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Broadband Dual-Polarized Aperture-Coupled Patch Antenna for 5G Applications

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Abstract: ***This paper presents the design of a dual-polarized aperture-coupled microstrip antenna array for Sub-6GHz 5G communication systems. The antenna operates at 3.5 GHz and consists of 4×4 square patches. The proposed 4×4 array antenna feds by aperture-coupled feed line provide broadband bandwidth to operate in the N78 sub-6GHz 5G frequency band. The dual-polarized is presented, which gives two communications channels. The antenna consists of three layers and is designed on Rogers RO4003C substrate with a dielectric constant of 3.55 and substrate thickness of 0.8 mm. The final design of the antenna array with an overall size of 269 mm × 269 mm × 12.5 mm, and the results show that the 4×4 array has a 10dB bandwidth between 3.3-3.8 GHz and a maximum gain of 14.9 dB at 3.5 GHz, and the isolation between the two ports was 30 dB. The proposed antenna's gain, radiation efficiency, and bandwidth satisfy the requirements of 5G base station systems.***
Keywords: Sub-6GHz, 5G Communication, Dual-*Polarized****, Aperture-coupled, and Antenna Array.***

I. INTRODUCTION

Mobile communication networks have undergone significant growth over the years. Beginning with the first generation (1G) of mobile communications, which was based on analog technology and provided only voice services, through the second generation (2G) and the third generation (3G) where digital-based technology was used from the first time, and finally progressed to the fourth generation (4G), which provided additional services, including the internet with greater efficiency and capacity [1]. Mobile communications have become an essential component of daily life.

It made the world a small village by providing access to many software and services and overcoming the distance barriers. Since the beginning of the use of cellular communications, it has become widespread with a continuous increase in the number of users. That resulted in a continuous need for greater traffic volume, device connectivity, speed. This need can only be satisfied by adopting new technologies, that is, the fifth generation (5G) mobile communications [2].

The 5G enhances the network performance with high capacity at a lower cost, which provides the user with very high data rates and a long-awaited end to congestion and latency issues relative to the 4G. Although sub-6-GHz and millimeter-wave frequency bands are recommended for the 5G, most countries have initially utilized the Sub-6 GHz frequency bands because of the readily available network [3].

The antenna module is crucial for realizing the 5G services in the evolution process. Also, due to features of combating multipath fading, increasing the channel capacity, and reducing the number and size of antennas, dual-polarized antennas have been widely adopted for the 5G antennas.

Several reported antennas research were focused on designing a dual-polarized antenna for 5G communication systems, such as patch antenna, filtering antenna, bowtie dipole, and opened-loop dipole [4][7]. Patch antennas are often preferred due to their small size, low cost, easy fabrication, and integration advantages.

Patch antennas suffer from some disadvantages like low gain and narrow bandwidth. Some research papers presented a single element design for 5G communication system [8][11]. But on the other hand, in 5G requirements, the antenna module should have, at least, a gain of 12 dB and a broadband bandwidth.

The gain of the microstrip antenna can be improved by forming an array of multiple patch elements, while the bandwidth of a microstrip antenna can be increased by either utilizing a second resonant structure or using an appropriate feeding method. In this paper, we propose an efficient dual-polarized antenna array that consists of 4x4 microstrip square patches and operates at 3.5 GHz.

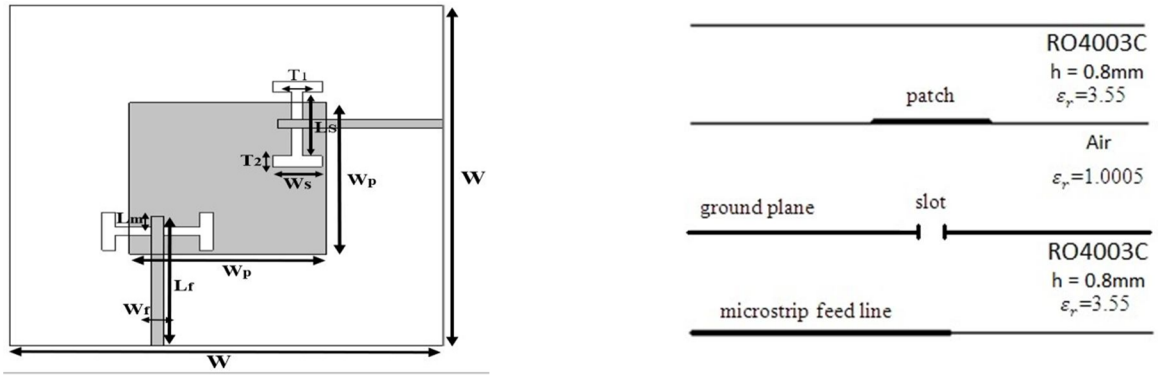
This paper is organized as follows. The antenna single element design procedure and analysis, along with the simulation results, are discussed in Section II. Section III presents the procedure and the simulated parameters results, with the radiation characteristics of the proposed 4x4 dual-polarized aperture-coupled antenna array. Conclusions of the proposed work are provided in Section IV.

