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# 20 GHz Dual-Polarized Array Antenna With Low Cross-Polarization and High Gain

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**Abstract**—In this paper, a dual-polarized  $8 \times 8$  antenna array with an orthomode transducer (OMT) is presented. To enable dual-polarization, the feed networks of the antenna array is incorporated into the subarray antenna design. A planar substrate integrated crossover is introduced in order to simplify the design and achieve high performance. Triple-resonance is excited in the subarray antenna. The proposed array antenna can work in the frequency bandwidth of 19.2–20.7 GHz. The measured results show that this antenna array has a cross-polarization level of  $-43$  dB, realized gain of 22.8 dBi and aperture efficiency of 51%. The designed dual-polarized antenna array can be used in the geostationary satellites that is able to radiate fixed beams illuminating areas with high density of users and devices.

**Keywords**—antenna array, crossover, dual-polarization, orthomode transducer (OMT), subarray antenna

## I. INTRODUCTION

In wireless communications, the antenna (or antenna array) able to operate with dual-polarization can significantly improve the system throughput and reliability [1], [2]. Besides, the dual-polarized wireless systems also show advantages in smaller size, lower cost, and lighter weight. In sub-mmWave and mmWave frequencies, due to the small size of the antenna elements, it is not easy to allocate all the feed networks into such a tiny footprint. However, it is noted that most of the reported dual-polarized antenna arrays feature prominently in high complexity, high cross-polarization level, low gain and high profile, etc [3], [4]. In this paper, a new approach of designing the low-complexity dual-polarized array antenna is developed. Unlike the conventional ones [5]–[7], the proposed design incorporates the feed networks into the subarray antenna design. The antenna array with dual-polarization is differentially driven by placing an OMT underneath its aperture. To exemplify and validate this design concept, the antenna array with  $8 \times 8$  antenna elements are designed, prototyped and tested. The proposed antenna array has simple structure, small size and low profile. Except that, this design also shows advantages in terms of low cross-polarization ( $> 43$  dB) and high gain ( $> 22.8$  dBi).

## II. $2 \times 2$ SUBARRAY ANTENNA

Fig. 1 shows the structure of  $2 \times 2$ -element subarray antenna. The subarray antenna is composed of four resonant patches which are placed inside a cylindrical cavity. The element separations are  $d_x = d_y = 0.68\lambda_0$ . The patch antennas

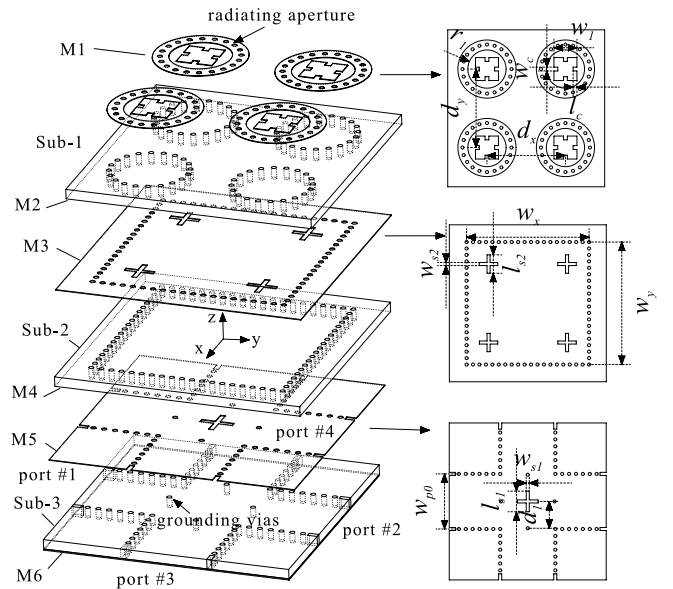


Fig. 1. Configuration of the dual-polarized  $2 \times 2$ -element subarray antenna.

are excited by the cross slots. Under the subarray, an SIW cavity supporting  $TE_{14}$  and  $TE_{41}$  modes is designed in Sub-2 to act as a four-way equal power splitter and excite the cross slots. Beneath the above structure, there is a crossover to enable the subarray antenna to be excited from the  $x$ -axis and  $y$ -axis direction for dual-polarization. To achieve high port isolation, four metallized vias are placed around the junction of the crossover. In the simulation, port #2 is short-circuited when port #1 is excited, to obtain the impedance characteristics of the subarray antenna [8].

