Northumbria Research Link

Dual-Polarized Broad-Band Microstrip Antennas Fed by Proximity Coupling

Steven (Shichang) Gao, *Member, IEEE,* and Alistair Sambell, *Member, IEEE*

***Abstract*—This paper presents a novel broad-band dual-polarized microstrip patch antenna, which is fed by proximity coupling. The microstrip line with slotted ground plane is used at two ports to feed the patch antenna. By using only one patch, the prototype antenna yields a bandwidth of 22% and 21.3% at the input port 1 and 2, respectively. The isolation between two input ports is below −34 dB across the bandwidth. Good broadside radiation patterns are observed, and the cross-polar levels are below −21 dB at both E and H planes. Due to its simple structure, it is easy to form arrays by using this antenna as an element.**

***Index Terms*—Antennas, broad-band antenna, dual-polarized antennas, microstrip antennas, patch antennas.**

I. Introduction

In MICROSTRIP antenna designs, there has been increasing interests in the dual-polarization operation, which could provide more information for synthetic aperture radars and collision warning radars, double the capacity of communication systems by means of the frequency reuse, reduce the multipath fading of received signals in mobile communication systems by means of the polarization diversity, and increase the transmit-receive isolation of transceivers or transponders, etc. Until now, many designs of dual-polarized microstrip antennas have been reported [1]–[31].

A dual-polarized microstrip antenna can be realized by feeding the rectangular microstrip patch at two orthogonal edges, through edge feed or probe feed, which excites TM_{01}- and TM_{10}-mode with orthogonal polarizations [1]–[4]. Both the element itself and its array often achieve isolation of about −20 dB [1]–[3]. The isolation of this kind of dual-polarized antennas could be increased significantly by using thin wire bonds [4], at the expense of additional complexity in antenna fabrication and matching circuits designs. The patch with dual parallel corner feeding is studied in [5] and its isolation is about −30 dB at the resonant frequency. Isolation of about −25 dB has been reported for the dual serial corner-fed patch antennas [6], [7]. Dual-polarized antennas with other patch shapes are also studied in [8]. It is shown by Huang in [9] that, by sequentially rotating the dual-polarized elements, isolation and cross-polar characteristics of the array can be improved. This is due to the canceling of both higher-order modes and the port-to-port coupling by the anti-phase technique. Isolation of about −40 dB has been achieved in [9].

Dual-polarized microstrip antenna fed by slot coupling is first reported by Adrian and Schaubert [10]. Dual offset slots are used in [10], and it achieves isolation of −18 dB. This dual-polarized antenna offers additional advantages of easy integration with active RF/microwave circuits, which would be useful for active arrays applications. A variety of techniques for improving the isolation and cross-polarization radiation characteristics between two polarizations have been demonstrated [11]–[31]. A popular technique of improving the isolation characteristics is to arrange the positions of two orthogonal slots into a "T" configuration, and isolation of about −30 dB or even better has been reported [12]–[14]. Dual U-shaped slots arranged in "T" configuration are used in [15], where it achieves a bandwidth of 10% and −38 dB isolation. The second technique is to choose a proper geometry of slot, which includes the narrow rectangular slot in [12], the H-shaped slot in [13], [14], [16], and the U-shaped slot in [15]. The modified H-slot is reported in [17] and isolation of −34 dB is achieved. The use of crossed slots is reported in [18]–[21], where multiple substrates have to be used for carrying the feed lines for each polarization. The antenna in [21] using crossed slots and stacked patches achieves isolation of about −20 dB and a bandwidth of 26%. The third technique is to use multiple slots, as in [22]–[25]. Other techniques include the use of a relatively complicated feed network [17], [26], hybrid feeds [27]–[30], corner feeding [16], and the use of two separate gridded patches [31].

To broaden the bandwidth of dual-polarized microstrip antennas, various techniques have also been reported, including the use of parasitic patches in stacked or co-planar structure [14], [16], [18]–[21], resonant or near-resonant slot [13], [17], L-probe feeding [29], or capacitively-coupled feeding [30]. By using the stacked patches and the air gap layer, the antenna in [16] achieves isolation of about −30 dB and a bandwidth of 24%. Recently, a broad-band proximity-coupled microstrip antenna using an H-slot in the ground is proposed in [32]. It has been experimentally demonstrated in [32] that the antenna has important advantages of simple structure, easy fabrication, low cost, broad bandwidth, low cross-polarization levels, etc.

