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Design of Linearly and Circularly Polarized Microstrip Phased Array Antennas

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Abstract: ***The design and simulation results of linearly polarized and circularly polarized microstrip patch phased antenna arrays operating at 5 GHz is presented. The phased arrays are employed by providing the progressive phase excitations at the source ports. The work presents the design structures of 1x4, 2x4 and 2x8 linearly polarized phased arrays and 1x4, 2x4 and 2x8 circularly polarized phased arrays upon a FR4 substrate of thickness 1.6 mm. The linear polarized phased array antennas were designed for comparison. From the simulation results, it is evident that return loss (RL) of all the designs is less than -10 dB, ensuring good impedance matching and axial ratio (AR) is less than 3 dB, satisfying the condition for circular polarization.***
Keywords: phased antenna array; progressive phase excitation; linear polarization (LP); circular polarization (CP);

I. INTRODUCTION

The recent developments of modern mobile communication in wireless technology has a limited frequency spectrum resource. Hence, demand for antennas seem difficult to fulfill the requirements of applications such as: mobile radio, aircraft, missile, satellite, and deep space communication, where the antenna size, cost, performance, and weight are the constraints. In such scenarios, a simple, low-profile, versatile, and robust antenna with satisfying application requirements may be essential. Hence, microstrip patch antennas and antenna arrays are commendable choice [1].

Similarly, polarization of an antenna is the significant consideration in selection and installation of communication antennas. Antenna polarization can either be linear, circular or elliptical and employed based on the application requirements. The antennas at transmitting and receiving stations employed in mobile, satellite, and space communication are consistently not aligned, hence persistent reorientation is required to avoid signal loss and multipath effects, due to which the CP patch antennas can be deployed to meet the requirements.

The next generation mobile communication develops a phased array subsystem, due to their versatility in electronically steering an antenna beam to a particular point in required unique directions without physically moving the antennas [2].

CP antennas have some crucial favorable circumstances compared to LP antennas. In space applications where amount of power availability is minimal, then reduction in at least a single module would contribute in a large amount of save in energy and size. Hence, elimination of external motors to align antenna orientation would be an advantage of CP antennas over LP antennas in satellite and mobile communications.

Due to increase in large number of mobile users, demand for data and data rate is huge. Hence, mobile technology must be capable to handle additional data traffic at much greater speeds than the present cellular network base stations. The previous work in the area of antennas and arrays accomplished CP radiation by exciting two orthogonal modes with 90° time-phase difference. However, the method ensued in relatively poor results in terms of gain, axial ratio and return loss, as it employed complex dual feed excitations and an external 90° power divider or 90° hybrid was incorporated [3]-[4].

In this paper, CP is obtained by corner trimming technique through coaxial probe feeding and phased arrays are accomplished by providing progressive phase excitations at the source ports. The design and optimization of dimensions of patch, feed locations, and truncating opposite corner to obtain CP phased array antennas at 5 GHz is performed using ANSYS High Frequency Structure Simulator (HFSS).

LP phased array structures of 1x4, 2x4 and 2x8 are designed at 5 GHz using inset feeding followed by CP phased array structures of 1x4, 2x4 and 2x8 designed at 5 GHz using coaxial probe feed technique. The designed phased array structures can perform beam scanning over a total scan of 40° (-20° to +20°) for LP antennas and a total scan of 40° (-20° to +20°) for CP antennas with best possible optimum results of RL, AR and gain.

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II. ANTENNA DESIGN – SINGLE PATCH

The antennas are designed using transmission-line model. Based on this model, practical design procedure using simplified formulas are described for rectangular patch antennas in [8]. Designs are modelled upon a FR4_epoxy substrate of 1.6 mm thickness with dielectric constant of 4.4 and loss tangent of 0.02.

A. LP Single Patch Antenna

The design and simulation result of RL, AR and gain radiation pattern for an inset fed single rectangular patch antenna operating at 5 GHz is shown in Fig.1 to 4 respectively. The design is used as reference for comparing gain and RL values for further array designs. The simulation results of RL of -35.52 dB with AR of 78.8 dB and gain of 4.73 dB was observed for a single LP patch antenna.

