International Journal of Electrical and Computer Engineering (IJECE)
Vol. 13, No. 1, February 2023, pp. 619~628
ISSN: 2088-8708, DOI: 10.11591/ijece.v13i1.pp619-628

An improved 2×2 array antenna using both-sided microwave integrated circuit technology for circular polarization

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Article Info

Article history:

Received Feb 7, 2022
Revised Sep 26, 2022
Accepted Oct 7, 2022

Keywords:

Axial ratio
Both-sided microwave integrated circuit
Polarization
Radio frequency signal
Reflection coefficient
Triple feed

ABSTRACT

A circularly polarized microstrip patch array antenna using both-sided microwave integrated circuit (MIC) technology with a triple feed network has been proposed in this article. The antenna elements, feed structure and both-sided MIC technology are used and arranged in such a way to obtain circular polarization alongside high gain without using an external matching circuit. The 50 Ω microstrip line is used to energize the antenna where the antenna's total feed network is made up of both series and parallel combinations of microstrip and slot line. The antenna was realized using Teflon glass fiber substrate *(ε_r)*=2.15 with a thickness of 0.8 mm. The antenna has some splendid parameters including S_{11} of less than -35 dB, a gain of 12 dBi with an omnidirectional pattern and an axial ratio of 0.7 dB at the operating frequency. The antenna possesses a bandwidth of 430 MHz (4.22%) after operating at X-band in the frequency spectrum. The antenna's simulated parameters were investigated with the help of advanced design system (ADS) simulation software in microwave momentum mode.

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1. INTRODUCTION

Since last few decades, microstrip antenna [1]–[40] and microstrip patch array antenna has received attention in microwave communication technology for its compact lightweight weight, low volume, low cost, easy fabrication and compatibility with integrated circuits [1]. Though the technique is feasible for both linear and circular polarization (CP), circular polarization is promptly designed for its special features over linearly polarized antenna. Usually, linearly polarized antennas are easy to design and require transmit and receive antennas to be in same polarization, but circular polarized antenna emerge better flexibility on the orientation of the receiver antenna with respect to the transmit antenna [2]. Circular polarized antennas are more preferable due to their intrinsic proficiencies of reducing multi-path fading, improvement in coverage area and fixed polarization [3]. For immunes to Faraday rotation, circular polarized antennas are used in almost all Earth-satellite communication systems [4]–[6].

Generation of circular polarized electromagnetic waves in antenna involves provoking two equal amplitude orthogonal degenerate modes. The excitation position alongside with excitation technique of an antenna decides the impedance bandwidth of the antenna. The usable bandwidth of a CP patch antenna is the overlapping bandwidth of impedance bandwidth (VSWR<2 or S_{11}<-10 dB) and axial ratio bandwidth

(AR<3 dB). To meet this requirement there is various approaches have been emerged in recent days to create CP where the same phenomena are inherent of creating orthogonal degenerate mode behind every approach that is applied on the patch including single, dual feed, and sequential feed. The single feeding technique includes numerous current perturbation techniques like incorporating cross slots [7], slits [8], stubs [9], spur lines and truncated corners [10]. The coaxial feed technique also can be considered as a simple technique under a single feed mechanism for creating CP and proposed in recent years [9]–[11]. This simple technique suffers from low impedance and axial ratio (AR) bandwidth response. Murshed *et al.* [7] proposes a reconfigurable structure that has low AR bandwidth (BW) with low omnidirectional gain, however, wide impedance BW is due to partial ground plane and parasitic radiator. Similarly, a small impedance BW and AR BW was spotted in [8], [9]. In study [10], U-shaped slot increased impedance BW although suffers from a low gain (4.5 dBi) and AR BW (3.2%).

The dual-feed technique can allow having greater AR BW at the expense of a large ground plane compared to single feed technique. Wong *et al.* [12] proposed a dual-feed CP antenna having AR BW of 35% (center frequency 1843 MHz) backed by a Wilkison-power divider containing a resistor on it to ensure more isolation between elements at the expense of reduced gain due to resistor. Apart from, quadrature hybrid [13], the ring hybrid, and the T-junction develop circular polarization [1].