In this paper, we will extend the work in [32] into the case of two-port antennas for achieving both the broad bandwidth and the dual-polarization operation. A novel design of the broad-band dual-polarized microstrip antennas is proposed by using the proximity coupling. A prototype antenna is then designed, and experimental results are presented.

Manuscript received February 2, 2004; revised April 5, 2004. This work was supported in part by EPSRC (U.K.) under Grant GR/S42538/01 and in part by the Nuffield Foundation (U.K.) under Grant NAL/00673/G.

The authors are with the School of Engineering and Technology, Northumbria University, Newcastle Upon Tyne NE1 8ST, U.K. (e-mail: shichang.gao@unn.ac.uk).

Digital Object Identifier 10.1109/TAP.2004.838763

0018-926X/$20.00 © 2005 IEEE

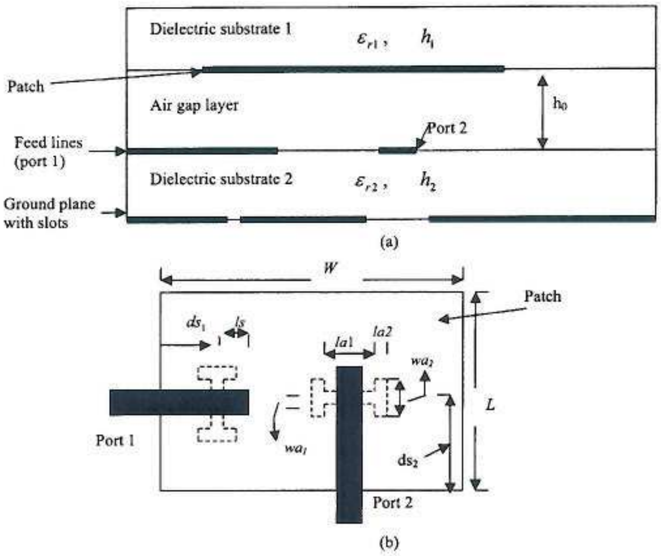


Fig. 1. Configuration of the antenna. (a) Side view and (b) top view.

II. Antenna Configuration

The configuration of the broad-band dual-polarized antenna is given in Fig. 1. The substrate consists of an air gap layer having a thickness of h_0, and two dielectric substrate layers (substrate 1 and 2, respectively). The bottom side of substrate 1 carries the rectangular microstrip patch, while the top side of substrate 1 is etched completely. This is kind of an inverted structure, where the substrate 1 serves as a radome for protection. For producing two orthogonal polarizations, two microstrip feed lines are placed on dielectric substrate 2. An H-shaped slot is cut in the ground plane below each feed line. The slot is important here, as it could enhance the coupling between the microstrip feed line and the patch [32]. The two H-slots are arranged in a "T" configuration for enhancing the isolation between two input ports [12]–[14]. An air gap is inserted between the patch and the feed lines, for the purpose of extending the impedance bandwidth. The air gap layer is formed by using plastic supporters having a height of h_0. The Duroid 5870 substrate ($\varepsilon_r = 2.33, h = 1.575$ mm) is used for both substrate 1 and 2. The open stub length has a length of ls. The distance between the slot center and the patch edge is denoted by ds_1, and ds_2, for port 1, and 2, respectively. The H slot is defined by the parameters $la1, la2, wa1$, and $wa2$.

III. Antenna Design and Parametric Study

The antenna design is achieved by tuning the length and width of the patch, the open-stub lengths, the slot dimensions, and the air gap thickness. The simulation results are obtained by using "Ensemble" from Ansoft Corporation, which is based on the method of moments.

