AIP Conference Proceedings

RESEARCH ARTICLE | DECEMBER 15 2023

Design and simulation of slotted circular microstrip antenna with dual feed at 5.84 GHz FREE

Doaa H. Hashim ; Wa'il A. Godaymi Al-Tumah

AIP Conf. Proc. 2862, 020040 (2023)
https://doi.org/10.1063/5.0172030

Design and Simulation of Slotted Circular Microstrip Antenna with Dual Feed at 5.84 GHz

Doaa H. Hashim[1,2,a)] , Wa'il A. Godaymi Al-Tumah[3,b)]

[1] Department of Physics, College of Education for Pure Science, University of Basrah, Basrah, Iraq

[2] Department of Physics, College of Education , University of Misan, Misan, Iraq

[3] Department of Physics, College of Science, University of Basrah, Basrah, Iraq

[a)] *doaa.hashim@uobasrah.edu.iq*

[b)] *wail.godaymi@uobasrah.edu.iq*

Abstract. In this study, three designs of circular microstrip antenna depended on two rectangular slots with dual feed in C-band frequency are designed and simulated. These rectangular slots have the same dimensions and located near the patch edge. Also, Ansoft High Frequency Structure Simulator (HFSS) is used to design and simulate the proposed antennas. Various parameters of these antennas which are include return loss, radiation patterns, gain, input impedance and surface currents were calculated. The optimum design makes the designed antenna to has the same impedance-bandwidth at each port of feeding. The simulated results showed that the optimum antenna (design B) has resonance frequency 5.84 GHz with a bandwidth of reflection coefficient of 224.9 MHz , and has gain 5.40 dB. Therefore, the proposed antenna has a good gain, simplified structure, ease of processing and low price, the suggested design is deemed an amazing choice for 5G communication and C-band applications.

Keywords: circular microstrip antenna, slot antennas, bandwidth, C-band, HFSS

INTRODUCTION

Microstrip antenna (MSA) was first used in the 1950s. However, development of this concept took about 20 years had to wait the evolution of printed circuit board technology in the 1970 [1]. In practice, MSA is the ideal solution for design in a constrained and small area. MSAs have been an alternate choice in recent years due to their tiny size when compared to normal antenna structures. Furthermore, the antenna has a low profile, can correspond to geometry planar and nonplanar surfaces, easy and affordable to produce utilizing electronic circuit devices and in concepts of resonance, polarizability, and patterns, it is extremely adaptable [2,3].

A Microstrip Patch Antenna, also defined as a printed antenna, would be an antenna that is created using Microstrip techniques on a printed circuit board [4]. Microwave frequencies are the most commonly employed for microstrip antennas [4]. Microstrip Antenna is constructed of a very thin metallic patch above the ground layer and isolated from it by a dielectric layer. Typically, the radiating elements (conducting patch) and feed line are photoetched on the dielectric layer [5]. Depending on the type of MSA application, the radiating patch can be different geometric shapes such as rectangular, circular and annular or any other shape. These patch shapes are the most common because they are the easiest to analyze and fabricate [6,7,8].

Microstrip Antennas are essential elements for wireless communication technology. These antennas are the best choice for future development of wireless communication due to their lightweight, small in size, ease of fabrication [9]. Moreover, MSAs come in a variety of geometric shapes which allow them to be used in a variety of applications. However, the conventional shapes of MSAs have some disadvantages such as leakage losses at the open border, low radiated power and narrow bandwidth, low power handling capabilities and low gain [10,11]. The features of MSAs like small size, low-price and low - profile are required for recent wireless communication applications, such as satellite communications and smart phone communication, global positioning system devices and wireless local area network, as well as medical applications [12,13].

MSAs are widely employed in a variety of microwave applications, including navigation, satellite communications, radars, biomedical systems, mobile phone, global positioning systems for remote sensing and missile defense systems and among others [8,14]. Moreover, circular and rectangular microstrip antennas have good features such as linear and circular polarizations, broad bandwidth, multiple frequency operation,

1st International Conference on Sustainable Development Techniques (ICSDT2022)
AIP Conf. Proc. 2862, 020040-1–020040-9; https://doi.org/10.1063/5.0172030
Published by AIP Publishing. 978-0-7354-4741-7/$30.00

frequency agility, and feed line flexibility. However, the volume of circular microstrip antenna (CMSA) is less than that of a rectangular microstrip antenna [15,16].

