MHz in regular corners and 36.7 ns in chaflanes. For NLoS, DS was around 60 ns in both environments, ant it was greater than for LoS in more than 15 ns for 450 MHz (50% increment), and 30 ns for 2400 MHz (100% increment).

Frequency correlation was higher in chaflanes than in regular street corners. In the regular corner, for LoS and NLoS, correlation was 0.8 and 0.7, respectively, and in chaflanes, it was 0.9 and 0.75, respectively. This meant that correlation was 10% higher in chaflanes for LoS, and a 5% higher for NLoS. In general, correlation decreased when the distance in frequency was increased.

Tapped delay line models were obtained at the four frequencies in regular corners and in chaflanes and for LoS and NLoS. For LoS, the maximum delay was around 200 ns in regular corners and 190 ns in chaflanes. And for NLoS, the maximum delay was around 330 ns in regular corners and 350 ns in chaflanes.

Finally, coherence bandwidth was analyzed in the two environments. For LoS, the coherence bandwidth was bigger in chaflanes than in regular corners. It was also observed that it grew as frequency increased, and this increment was greater in chaflanes. For NLoS the bandwidth remained steady around 4 MHz, and it decreased slightly with frequency.

References

[1] L. M. Correia, *Wireless Flexible Personalised Communications*. New York: Wiley, 2001, COST259.

[2] N. Papadakis, A. G. Kanatas, and P. Constantinou, "Microcellular propagation measurements and simulation at 1.8 GHz in urban radio environment," *IEEE Trans. Veh. Technol.*, vol. 47, no. 3, pp. 1012–1025, Aug. 1998.

[3] J. Kivinen, T. O. Korhonen, P. Aikio, R. Gruber, P. Vainikainen, and S. G. Häggman, "Wideband radio channel measurement system at 2 GHz," *IEEE Trans. Instrum. Meas.*, vol. 48, no. 1, pp. 39–44, Feb. 1999.

[4] T. Furuno and T. Taga, "Time delay spread in microcellular environment for personal communication systems," *IEICE Trans. Commun.*, vol. E79-B, no. 9, pp. 1199–1204, Sept. 1996.

[5] J.-M. Molina-Garcia-Pardo and L. Juan-Llácer, "Time delay spread at 2.1 GHz around regular and Chaflane street corners for microcellular communications," in *Proc. 13th IEEE Int. Symp. Personal, Indoor, and Mobile Radio Communication*, vol. 3, Lisbon, Portugal, Sept. 2002, pp. 1200–1202.

[6] J. Kivinen, X. Zhao, and P. Vainikainen, "Empirical characterization of wideband indoor radio channel at 5.3 GHz," *IEEE Trans. Antennas Propagat.*, vol. 49, no. 8, pp. 1192–1203, Aug. 2001.

[7] J. A. Wepman, J. R. Hoffman, and L. H. Loew, "Analysis of impulse response measurements for PCS channel modeling applications," *IEEE Trans. Veh. Technol.*, vol. 44, no. 3, pp. 613–620, Aug. 1995.

[8] European Telecommunications Standards Institute (ETSI), "Selection Procedures for the Choice of Radio Transmission Technologies for UMTS," ETSI Tech. Rep., 04-1998, vol. 101 112 V 3.2.0.

Low-Cost Dual-Polarized Printed Array With Broad Bandwidth

S. Gao and A. Sambell

***Abstract*—This paper presents a novel design of low-cost broad-band dual-polarized microstrip arrays. The antenna uses the slot-coupled feed for one polarization, while the microstrip line feed with slotted ground plane is used for the other polarization. It can make good use of the space on both sides of the ground plane, as the feed circuits for two orthogonal polarizations are placed on each side of the ground plane, respectively. The prototype four-element array designed at *C* band yields a bandwidth of more than 14% at both ports, and isolation below -30 dB. Good broadside radiation patterns are observed, and the cross-polar levels are below -20 dB at both *E*- and *H*-planes.**

***Index Terms*—Arrays, broad-band antenna, dual-polarized antennas, microstrip antennas, printed antennas.**

I. Introduction

The issue of designing broad-band dual-polarized microstrip antennas has been of considerable interest, and a number of designs have been reported. A dual-polarized antenna can be realized by feeding the patch at two orthogonal edges, through edge-feed or probe feed [1]. Dual-polarized slot-coupled microstrip antenna is first reported in [2] which uses dual offset slots, and achieves isolation of 18 dB. The slot-coupled structure is particularly interesting due to its important advantage of easy integration with active circuits.