The simulated  $S$ -parameters and realized gain of the subarray antenna are illustrated in Fig. 2. The subarray antenna resonates at 19.4 GHz, 19.8 GHz, and 20.3 GHz, respectively. The impedance bandwidth for  $|S_{11}| < -10$  dB is 19.3–20.5 GHz. Due to the existence of the four metallized vias around the crossover junction, the isolation between port #1 and #3 (or #4) is higher than 30 dB for  $f > 19.2$  GHz. The realized gain varying from 10.8 dBi to 12.2 dBi is obtained over the operation bandwidth 19.3–20.5 GHz. Fig. 3 presents the simulated radiation patterns of the subarray antenna. Symmetric co-polarization radiation patterns are obtained in both the E-plane ( $yo$ - $z$ -plane) and H-plane ( $xo$ - $z$ -plane). The

subarray antenna shows low cross-polarization level which is  $-58$  dB at the boresight. The front-to-back ratios of the co-polarization radiation patterns are higher than 17 dB in the E- and H-plane.

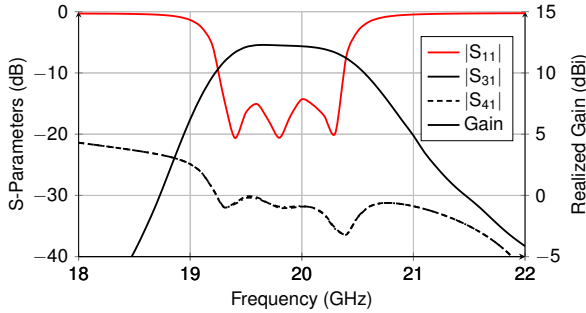


Fig. 2. Simulated  $S$ -parameters and realized gain of the subarray antenna.

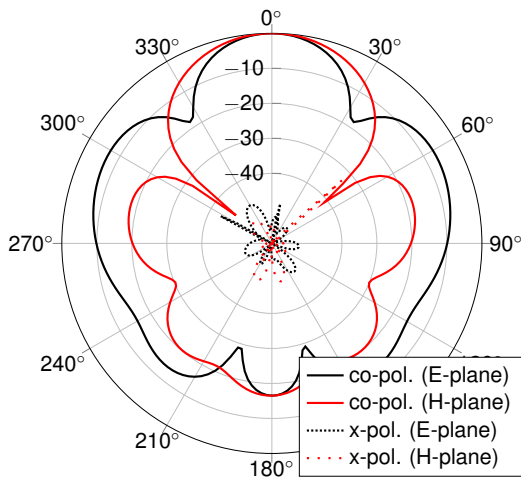


Fig. 3. Simulated far-field radiation patterns of the subarray antenna.

### III. $2 \times 8$ ANTENNA ARRAY WITH FOUR SUBARRAYS

From the above analysis, the  $2 \times 2$ -element subarray antenna has port isolation higher than 30 dB and thus it can be excited from the orthogonal directions for dual-polarization. To validate its performance in the antenna array, four  $2 \times 2$ -element subarray antennas with a series combination are investigated. Fig. 4 shows the simulated electric field inside the crossover structures and over the patch radiators of the four subarray antennas. In this  $2 \times 8$  antenna array, ports #1 and #2 are the differential feed pair, and ports #3 to #10 are connected to a matched load.

Fig. 4(a) presents the simulated electric pattern inside the crossover structures of the  $2 \times 8$  antenna array. It is seen that with the differential feed placed at ports #1 and #3 the electromagnetic waves inside the crossovers are constrained to travel along the  $y$ -axis direction, and ports #3 to #10 are isolated effectively. In addition, the  $TE_{12}$  mode field is observed inside each junction of the via-loaded crossover structures. It can be concluded from the above results that the electromagnetic waves can freely propagate along the

crossover structures in the  $y$ -axis direction and they cannot be coupled to other parallel antenna arrays. Fig. 4(b) shows that uniform electric field patterns are achieved among the patch antenna elements.

