Reduced Size, Dual-Polarized Microstrip Patch Antenna for Wireless Communications

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***Abstract*—A novel, compact, probe-fed microstrip patch antenna for operation in dual-polarization mode is proposed. The novel design is achieved by etching out a symmetric pattern of crossed slots from the surface of a square probe-fed patch. Reduction in patch size of up to 51% with respect to a traditional dual-polarized square patch operating at the same frequency is obtained. Results show linear polarizations in the +45 and −45° with a high isolation of 38 dB between the two ports. Moreover, the 50-Ω feed position can be achieved by moving the feed point along the diagonal of the square patch, leading to ease in fabrication.**

***Index Terms*—Compact microstrip antenna, dual polarization.**

I. INTRODUCTION

THE explosive growth in broadband wireless communications systems, with rapid advances in the variety and sophistication of the data-intensive wireless services being offered, has increased the demands to enhance information accessibility and created a need for more bandwidth-efficient communication techniques. One way to address the capacity increase is by employing polarization diversity [1], [2]. Recent results in communication theory [3] have demonstrated that deploying dual-polarized antennas at the transmitter and/or receiver can dramatically increase both the capacity and diversity of wireless communication links. For example, in the richly scattering environments considered in [3], a dual-polarized antenna at the transmitter can increase capacity by more than 50% over a single transmit antenna; employing dual-polarized transmit and receive antennas can increase capacity threefold over a comparable system with single antennas at the transmitter and receiver.

This paper focuses on the development of a novel microstrip antenna characterized by polarization diversity. The objective was to explore strategic antenna designs for dual-polarization coverage and determine the feasibility of seamlessly integrating such antenna systems on mobile nodes in a wireless system. Due to their intended application on mobile network nodes such as portable laptop platforms, compactness was a key issue that was considered in the designs.

Dual polarization can be accomplished by exciting modes in two orthogonal directions [4]–[7], while size reduction can be achieved by means of reactive loading in the form of notches or slots on the surface of the patch [8]–[10]. Such loading causes the meandering of the surface current, thus effectively increasing the surface current path and the electrical length of the element that leads to reduction of the patch size for a given resonant frequency. Simultaneous etching out of a symmetrical array of slots and the excitation of two orthogonal modes can lead to an antenna with reduced size operating in dual-polarization mode.

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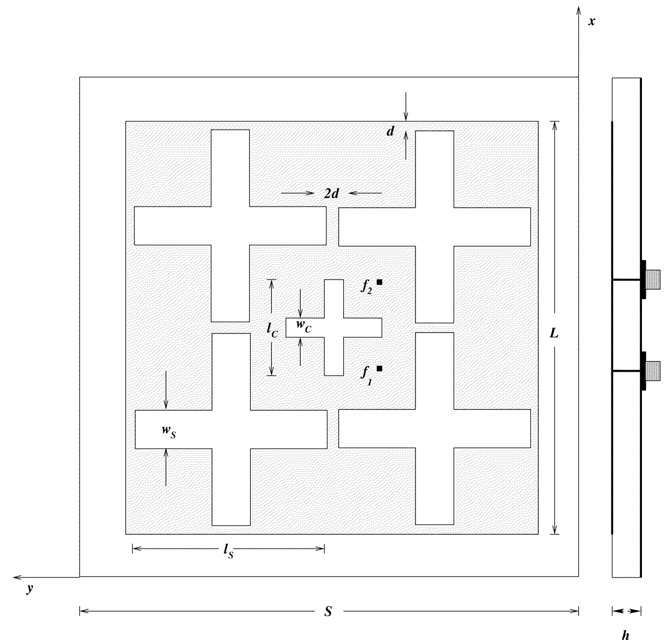
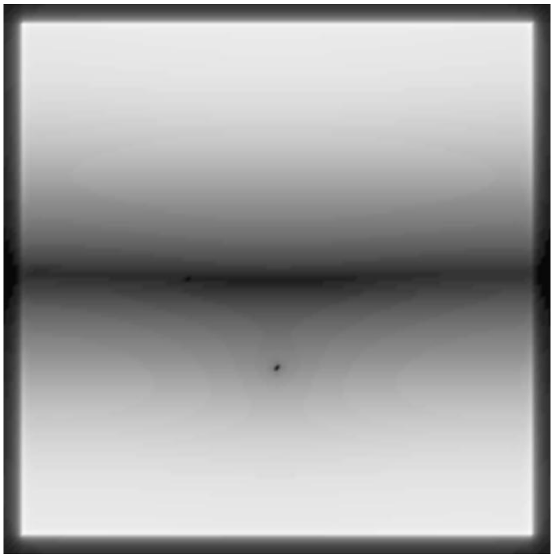


