Dual Orthogonal Feed Circular Polarization Array Antenna Using Microstrip Slot Feed Network

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Article Info	ABSTRACT
	This paper presents a new circularly polarized microstrip array antenna using dual-orthogonal feed technique. The feed network for 1×2 array is designed using microstrip lines and slot lines by applying double-sided MIC concept effectively. The 90° phase difference between two orthogonally feed signals is created by choosing appropriate feed point in the feed network to advance one of the feed signals by quarter wave length ($\lambda/4$) from other. Excellent radiation performance is obtained from this proposed antenna with low cross polar component. The impedance (< -10dB) bandwidth of the array is 9.1% and the 3-dB axial ratio bandwidth is 1.85% (from 9.905 GHz to 10.09 GHz). The average gain is higher than 9dBiC over the 3-dB AR bandwidth. The relation between antenna dimensions and characteristics is also investigated with a parametric analysis of the antenna.

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1. INTRODUCTION

Circular polarization (CP) antennas are suitable for many microwave applications as it has ability to reduce polarization losses. Linearly polarized antennas need strict alignment between transmitter and receiver where as circularly polarized antennas can communicate for variable or unknown orientation [1]. In case of array antenna, weight and size are two parameters to be kept at mind during design process as some applications require low weight and small size antenna. Microstrip antennas are good candidate to overcome this problem due to its inherent advantages of low profile, light weight, low cost and easy integration with microwave circuits [2]. Conventional array antennas use only microstrip lines to design feed network that lead to complex structure and longer microstrip line length for impedance matching circuit. As a result, antenna structure becomes larger and performance degrades due to higher feeding loss and cross polarized radiation [3]. Use of double-sided MIC concept that gives flexibility to put different types of transmission lines on the both sides of the substrate can be used to design small sized array antenna by overcoming these problems [4].

There are two main ways to excite circular polarization radiation. A microstrip patch element can be used to achieve circular polarization radiation by means of a perturbation segment. Sveral structures for a circularly polarized antenna using perturbation technique have been studied [5-9]. In [5], a method is reported to design circular polarized rectangular microstrip antenna with one point feed where feed point is located either on x axis or on the diagonal line of the patch. Truncating a pair of patch corners in rectangular or square patch for CP is discussed in [6]. An antenna with slits or spur lines to the boundary of the patch is reported in [7-8]. Design of trapezoidal shape slot antenna excited by CPW line is shown in [9]. Dual-orthogonal feed technique is another way to generate CP where two separate orthogonal feeds are excited

with a 90° phase difference. Dual feed CP antennas have been presented in [2,10]. On the other hand, single feed or dual feed antennas can be arrayed [11-15]. A serial feed sequentially rotated technique is used to design a CP array antenna [11] where each patch element is single feed. In this array, complete feed network is designed using microstrip lines. A CP slot array antenna with orthogonal feed is presented in [12]. In [13-14], single layer microstrip array antennas for CP are proposed where a 90° hybrid circuit is used to achieve circular polarization. Double-sided MIC technology is used to design the array antennas of [12-14] as the feed network in each array consists of microstrip lines and slot lines. Another 128 elements CP array antenna excited using a 1by 4 corporate feed network of hollow metallic waveguides is demonstrated in [15].

In this paper, a dual-orthogonal feed 1×2 microstrip array antenna is discussed. The feed network is formed by placing microsrip lines on the obverse side and slot lines on the reverse side of the substrate. Double-sided MIC concept is employed to design feed network successfully. A parametric study is conducted by simulation to optimize the antenna performance. The proposed array antenna has a 3-dB axial ratio bandwidth of 1.85%. The complete antenna structure along with antenna performances is presented and discussed in subsequent sections.

Literature review that has been done author used in the chapter "Introduction" to explain the difference of the manuscript with other papers, that it is innovative, it are used in the chapter "Research Method" to describe the step of research and used in the chapter "Results and Discussion" to support the analysis of the results [2]. If the manuscript was written really have high originality, which proposed a new method or algorithm, the additional chapter after the "Introduction" chapter and before the "Research Method" chapter can be added to explain briefly the theory and/or the proposed method/algorithm [4].

