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***Abstract*—The proposed study investigates dual circular polarization in the X-band (8-12 GHz) frequency range. Using a single input microstrip line feed approach, the design employs three microstrip patches (patch #1, #2, and #3) as an array. The design also incorporates both-sided MIC (microwave integrated circuit) technology, which simplifies the entire procedure. On Advanced Design System (ADS) software, the task is created and simulated with Teflon as a substrate material. The input signal from the input port is eventually routed to three patches using the U-shaped slot with flared arm ends in the ground plane. The meander line in the design is crucial for achieving circular polarization by allowing the phase difference between signals feeding to patches. Without the meander line, the antenna would only emit linear polarization. Left-hand circular polarization is achievable by meandering lines between Patch #1 and #3. Meander lines between the other patches (#1 and #2) gives polarization of other senses (right-hand circular polarization). At 10.05 GHz, the antenna has an axial ratio of 0.26 dB and an axial ratio bandwidth of 140 MHz. The antenna has a maximum gain of 9.5 dBi which is comparatively higher than other array antenna containing more than three elements in the design. The antenna has an impedance bandwidth of 6% for -10 dB return loss. The return loss less than -40 dB indicates that the antenna is properly matched in the resonant frequency.**

***Keywords*—Array, Three Element, Linear Polarization, Microstrip Patch, right-hand circular polarization, left-hand circular polarization, X-band**

I. Introduction

As multi-path loss and the antenna orientation of the transmitter and receiver are not concerns, circular polarization in communication is a highly fascinating and significant issue to be taken into consideration, in contrast to linear polarization, which must be followed meticulously to maintain efficient communication [1]–[3]. As a result, devices that have the potential to use circular polarization have had a remarkable influence on radar and satellite communication. Due to their numerous advantages over other antennas, including their low weight, ease of installation, and cost effectiveness, many communication systems favor circular polarized microstrip antennas. In addition, microstrip patch array for circular polarization is a popular option for communication engineers today [4], [5].

Using a microstrip patch array, circular polarization (CP) has been the subject of several studies. To get circular polarization, several combination of array elements and occasionally multiple feeds have been employed. The most often used technique for obtaining circular polarization is to corner truncate each patch of the array and feed them in the appropriate senses using a single or multiple feeds [6]–[8]. There has been some research on using a sequential feeding network to generate circular polarization on a microstrip patch array. In [9], [10], 2×2 array is created for CP, and each patch is either fed in succession by shifting the signal's phase by a quarter wavelength or by placing the patches sequentially. A dual port four-element array is presented in [11] to acquire both linear and circular polarization with an orthogonal electric field and a quarter wavelength phase difference between them. However, this array only has a gain of 4.51 dBi only and needs a 90-degree phase shifter in the feed circuit. Another study using an 8×8 patch array antenna to achieve circular polarization with increased gain has been published [12]. However, the added capacitive annular gaps required to counteract the increase in inductance caused by the probe feed which complicate the designing calculations. There have also been several reports

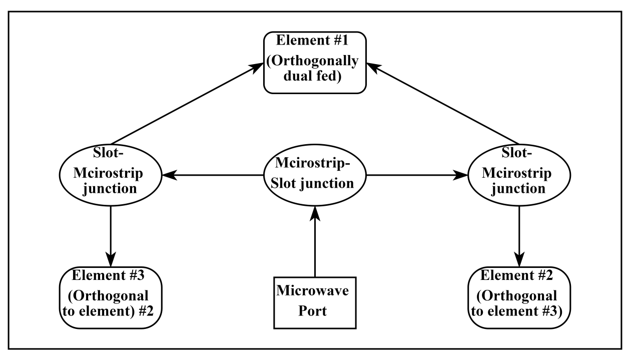


Fig. 1: Basic block diagram of the proposed three element microstrip patch array antenna.

of studies in recent years to accomplish CP for the application in X-band frequency range by combining various array components and various feeding mechanisms, each of which has its own limitation [13]–[15].

This study presents a single-fed, three-element patch array antenna that can operate in both linear and circular polarization for both senses. Three patches are fed by a single port input signal in the proposed work's idea block diagram as shown in Fig. 1. A microstrip-slot and two slot-microstrip junctions can distribute the signal to each patch, with element #1 being fed in an orthogonal way and the remaining patches being supplied in a single direction but with orthogonal feeding orientations. Section II discusses the design process while presenting the design materials with accurate specifications and the antenna's functioning mechanism. With a conclusion in section IV, section III gives the findings certifying the concepts' successful execution.

