AIP Conference Proceedings

RESEARCH ARTICLE | SEPTEMBER 13 2023

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AIP Conf. Proc. 2845, 070006 (2023)
https://doi.org/10.1063/5.0172034

Optimize the Performance of Slotted Circular Patch Antenna by Using Triangular Slots for C-Band Applications and Simulation It Using HFSS

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Abstract. Due to wide applications in the field of fifth-generation (5GHz) communications, this research proposes a novel design and develop a circular patch antenna that works within (C-band). The proposed antenna was designed using the HFSS simulation software, which is based on the finite element method (FEM) to solve electromagnetic equations. The proposed antenna was simulated in an FR4-epoxy substrate with a dielectric constant ε_r of 4.4 and dimensions of (L × W × h) 28× 28 ×1.6 mm^3. The antenna's return loss, input impedance, and radiation pattern were determined by plotting. The slots method help increase the bandwidth (B.W) so in this design was used etched triangular slots on the patch and also three rectangles were added to the upper edge of the patch's left side. These triangular slots all have the same size and shape, and they were cut near to the patch's edge.

Keywords: Circular Microstrip Patch Antenna, C-Band, HFSS, Slots, Bandwidth.

INTRODUCTION

Antennas are an important component of an energy transferrer for multipoint communication, as they improve efficiency and gain while reducing wave interference. In order to meet the needs of development, multiband communication systems are now being widely used. Users of communication networks can send and receive messages in the form of images or video, e-mail, text, sound, and other styles [1].

The addition of microstrip antennas has been a significant advancement in the field of telecommunications and wireless technologies. The 5th generation of antennas has made it possible to achieve high performance while maintaining a small size and low cost [2].

Due to the rapid adoption of communication systems, many research societies and businesses are now focusing on future 5th generation (5G) communication systems. The coming up soon 5G communication system is expected to provide a consistent data-throughput experience across a broad range of applications. The International Communication Union (ITU) has been prompted to launch a Fifth Generation (5G) action in the close future as a result of the everyday increased use of mobile communication users, and additional small antennas can be installed in some information network cells to provide additional coverage over some "unseen" areas. These additional small microstrip antennas can be placed on roads as well as inside buildings [3,4].

The microstrip antenna is made up of a radiating patch layer located on one side of the dielectric substrate layer, and the ground layer is located on the other side [5]. Depending on the application, the patch layers come in a variety of regular and irregular shapes. Circular, rectangular, annular, elliptic, square, and other patch shapes are common. Patch antennas are more common because of their ease of fabrication and design [6,7]. The dielectric layer does have a dielectric constant ($2.5 \leq \varepsilon r \leq 12$) and a high (h) that is lesser than the free space wavelength ($h \ll \lambda o$), also this layer should be thick to achieve a high antenna performance [8]. A lower dielectric constant is also desirable for improved efficiency, increased radiation, and bandwidth. However, such a setup necessitates a larger antenna. On the other hand, using a small MSA reduces the efficiency, gain, and bandwidth because the antenna size

The National University of Science and Technology International Conference for Pure and Applied Sciences
AIP Conf. Proc. 2845, 070006-1–070006-8; https://doi.org/10.1063/5.0172034
Published by AIP Publishing. 978-0-7354-4652-6/$30.00

is reduced. As a result, antenna dimensions and performance are always a trade-off. As a consequence, the researchers concentrated on patch modification using slots, dual patches, dual dielectric layers, and other techniques. MSAs are being used in a broad range of microwave systems, including navigation, telemetry, radars, smart phone, satellite systems, satellite communications global positioning system (GPS), medical and biological systems, missile systems, ect. [9].

MSA also has a very limited frequency bandwidth and a low efficiency. Many techniques exist for greatly lowering the impact of the problem discussed above, and many studies have focused on improving these coefficients. A number of theoretical and empirical studies have been developed to enhance the antenna's bandwidth [10]. Shorting pin loading and patch stacking are two techniques for increasing the bandwidth of microstrip antennas [11]. The antenna bandwidth is also improved by various shapes of slot loading in fed patch [12].

In this research, CMSA based on etched slots on the circular patch radiating are proposed and operating in the c-band frequency which we modified the patch's shape by cutting sixteen triangle-shaped parts in a circular shape close to the radiator's edge (patch). As shown in Fig. (1), this was achieved by using simple square symmetry shapes of the same size which were rotated by four angles.