Many research societies and industries are now focusing on future 5th generation (5G) communication systems due to the fast increase of 4th generation (4G) communication systems, the upcoming 5G communication system is expected to provide a consistent data-throughput experience across a wide range of applications. The International Telecommunication Union (ITU) has been prompted by the daily increase in mobile communication users to launch a Fifth Generation (5G) initiative in the near future [17] as well additional small antennas can be installed in some cells of the communication network in order to provide additional coverage over some "unseen" areas. These additional small antennas can be installed on the streets or inside buildings. On the other hand, to get a larger flow (close to the one obtained from fiber), the fifth generation 5G will use higher frequencies up to 26 GHz, which are used in some services such as speed radars, collision prevention systems in cars, airport security gates. The increased use of social media applications, as well as the current demand for high-quality multimedia content, necessitates the handling of high data rates and throughputs. 5G technology promises high-speed data rates ranging from 5 Gbps to 50 Gbps. [18].
In this paper, a compact CMSA design for circular polarization applications is proposed using a CMSA with rectangular slots. The C-band is also commonly used for weather radars, raw satellite feeds, or full-time satellite TV networks, satellite communications, and LAN radios in the 5 GHz range.

ANTENNA DESIGN

The radiating patch is the most essential part of MSA, because it influences on input impedance, radiation pattern and bandwidth, as well as surface current distribution. To improve the performance of MSAs, various geometry shapes of patch antennas are used.
This section explains the design of proposed antennas depend on CMSA as a standard antenna. The resonant frequency expression of a CMSA is given by [19]:

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

where χ_{nm} is often the first order Bessel function root and is determined by the patch's mode. The letters (n) and (m) represent the order of the derivatives of the Bessel function and its roots, respectively, c is the light's speed and the dielectric constant is ε_r, and a_e is the effective radius of a circular patch used in place of actual radius (due to fringing effect) as given by [20]:

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

This section explains the design of proposed antennas which excited by two feeders, as shown in Figure (1). These antennas are designed using FR4-epoxy as a dielectric substrate which has a dielectric constant of (ε_r =4.4), thickness (h=1.6 mm) and dimensions (28mm×28mm), the circular patch having radius (a = 6.8mm). Also, to satisfy the input impedance matching in the proposed antenna, the strip line is used for feeding at the coordinates (x=14mm) and (y=-1.75mm) and the patch is feed at (W_{f2}=3.5mm) and (Z=2.1mm). However, the advantage of this fed method is that the feeder can be etched on the same dielectric substrate. These dimensions of the designed antenna are specified to let the TM11-mode as the resonant mode [6]. The geometry shapes of the proposed antennas are shown in Figure (1). Figure (1a) shows CMSA with one feed, Figures (1b) and (1c) using dual feed of CMSAs without and with rectangular slots that etched on the circular patch, respectively. It should be noted that all of the designs in Figure 1 are the same size and dimensions.

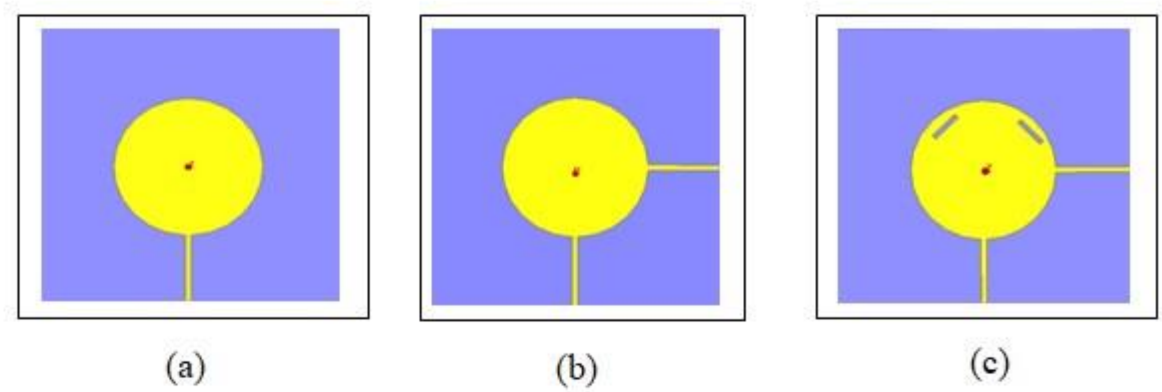


FIGURE 1. Steps to selecting CMSA as the proposed antenna (a) one feed, (b) dual feed without slots and (c) dual feed with slots.