2. ANTENNA DESIGN

The complete structure of the array antenna is shown in Figure 1. The antenna is designed on Teflon glass fiber substrate backed by the ground plane. Relative dielectric constant (ε_r) of the substrate is 2.15 with a thickness of 0.8 mm. Thickness of the copper sheet used for radiating and ground plane is 0.018 mm. The dimension of the ground plane is 61.35×37.23 mm^2.
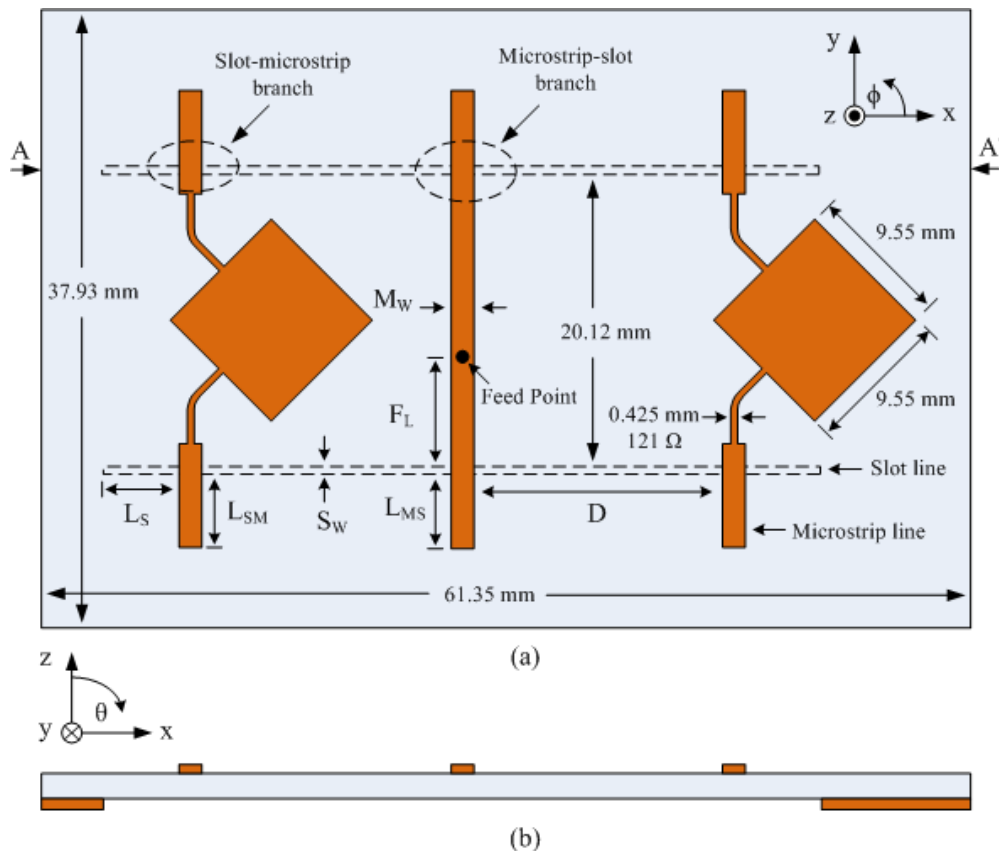

Figure 1. Complete structure of the 1×2 array antenna (a) Top view (b) Cross sectional view

Square microstrip patch is used as radiating element. As the patch length determines the resonant frequency [16], the following equation is used to calculate the patch length and then the width of the patch keeps as same length value because of square patch.

$$L = \frac{C}{2f_r\sqrt{\varepsilon_{re}}} - 2\Delta L \qquad (1)$$

Where C is the velocity of light and f_r is the resonant frequency.

Due to a fraction of the fields lies outside the physical dimension (W×L) of the patch called as the fringing field, the effective patch length L_e becomes $L + 2\Delta L$ and the relative dielectric constant ε_r is replaced by the effective dielectric constant ε_{re}. The value of ε_{re} can be calculated by the equation given in [17] as

$$\varepsilon re = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 10\frac{h}{W}\right]^{-1/2} \qquad (2)$$

where h is the thickness of the substrate.

