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# DESIGN AND ANALYSIS OF A CIRCULARLY POLARIZED OMNIDIRECTIONAL SLOTTED PATCH ANTENNA AT 2.4 GHZ

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***Abstract***

***In this paper, a circularly polarized omnidirectional slotted antenna is presented for ISM applications. The proposed antenna made with a feedline in the ground plane, an annular elliptical slot and four rectangular slots etched on radiating patch and semicircular patch slots are used to achieve circular polarization. The ground plane feed line impedance value is 50 ohms. The substrate used here is FR4 and its relative permittivity 4.4 and loss tangent 0.02. Antenna dimensions are 58mm×58mm×1.6mm. The antenna is resonating at 2.45 GHz with return loss of -31.12dB. The impedance bandwidth covers from 2.02 GHz to 2.77 GHz (% B.W is 30.6%). The proposed antenna design and simulation carried out using HFSS Simulator. The antenna show high gain characteristics, omnidirectional radiation pattern, high efficiency, circular polarization and better co and cross polarizations. The proposed antenna can be effectively useful for ISM and WLAN applications.***

***Keywords:***

***Local Area Network, HFSS, Omni-Directional Radiation Pattern and Circular Polarization***

## 1. INTRODUCTION

An Antenna is the major component and which is used to transmit and receive the information through free space. The principle advantages of micro-strip antennas are low volume, low fabrication cost and they can be easily made. Because of these attractive advantages we propose a circularly polarized Omni-directional slotted patch antenna for ISM band and Wireless Local Area Network applications. It is used to avoid orientation and the alignment faults of the receiver antennas and multipath fading with circular polarization. Microstrip antennas became very popular since 40 years. They became popular as they can be easily fabricated. They are low profile. These are light weight and low volume. They can be printer directly on printed circuit boards. Micro strip antennas are used in wireless communications. The main applications are pagers, satellite communications and mobile phones. As they have low profile occupy low volume these antennas are preferred. These antennas are mainly used at microwave frequencies and widely used in portable wireless devices because of its ease of fabrication. Patch antennas will have a substrate and a conducting layer on top representing the patch and a ground bottom of it. The slots are introduced in the conducting regions for better impedance matching and for good radiation characteristics.

Polarization of antenna gives the direction of oscillation of electric field components when the EM wave is travelling. In linear polarized antennas the direction of oscillation of electric field components will be either horizontal or perpendicular that is in single direction. In circular polarized antennas the field components rotate with equal magnitude at each and every point in the path and 90° out of phase. Of all the polarizations circular polarization is preferred as it do not suffer from polarization mismatch. If the receiving antenna is of circularly polarized the antenna can receive signals irrespective of polarization of the transmitter.

In radio communication, an Omni-directional radiation pattern represents the antenna which radiates equally in all directions in one plane and no radiation in the plane perpendicular to first plane. An antenna is said to be Omni-directional based on the E-field patterns and H-field patterns. Omni directional antennas are preferred these days to receive or send the signals irrespective of the large obstacles. In this article, the design of a circularly polarized omnidirectional slotted patch antenna is proposed and the literature survey of article is presented in section 2. The mathematical modeling of a circular patch antenna is described in section 3. The evolution of proposed antenna is explained in detail in section 4. The simulation and measurement results are reported in section 5. Finally, section 6 gives the apparent overview like conclusion and future scope followed by acknowledgement and references.

