A Low-Cost Dual-Polarized Array Antenna Etched on a Single Substrate

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***Abstract*—In this letter, a four-leaf clover slot element antenna, which has a planar feeding structure, is proposed for dual-polarization applications. A four-element array based on the proposed antenna is designed and measured. The feeding network and radiators of the array are on the same substrate, which results in low-cost and convenient fabrication. The bandwidths of two polarizations are 275 and 465 MHz, respectively. The isolation between the two ports is greater than 30 dB, and the front-to-back ratio is higher than 25 dB.**

***Index Terms*—Array antenna, dual-polarized, high isolation, slot antenna.**

I. Introduction

DUAL-POLARIZED antennas have drawn much attention in modern mobile communication systems because they are capable of providing two independent channels to enhance the channel capability on a single antenna and can also deal with the multipath fading problems. In the design of dual-polarized antennas, isolation, bandwidth and unidirectional radiation are important considerations. However, to our knowledge, most of the designs of the feeding structures are very complex.

Patch [1]–[7] and slot [8], [9] are two major types of antenna to realize dual polarization. To achieve high isolation and wide bandwidth, different feed mechanisms are applied to patch antenna design. An L-shaped probe and a near-resonant aperture were applied to excite two orthogonal modes of a suspended patch [1]. Two L-shaped probes with a coupled-line directional coupler were also used in [2] to improve the isolation. Slot-coupled patches were studied in [4] and [5], which had at least two substrates and were bidirectional radiation. Others such as stacked patches were proposed in [3] and [6], which needed more substrates. It can be noted that in most of the designs of the patch antennas, feeding structures were complex and fabrications were inconvenient. Another patch antenna with two pairs of T-shaped slots on two bowtie-shaped patches was proposed in [7], and the coaxial lines were used to excite the patches. Although the structure is simpler than that proposed in previous work [1]–[6], it still requires a three-dimensional feeding structure.

When compared to a patch antenna, the slot antenna is a better candidate for planar feeding structure. An isosceles triangular slot antenna was proposed in [8]. Two orthogonal microstrip lines were used to excite the TE_{10} and TE_{01} modes. However, its cross radiation was poor, and it was designed for bidirectional applications. Another rectangular slot excited by coplanar waveguide (CPW) feeding structure was discussed in [9], which faced the same issues as the one proposed in [8].

In this letter, a low-cost dual-polarized array antenna has been proposed. The array and its feeding network were fabricated on a single substrate, which resulted in extremely low cost in both material and labor. In the first part of Section II, a single element of the proposed array, a dual-polarized four-leaf clover slot element antenna, is studied. The element antenna demonstrates high isolation, wide bandwidth, and unidirectional radiation. In the second part of Section II, the design of the array is discussed. Measured results of a four-element array are given in Section III.

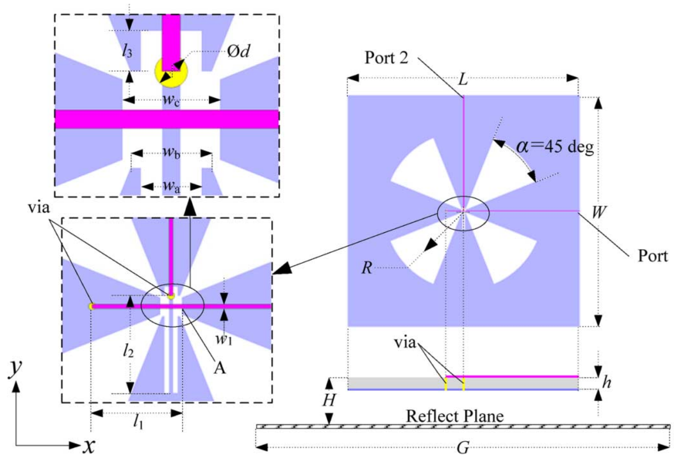

Fig. 1. Geometry and description of the proposed element antenna.