II. Antenna Geometry Design

A. Structure of the Antenna

As illustrated in Fig. 2, on top of a Teflon substrate with a relative dielectric constant of ϵ_r = 2.15 there are three square microstrip patches, numbered #1, #2, and #3, each of which can resonate in the X-band frequency. Additionally depicted in the picture is a cross-sectional view of the designed antenna along AA'. In order to create the microstrip to slot junction and

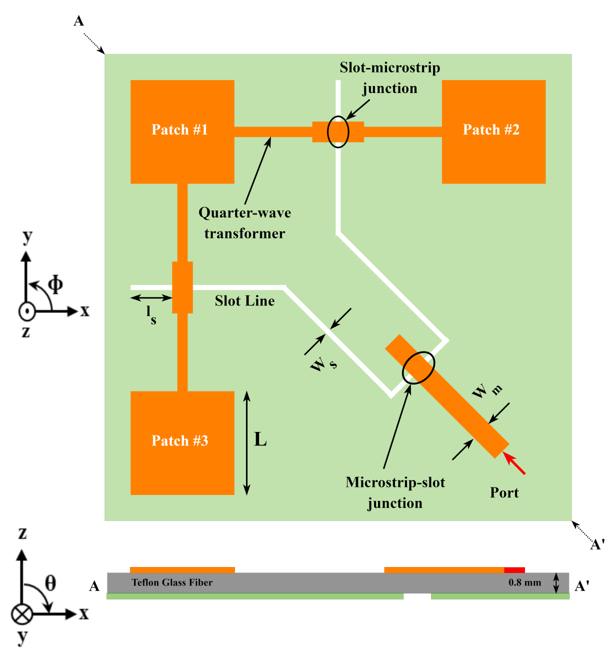


Fig. 2: Geometry of proposed three element microstrip patch array antenna.

the slot to microstrip junction, which serve as equal dividers of the input signal from the port, a slot line having 0.2 mm width of U shape with flared arms ends is cut in the ground plane. The microstrip lines connecting the patches and the slot's flared ends together create the slot-microstrip junction. Two signals from slot-microstrip junctions feed orthogonally patch #1, whereas edge-fed signals from the same junctions feed patches #2 and #3. The slot line in the ground plane was extended by $\lambda/4$ distance in the slot-microstrip junction to improve the isolation of the divided signals from those as denoted by l_s in the figure. The antenna's dimensions and parameters are listed in Table I.

TABLE I: Design parameters of the proposed microstrip antenna array

Parameter	Value
Substrate	Teflon Glass Fiber
Relative dielectric constant, ϵ_r	2.15
Patch length , L	9.7 mm
Microstrip line width, w_m	2.1 mm
$\lambda/4$ slot line length, l_s	4.8 mm
Slot line width, w_s	0.2 mm

B. Antenna Functioning Mechanism

This section demonstrates the antenna's basic operation. Following an explanation of how the antenna can produce circular polarization of both senses.

1) Basic Operation: The fundamental functionality of the proposed three-element microstrip patch array antenna is depicted in Fig. 3. The signal propagates from the input port along the 50 Ω microstrip line and divides into two equal amplitude equal phase signals in the microstrip-slot junction before traveling along the 0.2 mm slot line on the ground plane. When the signals reach the slot-microstrip junction, they split into two equal amplitude reverse phase signals that are sent to the microstrip patch edges through a quarter wavelength transformer. Patch #1 thus contains two equal

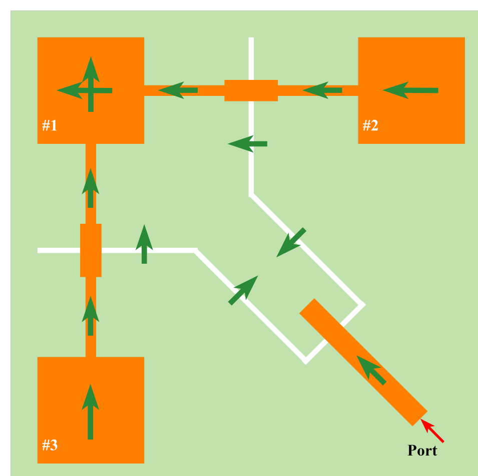


Fig. 3: Schematic diagram of basic behaviour of the proposed array antenna.

amplitude orthogonal electric vectors, while patches #2 and #3 each have one electric vector but are orthogonal to each other. It is worth noting that the electric vectors in patches #2 and #3 have the same amplitude. The green arrow in the picture depicts the direction of the electric field vector as the signal propagates from the input port to the patches. This basic behavior of the patch array radiates in a linear polarization way, as will be detailed in the result analysis.