Additional line length ΔL on either end of the patch length can be obtained from [18] as

$$\Delta L = 0.412h\left[\frac{\varepsilon_{re} + 0.3}{\varepsilon_{re} - 0.258}\right]\left[\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8}\right] \qquad (3)$$

Each side of the patches is set as 9.55 mm for 10 GHz frequency. The feed network is composed of microstrip lines and slot lines. The double-sided MIC concept is very effective to design this type of feed network and it is successfully employed in this design process. Radiating patches and microstrip lines are placed on the upper surface of the substrate and the slot lines lie on the lower surface of the substrate. The feed network consists of microstrip-slot branch circuit and slot-microstrip branch circuit. For proper impedance matching between microstrip line and slot line, the impedance of microstrip line should be half of the slot line impedance [19]. For a desired characteristic impedance Z_C, the width of the microstrip line can be calculated by [20] as

$$W = h\frac{8e^A}{e^{2A} - 2} \qquad (4)$$

Where A $= \frac{Z_c}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$ and B $= \frac{377\pi}{2Z_c\sqrt{\varepsilon_r}}$

For proper matching between the each patch and microstrip line of the slot-microstrip branch circuit, 121 Ω quarter-wave transformer is used that is computed by [21] as

$$Z = \sqrt{Z_0 Z_i} \qquad (5)$$

Where Z_0 is the impedance at feed point of the patch and Z_i is the microstrip line impedance of the slot-microstrip branch circuit.

3.   BASIC BEHAVIOR OF THE ARRAY

To generate circular polarized waves, two orthogonal signals of equal amplitude with 90° phase shift between them are needed. The basic behavior of the proposed circularly polarized array antenna can be explained using Figure 2. Two separate orthogonal feed Port I and Port II are used to excite two degenerate orthogonal modes in the patches. Moreover, the feed point as shown in figure is chosen in such a way that the signal of the lower feed circuit is ahead by quarter wave length from that of upper feed circuit that create 90° phase difference between two orthogonal input signal.

When RF signal is supplied to the feed point, the signals are divided in phase to the slot line through the microstrip-slot parallel branches and they are successively divided in out of phase to the microstrip lines

through the slot-microstrip series branches and feed the signals to each patch element. Microstrip-slot branch circuit acts as a parallel power divider with in-phase outputs and slot-microstrip branch is series power divider where outputs are in out of phase [19]. Therefore, in each patch of the array, two orthogonal signals are formed with 90° phase shift and as a result circularly polarized signal is excited. One interesting thing is that LHCP and RHCP can be excited using same array structure by changing feed point as shown in Figure 2. When feed point is placed at Feed-1, LHCP will be radiated and RHCP can be excited by changing feed point position from Feed-1 to Feed-2.
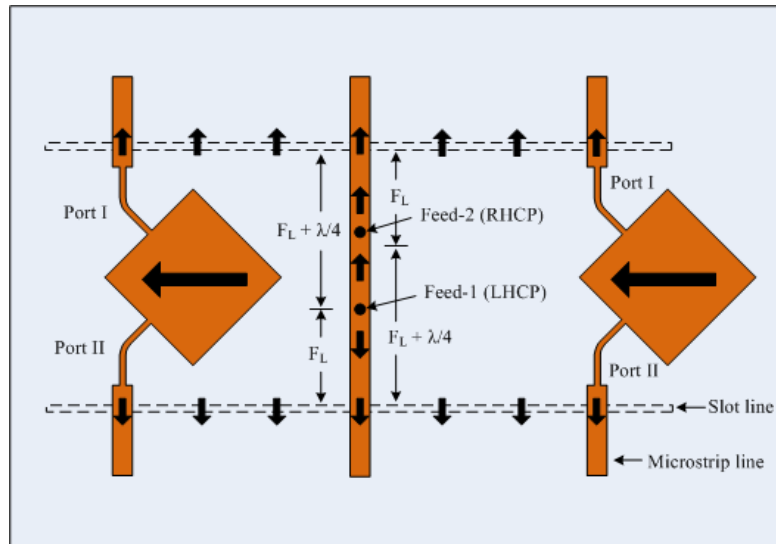