To understand the characteristics of the antenna, a parametric study on the single-port antenna is done first. During the simulation, the single-port antenna has the same configuration as that of the dual-port antenna in Fig. 1, except that the slot and the feed line for port 1 are removed. Fig. 2 shows the input impedance results of the single-port antenna with different patch length L. Both the input resistance R (real part of the input impedance) and the input reactance X (imaginary part of the input impedance) are given. As we can see from Fig. 2(a), when the patch length L equals to 24 mm, there is only a single resonance. When the patch length L is increased to 29 mm, the double resonances are appearing. The double resonances could lead to a broad bandwidth. With the further increase of the patch length, both resonances are shifted downwards to the lower frequency band, while the magnitude of the lower and upper resonance is reduced and increased, respectively.

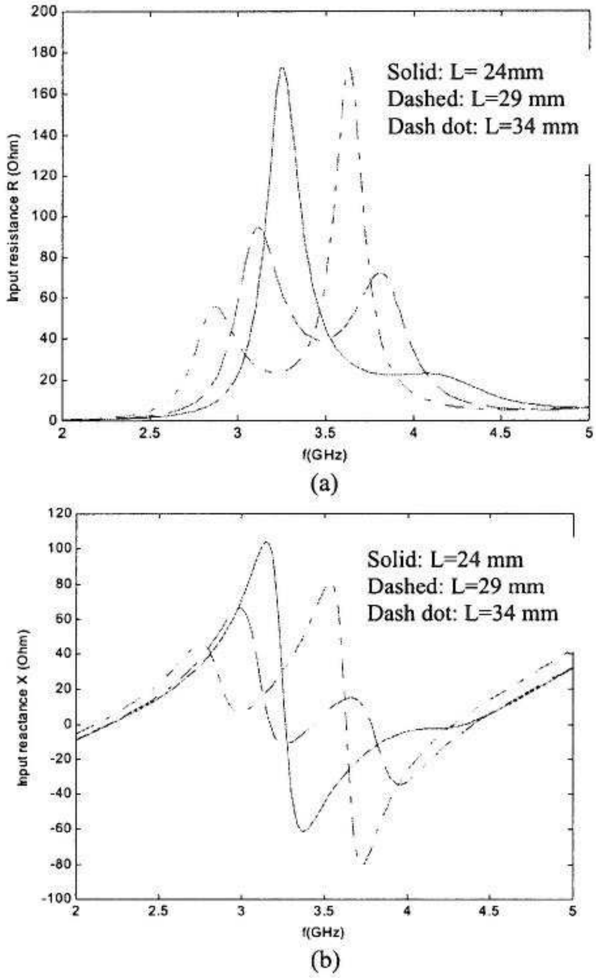


Fig. 2. Input impedance of the single-port antenna with different patch length L. Other parameters: $W = 30$ mm, $h_0 = 6.4$ mm, $la1 = 14$ mm, $la2 = 2$ mm, $wa1 = 1$ mm, $wa2 = 4$ mm, $ls = 5$ mm, $\mathrm{ds}_2 = L/2$. (a) Resistance R versus frequency f. (b) Reactance X versus frequency f.

The effects of open stub length (ls) on the input impedance are shown in Fig. 3. We can see that the magnitude of each resonance is very small at the low frequency band while the open stub length is very short ($ls = 1$ mm), which will lead to problems in the impedance matching. With the increase of the open stub length, the magnitude of each resonance is increased significantly, which means a stronger coupling between the microstrip patch and the microstrip feed line. However, the further increase of the open stub length ($ls = 12$ mm) will lead to the single resonance only. Thus, a compromise of the open stub length needs