Two key concerns in broad-band dual-polarized microstrip antennas designs include the isolation and the bandwidth. To achieve high isolation between two input ports, the antenna in [3] uses dual narrow rectangular slots arranged in "T" configuration and isolation of 34 dB is reported. Dual U-shaped slots are used in [4], where it achieves a bandwidth of 10% and 38 dB isolation. Dual H-shaped slots are applied in [5]–[7], while the modified H-slot is reported in [8] and high isolation of 34 dB is achieved. The use of crossed slots is reported in [9]–[12], and multiple slots are used in [8], [13]–[15]. It is noted in [8], [11], [13]–[15], a relatively complicated feed network is needed to achieve high isolation. Other methods of improving isolation characteristics include the use of hybrid feeds [16], [17], and the use of two separate gridded patches [18].

To broaden the bandwidth of dual-polarized microstrip antenna, various techniques are also reported, which include the use of parasitic patches arranged in stacked or co-planar configuration [1], [6], [7], [12]–[14], [18], resonant or near-resonant slot [5], [8], L-probe feed [16], capacitively coupled feed [17], and a combination of the above methods. Broad-band proximity-coupled microstrip antennas using an H-slot in the ground is reported in [19] recently.

In most of the previous designs, two feed network circuits for each polarization are placed on the same layer. However, it is very difficult to find enough space to accommodate two sets of feed networks on the same layer, when dual-polarized arrays or polarization-switching arrays are to be designed. Strong coupling between feed lines will occur if there is not enough space between them. The problem of limited

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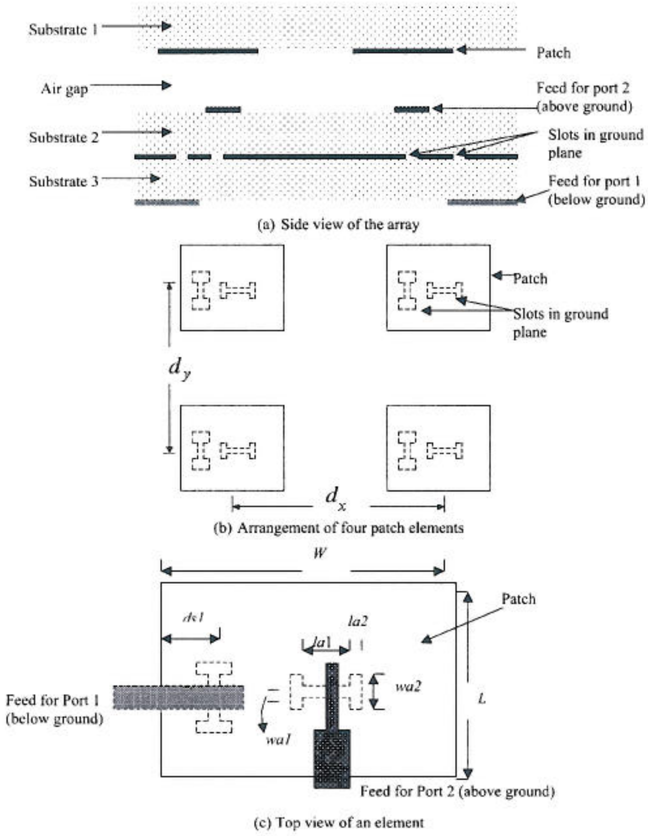


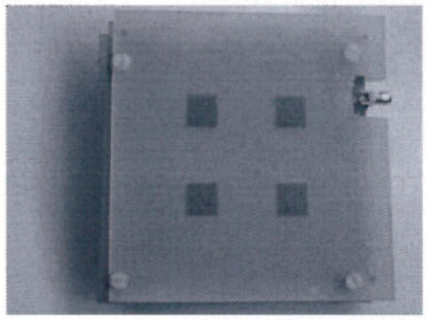
Fig. 1. Configuration of the dual-polarized array.

space will become even more serious if we wish to integrate active (amplifiers, mixers, oscillators) and passive circuits (phase shifters, filters) into the feed network circuits for each polarization. To overcome this problem, we may put the feed networks on different layers under the ground plane [20]. However, this will lead to crossovers between feed lines on each layer, and strong coupling between them may occur, which lead to the deterioration of antenna performances.

