DESIGN AND ANALYSIS OF AN INSET-FED CIRCLE
PATCH MICROSTRIP ANTENNA OPERATED
AT 28 GHZ FOR 5G APPLICATION

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Abstract: This paper presents a microstrip antenna design which it's radiating element is circular and applied to 5G systems. The model and parameters of the antenna were simulated and analyzed by High-Frequency Structure Simulator (HFSS) computer code on FR4-epoxy laminate microwave. The simulation results of the antenna show that it operates at 28 GHz with return loss S_{11}= -40 dB, bandwidth BW=2 GHz, power gain greater than 5 dB, radiation efficiency greater than 87% and Voltage Standing Wave Ratio (VSWR) is less than 2 in the operating band from 26.8 to 28.8 GHz, respectively. From the results achieved, the designed antenna is suitable to be used in devices using 5G technology.

Keywords: Microstrip antenna; inset-fed; circular patch; 5G technology.

1. Introduction

In the context of information and communication systems are running out of resources, 5G technology is an effective solution to meet current development and communication needs. Compared to 4G technology, 5G antennas work at higher resonant frequencies, thus allowing their devices to achieve a higher data rate. For high-mobility users, the expected rate of 5G technology is 5.0 Gbps while for low-mobility users it is 50.0 Gbps. Besides, the goal of the International Telecommunication Union on 5G is 3 times more spectrally effective than Long-Term Evolution (LTE). Researchers find a way to deal with this problem in the 5th generation of communication by providing a higher data rate, using an extremely high-frequency band (EHF) as around frequency bands 28 GHz, 38 GHz, and 68 GHz [1 - 9]. Federal communication commission (FCC) proposed the band spectrum of 27.5 to 28.25 GHz for 28 GHz band spectrum application while the ETSI proposed that for 5G communication antenna must have a bandwidth of 1GHz for S_{11} less than -10 dB [1], [2].

Moreover, modern wireless communication systems required low cost, lightweight, low profile, high-gain and simple to manufacture to ensure reliability, mobility, and high efficiency leads to innovations in designing antennas for 5G [3], [4]. Currently, there are many techniques used in the design of antennas, one of the most commonly applied methods is microstrip technology, which has outstanding advantages compared to other technologies such as compact, low profile, easy for feeding, easy to etch on any PCB should be convenient in integration on modern equipment, low production costs. Besides, microstrip technology can use many shapes to design radiation surfaces for antennas such as rectangles, squares, circles, triangles... This makes it easier to choose the shape of the antenna to suit the shape of each type of device [5],[6].

For the 28 GHz band, Park et al. have proposed an 8-element array antenna with a bandwidth of 2.3 GHz but its structure is complex especially [7], [8]. Abbas Awan et al. have proposed a patch antenna with improved performance using DGS, however, it has a quite narrow bandwidth of 1.38 GHz [11]. A simple microstrip based structure has also been reported such as that by Khalily et al. providing a gain of 15.6 dBi within around 20 × 20 mm size, its bandwidth also only achieved from 27.3 to 29 GHz [9], [10], [11].

In this paper, we propose a microstrip antenna design with a circular radiation element, which operates at the 28 GHz band for 5G systems. The antenna is fed by a compact inset-fed, the overall dimensions of the antenna are 5.6 mm x 5.6 mm x 0.8 mm. The antenna operating frequency range is from 26.8 to 28.8 GHz, which is suitable for application in 5G communication. The antenna is designed and investigated based on the HFSS full-wave simulation software.

2. Structural Design and Simulations

The proposed circle patch antenna using a microstrip line for feeding is given in Fig 1. The dimension of the overall antenna structure is 5.6 mm x 5.6 mm fabricated on an FR-4 substrate with a dielectric constant of 4.4, a substrate thickness of 0.8 mm, and a loss tangent of 0.02. The radiating and ground layers are made from copper, with thickness t of 0.035 mm and electric conductivity σ of 5.96×10^7 S/m. The radius of the patch, designed to operate at 28 GHz, the standard frequency for 5G communication antenna, is calculated using the formulas given in [12].

$$r = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \qquad (1)$$

where $\qquad F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \qquad (2)$

$$L = 4 * r + 3.75h \qquad (3)$$

r is the radius of the circular patch, f_r is the operating frequency, h and ε_r are the thickness and the dielectric constant of substrate.

Apply the formulas (1), (2) and (3) to calculate the circular radius of the patch r=1.5 mm, L=6 mm. To achieve the desired results, the designers used the PSO algorithm (Particle Swarm Optimization) used in familiar Ansoft HFSS software for antenna dimensions.

