Design of a soft circular patch antenna operating in the 60 GHz band for 5G/6G applications

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ABSTRACT

5G/6G technologies require higher-performance antennas in terms of bandwidth, gain, radiation, compact size, efficiency, and low cost. At the same time, fewer natural disturbances, such as rain and snow, and fewer non-natural disturbances. This is the challenge facing scientific research into antenna design and manufacture. In addition, in this paper we study and design a flexible circular microstrip patch antenna operating in the 60 GHz band for 5G/6G applications. This antenna is based on a biosourced substrate for industrial, scientific, and medical applications. For this study, we will use two techniques: one concerns the deformation of the ground plane deformation of the ground plane and substrate to improve the electrical performance of a proposed antenna. At the same time, the other is the parametric study of the appropriate position of a coaxial feed probe. This technique has the advantage of requiring no radiation contrition on the part of the coaxial probe. Next, specialized high-frequency structure simulator (HFSS) simulation software is used to design this antenna; it has a wide bandwidth above 3 GHz, a gain of 7.41 dB, a directivity of 7.53 dB, a radiated power of 13.55 dBm, an accepted power of 13.67 dBm, an incident power of 15.08 dBm, a radiation efficiency of 97.29 % and an efficiency of 98.4 %.

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1. INTRODUCTION

5G is the fifth generation of wireless cellular technology, offering faster upload and download speeds, smoother connections, and improved capacity over previous networks. This technology is much faster and more reliable than current 4G networks and could transform how we use the internet to access applications, social networks, and information. For example, technologies such as autonomous cars, advanced gaming applications, and live streaming of multimedia content, which require highly reliable, high-speed data connections, are set to benefit greatly from 5G connectivity [1], [2]. Printed antennas are technological devices that enable users to receive signals from mobile networks. Like 3G and 4G antennas, 5G antennas act as signal amplifiers. Thanks to them, users can receive 5G from a mobile operator [3]. Portable antennas have attracted much attention recently due to their many advantages, including flexibility, lightweight and low cost. They have many applications in wireless communications and sensors [4].

The structure of a microstrip patch antenna consists mainly of three stages: a main insulating stage, i.e., the substrate, a stage containing the metalized patch element on one side of the substrate, and the metallic ground plane on the opposite side. In the general case, patch antenna radiation depends on the fringing field produced at the edges of the patch element [5]. Indeed, the circular patch antenna has a number of advantages, including a high degree of controllability (radius), design flexibility, reduced dimensions compared with those of the rectangular patch antenna at the same design frequency of 16%, and better controllability of its radiation [6]. Wireless communication systems require high-performance microstrip patch antennas to transmit and receive high-quality signals. However, patch antennas have characteristics such as low gain and low bandwidth. To this end, we propose a circular patch antenna offering good performance. To achieve this, we use two techniques: one that deforms the ground plane and one that optimizes the feed point.

The choice of substrate for antenna manufacturing depends on the specific application. For wearable technology integrated into clothing, textiles are a popular choice due to their easy incorporation into fabrics [7]. Additionally, paper-based substrates, which are both affordable and widely accessible, present a promising option for eco-friendly electronics [8]. Polymer-based substrates are the most commonly used in antenna manufacturing. Among these, polyimide (Kapton) [9], polyethylene terephthalate (PET) [10], and polydimethylsiloxane (PDMS) [11] are the most prevalent. However, a key disadvantage of these materials is that they are derived from petroleum-based resources. This has led to increased interest in exploring alternatives that can minimize the reliance on such materials, thereby reducing the environmental impact and dependence on fossil fuels in electronic devices. In response, we suggest using a bio-based polymer as a substrate for a circular patch antenna designed to operate at 60 GHz [12].