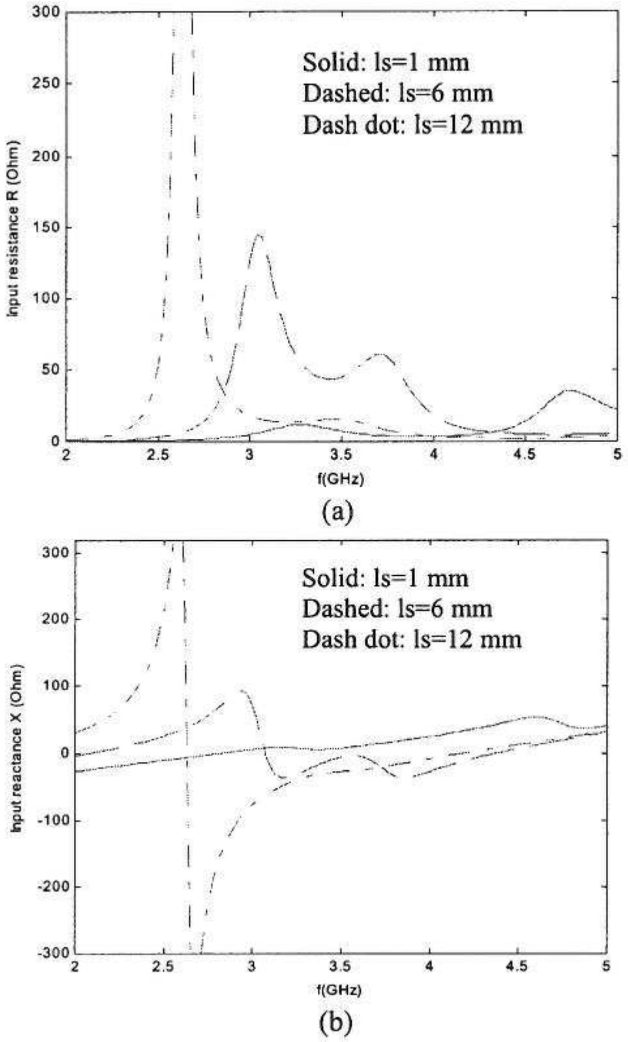


Fig. 3. Input impedance of the single-port antenna with different open stub length ls. Other parameters: $L = 29$ mm, $W = 30$ mm, $h_0 = 6.4$ mm, $la1 = 14$ mm, $la2 = 2$ mm, $wa1 = 1$ mm, $wa2 = 4$ mm, $ds_2 = 14.5$ mm. (a) Resistance R versus frequency f. (b) Reactance X versus frequency f.

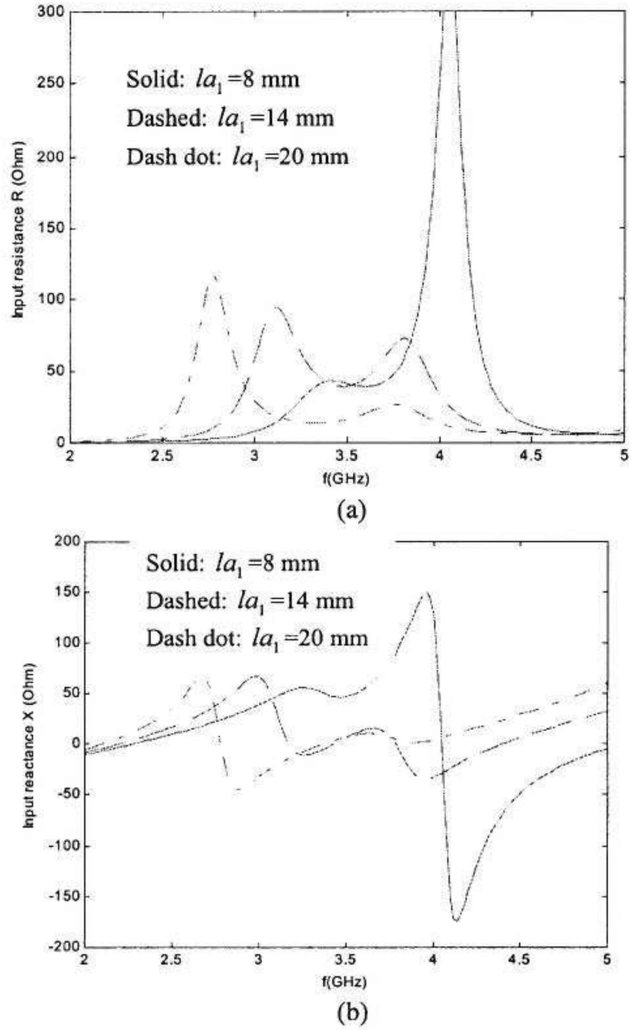


Fig. 4. Input impedance of the single-port antenna with different slot length $la1$. Other parameters: $L = 29$ mm, $W = 30$ mm, $h_0 = 6.4$ mm, $la2 = 2$ mm, $wa1 = 1$ mm, $wa2 = 4$ mm, $ls = 5$ mm, $ds_2 = 14.5$ mm. (a) Resistance R versus frequency f. (b) Reactance X versus frequency f.

to be considered in the design. Also noted that the frequency of each resonance is shifted downwards with the increase of the open stub length.

