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A simple feed orthogonal excitation X-band dual circular polarized microstrip patch array antenna

Debprosad Das, Md. Farhad Hossain, Md. Azad Hossain
Department of Electronics and Telecommunication Engineering, Chittagong University of Engineering and Technology, Chattogram, Bangladesh

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ABSTRACT

This work represents a microstrip patch array antenna which is designed and analyzed for the application of circular polarization in X band frequency range. The proposed antenna array has a very simple microstrip line feeding mechanism and each patch is energized orthogonally to acquire circular polarization without the need for any phase shifters. The array antenna has a slot line in the ground to electrically couple the signals from the microstrip feed line to feed each patch. The outcome demonstrates that the antenna is capable of radiating both left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP). The designed work has a return loss of -41.88 dB, that is the antenna is perfectly matched. The outcome also demonstrates the antenna's strong gain and directivity capabilities, which are 12.87 dBi and 13.30 dBi, respectively. The antenna resonates circularly at a frequency of 10 GHz.

Corresponding Author:

Md. Azad Hossain
Department of Electronics and Telecommunication Engineering, Chittagong University of Engineering and Technology
Kaptai Highway Road, Pahartali, Raozan, Chittagong-4349, Bangladesh
Email: azad@cuet.ac.bd

1. INTRODUCTION

Due to the simultaneous existence of both linear polarization directions, circular polarized antennas have desirable advantages over linear polarized antennas in terms of flawless transmission between sender and receiver signals. As well, they are a strong contender in the constantly evolving field of wireless military and civilian communication, which includes radar and satellite communications [1]–[5]. For the researchers, a microstrip patch array antenna is an excellent pick for obtaining circular polarization. Because of its remarkable design versatility and ease of use [6]–[8]. An antenna capable of radiating just one sense of circular polarization, either left-hand circular polarization (LHCP) or right-hand circular polarization (RHCP), has the drawback of being unable to receive other sense circular polarized signals. When multipath fading happens for a circularly polarized signal, the circular polarization (CP) handedness changes in its path, and a mismatch arises at the receiving end. As a result, having both handed CP radiation from the same antenna is both essential and desirable [9]. Several studies have been conducted in the past in order to acquire circular polarization of both senses (LHCP and RHCP) by employing a microstrip patch as an array element [10]–[13] and a dual circular polarized antenna has an attractive advantage in case of several communication systems along with target detection [14]–[15].

The fundamental idea behind forming a circularly polarized antenna is to excite the circuit so that there are two electric field components that are orthogonal to one another and that there is a quarter-wavelength phase shift between them. In order to achieve circular polarization for a microstrip patch antenna, two orthogonal resonant modes must be excited with a 90-degree phase shift between them. For the purpose of obtaining circular polarization, numerous experiments on microstrip patch antennas have been conducted. A square slot carved out of an elliptical patch is seen in [16]. The antenna tunes in two nearly-spaced resonance modes and finally produces circular polarization due to the slot length fluctuation inside the patch. Circular polarization can also be produced by the circular slot in a patch. In a patch, two asymmetric circular slots can cause the generation of two orthogonal modes, and as the number of slots is increased, both single-band and dual-band circular polarization can be produced [17], [18]. A dual-feed technique to obtain left- and right-handed circular polarization is a popular choice. But the single-feeding method of circular polarization has a number of advantages over the dual-feeding method since it simplifies the design [19]. Sequential feeding in an array arrangement to achieve right- and left-hand circular polarization is explained in [20], where two different elements show different polarization diversity. Each element is corner truncated to acquire circular polarization with a dual feed and complex aperture feed network. In [21], a series feed of five circular patches with a center slot in each element is shown to acquire CP and has a dual feed technique to acquire both-handed circular polarization. In [22], the feed network is simplified by a probe feed to a central patch but requires a dual feed technique.

In this study, a 2×2 microstrip patch array antenna is proposed, where each patch excited orthogonally, to obtain circular polarization by simple feed. Signals from the microstrip feed line are delivered to each patch by the structure using both-sided MIC technology. To have flexibility and compactness in the overall design, both-sided MIC technology is integrated into the structure [23], [24]. The proposed work has a drawback in terms of the ability to propagate circular polarization in both the left and right hands at the same time. A four-element array serves as the antenna and diagonal patches propagate in the same polarization sense. Incorporating the meander line into the modified design solves the drawback. This work is simulation-based and organized here in the following manner: structural description, outcome, and conclusion.