Figure 2. Basic behavior of the array antenna

4.   PARAMETRIC STUDY OF THE ARRAY

To obtain best performance, the parametric study of the proposed antenna is conducted. Different parameters for parametric study are illustrated in Figure 1. The microstrip line width of the branch circuits denoted by M_W, the spacing between the feed line and the slot-microstrip branch point denoted by D and the length of the slot line extension from microstrip line in slot-microstrip branch denoted by L_{SM} are main three parameters responsible for proper impedance matching.
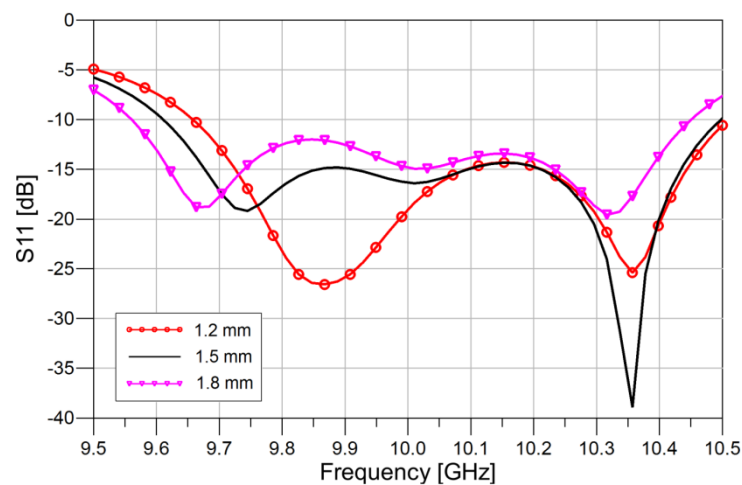

Figure 3. Effect of M_W on the return loss of the antenna

Hence, these parameters can be optimized by parametric study. The slot line width (S_W) and the position of the feed point (F_L) are another two parameters to be studied as they influence both impedance bandwidth and axial ratio.The effects of varying the width of microstrip lines (M_W) on the antenna performance are shown in Figure 3. It is observed that the operating bandwidth is shifted left and return loss decreases with increasing the microstrip line width. Figure 4 shows the simulated return loss obtained by changing the spacing between slot-microstrip branch and the feed line when other parameters are fixed. The value of D changes the operating frequency and the impedance bandwidth is decreased rapidly with increasing the spacing. But at an optimum point, it gives better retun loss value and impedance bandwidth and it is chosen as 16.935 mm.
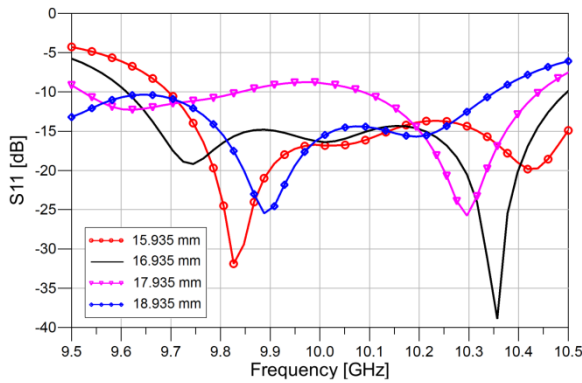

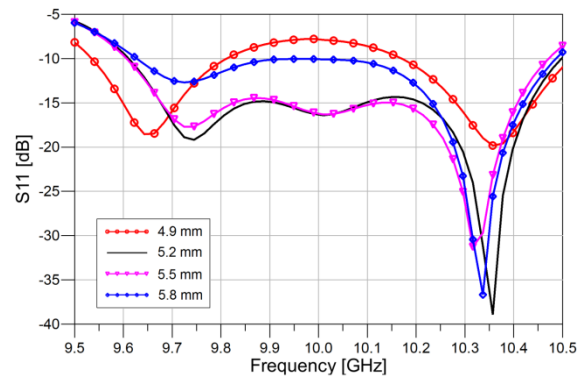Figure 4. Return loss for different values of D