Fig. 4 shows the effects of slot length (la_1) on the input impedance of the antenna. The magnitude of the resonance at lower frequency is increased significantly with the increase of slot length. The frequency of each resonance is shifted downwards with the increase of the slot length. The slot length cannot be too long, however, because the backward radiation will be increased with the increase of the slot length, which is undesirable.

The air gap thickness h_0 is one of the key parameters determining the bandwidth of the antenna, and the value of h_0 is chosen to be about 0.07 λ_0 in our design. The prototype antenna finally designed has the following parameters: $L = 30$ mm, $W = 30$ mm, $h_0 = 6.4$ mm. Port 1: $la1 = 16$ mm, $la2 = 2$ mm, $wa1 = 1$ mm, $wa2 = 4$ mm, $ds_1 = 6$ mm, $ls = 5$ mm; Port 2: $la1 = 14$ mm, $la2 = 2$ mm, $wa1 = 1$ mm, $wa2 = 4$ mm, $ds_1 = 15$ mm, $ls = 5$ mm.

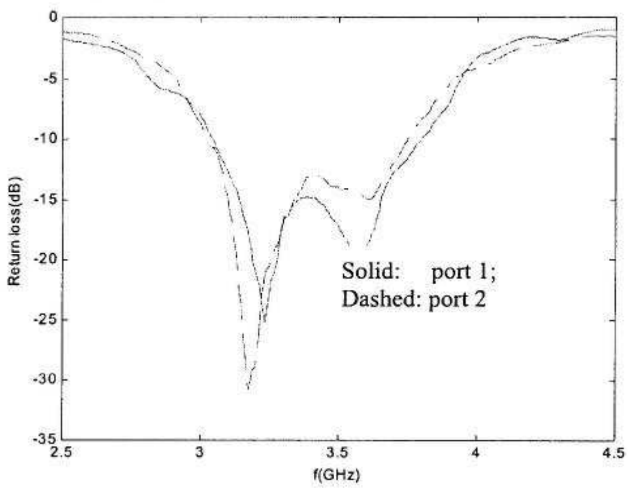


Fig. 5. Measured return loss of the antenna at two ports.

IV. Results and Discussions

In Fig. 5, the results of measured return loss at two ports are given. As we can see, the return loss is below -10 dB at port