A multilayer configuration of a 2×2 slot-ring array antenna and 1×2 microstrip slot array antenna with an orthogonal feed circuit is mentioned in [14] and [15] for orthogonal circular polarization. In studies [17]–[19], PIN diodes are used in array antenna to achieve circular polarization. To operate in LHCP, RHCP and linearly polarized (LP), a corner truncated square microstrip array antenna that used PIN diodes has been proposed in [21]. Further, a linearly polarized array antenna can be used for circular polarization with dual feeding arrangements [26]. In these array arrangements, two linearly polarized antennas are placed orthogonal to each other with one of them being fed 90° out of phase. The sequential feed technique also uses to achieve CP characteristics in microstrip antenna [27].

In this article, a triple feed circuit has been introduced to achieve circular polarization with wide AR BW in a microstrip array antenna. The author has already reported a microstrip antenna of triple feed network in [28]. Compare to [28], the proposed antenna of this article presents in depth analysis of all the necessary antenna parameters with a numerical value to grasp the reader's attention and highlight the novelty of this technique for realizing the CP antenna which is absent in [28]. This makes the proposed antenna incomparable with the antenna in [28]. This proposed antenna has better impedance matching with wide 3dB AR and appeared to be the upgraded CP version of that previously published CP antenna in [28].

Furthermore, the structural complexity of previous design has been removed and has got efficient data and impedance matching at a certain frequency. This proposed antenna consists of 2×2 array antenna elements to enhance the gain, microstrip lines alongside with microstrip slot lines. In addition, single-feed is converted into a triple feed circuit in the proposed antenna that helps to achieve wide AR BW. "Both-sided microwave integrated circuit (MIC) technology" has been employed in this antenna to maintain design flexibility [28], [31]. The microstrip lines and array elements are placed on the obverse side and microstrip slot lines are on reverse side to reduce the complexity of impedance matching circuits in microstrip array antenna. In this proposed antenna, the circular polarization in each patch element is ensured by feeding each of them an orthogonal radio frequency (RF) signal through a triple feed network circuit.

2. THE PROPOSED ARRAY ANTENNA STRUCTURE

An array antenna is made up of four square-shaped patch elements and employing a feed network composed of both microstrip lines and slot-lines are proposed. Both patches and microstrip lines are realized on obverse layers of dielectric material and a slot line in the ground plane. The proposed triple-feed array antenna was initially decorated on advanced design system (ADS) simulation software to operate at 10 GHz frequency.

Figure 1 illustrates the proposed 2×2 array antenna with its schematic layout where Figure 1(a) depicts top view and Figure 1(b) cross-sectional view. For the dielectric substrate, Teflon glass fiber is used with a thickness of 0.8 mm and relative permittivity (ε_r) of 2.15, while the main patch elements and ground plane are realized with the help of lossy Copper with thickness of 0.018 mm. Each squared patch element possesses a side length of 9.46 mm, is linearly polarized and placed at an angle of 90° with respect to a horizontal plane. To excite patch elements, each patch element is fed by both vertically and horizontally feed lines that create a 90° phase difference between two of the patch elements which are fed orthogonally. This arrangement helps to gain two orthogonal waves to excite circularly polarized waves. Each patch element on the obverse side is equally distanced from the slot line and a quarter wavelength (λ/4) impedance transformer has been employed to match the impedance perfectly between each patch element and slot microstrip branch circuit. In addition, to maintain a 90° phase difference between two orthogonal feed signals of the squared patch elements, the feedline length at the right side of the antenna is determined in such a way that the feedline length is a quarter wavelength (λ/4) greater than that of left side of the antenna. This arrangement makes sure that the proposed triple feed array antenna is excited for circular polarization after creating two orthogonal degenerate modes which are essential for the generation of CP.

2.1. The both-sided MIC technology

Basically, the feed circuit is a different combination of both a microstrip-slot parallel branch circuit and a slot-microstrip series branch circuit. Those combinations reduce the number of impedance matching circuit and generate orthogonal signals in each squared patch element. To obtain a feed network in this array, both-sided MIC technology is employed as it allows employing microstrip alongside with slot line on both sides of the substrate at a time [28], [30], [31] and simple circuit configuration of the antenna [28]. The circuit branch point of the proposed array antenna using both-sided MIC technology is illustrated in Figure 1(c).

