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Research Article

DESIGN AND SIMULATION OF TRIPLE BAND CIRCULAR PATCH MICROSTRIP ANTENNA BASED ON SHAPE OF RING AND RECTANGULAR SLOTS

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ABSTRACT

In this work, new structures of circular microstrip antenna based on slots are designed and simulated to operate with triple band applications. These slots are annular ring and rectangular shapes in different sizes. The annular ring slot is etched inside the circular patch while the other two rectangular slots are etched on the circular patch edge. The suggested antennas are simulated using version 13 of Ansoft High Frequency Structure Simulator (HFSS). The various parameters such as input impedance, reflection coefficient, gain, radiation patterns and surface currents were investigated. The present results observed that the optimum antenna designed is resonating at three frequencies 2.695, 5.799 and 8.323 GHz. Also, the bandwidths of simulated reflection coefficients at -10 dB are 106, 204 and 371 MHz which are identical with the S-, C- and X-bands frequencies, respectively. Therefore, the optimum antenna designed can be used in the space saving applications in addition to its important role in variety applications at these three frequency bands.

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INTRODUCTION

In the microwave frequency range, one of the most common used types of antennas for radio frequency and wireless systems applications are the microstrip antennas (MSAs) due to their unique characteristics (1,2). These features include low cost fabrication and compatible with design of monolithic microwave integrated circuits, relatively compact, low profile, conformability, light weight and other attractive characteristics which have made MSAs considerably interesting (3,4). However, the major weakness of MSAs is the suffering from various disadvantages like low gain, high-quality factor and narrow impedance bandwidth etc. (5). To overcome this weakness of MSAs, several various methods have been suggested, such as using different shapes for patch, proximity feeding, stacked patch, defected ground structures, metamaterials, fractals, multimode techniques and using thick dielectric substrate with low permittivity (6–9). Moreover, there are several methods for achieving multiband operation, one of these methods is etch slots on the patch of MSA. These slots have been used in different shapes such as binary tree slot, V-, U-, C- and L-shaped slots (10–14).

On one side of MSAs, the dielectric layer in its simplest configuration contains a radiating patch. This dielectric substrate has a ground plane (conductor) on the other side, these radiating patch and ground plane are usually made of copper or gold (15). The circular and rectangular microstrip antennas have linear and circular polarizations, good bandwidth, multiple frequency operation, frequency agility and feed line flexibility etc. Circular microstrip antenna (CMSA) has volume less than rectangular microstrip antenna. Therefore, the first antenna is preferred over the second antenna in the space saving applications (16,17).

In this work, a compact CMSA designs for applications of triple band have been proposed by using the CMSA which includes annular ring and rectangular slots. The features of the suggested antenna made it acceptable for S-, C- and X- bands application. The S-band is particularly used for Bluetooth, Wi-Fi, weather/ship radar systems, mobile satellite communications and mobile communications (18). On the other hand, the C-band is especially used for weather radars, raw satellite feeds or satellite TV network in full-time, satellite communications and the LAN Radio in 5 GHz range. In the applications of satellite communications, Ku-band is more susceptible to rain fade than C-band therefore, the second band is choosing onto the first band in these applications (19). Furthermore, the X-band (radar band) is widely used in the radar applications because the waves in this band have short wavelengths. This feature allows to used X-band in field of higher resolution imaging for obtaining target discrimination and identification. In addition, X-band is used for vehicle speed detection, military, civil, weather monitoring and in the control of air traffic and maritime vessel traffic. Also, in the radar band the meteorological satellites are generally used 8.175 to 8.215 GHz as frequency range for monitoring weather conditions (20).

ANTENNA DESIGN

The major part of MSAs which affecting on the performance of these antennas is radiating patch. This effect includes changing reflection coefficient (return loss), impedance matching, gain, bandwidth and surface current distribution, as well as radiation pattern. In MSAs, several shapes of the conducting patch are using to improve the antenna performance. Therefore, this study aims to obtain more efficient and easy ways to realize required results. A CMSA has been proposed as a first step of the new antenna design. Then, annular ring slot is etching inside the circular patch and the two rectangular slots are etching on edge of the circular patch to create the suggested antenna.