Fig. 1. Design parameters for the proposed configuration.

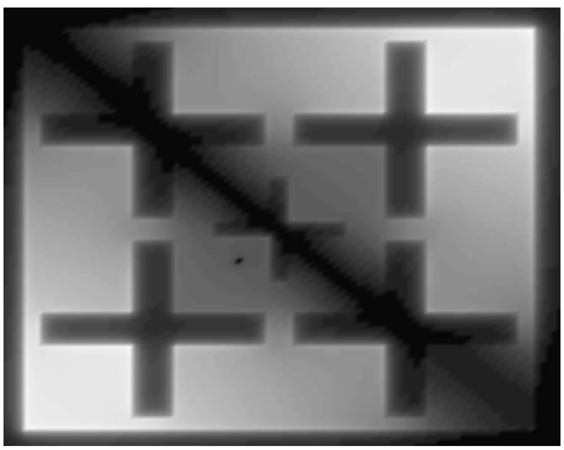
In this paper, we propose a dual-feed probe-fed antenna design with a symmetrical array of slots etched on the patch surface. Results show that the proposed antenna is characterized by excellent isolation between the two ports (38 dB) and is more than 50% smaller compared to a traditional dual-polarized square patch operating at the same frequency. Critical issues in the design are examined, and both simulated and experimental results are presented.

II. ANTENNA DESIGN

Fig. 1 shows the proposed probe-fed dual-polarized microstrip patch antenna. Four pairs of crossed slots are etched out—one from each quadrant of the surface and a smaller pair from the center of the patch. The square microstrip patch has a side length L and is printed on a substrate of thickness h and relative permittivity ε_r. For antennas in this paper, laminates with a relative permittivity $\varepsilon_r = 3.2$ were utilized. The quadrant slot pairs have their sides parallel to the edges of the patch and have length l_s and width w_s. The slot pair



(a)



(b)

Fig. 2. The null-line obtained by exciting one port and terminating the other in its resonant impedance. (a) Conventional microstrip antenna and (b) proposed compact microstrip antenna.

in the center has length l_c and width w_c. Due to the specific locations of the feed points, the polarizations at the two ports will be along the orthogonal diagonals of the square patch. The finite-difference time-domain (FDTD) algorithm is employed to design and analyze the antenna.

For least cross polarization, it is critical that the slots be etched out in a symmetrical pattern such that the surface currents in both the orthogonal directions have to traverse identical paths. To achieve good isolation between the two ports, each feed point is positioned along the "null-line" of the other port, which comprises all of the locations on the patch where the normal electric field to the patch obtained by feeding the other port is minimum. Fig. 2(a) and (b) shows the position of the null-line for a conventional dual-polarized antenna and the proposed compact dual-polarized antenna, respectively, as obtained by FDTD simulations. A D-H FDTD method with material independent perfectly matched layer (PML) boundary condition [11], [12] was used during the design phase of the antenna to locate the position of the null line and, therefore, the location of the feed points. A resolution of 0.762 mm has been used to model the antenna, leading to a total computational space of 160 × 160 × 60 cells. Fifteen PML layers have been used to absorb the outgoing waves with PML parameters chosen as specified in [11] and [12]. The FDTD method was also used to obtain the directivity in dBi of the final antenna designs. Confidence in the accuracy of the result was based on an extensive comparison of radiation patterns and directivity obtained for conventional antenna geometries as well as results reported in the literature. Excellent agreement between the numerical results and data reported in the literature was found for all the considered test cases.

