

A Single Feed Circularly Polarized Planar Antenna Array

Rabindra Kumar, Neha Kumari, Pradeep Kumar Jain, Priyanka Mondal

Abstract: A design of a circularly polarized planar antenna array of elliptical patches is presented. The designed prototype has been verified experimentally. Elliptical patches produce circular polarization by using a single feed only. A corporate feed network with quarter-wave transformers are used for uniform excitation of all the array elements. Primary advantages of the presented antenna array are structural simplicity, good circular polarization characteristics and no side lobes. Here, the design example is given for 2×2 elliptical patches at 2.8 GHz. Similar procedure can be extended for more number of array elements at the desired frequency of operation to cater the need of communication systems where circular polarization is essential.

Keywords: Antenna array, axial ratio, circular polarization, elliptical patch, microstrip, single feed

I. INTRODUCTION

Circularly polarized waves radiate energy in the horizontal and vertical plane, as well as every plane in between. So, circular polarization (CP) is more resistant to signal degradation due to atmospheric conditions, such as rotation of signal polarization. Circularly polarized waves do not observe Faraday rotation due to Earth's magnetic field while passing through ionosphere. Also, Faraday rotation is less noticeable at higher frequency, e.g., *Ku*-band. So, for Satellite communication at lower microwave frequencies circularly polarized antennas are very useful. Microstrip antennas [1] being low profile planar structure are very effective radiators. A single patch antenna can be made to radiate circular polarization if two orthogonal patch modes [2] are simultaneously excited with equal amplitude but in phase quadrature with sign determining the sense of rotation. Two types of feeding schemes can accomplish this task. The first type is a dual-orthogonal feed, which employs an external power divider network in the form of a quadrature hybrid or a T-junction power divider with a quarter-wavelength line.

Evidently, the design of feed network becomes complicated while designing an array antenna. The other is single feed and CP is obtained by slightly perturbing the microstrip patch at appropriate location with respect to the feed. In [3], it is shown that CP is obtained from single feed circular patch antenna tuned by passive metallic or shorting posts.

A class of CP antennas are derived from disk and square microstrip antennas by cutting slots in their interiors [4] or corners [5] off their perimeters. It eliminates the necessity of complex feed network as mentioned above but requires to cut the slots of appropriate size at the right position.

Another simple way to produce left handed or right handed circularly polarized radiation is to make a single feed circular patch elliptical in shape with small eccentricity [6], [7]. It creates two spatially orthogonal degenerate modes along the two axes of ellipse. These two modes are in phase quadrature if the feed line is chosen along the line made 45° with respect to the axes. Surface currents, internal fields and radiated fields are obtained and are expressed in terms of Mathieu functions.

In the present work gain is considered as an important parameter for the design of single element antenna and is further enhanced by using antenna array of proper configuration keeping circular polarization intact.

In this paper, a design of circularly polarized 2×2 planar antenna array of elliptical patches at 2.8 GHz is presented. The patches are excited uniformly. A suitable feed network is designed for impedance matching between the 50Ω probe and the patches. The design is optimized through the 3D EM simulator HFSS from ANSYS and the prototype is experimentally verified. The paper is organized as follows: Section II describes single element antenna and its performance matrices; Section III deals with the design of 2×2 antenna array along with the feed network. The design has been experimentally verified in Section IV. Finally, it has been concluded in Section V.

II. SINGLE PATCH ELEMENT

A. Design of elliptical microstrip patch element

To design an antenna array, at first it is required to design a single elliptical patch element and characterize it. Roger's RO4725 substrate having permittivity 2.55 and thickness 1.542 mm has been used for the present design. The dimension of elliptical patch antenna at the desired frequency of operation is derived from the circular patch. Radius of the circular patch for the fundamental TM_{110} mode is given by [8]

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$$a = \frac{F}{\left\{1 + \frac{2h}{\pi F \epsilon_r} \left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726 \right] \right\}^{3/2}} ; \quad (1)$$

$$\text{where } F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}}$$

h = height of the substrate,

ϵ_r = permittivity of the substrate and

f_r = desired resonant frequency.

Radius of the circular patch is calculated to be 18.4 mm for the present substrate at 2.8 GHz. It is taken as the minor axis of the ellipse and the major axis is taken as 18.8 mm to perturb the circular patch for the excitation of even and odd modes along the two perpendicular axes.

