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Performance Analysis of Patch Antenna Using Slot Shaped Metasurface

Jnana N J, Dr Sheeba O
Communication Systems, TKM College of Engineering, India, jnananj@gmail.com
Department of Electronics and Communication, TKM College of Engineering, India, shb.odattil@gmail.com

Abstract ***:*** Performance of a polarization reconfigurable antenna using Metasurface is analyzed. A patch antenna along with a metasurface (MS) is called Polarization Reconfigurable Metasurfaced Antenna (PRMS). The MS of circular shape with a rectangular slot is placed above the circular patch antenna having a circular substrate. By rotating the MS mechanically with respect to the patch antenna, the polarization of the antenna is reconfigured to Linear polarization (LP) and circular polarization (CP). The diameter of the MS and substrate of the patch antenna is 80mm. The radius of the patch is 16.65mm. The radiation pattern and reflection coefficient (S11) is analyzed. The gain and bandwidth of the patch antenna is improved by using a MS. Results show that the PRMS antenna in circular polarization achieves an operating bandwidth of 2.4 -3GHz.

Keywords : Reconfigurable Antenna, Metasurface (MS), Patch Antenna.

INTRODUCTION

Antennas are necessary and critical components of communication and radar systems. Each antenna possesses inherent benefits and detriments that make them more or less suitable for particular applications. In order to develop a new structure that produce an acceptable result, the engineers change and adapt the basic antennas using theoretical knowledge and design guidelines. Postures of mobile Communication devices in use are often dynamically changing which creates difficulties to have good polarization matching for antennas with only single polarization, it is desirable to have antennas to be able to work in different polarizations such as linear polarization (LP) and circular polarization (CP) [1]. A polarization reconfigurable antenna, can offer various polarizations at the same operating frequency (ie CP and LP), has received considerable attention because it has the potential to improve the performances of wireless communication systems [2].

To configure means to arrange or organize the parts of something to achieve a desire property [3]. The concept of reconfigurable antenna is relatively old. In early 1939's, direction of arrival of a signal was determined by steering the nulls of two element array using calibrated variable phase changer [4]. In 1979, the term "reconfigurability" was defined as "the ability to adjust beam shapes on command to meet changing user requirements or to avoid interference"[5]. In general, the reconfigurable antennas should able to alter their operating frequencies, bandwidths, polarizations, and radiation patterns independently to accommodate the changing operating requirements [6]. Reconfigurable antennas can change their performance characteristics by altering the current on an antenna. This can be achieved by using two methods. One is mechanically reconfigurable and the other one is electrically reconfigurable. Mechanical reconfiguration is less popular than electrical reconfiguration. The main reason for this is mechanically reconfigurable antenna requires movable parts, which are very complicated and require more space. They create instability in the operation of the antenna. Here a simple and cost efficient mechanically reconfigurable antenna technique is given [1]. By placing a planar structured metasurface along the base antenna, the polarization can be reconfigured [7].

In this paper a mechanically reconfigurable antenna is presented. The antenna is reconfigured to various polarizations by using a metasurface (MS) [1]. MS is a two dimensional equivalent of metamaterial. Metamaterials are typically engineered by arranging a set of small scatterers in a regular array throughout a region of space, thus obtaining some desirable bulk electromagnetic behavior [8]. The desired property is often one that is not normally found naturally. By placing a MS atop the patch antenna makes a noticeable change in the characteristics of the patch antenna [7]. The patch antenna is used here because of their low profile, light weight and easy fabrication [9]. By rotating the metasurface the polarization characteristics of the antenna varies from Linear polarization (LP) to Circular polarization (CP). Here the same patch antenna can be made to work with both LP and CP by placing a MS above it [10]. The Patch antenna along with the MS is called PRMS antenna [1]. The performance of the PRMS antenna with various shaped MS is analyzed in this paper.

The structure of this paper is as follows. Section 2 describes about the design of PRMS antenna. The modeling of the antenna is explained in section 3. Section 4 highlights the simulation and measurement results. Conclusion is discussed in section 5.