ANTENNA DESIGN

The behavior of MSAs is primarily influenced by the conducting patch design chosen, which modify the radiation pattern, surface current distribution, gain, bandwidth, and impedance matching. As a result, the aim of the research is to find more efficient and inexpensive methods of achieving desired outcomes, such as gain and bandwidth. The suggested antenna is designed using a CMSA as the first step. In addition, several design steps are used to achieve the best possible results from the proposed antenna. Fig. (1) depicts the proposed antenna's geometry design.

The relationship following can be used to calculate the resonant frequency of circular MSA for the TM11 mode using [13]:

$$f_{11} = \frac{1.841c}{2\pi a_e\sqrt{\epsilon_r}} \tag{1}$$

$$\chi_{11} = k_{11}a \tag{2}$$

Which

- a_{e} : is the effective radius of a circular patch , c : a light speed in space.
- $k11$: the wave number given by $\mathrm{k11} = \omega\sqrt{\mu\epsilon}$.
- χ_{11} :are the mth zeros of the derivative of the Bessel function $Jn(x)$ of the 1st kind of order n and ϵ_r is the dielectric constant of substrate [14].

Using the following relationship [15], the effective radius can be used to calculate the value of the circular patch radius.

$$a_{\mathrm{e}} = a\left[1 + \frac{2\mathrm{h}}{\pi a \varepsilon_{\mathrm{r}}}(\ln\left(\frac{\pi \mathrm{a}}{2\mathrm{h}}\right) + 1.7726)\right]^{1/2} \tag{3}$$

This section describes the structure of the proposed antenna, which using the two feeders of direct microstrip feed technique (microstrip line) as illustrated in Fig. (1). A circular microstrip antennas was designed with a FR4 -epoxy dielectric substrate have a dielectric constant of (ε_r =4.4) with dimensions of ($28\times28\times1.6mm^3$). In addition, to achieve input impedance matching in the proposed antenna, the strip line is used for feeding at the location (x=14mm) and (y=-1.75mm) and the patch is feed at (W_{f2}=3.5mm) and (Z=2.1mm). The advantage of this fed method, moreover, is that the feeder can be etched on the same dielectric substrate.

The current method relies on modifying the design of the patch antenna to enhance antenna performance. The suggested patch configuration is made up of simple symmetry shapes like circles and squares. Fig. (1) depicts the design steps for the suggested design using (HFSS) software. An regular dual-feed circular microstrip antenna provides a basis for basic antenna geometry.

As a first step, Fig. 1(C1) depicts the typical circular antenna shape. In the second step, one rectangle was added to the left-hand edge of the circular patch, as we can see in Fig. 1(C2) followed by the addition of two more rectangles in a sequential order As shown in Fig. 1(C3). The third step was to cut sixteen triangular slots in a circular patch near the patch's edge as explained in Fig. 1(C5).