B. Simulation Results

The single elliptical patch element is shown in Fig. 1. Probe feeding technique is used to excite the elliptical microstrip patch antenna where feed is located at a radial distance 10 mm from the centre of the ellipse at an angle 45° with respect to the major axis. The 3D EM simulator HFSS from ANSYS is used for the simulations with an appropriate size of radiation boundary. Simulated S-parameters are shown in Fig. 2. It ensures that the patch is resonating at 2.8 GHz. Fig. 3 shows that the maximum radiation is in the broadside direction and the broadside gain is 3.39 dBi. It can be seen from Fig. 4 that CP is also obtained in the broadside direction. The corresponding axial ratio is 2.01 dB.

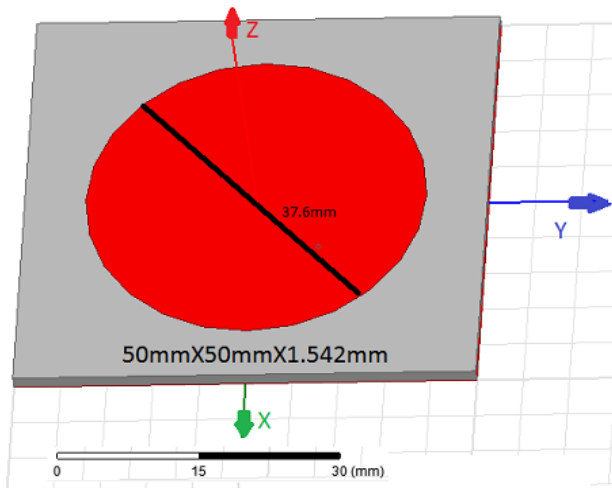


Fig.1 Single element elliptical patch antenna.

