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# Design & Analysis of a Modified Circular Microstrip Patch Antenna with Circular Polarization and Harmonic Suppression

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**ABSTRACT**: In this paper a circular microstrip patch antenna with embedded circular slots to obtain harmonic suppression and peripheral cuts for producing circular polarization (CP) is proposed and analyzed. Antenna is designed by taking into consideration the use of Active Integrated Antennas [1] and rectifying antennas (rectenna) [2]. Low cost FR4 epoxy is used as the substrate and 2.45GHz/802.11a as the design frequency. Simulated 10dB return loss bandwidth of 171MHz and CP 3dB axial ratio bandwidth of 46MHz is obtained. Size reduction of 4% is also obtained as compared to the conventional circular patch antenna with linear polarization (LP). Simulations and optimizations are performed by using High Frequency Structure Simulator (HFSS) software.

**KEYWORDS:** Circular Patch, Rectenna, Harmonic Suppression, Circular Polarization, HFSS.

## I. INTRODUCTION

Active Integrated Antennas and rectifying antennas (rectenna) applications in millimeter wave range are getting much attention in recent years especially in the field of power combining, beam steering and switching, and high efficiency power amplifiers. Rectennas were earlier proposed for high power transmission [3]. Nowadays application of rectennas in low power RFID tags, proximity cards, and contactless smart cards is well known. These applications lies within the allowed electromagnetic radiation power levels. Distance between electromagnetic source and antenna is within *5cms* [4]. Using a passive RFID tag makes the system more cost effective as the need for power supply to the tags will be eliminated by using rectenna. Proximity cards and contactless smart cards have become quite popular in ticketing and easy money payment systems. Delhi metro uses [5] cards which are rectenna based cards and which can be used without even removing the card from wallet or bag. In this paper a circular microstrip patch antenna with embedded circular slots to obtain harmonic suppression and peripheral cuts for producing circular polarization (CP) is proposed and discussed.

Design of a rectenna/AIA has two fundamental requirements:
1. Power added efficiency,
2. Position independent use.

First of these requirements has four major areas of concern:
1. Size of antenna,
2. Harmonics generated from non-linear rectifying circuits (Schottky diode or FET), [9]
3. Tuning circuits added to suppress these harmonics which causes extra insertion loss [4],
4. Easy integration with the circuit where it is used.

Antenna size can be reduced by embedding slots on the patch antenna. As slots enhance the current path lengths resulting in smaller patch size for higher frequencies (or longer wavelengths) [9]. Rectifying circuits or any other circuit attached after the antenna are essentially non-linear devices; which can generate harmonics [6]-[9]. These harmonics can reradiate from the antenna and can create electromagnetic interference and resulting in loss of power [9]. Power efficiency is very important aspect of rectenna design. To suppress these harmonics a low pass circuit [6]-[7] has been attached between antenna and rectifier. This will certainly increase the insertion loss [9]. An antenna with positioning (Linear Polarization) requirement has serious limitations while used as rectenna.

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All these concerns can be taken care of by making a compact slotted patch antenna [9] which is capable of suppressing the harmonics without any extra added circuits and generates circular polarization (CP) to ease us of the angular position requirement of linearly polarized antennas. Simulation software High Frequency Structure Simulator (HFSS) is used to design, and simulate the proposed antenna.

Yu-Jiun Ren et al. (2007), T. C. Yo et al.(2008), and S. Riviere et al. (2010) have proposed antennas with attached filtering circuits for rectenna. But addition of filter circuits lead to extra insertion losses; which again can degrade power efficiency of rectenna. To overcome this problem F. J. Huang et al. (2012) had proposed a patch antenna with inbuilt harmonic suppression capability; which eliminates the filter circuit. Designs of T. C. Yo et al., F. J. Huang et al. and Ren, Yu-Jiun et al. are circular polarization rectenna designs. Circular polarization enables the antenna to receive electromagnetic power from signal with any polarization; which is suitable for rectenna application [9]. This paper proposes an antenna for rectenna which has both inbuilt harmonic suppression and circular polarization features.