In the available scientific literature, we have found several types and structures of antennas exploited in the 60 GHz band to meet the needs related to current wireless applications for 5G and 6G networks. In the work of [13], we find a general overview of microstrip patch antennas with beamforming for future 5G/6G networks, it also presents the methods and techniques previously employed for antenna design, focusing in particular on the development and improvement of antenna performance such as analog, digital and hybrid beamforming, bandwidth, and radiation. Alanazi *et al.* [14], we find the design and manufacture of a 4×4 MIMO antenna array operating at 60 GHz. The authors propose a semicircular “P”-shaped antenna that achieves the following parameters: a gain of 9 dB and a bandwidth of 6 GHz. Furthermore, Alharbi *et al.* [15] is devoted to work on the development and design of a 60 GHz series-fed compliant antenna for 6G and beyond applications. It operates in the 57 GHz to 62 GHz band, has attractive return loss and radiation characteristics for 6G and beyond applications, and offers a gain of 14.7 dBi as well as a directional radiation beam in the hemispherical viewing direction. In addition, Patch antennas typically have a narrow bandwidth, often not exceeding 10%, which makes covering unlicensed 60 GHz frequency bands challenging. To address this limitation, various techniques have been proposed to enhance the bandwidth. These include modifications such as introducing a U-shaped slot in the patch [16], [17], using an E-shaped patch antenna [18], [19], incorporating an L-shaped probe [20], adding parasitic patches [21], and employing a horn antenna structure [22]. For example, the U-shaped patch antenna can achieve a bandwidth improvement of up to 15% due to the added slot. The E-shaped patch antenna shows a 21.7% increase in impedance bandwidth, thanks to the inclusion of the E-shaped notch. While horn antennas can also improve bandwidth, they tend to be more costly due to their complex design.

The use of circular patch antennas in the 60 GHz band is essential for high-speed wireless communication technologies such as 5G/6G and Wi-Fi. Indeed, this type of antenna benefits from new design techniques that optimize efficiency, miniaturization, and performance, particularly for mobile devices and connected objects. Their ability to operate in the 60 GHz band, combined with circular polarization, guarantees optimum performance in complex environments, making them crucial to the evolution of communication networks. The structure of this work is outlined as follows: We begin with an introduction, followed by a description of the antenna design process. Next, we perform simulations of the antenna using high-frequency structure simulator (HFSS) software. We then compare the obtained results with those found in the existing literature. Finally, we conclude the study with a summary of the findings.

2. CIRCULAR PARTCH ANTENNA DESIGN METHOD

2.1. The aim of selecting the 60 GHz frequency band

The 60 GHz band offers efficient throughput (up to several gigabits) with low latency. The 60 GHz frequency band suffers from path attenuation that is approximately a thousand times higher than that of a 2 GHz signal in free space. It is specifically intended to support wireless network applications that demand extremely high data transfer speeds. This band is suitable for transferring large files, streaming high-definition video, and other similar tasks. Additionally, it is commonly used in wireless local area networks (WLANs), wireless personal area networks (WPANs), and point-to-point communication links [23]. Previously, these frequencies were not suitable for body area networks (BANs). Because of its high atmospheric reduction, low interference with other networks, compact components, available bandwidth, and low skin absorption by the human body, the 60 GHz band is attractive for body network applications [24], [25]. Nevertheless, thanks to the evolution of circuit integration solutions, several technological and financial obstacles have been overcome.

2.2. Proposed antenna geometry

Designing the circular patch antenna involves calculating key parameters such as the substrate height and the physical radius of the patch. These calculations are based on the formulas provided in [26]–[28], including (1)-(4). For this study, we select a polyester substrate with a thickness of 0.3 mm, a relative permittivity of $\varepsilon r = 3.2$, a loss tangent of 0.003, and a patch radius of 0.85 mm. Figure 1 illustrates the proposed antenna configuration. In addition, the values of its parameters are shown in Table 1. For power supply, we use the coaxial probe power supply method. This method involves running a coaxial line through the ground plane and the dielectric.