III. Results and Discussion

Several antennas with the geometrical configuration proposed in Fig. 1 were implemented and studied both numerically and experimentally. The effect of the slot lengths and widths on the size reduction factor, impedance, and radiation characteristics of the antennas has been investigated. Table I summarizes the results (resonant frequency and directivity) obtained for the three antennas representative of the possible design parameter variations. Specifically, first we consider the effect of reducing the corner slot lengths l_s (Antenna-2) and then the effect of reducing the corner slot widths w_s (Antenna-3) with respect to that of Antenna-1, which is used as the benchmark antenna and found to be the antenna with the largest size reduction ratio. For comparison purposes, a reference antenna (a conventional unslotted patch) operating at the same frequency as Antenna-1 was also implemented and its characteristics measured. An HP 8510 network analyzer was utilized for all the measurements.

A. Impedance and Isolation Characteristics

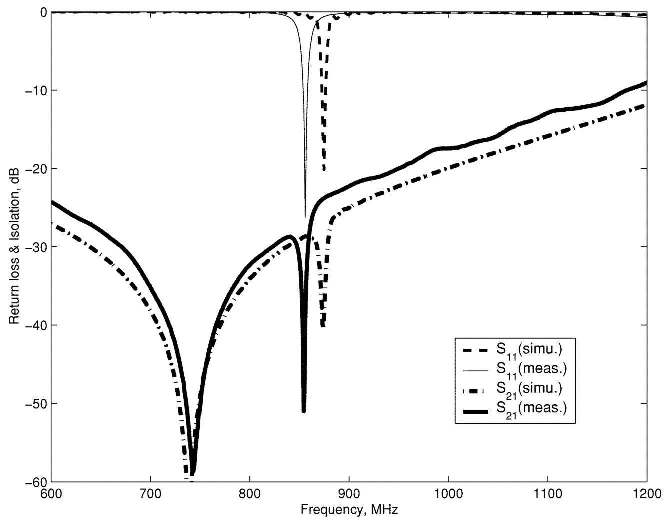
Fig. 3(a) shows the simulated and measured return loss and isolation of Antenna-1. It can be observed that the antenna exhibits excellent impedance matching to 50 Ω. Also, isolation greater than 36 dB throughout the operating impedance bandwidth (1:2 VSWR) is observed. The slight discrepancy between numerical and measured return losses (including a 20-MHz resonant frequency shift, which is, however, less than 2.5% shift with respect to the resonant frequency) can be attributed to both fabrication tolerances and FDTD tolerances in the precise modeling of slots and edges as well as the absence of losses in the computer model.

For the reference antenna, the measured and simulated impedance and isolation characteristics are plotted in Fig. 3(b). The agreement between measurements and simulation is good. Note that, in this case, due to the relatively simple structure, the shift in frequency between the simulated and measured is less than 3 MHz (less than .5% with respect to the resonant frequency). For the same resonant frequency, the proposed slotted design Antenna-1 had side dimensions of $L = 67.056$ mm, whereas the unslotted patch had dimensions of $L = 96.770$ mm. Hence, a size reduction of ∼51% is achieved with Antenna-1.

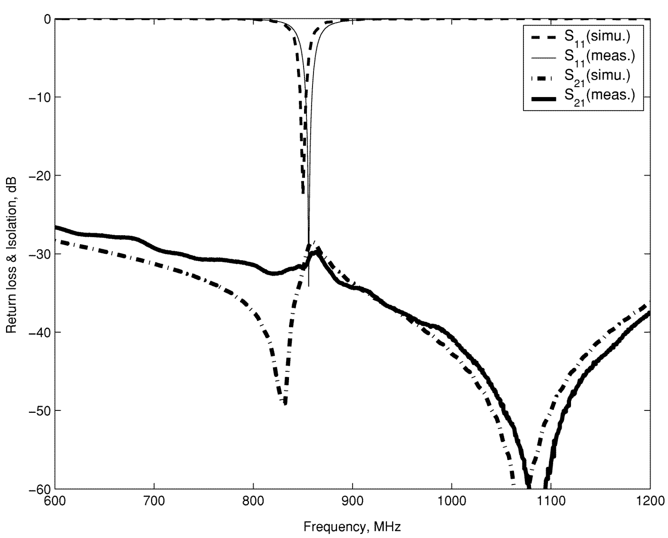
In Antenna-2, the side dimension was kept the same as Antenna-1 (i.e., $L = 67.056$ mm),while the corner slot lengths l_s were reduced to 25.9 mm. As shown in Table I, this has the

