Broadband Dual-Polarized Aperture-Coupled Patch Antennas With Modified H-Shaped Coupling Slots

Kin-Lu Wong, *Senior Member, IEEE*, Hao-Chun Tung, and Tzung-Wern Chiou

***Abstract*—This paper presents a new design of aperture-coupled patch antennas with modified H-shaped coupling slots for achieving dual-polarization radiation with high isolation over a wide bandwidth. By using the proposed coupling slots, whose two upper side arms are bent inward with a proper angle, the isolation between the two feeding ports of the patch antenna can greatly be improved, compared to the case with conventional H-shaped coupling slots. Also, when using a pair of modified H-shaped coupling slots for each feeding port, the isolation can further be improved; a high degree of isolation (< -34 dB) over the entire impedance bandwidth greater than 15% and good cross-polarization level (> 20 dB) for the two polarizations can be achieved. Details of the proposed design and experimental results are presented and discussed.**

***Index Terms*—Aperture coupling, dual polarization, patch antenna.**

I. Introduction

A variety of aperture-coupled patch antennas for achieving dual-polarization radiation have been reported [1]–[11]. These available designs in the open literature are mainly with the use of a cross-shaped coupling slot [1]–[8], two orthogonal offset slots [8]–[10], two orthogonal dual slots [11], and so on. When these designs are applied to patch antennas with a thick air or foam substrate to achieve dual-polarization radiation over a wide operating bandwidth, the required dimensions of the coupling slots for sufficient electromagnetic energy coupling are usually more than 0.7 times or even comparable to the patch's linear dimension [2], [4], [5]. This condition results in the increasing of the backward radiation of the patch antenna and is a disadvantage of such broadband dual-polarized aperture-coupled patch antennas.

To reduce the back radiation of aperture-coupled patch antennas, it has been reported that the use of an H-shaped coupling slot allows a reduction of the back radiation of the slot [12]. However, from experiments conducted, it is found that when applying the H-shaped coupling slots for dual-polarization radiation, good decoupling between the two feeding ports of the patch antenna is usually a problem. This is probably because, for such dual-polarized patch antennas, the two side arms of the H-shaped slot for one feeding port are in parallel with the center arm of the H-shaped slot for the other feeding port, and thus the decoupling between the two feeding ports is degraded. This disadvantage is overcome in this paper. It is found that by using the modified H-shaped coupling slots proposed here (see Figs. 1 and 2), the isolation between the two feeding ports of a broadband dual-polarized patch antenna can easily be reduced to be less than -30 dB. Two designs using the proposed modified H-shaped slots (Figs. 1 and 2) are demonstrated in this paper. Prototype antennas of the two designs have been implemented and experimentally studied. Measured results of the obtained dual-polarization radiation are presented and discussed.

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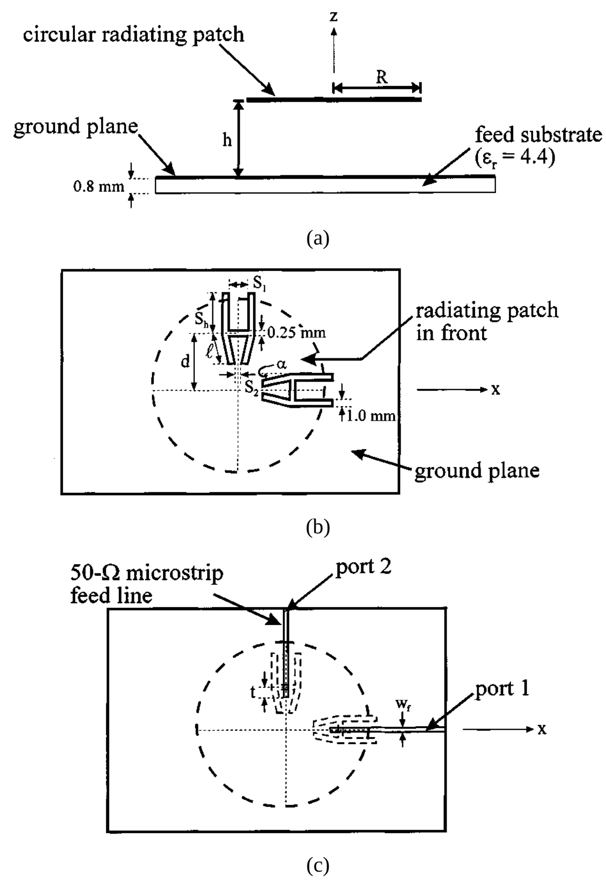