2) Mechanism of Circular Polarization: As observed in Fig. 3 of the preceding subsection, the electric fields that excite the patches are of equal amplitude for each patch, and for patch #1, they are orthogonal equal phase signals, whereas for patches #2 and #3, the fields are orthogonal to each other and have equal phase. Thus, the antenna end up offering linear polarization. A quarter wavelength phase difference

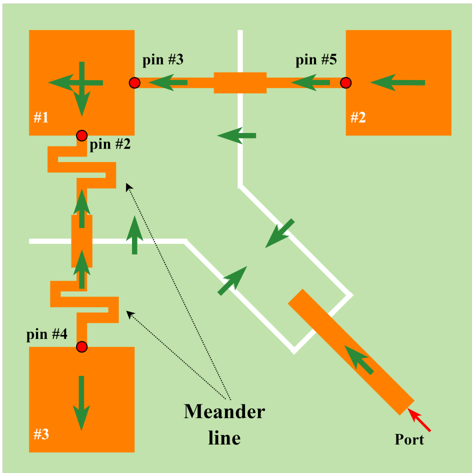


Fig. 4: Schematic diagram of the proposed antenna for circular polarization operation.

between two equal amplitude electric fields orthogonal to each other is necessary to generate circular polarization. A meander line is inserted between patch #1 and the slot-microstrip junction to generate the necessary phase differences between orthogonal electric fields. Because there is no meander line in the microstrip line that feeds the opposite edge of the patch, this provides the necessary phase difference between two equal amplitude signals of patch #1. In order to have a phase difference between the signals of patch #2 and patch #3, another meander line is added between patch #3 and the slot-microstrip junction. As seen in Fig. 4, inserting two meander lines between patches #1 and #3 has no influence on the patches having equal amplitude electric fields as indicated in Fig. 3, but results in a quarter wavelength phase difference. As a result, the antenna is able to produce circular polarization, and for this alignment, the antenna generates left-hand circular polarization (LHCP). Furthermore, meander lines in between patches #1 and #2 provide right-hand circular polarization (RHCP).

The four red circles with black boundary lines assigned at the four ends of the microstrip line are the four pins which are positioned to test the claimed phase difference that they provide to the patches. The simulation was done in Advanced Design System (ADS) by putting four pins at the designated locations as shown in the figure without the patches in the setup i.e. the feed network.

III. Simulation and Result Analysis

The simulation results are reported in this section. First, the feed network was analyzed to determine the phase difference of the network by inserting pins in place of the patch edge and simulation. The antenna is then simulated and analyzed for linear and circular polarization with impedance matching once the patch is inserted. Finally, the radiation pattern for CP is examined, and the effect of meander line lengths on CP is studied.

A. Phase Difference

Fig. 5 depicts the feed network's phase difference. Four pins were put at the ends of the microstrip line without the meander line and simulated in ADS. After adding meander lines, the simulation was repeated. As seen in the picture,

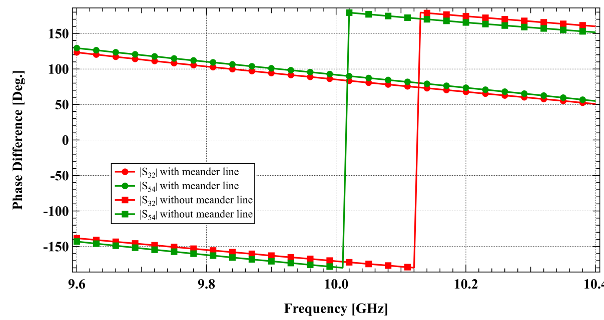


Fig. 5: Phase difference of the feed network.

with no meander lines in the network, the phase difference between pins #2 and #3, as well as pins #4 and #5, is zero at approximately 10 GHz. And with a meander line in the network, the phase difference is 90 degrees at 10.04 GHz. As a result, the claim of achieving phase differences between ports can be validated.

B. Return Loss and Axial Ratio

Following the completion of the feed network analysis, patches of determined length which are suitable for resonating in the X-band frequency are placed into the design, simulated, and the results are assessed. The suggested antenna's return loss and axial ratio are depicted in Fig. 6. The graphic clearly