TABLE I
A SPECIFICATION OF THE PARAMETERS DEFINED AS SHOWN IN FIG. 1 FOR THE PROPOSED DESIGN AND FOR THE REFERENCE ANTENNA. f_r IS THE OPERATING FREQUENCY FOR EACH DESIGN

	L (mm)	l_s (mm)	$w_s(mm)$	l_c (mm)	w_c (mm)	f_r (MHz)	$Gain$ (dBi)
Antenna-1	67.056	30.480	6.096	18.288	3.048	855.9	0.9
Antenna-2	67.056	25.908	6.096	15.240	3.048	979.7	2.5
Antenna-3	67.056	30.480	3.048	18.288	3.048	880.7	1.3
Reference Antenna	96.770	–	–	–	–	853.6	4.8



(a)



(b)

Fig. 3. Impedance and isolation characteristics. (a) Antenna-1. (b) Reference antenna.

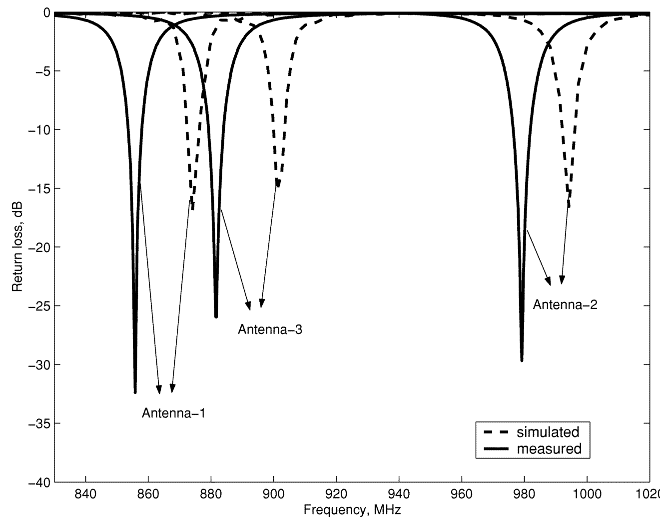


Fig. 4. Measured and simulated return losses of Antenna-1, 2, and 3.

effect of increasing the resonant frequency of the patch by approximately 124 MHz. Hence, the size reduction decreased to ~35% with respect to the reference conventional square patch antenna. To obtain a proper impedance match to 50 Ω, the center slot length was reduced to 15.24 mm. In fact, we have observed that a combination of altering the center slot parameters and shifting the feed points along the diagonal can be successfully employed to achieve an excellent 50-Ω matching. In the case of Antenna-3 ($L = 67.056$ mm), the corner slot widths w_s were reduced while keeping their lengths the same as Antenna-1. In this case, too, the resonant frequency of the patch increased as shown in Table I. Thus, the size reduction achieved with Antenna-3 is approximately ~47%.

Fig. 4 shows the measured and computed return loss for the considered antenna configurations (Antenna-1, Antenna-2, Antenna-3). The largest discrepancy in the simulated and measured resonant frequency for all the three configurations is limited to ~20 MHz, or less than 2.5% of the resonant frequency. As expected, from the above results we can conclude that the longer the slots, the greater the reduction in size offered. Interestingly, the isolation characteristics do not appear to be significantly affected by the variations in slot parameters.