Fig. 1 displays the geometry designs of the suggested antennas. The design steps of these antennas are illustrated as in Fig. 1a) CMSA, Fig. 1b) annular ring slot is etching inside the circular patch and Fig. 1c) two of rectangular slots are etching on the edge of the new suggested patch in Fig. 1b, respectively.

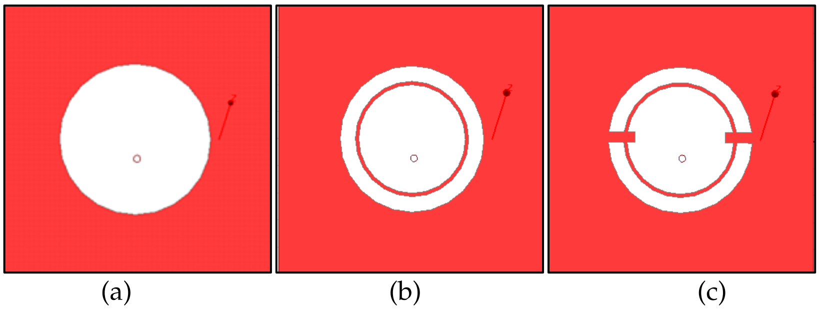


Fig. 1. Steps to selecting the designed antenna: (a) CMSA, (b) design A and (c) design B

The designed antenna (Design B) of Fig. 1(c) is chosen as the desired design antenna due to the best findings of gain, radiation pattern and reflection coefficient, as displayed in the results section. Fig. 2 displays the geometrical dimensions of the suggested antenna in Fig. 1c which are studied by using the HFSS software according to the optimum performance. The optimum sizes of the designed antenna are illustrated in Table 1.

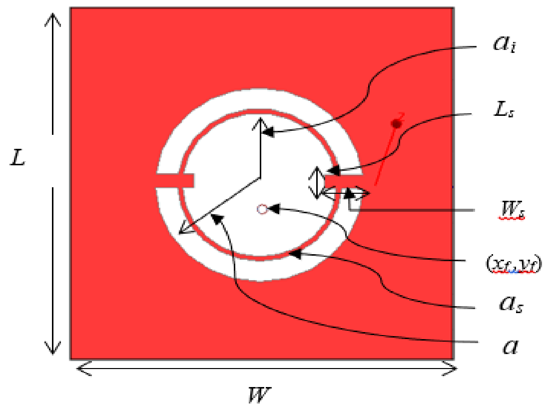


Fig. 2. Geometrical of the suggested antenna

Table 1: Dimensions of the suggested antenna

Parameters	Dimension (mm)
L	100.0
W	100.0
L_s	4.0
W_s	10.0
a	27.0
a_i	20.0
a_s	1.3
h	1.5
(x_f,y_f)	(8.19,0.7)

In the following equation, the resonant frequency (f_{nm}) is used to calculated the standard dimensions of CMSAs, as [5]:

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

Where χ_{nm} refer 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_e is the effective radius of a circular patch as shown in the following formula:

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

The dielectric material used to simulate the new antenna is Roger RT (Duroid 5870) with thickness (h=1.5mm) and dielectric constant ($\boldsymbol{\varepsilon_r}$ = 2.33). The circular patch having radius, a= 27 mm, while the annular ring slot has outer radius a_O=21.3 mm and inner radius a_I=20 mm. The ground plane has the dimensions 100 100mm^2. The coaxial line is used to feed the designed antenna, the location of feed was chosen at (x_f=8.19 mm) and (y_f=0.7 mm) to obtain the matching condition. The outer and inner of coaxial line radii are (r_O=4.10 mm) and (r_i=1.27 mm), respectively. Instead of multiple antennas, design B is simulated for multiband applications as a single antenna. This antenna is designed and simulated to resonate in S-, C- and X-bands frequency. Design B has been suggested and simulated by introducing the CMSA which contains slots in various sizes, these slots are etching on the circular patch, as displayed in Fig. 2.