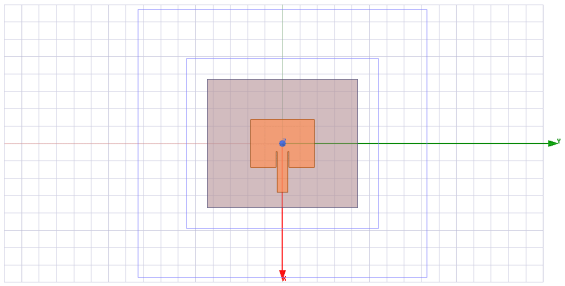

Figure 1: Design of LP Single Patch Antenna

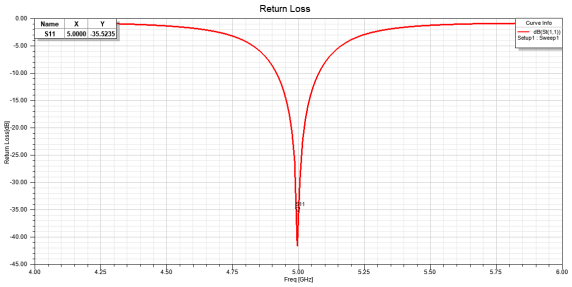

Figure 2: Return Loss of LP Single Patch Antenna

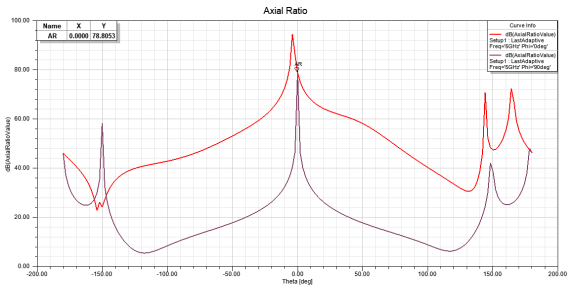

Figure 3: Axial Ratio of LP Single Patch Antenna

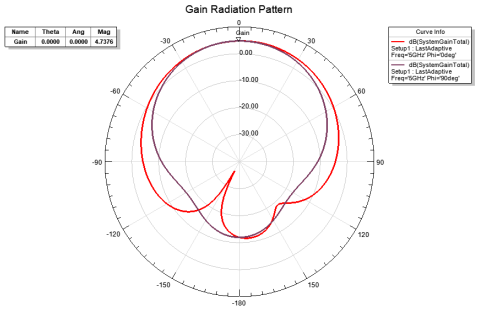

Figure 4: Gain Radiation Pattern of LP Single Patch Antenna

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B. CP Single Patch Antenna

The design and simulation results of RL, AR and gain radiation pattern for a coaxial probe fed single microstrip square patch antenna with opposite corner truncations to obtain CP radiation operating at 5 GHz is shown in Fig.5, 6, 7 and 8 respectively. The design is used as a reference for comparing gain, AR and RL values for further array design structures. The simulation results of RL -14.99 dB with AR of 2.57 dB and gain of 4.79 dB was observed for a single CP patch antenna.