In this paper, we propose a novel design of broad-band dual-polarized microstrip array antennas. It uses the slot-coupled feed for one polarization, while the microstrip line feed with slotted ground plane is used for the other polarization. The array antenna can make good use of the space on both sides of the ground plane, as the feed circuits for two orthogonal polarizations are placed on each side of the ground plane, respectively.

II. Antenna Design

Fig. 1 shows the configuration of the four-element array antenna. It consists of three dielectric substrates (substrate 1, 2 and 3) and an air gap layer with a thickness of h_0. Four patches are etched on the back of substrate 1, which serves as a radome for protection. At port 1, the slot coupling is used and the feed circuits are below the ground plane. At port 2, the patch is fed by the microstrip line through proximity coupling. For enhancing the coupling between the patch and feed line, a slot is cut in the ground plane below the feed line at port 2. As shown in Fig. 1(b), four rectangular patches are arranged in a square array. For achieving high isolation between two input ports, two H-shaped shots are arranged in "T" configuration under each patch element, as shown in Fig. 1(b) and (c). The H slot is defined by the parameters *la1*, *la2*, *wa1*, and *wa2*. A corporate feed network is designed to divide the power



(a) View from the front

(b) View from the back

Fig. 2. Photos of the array.

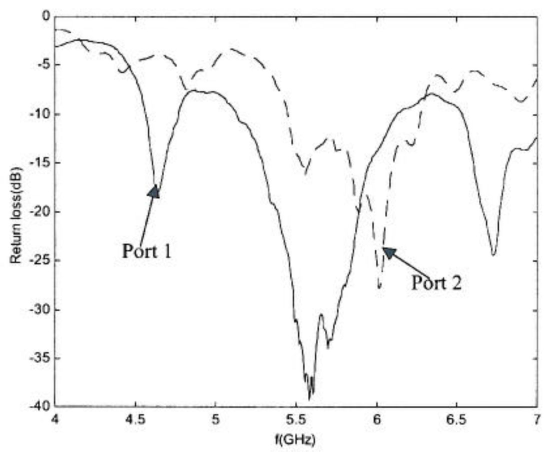


Fig. 3. Measured results of return loss at two ports.

equally into each element in the array. Two orthogonal polarizations are produced from port 1 and 2, respectively.

The antenna design is achieved by tuning the length of width of the patch, the dimensions of slots, the thickness of air gap, and the open stub length. The simulation results are obtained by using "*Ensemble*" from Ansoft Corporation, which is based on the method of moment. The array designed at *C* band has the following parameters: $L = 14$ mm, $W = 13$ mm, $h_0 = 3.2$ mm, $d_x = d_y = 37$ mm. Port 1: $la1 = 8$ mm, $la2 = 1$ mm, $wa1 = 1$ mm, $wa2 = 26$ mm, $ds1 = 2.5$ mm; Port 2: $la1 = 6$ mm, $la2 = 1$ mm, $wa1 = 1$ mm, $wa2 = 2.4$ mm. FR4 PCB's ($\varepsilon_r = 4.4, h = 1.6$ mm) are used for substrates 1, 2,and 3, which leads to a low cost. Plastic supporters having a height of 3.2 mm are used to realize the air gap. Fig. 2 gives the photos of the antenna viewed from the back and the front, respectively. Note that in the feed network we used the Wilkinson power dividers instead

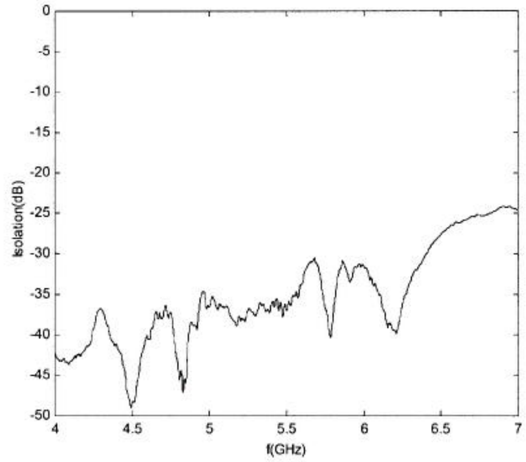


Fig. 4. Measured isolation between two ports.