Based on good simulation findings of gain, bandwidth and radiation pattern, the proposed antenna (design B) of Figure (1c) is selected as the optimum design antenna and its geometrical design is shown in Figure (2). Also, Table 1 displays the parameters and dimensions that used in Figure 2. This antenna was simulated using the commercial product (HFSS) software. This program is used to solve problems in physics and engineering mathematics. It is computed based on the finite element method technique and (MOM) method of moments.

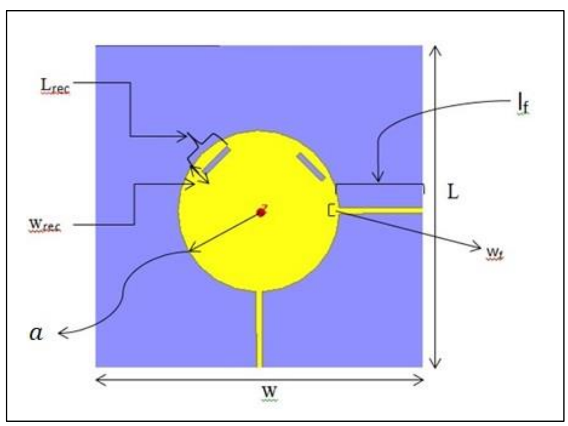


FIGURE 2. The geometrical of antenna design B.

Table 1. The Dimensions of antenna design B.

Parameters	Values (mm)
L	28.0
W	28.0
w_f	0.5
l_f	8.0
a	6.8
h	1.6
w_{f2}	0.5
L_{rec}	3.0
w_{rec}	0.5

For 3D full-wave electromagnetic field modeling, HFSS simulation tool is the industry standard. For near and far radiated fields, HFSS produces E-field and H-field, currents, return loss, and empirical results. Also, HFSS's appeal as an engineering design tool is inextricably related to its automated solution approach, which only needs users to specify geometry, material properties, and the proposed solution. To respond to the challenges, HFSS will generate a reasonable, efficient, and accurate grid.

RESULTS AND DISCUSSION

The patch of suggested antenna has a circular shape structure that is utilized to improve the antenna's gain and bandwidth.

Figure (3) shows the simulation results of return loss for the suggested antennas which is in the Figure (1). The optimum design, as shown in Table (2), has good simulation findings for the gain and bandwidth. As a result, the recommended antenna in Figure (1c) is selected as the preferred design. Also, the results of the return loss (S_{22}) of the suggested antennas designs A and B.

