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Enhancement the Gain and Bandwidth of a Circular Patch Microstrip Antenna in X-Band

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Abstract. This paper uses Ansoft High Frequency Structure Simulator software to designed new structures of a circular microstrip antenna operating in X-band microwave frequency. The new proposed antenna was designed by making an etch slots on the patch of this antenna to enhance bandwidth and gain. This antenna design consists of slots with an annular ring and square shapes in different sizes. The annular ring slot is inside the circular patch and the other four square slots are etched on patch edge. Several parameters like input impedance, radiation patterns, return loss and gain were studying in this work. The results of gain and bandwidth of simulated reflection coefficients at -10 dB were 8.10 dB and 1.129 GHz, with resonant frequency 10.06 GHz. Therefore, the new antenna satisfies the request of the application in system of modern wireless communication.

INTRODUCTION

Microstrip Patch Antennas (MPSAs) are mostly used Because of their light weight, easy fabrication, low-profile conformal design, and inexpensive design [1-3]. Also, these antennas have planar structure therefore they are widely used in wireless communication, satellite communication and in many fields of electromagnetic (EM) application [4]. However, the major weakness of MPSAs is the suffering from various disadvantages like low gain and narrow bandwidth [5,6]. To overcome this weakness of MPSAs, several various methods have been suggested, such as using different shapes for a patch, proximity feeding, stacked patch, defected ground structures, metamaterials, fractals, multimode techniques, and using a thick dielectric substrate with low permittivity [7–11]. Circular microstrip antenna (CMSA) has a volume less than square microstrip antenna. Therefore, the first antenna is preferred over the second antenna in the space saving applications [12,13]. Generally, MPSAs consist of three layers. The first layer is a ground plane that is made from conductor material and on one side of this ground plane is the second layer which is dielectric substrate. The third layer is metal patch and is fixed on the other side of the second layer [14].

The electromagnetic energy in microstrip antenna is navigated to the patch antenna from the excitation of negative charges (that are produced in the feed point) and positive charges (which are created at other parts of the patch) [15]. There are three types of radiated electromagnetic waves in microstrip antennas. The electromagnetic waves that radiated into the far-field region space is the first type and it is advantageous radiation. The second type of EM radiation waves is the diffracted waves which outcomes in the real power transmission. These waves are reflected into the dielectric substrate (the media between the patch and ground plane of MSA). The third type of EM radiation waves is the waves that trapped into the dielectric material layer and are generally unwanted [16-17]. When electromagnetic waves are radiated from an antenna in a particular orientation such as the direction of electric field, in same way the polarization of this antenna can be determined. The trace of figure through the vector of instantaneous electric field at a time. The type of antenna polarization can be linearly or circular. In fact, there are two sub-kinds of the linear polarization which are horizontal and vertical polarization [18]. The electromagnetic waves are classified as horizontal or vertical polarization depending on the vector of electric field when its parallel or perpendicular to the earth, respectively.

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Microstrip patch antennas are fed with various feeding techniques such as probe feed or coaxial cable, coupled feed, inset feed, quarter wavelength transmission line and aperture feed. These feeding techniques have a disadvantage which is unwanted impedance mismatch with traditional 50Ω line [19]. This mismatch can be minimize using transformer of quarter wavelength between microstrip feed and 50Ω line. However, this process unfavorable because it increases the antenna size [16,20]. If the fed of microstrip antenna from its center the input impedance is lower than 50Ω. While, if the fed of this antenna from its edges the input impedance is greater than 50Ω. Therefore, selecting optimum point of fed is lying down between the center and edges of this antenna [21].

In this work, MPSA is designed and simulated in the range of X-band with resonant frequency 10.06 GHz.
The proposed antenna was designed in the region of electromagnetic spectrum, this region is a segment of the microwave radio and is called X-band. In the communication engineering, the IEEE specified the frequency range of X-band at 8.0 GHz to 12.0 GHz [22]. This band frequency has widely used in radar applications because its wave characteristics have short wavelengths and high transmission rates. These two features allow researchers to use X-band in the medical, military, space communication, field of higher resolution imaging for obtaining target discrimination and identification [1,23]. Also, the sub-bands of X-band radar frequency are used in detection of vehicle speed for law enforcement, air traffic control, maritime vessel traffic control, military, civil, government institutions for weather monitoring, and defense tracking [24].