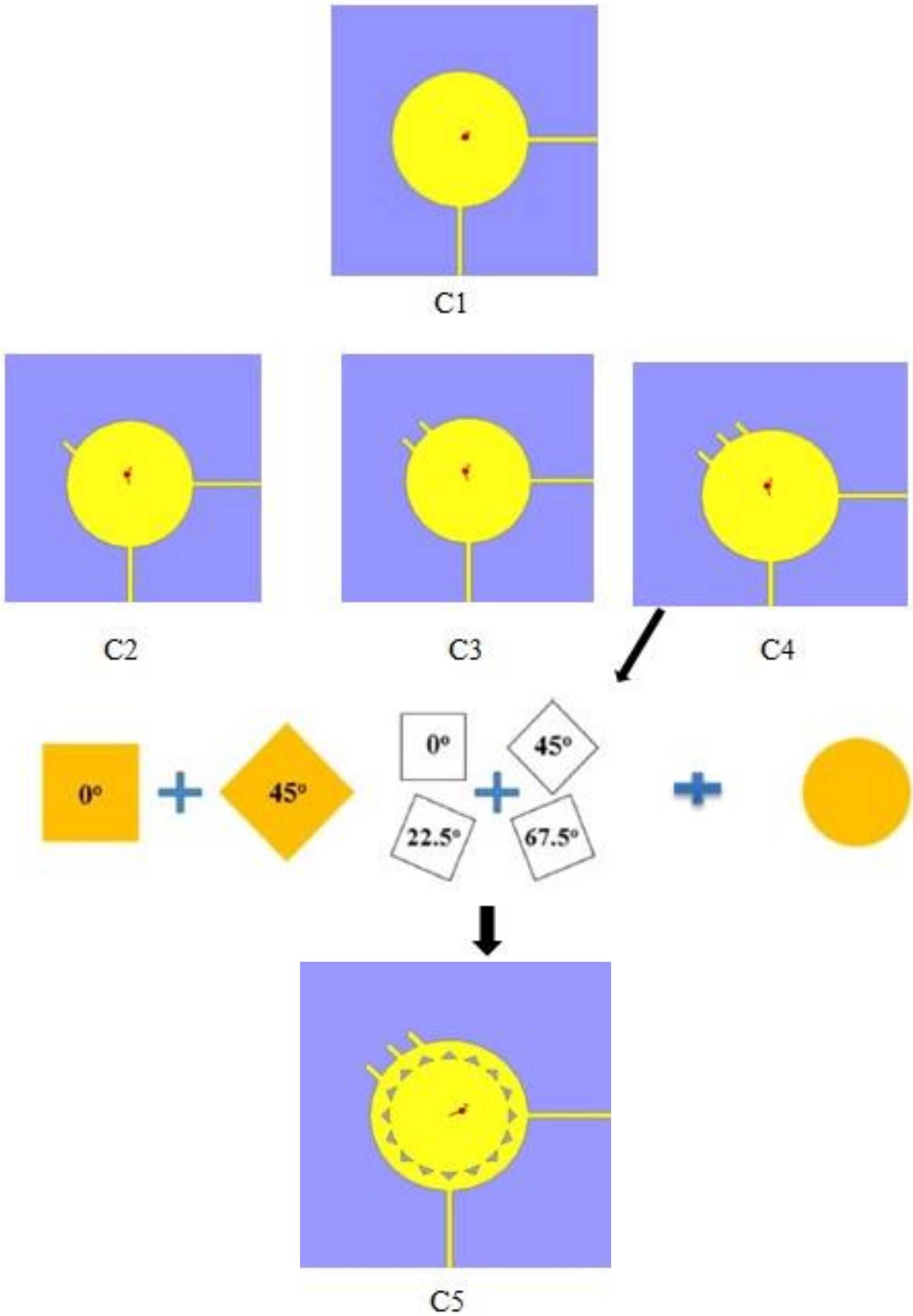

FIGURE 1. Steps designed of the suggested antenna

The proposed antenna (design C5) of Fig. (1) is selected as the best design antenna, and its geometrical structure is depicted in Fig. (2). Table (1) also displays the variables and dimensions used in Fig. (2).

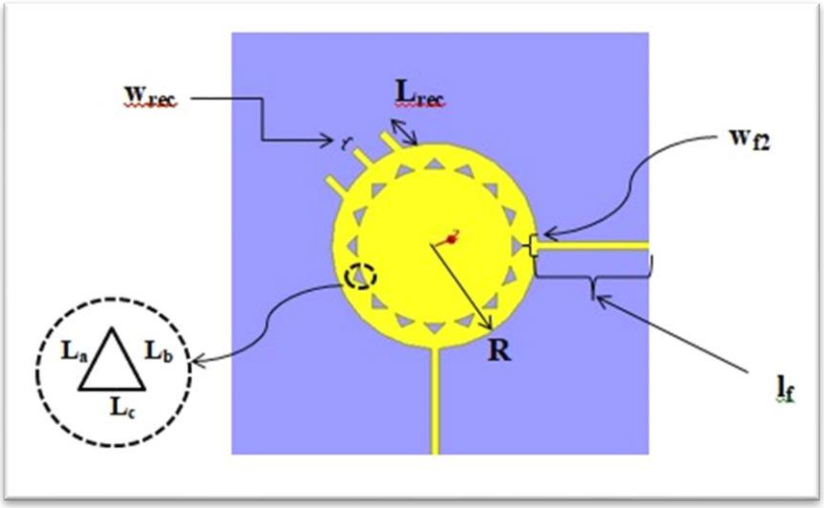

FIGURE 2. The geometrical of antenna design C5.

TABLE 1. The Dimensions of antenna design C5.

Parameters	Values (mm)
L	28.0
W	28.0
w_f	0.5
l_f	8.0
R	6.8
h	1.6
w_{f2}	0.5
L_{rec}	3
w_{rec}	0.5
l_a	3.78
l_b	3.78
l_c	5.35

RESULTS AND DISCUSSION

The decrease in the amplitude of the reflected energy from the energy emitted is known as return loss (S_{11}).

