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A NOVEL MIMO ANTENNA FOR LAPTOP TYPE DEVICE

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ABSTRACT

Exploitation of MIMO (Multiple–Input Multiple–Output) system in laptop type device, which size is adequate to integrate several antennas on it, would be the solution to increase attainable capacity e.g. in wireless local area networks (WLAN). Thus, a microstrip prototype antenna with two polarizations is developed for MIMO and also for diversity system purposes. Firstly, two antennas of this type were placed against to each other, which guarantees a good coverage over a whole propagation area. Secondly, two antennas of this type were placed next to each other. The simulated radiation patterns of the prototype antenna are used in the capacity studies of MIMO system using real indoor propagation data. The effect of shadowing by human body as well as different tilting angles of "laptop cover/screen" are considered. Further, different locations of the "device" in azimuth plane were considered identifying the fluctuation of the results due to the environmental and antenna properties. The developed antenna systems perform well as compared to the ideal dipole system.

Keywords: Adaptive antenna, antenna evaluation, MIMO capacity, microstrip antenna**,** radio channel measurements

1. Introduction

MIMO (Multiple–Input Multiple–Output) systems have been studied extensively during the recent years. It is clear from the theoretical point of view that the use of MIMO systems increases the capacity of transferred signal as compared to the use of SISO (Single–Input Single–Output) and SIMO (Single–Input Multiple–Output) systems [1]. However, the practical implementation of MIMO systems is still under consideration – e.g. the effect of real antennas and signal propagation environments could be considered more comprehensively to have clear insight into the possible capacity increment of MIMO systems.

In MIMO application point of view, a laptop type device would be a convenient platform e.g. for WLAN systems. Such device is sufficiently large to integrate several antennas on it. Especially, the use of dual–polarized microstrip antennas instead of dipole antennas would be a compact solution for such applications. Only some MIMO antenna considerations for the laptop were found in the literature. 4×4 MIMO system with slanted dipoles in laptop was considered e.g. in [2] and [3]. In this work, the dual–polarized microstrip antenna group prototype was developed for the laptop type device, and tested in indoor propagation environment, which is the most probable operating environment for that kind of device.

The paper is constructed as follows. The developed antenna design is presented in Section 2. The used antenna evaluation criteria and measurement campaign including measurement system are discussed in Section 3. Mean capacity results of two MIMO systems exploiting the developed antenna are presented in Section 4. Finally, the work is concluded in Section 5.

2. Antenna characteristics

In this work, the dual–polarized micro–strip antenna was developed at the frequency range of 5.3 GHz using a HP High–Frequency Structure Simulator 5.0 (HFSS). The basic principle of the structure of the microstrip antenna is presented in Fig.1. Total thickness of the structure is 11 millimeters, and the ground plane is quadratic with 40 mm side and 5 mm thickness. The used substrate is 1.52 mm thick duroid with ε_r = 2.94. In this structure, a skewed microstrip line feed is ended to the ground edge, where a standard SMA connector is mounted. The idea of the skewed line is to provide space for the connectors of the another two–polarization patch mounted at the backside of the ground metal plate giving a compact antenna structure with four ports.

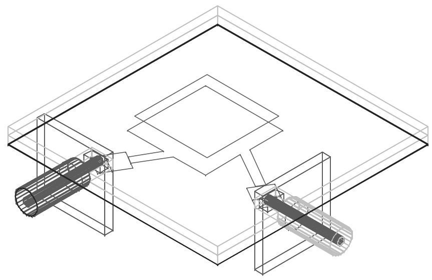


Figure 1. Sketch of two–polarized patch antenna.

Unfortunately, orthogonality loss caused by the skewing lines increases mutual coupling and degreases polarization isolation. However, the polarization isolation can be increased narrowing the width of the incoming line but the matching worsens at the same time. Because of that the skewed input microstrip line is divided into two parts: the part closer to the patch and to the connector is thinned and widened, respectively.

The bandwidth of antenna is increased using a layered structure with an additional patch. The realized antenna was optimised varying the dimensions and the placements of the basic and additional patches and the dimensions of the input lines. A 400 MHz bandwidth for 5 dB return loss was achieved by optimising the structure. The coupling between ports on the different side of the structure is less than −30 dB. The radiation pattern correlation, which can be calculated straightforwardly by using scattering parameters [4], [5], is also an important parameter for adaptive antenna groups. The bandwidth for the pattern correlation less than 0.2 is 1000 MHz for central frequency of 5.3 GHz for the manufactured antenna group shown in Fig.2.

