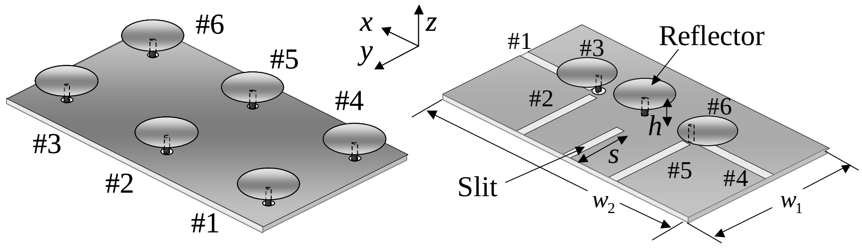
parasitic slit between the two notches, which are on the same long side of the rectangular substrate, reduces the degree of coupling between the two notches. A parasitic top loaded monopole antenna works as a reflector, and reduces the coupling between the two top loaded monopole antennas. From these mechanisms, a low antenna correlation can be expected even with six antennas configured in such a compact geometry. Furthermore, the proposed configuration is very thin because all six antennas are configured in low profile geometry.



(a) Six-monopole antenna (b) Proposed antenna

Fig. 2 Analysis models.

On the other hand, since this configuration employs a small ground plane, there is a relatively high level of cross polarization, which is expected to affect the coupling between the antennas. In the following section, the coupling level is evaluated in the proposed antenna.

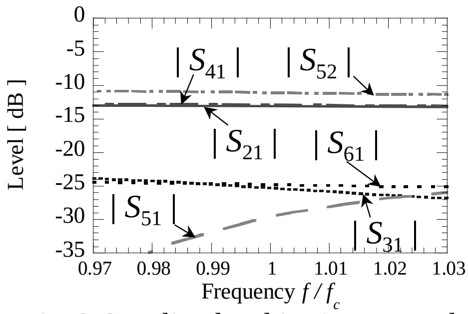


Fig. 3 Coupling level in six-monopole array.

3. *Numerical Analysis of Coupling Between Antennas*

Figure 2 illustrates the configuration of the conventional antenna with six monopoles and our new antenna. The spacing between neighboring antenna is 0.38 λ_0 for *x*-axis direction and 0.35 λ_0 for *y*-axis direction in the conventional configuration. The two configurations have the same substrate dimensions. The conductivities of the conductors are set to $\sigma = 5.7\times10^7$, and the other parameters are the same as those described in Section 2. To obtain a high degree of isolation between neighboring antennas with the same major polarization directions, we investigate slit length *s* and reflector height *h*.

Figure 3 shows the calculated coupling properties in the conventional antenna. The figure shows that there is a high coupling level of greater than –15 dB between neighboring antennas. This means that it is difficult to arrange six antennas in this size substrate.

To evaluate the isolation enhancement effect of the slit and the reflector, an antenna without them is calculated. Figure 4 indicates the coupling between the antennas in the proposed configuration without the slit and the reflector. The results show that the coupling levels between the different polarization antennas decrease to a value of less than –15 dB, and the coupling between the same polarization, such as | S_{52} | and | S_{63} |, becomes greater than –10 dB.

Figure 5 shows the relationship between the slit length, *s*, and the coupling level | S_{52} |. Here, the results are calculated using the configuration with only two notches and a slit on the rectangular substrate for the sake of simplicity in the analysis. The results show that the coupling level is greatly suppressed when *s* is 0.2λ_0. This is because the parasitic slit resonates when one of the closest notches is excited, and anti-phase

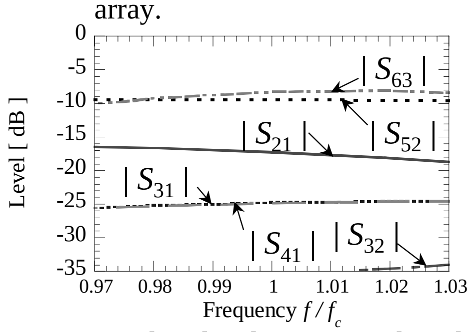


Fig. 4 Coupling level in proposed model without slit and reflector.

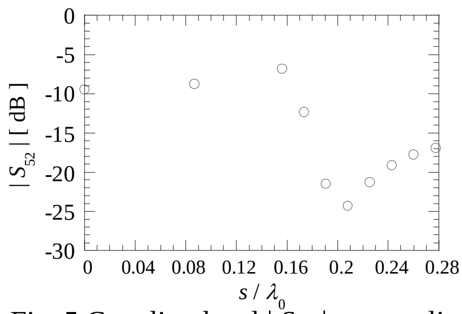


Fig. 5 Coupling level | S_{52} | versus slit length *s*.