Fig. 1. Geometry of a dual-polarized aperture-coupled circular patch antenna with two modified H-shaped coupling slots (antenna A). (a) Side view of the antenna. (b) Coupling slots in the ground plane. (c) Microstrip feed lines on the feed substrate.

II. Antenna Designs

Two designs of the aperture-coupled dual-polarized patch antenna with the proposed modified H-shaped coupling slots are shown in Figs. 1 and 2. The two upper side arms of the modified H-shaped slots are bent inward with an angle α, and the spacing between the tips of two upper side arms is S_2. (Note that in the proposed design, if S_2 is less than 3 mm, enhanced isolation between two feeding ports cannot be obtained.) The

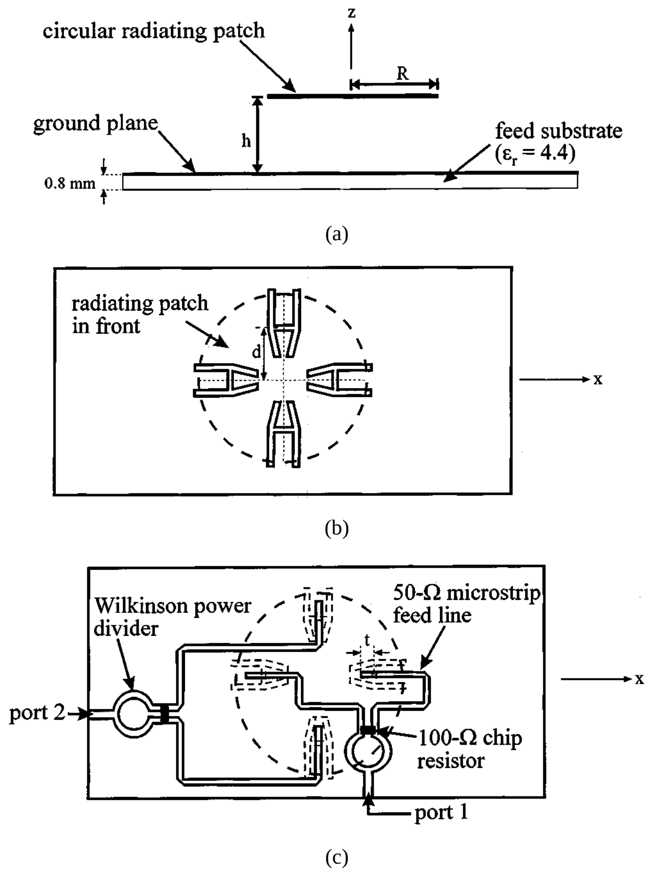

Fig. 2. Geometry of a dual-polarized aperture-coupled circular patch antenna with four modified H-shaped coupling slots (antenna B). (a) Side view of the antenna. (b) Coupling slots in the ground plane. (c) Microstrip feed lines including two Wilkinson power dividers on the feed substrate.