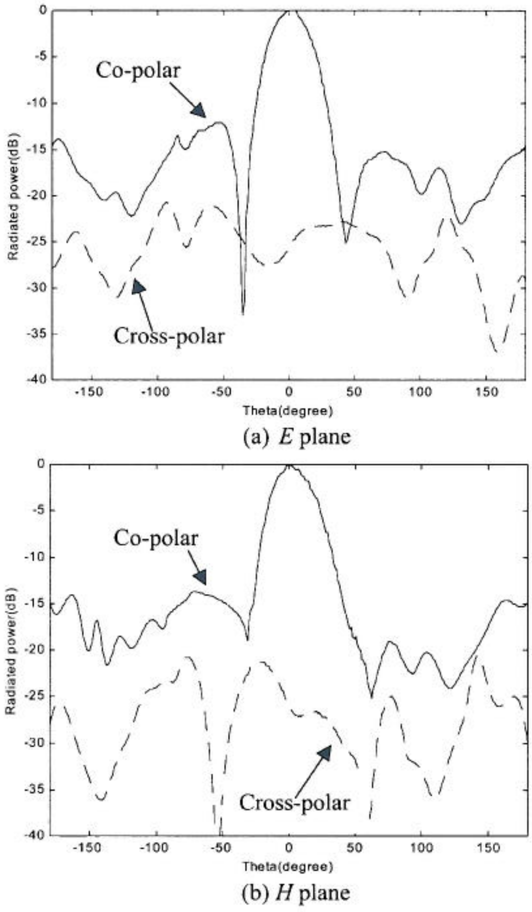


Fig. 5. Radiation patterns at 5.8 GHz for port 1 of the array.

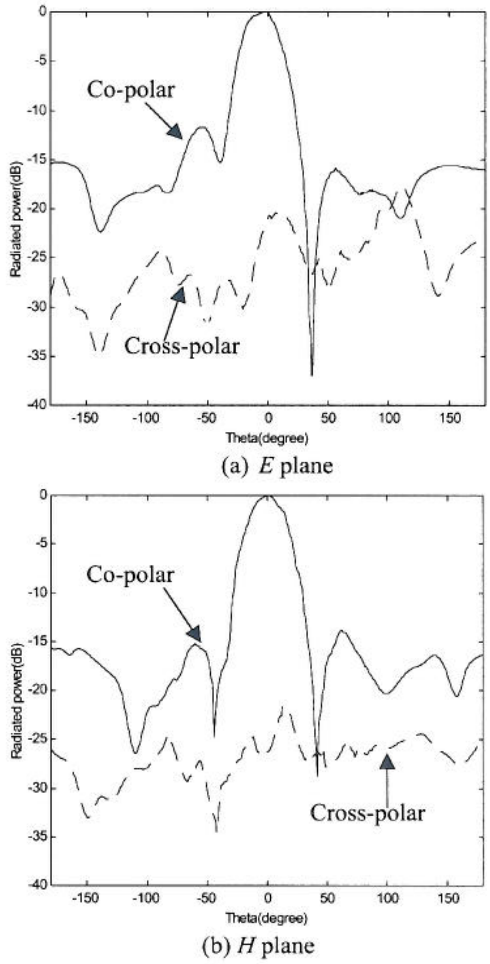


Fig. 6. Radiation patterns at 5.8 GHz for port 2 of the array.

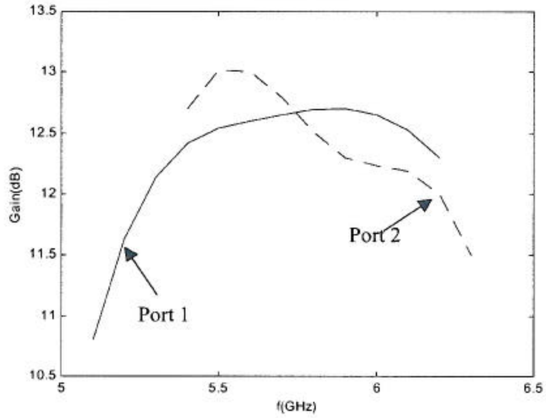


Fig. 7. Measured gain of the array versus frequency.

of simple microstrip T-junction, as the Wilkinson power dividers have better impedance matching characteristics.

