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A Novel Design of a Circularly Polarized Micro Strip Patch Antenna with Narrowed Radiation Pattern

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***Abstract*—** In the recent era of technological advancements, it becomes the basic needs of the day that every person wants a better and faster means of communication. Antennas design is of the greater importance to achieve better communication. With the development advances of communication systems in different fields of study such as development in the field of IoTs (internet of things) antenna design becomes the talk of the day. Antenna design also has many complications in its design, structure and working. Researchers are trying to achieve such antenna design which should be simple, easy to use and no complexities in structure. This research study circulates around a design and investigation of a newly designing of circularly polarized (CP) micro-strip antenna with a conical pattern of radiations. Major distinctive feature of such design includes single feeding mode, simple design and low profile. The octagon shaped patch can be obtained by two superimposed square patches. Omnidirectional circularly polarized radiation from two superimposed square patches is acquired by generating two mutually perpendicular degenerated TM11 modes. This research study is carried out to understand the fabrication and operation technique of CP micro-strip Patch antenna and the results are obtained. The obtained results shown the linearity with the simulation as well as theoretical results. The antenna is capable to generate conically CP radiation samples with average axial ratio (AR) of value 1.8 dB in azimuthal plane (ϴ=45̊). 3-dB AR BW covers GPS L1 band.

***Keywords*—** circularly polarized micro-strip patch antenna, conically radiated pattern, omnidirectional pattern, octagon star shaped patches.

I. Introduction

Antenna is referred to as “a source of transmitting & receiving radio waves for communication purpose”[1]. Vital role of antenna happens to be wireless communications; indeed without antenna wireless communication is impossible [2]. The signal generated by transmitter is fed to the air by antenna in the form of electromagnetic wave. As shown in Figure 1.1. At receiver this signal is captured by receiver antenna and fed to the receiver [3][4]. The significant properties of antenna are described below. Pattern of radiation for an antenna gives us the information about the direction of minimum and maximum radiations. The power transmitted per unit solid angle by an antenna is referred as radiation intensity [5].Practical antenna does not radiate equal energy in all direction. So directivity termed as “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions” [5]. Directivity related to an ideal antenna is one (1) while that of practical has directivity of more than 1.Gain is regarded as “ antenna radiation intensity in a specific direction divided by the antenna radiation intensity could be achieved if the power acknowledged by the antenna were radiated symmetrically in all orientation” [5]. Gives the information about the volume of power echoed back to the transmission line from the antenna input terminals. If magnitude of the reflected power less than-10 dB the reflected energy is minimum and maximum power is fed to the transmission line [1].It can also be defined as the Frequency range within which maximum power fed and power reflection at its minimum value [6]. “It is the ratio of voltage and current at the antenna’s input terminals” [5]. To avoid reflection at antenna we are required to comply with maximum power transfer theorem. It states that antenna’s input terminals impedance and transmission line must be complex conjugate of one another [7]. In small devices like mobile phones, laptops, etc. requires portable antenna featuring low profile to radiate and receive the electromagnetic waves and micro strip antenna is very applicable in this regard. Its installation is simple and invisible to the end user[5][8][9][10][11][12]. Micro strip patch antenna comprises of 3 various components i.e. patch, ground plane, and substrate. The two components, ground plane and patch are designed from such material which is good conductor of electricity mostly of copper. The patch & ground are detached by a dielectric material called substrate. Equally shown in Figure 1.3. Feeding mechanism is used for energizing purpose for micro-strip antenna, there are several methods for micro-strip antenna feeding. [5]. Micro-strip line feed is allied to the patch and imprinted on the same substrate, its width, height of substrate, and εr decides Its impedance [13]. Coaxial line feeding coaxial cable is utilized en route for feeding the antenna. Coaxial cable consists of two conductors along with dielectric flanked by them [5]. Fabrication of patch is done on the upper substrate while the fabrication of micro strip link is done on the lower side of the other substrate. They are so combined that upper substrate gives patch whereas lower substrate gives microstrip line. [14]. Proximity coupled feeding structural geometry is correspondingly comprises of two substrates. The ground is on lower substrate and micro-strip line at the upper face. [15]. Patch is needed to be approximately $\frac{\lambda}{2}$ (i.e., half of the wavelength). Stipulation the voltage at one end is extreme in positive direction at that time there should be minimum negative voltage at the other end. It is obvious that horizontal element of fringing field close to the plane of patch takes the identical route. So, owing to identical phase they encapsulate and give growth to radiation from antenna [5-15].