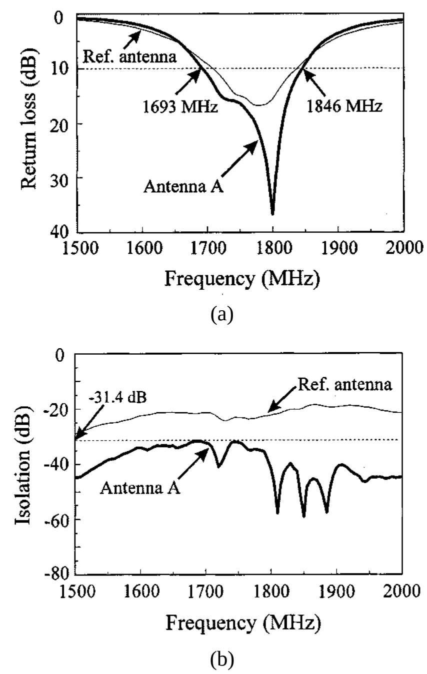

Fig. 3. Measured return loss and isolation against frequency for antenna A and reference antenna; $R = 37.25$ mm, $h = 9$ mm, $d = 27$ mm, $S_h = 14.5$ mm, $S_1 = 14$ mm, $S_2 = 6$ mm ($S_2 = 14$ mm for reference antenna), $\alpha = 40°$ ($\alpha = 0°$ for reference antenna), $l = 6.4$ mm ($l = 14.5$ mm for reference antenna), $t = 3.5$ mm, $w_f = 1.53$ mm, ground-plane size $= 100$ mm $\times$ 100 mm. (a) Return loss for antenna A and reference antenna. (b) Isolation between ports 1 and 2.

two lower side arms are perpendicular to the center arm of the modified H-shaped slot and have a length of S_h and a spacing of S_1 (S_1 is also the length of the center arm). The distance between the center arm and the patch center is d. The upper and lower side arms are all set to have the same width of 1.0 mm in this study, and a smaller width (0.25 mm) for the center arm is selected. The modified H-shaped slots are fed by 50-Ω microstrip lines, which have a tuning stub length of t and a width of w_f and are printed on a feed substrate (relative permittivity 4.4 and thickness 0.8 mm in this study). The radiating patch of a circular shape is used, and the circular patch has a radius of R. The circular patch is also supported by some nonconducting posts (not shown in the figures) of length h and placed above the ground plane of the microstrip feed lines.

In Fig. 1 (denoted as antenna A here), the electromagnetic energy is coupled from the microstrip feed lines to the circular radiating patch via a modified H-shaped slot for each feeding port. The decoupling between the two feeding ports is found to be greatly dependent on the bent angle α of the modified H-shaped slot. There exists an optimal α for achieving optimal decoupling between the two feeding ports. The optimal angle can be determined from the simulation results obtained from IE3D, and in this study, the optimal angle is found to be about 40°. It is also found that by using a pair of modified H-shaped slots fed by equal amplitudes and phases provided by a Wilkinson power divider for each feeding port (see Fig. 2, antenna B), decoupling between the two feeding ports can further be improved and enhanced polarization purity of the two polarizations can also be obtained. This improvement in decoupling and polarization purity is largely because some higher order modes that contribute to the polarization impurity can be suppressed with the use of two slots fed by equal amplitudes and phases and placed symmetrically with respect to the patch center [10].

III. Experimental Results and Discussion

Antenna A was first constructed and measured. The center frequency was designed to be at 1800 MHz, and the design parameters can be obtained from the simulation software IE3D. The radius of the circular patch was 37.25 mm. The air substrate's thickness (h) was 9 mm or about 5.4% of the center operating wavelength. The required center arm's length (S_1) was 14 mm and was only about 19% of the diameter ($2R$) of the circular patch. Fig. 3 shows the measured return loss and isolation against frequency for antenna A and the reference antenna. Note that since port-1 and port-2 excitation in this case is with almost identical measured results, only those of port-1 excitation are shown in Fig. 3. The modified H-shaped coupling slots used for antenna A were with an optimal value of $\alpha = 40°$, which was found to result in an optimal decoupling between ports 1 and 2. The reference antenna had the same parameters as antenna A, except that the coupling slots used were the conventional H-shaped slots; i.e., $\alpha = 0°$ and $S_2 = S_1$. For both antenna A and the reference antenna, the obtained 10-dB return-loss impedance bandwidths are 7.3 and 8.5%, respectively. The isolation between the two feeding ports for antenna A is less than −31.4 dB over the entire bandwidth, which is about