DESIGN OF PRMS ANTENNA

The PRMS antenna consists of (1) metasurface (2) source antenna. The source antenna used here is a single feed circular patch antenna [11]. Metasurface consist of a 4×4 square unit cells. The slot of small dimension is truncated with in the square unit cell. The MS is very simple in structure and it has only few parameters. The MS along with the truncated slot is shown in Fig 1. The MS contains a single

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sided substrate and the patch antenna consists of a double sided substrate. Both the circular patch antenna and MS are designed to have circular shape for easy mechanical operation. The polarization reconfigurability of the antenna is obtained by rotating the MS with respect to the patch antenna. The MS is rotated with respect to Y axis. The rotation is expressed in terms of rotation angle θ_R. When the MS is at 0^0 the antenna shows circularly polarized (CP) characteristics. When the MS is at 45^0 the antenna shows linearly polarized (LP) characteristics. When the MS is at 90^0 the antenna shows a CP characteristics. When the MS is at 135^0 the antenna shows linearly polarized characteristics.

The substrate portion of the MS is placed atop of the patch antenna. The SMA connector is used to feed to the feed line through the ground plane and the substrate material of the patch antenna. The PRMS antenna together with the coaxial feed is studied using CST EM simulation tool. The FR-4 (lossy) substrate with a thickness (h) of 1.5mm and a dielectric constant of ε_r = 4.3 is used.

The design procedures have the following steps.

- Design a patch antenna at 2.4GHz.
- Place a metasurface atop the patch antenna.
- Rotate the metasurface and plot the axial ratio graph.

MODELLING OF THE PRMS ANTENNA

The model of the patch antenna is given in Fig (2). The microstrip antenna is usually designed for linear polarization. For a circular polarization the patch antenna must have orthogonal field components with equal amplitude but in phase quadrature. The patch with perturbations can produce circular polarization [12]. Various types of antenna perturbations is available [13]. By in cooperating various perturbations in to the MS, then the patch antenna radiate in different polarization. The structure of the unit cell is shown in Fig (3). Here a denotes the length of the unit cell, b and c denotes the dimension of the square perturbation, d denotes the gap between two adjacent unit cells. The dimensions of the carved regions play a crucial role in reconfigurable antenna [14].

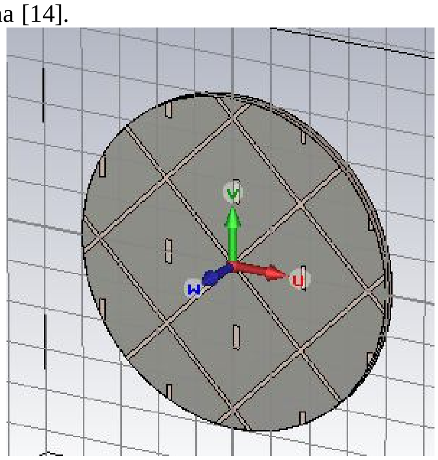

Fig 1: Geometry of MS

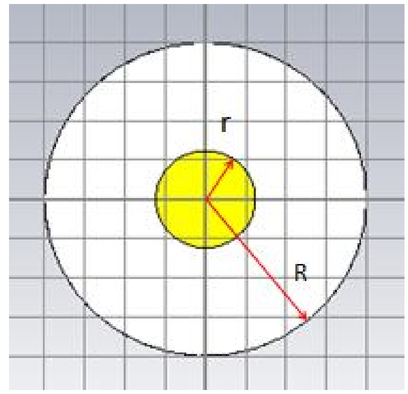

Fig 2: Patch Antenna

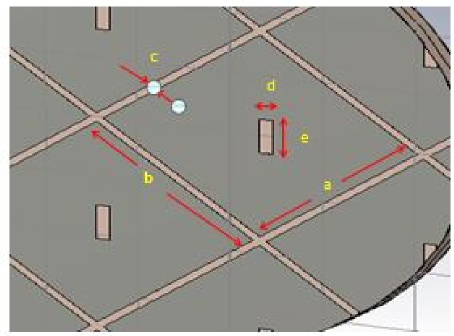

Fig 3: Unit Cell

The dimensions of the patch antenna and the metasurface are given in Table 1. These dimensions alter the antenna performance. The radius of the patch antenna is obtained from the equation (1) [15]. Here f_r denotes the resonant frequency.