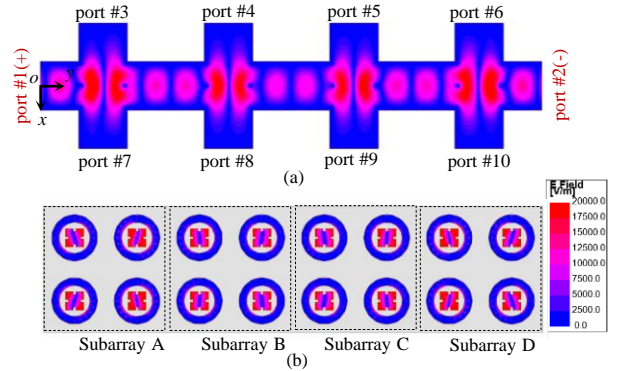


Fig. 4. Simulated electric field of (a) inside the crossover structures and (b) over the patch radiators of the four subarray antennas.

## IV. ANTENNA ARRAY

### A. Configuration

Fig. 5 illustrates the detailed configuration of the proposed 20 GHz  $8 \times 8$  dual-polarized array antenna. The whole structure is designed with five double-sided laminates. The antenna elements are realized on the upper three laminate layers, and the feed networks including the OMT and power dividers are placed in the lower two laminates. The proposed array antenna has  $8 \times 8$  dual-polarized radiating units, and they are allocated with a uniform spacing along the  $x$ - and  $y$ -axis direction. Every  $2 \times 2$  antenna elements is grouped as a subarray antenna. In this figure, the dashed arrows represent the signal paths from port #1 to the parallel SIWs in laminate Sub-3. The signals from feed port #1 are coupled to laminate Sub-4 through a cross slot cut out from the copper layers M8 and M9. They are equally divided by an OMT in the laminate Sub-4. Then, the signals travel to the four-way power dividers along the  $x$ -axis direction with opposite phase. Differential signals are coupled to feed the antenna array through the transverse slots designed in  $180^\circ$  SIW elbows. In this design, the antenna array and its feed networks are designed by using the low cost Rogers RO4003C which has a relative dielectric constant  $\epsilon_r$  of 3.55, loss tangent  $\tan \delta$  of 0.0027, and a thickness of 0.813 mm.

### B. Planar OMT

An OMT is a polarization duplexer [9]. It is usually found in the applications such as combining or splitting dual-polarized electromagnetic waves which are received by or transmitted from a differentially fed antenna with dual-polarization. The configuration of the planar OMT is shown in Fig. 6. The designed OMT is implemented with two laminates. Two feed ports placed orthogonally and a semi-open SIW cavity that supports  $TE_{12}$  and  $TE_{21}$  modes are designed in the bottom layer. In the top laminate, the output ports #3 to #6 are connected with a cross junction. Electromagnetic waves are coupled from the bottom laminate to the top laminate through

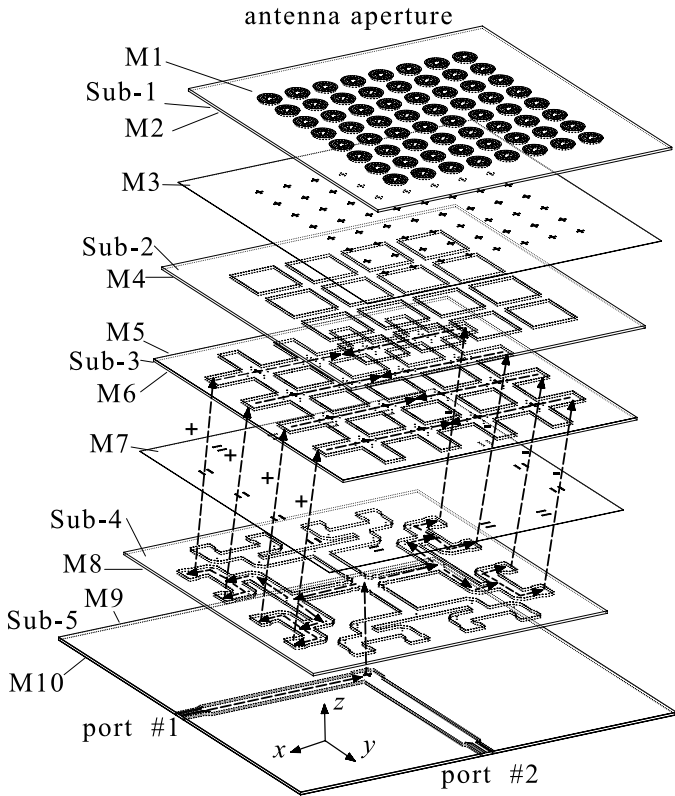


Fig. 5. Configuration of the dual-polarized  $8 \times 8$  antenna array.

a cross slot cut out from the copper layer between the two laminates. When port #1 is excited, electromagnetic waves get out from ports #3 and #4 with equal magnitude and opposite phase. In this case, ports #2, #5 and #6 are isolated to feed port #1. When feed port #2 is excited, the electromagnetic waves exit at ports #5 and #6 with equal magnitude and opposite phase, and ports #1, #3, and #4 are isolated. Thus, the antenna or antenna array connected to the output ports #3 to #6 can be differentially excited for dual-polarization.