Figure 5. Return loss for different values of L_S

The variation of return loss for different values of L_S is plotted in Figure 5. The cut-off frequency is almost fixed but impedance bandwidth is reduced when the length is increased. So L_S = 5.2 mm is the optimum value that provides higher return loss with best possible impedance bandwidth. Figure 6 shows the effects of varying the length of microstrip line extension of slot-microstrip branch circuit (L_{SM}) for two different values of microstrip line extension of microstrip-slot branch (L_{MS}). When L_{MS} (= 5.58 mm) is equal to the value of the wavelength (λ) at design frequency, variation of L_{SM} has little effect on the performance of the antenna. But in the case of L_{SM} = L_{MS}, the cut-off frequency is moved from lower frequency to a higher frequency and gives better return loss value.
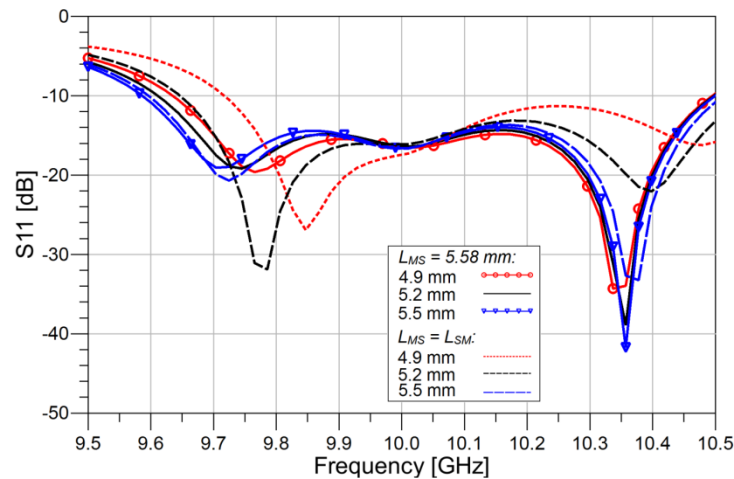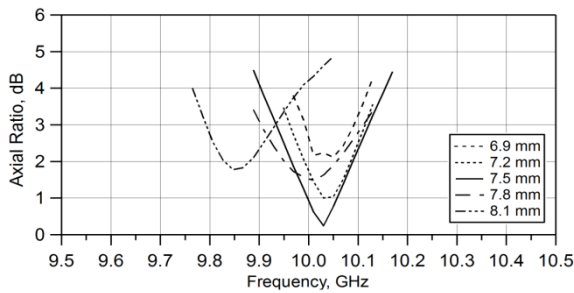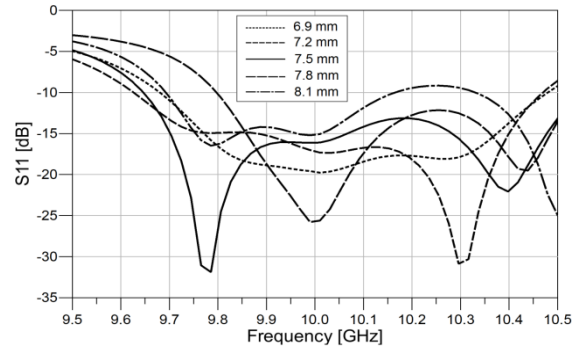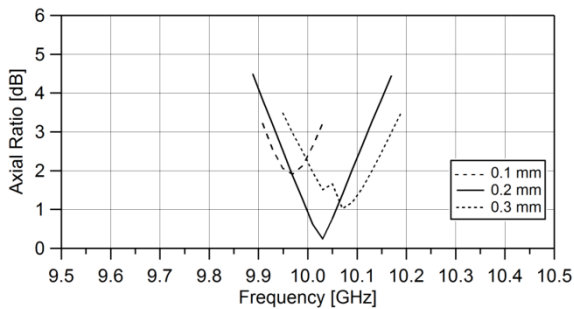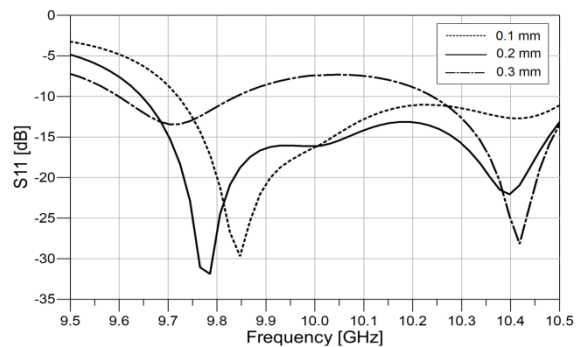

