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Analysis of High Gain 4X4 Square Patch Antenna Array for Wireless Applications

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Abstract

Objective: To design a high gain square patch array antenna, that can be applied in the communication modules to improve the system performance. The array performance will depend on the number of elements, geometry of the array and weighting vector used in the design. From array factor, we concentrated on the reception factor of the array with strong function of geometry. **Methods/Analysis:** Advanced array antennas generally use the planar structure for its numerous advantages. So, a planar square patch 4X4 array antenna is proposed to operate at 2.4 GHz (IEEE 802.11b) WLAN communication application in this paper. Quarter wave transformers are been used in the design to achieve impedance matching of 50 ohms. **Findings:** An impedance bandwidth of 20% is achieved from the proposed design. The proposed array antenna is showing gain more than 13 dB, efficiency more than 80% with good impedance matching and radiation characteristics. **Novelty/Improvement:** Planar structure with simple design is the novelty in this model. The improvement in the gain and directivity is unlocking the additional applications in the communication band and providing possible ways for long distance communication.

Keywords: Array Antenna, Array Factor, High Gain, Impedance Matching, Wireless Local Area Network (WLAN)

1. Introduction

Design and analysis of array antennas requires prior knowledge regarding several parameters like element size, spacing, coupling and feeding techniques etc. A single element patch will not provide large gain for long distance communication, so the alternative way is increasing the number of elements to form array[1-6]. The array antenna design involves several steps with respect to numerous parameters. Different feeding techniques are available for arrays like series feeding, parallel feeding and corporate feeding etc to attain proper impedance matching[7-12].

The mutual coupling losses should be decreased while placing the array elements. Researchers experimented different array antenna models and succeeded to certain extent to provide excellent performance parameters with reduction in back lobes and side lobes in radiation[13-15]. Phased arrays have different applications in communication fields especially in military communication. The simulation tools also will take certain amount of time for array simulation, particularly based on computational facility availability[16-18].

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2. Antenna Geometry

In a plane of $\theta=\Pi/2$ a uniform array of n-elements are placed with the separation of distance'd'. The probability of excitation currents with same amplitude and adjacent phase difference of β, then the corresponding weight vector is:

$$w = \begin{bmatrix} w_1 \\ w_2 \\ \cdot \\ \cdot \\ w_N \end{bmatrix} = \begin{bmatrix} I \\ Ie^{j\beta} \\ Ie^{j2\beta} \\ \cdot \\ Ie^{j(N-1)\beta} \end{bmatrix} \tag{1}$$

The general array factor (A_F) for specified array on the plane 'θ'= π / 2 is

$$AF = f_{array}\left(\theta = \frac{\pi}{2}, \emptyset\right) = \sum_{i=1}^{N} w_1 e^{jb_i} = I \sum_{i=1}^{N} e^{j(i-1)\beta} e^{j(i-1)d\cos\theta}$$

$$= \sum_{n-1}^{N} e^{j(n-1)\Psi} = \frac{\sin\left[(N)\frac{\Psi}{2}\right]}{\sin\left(\frac{\Psi}{2}\right)} e^{j(i-1)\frac{\Psi}{2}} \tag{2}$$

Where,

$$\Psi = Kd\cos\emptyset + \beta \text{ and } 0 \leq \emptyset, \beta \leq 2\pi \tag{3}$$

The normalized array factor is:

$$|AF_n| = \frac{1}{\Gamma}\frac{\sin\left[(N)\frac{\Psi}{2}\right]}{\sin\left(\frac{\Psi}{2}\right)} \tag{4}$$

The 4x4 array antenna structure is shown in Figure 1 and 2 depicts the formation of the array with its feeding structure. The geometrical parameters of the antenna are shown in Table 1.

