High-Isolation, Low Cross-Polarization, Dual-Polarization, Hybrid Feed Microstrip Patch Array Antenna for MPAR Application

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Abstract—This paper presents a high-isolation, low cross-polarization dual-polarized patch antenna for multifunction phased array radar applications. Its hybrid feed design has been implemented, and the vertical and horizontal polarizations are excited by a balanced-probe feed and a slot-coupled feed, respectively. Simulations and measurements have demonstrated an input isolation of 45 and 43 dB between the horizontal and vertical ports, respectively. For further improvement in the cross-polarization level, the image feed method is also implemented, and a 2 × 2-element array made up of designed elements with image configuration has been fabricated. The simulated and measured S-parameter and radiation patterns of the horizontal and vertical polarizations of the designed 2 × 2-element array are presented and the measured cross-polarization level of less than −37 dB is achieved. To examine the performance of the designed element in an array, a 3 × 3-element array of designed 2 × 2-element subarray is fabricated and tested. In the 6 × 6-element measurements, −35.4 and −36 dB cross-polarization levels for horizontal and vertical polarizations are achieved, respectively. Also, using the measured embedded element patterns, the cross-polarization level lower than −36 dB for scan angles up to 45° is achieved.

Index Terms—Array antenna, cross-polarization suppression, differential feed, dual-polarized, image arrangement, phased array radar (PAR).

I. INTRODUCTION

There are four radar networks in the United States that consist of eight different radar systems. Each radar system has its own designated specifications and serves its own mission. Since these radar systems have overlaps in coverage, and data sharing between them is difficult, it is cost-effective and beneficial to integrate these missions into a single radar system. The multifunction phased array radar (MPAR) is planned to concurrently perform weather and air surveillance by using a single PAR network [1], [2]. The national network of WSR-88D Doppler radars has been updated from singularly polarized (i.e., linear horizontal) radar to dual-polarized radars (i.e., WSR-88DP) [3]. The dual-polarized radar system can simultaneously transmit and receive horizontally and vertically polarized waves, which can significantly improve weather measurements and characterization [4]. This dual-polarization functionality provides more information about hydrometeors’ size, shape, orientation, density, etc. [5]. However, having accurate polarimetric measurements requires a highly isolated dual-polarized antenna with low cross-polarization levels.

Any proposed radar for the multifunction application (MPAR) should operate according to the Manual of Regulations and Procedures for Radio Frequency Management (47 Code of Federal Regulations Part 300) and FAA Order 6050.19. MPAR is planned to operate from 2.7 to 2.9 GHz when replacing Airport Surveillance Radar and Terminal Doppler Weather Radar. The frequency band 2.7–2.9 GHz is allocated for aeronautical radio navigation [6].

The Planar Polarimetric Phased Array Radar (PPPAR) [7] and Cylindrical Polarimetric Phased Array Radar (CPPAR) [8], [9] are two possible configurations for MPAR. Significant efforts have been made to achieve a dual-polarized antenna with high isolation and low cross-polarization levels necessary for accurate weather measurements [10]. Toward this goal, various feeding techniques for a microstrip patch antenna were proposed, including an aperture coupled feed [11], [12], a combination of an aperture coupled feed and an L-shaped probe feed, a capacitively coupled probe feed, and various other probe feed methods [13].

Dual-polarized microstrip patch antennas with hybrid feed design can be implemented in applications which require low cross-polarization and high isolation between horizontal and vertical polarizations. Compared to the dual-polarized differential feed design, the hybrid feed design requires less space for feed lines, which results in a more compact design [14]. Also, the hybrid feed design provides a more symmetric feature which will improve the isolation between horizontal and vertical ports. In [15], a dual-polarized microstrip patch antenna is fed by two hybrid ports. These hybrid ports consist of two in-phase aperture coupled feeds and two out-of-phase gap-coupled probe-feeds and the cross-polarization level of −20 dB and input isolation of −40 dB were realized. In [16], a dual-polarized patch antenna is fed by an aperture coupled feed and two capacitively coupled feeds of a 180° phase shift. In this design, the input isolation of −32 dB and cross-polarization level of −14.4 dB were reported.
Considering its low cross-polarization and high-input isolation, the hybrid feed design could be an ideal fit for MPAR applications. This design is being introduced for MPAR applications, and its potential deserves to be explored.