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II. SINGLE ELEMENT DESIGN

In this section, Single element dual-polarized patch antenna for sub-6GHz 5G communication systems is presented. A single element patch antenna is designed on Rogers RO4003C substrate with a dielectric constant ε_r =3.55, thickness of 0.8 mm, and loss tangent tan δ = 0. 0.0027. The geometry of the proposed antenna is shown in Fig. 1 where (a) shows the top view, (b) shows the side view of the antenna, and W is the antenna's length and width. The square patch is designed to achieve the same performance and results in the two ports of the antenna.



(a) (b)

Fig. 1 Dual-polarized aperture coupled patch antenna structure (a) top view, and (b) side view.

A. Design Parameters

The proposed antenna design is aimed to cover the N78 frequency band of sub-6-GHz 5G-communication systems which is operating between 3.3GHz and 3.8GHz with 3.5GHz center frequency. In general, there are four popular methods to feed a microstrip antenna which are: microstrip line, coaxial probe, aperture coupling and proximity coupling. This paper selected the aperture-coupled method to feed the antenna because it provides enough bandwidth to cover the N78 band, better isolation, and a large number of optimization parameters. The microstrip patch is printed on the upper metal layer, and the microstrip feed line is printed on the lower metal layer. The coupling between the patch and the feed line is conducted by inserting a slot on the ground plane; where H-shaped has been used to provide a wideband characteristic with a shorter slot length compared to other shapes like rectangular shape, bowtie-shaped, and hourglass-shaped [12]. To achieve better performance for the antenna. H-shaped parameters (Ws, Ls, T1, and T2) are considered in the design. A parametric optimization study using CST microwave studio 3D simulation is conducted to select the best values for H-shaped parameters to achieve the best isolation, wider bandwidth, and efficient radiation. Table I shows the optimized parameters of the proposed antenna.

TABLE I
Optimized parameters of single element patch antenna

Parameters	Description	Value (mm)
W	Width/length of the antenna	61.93
Wp	Width/Length of the patch	28.11
Ws	Width of the H slot	11.81
Ls	Length of the H slot	7.04
T1	Thickness of the H slot center leg	1.55
T2	Thickness of the H slot side leg	1.98
Wf	Width of the microstrip feed line	1.68
Lf	Length of the microstrip feed line	21.15
Lm	Length of the Stub	2.80
Off	Patch offset in X/Y direction	10.00
T	Thickness of the Patch	0.035
D1	Thickness of the upper substrate	0.80
D2	Thickness of the lower substrate	0.80
D3	Thickness of the Air	6.37

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B. Simulation and Result

The single element simulation return loss Fig. 2 shows a good return loss with a 10-dB for both port1 and port2 having a bandwidth of 3.23-4.92 GHz which it is cover the N78 frequency band of the Sub-6GHz 5G communication systems. From Fig. 3 it can be observed that simulated isolation is better than 19 dB. From Fig. 4 It can be noticed that the maximum realized gain of the single element dual-polarized antenna is 8.25 dB. The normalized co and the cross-polarization radiation pattern is simulated and measured for both the horizontal plane (xz-plane) and the vertical plane (yz-plane) as shown in Fig. 5 and Fig. 6.