RESULTS AND DISCUSSION

As a size reduction, design B is simulated for multiband applications instead of multiple antenna. This antenna is designed and simulated to resonate in S-, C- and X-bands frequency. The proposed antenna (design B) was suggested and simulated using the CMSA that includes slots in various sizes are etching on the circular patch, as illustrated in Fig. 2. The appropriate sizes and positions of these slots (from the edge of circular patch) give the suitable phase reflection in surface currents. The commercial tool (Ansoft HFSS) was used to designed and simulated the suggested antenna on a cost-efficient substrate (Roger RT (Duroid 5870)) of size 100 100 mm^2, thickness h=1.5 mm and dielectric constant ($\boldsymbol{\varepsilon_r}$ = 2.33). This antenna is fed by a coaxial probe with 50.24 , as illustrated in Fig.3. Table 1 predicts the sizes of the optimum suggested antenna (design B).

Fig. 3 displays the results of reflection coefficient of the suggested antennas that are shown in Fig. 1. It can be concluded from Fig. 3 that the optimum design has a good simulation findings of reflection coefficient. Therefore, the suggested antenna in Fig. 1c is chosen as the desirable design. It is noticed that, the desirable antenna has multiband feature at the resonance (operating) frequencies 2.695 GHz, 5.799 GHz and 8.323 GHz.

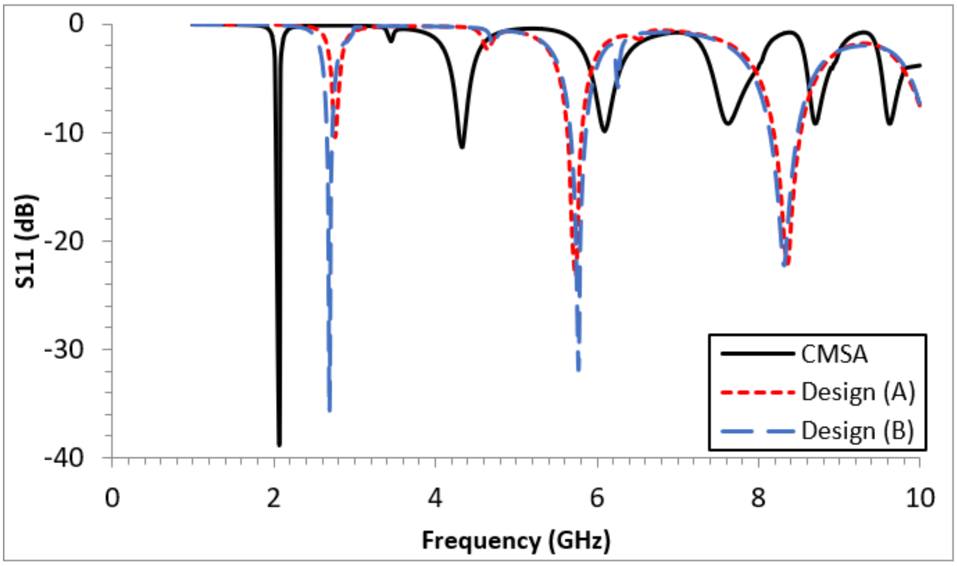


Fig. 3. Simulation findings of the reflection coefficient for designed antennas in Fig. 1

Table 2 explains the comparison of the simulation findings of the reflection coefficient for the designed antennas

in Fig. 1. The simulation data of the optimum antenna designed (B) includes a triple band feature at the resonance frequencies 2.695 GHz, 5.779 GHz and 8.323 GHz with impedance bandwidth of 106 MHz, 204 MHz and 371 MHz, respectively. As resulting, the optimum antenna designed (B) has three bandwidths of the simulated reflection coefficients at -10 dB which are identical with the S-, C- and X-bands frequency. Table 2 illustrates the simulated gain of the optimum suggested antenna (design B). Table 2 illustrates that the simulated gain of the suggested antenna design (B) around 3.91 dB, 6.33 dB and 7.21 dB in the S-, C- and X-band frequency, respectively.