ANTENNA DESIGN

The performance of MPSAs is mainly affected by the metal patch design through changing radiation pattern, surface current distribution, gain, bandwidth and impedance matching. Therefore, this study aims to obtain more efficient and easy ways to realize the required results such as gain and bandwidth. In MPSAs, several shapes of the conducting patch are using to improve the antenna performance [7]. A CMSA is used as the first step of the suggested antenna, **Fig. (1A)**. The annular ring slot is etching on the circular patch as a second step of the suggested antenna, **Fig. (1B)**. Then, two square slots are etching horizontally on edge of the circular patch, as the third step, **Fig. (1C)**. The final step is etching two square slots vertically on edge of the circular patch, as shown in **Fig. (1D)**.

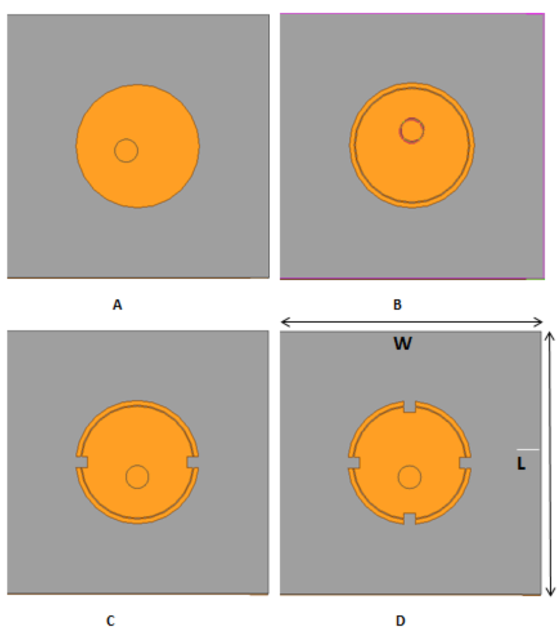


FIGURE 1. The steps of designed antenna. (A) CMSA, (B) annular ring slot on the circular patch, (C) two horizontal square slots on the edge of the circular patch and (D) two vertical square slots on the edge of the circular patch.

After parametric study, the designed antenna (D) is chosen as the optimum proposed design due to the best findings of gain, reflection coefficient, and radiation pattern as illustrated in the section of results and discussion. The geometrical dimensions of the optimum patch antenna are shown in Figure 2. Also, Table 1 displayed the dimensions of the designed antenna.

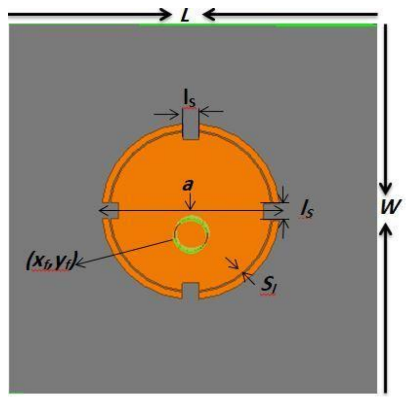


FIGURE 2. Geometry design of the optimum patch antenna.

TABLE 1. Geometrical dimensions of the proposed antenna.