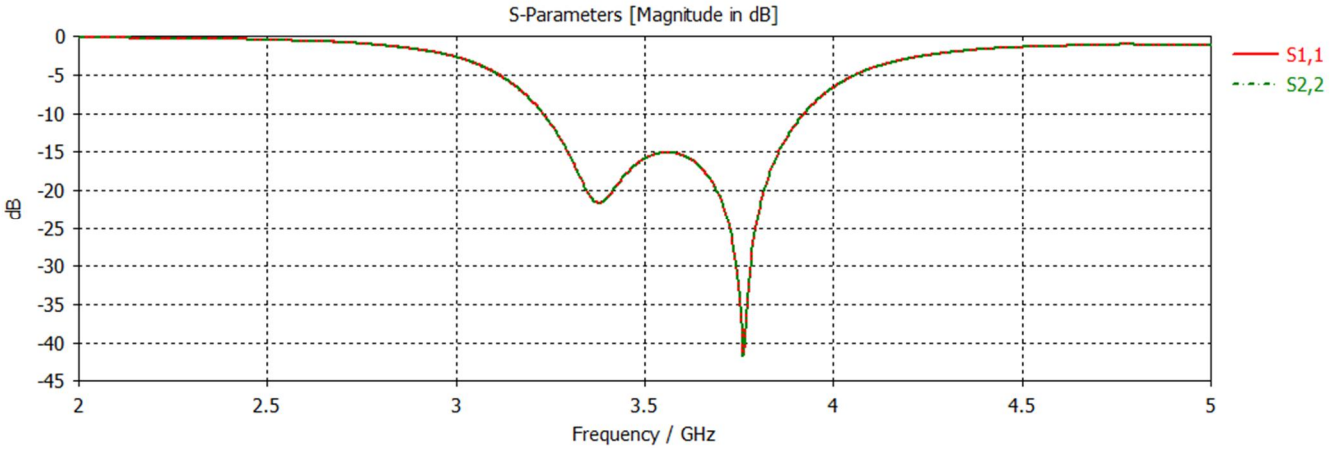


Fig. 2 Return loss graph for S11 and S22 simulation result.

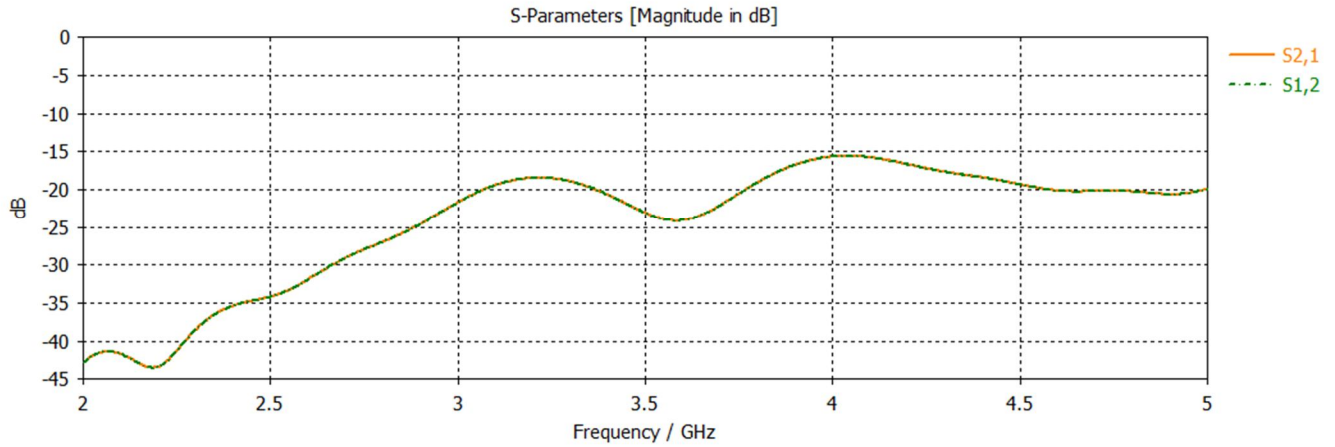


Fig. 3 Isolation between Ports graph for S21 and S12 simulation result.