Table 2: Comparison of the reflection coefficient features and gain values of the proposed antennas in Fig. 1

Designed Antenna	Resonant Frequency (GHz)	Reflection Coefficient (dB)	Bandwidth (MHz)	Gain (dB)
CMSA	2.075	-38.85	40	7.72
Design (A)	5.748	-26.28	183	5.16
Design (A)	8.371	-21.22	335	7.10
Design (B)	2.695	-35.74	106	3.91
Design (B)	5.779	-31.77	204	6.33
Design (B)	8.323	-22.23	371	7.21

The simulation findings of input impedance (Z_{in}) for the optimum antenna designed (B) investigated for different frequency values, is displayed in Fig. 4. From this figure it can be noticed that the simulation values of input impedance values are 48.52, 50.24 and 50.40 at the operating frequencies 2.695 GHz, 5.779 GHz and 8.323 GHz, respectively.

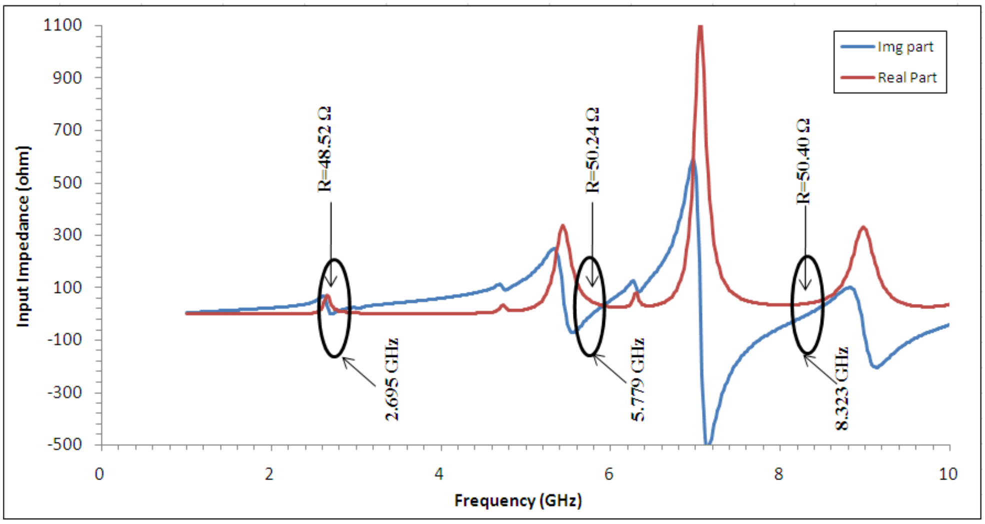
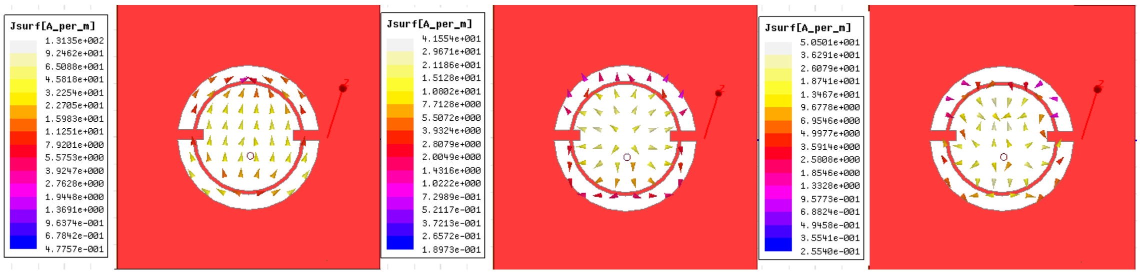


Fig. 4. Simulation findings of the Z_{in} for designed antenna (B)