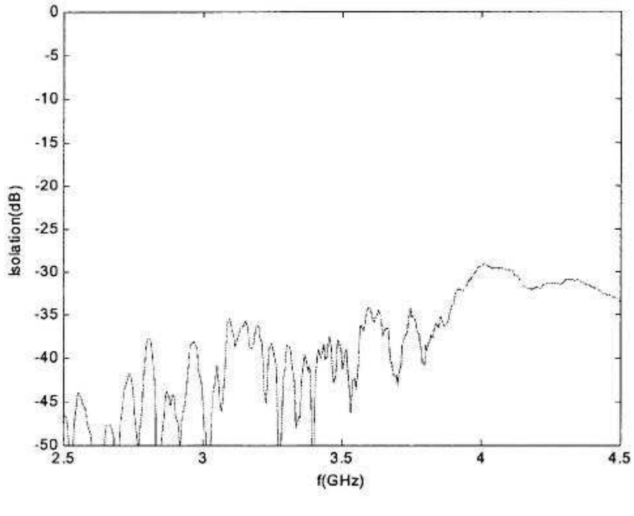
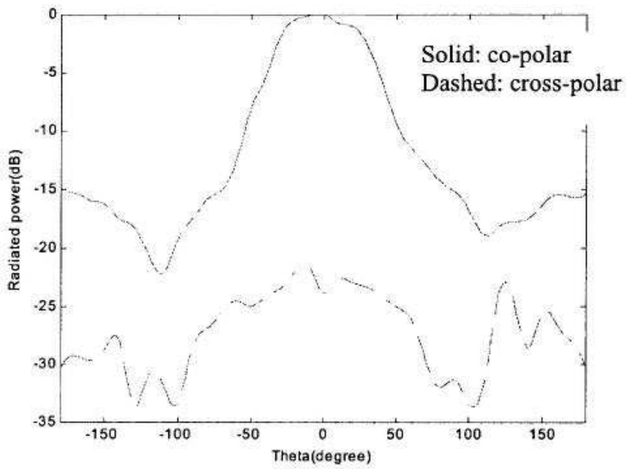
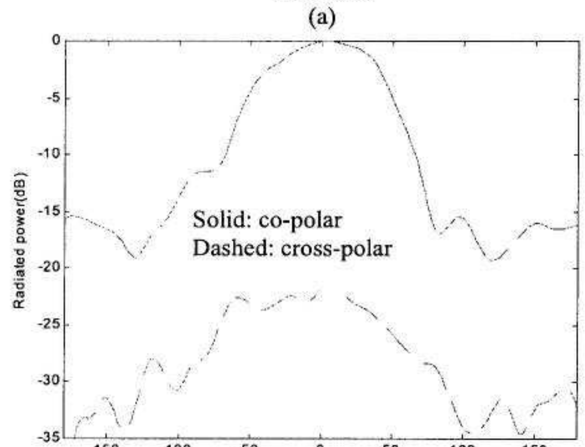


Fig. 6. Measured isolation of the antenna.



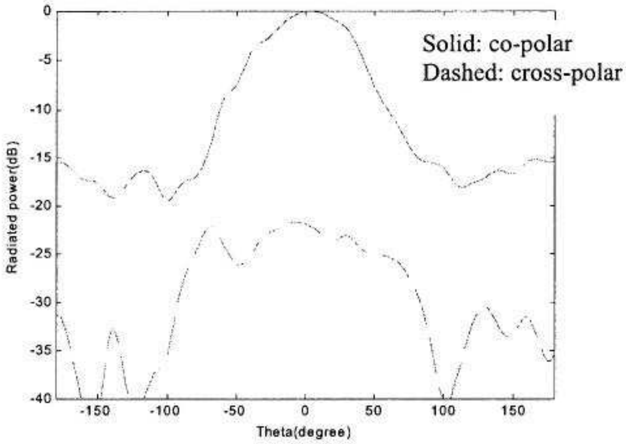
(a)



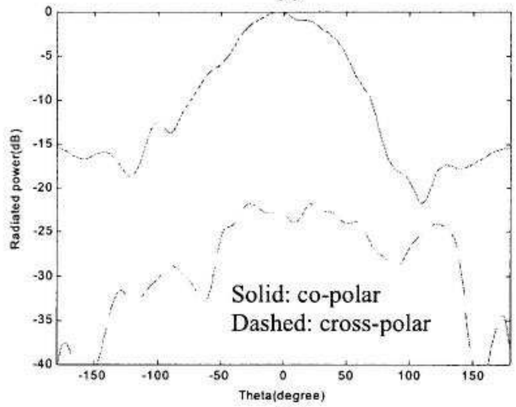
(b)

Fig. 7. Measured radiation patterns at 3.4 GHz for port 1. (a) E plane and (b) H plane.

1 within the frequency range between 3.045 and 3.8 GHz, corresponding to a bandwidth of 22%. At port 2, the return loss is below −10 dB within the frequency range between 3.025 and 3.745 GHz, which corresponds to a bandwidth of 21.3%.



(a)



(b)

Fig. 8. Measured radiation patterns at 3.4 GHz for port 2. (a) E plane and (b) H plane.

The results of measured isolation between two ports are given in Fig. 6. It is seen the isolation is at least below −34 dB within the frequency bandwidth between 2.5 and 3.8 GHz, which means a low coupling between two input ports has been achieved.