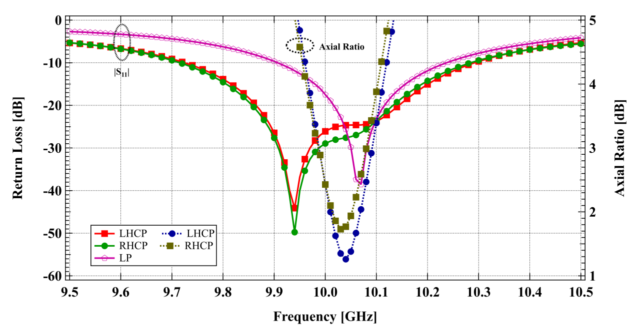
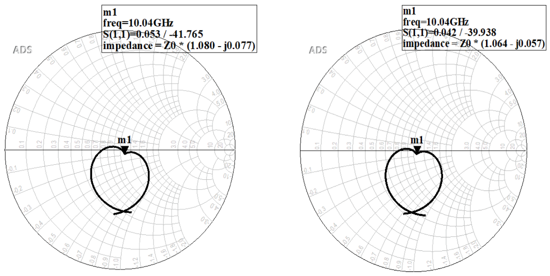


Fig. 6: Simulated return loss for all polarization state and axial ratio for left-hand circular polarization and right-hand circular polarization of the proposed antenna.

shows that the suggested constructed antenna can radiate both linear polarization (LP) and circular polarization (CP) of both senses. The peak and fall of the return loss curve at 10.04 GHz frequency in Fig. 6 suggest that the antenna can produce two orthogonal degenerative modes. The dip near one in the Smith chart, as seen in Fig. 7, also indicates the generation of



(a) LHCP (b) RHCP

Fig. 7: Input impedance of the array antenna on smith chart.

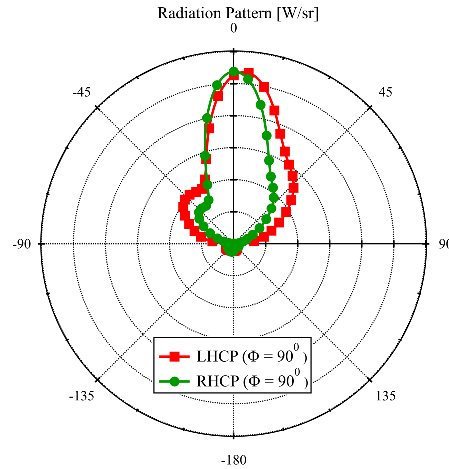


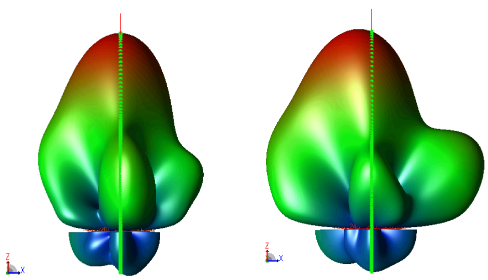
Fig. 9: 2D radiation pattern of the proposed three element patch array antenna.

two orthogonal degenerative modes. As shown in Fig 6, the axial ratio at 10.04 GHz is less than 3 dB for both senses of circular polarization.

The antenna has a linear polarization impedance bandwidth of 300 MHz and a circular polarization impedance bandwidth of 600 MHz. The antenna has an axial ratio bandwidth (ARBW) of 112 MHz.

C. Radiation Pattern

Fig. 8 and Fig. 9 depict the antenna's 3D and 2D radiation patterns, respectively. The figures show that the antenna emits



(a) LHCP (b) RHCP

Fig. 8: Simulated 3D radiation pattern of the proposed three element patch array antenna.

a very well-directed beam in the broadside direction. The 2D radiation pattern is for a sliced plane with a phi of 90 degrees. The pattern is greatest at zero (0) degrees on the polar plot, indicating that the antenna radiates strongly in the broadside direction for both left-hand circular polarization and right-hand circular polarization.

Fig. 10 depicts the simulated gain in dBi for various frequencies, considering both linear and circular polarization. The antenna has a gain of 7.6 dBi at the resonance frequency and a maximum gain of 8.5 dBi throughout the frequency ranges for linear polarization; this is without a meander line in the design. The antenna, which is designed with a meander line, has a gain of 9.1 dBi for left-hand circular polarization and 9.2 dBi for right-hand circular polarization at the resonance frequency and a maximum gain of 9.5 dBi for circular polarization over the frequency range.

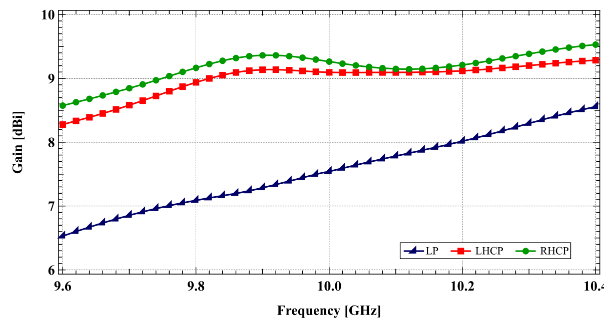


Fig. 10: Simulated Gain for different frequencies of the array antenna.