In this design, a dual-polarized patch antenna is excited by an aperture coupled feed and a differential probe feed. The measured input isolation of 43 dB is achieved. For further improvement in the cross-polarization levels, the image feed method has been implemented, resulting in measured cross-polarization levels as low as −37 dB.

This paper is organized as follows. Section II presents the single element design. In Section III, the 2 × 2-element design with image configuration is described and measured radiation pattern of the designed subarray is presented. The radiation pattern of fabricated 6 × 6-element array is measured and presented in Section IV. Also, the radiation pattern of the center 2 × 2-element subarrays of a 6 × 6-element array is measured and used to predict the radiation characteristics of 20 × 20-element array and the results are presented. Finally, the conclusion is provided in Section V.

II. ANTENNA DESIGN

The geometry of the designed and fabricated single dual-polarized patch antenna is shown in Fig. 1. As shown in Fig. 1(b), the vertical polarization is excited by a differential feed method. The vertical polarization is excited by a pair of 180° out-of-phase currents to attain a low cross-polarization level. In this design, the length of the transmission lines is adjusted to provide a 180° phase difference between two probes’ currents. Having a 180° phase difference will suppress the vertical polarization cross-polarization and increase the isolation between the horizontal and vertical polarizations.

The material used for this design is Rogers RT/duriod 5880 with a dielectric constant of 2.2. As shown in Fig. 2, the feed lines are laid on the back side of the first substrate and the ground plane and slots are laid on the front side of the first substrate. Since the microstrip patch antenna has a limited bandwidth, the stacked patch method is implemented and a parasitic square patch is placed on the front side of the third substrate with a thickness of h3. The ground plane and slots are laid on the front side of the first substrate. The first radiating patch is etched on the front side of the second substrate with a thickness of h2. Since the microstrip patch antenna has a limited bandwidth, the stacked patch method is implemented and a parasitic square patch is placed on the front side of the third substrate with a height of h3. The key parameters in this design are attained by optimization performed in CST Microwave Studio and ANSYS HFSS. The dimensions of the designed single element are listed in Table I.

The ～-shaped part of the feed line increases the distance between the horizontal and vertical polarization feed lines.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Size</th>
<th>Parameter</th>
<th>Size</th>
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</table>
Fig. 3. Simulated and measured reflection coefficient and isolation of horizontal and vertical ports of a designed single element.

Fig. 4. Reflection coefficient magnitude versus scan angle in $\phi = 0^\circ$ plane for horizontal and vertical polarizations.

Fig. 5. Reflection coefficient magnitude versus scan angle in $\phi = 90^\circ$ plane for horizontal and vertical polarizations.

Fig. 6. Simulated normalized radiation pattern of designed single element. (a) 2.7 GHz, $\phi = 0^\circ$. (b) 2.7 GHz, $\phi = 90^\circ$. (c) 2.8 GHz, $\phi = 0^\circ$. (d) 2.8 GHz, $\phi = 90^\circ$. (e) 2.9 GHz, $\phi = 0^\circ$. (f) 2.9 GHz, $\phi = 90^\circ$.

Fig. 7. Geometry of fabricated 2×2-element array of designed single element with image configuration. (a) Top view. (b) Bottom view.

RT/duroid 5880 with a dielectric constant of 2.2, the required length difference for a 180° phase shift ($L$) can be approximately calculated as follows [17]:

$$
\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + \frac{12 h}{w} \right]^{-0.5} \quad (1)
$$

$$
\beta = \frac{2\pi}{\lambda} = \frac{2\pi f}{c} \sqrt{\varepsilon_{\text{reff}}} \quad (2)
$$

$$
L = \frac{\pi}{\beta} = \frac{\pi}{2f} \sqrt{\varepsilon_{\text{reff}}} \quad (3)
$$

where $\varepsilon_r$, $\varepsilon_{\text{reff}}$, and $h$ are the dielectric constant, effective dielectric constant, thickness of the substrate, $c = 3 \times 10^8$ (m/s), and $f = 2.8$ GHz, respectively, and $w$ is the width of the transmission line. According to (1) and (3), the effective dielectric constant and required length difference...
at 2.8 GHz would be 1.77 and 40.2 mm, respectively, which the length difference has been optimized in the final design in ANSYS HFSS and is reduced to 39.9 mm.

