A Planar Wideband Dual-Polarized Array for Active Antenna System

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***Abstract*—A $\pm 45^\circ$ polarized wideband slot array antenna is proposed for active antenna system (AAS). The proposed array has a planar structure that integrates all the elements on a single substrate. Metal columns are used to reduce the coupling between adjacent elements. A prototype of a 2×2 array antenna is fabricated and measured. The measured results show that the proposed array covers the bands LTE2300 (2300–2400 MHz) and LTE2500 (2500–2690 MHz), and the polarization isolation is higher than 30 dB while the coupling between elements is less than -22 dB.**

***Index Terms*—Active antenna system (AAS), array antenna, dual polarization, slot antenna, wideband.**

I. Introduction

In RECENT years, active antenna system (AAS) has been proposed as a new technology for cellular base stations [1] and has received much attention from the industry [2], [3]. In traditional base stations, element antennas in an array antenna are connected together along vertical direction, and they are fed with fixed power ratio and relative phase to compress the vertical beam and enhance the broadside gain. In a multiple-input–multiple-output (MIMO) system, multiple arrays are configured in horizontal direction to enhance the channel capacity. However, as the beam in vertical direction has a fixed tilt angle, beamforming or precoding technology can be only realized by horizontal channel information.

In contrast, each element antenna in AAS is integrated with low-power RF transceivers and can be controlled independently. Therefore, the AAS can fully utilize the horizontal and vertical domain of the array's beam pattern by feeding each element with different power and phase. The AAS could obtain many benefits including capacity enhancement, improved network availability, higher energy efficiency, and so on [2], [3]. AAS is also the basis for the 3-D/Massive MIMO technology [4]. Antenna design is an important part of AAS; it needs good integrated feature for RF components, high port isolation, low element coupling, and low cost.

Dual-polarized antenna with the capability of enhancing the channel capacity has been the basic configuration for base stations in the past years, and it is still the requirement for the AAS. Patch antenna with various feeding methods has been a hot research topic in the past [5]–[7]. However, to achieve wideband characteristic, the structures in these antennas are complex, and implementations are inconvenient. The slot antenna is a better alternative due to its planar structure [8], high port isolation [9], as well as wideband characteristic [10]. To achieve unidirectional radiation for base-station applications, a slot array antenna backed with a reflector is proposed in [11]. With the integration of radiators and feeding networks, the proposed array in [10] benefits low-cost and easy fabrication. However, strong coupling between elements deteriorates its performance.

In this letter, we present a novel planar dual-polarized array antenna. Metal columns are implemented around the element to reduce the coupling between elements. The rest of this communication is organized as follows. Section II describes the design of both element and array antennas. Section III discusses the effect of the metal columns on element coupling. Measured results and conclusions are given in Sections IV and V, respectively.

II. Antenna Design

A. Element Antenna

Fig. 1 shows the geometry of the element antenna from the perspective, top, and side views. The proposed structure is composed of a printed circuit board, a copper plate, and 16 metal columns. The substrate of the printed circuit board is FR4-epoxy with permittivity $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.02$, and thickness $t = 1$ mm. A ring slot along with four narrow slots are etched on the ground plane, serving as the radiator. The ground is printed on the bottom layer of the substrate, while the feeding lines are printed on the top. The crossover of the feedlines from the two ports is shown in the inset of Fig. 1, which is made of two via holes and a short strip on the bottom layer, and such a structure finally integrates the feedlines and radiators on a single substrate.

As the pattern of a slot antenna is bidirectional, a square copper plate is put under the antenna with a distance h, serving as a reflector to realize the unidirectional radiation. The metal columns are hexagon copper pillars and they serve as the support for the FR4 substrate as well as a method to reduce the coupling between the adjacent elements in array antenna. The

Manuscript received January 16, 2014; revised March 03, 2014; accepted March 10, 2014. Date of publication March 12, 2014; date of current version April 02, 2014. This work was supported by the National Basic Research Program of China under Contract 2013CB329002, in part by the National High Technology Research and Development Program of China (863 Program) under Contract 2011AA010202, the National Natural Science Foundation of China under Contract 61271135, the National Science and Technology Major Project of the Ministry of Science and Technology of China under Grant 2013ZX03003008-002, and the China Postdoctoral Science Foundation under Project 2013M530046. *(Corresponding author: Z. Zhang)*

