2-D Planar Scalable Dual-Polarized Series-Fed Slot Antenna Array Using Single Substrate

Yue Li, Zhijun Zhang, Changjiang Deng, Zhenghe Feng, and Magdy F. Iskander

***Abstract*—This communication proposes a dual-polarized slot antenna array, which is able to expand two-dimensionally (2-D), using only one layer of substrate board. Two identical coplanar waveguide (CPW) series-fed slot arrays are positioned orthogonally, providing dual polarization with high port isolation. The overall array is arranged on both sides of a single substrate, achieving low cost in fabrication. To validate the design concept, a model of the proposed array is built for the 2.4-GHz wireless local area network (WLAN) application. We have measured S parameters, radiation patterns and gain, and compared them with the simulation results.**

***Index Terms*—Antenna arrays, antenna array feeds, antenna diversity, slot antenna.**

I. Introduction

For modern wireless communication, dual-polarization antenna systems are widely developed for their merits of increasing channel capacity and mitigating multi-path fading. For dual-polarized operations, orthogonal modes are provided by patches [1], cross dipoles [2], slots [3], [4] and loops [5]. The port isolation and the feeding structure are two important considerations. Moreover, in order to compensate for the path loss during long distance communication, a dual-polarized array with high gain is preferred. In recent literatures, different types of dual-polarized arrays with high port isolation are reported [6]–[10]. In [6], a dual polarized patch array is proposed for adaptive beam steering. Similar designs are also presented in [7]–[10] with different orthogonal feeding structures. In these designs, the overall array needs multiple substrate layers for the radiating apertures and the feeding structure. The feeding lines are distributed around the radiating apertures, making it difficult to design a larger-scaled array with more elements.

In this communication, a 2-D scalable dual-polarized series fed slot array is proposed. Two identical single polarized CPW-fed slot arrays are arranged orthogonally on both sides of a single substrate, by employing CPW-based crossovers. For this dual-polarized array topology, high port isolation and low cross-polarization are achieved. We have built such an array at 2.4-GHz WLAN band to prove the design strategy. The measured results are also discussed, including S parameters, radiation patterns and gain.

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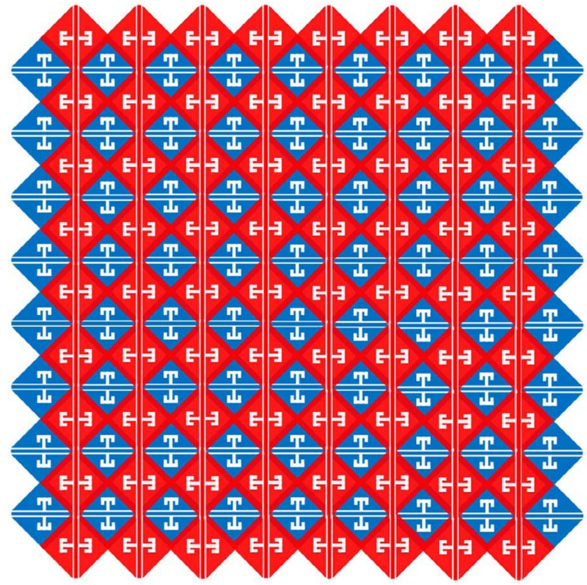

Fig. 1. Geometry the proposed array.

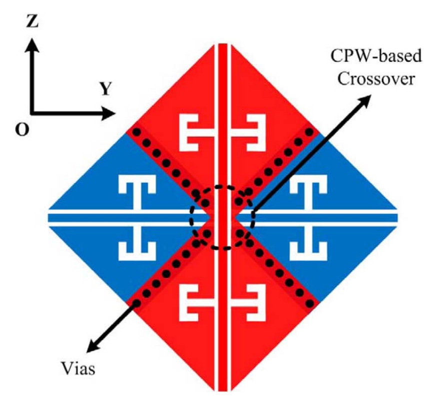

Fig. 2. Detailed view of element connection and CPW-based crossover.