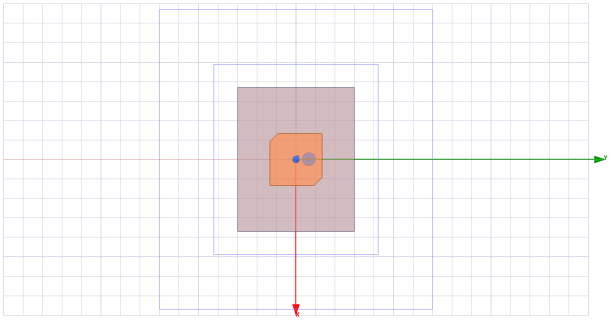

Figure 5: Design of CP Single Patch Antenna

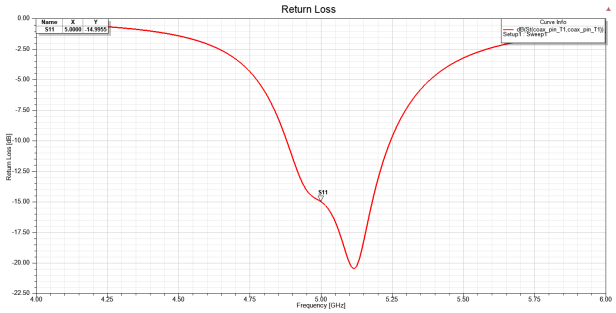

Figure 6: Return Loss of CP Single Patch Antenna

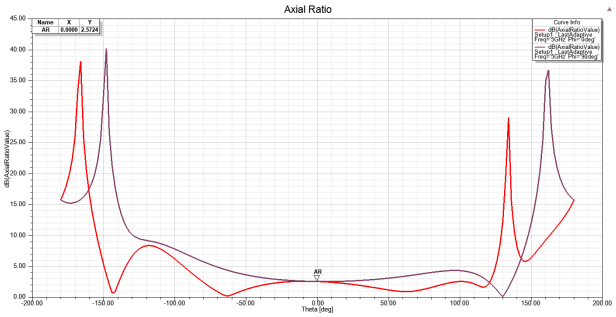

Figure 7: Axial Ratio of CP Single Patch Antenna

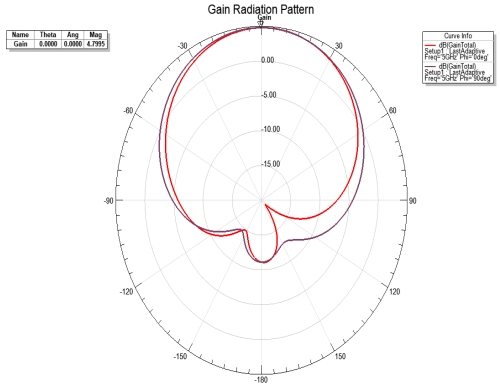

Figure 8: Gain Radiation Pattern of CP Single Patch Antenna

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III. PHASED ARRAY ANTENNA DESIGNS

The LP phased array structures of 1x4, 2x4 and 2x8 followed by CP phased array structures of 1x4, 2x4 and 2x8 are designed at 5 GHz. Interelement spacing between any two consecutive patches of array elements is maintained to be d = λ/2 where, λ is free space wavelength.

A. 1x4 LP Phased Array Antenna

The design and simulation result of gain radiation pattern for an inset fed two 1x2 LP phased array antenna is shown in the Fig.9 and 10 respectively.

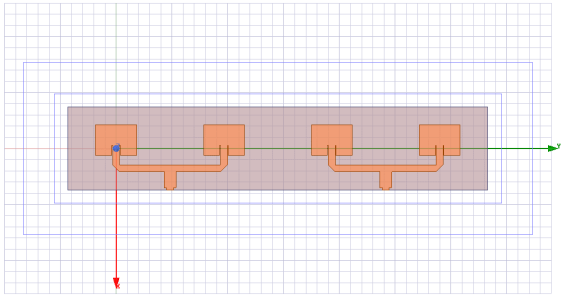

Figure 9: Design of two 1x2 LP Phased Array Antenna

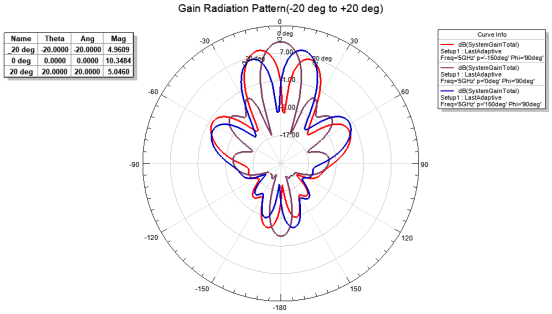

Figure 10: Gain Radiation Pattern of two 1x2 LP Phased Array

The Phased antenna array is accomplished by employing progressive phase excitation of 45° at source ports for every 5° steering of beam angle. The simulation results of RL -23.63 dB with gain of 10.34 dB was observed for a two 1x2 LP phased array antenna.

B. 2x4 LP Phased Array Antenna

The design and simulation result of gain radiation pattern for an inset fed four 1x2 LP phased array antenna is shown in the Fig.11 and 12 respectively. The phased antenna array is accomplished by employing progressive phase excitation of 45° at source ports for every 5° steering of beam angle. The simulation results of RL -19.12 dB with gain of 13.12 dB was observed for the four 1x2 LP phased array antenna.