## 2. LITERATURE SURVEY

The design of circularly polarized omnidirectional patch antenna is a most important at ISM band applications. The authors of the paper [2] designed the antenna which will be applicable for wireless local area network applications. The antenna that was designed will be working for two frequency bands that were clearly mentioned in the paper. Also with wireless application along with working under two frequencies it was also managed to recept both horizontal and vertical fields in the free space which is also termed as circular polarization. With all these specifications enabled in this research will ease the installation process of the antenna. This design from the reference numbered [3] also operates for two frequency bands. The frequency bands were the part of industrial, scientific and medical field. The research by these authors is majorly to attain the Omni-directional type of radiation pattern. The antenna design was made on a substrate that would be price compromising. Meanwhile the theme of this antenna was just to introduce a different type of radiation pattern when compared with the earlier reference [1]. As a result the matching of impedance was greatly obtained and also the percentage of its radiation is also high making it effective in the areas of wireless communication network and applications. The industrial, medical and scientific applications plays an important in our day to day life, keeping that as a key point several researchers have been working in that field to contribute something that's useful. The major limitation in designing a micro-strip patch antennas is the bandwidth. So in the reference numbered [14] used X-slot to improve bandwidth. The authors also tried to improve it by using diagonal slots. In paper [4] shown the importance of the range in which antenna can be operable. In some other terms it can be called as the bandwidth. Neglecting the type of the pattern of radiation and also the direction in which the fields are radiated, it shows the bandwidth as a major topic that is to be developed in the antenna designing. The more the bandwidth the more the number of applications can get involve. Further modifications were made to obtain better antenna parameters and also got improvised. One of those important factors is the amount of power that did not get radiated of the total input power which will be termed as in the names of return loss and matching of impedance. The paper referenced [5] had a clear research about the importance of Omni-directional radiation type of pattern and also had a clear study on the usage of circular polarization. So the authors worked on the design satisfying these needs and also to obtain better antenna results. Also it explains about the losses that are related with the antenna as well as the losses related to the transmission of EM waves. The impedance matching plays an important role in minimizing the major losses, so they worked to obtain a better value of it and the remaining properties as well. In this paper [6] has shown the importance of elements with the excitation which is not the supply. The antenna with the feed will tend to radiate in different directions, the radiated power in different directions will excite the antennas in the respective direction. In antenna terms called as parasitic effect. This research totally focussed on these types of elements.

## 3. DESIGN OF A CIRCULAR PATCH ANTENNA DESIGN

The effective radius of a circular microstrip patch antenna can calculated by using Eq.(1).

$$(f_r)_{110} = \frac{1.1412v_0}{2\pi a_e\sqrt{\varepsilon_r}} = \frac{8.791\times10^9}{a_e\sqrt{\varepsilon_r}} \Rightarrow a_e = \frac{8.791\times10^9}{f_{rc}\sqrt{\varepsilon_r}} \quad (1)$$

where;

$f_r$ = resonant frequency;

$v_0$ = velocity of EM waves in free space.

The actual radius of a microstrip patch antenna can be calculated by Eq.(2). This radius of circular patch antenna gives dominant mode operation of the designed antenna.

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{0.5}} \quad (2)$$

where,

$a$ = actual radius of the patch;

$F$ = effective radius of the patch;

$h$ = height of the substrate;

$\varepsilon_r$ = dielectric constant of the substrate.

The width of the feed line can calculated by using the Eq.(3).

$$W = \frac{1}{8}\left[\frac{5.98h}{e^{\left(Z_0\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - t\right] \quad (3)$$

where, $h$ = height of the substrate; $Z_0$ = characteristic impedance; $\varepsilon_r$ = dielectric constant.

The length of the feed line can calculated by using Eq.(4).

$$L_x = \lambda/4 \quad (4)$$

where, $\lambda$ = wavelength.

