A Dual-Polarized Cross-Stacked Patch Antenna with Wide-Angle and Low Cross-Polarization for Fully Digital Multifunction Phased Array Radars

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***Abstract*—In the following contribution, the design of a high performance antenna element with dual-polarization, wide scan angle, and low cross-polarization levels for phased array radars is reported. The antenna was optimized to operate in the federal radionavigation and meteorological band (2.7 - 2.9 GHz). Cross-polarization levels for E- , D-, and H-plane $\leq$ -45 dB based on Ludwig's 3rd definition were obtained. Scanning performance of $\pm$ 60° for all scanning ranges in the frequency band was achieved. Isolation greater than -40 dB and bandwidths greater than 10 % were reached at the array level.**

***Index Terms*—cross-stacked patch, microstrip patch antenna, stacked patch, wide band, wide angle, dual-polarized, aperture coupled, phased array radar, multifunction phased array radar (MPAR).**

I. Introduction

As a part of the initiative to replace the existing weather and air surveillance radar networks, the Advanced Radar Research Center (ARRC) at the University of Oklahoma initiated the development of a fully digital Line Replaceable Unit (LRU, see Fig. 1), as part of the NOAA/FAA Multifunction Phased Array Radar program. This fully digital project, named "Horus," after the Egyptian god of war and sky, allows for full control of transmitted and returned signals of each antenna element, providing high flexibility for beam forming techniques and scanning strategies [1]. The design of the antenna for ARRC's Horus project is focused on achieving the same or improved performance compared to WSR-88D parabolic antennas. These design specifications are critical, given that the weather mission presents more challenging polarimetric requirements, in terms of target identification, than aircraft surveillance.

Dual-polarized radars require both low cross-polarization levels and well matched patterns to successfully determine the polarimetric variables of the scanned atmosphere sector [2], [3]. In general, when the cross-polarization levels of the antenna increase, all of the biases in the polarimetric variables are increased [4]. MPAR's weather mission has established the most stringent and restraining requirements among all radar users in terms of the antenna performance, due to the high cross-polarization purity required. This article presents the design and measured results of a cross-stacked patch antenna array for the Horus project. The results presented show excellent characteristics to satisfy the cross-polarization requirements for MPARs.

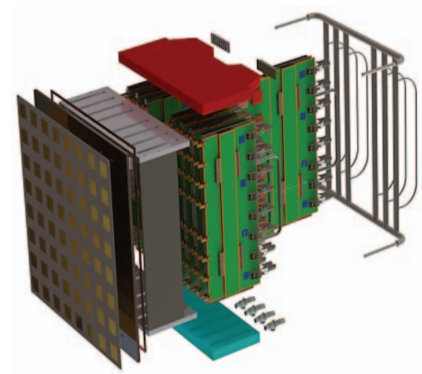

Fig. 1: Rendering of the fully digital line replaceable unit for ARRC's Horus project.

II. Design considerations and Simulated Results

Multiple factors in the antenna element were investigated during the design process of the 8x8 array in order to comply with the current antenna requirements of MPAR. These factors include bandwidth in excess of 10 % with a central frequency of 2.8 GHz; port-to-port isolation in the element $\leq$ -50 dB; cross-polarization levels $\leq$ -45 dB at $\pm$ 60° and $\pm$ 10° for scanning range at the azimuth and elevation planes, respectively; active reflection coefficient $<$ -10 dB at $\pm$ 60° and $\pm$ 10° for scanning range at the azimuth and elevation planes, respectively; and the use of materials that would not compromise the antenna performance with temperature changes. It is important to point out that these design considerations should hold for all the frequency ranges of the antenna.