The suggested antenna patch has a circular shape structure that is used to increase the antenna's bandwidth. Fig. (3) shows the return loss simulation results for these antennas. This Fig. shows that the antenna designed in Fig. (1, C5) produces the best results with a bandwidth of 273 MHz. As a result, this is the best antenna design, with a resonance frequency of 5.86GHz and a return loss of -19.01 dB for the first feed, as well as with a resonance frequency of 5.81GHz and a return loss of -18.71 dB for the second feed.

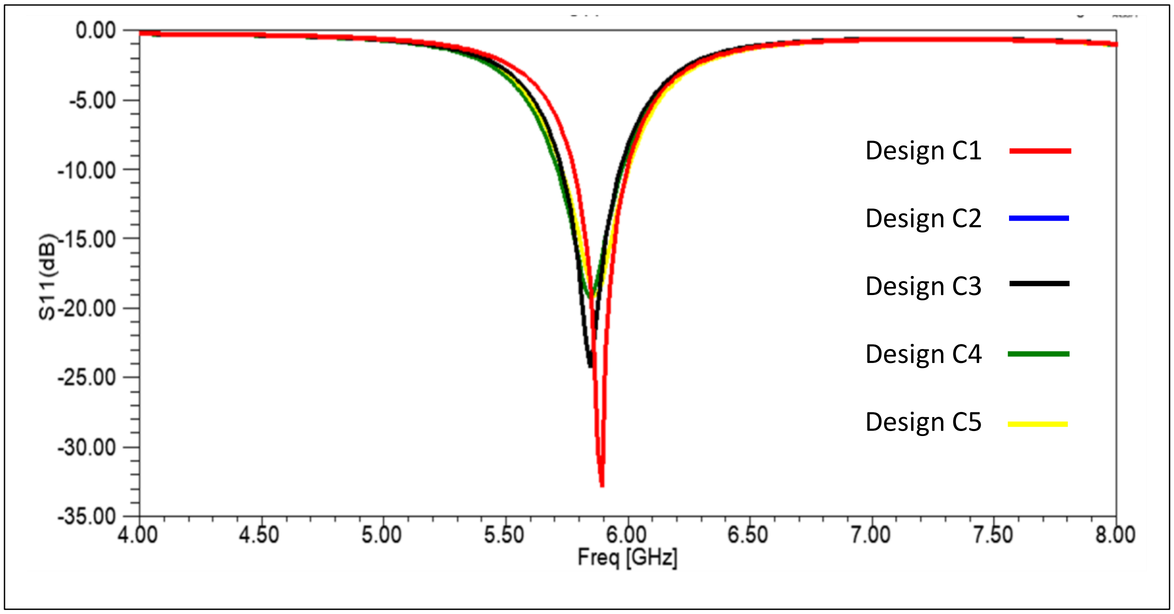

FIGURE 3. Simulation results of return loss (S_{11}) for the designed antennas in Fig. 1

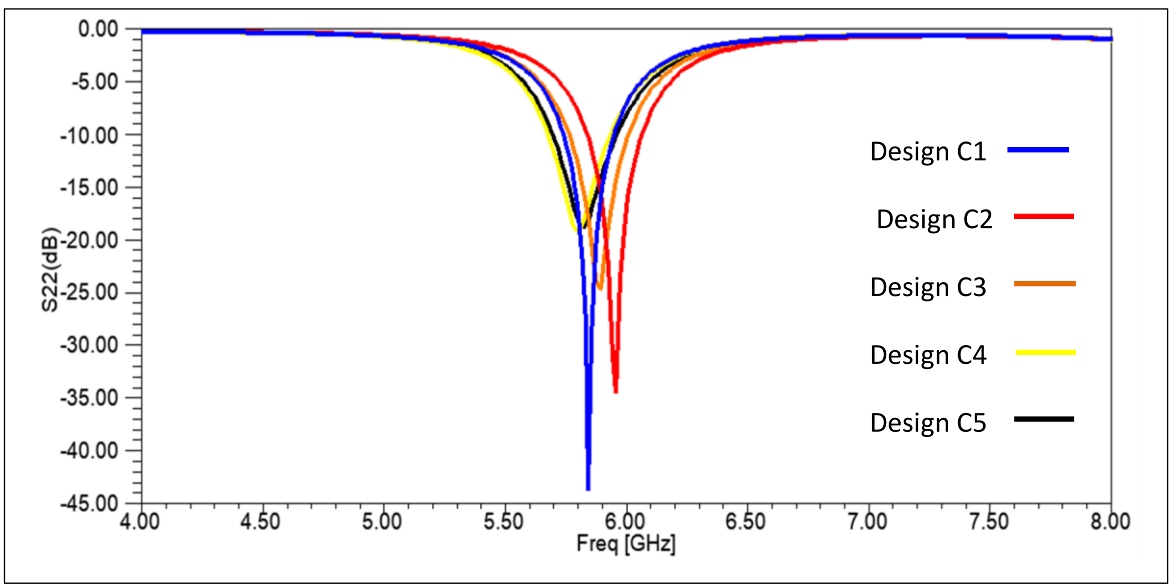

FIGURE 4. Simulation results of return loss (S_{22}) for the designed antennas in Fig. 1