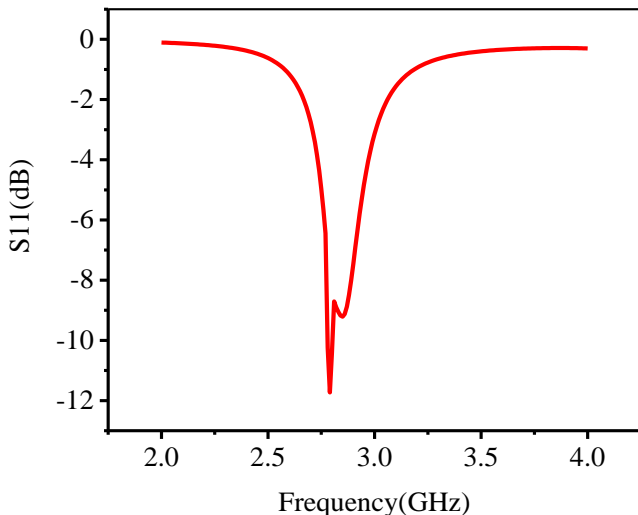


Fig.2 Simulated S11 of the single patch element

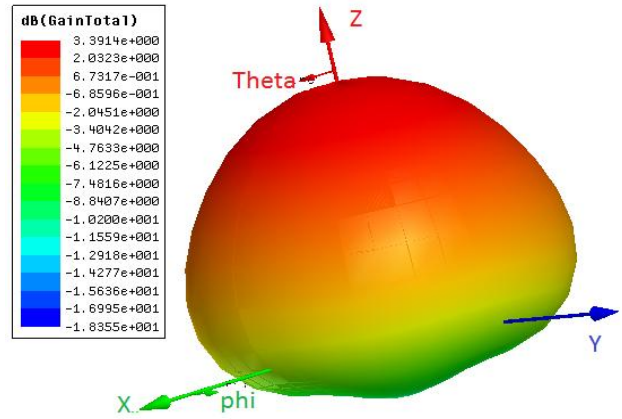


Fig. 3 Simulated 3D radiation pattern of the single element

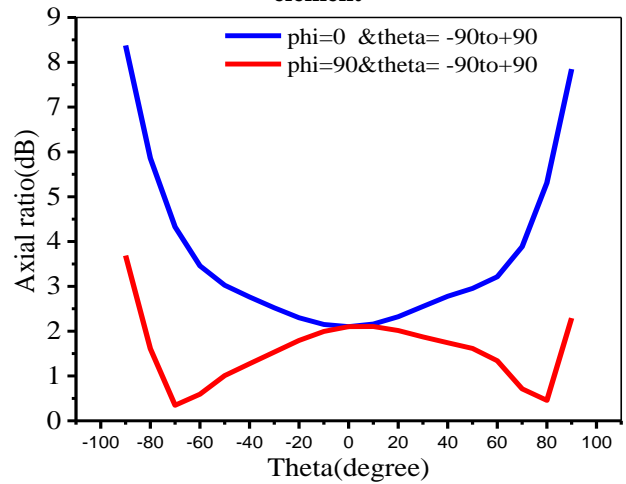


Fig. 4 Simulated axial ratio for the single element.

III. DESIGN OF AN ANTENNA ARRAY

A. Theory

Antenna array can be formed by assembling the radiating elements in geometrical and electrical configuration without increasing the size of the individual elements to achieve high gain. The total field radiated by the antenna array will be vector addition of radiated fields of individual elements. The array factor defined for $M \times N$ elements while the individual elements are excited uniformly is given as [2]

$$(AF_n)(\theta, \phi) = \left\{ \frac{1 \sin\left(\frac{M}{2}\phi_x\right)}{M \sin\left(\frac{1}{2}\phi_x\right)} \right\} \left\{ \frac{1 \sin\left(\frac{N}{2}\phi_y\right)}{N \sin\left(\frac{1}{2}\phi_y\right)} \right\} \quad (2)$$

where, $\phi_x = kd_x \sin \theta \cos \phi + \beta_x$

$\phi_y = kd_y \sin \theta \sin \phi + \beta_y$.

Proposed array structure of size 2×2 , i.e., $M = 2$; $N = 2$ is designed by considering the patches of elliptical shape.

B. 2x2 array design

The elliptical patch element designed in Section 2 is used for the array design. To avoid mutual coupling between antenna array elements, inter-element spacing is chosen as λ_g . The corporate feed structure is considered to excite the individual antenna element as shown in Fig. 5.

The feedline is connected at the edge of individual patch at angle of 45° to excite the odd and even TM_{110} modes necessary for circular polarization. Input impedance of each single patch is the minimum at the centre of the patch and the maximum at the edge of the patch. The antenna input impedance at the edge is found to be 100Ω with a small imaginary part. So, all of the elliptical patches are connected to 100Ω lines each. Hence, the equivalent impedance at the junctions of each pair is 50Ω . A quarter-wave impedance transformer at 2.8 GHz is placed between a 50Ω impedance and 100Ω line whose characteristic impedance is calculated as $Z = \sqrt{Z_{in} \times Z_{out}} = \sqrt{50 \times 100} \Omega = 70.7 \Omega$. Finally, the two pairs of 100Ω lines from each side results in an equivalent of 50Ω where the co-axial feeding is considered. The simulated 3D radiation pattern of the antenna array is shown in Fig. 6. There is no side lobe. Gain in the broadside direction is found to be 9.82 dBi. Fig. 7 shows that the 3 dB axial ratio bandwidth is 15.4 MHz around 2.8 GHz.

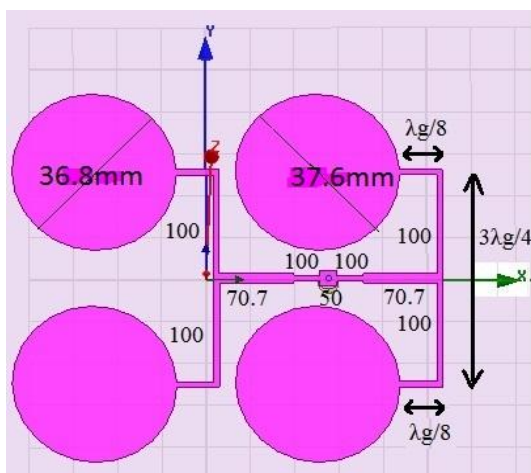


Fig. 5. Configuration of the 2x2 elliptical patch antenna array.

The substrate size is $150 \times 150 \times 1.542$. Semi major axis of each individual patch = 18.8 and semi minor axis = 18.4. Total length of 100Ω line = $\lambda_g @ 2.8 \text{ GHz} = 67.30$, width of the 100Ω line = 1.20, length 70.7Ω line = $\frac{\lambda_g}{4} = 16.83$, width of 70.7Ω feedline = 2.36, width of 50Ω feedline = 3.80. All dimensions are in mm.