II. Antenna Description and Design

A. Element Antenna

The geometry of the proposed element antenna is shown in Fig. 1. The element is made of a 1-mm-thick FR-4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) with an area of 120×120 mm^2. A

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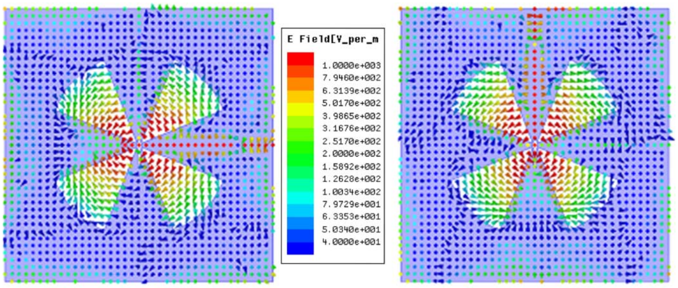

Fig. 2. Electric field distribution of element antenna at 2.5 GHz: fed from (a) Port 1 and (b) Port 2.

TABLE I
ANTENNA PARAMETERS

Parameter	L	W	G	H	h	R	d
Value (mm)	120	120	300	20	1	41	0.8
Parameter	l_1	l_2	l_3	w_1	w_a	w_b	w_c
Value (mm)	10	11	1	0.45	1.5	2	2.4

reflect plane, whose size is 300×300 mm^2, is placed 20 mm below the top surface of the printed circuit board (PCB). The bottom layer of the PCB is covered by copper and four-leaf clover-shaped slots with radius R and angle α etched on it, serving as the radiation aperture and leaving the other part of the copper as the ground of the microstrip line. This geometry is convenient for the deployment of the feeding network of the array antenna, which will be addressed later. Two orthogonal feedlines are printed on the top layer to generate 0° and 90° polarization. The microstrip line fed from Port 1 is directly shorted to the bottom layer through a via, while the other one fed from Port 2 is connected to a shorted CPW with length l_2. Detailed values of each parameter are listed in Table I.

Fig. 2 depicts the electric field distribution at 2.5 GHz fed from two ports. As shown in Fig. 2(a), when Port 1 is exited and Port 2 is terminated with a match load, the electric fields in the four-leaf clover-shaped slots cancel out with each other along y-direction, and the final electric field is along the x-direction, which generates 0° polarization. Similarly, when Port 2 is exited, 90° polarization is obtained.

B. Impedance Matching

The center region of the element, whose dimensions are also presented in Fig. 1, serves as the matching impedance of the two polarizations, which is realized by tuning length l_1 and l_2, respectively. Fig. 3 shows the impedance curves of 0° polarized element antenna at Reference point A, as illustrated in Fig. 1. As length l_1 increases, the impedance curve moves almost along the $r_L = 1$ circle toward the matching point on the Smith chart. Due to the consideration of convenience of array design, 120 Ω was selected as the normalized impedance.

Here, the shorted feeding line l_1 is equivalent to a series inductance, as shown in Fig. 3, pulling the impedance curve from capacitive plane toward the inductive plane along the constant r_L circle on the Smith chart [10]. With increasing l_1, the equivalent inductance value will be greater, and the distance traveled by the impedance curve on the Smith chart will be longer. The shorted CPW line l_2 has the same matching characteristic as l_1

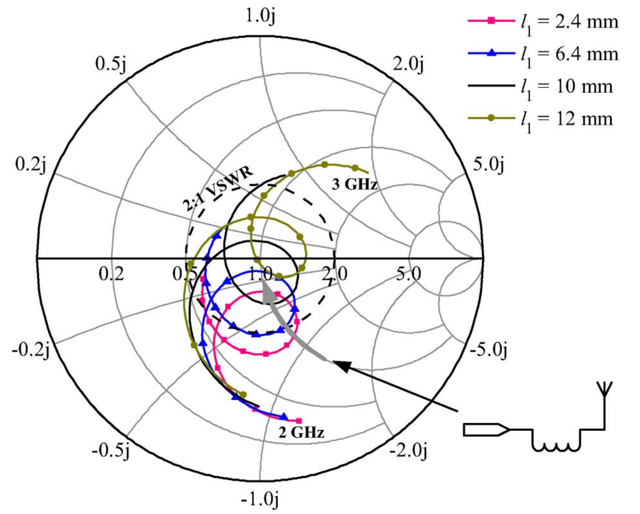

Fig. 3. Impedance curves of 0° polarized element antenna on Smith chart with different l_1 (fed at point A as shown in Fig. 1, normalized impedance value equals 120 Ω).