## II. ANTENNA DESIGN & OPTIMIZATION

While designing a circular microstrip antenna taking into account the fringing [9,10] the equation for the radius of the circular patch becomes

$$a = \frac{F}{\left\{1+\frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \text{ , where } F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \qquad (1)$$

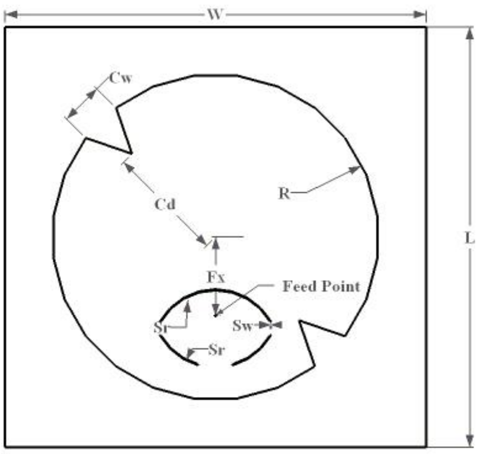
h=height of the substrate,
$\varepsilon_r$=dielectric constant of substrate

Initial calculations based on the above design formulae (1) for the basic circular microstrip antenna is given in Table 1.

| Substrate Material | Resonant frequency $f_r(GHz)$ | $\varepsilon_r$ | Radius of patch *R(in mm)* | Height of substrate *h(in mm)* | Feeding point location $(x_f, y_f)$ in mm |
|---|---|---|---|---|---|
| FR4 | *2.45* | *4.4* | *16.60776455* | *1.6* | *(7.8, 0)* |

Table 1: Calculations for radius of basic circular patch antenna.

Feeding point is obtained from HFSS optimization for 50Ω terminal impedance to avoid use of any impedance matching network between patch and coaxial cable [3,4,5]. Feed point is optimized so that it must exhibit a terminal impedance equal to the characteristic impedance of a coaxial cable (50 Ω).




| | |
|---|---|
| *R* | *16.598mm* |
| *L* | *42.796mm* |
| *W* | *42.796mm* |
| *Fx* | *7.8mm* |
| *Cd* | *12mm* |
| *Cw* | *4.346mm* |
| *Sr* | *6.5mm* |
| *Sw* | *0.102mm* |

Fig. 1 Proposed circular microstrip antenna for circular polarization and harmonic suppression at 2.45GHz

Fig.1 shows the proposed antenna with two peripheral cuts and three circular slots. Which is a circular microstrip patch built on a low cost FR4 epoxy substrate of relative permittivity $\varepsilon_r$*=4.4*, loss tangent *tan*$\delta$*=0.02* and thickness *h=1.6mm*. Two peripheral triangular cuts are introduced in the patch at a line 45° counterclockwise to vertical central line of the patch. This excites two orthogonal field components which are equal in magnitude and opposite in phase; resulting in circularly polarized radiation. This placement of peripheral cuts generates Left Hand Circular Polarization (LHCP) to

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obtain RHCP the *45°* line has to be shifted at a position which is mirror image of that used in LHCP at vertical plane [6-9].