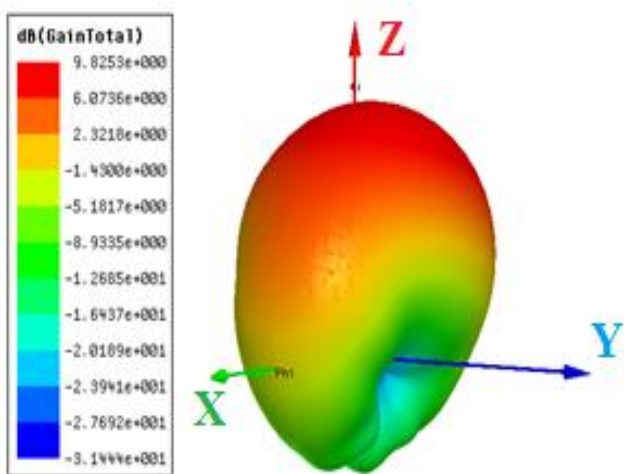


Fig.6. Simulated 3D Radiation Pattern of the antenna array.

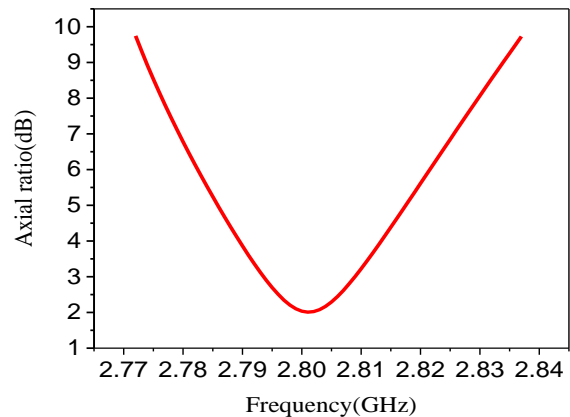


Fig.7 Axial ratio bandwidth of the array antenna.

IV. FABRICATION AND MEASUREMENT RESULTS

The designed array antenna has been fabricated using the same substrate. A photograph of the fabricated antenna is shown in Fig. 8. Measured and simulated S_{11} of the designed prototype is shown in Fig. 9 shows good impedance matching. Radiation pattern of the antenna has been measured in laboratory environment and the normalized radiation patterns at the two principal planes are shown in Fig. 10. Measured axial ratio in the broadside direction is obtained as 1.93 dB. The axial ratio measurement set up is shown in Fig. 11.

Gain of the designed antenna array has been measured using a horn antenna with known gain as the transmitting antenna. Friis Transmission Law for the received power calculation is given by [2]

$$P_r = G_t G_r P_t \left(\frac{\lambda}{4\pi r} \right)^2 \quad (3)$$

where, P_t = Transmitted power,

P_r = Received power,

G_t = Gain of the transmitting antenna,

G_r = Gain of the receiving antenna,

r = Distance between the transmitting and receiving antennas and λ = Wavelength corresponding to operating frequency.

Considering $P_t = -15.1 \text{ dBm}$, P_r is obtained as -42.1 dBm at 2.8 GHz at a distance of 132 cm. Hence, the gain of the fabricated antenna array is found to be 8.2 dBi while the simulated realized gain of the designed prototype is 9.82 dBi



Fig. 8 Photograph of the fabricated antenna array.