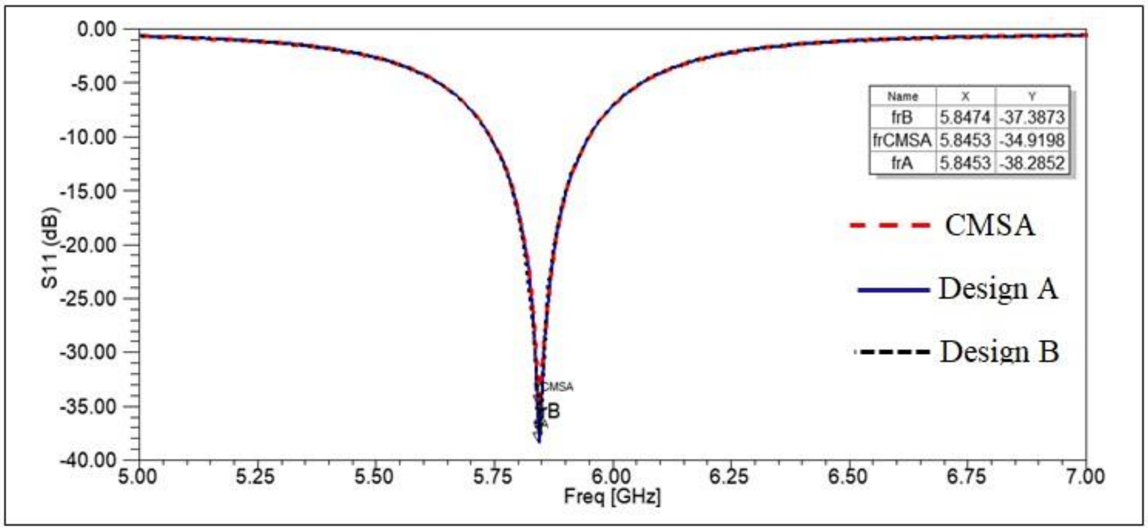


FIGURE 3. Simulation results of return loss (S_{11}) for the proposed antennas in Fig. (1)

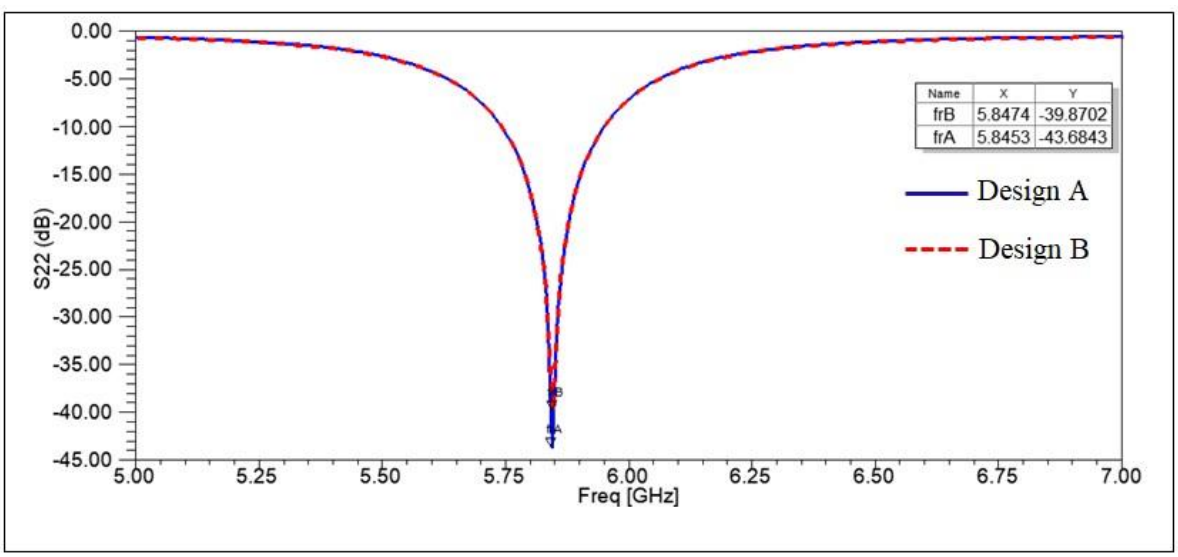


FIGURE 4. Simulation results of return loss (S_{22}) for the proposed antennas.

The bandwidth of proposed antennas operates within the C-band. This bandwidth is quite useful for C-band applications. Table (2) illustrates the results of the suggested antennas in Figure (1).

Table 2. Simulation results of the parameters of suggested antennas in Figure (1).

Designed Antenna	**f_{r1} (GHz)**	**f_{r2} (GHz)**	**S_{11} (dB)**	**S_{22} (dB)**	**Z_{11} (Ω)**	**Z_{22} (Ω)**	**$VSWR_1$ $VSWR_2$**	**Gain (dB)**	**$B.W_1$ $B.W_2$ (MHz)**
CMSA	5.845	------	-34.9198	------	(51.5,-0.9)	------	1.036 ------	5.23	217.8
Design A	5.845	5.845	-38.2852	-43.6843	(51.1,-0.5)	(50.5,-0.4)	1.024 1.013	5.30	206.3 206.3
Design B	5.8474	5.8474	-37.3873	-39.8702	(51.2,0.81)	(51.1,-0.21)	1.027 1.020	5.40	224.9 224.9

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

f_{r1} , S_{11} , Z_{11}, $VSWR_1$, $B.W_1$

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

f_{r2} , S_{22} , Z_{22} , $VSWR_2$, $B.W_2$

Antenna gain is described as the quantity of transmitted power in the direction of the high-radiation. Table (2) shows the simulated gain of the suggested antenna design (B) around 5.4091 dB at the resonance frequency of 5.84 GHz. This value of gain is acceptable value.