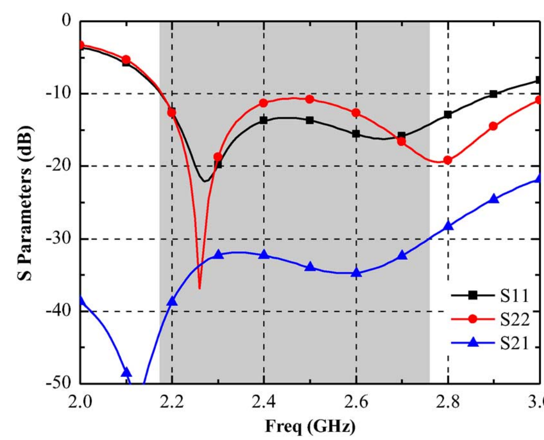

Fig. 4. Simulated S-parameters of the proposed element antenna (normalized impedance value equals 120 Ω).

for matching the 90° polarized counterpart, which will not be discussed in this letter.

The simulated S-parameters, obtained by using Ansoft High Frequency Structure Simulator (HFSS), are depicted in Fig. 4. A bandwidth of 580 MHz (2.18–2.76 GHz) with a return loss of 10 dB and isolation of 30 dB could be achieved.

C. Array Antenna

A four-element array antenna based on the mentioned element antenna is illustrated in Fig. 5(a). The element spacing has been chosen to be $0.73\lambda_{2.5\text{ GHz}}$ to avoid the overlap between two adjacent elements as well as the grating lobes. As the leaf-shaped slots occupy only a part of the substrate, there exists enough room on the edge of the board, which can be used to deploy the microstrip lines. As can be seen from the figure, the feeding network is printed on the top layer of the substrate. The overall size of the array antenna is 384×123 mm^2 (3 mm wider on the Port-1 side for SMA connecting), and the reflect plane is 564×300 mm^2. As we need to ensure the impedance of the array to be 50 Ω to connect the SMA, the feeding network

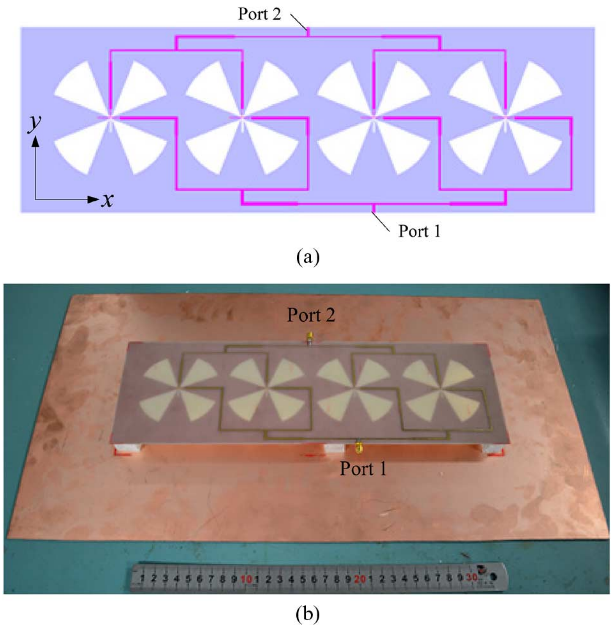

Fig. 5. Dual-polarized array antenna: (a) Top view. (b) Prototype.