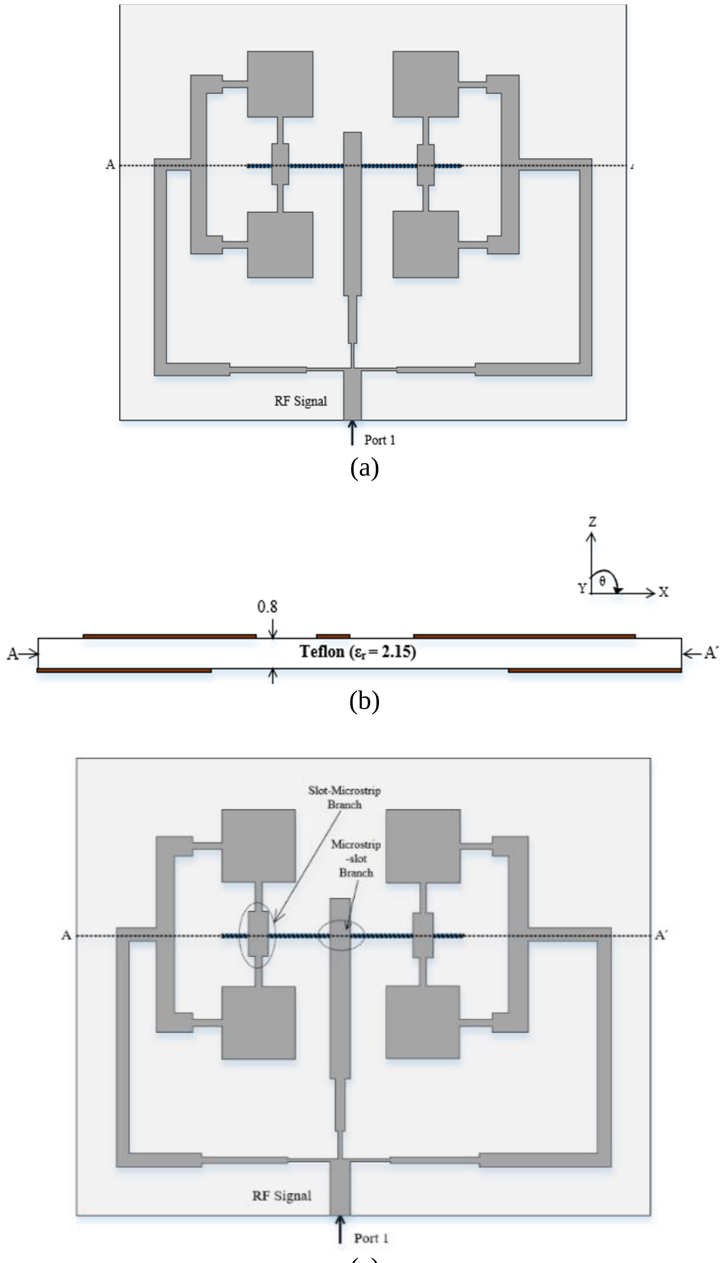


Figure 1. The proposed antenna layout (a) top view, (b) cross-sectional view, and (c) circuit branch points

In this feed network, both the microstrip-slot branch circuit and slot-microstrip branch circuit are used. The equivalent circuit of the branch circuits is shown in Figure 2. The microstrip-slot branch circuit is connected in parallel and for proper impedance matching, the impedance of the slot line needs to be double that of microstrip line (Z_2=Z_3=2Z_1) shown in Figure 2(a). In this case, two output signals at an equal distance from the branch point on the slot line are of the same amplitude and in phase [31]. The slot-microstrip branch circuit, on the other hand, is series coupled and the condition for impedance matching is the impedance of the microstrip line has to be half of the slot line (Z_2=Z_3=Z_1/2) in Figure 2(b). Because of series coupling, two output signals at the identical distance from the branch point on the microstrip line are of equal amplitude and 180° out of phase.