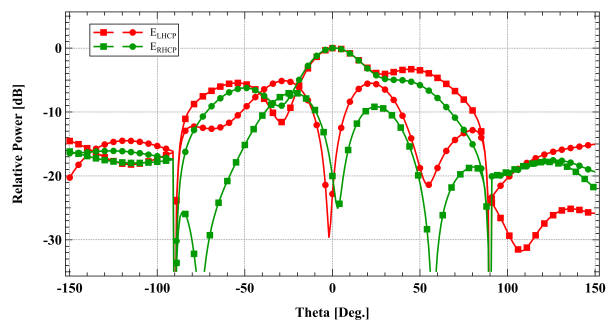


Fig. 11: Simulated relative power for both LHCP and RHCP mode at 10.04 GHz frequency.

The cross-polarization level for both left-hand and right-hand circular polarization is shown in Fig. 11. The graph's red color represents the LHCP level, whereas the green color represents the RHCP level. The square marker represents left-hand circular polarization, whereas the circle marker represents right-hand circular polarization. The figure indicates that the cross-polarization level is greater than 20 dB in both cases, ensuring accurate circular polarization radiation for both senses (LHCP and RHCP).

D. Effect of Meander Line Length

As it was established in the preceding section, the design's meander lines are what produce the necessary quarter-wavelength phase difference between equal amplitude orthogonal signals, leading to the propagation of circular polarization. Therefore, changing the meander line length has a varied effect on how well the antenna performs with circular polarization, and this can be discovered by looking at the axial ratio of the suggested antenna. Fig. 12 depicts the impact of changing the

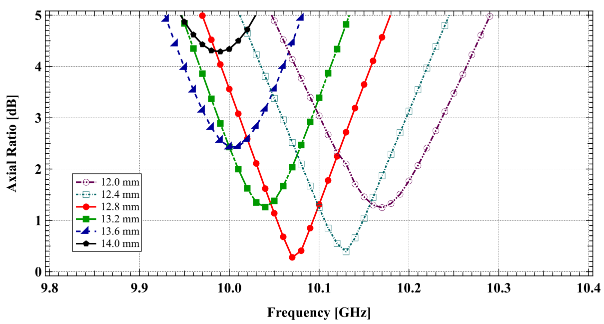


Fig. 12: Effect of meander line length on CP performances of the proposed microstrip array antenna.

design's meander line's length on the axial ratio. The graphic clearly shows that the meander line added to the design has an influence on the CP performance of the antenna. The axial ratio seems to rise in value as the length increases, and for line lengths more than 13.6 mm, it appears to be greater than 3 dB. And lowering the length of the meander line improves the axial ratio, but for lengths smaller than 12 mm, the axial ratio appears to degrade. As a result, choosing the right length results in the proper phase difference between signals, which leads to proper CP radiation. The antenna has an axial ratio bandwidth of up to 140 MHz.

E. Performance Comparison

Table II compares the proposed work's performance to those of other works. The data clearly shows that the antenna performs substantially better as a three element array. The

TABLE II: Perormance comparison of the proposed antenna with other works

[Ref]	No of Element	No of Port	Gain	ARBW
[2]	Four (2 × 2)	Dual	-	-
[3]	Four (2 × 2)	Dual	-	100 MHz
[7]	Four (2 × 2)	Single	4.83 dB	< 1%
[9]	Four (2 × 2)	Single	8.11 dB	< 1%
[11]	Four (2 × 2)	Dual	4.51 dB	160 MHz
[15]	Nine (3 × 3)	Single	1.00 dBi	27 MHz
[This work]	Three	Single	9.50 dBi	140 MHz

majority of current work contains more than four elements in an array. The suggested antenna has a maximum gain of 9.50 dBi, which is significantly superior to the previous works, as well as a substantially better axial ratio bandwidth of 140 MHz. It is also worth noting that the proposed antenna of three elements forming an array with a single feed and obtaining both LP and CP is a relatively new concept to work on, and that some of the comparable previous works use both-sided MIC technology, as shown in Table 2, indicating that the presented work has better performance.

IV. Conclusion

In the fundamental antenna design, the study investigates a three-element microstrip patch array antenna for linear polarization. The meander line in the antenna's design that allows it to radiate both LHCP and RHCP. The simulation results demonstrate that the axial ratio for both polarization senses is less than 3 dB and has an axial ratio bandwidth of 140 MHz. In the simulated frequency ranges, the antenna exhibits a return loss of less than -40 dB and impedance bandwidth of 6%. The constructed antenna has a maximum gain of 9.5 dBi in the X-band frequency range.

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