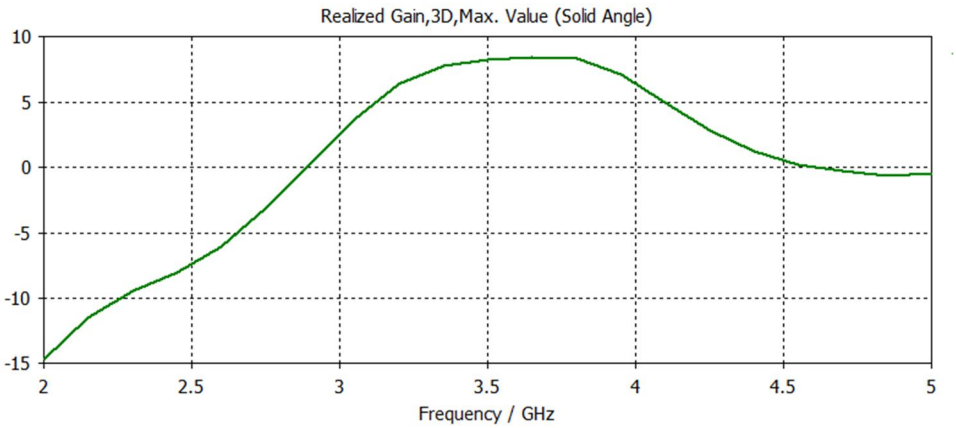


Fig. 4 Realized gain graph for simulation result.

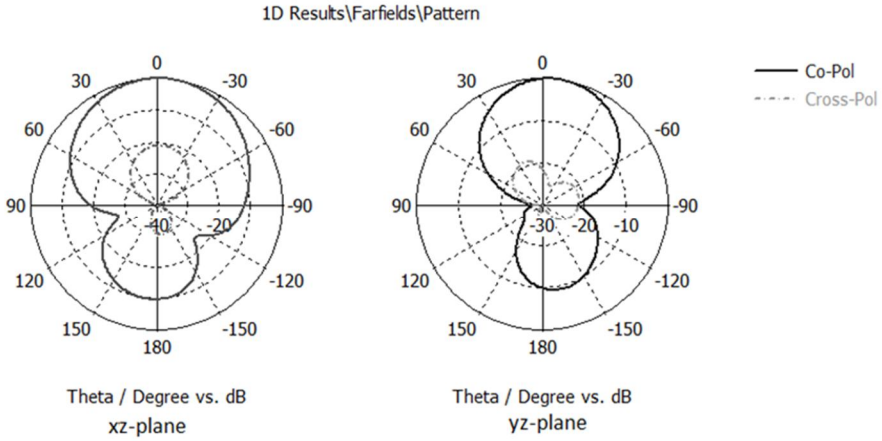


Fig. 5 Radiation pattern of ~~xy~~xz-plane and yz-plane for port1.

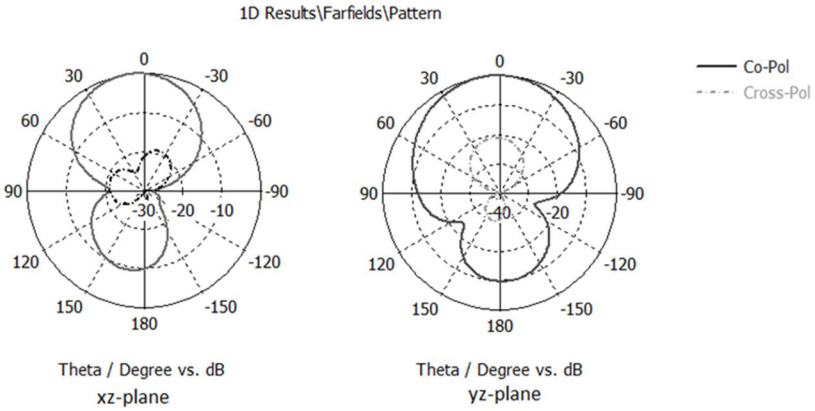


Fig. 6 Radiation pattern of xz-plane and yz-plane for port2.

III. ANTENNA ARRAY DESIGN

A 4x4 dual-polarized patch antenna array is designed. The array's feeding network is first formed by corporate feeding of microstrip T-junction power dividers and λ/4 impedance transformers to obtain 50Ω impedance at the input port of the array. Finally, the array's feeding network continues with series feeding where each patch feeds from the previous one. Hence, Series - Corporate Feeding is used in the antenna array [13]. The geometry of the proposed antenna array is shown in Fig. 7.