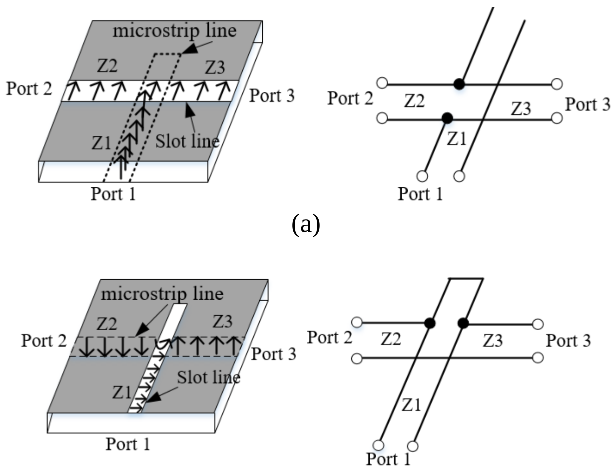


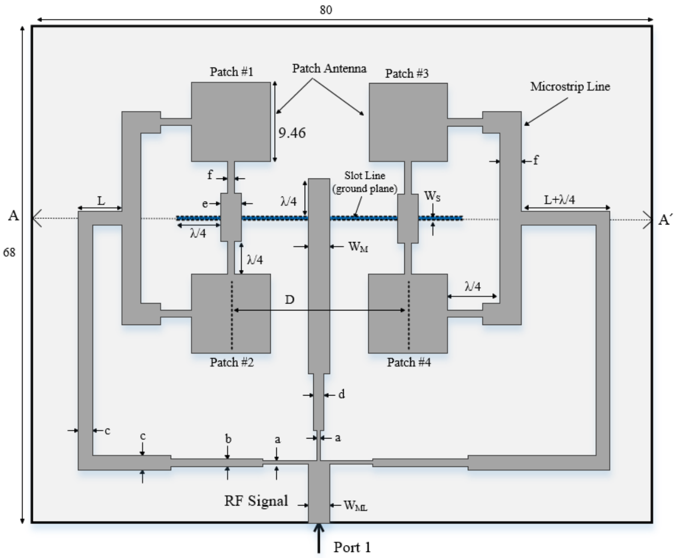
Figure 2. Equivalent circuit of proposed feed network (a) microstrip-slot branch circuit and (b) slot-microstrip branch circuit

2.2. The triple feed network

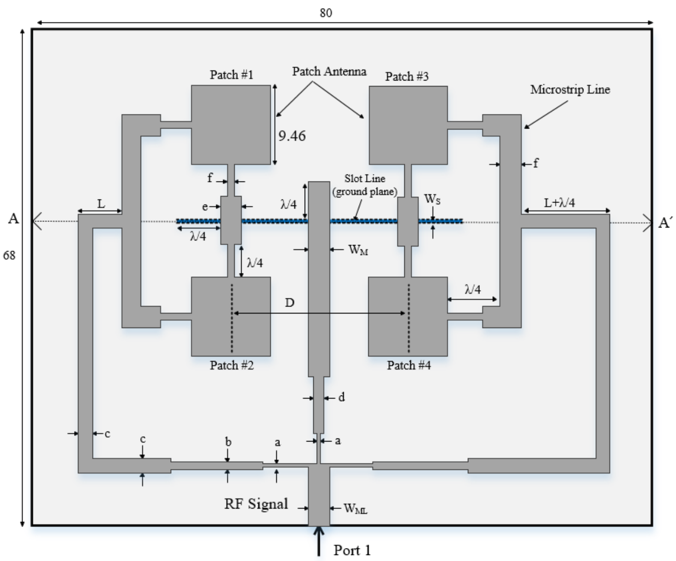
In this proposed triple feed array antenna design, the input impedance of the microstrip line is to be chosen as 50 Ω (2.4 mm). Figure 3 represents both the proposed antenna parameters and RF signals. From Figure 3(a), it can be seen that the RF signal is divided into 3 feed lines with an equal thickness of ‘a’ where each feed line has an impedance of 161 Ω. For proper matching between two feed lines at both left and right sides of the four patch elements (shown as a thickness of ‘a’ and ‘c’ in the figure), 102 Ω (‘b’ thickness) quarter wavelength transmission lines are used. The horizontal length of right-side feed line is a quarter wavelength greater than that of the left-side feed line. In contrast, in the middle of four patches, a 92 Ω (‘d’ thickness) quarter wavelength transmission line is used between two feed lines and the feed line ends with microstrip-slot branch circuit. The slot line has an impedance of 108 Ω and a thickness of ‘W_S’. The two ends of this slot line create two slot-microstrip series branch circuits from where the two sides of microstrip lines are fed to patch #1, patch #2, patch #3 and patch #4 through an impedance transformer of ‘e’ thickness and maintain impedance of 62 Ω. By this proposed design, the feeding point of the RF signal is converted to three feeding point and feed two RF signal of a different phase in each antenna element.