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Digital Object Identifier 10.1109/LAWP.2014.2311583

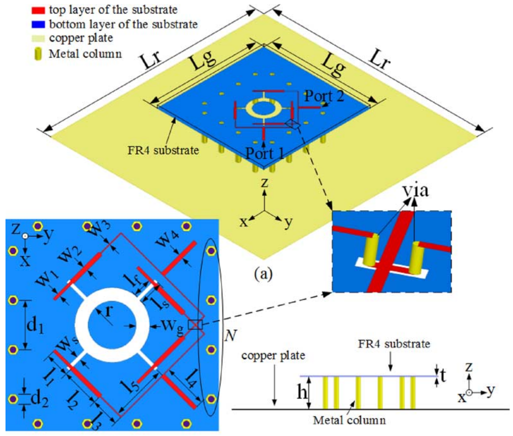

Fig. 1. Geometry of the element antenna: (a) perspective view; (b) top view; (c) side view.

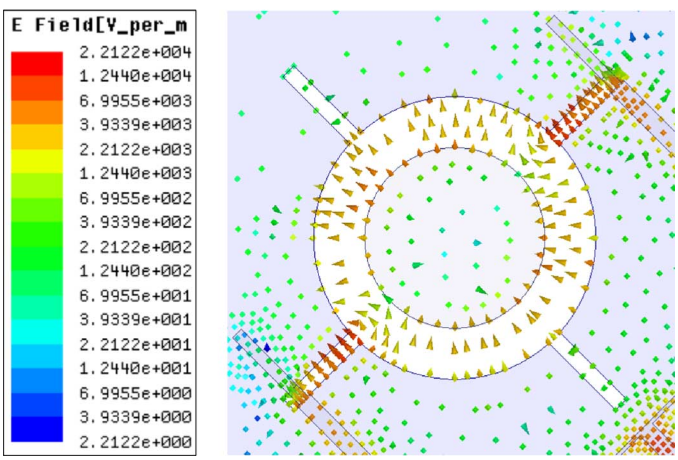

Fig. 2. Electric field distribution when only port 1 is excited.

effect of the metal columns, especially the number N, will be explicitly discussed in Section III.

The feeding mechanism is similar to that in [10]. The microstrip lines first excite the narrow slots and then couple to the ring slot. Fig. 2 shows the electric field distribution in the ring slot at 2.4 GHz. Considering the symmetry of the structure, it shows only the case when port 1 is excited. From the figure, we can see that the field in the slot is similar to that of the TE_{11} mode in a coaxial line, and its total field can be regarded as resonating along the direction of $\varphi = 45°$, thus generating the 45° polarization in the broadside. Meanwhile for port 2, the field distribution can be obtained by counterclockwise rotating that of port 1 by 90°, so that it generates the other polarization along $\varphi = -45°$. Such favorable orthogonality of the field distribution for the two cases guarantees good isolation between the two input ports.

B. Array Antenna

A 2×2 array antenna based on the proposed element antenna is designed and studied in this letter, and its configuration is shown in Fig. 3. The metal columns are shared with adjacent element and the element space along both x- and y-direction is d. It shows that all of the eight ports are fed separately, and this is

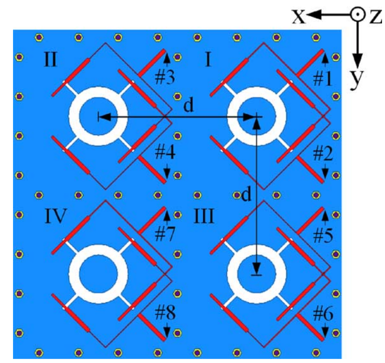

Fig. 3. Configuration of the array antenna.

the requirement for the application in AAS. Such feeding structure is also convenient to see the effect of the metal columns on the coupling between the adjacent elements.

It is worth noting that all the element antennas along with their feeding networks are printed on a single substrate, which could bring much benefit in manufacturing and fabricating. In addition, this configuration is scalable so that it could expand to a larger array with much more element antennas while keeping them still on a single substrate. As most of the area of this configuration is covered by a metal layer, it is good for heat dissipation in operating systems.