2. PROPOSED ANTENNA DESIGN

This section describes the suggested antenna design approach along with the working principle and any modifications needed to acquire CP. First off, the antenna that is suggested in this paper is made with CP acquisition in mind. The renovated design is then presented after going over the array's basic operating principle.

2.1. Design method and dimension

The dimensions and design structure of the proposed antenna array is shown in Figure 1. Four microstrip square patches are etched on top of a 0.8 mm thick teflon glass fibre substrate of relative dielectric constant 2.15. An 0.2 mm slot line is created in the ground plane. A microstrip line of 50 Ω impedance receives input signal from the port, which then propagates to a slot line through a microstrip-slot branch (denoted by solid line circle in the figure). Two microstrip lines from slot-microstrip junctions (denoted by dotted line circle in the figure) feed orthogonally into each patch of the array, and both junctions draw their power from the same slot line.

The microstrip-slot junction is a parallel divider, hence the slot line impedance had to be double that of the microstrip line impedance [25]. As a result, the slot line impedance is 100 Ω. And the slot-microstrip junction forms the series divider.

The slot line is extended by quarter wavelength for improved isolation is denoted by l_s. D is the distance between two slot-microstrip junctions. W_m is the width of the microstrip line. l_t and l_{to} are the length of two orthogonal quarter wave transformers coming from slot-microstrip junctions. All the dimensional parameters of the design and their optimized values are recorded in Table 1.

2.2. Working principle of the array

As the signal propagates through microstrip line, it splits into two equal in phase signal in the microstrip-slot junction (denoted by circle) and then again splits into two equal out of phase signal in the slot-microstrip junction (denoted by dotted circle). As shown in Figure 2, green colored arrow and blue colored arrow indicates in phase and out of phase signal respectively. Two microstrip lines that originate from two successive slot-microstrip junctions that develop in the same slot line connect each patch orthogonally.

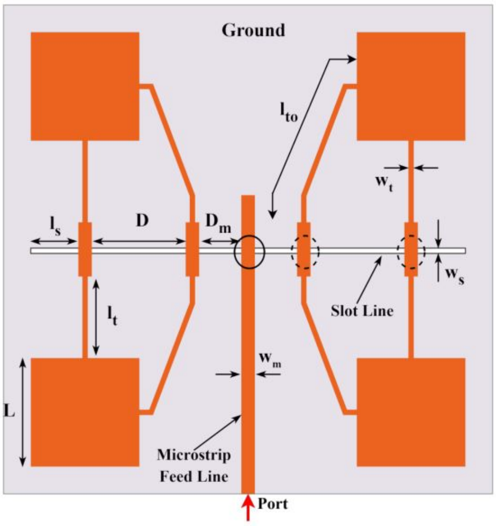

Figure 1. Geometry of the proposed circular polarized microstrip array antenna

Table 1. Design parameters of the proposed circular polarized microstrip patch array antenna

Parameter	Value
Patch dimension, L×L	9.7 × 9.7 mm^2
Copper thickness (ground, patch)	0.018 mm
Slot-line width, w_s	0.2 mm
Microstrip feed line width, w_m	1.6 mm
Quarter-wavelength transformer width, w_t	0.6 mm
Quarter-wavelength transformer length, l_t	7.8 mm
Orthogonal transformer length, l_{to}	15.44 mm
Slot-line stub length, l_s	4.8 mm
Line to line distance, D	10.5 mm
Line to line distance, D_m	4.4 mm

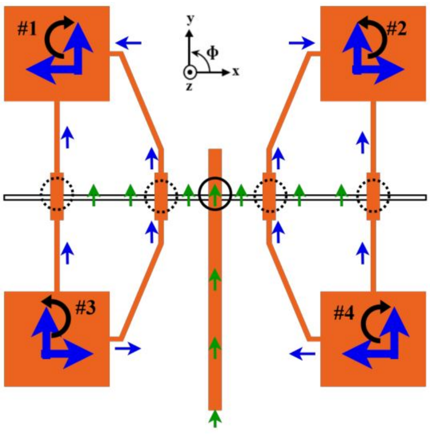

Figure 2. Schematic diagram of the proposed circular polarized microstrip array antenna

All of the signals are of equal amplitude, but the U-shaped microstrip lines' longer length than the other lines ensures a 90^0 phase shift between the two orthogonal signals. Thus making each element of the array possible to propagate in a circular polarized manner. Moreover, the feed network is constructed in such a way that patches #1 and #4 and patches #2 and #3 receive a comparable field distribution. Hence, patch #1 and #4 radiate in a left-handed fashion, but patch #2 and #3 radiate in a right-handed circular manner.

