individual rays, resulting in better-conditioned channel matrices yielding higher MIMO capacity. The convergence of MC results with no-MC results for both LOS and NLOS environments can be attributed to the fact that MC decreases as inter-element spacing increases.

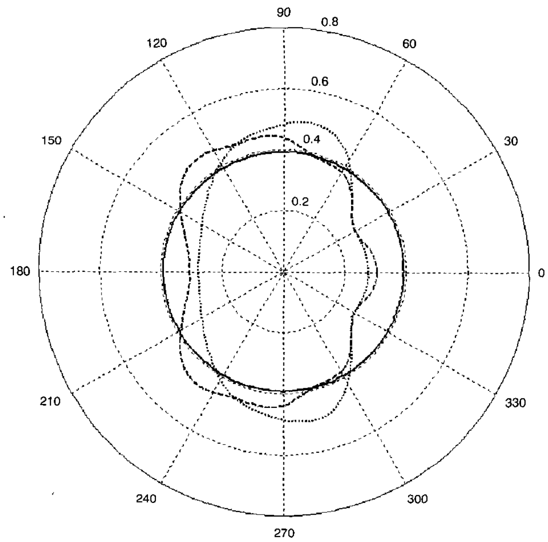

Fig. 2 *Antenna array element radiation patterns*
– – – outer element patterns
. . . . . . inner element patterns
—— element pattern without mutual coupling

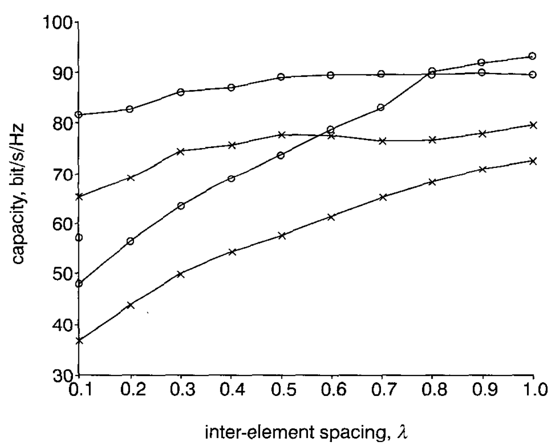

Fig. 3 *Effect of mutual coupling on MIMO channel capacity*
—O— LOS – MC
—×— NLOS – MC
– –O– – LOS – no MC
– –×– – NLOS – no MC

Conclusions: A hybrid electromagnetic simulator allows the spectral efficiency in MIMO systems to be studied as a function of the array geometry and the far-field scattering environment. As an application, we showed in two typical urban propagation scenarios how the pattern diversity introduced by near-field mutual coupling actually reduces the loss of capacity due to small antenna spacings.

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K.R. Dandekar and R.W. Heath, Jr. (*Department of Electrical and Computer Engineering, University of Texas at Austin, Engineering Science Building 143, Austin, TX 78712, USA*)

E-mail: dandekar@ece.drexel.edu

References

1 FOSCHINI, G.J.: 'Layered space-time architecture for wireless communication in a fading environment when using multiple antennas', *Bell Labs Tech. J.*, 1996, **1**, pp. 41–59
2 SVANTESSON, T., and RANHEIM, A.: 'Mutual coupling effects on the capacity of multi-element antenna systems'. Proc. IEEE Int. Conf. Acoustics, Speech, and Signal Processing, Salt Lake City, USA, May 2001
3 MCNAMARA, D.P., BEACH, M.A., and FLETCHER, P.N.: 'Experimental investigation into the impact of mutual coupling on MIMO communication systems'. Proc. Int. Symp. on Wireless Personal Multimedia Communications (WPMC'01), Aalborg, Denmark, September 2001
4 DANDEKAR, K.R.: 'Space division multiple access systems: computational electromagnetic studies of the physical and network layers'. PhD Thesis, University of Texas, Austin, 2001
5 SWINDLEHURST, A.L., GERMAN, G., WALLACE, J., and JENSEN, M.: 'Experimental measurements of capacity for mimo indoor wireless channels'. IEEE Workshop on Signal Processomg Advances In Wireless Communications, 2001, pp. 30–33

Printed diversity monopole antenna for WLAN operation

Tzuenn-Yih Wu, Shyh-Tirng Fang and Kin-Lu Wong

A printed diversity monopole antenna for WLAN operation in the 2.4 GHz band is presented. The antenna comprises two orthogonal linear monopoles placed symmetrically with respect to a T-shaped ground plane between them. The antenna has two highly decoupled ports and can provide spatial diversity to combat the multipath interference problem.