Parameters	Dimension (mm)
L	23.00
W	23.00
L_s	1.00
s_l	0.10
a	5.50
h	1.40
(x_f,y_f)	(1.26,0.70)

In the following equation, the resonant frequency (f_{nm}) is used to calculate the standard dimensions of CMSAs, as [25]:

$$f_{nm} = \frac{\chi_{nm} c}{2\pi a_e \sqrt{\varepsilon_r}} \qquad (GHz) \tag{1}$$

Where χ_{nm} refers to the roots of the Bessel function derivatives. Both n and m are referring to the order of the Bessel function derivatives and its roots, respectively. Both c and $\boldsymbol{\varepsilon_r}$ refer to light speed (in free space) and dielectric constant, respectively. While a_ε is the effective radius of a circular patch as shown in the following formula [19]:

$$a_e = a\left[1 + \frac{2h}{\pi\varepsilon_r a}\left(1.7726 + ln\left(\frac{a\pi}{2h}\right)\right)\right]^{1/2} \tag{2}$$

The dielectric material used to simulate the new antenna, is Roger RT (Duroid 5870) with the thickness (h=1.4mm) and dielectric constant ($\boldsymbol{\varepsilon_r}$ = 2.33). The circular patch having a radius, a= 5.5mm, while the annular ring slot has a width, 0.1 mm. The ground plane has the dimensions 23×23 mm^2. The coaxial line is used to feed the designed antenna and its location was chosen at (x_f= 1.5mm) and (y_f=0.7 mm) to obtain the matching condition. The outer and inner radius of coaxial line are (r_o=2.5 mm) and (r_i=1mm), respectively.

RESULTS AND DISCUSSION

The commercial tool (Ansoft HFSS) is used to design the proposed antenna. This antenna has the dielectric substrate (Roger RT (Duroid 5870)) as a cost-efficient, with size 23×23 ×1.4 $mm^3$and dielectric constant ($\varepsilon_r = 2.33$). This antenna is fed by a coaxial probe with impedance (49.44, 0.11) Ω, as shown in Figure 3.
Figure 3 displays the results of the return loss of the suggested antennas that are shown in Figure 1. It can be concluded from this figure that the optimum design has the best findings of the reflection coefficient. Therefore, the suggested antenna in Figure 1 (D) is chosen as the desirable design. It is noticed that the desirable antenna has bandwidth (1.129 GHz) at resonance frequency 10.06 GHz.

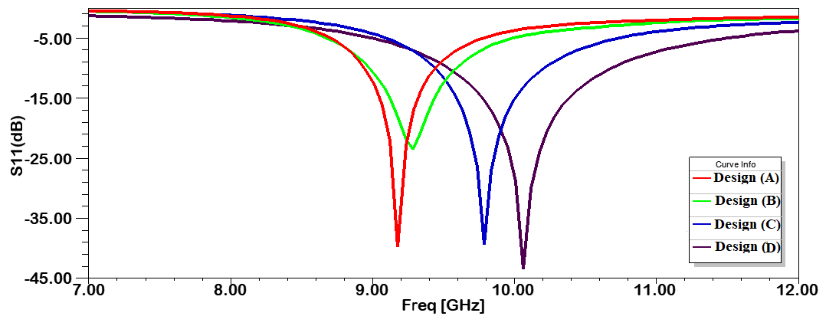


FIGURE 3. Simulation findings of the reflection coefficient for designed antennas in Fig. 1

As a result of, the optimum antenna design (D) has maximum bandwidth of the simulated reflection coefficients at -10 dB which are identical with the X-bands frequency. Table 2 compares the simulation results for the four antennas designed in Figure 1, This comparison included the resonant frequency, reflection coefficient features, bandwidth and gain.

TABLE 2. Comparison of the resonant frequency, reflection coefficient features, bandwidth and gain value of the proposed antennas in Fig. 1

Designed antenna	Resonant frequency (GHz)	Reflection coefficient (dB)	Bandwidth (MHz)	Gain (dB)
Design (A)	9.185	-38.13	498.00	5.891
Design (B)	9.286	-23.49	603.30	7.900
Design (C)	9.939	-40.93	781.19	7.830
Design (D)	10.06	-41.78	1129.00	8.102

The reflection coefficient (S11) is parameter which is used to quantify how much of electromagnetic waves is reflected back at antenna terminals in the transmission medium. an S11 value is calculated and compared for three parameters of the proposed antenna :
Figure 4, shows the results of the comparison study for different values of the feed position (x_f). It is apparent from this figure that a very low return loss (-41.78 dB) can be recorded at the frequency of (10.06GHz) with feed position (1.5,0.7).