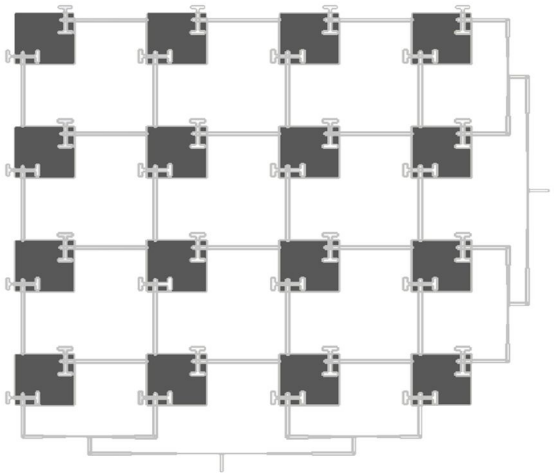


Fig. 7 4x4 dual-polarized aperture-coupled patch antenna array top view.

The simulated S11 and S22 of the array are presented in Fig. 8; from the figure, we can recognize that the array bandwidth achieved 18%, Fig. 9shows the isolation between the array's two ports, which is better than 32 dB. Fig. 10 and Fig. 11. Represent the radiation pattern of the array for the two ports, and it can be noticed that the proposed array has a maximum simulated gain of 14.9 dB, and the half power beamwidth of the two ports is 49.5 degree and 17.8 degree in the xz-plane and yz-plane, respectively.

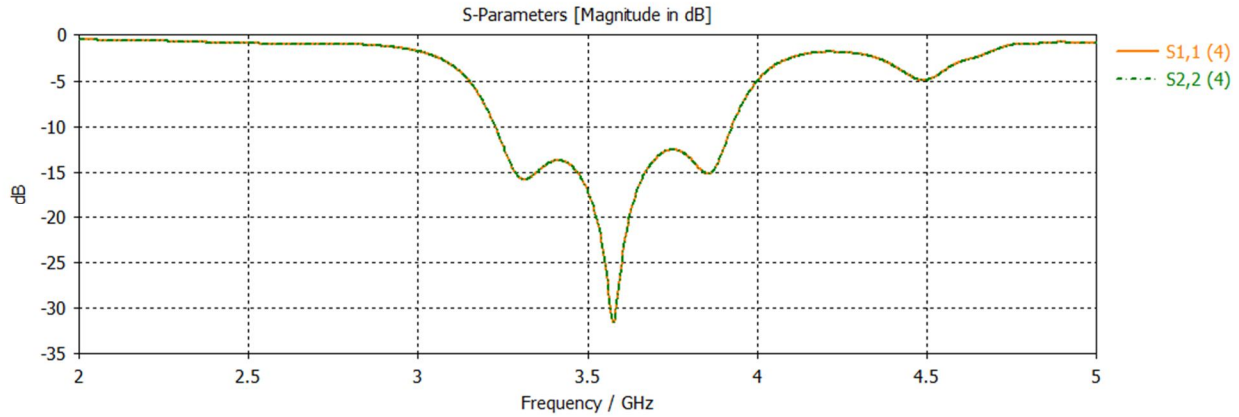


Fig. 8 Return loss graph for S11 and S22 simulation result for the antenna array.

