A Low Profile Dual-Polarized Directional Antenna for Enhancing Channel Capacity in Indoor MIMO Systems

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1. Introduction

Large channel capacity is achieved by MIMO (Multiple-Input Multiple-Output) technology with multi-antenna at the transmitting and receiving side [1]. Many studies to maximize the MIMO channel capacity have been performed, and measurements show that channel capacity is enhanced by directional antennas [2] and multi-polarization [3] in indoor environment. Various MIMO antennas with pattern and polarization diversity have been proposed, such as combinations of circular patch and monopole [4], and 12 electric dipole antennas at the edges of a cube (MIMO cube) [5]. In MIMO antenna, small and low profile structure are desired for easy installation, and several antennas proposed in [4] and [5] are achieved with compact size.

In this paper, we propose uni-directional, dual-polarized MIMO antenna with its thickness of 30 mm. Proposed antenna is designed based on analytical guidelines to achieve large channel capacity shown in [6], and spatially orthogonal beams can be radiated into four directions. This antenna consists of dipole antennas mounted horizontally to the ground plane, and cavity backed slot antennas for vertical polarization. We also propose the application of this antenna to 2 × 2 MIMO considering antenna spacing at Mobile Station (MS), and show the effect of channel capacity enhancement by MIMO channel measurements in actual environment.

2. Dipole and slot antenna

Initially, we show design guidelines of the proposed antenna. In [6], we used ray-tracing method, and revealed the channel capacity enhancement by uni-directional antennas with dual-polarization (two elements are vertical, and the other two are horizontal polarized antennas) at Tx. In this simulation, the room size is 6 m × 6 m × 2.7 m, and Tx is fixed at the center of ceiling. The antenna configurations are optimized based on the channel capacity, and the HPBW (Half-Power Beam Width) is 80°, the main beam is directed toward side wall with tilt angle of 30° from horizontal plane (60° from negative zenith direction) as shown in Fig. 1.

Figure 3 (a) shows the proposed antenna structure for 2.4 GHz-band. The antenna specifications are shown in Fig. 1, and the design procedures are partly described in [7]. This antenna has 8-port, and is composed of four vertical polarized antennas (V) and four horizontal ones (H). In the former, cavity backed slot antennas in Fig. 2 (a), and in the latter, printed dipole in Fig. 2 (b) are used. Each dipole antenna is mounted in front of each slot antenna, however, the isolation between them is less than -20 dB because of the polarization orthogonality. The height of slot antennas and dipole antennas are 30 mm and 20.5 mm, respectively. Consequently, 30 mm thickness MIMO antenna is achieved by this structure. Corner reflector realized by the ground plane and conducting surface of cavity provide uni-directional pattern for dipole antennas. The cavity backed slot antennas consist of partitions inside the cavity as shown in Fig. 3 (b). This structure suppresses the backward radiation for uni-directional pattern for slot antennas, and also reduces the mutual coupling between slot antennas. The beam tilt from horizontal plane is adjusted by the height of the cavity and size of the ground plane.

Next, we present the characteristics of a prototype MIMO antenna. The reflection characteristics of slot and dipole antennas are shown in Table 1. We show the characteristics of a single pair of V and H elements (1V and 1H) in Fig. 3 (a) because those four pairs of dipole/slot antennas are the same. The reflection of both antennas is less than -10 dB at 2.4 GHz-band. Figure 4 (a) shows the radiation patterns in the vertical plane of the dipole and slot antenna. Fig. 4 (a) represents that both beams are tilted from z-direction in Fig. 3 (a) (0° in Fig. 4 (a)) to x- direction (270°). The HPBW and angle of Maximum Radiation Direction (MRD) are 84° and 45° from z-direction for the slot antenna, while they are 85.5° and 23.5° for the dipole antenna. Figure 4 (b) shows horizontal radiation pattern in the 60° tilted direction from z-direction to x-direction, where the 0° indicates the tilted direction. The HPBW for a slot and dipole antenna are 61° and 53°, respectively. Figures 4 (a) and (b) represent that uni-directional pattern is obtained by slot and dipole antennas, and the beams are radiated into four directions with spatial orthogonality because four slot/dipole antennas are mounted at right angles to each other.