Figure (5) depicts the simulation results of the input impedance Z_{11} and Z_{22} of the two ports of the designed antenna B as a function of frequency. This figure shows that the input impedance values Z_{11} and Z_{22} are 51.02 , 51.01Ohm respectively at the frequency 5.84 GHz.

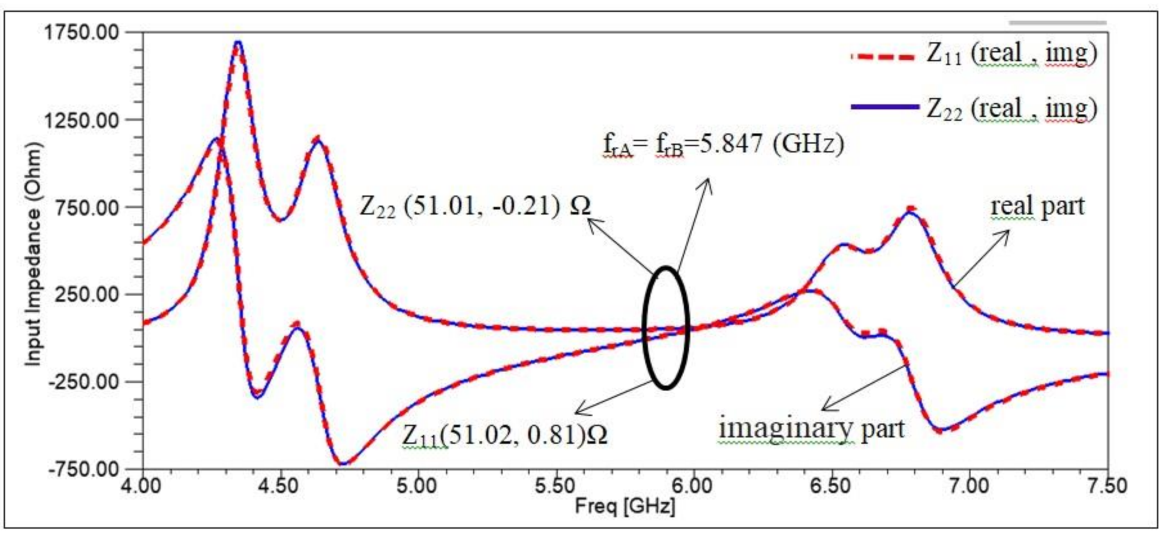


FIGURE 5. Simulation results of the input impedances Z_{11} and Z_{22} (the input impedance coefficients for the first feeder and the second feeder) for designed antenna (B).

Figure (6) and (7) show the simulation results of radiation patterns and gain of the proposed antenna B at the resonance frequency of 5.84 GHz, respectively. These radiation patterns have desired features in wireless applications.