II. Related Work

Most common design of CP antennas are obtained by the excitation of two orthogonal modes at different resonance frequency, mostly such antennas are unidirectional [16]. Omnidirectional radiation pattern for CP have been developed such as Introduction of Curved branches [17] and [18], asymmetric slits implemented [19] and parasitic stubs implanted [20].By rearranging the CP radiating antennas elements through a cylindrical surface [21] having high profile, fabrication issues and complex feeding network. Omnidirectional CP antenna through four bended dipoles [22]. While another technique is based on shorted monopole and 4-dipoles [23]. Both of these techniques are characterized by wide bandwidth, high profile structure and complex feeding circuit. Omnidirectional circular polarized antenna with two faced slot radiator and 2 planar inverted F antenna [24]. Characteristics of such model are low profile and compact structure but associated issue with such model are complex design with addition of extra feeding network.

Dual band omnidirectional CP antennas with planner structure and low profile [25] and [26] however its configuration complex. the design is made in such a way to have the axial ratio (AR) the L1 band i.e. GPS band but the applied limit of 3 dB has been exceeded [27]. Circularly polarized antenna is superior to that of linearly polarized antenna in many aspects including wireless communications [28]. Circular mushroom structure with curved branches using ZOR and ENG TL modes operated at vertical polarization to achieve omnidirectional radiations, while the horizontal polarization is attained by curved branches [29]. Circularly patches wideband. Omnidirectional CP antenna with various prolonged curvy branches works as a polarizer, [30].

Wideband omnidirectional CP antenna designed for broadband [31]. A low profile, wideband CP antenna with conical-beam centrally fed mono-polar patch designed to achieve the wideband CP radiations [32].

Omnidirectional circular polarized micro-strip antenna without the curvature effect for mounting cylinders with radius of each is greater than the guided wavelength [33]. A broadband CP omnidirectional antenna with 4 broadband CP rectangular prototype best suits for 2G/3G base stations [34]. Omnidirectional radiated CP using bended dipoles and integrated baluns is fabricated for a bandwidth of 220MHz with LHCP gain of greater than 0.15 dBic [35]. Omnidirectional CP antenna is designed by placing spiral elements above the conducting drums in horizontal plane, by increasing the numbers of spiral elements leads to the omnidirectional radiations [36]. Omnidirectional CP antenna having non-linearity in results been controlled at 1.5 dB in azimuthal plane [37]. Omnidirectional patch antenna having equilateral triangular patch and a number shorting vias with circular slot rings, triangular patch gives twofold uses, minimizing patch size as well as produces radiation null at upper band [3]. DPDB antenna with to achieve omnidirectional radiation pattern, with the horizontal polarization is achieved through eight asymmetrical open slots, in the upper band in order to get omnidirectional linear polarization the TM01 is excited [38]. Omnidirectional radiations at single plane for GPS system a differentially fed back-back patch antenna [39]. In order to generate the circularly polarized conical radiations a circular micro-strip antenna has been excited at higher order modes, at different higher order modes or substrate is loaded with different materials of changed dielectric constants the peak of the conical radiations has been changed, for this different feeding modes are needed [40]. For the purpose to achieve wide impedance, AR and gain bandwidths along with low profile and high gain a CP conical beam patch with featuring wideband is design [41]. Dual CP micro-strip with conically radiated pattern integrated with hybrid coupler to achieve better results through 2nd order exciting mode gives conical peak around 46 degrees can be applied on vehicle mounted satellite communication [42]. An omnidirectional azimuthal coverage is archived through TM21 mode circularly polarized ARMSA with a feeding line in ring shapes provides better impedance matching and annular ring provides the better CP with carefully designed feeding line inside the ring [43]. With the intention of lessen the frequency ratio of the slotted patch dual band antenna for the application of GPS system transmission or receiving an antenna design featuring low profile and cost using short circuited micro-strip stub for defining reactive loading, moreover the frequency ratio dual band can further be reduced by optimizing the antenna [44]. In order to minimize the multipath fading and to acquire CP with high gain a CP antenna designed for the GPS use with 12 elements antenna array, by increasing the elements gives CP with high gain and reduced multipath fading [45]. With the purpose of accomplishing wideband CP radiations a metasurface single feed, rectangular shaped with slotted patch implemented, the given results states that AR mainly depends on the metasurface configuration, patch radiator size and feeding point location [46]. Enhancement of Circular polarization achieved with feeding the L- shaped probe feed, CP is obtained via two perpendicular polarized fields from L-shaped probe, using 4 L- shaped feeding probes reduces more mutual coupling than 2 L- feeding probe [47]. L-shaped probe with single feeding patch with horizontal portion act as transmission line with ground plane designed to get impedance, gives limitations in bandwidth because of inductance associated with L-shaped probe [48]. Differentially fed patch with symmetrical arrangement for CP with L- shaped probes feeding is done through capacitive coupling gives linear pattern, serves in desired in mm-wave phase antenna [49]. CP performance with reduced size of the antenna by reducing annular ring patch size , using cross slots in ground plane is designed and implemented [50]. CP embedded with square micro-strip having singly fed tri-band features, parallel to the sides of upper square patch two pairs of narrow slots are capable of generating circularly polarized radiations with a better performance of the antenna design [51].