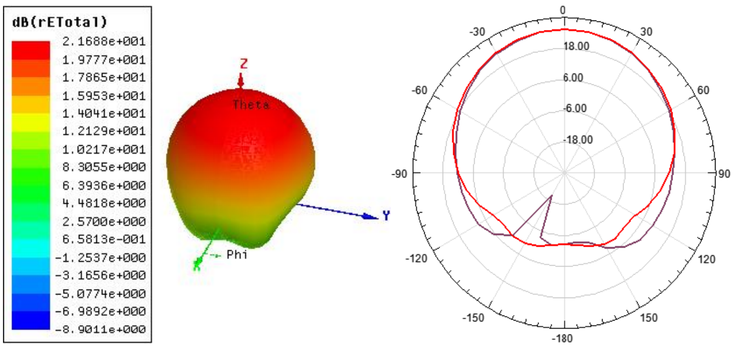
The simulations of the electric current distributions on the new patch of designed antenna (B) at the operation frequencies 2.695 GHz, 5.779 GHz and 8.323, are displayed in Fig. 5.

Fig. 6 illustrates the simulated results of radiation patterns of the designed antenna (B) at operation frequencies 2.695 GHz, 5.779 GHz and 8.323 GHz. These radiation patterns are in two (H- and E-planes) and three dimensions.

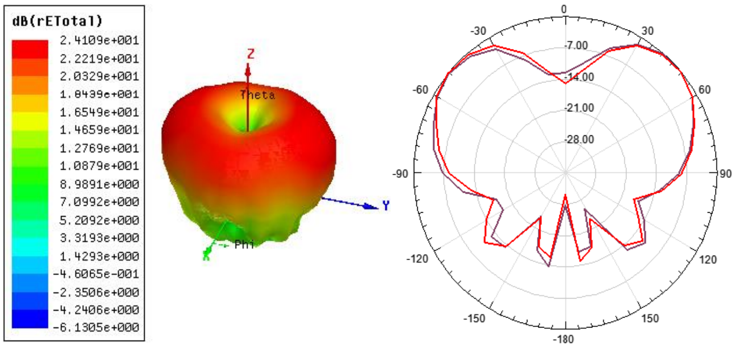


(a) (b) (c)

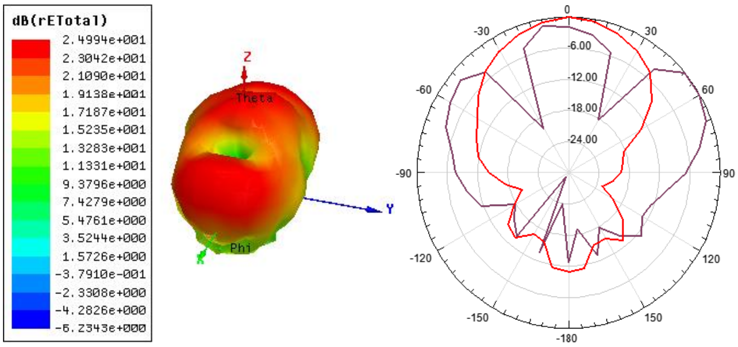
Fig. 5. Distributions of the electric currents on the patch of optimum antenna designed (B) at resonance frequencies (a) 2.695 GHz, (b) 5.779 GHz and (c) 8.323 GHz



(a)



(b)



(c)

Fig. 6. Simulated results of radiation patterns of the designed antenna (B) in two and three dimensions at resonance frequencies (a) 2.695 GHz, (b) 5.779 GHz and (c) 8.323 GHz

CONCLUSION

The present study proposed annular ring and rectangular slots which are etched in the patch of circular microstrip antenna, with size of 100 100 1.5 mm^3. These slots have been optimized in their dimensions and positions to obtained the good matching condition of the input impedance. The new circular patch with slots is able to product triple band characteristics of the designed antenna (B). The optimum antenna designed (B) is desirable for S-, C- and X-band applications in addition to its use in the space saving applications. Also, it concludes that, the suggested antenna operates at three resonance frequencies 2.695 GHz, 5.799 GHz and 8.323 GHz.

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