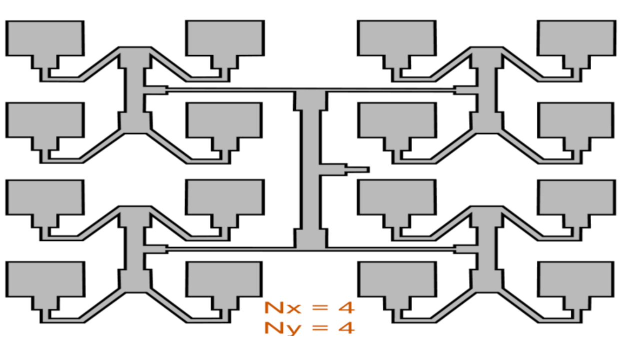

Figure 1. 4 x 4 Square patch array Antenna.

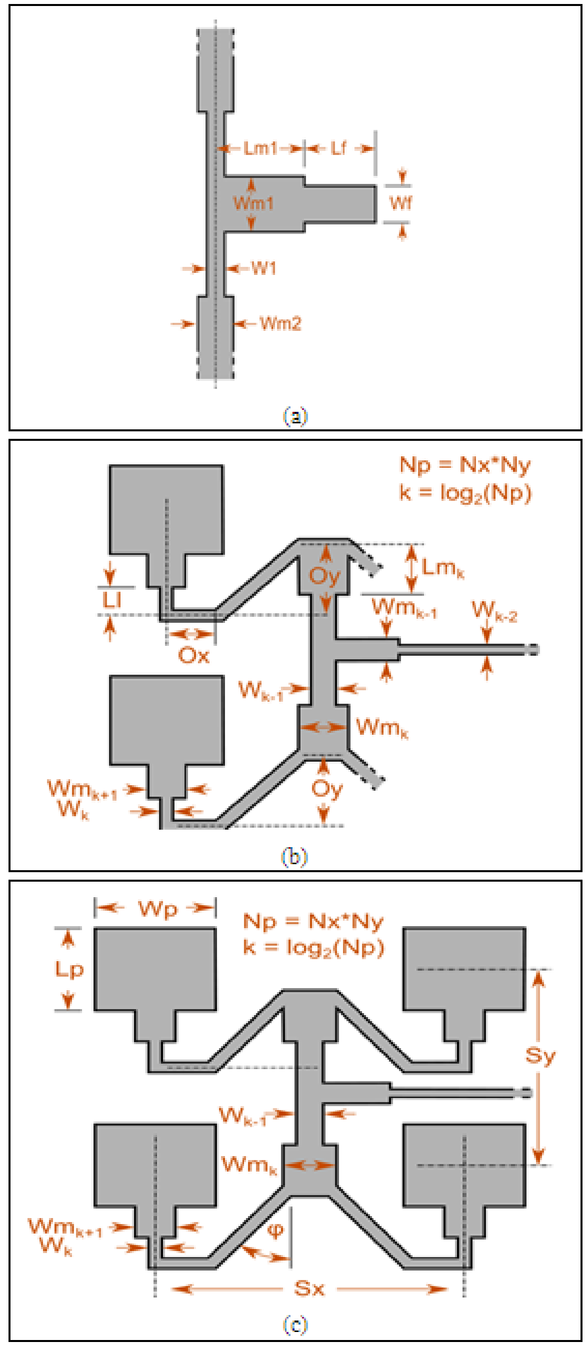

Figure 2. Construction of Array, (a) Power divider node (b) Connection of patch elements with power divider for Impedance matching, (c) Formation of 2x2 array with Impedance matching.

3. Results and Analysis

Array antenna simulations results are presented in this section. In Figure 3 and 4 projecting the return loss and VSWR

Table 1. Antenna geometrical parameters.