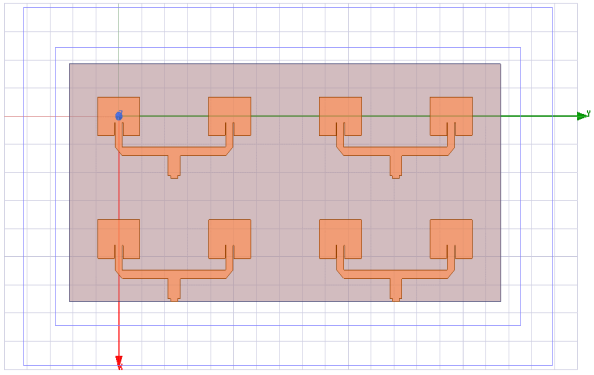

Figure 11: Design of four 1x2 LP Phased Array Antenna

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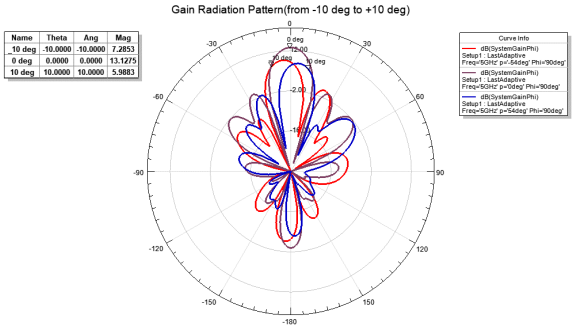

Figure 12: Gain Radiation Pattern of four 1x2 LP Phased Array

C. 2x8 LP Phased Array Antenna

The design and simulation result of gain radiation pattern for an inset fed four 2x2 LP phased array antenna is shown in the Fig.13 and 14 respectively. The Phased antenna array is accomplished by employing progressive phase excitation of 45° at source ports for every 5° steering of beam angle. The simulation results of RL -26.53 dB with gain of 14.75 dB was observed for the two 2x2 LP phased array antenna.

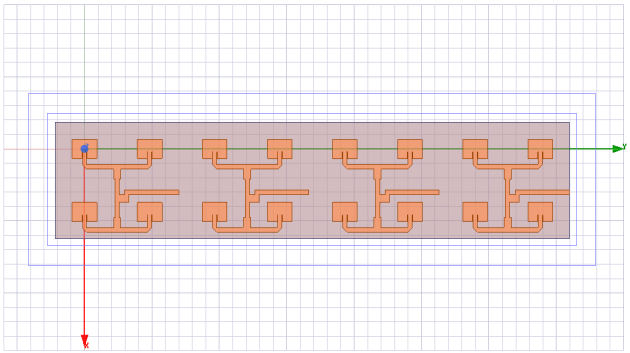

Figure 13: Design of four 2x2 LP Phased Array Antenna

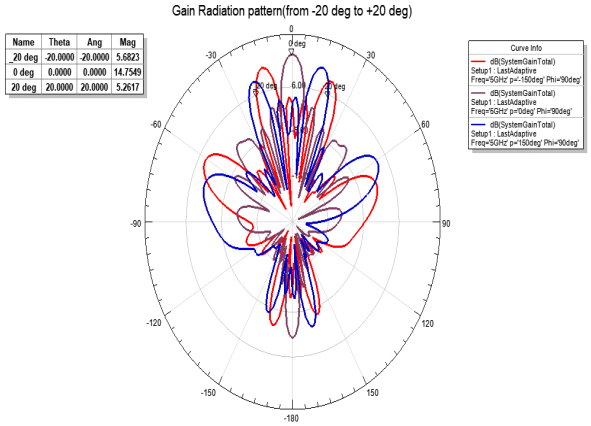

Figure 14: Gain Radiation Pattern of four 2x2 LP Phased Array

The simulated results in terms of RL and gain along with the corresponding values of progressive phase shifts applied for every 5° steering of beam angle, of all the LP phased array structures is tabulated below as in Table 1.

Table 1: Simulation Results of LP Phased Arrays

Design Structures	Single Patch	1x4 Array	2x4 Array	2x8 Array
S11 (dB)	-35.52	-23.63	-19.12	-26.53
Gain (dB)	4.73	10.34	13.12	14.75
Progressive Phase	0°	45°	45°	45°

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D. 1x4 CP Phased Array Antenna

The design and simulation results of AR and gain radiation pattern for a coaxially fed 1x4 CP phased array antenna is shown in Fig.15, 16 and 17 respectively.