3. THE FUNDAMENTAL BEHAVIOUR OF THE ARRAY ANTENNA

The fundamental behavior of the proposed array antenna using a triple feed circuit has been discussed in Figures 3(a) and 3(b) where the direction of RF signals is also given in different colors for the clear realization of the antenna behavior. In this design, each patch element is fed by two different RF signals which are orthogonal to each other resulting in circular polarization after creating two orthogonal degenerate modes. RF signal is provided to microstrip line at Port1 of 50 Ω impedance. The RF signal is then divided into three feed lines. From Figure 3(b), it is seen that two RF signals are fed to antenna array elements in the same way and each of these RF signals is carried along three different microstrip lines to two array elements. From the middle branch, the RF signal is initially divided into two ways through a parallel branch in phase with microstrip line signals. Further, the RF signal then comes to two patch elements through another slot-the microstrip branch. This incident happens on both sides of the slot line. But this RF signal is out of phase and orthogonal with the RF signal from the side branch RF signal in Figure 3(b). As a result, the two RF signals of 90° phase difference generate orthogonal degenerate modes in each array element.



(a)



(b)

Figure 3. The fundamental behavior of the array antenna: (a) dimension of proposed array antenna. Parameters are W_{ML}=2.4 mm, a=0.2 mm, b=0.4 mm, c=0.7 mm, d=0.86 mm, e=1.8 mm, f=0.4 mm, W_M=2.1 mm, W_S=0.2 mm, L=7.0817 mm, D=19 mm and (b) RF signal direction of the proposed array antenna

4. SIMULATION RESULT ANALYSIS

ADS simulation software was used to scrutinize the proposed triple feed array antenna's performance. Figure 4 depicts some ADS simulated antenna parameters where Figure 4(a) depicts, the ADS simulated reflection coefficient (RC) parameters of the proposed array antenna and it is vivid that the antenna operates at 10.04 GHz frequency which lies within X-band (8-12 GHz) having a bandwidth of 420 MHz or 4.22% with reference to the center frequency at 10 GHz. The simulated RC of the antenna obtained in this case is -35.8 dB which makes the antenna have good impedance matching at the design frequency.

Figure 4(b) shows the ADS simulated results of input impedance as a function of frequency of the proposed antenna also known as the Smith chart of the antenna. It is seen from the corresponding figure that there is a dip near 10 GHz in impedance locus which results in two resonant modes exciting at the very near design frequency. It can be mentioned that the fundamental mode of the designed antenna is broken into two near orthogonal degenerate resonant modes and these modes form a dip in the Smith chart indicating the existence of circular polarization in the antenna. For realization, when an RF signal of a patch is a quarter wavelength leading to another RF signal of the same patch, these two resonant modes will be stimulated at the same amplitude but in 90° phase differences. Figure 4(c) illustrates two axial ratios (AR) over the operating frequency of the proposed array antenna. The axial ratio is nothing but the ratio of two orthogonal electric fields that were generated after feeding each element by two different RF signals. The axial ratio below 3 dB is accepted for antenna to be recognized as a circularly polarized antenna. At the operating frequency, antenna achieves an axial ratio value of almost 0.7 dB far deeper than 3 dB which indicates a good CP generation of antennas radiated field. Here, the bandwidth of the axial ratio is about 0.8 GHz, which is about 80% reference to the center frequency of 10 GHz. This implies that the presented antenna has good circular polarization at design frequency. The simulated ADS gain of the proposed triple feed array antenna over its frequency range is demonstrated in Figure 4(d). The peak gain simulated by ADS is near 12 dBi obtained at near 10 GHz which is reasonable being an array antenna. The simulated gain is smooth over its operating frequency and highest at a resonant point.