Parameter	N_x	N_y	W_p	L_p	S_x	S_y	O_x	O_y	H
Dimensions	8 patches	4 patches	48.49 mm	40.59 mm	87.44 mm	103.9 mm	24.24 mm	34.47 mm	1.575 mm
Parameter	εr	tan_{δ}	W_f	L_f	L_{m1}	L_{m2}	L_{m3}	L_{m4}	L_{m5}
Dimensions in mm	2.2	0.009	4.853 mm	4.751 mm	22.83 mm	23.55 mm	23.83 mm	23.73 mm	23.73 mm
Parameter	L_{m6}	L_{m7}	W_{m1}	W_{m2}	W_{m3}	W_{m4}	W_{m5}	W_{m6}	W_{m7}
Dimensions	23.55 mm	24.1 mm	4.85 mm	1.412 mm	752 µm	958 µm	958 µm	1.408 mm	339.1 µm
Parameter	L_1	W_1	W_2	W_3	W_4	W_5	W_6		
Dimensions	4.751 mm	1.412 mm	167.4 µm	339.1µm	339.1µm	339.1µm	907 µm		

characteristics of the antenna w.r.t the operating frequency in GHz respectively. We noticed that the current antenna is working at 2.4 GHz band with impedance bandwidth of 20%. VSWR value is < 2 at operating frequency and the current antenna is showing bandwidth of 70 MHz. The impedance of the designed antenna can be obtained from in Figure 5 and 6. Figure 5 shows the impedance characteristics of the antenna 50 ohms at resonant frequency and Figure 6 are providing the support to the evidence.

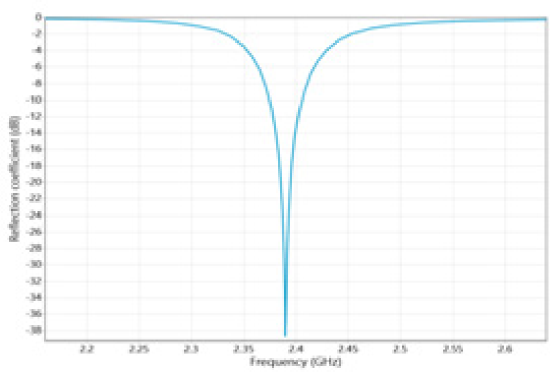

Figure 3. Return loss Vs Frequency in GHz.

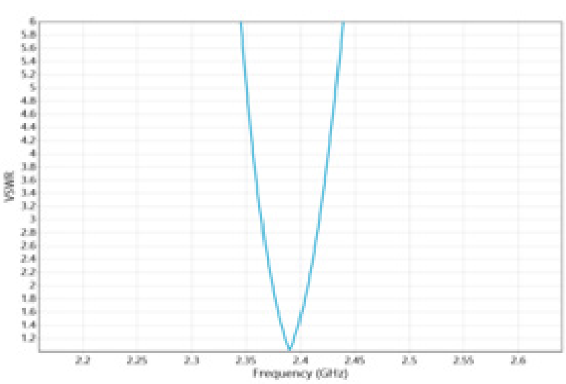

Figure 4. VSWR Vs Frequency in GHz.

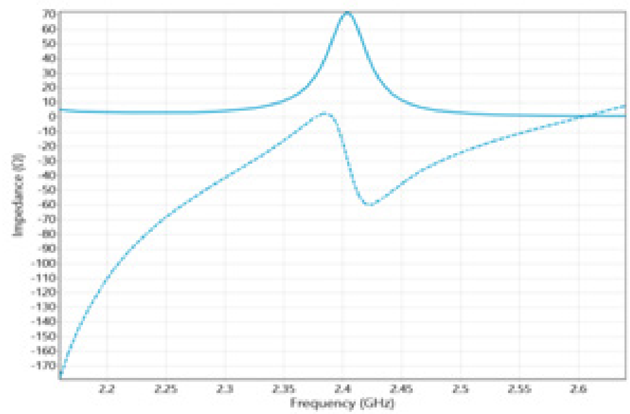

Figure 5. Impedance vs frequency in GHz.