## 4. PROPOSED ANTENNA DESIGN WITH AN ANNULAR SLOT AND RECTANGULAR SLOTS

This section describes the evolution of a circularly polarized omnidirectional slotted patch antenna at 2.4 GHz. The proposed slotted microstrip patch antenna is shown in Fig.1. The design consists of a ground plane with feedline, substrate and microstrip patch with different kind of slots. The total size of antenna is 58mm×58mm×1.6 mm. The proposed antenna has been developed on low cost Forgotten Realms (FR4) epoxy dielectric substrate with relative permittivity 4.4 and loss tangent 0.02. A 50 ohm microstrip line is used to feed the antenna. Feedline is used to couple power from generator to antenna terminals. Microstrip feedline dimensions are calculated such that it matches with port impedance. An annular Elliptical slot and semi-circular slots are used to produces circular polarization. Rectangular slots are attached to the annular slot with $90^0$ phase shift between two adjacent rectangular slots. Semi-circular cuts in the circular patch increase the circular polarization. In this antenna rectangular slots are introduced to obtain Omni-directional radiation pattern also slots are used to provide impedance matching which is working at 2.45 GHz. The design of proposed antenna follows ratio of the major axis to the minor axis is 0.9, radius of the major axis of the annular slot is 21.15 mm, length of the rectangular slots is 8 mm, and width of the rectangular slots is 2.25 mm. Radius of semi-circular cuts is of order 3mm. The designed antenna dimensions are given in Table.1.

Table.1. Antenna characteristics at 2.45GHz

| Parameters | Description | Value (mm) |
|---|---|---|
| $L$ | Substrate length | 58 |
| $W_X$ | Substrate width | 58 |
| $H_X$ | Substrate height | 1.6 |
| $R_1$ | Radius of major axis of ellipse | 21.15 |
| $R_2$ | Radius of circular back patch | 15.75 |
| $l_1$ | Length of rectangular slots | 8 |
| $W_1$ | Width of rectangular slots | 2.25 |
| $l_f$ | Transmission line length | 33.5 |
| $w_f$ | Transmission line width | 3 |
| $R_3$ | Radius of semi-circular slot | 3 |

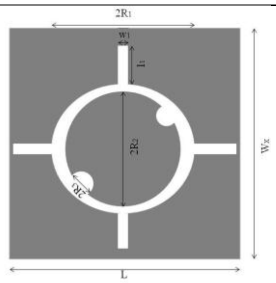


Fig.1. Front view of the proposed antenna

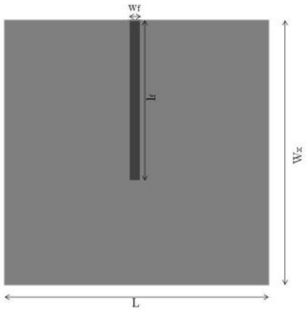


Fig.2. Back view of the proposed antenna

## 5. RESULTS AND DISCUSSION

In this sections, the simulated results of the proposed antenna is presented. The ANSYS HFSS EM simulator is used to simulate the proposed antenna. The optimized antenna is radiating at 2.45 GHz. It is shown in the Fig.3 as return loss ($|S_{11}|$) vs frequency plot. $|S_{11}|$< -10 dB is covered from 2.02 GHz to 2.77 GHz with 30.6% impedance bandwidth and the peak return loss value is equal to -31.12dB.

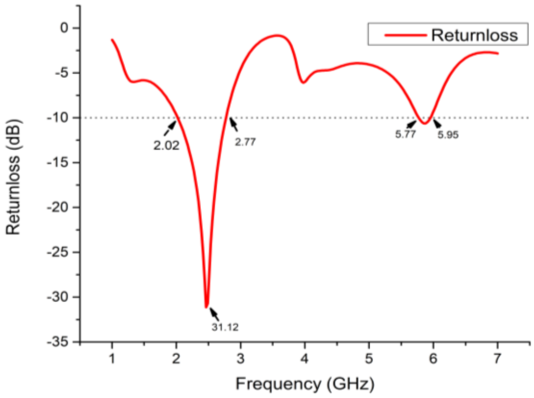


Fig.3. $S_{11}$ vs frequency plot

The proposed antenna characteristics and results are shown in Table.2. The antenna shown good values of every parameter.