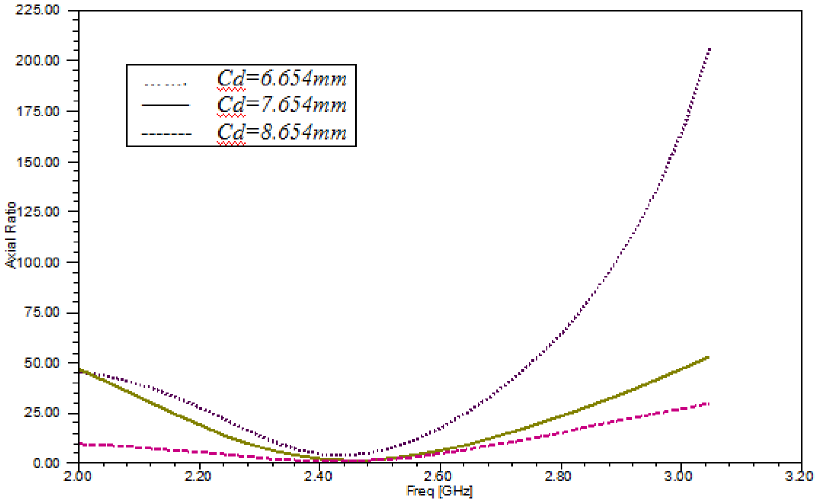


Fig. 2(a) axial ratio for the different values of peripheral cut depths *Cd*

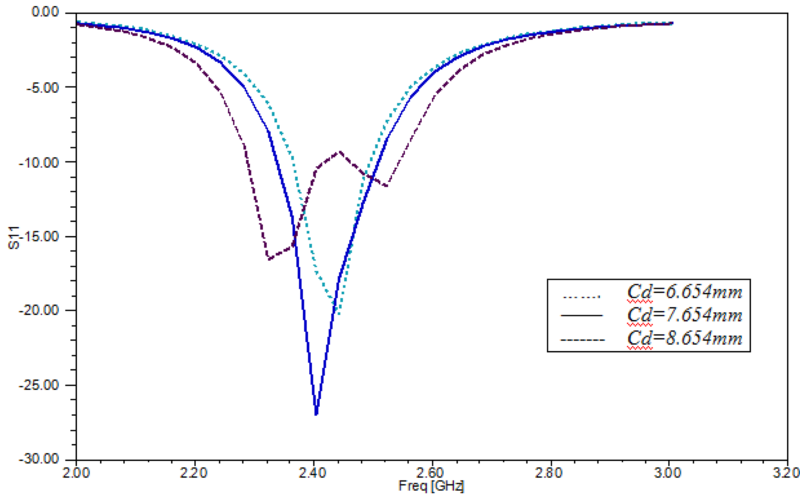


Fig. 2(b) return loss $S_{11}$ for different values of peripheral cut depths *Cd*

Fig. 2(a) shows the axial ratio vs. frequency for different values of cut depths *Cd* and Fig. 2(b) shows the $S_{11}$ plots for different values of cut depths *Cd*. From these graphs the optimum *Cd=7.654 mm* is selected as axial ratio value at resonant frequency is below *3dB* level and at the same time $S_{11}$ values are well below the *-10dB* level.

Three circular slots are embedded near the coaxial feed position to suppress harmonics. These embedded slots increase the current path length resulting in decrease in antenna dimensions for a given frequency [2, 10]. Also embedded slots are designed and placed in such a way so as not to disturb the symmetry of the patch which otherwise can cause problems in CP.

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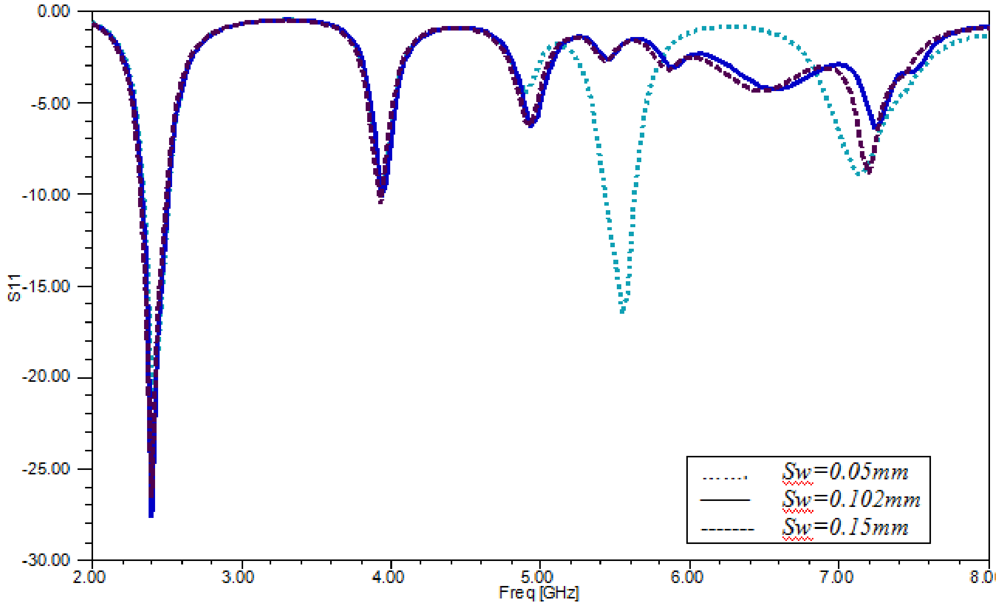