Figure 6. Return loss for different values of L_{MS}

Figure 7. Axial ratio for different feed location (F_L)   Figure 8. Return loss for different values of F_L

After proper impedance matching, it is required to analysis those parameters which influence the axial ratio bandwidth. Feed point location (F_L) is very important parameter that required fine tuning to get optimum axial ratio. Figure 7 and Figure 8 show the axial ratio and return loss for different feed location respectively. Though the position of the feed point shifts the operating frequency bandwidth as shown by Figure 8 but it is also necessary to place feed point in such a location that can create 90° phase difference between the orthogonal feed signals of the patch. When the position is at the optimum point, the radiation will be perfectly circularly polarized and the axial ratio curve at operating frequency will be approached to a minimum value. The minimum axial ratio of 0.243 dB is found when F_L = 7.5 mm as shown in Figure 7 and it can be taken as an optimum point as it also gives better return loss value.

Figure 9. Axial ratio for different values of S_W Figure 10. Return loss for different values of S_W

Slot line width should be optimized to get better axial ratio and return loss. Variations of axial ratio and return loss for changing S_W are shown in Figure 9 and Figure 10 respectively. For fine tuning of axial ratio, it is necessary to adjust slot line width and select an optimum value that will give good axial ratio with better impedance matching. But it is also observed that at a longer width, the axial ratio and return loss again start to decrease. So S_W = 0.2 mm is the optimum value to get better performance.

5.   RESULTS AND DISCUSSIONS

The antenna is designed and simulated using commercial EM software package, Advanced Design System (ADS) based on the Method of Moments (MOM). The optimal dimensions of the antenna obtained by parametric analysis are: M_W = 1.5 mm, S_W = 0.2 mm, D = 16.935 mm, L_{MS} = L_{SM} = L_S = 5.2 mm and F_L = 7.5 mm. Return loss (S11) of the array is shown in Figure 11. The result indicates that the return loss is smaller than -10 dB from 9.65 to 10.57 GHz. So the impedance bandwidth is 9.1% with respect to the center frequency of 10.11 GHz. Figure 12 shows the axial ratio performance of the proposed antenna. From 9.905 GHz to 10.09 GHz, the axial ratio is below 3 dB level. So the axial ratio (AR < 3 dB) bandwidth of the designed array antenna is 185 MHz or about 1.85% respect to the center frequency of 9.99 GHz and the minimum value of axial ratio is 0.026 dB at 9.99 GHz. This result shows a good axial ratio smaller than 3 dB at the design frequency and it confirms that the proper circular polarization is achieved.
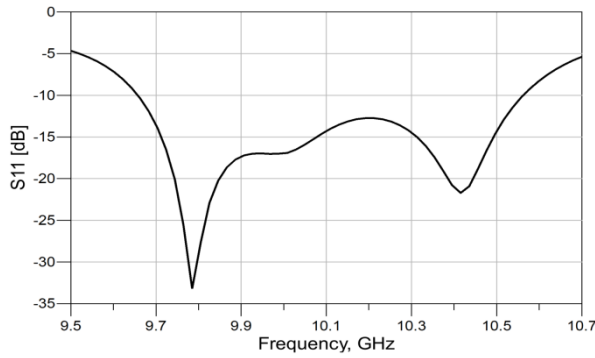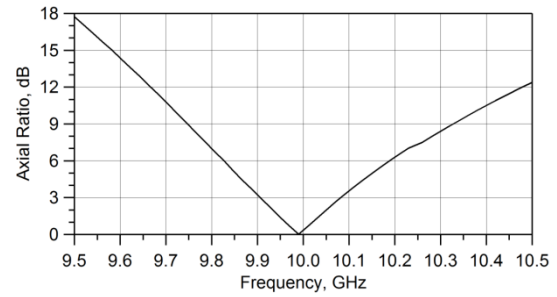
Figure 11. Return loss of the antenna