III. Results and Discussions

Fig. 3, gives the results of measured return loss at two ports. As we can see, the return loss is below -10 dB for port 1 within the frequency range between 5.13 and 6.12 GHz, corresponding to a bandwidth of 18%. At port 2, the return loss is below -10 dB within the frequency range between 5.45 and 6.28 GHz, which corresponds to a bandwidth of 14%. The results of measured isolation between two ports are given in Fig. 4. It is seen the isolation is below -30 dB within the frequency range 5.1 GHz–6.3 GHz.

Fig. 5 gives the measured radiation patterns of the array excited at port 1 at 5.8 GHz, and the measured radiation patterns of the array excited at port 2 at 5.8 GHz are given in Fig. 6. Broadside radiation patterns are observed at both E- and H-planes, and the cross-polar levels are below -20 dB within the half space above the ground plane. The backward radiation is below -14.5 dB. The array is also measured at two ports at several other frequencies, and it is observed that radiation patterns are stable across the frequency bandwidth 5.13–6.12 GHz for port1, and the frequency bandwidth 5.45–6.28 GHz for port 2, respectively.

Finally, the antenna gain is measured and the measured results are shown in Fig. 7. As we can see, the maximum gain is 12.7 dBi at 5.9 GHz for port 1, and 13.0 dBi at 5.6 GHz for port 2, respectively. The gain variation within the bandwidth is less than 2 dBi. The antenna efficiency is about 76%.

IV. Conclusion

A novel design of low-cost broad-band dual-polarized microstrip array antennas is presented. It uses the slot-coupled feed for one polarization, while the microstrip line feed with slotted ground plane is used for the other polarization. The array antenna can make good use of the space on both sides of the ground plane, as the feed circuits for two orthogonal polarizations are placed on each side of the ground plane, respectively. The prototype four-element array antenna designed at C band yields a bandwidth over 14% at both ports, and isolation below -30 dB is obtained. The cross-polar levels are below -20 dB at both E- and H-panes. The array is simple in structure, easy to fabricate, and low in lost. The findings are promising for RFID, mobile communication base station, and satellite communication applications.

Acknowledgment

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References

[1] D. M. Pozar and D. H. Schaubert, Eds., *Microstrip Antennas: The Analysis and Design of Microstrip Antennas and Arrays*. New York: IEEE Press, 1995.

[2] A. Adrian and D. H. Schaubert, "Dual aperture-coupled microstrip antenna for dual or circular polarization," *Electron. Lett.*, vol. 23, pp. 1226–1228, 1987.

[3] B. G. Porter, L. L. Rauth, J. R. Mura, and S. S. Gearhart, "Dual-polarized slot-coupled patch antennas on duroid with teflon lensens for 76.5-GHz automotive radar systems," *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 1836–1842, 1999.

[4] M. E. Bialkowski and H. J. Song, "Investigations into a power-combining structure using a reflect arry of dual-feed aperture-coupled microstrip patch antennas," *IEEE Trans. Antennas Propagat.*, vol. 50, no. 6, pp. 841–850, 2002.

[5] S. Hienonen, A. Lehto, and A. V. Raisanen, "Simple broadband dual-polarized aperture-coupled microstrip antenna," in *Proc. IEEE Antennas Propagation Soc. Int. Symp. Dig.*, 1999, pp. 1228–1231.

[6] S. Gao, L. W. Li, P. Gardner, and P. S. Hall, "Dual-polarized wideband microstrip antenna," *Electron. Lett.*, vol. 37, no. 18, pp. 1106–1107, Aug. 2001.

[7] S. Gao, L. W. Li, M. S. Leong, and T. S. Yeo, "Dual-polarized slot-coupled microstrip antenna with wide bandwidth," *IEEE Trans. Antennas Propagat.*, vol. 51, pp. 441–448, 2003.