Fig. 3 comparison of Return loss $S_{11}$ for different values of slot widths *Sw*.

Fig. 3 shows the plots of return loss for different values of slot widths *Sw*. From this figure optimum *Sw =0.102mm* is selected as the $S_{11}$ plot shows very little 2$^{nd}$ and 3$^{rd}$ harmonic components and excellent $S_{11}$ results at fundamental frequency.

## III. RESULTS & DISCUSSION

Final antenna design obtained after parametric and optimization analysis through HFSS simulations exhibits both circular polarization and harmonic suppression properties as shown in S11 plot of Fig. 4. Due to change in path length of current on the patch new resonant frequency of the proposed antenna becomes *2.4027GHz*. That means for the same frequency the proposed antenna takes less space as compared to a conventional circular microstrip antenna. In fact proposed antenna offers a 4% size reduction in comparison to conventional circular patch.

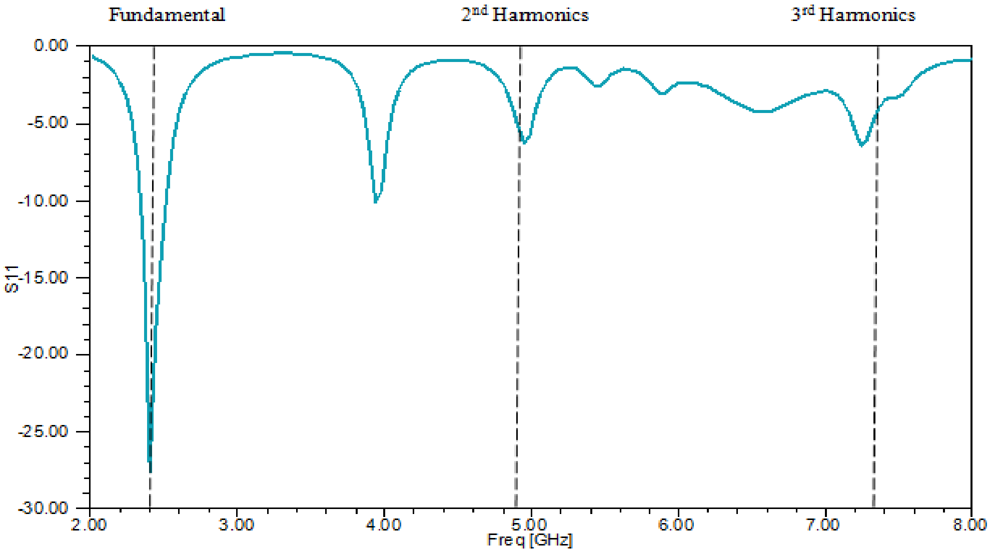


Fig. 4 return loss plot for the proposed antenna.

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Fig.4 shows that $S_{11}$ values for 2nd harmonics (*4.9GHz*) is only *-5.98dB* and that for 3rd harmonic (*7.35GHz*) is only *7.97dB* which are below *-10dB* level. That means there is no significant radiation at 2nd and 3rd harmonics from the proposed antenna.