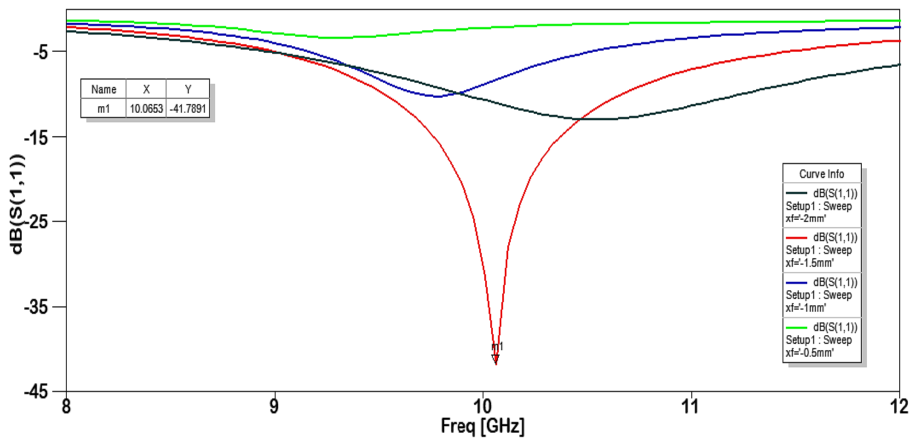


FIGURE 4. Simulation findings of the reflection coefficient for proposed design (D).

The slots are implanted on the patch radiator to improve the impedance matching, particularly at higher frequencies. Figure 5, illustrates the comparison of S11 for multi values of annular ring slot width(S_l). In this figure the simulated results of return loss show that the lowest value of S11 occur at the resonant frequency (10.06GHz)

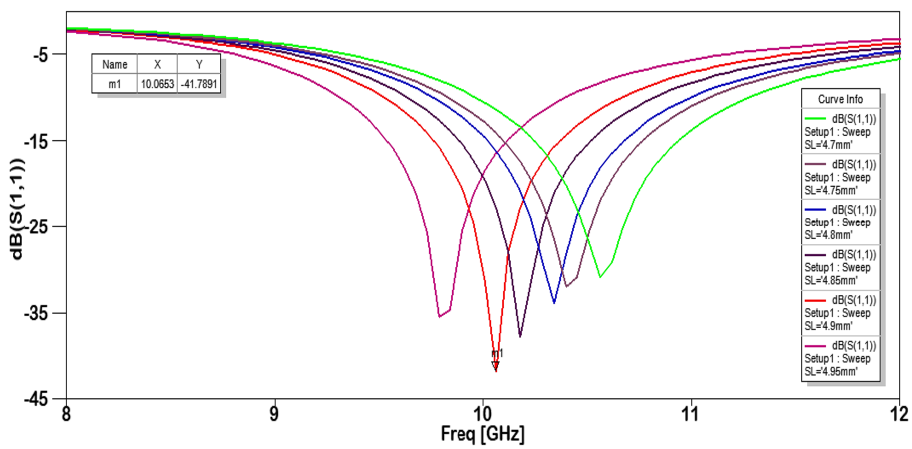


FIGURE 5. Simulation findings of the reflection coefficient for proposed design (D).

Figure 6, illustrates the simulated results of s11 for various value of square slot width (l_s).when l_s=1.00mm,the reflection coefficient has optimum value of frequency (10.06GHz)