Rectangular patch embedded on the glass epoxy FR-4 with a singly fed stacked design to achieve better results of impedance and AR bandwidths and gain found applications like wireless satellite communication where high AR bandwidth are required which is in most cases desired [52].

Based on the mode analysis a new design is implemented where higher mode frequencies (TM20-TM50) reduced and combined with resonant mode dominating TM10, in order to get CP radiation pattern for a wide band [53]. Comparison of Yagi antenna tilted beam inclined on a wall is made with the patch antenna [54]. An asymmetrical feeding point is proposed for the CP UWB HRMSA for calculating impedance matching, AR, gain and radiation pattern found its applications in S, C, and X-band applications [55]. Four feed with TM21 mode right hand CP to cover L1 band for GNSS receiver application, gives the conical radiation pattern achieving null at boresight and peak at desired phase [56]. CP micro-strip feeding patch antenna operating at 5.8 GHz frequency design [57].CP-MPA with a conical grounded plane operating at an X-Band with a composite single-feeding operating mode found the application in the SMP connector based termination [58]. A pressure driven enabled antenna having reconfigurable polarization antenna design having micro channel developed to multiple contact points for low loss conducting pathways [59]. MSA antenna operating having linearly polarized designed for the application like Altimeter [60].

III. METHODOLOGY

In this section the stepwise approach for design is covered. The following steps are illustrated below for the anticipated antenna design.

Step 1 antenna parameters:

TABLE I. ANTENNA PARAMETERS DESCRIPTION AND VALUES.

Name	Description	value
Theta d	Feeding point phase angle	22.5
Theta	Phase angle	45
t	time	0.05
h	height	5
d_{out}	Outer distance	1.7
d_{in}	Inside distance	0.5
dL	Change in length	2
d	Distance from the patch center	32.2
R	Radius of substrate	80
L_{coax}	Coaxial cable length	15
L	Length	94.4
ε_r	Relative permeability	2.164

Step 2 design simulation:

Step 3: theoretical analysis:

- *TM_{11} – Mode Square Patch Antenna.*

The tangential electric field at the patch sides can be calculated in from equation 1 given below.

$$Ez(x',y') = -A/2h(\sin\frac{\pi}{L}x')((\sin\frac{\pi}{L}y'), -h \leq x' \leq 0 \qquad (1)$$

The magnetic field can be premeditated via equations given below.

$$\begin{Bmatrix} Mx1 = A\left(\sin\frac{\pi}{L}x\right), y = \frac{L}{2} \\ Mx2 = A\left(\sin\frac{\pi}{L}x\right), y = -\frac{L}{2} \\ My1 = -A\left(\sin\frac{\pi}{L}y\right),\ x = \frac{L}{2} \\ My2 = -A\left(\sin\frac{\pi}{L}y\right),\ x = -\frac{L}{2} \end{Bmatrix} \qquad (2)$$

Source of magnetic lines producing the far-field is given by equation.