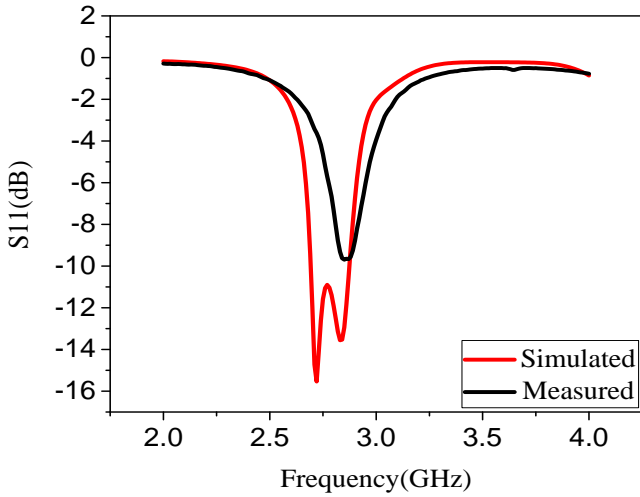


Fig. 9 Measured and simulated S_{11}

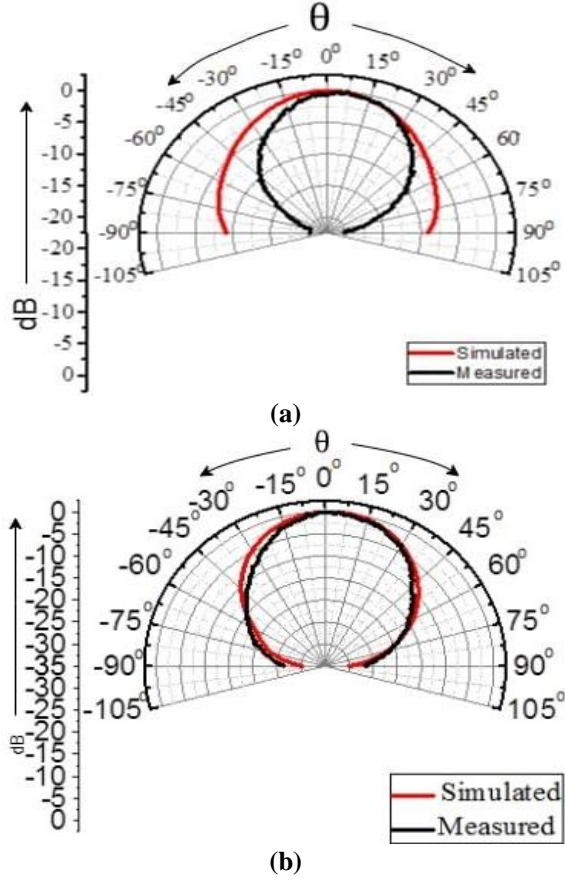
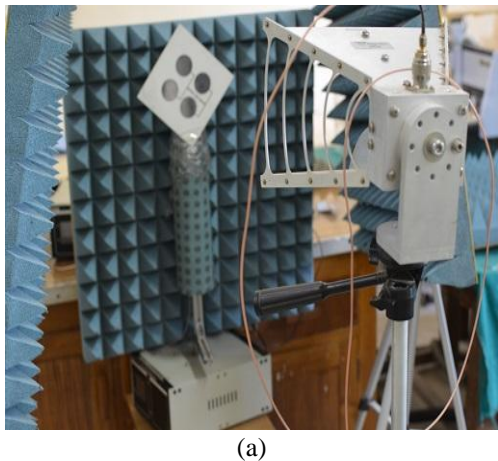
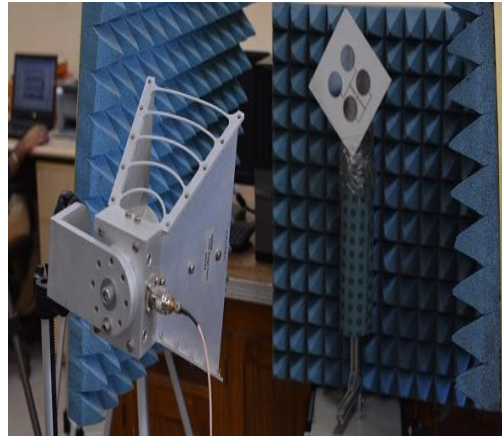


Fig.10 Measured and simulated normalized radiation patterns at the plane (a) X - Z and (b) Y - Z.



(a)



(b)

Fig. 11 Axial ratio measurement set up.

V. CONCLUSION

Detailed design procedure, fabrication and measurements of a circularly polarized antenna array of elliptical patches have been demonstrated. Experimental results show good agreement with measurements. Primary advantages of the presented antenna array are: good circular polarization characteristics, single feed, structural simplicity, and no lobes. Here, a design example of a planar antenna of 2×2 patches at 2.8 GHz has been reported. Similar design procedure can be extended for more number of array elements at the desired frequency of operation and can find applications for Global Positioning System, Global Navigation Satellite System and other communication systems where circular polarization is required.

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