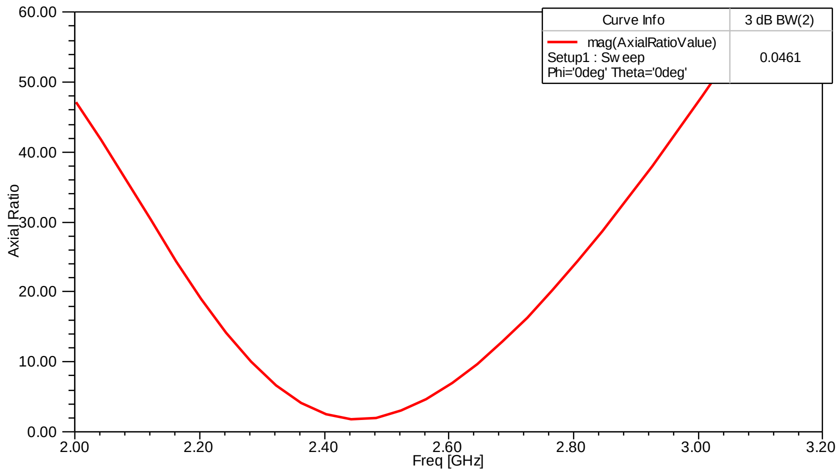


Fig. 5 simulated axial ratio vs. frequency for the proposed circular patch antenna.

Fig.5 shows the axial ratio vs. frequency for the proposed antenna. Axial ratio values in the plot clearly indicate the presence of circular polarization as the axial ratio curve passes the *3dB* level near the design frequency of *2.45GHz*. This design is for generating Left Hand Circular Polarization (LHCP); to get RHCP the position of the peripheral cuts has to be shifted at a position which is the mirror image at a plane passing through a vertical line from the centre of the circular patch. From Fig. 4 *-10dB* return loss bandwidth obtained is *174.3MHz* (*7.3%*) and from Fig. 5 *3dB* axial ratio bandwidth is *46.1MHz.*

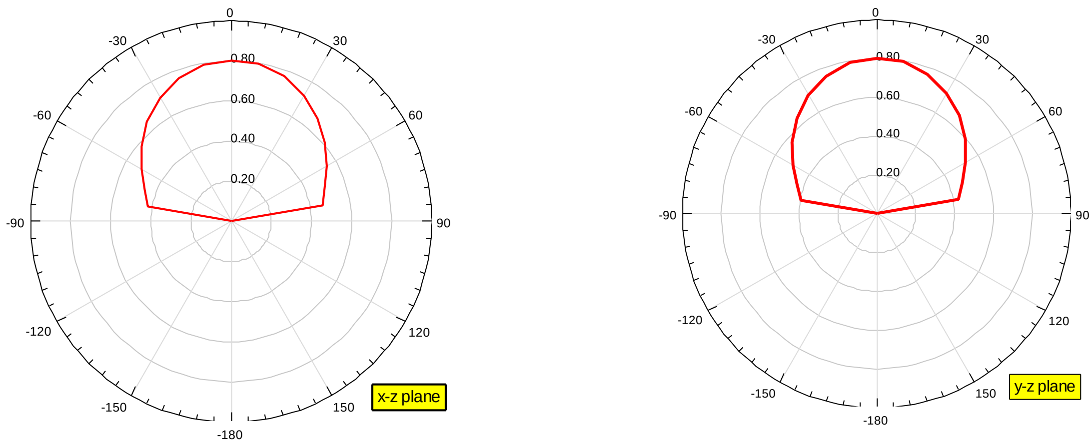


Fig. 6 radiation patterns at x-z and y-z plane.

Fig. 6 shows the radiation pattern at x-z and y-z planes obtained from the proposed antenna; which shows that the radiation pattern is symmetrical about the line perpendicular to the plane of the antenna.