Fig. 7 shows the simulated  $S$ -parameters of the planar OMT. The impedance bandwidth of  $|S_{11}| < -15$  dB is in the frequency range 19.1–20.7 GHz. The isolation between the feed ports #1 and #2 is higher than 15 dB in 19–21.6 GHz, and it is higher than 20 dB at the centre frequency 20 GHz. The isolation between the feed port #1 and output ports #5 and #6 is higher than 20 dB over the frequency range 19–22 GHz. Fig. 7 also shows the phase responses at the output ports #3 to #6. When feed port #1 is excited the output ports #3 and #4 has almost the same phase response as the output ports #5 and #6 with feed port #2 excited. The phase differences at the two output port pairs are varied from  $179.6^\circ$  to  $180.1^\circ$  over the frequencies 18–22 GHz. This demonstrates that differential excitations to the antenna array for dual-polarization are obtained.

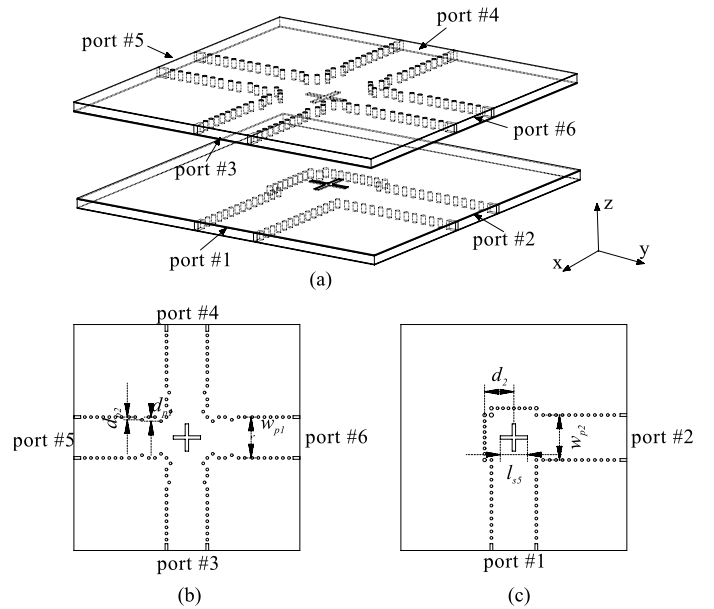


Fig. 6. Planar OMT. (a) Exploded view. (b) Top layer. (c) Bottom layer.

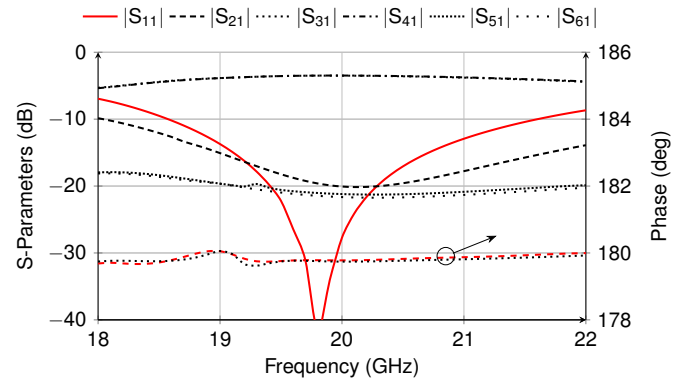


Fig. 7. Simulated  $S$ -parameters and phase responses of the designed OMT.