In this design process, we can see that the antenna is capable of producing both right- and left-handed circular polarization in a single array. However, as they are in opposition to one another when propagating, this type of propagation cancels each other out. In the following sub-subsection, the issue with this shortcoming is addressed.

2.2.1. Modified design

Two arms of the U-shaped microstrip line are out of phase because, as can be seen in Figure 2, they originate from a slot-microstrip junction. Therefore, the horizontal electric fields in patches #3 and #4 are in the opposite direction from each other as is the horizontal electric field, E_x of patches #1 and #2. The orthogonal patches radiate in two separate-handed polarizations as a result of this feed network's orientation. This issue may subside with a meander line. As shown in Figure 3, the E_x field line is oriented in the same direction due to the meander line in the orthogonal arm of the U-shaped microstrip line.

Figure 4 shows the capacity of the meander lines to make the out-of-phase signals to in-phase signals at the microstrip line ends denoted by yellow colored black line circle (as shown in Figure 3). The simulation for this purpose was done by inserting four pins (Pin #1, #2, #3, and #4) in place of the yellow-colored circle without patches. However, Left-hand circular polarization (LHCP) is produced by a meander line in the microstrip lines' arms, which feed patches #2 and #3. Additionally, a meander line (in place of the dotted circle in Figure 3) is used to provide right-hand circular polarization (RHCP) in the microstrip lines that feed patches #1 and #4. Also, the U-shaped microstrip line is slightly modified to fit accordingly the meander line into the design.

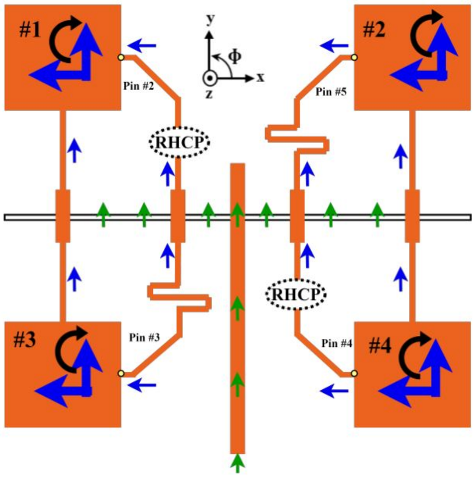

Figure 3. Schematic diagram of the proposed circular polarized microstrip array antenna with meander line in the microstrip feed line

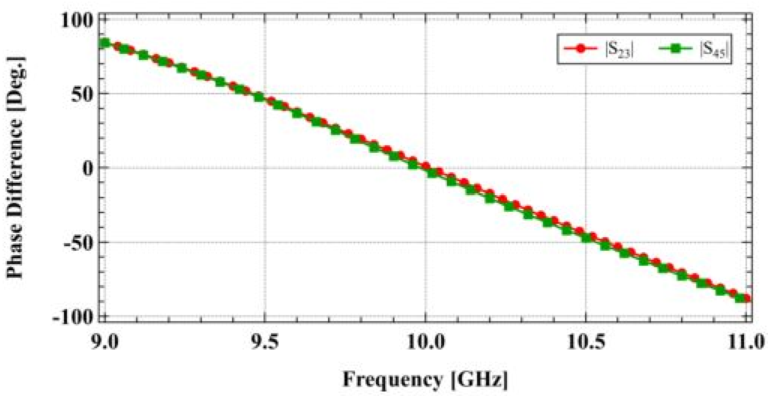

Figure 4. Phase difference between ports of the feed network

3. RESULTS AND DISCUSSION

This part, which is broken up into two subsections, analyzes the simulated outcomes of the suggested design. The design without a meander line is discussed in the first subsection, where the proposed microstrip array antenna is first constructed, followed by a parametric analysis that involves adjusting a number of dimensions, which is then evaluated to determine the optimal outcomes. Data from simulations with a meander line are in the second subsection.

3.1. Without meander line

In this subsection, the suggested antenna's optimal results for the X band frequency range are shown together with some of the antenna's other parameters for the design of the antenna without meander line. In this section the antenna is optimized for the proposed frequency range with parametric analysis and observed if the elements of the array are capable of producing CP.

3.1.1. Parametric study

In this work, slot stub length (l_s), orthogonal microstrip length (l_{to}), and various length for microstrip line spacing (D_m) above the slot line is studied. In Figures 5 to 8, the return losses for various dimensions are depicted. As it can be seen from Figure 5 that varying slot stub length has little impact on the circular polarization of the proposed array. It only has an impact on the impedance matching of the array. Also, it does not have an effect on impedance bandwidth.