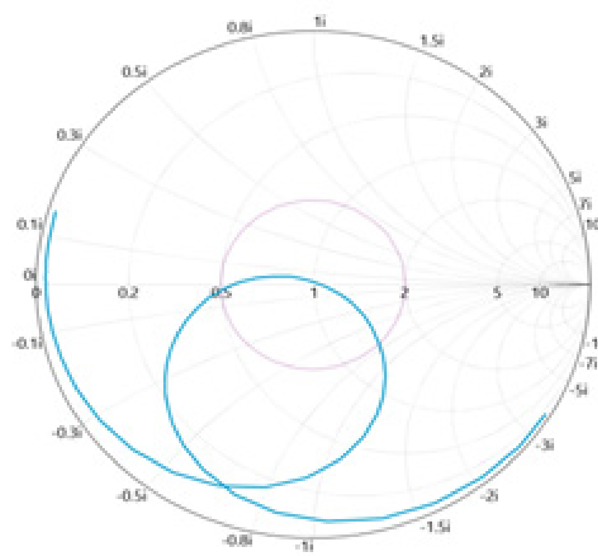

Figure 6. Smith chart.

The radiation representation of the antenna is the graphical representation of its radiation characteristics to analyze the antenna performance. By choosing an arbitrary array antenna in to consideration, the field patterns and their orientation is duscussed in the subsequent section.

In the Figure 7, P_1 to P_n are the position vectors of the antenna elements r_1 to r_n are the distances between the antenna elements from observing point r_0 is the distance of the origin from the observation point.

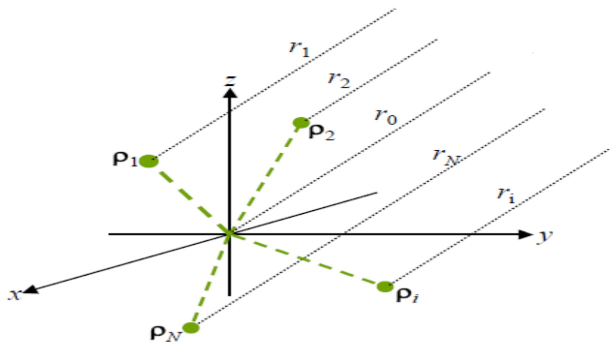

Figure 7. Arbitrary Antenna array.

The total far-fields 'E' radiating from the given array is:

$$E = \sum_{i=1}^{N} E_i \tag{5}$$

Where E_i is the far field of the i^{th} antenna given by:

$$E_i = \left[\hat{a}_\theta f_{\theta i}(\theta, \phi) + \hat{a}_\phi f_{\phi i}(\theta, \phi)\right] w_i K_i e^{-jkr_i} \tag{6}$$

$f_{\theta i}(\theta, \phi)$ = the 'θ ' component in the radiation pattern.

w_i is the proposed weighting factor in the excitation source.

K_i is the constant generally accounting for the path loss.

$$E_i = \left[\hat{a}_\theta f_\theta(\theta, \phi) + \hat{a}_\phi f_\phi(\theta, \phi)\right] \sum_{i=1}^{N} w_i K_i e^{-jkr_i} \tag{7}$$

In general, we assume that 'K_i 'is approximately constant such that:

$$K_1 = K_2 = \cdots = K_N = K \tag{8}$$

We can also write,

$$r_i = r_0 - \Delta r = r_0 - \rho_i . \hat{a}_r(\theta, \phi) \tag{9}$$

$$E = Ke^{-jkr_0}\left[\hat{a}_\theta f_\theta(\theta, \phi) + \hat{a}_\phi f_\phi(\theta, \phi)\right] \sum_{i=1}^{N} w_i K_i e^{-jK\rho_i . \hat{a}_r(\theta, \phi)}$$

$$= Ke^{-jkr_0}\left[\hat{a}_\theta f_\theta(\theta, \phi) + \hat{a}_\phi f_\phi(\theta, \phi)\right] f_{array}(\theta, \phi) \tag{10}$$

Here after, we concentrated on the analysis of array factor.