[8] K. L. Wong, H. C. Tung, and T. W. Chiou, "Broadband dual-polarized aperture-coupled patch antennas with modified H-shaped coupling slots," *IEEE Trans. Antennas Propagat.*, vol. 50, no. 2, pp. 188–191, 2002.

[9] M. Yamazaki, E. T. Rahardjo, and M. Haneishi, "Construction of a slot-coupled planar antenna for dual polarization," *Electron. Lett.*, vol. 30, pp. 1814–1815, 1994.

[10] F. Rostan and W. Wiesbeck, "Design considerations for dual-polarized aperture-coupled microstrip patch antennas," in *Proc. IEEE Antennas Propagation Symp. Dig.*, 1995, pp. 2086–2089.

[11] B. Lindmark, "A novel dual-polarized aperture coupled patch element with a single layer feed network and high isolation," in *Proc. IEEE Antennas Propagation Symp. Dig.*, 1997, pp. 2190–2193.

[12] S. B. Chakrabarty, F. Klefenz, and A. Dreher, "Dual-polarized wide-band stacked microstrip antenna with aperture coupling for SAR applications," in *Proc. IEEE Antennas Propagation Symp. Dig.*, 2000, pp. 2216–2219.

[13] P. Brachat and J. M. Baracoo, "Printed radiating element with two highly decoupled input ports," *Electron. Lett.*, vol. 31, pp. 245–246, 1995.

[14] J. F. Zucher and F. Gardiol, *Broadband Patch Antenna*. Boston, MA: Artech House, 1995.

[15] G. S. Parker, Y. M. M. Antar, A. Ittipiboon, and A. Petosa, "Dual-polarized microstrip ring antenna with good isolation," *Electron. Lett.*, vol. 34, pp. 1043–1044, 1998.

[16] Y. X. Guo, K. M. Luk, and K. F. Lee, "Broadband dual-polarization patch element for cellular-phone base stations," *IEEE Trans. Antennas Propagat.*, vol. 50, no. 3, pp. 346–351, 2002.

[17] K. L. Wong and T. W. Chiou, "Broadband dual-polarized patch antennas fed by capacitively coupled feed and slot-coupled feed," *IIEEE Trans. Antennas Propagat.*, vol. 50, no. 2, pp. 251–253, 2002.

[18] P. Brachat and J. M. Baracco, "Dual-polarization slot-coupled printed antennas fed by stripline," *IEEE Trans. Antennas Propagat.*, vol. 43, pp. 738–742, 1995.

[19] S. Y. Ke, "Broadband proximity-coupled microstrip antennas with an H-shaped slot in the ground plane," in *Proc. IEEE Antennas Propagation Symp. Dig.*, 2002, pp. 530–533.

[20] C. H. Tsao, Y. M. Hwang, F. Kilburg, and F. Dietrich, "Aperture-coupled patch antenna with wide-bandwidth and dual-polarization capabilities," in *Proc. IEEE Antennas Propagation Symp. Dig.*, 1988, pp. 936–939.

Modified Aperture Coupled Microstrip Antenna

Qinjiang Rao and Ronald H. Johnston

***Abstract*—This paper proposes a class of cavity-backed aperture coupled microstrip antennas and relevant design procedures. In the proposed structure, the radiating patch and the microstrip feed line are both fabricated on the top of a substrate, a coupling slot is etched on the bottom of the substrate, and a back-cavity is employed to block back radiation from the slot. The proposed antenna structures have potential for the implementation of lower profile and compact antenna size. Simulations and measurements show that the proposed antennas can operate at multiple frequencies with very good the ratio of front-back radiation and very low cross-polarized radiation.**

***Index Terms*—Aperture coupled microstrip antenna (ACMSA), cross and co-polarized radiation, ratio of front-back radiation.**

I. Introduction

A conventional aperture coupled microstrip antenna (ACMSA) consists of two substrate layers separated by a ground plane. The radiating patch on the top substrate is fed through the coupling slot cut in the ground plane by a microstrip feed line lying on the bottom of the lower substrate. The ACMSA has many attractive features [1]–[7], one is more degrees of freedom for adjusting the antenna impedance and

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