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A novel design of circularly polarized pentagonal planar antenna for ISM band applications

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ABSTRACT

This paper presents a new circular polarized micro-strip antenna with a pentagonal shape radiator. The proposed antenna is designed to operate in the industrial scientific medical (ISM) band at the frequency of 2.45GHz for Wireless applications. The antenna consists of a radiating pentagon patch with appropriate dimensions on the upper side of a dielectric substrate and a defective ground structure (DGS) on the other side. The pentagon patch is fed through a 50Ω microstrip line. The structure is implemented on an FR-4 substrate with a relative permittivity of 4.4, loss tangent equal to 0.025 and thickness 1.58 mm. The antenna is designed and simulated by using advanced design system (ADS) electromagnetic solver and the achieved results are validated by using another electromagnetic solver. The simulation results indicate that the designed circularly polarized (CP) pentagonal microstrip patch antenna gives good results in terms of the reflection coefficient, voltage standing wave ratio (VSWR) and, axial ratio of 1.025 at 2.45 GHz.

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1. INTRODUCTION

Microstrip patch antennas represent one family of compact antennas that provide a conforming nature and the ability to be integrated with communication system's printed circuitry. Since demand for its application has been increasing rapidly, especially within the past two decades [1]-[3]. Because of microstrip antennas' many unique and attractive properties, there seems to be little doubt that they will continue to find many applications in the future. These properties include low profile, lightweight, compact, and conformable to a mounting structure, easy to fabricate and integrate with solid-state devices [4]-[6]. It can be easily placed inside packages, making them a suitable choice for numerous consumer applications [7]. Because of their low-power handling capability, these antennas are suitable to be used in low power transmission and reception applications [8]-[10].

The development of modern wireless communication systems in recent years has spurred a lot of research interests in antennas that are capable of switching polarization sense. The necessity is more for dedicated and compact antennas [11]-[13]. A microstrip antenna is a resonator-type antenna. It is generally designed for single-mode operation which mainly radiates in linear polarization [14]. For circular polarized radiation, a patch has to be able to support the orthogonal fields with identical amplitude but in quadrature of phase [15]. For this requirement can be accomplished, two methods are available: a single patch with proper excitations or an array of patches with an appropriate arrangement and phasing. Various shapes of microstrip antennas capable of operating in circular polarization have been reported in the literature such as square, circular, pentagonal, equilateral, ring, and elliptical ones [16], [17].

A single patch antenna can be configured to radiate a circular polarization by simultaneously exciting two orthogonal patch modes with equal amplitude and ±90 degrees out of phase with the sign determining the sense of rotation. This task can be accomplished by two types of feeding schemes. For the first type, a double-orthogonal power feed is used, which uses an external power divider network. Whereas the other is a single-point power supply for which an external power divider is not needed [18].

A pentagonal microstrip patch antenna offers better performance in comparison to the rectangular one. In particular, it supports both linear and circular polarizations. The pentagonal patch antenna gives circular polarization with only one feed whereas the rectangular patch antenna requires multiple feeds to get circular polarization [19], [20]. The pentagonal patch antenna can have multiband operations [21]. In a single-fed circularly polarized (CP) pentagonal patch antenna, the generated mode usually is smooth in an electrically thin cavity region of the micro-strip antenna [22]. Accordingly, the operations principle of this antenna is based on the fact that the generated mode can be separated into two orthogonal modes [23]-[25]. This paper presents a new design of pentagon circularly polarized patch antenna with the defected ground structure (DGS), which is operating at a frequency of 2.45 GHz in the industrial scientific medical (ISM) band.

2. DESIGN PROCEDURES

A circular polarization microstrip antenna operating at 2.45 GHz is designed in this paper. The geometry of the proposed antenna is composed of two sides deployed on an FR4-Epoxy dielectric substrate. The thickness and tanδ of the dielectric substrate are 1.58 mm, and 0.025 respectively. The upper side consists of radiating element as the most important part, which is fed by a microstrip line extended from the center pin of 50 Ω connector type. Besides being as a feeding line, the microstrip line also serves as a λ/4 transformer to match the input impedance of radiating element and the connector. The radiating element, which is made of metal copper, has a shape of pentagonal. On the lower side, a partial ground plane is printed only under the microstrip line-feeding network. The metal thickness copper for pentagonal-patch radiating element, as well as feeding line network and ground plane is 0.035 mm.