The horizontal polarization is excited through an H-shaped slot which is fed by a microstrip line laid below the ground plane. The H-shaped slot is placed exactly in the middle of the ground plane to increase the symmetry of radiation pattern. Although the spacing between vertical polarization probes and horizontal polarization feed line and slots is less than 1 mm, since the currents at the two probes are 180° out of phase, they cancel each other’s coupling effect, which results in a high-input isolation.

The simulated and measured reflection coefficient and input isolation between horizontal and vertical polarizations are shown in Fig. 3. As shown in Fig. 3, the simulated and measured $S_{hh}$ and $S_{vv}$ are below $-10$ dB from 2.7 to 2.9 GHz, and there is a satisfactory agreement simulated and measured results. The isolation between horizontal and vertical ports is better than 45 dB in simulation and around 43 dB in measurement, indicating a very good agreement between simulated and measured results.

The simulated reflection coefficient of the proposed hybrid feed patch antenna at the scan angles in $\phi = 0^\circ$ and $\phi = 90^\circ$ planes are shown in Figs. 4 and 5, respectively. The minimum required reflection coefficient is taken to be $-10$ dB for the intended scan volume. For a four-faced planar array antenna or a cylindrical array antenna which has a 90° active sector, the minimum required scanning angle is 45°. As shown in Figs. 4 and 5 in the $\phi = 0^\circ$ and $\phi = 90^\circ$ planes at the entire frequency band, the reflection coefficients for horizontal and vertical ports remain under $-10$ dB across the scan angle from 0° to 45°, except $S_{VV}$ at 2.8 GHz in $\phi = 90^\circ$ plane which approaches $-10$ dB at 43° scan angle.

The copolarization and cross-polarization radiation pattern of the horizontal and vertical polarizations at 2.7, 2.8, and 2.9 GHz in $\phi = 0^\circ$ and $\phi = 90^\circ$ planes are shown in Fig. 6. In $\phi = 0^\circ$ plane, the cross-polarization level above the ground plane is better than $-48$ dB for horizontal polarization and $-39$ and $-32$ dB for vertical polarization. In $\phi = 90^\circ$ plane, the maximum cross-polarization level above the ground plane is $-39$ and $-32$ dB for horizontal polarization and vertical polarization, respectively.

III. 2 × 2-ELEMENT ARRAY CONFIGURATION

For further improvement on the cross-polarization level, the image feed method is applied to the 2 × 2-element array of the designed single element [18], [19]. In this configuration, the upper right and lower left elements in the 2 × 2-element array are mirrored with respect to the vertical
plane. In this configuration, the phase of the copolarization pattern of mirrored element will be 180° out of phase, compared to the original element. On the other hand, the phase of cross-polarization pattern will not change by mirroring the element. To compensate for the 180° phase shift in the copolarization pattern, the mirrored elements are excited with a 180° phase shift. Consequently, the copolarization pattern of two elements will be in phase and the cross-polarization patterns will be 180° out of phase, so the cross-polarization pattern will be canceled, especially in the principal planes.

The geometry of the fabricated 2×2-element array antenna is shown in Fig. 7. The fabricated array antenna is tested in the far-field anechoic chamber of the Advanced Radar Research Center (ARRC) and the measured results at 2.7, 2.8, and 2.9 GHz are presented in Fig. 8. Also, not shown here, the simulated cross-polarization level of the 2×2-element array with image configuration is below −80 dB for horizontal polarization and below −56 dB for vertical polarization. As shown in Fig. 8 the maximum measured cross-polarization level in the whole bandwidth is below −40 dB above the ground plane (θ = −90° to θ = 90°) for both polarizations in the ϕ = 0° plane. In the ϕ = 90° plane the cross-polarization level is below −37 dB.

Although there is a gap between the maximum measured and simulated cross-polarization levels, it should be noted that the difference between −56 and −40 dB is less than 10−4. Therefore, small backscattering from the cable and pedestal could increase the cross-polarization to −40 dB. Also, the cross-polarization level of the standard transmitter antenna in the test will increase the measured cross-polarization level.