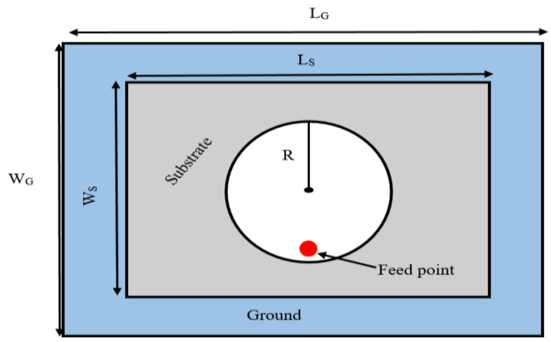


Figure 1. Proposed antenna geometry

Table 1. The parameters of this antenna

Parameters	Values (mm)
h	0.3
(Ls - Ws)	(4.2 - 4.4)
(L_G - W_G)	(5 - 5)
R	0.85

As a result, contact between the central conductor and the radiating element is made at a point on the axis of symmetry, approximately near the edge. It is directly soldered to the radiating element at a point where matching is achieved, while the outer conductor is connected to the ground plane. The actual radius of the patch is determined using (1):

$$R = \frac{A}{\left(1+\frac{2h}{A\pi\varepsilon_r}\left[ln\frac{A\pi}{2h}\right]+1.7726\right)^{0.5}} \quad (1)$$

where:

$$A = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

As shown in (1) does not account for the edge effect. Since the edge effect increases the electrical size of the patch, the effective patch radius is applied, which is given by (3).

$$R_e = \frac{R}{\left(1+\frac{2h}{A\pi\varepsilon_r}\left[ln\frac{A\pi}{2h}\right]+1.7726\right)^{-0.5}} \quad (3)$$

Consequently, the resonant frequency of the TMZ^{110} dominant is calculated by (2).

$$(f_r)_{110} = \frac{1.8412c}{2\pi R_e\sqrt{\varepsilon_r}} \quad (4)$$

where c is the speed of light in free space.

3. RESULTS AND DISCUSSION

In this section, we use the HFSS simulation software to produce results for this antenna. These results include electrical parameters such as S11, standing wave ratio, and bandwidth, as well as radiation parameters such as gain, directivity, and efficiency [4], [29].

3.1. Electrical parameters

The electrical characteristics of an antenna are used to determine the appropriate matching circuit and interconnection needed to connect an antenna to a transmitter/receiver. For more complex antenna types, the electrical characteristics of an antenna are also used to design the RF algorithms and circuits used to drive the antenna. This antenna achieves good results such as S_{11}=-50.77 dB with a wide bandwidth above 4 GHz, ranging from 60.5 GHz to 64.91 GHz, as shown in Figure 2, and VSWR=1.0058 at resonant frequency, as shown in Figure 3. Therefore, the proposed antenna's electrical performance is suitable for 5G medical applications.