$$f_{array}(\theta, \phi) = \sum_{i=1}^{N} w_i K_i e^{-jK\rho_i . \hat{a}_r(\theta, \phi)}$$

$$= \sum_{i=1}^{N} w_i e^{jb_1} \tag{11}$$

Putting in the generalized matrix form, we have:

$$f_{array}(\theta, \phi) = W^T b \tag{12}$$

$$w = \begin{bmatrix} W_1 \\ W_2 \\ \cdot \\ \cdot \\ W_N \end{bmatrix} \quad b = \begin{bmatrix} e^{jb_1} \\ e^{jb_2} \\ \cdot \\ \cdot \\ e^{jb_N} \end{bmatrix} = \begin{bmatrix} e^{jk\rho_1 . \hat{a}_r(\theta, \phi)} \\ e^{jk\rho_2 . \hat{a}_r(\theta, \phi)} \\ \cdot \\ \cdot \\ e^{jk\rho_N . \hat{a}_r(\theta, \phi)} \end{bmatrix} \tag{13}$$

$$f_{array}(\theta, \phi) = \mathfrak{F}^{-1}\left(w\left(x, y, z\right)\right) \tag{14}$$

Similarly, the normalized weight function $w(x, y, z)$ can be calculated from the given needed array factor function.

$$w\left(x, y, z\right) = \mathfrak{F}^{-1}\left(f_{array}(\theta, \phi)\right) \tag{15}$$

Figure 8 shows the horizontal gain of the antenna in two-dimensional view and Figure 9 shows the same in three-dimensional view. The main lobe is showing the gain of more than 13.7 dB and sidelobes showing the gain of -2dB, which is a good sign of radiation E-plane. In Figure 10 shows the vertical gain of the antenna in two-dimensional view and Figure 11 shows the same in three-dimensional view. The main lobe is showing the gain of more than 13.7 dB and sidelobes showing the gain of 5dB, which indicates the poor polarization in H-plane.