Table.2. Proposed antenna results at 2.45GHz

| Antenna Characteristics | Values at 2.4 GHz |
|---|---|
| Return loss | -31.12 dB |
| Bandwidth | 750 MHz |
| Gain | 3.6 dBi |
| Axial ratio | 1.2 dB |
| Radiation efficiency | ~95% |
| VSWR | ~1.06 |
| Half power beam-width | $78.18^0$ |

The radiation pattern of the proposed antenna is shown in Fig.4. It clearly displayed that the radiation pattern plot is an omnidirectional radiation pattern. The electric fields are present in XZ plane (E-Plane) and magnetic fields are presented in XY plane (H-Plane). The gain obtained is about 3.6dBi. It has a doughnut shape which clearly shows that the antenna radiates in Omni-directional type of pattern.

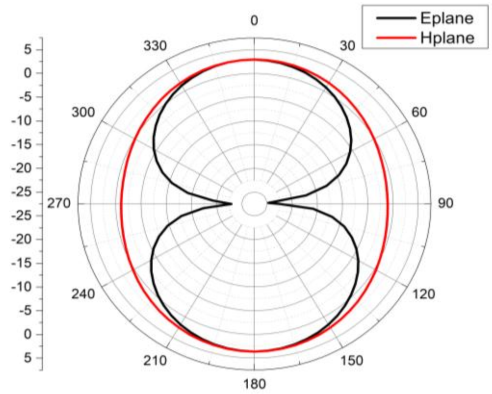


Fig.4. 2D radiation pattern at 2.45 GHz on

### 5.1 E-PLANE

The radiation efficiency of the proposed antenna is shown in Fig.5. The antenna radiation efficiency at 2.45 GHz is about 95%. Antenna is effectively working at 2.45 GHz with minimum conductor and dialectic losses of the antenna so the maximum electrical signals are radiated into the free space as electromagnetic waves.

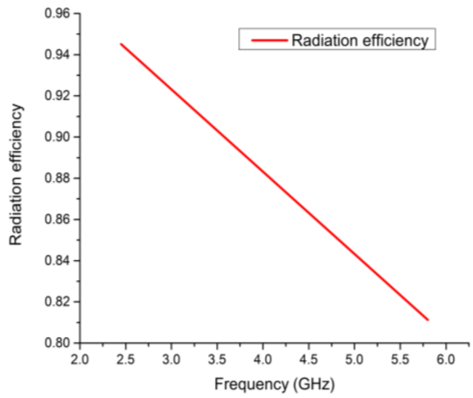


Fig.5. Radiation efficiency

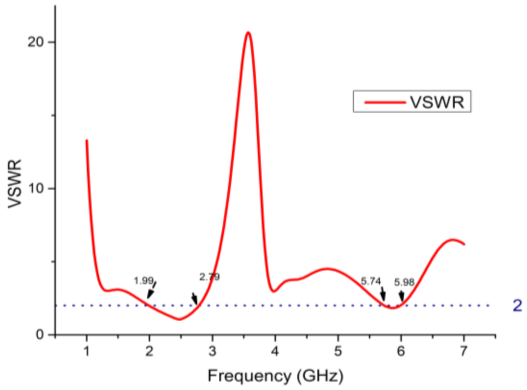


Fig.6. VSWR vs frequency

The Fig.6 shows VSWR at 2.45 GHz is ~1.06 which clearly shows there are very less reflections at the resonant frequency.

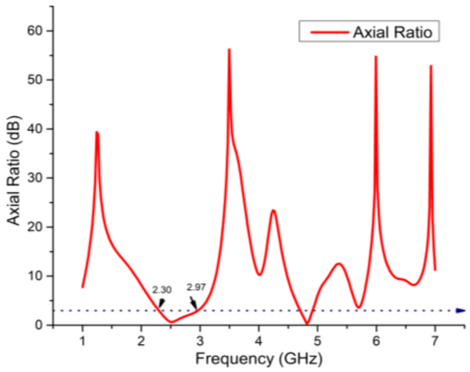


Fig.7. Axial ratio vs frequency

There are two ways to design the patch in order to obtain circular polarization. One is the truncated square and the other is a circular patch. Also we do have a single-fed and dual-fed circular polarization and we chose singe-fed circular polarization which can be done by introducing the asymmetric structures in the antenna. Therefore the circular patch is placed with two semi-circular cuts. Also to obtain the accuracy in the circular polarization we chose the circular patch in this design.