3. Measurement in actual environment

In the case of MIMO systems with large number of elements, the problems are cost and antenna spacing. RF components are expensive, and large antenna spacing to mount multi-antenna element is very difficult, especially at Mobile Station (MS). Thus, we apply proposed antenna to Tx in 2×2 MIMO systems. 2 elements are selected from 4-port, which are 1V, 2H, 3V and 4H shown in Fig. 3 (a).

We fix proposed antenna at the center of the room ceiling as shown in Fig. 5 (a), and performed 2×2 MIMO channel measurements by experiment systems as shown in [8]. The measurement frequency is 2.45 GHz, and measured environment is quasi-static. The antenna height of Tx is 2.57 m and the size of this room is 5.75 m × 6.15 m × 2.70 m. The height of Rx is fixed 1.02 m, and the position is changed at intervals of 1 m in the horizontal plane as shown in Fig. 5 (b). It is open area between Tx and Rx at all the receiving positions. Main beams of Tx are pointed to side wall, and elements 2H and 3V are selected to cover received area as shown in Fig. 5 (a). We also conduct channel measurements by substituting sleeve antennas for the flat antenna to compare the characteristics. The polarization, array arrangement and element spacing of sleeve antennas are same as proposed antenna, and elements 2H and 3V are also used. Figure 5 (c) shows Rx configuration. Two sleeve antennas are used, where 1V and 2H are closely positioned. The antenna mounted horizontally to the ground (2H) is parallel to y-axis at each receiving position.

Figure 6 shows time averaged Signal-to-Noise Ratio (SNR) of the proposed and the sleeve antenna configurations at each receiving position in Fig. 5 (b). The SNR of the proposed antenna is changed with positions. Higher SNR is observed at positions near the Tx, such as positions 2, 4 and 5. The reason is that uni-directional beams are tilted downward from horizontal plane. Considerable enhancement (+10.1 dB) by proposed antenna is confirmed at position 2. At positions 1 and 7 far from the Tx, the SNR is lower than the positions near the Tx, however, higher than that of sleeve antenna. Place averaged SNR of sleeve and proposed antennas are 14.5 and 17.1 dB, respectively, and the SNR is elevated overall by proposed antenna. Figure 7 shows the channel capacity in a similar way as the SNR. The channel capacity is dependent on the SNR. Especially, large channel capacity enhancement by proposed antenna is confirmed at position 2 (1.9 times). This is due to the high SNR because the spatial correlation of each configuration is almost same (Sleeve: 0.68, Proposed: 0.65). Compared with place average values, channel capacity of the sleeve and the proposed antenna are 7.7 and 8.8 bits/s/Hz, respectively. Improvement factor by the proposed antenna is 13.5 %. The predominant feature is that the channel capacity is enhanced at positions 1, 2 and 7 with small channel capacity for the sleeve antenna configuration. The maximum and minimum capacity of the sleeve antennas in all the positions are 9.7 and 5.4 bits/s/Hz, while those of proposed antenna are 11.4 and 6.7 bits/s/Hz. Consequently, both channel capacities are also enhanced by the proposed antenna.

4. Conclusion

We proposed uni-directional and dual-polarized low profile MIMO antenna, and measured channel capacity in actual environment. Proposed antenna was based on the design guidelines in [6], and comprised four cavity backed slot antennas and four printed dipole antennas to achieve them. We showed the scattering parameters and radiation patterns of the prototype MIMO antenna. The reflection characteristics of V and H were less than -10 dB, and isolation between V and H were less than -20 dB at 2.4 GHz-band. The HPBW in the vertical and 60° tilted horizontal plane off zenith axis were 84° and 61° for the slot antenna (1V), and 85.5° and 53° for the dipole antenna (1H), respectively. The angle of Maximum Radiation Direction (MRD) for the slot and the dipole antennas were 45.5° and 23.5° from zenith direction, respectively. Then, the 2 × 2 MIMO channel measurements with proposed antenna fixed at Tx were performed at several receiving positions. The measurement results showed that both maximum and minimum capacity were enhanced, and the enhancement of the channel capacity in place average was 13.5 %, compared to sleeve antennas.