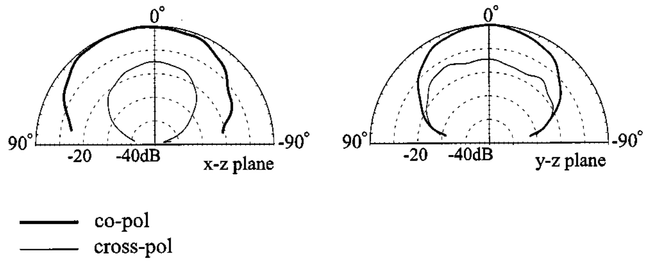

Fig. 4. Measured radiation patterns in two orthogonal planes at 1800 MHz for port-1 excitation of antenna A studied in Fig. 3.

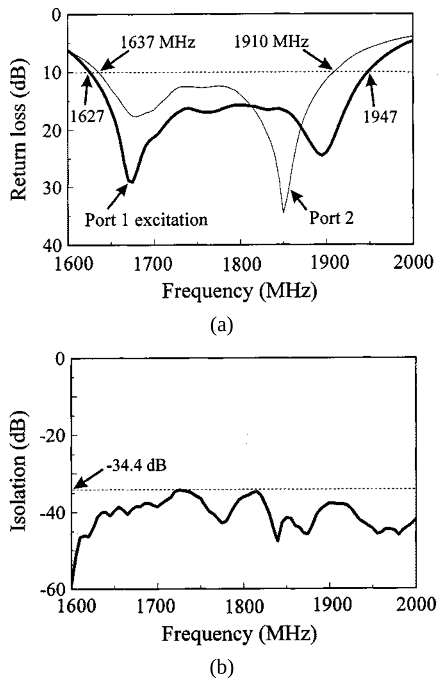

Fig. 5. Measured return loss and isolation against frequency for antenna B; size ground plane $= 110$ mm $\times 150$ mm. Other parameters are the same as given in Fig. 3. (a) Return loss at ports 1 and 2 of antenna B. (b) Isolation between ports 1 and 2.

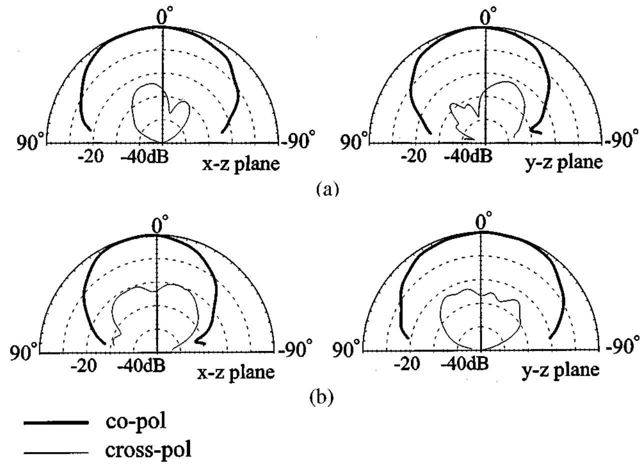

Fig. 6. Measured radiation patterns in two orthogonal planes at 1800 MHz for antenna B studied in Fig. 5. (a) Port-1 and (b) port-2 excitation.

-10 to -35 dB less than that of the reference antenna. The measured radiation patterns in two orthogonal planes at 1800 MHz for port-1 excitation of antenna A are also plotted in Fig. 4. Good broadside radiation patterns are observed, with an on-axis antenna gain of 6.8 dBi. However, the cross-polarization levels (XPLs) in both planes are seen to be only about 14 dB, which is worse than that of the reference antenna. As for the backward radiation, both the proposed antenna and the reference antenna are about the same.