$$E = -\frac{1}{\varepsilon o}\nabla \times F \qquad (3)$$

Electric potential vector is represented by F.

$$F(r) = \frac{\varepsilon o}{4\pi r}e^{-jkor}\int Me^{jkor'.\hat{e}r}\,dl' \qquad (4)$$

$$\begin{Bmatrix} E_\theta^{TM11}(\theta,\varphi) = -jk_o\frac{e^{-jk_o r}}{4\pi r}\left(-f_{mx}\sin\varphi + f_{my}\cos\varphi\right) \\ E_\varphi^{TM11}(\theta,\varphi) = jk_o\frac{e^{-jk_o r}}{4\pi r}\left(f_{mx}\cos\theta\cos\varphi + f_{my}\cos\theta\sin\varphi\right) \end{Bmatrix} \qquad (5)$$

Whereas

$$\begin{Bmatrix} f_{mx} = \int_{-\frac{L}{2}}^{\frac{L}{2}}\left(M_{x1}e^{j\frac{k_oL}{2}\sin\theta\sin\varphi} + M_{x2}e^{-j\frac{k_oL}{2}\sin\theta\sin\varphi}\right)\times e^{jk_o x\sin\theta\cos\varphi}dx \\ f_{my} = \int_{-\frac{L}{2}}^{\frac{L}{2}}\left(M_{y1}e^{j\frac{k_oL}{2}\sin\theta\cos\varphi} + M_{y2}e^{-j\frac{k_oL}{2}\sin\theta\cos\varphi}\right)\times e^{jk_o y\sin\theta\sin\varphi}dy \end{Bmatrix} \qquad (6)$$

- *Octagon-Star Shaped Patch Antenna.*

Design of the desired antenna obtained by making two TM_{11} superimposed square patches at angle of 45° having size of Δι. The far field of the proposed antenna can be calculated as.

$$\begin{cases} E_{\theta}^{star}(\theta,\varphi) = E_{\theta}^{TM11}(\theta,\varphi) + jE_{\theta}^{TM11}(\theta,\varphi+45^{o}) \\ E_{\varphi}^{star}(\theta,\varphi) = E_{\varphi}^{TM11}(\theta,\varphi) + jE_{\varphi}^{TM11}(\theta,\varphi+45^{o}) \end{cases} \quad (7)$$

- *Resonance Frequency*

$$f_1 = \frac{c}{L\sqrt{2\varepsilon_r}} \quad (8)$$

Resonance frequency of the patch having length (L+l) *(L+l) can be found

$$f_2 = \frac{c}{(L+\Delta\iota)\sqrt{2\varepsilon_r}} \quad (9)$$

Step 4: Effect of variations in variables on results.

Step 5: comparative analysis.

IV. Results

A. S_{11}-Parameters of the Proposed Antenna.

As already stated that the antenna is deliberated to function in the frequency of 1.55 GHz. The resonance frequency of the antenna is 1.575 GHz while the Bandwidth is 23.8 MHz that is1.54 %, the operative frequency range of the antenna in -10dB range is as of 1.545 to 1.569 GHz. As shown in figure.1

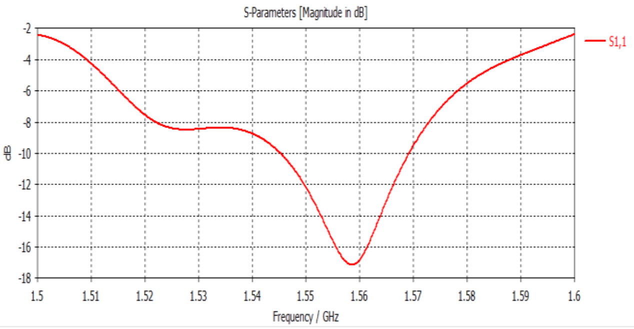

Figure .1 S11 parameters for the proposed antenna.

B. 3-dB Axial Ratio Bandwidth and Directivity.

The figure 2 shows the simulated results for the axial ratios ARs of the presented antenna design. The bandwidth measured for the antenna at φ =0o and θ =45o is between the frequencies operating within the range of 3dB. The range of frequencies for presented antenna is measured in the range of (1.53-1.5415) GHz, having a Bandwidth of 11.5 MHz which is 0.74%.