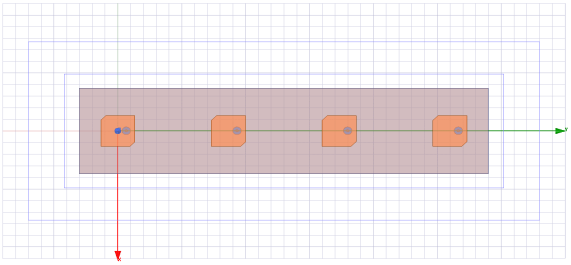

Figure 15: Design of 1x4 CP Phased Array Antenna

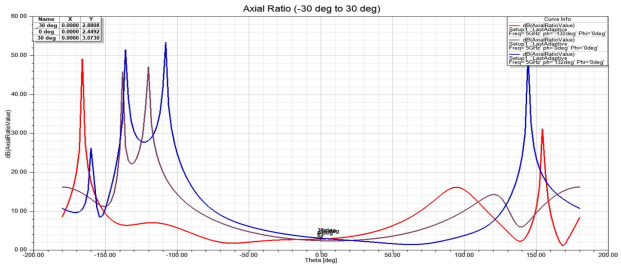

Figure 16: Axial Ratio of 1x4 CP Phased Array Antenna

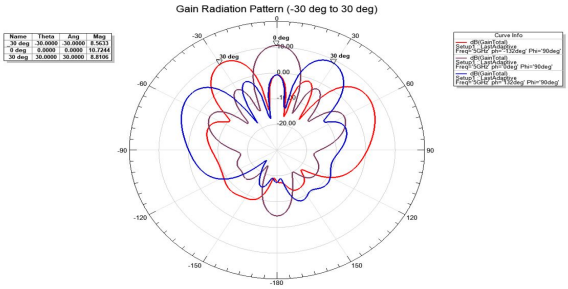

Figure 17: Gain Radiation Pattern of 1x4 CP Phased Array

Phased antenna array is accomplished by employing progressive phase excitation of 22° at source ports for every 5° steering of beam angle. The simulation results of RL -13.58 dB with AR of 2.44 dB and gain of 10.72 dB was observed for a 1x4 CP phased array.

E. 2x4 CP Phased Array Antenna

The design and simulation results of AR and gain radiation pattern for a coaxially fed 2x4 CP phased array antenna is shown in Fig.18, 19 and 20 respectively. Phased antenna array is accomplished by employing progressive phase excitation of 13° at source ports for every 5° steering of beam angle. The simulation results of RL -14.12 dB with AR of 1.92 dB and gain of 13.74 dB was observed for a 2x4 CP phased array.

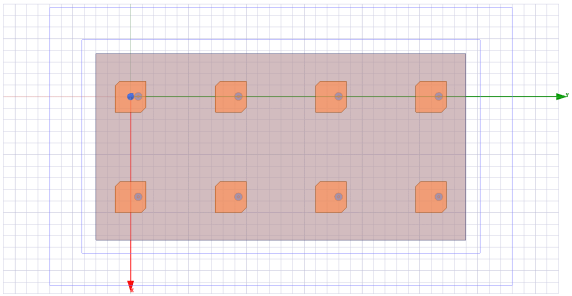

Figure 18: Design of 2x4 CP Phased Array Antenna

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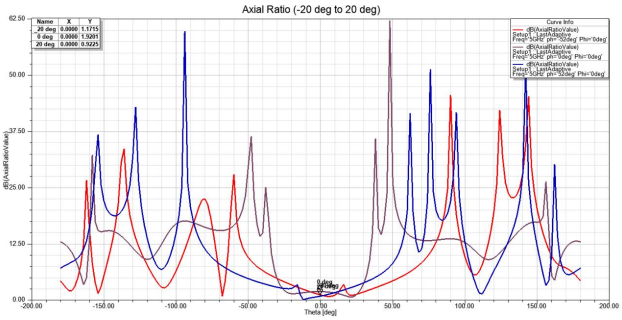