Table 1: Dimension of PRMS Antenna (Units : mm)

a	b	c	d	e	r	R
24	24	1	1.414	5.656	16.65	40

$$r = \frac{F}{\left\{1+\frac{2h}{\varepsilon_r \pi F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \quad (1)$$

$$\text{Where} \quad F = \frac{8.791 \times 10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

SIMULATION AND MEASUREMENT RESULTS

Reflection Coefficient S11

The PRMS antenna is designed and simulated. The reflection coefficient at different rotation angle θ_R is studied and it is shown in Fig 4. When $\theta_R = 0^0$, the S11 obtained is -16.113 dB and is shown in Fig 4(a). When $\theta_R - 45^0$, the S11 obtained is -11.213 dB and it is given in Fig 4(b).

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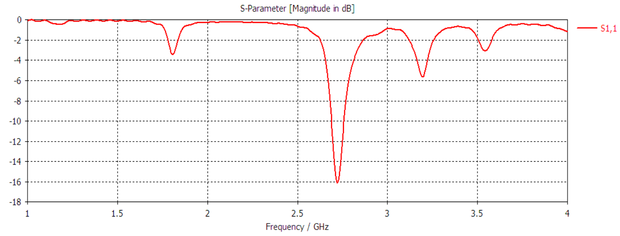