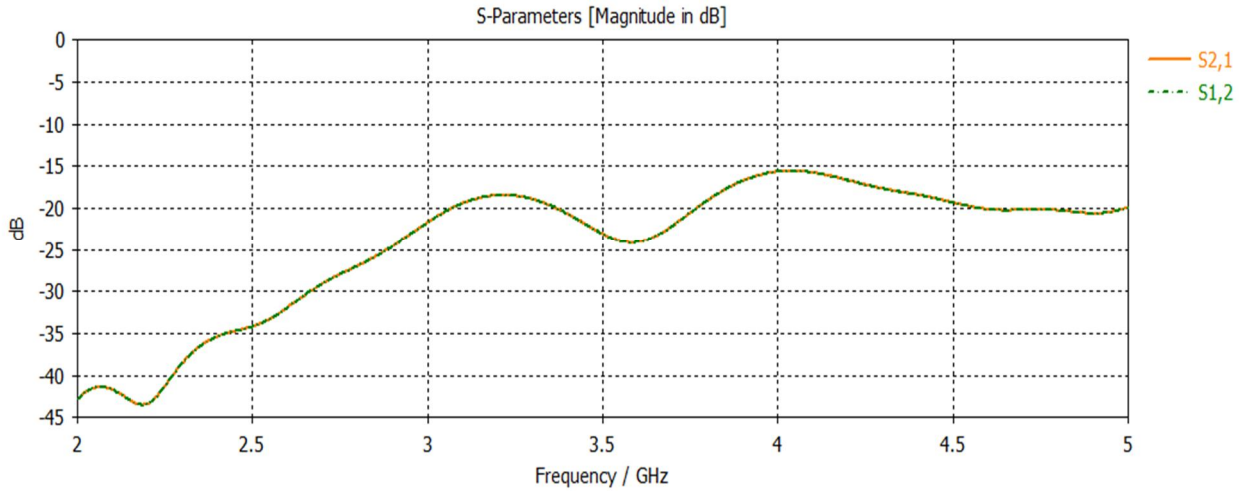


Fig. 9 Isolation between Ports graph for S21 and S12 simulation result for the antenna array.

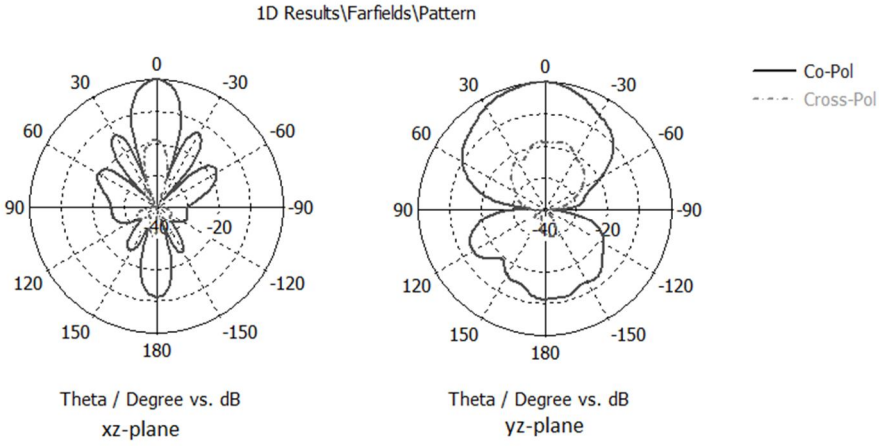


Fig. 10 Radiation pattern of xz-plane and yz-plane for port1 of the array.