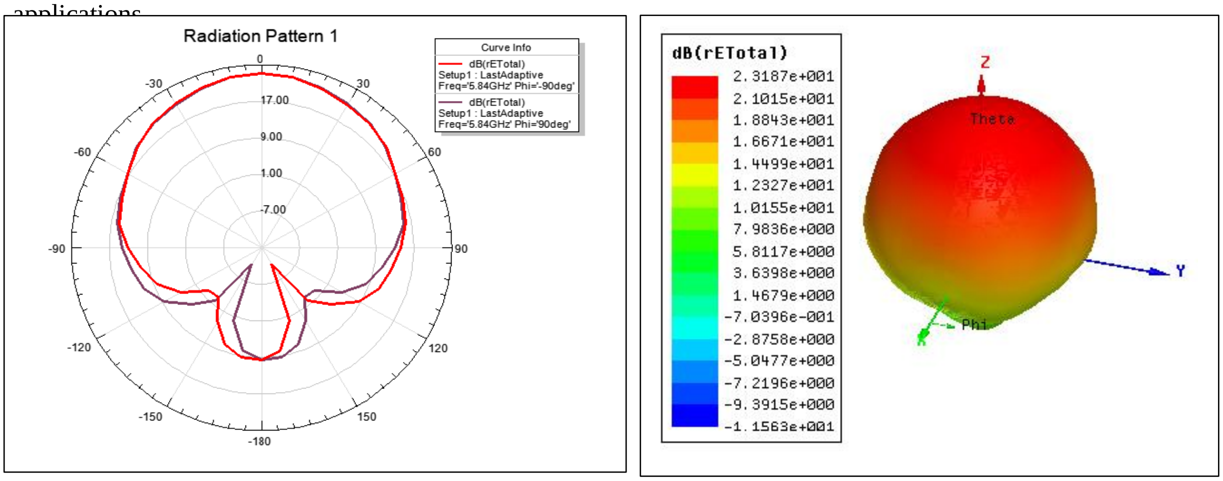


FIGURE 6. Simulation results of radiation pattern of the proposed antennas (design B) in two and three dimensions at resonance frequency (5.84GHz).

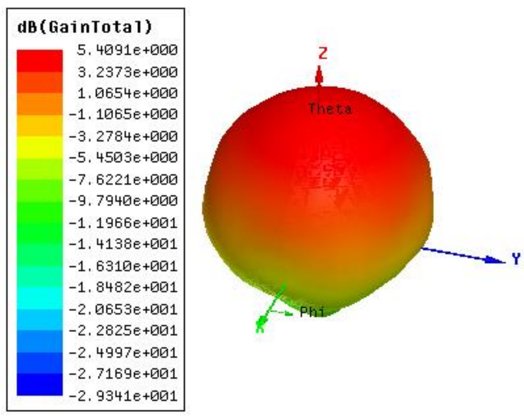
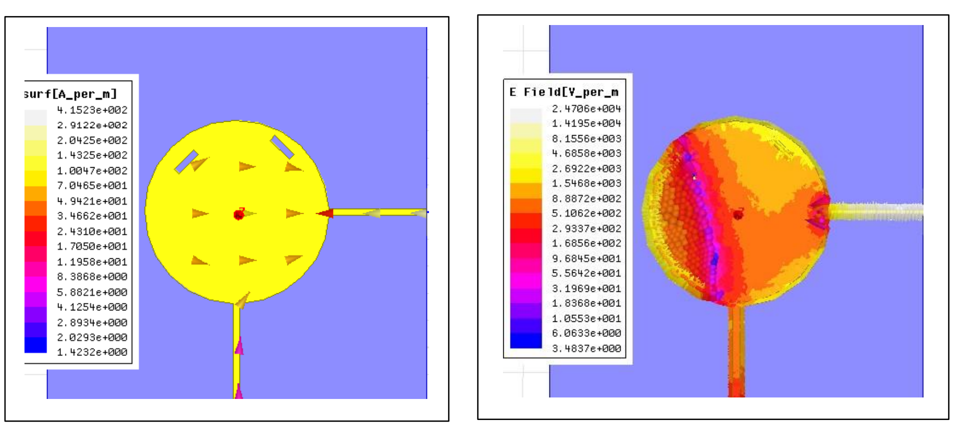


FIGURE 7. Simulation results of gain for the proposed antenna (design B) in three dimensions.

Figure (8) shows a simulation of the electric current distributions and electric field on the new patch of the proposed antenna (design B) at the resonance frequency 5.84 GHz. Surface currents result from increased electric field variation, as shown in Figure (8b).



(a) (b)

FIGURE 8. shows a simulations of the electric current distributions fig (a) and electric field fig (b) on the new proposed antenna (design B).

To optimize the performance of proposed antenna B the parametric study on the dimensions of slots Lrec and Wrec is done, as we can see in Table 3, 4, 5 and 6, respectively. From these tables, it can be concluded that when Lrec=2.0 mm and Wrec=0.5 mm the parameters input impedance and gain have the optimum values.

Table 3. Resonant frequencies, Bandwidth and gain values of the designed antenna B as a function of L_{rec}.