References

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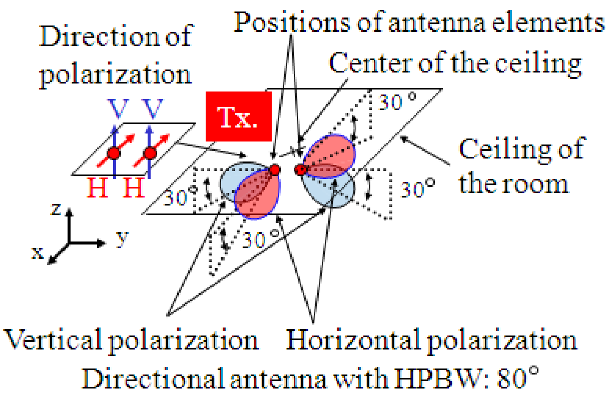

Figure 1: Design guidelines of antenna configuration.

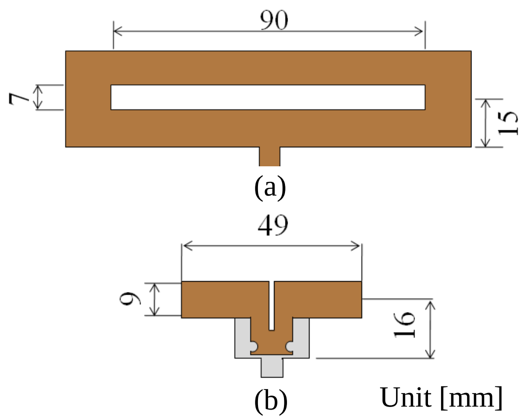

Figure 2: Vertical and horizontal polarized antenna elements. (a) slot antenna, and (b) dipole antenna.

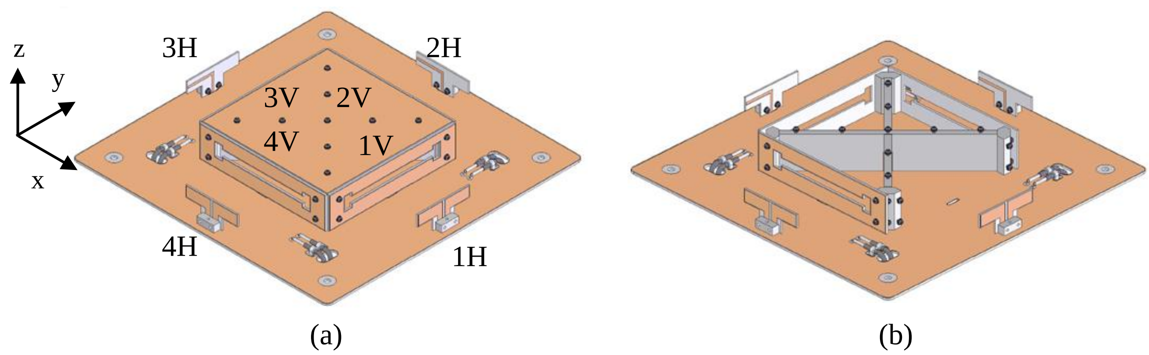

Figure 3: (a) proposed antenna structure, and (b) inner structure of cavity backed slot antennas.

Table 1: Reflection characteristics of proposed antenna elements.

Antenna	Reflection [dB]		
	2.4 GHz	2.45 GHz	2.5 GHz
Slot	-15.8	-13.3	-11.4
Dipole	-15.1	-16.0	-22.8