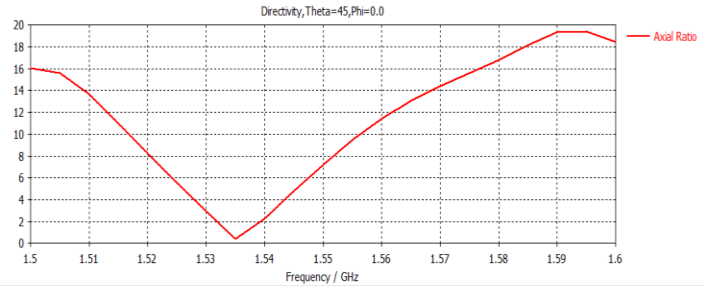

Figure 2. Simulated Axial Ratio Bandwidth

The effect of varying different variable parameters have significant impact on the 3dB AR Bandwidth. Some of them are explained as follows. First of all we have seen the effect of changing the length shown that AR is very sensitive to the change in length. Changing the length may deteriorates the AR, in order to operate in an optimum region the two TM11 modes should in separated in such a way that conditions for circularly polarized radiation must not be violated.

By changing the position of feeding point may not affect the AR parameters much but feeding point must be at a point where optimum impedance matching is achieved which will be sited at the center of the patch specified in the parameters description which is 22.5o. By varying the thickness of the substrate from 3-5mm results in an increased AR bandwidth from 0.5-0.8%, also by lowering the constant dielectric constant from 2.164 to 1 further enhance the AR bandwidth from 0.6 to 1.1 %.

Omnidirectional pattern of radiation is produced at an azimuthal plane. The proposed antenna is not capable of generating desired pattern in omnidirectional because of ground plane, thus due to this the sedated level of cross polarization is less than -18dB at theta=45o.

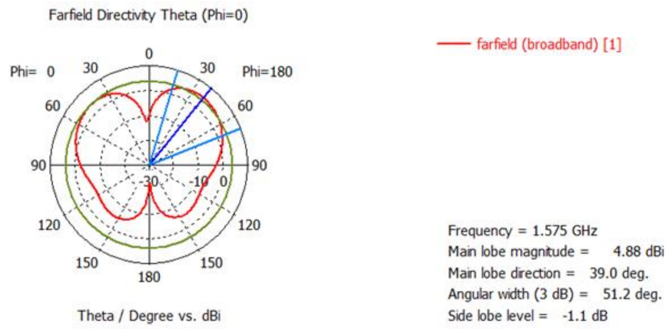

Figure 3. Farfield directivity theta with (phi=0o)

Figure below shows the graphical view of the Farfield Directivity phi

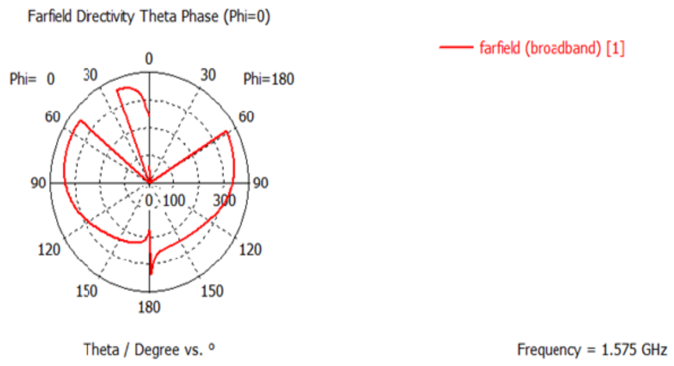

FIGURE IV. FARFIELD DIRECTIVITY PHI WITH (PHI=0O)

C. *Gain of the anticipated antenna.*

Figure 5 provides the insight into the gain of the offered antenna. The peak gain which shown in the results is 5.64 dBi at 1.575 GHz having gain variation over the period of 1.55-1.575 GHz is 0.59 dBic. The measured gain is less than that of the simulated gain because of the losses at different stages of the antenna design.