II. Dual-Polarized Slot Array Design

Fig. 1 shows the geometry of the proposed CPW-based series-fed dual-polarized array, which is supported by a 1 mm thick layer of Teflon substrate ($\varepsilon_r = 2.65, \tan\delta = 0.001$). The proposed array consists of two identical single-polarized arrays. The vertical polarized array is arranged in the front (red color area), and another identical array providing horizontal polarization is arranged at the back (blue color area). For the vertical polarized array, each column of elements along z-axis is series-fed by CPW, and all the z-direction columns are fed by the power divider. The elements of the horizontal polarized array are arranged in the space between the vertical polarized elements, and fed by the same method. As shown in Fig. 2, the overlapping parts at the front and back are connected by a series of vias. As a result, the overall array, including the radiating apertures and the feeding network, is connected together, using a single substrate. A detailed view of the cross-part is also shown in Fig. 2, and we call it the CPW-based crossover. Thus, the proposed antenna array is composed of slot elements, CPW feeds and CPW-based crossovers. The proposed antenna array operates with bi-directional radiation pattern, which are employed in the base station and relay networks [11], [12]. By adding a reflector, the unidirectional radiation pattern can be achieved [13], [14]. The performance of the proposed array is illustrated in the following section.

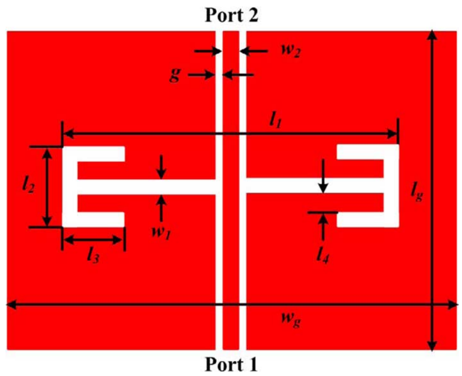

Fig. 3. Geometry and dimension of CPW-fed slot element.

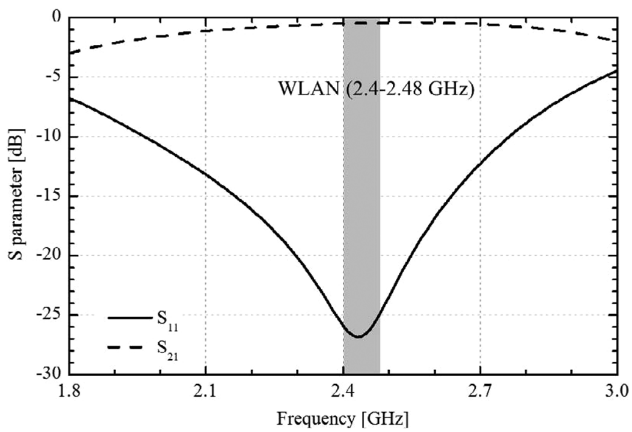

Fig. 4. Simulated S parameters of the CPW-fed slot element.

TABLE I
DETAILED DIMENSIONS OF ELEMENTS (UNIT: mm)

l_1	l_2	l_3	l_4	l_g	w_g	w_1	w_2	g
70	17	18	4	80	100	3	3	0.2

A. CPW-Fed Slot Element Design

In this part, we will examine the performance of the CPW-fed slot element. The slot is cut on the outer conductor of the CPW transmission line. In order to excite a series-fed slot array, the traveling wave is required on the CPW transmission line. As shown in Fig. 3, the length of $l_1/2 + l_2/2 + l_3$ is 61.5 mm, approximately half the wavelength on the substrate at 2.4 GHz. Therefore, a virtual short boundary condition appears at the position of the slot. However, due to space limitation, the H-shaped slot is used and folded at the end. The proposed H-shaped slot element is fed through Port 1. The values of each parameter are optimized by using the Ansoft High-Frequency Structure Simulator (HFSS) software. The detailed values are listed in Table I. The size of the ground has little effect on the performance of the slot. For a large scaled series-fed array design, the radiated energy of each element must be controlled according to the gain specification. For this design, the simulated optimized S parameters of the slot element are shown in Fig. 4. In the WLAN band of 2.4–2.48 GHz, the reflection coefficient (S11) fluctuates from -24.8 dB to -26.8 dB and the S21 fluctuates from -0.52 dB to -0.46 dB.