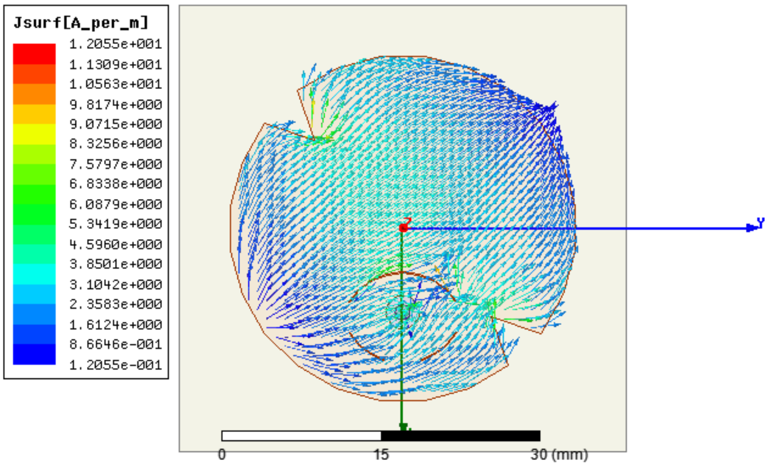


Fig. 7 Surface current density of the proposed circular patch.

Fig. 7 shows that the presence of slots are disturbing the current path in such a way so as to increase the path length leading to reduction in resonant frequency; which is equivalent to reduction in overall size of the patch itself.

| **S.No.** | **Property** | **Conventional Circular Patch** | **Proposed Circular Patch** |
|---|---|---|---|
| **1.** | Return Loss($S_{11}$) | *-23.9476dB* | *-29.667dB* |
| **2.** | VSWR | *1.6688* | *1.067* |
| **3.** | Terminal Impedance | *62.3843* | *50.6107* |
| **4.** | Bandwidth(10dB return loss) | *121.8MHz (4.97%)* | *174.3MHz (7.3%)* |
| **5.** | Bandwidth(3dB AR) | - | *46.2MHz* |
| **6.** | $2^{nd}$ harmonic $S_{11}$ | *-10.3734dB* | *-6.2865dB* |
| **7.** | $3^{rd}$ harmonic $S_{11}$ | *-7.1517dB* | *-6.5478dB* |
| **8.** | Resonant frequency for patch radius of *1.6598mm* | *2.45GHz* | *2.4037GHz* |

Table 2 Comparison between conventional and proposed circular patch.

Table 2 gives the comparison of some of the parameter values of conventional and proposed circular patch antenna. Circular patch with three circular slots and peripheral cuts shows good fundamental return loss of *-29.667dB* which is greater than that of a basic circular patch. VSWR value of *1.067* is observed from the simulation result which is an improvement of 36% over that of basic design value. Terminal impedance close to 50Ω is obtained as compared to 62Ω terminal impedance of basic design, which means 50Ω coaxial cable is suitable for feeding with less impedance mismatch. Bandwidth improvement of 2% is obtained in the proposed design as compared to the basic design. $2^{nd}$ and $3^{rd}$ harmonics obtained are within the limits of *-10dB*. Resonant frequency of the proposed antenna has become *2.4037GHz* from *2.45GHz* which is equivalent to reduction in size of the patch.

## IV. CONCLUSION

Proposed design with peripheral cuts and three circular slots has been designed which exhibits excellent gain at fundamental frequency *(-29.6677 dB* return loss) while suppressing $2^{nd}$ and $3^{rd}$ harmonic (return loss of *-6.2865dB* and *-6.5478dB* respectively) without affecting the circular polarization (*3dB* axial ratio bandwidth of *46.2MHz* around center frequency of *2.45GHz*). The proposed antenna with its excellent features is especially useful for active integrated antenna or rectifying antenna where compact low profile antenna with circular polarization and inbuilt harmonics suppression capability is required.

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