Figure 12. Axial ratio of the antenna

Gain of the array antenna is illustrated in Figure 13. Maximum gain of 9.49 dBic is achieved at 9.91 GHz. It is also observed that average gain over the complete operating bandwidth is higher than 9 dBic. Figure 14 exhibits the radiation pattern of 1×2 array antenna at 9.99 GHz. Figure shows good radiation performance of the array antenna. Antenna radiation is left hand circularly polarized (LHCP). But it is also possible to radiate right hand circularly polarized (RHCP) waves using same antenna structure by changing only feed point. When Feed-2 is used to excite the antenna, input signal of Port I is ahead by quarter wavelength than that of Port II. As a result, the radiation will be RHCP. The cross polar level of the antenna is better than -45 dB that indicates very good radiation performance of the antenna. To compare the antenna performance, four previous works are listed in Table 1.
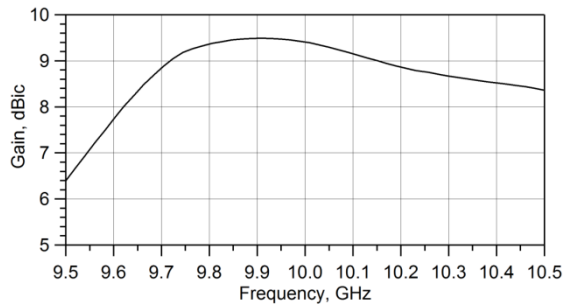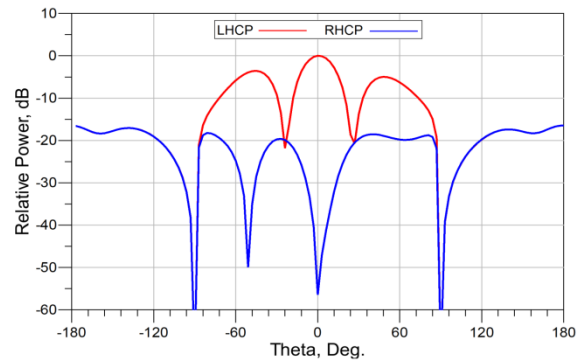

Figure 13. Gain of the array antenna

Figure 14. Radiation pattern at 9.99 GHz

Table 1. Comparison

Ref. No.	Year	Array Size	Frequency, GHz	Impedance BW (< -10dB)	Axial Ratio BW (< 3 dB)	Gain, dBic
[11]	2006	2×2	2.45	0.073 GHz	0.02 GHz	---
[12]	2010	2×2	7.5	1.8 GHz	12%	---
[13]	2012	2×2	10	1.25 GHz (<-15dB)	10%	12.5
[14]	2012	2×2	10	1.5 GHz	3.8%	---
Proposed Antenna	2014	1×2	10	0.92 GHz / 9.1%	0.185 GHz / 1.85%	9.49

6.   CONCLUSIONS

A new dual-orthogonal feed circularly polarized microstrip array antenna at 10 GHz has been demonstrated in this paper. Microstrip lines and slot lines are used to design antenna feed network with the help of double-sided MIC concept and this feed network eliminates the use of any types of power divider or hybrid circuits. Parametric analysis has been done to optimize the antenna parameters. Impedance bandwidth (< -10 dB) and axial ratio bandwidth (< 3-dB) of the array antenna are 9.1% and 1.85% respectively. Antenna

shows high gain all over the operating bandwidth and maximum gain is 9.49 dBic at 9.91 GHz. Excellent radiation performance is also observed where cross polar component is lower than -45 dB. Due to the excellent radiation performance and high gain, the proposed antenna is suitable for many microwave application such portable radar, RF sensors, RFID etc.

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