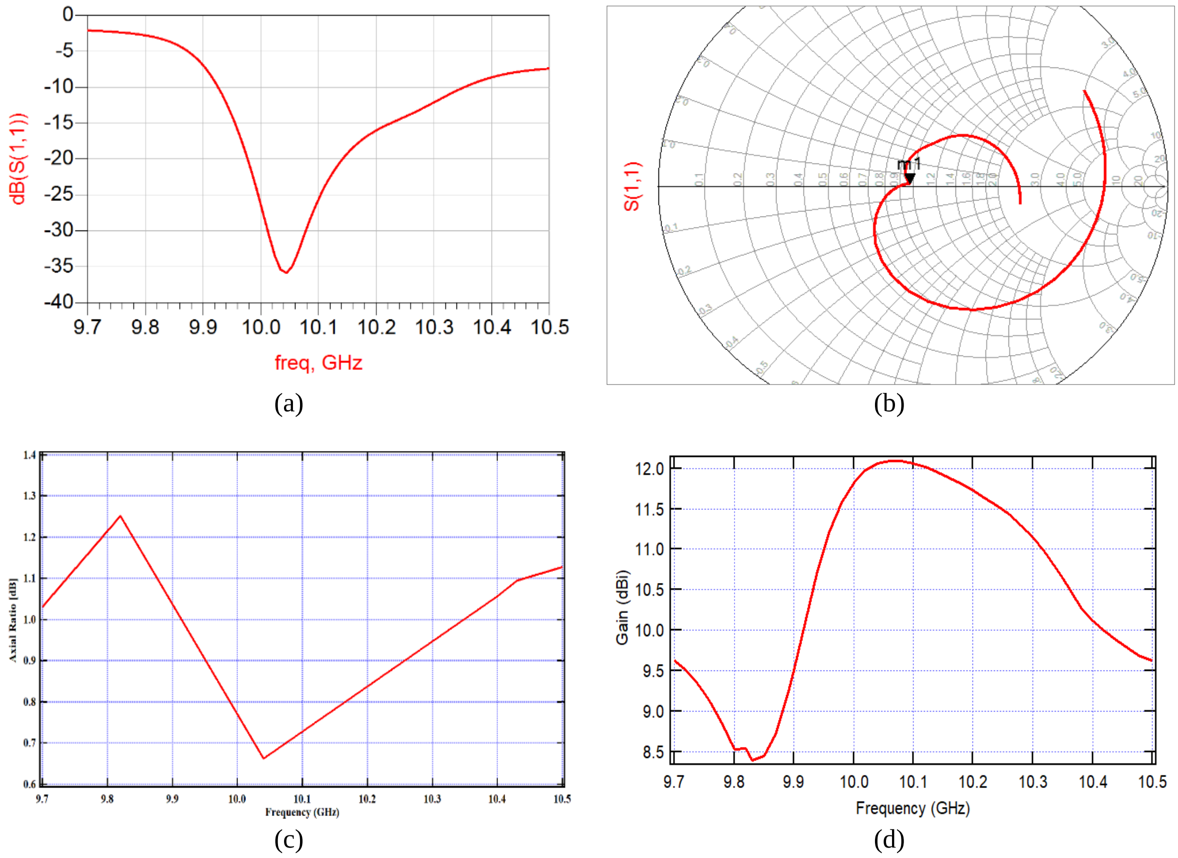
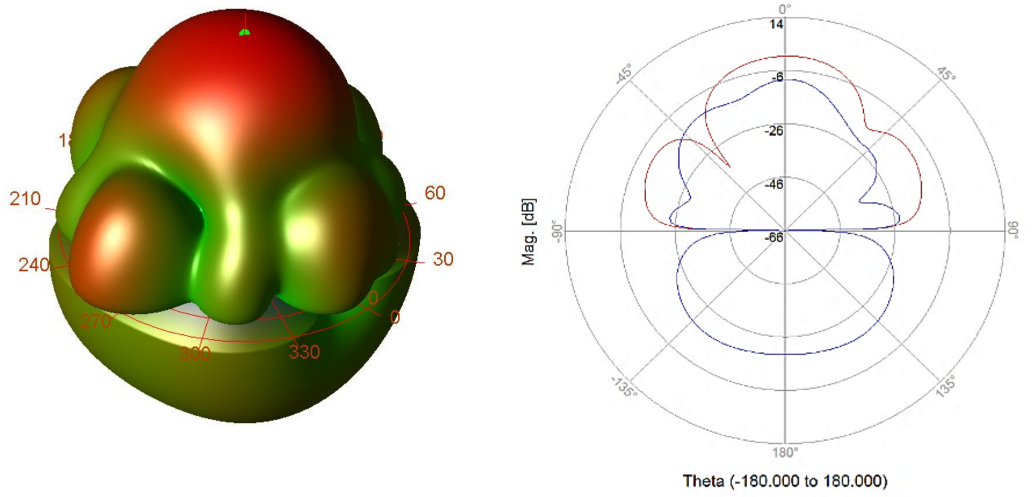