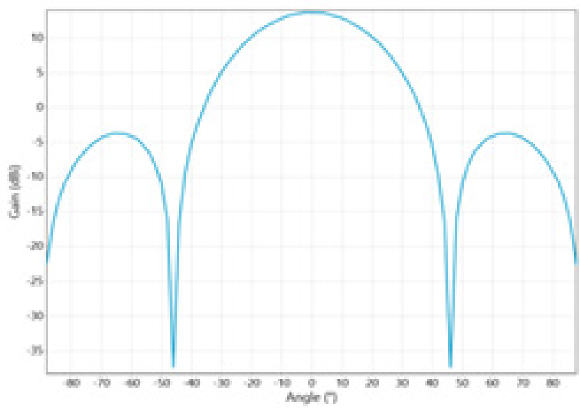

Figure 8. 2D-horizontal gain

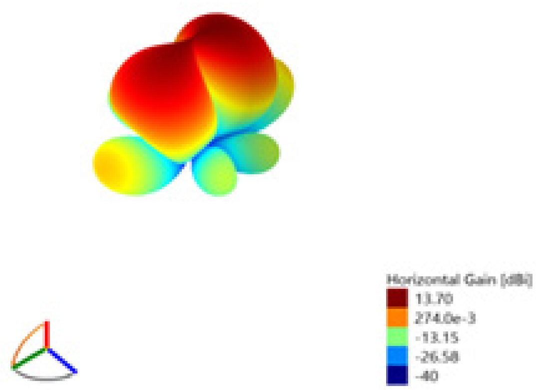

Figure 9. 3D-horizontal gain

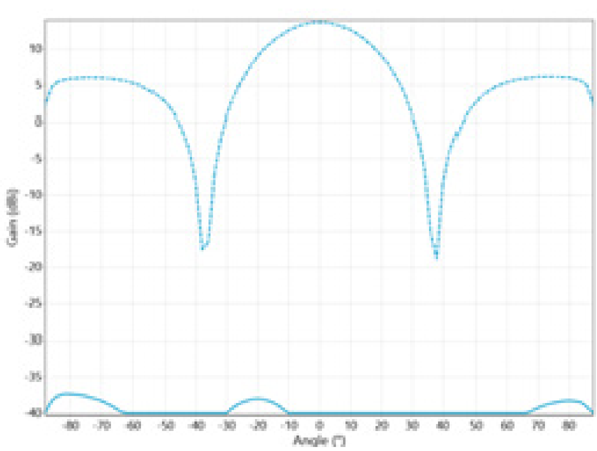

Figure 10. 2D-vertical gain

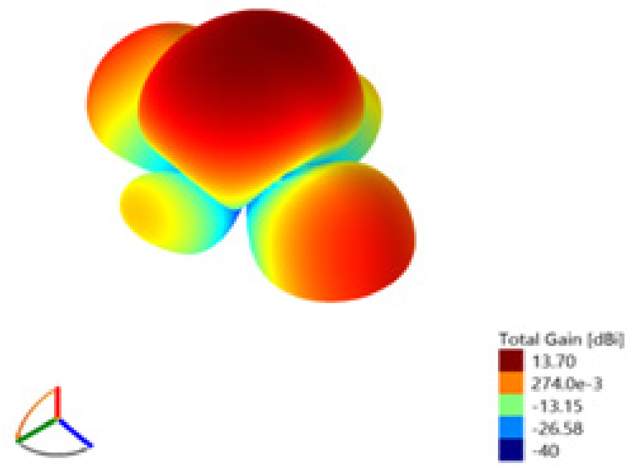

Figure 11. 3D-vertical gain

Figure 12 shows the left hand circular gain in two dimensional and Figure 13 shows the same in three-dimensional view. It is been observed that a gain value of more than 10 dB can be observed from main lobe and cross polarization is less than -5dB. Similar kind of results can be observed from Figure 14 and 15 also for the case of right hand circular gain. In Figure 16 and 17 shows the radiation characteristics of the proposed 4x4 array antenna in polar coordinates. The array antenna is showing high gain and low cross polarization in H-plane. The side lobes also showing low amplitude levels with directive radiation patterns in both the planes.

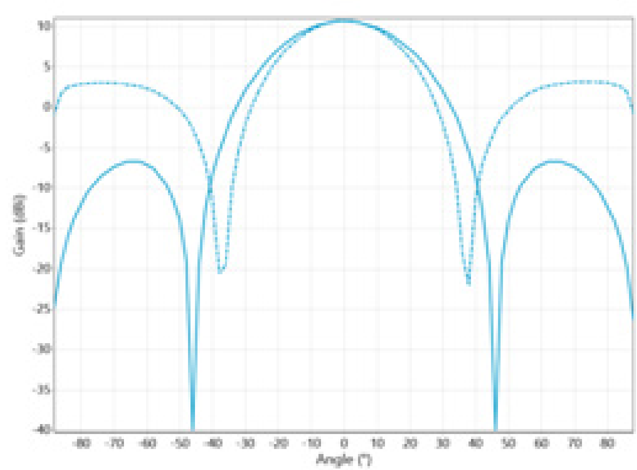

Figure 12. 2D-left hand circular gain.

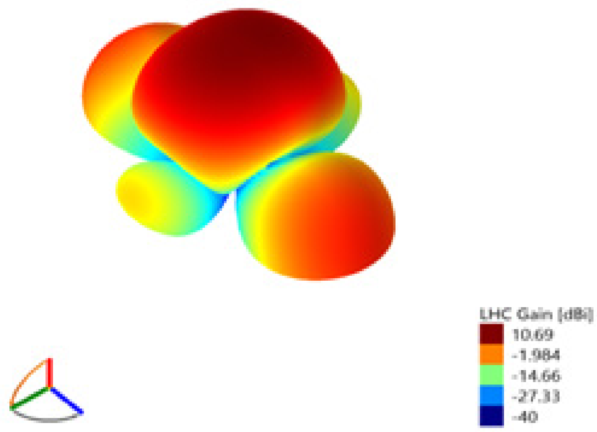

Figure 13. 3D-left hand circular gain.