III. Discussion of Metal Columns

In order to simplify the discussion and decrease the computing cost, we investigate a two-element array antenna, that is, the upper half of the configuration with elements I and II in Fig. 3. Different numbers N of metal columns are studied: $N = 0$ (i.e., without columns), $N = 2$, $N = 4$, and $N = 6$ with the help of High Frequency Structure Simulator (HFSS ver. 14). The results are shown in Fig. 4(a)–(d). Return loss and three kinds of coupling are shown in this figure. $S_{11} \sim S_{44}$ represent the return loss for the four input ports. S_{12} and S_{34} represent the coupling of the orthogonal polarizations inside the element antenna. S_{13} and S_{14} represent the copolarization coupling between the two elements. S_{14} and S_{23} represent coupling of the orthogonal polarizations between the two elements. As can be seen from these figures, results of -10 dB return loss from any ports in any cases could almost cover bands LTE2300 and LTE2500. Thus, we will focus the discussion on the effect of metal columns on port coupling.

Fig. 4(a) shows the results when there is no metal column. All the three kinds of couplings are relatively high in this case. Polarization isolation inside the element also deteriorates due to the coupling between the elements. When there are two columns, coupling between elements is reduced to -20 dB. However, the polarization isolation inside the element is still lower than 30 dB. After four columns are used, the polarization isolation inside the element finally reaches 30 dB. However, performance would not be improved with more than four columns, as it is indicated by Fig. 4(d).

The metal columns in the proposed array are used to suppress the parallel-plate waveguide mode supported by the ground plate and reflect plate especially when height h is small. The vertical electric field around the vertical metal columns cannot

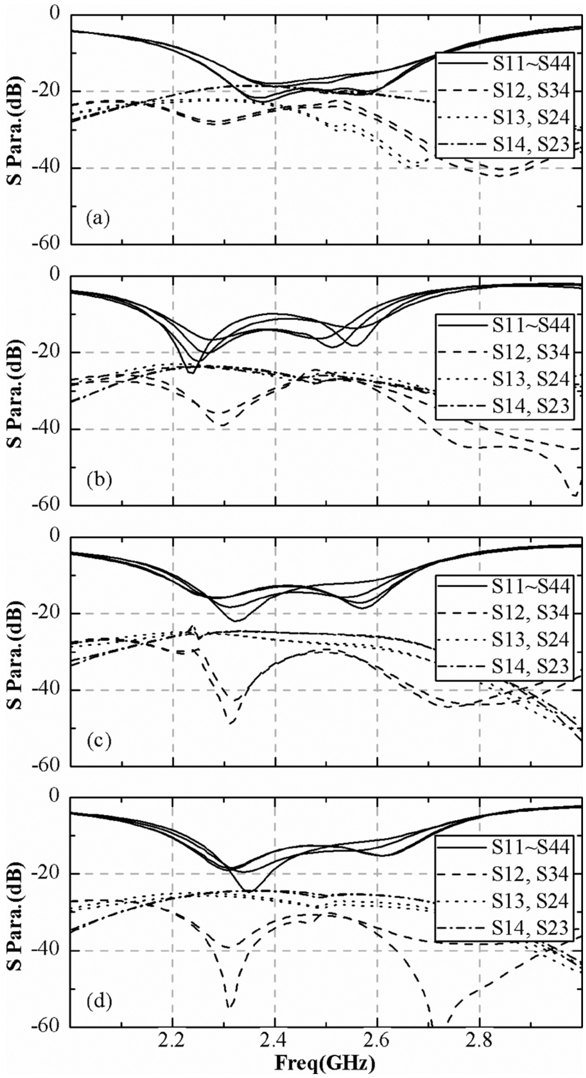

Fig. 4. Investigation on the effect of the metal columns: (a) $N = 0$ (without columns); (b) $N = 2$; (c) $N = 4$; (d) $N = 6$.

exist between the two plates, thereby effectively reducing the coupling from parallel plate and more columns lead to better results. However, space coupling above the antenna still exists, and that is why coupling between elements, as shown in Fig. 4(b)–(d), cannot be improved even with more columns.