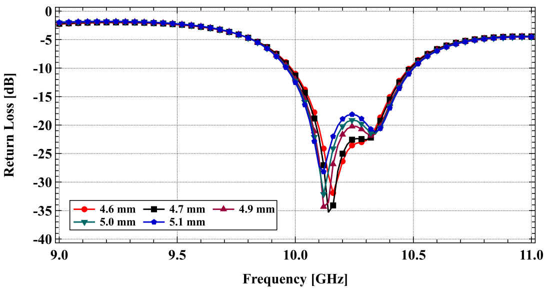

Figure 5. Return loss of the proposed microstrip array antenna for various slot stub length l_s

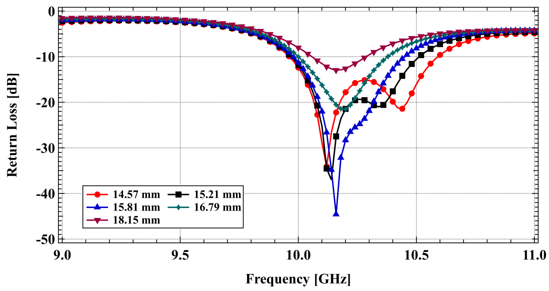

Figure 6. Return loss of the proposed microstrip array antenna for various length l_{to}

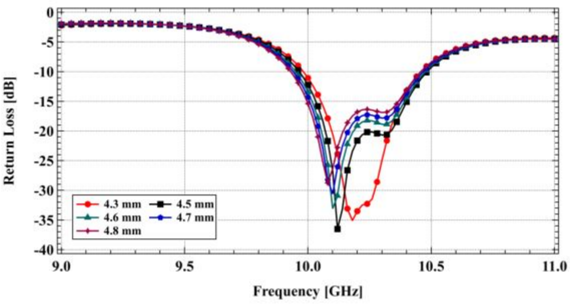

Figure 7. Return loss of the proposed microstrip array antenna for various lengths D_m

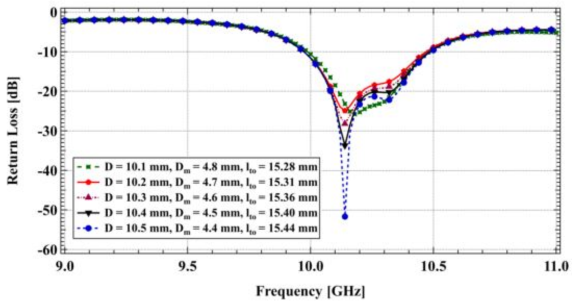

Figure 8. Return loss of the proposed microstrip array antenna for various length parameters

In Figure 6, return losses for various length of the U-shaped microstrip line, l_{to} is shown. The graphic makes it evident that for lengths longer than 16 mm, the suggested array antenna's impedance bandwidth increases but its impedance matching reduces. Due to its inability to offer the 90-degree phase shift with length reduction, the antenna loses its ability to provide circular polarization for lengths smaller than 15 mm.

Figure 7, return loss for various spacing lengths between two microstrip lines above the slot line is shown. And in Figure 8 Return losses for several spacing parameters among microstrip lines, and to compromise with that length to keep the array in a square shape, different microstrip line lengths, l_{to} are shown. It is seen that only impedance matching of the antenna varies with this dimensional variation. And from these analyses optimized dimension for the array is selected and simulated.

3.1.2. Optimized results

Following several simulations, the proposed antenna's optimum outcome is attained. The antenna exhibits an excellent radiation pattern. The circular polarized microstrip array antenna's 3D radiation pattern is depicted in Figure 9, where well-directional beam is evident.

Figure 10 depicts the proposed antenna's return loss. At its resonance frequency of 10.14 GHz, the antenna is shown to be properly matched and has a return loss of -51.68 dB. The antenna has a -10 dB return loss range from 9.95 to 10.50 GHz, indicating an impedance bandwidth of 5.38 %. A dip in the graph of Smith chart as shown in Figure 11 at about 10.26 GHz suggests that the antenna can produce two closely spaced orthogonal resonant modes, which produce circularly polarized radiation [26]. Moreover, in Figure 10, the fall and rise of the curve at 10.26 GHz shows that the antenna is circularly polarized at that frequency. The antenna has a high gain and directivity in the X-band frequency range. The gain and directivity versus frequency curve of the proposed antenna is shown in Figure 12.