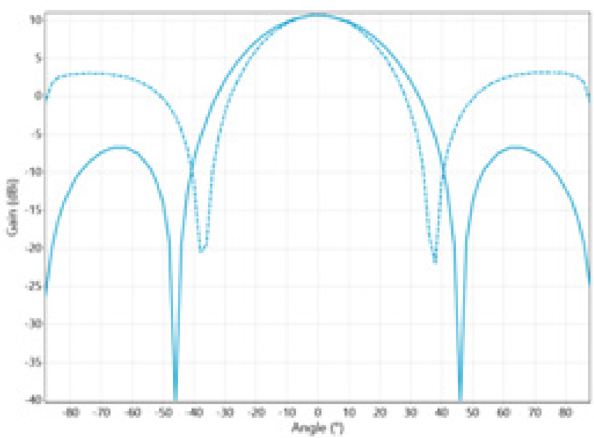

Figure 14. 2D-right hand circular gain.

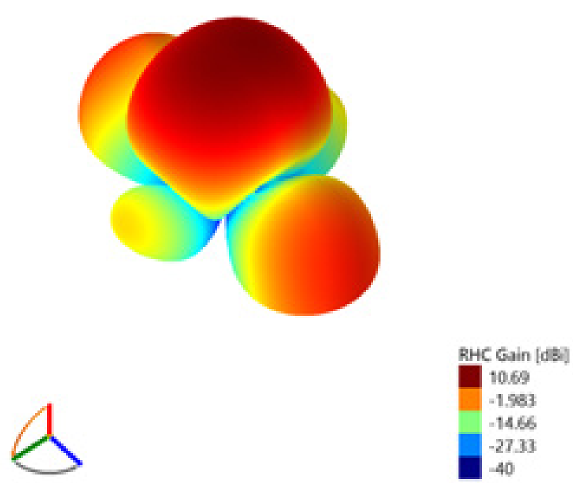

Figure 15. 3D-right hand circular gain.

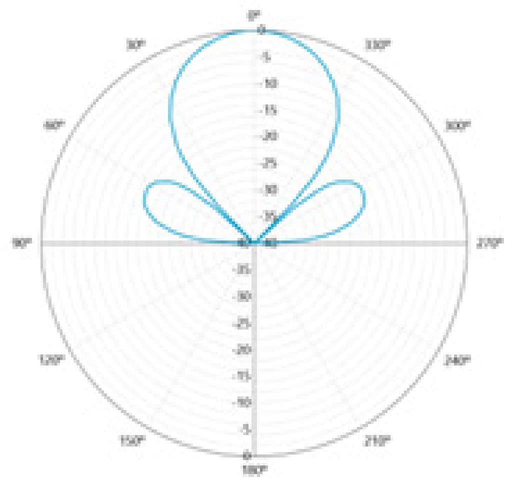

Figure 16. Radiation in E-Field.

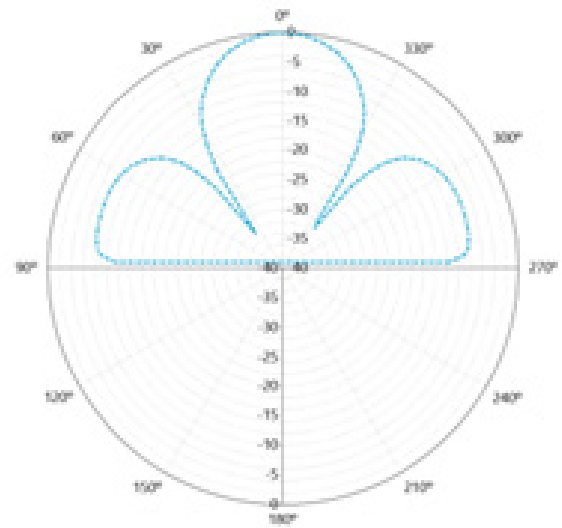

Figure 17. Radiation in H-Field.

4. Conclusion

An array of 4 x 4 sizes is designed in this model with square patch elements. The modelled design is showing gain more than 13 dB and directivity 14 dB. The radiation characteristics are analyzed and showing directive pattern with minimum side lobes. Right hand circular polarized gain of 10.9 dB and left hand circular polarized gain of 11 dB is attained from the current design. The current model is more suitable for the wireless communication applications under 2.4 GHz with moderate radiation characteristics.

5. Acknowledgements

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