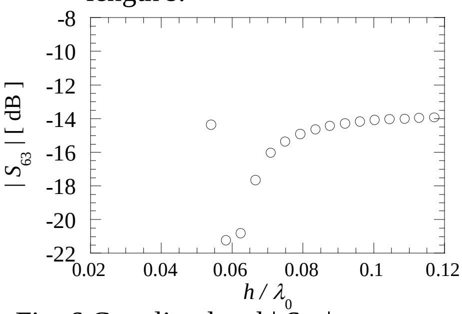


Fig. 6 Coupling level | S_{63} | versus reflector height *h*.

radiation can be observed from the other notch. Figure 6 shows the calculated coupling level versus the reflector height. Here, the results are also calculated using the configuration with only two monopoles and a reflector on the rectangular substrate. The results also show that the optimum height exists, and that the reflector with the optimum height of 0.06 λ_0 improves the coupling level by more than 10 dB compared to that without a reflector. These numerical analyses indicate that employing the slit and the reflector achieves a coupling level of less than –20 dB between the same polarization antenna even in a compact configuration.

4. *Experimental Verification of Proposed Triple Polarization Antenna*

The proposed antenna is fabricated and tested at 5.2 GHz to verify the antenna properties and MIMO channel capacity. Here, the substrate size, the dielectric constant, and the dimensions of the antenna are the same as the parameters described in Sections 2 and 3.

Figure 7 shows the coupling between the three polarization antennas. Since the proposed configuration has a symmetric geometry, the relationship between Ports #1, #2, and #3 is shown. This result shows that $|S_{21}|$, $|S_{31}|$, and $|S_{32}|$ are less than –15 dB at the center frequency of f_c in the measurement and calculation. Figure 8 shows the coupling between the antennas whose major polarization directions are the same. The measured and calculated coupling levels are less than –20 dB at f_c. These results shown in Figs. 7 and 8 mean that the proposed antenna functions as designed at 5.2 GHz because a sufficiently low coupling level can be achieved even in the fabricated antenna.

Figure 9 shows the measured and calculated radiation patterns. Figure 9(i) is the *zx*-plane radiation pattern when Port #1, i.e., one notch, is exited, and Fig. 9(ii) is the *yz*-plane radiation pattern when Port #2, i.e., the other notch, is exited. These radiation patterns show that the major polarization component of the antenna connected to Port #1 is parallel to the *y*-axis, and the major polarization component of the antenna connected to Port #2 is parallel to the *x*-axis. Figure 9(iii) shows the *xy*-plane radiation pattern when Port #3, i.e., a monopole, is exited, and we find that the major polarization component is parallel to the *z*-axis. These results indicate that the three different polarizations can be obtained using the proposed antenna. On the other hand, relatively high-level cross polarizations are also generated. This is because the antenna configuration has a small rectangular ground plane. Considering the results shown in Figs. 7 and 8, the proposed antenna can achieve a high degree of isolation even in the presence of a high level of cross polarization radiation. In MIMO systems, cross polarization radiation is not a problem and a low level of coupling between the antennas is more important because a high level of coupling affects the antenna correlation and the radiation efficiency.

The channel capacity of a 6x6 MIMO matrix is evaluated using the proposed antenna. Conventional six-monopole antennas are also evaluated for comparison.

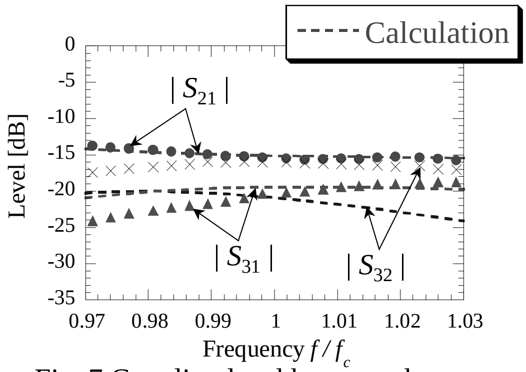


Fig. 7 Coupling level between three polarization antennas.

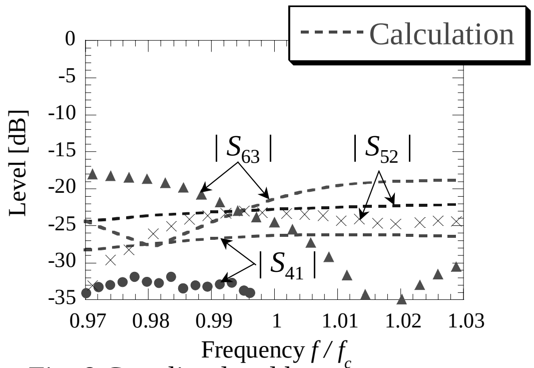
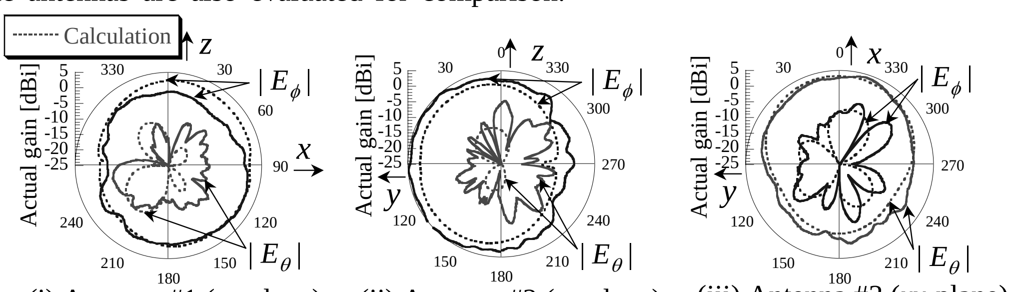