The optimization process is carried out by investigating the effect of the return loss S_{11} versus changes in the dimension of the radiation element's radius. Because the original antenna (r = 1.5 mm) operates at frequencies lower than 28 GHz, so the size of the antenna must be reduced in order for it to operate at higher frequencies. Initial initialization parameters are r from 1 to 1.5 mm, with step = 0.1 mm and the optimum results are calculated and displayed at 28 GHz. After optimization, the most suitable result is selected corresponding to r = 1.3 mm.

Two symmetrical rectangular notches of dimensions m x g are etched in radiating circular patch with the 0.5 mm length (m) and 0.15 mm width (g). To obtain a characteristic impedance of 50 Ω, the feedline width (w) and length (k) are determined 0.3 mm and 1.8 mm respectively. The detailed dimensions of the proposed circular patch antenna are shown in Tab 1 and simulated by HFSS software.
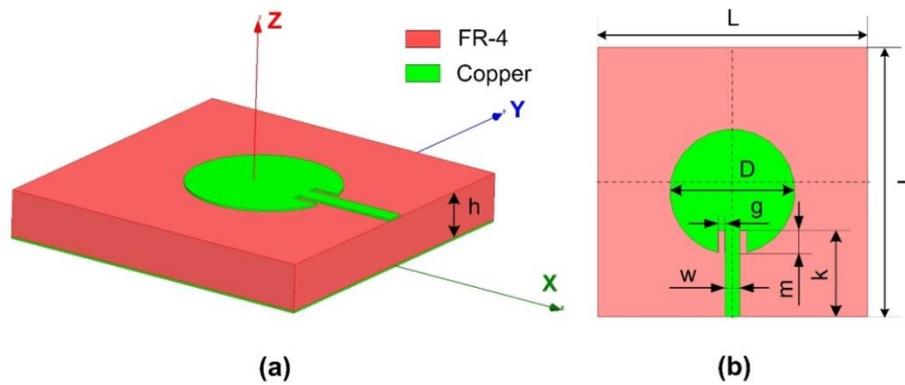
Fig. 1: *Schematic of proposed circle patch microstrip antenna (a) 3D view and (b)Top view*

Tab. 1: *Dimensions of proposed patch antenna*

Parameters	Value (mm)
L	5.6
h	0.8
t	0.035
D	2.6
k	1.8
w	0.3
g	0.15
m	0.5

3. Results and Discussion

3.1. Return Loss Parameter

The simulated S-parameter shown in Fig. 2 indicates that the value of return loss (S_{11}) is -40 dB at 28 GHz with bandwidth ranging from 26.8 GHz to 28.8 GHz, which entirely covers 5G frequency band allocated from GHz 27.5 to 28.25 GHz.
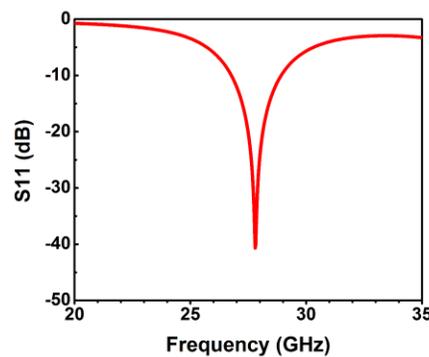
Fig. 2: *Simulated S-parameter of circular patch microstrip antenna*

3.2. Voltage Standing Wave Ratio

Voltage Standing Wave Ratio (VSWR) of the proposed circle patch antenna is shown in Fig. 3. The value of VSWR at 28 GHz is reported to be 1.25 which value is less than 2 indicating improved matching conditions.
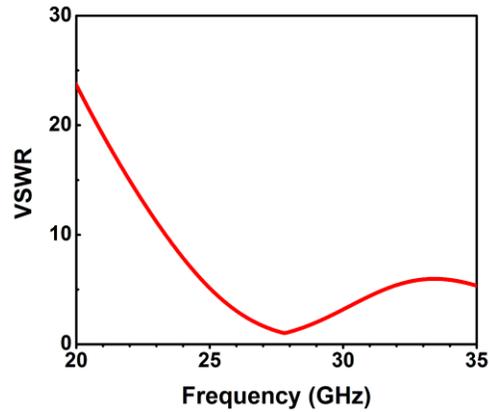

Fig. 3: *VSWR of circular patch microstrip antenna*

3.3. Smith Chart

The Fig. 4 shown the scattering parameter S_{11} for the proposed circular patch microstrip antenna at the range of frequency 20 GHz -30 GHz on the Smith chart exhibits a good impedance matching of approximately 50 Ω at the resonate frequency.