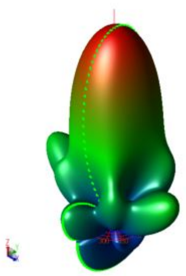

Figure 9. 3D radiation pattern of the proposed circular polarized microstrip array antenna

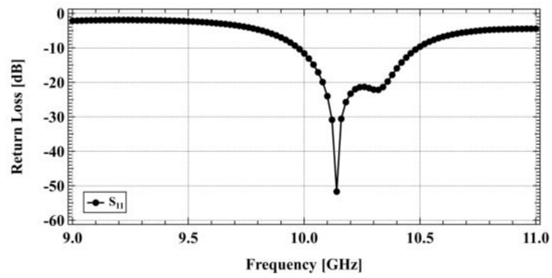

Figure 10. Optimized return loss of the proposed circular polarized microstrip array antenna

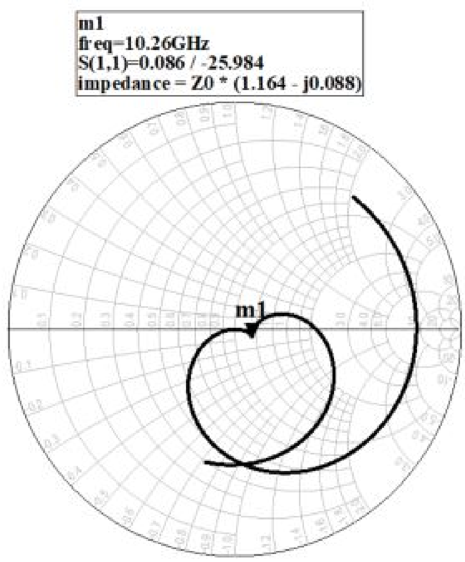

Figure 11. Smith chart of the proposed circular polarized microstrip array antenna

It demonstrates that in the X band frequency region, it has a maximum gain and directivity of 12.56 dBi and 13.19 dBi, respectively. Moreover, it has roughly 10.59 dBi gain and 10.81 dBi directivity at

10.26 GHz, making it a high gain and well-directed antenna. The antenna has a side lobe gain of less than 10 dB as depicted in Figure 13 and a maximum gain of 23 dB at $\theta = 0^0$ which is in the direction of propagation that is broadside direction.

Figure 14 depicts the presented antenna's current distribution. As can be seen from the illustration, the antenna's diagonal patches radiate similarly. The diagonal patches' electric field vectors are parallel to one another.

So, the electric field vectors of two patches rotate in a clockwise direction, whereas the field vectors of the other two patches rotate in an anti-clockwise direction. Therefore, right-hand and left-hand circular polarization is obtained from the same array, which is a disadvantage of the antenna since two different-handed polarizations that propagate simultaneously can cancel out one another.

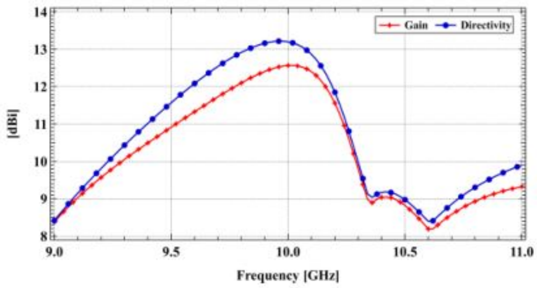

Figure 12. Gain and directivity versus frequency of the proposed microstrip array antenna

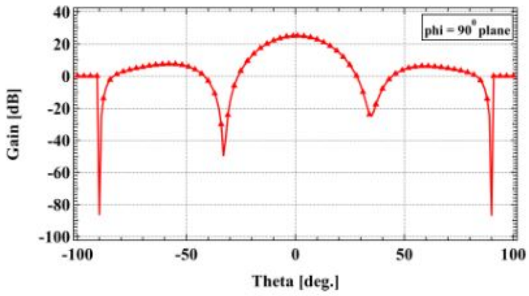

Figure 13. Gain of the proposed circular polarized microstrip array antenna. $\Phi = 90^0$ cut

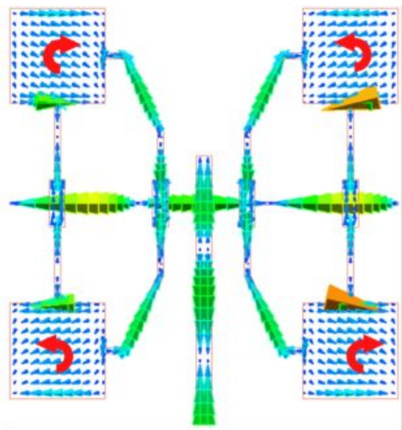

Figure 14. Current distribution of the proposed circular polarized microstrip array antenna without meander line. Phase 0°

3.2. With meander line

The horizontal electric field direction can be turned around by adding two meander lines to the U-shaped microstrip line's arm, which causes the entire array to propagate with the same-handed polarization. This section presents the outcomes after a meander line has been added. Additionally, a little shift in resonance frequency is made to achieve circular polarization at 10 GHz by modifying the design's dimension. The patch array is 1.2×1.2 mm^2 larger than the patch array without meander line, bringing the total array size to 41×41 mm^2.