Fig 4 (a): When $\theta_R = 0^0$

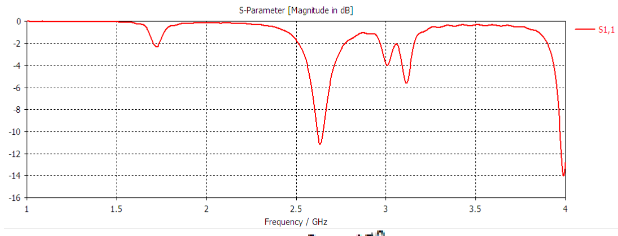

Fig 4 (b): When $\theta_R = 45^0$

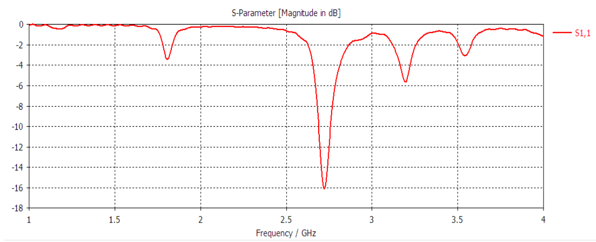

Fig 4.(c): When $\theta_R = 90^0$

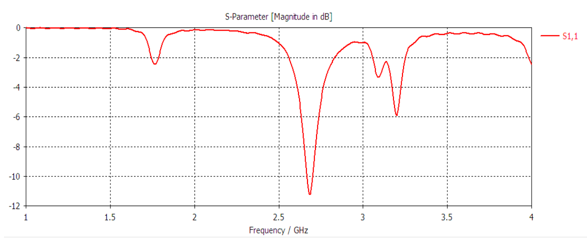

Fig 4(d): When $\theta_R = 135^0$

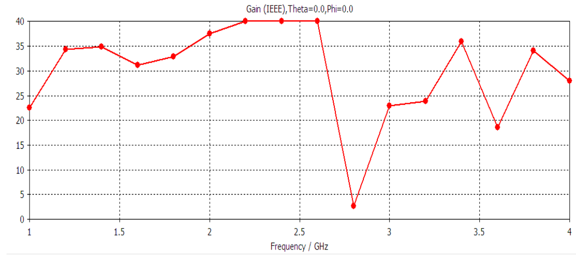

Fig 5 (a): When $\theta_R = 0^0$

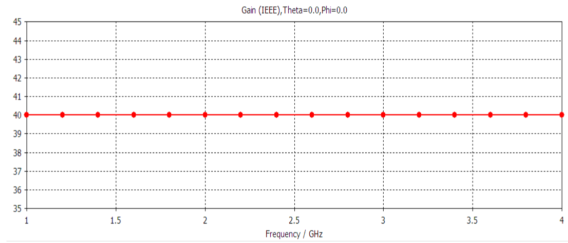

Fig 5 (b): When $\theta_R = 45^0$

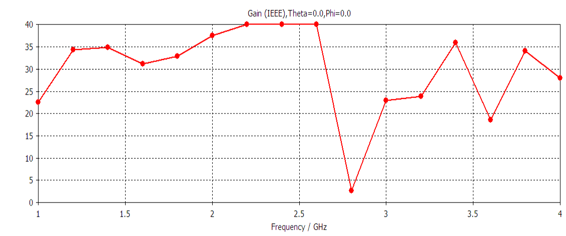

Fig 5.(c): When $\theta_R = 90^0$

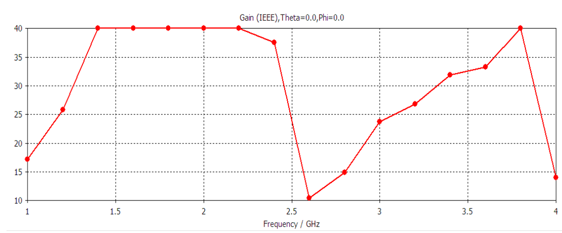

Fig 5(d): When $\theta_R = 135^0$

Here two bands of frequencies(one is at 4GHz) are available t is due to the capacitance offered by the MS. When $\theta_R = 90^0$, the S11 obtained is -16.173 dB and it is shown in Fig 4(c). When $\theta_R = 135^0$, the S11 obtained is -11.321 dB , it is shown in Fig 4(d). Here the antenna is designed at 2.4GHz because of its wide range of applications. After placing a MS above the antenna there is a frequency shift occurs. This is due to the resonance effect of the MS.

Axial Ratio AR

The simulated AR of PRMS antenna is shown in Fig 5. When $\theta_R = 0^0$,the AR is a small value ie 2.0887dB (which is <3dB). It indicates that the antenna operated in CP. The ARBW obtained is 42.2MHz. When the rotation angle $\theta_R = 45^0$ the AR is a high value ie 40dB. It indicates that the antenna operated in LP. When $\theta_R = 90^0$ the AR obtained is a low value of 2.2214dB (which is <3dB). It indicate that the antenna operated in CP. The ARBW obtained is 49.405MHz.

When $\theta_R = 135^0$ the AR is a high value of 10dB. It indicates that the antenna is operated in LP.

Radiation Pattern

The simulated radiation pattern of the patch antenna and the PRMS antenna is shown in Fig 6. The patch antenna radiate unidirectional signal. The PRMS antenna radiates a bidirectional signal. The radiation pattern of a patch antenna is shown in Fig 6(a). The main lobe of the radiation pattern is towards 0^0. By placing a metasurface with it the radiation pattern changed and it become bidirectional. The Fig 6(b) shows the radiation pattern of the antenna when the rotation angle $\vartheta_R = 0^0$. The main lobe is pointed towards 54^0 with a magnitude of 8.48dBi. The angular width (3dB) is 123.7^0 and has a side lobe level of -1.1dB. In Fig 6(c) shows the radiation pattern of the antenna when the rotation angle $\theta_R = 45^0$. The main lobe is pointed towards 125^0 with a magnitude of -2.18dB. The angular width (3dB) is 126.9^0.

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In Fig 6(d) shows the radiation pattern of the antenna when the rotation angle $\theta_R = 90^0$. The main lobe is pointed towards -40^0 with a magnitude of -.0.792dB.