The single pentagon antenna is designed and is based on the analytical equations available for microstrip patch antenna [3], the final proposed antenna structure is illustrated in Figures 1 (a) and (b). Where the guided wavelength is given by:

$$\lambda = \frac{c}{f_r\sqrt{\varepsilon_{eff}}} \tag{1}$$

where ε_{eff} *is* the effective dielectric given by:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2}$$

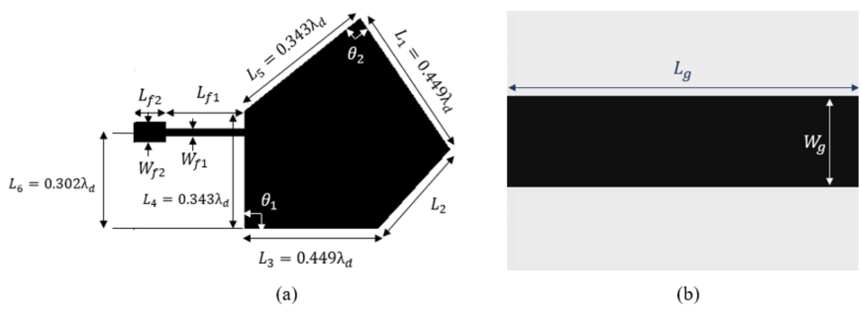

Figure 1. (a) Top view of the proposed antenna, (b) Bottom view of the ground plane structure

It is very important to choose the location of the feed point in the design of microstrip antennas for which the feed point determines the excitation modes as well as its effect on the radiation characteristic of the antennas. The location of the feed chosen in this antenna is with height L_6. In order to achieve a good performance of the proposed antenna without necessarily increasing its size, a lot of methods have recently been proposed such as the utility of the DGS. Figure 2 presents the effect of the DGS on the reflection coefficient whose S11_f shown in the figure presents the reflection coefficient obtained with the mass plane.

However, the pentagonal antenna with those sides cannot achieve satisfying circular polarization (CP) radiation. Theoretically, after the dimensions of the pentagon are confirmed, CP radiation can be achieved by slightly changing the dimension of the pentagon or feed line while altering the location of the feed point. We carried out a series of simulations to choose the position of the feed point and the dimensions of the proposed antenna. Figures 3 and 4 show the change curves of the reflection coefficient and the axial ratio as a function of the parameters L5 and L4.

From the simulated data, we can see that even minute changes of the length of the pentagon dimensions can affect the performance of the antenna a lot which leads to repeated modification and optimization which is one of the most difficult tasks while designing a pentagon circularly polarized antenna. After several optimizations, the final dimensions of the proposed pentagon units are shown in Table 1.

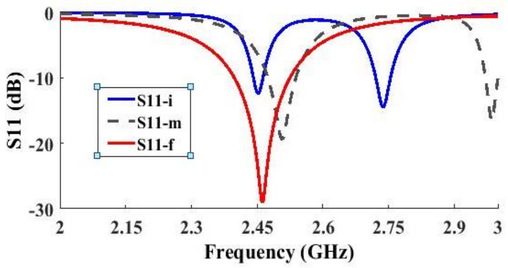

Figure 2. Simulated curves of return loss against frequency for varying W_g

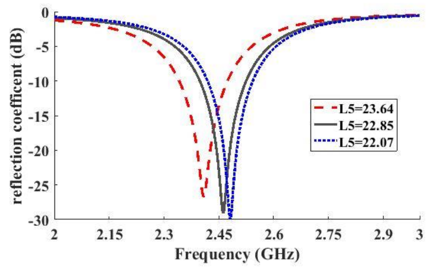

Figure 3. Simulated curves of return loss against frequency for varying L5

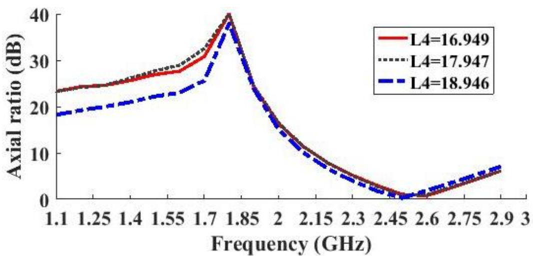

Figure 4. Simulated curves of the axial ratio against frequency for varying L4

Table 1. Dimensions of the proposed antenna

Parameters	Dimensions	Parameters	Dimensions
L_1	22.85432 mm	W_{f1}	1.08 mm
L_2	24.40765 mm	W_{f2}	3 mm
L_3	16.45438 mm	L_g	60 mm
L_4	20.81027 mm	W_g	15 mm
L_5	17.92 mm	θ_1	90°
L_{f1}	13.5 mm	θ_2	90°
L_{f2}	5 mm		

3. RESULTS AND ANALYSIS

After optimizing the antenna parameters and validating the results by using the advanced design system (ADS) Keysight which is based upon method of moment (MoM); we have conducted a study with another simulator taking into consideration the dimensions of the substrate by using computer simulation technology (CST) microwave studio, which is based upon finite integration technique (FIT). Figures 5 (a) and (b) show the upper and the lower view respectively of the 3D layout of the proposed pentagonal patch antenna using CST. The substrate has a dimension of 60×45 mm².

Figure 6 presents the simulated reflection coefficient obtained by using CST and ADS. It is about -13.8 dB with ADS and -30 dB with CST, this difference is due to the numerical method used by the solvers and the substrate dimensions. Where ADS is based on the MoM and is a 2D simulator with an infinite ground while the CST microwave studio is a 3D simulator based on the FIT with a finite ground.

The designed antenna is capable of generating CP with an axial ratio of 1.025 dB at the operating frequency as shown in Figure 7. The computed voltage standing wave ratio (VSWR) versus frequency of the proposed antenna is shown in Figure 8. As seen, the VSWR at the operating frequency band is about 1.2 dB.