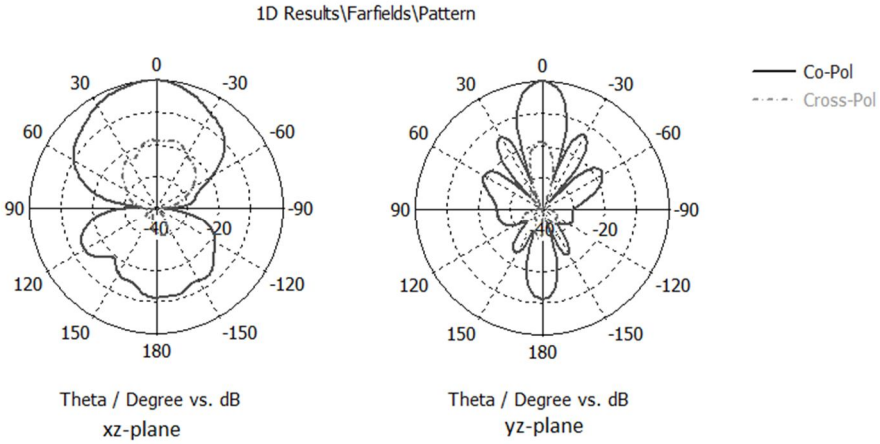


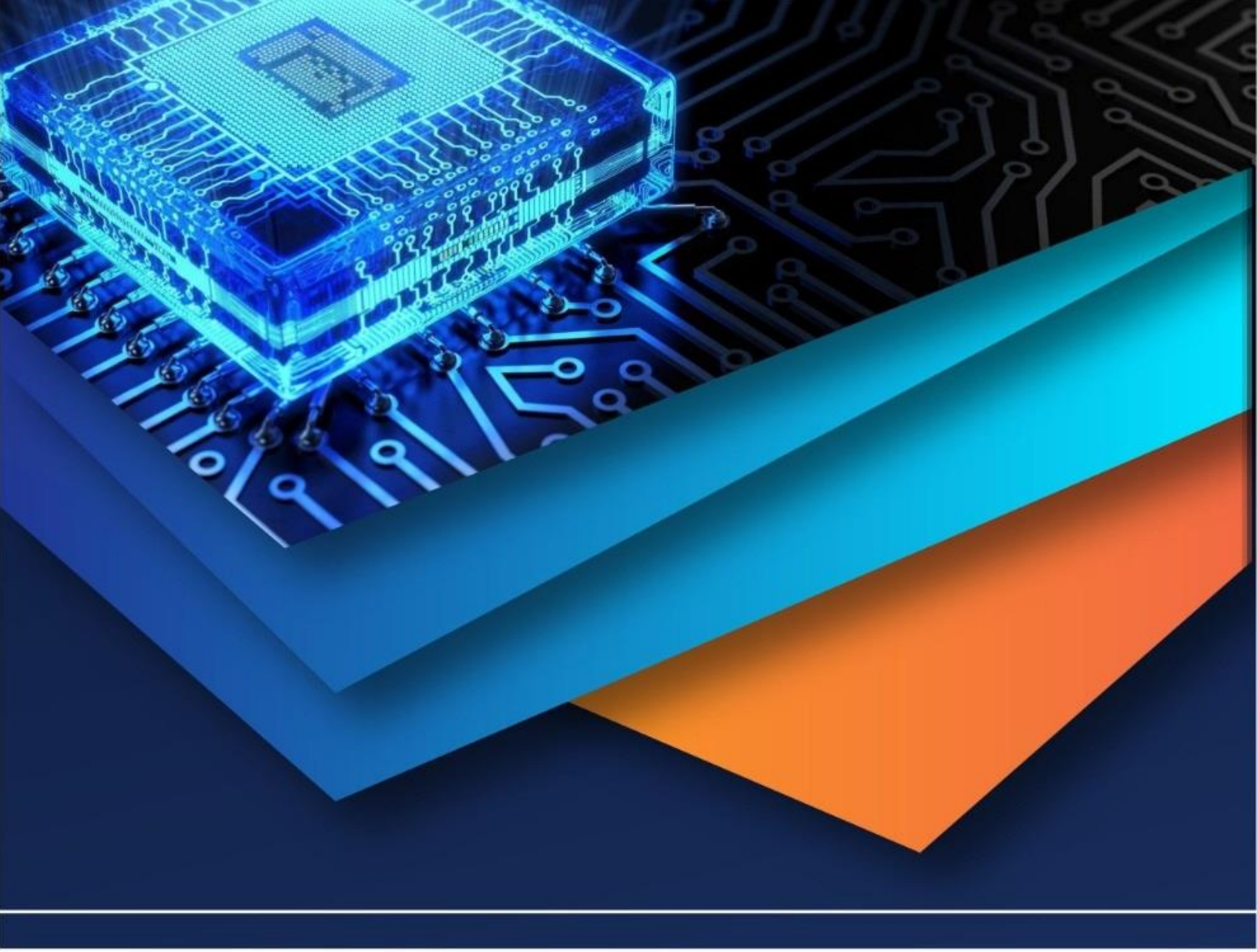
Fig. 11 Radiation pattern of xz-plane and yz-plane for port2 of the array.

IV. CONCLUSIONS

A dual-polarized H-shaped aperture-coupled 4x4 patch antenna array operating at N78 sub-6GHz is presented. The antenna array parameters have been optimized and simulated. The proposed antenna module exhibits a maximum realized gain of 14.9 dB, and isolation between ports of 32 dB. Also, good cross-polarization levels for the design of the antenna are observed. The simulation shows that the antenna performance meets 5G base station system requirements.

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