Once all of the aforementioned considerations for the design were carefully analyzed, a comprehensive analysis for selecting a single radiating element was conducted. The analysis revealed that for driving the antenna, the feeding network introduced in [5] was the best option to cover the requirements when a stacked parasitic patch is included, as studied in [6]. This configuration allows for the polarizations to be separated

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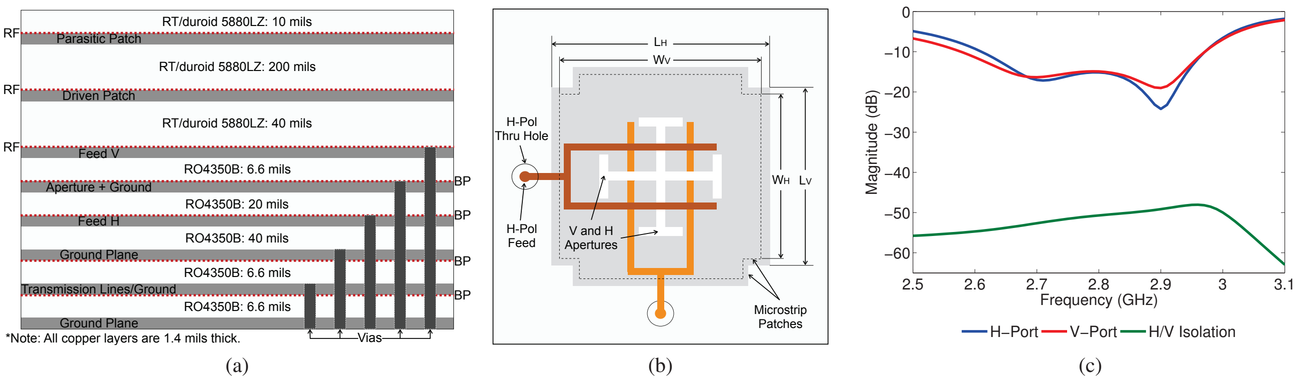

Fig. 2: ARRC's Horus antenna element stack-up and top view. The driven patch dimensions are L_V = 32.7 mm and W_V = 22.7 mm. For the parasitic patch, L_H = 33.9 mm and W_H = 23.9 mm. RF and BP refers to different prepeg layers. Drawings not to scale.

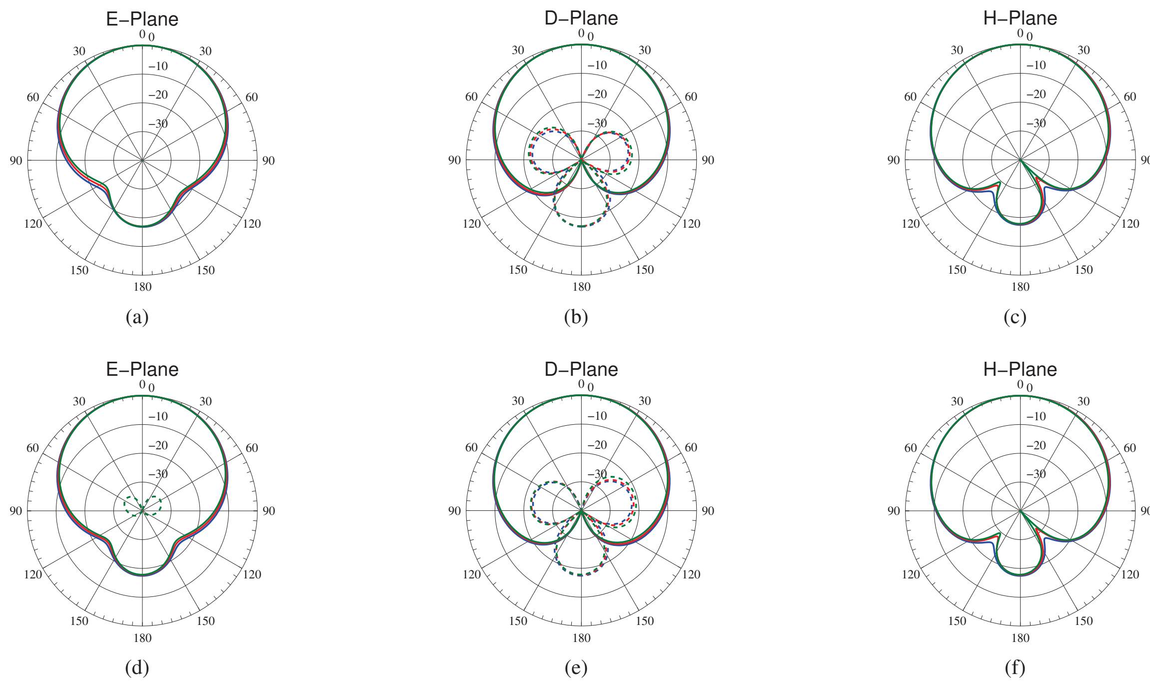

Fig. 3: Simulated patterns for both H- (top row) and V-polarizations (bottom row) for the antenna. Solid (–) and dashed (- -) lines refers to co- and cross-polarization, respectively (2.7 Blue, 2.8 Red, and 2.9 GHz Green).