Therefore, we use four columns in the proposed 2×2 array. A more important parameter to evaluate the coupling is the active S_{11} [12]. As the array is designed for beamforming in both horizontal and vertical directions, all the input ports with the same polarization will be fed simultaneously but with different power and phase for a specific pattern. Consequently, coupling coming from other ports will affect the impedance matching at one certain port. Fig. 5 shows the active S_{11} when ports #1, #3, #5, and #7 are fed with the same magnitude but different phases to direct the main beam to different directions. We suppose that the array steers the beam on the plane of $\varphi = 45°$, and the four exciting phases are obtained from the conjugate value of the simulated pattern phase of the electric filed at a specific fictitious angle. The results are given at two center frequencies in LTE2300 and LTE2500, respectively. The results show that

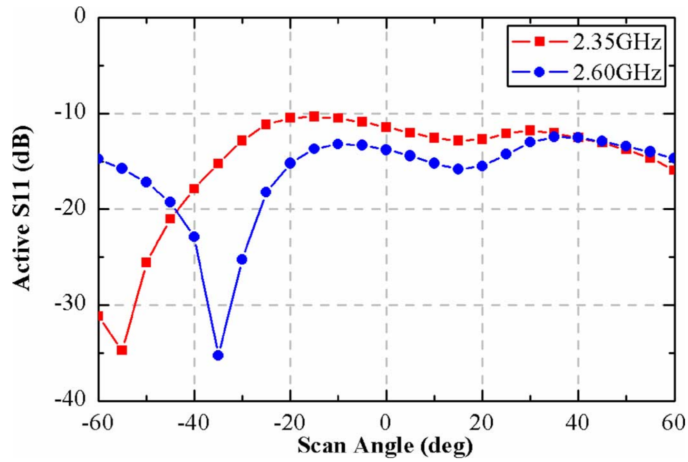

Fig. 5. Active S_{11} varies with different fictitious scan angles on the plane of $\varphi = 45°$.

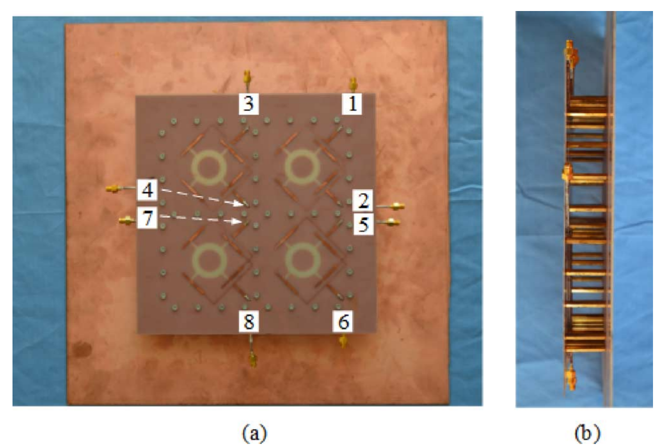

Fig. 6. Fabricated 2×2 array antenna prototype: (a) top view; (b) side view.

TABLE I
PARAMETERS OF ELEMENT ANTENNA

Parameter	Value	Parameter	Value	Parameter	Value
Lg	150	lf	9.5	w_1	1.5
Lr	300	ws	2	w_2	2.3
h	35	l_1	12.05	w_3	0.44
t	1	l_2	19.3	w_4	2.2
r	11.5	l_3	14	d_1	23.75
wg	6.5	l_4	22	d_2	4.7
ls	12	l_5	28	d	95

Unit: mm

all the values of the active S_{11} are below -10 dB for both the frequencies. Therefore, it demonstrates that using the metal columns around the element is an efficient way to reduce the element coupling, and this can be applied to large-scale arrays in the future.

IV. FABRICATION AND MEASURED RESULTS

The parameters of the element antenna for fabrication are listed in Table I, and a prototype of the 2×2 array antenna with element space $d = 95$ mm ($0.73\ \lambda_{2.3\ \mathrm{GHz}}$) is fabricated as shown in Fig. 6. The array antenna has a substrate of 245×245 mm^2 and a reflect plate of 395×395 mm^2. Eight semi-rigid cables are used to extend the input ports to the edge

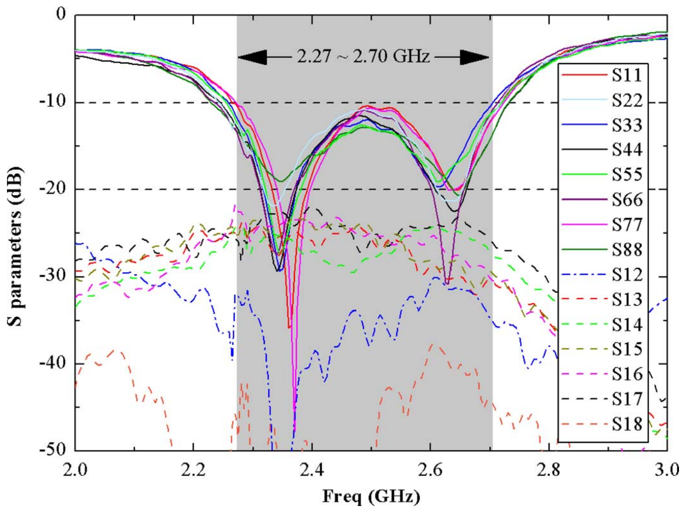

Fig. 7. Measured S-parameters of the proposed 2×2 array antenna.