Figure 19: Axial Ratio of 1x4 CP Phased Array Antenna

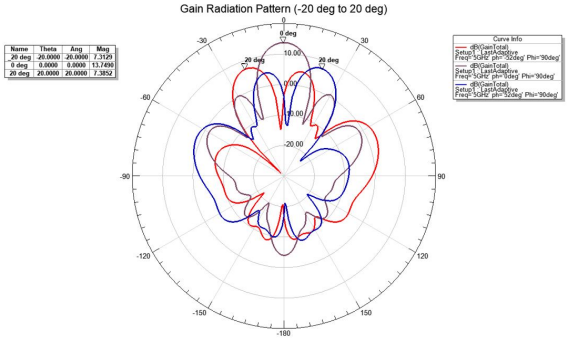

Figure 20: Gain Radiation Pattern of 2x4 CP Phased Array

F. 2x8 CP Phased Array Antenna

The design and simulation results of AR and gain radiation pattern for a coaxially fed 2x8 CP phased array antenna is shown in Fig.21, 22 and 23 respectively. Phased antenna array is accomplished by employing progressive phase excitation of 13° at source ports for every 5° steering of beam angle. The simulation results of RL -14.12 dB with AR of 2.05 dB and gain of 16.84 dB was observed for a 2x8 CP phased array.

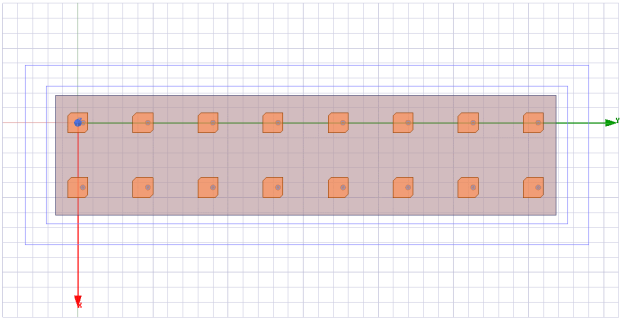

Figure 21: Design of 2x8 CP Phased Array Antenna

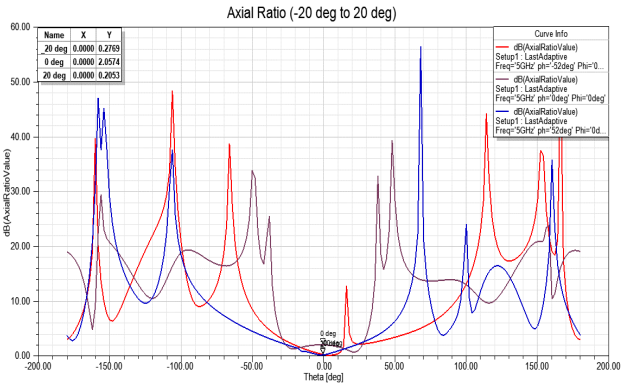

Figure 22: Axial Ratio of 2x8 CP Phased Array Antenna

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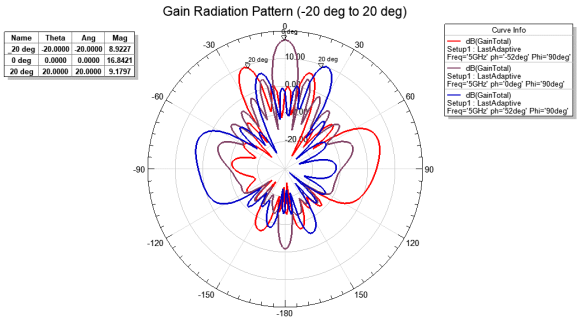

Figure 23: Gain Radiation Pattern of 2x8 CP Phased Array

The simulated results in terms of RL, AR and gain along with the corresponding values of progressive phase shifts applied for every 5° steering of beam angle, of all the CP phased array structures is tabulated below as in Table 2.

Table 2: Simulation Results of CP Phased Arrays

Design Structures	Single Patch	1x4 Array	2x4 Array	2x8 Array
S11 (dB)	-14.99	-13.58	-14.12	-14.12
Axial Ratio (dB)	2.57	2.44	1.92	2.05
Gain (dB)	4.79	10.72	13.74	16.84
Progressive Phase	0°	22°	13°	13°

IV. CONCLUSION

Upon observation and comparison of the simulation results, it is evident that the corner trimming technique applied to the microstrip square patch antennas generates CP radiation. Then, the doubling of antenna elements to create LP and CP arrays resulted in approximately 3 dB enhancement in gain. The implementation of phased array approach by progressive phase excitations at source ports, proved to perform beam steering from -20 degrees to +20 degrees for LP phased arrays and CP phased arrays. The obtained results of |S11| is below -10 dB, indicating good impedance matching and AR less than 3 dB for the designed antenna configurations.