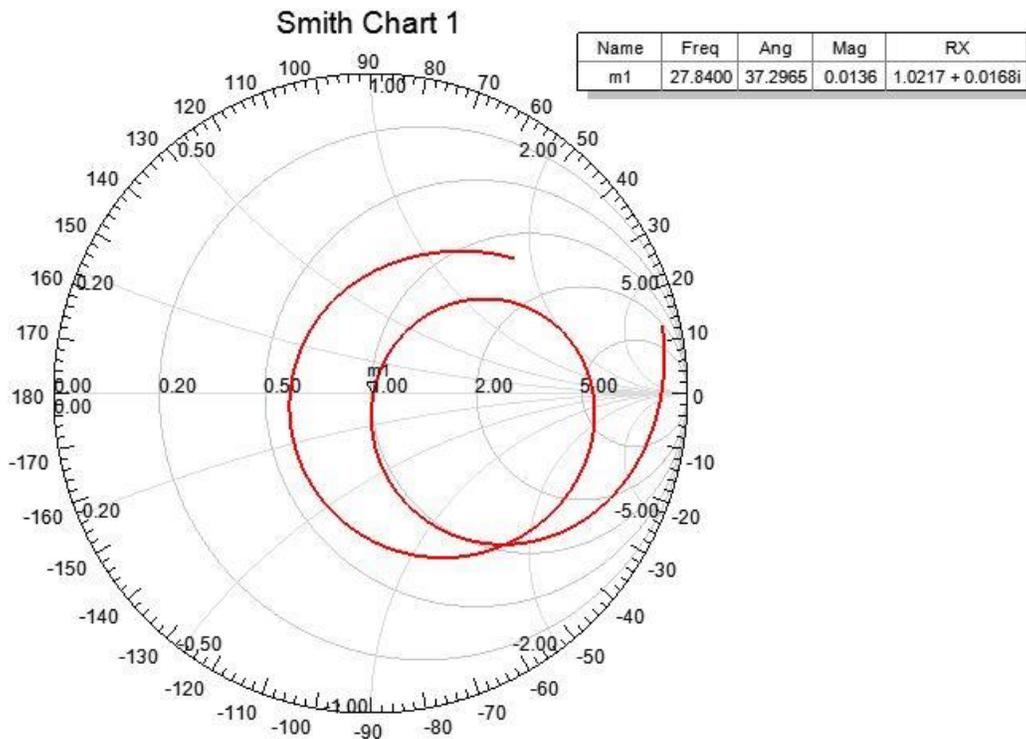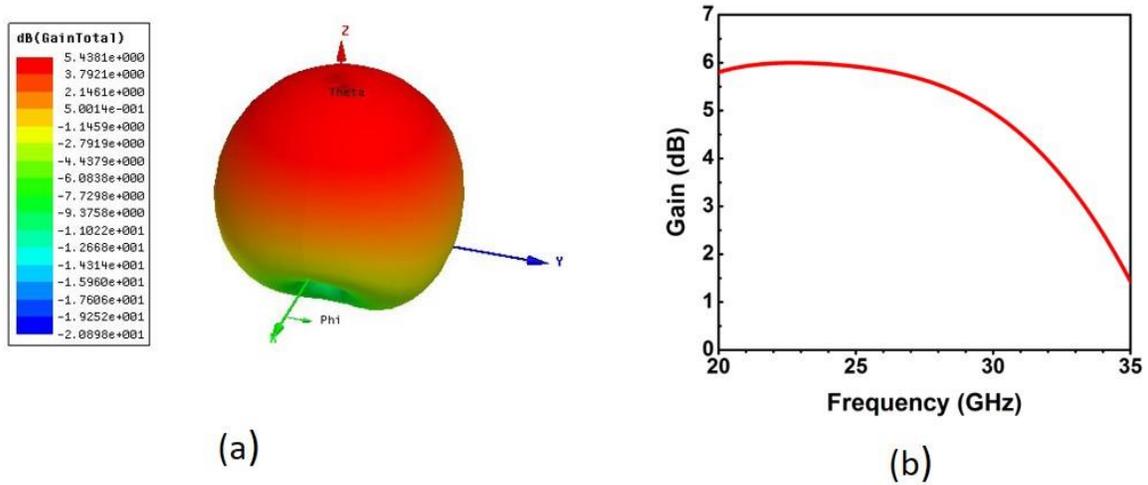| Name	Freq	Ang	Mag	RX
m1	27.8400	37.2965	0.0136	1.0217 + 0.0168i

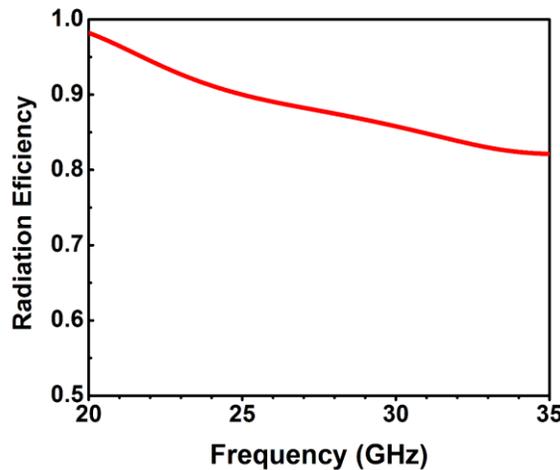**Fig. 4:** *Smith chart of circular patch microstrip antenna*

3.4. Gain and Radiation Efficiency

The gains of the proposed antenna were given in Fig. 5. As shown in Fig. 5, the proposed antenna provides a total maximum gain of 5.44 dB and the gains stay above 5 dB throughout the band.