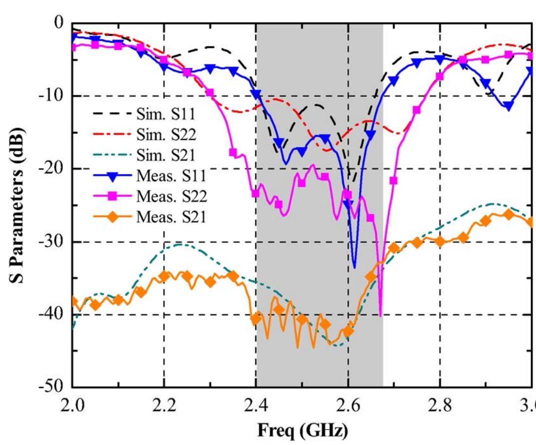

Fig. 6. Measured and simulated S-parameters of the proposed array antenna.

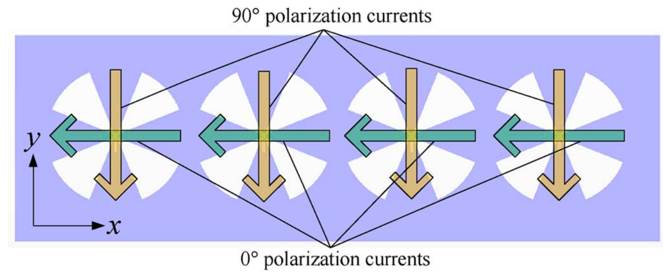

Fig. 7. Current direction of the two polarizations on each element.

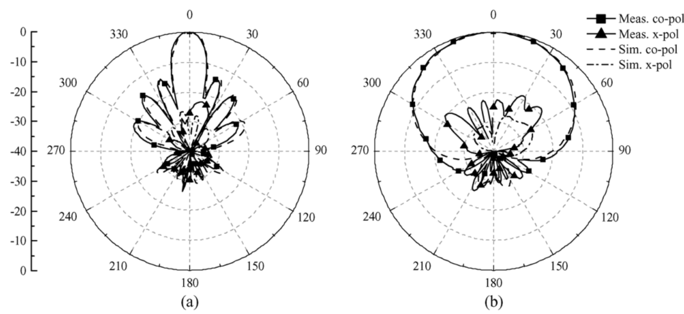

Fig. 8. Measured and simulated radiation patterns of Port 1 feeding at 2.5 GHz: (a) xz-plane; (b) yz-plane.

should achieve the impedance transformation from four 120 Ω to a single 50 Ω.

As the coupling between these element antennas is strong in the same direction of polarization, which will be discussed in Section III, the impedance characteristics of the element antennas are different from that of the single one. Therefore, we extract the parameters of the characteristic of the ports and design and optimize the feeding network as a whole by circuit design software. Strong coupling also results in different degrees of deterioration for the two polarizations, which can be noted from the simulated S-parameters shown in Fig. 6.

III. Measurement Results and Discussion

To validate the array design, a prototype of the four-element array antenna, as shown in Fig. 5(b), was fabricated and measured.

Fig. 6 depicts the comparison of the measured S-parameters to the simulated ones. As can be seen from the figure, the bandwidths of -10-dB reflection coefficient are 275 MHz (2.4–2.675 GHz) and 465 MHz (2.305–2.77 GHz) for Port 1 (0° polarization) and Port 2 (90° polarization), respectively. The isolation between the two ports is more than 30 dB throughout the required band.

As mentioned earlier, the bandwidth of 0° polarization is seriously reduced due to the strong coupling. However, it could still cover the WLAN and LTE bands. For the case of 90° polarization, bandwidth reduction is not as severe as that of 0° polarization. The reason for the strong coupling can be explained by the current distribution at the bottom layer of the PCB, as shown in Fig. 7. For 0° polarization, the electric currents of each element antenna are along x-direction. The currents are in phase and connected end-to-end to their neighbors, leading to strong current coupling between two adjacent elements. Therefore, active S-parameters must be taken into account when studying the element antenna. The simulated results show that the bandwidth obtained from active S_{11} (element in an array) is much narrower than that from passive S_{11} (standalone element). For 90° polarization, however, the currents are along y-direction, and two adjacent currents are in parallel with each other with a distance of element spacing. Furthermore, the distance makes the coupling weaker than that of 0° polarization. Hence, the deterioration is not as severe as that of 0° polarization.