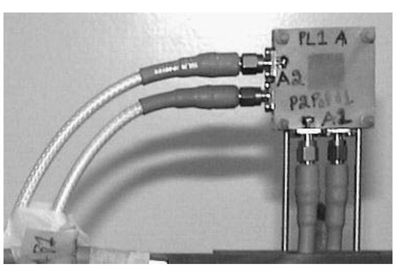
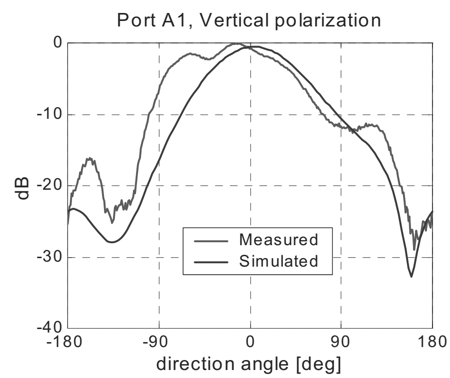


Figure 2. Developed prototype antenna.

The complex 3D–radiation patterns including amplitude and phase information were simulated with 3° steps for the horizontal and vertical polarizations using HFSS. Further, the 2D–pattern measurements (horizontal cut) were carried out in an anechoic chamber. Due to symmetry in the structure, the radiation patterns of the different ports are only slightly different. The measured and simulated radiation patterns of the first antenna port (vertical– and cross–polarization) are presented in Fig. 3. The measured radiation patterns of two polarizations are more rippled than the simulated ones caused mainly by the unidealities, near–field effects, and the lack of mutual coupling effect on the simulated antenna patterns. The radiation patterns of the antenna ports were normalized so that the integration over a whole solid angle gives the value of 4π for both the measured and simulated radiation patterns.



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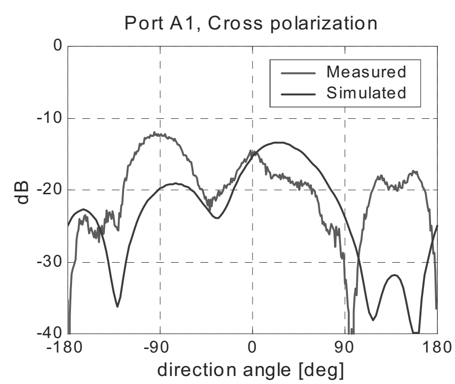

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Figure 3. The simulated and measured radiation patterns of antenna port A1 (horizontal cut). a) Vertical polarization. b) Cross–polarization.

3. Measurement system and capacity study

Indoor picocell route was measured on the first floor of computer science building in the campus area of Helsinki University of Technology (HUT) using wideband radio channel sounder extended for MIMO measurements [6]. A linear transmitter (Tx) antenna array of dual polarized microstrip patch antennas (2×8 feeds) with inter–element spacing of 0.7 λ was located inside the library area at a height of 3.8 m. A spherical receiver (Rx) antenna array of dual polarized microstrip patch antennas (2×32 feeds) better described in [7] was mounted for the trolley of the channel sounder, which moved along the measurement route. Fast microwave switches were used at both ends of the link to measure all Tx and Rx channels almost simultaneously [6]. The measurement time of the channels is about 9 ms and the waiting time between measurements 63 ms. Thus, the trolley moved only 3.6 mm during the complete measurement of the channels for the used 0.4 m/s speed of the device. The 50 m route of the trolley as well as the transmitter location is marked to the Fig. 4.

Direction–of–arrival estimation implemented for the spherical array was performed as a post–processing to obtain an estimate of the distributions of signals at Rx end of the link [7]. The post–processed data contains information about amplitude, phase, polarization, delay and angle of arrival of different signal components (multi–paths). The data was combined with the complex 3–D radiation patterns of antennas [8]. The radiation pattern of an antenna configuration under test was simulated and measured in an anechoic chamber as described in Chapter 2.

The measurement results were analyzed using mutual information, which is defined by

$$C_{\mathbf{H}}^{(i)} = \log_2 \left| \mathbf{I} + \frac{\rho}{n_t} \mathbf{H}_{norm}^{(i)} \mathbf{H}_{norm}^{(i)H} \right|, \qquad (1)$$

where a slightly different notation from [1] is adopted. In (1), ρ is signal to noise ratio, and $\mathbf{I}$ is identity matrix. Further, $(\cdot)^H$ stands for complex conjugate transpose, and i indicate realization of the channel. $\mathbf{H}_{norm}^{(i)}$ is normalized channel matrix of size $n_t \times n_r$. Thus, $\mathbf{H}_{norm}^{(i)}$ consists of connections between the Tx and Rx antennas. At Tx, the normalization of the signals is performed for the Tx antennas itself. At Rx, the sum of the post–processed signal components without effecting of the antenna called “isotropic sensor” is used in the normalization [9]. The effect of slow fading was removed from the signal. That describes the effect of slow power control, which is typically used in wireless communication systems.