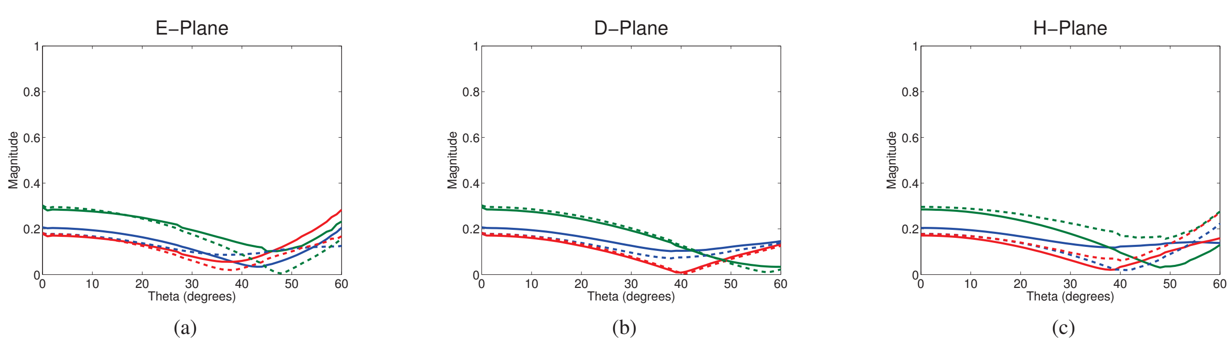

Fig. 4: Simulated active reflection coefficients (ACRs) for the antenna both H- and V-polarizations. Solid (–) and dashed (- -) lines refer to H and V (2.7 Blue, 2.8 Red, and 2.9 GHz Green). The unit cell size is 50.8mm.

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by a ground plane which improves the port isolation and cross-polarization. The stacked-patch allows for higher bandwidths due to the presence of the parasitic patch resonance. The design of the antenna element follows guidelines discussed in [7] which apply to dual-polarization antennas. Fig. 2a shows the stack-up and Fig. 2b shows the top view of the antenna element. When compared to the work of [6] and [8], the proposed element includes a ground plane below the horizontal feed in order to minimize back-lobe radiation. (see Fig. 2a) This is achieved by incorporating a design of strip lines for one polarization instead of microstrips.

The S-parameters of the antenna element are presented in Fig. 2c. The overlapped bandwidth between the polarizations is roughly 400 MHz and the isolation between the ports peaks at 2.97 GHz, around -48 dB. Fig. 3 shows the radiation patterns for the antenna element. It is clear that the cross-polarization levels across frequencies are below -40 dB for both polarizations and all frequencies in the principal planes, with the exception of the V-polarization at 2.9 GHz. In the diagonal plane (D-Plane), levels are kept below -21 dB for all frequencies in the element. The simulated active reflection coefficient (ARC) is presented in Fig. 4. The wavering in the results can be attributed to numerical simulation errors, given that every scanning angle is an independent solution. The element shows some degradation at the highest frequency (2.9 GHz) however, its performance exceeds the requirements for all scanning angles with reflections below -10 dB from 0 to 60°.

III. Array Measurements

Fig. 6 shows the overlapped S-parameters measured for rows 4 and 5 of the array. A small shift of the S-parameters to higher frequencies was observed compared to simulation results, and some degradation in the amplitude of the return loss for V-pol was encountered. This effect can be attributed to the inaccuracies inherent in the fabrication process. The inner elements (2-7) exhibit port-to-port isolation below -42 dB. However Fig. 6c and Fig. 6f show that the isolation peaks on elements 1 and 8 to -39 dB at 2.97 GHz. This can be attributed to the edge effects that occur in these particular positions in the array.