Therefore, the radiation pattern is taken into account to predict the capabilities of the proposed antenna. It is depicted from Figure 9 for the proposed CP antenna at the operating frequency of 2.45 GHz. It is clearly seen that the antenna has an omnidirectional radiation pattern at the E-plane(Phi=90) and bi-directional at the H-plane(Phi=0).

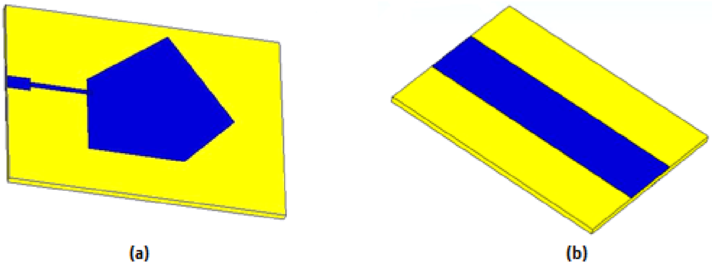

Figure 5. (a) Top view and, (b) Bottom view of the 3D layout of the proposed antenna using CST

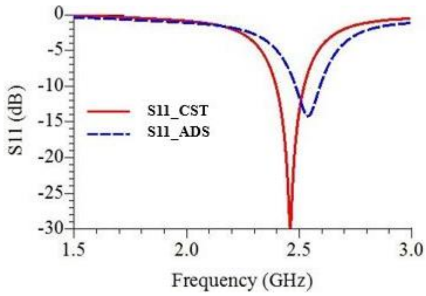

Figure 6. Comparison between the antenna reflection coefficient obtained by ADS and CST

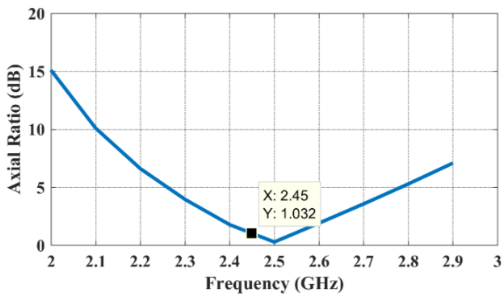

Figure 7. Axial ratio vs frequency

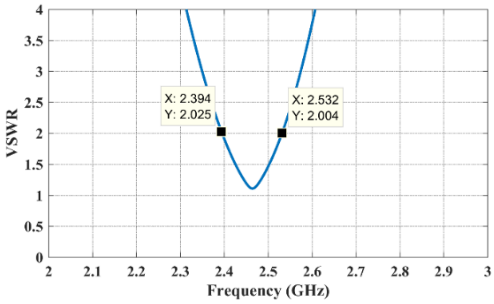

Figure 8. VSWR vs frequency

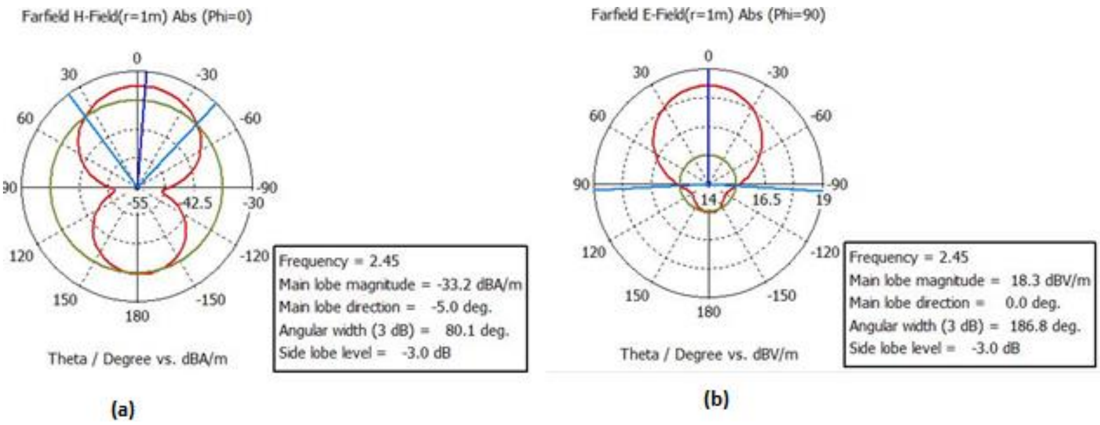

Figure 9. 2D radiation patterns of the proposed antenna at: (a) H-plane, (b) E-plane

4. CONCLUSION

There are various types of microstrip structures that are able to achieve circular polarization. In this paper, a simple CP patch antenna with a pentagonal patch is presented. The proposed antenna has been designed, simulated, and optimized by using momentum integrated into ADS and the achieved results have been validated by another electromagnetic solver. The performance criteria extracted from the software includes return loss, axial ratio, VSWR and radiation pattern, provide a clear indication that the antenna present good features and it is suitable for wireless power transmission in the ISM band at 2.45 GHz.

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