W_{rec} (mm)	**L_{rec} (mm)**	**f_{r1} (GHz)**	**f_{r2} (GHz)**	**Bandwidth (MHz)**	**Gain (dB)**
0.5	0.5	5.847	5.847	224.9	5.3927
0.5	1	5.847	5.847	208.8	5.5333
0.5	2	5.847	5.847	224.9	5.4091
0.5	3	5.847	5.847	208.9	5.3165
0.5	4	5.8313	5.8313	208.9	5.2378

Table 4. Resonant frequencies, Bandwidth, input impedances and gain values of the designed antenna B as a function of w_{rec}

W_{rec} (mm)	**f_{r1} (GHz)**	**f_{r2} (GHz)**	**Z_{11} (Ω)**	**Z_{22} (Ω)**	**Gain (dB)**	**Bandwidth (MHz)**
0.25	5.847	5.847	(51.3, 0.6)	(51.3,1.06)	5.3673	208.9
0.5	5.847	5.847	(51.2,1.4)	(51.2,2.0)	5.4091	224.9
0.75	5.847	5.847	(50.9,-0.9)	(51.5,-0.4)	5.2771	208.9
1	5.847	5.847	(49.9,0.4)	(51.1,0.6)	5.4581	208.9

The last study to optimize the performance of proposed antenna B are the feed locations and width of feed line and it's included in the Tables 5 and 6, respectively. From these tables, it can be concluded that when the first and second feed locations (-5.5,-1.0) and (-6.0,-2.0) , respectively in addition to that when the width of feed lines is 0.5 mm L_{rec} the parameters of designed antenna B such as input impedance and gain have the optimum values.

Table 5. Resonant frequencies, Bandwidth and gain values of the designed antenna B as a function of the feed locations.

x (mm)	**y (mm)**	**f_{r1} (GHz)**	**f_{r2} (GHz)**	**Gain (dB)**	**B.W1 B.W2 (MHz)**
-5.5 -4.5	-1 -1	5.8474	5.8474	5.2616	208.9 208.9
-5.5 -5.5	-1 -1	5.8474	5.8474	5.2388	208.9 208.9
-5.5 -6	-1 -2	5.8474	5.8474	5.4091	224.9 224.9
-5.5 -4.5	-1 0	5.8474	5.8474	5.3310	208.9 208.9
-4.5 -4.5	2 -3.5	5.8313	5.8474	5.3922	208.9 208.9

Table 6. Resonant frequencies, input impedances and gain values of the designed antenna B as a function of the width of feed lines.

W (mm)	f_{r1} (GHz)	f_{r2} (GHz)	Z_{11} (Ω)	Z_{22} (Ω)	Gain (dB)
0.3	5.845	5.833	69.42,-0.35	68.88 , -3.10	5.3991
0.5	5.845	5.845	51.16,-0.50	50.56 , -0.42	5.3073
0.7	5.856	5.856	40.74,2.57	40.72 , 2.23	5.3141
0.9	5.856	5.856	33.81,1.90	33.82 , 2.10	5.1490
1.1	5.868	5.868	29.14,4.15	28.85 , 4.69	5.2352

CONCLUSIONS

This paper presents slotted circular patch microstrip antenna with small size with dimensions of 28 x 28 x 1.6 mm3 with dual feed and operate at resonance frequency 5.84GHz. These slots have rectangular shapes with same dimensions 2.0x0.5 mm and located near the patch edge. The optimum designed antenna was selected after the parametric study. This antenna has the simulation results of the gain and bandwidth which are 5.40 dB and 224.9 MHz, respectively. This value of gain is acceptable value. Also, the radiation pattern has symmetrical shape and desired features in wireless applications. Moreover, the designed antenna produces two reflection coefficients which are S_{11}= -37dB and S_{22}= -39 dB. Therefore, the proposed antenna meets the applications in C-band and 5G mobile communication networks.

REFERENCES

[1] Garg, R., Bhartia, P., Bahl, I. J. and Ittipiboon, A. , Microstrip antenna design handbook, Artech house, (2001).

[2] Subahir, S., Ali, M. T., Ramli, N. A., Kamaruddin, S. N., Awang, A. H. and Kamarudin, M. R. "Development of Rectangular Loop Microstrip Antenna Integrated With Light Emitting Diode (LED) for Wi-fi Application", In Applied Mechanics and Materials ,Trans Tech Publications Ltd, Vol. 781, pp. 116-119, (2015).