Measurements for the patterns were conducted in a far-field chamber using a customized NSI-RF-WR284 waveguide probe that operates in a frequency range from 2.6 - 3.95 GHz. A customized fixture (see Fig. 5) constructed of high performance Rohacell 110 IG/A with ϵ_r = 1.12 was used to support the array on a pedestal. This feature minimized reflections and disruption of patterns on the specular region of the far-field chamber. The antenna was attached to a solid aluminum plate that extended 1 inch from the border of the array, and the patterns were obtained at 3.0 GHz. Measurements for both polarizations were taken while exciting the two middle rows on the 8x8 array. Fig. 7 shows the measured co- and cross-polarization patterns using Ludwig's 3rd definition. It can be seen that the cross-polarization level is below -44.5 dB for both polarizations in the measured planes from ± 45° in azimuth.

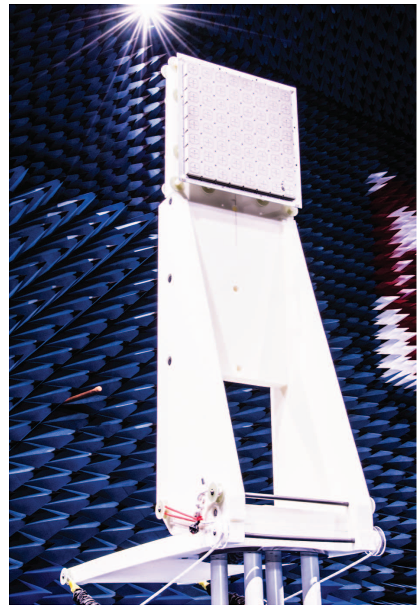

Fig. 5: Antenna fixture in the ARRC's far-field chamber at The University of Oklahoma to measure the 8x8 array.

IV. Conclusion

In this article, a combination of multiple techniques to improve the performance of an antenna element that satisfies MPAR's requirements is presented. The antenna element satisfies the required performance which indicates that mutual coupling and surface waves are well mitigated in the scanning range. An 8x8 array made of this element demonstrated promising results in satisfying the cross-polarization requirements for MPARs in alternate and simultaneous transmission modes.

Acknowledgment

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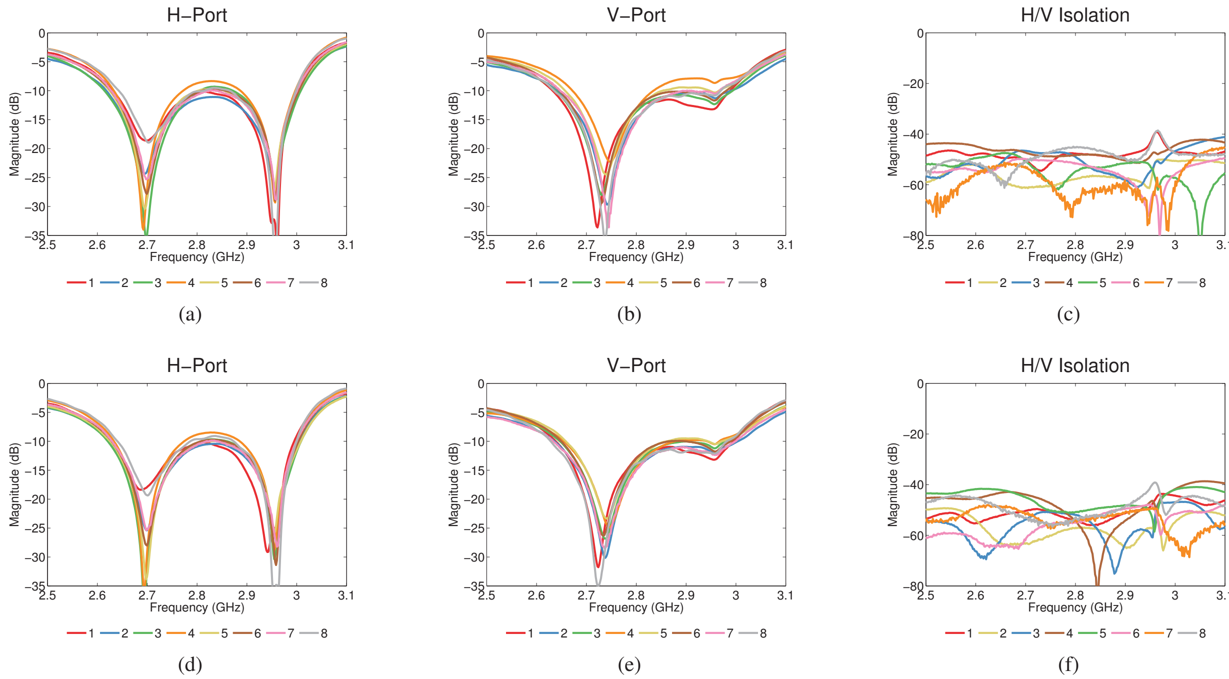