The simulated return loss for the suggested antenna design with meander lines is shown in Figure 15. The figure makes it obvious that the antenna exhibits good impedance matching in the X band frequency spectrum with a return loss of -41.86 dB at a frequency of 9.88 GHz. The rise and fall of the curve at frequency 10 GHz point to two orthogonal modes with closely separated resonance frequencies, which is essential for circular polarization.

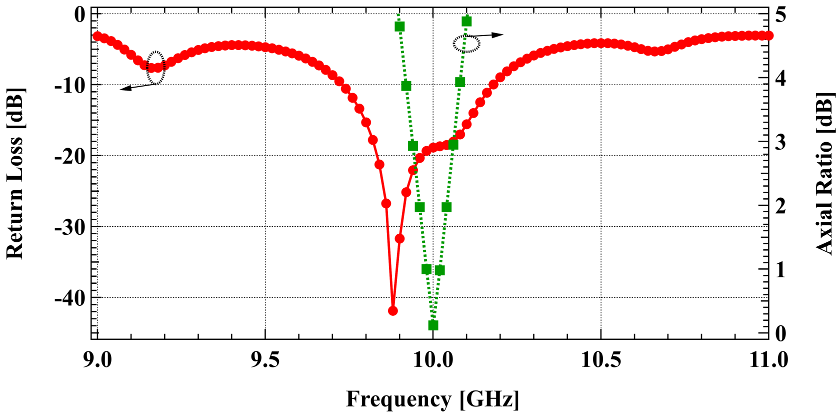

Figure 15. Return loss and axial ratio of the antenna for RHCP

The figure also shows that the antenna's impedance bandwidth is 460 MHz, with a -10 dB return loss range between 9.72 GHz and 10.18 GHz. The figure additionally demonstrates that the axial ratio is 0.12 dB at 10 GHz frequency, near the place where the return loss curve peaks and dips, indicating two orthogonal resonant modes. Thus, the antenna can produce CP radiation at a frequency of 10 GHz.

When a meander line is added to the design's feeding network, the array can operate as either a left-hand or right-hand circular polarization antenna, depending on which arm has meander lines. Due to the meander lines, all patches radiate uniformly. When the entire array performs as an LHCP or RHCP antenna, the gain and directivity of the array antenna increase in comparison to the array without a meander line in the design. Figure 16 displays the simulated gain and directivity of the proposed antenna for RHCP. At 10 GHz, the antenna's gain and directivity are 2.28 dB and 2.49 dB greater than those of the array without a meander line, respectively. The antenna's directivity is 13.30 dBi, and its gain is 12.87 dBi at a resonance frequency of 10 GHz.

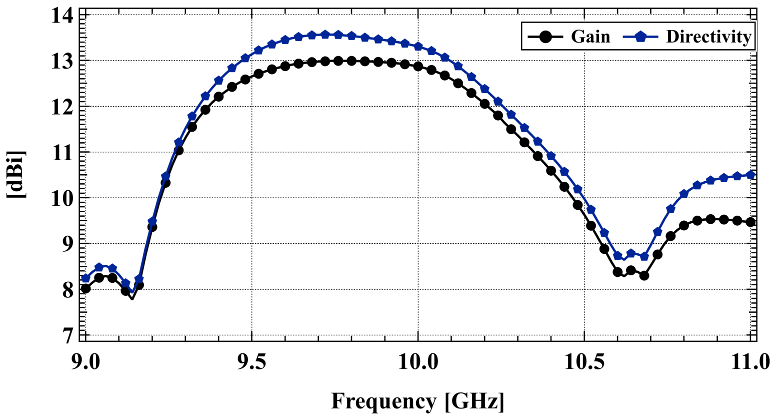

Figure 16. Gain and directivity versus frequency of the proposed antenna for RHCP

Figure 17 and 18 illustrate the current distributions of the proposed antenna array for RHCP and LHCP operations, respectively. Patches #1 and #4 release energy with right-handed circular polarization, as can be observed in Figure 14. In order to make them match the distribution of the other two patches, the meander line in the arms of the U-shaped microstrip lines, feeding those patches reverses the direction of the horizontal field distribution. As a result, patches #2 and #3 radiate similarly with the two patches (patch #1 and #4). This results in right-hand circular polarization throughout the entire array antenna.