IV. 6×6-ELEMENT ARRAY

A 6×6-element array of proposed dual-polarized hybrid feed patch antenna has been designed and fabricated to validate the radiation characteristics of the 2×2-element subarray, especially its low cross-polarization level. As shown in Fig. 9, the fabricated 6×6-element array is made of nine 2×2-element subarrays, mounted on a fixture made of polycarbonate and acrylic.

The radiation pattern of the fabricated 6×6-element array is measured in the far-field anechoic chamber of ARRC. Fig. 10 shows the array antenna horizontal and vertical polarizations’ radiation patterns at 2.7, 2.8, and 2.9 GHz. In the ϕ = 0° plane, the cross-polarization level is below −35.4 and −36.1 dB for horizontal and vertical polarization, respectively. As shown in Fig. 10, in ϕ = 90° plane, the cross-polarization level for
Fig. 12. Calculated radiation pattern of 10 x 10-element array of designed 2 x 2-element subarray based on measured embedded element patterns at 2.8 GHz. (a) H-Pol, $\phi = 0^\circ$. (b) H-Pol, $\phi = 90^\circ$. (c) V-Pol, $\phi = 0^\circ$. (d) V-Pol, $\phi = 90^\circ$.

The simulated gain of the designed single element and 6 x 6-element array is shown in Fig. 11. As shown in Fig. 11, the difference between the simulated and measured gain of the 6 x 6-element array does not exceed 1.23 dB.

The 6 x 6-element array is used to predict the copolarization and cross-polarization level of large arrays by using its measured embedded element pattern. Since the elements in the center 2 x 2-element subarray are not identical, each element in the center 2 x 2-element subarray is separately excited while all other elements are terminated. Accordingly, the four measured embedded element patterns are used to characterize a large array radiation pattern. The measured embedded element patterns have been used to calculate the radiation pattern of a 20 x 20-element array. The horizontal and vertical polarizations radiation patterns of the 20 x 20-element array in $\phi = 0^\circ$ and $\phi = 90^\circ$ planes at 0°, 15°, 30°, and 45° scan angles are shown in Fig. 12. For horizontal polarization in $\phi = 0^\circ$ and $\phi = 90^\circ$ planes, the maximum cross-polarization level at broadside is below $-38.55$ dB and cross-polarization level remains under $-36$ dB across the scanning to 45°. For the vertical polarization in $\phi = 0^\circ$ and $\phi = 90^\circ$ planes, the cross-polarization level at broadside is below $-38$ dB and it remains below $-36$ dB while the main beam direction is steered to 45°.

V. CONCLUSION

The design, simulation, and measurement results of a 2 x 2-element array of low cross-polarization, high-isolation hybrid feed dual-polarized microstrip patch antenna are presented. An input isolation of better than 45 and 43 dB is achieved in simulation and measurement, respectively. The elements in 2 x 2-element array are arranged in image configuration and $-56$ dB maximum cross-polarization level is achieved in simulations. The radiation pattern of the 2 x 2-element array was measured in the ARRC far-field anechoic chamber and showed a $-37$ dB maximum cross-polarization level. Also, the cross-polarization level of less than $-40$ dB at the location of the copolarization peak is achieved which shows that the proposed element could be an ideal choice for the weather and MPAR applications.

To examine the copolarization and cross-polarization radiation pattern characteristics of the designed 2 x 2-element subarray at the scan angles, a 3 x 3-element array of 2 x 2-element subarray is fabricated and tested. The radiation pattern of the 6 x 6-element array is measured and the cross-polarization levels of $-35.4$ dB for horizontal polarization and $-36$ dB for vertical polarization are achieved. Also, the radiation pattern of each element in the center 2 x 2-element subarray is measured and the measured embedded element patterns are used for calculating the radiation pattern of 20 x 20-element array at four scan angles from $\theta = 0^\circ$ to $\theta = 45^\circ$ in $\phi = 0^\circ$ and $\phi = 90^\circ$ planes and the cross-polarization level of lower than $-36$ dB is achieved.

REFERENCES


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