Fig. 5: *Power gain 3D (a) and 2D versus frequency (b)*
of circular patch microstrip antenna

The radiation efficiency and patterns of the proposed antenna are provided in Fig. 6 and Fig. 7. As shown in Fig. 6, the radiation efficiency of antenna obtains above 87% in the bandwidth ranging from 26.7 GHz to 28.25 GHz. The 3-D total gain confirms that the maximum power of the antenna could be achieved along the z-axis. In YOZ-plane and XOZ-plane, the radiation patterns of the designed antenna are quite similar to the directional radiation patterns with maximum power along the Z-axis, while it exhibits an omnidirectional radiation pattern in the XOY-plane

Fig. 6: *Radiation Efficiency of circular patch microstrip antenna*
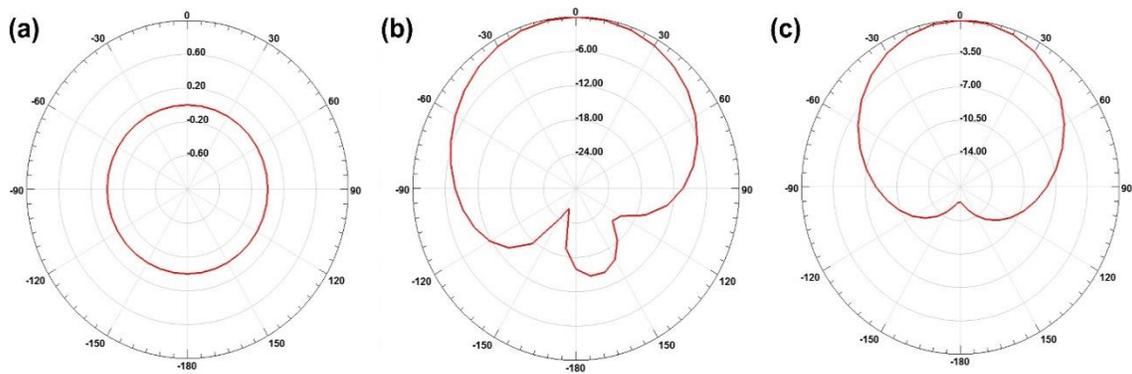
Fig. 7: *(a) Radiation pattern in XOY plane, (b) XOZ plane, and YOZ plane*

4. Conclusion

This paper presents an antenna design on the FR4-epoxy substrate for 5G technology. The radiation element of the antenna is circular and fed by a microstrip line. The model and parameters of the antenna are simulated and extracted by HFSS 13.0. The simulated results show that the proposed antenna achieves the resonate frequency at 28 GHz, the total gain of 5.4 dB, the impedance of 50 Ω, the bandwidth of 2 GHz, the radiation efficiency of more than 87% through the whole the frequency band. Compared to the before microstrip antennas for 5G communication, the ones that have used different shapes to design. This our design, the total dimension is smaller, the bandwidth is wider, and the power gain is improved. The obtained results prove that the proposed antenna is suitable for 5G standard from 27.5 to 28.25 GHz.

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TÓM TẮT

PHÂN TÍCH VÀ THIẾT KẾ ĂNG-TEN VI DẢI HÌNH TRÒN HOẠT ĐỘNG Ở TẦN SỐ TRUNG TÂM 28 GHZ CHO ỨNG DỤNG 5G

Bài báo này trình bày một thiết kế ăng-ten vi dải áp dụng cho các hệ thống 5G với phần tử bức xạ hình tròn. Các thông số của ăng-ten được mô phỏng và phân tích bằng phần mềm HFSS trên vật liệu điện môi FR4-epoxy. Kết quả mô phỏng cho thấy ăng-ten hoạt động ở băng tần 28 GHz với mức suy hao bằng -40 dB, băng thông 2 GHz, độ lợi công suất lớn hơn 5 dB, hiệu suất bức xạ lớn hơn 87% và tỷ lệ sóng điện áp đứng nhỏ hơn 2 trong băng tần hoạt động tương ứng từ 26,8 đến 28,8 GHz. Từ kết quả đạt được, ăng-ten được thiết kế phù hợp để sử dụng trong các thiết bị sử dụng công nghệ 5G.

Keyword: Ăng-ten vi dải; phần tử bức xạ hình tròn; công nghệ 5G.