Fig. 6: Measured S-parameters of Horus 8x8 antenna array for rows 4 (a-c) and 5 (d-f).

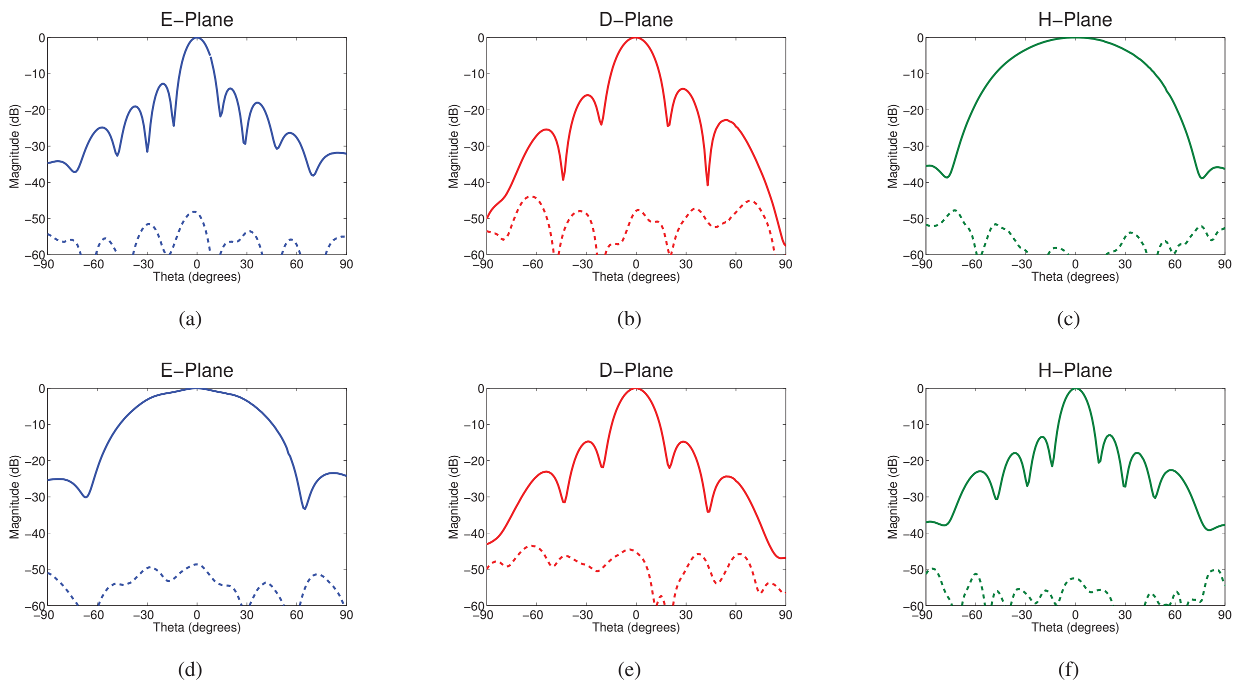

Fig. 7: Measured patterns of Horus 8x8 array at 3 GHz while exciting the two middle rows for H-(top) and V-polarizations (bottom row). Solid (–) and dashed (- -) lines refers to co- and cross-polarization, respectively.

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