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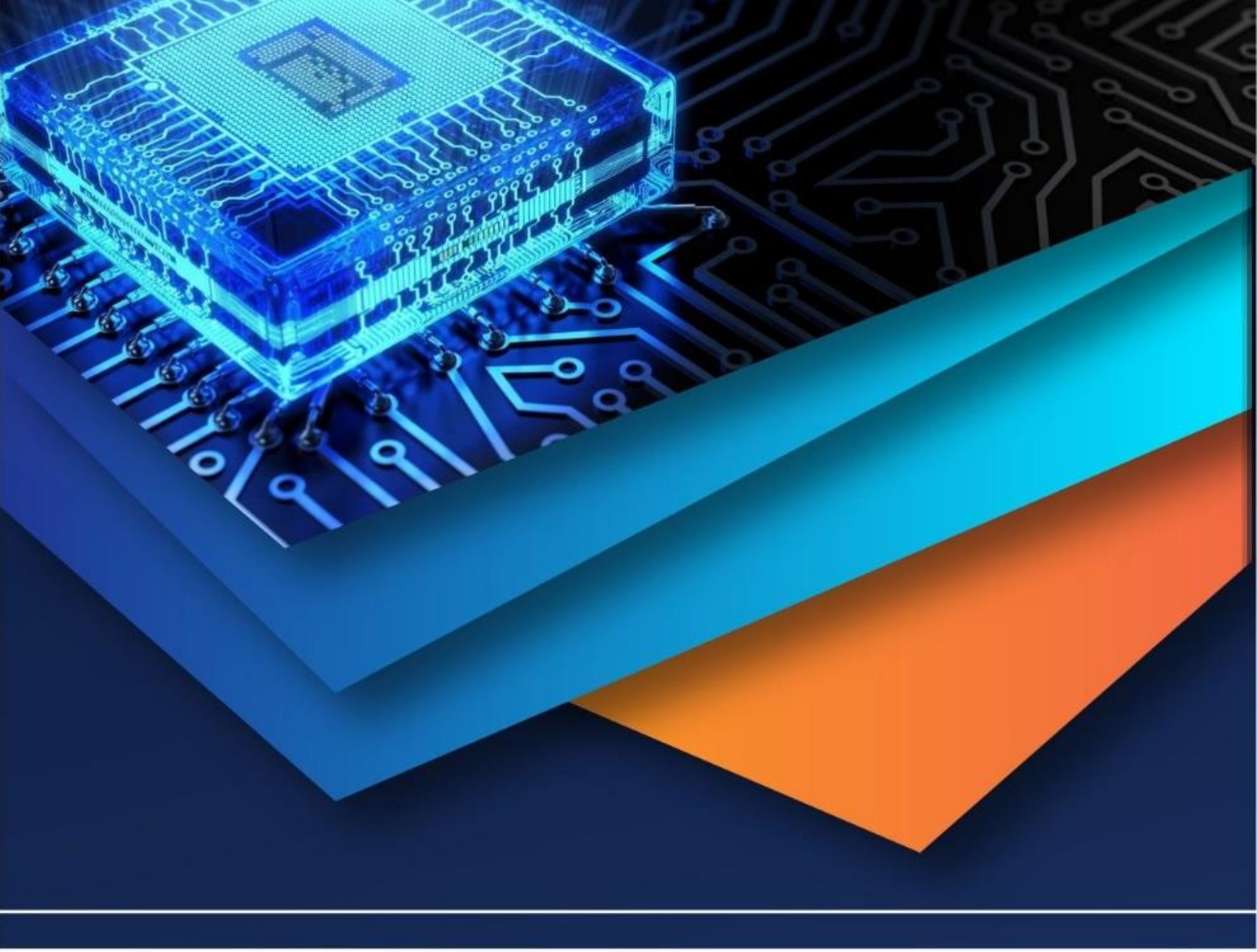

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