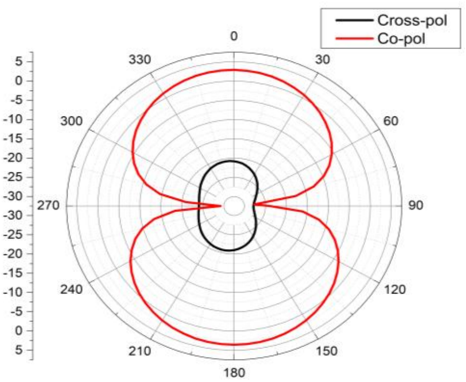


Fig.8. Co and cross polarization in E-plane

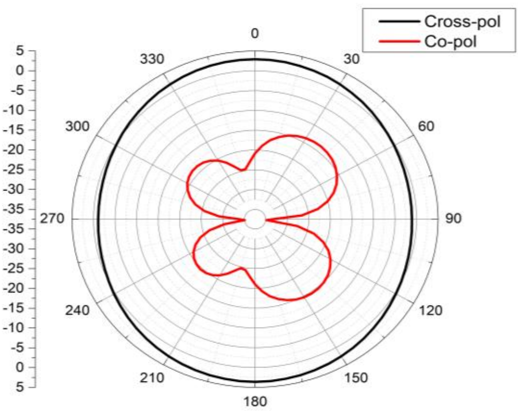


Fig.9. Co and cross polarization in H-plane

The Fig.7 shows axial ratio at 2.45GHz is less than 3dB which clearly depicts it is a circular polarization. Generally axial ratio is considered in the direction of major lobe but here the antenna is Omni-directional hence we have to look for all values of the phi by keeping theta 90°. Here for this design axial ratio is obtained at phi=5°. From [15] it is clear that if the semicircular slots are made at 45° and 225° the antenna propagates in RHCP.

In compact size antennas, cross polarization is drastically change by etching slots in radiating elements. The co and cross polarization of the proposed antenna in E-plane and H-plane shown in Fig.8 and Fig.9 respectively. The antenna obeys sufficient co and cross polarization levels.

Table.3. Antenna characteristics comparison of proposed work with recent literatures

| Method | $f_r$ (GHZ) | $\|S_{11}\|$BW (MHZ) | ARBW (MHz) | Gain (dB) | $S_{11}$ (dB) | Dimensions (mm$^3$)/Substrate |
|---|---|---|---|---|---|---|
| Proposed | 2.45 | 744 | 700 | 5 | -31.12 | 58×58×1.6/FR4 |
| [2] | 2.45 | 221 | 150 | 2.51 | -25 | 40×54×1.6/FR4 |
| [3] | 2.45 | 1000 | - | 0.35 | -50 | 66×66×1.6/FR4 |
| [13] | 2.4 | 200 | 150 | 2.93 | -31 | 35×35×5.3/R04003 |
| [16] | 2.45 | 220 | 150 | 1.98 | -45 | 52×52×56/DBC |

## 6. CONCLUSION AND FUTURE SCOPE

A circularly polarized omnidirectional patch antenna is presented for ISM band and WLAN frequency at 2.45 GHz. The proposed antenna consists of an annular elliptical slot and four rectangular slots to achieve radiation pattern with doughnut shaped Omni-directional. Circular polarization is achieved with single feed and two semicircular slots. The antenna shows good return loss of -31.12 dB and the maximum gain is about 5dB. The antenna has been proposed, modelled, simulated and analyzed with the help of Finite Element Method based simulator, HFSS. The radiation efficiency is also high nearly 95% at 2.45 GHz. The dimensions of antenna 58mm×58mm can be easily fabricated on any mobile device. Hence it can be used in Wireless Communications. The antenna is also radiating at 5.8 GHz. In future, it is possible to design dual band CP antenna with omnidirectional radiation patterns.

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