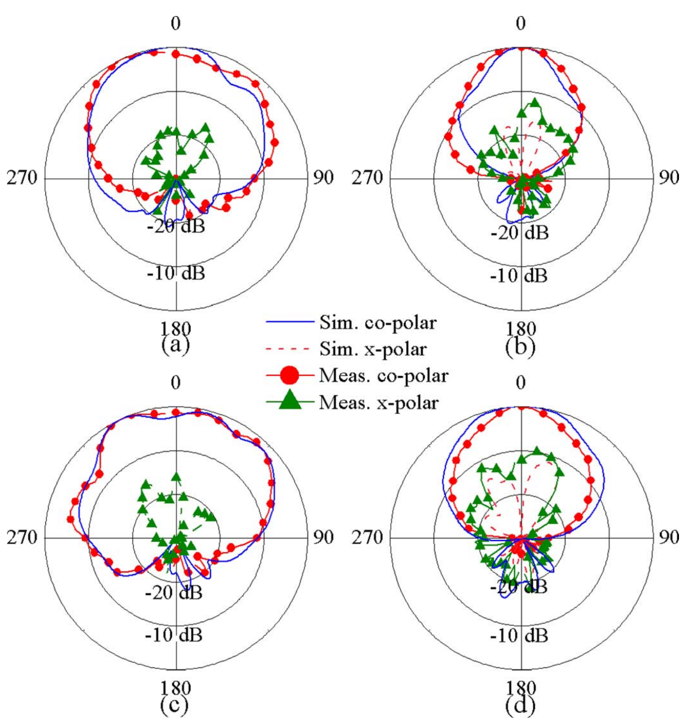

Fig. 8. Measured and simulated radiation patterns from port 1: (a) E-plane at 2.35 GHz; (b) H-plane at 2.35 GHz; (c) E-plane at 2.6 GHz; (d) H-plane at 2.6 GHz.

of the substrate for measurement. The substrate and the reflect plate are strewed to the hexagon copper pillars as shown in Fig. 6(b).

The S-parameters measured by Agilent E5071B network analyzer are shown in Fig. 7. Port distribution is labeled in Fig. 3. The results indicate that all of the eight ports have similar bandwidth and common frequency band is from 2.27 to 2.70 GHz, which means the proposed antenna could operate at communication standards LTE2300 (2300–2400 MHz) and LTE2500 (2500–2690 MHz). The measured results also show that the coupling between elements is less than -22 dB, and the polarization isolation inside the element is higher than 30 dB.

Fig. 8 shows the measured radiation patterns from port 1 at two center frequencies 2.35 and 2.6 GHz for LTE2300 and LTE2500, respectively. Simulated cross polarization on E-plane is too small to be seen in the figures. Due to the high isolation, other ports are opened when the pattern is measured at one port. The simulated patterns are also shown for comparison. The results show that the measured and simulated results agree well with each other. The measured gain for 2.3–2.7 GHz is between 6.0 and 7.6 dB, while the simulated gain is between 5.8 and 8.2 dB.

V. Conclusion

A planar wideband dual-polarized array antenna has been presented. It uses four metal columns to reduce the coupling between the elements. Simulated active S_{11} demonstrates the effectiveness of such method. Measured results show the array has a bandwidth in the frequency range 2.27–2.7 GHz, which covers two major LTE operating bands (LTE2300 and LTE2500) in China. Polarization isolation is higher than 30 dB, and element coupling is less than -22 dB. In mass production, the integrated design of antenna and feeding network on a single substrate could reduce the manufacturing cost and simplify the fabricating process. Stamping technology can be applied to produce a folded slice from the ground plate to replace the metal columns, which could also make the cost cheap and fabrication easy. In addition, large metal area in the proposed structure is good for heat dissipation. All these above features are suitable for the proposed array working in an active antenna system.

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