B. Series-Fed CPW-Based Slot Array

Based on the CPW-based slot element, we have built a series-fed array, as shown in Fig. 5. The distance between two adjacent slot element centers is 92 mm, which is one guided wavelength of CPW at 2.4 GHz on the substrate, also 0.736 wavelengths in the free space. The

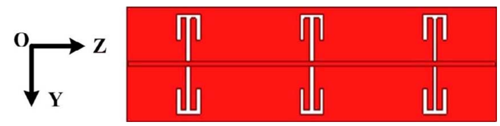

Fig. 5. Geometry of the CPW-based series-fed slot array.

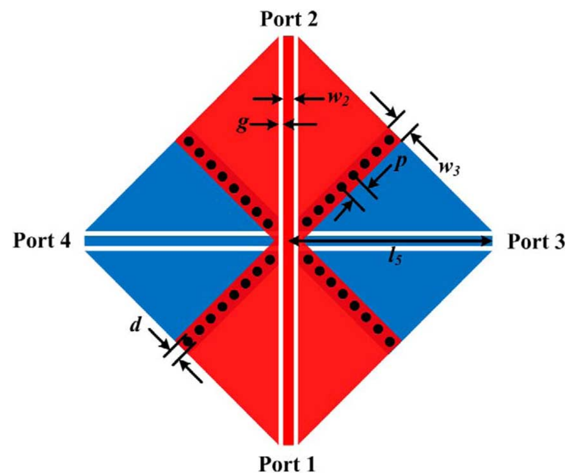

Fig. 6. Geometry and dimensions of the CPW-fed crossover.

other dimensions of the slots use the values of Table I. When the antenna array operates at the frequency near 2.4 GHz, all the slot elements are fed with equal amplitude and equal phase, which can be treated as a standing-wave array. Broadside radiation pattern is achieved at this frequency. In the theory of periodic leaky-wave antennas, operating at this frequency corresponds to operating at the "open stopband" point, where the attenuation constant is zero. For an infinitely long structure, this would also correspond to operating at a point where the input impedance becomes purely reactive, and hence no power can be fed into the structure. However, for a finite-length structure, operating at this frequency corresponds to practical broadside radiation, and an input match is easily achievable at this frequency for this structure, just as it is with other types of standing-wave arrays such as waveguide-fed slot arrays. As the frequency is changed from the broadside frequency the beam will begin to scan, and the antenna will then operate as a leaky-wave antenna. The input match will change rapidly as the frequency is scanned through broadside however, as is typical with most periodic leaky-wave antennas (unless the leaky-wave antenna has been specifically designed to allow for smooth scanning through broadside, by using metamaterial concepts or other methods). A leaky-wave antenna typically requires a load at the end to absorb the remaining (non-radiated) power, while a standing-wave array requires no load at the end. Although the structure here could easily be designed to operate as a leaky-wave antenna radiating at some arbitrary specified beam angle by including a load at the end and changing the frequency, this is not the subject of the present investigation. The focus here is on broadside radiation, with the structure operating as a standing-wave array.

C. CPW-Based Crossover Design

The leaky slot elements are connected by the CPW-based crossover, which is shown in Fig. 6. The red and blue areas are the front and back of the substrate board, with an overlap area, and connected by four lines of vias. The width of the overlap part w_3 is 4 mm. The diameter of the vias (d) is 1 mm and pitch (p) between vias is 2 mm. The value of l_5 is 25 mm. The simulated S parameters are shown in Fig. 7. In the band of 2.4–2.48 GHz, the reflection coefficient (S11) is lower than -23 dB. The transmission coefficient (S21) is higher than -0.1 dB.

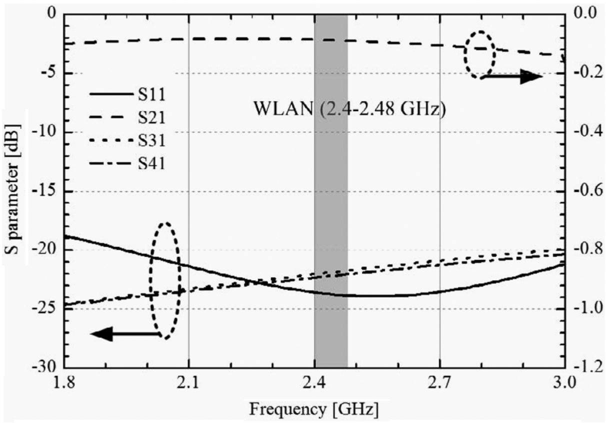

Fig. 7. Simulated S parameters of the CPW-based crossover.