Fig. 7 shows the measured radiation patterns of the antenna excited at port 1 at 3.4 GHz. Broadside radiation patterns are observed at both E and H planes, and the cross-polar levels are below −21 dB within the half space above the ground plane. The backward radiation is below −15 dB. The measured radiation patterns of the antenna excited at port 2 at 3.4 GHz is given in Fig. 8. We also measure the antenna at several other frequencies, and it is observed that the radiation patterns are stable across the bandwidth.

V. Conclusion

By using the proximity-coupled feeds, a novel design of the broad-band dual-polarized microstrip antennas is proposed. H-shaped slots are cut in the ground plane under microstrip feed lines. The prototype antenna yields a bandwidth of 22% and 21.3% at the input port 1 and 2, respectively. The isolation between two input ports is below −34 dB across the bandwidth. Good broadside radiation patterns are observed, and the cross-polar levels are below −21 dB at both E and H planes.

The antenna has advantages including simplified structure, broad bandwidth, high isolation between two input ports, and low cross-polarization levels. It is also easy to form arrays by using this antenna as an element. Thus, it is promising for practical applications in various wireless systems.

ACKNOWLEDGMENT

The authors thank the anonymous reviewers for their constructive comments.

REFERENCES

[1] K. F. Lee and W. Chen, Eds., *Advances in Microstrip Antennas and Printed Antennas*, New York: Wiley, 1997, pp. 163–217.
[2] *Handbook of Microstrip Antennas*, J. R. James and P. S. Hall, Eds., Peter Peregrinus, U.K., 1989.
[3] L. J. Du Toit and J. H. Cloete, "Dual polarized linear microstrip patch array," in *Proc. IEEE Antennas and Propagation Symp. Dig.*, 1987, pp. 810–813.
[4] M. J. Cryan and P. S. Hall, "Integrated active antenna with simultaneous transmit-receive operation," *Electron. Lett.*, vol. 32, no. 4, pp. 286–287, 1996.
[5] S. Gao and S. S. Zhong, "Analysis and design of dual-polarized microstrip arrays," *Int. J. RF and Microwave CAE*, vol. 9, no. 1, pp. 42–48, 1999.
[6] S. Gao and J. Li, "FDTD analysis of serial corner-fed square patch antennas for single- and dual-polarized applications," *Proc. Inst. Elect. Eng. Microw. Antennas Propag.*, vol. 146, pp. 205–209, 1999.
[7] S. Gao and S. S. Zhong, "Dual-polarized microstrip antenna array with high isolation fed by coplanar network," *Microwave Opt. Technol. Lett.*, vol. 19, no. 3, pp. 214–216, 1998.
[8] A. Tavakoli, N. Damavandi, and R. Mazandaran, "Analysis of cross-shaped dual-polarized microstrip patch antenna," in *Proc. IEEE Antennas and Propagation Symp. Dig.*, 1995, pp. 994–997.
[9] J. Huang, "Dual-polarized microstrip array with high isolation and low cross polarization," *Microwave Opt. Technol. Lett.*, vol. 41, no. 3, pp. 99–103, 1991.
[10] A. Adrian and D. H. Schaubert, "Dual aperture-coupled microstrip antenna for dual or circular polarization," *Electron. Lett.*, vol. 23, pp. 1226–1228, 1987.
[11] D. M. Pozar and D. H. Schaubert, Eds., *Microstrip Antennas, the Analysis and Design of Microstrip Antennas and Arrays*. New York: IEEE Press, 1995.
[12] 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 Propag.*, vol. AP-47, pp. 1836–1842, 1999.
[13] S. Hienonen, A. Lehto, and A. V. Raisanen, "Simple broadband dual-polarized aperture-coupled microstrip antenna," in *Proc. IEEE Antennas Propagation Society Int. Symp. Dig.*, 1999, pp. 1228–1231.
[14] S. Gao, L. W. Li, P. Gardner, and P. S. Hall, "Wide-band dual-polarized microstrip patch antenna," *Electron. Lett.*, vol. 37, pp. 1213–1214, 2001.
[15] M. E. Bialkowski, A. W. Robinson, and H. J. Song, "Design, development, and testing of X-band amplifying reflectarrays," *IEEE Trans. Antennas Propag.*, vol. AP-50, no. 8, pp. 1065–1076, Aug. 2002.