The measured and simulated radiation patterns of the proposed array antenna when feeding from Port 1 and Port 2 on xz-plane and yz-plane are shown in Figs. 8 and 9. It can be seen that cross polarization is lower than -25 dB of the simulated result and -18.7 dB of the measured result. The front-to-back ratios of simulated and measured results are better than 25 dB for both the ports.

Fig. 10 shows the measured and simulated gain of the proposed array antenna. The gain difference between the two polarizations is mainly due to their different arrangements

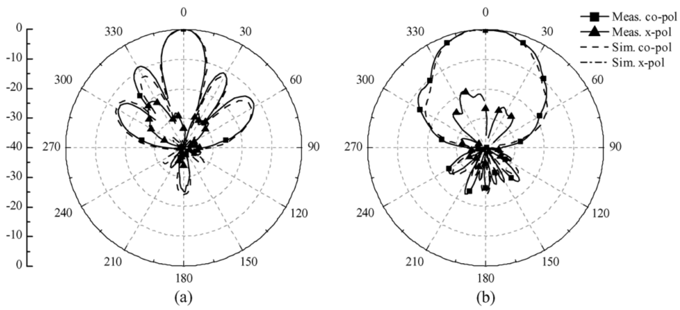

Fig. 9. Measured and simulated radiation patterns of Port 2 feeding at 2.5 GHz: (a) xz-plane; (b) yz-plane.

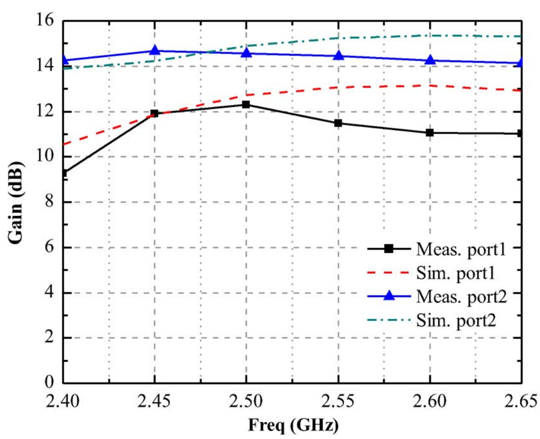

Fig. 10. Measured and simulated gain of the proposed array antenna.

along the x- and y-direction. To validate this assumption, we simulated two kinds of four-element dipole arrays with the same element spacing along the x-direction as the proposed array. One of the two arrays had its dipoles parallel to the x-axis, and the other one was parallel to the y-axis. The simulated results showed that they had an average gain difference of about 2.9 dB, which is similar to our proposed array. It is worth noting that the coupling between adjacent elements in the dipole arrays was not strong, which demonstrates that coupling is not responsible for the gain difference in our proposed array. However, it can be seen from Fig. 10 that the simulated gain is different from the measured one when the frequency is above 2.5 GHz, which might result from the anechoic chamber that has calibration data only up to 2.5 GHz.

IV. CONCLUSION

A dual-polarized antenna with integrated feeding network is proposed and a four-element array antenna was proposed, fabricated, and measured. The bandwidth of the element itself was 580 MHz, while that one of the array deteriorated due to the strong coupling between the elements. However, the isolation maintained was greater than 30 dB, and front-to-back ratio was higher than 25 dB. This array antenna can be used in a base station for WLAN and LTE applications. As the whole array could be constructed on a single PCB, this structure could bring much benefit with respect to manufacturing and fabrication. The array with the feeding network is manufactured by one-step photo-etching progress, ensuring consistency of the final products. In mass production, one only needs to solder two SMA connectors and put the array above a metal board, which is extremely convenient and reduces the errors introduced by fabrication.

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