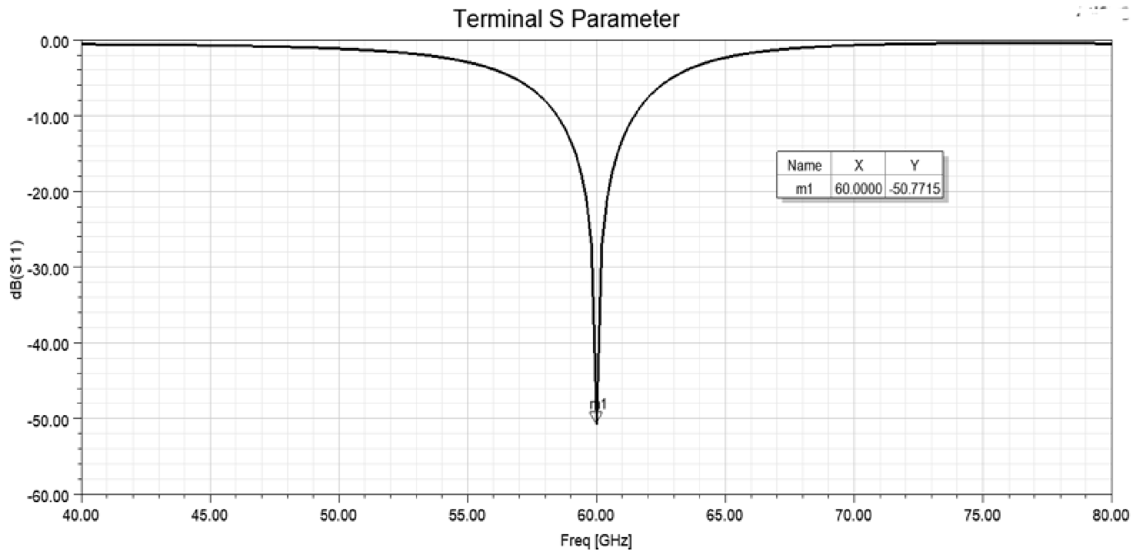


Figure 2. Graphical representation of S_{11}

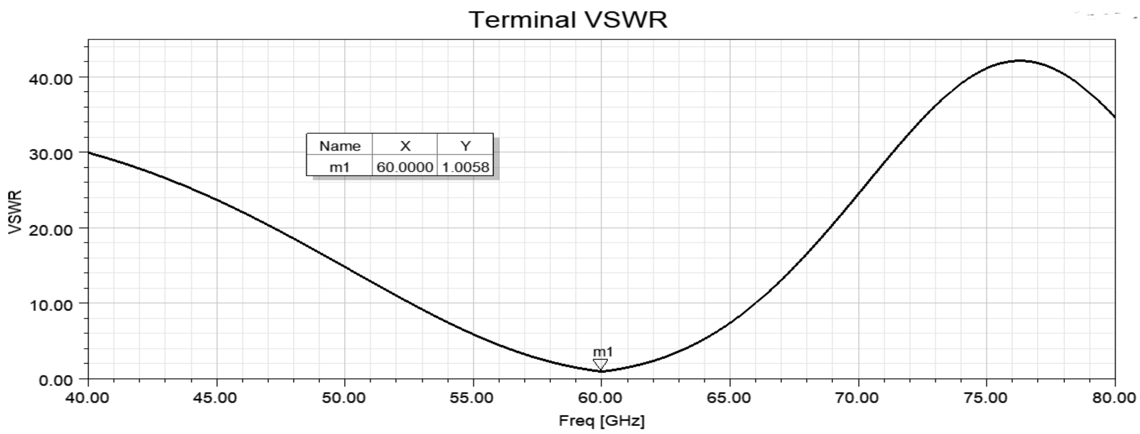
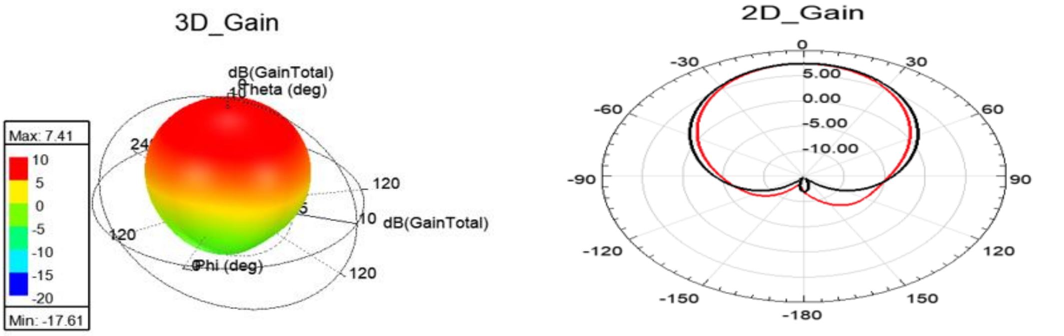