Introduction: Printed antennas integrated on the circuit board of a communication device have the advantages of occupying a very small volume of the system, easily integrating with the associated circuitry, and decreasing the fabrication cost of the final product. Some related designs of the printed antennas with a hook-like monopole [1], an inverted-F monopole [2], and so on applied for wireless local area network (WLAN) operations have also been reported. These designs, however, cannot overcome the multipath interference problem, which usually exists in practical environments for WLAN operation. In this case, signals reflecting from interfering objects arrive at the antenna from different directions and at slightly different times, and destructive interference between the signals may occur. This could result in a decrease in the signal strength, and degrade the system performance.

To combat the multipath interference problem, we present a printed monopole antenna for providing spatial diversity for WLAN operation in the 2.4 GHz band (2400–2484 MHz). The antenna is to be applied to a PCMCIA (personal computer memory card international association) network card for a laptop, and, with a switching circuit added to the system transceiver, the system can switch between the two ports of the antenna for WLAN operation with maximum signal strength. In this case, the multipath interference problem can be eased, and system performance can be enhanced.

Antenna design: Fig. 1 shows the antenna printed on an FR4 substrate of relative permittivity 4.4. The antenna consists of two orthogonal linear monopoles (length 25 mm and width 1.5 mm) printed on the front surface of the substrate. Note that the length of the two linear monopoles, which operate as quarter-wavelength structures in this design, is only about 20%, less than 0.25 free-space wavelength of the desired centre frequency at 2442 MHz. This behaviour is largely due to the presence of the FR4 substrate, which decreases the resonant length of the two printed monopoles.

Each monopole is directly fed using a 50 Ω microstrip line printed on the front surface of the substrate, and good impedance matching (VSWR < 1.5 or $S_{11} < -14$ dB) is obtained without the need of adding additional matching circuitry. Between the two monopoles, there is a T-shaped ground plane protruding from the main ground plane (size 50 × 80 mm^2), which is about the ground size of a practical PCMCIA network card. The protruded and main ground planes are both printed on the back surface of the substrate, and the T-shaped ground plane comprises a central vertical strip (length 16 mm) and a top horizontal strip (length L), both of a constant width 4 mm. Note that the T-shaped ground plane not only serves as a reflecting plate for the two monopoles to have their radiation patterns covering complementary space regions to provide spatial diversity, but also enhances the isolation between the two ports of the antenna. High port isolation ($S_{21} < -30$ dB) is possible by selecting a proper length (about 20 mm in this study) of the top horizontal strip of the T-shaped ground plane.

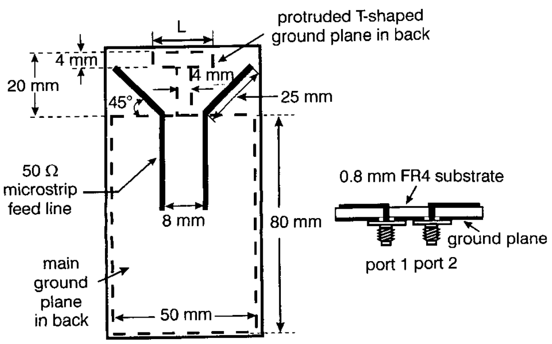

Fig. 1 *Geometry of proposed antenna for WLAN operation in 2.4 GHz band*

Results: Prototypes with various lengths of the top horizontal strip were constructed and studied. The measured data are listed in Table 1. The measured S_{11} and S_{21} for $L = 0$ and 20 mm are also shown in Fig. 2. From the results, it is seen that the impedance bandwidths all cover the 2.4 GHz band (2400–2484 MHz). However, the maximum S_{21} across the 2.4 GHz band varies greatly from −11.7 to −31.0 dB, which suggests that the port isolation strongly depends on L. In addition, there is an optimal value of L for obtaining maximum port isolation. In this study, the optimal value of L is 20 mm, and the isolation is less than −31 dB.

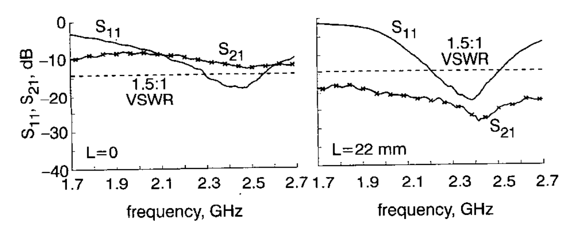

Fig. 2 *Measured S_{11} and S_{21} for $L = 0$, 20 mm*

Table 1: Performance of prototypes with various values of L; f_L and f_H are, respectively, lower and upper frequencies with $S_{11} = -14$ dB.