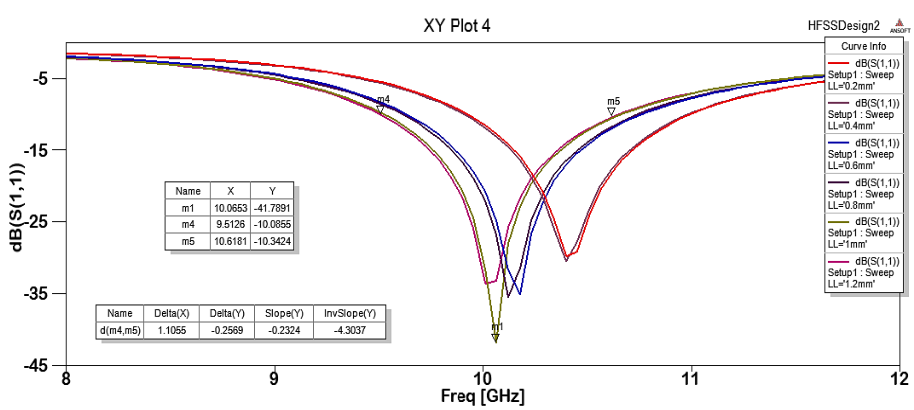


FIGURE 6. Simulation findings of the reflection coefficient for proposed design (D).

After parametric study ,The simulation findings of input impedance (Zin) for the optimum proposed design (D), is illustrated in Fig. 7. From this figure, it can be noticed that the input impedance value is (49.44 , 0.11) Ω at the operating frequency 10.06 GHz.

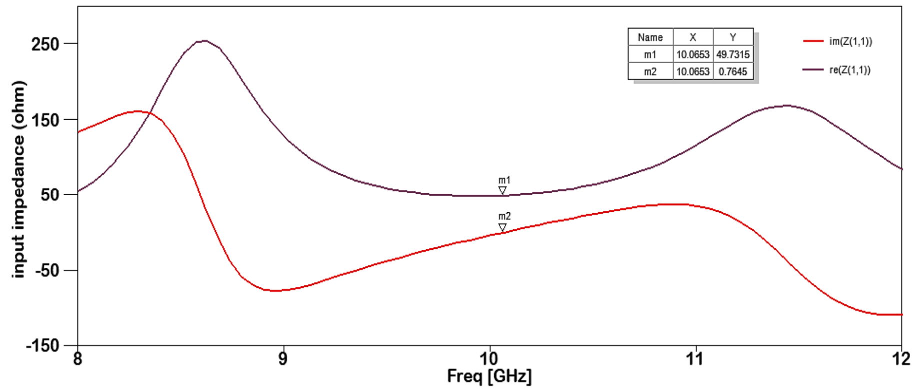
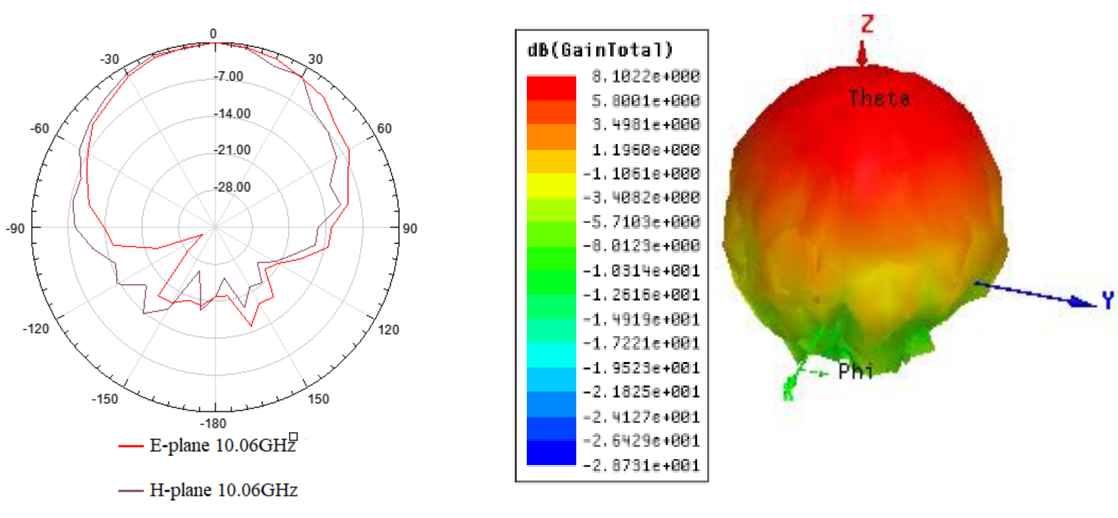


FIGURE 7. Simulation results of the input impedance for the optimum proposed design (D).