B. Radiation Characteristics

The E and the H planes for the proposed antennas (Antenna-1, Antenna-2, Antenna-3) are obtained along the $\pm 45^\circ$ planes—along the diagonals of the square patch instead of the conventional $x-z$ and $y-z$ planes as obtained for the reference antenna [13], [14]. While obtaining the radiation patterns in the E and the H planes due to port 1, port 2 was terminated in its resonant impedance and vice versa. Computed radiation patterns in the E and H planes for Antenna-1 and the reference antenna are plotted in Fig. 5(a) and (b), respectively. The cross-polarization level for Antenna-1 remains below −34 dB in the E plane, but in the H plane, it deteriorates as we move away from the broadside direction. As expected, a reduction in patch area results in reduction in directivity by approximately 3.9 dBi. The directivity calculated for Antenna-1 is 0.9 dBi which is 3.9 dBi less than that of the reference antenna.

For Antenna-2 and Antenna-3, the E and H plane radiation patterns are plotted in Fig. 6. Cross-polarization levels less than

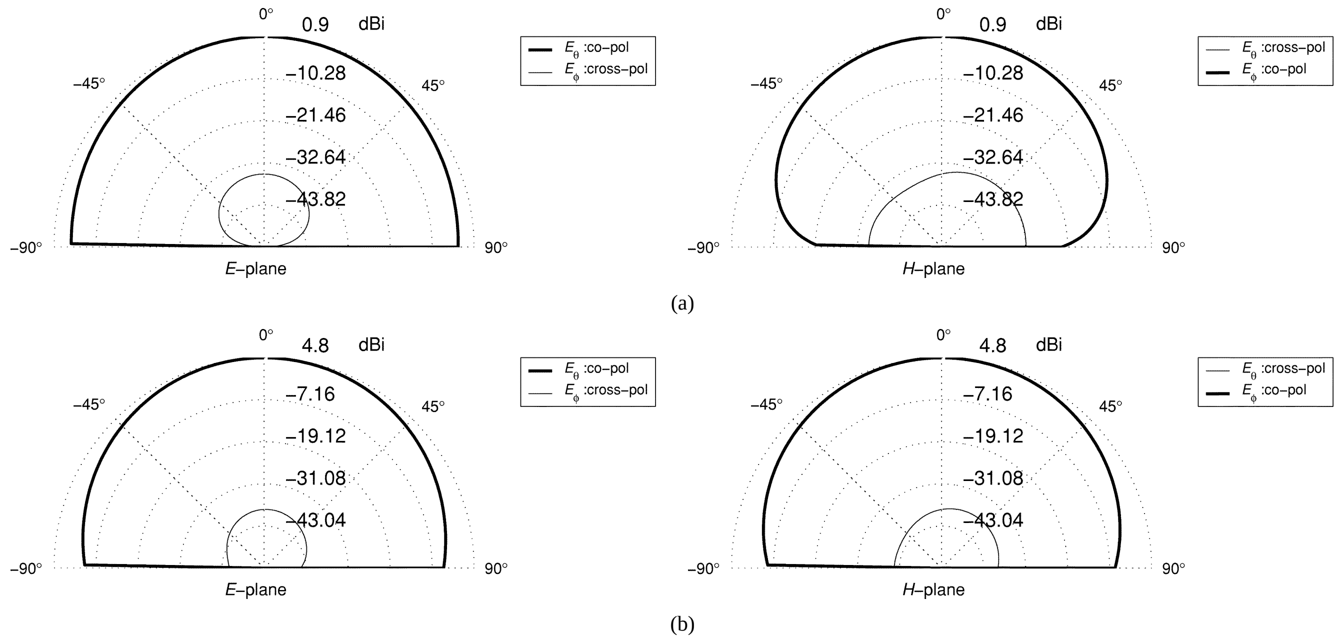


Fig. 5. Radiation characteristics. (a) Antenna-1. (b) Reference antenna.