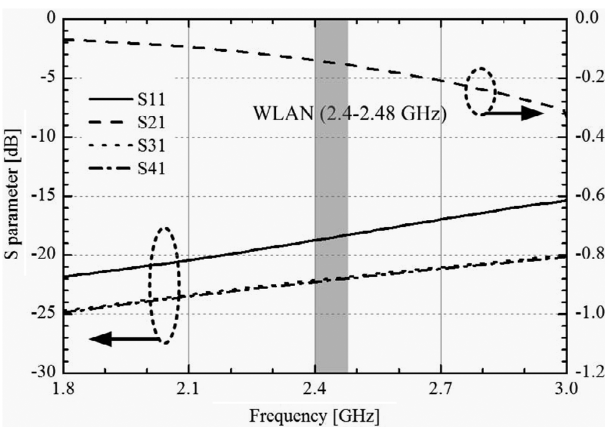

Fig. 8. Simulated S parameters of the CPW-based crossover without vias.

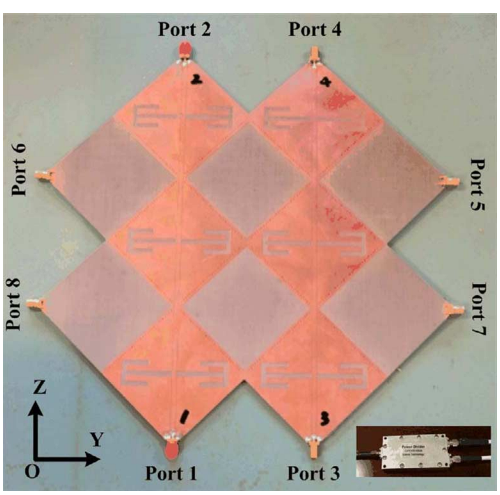

Fig. 9. Photograph of the proposed array.

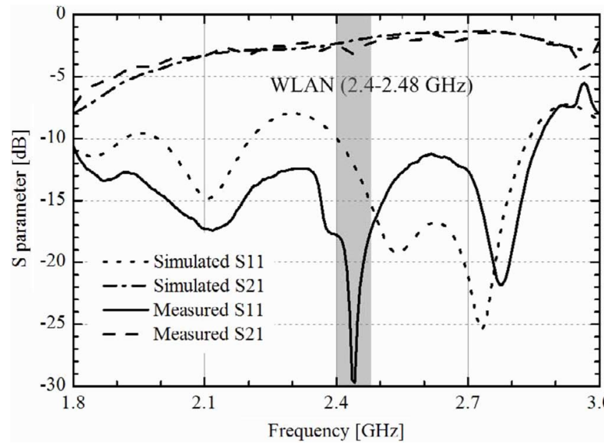

Fig. 10. Measured and simulated S11 and S21 of the proposed array.