[3] Godaymi, W. I. A., Mohammed, A. K. A. A. and Ahmed, Z. A. , "Determination of surface currents on circular microstrip antennas", Journal of electromagnetic engineering and science, 12, 4, pp. 260-270, (2012).

[4] Yadav, M. B., Singh, B. and Melkeri, V. S. , "Design of rectangular microstrip patch antenna with DGS at 2.45 GHz", In 2017 International conference of Electronics, Communication and Aerospace Technology (ICECA), IEEE, Vol. 1, pp. 367-370, (2017).

[5] Ahmed, R. M. S. Z. A. and Wa'il, A. G. , "Radiation patterns account of a circular microstrip antenna loaded two annular", vol, 6, 71-81, (2016).

[6] Patel, B. D., Narang, T. and Jain, S. , "Microstrip patch antenna-A historical perspective of the development", In Conference on advances in communication and control systems, (2013).

[7] Wa'il, A., Shaaban, R. M. and Duffy, A. P. , "Design, simulation, and fabrication of a double annular ring microstrip antenna based on gaps with multiband feature", Engineering Science and Technology, an International Journal, 29, 101033, (2022).

[8] Wa'il, A., Shaaban, R. M. and Tahir, A. " Design, simulation and measurement of triple band annular ring microstrip antenna based on shape of crescent moon", AEU-International Journal of Electronics and Communications, 117, 153133, (2020).

[9] Wa'il, A., Shaaban, R. M., Tahir, A. S. and Ahmed, Z. A. , "Multi-forked microstrip patch antenna for broadband application", In *Journal of Physics: Conference Series* , Vol. 1279, No. 1, p. 012025, IOP Publishing, (2019).

[10] Collin, R. E. , Antennas and radiowave propagation, McGraw-Hill College, (1985).

[11] Yon, H., Awang, A. H., Ali, M. T., Subahir, S., Kamaruddin, S. N., Aris, M. A. and Ab Wahab, N. , "Integrated stacked microstrip antenna with Light Emitting Diode (LED) for Wi-Fi application", In International Communication and Computer Engineering Conference, 25–27, (2016).

[12] Balanis, C. A. , Antenna Theory Analysis and Design , 2nd edition, john Willey & Sons Inc. New York, (1997).

[13] Shaaban, R. M., Ahmed, Z. A. and Godaymi, W. A. ,"Design and analysis for circular microstrip antenna loaded by two annular rings", Global Journal of Computer Science and Technology, (2017).

[14] Wa'il, A., Shaaban, R. M., & Ahmed, Z. A. , "A modified E-shaped microstrip patch antenna for dual band in x-and ku-bands applications", In Journal of Physics: Conference Series, Vol. 1234, No. 1, p. 012028, IOP Publishing, (2019).

[15] Lin, Y. F., Chen, H. M. and Lin, S. C. , "A new coupling mechanism for circularly polarized annular-ring patch antenna", IEEE Transactions on antennas and Propagation, 5, 1, 11-16, (2008).

[16] Guo, Y. X., Bian, L. and Shi, X. Q. , "Broadband circularly polarized annular-ring microstrip antenna", IEEE Transactions on Antennas and Propagation, 57, 8, 2474-2477, (2009).

[17] Wang, Y., Li, J., Huang, L., Jing, Y., Georgakopoulos, A. and Demestichas, P. , "5G mobile: Spectrum broadening to higher-frequency bands to support high data rates", IEEE Vehicular technology magazine, 9, 3, pp. 39-46, (2014).

[18] Ahmad, I., Houjun, S., Ali, Q. and Samad, A. , "Design of Umbrella shape single element patch antenna with high gain and high efficiency for 5G wireless communication in 28 GHz", International Bhurban Conference on Applied Sciences and Technology (IBCAST), IEEE, pp. 710-713, (2020).

[19] Godaymi, W. I. A., Mohammed, A. K. A. A. and Ahmed, Z. A. , "Determination of surface currents on circular microstrip antennas", Journal of electromagnetic engineering and science, 12, 4, 260-270, (2012).

[20] Saxena, K. , "Comparison of Rectangular, Circular and Triangular Patch Antenna with CPW Fed and DGS", IJECT, Vol. 7, (2016).