Where: (S_{11}) return loss for the port1, (S_{22}) return loss for the port2.
Table 2. shows that the proposed antenna in Fig.(1) is the best design for the antenna's bandwidth value.

TABLE 2. Simulation results of the parameters of suggested antennas in Fig. (1).

Designed Antenna	f_{r1} (GHz)	f_{r2} (GHz)	S_{11} (dB)	S_{22} (dB)	VSWR1 VSWR2	Gain (dB)	B.W1 B.W2 (MHz)
C1	5.84	5.84	-38.28	-43.68	1.02 1.01	5.3073	206.3 206.3
C2	5.89	5.95	-32.38	-34.45	1.04 1.03	5.2926	224.9 224.9
C3	5.84	5.89	-24.23	-24.57	1.13 1.12	5.3165	241 241
C4	5.84	5.79	-19.29	-19.22	1.24 1.2	5.1478	257 257
C5	5.86	5.81	-19.01	-18.71	1.25 1.26	5.1705	273 273

The parameters of the first feeder are denoted by the symbols below:

f_{r1} , S_{11} , VSWR1 , B.W1

The parameters of the second feeder are denoted by the symbols below:

f_{r2} , S_{22} , VSWR2 , B.W2

Fig.(5) depicts the simulation results of the radiation pattern in two dimension and gain in three dimension for the proposed antenna in Fig.(2). The antenna in Fig. (2) has a maximum bandwidth of 273MHz at an operating frequency of 5.8 GHz.

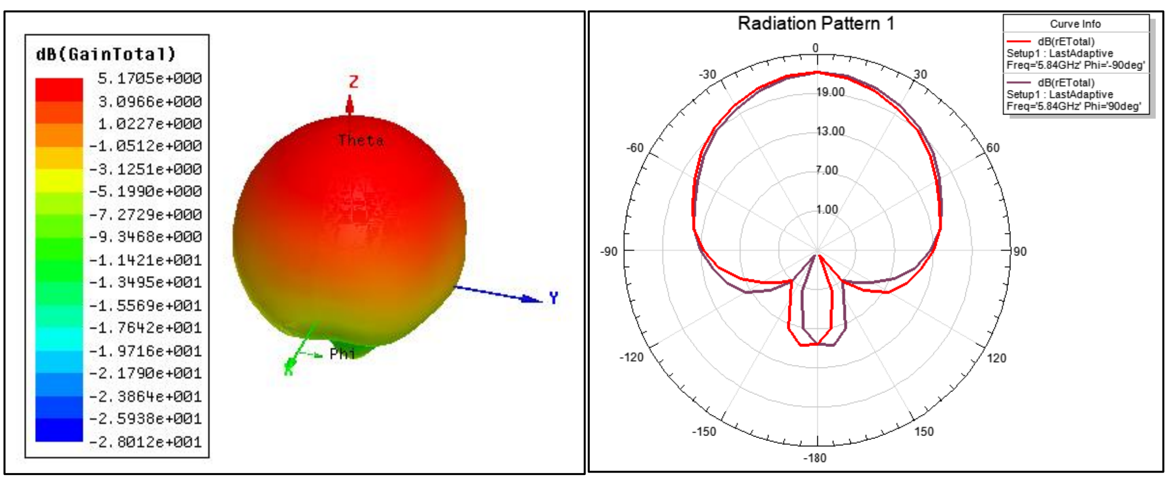

FIGURE 5. Simulation results of radiation pattern in the two dimension and gain in three dimension for proposed antenna in Fig.(2), (H-plane black curve and E-plane red curve).

The simulation results of the input impedance Z_{11} and Z_{22} of the two ports of the antenna design (C5) as a function of frequency can be seen in Fig.(5). At the frequency of 5.8 GHz, the input impedance values Z_{11} and Z_{22} are 45,1.8 and 45,-3.6 Ohm, respectively.