L [mm]	BW ($= f_H - f_L$) [MHz]	$S_{21,\ max}$ [dB]
26	292 (= 2544 − 2252)	−18.0
22	316 (= 2516 − 2200)	−26.2
20	200 (= 2500 − 2300)	−31.0
18	124 (= 2508 − 2384)	−21.3
0	268 (= 2560 − 2292)	−11.7

Fig. 3 and 4 show, respectively, the typical measured radiation patterns of ports 1 and 2 for $L = 20$ mm. It is seen that the measured radiation patterns tend to cover complementary space regions, which provides spatial diversity for the proposed antenna. Fig. 5 shows the measured peak antenna gain. Owing to the symmetric structures of the two monopoles, the antenna gain for ports 1 and 2 is about the same, and both shows a peak gain of about 4.2 dBi, with gain variations less than 1.2 dBi.

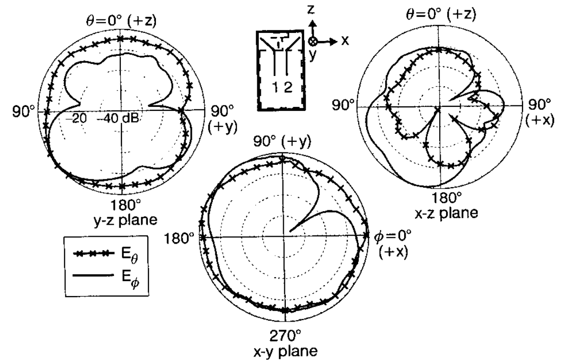

Fig. 3 *Measured radiation patterns of port 1 at 2442 MHz for $L = 20$ mm*

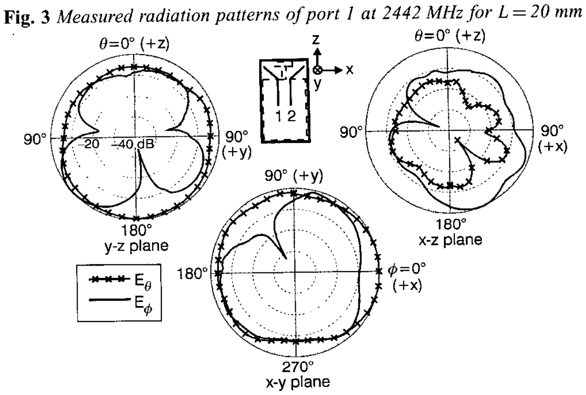

Fig. 4 *Measured radiation patterns of port 2 at 2442 MHz for $L = 20$ mm*

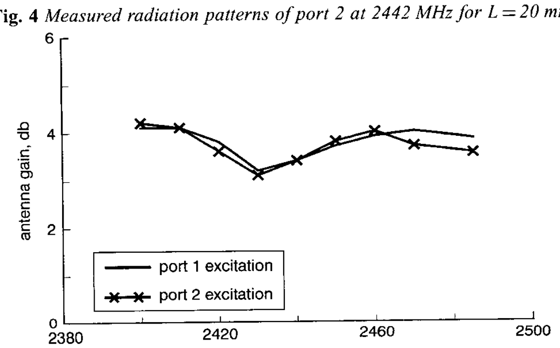

Fig. 5 *Measured peak antenna gain for $L = 20$ mm*

Conclusions: A printed diversity monopole antenna suitable to be integrated on a PCMCIA network card has been presented. The two ports of the antenna show high isolation ($S_{21} < -31$ dB) and have good impedance matching ($S_{11} < -14$ dB) for frequencies across the 2.4 GHz WLAN band. The antenna can also provide spatial diversity, capable of combating the multipath interfering problem for WLAN operation.

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Tzuenn-Yih Wu and Kin-Lu Wong (*Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung 804, Taiwan*)

E-mail: wongkl@ema.ee.nsysu.edu.tw

Shyh-Tirng Fang (*Computer & Communications Research Laboratories, Industrial Technology Research Institute, Hsinchu 310, Taiwan*)

References

1 WU, C.: 'Printed antenna structure for wireless data communications', US Patent No. 6008774, Dec. 1999
2 ALI, M., and HAYES, G.J.: 'Small printed integrated inverted-F antenna for Bluetooth application', *Microwave Opt. Technol. Lett.*, 2002, **33**, (5), pp. 347–349

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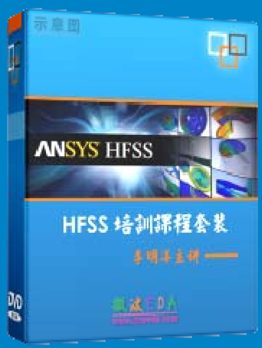

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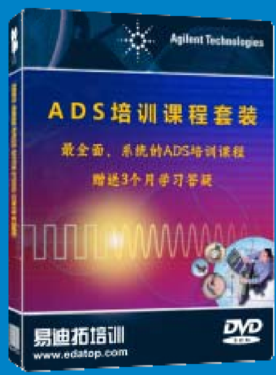

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