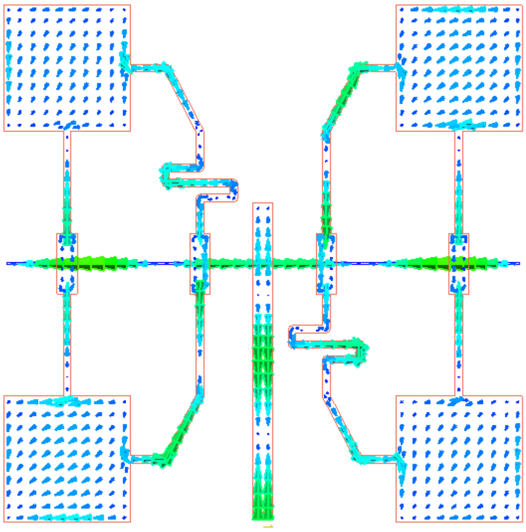

Figure 17. Current distribution of the proposed circular polarized microstrip array antenna operated in RHCP mode. Phase 0°

Similar to this, when there are no meander lines in the corresponding feeding microstrip lines for patches #1 and #4, the meander line in the arms of U-shaped microstrip lines feeding patches #2 and #3 alters the fields in a way that matches the field distribution with those patches. With the meander line present, patches #2 and #3 radiate in a LHCP fashion, whereas they were previously radiating in a RHCP manner.

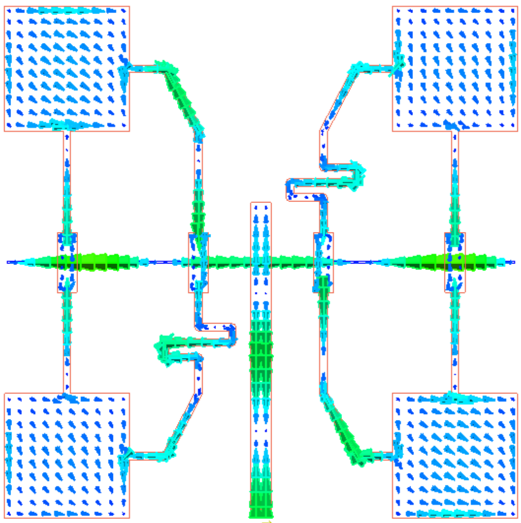

Figure 18. Current distribution of the proposed circular polarized microstrip array antenna operated in LHCP mode. Phase 0°

As is evident from the Figures 17 and 18, the surface current for the antenna intended for RHCP operation moves in the opposite direction of the surface current for the antenna designed for LHCP operation. Also, it is evident in both situations that the feeding network has been slightly altered from the design without a meander line shown in Figure 14. The adjustment is made in order to incorporate the meander line into the design. The proposed antenna's radiation pattern for RHCP and LHCP operation is shown in Figures 19 and 20 respectively.

It is clear from both figures that the antenna can radiate both RHCP and LHCP operations. Figure 19 shows that the cross-polarization level for RHCP operation is larger than 42 dB. When an antenna is intended to operate with LHCP, a similar outcome is seen in Figure 20. Therefore, the radiation pattern from both figures shows that the proposed circular polarized array antenna has outstanding radiation performance for both RHCP and LHCP operations.

As previously shown in Figure 4, the meander line in the design is the basis for an accurate CP array, it can be clearly stated that the length will have an influence on the overall CP performances of the array antenna. Figure 21 depicts the influence of meander line length on array antenna CP performance as well as impedance performance.

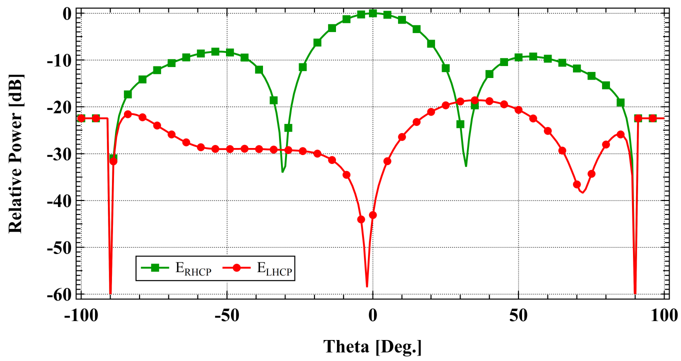

Figure 19. Radiation pattern of the proposed design for RHCP operation

According to the graph, the antenna performs best for CP and impedance matching at a meander line length of 13.2 mm. When the line length is more than 14 mm or less than 12.4 mm, both CP and impedance performance decline but the bandwidth percentage stays constant. The axial ratio bandwidth is approximately 132 MHz.