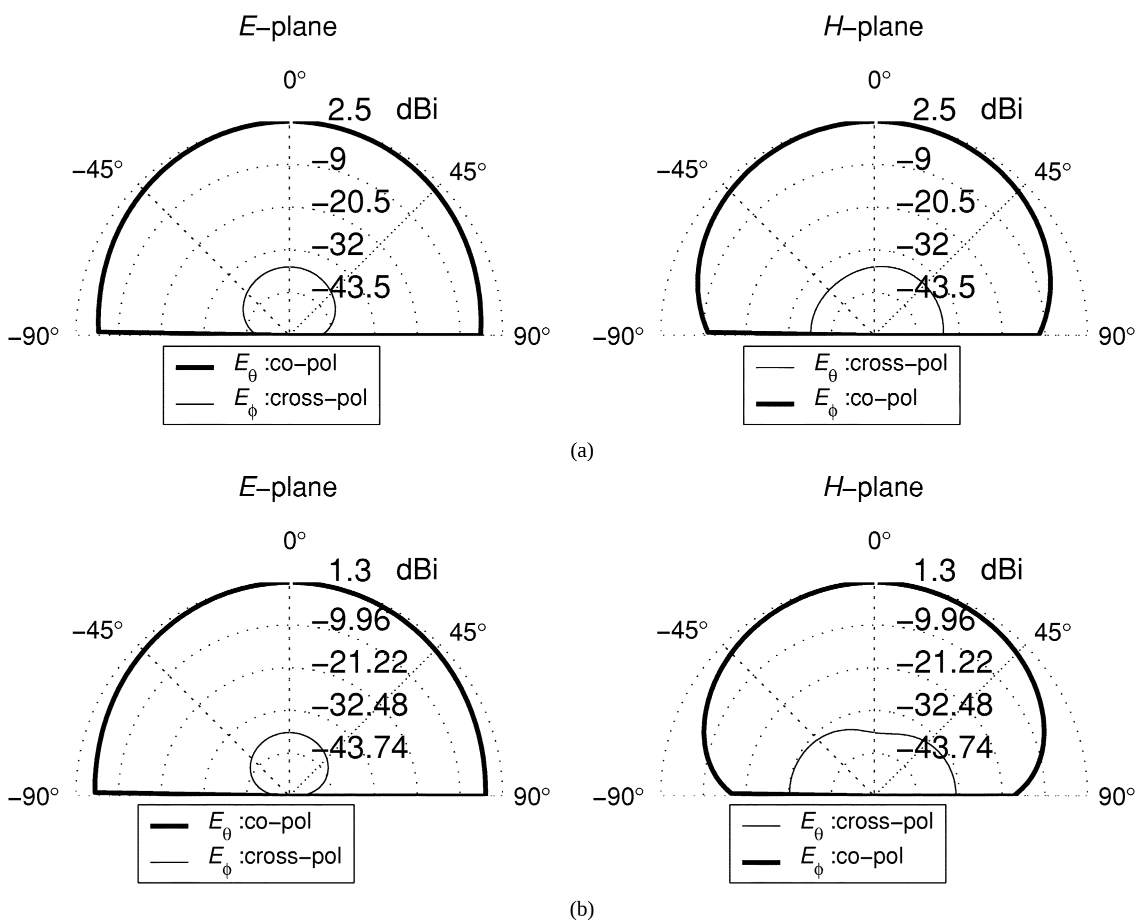


Fig. 6. Radiation characteristics. (a) Antenna-2. (b) Antenna-3.

−32 dB are observed for both of these antennas similar to Antenna-1. Also, due to the fact that lesser patch area is removed in the form of slots from Antenna-2 and Antenna-3 as compared to Antenna-1, a slightly higher directivity is obtained for both of these antennas (as seen from Fig. 6).

IV. Conclusion

A novel, compact, dual polarized microstrip patch antenna is presented. In the proposed design a size reduction of 51% with a high isolation (38 dB) and low cross polarization level is demonstrated, albeit, with a reduction in the broadside directivity (by 3.9 dBi). The influence of the slot parameters was investigated, and a tradeoff between slot dimensions, directivity and size reduction factor is shown. Due to their compactness the proposed antennas are suitable for application on mobile wireless nodes operating in dual polarization mode.

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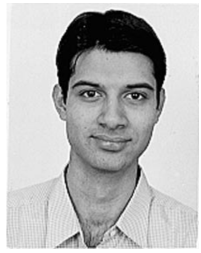

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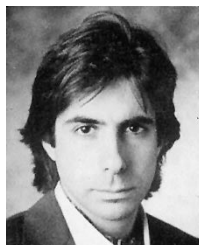

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