Fig. 8 Coupling level between antennas with the same polarization.



(i) Antenna #1 (*zx*-plane) (ii) Antenna #2 (*yz*-plane) (iii) Antenna #3 (*xy*-plane)

Fig. 9 Radiation patterns.

Figure 10 shows the indoor environment for the MIMO channel capacity evaluation experiment. The size of the room is 12x16x2.6 m and the terminal antennas are located at (x, y, z) = (3.0, 3.0, 0.7), (3.0, 8.0, 0.7), and (3.0, 14.0, 0.7) m. The base station antenna is located at (x, y, z) = (2.0, 2.0, 1.0) m. The 6x6 MIMO channel matrix is obtained by using a network analyzer. As the transmit antennas, a six dipole array is used. Three dipoles are arranged such that they are orthogonal to each other at the same position, and two sets of three dipoles are employed when the proposed antenna is verified. Six vertical polarization dipoles with identical element spacing are employed for the conventional configuration. The array length in both of two types of the transmit array is same and set to 1.0 λ_0. The carrier frequency is 5.2 GHz and the measured bandwidth is 100 MHz.

Figure 11 shows the measured results of the channel capacity in a 6x6 MIMO indoor propagation channel by employing the proposed triple polarization antennas. Figure 11 shows that the proposed triple polarization antennas achieves a channel capacity that is about 20% higher than that of the conventional vertical polarization antennas. Therefore, the proposed antenna achieves a high channel capacity even with a compact antenna configuration, which is suitable for small MIMO terminals.

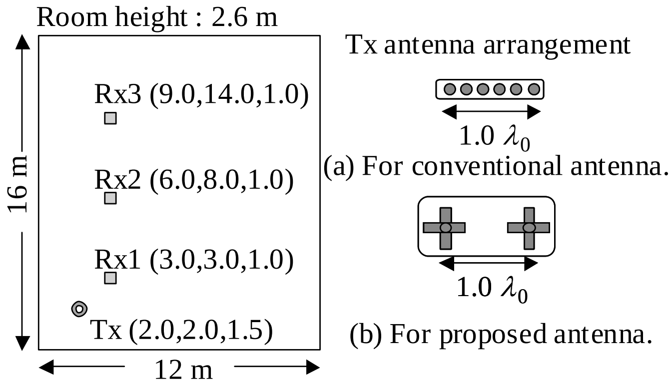


Fig. 10 Environment for MIMO channel capacity verification.

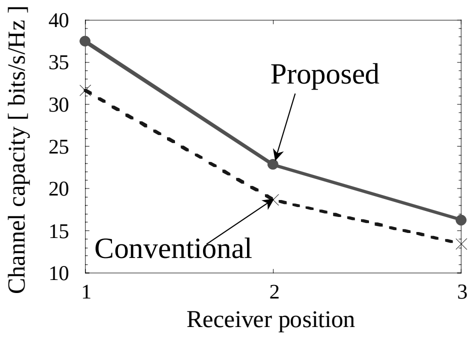


Fig. 11 Measured channel capacities versus receiver position.

5. *Conclusion*

This paper proposed a low profile and small triple-polarization antenna, which has six ports, in a compact configuration and is suitable for a PCMCIA card terminal. Two orthogonal notches are configured around a corner of the rectangular ground plane of the dielectric substrate and a top-loaded low-profile monopole antenna is placed near the two notches. The calculation results showed that there is a low coupling level of less than –15 dB between the notches. Two sets of these three antennas are configured at two corners of the substrate, and it is shown that the coupling level of less than –20 dB can be obtained using the optimized slit and reflector.

To evaluate the validity of the proposed antenna in MIMO systems, we measured the electrical properties of a fabricated antenna. We found that three orthogonal polarization radiation patterns can be obtained using two notches and one monopole. Furthermore, we found that our fabricated antenna has a low coupling level of less than –15 dB between all ports even with a pattern that has a high level of cross polarization radiation. We verified the MIMO channel capacity using the proposed antenna, and found that it can enhance the channel capacity by 20% compared to the conventional six-monopole antennas with the same antenna size.

These results indicate that the proposed antenna can provide a high MIMO channel capacity even with a compact configuration, which is suitable for small MIMO terminals.

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