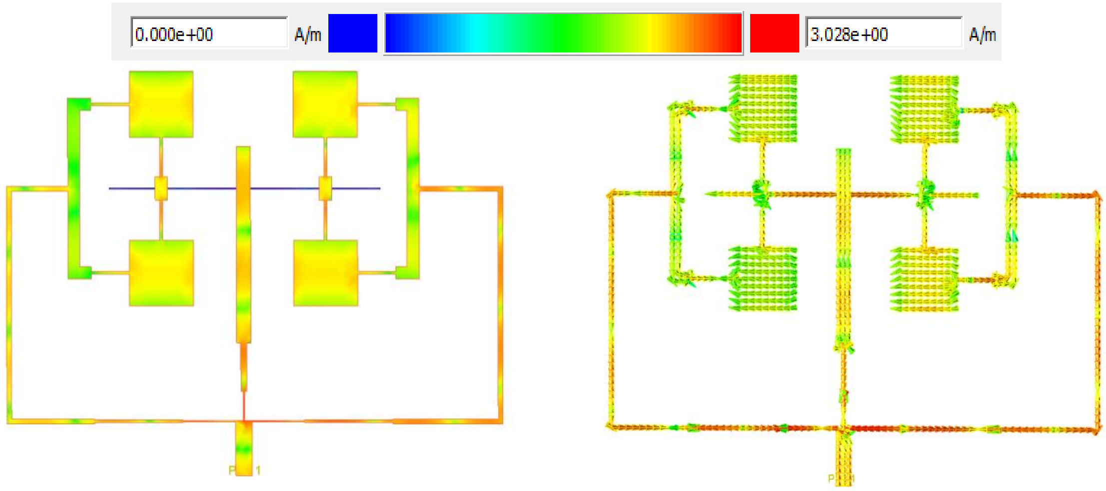
Figure 4. The simulated parameters (a) reflection coefficient and (b) input impedance of the antenna, (c) axial ratio, and (d) gain curve of the array antenna over its operating frequency

At the resonant point, the radiation diagram of the antenna is shown in Figure 5 by both 3D and 2D polar plot after carrying out far field analysis. From Figure 5(a) it is vivid that antenna has neat omnidirectional radiation pattern. The both E and H-plane leading beam is pointing at the boresight direction where H-plane possesses 'dumb-bell' shape radiation pattern in Figure 5(b). From the 2D radiation pattern, some sidelobe is seen which could be a reason for unwanted radiation from slot line placed on backside. The width of the slotted line should be kept as low as possible in order to prevent it working from as a slot-line antenna. Apart from spurious radiation from feed line could hamper antennas radiation pattern. The current distribution of the proposed antenna is shown in Figure 6 where from Figure 6(a) to observe the maximum and minimum current flowing in the antenna. It is clear that antennas current is almost uniformly distributed all over the antenna. The whole antenna is taken apart during resonance. Figure 6(b) depicts the current directions which is important for CP antenna. Due to orthogonal degenerate modes antenna has a rotational surface current at each element which can be visualized from current direction from Figure 6(b). Due to this rotational movement of this surface current is responsible for CP of the antenna. For this reason, a surface current is important for circularly polarized antenna and helps to determine the types of circular polarization.



(a) (b)

Figure 5. The radiation pattern of the antenna (a) 3D view and (b) 2D polar plot



(a) (b)

Figure 6. The surface current view (a) surface current intensity and (b) current direction

5. CONCLUSION

A high gain compact array antenna radiating circularly polarized electromagnetic wave is proposed using novel both-sided MIC technology. The triple feed network is employed to excite the antenna elements with orthogonal degenerate modes. The mentioned simulated parameters proved its worthiness being an array antenna operating at X-band. The antenna obtained a good impedance matching by using this technique which is vivid from antennas input impedance chart, without using an external matching circuit. This makes this antenna compact and easier for employing on a printed circuit board (PCB). The proposed circularly polarized triple feed array antenna is suitable for radar applications, satellite applications and various types of astronomical applications as it operates within the IEEE X-band.

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