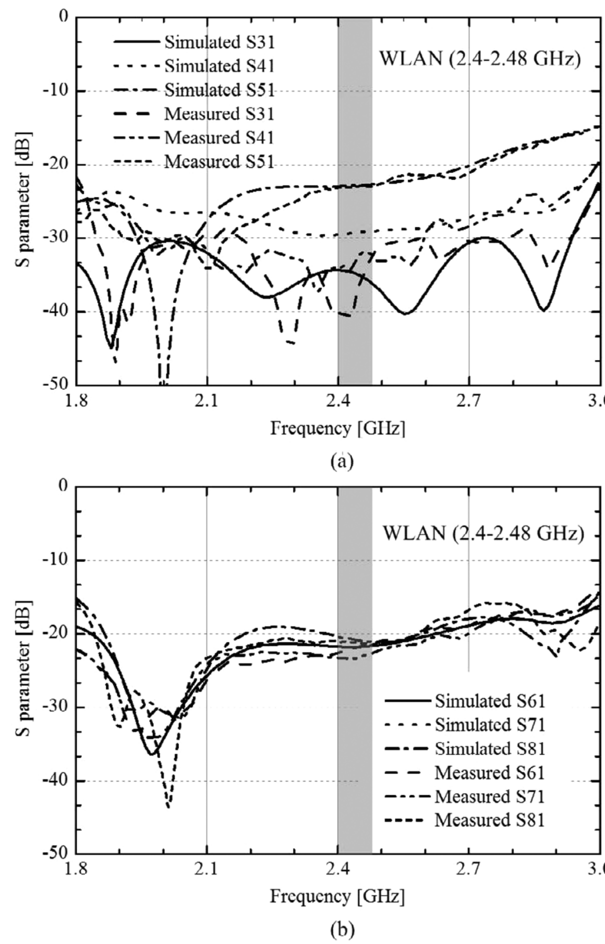

Fig. 11. Simulated and measured ports isolation, Port 1 with (a) Port 3, 4, 5; (b) Port 6, 7, 8.

For the ports isolation, S31 and S41 are both lower than −22 dB. From the results, we can see that good performance is achieved by using the proposed CPW-based crossover.

For slot antenna array, each piece of ground should be connected by vias to provide equal electric potential for each slot. We also examine the CPW-based crossover without using the vias. The simulated S parameters are shown in Fig. 8. Comparing with the results in Fig. 9, the reflection coefficient increases and the transmission coefficient decreases.

III. Experimental Results

To validate the design concept, a prototype of the proposed dual-polarized array is built and measured. Fig. 9 shows a 12-element array with a 3×2-element for each polarization. The dimensions of each element use the values listed in Table I. The distance between two adjacent element centers is 92 mm, for both z and y directions. This value is one wavelength of CPW at 2.4 GHz on the substrate. Therefore, all elements are excited in-phase by the CPW transmission line.

The measured S parameters are shown in Figs. 10 and 11, which agree well with the simulated results. The antenna array is fed though

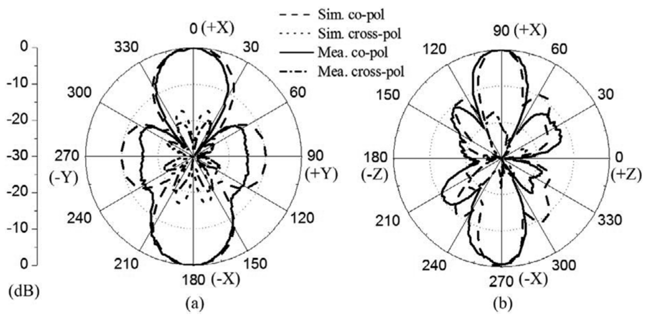

Fig. 12. Simulated and measured normalized radiation pattern of the proposed array at 2.4 GHz, (a) xy-plane, (b) xz-plane.

port 1 and loaded at other ports. As shown in Fig. 10, in the band of 2.4–2.48 GHz, the reflection coefficient is lower than -18 dB and the transmission coefficient is from -2.6 dB to -3.2 dB. For the port isolation, as illustrated in Fig. 11, all are lower than -20 dB in the WLAN band.

For this prototype, a 1-to-2 power divider (shown in Fig. 11) is employed to feed the array through Port 1 and Port 3 in the radiation pattern measurement. In the band of 2.4–2.48 GHz, the transmission coefficient of the power divider is better than -3.2 dB and the reflection coefficient is lower than -25 dB. The measured normalized radiation patterns in xy-plane and xz-plane at 2.4 GHz are shown in Fig. 12(a) and (b). Bidirectional patterns are achieved with the sidelobe level lower than 10 dB. In xy-plane, the 3-dB beam width is $40°$ along $+\mathrm{x}$ and $-\mathrm{x}$ directions. In xz-plane, the 3-dB beam width is $20°$ along $+\mathrm{x}$ and $-\mathrm{x}$ directions. The cross-polarization level is 16 dB lower than the co-polarization one. The measured results agree well with the simulated ones.

At 2.4 GHz, the simulated directivity, gain and realized gain of the 3×2-element array for each polarization are 11.54 dBi, 11.44 dBi, and 6.35 dBi, respectively. The radiation efficiency is only 30.3% accounting for the input mismatch. This could be improved by using a matching network, but this was not done here. This is due to the open-stop band effect of the series-fed array. The radiation efficiency that does not include the mismatch (and only accounts for the dielectric and conductor loss) is 97.7%. The measured realized gain at 2.4 GHz is 6.05 dBi, which agrees well with the simulated one.