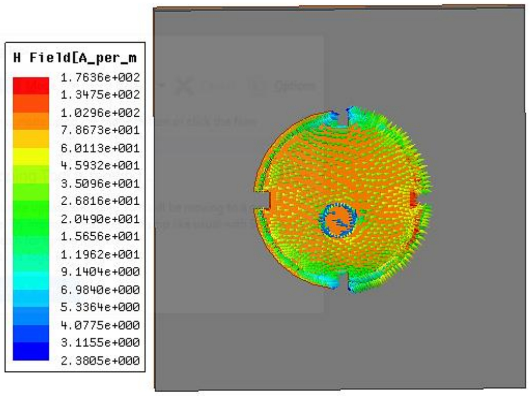
The results of the resonant frequency that belong to the radiation patterns, magnetic and electric fields, and surface distribution of electric current have good performance. Figure 8, shows the simulation results of radiation patterns for the antenna design (D) at the resonance frequency 10.06 GHz. These radiation patterns are in three and two dimensions, also these patterns have appropriate behavior for wireless system applications.

Figure 9, shows the simulation results of the electric and magnetic fields and surface current distribution for the optimum proposed design (D) at the resonance frequency 10.06 GHz. It is shown from this figure that all simulation results are concentrated at the edges of slots. While, around the feed point the simulation results of Figure 9, become low concentration.

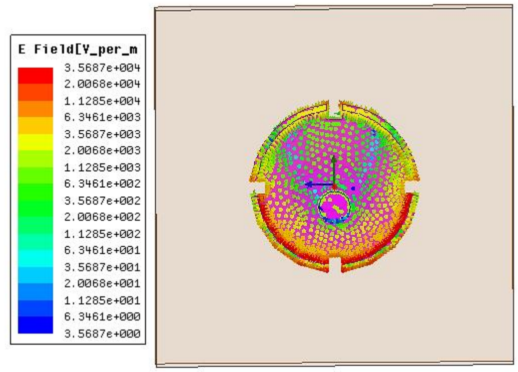


(a) **(b)**

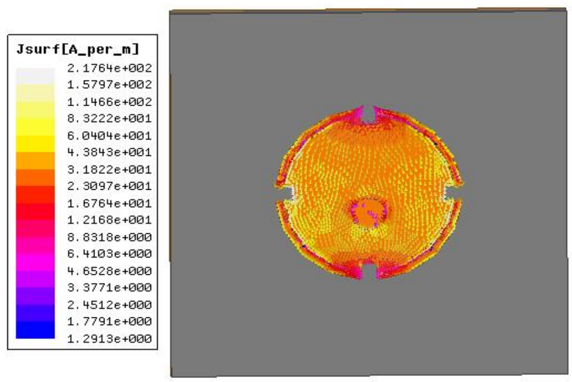
FIGURE 8. Simulated findings of radiation patterns of the optimum proposed design (D) at resonance frequency, (a) Two and (b) Three dimensions



(a) Magnetic field



(b) Electric field



(c) Electric current

FIGURE 9. Magnetic and electric fields and surface distribution of electric current on the patch of the optimum suggested antenna, (a) Magnetic field, (b) Electric field , (c) Electric current.

CONCLUSION

In this paper, the suggested design of CMSA with etched annular ring and square slots on the patch of this antenna has been proposed with a size of 23×23×1.4 mm3. The simulated result of the reflection coefficient is -43.46 dB at the resonance frequency 10.06 GHz that achieve bandwidth 1.129 GHz (9.54 –10.67) GHz with gain value 8.102 dB. These parameters are relatively good and can be improved by making an array of the proposed antennas. The optimum antenna design (D) is desirable for X-band applications

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