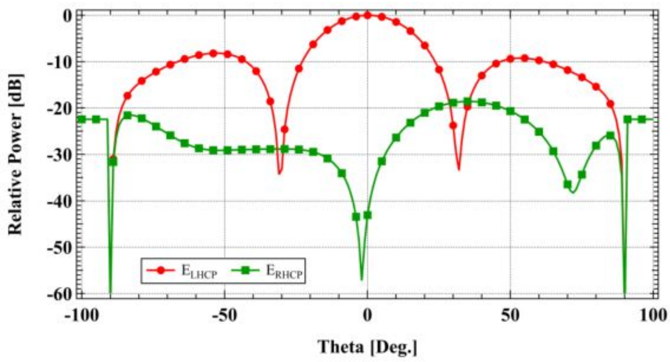

Figure 20. Radiation pattern of the proposed design for LHCP operation

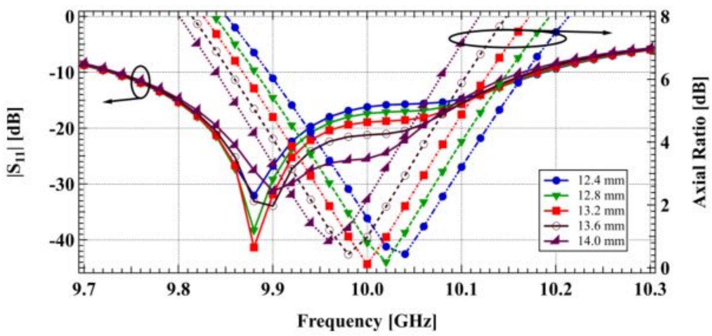

Figure 21. Effect of meander line length on the microstrip array antenna operated in LHCP mode

4. CONCLUSION

This study designs and analyzes a circularly polarized microstrip patch array antenna for X band application. Without modifying the feed position or the feed mechanism, the work that is being presented simultaneously radiate both left and right hand circular polarization. Meander line in the feed network resolves the issue end up increasing gain and directivity of the array. The designed antenna has a return loss of -41.88 dB and exhibits good impedance matching. The radiation pattern of the antenna exhibits a well-directional pattern. and it has a directivity of 13.30 dBi and a high gain of 12.87 dBi at 10 GHz. The antenna's circular polarization resonance occurs at a frequency of 10 GHz. The antenna has a 3 dB axial ratio bandwidth of 132 MHz and excellently radiates CP at 10 GHz.

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BIOGRAPHIES OF AUTHORS

Debprosad Das received the B.Sc. degree in electronics and telecommunication engineering from Chittagong University of Engineering and Technology, Chattogram, Bangladesh in 2018. Currently pursuing an M.Sc. degree in electronics and telecommunication engineering under the supervision of Prof. Dr. Md. Azad Hossain. He is currently working as a research assistant at the Department of Electronics and Telecommunication Engineering under Prof. Dr. Md. Azad Hossain. His research interests include antenna design, related circuit simulation, performance analysis, and artificial intelligence. He can be contacted at email: u19mete024p@student.cuet.ac.bd, debudas670@gmail.com.

Md. Farhad Hossain received the B.Sc. degree in electronics and telecommunication engineering from Chittagong University of Engineering and Technology, Chattogram, Bangladesh in 2018. Currently pursuing an M.Sc. degree in electronics and telecommunication engineering under the supervision of Prof. Dr. Md. Azad Hossain. Presently he is working as a lecturer at the institution. His research interests include antenna design and related readout circuit simulation, experimental analysis, and artificial intelligence. He can be contacted at email: farhad.hossain@cuet.ac.bd.

Md. Azad Hossain (MIEEE) was born in Dhaka, Bangladesh, in 1981. He received his B.Sc. degree in electrical and electronic engineering from Rajshahi University of Engineering and Technology (RUET), Rajshahi, Bangladesh, in 2004. The M.Sc. degree in EEE from Saga University, Saga, Japan, in 2010; and the Ph.D. degree in Science and Advanced Technology, in 2013 from the same Institute. From 2013 to 2014, he was with Chittagong University of Engineering and Technology (CUET) as a lecturer. Presently he is working as a professor, Head of the department of ETE at CUET. His research interests include microwave antenna design and related readout circuit simulation and experimental characterization. He can be contacted at email: azad@cuet.ac.bd.