Antenna B was also constructed and measured. The parameters of antenna B were selected to be the same as those of antenna A, except that two identical modified H-shaped coupling slots, including their associated feed networks, were used for each feeding port of antenna B. Fig. 5 shows the measured return loss and isolation against frequency for antenna B. Both return-loss results for port-1 and port-2 excitation are shown in Fig. 5(a) and some variations are observed, which are largely because the feed networks for ports 1 and 2 are not symmetrical for antenna B. The obtained impedance bandwidths reach 17.8% (1627–1947 MHz) and 15.2% (1637–1910 MHz), respectively, for port-1 and port-2 excitation, which are about two times that of antenna A. This increase in the impedance bandwidth is probably because an additional resonance is excited due to the coupling between two modified H-shaped slots and the radiating patch. Also, the results shown in Fig. 5(b) indicate that the isolation over the entire bandwidth is further improved, with $S_{21} < -34.4$ dB. As for the radiation patterns given in Fig. 6, good cross-polarization levels (XPL $>$ 20 dB) in two orthogonal planes of the two polarizations are obtained. However, the on-axis antenna gains of port-1 and port-2 excitation are measured to be 6.6 and 6.5 dBi, respectively, which are 0.3 to 0.4 dBi less than that of antenna A. This decrease in antenna gain is probably because relatively more complicated feed networks are used for the two feeding ports of antenna B and increased energy losses in the feed network can be expected. Also, it is found that the measured isolation is very slightly affected when a reflecting conducting plate is added behind the ground plane, which suggests that the backward radiation of the proposed design is small. Thus the possible coupling between the two feeding ports, due to the possible waves propagating within the region between the ground plane and the reflecting plate, is also small.

IV. Conclusion

Dual-polarized aperture-coupled patch antennas with modified H-shaped coupling slots for achieving a high degree of isolation between the two feeding ports over a wide bandwidth have been demonstrated. Two designs of using a modified H-shaped slot (antenna A) or two modified H-shaped slots (antenna B) for each feeding port have been experimentally studied. With an air-substrate thickness about 5.4% of the center operating wavelength, the isolation can be less than -31.4 dB over a bandwidth of 8.5% (ports 1 and 2) for antenna A and -34.4 dB over a bandwidth of 17.8% (port 1) or 15.2% (port 2) for antenna B. Also, good cross-polarization levels for the design of antenna B are observed.

References

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

[2] E. Edimo, A. Sharaiha, and C. Terret, "Optimized feeding of dual polarized broadband aperture-coupled printed antenna," *Electron. Lett.*, vol. 28, pp. 1785–1787, 1992.

[3] 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.

[4] J. R. Sanford and A. Tengs, “A two substrate dual polarized aperture coupled patch,” in *1996 IEEE Antennas Propagat. Soc. Int. Symp. Dig.*, pp. 1544–1547.

[5] B. Lindmark, “A novel dual polarized aperture coupled patch element with a single layer feed network and high isolation,” in *1997 IEEE Antennas Propagat. Soc. Int. Symp. Dig.*, pp. 2190–2193.

[6] I. Nystrom and D. Karlsson, “Reduction of back radiation and cross-coupling in dual polarized aperture coupled patch antennas,” in *1997 IEEE Antennas Propagat. Soc. Int. Symp. Dig.*, pp. 2222–2225.

[7] B. Lindmark, S. Lundgren, J. R. Sanford, and C. Beckman, “Dual-polarized array for signal-processing applications in wireless communications,” *IEEE Trans. Antennas Propagat.*, vol. 46, pp. 758–763, 1998.

[8] F. Rostan and W. Wiesbeck, “Design considerations for dual polarized aperture-coupled microstrip patch antennas,” in *1995 IEEE Antennas Propagat. Soc. Int. Symp. Dig.*, pp. 2086–2089.

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

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

[11] J.-F. Zuercher, Ph. Gay-Balmaz, R. C. Hall, and S. Kolb, “Dual polarized, single- and double-layer strip-slot-foam inverted patch (SSFIP) antennas,” *Microwave Opt. Technol. Lett.*, vol. 7, pp. 406–410, 1994.

[12] M. El Yazidi, M. Himdi, and J. P. Daniel, “Transmission line analysis of nonlinear slot coupled microstrip antenna,” *Electron. Lett.*, vol. 28, pp. 1406–1408, 1992.

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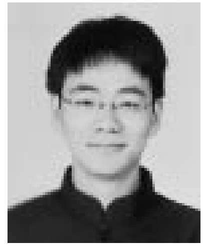

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