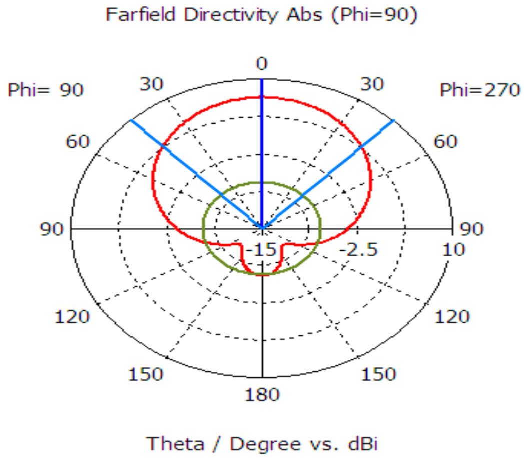

Fig 6 (a): Radiation Pattern of the patch antenna

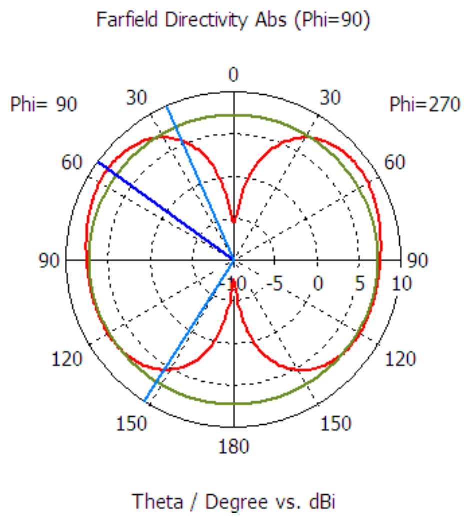

Fig 6 (b): Radiation Pattern when $\theta_R = 0^0$

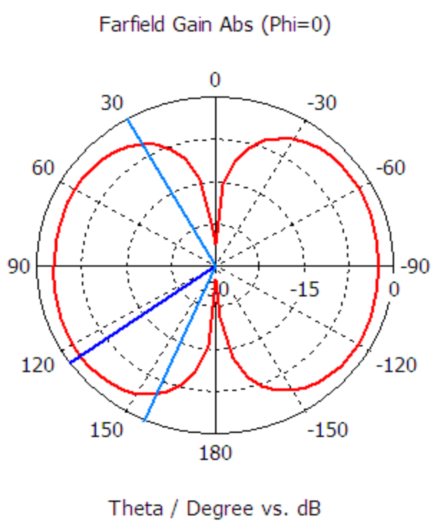

Fig 6 (c): Radiation Pattern when $\theta_R = 45^0$

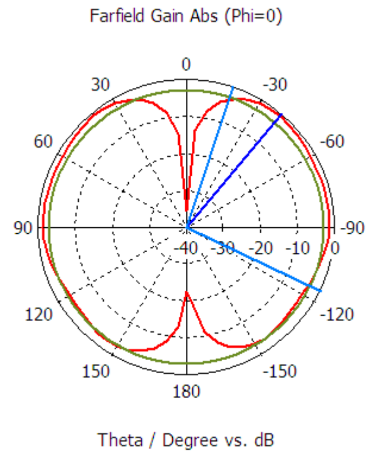

Fig 6 (d): Radiation Pattern when $\theta_R = 90^0$

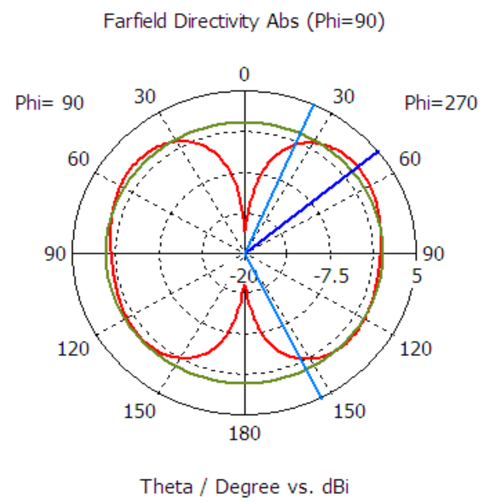

Fig 6(e): Radiation Pattern when $\theta_R = 135^0$

The angular width (3dB) is 97.6^0 and has a side lobe level of -2dB. The Fig 6(e) shows the radiation radiation pattern of the antenna when the rotation angle $\theta_R = 135^0$. The main lobe is pointed towards 51^0 with a magnitude of 1.11dBi. The angular width (3dB) is 130.2^0 with a side lobe level of -0.9 dB.

CONCLUSION

A PRMS antenna with circular patch antenna and MS was analyzed using the EM simulation Tool CST STUDIO. The polarization of the antenna can be mechanically reconfigured to LP and CP by rotating the MS with respect to the patch antenna. When the MS is at $0^0$the PRMS antenna shows a circularly polarized characteristics. By rotating the MS to 45^0 the PRMS antenna shows a LP characteristics. When the MS is at $90^0$the PRMS antenna showed a CP characteristics. When the MS is at 135^0 the PRMS antenna showed a LP characteristics. The simulated results of polarization

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reconfigurability, reflection coefficient and the radiation pattern were analyzed. The results showed that the polarization reconfigurability was achieved with in an operating bandwidth of 2.4 -3GHz. From this analysis using metasurface it can be easily deducted that the simple patch antenna can be made to work with different polarizations by placing the metasurface above the patch antenna.

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