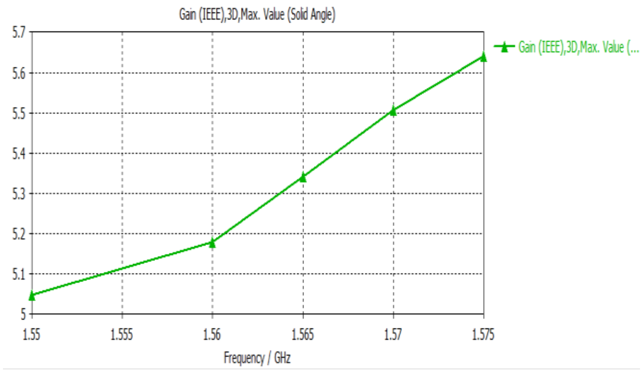

FIGURE 5. GAIN OF THE ANTICIPATED ANTENNA DESIGN

D. *Efficiency of the anticipated Antenna.*

Efficiency of the presented antenna design is given in the figure 6. The results shown comprises two types of efficiencies which are radiated efficiency and the total efficiency. Radiated efficiency over the period of 1.5-1.6 GHz ranges from -0.15-0.35 dBs. With a maximum value of 0.35dB. Total efficiency of the antenna design over the frequency range of 1.5 – 1.6 GHz is in the range of the -4dB to -0.1dB. The peak of the total efficiency is -0.1dB which is occurring at the frequency of 1.56 GHz, the point where the radiated and total efficiencies are almost equal. The graphical view of the efficiencies related to the antenna are given in the figure below.

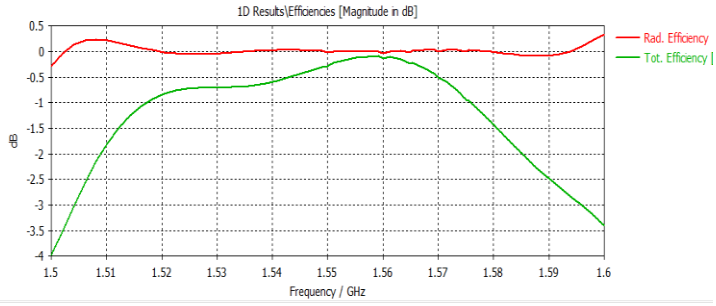

FIGURE 6. EFFICIENCY OF THE ANTICIPATED ANTENNA DESIGN

E. *Evaluation of the anticipated antenna design with literature study.*

In this a proposed antenna design comparison is made with the previous work illustrated in the literature review shown in the table 4.1 given below.

On comparison with the [2-4] the presented antenna shows the similarities in respect to low profile, single layer and single feeding mode and few design variables leads to easy design of the antenna. On comparison with [12-13] dual band antenna design gives good agreement of the AR bandwidth, same design and gives higher gain. The comparison with multilayered antenna design [9-11] presented antenna design features higher gain, low profile, simple design with no extra feeding point. Comparing the presented model with a TM21 mode based antenna design in [15, 16, and 18] gives easy design without any extra feeding point for the excitation of orthogonal mode thus giving less design complexities. While when compared with [21] shown that previous work suffered from the issues like poor radiation pattern and high profile design. On the other hand the proposed design has narrow AR bandwidth when compared with the previous work, thus results in such a way that the proposed antenna design suits for the application of GPS L1 band. The AR bandwidth can be improved by selecting thicker substrate and having permittivity of 1. While comparing with truncated antenna design our antenna design shows the same behavior such as simple design, single feed, easy design, and narrow AR bandwidth of less than 1%. The only mismatch between them is that the offered antenna gives conical radiation while the corner truncated antenna gives the unidirectional radiation pattern. At the end the comparison is made [paper] the results shown that the offered antenna has higher gain and AR bandwidth as compared to the previous work, while keeping antenna dimensions same.

CONCUSLION

This research work is carried out to design and simulate a circularly polarized octagon-star shaped micro-strip patch antenna having radiation pattern of conical shape. The features of this antenna design includes low profile, single feed, and simple and easy design without having any extra feeding connections. The two orthogonal degenerated TM_{11} having radiator forming an octagon-star shaped patch is responsible for the generation of an omnidirectional circularly polarized radiation pattern. The working techniques of the presented work is explained with an appropriate cavity model analysis. The simulated results of the design gives the conical radiation pattern with a peak positioned at $\theta = \pm 45^{\circ}$ while the 3dB AR bandwidth covers the GPS L1 band.

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