Figure 3. The representative curve of VSWR

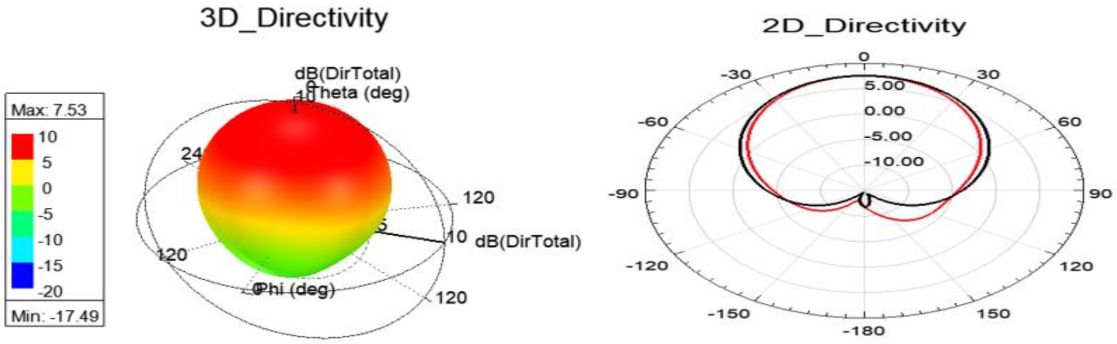
3.2. Radiation parameters

When electrons generated by a time-varying signal with sufficient high-frequency components pass through an unshielded conductor, the result is the creation of an electromagnetic wave, or antenna radiation. An antenna's far field is the specific distance at which the electric and magnetic fields of the antenna's electromagnetic radiation pattern are perfectly orthogonal. Antenna parameters are generally measured in the far field. The radiation behavior of an antenna is described by several key parameters, including radiation pattern, aperture angle, directivity, gain, efficiency and polarization. This antenna also produces interesting results, notably gain G=7.41 dB as shown in Figure 4, since Figure 4(a) illustrates the gain pattern in 3D but Figure 4(b) demonstrates the gain pattern in 2D, as does directivity D=7.53 dB as shown in Figure 5, while Figure 5(a) shows the 3D directivity pattern and Figure 5(b) the 2D directivity pattern for efficiency of η=98.44 % at a resonant frequency of 60 GH. It can be seen that the proposed antenna also offers good radiation performance for 5G medical applications.



(a) (b)

Figure 4. Illustration of (a) the 3D gain and (b) the 2D gain



(a) (b)

Figure 5. Illustration of (a) the 3D directivity and (b) the 2D directivity

3.3. The comparison of the results obtained by the proposed antenna to previous research

In this section, we present a comparative study of the results obtained by the proposed antenna and those in the literature. In addition, we summarize the results obtained by this work and those existing in the current literature, as shown in Table 2.

Table 2. Comparative results

Ref	S_{11} (dB)	BW (GHz)	Gain (dB)	η (%)
[30]	-19.26	0.657	4.43	73.7
[31]	-23.28	2.8	5.24	67.61
[32]	-29.6	2.62	5.17	-
[33]	-65	2.82	5.25	92.5
Proposed antenna	-50.77	3.01	7.41	98.4

Table 2 shows the simulation results obtained by the proposed antenna and the results of current work available in the scientific literature. It can be seen that the proposed antenna generates interesting performances compared to other works in terms of bandwidth, gain, and efficiency, as shown in Table 2. For example, the work of [30] performs less well than that of [31] in terms of S_{11}, bandwidth, and gain, while its efficiency is higher than that of [31], as shown in Table 2. Furthermore, the antenna proposed by the authors of [31] outperforms that of [32], with the exception of S11. Furthermore, the work of [33] produces a better reflection coefficient and higher gain than the other work, with the exception of the proposed antenna, as shown in Table 2.

4. CONCLUSION

In this paper, we have carried out a study and design of a circular-shaped flexible patch antenna for a frequency of 60 GHz in 5G/6G medical applications. In this case, we proposed design methods that achieved good parameters; one of these methods is the deformation of the ground plane as well as the substrate while another method is related to the coaxial feedline. In addition, this work achieves better performance than the literature, such as S11, bandwidth, gain and efficiency. The results obtained are S11 of -50.77 dB, bandwidth of 3.01 GHz, gain of 7.41 dB and efficiency of 98.4 %. We hope that this antenna will serve as a simplified, low-cost, highly integrated, low-power information transmitter or receiver, paving the way for numerous applications in diverse fields such as augmented reality, holography, sensing, and artificial intelligence, as well as quantum optics and quantum information science. In the future, the proposed antenna will be used to design and build a new antenna array dedicated to artificial intelligence.

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