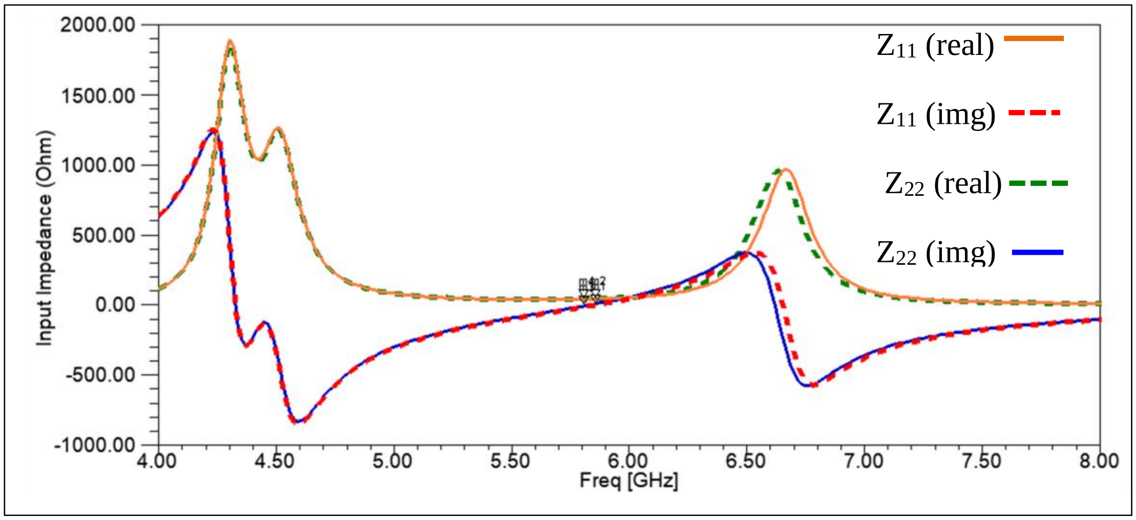

FIGURE 6. Simulation results of the input impedances (Z_{11} and Z_{22}) for designed antenna (C5).

The following Fig. depicts the simulation result of the surface current distributions on the optimum patch antenna at the resonance frequency of 5.8 GHz. Furthermore, with the exception of the patch's side edges on the right and left sides, the current distribution behaves symmetrically on the upper and lower halves of the optimum patch. The density distribution of surface current is also strong at the edges of the optimum patch.

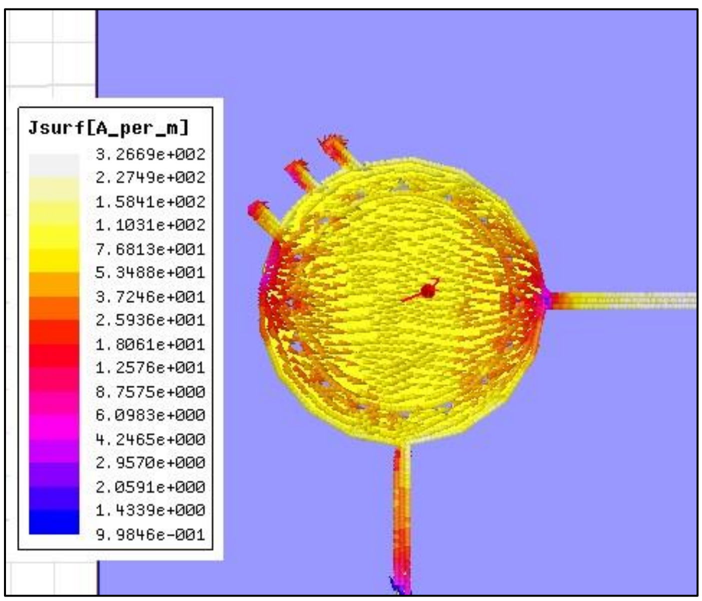

FIGURE 7. Electric current distribution simulation on the new suggested antenna (design C5).

CONCLUSIONS

This paper presents slotted circular patch microstrip antenna with small size 28 x 28 x 1.6 mm3 with dual feed and operates in C-band frequency at resonance frequency 5.8 GHz with bandwidth of return loss of 273 MHz and gain 5.1705 dB. Based on the circular microstrip antenna, a new patch antenna is simulated with etched triangular slots on the patch and three rectangles added to the top potion of the patch's left side. The radiation pattern has symmetrical shape and desired features in wireless applications. As a result, the designed antenna is suitable for C-band and wireless communication applications.

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