[16] S. Gao, L. W. Li, T. S. Yeo, and M. S. Leong, "A novel wide-band, dual-polarized microstrip antenna with aperture coupling," *IEEE Trans. Antennas Propag.*, vol. AP-51, pp. 898–900, 2003.
[17] 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 Propag.*, vol. AP-50, no. 2, pp. 188–191, Feb. 2002.
[18] 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 and Propagation Symp. Dig.*, 2000, pp. 2216–2219.
[19] 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.
[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 and Propagation Symp. Dig.*, 1988, pp. 936–939.
[21] M. Edimo, A. Sharaiha, and C. Terret, "Optimized feeding of dual polarized broadband aperture-coupled printed antenna," *Electron. Lett.*, vol. 28, pp. 1785–1787, 1992.
[22] J. F. Zucher and F. Gardiol, *Broadband Patch Antenna*. Boston, MA: Artech House, 1995.
[23] P. Brachat and J. M. Baracoo, "Printed radiating element with two highly decoupled input ports," *Electron. Lett.*, vol. 31, pp. 245–246, 1995.
[24] J. F. Zucher, P. G. Balmaz, R. C. Hall, and R. Kolb, "Dual-polarized single- and double-layer strip-slot-foam inverted patch (SSFIP) antennas," *Microwave and Opt. Technol. Lett.*, vol. 7, no. 9, pp. 406–410, Jun. 1994.
[25] 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.
[26] B. Lindmark, "A novel dual-polarized aperture coupled patch element with a single layer feed network and high isolation," in *Proc. IEEE Antennas and Propagation Symp. Dig.*, 1997, pp. 2190–2193.
[27] T. W. Chiou, H. C. Tung, and K. L. Wong, "A dual polarization wideband circular patch antenna with hybrid feeds," *Microwave and Opt. Technol. Lett.*, vol. 26, no. 1, pp. 37–39, 2000.
[28] K. L. Wong and T. W. Chiou, "Design of dual-polarized patch antennas fed by hybrid feeds," in *Proc. IEEE Antennas and Propagation Symp. Dig.*, 2000, pp. 22–25.
[29] Y. X. Guo, K. M. Luk, and K. F. Lee, "Broadband dual-polarization patch element for cellular-phone base stations," *IEEE Trans. Antennas Propag.*, vol. AP-50, no. 2, pp. 251–253, Feb. 2002.
[30] K. L. Wong and T. W. Chiou, "Broadband dual-polarized patch antennas fed by capacitively coupled feed and slot-coupled feed," *IEEE Trans. Antennas Propag.*, vol. AP-50, no. 3, pp. 346–351, Mar. 2002.
[31] P. Brachat and J. M. Baracco, "Dual-polarization slot-coupled printed antennas fed by stripline," *IEEE Trans. Antennas Propag.*, vol. AP-43, pp. 738–742, 1995.
[32] S. Y. Ke, "Broadband proximity-coupled microstrip antennas with an H-shaped slot in the ground plane," in *Proc. IEEE Antennas and Propagation Symp. Dig.*, 2002, pp. 530–533.

Steven (Shichang) Gao was born in 1972. He received the Ph.D. degree in microwave engineering from Shanghai University, Shanghai, China, in 1999.

He was a Research Engineer at the China Research Institute of Radiowave Propagation, a Postdoctoral Research Fellow at the National University of Singapore, a Research Fellow at the University of Birmingham, Birmingham, U.K., and a Visiting Scientist at the Swiss Federal Institute of Technology, Zurich, Switzerland.

Currently, he is a Senior Lecturer at the University of Northumbria, Newcastle Upon Tyne, U.K., where he is leading a research group working on active integrated antennas and broad-band high-efficiency microwave power amplifiers.

Alistair Sambell received the B.Sc. and D.Phil. degrees in electronics from York University, York, U.K., in 1987 and 2001, respectively.

His doctoral and subsequent postdoctoral research focused on novel III-V device structures and solar cells for space applications. Since 2001, he has been at Northumbria University, Newcastle Upon Tyne, U.K., where he is currently Professor and Dean of the School of Engineering and Technology. His current research interests include the design of microwave antennas for road-tolling and other applications.