### C. Experimental Results

Fig. 8 shows the measured and simulated reflection coefficients and the port coupling coefficients of the  $8 \times 8$  dual-polarized antenna array. The measured results are in good agreement with the simulations. The measured reflection coefficients for  $|S_{11}|$  and  $|S_{22}|$  less than  $-10$  dB are in the frequency bandwidth from 19.2 GHz to 20.7 GHz. The measured coupling coefficient  $|S_{21}|$  between feed ports #1 and #2 are less than  $-20$  dB over the impedance bandwidth 19.2–20.7 GHz. Fig. 9 shows the measured and simulated realized gains of the antenna array. It is seen that the maximum realized gain measures 22.8 dBi at the frequency 19.9 GHz when port #1 is excited. Over the frequency bandwidth from 19.2 GHz to 20.6 GHz, the designed antenna array shows stable gain, which is on an average of 22.2 dBi. The radiation efficiency reaches to its maximum 71% at 19.9 GHz and the radiation efficiency is higher than 61% over the operation bandwidth, 19.2–20.6 GHz. Fig. 10 shows the measured and simulated normalized far field radiation patterns

at 20 GHz when port #1 is excited. It is seen that the designed antenna array shows excellent radiation performance with the main beam pointing to the broadside. The measured cross-polarization levels in the  $xoz$ - and  $yoz$ - planes are  $-43$  dB.

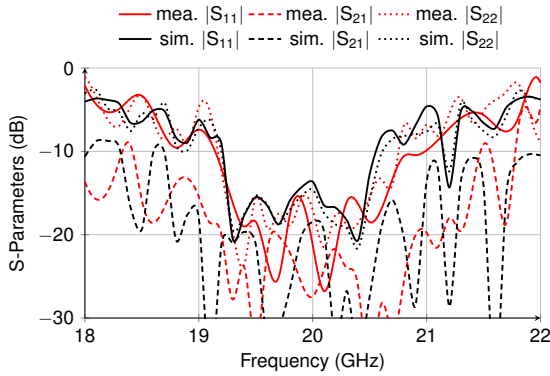


Fig. 8. Measured and simulated reflection coefficients  $|S_{11}|$  and  $|S_{22}|$ , and the port coupling coefficient  $|S_{21}|$ .

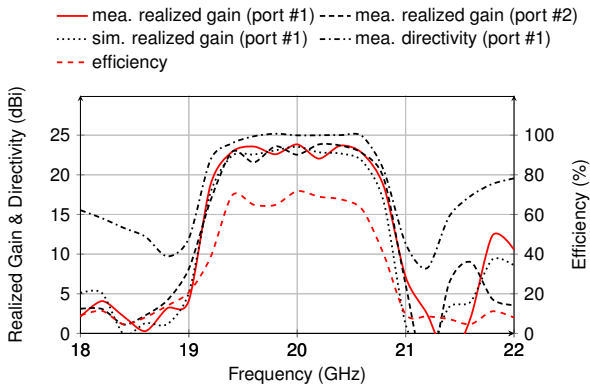


Fig. 9. Measured and simulated gain, directivity and radiation efficiency of the dual-polarized antenna array.

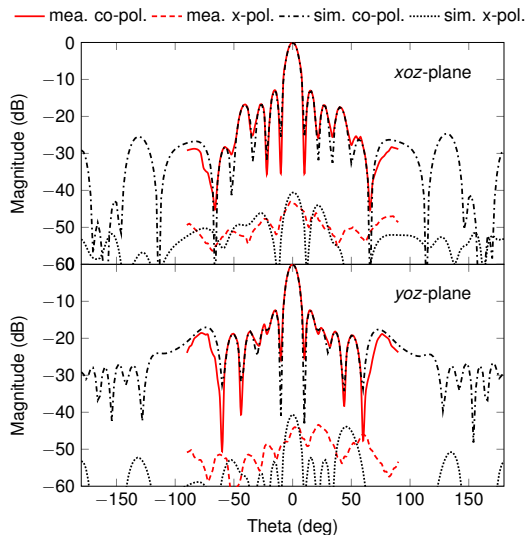


Fig. 10. Normalized far-field radiation patterns at the frequency 20 GHz when port #1 is excited.

## V. CONCLUSION

This paper reports a dual-polarized planar antenna array differentially fed by an OMT. Low complexity is enabled by using an SIW crossover structure. The antenna array can operate in the frequency bandwidth 19.2–20.7 GHz. The operation bandwidth of this antenna is enhanced by introducing triple-resonance. The measured results show that the antenna array has a low cross-polarization level of  $-43$  dB, high gain of 22.8 dBi, stable radiation patterns and high aperture efficiency (51%).

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