IV. Conclusion

In this communication, we have presented a 2-D scalable dual-polarized series-fed slot array. This structure is similar to a leaky-wave antenna, but it operates as a standing-wave array so that broadside radiation is easily achievable and there is no need for a load at the end of structure. Compared with previous dual-polarized array design, there are three advantages obtained from the proposed array simultaneously. The first is that the proposed array can expand along two orthogonal directions, without introducing any complexity of the dual-polarization feed. The second is that only one layer of substrate board is used for radiating apertures and feeding network, making the overall dual-polarized array low cost. The third is that the horizontal polarized array is properly arranged in the space of the vertical polarized array by employing CPW-based crossovers, making the overall dual-polarized array compact with good port isolation.

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References

[1] M. Barba, "A high-isolation, wideband and dual-linear polarization patch antenna," *IEEE Trans. Antennas Propag.*, vol. 56, no. 5, pp. 1472–1476, Aug. 2008.

[2] K. Mak, H. Wong, and K. Luk, "A shorted bowtie patch antenna with a cross dipole for dual polarization," *IEEE Antennas Wireless Propag. Lett.*, vol. 6, pp. 126–129, 2007.

[3] Y. Li, Z. Zhang, W. Chen, Z. Feng, and M. F. Iskander, "Dual-mode loop antenna with compact feed for polarization diversity," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 95–98, 2011.

[4] C. Lee, S. Chen, and P. Hsu, "Isosceles triangular slot antenna for broadband dual polarization applications," *IEEE Trans. Antennas Propag.*, vol. 57, no. 10, pp. 3347–3351, May 2009.

[5] Y. Li, Z. Zhang, W. Chen, Z. Feng, and M. F. Iskander, "A dual-polarization slot antenna using a compact CPW feeding structure," *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 191–194, 2010.

[6] C. Song, A. Mak, B. Wong, D. George, and R. Murch, "Compact low cost dual polarized adaptive planar phased array for WLAN," *IEEE Trans. Antennas Propag.*, vol. 53, no. 8, pp. 2406–2416, Aug. 2005.

[7] H. Wong, K. G. Lau, and K. Luk, "Design of dual-polarized L-probe patch antenna arrays with high isolation," *IEEE Trans. Antennas Propag.*, vol. 52, no. 1, pp. 45–52, Jan. 2004.

[8] S. Gao and A. Sambell, "Low-cost dual-polarized printed array with broad bandwidth," *IEEE Trans. Antennas Propag.*, vol. 52, no. 12, pp. 3394–3397, Dec. 2004.

[9] D. Pozar and S. Targonski, "A shared-aperture dual-band dual-polarized microstrip array," *IEEE Trans. Antennas Propag.*, vol. 49, no. 2, pp. 150–157, Feb. 2001.

[10] G. Vetharatnam, C. Kuan, and C. Teik, "Combined feed network for a shared-aperture dual-band dual-polarized array," *IEEE Antennas Wireless Propag. Lett.*, vol. 4, pp. 297–299, 2005.

[11] H. lwasaki, "Slot-coupled back-to-back microstrip antenna with an omni- or a bi-directional radiation pattern," *IEE Proc.—Microw. Antennas Propag.*, vol. 146, no. 3, pp. 219–223, June 1999.

[12] T. Pham, Y. Liang, A. Nallanathan, and H. Garg, "Optimal training sequences for channel estimation in bi-directional relay networks with multiple antennas," *IEEE Trans. Commun.*, vol. 58, no. 2, pp. 474–479, Feb. 2010.

[13] A. Weily and Y. Guo, "Circularly polarized ellipse-loaded circular slot array for millimeter-wave WPAN applications," *IEEE Trans. Antennas Propag.*, vol. 57, no. 10, pp. 2862–2870, Oct. 2009.

[14] R. Bayderkhani and H. Hassani, "Wideband and low sidelobe slot antenna fed by series-fed printed array," *IEEE Trans. Antennas Propag.*, vol. 58, no. 11, pp. 3898–3904, Dec. 2010.