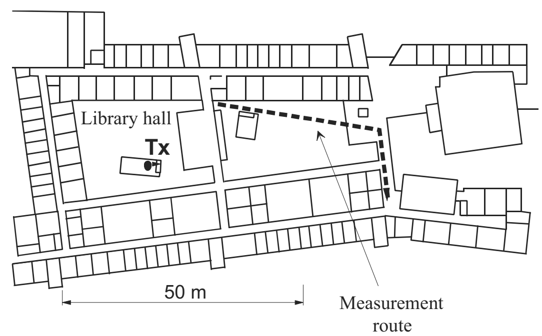
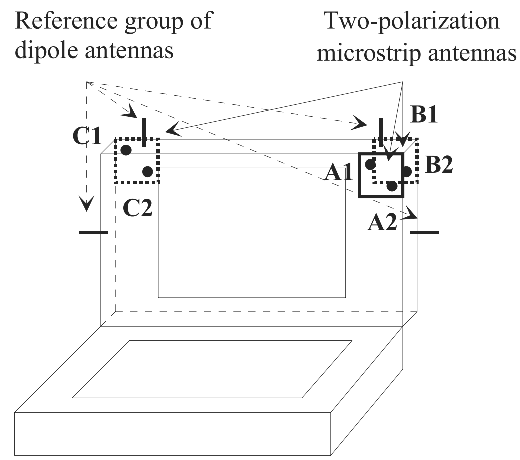


Figure 4. The indoor measurement route.

4. Antenna evaluation results

In this paper, two different MIMO antenna systems of $n_t \times n_r$ = 4×4 were investigated from the mean capacity point of view. Two vertically and two horizontally polarized feeds from the adjacent elements of the linear Tx antenna array were considered. The developed two–polarized antenna was used as the Rx antenna system using it as a basic element of two cases. The Rx antenna elements as well as the group of the ideal half wavelength dipoles, which are used as reference antennas, are depicted in Fig. 5a. In the first case (Rx1), one dual–polarized patch antenna (Fig. 1) is located at both sides of the ”laptop cover” (feeds A1, A2, B1, B2), as in Fig. 2. In the second case (Rx2), two dual–polarized patch antennas are located at the same side of the cover pointing away from the user (feeds B1, B2, C1, C2). Inter–element spacing of the antennas using Rx2 is 2λ.

The results of with and without shadowing of “human body” were considered. The shadowing was performed artificially by blocking part of the power out from the radiation patterns in that direction of laptop. The selected shadowing area, which emulates the effect of human body, was −30°…+30° in azimuth and −70°…+70 in elevation. Further, the investigated Rx antenna system is rotated using 30° steps in azimuth plane to guarantee a statistically sufficient analysis. The evaluation of the antenna systems in elevation direction is also important in such a device, which can be tilted in various directions in the typical operating situation. Thus, the “cover” of the device is tilted at the angles of 90°, 60°, 30°, and 0° from the ground plane as presented in Fig. 5b.



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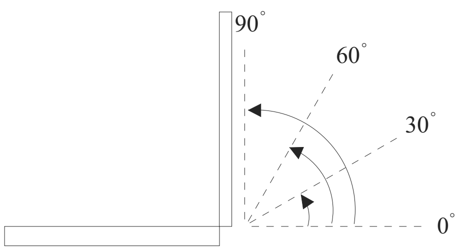

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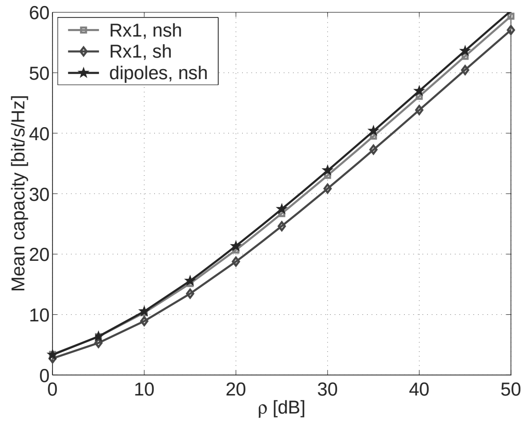
Figure 5. Sketch of laptop type device. a) Front view. b) Side view.