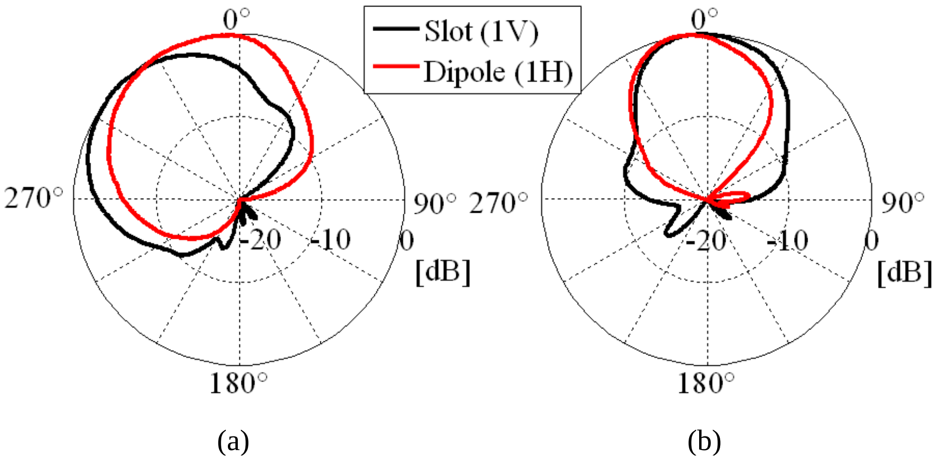

Figure 4: Radiation patterns of the prototype MIMO antenna. (a) vertical plane, and (b) 60° tilted horizontal plane off zenith axis.

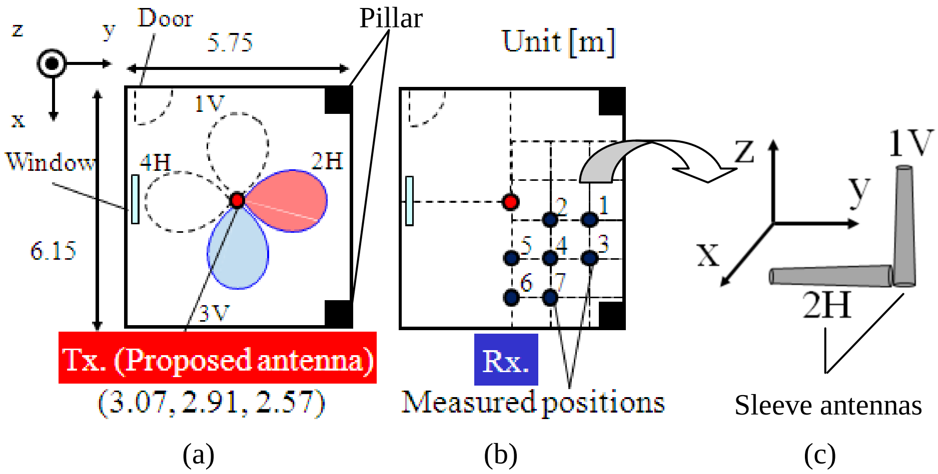

Figure 5: Overhead view of the measurement environment.
(a) positions and patterns of Tx, (b) positions and (c) configuration of Rx.

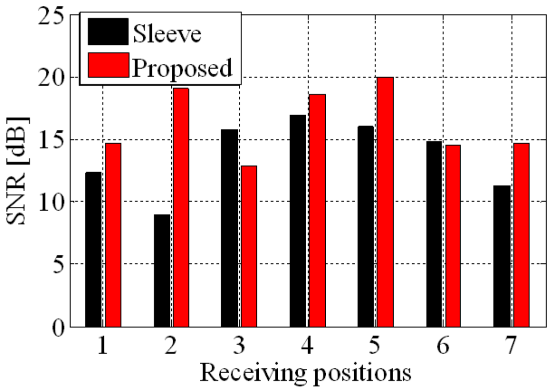

Figure 6: SNR in each receiving position.

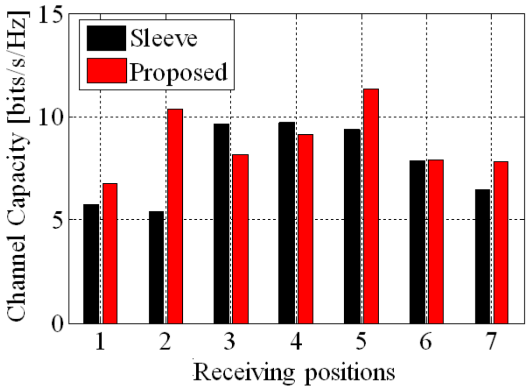

Figure 7: Capacity in each receiving position.