The comparison of mean capacity results (mean of (1)) of the 4×4 MIMO systems adopting Rx1 and Rx2 with the simulated radiation patterns are presented in Fig. 6a and Fig. 6b, respectively. Further, the mean capacity of the system considering the different orientations of the laptop without and with shadowing is presented in Tables 1 and 2. The mean capacity over all positions of the antennas for the selected tilting angles of the "laptop cover" is presented in Table 3. The both cases (Rx1 and Rx2) deliver almost the same mean capacity than the ideal dipole array system (see Fig. 6a and 6b). The effect of shadowing for the mean capacity results is stronger for the Rx1 since the other patch antenna is pointing partly towards the user.



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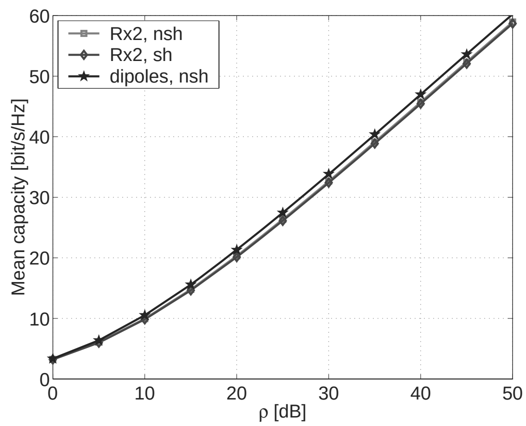

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Figure 6. Mean capacity results over all orientations of the device as a function of ρ. Tilting angle of the "cover" is 90°. a) Antenna group Rx1. b) Antenna group Rx2. The curves of Rx2 with (sh) and without (nsh) shadowing overlap completely.

The effect of tilting angle of the "laptop cover" and position of the "device" are about equal for the capacity results in the case of Rx1, whereas the effect of position is more dominant in the case of Rx2 (see Tables 1, 2 and 3). That is evident since the antennas are pointing to the same direction in the case of Rx2. Changing of tilting angle from 0° to 90° has minor effect for the mean capacity results but variance of the results increases in the case of Rx2. Variance of the results increases also in the presence of shadowing in both the cases (see Table 3).

Table 1. Mean capacity results for different orientations of the device (ρ = 10 dB). Tilting angle of the laptop "cover" from the ground plane is 90°. Shadowing of "human body" is not considered.

Ori. a.	Rx1	Rx2	Dip
0°	10.4	13.3	10.9
30°	10.6	13.6	11.2
60°	10.9	13.4	11.0
90°	10.5	11.2	10.3
120°	10.3	9.3	10.4
150°	10.2	7.5	10.7
180°	10.4	6.6	10.9
210°	10.6	6.7	11.2
240°	10.9	7.9	11.0
270°	10.5	9.2	10.3
300°	10.3	10.9	10.4
330°	10.2	12.3	10.7

Table 2. Mean capacity results for different orientations of the device (ρ = 10 dB). Tilting angle of the laptop "cover" from the ground plane is 90°. Shadowing of "human body" is considered.

Ori. a.	Rx1_sh	Rx2_sh	Dip_sh
0°	9.8	13.3	10.7
30°	10.1	13.6	11.0
60°	10.2	13.4	10.6
90°	9.2	11.1	9.5
120°	8.7	9.1	8.8
150°	8.3	7.4	9.0
180°	7.9	6.3	8.1
210°	7.5	6.4	7.8
240°	8.8	7.6	8.9
270°	9.2	9.1	9.1
300°	9.6	10.8	9.7
330°	9.8	12.2	10.4

Table 3. Mean (*m*) and variance (σ^2) of capacity results calculated over the whole route and over all orientations of the device. Analysis performed for the different tilting angles (ρ = 10 dB).

Til. a.	Rx1 m/σ^2	Rx1_sh m/σ^2	Rx2 m/σ^2	Rx2_sh m/σ^2
90°	10.5/3.0	9.1/3.5	10.2/12.9	10.0/13.7
60°	10.0/2.4	8.8/3.4	9.7/10.8	9.6/12.0
30°	8.9/2.2	8.2/3.5	8.6/6.4	8.3/7.6
0°	8.3/2.5	7.9/3.7	7.7/2.9	7.2/3.9

5. Conclusion

The new compact antenna group consisting of the two dual–polarized microstrip antennas has been developed and evaluated for the laptop type device. The antenna prototype would be feasible to be used e.g. in WLAN applications. Two different dual–polarized antenna systems were compared. The cases in which the antennas are mounted against as well as next to each other perform well as compared to the antenna system of the ideal dipole antennas. The performance of the investigated antenna systems is surprisingly robust for different tilting angles of the "laptop cover". Further, the capacity results fluctuate not much considering different orientations of the "device" in azimuth direction. However, fluctuation is worse when the antennas are located at the same side of the "laptop cover". The developed compact antenna systems are feasible to be used in the laptop type device.

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